Lake Holden
Revised Hydrologic / Nutrient Budget and Management Plan

Final Report

July 2004

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SECTION 1

INTRODUCTION

This report provides a summary of work efforts performed by Environmental Research & Design, Inc. (ERD) for Professional Engineering Consultants, Inc. (PEC), the Orange County Environmental Protection Department (OCEPD), and the Lake Holden Water Advisory Board (LHWAB) to develop revised hydrologic and nutrient budgets, along with an updated management plan, for Lake Holden. During 1991-1992, ERD conducted a water quality investigation on Lake Holden which included an evaluation of watershed areas discharging into Lake Holden, review of historical and existing water quality within the lake, characterization of stormwater runoff inputs, and estimation of inputs from septic tanks, along with development of nutrient and hydrologic budgets for the lake. Stormwater retrofit options were also evaluated for each of the five primary drainage basins entering Lake Holden. A report was issued titled, "Lake Holden Water Quality and Restoration Study" in June 1992 which summarized the findings of the work efforts performed by ERD.

Since the original report prepared by ERD in 1992, a number of changes have occurred in the Lake Holden watershed which impact the quantity and quality of runoff inputs entering the lake. Alum injection systems have been constructed to provide treatment for stormwater inputs from the Division Street sub-basin, Michigan Street sub-basin, and Paseo Street sub-basin (Sub-basins 1, 2, and 21, respectively) on the north end of the lake. Two wet detention ponds have also been constructed to provide treatment for runoff inputs from Orange Blossom Trail (Sub-basin 13) and a large shopping center plaza (Sub-basin 12). In addition, the original study did not directly quantify the impacts of either groundwater seepage or sediment recycling and resuspension on water quality within the lake.

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The work efforts summarized in this report include an evaluation of current conditions within the watershed and development of new estimates of loadings and impacts on water quality. In addition, field monitoring is performed to quantify impacts from groundwater seepage and sediment recycling which were not evaluated directly as part of the original water quality study. New hydrologic and nutrient budgets are developed and a revised management plan is provided which addresses the remaining significant pollutant inputs into the lake.

This report has been divided into five separate sections for presentation of the work efforts performed by ERD. Section 1 contains an introduction to the report and provides a general overview of the work efforts performed by ERD. Current characteristics of the lake are discussed in Section 2, including lake bathymetry, sediment accumulation, and water quality characteristics. The revised hydrologic budget is presented in Section 3. A nutrient budget, which includes inputs from total nitrogen, total phosphorus, TSS, and BOD, is given in Section 4. Alternatives for improvement of water quality in Lake Holden are discussed in Section 5. Recommendations for managing water quality in Lake Holden are given in Section 6. Appendices are also attached which contain technical data and analyses used to support the information contained within the report.

The June 1992 report contains a detailed evaluation of existing and historical physical and chemical characteristics of Lake Holden, hydrologic/hydraulic characteristics of the drainage basin, evaluation of sources and magnitudes of pollutant inputs, and evaluation of treatment options for improvement of water quality. In general, the information contained in the June 1992 report is not repeated in the current report except where changes or modifications to the previously reported information or data may have occurred.

SECTION 2

PHYSICAL AND CHEMICAL
CHARACTERISTICS OF LAKE HOLDEN

2.1 Physical Characteristics of Lake Holden

A bathymetric map of Lake Holden was provided in the June 1992 report based upon survey information collected by the Orange County Environmental Protection Department. This map indicated relatively steep side slopes in both the north and south lobes of Lake Holden, extending to deep areas of approximately 30 feet or more. Revised bathymetric surveys were performed in Lake Holden during September 2003 to evaluate water column depth as well as thickness of unconsolidated sediments within the lake. Measurements of water depth and sediment thickness were conducted at 147 individual sites in Lake Holden. Probing locations used for the bathymetric study are indicated on Figure 2-1. Each of the data collection sites was identified in the field by longitude and latitude coordinates using a portable GPS device. The vast majority of the probing measurements were performed on September 15, 2003, with supplemental probings performed over a period of approximately seven days.

Water depth at each of the data collection sites was determined by lowering a 20-cm diameter Secchi disk attached to a graduated line until resistance from the sediment layer was encountered. The depth on the graduated line corresponding to the water surface was recorded in the field and is defined as the water depth at each site. After measurement of the water depth at each site, a 1.5-inch graduated aluminum pole was then lowered into the water column and forced into the sediments until a firm bottom material, typically sand or clay, was encountered. The depth corresponding to the water surface is defined as the depth to the firm lake bottom. The difference between the depth to the firm lake bottom and the water depth at each site is defined as the depth of unconsolidated sediments.

Figure 2-1. Probing Locations for Water and Muck Depth in Lake Holden.

The generated field data was converted into bathymetric maps for both water depth and unconsolidated sediment depth in Lake Holden using AutoCAD 2002. Estimates of water volume and unconsolidated sediment volume within Lake Holden were generated using the Autodesk Land Desktop 2004 Module.

A water depth contour map for Lake Holden, based upon the field monitoring program performed by ERD, is given in Figure 2-2. Lake Holden appears to have relatively steep side slopes, extending down to water depths of approximately 25 ft or more. Several deep holes are apparent in northern, eastern, and southern portions of the lake. Based on the shape of the contours summarized in Figure 2-2, and the depth of the existing water column within the lake, it appears that Lake Holden may have originated as several separate sinkholes which combined together to form the lake.

Based upon recorded lake levels provided on the www.lakeholden.org website, the water surface elevation in Lake Holden on September 15, 2003 was 90.6146 ft (NGVD), compared with an average water surface elevation of 89.95 ft. As a result, the water surface elevation in Lake Holden at the time of collection of the bathymetric information summarized on Figure 2-2 was approximately 0.66 ft or 8.0 inches higher than the average water surface elevation within the lake.

Stage-storage relationships for Lake Holden are summarized in Table 2-1. At the water surface elevation present on September 15, 2003, the lake surface area is approximately 266.2 acres. The lake volume at this surface area is 3211.5 ac-ft which corresponds to a mean water depth of approximately 12.1 ft. This value is relatively deep for a Central Florida lake. A summary of bathymetric characteristics of Lake Holden is given in Table 2-2.

A bathymetric contour map of the depth of unconsolidated organic sediments in Lake Holden is given in Figure 2-3. A substantial accumulation of organic muck is apparent in the northern portion of the lake where muck depths exceed 13 ft. Muck depths of approximately 9-10 ft were observed in north-central portions of the lake, with accumulations exceeding 6-8 ft in western portions of the lake. The remaining portions of the lake appear to have organic muck depths of approximately 1 ft or less.
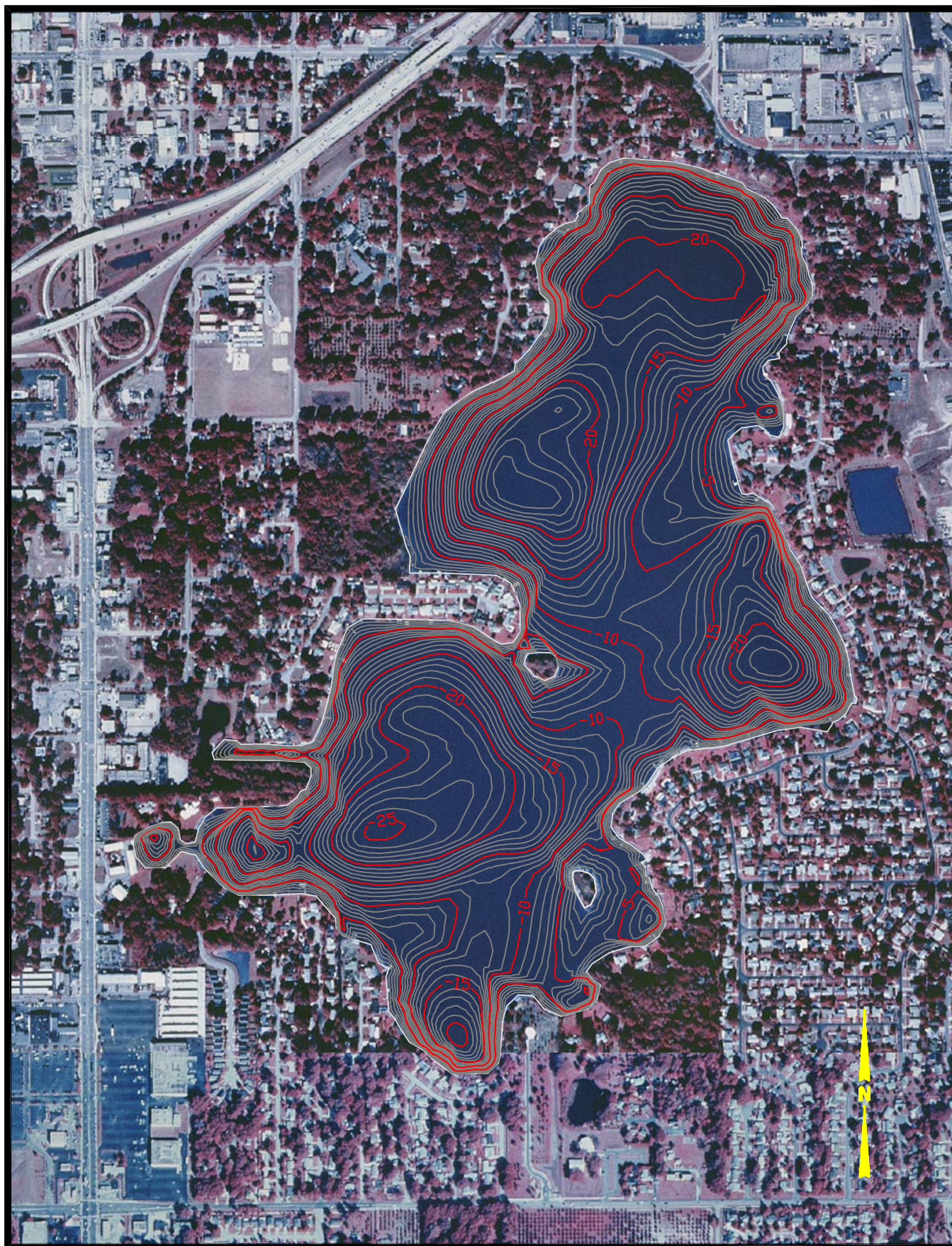
Figure 2-2. Lake Holden Water Depth Contours (ft) on September 15, 2003.
(Water Surface Elev. = 90.61 ft.)
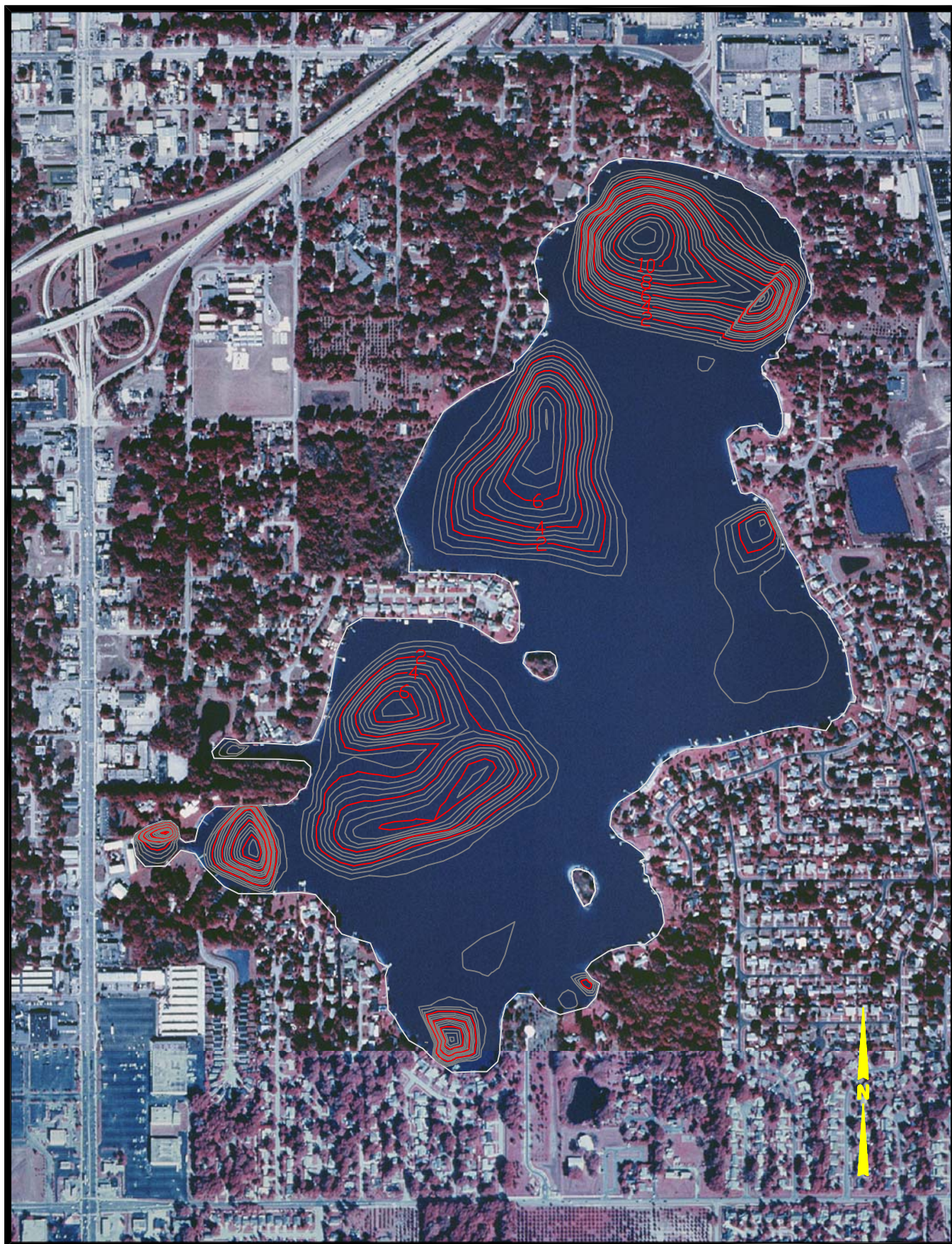
Figure 2-3. Unconsolidated Muck Depth Contours in Lake Holden (ft.).

TABLE 2-1

**STAGE-AREA-VOLUME RELATIONSHIPS
FOR LAKE HOLDEN[1]**

WATER ELEVATION (ft, NGVD)	AREA (acres)	VOLUME (ac-ft)
91	266.2	3211.5
90	263.1	2945.3
89	252.5	2682.2
88	241.4	2429.7
87	229.7	2188.3
86	221.8	1958.6
85	212.9	1736.8
84	206.8	1523.9
83	195.2	1317.0
82	177.0	1121.8
81	162.1	944.8
80	140.0	782.7
79	124.5	642.7
78	111.8	518.1
77	93.6	406.3
76	79.1	312.7
75	70.1	233.6
74	57.5	163.4
73	42.4	106.0
72	26.0	63.6
71	19.6	37.6
70	12.5	18.1
69	4.6	5.6
68	1.0	1.0

1. Based on a water surface elevation of 90.6146 ft (NGVD) on September 15, 2003

TABLE 2-2

BATHYMETRIC CHARACTERISTICS OF LAKE HOLDEN

BATHYMETRIC PARAMETER[1]	VALUE
Surface Area	266.2 ac 11,595,672 ft^2 1,077,825 m^2
Total Volume	3211.5 ac-ft 139,892,940 ft^3 3,964,371 m^3
Mean Depth	12.1 ft 3.7 m
Maximum Depth	> 30 ft > 9.1 m
Shoreline Length	22,153 ft 6,754 m 4.2 miles

1. Based upon a mean surface elevation of 90.6146 ft (NGVD) on September 15, 2003

TABLE 2-3

**AREA-VOLUME RELATIONSHIPS FOR
ORGANIC MUCK IN LAKE HOLDEN**

MUCK DEPTH (ft)	AREA (acres)	VOLUME (ac-ft)
0-1	142.5	142.5
1-2	97.9	240.4
2-3	70.7	311.1
3-4	40.4	351.5
4-5	22.7	374.2
5-6	13.2	387.2
6-7	6.0	393.4
7-8	2.9	396.4
8-9	1.6	398.0
9-10	1.3	399.4
10-11	0.2	399.5

Estimates of area-volume relationships for organic muck accumulations in Lake Holden are given in Table 2-3. Approximately 54% of the lake area has existing muck accumulations ranging from 0-1 ft in depth, with 10% of the lake bottom covered by muck accumulations ranging from 4-5 ft in depth. Overall, Lake Holden contains approximately 399.5 ac-ft (17,402,220 ft^3) of unconsolidated organic sediments. The volume of unconsolidated sediment in Lake Holden is sufficient to cover the entire lake bottom to a depth of approximately 1.5 ft.

2.2 Sediment Characteristics

Sediment core samples were collected in Lake Holden by ERD to assist in evaluating the characteristics of existing sediments and potential impacts on water quality within the lake. Sediment core samples were collected at 44 separate locations within the lake. Locations of sediment sampling sites in Lake Holden are illustrated on Figure 2-4.

2.2.1 Sampling Techniques

Sediment samples were collected at each of the 44 monitoring sites using a stainless steel split-spoon core device, which was penetrated into the sediments at each location to a minimum distance of approximately 0.5 m. After retrieval of the sediment sample, any overlying water was carefully decanted before the split-spoon device was opened to expose the collected sample. Visual characteristics of each sediment core sample were recorded, and the 0-10 cm layer was carefully sectioned off and placed into a polyethylene container for transport to the ERD laboratory. Duplicate core samples were collected at each site, and the 0-10 cm layers were combined together to form a single composite sample for each of the 44 monitoring sites. The polyethylene containers utilized for storage of the collected samples were filled completely so no air space was present in the storage container above the composite sediment sample. Each of the collected samples was stored on ice and returned to the ERD laboratory for physical and chemical characterization.
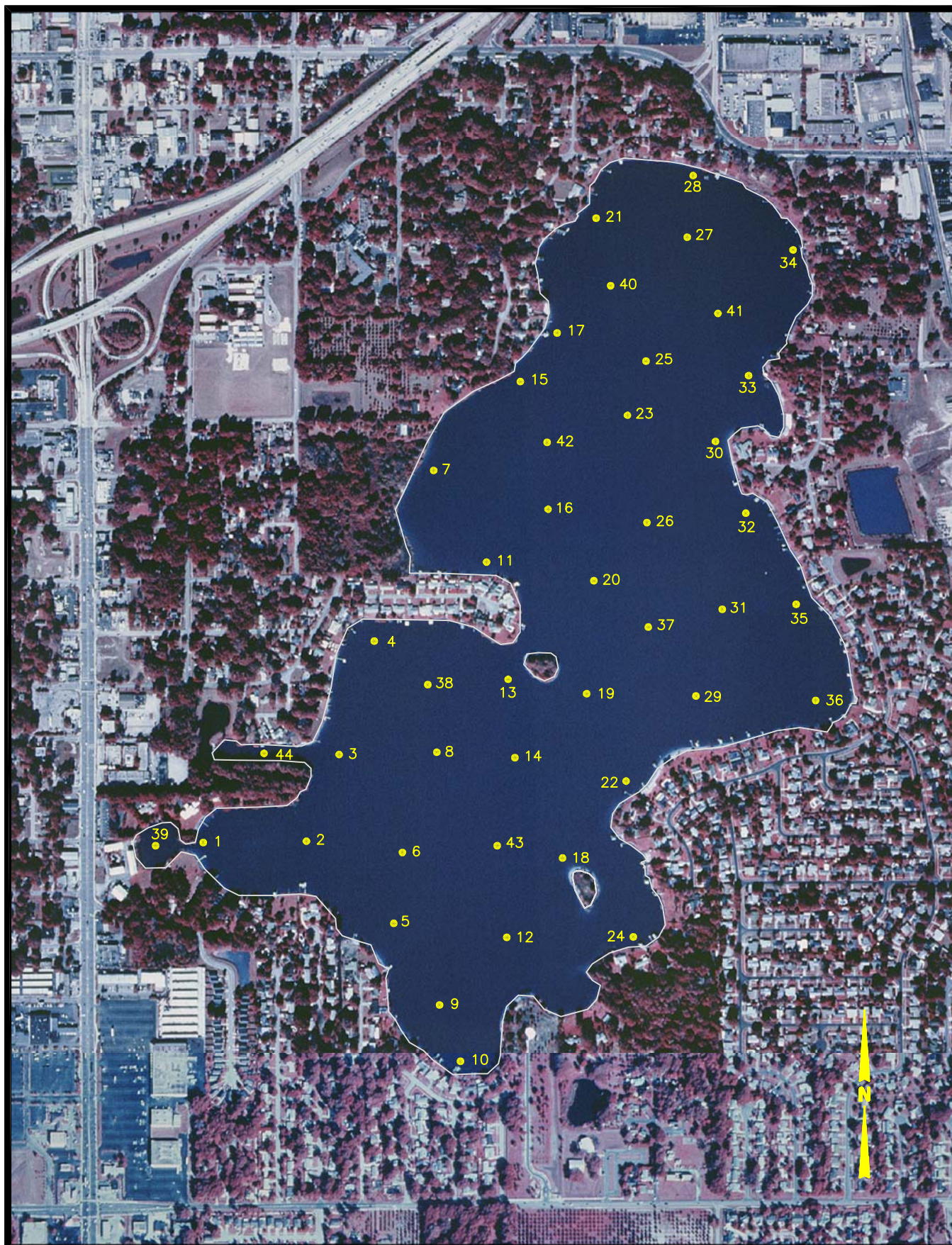
Figure 2-4. Locations of Sediment Sampling Sites in Lake Holden.

2.2.2 Sediment Characterization and Speciation Techniques

Each of the 44 collected sediment core samples was analyzed for a variety of general parameters, including moisture content, organic content, sediment density, total nitrogen, and total phosphorus. Methodologies utilized for preparation and analysis of the sediment samples for these parameters are outlined in Table 2-4.

TABLE 2-4

ANALYTICAL METHODS
FOR SEDIMENT ANALYSES

MEASUREMENT PARAMETER	SAMPLE PREPARATION	ANALYSIS REFERENCE	REFERENCE PREP./ANAL.	METHOD DETECTION LIMITS (MDLs)
pH	EPA 9045	EPA 9045	3/3	0.01 pH units
Moisture Content	p. 3-54	p. 3-58	1/1	0.1%
Organic Content (Volatile Solids)	p. 3-52	pp. 3-52 to 3-53	1/1	0.1%
Total Phosphorus	pp. 3-227 to 3-228 (Method C)	EPA 365.4	½	0.005 mg/kg
Total Nitrogen	p. 3-201	pp. 3-201 to 3-204	1/1	0.010 mg/kg
Specific Gravity Density)	p. 3-61	pp. 3-61 to 3-62	1/1	NA

REFERENCES:

1. Procedures for Handling and Chemical Analysis of Sediments and Water Samples, EPA/Corps of Engineers, EPA/CE-81-1, 1981.

2. Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, Revised March 1983.

3. Test Methods for Evaluating Solid Wastes, Physical-Chemical Methods, Third Edition, EPA-SW-846, Updated November 1990.

In addition to general sediment characterization, a fractionation procedure for inorganic soil phosphorus was conducted on each of the 44 collected sediment samples. The modified Chang and Jackson Procedure, as proposed by Peterson and Corey (1966), was used for phosphorus fractionation. The Chang and Jackson Procedure allows the speciation of sediment phosphorus into saloid-bound phosphorus (defined as the sum of soluble plus easily exchangeable sediment phosphorus), iron-bound phosphorus, and aluminum-bound phosphorus. Although not used in this project, subsequent extractions of the Chang and Jackson procedure also provide calcium-bound and residual fractions.

Saloid-bound phosphorus is considered to be available under all conditions at all times. Iron-bound phosphorus is relatively stable under aerobic environments, generally characterized by redox potentials greater than 200 mv (E_h), while unstable under anoxic conditions, characterized by redox potential less than 200 mv. Aluminum-bound phosphorus is considered to be stable under all conditions of redox potential and natural pH conditions. A schematic of the Chang and Jackson Speciation Procedure for evaluating soil phosphorus bounding is given in Figure 2-5.
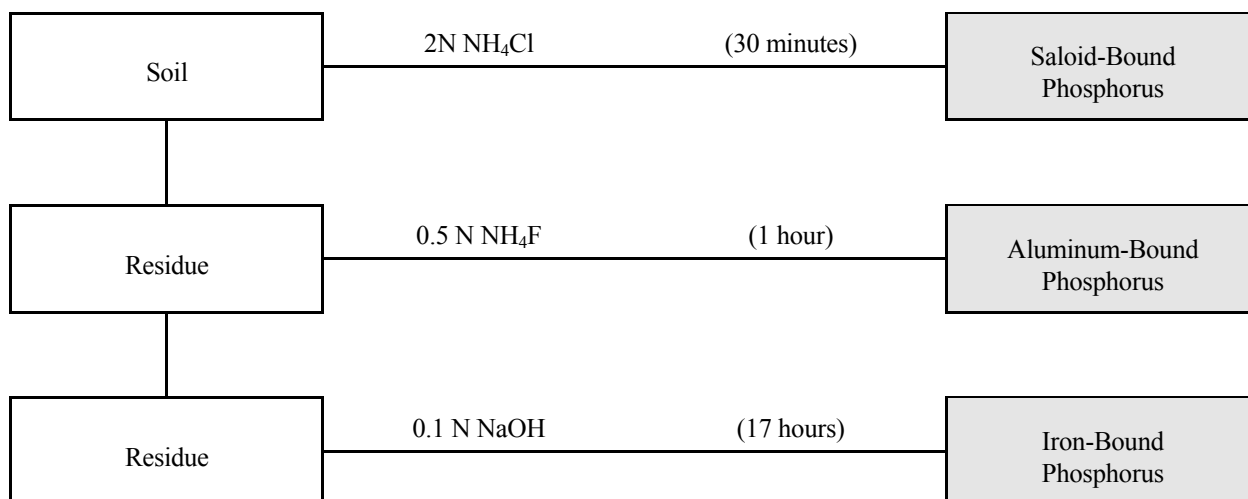
Figure 2-5.   Schematic of Chang and Jackson Speciation Procedure for Evaluating Soil Phosphorus Bonding.

For purposes of evaluating release potential, ERD typically assumes that potentially available inorganic phosphorus in soils/sediments, particularly those which exhibit a significant potential to develop reduced conditions below the sediment-water interface, is represented by the sum of the soluble inorganic phosphorus and easily exchangeable phosphorus fractions (collectively termed saloid-bound phosphorus), plus iron-bound phosphorus which can become solubilized under reduced conditions. Aluminum-bound phosphorus is generally considered to be unavailable in the pH range of approximately 5.5-7.5 under a wide range of redox conditions.

2.2.3 Sediment Characteristics

2.2.3.1 Visual Characteristics

Visual characteristics of sediment core samples were recorded for each of the 44 sediment samples collected in Lake Holden during September 2003. A summary of visual characteristics of sediment core samples is given in Table 2-5. In general, shoreline areas of Lake Holden are characterized by sandy sediments with little or no visual accumulations of unconsolidated organic muck. The base material beneath the lake bottom consists primarily of light brown and dark brown fine sand.

As water depths increase within the lake, the accumulations of organic muck become deeper. Areas where deep deposits of organic muck have accumulated are characterized by a surface layer of unconsolidated organic muck, approximately 1-6 inches in thickness. This unconsolidated layer is comprised primarily of fresh organic material, such as dead algal cells, which have accumulated onto the bottom of the lake. This organic material is easily disturbed by wind action or boating activities. As the sediment depth increases, the organic layer becomes more consolidated with a consistency similar to pudding. These layers typically do not resuspend into the water column except during relatively vigorous mixing action within the lake.

TABLE 2-5

**VISUAL CHARACTERISTICS OF
SEDIMENT CORE SAMPLES COLLECTED IN
LAKE HOLDEN DURING SEPTEMBER 2003**

SITE NO.	LAYER (cm)	VISUAL APPEARANCE
1	0-2 2-13 > 13	Dark brown unconsolidated organic muck with light brown sand Dark brown fine sand Dark brown consolidated organic muck with dark brown sand
2	0-6 > 6	Light brown sand with detritus Dark brown fine sand
3	0-18 > 18	Dark brown unconsolidated organic muck Dark brown consolidated organic muck
4	0 - > 10	Dark brown fine sand
5	0-2 > 2	Light green fine sand Light brown fine sand
6	0 - > 10	Dark brown fine sand
7	0-4 4-7 > 7	Light green fine sand Light brown fine sand Dark brown consolidated organic muck with dark brown sand
8	0-2 > 2	Light green fine sand with detritus Dark brown fine sand with shells
9	0-10 > 10	Dark brown fine sand with detritus Dark brown fine sand
10	0-7 7-11 11-16 > 16	Unconsolidated dark brown organic muck with dark brown sand Dark brown fine sand Dark brown fine sand with detritus Dark brown fine sand
11	0-5 > 5	Light green fine sand Dark brown fine sand
12	0-30 > 30	Dark brown unconsolidated organic muck Consolidated dark brown organic muck with dark brown sand
13	0-4 > 4	Dark brown fine sand Dark brown consolidated organic muck with sand
14	0-3 3-6 6-17 > 17	Light green fine sand Light brown fine sand Consolidated organic muck with dark brown fine sand Consolidated organic muck with light brown fine sand
15	0 - > 10	Dark brown fine sand

TABLE 2-5 -- CONTINUED

SITE NO.	LAYER (cm)	VISUAL APPEARANCE
16	0 - > 22	Dark brown unconsolidated organic muck
17	0 - > 10	Dark brown fine sand
18	0-2 > 2	Light green fine sand Dark brown fine sand
19	0 - > 10	Dark brown fine sand
20	0-7 7-15 > 15	Dark brown unconsolidated organic muck Dark brown fine sand Light gray fine sand
21	0-11 11-20 20-22 > 22	Dark brown fine sand Light brown fine sand Medium gray fine sand Light brown fine sand
22	0-8 8-14 > 14	Dark brown fine sand Light gray fine sand Light brown fine sand
23	0-6 6-11 11-14 14-16 > 16	Dark brown fine sand Medium gray fine sand Light brown fine sand Medium gray fine sand Light brown fine sand
24	0-2 2-6 6-8 8-13 > 13	Light green fine sand Dark brown fine sand Light brown fine sand Light gray fine sand Light brown fine sand
25	0-13 13-15 > 15	Dark brown fine sand Medium gray fine sand Light brown fine sand
26	0-22 > 22	Dark brown unconsolidated organic muck Dark brown consolidated organic muck
27	0 - > 10	Light brown fine sand
28	0-15 > 15	Dark brown fine sand Dark brown consolidated organic muck with detritus
29	0 - > 17	Dark brown fine sand
30	0-21 > 21	Dark brown unconsolidated organic muck Dark brown consolidated organic muck

TABLE 2-5 – CONTINUED

SITE NO.	LAYER (cm)	VISUAL APPEARANCE
31	0-2 > 2	Light green fine sand Light brown fine sand
32	0-2 2-7 7-10 10-13 13-18 18-22 > 22	Medium gray fine sand Light brown fine sand Medium gray fine sand Light brown fine sand Medium gray fine sand Light brown fine sand Medium gray fine sand
33	0-9 9-12 > 12	Dark brown fine sand Medium gray fine sand Light brown fine sand
34	0-6 6-8 8-11 > 11	Dark brown unconsolidated organic muck Dark brown fine sand Light gray fine sand Dark brown fine sand
35	0-14 14-27 > 27	Dark brown unconsolidated organic muck Dark brown consolidated organic muck Dark brown consolidated organic muck with dark brown sand
36	0-8 8-14 > 14	Dark brown unconsolidated organic muck Dark brown fine sand Dark brown consolidated organic muck
37	0-3 3-12 12-17 > 17	Dark brown unconsolidated organic muck Brown fine sand Tan/brown fine sand Light gray fine sand
38	0-7 > 7	Brown fine sand Brown/black fine sand mix
39	0-7 > 7	Dark brown unconsolidated organic muck Dark brown consolidated organic muck
40	0-23 > 23	Dark brown unconsolidated organic muck Dark brown consolidated organic muck
41	0-7 > 7	Dark brown unconsolidated organic muck Dark brown consolidated organic muck
42	0-2 2-16 > 16	Dark brown unconsolidated organic muck Dark brown consolidated organic muck Brown/black fine sand
43	0-7 > 7	Dark brown unconsolidated organic muck Dark brown consolidated organic muck
44	0 - > 10	Brown fine sand

2.2.3.2 Gesneral Sediment Characteristics

After return to the ERD Laboratory, the collected sediment core samples were evaluated for general sediment characteristics, including pH, moisture content, organic content, sediment density, total nitrogen, and total phosphorus. A summary of general characteristics measured in each of the 44 collected sediment core samples is given in Table 2-6. In general, sediments in Lake Holden were found to be slightly acidic to approximately neutral in pH, with measured pH values ranging from 5.05-7.36, with an overall mean of 6.60. These values are typical of pH measurements commonly observed in eutrophic urban lakes.

Measurements of sediment moisture content and organic content in Lake Holden were found to be highly variable throughout the lake. Many of the collected sediment samples are characterized by a relatively low moisture content and low organic content, suggesting that these sediments are comprised primarily of fine sand. In contrast, other sediment core samples are characterized by elevated values for both moisture content and organic content, suggesting areas of accumulated organic muck.

Isopleths of sediment moisture content in Lake Holden are summarized in Figure 2-6 based upon the information provided in Table 2-6. Areas of elevated moisture content are present in northern, central, and western portions of the lake. Sediment moisture contents in excess of 50% are often indicative of highly organic sediments, while moisture contents less than 50% reflect either sand or mixtures of sand and muck.

Isopleths of sediment organic content in Lake Holden are illustrated on Figure 2-7 based upon the information provided in Table 2-6. In general, sediment organic content values in excess of 20-30% are often indicative of organic muck type sediments, with values less than 20-30% representing either sand or mixtures of muck and sand. Based upon these criteria, areas of concentrated organic muck are apparent in northern, central, and western portions of Lake Holden. These areas of high organic content correspond closely with the areas of accumulated organic muck deposits illustrated on Figure 2-3. Measured sediment organic content within Lake Holden ranges from 0.5-43.4%, with an overall mean of 8.4%.

TABLE 2-6

GENERAL CHARACTERISTICS OF SEDIMENT CORE SAMPLES
COLLECTED IN LAKE HOLDEN DURING SEPTEMBER 2003

SITE	MOISTURE CONTENT (%)	ORGANIC CONTENT (%)	WET DENSITY (g/cm^3)	pH	TOTAL P (µg/g wet wt.)	TOTAL N (µg/g wet wt.)
1	25.4	0.5	2.11	6.90	203	252
2	28.0	1.2	2.07	5.05	164	570
3	90.7	41.3	1.08	6.72	744	3267
4	28.5	0.9	2.06	6.87	185	641
5	28.7	0.8	2.06	7.09	130	674
6	26.7	0.5	2.09	5.66	218	267
7	24.7	0.8	2.12	6.08	125	496
8	26.6	0.6	2.09	7.12	128	540
9	34.1	1.7	1.97	6.50	187	864
10	32.1	3.3	1.99	7.25	146	984
11	28.0	1.1	2.07	6.68	514	716
12	63.4	12.1	1.48	6.08	780	3323
13	23.5	1.0	2.14	6.75	444	340
14	22.7	1.2	2.15	6.65	298	460
15	26.2	0.7	2.10	6.72	245	588
16	32.3	1.9	2.00	6.23	300	875
17	25.5	0.8	2.11	6.66	513	422
18	24.8	0.8	2.12	7.03	285	333
19	29.5	0.8	2.05	7.03	640	588
20	39.1	1.7	1.90	6.45	550	1138
21	26.8	0.7	2.09	6.10	133	622
22	27.7	0.9	2.07	6.68	189	806
23	26.1	1.0	2.10	6.77	275	812
24	26.4	0.6	2.10	7.24	218	508
25	31.5	1.3	2.01	6.72	263	904
26	91.4	42.3	1.07	6.28	1308	3028
27	32.3	1.0	2.01	6.51	1081	641
28	31.2	1.5	2.02	7.03	289	686
29	26.8	0.9	2.09	7.04	1031	457
30	88.9	36.4	1.11	6.18	972	3233
31	25.4	0.4	2.11	7.36	162	340
32	28.9	0.9	2.06	7.29	255	734
33	28.5	0.9	2.06	7.32	292	776
34	31.3	1.2	2.02	7.04	292	675
35	83.5	25.0	1.19	6.43	718	3461
36	46.0	7.1	1.75	6.77	348	1778
37	46.8	4.6	1.76	6.02	1496	1367
38	26.3	0.5	2.10	6.52	129	414
39	91.9	43.4	1.07	6.19	648	2923
40	89.0	36.6	1.11	6.28	489	3231
41	92.6	43.1	1.06	6.09	588	2917
42	46.3	3.8	1.77	6.35	546	1534
43	91.7	40.2	1.07	6.10	590	2982
44	22.0	0.5	2.16	6.78	198	534
Mean	**41.4**	**8.4**	**1.86**	**6.60**	**439**	**1198**
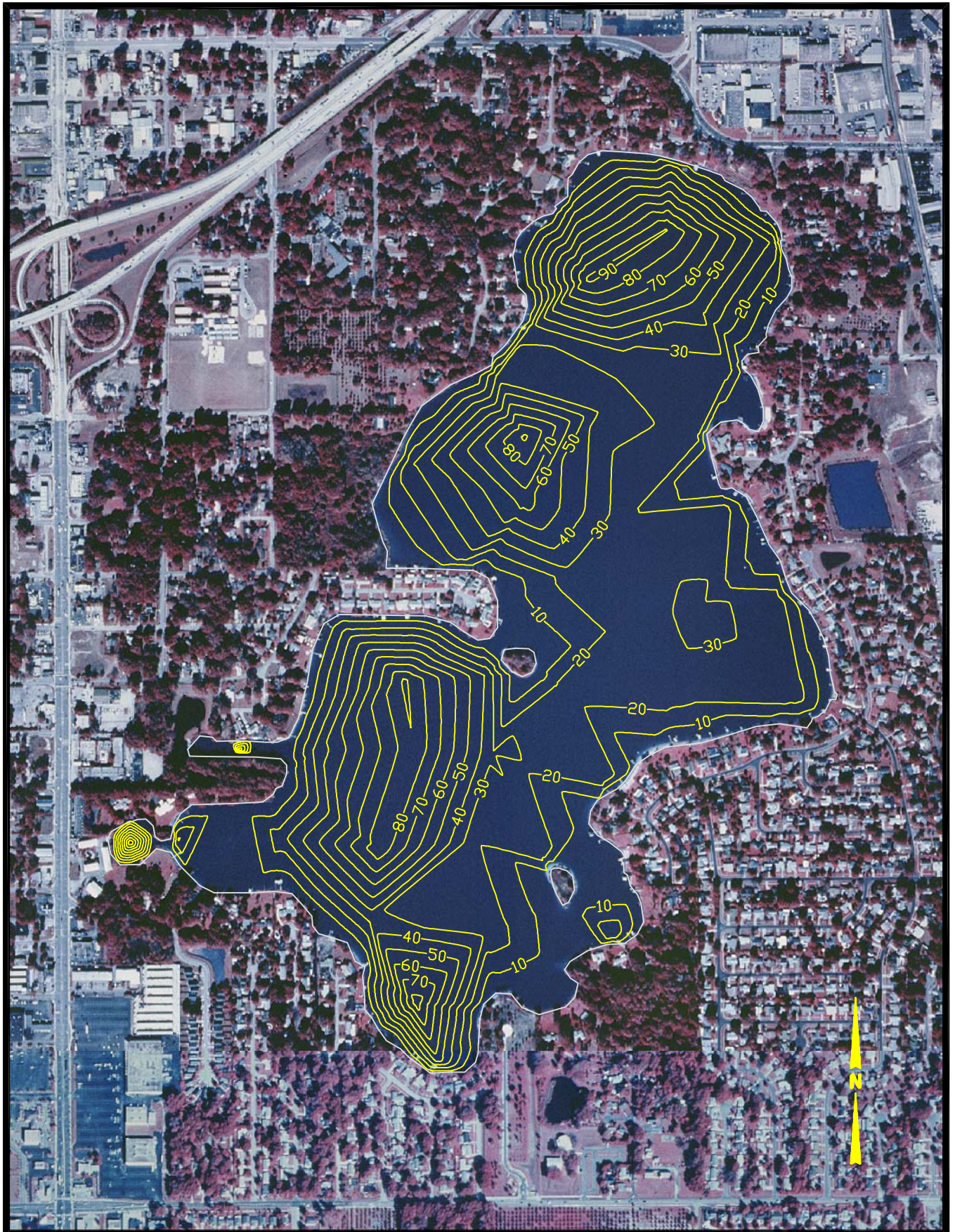
Figure 2-6.   Isopleths of Sediment Moisture Content (%) in the Top 10 cm of
Lake Holden.

Figure 2-7.   Isopleths of Sediment Organic Content (%) in the Top 10 cm in Lake Holden.

Measured sediment density values are also useful in evaluating the general characteristics of sediments within a lake. Sediments with calculated densities between 1.0 and 1.5 are indicative of highly organic muck type sediments, while sediment densities of approximately 2.0 or greater are indicative of sandy sediment conditions. Measured sediment density values in Lake Holden range from 1.07-2.16 g/cm^3, with an overall mean of 1.86 g/cm^3.

Measured concentrations of total phosphorus in Lake Holden sediments were found to be highly variable throughout the lake. Measured total phosphorus concentrations range from 125-1496 µg/cm^3, with an overall mean of 439 µg/cm^3. In general, sandy sediments are often characterized by low total phosphorus concentrations, while highly organic muck type sediments are characterized by elevated total phosphorus concentrations.

Isopleths of sediment phosphorus concentrations in Lake Holden are presented on Figure 2-8, based on information contained in Table 2-6. Areas of elevated sediment phosphorus concentrations are present in the northern, central, and western portions of the lake, similar to the areas of elevated moisture and organic content illustrated on Figures 2-6 and 2-7, respectively. In general, overall total phosphorus concentrations observed in Lake Holden appear to be somewhat elevated compared with phosphorus sediment concentrations typically observed in urban lakes.

Similar to the trends observed for sediment phosphorus concentrations, sediment nitrogen concentrations are also highly variable throughout Lake Holden. Measured sediment nitrogen concentrations in the lake range from 252-3461 µg/cm^3, with an overall mean of 1198 µg/cm^3. However, in contrast to the trends observed for total phosphorus, measured sediment nitrogen concentrations in Lake Holden do not appear to be elevated compared with values normally observed in urban lakes.

Isopleths of sediment nitrogen concentrations in Lake Holden are illustrated on Figure 2-9. In general, patterns of elevated nitrogen concentrations are similar to the patterns exhibited by total phosphorus.
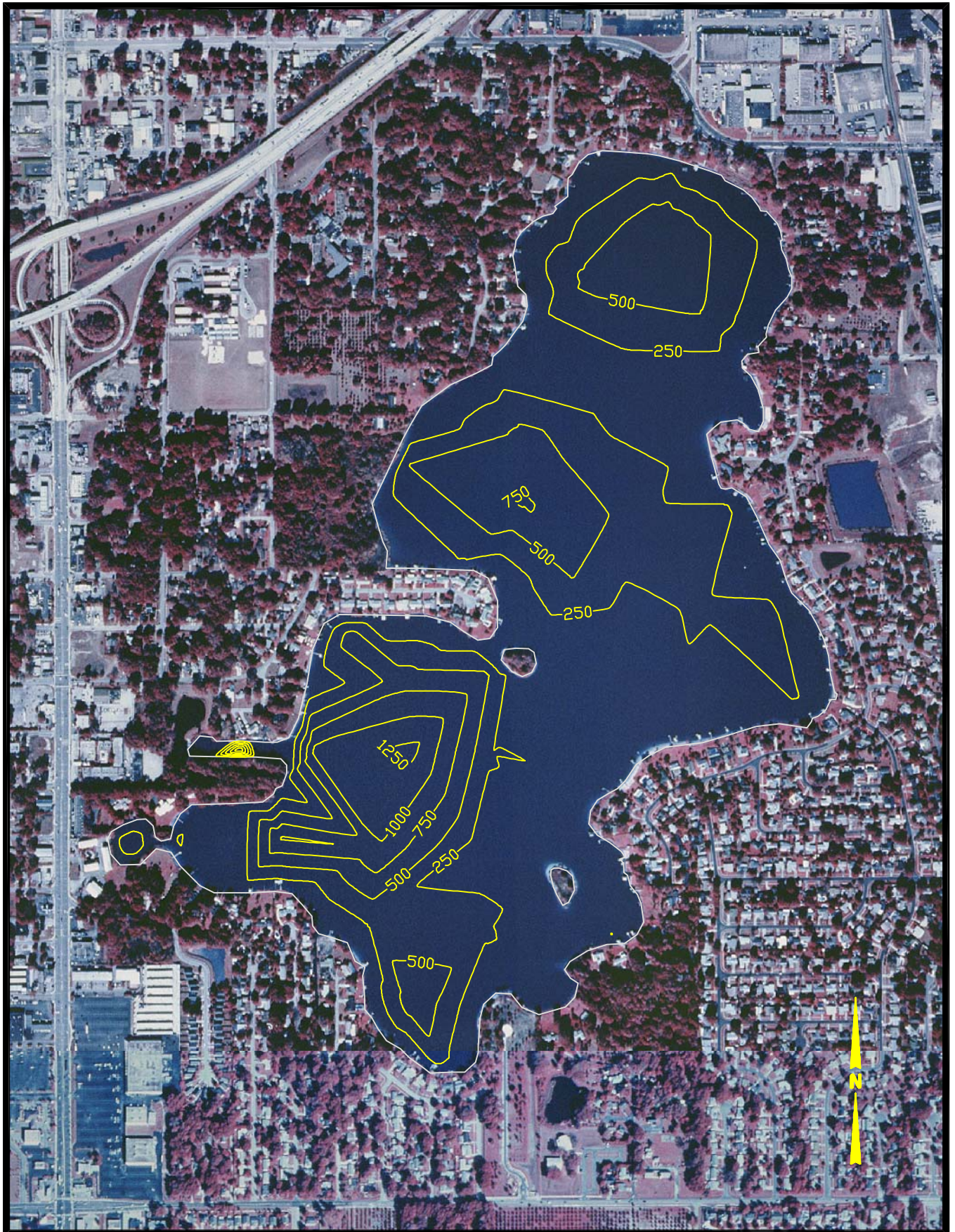
Figure 2-8.   Isopleths of Total Phosphorus (µg/g wet wt.) in the Top 10 cm of Sediments in Lake Holden.
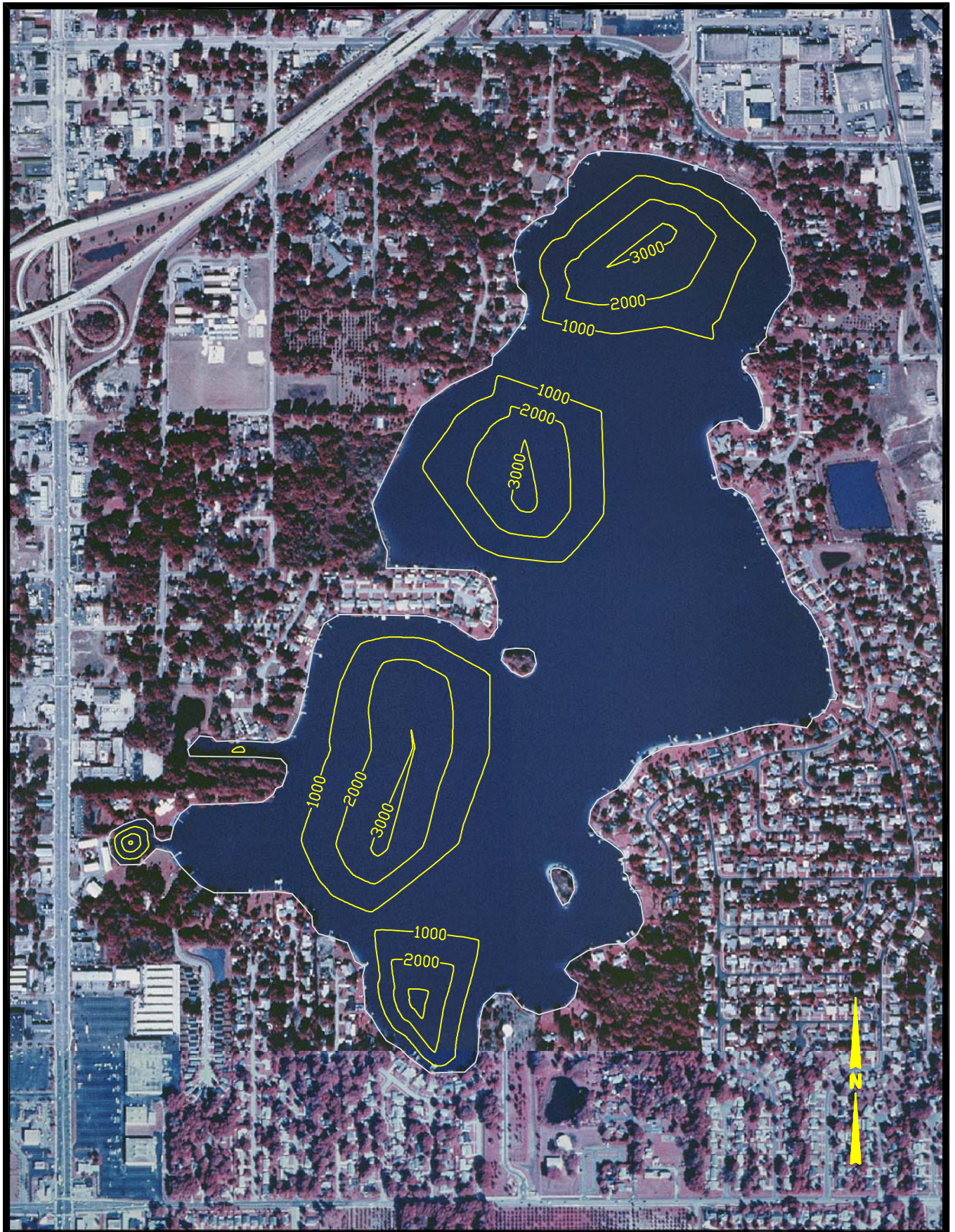
Figure 2-9.   Isopleths of Total Nitrogen (μg/g wet wt.) in the Top 10 cm of
Sediments in Lake Holden.

2.2.3.3 <u>Phosphorus Speciation</u>

As discussed in Section 2.2.2, each of the collected sediment core samples was evaluated for phosphorus speciation based upon the Chang and Jackson speciation procedure. This procedure allows phosphorus within the sediments to be speciated with respect to bonding mechanisms within the sediments. This information is useful in evaluating the potential for release of phosphorus from the sediments under anoxic or other conditions.

A summary of phosphorus speciation in sediment core samples collected from Lake Holden during September 2003 is given in Table 2-7. Saloid-bound phosphorus represents sediment phosphorus which is either soluble or easily exchangeable and is typically considered to be readily available for release from the sediments into the overlying water column. As seen in Table 2-7, saloid-bound phosphorus concentrations appear to be fairly uniform throughout the sediments of Lake Holden. Measured values for saloid-bound phosphorus range from 0.6-4.4 $\mu g/cm^3$, with an overall mean of 1.9 $\mu g/cm^3$.

In general, iron-bound phosphorus associations in the sediments of Lake Holden appear to be somewhat elevated in value. Iron-bound phosphorus is relatively stable under oxidized conditions, but becomes unstable under a reduced environment, causing the iron-phosphorus bonds to separate, releasing the bound phosphorus directly into the water column. Iron-bound phosphorus concentrations in the sediments of Lake Holden range from 15-257 $\mu g/cm^3$, with an overall mean of 69 $\mu g/cm^3$. Since iron-bound phosphorus can be released under anoxic conditions, large portions of Lake Holden appear to have conditions favorable for release of iron-bound sediment phosphorus into the water column throughout much of the year. The iron-bound phosphorus concentrations summarized in Table 2-7 appear to be somewhat elevated compared with values commonly observed in urban lake systems.

Total available phosphorus represents the sum of the saloid-bound phosphorus and iron-bound phosphorus associations in each sediment core sample. Since the saloid-bound phosphorus is immediately available, and the iron-bound phosphorus is available under reduced conditions, the sum of these speciations represents the total phosphorus which is potentially available within the sediments. This information can be utilized as a guide for future sediment inactivation procedures.

TABLE 2-7

PHOSPHORUS SPECIATION IN SEDIMENT CORE SAMPLES
COLLECTED IN LAKE HOLDEN DURING SEPTEMBER 2003

SITE	SALOID-BOUND P (μg/wet wt.)	Fe-BOUND P (μg/g wet wt.)	AVAILABLE P (μg/g wet wt.)	Al-BOUND P (μg/g wet wt.)
1	0.9	45	46	12
2	1.7	41	42	10
3	2.7	77	80	104
4	2.6	44	46	22
5	1.7	21	23	7
6	1.8	25	27	5
7	0.8	15	16	2
8	0.8	25	26	3
9	2.4	22	24	12
10	0.6	18	19	14
11	1.9	68	70	68
12	0.8	88	89	97
13	1.5	68	69	36
14	1.1	67	69	15
15	1.9	43	45	37
16	2.5	62	64	31
17	2.6	82	85	82
18	2.7	46	49	58
19	3.3	76	79	106
20	2.7	90	93	101
21	2.7	27	30	6
22	1.7	31	33	8
23	2.5	44	47	22
24	1.4	38	39	10
25	1.3	47	48	25
26	0.6	238	239	215
27	1.6	179	181	215
28	2.0	60	62	28
29	0.8	179	180	118
30	1.7	139	140	162
31	1.0	35	36	16
32	1.7	38	40	10
33	2.3	53	56	26
34	1.4	48	49	52
35	2.9	79	82	124
36	1.2	32	33	55
37	0.6	257	258	168
38	1.3	16	17	6
39	3.1	192	195	68
40	1.2	63	64	36
41	4.3	74	79	41
42	2.1	44	46	77
43	4.4	65	69	70
44	0.9	20	21	41
Mean	**1.9**	**69**	**71**	**55**

A summary of total available phosphorus in each of the 42 collected sediment core samples is given in Table 2-7. Total available phosphorus concentrations within the lake range from 16-258 $\mu g/cm^3$, with an overall mean of 71 $\mu g/cm^3$. Based upon the mean total sediment phosphorus concentration of 439 $\mu g/cm^3$, approximately 16% of the total phosphorus contained within the sediments of Lake Holden is potentially available for release into the overlying water column.

Isopleths of total available phosphorus in the top 10 cm of sediments in Lake Holden are illustrated on Figure 2-10. Areas of elevated total available phosphorus are apparent in the northern, central, and western portions of the lake. The isopleths presented on Figure 2-10 can be utilized directly as a guide for future sediment inactivation activities.

Aluminum-bound phosphorus represents an unavailable species of phosphorus within the sediments. Phosphorus bound with aluminum is typically considered to be inert under a wide range of pH and redox conditions within the sediments. Aluminum-bound phosphorus concentrations range from 2-215 $\mu g/cm^3$, with an overall mean of 55 $\mu g/cm^3$. These values appear to be low to moderate compared with aluminum-bound phosphorus concentrations commonly observed in urban lake systems. These values suggest that only a small portion of the existing phosphorus within the sediments is bound in sediment associations which are considered to be unavailable.

2.3 Water Quality Characteristics of Lake Holden

2.3.1 Historical and Current Monitoring Efforts

An extensive data set of physical, chemical and biological data has been collected on Lake Holden by the Orange County Environmental Protection Department since 1972. Water quality monitoring was initiated in Lake Holden at a single station located in the north lobe of the lake. In addition to collection of field data such as pH, temperature and dissolved oxygen, water samples were also collected and returned to the Orange County Environmental Protection Department
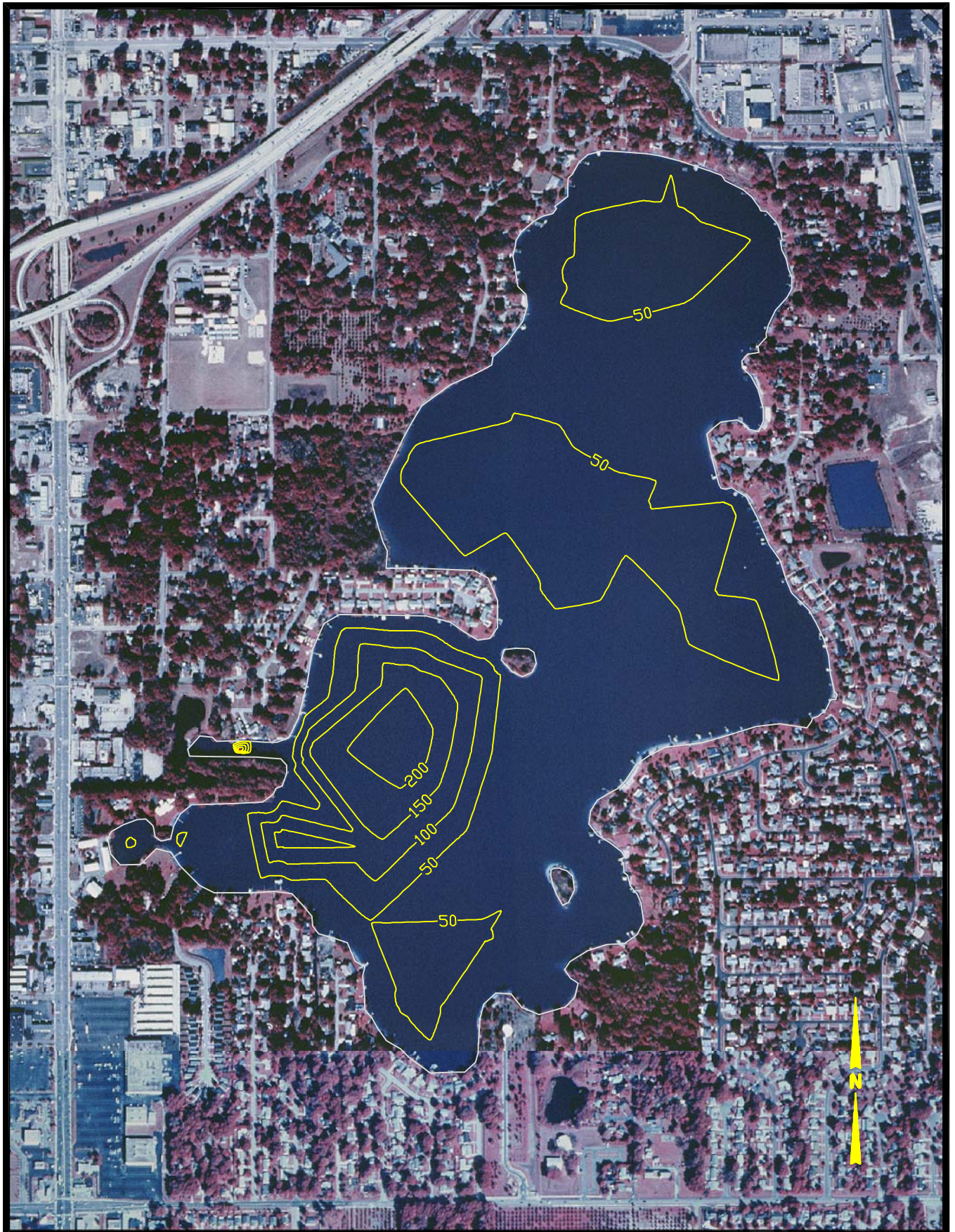
Figure 2-10.   Isopleths of Total Available Phosphorus (µg/g wet wt.) in the Top 10 cm of Sediments in Lake Holden.

Laboratory and evaluated for a wide range of chemical and biological parameters such as nutrients, suspended and dissolved solids, chlorides, metals (such as sodium, calcium, magnesium, potassium, iron, copper, lead, zinc, cadmium, aluminum, nickel and manganese), chlorophyll (a, b, and c), algal cell counts, and bacteriological analyses. Beginning in 1978, a second water quality monitoring station was established in Lake Holden in the south lobe of the lake.

From 1972 to 1976, water quality samples were collected at a frequency of one per year. On most occasions, separate water quality samples were collected from surface, middle and bottom layers of the water column to evaluate differences in water quality characteristics with increasing depth. Beginning in 1977, water quality monitoring was conducted on a more frequent basis with sample collection conducted on a semi-annual or quarterly basis through 1980. The frequency of water quality monitoring was increased to a bi-weekly basis at both the north and south stations from 1981 through 1987. Beginning in 1988, the frequency of water quality monitoring was reduced to a quarterly basis at both stations. However, only one sampling event was conducted during 1989. Also, beginning in 1988, water quality samples were collected from the surface only rather than the separate surface, middle and bottom water quality samples collected prior to 1988.

In addition to routine water quality data collection by Orange County, Lake Holden is also monitored by LAKEWATCH. LAKEWATCH is a volunteer water quality monitoring network conducted by concerned citizens who live on lakes which participate in the program. Lake Holden has been participating in this effort since 1989. Water quality samples and physical measurements are collected on a periodic basis and shipped to the University of Florida for analysis.

Routine water quality monitoring in Lake Holden was initiated by the City of Orlando Stormwater Utility Bureau during 2001. Monitoring is conducted on a quarterly basis for general parameters, nutrients, chlorophyll-a, and fecal coliform bacteria.

2.3.2 **Historical Water Quality Characteristics**

A historical water quality database was developed for Lake Holden by ERD by combining the original database described in the June 1992 report, with additional data collection efforts performed subsequent to this original data set. Although data have been collected by Orange County, LAKEWATCH, and the City of Orlando, only Orange County water quality data is used for purposes of this evaluation due to the extensive nature of the Orange County database and to eliminate potential variability caused by differences in collection and analysis techniques between the three collection agencies.

The historical data collected by Orange County was carefully reviewed by ERD and modified into an annotated database for purposes of evaluating long-term trends in water quality characteristics. First, the database was reviewed for obvious data anomalies, such as orthophosphorus values exceeding total phosphorus concentrations or highly improbable concentrations or values for any measured value. All questionable data was subsequently removed from the data set. In addition, only water quality samples collected from the "surface" monitoring sites are included in the database. Analyses for samples collected at "middle" and "bottom" layers of the water column, performed from 1972-1988, were eliminated from the database to provide a consistency of sampling depth for all comparative samples. On monitoring dates when samples were collected at multiple locations within Lake Holden, the results at each of the individual monitoring sites were averaged to provide a single mean value for the lake for each collection date.

An analysis of variance comparison (ANOVA) was performed by ERD to evaluate whether statistically significant differences exist between any of the monitoring sites included in Lake Holden. This analysis indicated that the monitoring sites are statistically similar for all measured parameters, supporting the conclusion to average separate measurements performed on a single monitoring date.

The procedures outlined above resulted in an annotated data set which was used for subsequent evaluations of historical water quality trends in Lake Holden. The historical water quality evaluations begin in 1977, since water quality samples were collected only once per year from 1972-1976, compared with multiple events performed from 1977 to the present. A digital copy of the annotated data set, in the form of a Microsoft Excel file, is given in Appendix A.

Historical water quality characteristics in Lake Holden were evaluated by ERD based upon annual average concentrations for total phosphorus, total nitrogen, Secchi disk depth, chlorophyll-a, TN/TP ratio, and TSI. Annual average values for these parameters are utilized rather than the results of individual monitoring dates since annual average values provide a less cluttered view of potential trends than a large scattering of individual data points.

Annual average concentrations of total phosphorus and total nitrogen in Lake Holden from 1977-2003 are indicated on Figure 2-11. Total phosphorus concentrations in Lake Holden appear to increase rapidly from 1977 to 1988, increasing by a factor of approximately 2 over this time. However, during the period from 1990-1995, annual average total phosphorus concentrations in Lake Holden appear to exhibit a gradual decrease. Current total phosphorus concentrations in Lake Holden appear to be similar to those which existed in the lake during the late-1970s. The gradual but consistent trend of decreasing phosphorus concentrations observed in Lake Holden from the early-1990s to the present appears to be a direct result of water quality improvement and stormwater management projects conducted in the Lake Holden watershed during this period. Improvements in total phosphorus within the lake are particularly apparent since the water quality improvement projects constructed in the Lake Holden basin have primarily targeted phosphorus removal.

A summary of annual average concentrations of total nitrogen in Lake Holden from 1977-2003 is also given on Figure 2-11. In contrast to the trends exhibited by total phosphorus, total nitrogen concentrations do not appear to exhibit a steady trend of either increasing or decreasing concentrations from 1980 until the present. Nitrogen concentrations within the lake have exhibited both upward and downward trends. The obvious trend of decreasing total phosphorus concentrations in Lake Holden is not apparent for total nitrogen since the water quality improvements constructed within the watershed have primarily targeted removal of total phosphorus.

Variations in annual average Secchi disk depth and chlorophyll-a concentrations from 1977-2003 are illustrated on Figure 2-12. Annual average Secchi disk depth in Lake Holden peaked at a value of approximately 1.85 m during 1980. However, since that time, annual average Secchi disk depth in Lake Holden has been consistently less than 1 m. Periods of upward and downward trends

Lake Holden

Annual Average Total Phosphorus

Annual Average Total Nitrogen
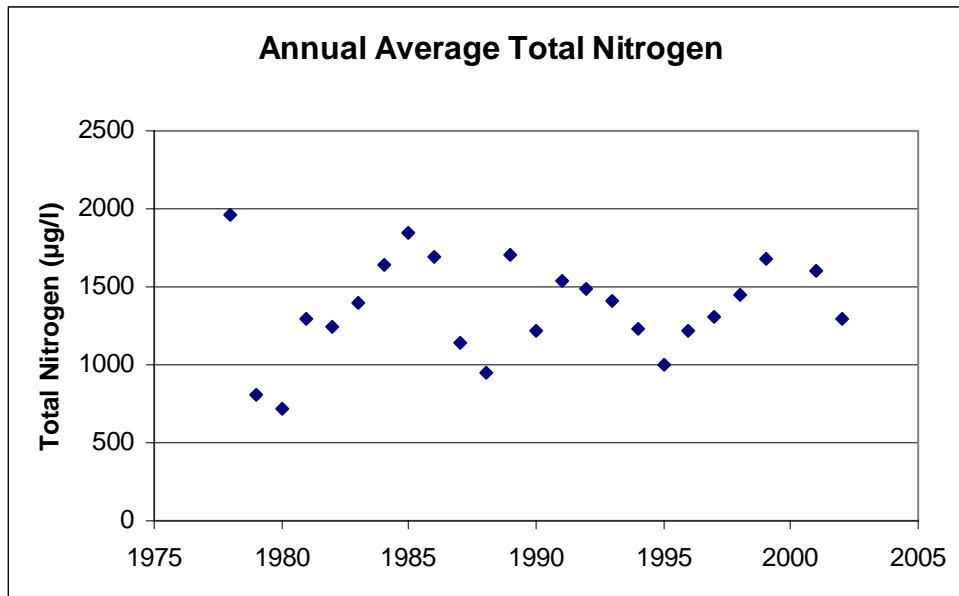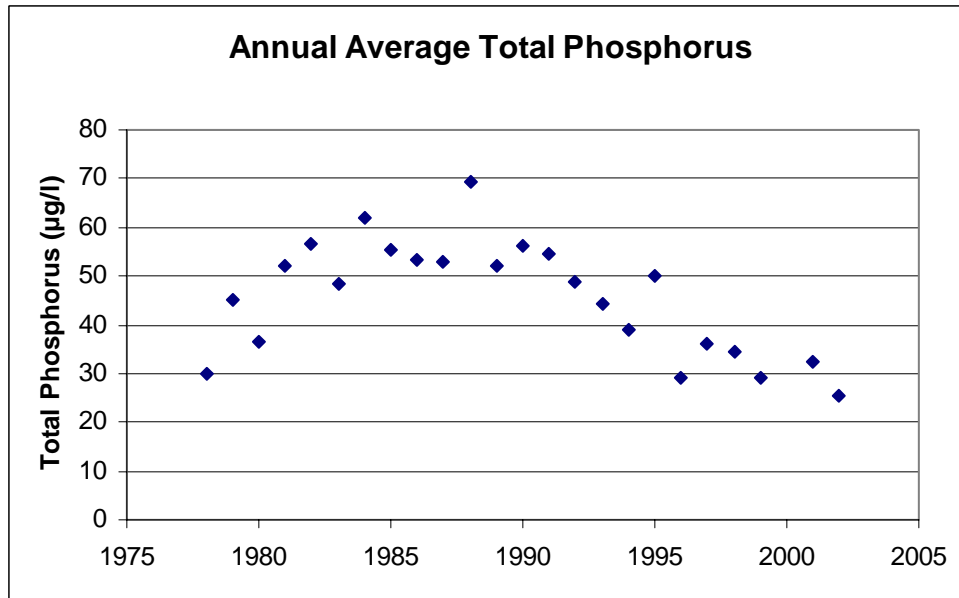
Figure 2-11. Annual Average Concentrations of Total P and Total N in Lake Holden from 1977 -2003.

Lake Holden
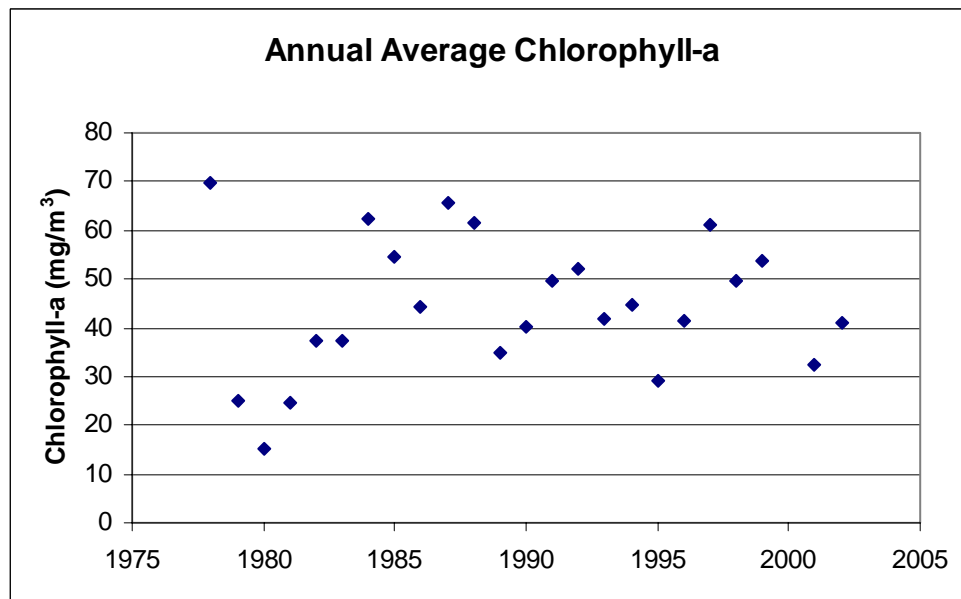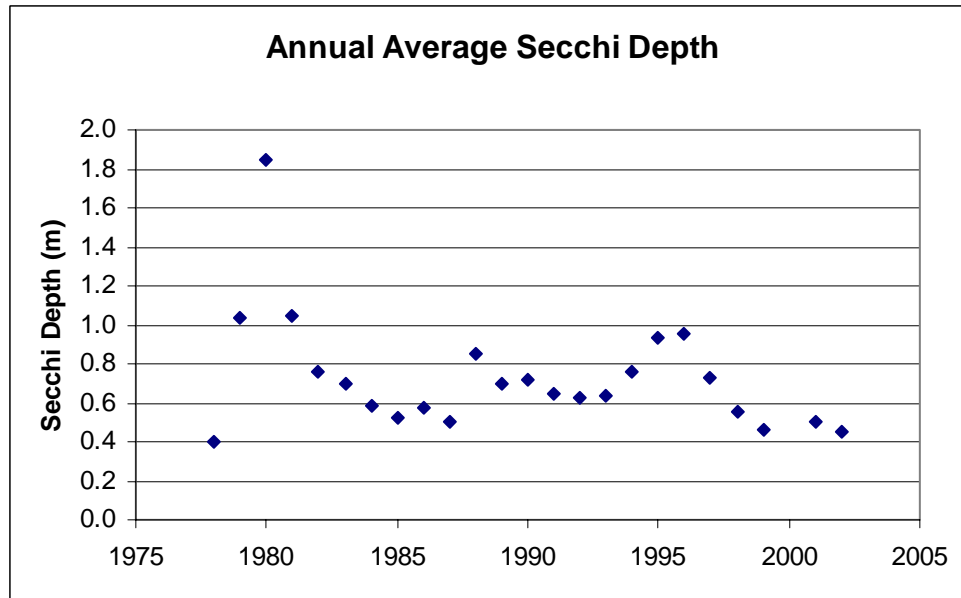
Figure 2-12. Annual Average Concentrations of Secchi Depth and Chlorophyll-a in Lake Holden from 1977 -2003.

in Secchi disk depth are apparent from 1980 until the present. Unfortunately, the obvious trend of decreasing phosphorus concentrations in the lake, illustrated on Figure 2-11, does not coincide with a corresponding increase in water column transparency within the lake.

Annual average chlorophyll-a concentrations in Lake Holden from 1977-2003 are also illustrated on Figure 2-12. A minimum in chlorophyll-a concentrations in Lake Holden was observed during 1980, corresponding to the maximum Secchi disk depth for the lake. However, since approximately 1985, chlorophyll-a concentrations within Lake Holden have averaged between 30-60 mg/m^3. No apparent trend of increasing or decreasing values is apparent for chlorophyll-a concentrations during this period, although since 2000, annual average chlorophyll-a concentrations within the lake have ranged between 30-40 mg/m^3.

Annual average TN/TP ratios in Lake Holden from 1977-2003 are illustrated on Figure 2-13. Annual average TN/TP ratios appear to exhibit a pronounced upward trend from 1980 until the present, indicating that Lake Holden is becoming more phosphorus-limited as time goes on. This conclusion follows closely with the trend of decreasing total phosphorus concentrations within the lake, suggesting that phosphorus is becoming more limited as phosphorus reduction efforts continue within the watershed. In general, TN/TP ratios less than 20 indicate nitrogen-limited conditions, with ratios between 20-30 indicating nutrient-balanced conditions, and ratios in excess of 30 indicating phosphorus-limited conditions. Based upon the annual average TN/TP ratios from 1995 to the present, it appears that Lake Holden is a strongly phosphorus-limited ecosystem.

Annual average TSI values in Lake Holden from 1977-2003 are also summarized in Figure 2-13. In general, Lake Holden exhibited borderline mesotrophic/oligotrophic conditions during 1980, followed by a rapid decline in water quality to eutrophic and hypereutrophic conditions during the 1980s. Since approximately 1990, Lake Holden has exhibited eutrophic water quality characteristics, with mesotrophic characteristics exhibited during 1995. A gradual trend of improving TSI value in Lake Holden is apparent since approximately 1985.

Additional evaluations were performed by ERD to examine seasonal variations in water quality in Lake Holden. For this evaluation, only data from 1995-2003 were utilized since water quality characteristics, particularly for total phosphorus, appear to have improved in Lake Holden from 1995 until the present.

Lake Holden
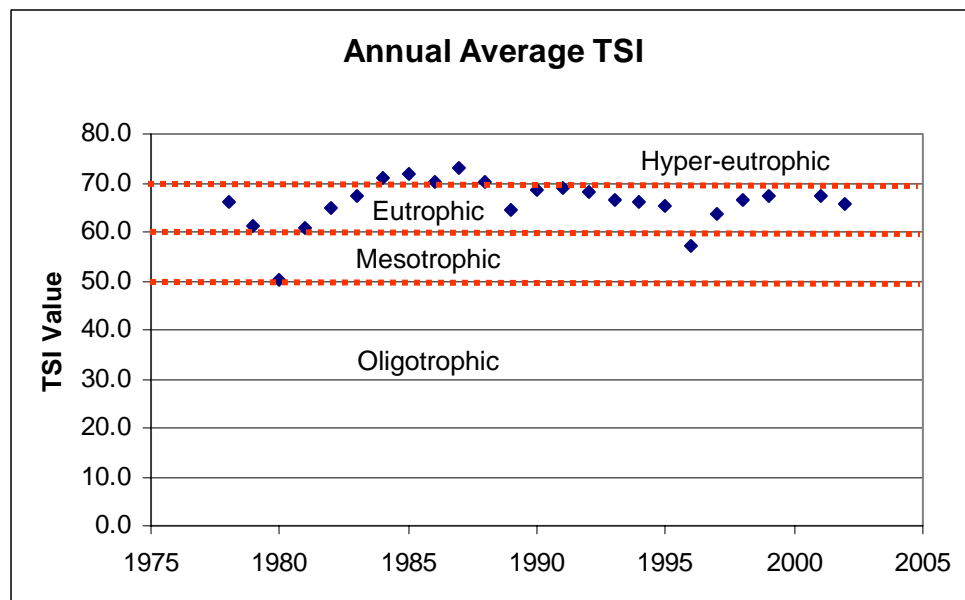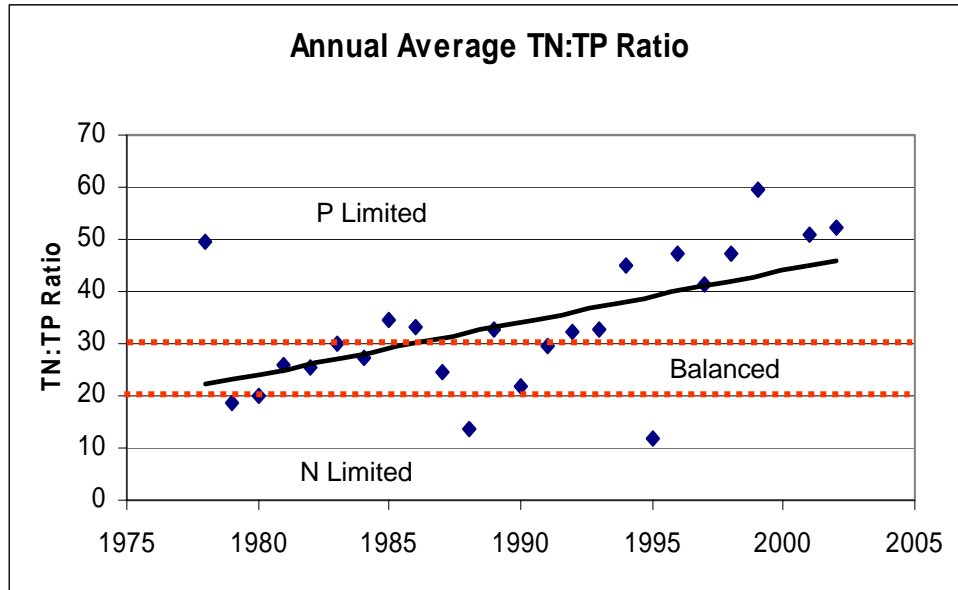
Figure 2-13. Annual Average TN:TP Ratios and TSI Values in Lake Holden from 1977 -2003.

Average monthly concentrations of total phosphorus in Lake Holden, based upon 1995-2003 data, are illustrated on Figure 2-14. In general, it appears that phosphorus concentrations in Lake Holden are lower during wet season months and higher during dry season conditions. If stormwater runoff were a primary contributor to phosphorus loadings in Lake Holden, it would be expected that total phosphorus concentrations would increase substantially during the wet season when runoff inputs are greatest, and a decrease in phosphorus concentrations would be observed during dry season conditions when runoff inputs are minimal. The trend apparent for total phosphorus in Figure 2-14 suggests that significant internal recycling may be occurring in Lake Holden. During late-spring through early-fall, lakes in Central Florida typically become stratified, with anoxic conditions developing in lower portions of the lake. This often causes the release of phosphorus from anoxic bottom sediments which begins to accumulate in lower isolated portions of the waterbody. During late-fall and winter conditions, when temperatures cool off and the water column begins to circulate readily, the accumulated phosphorus concentrations in lower layers of the lake migrate throughout the entire water column, resulting in substantial increases in phosphorus concentrations within the lake. The trend exhibited by total phosphorus for Lake Holden suggests that significant internal recycling, and subsequent resuspension during dry periods, may be occurring within the lake.

Average monthly concentrations of total nitrogen in Lake Holden from 1995-2003 are also indicated on Figure 2-14. No significant trends are apparent in total nitrogen during either wet season or dry season conditions. Since nitrogen is not substantially recycled from bottom sediments, the influence of this internal process is not apparent as it is for total phosphorus.

Average monthly concentrations for chlorophyll-a in Lake Holden are illustrated on Figure 2-15. Chlorophyll-a concentrations within the lake appear to correspond closely to the phosphorus concentrations indicated on Figure 2-14, with concentrations lowest during the wet season period and highest during dry season conditions.

Average monthly TN/TP ratios in Lake Holden from 1995-2003 are also illustrated on Figure 2-15. Phosphorus limitation increases during wet season conditions as phosphorus concentrations decrease within the lake. However, during other portions of the year, when phosphorus concentrations increase, the TN/TP ratio decreases, indicating that phosphorus is less

Lake Holden (1995-2003)
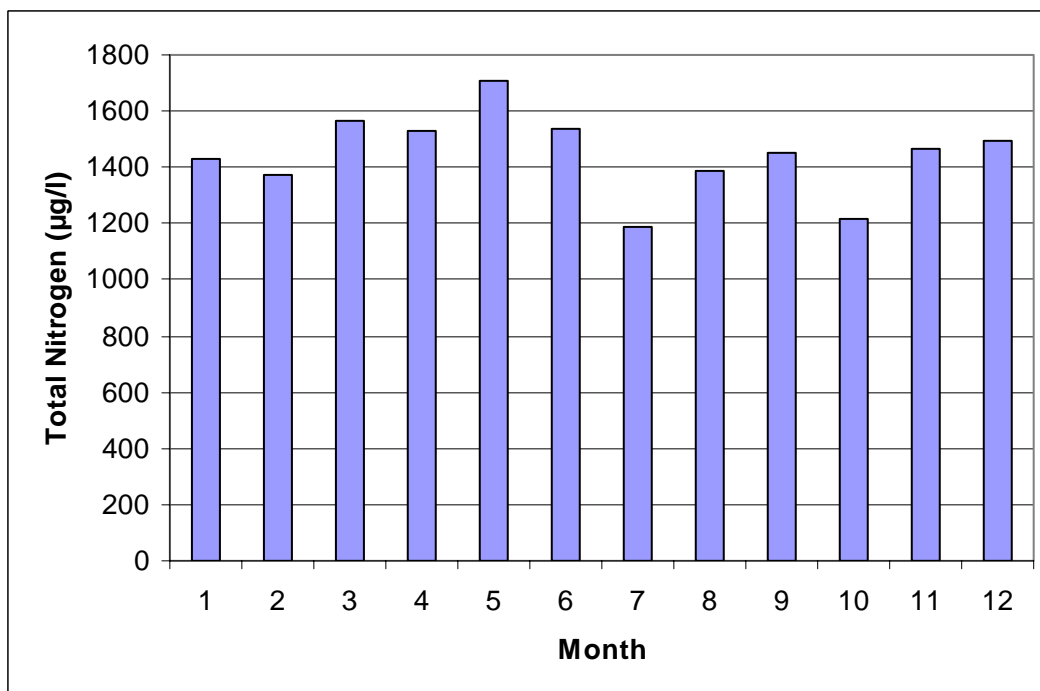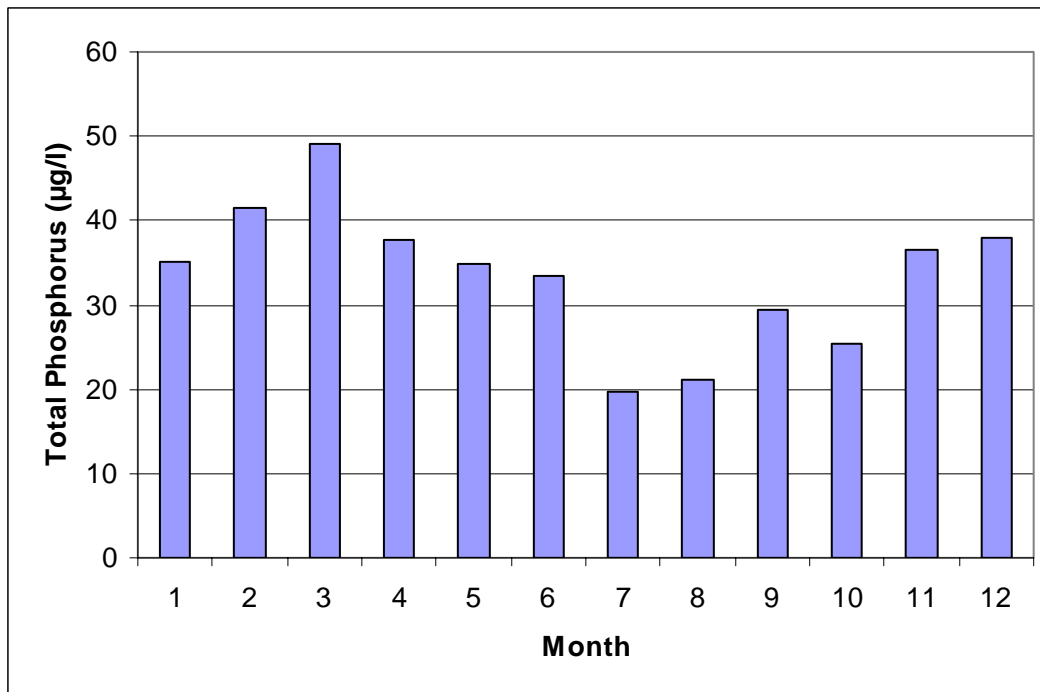
Figure 2-14. Average Monthly Concentrations of Total P and Total N in Lake Holden
         from 1995 -2003.

Lake Holden (1995-2003)
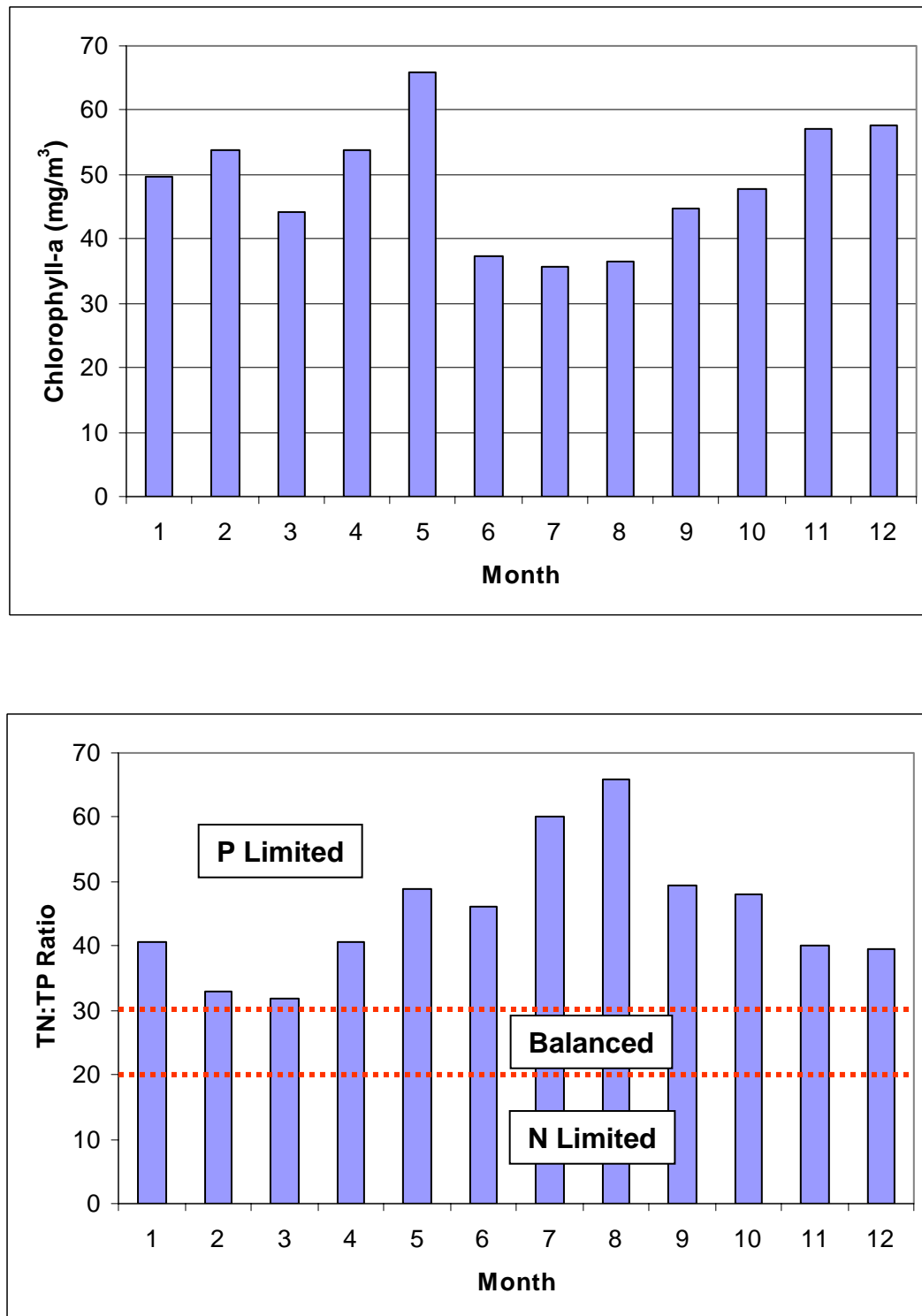
Figure 2-15. Average Monthly Concentrations of Chlorophyll-a and TN:TP Ratios
in Lake Holden from 1995 -2003.

limiting during these conditions than during the summer wet season months. This further supports the fact that phosphorus concentrations are closely related to circulation patterns within the lake which mix elevated concentrations of phosphorus from lower portions of the lake into the overlying water column.

2.3.3   Current Water Quality Characteristics

Current water quality characteristics in Lake Holden were evaluated by examining mean water quality characteristics within the lake from 1995-2003. As seen in Figure 2-11, total phosphorus concentrations within Lake Holden appear to have been relatively consistent from 1995 to the present with substantially lower levels than have existed in the lake during the 1980s or early-1990s. The lower total phosphorus concentrations observed since 1995 appear to reflect new equilibrium conditions within the lake as a result of recent water quality improvement projects. Since water quality appears to be relatively stable over this period, mean water quality characteristics in Lake Holden from 1995-2003 are used to represent existing ambient conditions within the lake.

Mean concentrations were calculated for total nitrogen, total phosphorus, BOD, chlorophyll-a, and Secchi disk depth for Lake Holden from 1995-2003 based upon the historical water quality data collected by OCEPD. During this period, a total of 89 separate samples were analyzed for total nitrogen, with more than 100 samples analyzed for the remaining parameters. A summary of water quality characteristics in Lake Holden from 1995-2003 is given in Table 2-8. Over this period, total nitrogen concentrations in the lake have exhibited an average of 1461 μg/l, with a mean of 34 μg/l for total phosphorus, 3.6 mg/l for BOD, 48.1 mg/m^3 for chlorophyll-a, and 0.61 m for Secchi disk depth. In addition to representing ambient water quality characteristics within Lake Holden, the values listed in Table 2-8 are also utilized in a subsequent section for calibration of a water quality model for the lake.

TABLE 2-8

**HISTORICAL MEAN WATER
QUALITY CHARACTERISTICS OF LAKE
HOLDEN FROM 1995-2003**

PARAMETER	UNITS	MEAN VALUE	NO. OF SAMPLES
Total N	μg/l	1461	89
Total P	μg/l	34	126
BOD	mg/l	3.64	104
Chlorophyll-a	mg/m^3	48.1	122
Secchi Disk	m	0.61	126

SECTION 3

HYDROLOGIC BUDGET

A hydrologic budget was developed for Lake Holden which includes inputs from stormwater runoff, direct precipitation, and shallow groundwater seepage. Hydrologic losses from Lake Holden are included for lake surface evaporation and discharges to existing drainage wells. The resulting hydrologic budget is used as an input for development of a nutrient budget and water quality model for Lake Holden and for estimation of the hydraulic residence time within the lake. Details and methodologies used for estimation of hydrologic inputs from the evaluated sources are included in the following sections.

3.1 Direct Precipitation

Estimates of mean monthly precipitation in the project area were generated by ERD based upon a statistical evaluation of total monthly rainfall at the Orlando International Airport (OIA) Meteorological Station over the period from 1974-1994. Only National Climatic Data Center (NCDC) valid years, defined as a year with valid data for all 12 months, were used in the analysis. A summary of mean monthly rainfall at the OIA Meteorological Station is given in Table 3-1. Mean monthly rainfall depths range from a low of 2.02 inches during December to a high of 7.55 inches in July, with an annual total of approximately 49.63 inches.

Based upon an estimated lake surface area of 266.2 acres and an annual average rainfall of 49.63 inches/year, direct precipitation contributes approximately 1101 ac-ft of water per year to Lake Holden. This estimate is approximately 0.5% greater than the estimated inputs from direct precipitation of 1096 ac-ft/yr given in the June 1992 report.

3-1

TABLE 3-1

**SUMMARY OF MEAN MONTHLY RAINFALL
IN THE ORLANDO AREA FROM 1974-1994**

MONTH	RAINFALL DEPTH		MONTH	RAINFALL DEPTH	
	inches	cm		inches	Cm
January	2.51	6.38	July	7.55	19.18
February	2.44	6.20	August	6.11	15.52
March	3.59	9.12	September	6.22	15.80
April	2.80	7.11	October	2.58	6.55
May	3.79	9.63	November	2.59	6.58
June	7.43	18.87	December	2.02	5.13
			TOTAL:	49.63	126.06

3.2 Stormwater Runoff

3.2.1 Description of Lake Holden Watershed

A delineation of watershed sub-basin areas contributing stormwater runoff to Lake Holden was prepared by ERD as part of the June 1992 report. For purposes of this evaluation, a sub-basin is defined as an area which discharges into Lake Holden through a single stormsewer outfall, consisting of either underground stormsewer pipes, vegetated conveyance channels, or overland flow. The June 1992 report indicated 22 separate drainage sub-basin areas with a total watershed area of 741.9 acres discharging into Lake Holden.

The original sub-basin delineations contained in the June 1992 report were reviewed by ERD as part of the current work efforts to include changes which may have occurred within the watershed as a result of development along with new stormsewer and hydrologic information which may have become available since the previous sub-basin delineation. Each stormsewer line was traced back through the watershed, beginning at the lake, and extending through the end of the stormsewer system. To the extent possible, manholes within the drainage basin were opened and visually inspected to verify the drainage system and to outline the extent of each drainage sub-basin.

Based upon the updated drainage basin review performed as part of the current study, ERD developed revised delineations for the overall Lake Holden drainage basin area and for individual sub-basin areas discharging to the lake. An overview of drainage sub-basin areas, based upon the revised delineations, is given in Figure 3-1. In general, the overall watershed shape and sub-basin delineations provided in Figure 3-1 are similar to the delineations contained in the June 1992 report with several significant modifications. First, the area of Sub-basin 2 has been increased to include additional areas which are now thought to discharge into Lake Holden. Sub-basin 4 has been divided into two separate areas, identified as Sub-basins 4A and 4B. Sub-basin 4A discharges through a 36-inch RCP to the lake, while Sub-basin 4B is believed to be a pumped discharge from a wet detention pond.

The area identified as Sub-basin 10 in the June 1992 report has been divided into two separate drainage basins, identified as Sub-basins 10A and 10B, which discharge through separate culverts into the lake. Areas contained within Sub-basins 12 and 13 have been increased slightly. The area contained within Sub-basin 19 has been reduced substantially, with the removed areas being allocated to Sub-basin 20. An area southeast of the intersection of I-4 and Michigan Street which was identified as "out of the basin" in the June 1992 report is now included as part of Sub-basin 20.

Overall, the drainage sub-basins indicated on Figure 3-1 include 24 separate sub-basin areas covering 769.2 acres. The drainage sub-basin areas indicated on Figure 3-1 contain an additional 27.3 acres not included in the June 1992 sub-basin areas, resulting in a sub-basin increase of approximately 3.7%. A summary of revised sub-basin areas and stormsewer conveyance system details is given in Table 3-2.

Based upon the estimated watershed area of 769.2 acres, and a lake surface area of 266.2 acres, the watershed area/lake surface area ratio for Lake Holden is approximately 2.89 (769.2 acres/266.2 acres). In general, watershed/lake surface area ratios less than 7 are often indicative of lakes where stormwater runoff contributes a relatively minor portion of the overall loadings into the lake system, while ratios substantially in excess of 7 indicate lakes which may be heavily impacted

Figure 3-1. Drainage Sub-Basin Areas Discharging to Lake Holden.

TABLE 3-2

**CHARACTERISTICS OF DRAINAGE SUB-BASIN
AREAS WITHIN THE LAKE HOLDEN DRAINAGE BASIN**

DRAINAGE SUB-BASIN	AREA (ac)	STORMSEWER SYSTEM
1	98.8	54" RCP along Division Avenue
2	65.7	48" x 76" RCP along Lake Holden Terrace
3	19.7	18" culvert at west end of Pineloch Avenue
4A	89.3	36" RCP west of detention pond
4B	12.8	Pumped overflow from wet detention pond
5	10.4	24" culvert along MacArthur Drive
6	8.8	Two 18" culverts along DeKalb Drive
7	52.9	48" RCP along Krueger Street
8	7.8	Drainage canal
9	6.8	24" culvert along Springwood Drive
10A	10.9	24" culvert to canal along Raymar Drive
10B	8.0	18" culvert to canal along South Shore Road
11	10.8	24" culvert at end of Almark Road
12	26.3	48" RCP into small west lobe
13	81.5	60" RCP along U.S. 441 to FDOT Pond
14	3.6	30" RCP from Days Inn
15	(4.5)	Land-locked basin
16	12.1	18" RCP along 38th Street
17	4.4	18" RCP along 37th Street
18	35.9	Vegetated channel
19	16.8	36" RCP from detention basin
20	60.9	36" culvert at end of 33rd Street
21	19.4	42" RCP along Paseo Street
22	105.5	Overland flow
Total:	**769.2**[1]	

1. Does not include land-locked Sub-basin 15

by stormwater runoff. The low watershed/lake area ratio of 2.89 for Lake Holden suggests that under ordinary conditions, stormwater runoff would not be a significant contributor to pollutant loadings in Lake Holden. However, due to the type and intensity of watershed activities in portions of the Lake Holden drainage basin, pollutant loadings from runoff have more impact in the Lake Holden watershed than typically observed in other watersheds in the Central Florida area. Therefore, even though the watershed/lake area ratio is relatively low, stormwater runoff still remains a significant contributor to pollutant loadings in Lake Holden.

General land use categories in the Lake Holden drainage basin are indicated on Figure 3-2. The majority of areas immediately adjacent to Lake Holden consist primarily of residential communities. Strips of commercial activities are present adjacent to Orange Blossom Trail and Orange Avenue, with industrial activities located north and northeast of the lake. Institutional land uses, consisting of a nursing home and elementary school, are located in the northwestern portions of the sub-basin. A relatively small area of agricultural activities is also located west of the lake. Major transportation corridors within the drainage basin include Orange Blossom Trail and Michigan Street.

General soil characteristics in the Lake Holden basin, presented in the form of Hydrologic Soil Groups (HSG) is given in Figure 3-3. Characteristics of hydrologic soil groups are summarized in Table 3-3. Soils classified in HSG A consist primarily of deep sandy soils, with high infiltration rates and a low runoff potential. Soils classified in HSG B exhibit moderate infiltration rates and a moderate runoff potential. Soils classified in HSG C consist primarily of sandy clay loams, with a low infiltration rate and a high runoff potential. Soils classified in HSG D consist primarily of clay or clay mixtures, with very low infiltration rates and a very high runoff potential.

As seen in Figure 3-3, the dominant soil group in the Lake Holden watershed is HSG A, indicating deep sandy soils with a low runoff potential. Many of these areas were historically used for agricultural and citrus activities prior to development into the existing land use categories. Areas adjacent to the western shoreline of Lake Holden exhibit soils in HSG C, with small pockets in HSG B. A small fringe of soils in HSG D are located along the southeastern shoreline of the lake.
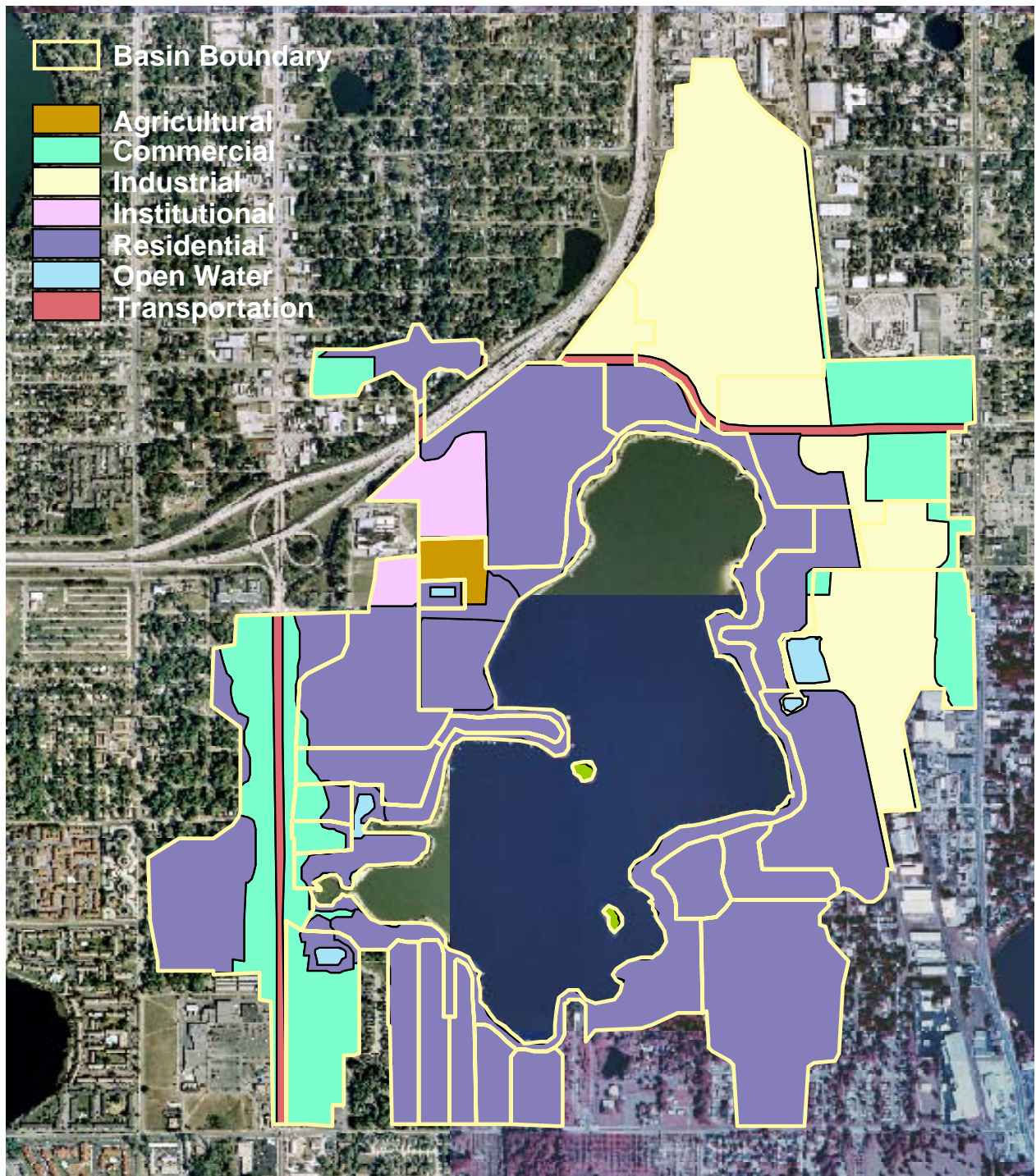
Figure 3-2. Land Use in the Lake Holden Drainage Basin.
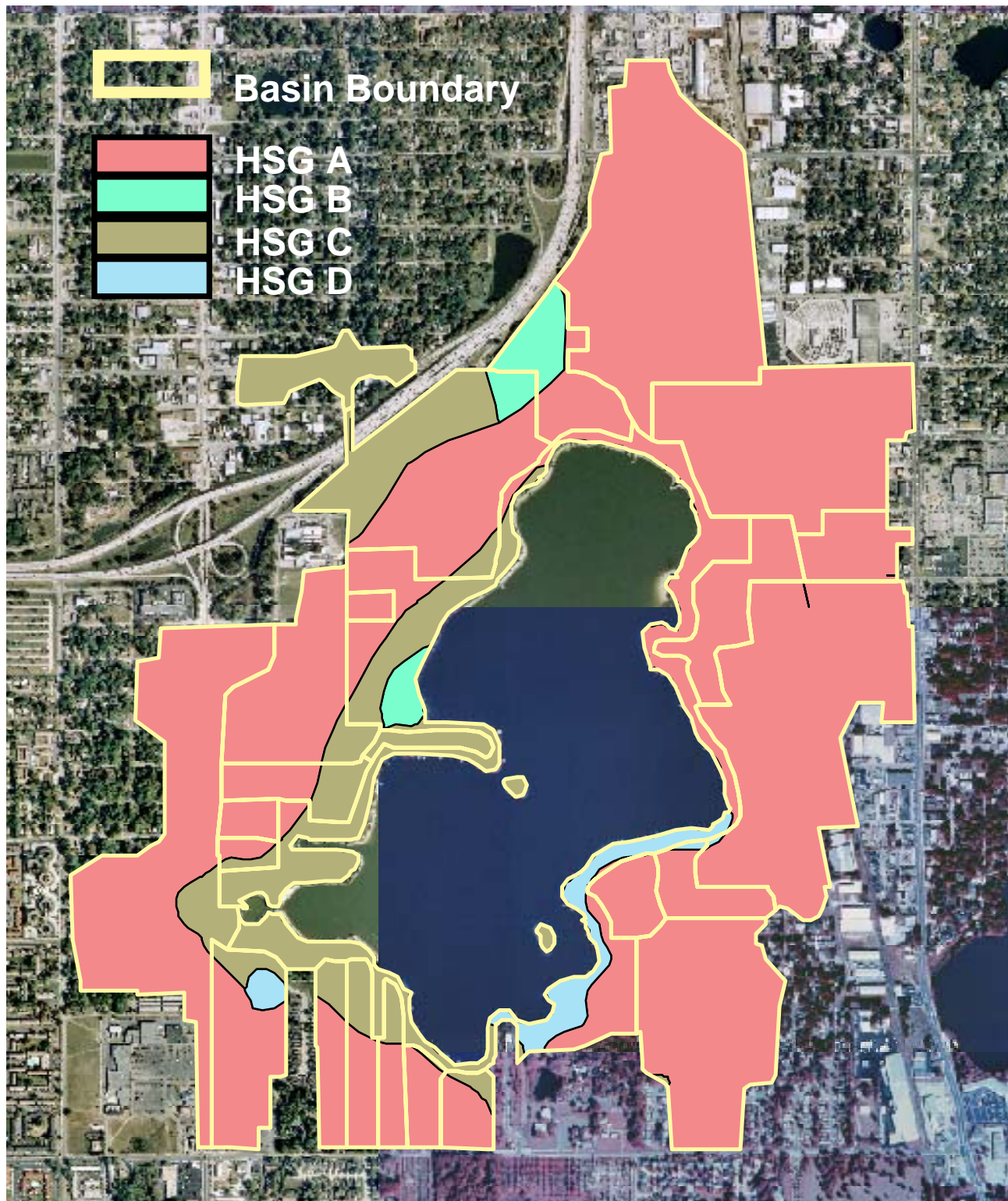
Figure 3-3. Hydrologic Soil Groups in the Lake Holden Drainage Basin.

TABLE 3-3

**CHARACTERISTICS OF
HYDROLOGIC SOIL GROUPS (HSG)**

HSG	SOIL TEXTURES	INFILTRATION RATE	RUNOFF POTENTIAL
A	Sand, loamy sand, or sandy loam	High (> 0.30 in/hr)	Low
B	Silt loam or loam	Moderate (0.15-0.30 in/hr)	Moderate
C	Sandy clay loam	Low (0.05-0.15 in/hr)	High
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay	Very low (0-0.05 in/hr)	Very high

3.2.2   Estimation of Runoff Inputs

Hydrologic modeling was performed by ERD to provide estimates of the annual runoff volume generated within each of the 24 sub-basin areas discharging to Lake Holden. Hydrologic characteristics for use in modeling purposes were obtained from the soils information in Figure 3-3 and from a visual inspection of 2000 aerial photography of the sub-basin area provided by the St. Johns River Water Management District (SJRWMD).   Information obtained from the aerial photographs, which is needed for modeling purposes, includes percentage of impervious areas within each sub-basin area and the percentage of directly connected impervious areas (DCIA). A summary of assumed hydrologic characteristics for each sub-basin area is included in the runoff modeling output provided in Appendix B.

Hydrologic modeling was performed by ERD based upon estimates of runoff volumes generated by common ordinary rain events and the statistical distribution of rain events occurring in the Orlando area during the period from 1965-1994 given in Table 3-4. A total of 19 rainfall event intervals were established to categorize typical rainfall amounts for single rain events within the project area. Next, the number of annual rain events falling within each of the selected interval ranges was estimated based upon a probability distribution of individual rainfall amounts occurring at the Orlando International Airport (OIA) Meteorological Station over the period from 1965-1994. During this period, approximately 43.6% of all rain events were 0.10 inch or less, 58.1% were 0.20 inch or less, and 76.7% were 0.50 inch or less.

TABLE 3-4

**DISTRIBUTION OF RAIN EVENTS IN THE
CENTRAL FLORIDA AREA FROM 1965-1994**

RAINFALL EVENT RANGE (in)	MEDIAN INTERVAL POINT (in)	NUMBER OF ANNUAL EVENTS IN RANGE
0.00-0.10	0.041	56.683
0.11-0.20	0.152	18.866
0.21-0.30	0.252	10.590
0.31-0.40	0.353	7.312
0.41-0.50	0.456	6.325
0.51-1.00	0.713	17.102
1.01-1.50	1.221	6.733
1.51-2.00	1.726	3.145
2.01-2.50	2.217	1.470
2.51-3.00	2.704	0.726
3.01-3.50	3.246	0.391
3.51-4.00	3.667	0.260
4.01-4.50	4.216	0.149
4.51-5.00	4.796	0.056
5.01-6.00	5.454	0.167
6.01-7.00	6.470	0.019
7.01-8.00	7.900	0.019
8.01-9.00	8.190	0.019
> 9.00	10.675	0.075

The SCS methodology was used to generate estimates of the runoff volumes produced within each identified sub-basin area for the 19 rainfall event intervals discussed previously. The value used for modeling in each interval represents the median of individual rain events in each of the 19 event intervals. Individual interval runoff coefficients were calculated by comparing computer estimates of the generated runoff volume with the corresponding rainfall volume selected for modeling purposes within each interval. This procedure allows the estimation of a runoff coefficient for a particular rainfall event within each sub-basin area.

Because of initial abstraction and infiltration by pervious areas, the modeled areas were found to generate little measurable runoff for rain events in the 0.0-0.05 inch interval, resulting in an estimated runoff coefficient of 0.00 for this interval. In general, runoff coefficients for rainfall events increase with increasing rainfall amounts as the influence of initial abstraction and infiltration becomes less significant in relation to the total rainfall volume.

The estimated annual runoff volumes for the 24 sub-basin areas were calculated by summing the estimated annual runoff volume generated by rain events in each of the selected rainfall interval ranges. A weighted annual runoff coefficient was calculated for each sub-basin based upon the annual estimated runoff volume and an average annual rainfall of 49.63 inches. Details of annual runoff volume estimation for the 24 sub-basin areas are given in Appendix B.

A summary of the estimated annual runoff volume generated in each of the 24 contributing sub-basin areas is given in Table 3-5. The annual runoff volume generated in the Lake Holden basin is estimated to be approximately 1073.4 ac-ft, which corresponds to a weighted basin "C" value of 0.337. This value indicates that approximately 33.7% of the annual rainfall volume which falls within the Lake Holden drainage basin is discharged into Lake Holden as stormwater runoff. The estimated annual runoff inflow of 1073.4 ac-ft is approximately 8.6% less than the estimated annual runoff inputs of 1074.8 ac-ft/yr given in the June 1992 report.

As seen in Table 3-5, approximately 24.3% of the annual runoff inputs to Lake Holden originate in Sub-basin 1, which is the large industrial area along Division Street north of Lake Holden. Approximately 12.6% of the annual runoff inputs originate in the residential/commercial sub-basin along Orange Blossom Trail. Approximately 12.5% of the annual runoff inputs are generated in Sub-basin 2, which includes the commercial and residential areas on the northeastern corner of the lake, with an additional 12.6% of annual runoff inputs contributed by Sub-basin 13 along Orange Blossom Trail. Approximately 10.9% of the runoff inputs into Lake Holden originate in the residential and industrial areas identified as Sub-basin 4A. Inputs into Lake Holden from the remaining sub-basin areas are approximately 6% or less of the total runoff volume discharging to the lake.

TABLE 3-5

**CALCULATED ANNUAL RUNOFF
VOLUMES DISCHARGING FROM SUB-BASIN
AREAS TO LAKE HOLDEN**

SUB-BASIN	AREA (acres)	ANNUAL RUNOFF VOLUME (ac-ft/yr)	RUNOFF COEFFICIENT ("C" VALUE)	PERCENT OF TOTAL
1	98.9	260.8	0.638	24.3
2	65.7	134.5	0.495	12.5
3	19.7	14.0	0.171	1.3
4A	89.3	117.3	0.318	10.9
4B	12.8	25.9	0.489	2.4
5	10.4	9.8	0.227	0.9
6	8.8	7.4	0.203	0.7
7	52.9	51.0	0.233	4.8
8	7.8	7.0	0.216	0.7
9	6.8	6.6	0.235	0.6
10A	10.9	11.2	0.248	1.0
10B	8.0	8.1	0.246	0.8
11	10.8	11.2	0.250	1.0
12	26.3	66.4	0.610	6.2
13	81.5	134.7	0.400	12.6
14	3.6	7.7	0.520	0.7
15	4.5[1]	0.0	0.000	0.0
16	12.1	12.3	0.247	1.1
17	4.4	5.6	0.311	0.5
18	35.9	32.5	0.219	3.0
19	16.8	22.6	0.326	2.1
20	60.9	64.0	0.254	6.0
21	19.4	35.2	0.440	3.3
22	105.5	27.6	0.063	2.6
Totals:[2]	**769.2**	**1073.4**	**0.337**	**100.0**

1. Land-locked basin
2. Does not include Sub-basin 15

3.3 Evaluation of Hydraulic Inputs
from Shallow Groundwater Seepage

Field investigations were performed by ERD to evaluate the quantity and quality of shallow groundwater seepage entering Lake Holden under existing conditions. Groundwater seepage was quantified using a series of seepage meters installed at strategic locations throughout the lake. Seepage meters provide a mechanism for direct measurement of groundwater inflow into a lake by isolating a portion of the lake bottom so that groundwater seeping up through the bottom sediments into the lake can be collected and characterized. Use of the direct seepage meter measurement technique avoids errors, assumptions, and extensive input data required when indirect techniques are used, such as the Gross Water Budget or Subtraction Method, as well as computer modeling and flow net analyses.

The seepage meter technique has been recommended by the U.S. Environmental Protection Agency (EPA) and has been established as an accurate and reliable technique in field and tank test studies (Lee, 1977; Erickson, 1981; Cherkauer and McBride, 1988; Belanger and Montgomery, 1992). With installation of adequate numbers of seepage meters and proper placement, seepage meters are a very effective tool to estimate groundwater-surface water interactions. One distinct advantage of seepage meters is that seepage meters can provide estimates of both water quantity and quality entering a lake system, whereas estimated methods can only provide information on water quantity.

3.3.1 Seepage Meter Construction and Locations

A schematic of a typical seepage meter installation used in Lake Holden is given in Figure 3-4. Seepage meters were constructed from a 2-ft diameter aluminum container with a closed top and open bottom. Each seepage meter isolated a sediment area of approximately 3.14 ft^2. Seepage meters were inserted into the lake sediments to a depth of approximately 8-12 inches, isolating a portion of the lake bottom. Approximately 3 inches of water was trapped inside the seepage meter above the lake bottom.

Typical Seepage
Meter Installation

FLOATING MARKER

WATER SURFACE

PVC CAMLOCK

ALUMINUM
CHAMBER
OPEN BOTTOM
(0.60m DIA.)

PVC BALL VALVE

FLEXIBLE
HDPE CONTAINER
(151 LITERS)

WEIGHT

LAKE BOTTOM

ORGANIC SEDIMENTS
(DEPTH VARIES)
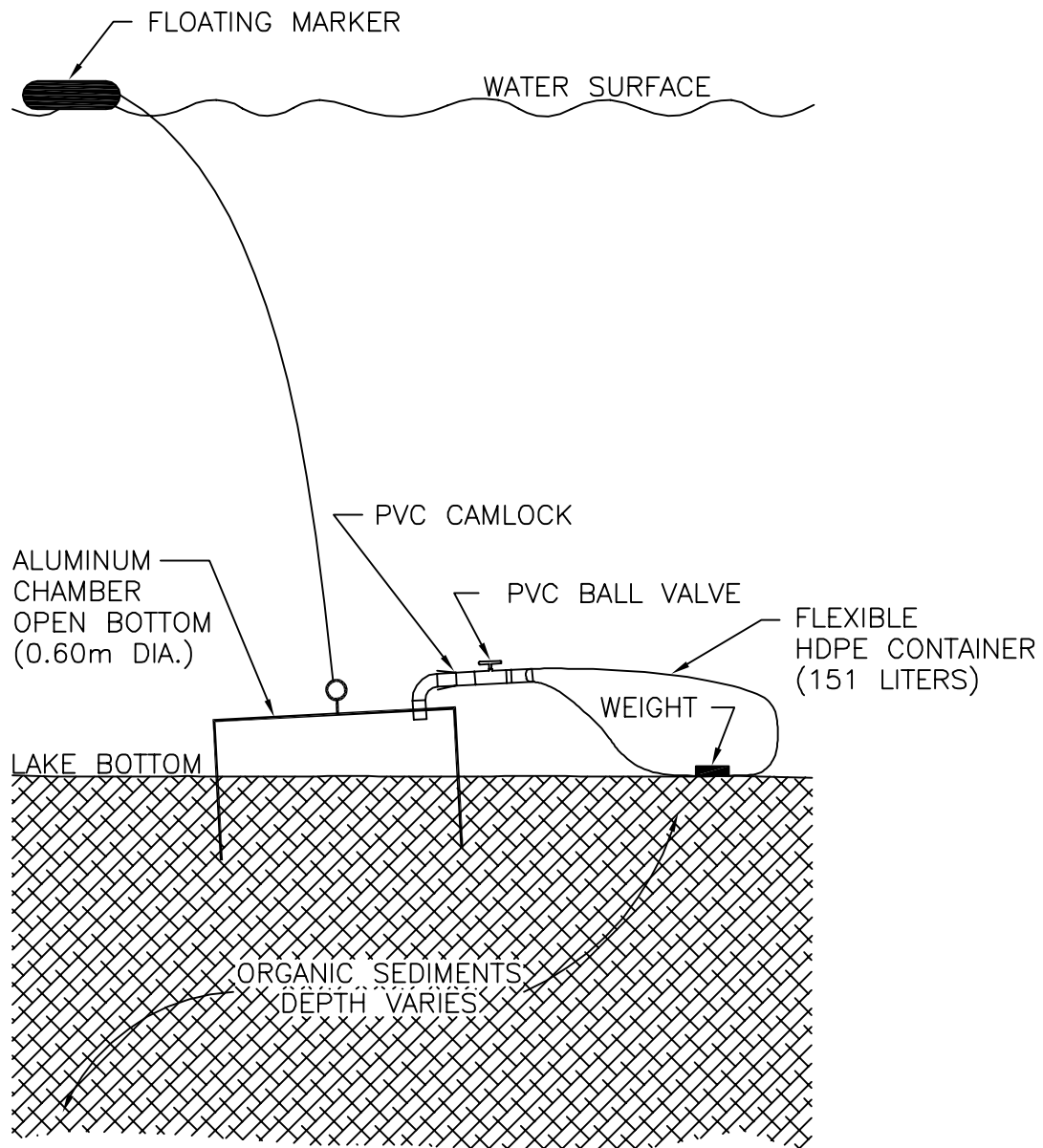
Figure 3-4. Typical Seepage Meter Installation.

A 0.75-inch threaded PVC fitting was threaded into the top of each aluminum container. The 0.75-inch PVC fitting was attached to a female quick-disconnect PVC camlock fitting. A flexible polyethylene bag, with an approximate volume of 40 gallons, was attached to the seepage meters using a quick-disconnect PVC male camlock fitting with a terminal ball valve. Each of the collection bags was constructed of black polyethylene to prevent light penetration into the bag. Light could potentially stimulate photosynthetic activity within the sample prior to collection and result in an undesirable alteration of the chemical characteristics of the sample.

Prior to attachment to the seepage meter, all air was removed from inside the polyethylene collection bag, and the PVC ball valve was closed so that lake water would not enter the collection container prior to attachment to the seepage meter. A diver then connected the collection bag to the seepage meter using the PVC camlock fitting. After attaching the collection bag to the seepage meter, the PVC ball valve was then opened. As groundwater influx occurs into the open bottom of the seepage meter, it is collected inside the flexible polyethylene bag.

Each seepage meter was installed with a slight tilt of approximately 2-3E toward the outlet point so that any gases which may be generated inside the seepage meter would exit into the collection container. A plastic-coated fishing weight was placed inside each of the collection bags to prevent the bags from floating up towards the water surface as a result of trapped gases. The location of each seepage meter was indicated by a floating marker in the lake which was attached to the seepage meter using a coated wire cable.

A total of 10 seepage meters was installed in Lake Holden during March 2003. Locations for the seepage meters are indicated on Figure 3-5. Since seepage inflow is often most variable around the perimeter of a lake, the majority of the seepage meters were installed around the lake perimeter at a uniform water depth of approximately 5 ft. Seepage meters were also installed in the central portions of the lake in areas of maximum water depth.

Each of the 10 seepage meters was monitored on approximately a monthly basis from April-October 2003. A total of seven separate seepage monitoring events was conducted for evaluation of quantity and quality at each of the monitoring sites, with a total of 59 samples collected between the 10 sites.
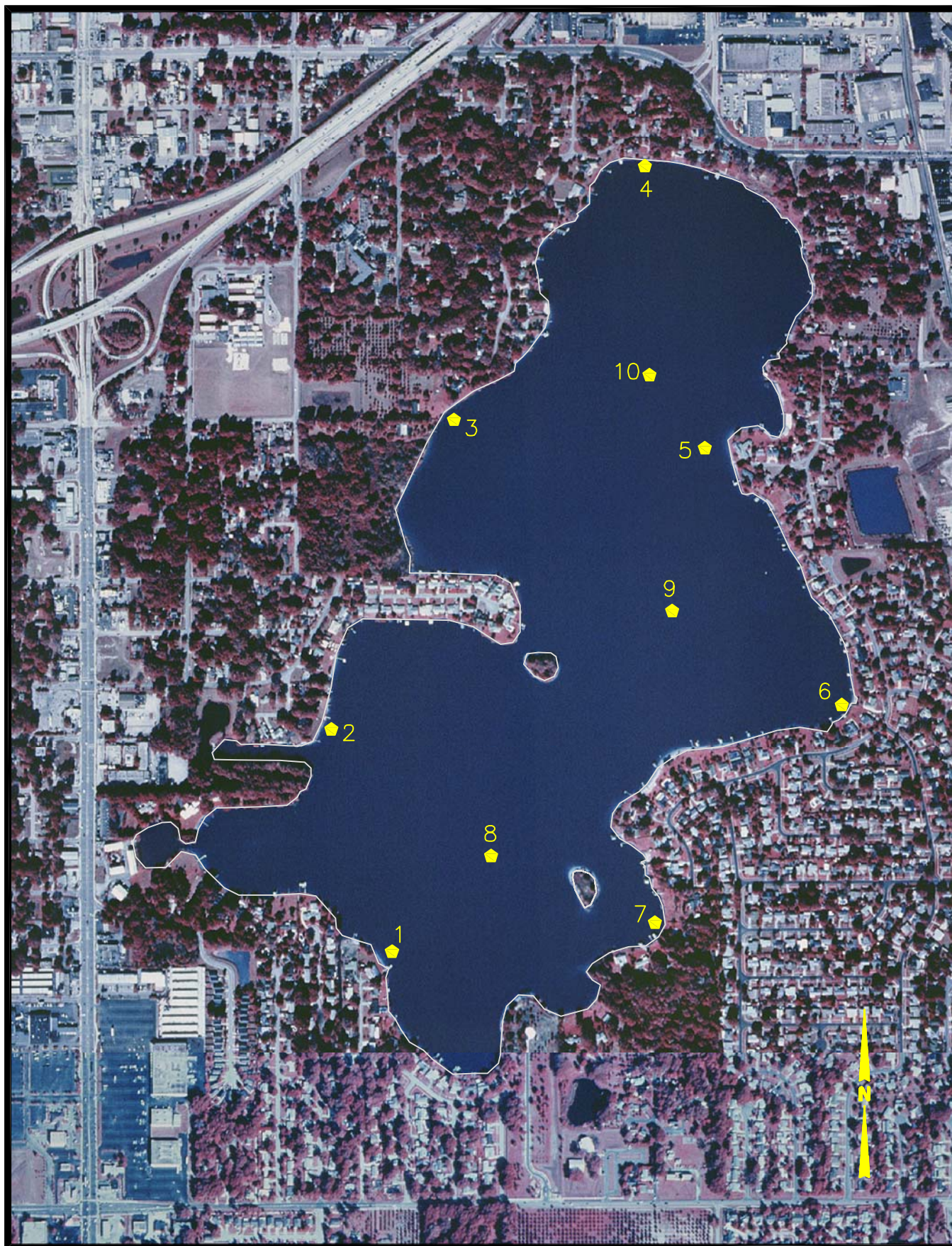
Figure 3-5. Seepage Meter Monitoring Sites.

3.3.2   Seepage Meter Sampling Procedures

After the initial installation of collection bags, site visits were performed on 4- to 6-week intervals to collect groundwater samples. During the collection process, a diver was used to close the PVC ball valve and remove the collection bag from the seepage meter using the quick-disconnect camlock fitting. The collection bag was placed onto the boat and the volume of seepage collected in the container was measured using a 4-liter graduated cylinder. Seepage samples which contained larger volumes of water were measured using a graduated polyethylene bucket.

Following the initial purging, seepage meter samples were collected for return to the laboratory for chemical analysis. On many occasions, seepage meter samples were found to contain turbidity originating from the sediments isolated within the seepage meter. As a result, seepage meter samples collected for chemical analyses were field-filtered using a 0.45 micron disposable glass fiber filter typically used for filtration of groundwater samples. A new filter was used for each seepage sample. Seepage samples were filtered immediately following collection using a battery operated peristaltic pump at a flow rate of approximately 0.25 liter/minute. The filtered seepage sample was placed on ice for return to the ERD laboratory for further chemical analyses.

A summary of field measurements of seepage inflow over the monitoring period from April-October 2003 is given in Appendix C. During collection of groundwater seepage, information was recorded on the time of sample collection, the total volume of seepage collected at each site, and general observations regarding the condition of the seepage collection bags and replacement/repair details. The seepage flow rate at each location is calculated by dividing the total collected seepage volume (liters) by the area of the seepage meter (0.27 m^2) and the time (days) over which the seepage sample was collected. As seen in Appendix C, a number of seepage meter sites contain missing data for one or more events as a result of missing or damaged collection bags and seepage meters.

3.3.3   <u>Field Measurements of Seepage Inflow</u>

A summary of mean seepage values measured at each of the 10 monitoring sites is given in Table 3-6. In general, seepage influx into Lake Holden appears to be greatest in shoreline perimeter areas, with decreased seepage inflow in central portions of the lake. Areas of particularly elevated seepage inflow were observed along the northern and eastern boundaries of the lake.

TABLE 3-6

MEAN SEEPAGE INFLOW TO LAKE
HOLDEN BY SITE FROM APRIL-OCTOBER 2003

SITE	MEAN INFLOW (liters/m^2-day)
1	2.8
2	3.1
3	1.5
4	4.6
5	2.0
6	6.4
7	1.8
8	0.2
9	2.0
10	0.1

Estimated seepage inflow isopleths for Lake Holden are illustrated on Figure 3-6. The isopleths present estimates of mean groundwater inflow into the lake in terms of liters per square meter of surface area per day. The highest rates of seepage influx appear to occur in northern, eastern, and western portions of the lake, with lower estimated seepage influx in central portions of the lake.

Figure 3-6.   Isopleths of Groundwater Seepage (l/m$^2\cdot$ day) inflow to Lake Holden.

The seepage isopleths indicated on Figure 3-6 were graphically integrated to obtain estimates of mean daily seepage influx into Lake Holden. This mean value was converted to an annual average by multiplying by 365 days/year. Based upon this analysis, seepage influx into Lake Holden is estimated to contribute approximately 564.75 ac-ft/yr of water inputs into the lake. This corresponds to an areal loading of 2.156 ac-ft per acre of lake area per year. These values are utilized in subsequent sections for development of an overall hydrologic budget for Lake Holden.

3.4 Evaporation Losses

Estimates of monthly lake evaporation data were generated based upon mean monthly evaporation data collected at the Lake Alfred Experimental Station over the 30-year period from 1965-1994. This evaporation site appears to be the closest long-term monitoring station to the Central Florida area. A summary of mean monthly evaporation for this site is given in Table 3-7. For purposes of this project, the mean evaporation measured at the Lake Alfred site is assumed to be similar to evaporation at Lake Holden. The recorded data at the Lake Alfred site reflects pan evaporation, with lake evaporation assumed to be equal to 70% of the pan evaporation values.

TABLE 3-7

**MEAN MONTHLY LAKE EVAPORATION AT
THE LAKE ALFRED EXPERIMENTAL STATION SITE**

MONTH	MEAN PAN EVAPORATION (inches)	LAKE EVAPORATION[1] (inches)	MONTH	MEAN PAN EVAPORATION (inches)	LAKE EVAPORATION[1] (inches)
January	3.47	2.43	July	7.57	5.30
February	4.21	2.95	August	7.16	5.01
March	6.26	4.38	September	6.28	4.40
April	7.60	5.32	October	5.51	3.86
May	8.47	5.93	November	3.98	2.79
June	7.65	5.36	December	3.22	2.25
			TOTAL:	**71.38**	**49.98**

1. Assumed to be 70% of pan evaporation

Based upon the information contained in Table 3-7, mean monthly lake evaporation ranges from a low of 2.25 inches/month in December to a high of 5.93 inches/month in May. The estimated total annual lake evaporation is 49.98 inches. Based upon an average lake area of 266.2 acres, and an annual lake evaporation loss of 49.98 inches, the estimated annual evaporation losses from the surface of Lake Holden are equivalent to approximately 1108.7 ac-ft/yr.

3.5 Hydrologic Budget

A summary of estimated annual hydrologic inputs to Lake Holden, based upon inputs from direct precipitation, stormwater runoff, and groundwater seepage, is given in Table 3-8. The average annual inflow to Lake Holden is estimated to be approximately 2739 ac-ft/yr, with approximately 40.2% of this volume contributed by direct precipitation, 39.2% contributed by stormwater runoff, and 20.6% contributed by groundwater seepage. A graphical comparison of annual hydrologic inputs to Lake Holden is given in Figure 3-7.

TABLE 3-8

**ESTIMATED ANNUAL HYDROLOGIC
INPUTS TO LAKE HOLDEN**

SOURCE	ANNUAL INFLOW (ac-ft/yr)	PERCENT OF TOTAL
Stormwater Runoff	1073	39.2
Direct Precipitation	1101	40.2
Groundwater Seepage	564.8	20.6
TOTAL:	**2739**	**100.0**

Hydrologic losses from Lake Holden occur as a result of surface evaporation and discharge into the drainage wells within the lake. As indicated in Section 3.4, evaporation losses from Lake Holden are estimated to be approximately 1108.7 ac-ft/yr. The different between this value and the total estimated annual inputs of 2739.2 ac-ft/yr is assumed to be the volume which discharges into the drainage well structures. On an annual basis, this inflow is estimated to be approximately 1630.5 ac-ft/yr.

Hydrologic Inputs

Groundwater Seepage, 564.8 ac-ft/yr

Stormwater Runoff, 1073.4 ac-ft/yr

Bulk Precipitation, 1101 ac-ft/yr

Hydrologic Losses

Evaporation, 1108.7 ac-ft/yr

Discharge to Drainage Wells, 1630.5 ac-ft/yr
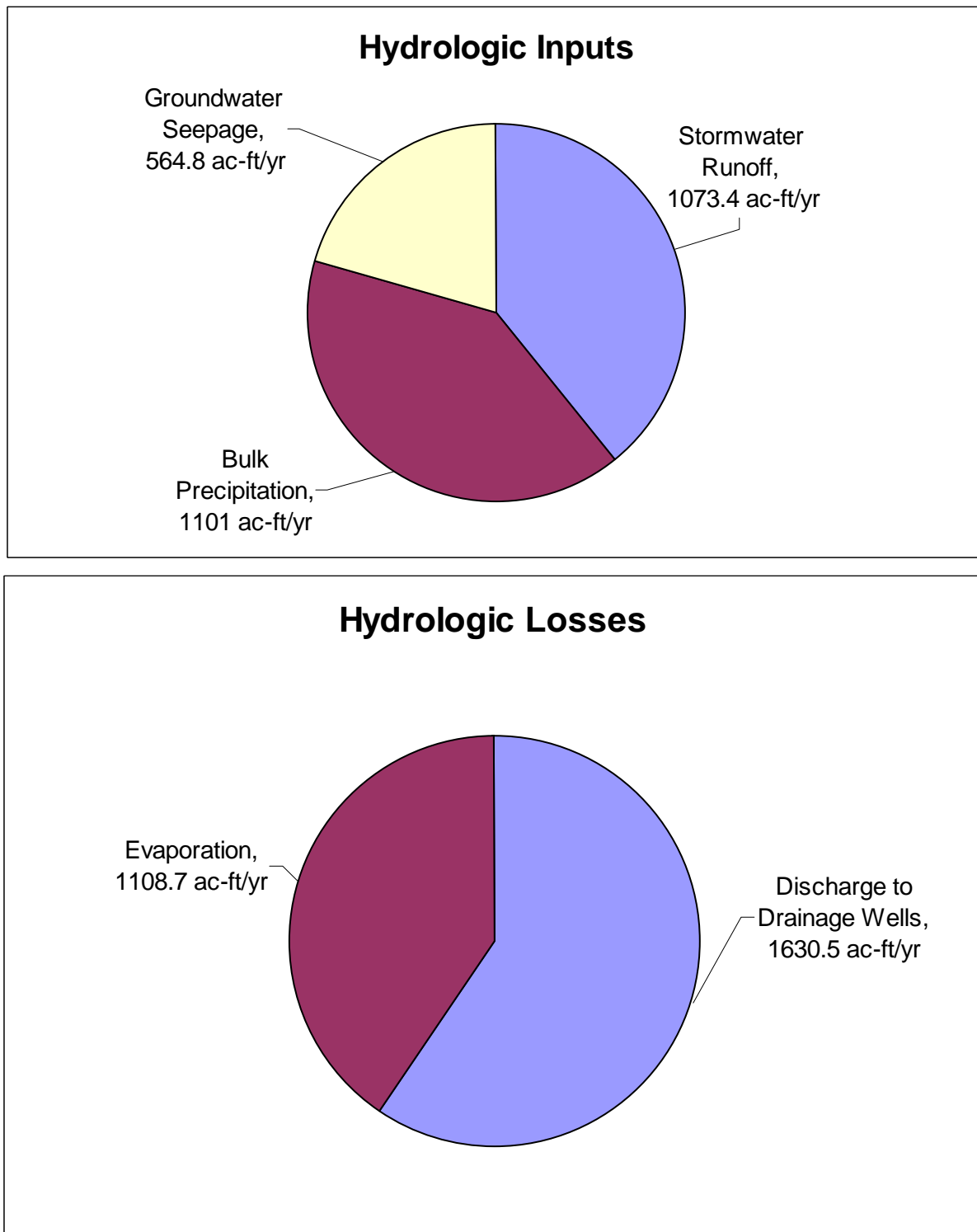
Figure 3-7. Annual Hydrologic Inputs and Losses to Lake Holden.

A summary of estimated volumetric losses from Lake Holden is given in Table 3-9. Approximately 59.5% of the annual hydrologic losses from the lake occur into the drainage well structures, with 40.5% of the annual losses occurring as a result of evaporation. A comparison of hydrologic losses from Lake Holden is also included on Figure 3-7.

TABLE 3-9

**ESTIMATED ANNUAL VOLUMETRIC
LOSSES FROM LAKE HOLDEN**

PARAMETER	ANNUAL LOSS (ac-ft/yr)	PERCENT OF TOTAL
Discharge to Drainage Wells	1630.5	59.5
Evaporation[1]	1108.7	40.5
TOTAL:	**2739.2**	**100.0**

1. Based on an assumed lake evaporation rate of 49.98 inches/year

3.6 Annual Residence Time

Residence time in a lake is calculated by dividing the lake volume by the estimated annual inputs per year. Based upon an estimated lake volume of 3211.5 ac-ft, and estimated annual hydrologic inputs of 2739.2 ac-ft/yr, the annual residence time in Lake Holden is approximately 1.17 years or 427 days. This value is relatively long for a Central Florida lake and is due primarily to the large water volume contained within Lake Holden.

SECTION 4

NUTRIENT BUDGET

A nutrient budget was prepared for Lake Holden which includes inputs of total phosphorus, total nitrogen, BOD, and total suspended solids (TSS) resulting from bulk precipitation, stormwater runoff, groundwater seepage, and internal recycling. The nutrient budget is based upon components of the hydrologic budget outlined in Section 3 and the results of field monitoring efforts performed by ERD to evaluate the characteristics of stormwater runoff, groundwater seepage, and internal recycling. A summary of estimated inputs from each of these sources is given in the following sections.

4.1 Bulk Precipitation

ERD has performed several evaluations of the characteristics of bulk precipitation in the Central Florida area as a part of research projects conducted for the St. Johns River Water Management District (SJRWMD) and the Florida Department of Environmental Protection (FDEP). Bulk precipitation includes the combined inputs of direct precipitation and dry fallout. A summary of typical characteristics of bulk precipitation measured in the Central Florida area by ERD is given in Table 4-1. These values represent a total of 17 bulk precipitation samples collected during the period from June-November 1992 in a combined residential/highway land use area. For purposes of this evaluation, it is assumed that the bulk precipitation characteristics in Table 4-1 are similar to bulk precipitation which falls on Lake Holden.

TABLE 4-1

**MEAN CHARACTERISTICS OF BULK
PRECIPITATION IN THE CENTRAL FLORIDA AREA**

PARAMETER	UNITS	CONCENTRATION
Nitrogen	µg/l	671
Phosphorus	µg/l	45
TSS	mg/l	6.2
BOD	mg/l	2.0

Estimates of annual mass loadings from bulk precipitation to Lake Holden were calculated for total nitrogen, total phosphorus, BOD, and TSS based upon the typical characteristics listed in Table 4-1 and the estimated annual volumetric inputs from direct precipitation listed on Table 3-8. A summary of estimated annual loadings to Lake Holden from bulk precipitation is given in Table 4-2. Inputs from bulk precipitation contribute approximately 911 kg/yr of total nitrogen, 61.1 kg/yr of total phosphorus, 2716 kg/yr of BOD, and 8418 kg/yr of TSS.

TABLE 4-2

**ESTIMATED ANNUAL LOADINGS TO
LAKE HOLDEN FROM BULK PRECIPITATION**

PARAMETER	MASS LOADINGS (kg/yr)
Total N	911
Total P	61.1
BOD	2716
TSS	8418

4.2 Stormwater Runoff

4.2.1 Stormwater Monitoring Program

A stormwater monitoring program was conducted by ERD from June-September 2003 to evaluate the chemical characteristics of stormwater runoff entering Lake Holden from six major drainage sub-basin areas. Approximate locations used for collection of stormwater runoff samples in the Lake Holden drainage basin are indicated on Figure 4-1 and summarized in Table 4-3. The sampling sites used for collection of stormwater runoff during the 2003 monitoring program are the same sites utilized by ERD for characterization of stormwater runoff in the Lake Holden basin during June 1991 and January 1992. Based upon the revised sub-basin areas summarized in Table 3-2, and the calculated annual runoff inputs from sub-basin areas listed in Table 3-5, the sub-basin areas monitored by ERD during 2003 reflect 44.8% of the total drainage basin area discharging to Lake Holden and contribute approximately 63.6% of the total annual runoff inputs to Lake Holden.

TABLE 4-3

LOCATIONS USED FOR COLLECTION OF STORMWATER RUNOFF SAMPLES IN THE LAKE HOLDEN DRAINAGE BASIN

SUB-BASIN	SUB-BASIN AREA (ac)	ANNUAL RUNOFF (ac-ft)	DESCRIPTION	TREATMENT TYPE
1	98.9	260.8	54" RCP along Division Avenue	Alum injection
2	65.7	134.5	48" x 76" RCP along Lake Holden Terrace	Alum injection
7	52.9	51.0	48" RCP along Krueger Street	None
12	26.3	66.4	Outfall from pond which treats 48" RCP from commercial area at corner of South Orange Blossom Trail (U.S. 441) and Holden Avenue	Wet detention pond
13	81.5	134.7	Outfall from pond which treats 60" RCP along South Orange Blossom Trail (U.S. 441)	Wet detention pond
21	19.4	35.2	42" RCP along Paseo Street	Alum injection
Total:	**344.7** **(44.8% of total)**	**682.6** **(63.6% of total)**		

Figure 4-1.   Locations of Stormwater Monitoring Sites

Five of the six monitoring sites listed in Table 4-3 have been retrofitted with stormwater management systems since the previous monitoring performed by ERD during 1991-1992. Sub-basins identified as 1, 2, and 21 have been retrofitted with alum injection stormwater treatment systems. Sub-basin areas identified as 12 and 13 have been retrofitted with wet detention ponds. No stormwater retrofit activities have been performed in Sub-basin 7 which consists of a large residential area which discharges along Krueger Street.

The monitoring sites indicated on Table 4-3 were selected for two reasons. The monitoring program was designed primarily to evaluate the characteristics of stormwater runoff entering Lake Holden under existing conditions to assist in preparation of an updated nutrient budget for the lake. However, the results of the monitoring performed during 2003 are also compared with monitoring performed during 1991-1992 to evaluate improvements in runoff characteristics achieved by the stormwater treatment systems installed at five of the six monitoring sites.

A summary of stormwater monitoring performed during June-September 2003 at the six monitoring sites is given in Table 4-4. A total of 87 separate composite stormwater samples was collected during this period, with 8-25 separate runoff samples collected at each individual monitoring site. Composite flow-weighted runoff samples were collected from Sub-basins 1, 2, 7, and 21 using portable automatic stormwater samplers with integral flow meters so that sampling is paced based upon the volume of stormwater flow through each stormsewer system. Each of the automatic samplers was installed in the final manhole prior to discharge into Lake Holden, downstream from stormwater treatment areas, so that the collected samples reflected runoff characteristics following stormwater treatment. In general, the collected runoff samples were retrieved from the field within 24 hours following each storm event and returned to the ERD Laboratory for analysis of evaluated parameters.

Stormwater treatment in Sub-basins 12 and 13 consists of wet detention ponds which have a relatively constant discharge rather than an event-based discharge which would occur with a stormsewer system. For these sub-basins, samples were collected from the pond discharge on approximately a weekly basis during the period from June-September 2003. A listing of analytical methods and detection limits for laboratory analyses performed by ERD on the collected stormwater samples is given in Table 4-5.

TABLE 4-4

**SUMMARY OF STORMWATER MONITORING
PERFORMED DURING JUNE-SEPTEMBER 2003**

SUB-BASIN	SITE DESCRIPTION	NUMBER OF SAMPLES COLLECTED
1	Division Street	18
2	Lake Holden Terrace	18
7	Krueger Street	8
12	43rd Street Pond	9
13	FDOT Pond off South Orange Blossom Trail	9
21	Paseo Street	25
Total:		**87**

TABLE 4-5

**ANALYTICAL METHODS AND DETECTION
LIMITS FOR LABORATORY ANALYSES**

MEASUREMENT PARAMETER	METHOD	METHOD DETECTION LIMITS (MDLs)[1]
General Parameters		
Hydrogen Ion (pH)	EPA-83[2], Sec. 150.1/Manf. Spec.[3]	NA
Specific Conductivity	EPA-83, Sec. 120.1/Manf. Spec.	0.1 μmho/cm
Alkalinity	EPA-83, Sec. 310.1	0.5 mg/l
Color	EPA-83, Sec. 110.3	1 Pt-Co Unit
Turbidity	EPA-83, Sec. 180.1	0.1 NTU
T.S.S.	EPA-83, Sec. 160.2	0.7 mg/l
Nutrients		
Ammonia-N (NH_3-N)	EPA-83, Sec. 350.1	0.01 mg/l
Nitrate + Nitrite (NO_x-N)	EPA-83, Sec. 353.3	0.004 mg/l
Organic Nitrogen	Alkaline Persulfate Digestion[5]	0.03 mg/l
Orthophosphorus	SM-19[4], Sec. 4500-P E.	0.001 mg/l
Total Phosphorus	Alkaline Persulfate Digestion[5]	0.001 mg/l
Biological Parameters		
Fecal Coliform	SM-19, Sec. 9222 D.	NA

1. MDLs are calculated based on the EPA method of determining detection limits.
2. Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, Revised March 1983.
3. Subject to manufacturer's specifications for test equipment used.
4. Standard Methods for the Examination of Water and Wastewater, 19th Ed., 1995.
5. FDEP-approved alternate method.

4.2.2   Characteristics of Stormwater Runoff

A complete listing of the characteristics of stormwater samples collected in the Lake Holden basin during June-September 2003 is given in Appendix D. Mean characteristics of stormwater samples collected at each of the six monitoring sites are given in Table 4-6. Stormwater runoff collected at each of the six sites appears to be approximately neutral in pH, with mean alkalinity values ranging from poorly to moderately buffered. Mean specific conductivity values at the six sites range from approximately 55-250 µmho/cm.

TABLE 4-6

MEAN CHARACTERISTICS OF STORMWATER SAMPLES COLLECTED IN THE LAKE HOLDEN BASIN DURING JUNE-SEPTEMBER 2003

LOCATION	PARAMETER												
	pH (s.u.)	Alk. (mg/l)	Cond. (µmho/cm)	NH₃ (µg/l)	NOₓ (µg/l)	TN (µg/l)	OP (µg/l)	TP (µg/l)	Turb. (NTU)	TSS (mg/l)	BOD₅ (mg/l)	Fecal Colif. (#/100 ml)	Color (Pt-Co)
Division Ave.	7.04	57.5	250	179	183	788	83	296	8.9	14.2	4.8	2,146	14
Holden Terr.	7.13	58.6	232	79	514	1206	19	54	9.3	23.0	8.2	1,641	10
Krueger St.	6.66	36.0	154	3,665	1,091	3,988	78	182	6.6	41.8	17.1	15,466	17
43rd St. Pond	6.99	23.0	55	83	13	506	4	37	2.3	4.8	3.2	74	16
FDOT Pond	6.60	58.4	165	316	45	503	17	59	2.6	3.0	2.6	678	14
Paseo St.	6.92	33.4	227	110	474	1,022	31	102	8.0	12.0	4.0	790	15

Measured concentrations of nitrogen species at the six monitoring sites were found to be highly variable, particularly at the Krueger Street site. Concentrations of ammonia, NO_x, and total nitrogen at the Division Street, Holden Terrace, Paseo Street, 43rd Street Pond, and FDOT Pond sites are typical of values commonly observed in urban runoff. However, substantially elevated levels of nitrogen species were observed at the Krueger Street site, particularly for ammonia and NO_x. These elevated values suggest influence from fertilizer use within the watershed which has entered the stormwater flow.

Measured concentrations of phosphorus species were also found to be highly variable between the six monitoring locations, with low total phosphorus concentrations measured at the 43rd Street Pond, FDOT Pond, and Holden Terrace sites, and more elevated values observed at the remaining sites. The highest total phosphorus and orthophosphorus concentrations were observed at the Division Street site which is one of the site which receives alum stormwater treatment.

Mean concentrations of turbidity, TSS, and BOD are typical of values commonly observed in stormwater runoff in the Central Florida area, particularly after treatment with alum or a wet detention pond. The most elevated values for TSS and BOD were observed at the Krueger Street site which has no current stormwater treatment facility. Substantially elevated levels of fecal coliform bacteria were also observed at the Krueger Street site compared with values measured at the remaining sites. In general, fecal coliform bacteria at the Krueger Street site is approximately ten times greater than bacteria concentrations measured elsewhere in the Lake Holden basin.

In general, stormwater samples collected within the Lake Holden basin contained no significant unusual odors or appearance other than odors and appearances commonly observed in urban stormwater runoff. However, the composite runoff sample collected from the Paseo Street site on July 26, 2003 had a strong odor of bleach or chlorine solution. A total chlorine test was performed on the sample which indicated a concentration of 7.25 mg/l. Since the collected stormwater sample is a flow-weighted composite which reflects the event mean concentration for the entire storm event, a significant spill or release of chlorine-containing compound would be required to raise the entire stormwater volume generated by the rain event to a concentration of more than 7 mg/l.

A statistical comparison of runoff characteristics for total nitrogen, total phosphorus, TSS, and BOD at the Lake Holden monitoring sites is given in Figure 4-2. A graphical summary of data at each site is presented in the form of Tukey box plots, also often called "box and whisker plots". The bottom line of the box portion of each plot represents the lower quartile, with 25% of the data points lying below this value. The upper line of the box represents the 75% upper quartile, with 25% of the data lying above this value. The horizontal line within the box represents the
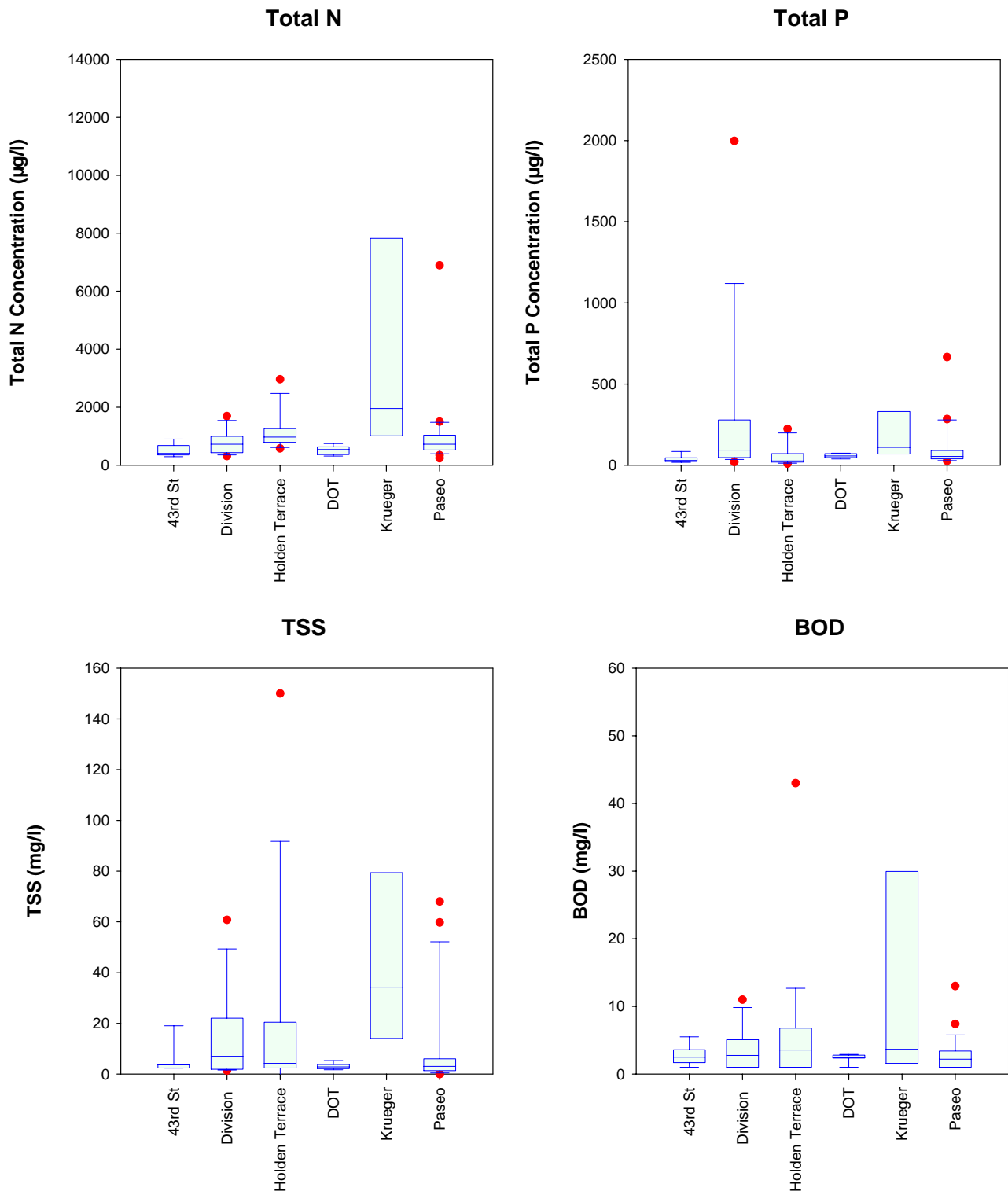
Figure 4-2. Statistical Comparison of Runoff Characteristics at the Lake Holden Monitoring Sites.

median value, with 50% of the data lying both above and below this value. The vertical lines, also known as "whiskers", represent the 5 and 95 percentiles for the data sets. Individual values which lie outside of the 5-95 percentile range, sometimes referred to as "outliers", are indicated as red dots.

As seen in Figure 4-2, a relatively low degree of variability is apparent in total nitrogen concentrations measured at the majority of the monitoring sites. However, a relatively large degree of variability is apparent in nitrogen concentrations measured at the Krueger Street site. As seen in Appendix D, individual total nitrogen concentrations measured at this site range from 592-13,323 μg/l. These elevated total nitrogen concentrations reflect significant impact from fertilization activities within the watershed. The relatively low degree of variability observed at the remaining sites is due primarily to the presence of stormwater treatment systems in each of these basins.

A relatively low degree of variability is apparent in total phosphorus concentrations measured at the 43rd Street Pond, Holden Terrace, and FDOT Pond sites. A higher degree of variability is apparent at the Krueger Street site and, in particular, the Division Street site. Measured total phosphorus concentrations at the Division Street site range from 20-1997 μg/l, reflecting a significantly high degree of variability at this site. Thirteen of the 18 storm events monitored at this site are characterized by total phosphorus concentrations of approximately 130 μg/l or less. However, substantially elevated phosphorus concentrations are apparent for the remaining events. Since this site receives treatment from an alum injection system, the variability in total phosphorus concentrations observed at this site reflects either lack of treatment by the system during certain storm events or excessively high total phosphorus concentrations which could not be adequately treated by the alum treatment system. However, regardless of the nature of this variability, further evaluations need to be performed to define the source of this variability.

As seen in Figure 4-2, substantial differences are apparent in measured TSS concentrations between the six monitoring sites. A low degree of variability is apparent in discharges from the 43rd Street Pond and FDOT Pond sites, while the remaining sites, particularly the Krueger Street site, indicate substantial variability. Elevated TSS concentrations

were observed for at least one storm event at the Division Street, Holden Terrace, and Paseo Street sites.

Measured BOD concentrations at the 43rd Street Pond, Division Street, Holden Terrace, FDOT Pond, and Paseo Street sites were relatively low in value, although outliers are apparent at the Division Street, Holden Terrace, and Paseo Street sites for at least one monitoring event. However, a high degree of variability in BOD is present at the Krueger Street site, again suggesting the influence of activities within the watershed.

A comparison of mean concentrations of total phosphorus in stormwater runoff entering Lake Holden during 1991-92 and 2003 is given in Figure 4-3. Total phosphorus concentrations at each of the six monitoring sites were found to be substantially higher during the 1991-92 monitoring compared with measurements performed during 2003. For Sub-basins 1, 2, 12, 13, and 21, these differences probably reflect the impacts of stormwater treatment systems constructed within the basin. Since no stormwater treatment system has been constructed for Sub-basin 7, the differences between the 1991-92 and 2003 values indicated in Figure 4-3 probably reflect an elevated estimate of total phosphorus concentrations at this site measured during the 1991-92 monitoring events since the mean for the 1991-92 monitoring is approximately 5 times greater than phosphorus concentrations commonly observed in urban runoff.

A comparison of total nitrogen concentrations at the six monitoring sites is also given in Figure 4-3. Substantial reductions in nitrogen concentrations are apparent at each of the five sites where stormwater treatment systems have been constructed. Total nitrogen concentrations at Sub-basin 7, which has not received stormwater treatment retrofit, are relatively similar between the two periods.

A comparison of mean concentrations of BOD in stormwater runoff entering Lake Holden during 1991-92 and 2003 is given in Figure 4-4. Substantial reductions in BOD concentrations are apparent at each of the five sites where stormwater treatment activities have occurred. A lesser degree of reduction is apparent in Sub-basin 7, although the observed differences are probably related to elevated BOD concentrations measured during the 1991-92 monitoring period at this site.

Lake Holden
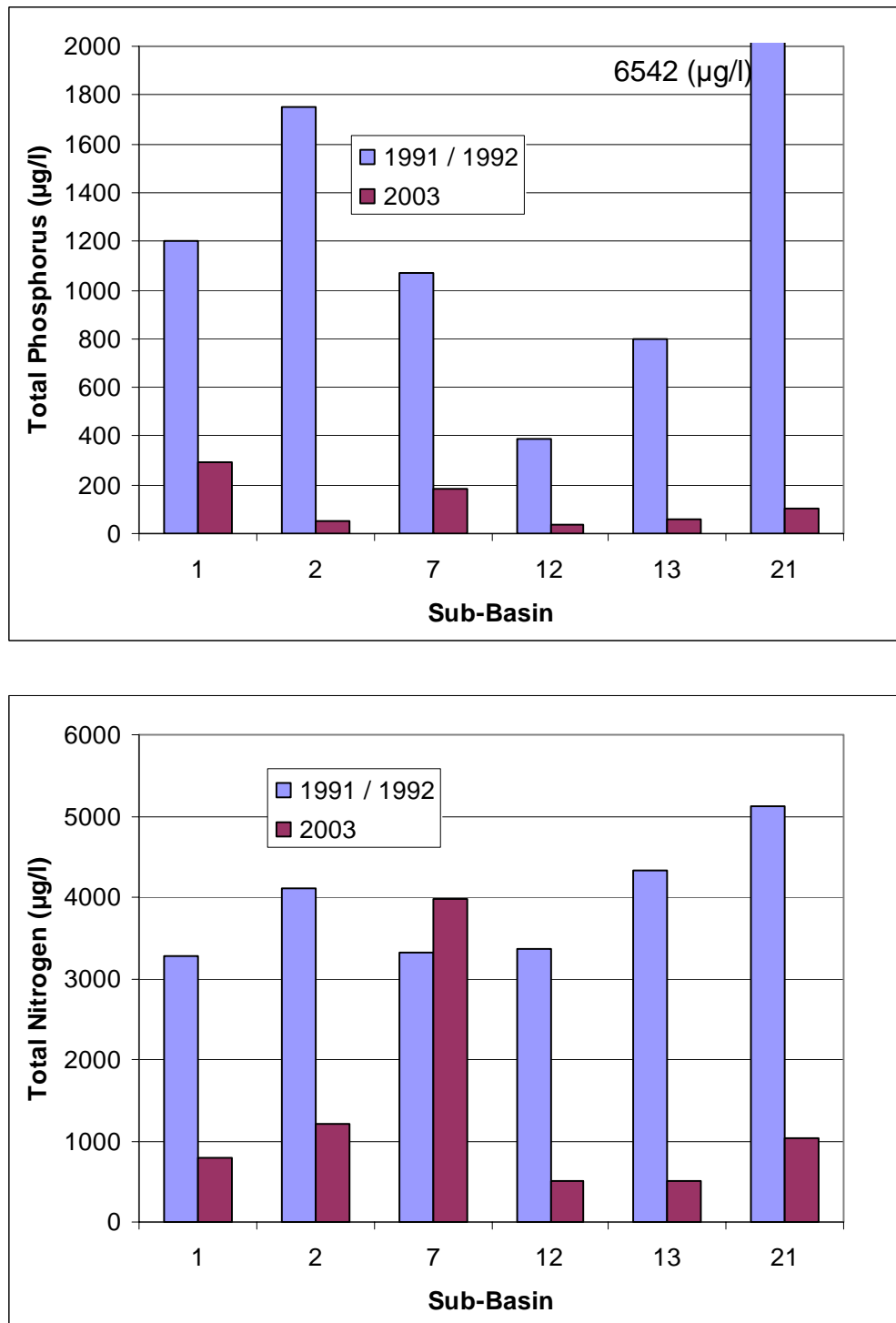
Figure 4-3. Comparison of Mean Concentrations of Total Nitrogen and Total Phosphorus in Stormwater Runoff entering Lake Holden during 1991/1992 and 2003.

Lake Holden
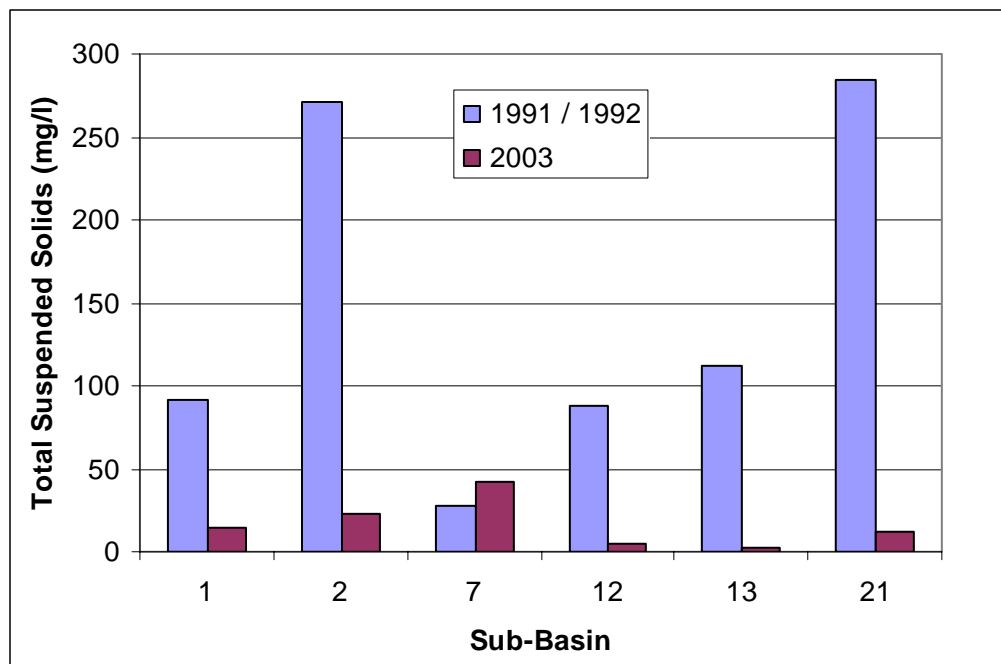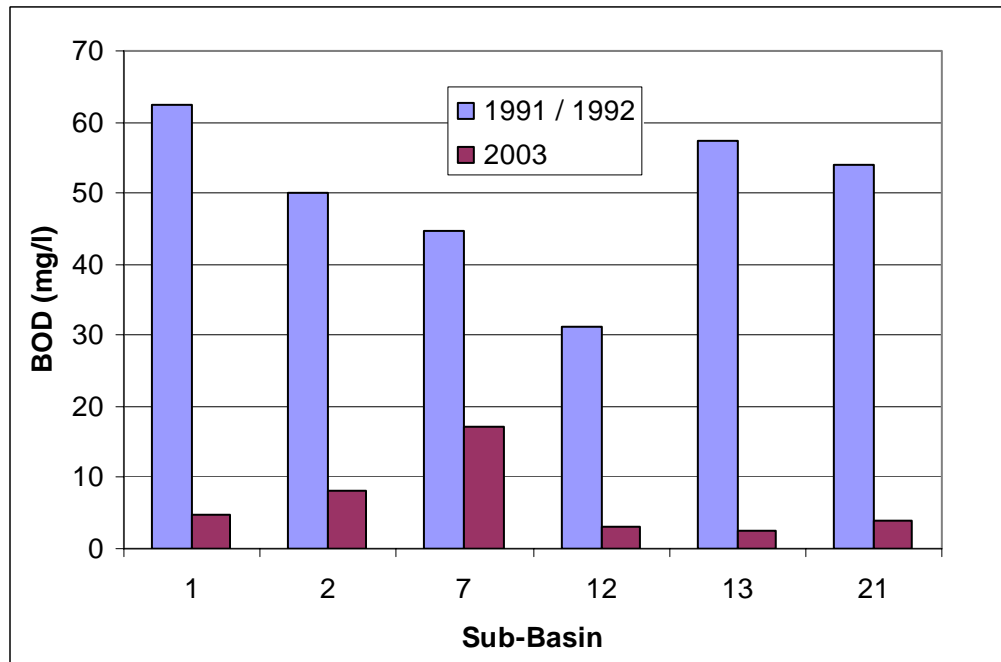
Figure 4-4. Comparison of Mean Concentrations of BOD and TSS in Stormwater Runoff entering Lake Holden during 1991/1992 and 2003.

A comparison of mean concentrations of TSS concentrations in stormwater runoff entering Lake Holden during 1991-92 and 2003 is also given in Figure 4-4. Substantial reductions in TSS concentrations are apparent at each of the five sites where stormwater treatment systems have been installed. TSS concentrations in Sub-basin 7, where stormwater treatment has not occurred, are relatively similar between the two monitoring periods.

4.2.3   Estimation of Runoff Generated Loadings to Lake Holden

Estimates of runoff generated loadings to Lake Holden were calculated by multiplying assumed runoff characteristics for each of the 24 sub-basin areas times the annual runoff volumes generated in each sub-basin, summarized in Table 3-5. Runoff characteristics for Sub-basins 1, 2, 7, 12, 13, and 21 were monitored directly as part of this project, and the mean values measured at each of these sites are assumed to be representative of runoff characteristics from each sub-basin area. Estimates of runoff characteristics from the remaining sub-basin areas were generated based upon several methods. A summary of the assumed characteristics of stormwater runoff entering Lake Holden is given in Table 4-7.

Stormwater monitoring performed in Sub-basin 7 reflects primarily residential characteristics. Land use characteristics in other watershed areas, including Sub-basins 5, 6, 8, 9, 10A, 10B, 11, and 17 appear to be similar to characteristics which exist in Sub-basin 7. Therefore, runoff characteristics measured in Sub-basin 7 are assumed to be similar to characteristics which occur in the other listed residential areas.

Several residential areas, including Sub-basins 3, 16, 18, 20, and 22, appear to have land use activities which are less intense than those which occur in Sub-basin 7. Therefore, for these sub-basin areas, runoff characteristics are assumed to be similar to the residential runoff characteristics summarized by Harper (1994) in the document titled "Stormwater Loading Rate Parameters for Central and South Florida". Runoff characteristics from this document were also used for commercial areas located in Sub-basin 4B. Runoff characteristics for Sub-basin 19 are based upon monitoring efforts performed in this sub-basin by ERD during 1995 as part of a stormwater evaluation project for Orange County.

TABLE 4-7

**ASSUMED CHARACTERISTICS OF
STORMWATER RUNOFF ENTERING LAKE HOLDEN**

SUB-BASIN	DOMINANT LAND USE	ASSUMED RUNOFF CHARACTERISTICS				DATA SOURCE
		TN (µg/l)	TP (µg/l)	BOD (mg/l)	TSS (mg/l)	
1	Commercial	788	296	4.8	14.2	Field monitoring
2	Commercial/Residential	1206	54	8.2	23.0	Field monitoring
3	Residential	1770	177	4.4	19.1	Harper (1994)
4A	Commercial/Residential	505	48	2.9	3.9	Avg. of B-12 and B-13
4B	Commercial	1180	150	8.2	81.0	Harper (1994)
5	Residential	3988	182	17.1	41.8	Similar to B-7
6	Residential	3988	182	17.1	41.8	Similar to B-7
7	Residential	3988	182	17.1	41.8	Field monitoring
8	Residential	3988	182	17.1	41.8	Similar to B-7
9	Residential	3988	182	17.1	41.8	Similar to B-7
10A	Residential	3988	182	17.1	41.8	Similar to B-7
10B	Residential	3988	182	17.1	41.8	Similar to B-7
11	Residential	3988	182	17.1	41.8	Similar to B-7
12	Commercial	506	37	3.2	4.8	Field monitoring
13	Commercial/Residential	503	59	2.6	3.0	Field monitoring
14	Commercial	1180	150	8.2	81.0	Harper (1994)
15	Commercial	--[1]	--[1]	--[1]	--[1]	--[1]
16	Residential	1770	177	4.4	19.1	Harper (1994)
17	Residential	3988	182	17.1	41.8	Similar to B-7
18	Residential	1770	177	4.4	19.1	Harper (1994)
19	Commercial/Residential	714	105	2.3	2.8	ERD (1995)
20	Residential	1770	177	4.4	19.1	Harper (1994)
21	Residential	1022	102	4.0	12.0	Field monitoring
22	Residential	2290	300	7.4	27.0	Harper (1994)

1. Land-locked basin

Estimates of mass loadings of total nitrogen, total phosphorus, TSS, and BOD discharging to Lake Holden from stormwater runoff were calculated by multiplying the assumed runoff characteristics listed in Table 4-7 times the estimated annual runoff volumes summarized in Table 3-5. A summary of the calculations used for estimation of mass loadings from stormwater runoff is given in Appendix E.

A summary of estimated annual generated loadings of total nitrogen, total phosphorus, BOD, and TSS to Lake Holden is given in Table 4-8. Loading estimates are provided for each evaluated parameter in the 24 sub-basins in terms of kg of each constituent per year. The percentage of the overall runoff generated loadings contributed by each sub-basin is also provided. The largest contributors of total nitrogen to Lake Holden are Sub-basins 1, 7, and 2. Each of the remaining sub-basin areas contributes approximately 5% or less of the total annual nitrogen loadings to the lake.

The dominant contributor of total phosphorus loadings from runoff to Lake Holden is Sub-basin 1. This basin is ranked #1 due to the high mean total phosphorus value in runoff measured at this site in spite of the alum stormwater treatment system associated with this sub-basin. As discussed previously, this elevated mean value is influenced by spikes in total phosphorus concentrations which were monitored during approximately 25% of the stormwater events monitored at this site. The remaining sub-basin areas contribute approximately 5% or less of the total phosphorus loadings to Lake Holden.

The primary contributors of BOD loadings to Lake Holden include Sub-basins 1, 2, and 7, with the remaining sub-basin areas contributing approximately 5% or less of the annual loading. A similar pattern is apparent for annual loadings of TSS, with Sub-basins 1, 2, 4B, and 11 being the major contributors of TSS to the lake. The remaining sub-basin areas contribute approximately 5% or less of the annual runoff generated loadings.

On an annual basis, stormwater runoff contributes approximately 1688 kg/yr of total nitrogen to Lake Holden. Approximately 201 kg/yr of total phosphorus are discharged to the lake, with 7989 kg/yr of BOD, and 23,651 kg/yr of TSS. These values are utilized in a subsequent section for development of an overall nutrient budget for the lake.

TABLE 4-8

ESTIMATED ANNUAL RUNOFF
GENERATED INPUTS OF TOTAL N, TOTAL P
BOD, AND TSS TO LAKE HOLDEN

SUB-BASIN	TOTAL N		TOTAL P		BOD		TSS	
	(kg/yr)	(%)	(kg/yr)	(%)	(kg/yr)	(%)	(kg/yr)	(%)
1	253.1	15.0	95.1	47.5	1542	19.3	4561	19.3
2	199.8	11.8	8.9	4.4	1358	17.0	3810	16.1
3	30.5	1.8	3.0	1.5	75.8	0.9	329	1.5
4A	72.9	4.3	6.9	3.4	419	5.2	563	2.4
4B	37.6	2.2	4.8	2.4	261	3.4	2582	10.9
5	48.0	2.8	2.2	1.1	206	2.6	503	2.2
6	36.4	2.2	1.7	0.8	156	2.0	382	1.6
7	250.7	14.9	11.4	5.8	1075	13.5	2628	11.1
8	34.3	2.0	1.6	0.8	147	1.8	359	1.5
9	32.5	1.9	1.5	0.7	139	1.7	340	1.4
10A	55.1	3.3	2.5	1.3	236	3.0	578	2.4
10B	39.9	2.4	1.8	0.9	171	2.1	418	1.8
11	54.9	3.3	2.5	1.2	235	2.9	575	2.4
12	41.4	2.5	3.0	1.5	262	3.3	393	1.7
13	83.4	4.8	9.8	4.9	431	5.4	498	2.1
14	11.2	0.7	1.4	0.7	77.8	1.0	768	3.2
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	26.9	1.6	2.7	1.3	66.8	0.8	290	1.2
17	27.5	1.6	1.3	0.6	118	1.5	288	1.2
18	70.8	4.2	7.1	3.6	176	2.2	764	3.2
19	19.9	1.2	2.9	1.4	64.0	0.8	77.9	0.3
20	139.5	8.3	13.9	6.9	347	4.3	1505	6.4
21	44.4	2.6	4.4	2.2	174	2.2	521	2.2
22	77.9	4.6	10.2	5.1	251	3.1	919	3.9
Totals:	1688	100.0	201	100.0	7989	100.0	23,651	100.0

4.3 Evaluation of Pollutant Loadings from Groundwater Seepage

Field investigations were performed from April-October 2003 to evaluate the chemical characteristics of groundwater seepage entering Lake Holden during both dry and wet season conditions. Hydrologic characteristics of groundwater seepage were discussed in Section 3.3. A complete listing of chemical analyses conducted on groundwater seepage samples collected at the 10 monitoring sites in Lake Holden is given in Appendix F.

Mean characteristics of groundwater seepage entering Lake Holden at each of the 10 monitoring sites from April-October 2003 are given in Table 4-9. In general, groundwater seepage entering Lake Holden appears to be approximately neutral to slightly alkaline in pH, with alkalinity values ranging from moderately to well buffered. Measured conductivity values appear to be relatively consistent between the 10 monitoring sites and are typical of conductivity values commonly observed in shallow groundwater seepage.

TABLE 4-9

MEAN CHARACTERISTICS OF GROUNDWATER SEEPAGE ENTERING LAKE HOLDEN FROM APRIL-OCTOBER 2003

SITE	PARAMETER				
	pH (s.u.)	ALKALINITY (mg/l)	CONDUCTIVITY (µmho/cm)	TOTAL N (µg/l)	TOTAL P (µg/l)
1	7.46	81.3	299	2076	8
2	7.69	122	385	4120	66
3	7.35	71.7	239	1461	10
4	7.09	57.2	213	1941	19
5	7.80	105	306	3524	14
6	7.09	51.0	239	2434	10
7	7.29	92.5	294	5420	12
8	7.33	132	330	7176	64
9	7.54	72.0	262	2570	14
10	7.35	81.8	271	3172	29

Total nitrogen concentrations in groundwater seepage appear to be somewhat variable within Lake Holden. The lowest total nitrogen concentrations were observed along the northwest shoreline of the lake, with elevated concentrations observed in the southeast and south-central portions of the lake. Total phosphorus concentrations in groundwater seepage appear to be relatively low in value. These values are not surprising since total phosphorus is relatively immobile during transport through surficial soils.

The mean seepage characteristics summarized in Table 4-9 were combined with the inflow seepage isopleths, summarized in Figure 3-6, to generate estimates of the daily influx of nitrogen and phosphorus to Lake Holden at each of the 10 monitoring sites. This information was used to develop isopleths of influx of total nitrogen and total phosphorus from groundwater seepage entering Lake Holden on a daily basis.

Isopleths of total nitrogen influx from groundwater seepage entering Lake Holden are illustrated on Figure 4-5. Areas of elevated nitrogen influx are apparent along the northern, eastern, and western portions of the lake, with lower nitrogen influx values in central portions of the lake. Areas of elevated total nitrogen influx are often associated with septic tank influence in lakes which have a significant number of septic tanks within the watershed area.

Isopleths of total phosphorus influx from groundwater seepage entering Lake Holden are illustrated on Figure 4-6. Elevated areas of phosphorus influx are apparent along the northern and western portions of the lake.

Estimates of daily influx of total nitrogen and total phosphorus from groundwater seepage into Lake Holden were generated by graphically integrating the total nitrogen and total phosphorus influx isopleths provided in Figures 4-5 and 4-6. A summary of these calculations is given in Table 4-10. Groundwater seepage is estimated to contribute approximately 5.805 kg/day of total nitrogen and 0.0303 kg/day of total phosphorus to Lake Holden.

A summary of estimated annual influx of total nitrogen and total phosphorus into Lake Holden is given in Table 4-11. Groundwater seepage contributes approximately 2119 kg/yr of total nitrogen and 11.06 kg/yr of total phosphorus to Lake Holden. These values are utilized in a subsequent section for generation of an annual nutrient budget for the lake.

Figure 4-5. Isopleths of Total Nitrogen Influx (μg/m$^2 \cdot$ day) from Groundwater Seepage Entering Lake Holden.

Figure 4-6.   Isopleths of Total Phosphorus Influx ($\mu g/m^{2} \cdot$ day) from Groundwater Seepage Entering Lake Holden.

TABLE 4-10

**CALCULATED DAILY INFLUX OF TOTAL
NITROGEN AND TOTAL PHOSPHORUS FROM
GROUNDWATER SEEPAGE TO LAKE HOLDEN**

PHOSPHORUS			NITROGEN		
INTERVAL (μg/m^2-day)	AREA (m^2)	MASS (kg/day)	INTERVAL (μg/m^2-day)	AREA (m^2)	MASS (kg/day)
210	1,939	0.0004	15,000	4,341	0.065
190	9,757	0.0019	13,000	21,764	0.282
170	3,212	0.0006	11,000	22,751	0.250
150	4,329	0.0007	9,000	49,910	0.448
130	5,990	0.0008	7,000	294,544	2.059
110	6,826	0.0008	5,000	403,527	2.014
90	11,000	0.0010	3,000	210,234	0.630
70	29,484	0.0021	1,000	56,068	0.056
50	36,588	0.0019	**Total:**	**1,063,139**	**5.805**
30	523,863	0.0159			
10	430,151	0.0044			
Total:	**1,063,139**	**0.0303**			

TABLE 4-11

**ESTIMATED ANNUAL INFLUX OF TOTAL
NITROGEN AND TOTAL PHOSPHORUS FROM
GROUNDWATER SEEPAGE TO LAKE HOLDEN**

PARAMETER	MEAN INFLUX RATE[1]	ANNUAL INFLUX TO LAKE HOLDEN
Nitrogen	5.805 kg/day	2119 kg/yr
Phosphorus	0.0303 kg/day	11.06 kg/yr

1. Based on field measured values

4.4 Internal Recycling

Field and laboratory investigations were performed by ERD to quantify the mass of phosphorus released as a result of internal recycling from the sediments of Lake Holden to the overlying water column under both aerobic and anoxic conditions. Large diameter sediment core samples were collected at multiple locations in the lake and incubated under anoxic and aerobic conditions. Periodic measurements of orthophosphorus and other water quality parameters were conducted to estimate sediment phosphorus release under the evaluated conditions.   This information can be utilized to provide an estimate of the significance of mass loadings of phosphorus from lake sediments as part of the overall nutrient budget for the lake.

4.4.1   Field and Laboratory Procedures

Multiple sediment core samples were collected in Lake Holden using 4-inch diameter clear acrylic core tubes. Each of the acrylic tubes was driven into the sediments to the maximum possible depth using a large sledge hammer. A 4-inch x 4-inch wooden beam was placed on top of the acrylic core tube to evenly distribute the force of each sledge hammer blow and to prevent direct contact between the sledge hammer and the acrylic tube. Separate core samples were collected at water depths of 5, 10, 15, 20 (two separate sites), and 25 ft, comprising a total of six separate large diameter core samples collected for this evaluation.

Each of the acrylic tubes was penetrated into the sediments to depths ranging from approximately 2-6 ft, depending upon the physical characteristics of the sediments at each of the selected monitoring sites, until a firm bottom material was encountered. Each of the core tubes was retrieved intact, along with the overlying water column present at each of the collection sites. Upon retrieval, a rubber cap was attached to the bottom of each core tube to prevent loss of sediments. The collected water volume above the trapped sediments was carefully siphoned off until a water depth of 18 inches remained in each of the collected columns above the sediment-water interface. Each of the acrylic core tubes was then cut at a height of 6 inches above the water level, leaving a 6-inch space between the water level and the top of the column. A 4-inch PVC cap was then placed

on the top of each collected core tube. The collected core tubes were then returned to the ERD laboratory for incubation experimentation. All samples were transported to the ERD laboratory in a vertical position so that mixing of the sediment layers did not occur during transport.

After return to the laboratory, each of the six collected core samples was attached to a laboratory work bench in a vertical position. Two separate ¼-inch diameter holes were then drilled into the PVC cap attached to the top of each core sample. A ¼-inch diameter semi-rigid polyethylene tube was inserted through one of the holes to a depth of approximately 2-3 inches above the sediment surface. An air stone diffuser was attached to the end of the tubing inside each core tube. This system was used to introduce selected gases into the core tubes to encourage aerobic and anoxic conditions.

A separate piece of polyethylene tubing was inserted into the second hole in the top of each core tube, approximately 1 inch below the level of the cap, but well above the water level contained in each tube. The other end of the tubing was connected to a water trap to minimize loss of water from each column as a result of evaporation. This tubing also provided a point of exit for gases which were bubbled into each core tube. A schematic of the sediment incubation apparatus is given in Figure 4-7.

After initial set-up of the incubation apparatus, compressed air was introduced into each of the core tubes, through the individual diffusers, using a compressed air source. This process quickly created aerobic conditions within each of the six core tubes. This aeration process was continued in each of the core tubes for a period of approximately 60 days. During the aeration process, the water within each of the core tubes was well mixed, so that phosphorus released from the sediments could be quantified as a function of changes in phosphorus concentrations within the water column of each core tube. On approximately a 1-2 day interval, 15 ml of water was withdrawn from each of the columns using a ¼-inch polyethylene tube and a plastic laboratory syringe. Each of the collected samples was immediately filtered using a 0.45 micron syringe type membrane filter and analyzed for orthophosphorus along with other significant laboratory parameters for research purposes. However, only the results of the orthophosphorus analyses are utilized in this report for purposes of estimating sediment phosphorus release rates.

1/4" POLYETHYLENE TUBING
FROM AIR OR NITROGEN SOURCE

4"(SCH 40) CLEAR PVC

6"

WATER TRAP

18"

LAKE WATER

AIR STONE

LAKE SEDIMENTS

VARIES (2'-6')

4" RUBBER CAP W/
STAINLESS STEEL BAND
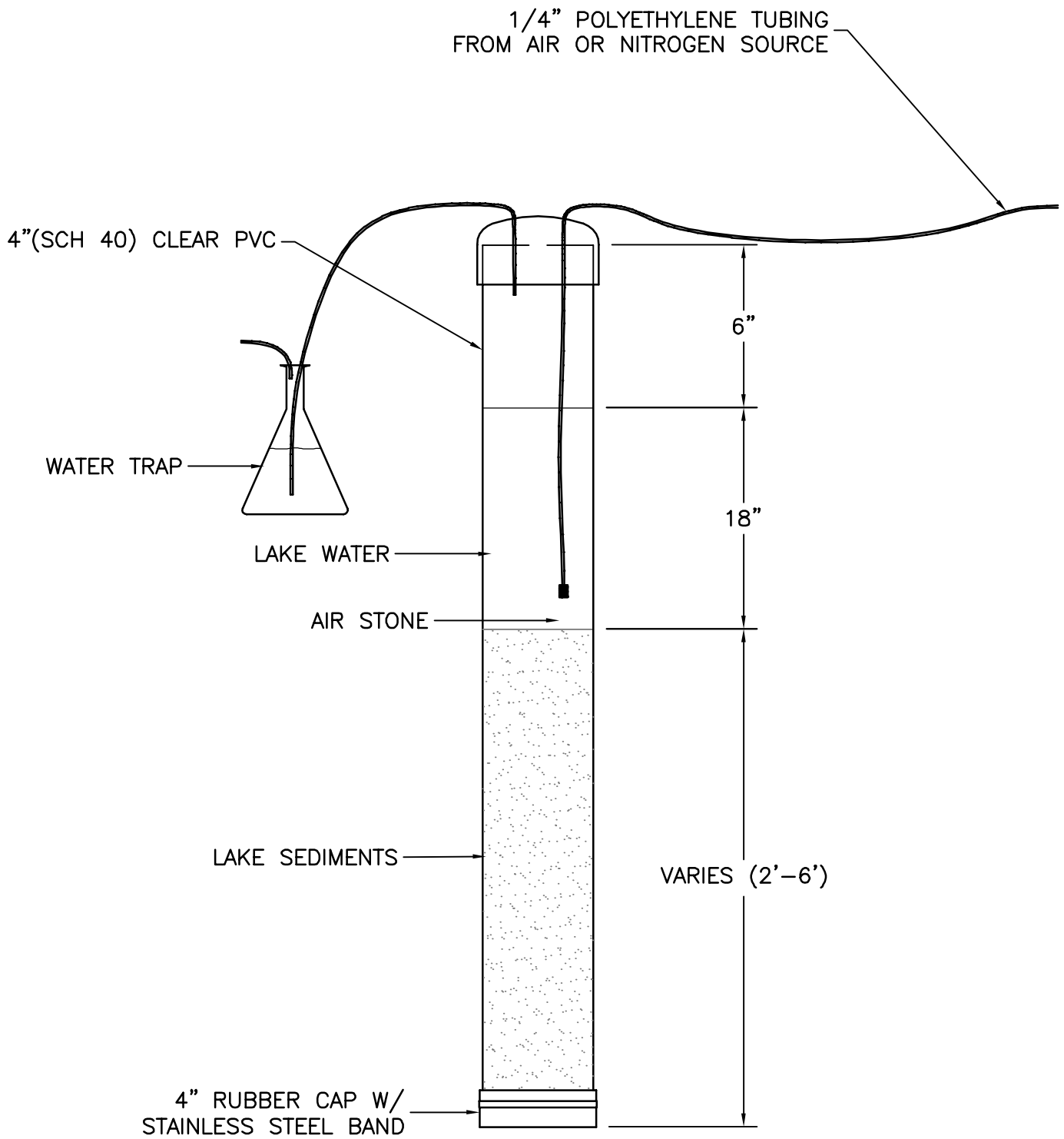
Figure 4-7. Schematic of Sediment Incubation Apparatus.

At the conclusion of the experimentation under aerobic conditions, the compressed air source was replaced with a pure nitrogen source. Nitrogen gas was gently bubbled through each of the six columns to remove existing dissolved oxygen and create anoxic conditions within each tube. In general, creation of anoxic conditions, as indicated by measurements of redox potential (< 200 mv) within each of the columns, occurred after approximately 5-7 days. At the onset of anoxic conditions, sample collection was conducted on a 1-2 day basis from each of the six columns using the method previously outlined for aerobic conditions. Incubation of samples under anoxic conditions was continued for approximately 30 days.

Collection of the large diameter (4-inch) sediment core samples was performed during July 2003. Experimentation under aerobic conditions was initiated in July 2003, with anoxic experimentation initiated during September 2003.

4.4.2   Results of Field and Laboratory Testing

A graphical comparison of orthophosphorus release from the six sediment core samples under aerobic and anoxic conditions is given in Figure 4-8. Virtually no release of orthophosphorus was observed from Lake Holden sediments under aerobic conditions in any of the six core samples. In fact, the sediments appear to absorb orthophosphorus which was present in the water column at the start of the incubation process, with virtually no release recorded after that time.

However, under anoxic conditions, substantial release of orthophosphorus was observed from the sediments in each of the sediment core tubes. This initial release occurred after approximately 5-10 days of incubation, followed by a rapid decrease in orthophosphorus concentrations as biological activity within the water column and sediments rapidly absorbed the available phosphorus as it was released. The large release of orthophosphorus released under anoxic conditions supports the presumption that sediments within Lake Holden are capable of releasing large amounts of phosphorus into the overlying water column during certain times of the year.
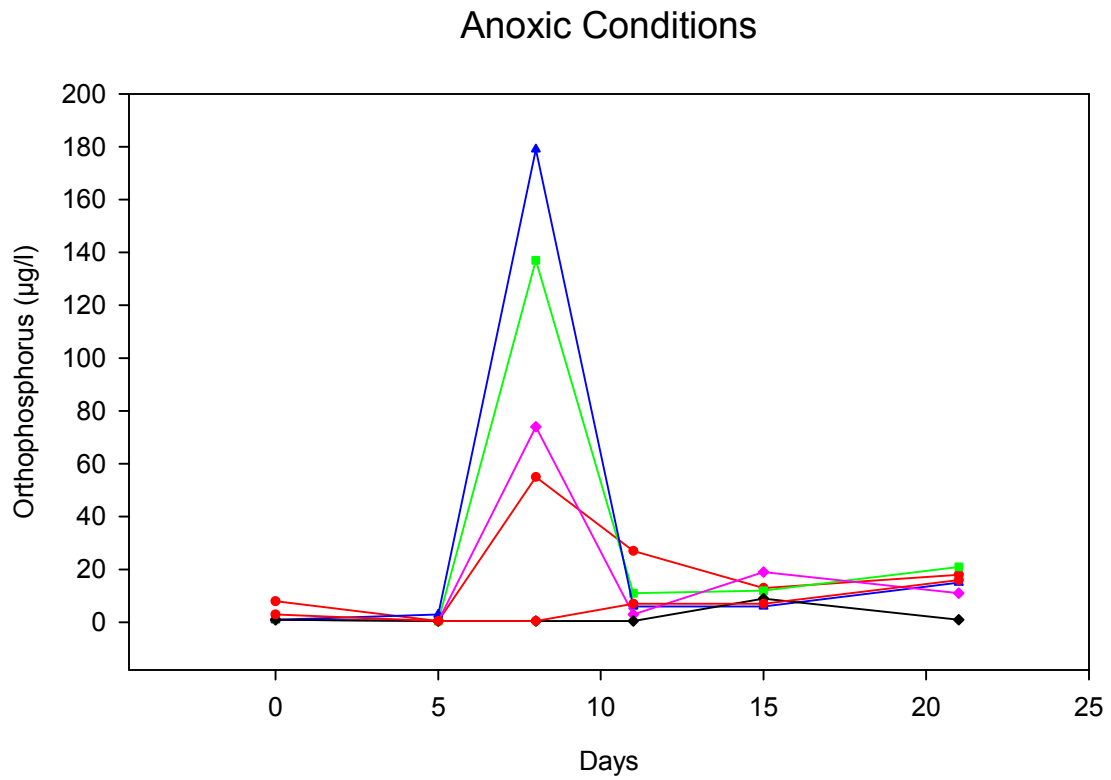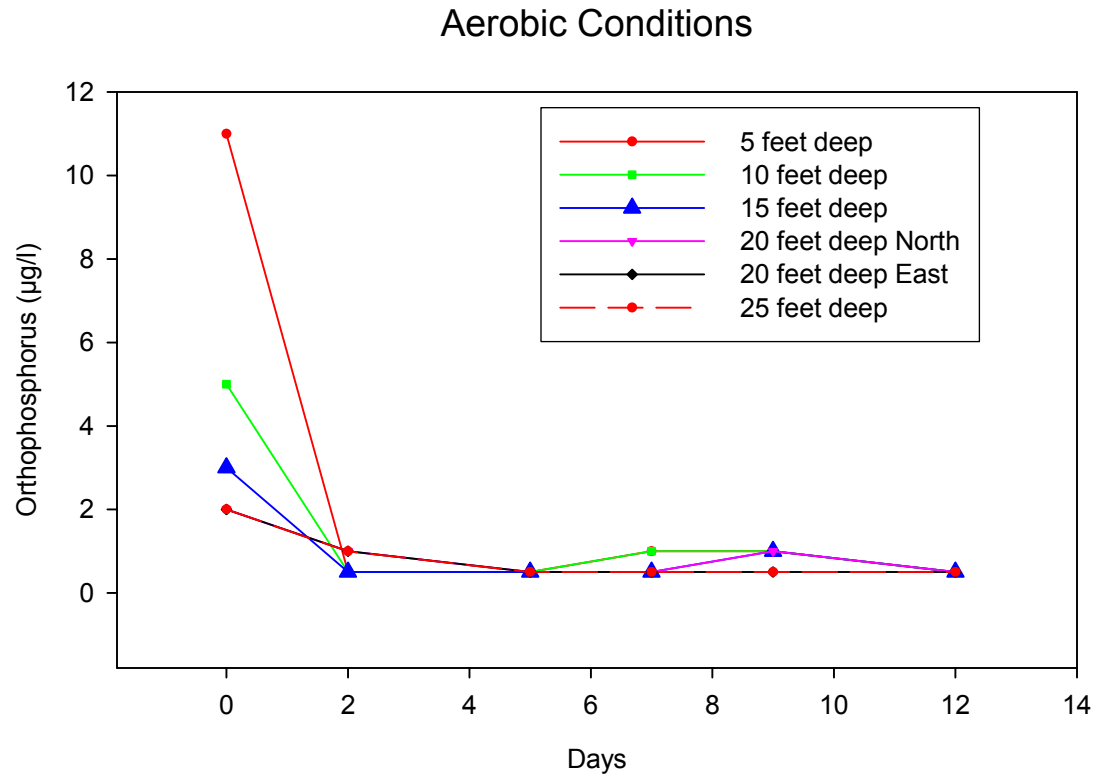
Figure 4-8. Orthophosphorus Release from Lake Holden Sediment Cores During Aerobic and Anoxic Conditions.

In order to extrapolate the information contained in Figure 4-8 into estimates of orthophosphorus release from internal recycling on an annual basis, information must be known on the vertical oxygen regimes which exist in Lake Holden throughout the year. In other words, the areal coverage of anoxic conditions must be known based upon the results of vertical profiles collected as a result of field monitoring within the lake.

Unfortunately, the historical data available for Lake Holden does not contain sufficient information on oxygen regimes within the lake to estimate the areal coverage of anoxic conditions on a monthly basis. Although the sediment core experiments clearly indicate that orthophosphorus is released under anoxic conditions, since the extent of anoxic areas cannot be documented, the information contained in Figure 4-8 cannot be extrapolated into an annual sediment phosphorus release value.

4.4.3   Estimation of Internal Recycling Using Trophic State Modeling

Since phosphorus loadings from internal recycling cannot be calculated directly due to limitations in the historical database, the extent of internal recycling is estimated using a trophic state model developed specifically for Lake Holden. Trophic state modeling analyses were conducted to provide an estimate of predicted water quality characteristics in Lake Holden resulting from estimated nutrient inputs into the lake from stormwater, groundwater seepage, and bulk precipitation based upon the analyses presented in previous sections. This modeling exercise is used to predict in-lake concentrations of total phosphorus based upon estimated current loadings. Discrepancies between estimated concentrations of total phosphorus and mean ambient values measured in Lake Holden is used to estimate the loadings contributed by internal nutrient recycling.

Predicted concentrations of total phosphorus in Lake Holden were estimated using a modified Vollenweider phosphorus limitation model as proposed by Vollenweider (1976), Vollenweider and Dillon (1974), and Dillon and Rigler (1974). Prediction of in-lake phosphorus concentrations are based upon four parameters, including the estimated annual phosphorus input to the lake, a phosphorus retention coefficient which is based upon phosphorus sedimentation dynamics, the mean depth of the lake and the lake flushing rate for the lake system.

The first step in modeling involves estimation of the phosphorus retention coefficient, R_{TP}. The phosphorus retention coefficient for any lake can be estimated based upon the lake flushing time and mean depth as proposed by Vollenweider (1976):

$$R_{TP} = \frac{10}{\rho \bar{z} + 10}$$

where:

R_{TP} = phosphorus retention coefficient (dimensionless)

ρ = lake flushing rate, Q/V (units of 1/time)

$\bar{z}$ = lake mean depth = lake volume/surface area (m)

Estimates of equilibrium total phosphorus concentrations within the lake are developed based upon the relationship proposed by Vollenweider and Dillon (1974):

$$TP = \frac{L_p\ (1 - R_{TP})}{\bar{z} * \rho}$$

where:

L_p = annual areal total phosphorus loading (mg/m^2-yr)

R_{TP} = phosphorus retention coefficient (dimensionless)

ρ = lake flushing rate (1/time)

$\bar{z}$ = mean depth (m)

Estimates of in-lake equilibrium chlorophyll-a concentrations can also be calculated based on the empirical relationship between chlorophyll-a and total phosphorus as proposed by Dillon and Rigler (1974):

$$\log \ (chyl\text{-}a) \ = \ 1.449 \ \log \ TP \ - \ 1.136$$

where:

TP   =   mean total phosphorus concentration (μg/l)

The trophic state model can also be used to estimate mean Secchi disk depth based upon the empirical relationship presented by Dillon and Rigler (1974) which results in an estimated Secchi disk depth in meters, based upon a chlorophyll-a input in units of mg/m^3:

$$SD \ = \ 8.7 \left(\frac{1}{1 \ + \ 0.47 \ chyl\text{-}a} \right)$$

where:

SD   =   Secchi disk depth (m)

chyl-a =   chlorophyll-a concentration (mg/m^3)

Trophic State Index (TSI) values are calculated based upon the Florida Trophic State Index proposed by Brezonik (1984) which was developed specifically for Florida lakes. The empirical equations for calculating the Florida Trophic State Index are as follows for phosphorus-limited lakes:

TSI (Chyl-a)	=	$16.8 + 14.4 \ln (\text{Chyl-a})$	(Chyl-a in mg/m^3)
TSI (SD)	=	$60.0 - 30.0 \ln (\text{SD})$	(SD in m)
TSI (TP)	=	$23.6 \ln (\text{TP}) - 23.8$	(TP in μg/l)
TSI (Avg)	=	$1/3 \ [\text{TSI (Chyl-a)} + \text{TSI (SD)} + \text{TSI (TP)}]$	

Average trophic state values less than 50 indicate oligotrophic conditions, values between 50 and 60 indicate mesotrophic conditions, and values from 61 to 70 indicate eutrophic conditions. Values over 70 represent hypereutrophic conditions.

A modified Vollenweider mass balance model was developed for Lake Holden on a monthly basis. Monthly evaluations were performed to examine fluctuations in water quality characteristics on a seasonal basis throughout the year. The model includes monthly hydrologic inputs to Lake Holden from direct precipitation, stormwater runoff, and groundwater seepage. Nutrient inputs to Lake Holden include estimated loadings from bulk precipitation, stormwater runoff, and groundwater seepage. Precipitation-based inputs, such as direct precipitation, bulk precipitation and stormwater runoff, are allocated on a monthly basis based upon mean monthly rainfall in the Orlando area. Inputs from groundwater seepage are allocated on a seasonal basis based upon mean monthly precipitation patterns.

Hydrologic and mass losses from Lake Holden are assumed to occur as a result of evaporation and discharge through the outfall structure. The net hydrologic inputs into the lake are used to provide an estimate of mean detention time as well as the flushing rate for Lake Holden which is utilized in calculation of the phosphorus retention coefficient and the equilibrium total phosphorus concentration. Nutrient inputs to Lake Holden are used to generate estimates of the annual areal phosphorus loading rate and the final in-lake phosphorus concentration. Estimates of equilibrium chlorophyll-a concentrations and Secchi disk depth in the lake are calculated based upon the predicted in-lake phosphorus concentration.

After developing the trophic state model, initial model runs were performed to examine predicted water quality characteristics in Lake Holden based upon the estimated annual loadings of total phosphorus to the lake from stormwater, bulk precipitation, and groundwater seepage. However, these initial model runs were found to substantially underestimate in-lake concentrations of total phosphorus based upon the mean ambient water quality characteristics of Lake Holden summarized in Table 2-8. Additional inputs of phosphorus were added to the model on an incremental basis, and the model was rerun with each incremental addition to evaluate changes in water quality characteristics.

Predicted water quality characteristics in Lake Holden began to closely approach actual measured water quality characteristics after the addition of 22 kg of total phosphorus to the lake on a monthly basis. This represents an additional loading to Lake Holden of approximately 265 kg/yr over a 12-month period.

A listing of trophic state modeling performed for model verification under current conditions is given in Appendix G.1. Assuming the additional monthly phosphorus loading described previously, the trophic state model for Lake Holden predicts an annual in-lake total phosphorus concentration of 34 μg/l. The trophic state model also predicts a mean phosphorus retention coefficient of approximately 0.821 for Lake Holden, indicating that approximately 82% of the phosphorus inputs into the lake are retained within the sediments throughout the year. On an annual cycle, monthly phosphorus retention coefficients for Lake Holden range from a low of 0.706 to a high of 0.900. Phosphorus retention coefficients in this range are typical of retention coefficients typically measured in lake systems in Central Florida.

A comparison of measured and predicted water quality characteristics in Lake Holden under current conditions is given in Table 4-12. Mean water quality characteristics in Lake Holden over the period from 1995-2003 reflect a mean total phosphorus concentration of 34 mg/l, a mean chlorophyll-a of 48 mg/m^3 and a mean Secchi disk depth of 0.61 m. 104. The Vollenweider model outlined in Appendix G.1, with the additional phosphorus loading of 265 kg/yr, predicts virtually the same values for each of these parameters.

TABLE 4-12

**COMPARISON OF MEASURED AND
PREDICTED WATER QUALITY CHARACTERISTICS
IN LAKE HOLDEN UNDER CURRENT CONDITIONS**

PARAMETER	UNITS	MEASURED VALUES 1995-2003	ESTIMATED MODEL VALUES
Total Phosphorus	μg/l	34	34
Chlorophyll-a	mg/m^3	48.1	48
Secchi Disk Depth	m	0.61	0.61

In view of the relatively close agreement between the measured and predicted values indicated in Table 4-12, the trophic state model outlined in Appendix G.1 is assumed to be reasonably correct for prediction of water quality characteristics in Lake Holden, The model is used in subsequent sections to predict anticipated phosphorus reductions as a result of recommended water quality improvement options for Lake Holden.

4.5 Summary of Nutrient Inputs

A summary of estimated annual mass inputs of total nitrogen to Lake Holden is given in Table 4-13. The largest contributor of total nitrogen to Lake Holden appears to be groundwater seepage, which contributes approximately 44.9% of the total annual loading. An additional 35.8% of the total nitrogen inputs are contributed by stormwater runoff, with 19.3% contributed by bulk precipitation.

TABLE 4-13

ESTIMATED ANNUAL MASS INPUTS
OF TOTAL NITROGEN TO LAKE HOLDEN

SOURCE	ANNUAL MASS INPUT (kg/yr)	PERCENT OF TOTAL
Stormwater Runoff	1688	35.8
Bulk Precipitation	911.1	19.3
Groundwater Seepage	2119	44.9
Internal Recycling	Negligible	Negligible
TOTAL:	**4718**	**100.0**

A summary of estimated annual mass inputs of total phosphorus to Lake Holden is given in Table 4-14. The largest single contributor of total phosphorus to the lake is internal recycling, which contributes approximately 49.2% of the annual loading. Stormwater runoff contributes approximately 37.3% of the annual phosphorus inputs, with 11.4% contributed by bulk precipitation and 2.1% contributed by groundwater seepage.

TABLE 4-14

**ESTIMATED ANNUAL MASS INPUTS
OF TOTAL PHOSPHORUS TO LAKE HOLDEN**

SOURCE	ANNUAL MASS INPUT (kg/yr)	PERCENT OF TOTAL
Stormwater Runoff	201	37.3
Bulk Precipitation	61.1	11.4
Groundwater Seepage	11.1	2.1
Internal Recycling	265	49.2
TOTAL:	**538.2**	**100.0**

Estimated annual inputs of TSS to Lake Holden are summarized in Table 4-15. Suspended solids inputs into the lake occur primarily as a result of stormwater runoff and bulk precipitation. Inputs of TSS from groundwater seepage and internal recycling are generally considered to be negligible. Approximately 73.8% of the annual TSS inputs to Lake Holden originate from stormwater runoff, with 26.2% contributed by bulk precipitation.

TABLE 4-15

**ESTIMATED ANNUAL MASS
INPUTS OF TSS TO LAKE HOLDEN**

SOURCE	ANNUAL MASS INPUT (kg/yr)	PERCENT OF TOTAL
Stormwater Runoff	23,651	73.8
Bulk Precipitation	8,418	26.2
Groundwater Seepage	Negligible	Negligible
Internal Recycling	Negligible	Negligible
TOTAL:	**32,069**	**100.0**

A summary of estimated annual mass inputs of BOD to Lake Holden is given in Table 4-16. Stormwater runoff is the single largest contributor of BOD inputs to Lake Holden, contributing 74.6% of the estimated total annual loading. The remaining loading is contributed by bulk precipitation. Inputs of BOD from groundwater seepage and internal recycling are typically negligible.

TABLE 4-16

**ESTIMATED ANNUAL MASS
INPUTS OF BOD TO LAKE HOLDEN**

SOURCE	ANNUAL MASS INPUT (kg/yr)	PERCENT OF TOTAL
Stormwater Runoff	7,989	74.6
Bulk Precipitation	2,716	25.4
Groundwater Seepage	Negligible	Negligible
Internal Recycling	Negligible	Negligible
TOTAL:	**10,705**	**100.0**

4.6 Summary of Nutrient Losses

Losses of total nitrogen, total phosphorus, TSS, and BOD in Lake Holden occur as a result of discharges into the drainage well structures and accumulation of nutrients, TSS, and BOD in lake sediments. Estimates of the annual losses into the drainage wells were obtained by multiplying the estimated annual volumetric discharge to the drainage wells of 1630.5 ac-ft/yr times the ambient water quality characteristics for Lake Holden summarized in Table 2-8.

Estimated annual losses of total nitrogen from Lake Holden are summarized in Table 4-17. Approximately 62.3% of the total nitrogen inputs to Lake Holden are discharged to the drainage well structures within the lake. The remaining 37.7% of nitrogen inputs are deposited into sediments within the lake. A graphical comparison of inputs and losses of total nitrogen in Lake Holden is given in Figure 4-9.

Total Nitrogen Inputs

Stormwater Runoff, 1688 kg/yr

Groundwater Seepage, 2119 kg/yr

Bulk Precipitation, 911.1 kg/yr

Total Nitrogen Losses

Loss to Sediments, 1780 kg/yr

Discharge to Drainage Wells, 2938 kg/yr
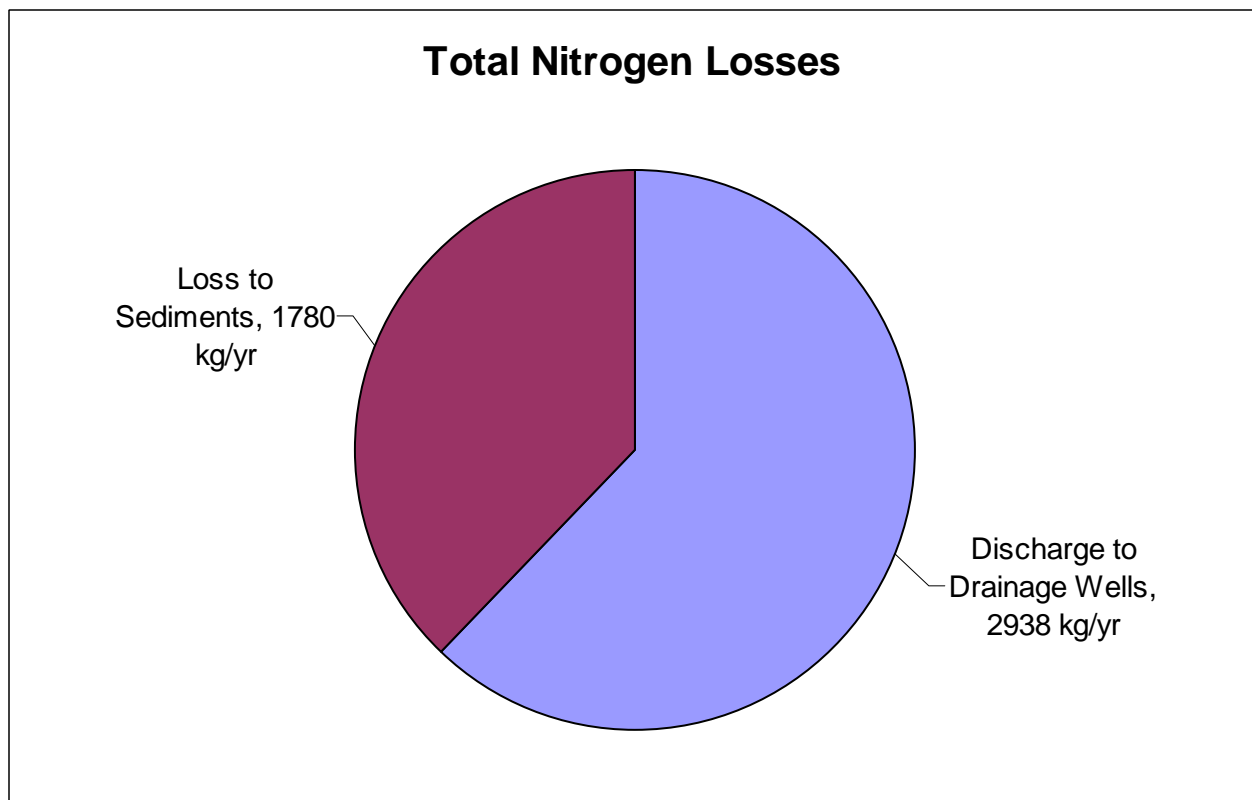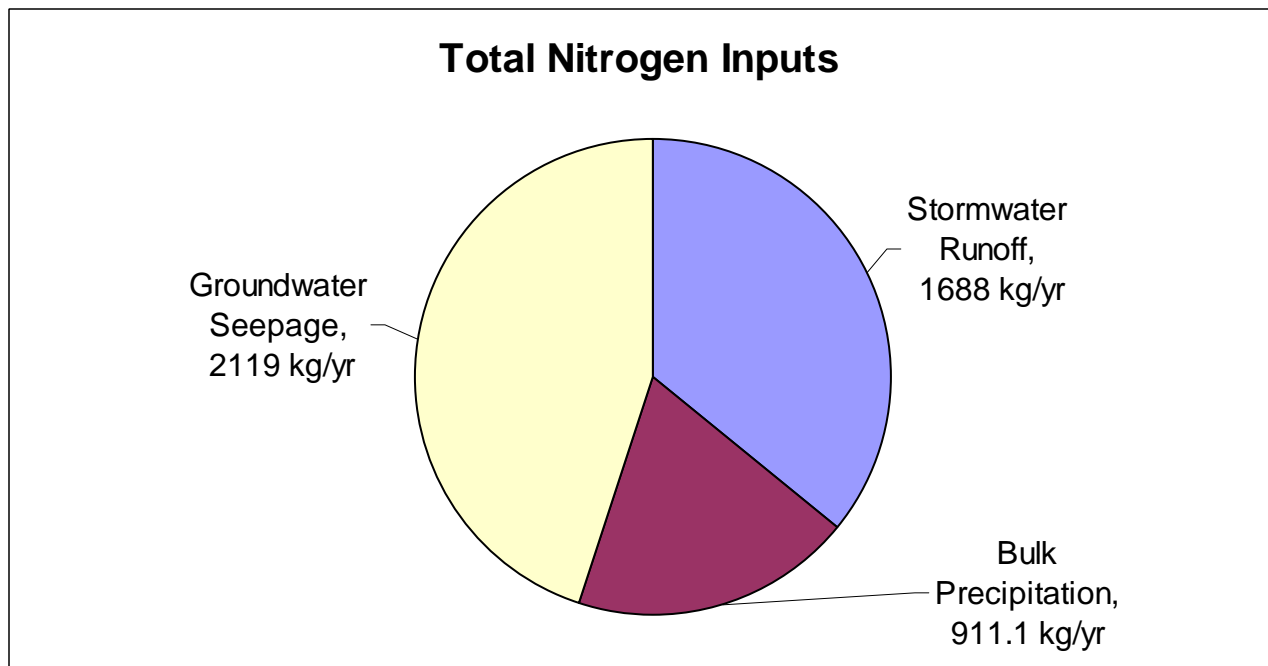
Figure 4-9. Comparison of Inputs and Losses of Total Nitrogen in Lake Holden.

TABLE 4-17

**ESTIMATED ANNUAL LOSSES OF
TOTAL NITROGEN IN LAKE HOLDEN**

SOURCE	ANNUAL LOSS (kg/yr)	PERCENT OF TOTAL
Discharge to Drainage Wells	2938	62.3
Loss to Sediments	1780	37.7
TOTAL:	**4718**	**100.0**

Estimated annual losses of total phosphorus from Lake Holden are summarized in Table 4-18. Approximately 87.3% of the total phosphorus inputs are deposited within the sediments, with 12.7% of the inputs discharging to drainage well structures. A graphical comparison of inputs and losses of total phosphorus in Lake Holden is given in Figure 4-10.

TABLE 4-18

**ESTIMATED ANNUAL LOSSES OF
TOTAL PHOSPHORUS IN LAKE HOLDEN**

SOURCE	ANNUAL LOSS (kg/yr)	PERCENT OF TOTAL
Discharge to Drainage Wells	68.4	12.7
Loss to Sediments	470.1	87.3
TOTAL:	**538.5**	**100.0**

Estimated annual losses of TSS from Lake Holden are summarized in Table 4-19. On an annual basis, approximately 87.5% of the annual suspended solids inputs are deposited into the sediments of the lake. The remaining 12.5% is discharged to the drainage well structures.

Total Phosphorus Inputs

Stormwater Runoff, 201 kg/yr

Internal Recyling, 265 kg/yr

Bulk Precipitation, 61.1 kg/yr

Groundwater Seepage, 11.1 kg/yr

Total Phosphorus Losses

Discharge to Drainage Wells 68.4 kg/yr

Loss to Sediments 470.1 kg/yr
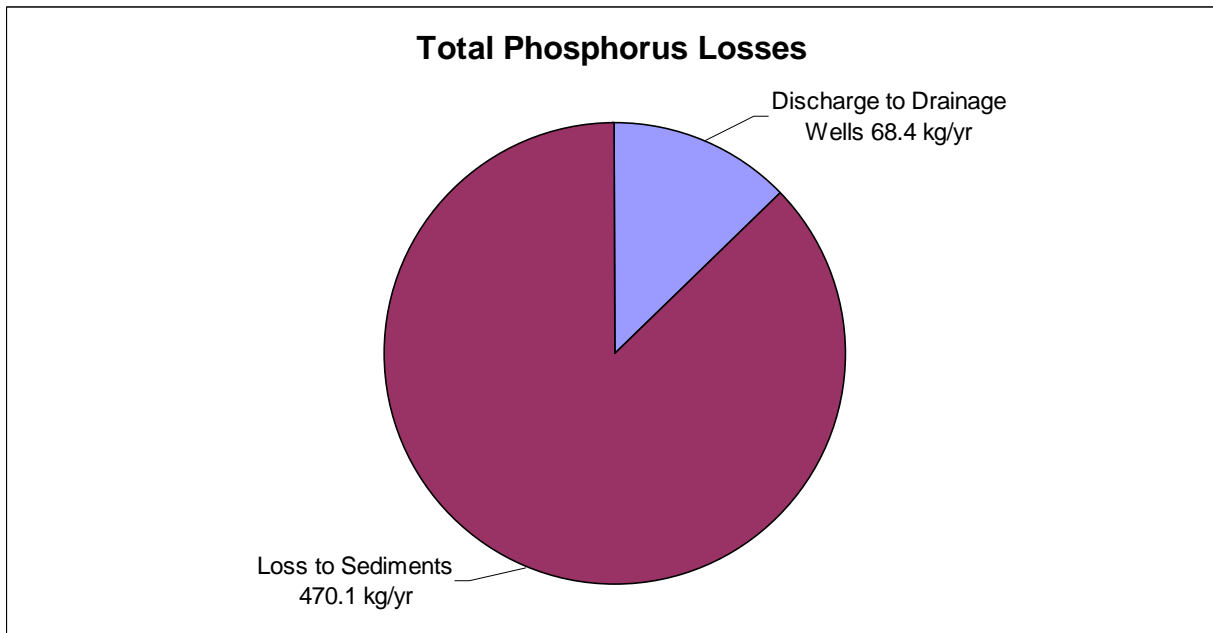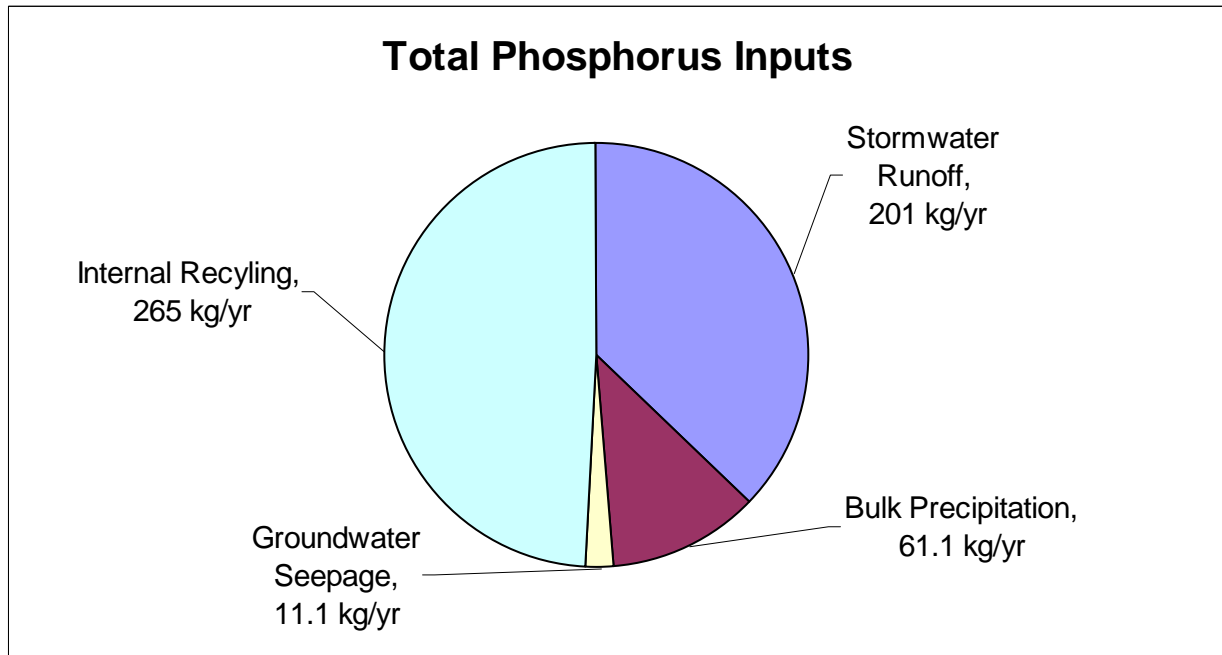
Figure 4-10. Comparison of Inputs and Losses of Total Phosphorus in Lake Holden.

TABLE 4-19

**ESTIMATED ANNUAL LOSSES
OF TSS IN LAKE HOLDEN**

SOURCE	ANNUAL LOSS (kg/yr)	PERCENT OF TOTAL
Discharge to Drainage Wells	4,022	12.5
Loss to Sediments	28,047	87.5
TOTAL:	**32,069**	**100.0**

Estimated annual losses of BOD from Lake Holden are summarized in Table 4-20. Approximately 68.4% of the BOD inputs to Lake Holden are discharged to the drainage well structures, with 31.6% deposited into the lake sediments.

TABLE 4-20

**ESTIMATED ANNUAL LOSSES
OF BOD IN LAKE HOLDEN**

SOURCE	ANNUAL LOSS (kg/yr)	PERCENT OF TOTAL
Discharge to Drainage Wells	7,319	68.4
Loss to Sediments	3,386	31.6
TOTAL:	**10,705**	**100.0**

SECTION 5

EVALUATION OF WATER
QUALITY IMPROVEMENT OPTIONS

As discussed in Section 3.3.2, Lake Holden is a phosphorus-limited ecosystem, and phosphorus inputs must be controlled to achieve improvements in water quality characteristics within the lake. Based upon the estimated annual phosphorus budget for Lake Holden, summarized in Table 4-14, internal recycling contributes approximately 49.2% of the annual phosphorus loading to Lake Holden, with stormwater runoff contributing an additional 37.3%. Inputs of total phosphorus to Lake Holden from bulk precipitation and groundwater seepage appear to be relatively minimal. Since water quality improvements in Lake Holden can best be achieved by limiting phosphorus inputs to the lake, the most logical targets for reducing phosphorus inputs into the lake appear to be reductions in loadings from internal recycling and stormwater runoff.

Several different treatment options were evaluated for Lake Holden for improvement of water quality within the lake. First, a sediment inactivation treatment is evaluated which will reduce internal recycling by approximately 75%. This treatment is performed using aluminum sulfate, commonly called alum, which is applied at the surface in a liquid form. Upon entering the water column, the alum forms an insoluble precipitate of aluminum hydroxide which attracts phosphorus, bacteria, algae, and suspended solids within the water column, settling these constituents into the bottom sediments. Upon reaching the bottom sediments, the residual aluminum binds tightly with phosphorus within the sediments, forming an inert precipitate which will not be re-released under any conceivable condition of pH or redox potential which could occur in a natural lake system. These sediment treatments have been shown to be effective from 2-20 years, depending upon the sediment accumulation rate within the lake from the remaining phosphorus sources.

The second option evaluated includes a series of stormwater treatment projects which are sufficient in magnitude to reduce phosphorus inputs from stormwater runoff by approximately 30-40%. A reduction of this magnitude can be achieved by improvement of the existing stormwater treatment in Sub-basin 1 and by construction of stormwater treatment facilities for discharges originating in Sub-basins 7 and 20. Additional water quality improvement options are also discussed which include street sweeping and public education programs. Details of each of these evaluated options are given in the following sections.

5.1 Sediment Inactivation Details

5.1.1 Chemical Requirements and Costs

Sediment inactivation in Lake Holden would involve the addition of liquid aluminum sulfate at the water surface. Upon entering the water, the alum would form insoluble precipitates which would settle onto the lake bottom while also clarifying the existing water column within the lake. Upon entering the sediments, the alum will combine with existing phosphorus within the sediments, forming insoluble inert precipitates which will bind the phosphorus, making it unavailable for release into the overlying water column. It is generally recognized that the top 10 cm layer of the sediments is the most active in terms of release of phosphorus under anoxic conditions.

Estimates of the mass of total available phosphorus within the top 0-10 cm layer of the sediments in Lake Holden were generated by graphically integrating the total available phosphorus isopleths presented on Figure 2-10. Areas contained within each isopleth contour were calculated using AutoCAD Release 12.0. The top 0-10 cm layer of the sediments in the lake is considered to be an active layer with respect to exchange of phosphorus between the sediments and the overlying water column. Inactivation of phosphorus within the 0-10 cm layer is typically sufficient to inactivate sediment release of phosphorus within a lake.

A summary of estimated total available phosphorus in the sediments of Lake Holden is given in Table 5-1. On a mass basis, the sediments of Lake Holden contain approximately 5704 kg of available phosphorus in the top 10 cm. On a molar basis, this equates to approximately 184,000 moles of available phosphorus to be inactivated as part of the sediment inactivation process.

TABLE 5-1

**ESTIMATES OF AVAILABLE SEDIMENT PHOSPHORUS
AND INACTIVATION REQUIREMENTS FOR LAKE HOLDEN**

AVAILABLE P CONTOUR INTERVAL (μg/cm^3)	INTERVAL MID-POINT (μg/cm^3)	AREA (ac)	AVAILABLE P (kg)		INACTIVANT REQUIREMENT	
			kg	moles	moles Al[1]	alum (gallons)
0-50	25	164.6	1,665	53,710	537,100	65,401
50-100	75	74.2	2,252	72,645	726,450	88,458
100-150	125	12.2	617	19,903	199,030	24,235
150-200	175	10.6	751	24,226	242,260	29,499
> 200	225	4.6	419	13,516	135,160	16,458
Total:		**266.2**	**5,704**	**184,000**	**1,840,000**	**224,051**

1. Based on an Al:P molar ratio of 5:1

Estimated inactivation requirements were calculated for Lake Holden based upon a molar Al:P ratio of 10:1, as utilized by ERD in previous inactivation evaluations. Prior research involving sediment inactivation has indicated that an excess of aluminum is required within the sediments to cause phosphorus to preferentially bind with aluminum rather than other available complexing agents. A 10:1 molar ratio of Al:P has been shown to be adequate to create this driving force. Based upon this ratio, inactivation of phosphorus release from sediments in Lake Holden will require approximately 1,840,000 moles of aluminum which equates to approximately 225,000 gallons of alum.

An average water column dose of alum required for sediment inactivation was calculated by dividing the alum requirements of 225,000 gallons by the overall volume of the lake. Since the alum application would occur at the surface, the overall whole-lake alum dose must be evaluated in addition to sediment requirements. Application of approximately 225,000 gallons of alum to Lake Holden into a water column volume of approximately 3211.5 ac-ft would result in an applied alum dose of 12.6 mg Al/liter. This dose is within the range of concentrations typically outlined in sediment inactivation projects in the Central Florida area. However, a dose in this range would probably have to be divided into 2-3 individual applications to minimize the impact on aquatic life in the lake.

A summary of estimated application costs for sediment inactivation in Lake Holden is given in Table 5-2. The estimated quantity of alum required for sediment inactivation is based upon the information provided in Table 5-1. Planning and mobilization costs are estimated to be approximately $5000, which includes initial planning, testing, mobilization of equipment to the site, and demobilization at the completion of the application process. Estimates of man-hour requirements for the application are provided based upon experience with similar previous applications by ERD. A labor rate of $100/hour is assumed which includes labor costs, expenses, equipment rental, insurance, mileage, and application equipment fees. Pre- and post-treatment water quality testing is also included. The estimated cost for sediment inactivation in Lake Holden is $203,750.

TABLE 5-2

ESTIMATED APPLICATION COSTS FOR
SEDIMENT INACTIVATION IN LAKE HOLDEN

ALUM / TREATMENT		APPLICATION EXPENSES / TREATMENT				WATER QUALITY TESTING	TOTAL COST ($)
		PLANNING/ MOBILIZATION ($)	LABOR				
QUANTITY (gallons)	COST[1] ($)		MAN-HOURS	LABOR[2] ($)	TOTAL LABOR ($)		
225,000	146,250	5,000	500	$ 100/hr	50,000	2,500	203,750

1. Based on a cost of $0.65/gallon which includes raw material, shipping, and on-site unloading charges
2. Includes raw labor, insurance, expenses, application equipment, mileage, and rentals

5.2.1 <u>Longevity of Treatment</u>

After initial application, the alum precipitate will form a visible floc layer on the surface of the sediments within the lake. This floc layer will continue to consolidate for approximately 30 days, reaching maximum consolidation at that time. Due to the unconsolidated nature of the sediments in much of the lake, it is anticipated that a large portion of the floc will migrate into the existing sediments rather than accumulate on the surface as a distinct layer. This process is

beneficial since it allows the floc to sorb soluble phosphorus during migration through the surficial sediments. Any floc remaining on the surface will provide a chemical barrier for adsorption of phosphorus which may be released from the sediments.

Based on previous experiences by ERD, as well as research by others, it appears that a properly applied chemical treatment will be successful in inactivation of the available phosphorus in the sediments of Lake Holden. However, several factors can serve to reduce the effectiveness and longevity of this treatment process. First, wind action can cause the floc to become prematurely mixed into deeper sediments, reducing the opportunity for maximum phosphorus adsorption. Significant wind resuspension has been implicated in several alum applications in shallow lakes which exhibited reduced longevity. However, in the absence of wind resuspension, alum inactivation in lake sediments has resulted in long-term benefits ranging from 3 to more than 10 years. Due to the depth of Lake Holden, it is not anticipated that wind-induced resuspension will be a problem.

Another factor which can affect the perceived longevity and success of the application process is recycling of nutrients by macrophytes from the sediments into the water column. This recycling will bypass the inactivated sediments since phosphorus will cross the sediment-water interface using vegetation rather than through the floc layer. Although this process will not affect the inactivation of phosphorus within the sediments, it may result in increases in dissolved phosphorus concentrations which are unrelated to sediment-water column processes. However, the degree of macrophyte growth in Lake Holden appears to be limited to shoreline areas, and recycling of phosphorus by macrophytes does not appear to be a significant concern.

A final factor affecting the longevity of an alum treatment is significant upward migration of groundwater seepage through the bottom sediments. This seepage would almost certainly contain elevated phosphorus levels which would be adsorbed onto the aluminum floc, reducing the floc which is available for interception of sediment phosphorus release. An additional available pool of aluminum will be present within the sediments. If necessary, repeat alum applications at lower doses can be performed every 3-5 years to inactivate newly formed sediments and to adsorb phosphorus migrating upward as a result of groundwater seepage.

5.2 <u>Stormwater Treatment</u>

5.2.1 <u>Sub-basin 1</u>

As indicated in Table 4-8, the most significant remaining stormwater-related inputs of total phosphorus to Lake Holden originate in Sub-basins 1, 7, and 20, with Sub-basin 1 contributing 47.5% of the remaining total phosphorus inputs, Sub-basin 7 contributing 5.8%, and Sub-basin 20 contributing 6.9%. Discharges into Lake Holden through Sub-basin 1 currently receive alum treatment through an existing alum injection system for the Division Street outfall. Although the monitoring performed by ERD indicates that this system achieved extremely low levels of total phosphorus during a majority of the monitored events, several episodes of elevated phosphorus concentrations were observed entering the lake in spite of the alum addition. These elevated concentrations could be due to either non-operation of the system during these monitored events or that the total phosphorus concentrations were so elevated in the runoff flow that the current alum dose is insufficient to provide the desired level of treatment.

A thorough review of the operation of the alum injection system should be performed by the City of Orlando to verify the operation of the system during the monitored events where elevated phosphorus levels were recorded. If it is determined that the system was operating properly during these events, then it appears that the current alum dose may be too low to achieve the desired level of phosphorus reduction. If this in the case, the alum dose should be increased to the maximum dose allowed under the current permit for this system, which is currently 15 mg/l. An alum dose in this range should be more than sufficient to provide the desired phosphorus reduction for virtually any input of concentrations of total phosphorus likely to be reported at this site.

5.2.2 <u>Sub-basin 20</u>

Options for stormwater treatment in Sub-basin 20 are severely limited due to the lack of available land within the basin. However, Sub-basin 20 is immediately adjacent to the existing alum stormwater treatment facility, and an additional pump and flow meter could easily be added

to the existing system which would provide treatment for inflow from Sub-basin 20. The addition of this system would be relatively inexpensive since the building and alum storage tank are already in place. Alum feed lines and electrical sensor lines would need to be extended along Alamo Drive to the southern boundary of Sub-basin 20 where the 36-inch culvert discharges into Lake Holden. The estimated installed cost for this additional injection site is approximately $100,000-125,000. The existing permit for the alum stormwater treatment system would need to be modified to include incorporation of the additional sub-basin area. It should be noted that current permits for alum stormwater treatment systems frequently require collection of the floc prior to discharge into the ultimate receiving waterbody. If this were to be required for the retrofit in Sub-basin 20, additional costs would be incurred for floc collection equipment or facilities.

5.2.3   Sub-basin 7

Sub-basin 7 is located on the southeastern side of Lake Holden and includes an area of single-family homes. This area discharges through a 48-inch RCP along Krueger Street into the southeast lobe of the lake. The 48-inch RCP discharges through portions of Sub-basin 22 along its path to the lake. A small amount of land may be available in the vicinity of the stormsewer pipe which could be used to construct a small wet detention facility. However, for a wet detention pond to provide effective stormwater treatment, the pond surface area must be approximately 5-10% of the basin area which the pond is designed to treat. Based upon a basin area of 52.9 acres for Sub-basin 7, the required pond size would range from approximately 2.6-5.3 acres. It seems unlikely that this amount of land is available in the area between Sub-basin 7 and the lake.

An additional option for providing stormwater treatment in Sub-basin 7 is to install an additional small alum stormwater treatment system for this basin. This system could be constructed as an underground facility which would require no additional land or right-of-way acquisition. The estimated cost for an underground alum injection facility to treat this sub-basin is approximately $175,000. Points of injection could also be extended easily into Sub-basins 5

and 6 from this facility, although Sub-basins 5 and 6 represent a relatively small amount of phosphorus inflow into the lake. However, it should be noted that current regulations may require collection of the alum floc prior to discharge into the ultimate receiving waterbody which may increase overall costs.

5.3 Street Sweeping

Street sweeping is an effective best management practice (BMP) for reducing total suspended solids and associated pollutant wash-off from urban streets. Street sweeping is well suited to an urban environment where little land is available for installation of structural controls. Street sweeping can be extremely effective in commercial business districts, industrial sites, and intensely developed areas in close proximity to receiving waters.

Street sweeping involves the use of machines which basically pick-up contaminants from the street surface and deposit them in a self-contained bin or hopper. Mechanical sweepers are the most commonly used sweeping devices and consist of a series of brooms which rotate at high speeds, forcing debris from the street and gutter into a collection hopper. Water is often sprayed on the surface for dust control during the sweeping process. The effectiveness of mechanical sweepers is a function of a number of factors, including: (1) particle size distribution of accumulated surface contaminants; (2) sweeping frequency; (3) number of passes during each sweeping event; (4) equipment speed; and (5) pavement conditions. Unfortunately, mechanical sweepers perform relatively poorly for collection of particle sizes which are commonly associated with total phosphorus in stormwater runoff.

Over the past decade, improvements have been made to street sweeping devices which substantially enhance the performance efficiency. Vacuum-type sweepers, which literally vacuum the roadway surface, have become increasingly more popular, particularly for parking lot areas. The overall efficiency of vacuum-type sweepers is generally higher than that of mechanical cleaners, especially for particles larger than 3 mm. Estimated efficiencies of mechanical and vacuum-assisted sweepers are summarized in Table 5-3 based upon information

provided by the Federal Highway Administration. Mechanical sweepers can provide approximately 40% removal of phosphorus in roadway dust and debris, while vacuum-assisted sweepers can provide removals up to 74%.

TABLE 5-3

**EFFICIENCIES OF MECHANICAL
(BROOM) AND VACUUM-ASSISTED SWEEPERS**

CONSTITUENT	MECHANICAL SWEEPER EFFICIENCY (%)	VACUUM-ASSISTED SWEEPER EFFICIENCY (%)
Total Solids	55	93
Total Phosphorus	40	74
Total Nitrogen	42	77
COD	31	63
BOD	43	77
Lead	35	76

SOURCE: Federal Highway Administration (FHWA)

The efficiency of street sweepers is highly dependent upon the sweeping interval. To achieve a 30% annual removal of street dirt, the sweeping interval should be less than two times the average interval between storms. Since the average interval between storms in the Central Florida area is approximately three days, a sweeping frequency of once every six days is necessary to achieve a 30% removal of street dirt. To achieve a 50% annual removal, sweeping must occur at least once between storm events. In the Central Florida area, a 50% removal would require street sweeping to occur approximately once every three days.

Street sweeping activities can be particularly effective during periods of high leaf fall by removing solid leaf material and the associated nutrient loadings from roadside areas where they can easily become transported by stormwater flow. Previous research has indicated that leaves release large quantities of both nitrogen and phosphorus into surface water within 24-48 hours after

becoming saturated in an aquatic environment. Loadings to waterbodies from leaf fall are often the most significant loadings to receiving waters during the fall and winter months. Street sweeping operations are typically performed on a monthly basis, with increased frequency during periods of high leaf fall.

Costs for street sweepers range from approximately $70,000-130,000, with the lower end of the range associated with mechanical street sweepers and the higher end of the range associated with vacuum-type sweepers. The useful life span is typically 4-7 years, with an operating cost of approximately $70/hour.

5.4 **Public Education**

Public education is one of the most important nonpoint source controls which can be used in a watershed. Many residents appear to be unaware of the direct link between watershed activities and the water quality in adjacent waterbodies and estuaries. The more a resident or business owner understands the relationship between nonpoint source loadings and receiving water quality, the more that person may be willing to implement source controls.

Several national studies have indicated that it is an extremely worthwhile and cost-effective activity to periodically remind property owners of the potential for water quality degradation which can occur due to misapplication of fertilizers and pesticides. Periodic information pamphlets can be distributed by hand or enclosed with water and sewer bills which will reach virtually all residents within the watershed. These educational brochures should emphasize the fact that taxpayer funds are currently being utilized to treat nonpoint source water pollution, and the homeowners have the opportunity to reduce this tax burden by modifying their daily activities. A comprehensive public education program should concentrate, at a minimum, on the following topics:

1.   Relationship between land use, stormwater runoff, and pollutants

2.   Functions of stormwater treatment systems

3. How to reduce stormwater runoff volume

4. Impacts of water fowl and pets on runoff characteristics and surface water quality

5. County stormwater program goals and regulations

6. Responsible use of fertilizer, pesticides and herbicides

7. Elimination of illicit connections to the stormwater system

8. Controlling erosion and turbidity

9. Proper operation and maintenance of stormwater systems

The public education program can be implemented in a variety of ways, including homeowner and business seminars, newsletters, performing special projects with local schools (elementary, middle and high schools), Earth Day celebrations, brochures, and special signage at stormwater treatment construction sites. Many people do not realize that stormsewers eventually drain to area lakes. Many cities and counties in Florida have implemented a signage program which places a small engraved plaque on each stormsewer inlet indicating "Do Not Dump, Drains to Lake". ERD recommends that an aggressive public education program be implemented in the Lake Holden watershed which incorporates all of the elements discussed previously.

Anticipated load reductions for implementation of public education programs are difficult to predict and depend highly upon the degree of implementation by the homeowners within the basin. The impacts of public education programs also depend, to a large extent, on the degree to which water quality within the Lake Holden basin is currently being impacted by uneducated and uninformed activities by current homeowners. Several regional and national studies are currently being performed which will attempt to document the results of public education programs.

5.5 Water Quality Improvements for Evaluated Treatment Options

Four separate treatment options were evaluated for Lake Holden for improvement of water quality within the lake. A summary of the evaluated treatment options is given in Table 5-4. First, a sediment inactivation treatment is evaluated which will reduce internal recycling by approximately 75%. The second option evaluated includes additional stormwater improvement projects in Sub-basins 1, 7, and 20 which are sufficient to reduce existing total phosphorus loads from these basins by approximately 50%. The third treatment option evaluated includes sediment inactivation plus stormwater treatment in Sub-basin 1 sufficient to reduce runoff loadings of total phosphorus by 50% in this basin. The final option evaluated includes sediment inactivation plus the previously discussed stormwater treatment in Sub-basins 1, 7, and 20.

TABLE 5-4

EVALUATED WATER QUALITY
IMPROVEMENT OPTIONS FOR LAKE HOLDEN

OPTION	ESTIMATED PHOSPHORUS REMOVAL
Sediment Inactivation	* 75% of internal recycling load * 212 kg/yr
Stormwater Treatment in Sub-basins 1, 7, and 20	* 50% of runoff load in each basin * 60.2 kg/yr
Sediment Inactivation + Stormwater Treatment in Sub-basin 1	* 75% of internal recycling load + 50% of runoff load * 47.6 kg/yr
Sediment Inactivation + Stormwater Treatment in Sub-basins 1, 7, and 20	* 75% of internal recycling load + 50% of runoff load * 272 kg/yr

Each of the selected water quality improvement options was evaluated using the calibrated water quality model for Lake Holden. A complete listing of modeled outputs for evaluation of water quality improvement options is given in Appendix G.2. A summary of predicted water quality improvements in Lake Holden from the evaluated treatment options is given in Table 5-5. Sediment inactivation within Lake Holden will reduce water column

concentrations of total phosphorus by approximately 38%, with a 48% reduction in chlorophyll-a, and a 102% increase in Secchi disk depth (water column clarity). In terms of trophic status, Lake Holden would be converted from its current hypereutrophic status to a eutrophic condition. The stormwater treatment option, which reduces total phosphorus runoff inputs in Sub-basins 1, 7, and 20 by approximately 50%, will result in only a minimal improvement in concentrations of total phosphorus, chlorophyll-a, and water column clarity. This lack of significant water quality improvements is due to the fact that stormwater is estimated to be a relatively small contributor to existing water quality problems within the lake.

TABLE 5-5

PREDICTED WATER QUALITY
IMPROVEMENTS IN LAKE HOLDEN FROM
EVALUATED TREATMENT OPTIONS

OPTION	TOTAL P (µg/l)	CHYL-A (mg/m^3)	SECCHI DISK (m)	TSI
Current Conditions	34	48	0.61	77
Sediment Inactivation (75% Effectiveness)	21	25	1.23	63
Stormwater Treatment in Sub-basins 1, 7, and 20 (50% TP Reduction)	31	40	0.71	74
Sediment Inactivation + Stormwater Treatment in Sub-basin 1	18	20	1.48	59
Sediment Inactivation + Stormwater Treatment in Sub-basins 1, 7, and 20	17	18	1.57	58

The best water quality in Lake Holden can be achieved by a combination of the two treatment options involving both sediment inactivation and stormwater treatment. Sediment inactivation plus stormwater treatment in Sub-basin 1 will reduce total phosphorus

concentrations by approximately 47%, with a 58% reduction in chlorophyll-a and a 143% improvement in Secchi disk. The trophic status of Lake Holden will be modified from its current hypereutrophic status to a borderline mesotrophic/eutrophic range. Sediment inactivation plus additional stormwater treatment in Sub-basins 1, 7, and 20 will result in even further incremental improvements in water quality within the lake.

SECTION 6

RECOMMENDATIONS

Based upon the results of the field and laboratory evaluations, and computer modeling discussed in the previous sections, the following recommendations are made for improvement of water quality in Lake Holden. The recommended options are listed in the approximate order of potential benefits to water quality within the lake.

1.   An alum treatment should be performed to inactivate sediment phosphorus release within the lake. This appears to be the least expensive treatment option which could provide the most significant reduction in phosphorus loadings within the lake. The treatment should be repeated, as appropriate, approximately every 5-10 years.

2.   Investigate the current operational status of the alum stormwater treatment system which currently provides treatment for Sub-basins 1, 2, and 21. Increase the alum injection rate at the existing sites to the maximum extent allowed under the current permit, currently 15 mg/l.

3.   Conduct preliminary evaluations to investigate the feasibility of providing stormwater treatment for Sub-basins 7 and 20. Although it appears that alum injection systems may be the most appropriate systems at this time, other options should also be evaluated for these areas.

4.   After water clarification has occurred following the alum treatment to the lake, an aggressive planting program should be established for submergent species within the lake. Submergent species provide the best opportunity for additional uptake of nutrients and further improvement of water quality characteristics within the lake.

5.   Conduct an aggressive educational program throughout the watershed area concerning proper landscaping and irrigation techniques, and the link between watershed practices and lake water quality. Educational pamphlets can be delivered door-to-door or included in utility bills distributed within the Lake Holden basin.

6.   Initiate a program to create reverse swales or berms in shoreline areas around the lake to reduce direct runoff inputs into the lake. Direct runoff inputs into the lake are currently estimated to be approximately 10% of the runoff related phosphorus inputs into the lake. Grants may be available from Orange County and other agencies to assist homeowners in construction of the swales or berms.

7.   Improve the overall cleanliness of the watershed by increasing street sweeping frequency, particularly during periods of leaf fall. The Homeowners Association should investigate the feasibility of either purchasing a dedicated street sweeper for the Lake Holden basin or contracting with private street sweeping companies if sufficient street sweeping activities cannot be obtained from either Orange County or the City of Orlando.

8.   Pursue additional watershed stormwater treatment projects, as available, as part of development or repair projects to stormsewer systems in the area. The Lake Holden Advisory Board should remain aware of ongoing development activities within the basin and pursue additional water quality opportunities as appropriate.

9.   Large quantities of shad and tilapia currently exist within Lake Holden. These fish species are detrimental to water quality since they consume algae and excrete the algae as soluble nutrients rather than allowing the algae to settle into the bottom sediments where they potentially become unavailable. The Lake Holden Advisory Board should consider encouraging commercial fishermen to harvest and remove shad and tilapia from the lake as part of an aggressive program to limit the populations of these species within the lake.

10. The most polluting watershed activities in the Lake Holden basin appear to occur in Sub-basin 1 (Division Street). Residents should keep close watch on routine activities within this basin and inform City and/or County officials, as appropriate, of activities within the basin which have the potential to threaten the lake or substantially increase runoff related inputs during storm events.

APPENDICES

APPENDIX A

DIGITAL COPY OF THE
ANNOTATED HISTORICAL DATA
SET FOR LAKE HOLDEN

APPENDIX B

HYDROLOGIC MODELING FOR ESTIMATION OF RUNOFF INPUTS TO LAKE HOLDEN

Parameter	B-1	B-2	B-3	B-4A	B-4B	B-5	B-6
Area	98.9	65.7	19.7	89.3	12.8	10.4	8.8
DCIA	76	60	19	38	59	26	23
non DCIA CN	75.3	59.9	51.7	53.4	58.1	55.4	53.5

S	3.28	6.70	9.33	8.72	7.21	8.04	8.69

Rainfall Event Range (in)	Rainfall Interval Point (in)	Number of Annual Events in Range	B-1	B-2	B-3	B-4A	B-4B	B-5	B-6
0.00-0.10	0.041	56.683	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11-0.20	0.152	18.866	6.09	3.18	0.31	2.73	0.61	0.22	0.17
0.21-0.30	0.252	10.590	10.12	5.28	0.51	4.54	1.02	0.36	0.28
0.31-0.40	0.353	7.312	11.57	6.04	0.59	5.19	1.16	0.41	0.31
0.41-0.50	0.456	6.325	14.13	7.37	0.72	6.34	1.42	0.51	0.38
0.51-1.00	0.713	17.102	65.73	34.28	3.34	29.47	6.62	2.35	1.79
1.01-1.50	1.221	6.733	48.39	24.67	2.41	21.21	4.76	1.69	1.29
1.51-2.00	1.726	3.145	33.68	16.87	1.63	14.37	3.24	1.15	0.87
2.01-2.50	2.217	1.470	20.96	10.50	1.02	8.91	2.01	0.74	0.55
2.51-3.00	2.704	0.726	12.98	6.55	0.67	5.64	1.25	0.49	0.36
3.01-3.50	3.246	0.391	8.58	4.38	0.48	3.85	0.84	0.35	0.26
3.51-4.00	3.667	0.260	6.56	3.38	0.40	3.03	0.65	0.28	0.21
4.01-4.50	4.216	0.149	4.38	2.28	0.29	2.10	0.44	0.20	0.15
4.51-5.00	4.796	0.056	1.90	1.00	0.14	0.94	0.19	0.09	0.07
5.01-6.00	5.454	0.167	6.56	3.51	0.51	3.38	0.67	0.33	0.26
6.01-7.00	6.470	0.019	0.88	0.48	0.08	0.48	0.09	0.05	0.04
7.01-8.00	7.900	0.019	1.10	0.61	0.10	0.63	0.12	0.07	0.05
8.01-9.00	8.190	0.019	1.14	0.64	0.11	0.66	0.12	0.07	0.05
>9.00	10.675	0.075	6.06	3.47	0.67	3.78	0.67	0.41	0.33

	B-1	B-2	B-3	B-4A	B-4B	B-5	B-6
Generated Volume (ac-ft/yr)	260.81	134.49	13.98	117.25	25.88	9.77	7.42
Weighted Basin "C" Value	0.638	0.495	0.171	0.318	0.489	0.227	0.203

Parameter	B-7	B-8	B-9	B-10A	B-10B	B-11	B-12
Area	52.9	7.8	6.8	10.9	8.0	10.8	26.3
DCIA	27	24	27	27	27	28	72
non DCIA CN	53.6	58.0	54.5	62.5	61.1	60.3	77.0

S	8.65	7.25	8.35	5.99	6.37	6.57	2.99

Rainfall Event Range (in)	Rainfall Interval Point (in)	Number of Annual Events in Range	B-7	B-8	B-9	B-10A	B-10B	B-11	B-12
0.00-0.10	0.041	56.683	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11-0.20	0.152	18.866	1.16	0.15	0.15	0.24	0.17	0.24	1.53
0.21-0.30	0.252	10.590	1.92	0.25	0.25	0.40	0.29	0.40	2.53
0.31-0.40	0.353	7.312	2.20	0.29	0.28	0.45	0.33	0.46	2.90
0.41-0.50	0.456	6.325	2.68	0.35	0.35	0.55	0.41	0.56	3.54
0.51-1.00	0.713	17.102	12.48	1.64	1.61	2.58	1.88	2.63	16.50
1.01-1.50	1.221	6.733	8.98	1.18	1.16	1.86	1.36	1.89	12.30
1.51-2.00	1.726	3.145	6.09	0.82	0.78	1.35	0.97	1.33	8.63
2.01-2.50	2.217	1.470	3.83	0.54	0.50	0.91	0.65	0.88	5.41
2.51-3.00	2.704	0.726	2.48	0.36	0.32	0.61	0.43	0.59	3.36
3.01-3.50	3.246	0.391	1.75	0.26	0.23	0.44	0.31	0.42	2.23
3.51-4.00	3.667	0.260	1.40	0.21	0.18	0.35	0.25	0.34	1.71
4.01-4.50	4.216	0.149	0.99	0.15	0.13	0.25	0.18	0.24	1.15
4.51-5.00	4.796	0.056	0.46	0.07	0.06	0.11	0.08	0.11	0.50
5.01-6.00	5.454	0.167	1.67	0.26	0.22	0.42	0.30	0.40	1.72
6.01-7.00	6.470	0.019	0.24	0.04	0.03	0.06	0.04	0.06	0.23
7.01-8.00	7.900	0.019	0.33	0.05	0.04	0.08	0.06	0.08	0.29
8.01-9.00	8.190	0.019	0.35	0.05	0.05	0.08	0.06	0.08	0.30
>9.00	10.675	0.075	2.03	0.31	0.27	0.48	0.35	0.46	1.60

	B-7	B-8	B-9	B-10A	B-10B	B-11	B-12
Generated Volume (ac-ft/yr)	51.04	6.98	6.61	11.22	8.12	11.17	66.43
Weighted Basin "C" Value	0.233	0.216	0.235	0.248	0.246	0.250	0.610

Parameter	B-13	B-14	B-15	B-16	B-17	B-18	B-19
Area	81.5	3.6	4.5	12.1	4.4	35.9	16.8
DCIA	48	63	39	26	26	25	34
non DCIA CN	56.3	59.7	42.8	63.7	79.1	53.9	71.5

S	7.76	6.75	13.34	5.69	2.64	8.55	3.99

Rainfall Event Range (in)	Rainfall Interval Point (in)	Number of Annual Events in Range	B-13	B-14	B-15	B-16	B-17	B-18	B-19
0.00-0.10	0.041	56.683	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11-0.20	0.152	18.866	3.16	0.18	0.14	0.26	0.09	0.73	0.46
0.21-0.30	0.252	10.590	5.25	0.30	0.24	0.43	0.15	1.21	0.76
0.31-0.40	0.353	7.312	6.00	0.35	0.27	0.49	0.17	1.39	0.87
0.41-0.50	0.456	6.325	7.33	0.42	0.34	0.60	0.21	1.69	1.06
0.51-1.00	0.713	17.102	34.10	1.97	1.56	2.79	1.04	7.87	4.95
1.01-1.50	1.221	6.733	24.55	1.42	1.12	2.01	0.97	5.67	3.81
1.51-2.00	1.726	3.145	16.68	0.97	0.76	1.49	0.80	3.84	2.92
2.01-2.50	2.217	1.470	10.40	0.60	0.46	1.01	0.55	2.43	1.97
2.51-3.00	2.704	0.726	6.53	0.37	0.28	0.68	0.37	1.59	1.31
3.01-3.50	3.246	0.391	4.41	0.25	0.18	0.49	0.26	1.13	0.92
3.51-4.00	3.667	0.260	3.44	0.19	0.14	0.40	0.21	0.91	0.73
4.01-4.50	4.216	0.149	2.35	0.13	0.10	0.28	0.14	0.65	0.51
4.51-5.00	4.796	0.056	1.04	0.06	0.04	0.13	0.06	0.30	0.23
5.01-6.00	5.454	0.167	3.69	0.20	0.15	0.47	0.23	1.10	0.81
6.01-7.00	6.470	0.019	0.51	0.03	0.02	0.07	0.03	0.16	0.11
7.01-8.00	7.900	0.019	0.66	0.03	0.03	0.09	0.04	0.22	0.15
8.01-9.00	8.190	0.019	0.69	0.04	0.03	0.09	0.04	0.23	0.15
>9.00	10.675	0.075	3.87	0.19	0.17	0.54	0.24	1.36	0.86

	B-13	B-14	B-15	B-16	B-17	B-18	B-19
Generated Volume (ac-ft/yr)	134.66	7.70	6.03	12.32	5.60	32.48	22.58
Weighted Basin "C" Value	0.400	0.520	0.322	0.247	0.311	0.219	0.326

Parameter	B-20	B-21	B-22
Area	60.9	19.4	105.5
DCIA	28	53	1
non DCIA CN	61.5	59.4	66.3

	B-20	B-21	B-22
S	6.26	6.82	5.08

Rainfall Event Range (in)	Rainfall Interval Point (in)	Number of Annual Events in Range	B-20	B-21	B-22
0.00-0.10	0.041	56.683	0.00	0.00	0.00
0.11-0.20	0.152	18.866	1.38	0.83	0.09
0.21-0.30	0.252	10.590	2.30	1.37	0.14
0.31-0.40	0.353	7.312	2.63	1.57	0.16
0.41-0.50	0.456	6.325	3.21	1.91	0.20
0.51-1.00	0.713	17.102	14.91	8.91	0.93
1.01-1.50	1.221	6.733	10.73	6.41	1.13
1.51-2.00	1.726	3.145	7.66	4.39	2.83
2.01-2.50	2.217	1.470	5.12	2.75	3.21
2.51-3.00	2.704	0.726	3.42	1.73	2.82
3.01-3.50	3.246	0.391	2.43	1.16	2.42
3.51-4.00	3.667	0.260	1.96	0.90	2.14
4.01-4.50	4.216	0.149	1.39	0.62	1.65
4.51-5.00	4.796	0.056	0.63	0.27	0.81
5.01-6.00	5.454	0.167	2.31	0.96	3.09
6.01-7.00	6.470	0.019	0.33	0.13	0.47
7.01-8.00	7.900	0.019	0.44	0.17	0.66
8.01-9.00	8.190	0.019	0.46	0.18	0.70
>9.00	10.675	0.075	2.67	0.98	4.18

	B-20	B-21	B-22
Generated Volume (ac-ft/yr)	63.98	35.24	27.63
Weighted Basin "C" Value	0.254	0.440	0.063

APPENDIX C

FIELD MEAUSREMENTS OF
SEEPAGE INFLOW TO LAKE HOLDEN
FROM APRIL-OCTOBER 2003

Seepage Meter Field Measurements

Location:____Lake Holden____   Date:____3/15/03____

Date Installed:____3/15/03____   Chamber Diameter:____0.58 m____   Sediment Area Covered:____0.27 m^2____

Site / Location	Time Collected	Volume Collected (liters)	Previous Collection Event		Seepage Time (days)	Seepage (liters/m^2-day)	Comments / Observations
			Date	Time			
1	10:40	-----	-----	-----	-----	-----	Bags Installed
2	9:40	-----	-----	-----	-----	-----	Bags Installed
3	9:50	-----	-----	-----	-----	-----	Bags Installed
4	10:00	-----	-----	-----	-----	-----	Bags Installed
5	10:10	-----	-----	-----	-----	-----	Bags Installed
6	10:20	-----	-----	-----	-----	-----	Bags Installed
7	10:30	-----	-----	-----	-----	-----	Bags Installed
8	10:50	-----	-----	-----	-----	-----	Bags Installed
9	11:20	-----	-----	-----	-----	-----	Bags Installed
10	11:45	-----	-----	-----	-----	-----	Bags Installed

Seepage Meter Field Measurements

Location: Lake Holden   Date: 4/18/03

Date Installed: 3/15/03   Chamber Diameter: 0.58 m   Sediment Area Covered: 0.27 m^2

Site / Location	Time Collected	Volume Collected (liters)	Previous Collection Event		Seepage Time (days)	Seepage (liters/m^2-day)	Comments / Observations
			Date	Time			
1	13:30	22.0	3/15/03	10:40	34.1	2.39	Sample collected, bag replaced
2	13:40	23.0	3/15/03	9:40	34.2	2.49	Bag in good condition, sample collected
3	13:50	3.9	3/15/03	9:50	34.2	0.42	Bag in good condition, sample collected
4	14:05	43.0	3/15/03	10:00	34.2	4.66	Sample collected, bag replaced
5	14:15	17.0	3/15/03	10:10	34.2	1.84	Bag in good condition, sample collected
6	14:25	53.0	3/15/03	10:20	34.2	5.74	Bag in good condition, sample collected
7	14:35	13.7	3/15/03	10:30	34.2	1.48	Sample collected, bag replaced
8	14:55	1.9	3/15/03	10:50	34.2	0.21	Bag in good condition, sample collected
9	15:10	5.6	3/15/03	11:20	34.2	0.61	Bag in good condition, sample collected
10	15:25	1.0	3/15/03	11:45	34.2	0.11	Bag in good condition, sample collected

Seepage Meter Field Measurements

Location:____Lake Holden____   Date:____5/20/03____

Date Installed:____3/15/03____   Chamber Diameter:____0.58 m____   Sediment Area Covered:____0.27 m^2____

Site / Location	Time Collected	Volume Collected (liters)	Previous Collection Event		Seepage Time (days)	Seepage (liters/m^2-day)	Comments / Observations
			Date	Time			
1	10:10	---	4/18/03	13:30	31.9	---	Bag missing, Installed new bag
2	10:40	19.5	4/18/03	13:40	31.9	2.27	Bag in good condition, sample collected
3	10:55	8.0	4/18/03	13:50	31.9	0.93	Bag in good condition, sample collected
4	11:12	43.5	4/18/03	14:05	31.9	5.05	Bag in good condition, sample collected
5	11:19	---	4/18/03	14:15	31.9	---	Bag torn, no sample collected, Installed new bag
6	11:31	42.5	4/18/03	14:25	31.9	4.94	Bag in good condition, sample collected
7	11:43	13.0	4/18/03	14:35	31.9	1.51	Bag in good condition, sample collected
8	12:01	0.25	4/18/03	14:55	31.9	0.03	Bag in good condition, sample collected
9	12:15	6.3	4/18/03	15:10	31.9	0.73	Bag in good condition, sample collected
10	12:25	1.5	4/18/03	15:25	31.9	0.17	Bag in good condition, sample collected

Seepage Meter Field Measurements

Location:_____Lake Holden_____   Date:___6/17/03___

Date Installed:___3/15/03___   Chamber Diameter:___0.58 m___   Sediment Area Covered:___0.27 m^2___

Site / Location	Time Collected	Volume Collected (liters)	Previous Collection Event		Seepage Time (days)	Seepage (liters/m^2-day)	Comments / Observations
			Date	Time			
1	12:35	17.5	5/20/03	10:10	28.1	2.31	Bag in good condition, sample collected
2	12:45	22.3	5/20/03	10:40	28.1	2.94	Bag in good condition, sample collected
3	12:50	7.4	5/20/03	10:55	28.1	0.98	Bag in good condition, sample collected
4	13:05	45.3	5/20/03	11:12	28.1	5.98	Bag in good condition, sample collected
5	13:12	15.3	5/20/03	11:19	28.1	2.02	Bag in good condition, sample collected
6	13:22	43.0	5/20/03	11:31	28.1	5.67	Bag in good condition, sample collected
7	13:30	23.6	5/20/03	11:43	28.1	3.11	Bag in good condition, sample collected
8	13:42	2.4	5/20/03	12:01	28.1	0.32	Bag in good condition, sample collected
9	14:00	36.3	5/20/03	12:15	28.1	4.79	Bag in good condition, sample collected
10	14:10	1.7	5/20/03	12:25	28.1	0.22	Bag in good condition, sample collected

Seepage Meter Field Measurements

Location: Lake Holden   Date: 7/15/03

Date Installed: 3/15/03   Chamber Diameter: 0.58 m   Sediment Area Covered: 0.27 m^2

Site / Location	Time Collected	Volume Collected (liters)	Previous Collection Event		Seepage Time (days)	Seepage (liters/m^2-day)	Comments / Observations
			Date	Time			
1	11:45	9.5	6/17/03	12:35	28.0	1.26	Bag in good condition, sample collected
2	11:55	27.5	6/17/03	12:45	28.0	3.64	Bag in good condition, sample collected
3	12:05	14.3	6/17/03	12:50	28.0	1.89	Bag in good condition, sample collected
4	12:15	47.5	6/17/03	13:05	28.0	6.29	Bag in good condition, sample collected
5	12:22	---	6/17/03	13:12	28.0	---	Conection from bag to meter broken, replaced
6	12:35	65.3	6/17/03	13:22	28.0	8.64	Bag in good condition, sample collected
7	12:45	11.0	6/17/03	13:30	28.0	1.46	Bag in good condition, sample collected
8	13:00	1.8	6/17/03	13:42	28.0	0.23	Bag in good condition, sample collected
9	13:15	17.8	6/17/03	14:00	28.0	2.35	Bag in good condition, sample collected
10	13:25	0.43	6/17/03	14:10	28.0	0.06	Bag in good condition, sample collected

Seepage Meter Field Measurements

Location:____Lake Holden____   Date:____8/28/03____

Date Installed:____3/15/03____   Chamber Diameter:____0.58 m____   Sediment Area Covered:____0.27 m^2____

Site / Location	Time Collected	Volume Collected (liters)	Previous Collection Event		Seepage Time (days)	Seepage (liters/m^2-day)	Comments / Observations
			Date	Time			
1	15:30	36.3	7/15/03	11:45	44.2	3.04	Bag in good condition, sample collected
2	15:40	38.8	7/15/03	11:55	44.2	3.25	Bag in good condition, sample collected
3	15:55	19.0	7/15/03	12:05	44.2	1.59	Bag in good condition, sample collected
4	16:00	25.3	7/15/03	12:15	44.2	2.12	Bag in good condition, sample collected
5	16:05	---	7/15/03	12:22	44.2	---	Bag torn, bag replaced
6	15:15	85.0	7/15/03	12:35	44.1	7.14	Bag in good condition, sample collected
7	16:25	14.0	7/15/03	12:45	44.2	1.17	Bag in good condition, sample collected
8	16:35	2.0	7/15/03	13:00	44.1	0.17	Bag in good condition, sample collected
9	16:40	---	7/15/03	13:15	44.1	---	Seepage meter missing
10	16:45	0.40	7/15/03	13:25	44.1	0.03	Bag in good condition, sample collected

Seepage Meter Field Measurements

Location:___Lake Holden___ Date:___9/29/03___

Date Installed:___3/15/03___ Chamber Diameter:___0.58 m___ Sediment Area Covered:___0.27 m^2___

Site / Location	Time Collected	Volume Collected (liters)	Previous Collection Event		Seepage Time (days)	Seepage (liters/m^2-day)	Comments / Observations
			Date	Time			
1	13:00	24.8	8/29/03	15:30	30.9	2.97	Bag in good condition, sample collected
2	13:20	24.5	8/29/03	15:40	30.9	2.94	Bag in good condition, sample collected
3	13:30	17.3	8/29/03	15:55	30.9	2.07	Bag in good condition, sample collected
4	13:40	32.3	8/29/03	16:00	30.9	3.87	Bag in good condition, sample collected
5	13:45	---	8/29/03	16:05	30.9	---	Bag torn, bag replaced
6	13:50	43.5	8/29/03	15:15	30.9	5.21	Bag in good condition, sample collected
7	14:00	15.3	8/29/03	16:25	30.9	1.83	Bag in good condition, sample collected
8	14:10	1.4	8/29/03	16:35	30.9	0.17	Bag in good condition, sample collected
9	14:25	---	8/29/03	16:40	30.9	---	Seepage meter missing
10	14:35	---	8/29/03	16:45	30.9	---	Seepage meter missing

Seepage Meter Field Measurements

Location: Lake Holden

Date: 10/7/03

Date Installed: 3/15/03

Chamber Diameter: 0.58 m

Sediment Area Covered: 0.27 m^2

Site / Location	Time Collected	Volume Collected (liters)	Previous Collection Event		Seepage Time (days)	Seepage (liters/m^2-day)	Comments / Observations
			Date	Time			
1	10:30	20.3	9/29/03	13:00	7.9	9.50	Bag in good condition, sample collected
2	10:40	16.3	9/29/03	13:20	7.9	7.63	Bag in good condition, sample collected
3	10:50	12.0	9/29/03	13:30	7.9	5.63	Bag in good condition, sample collected
4	11:05	18.8	9/29/03	13:40	7.9	8.80	Bag torn, sample collected
5	11:15	6.5	9/29/03	13:45	7.9	3.05	Bag in good condition, sample collected
6	11:25	23.8	9/29/03	13:50	7.9	11.14	Bag in good condition, sample collected
7	11:35	7.5	9/29/03	14:00	7.9	3.52	Bag in good condition, sample collected
8	11:55	0.73	9/29/03	14:10	7.9	0.34	Bag in good condition, sample collected
9	12:10	---	9/29/03	14:25	7.9	---	Seepage meter missing
10	12:20	---	9/29/03	14:35	7.9	---	Seepage meter missing

APPENDIX D

**CHARACTERISTICS OF STORMWATER
SAMPLES COLLECTED IN THE LAKE HOLDEN
BASIN DURING JUNE-SEPTEMBER 2003**

Lake Holden Stormwater Monitoring

Sample Location	Date Collected	pH	Alkalinity	Conductivity	Ammonia	NOx	Total N	Ortho - P	Total P	Turbidity	TSS	BOD-5	Fecal	Color
43rd St Pond	6/24/03	6.68	18.8	53	83	<5	556	< 1	49	1.2	2.4	2.7	15	19
43rd St Pond	7/1/03	8.92	17.8	53	<5	5	487	11	35	1.3	2.3	<2.0	5	13
43rd St Pond	7/8/03	5.70	19.8	58	12	13	387	2	26	1.3	2.3	<2.0	88	15
43rd St Pond	7/18/03	7.89	43.6	53	97	9	798	6	42	2.9	3.6	4.5	<1	14
43rd St Pond	7/25/03	8.27	21.8	44	89	28	410	1	30	1.3	3.6	2.5	< 1	17
43rd St Pond	7/29/03	6.70	19.2	42	17	9	386	< 1	26	1.3	2.6	2.5	52	15
43rd St Pond	8/5/03	6.25	17.1	49	242	<1	901	< 1	85	6.3	19.0	5.5	350	17
43rd St Pond	8/14/03	6.35	20.0	55	44	<5	330	1	20	2.4	4.0	2.6	7	17
43rd St Pond	9/11/03	6.17	29.3	90	< 5	13	297	< 1	18	2.3	3.6	2.4	2	17
	average	6.99	23.0	55	83	13	506	4	37	2.3	4.8	3.2	74	16
	minimum	5.70	17.1	42	< 5	< 5	297	< 1	18	1.2	2.3	< 2.0	< 1	13
	maximum	8.92	43.6	90	242	28	901	11	85	6.3	19.0	5.5	350	19
Division	6/3/03	7.44	112.0	390	490	108	1690	< 1	1022	21.3	28.0	9.7	2700	24
Division	6/4/03	6.00	25.3	332	< 5	263	659	1	104	17.3	48.0	3.8	52	4
Division	6/6/03	5.52	6.0	710	10	125	1168	< 1	120	17.1	20.0	<2.0	<1	< 1
Division	6/7/03	7.60	64.8	225	52	177	427	< 1	43	19.5	12.0	2.2	2400	< 1
Division	6/8/03	6.57	22.0	290	< 5	111	435	< 1	1997	27.5	60.7	4.9	2300	3
Division	6/12/03	7.50	72.3	233	324	119	981	103	216	3.8	4.5	3.7	128	30
Division	6/13/03	5.40	1.5	365	148	56	798	< 1	70	9.6	37.3	< 2.0	< 1	22
Division	6/16/03	7.62	65.9	199	<5	102	982	365	681	5.8	7.1	5.6	80	17
Division	6/17/03	6.75	65.3	177	180	55	519	16	82	1.0	1.3	< 2.0	<1	37
Division	6/18/03	6.81	25.5	114	132	190	684	< 1	46	4.0	6.8	2.7	255	7
Division	6/20/03	7.38	42.6	147	111	61	309	1	37	1.5	2.2	< 2.0	4700	7
Division	6/29/03	7.45	143.0	399	<5	57	1524	258	467	10.9	9.3	7.3	3000	9
Division	7/2/03	7.46	77.2	172	319	330	767	111	133	0.8	1.8	2.8	7	15
Division	7/3/03	7.42	50.5	119	<5	395	822	42	62	1.6	1.6	2.3	8	12
Division	7/12/03	7.48	92.3	194	<5	564	1032	49	109	5.5	4.0	2.2	10	8
Division	7/13/03	7.58	71.1	202	22	163	620	4	20	3.0	1.9	<2.0	33	5
Division	7/15/03	7.39	54.1	125	<5	147	409	17	74	8.0	8.3	4.4	16500	12
Division	7/18/03	7.32	43.8	103	<5	267	362	28	48	1.6	1.6	11.0	11	9
	average	7.04	57.5	250	179	183	788	83	296	8.9	14.2	4.8	2146	14
	minimum	5.40	1.5	103	< 5	55	309	< 1	20	0.8	1.3	< 2.0	< 1	< 1
	maximum	7.62	143.0	710	490	564	1690	365	1997	27.5	60.7	11.0	16500	37

Lake Holden Stormwater Monitoring

Sample Location	Date Collected	pH	Alkalinity	Conductivity	Ammonia	NOx	Total N	Ortho - P	Total P	Turbidity	TSS	BOD-5	Fecal	Color
FDOT Pond	6/27/03	6.77	56.4	150	<5	14	589	1	39	1.6	1.7	2.4	20	17
FDOT Pond	7/1/03	6.91	61.9	184	<5	18	744	31	75	2.5	5.3	2.3	705	15
FDOT Pond	7/8/03	6.75	51.5	159	223	5	561	14	71	3.3	2.9	2.9	1226	15
FDOT Pond	7/18/03	7.05	57.0	147	<5	7	542	10	72	5.2	4.2	2.8	1200	17
FDOT Pond	7/25/03	6.41	53.5	161	<5	244	675	42	70	1.9	2.7	2.8	410	13
FDOT Pond	7/29/03	6.49	55.0	155	876	12	362	4	48	1.8	1.8	2.4	1053	12
FDOT Pond	8/5/03	6.27	49.1	142	57	<1	367	12	57	2.5	2.8	<2.0	1200	14
FDOT Pond	8/28/03	6.46	66.1	178	< 5	<5	373	18	48	1.7	3.3	2.8	136	10
FDOT Pond	9/11/03	6.25	74.8	212	106	18	313	25	47	2.5	2.4	2.4	150	11
	average	6.60	58.4	165	316	45	503	17	59	2.6	3.0	2.6	678	14
	minimum	6.25	49.1	142	< 5	5	313	1	39	1.6	1.7	2.3	20	10
	maximum	7.05	74.8	212	876	244	744	42	75	5.2	5.3	2.9	1226	17
Holden Terrace	6/4/03	7.47	66.7	259	< 5	1868	2420	< 1	10	0.6	1.8	< 2.0	5	< 1
Holden Terrace	6/6/03	4.39	< 0.6	398	198	1488	2961	< 1	18	11.3	32.0	<2.0	<1	< 1
Holden Terrace	6/7/03	6.50	42.6	233	101	910	1412	< 1	31	5.5	16.5	< 2.0	17091	< 1
Holden Terrace	6/12/03	7.40	39.8	447	55	1272	2194	< 1	27	2.7	4.0	3.4	5	6
Holden Terrace	6/13/03	7.40	39.6	297	<5	550	1171	4	15	5.8	9.3	3.9	92	2
Holden Terrace	6/16/03	7.24	43.6	186	55	323	809	6	29	1.9	3.8	3.8	540	20
Holden Terrace	7/2/03	7.36	54.5	107	106	559	740	59	71	1.6	2.5	< 2.0	11	14
Holden Terrace	7/12/03	7.31	66.5	227	30	39	1047	22	26	0.8	< 0.7	<2.0	27	10
Holden Terrace	7/13/03	7.34	69.3	255	150	94	887	1	12	1.1	8.0	3.6	21	7
Holden Terrace	7/15/03	7.55	36.6	83	28	177	612	40	73	4.4	3.2	<2.0	1437	12
Holden Terrace	7/18/03	6.79	45.5	116	<5	334	577	48	61	0.9	< 0.7	43.0	43	6
Holden Terrace	7/26/03	7.50	68.9	250	66	79	904	3	20	2.7	2.0	9.3	120	6
Holden Terrace	7/27/03	7.59	67.1	253	61	16	919	3	23	3.4	8.0	7.7	92	8
Holden Terrace	7/28/03	7.49	87.8	252	89	<5	983	3	20	5.1	3.0	6.7	92	7
Holden Terrace	7/29/03	7.56	66.9	250	136	11	962	2	21	4.8	4.4	7.1	4487	6
Holden Terrace	7/30/03	7.31	55.6	198	69	554	1215	42	196	15.9	85.2	2.4	1271	17
Holden Terrace	8/9/03	7.40	75.0	233	14	316	1183	4	99	18.6	35.0	4.3	1025	13
Holden Terrace	8/25/03	6.69	70.3	138	21	140	704	30	224	79.6	####	3.5	1544	10
	average	7.13	58.6	232	79	514	1206	19	54	9.3	23.0	8.2	1641	10
	minimum	4.39	< 0.6	83	< 5	11	577	< 1	10	0.6	< 0.7	< 2.0	< 1	< 1
	maximum	7.59	87.8	447	198	1868	2961	59	224	79.6	####	43.0	17091	20

Lake Holden Stormwater Monitoring

Sample Location	Date Collected	pH	Alkalinity	Conductivity	Ammonia	NOx	Total N	Ortho - P	Total P	Turbidity	TSS	BOD-5	Fecal	Color
Krueger	7/29/03	6.86	32.7	272	7258	5454	13323	< 1	100	4.0	21.0	48.5	700	6
Krueger	7/30/03	6.91	26.5	85	337	530	1915	136	318	8.7	55.6	4.0	59000	34
Krueger	8/5/03	6.30	22.8	61	466	343	1314	55	100	3.9	13.4	<2.0	3100	14
Krueger	8/6/03	7.06	50.7	119	< 5	293	592	22	47	1.2	2.4	<2.0	202	9
Krueger	8/9/03	6.91	57.8	206	9972	262	9722	< 1	58	6.9	47.5	38.1	14188	8
Krueger	8/29/03	6.25	39.2	176	< 5	1599	2127	63	119	5.3	15.8	3.3	5000	22
Krueger	9/3/03	6.39	25.7	204	< 5	207	2000	112	335	3.8	91.3	3.3	1938	26
Krueger	9/30/03	6.63	32.3	109	291	39	913	82	379	18.7	87.3	5.5	39600	20
	average	6.66	36.0	154	3665	1091	3988	78	182	6.6	41.8	17.1	15466	17
	minimum	6.25	22.8	61	< 5	39	592	< 1	47	1.2	2.4	< 2.0	202	6
	maximum	7.06	57.8	272	9972	5454	13323	136	379	18.7	91.3	48.5	59000	34
Paseo	5/22/03	6.23	8.9	68	27	232	761	1	124	10.2	59.7	<2.0	153	1
Paseo	5/24/03	6.29	9.9	282	196	74	1464	3	275	25.4	47.0	4.7	<20	2
Paseo	6/5/03	6.26	18.0	158	24	331	1341	< 1	193	33.2	68.0	7.4	6000	2
Paseo	6/6/03	5.21	4.0	138	5	574	1121	< 1	61	32.9	31.2	3.0	200	2
Paseo	6/7/03	6.81	9.9	59	43	228	474	< 1	34	2.9	2.8	2.0	2600	2
Paseo	6/8/03	6.76	19.0	76	26	238	497	< 1	26	3.5	5.4	2.1	3000	< 1
Paseo	6/12/03	6.99	33.3	101	142	335	926	16	94	2.3	5.0	< 2.0	30	24
Paseo	6/13/03	7.30	32.9	94	67	342	800	12	62	4.0	5.0	< 2.0	440	18
Paseo	6/16/03	6.70	22.6	76	70	307	725	17	63	5.8	3.0	2.5	216	18
Paseo	6/18/03	7.31	72.9	249	221	5u	672	65	284	7.7	5.1	2.2	620	13
Paseo	6/20/03	7.71	54.5	152	65	5u	240	1	54	22.4	6.6	< 2.0	275	2
Paseo	6/29/03	7.39	38.4	117	<5	321	868	25	87	6.5	3.8	3.0	662	15
Paseo	7/2/03	6.99	28.1	59	108	426	590	42	53	1.0	1.6	< 2.0	19	10
Paseo	7/3/03	6.78	16.2	36	189	289	431	22	29	1.0	0.9	< 2.0	84	9
Paseo	7/9/03	7.27	41.6	110	<5	797	1318	31	44	1.3	1.0	<2.0	1	23
Paseo	7/12/03	7.05	33.3	85	<5	256	606	64	66	1.0	< 0.7	<2.0	76	14
Paseo	7/13/03	6.74	37.8	93	<5	139	480	15	29	1.3	1.0	<2.0	5	17
Paseo	7/15/03	7.45	24.4	58	53	209	549	29	52	3.5	1.6	<2.0	500	16
Paseo	7/18/03	6.87	20.2	43	<5	234	345	32	41	0.8	0.8	13.0	13	16
Paseo	7/19/03	6.67	34.3	67	<5	380	654	30	35	1.0	3.0	4.0	4	19
Paseo	7/21/03	7.15	21.8	97	<5	883	1500	30	56	2.1	4.0	4.3	10	20
Paseo	7/22/03	7.28	29.3	82	<5	320	588	23	38	1.1	< 0.7	3.8	85	17
Paseo	7/23/03	7.24	37.6	85	<5	371	763	24	43	1.1	2.0	2.3	104	13
Paseo	7/25/03	7.19	38.2	90	90	536	952	20	50	3.5	2.5	3.0	3080	21
Paseo	7/26/03	7.46	147.0	3214	439	3086	6896	153	666	25.2	15.0	3.0	< 1	57
	average	6.92	33.4	227	110	474	1022	31	102	8.0	12.0	4.0	790	15
	minimum	5.21	4.0	36	< 5	74	240	< 1	26	0.8	< 0.7	< 2.0	< 1	< 1
	maximum	7.71	147.0	3214	439	3086	6896	153	666	33.2	68.0	13.0	6000	57

APPENDIX E

CALCULATED RUNOFF GENERATED LOADINGS FROM SUB-BASIN AREAS TO LAKE HOLDEN

Parameter	B-1	B-2	B-3	B-4A	B-4B	B-5	B-6
Area	98.9	65.7	19.7	89.3	12.8	10.4	8.8
DCIA	76	60	19	38	59	26	23
non DCIA CN	75.3	59.9	51.7	53.4	58.1	55.4	53.5

	B-1	B-2	B-3	B-4A	B-4B	B-5	B-6
S	3.28	6.70	9.33	8.72	7.21	8.04	8.69

Rainfall Event Range (in)	Rainfall Interval Point (in)	Number of Annual Events in Range	B-1	B-2	B-3	B-4A	B-4B	B-5	B-6
0.00-0.10	0.041	56.683	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11-0.20	0.152	18.866	6.09	3.18	0.31	2.73	0.61	0.22	0.17
0.21-0.30	0.252	10.590	10.12	5.28	0.51	4.54	1.02	0.36	0.28
0.31-0.40	0.353	7.312	11.57	6.04	0.59	5.19	1.16	0.41	0.31
0.41-0.50	0.456	6.325	14.13	7.37	0.72	6.34	1.42	0.51	0.38
0.51-1.00	0.713	17.102	65.73	34.28	3.34	29.47	6.62	2.35	1.79
1.01-1.50	1.221	6.733	48.39	24.67	2.41	21.21	4.76	1.69	1.29
1.51-2.00	1.726	3.145	33.68	16.87	1.63	14.37	3.24	1.15	0.87
2.01-2.50	2.217	1.470	20.96	10.50	1.02	8.91	2.01	0.74	0.55
2.51-3.00	2.704	0.726	12.98	6.55	0.67	5.64	1.25	0.49	0.36
3.01-3.50	3.246	0.391	8.58	4.38	0.48	3.85	0.84	0.35	0.26
3.51-4.00	3.667	0.260	6.56	3.38	0.40	3.03	0.65	0.28	0.21
4.01-4.50	4.216	0.149	4.38	2.28	0.29	2.10	0.44	0.20	0.15
4.51-5.00	4.796	0.056	1.90	1.00	0.14	0.94	0.19	0.09	0.07
5.01-6.00	5.454	0.167	6.56	3.51	0.51	3.38	0.67	0.33	0.26
6.01-7.00	6.470	0.019	0.88	0.48	0.08	0.48	0.09	0.05	0.04
7.01-8.00	7.900	0.019	1.10	0.61	0.10	0.63	0.12	0.07	0.05
8.01-9.00	8.190	0.019	1.14	0.64	0.11	0.66	0.12	0.07	0.05
>9.00	10.675	0.075	6.06	3.47	0.67	3.78	0.67	0.41	0.33

	B-1	B-2	B-3	B-4A	B-4B	B-5	B-6
Generated Volume (ac-ft/yr)	260.81	134.49	13.98	117.25	25.88	9.77	7.42
Weighted Basin "C" Value	0.638	0.495	0.171	0.318	0.489	0.227	0.203

TN	788	1206	1770	505	1180	3988	3988
TP	296	54	177	48	150	182	182
BOD	4.8	8.2	4.4	2.9	8.2	17.1	17.1
TSS	14.2	23	19.1	3.9	81	41.8	41.8

Parameter	B-1	B-2	B-3	B-4A	B-4B	B-5	B-6
TN (kg/yr)	253.1	199.8	30.5	72.9	37.6	48.0	36.4
TP (kg/yr)	95.1	8.9	3.0	6.9	4.8	2.2	1.7
BOD (kg/yr)	1541.9	1358.3	75.8	418.8	261.4	205.8	156.3
TSS (kg/yr)	4561.4	3809.8	328.9	563.2	2581.8	503.0	382.0

Parameter	B-7	B-8	B-9	B-10A	B-10B	B-11	B-12
Area	52.9	7.8	6.8	10.9	8.0	10.8	26.3
DCIA	27	24	27	27	27	28	72
non DCIA CN	53.6	58.0	54.5	62.5	61.1	60.3	77.0

	B-7	B-8	B-9	B-10A	B-10B	B-11	B-12
S	8.65	7.25	8.35	5.99	6.37	6.57	2.99

Rainfall Event Range (in)	Rainfall Interval Point (in)	Number of Annual Events in Range	B-7	B-8	B-9	B-10A	B-10B	B-11	B-12
0.00-0.10	0.041	56.683	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11-0.20	0.152	18.866	1.16	0.15	0.15	0.24	0.17	0.24	1.53
0.21-0.30	0.252	10.590	1.92	0.25	0.25	0.40	0.29	0.40	2.53
0.31-0.40	0.353	7.312	2.20	0.29	0.28	0.45	0.33	0.46	2.90
0.41-0.50	0.456	6.325	2.68	0.35	0.35	0.55	0.41	0.56	3.54
0.51-1.00	0.713	17.102	12.48	1.64	1.61	2.58	1.88	2.63	16.50
1.01-1.50	1.221	6.733	8.98	1.18	1.16	1.86	1.36	1.89	12.30
1.51-2.00	1.726	3.145	6.09	0.82	0.78	1.35	0.97	1.33	8.63
2.01-2.50	2.217	1.470	3.83	0.54	0.50	0.91	0.65	0.88	5.41
2.51-3.00	2.704	0.726	2.48	0.36	0.32	0.61	0.43	0.59	3.36
3.01-3.50	3.246	0.391	1.75	0.26	0.23	0.44	0.31	0.42	2.23
3.51-4.00	3.667	0.260	1.40	0.21	0.18	0.35	0.25	0.34	1.71
4.01-4.50	4.216	0.149	0.99	0.15	0.13	0.25	0.18	0.24	1.15
4.51-5.00	4.796	0.056	0.46	0.07	0.06	0.11	0.08	0.11	0.50
5.01-6.00	5.454	0.167	1.67	0.26	0.22	0.42	0.30	0.40	1.72
6.01-7.00	6.470	0.019	0.24	0.04	0.03	0.06	0.04	0.06	0.23
7.01-8.00	7.900	0.019	0.33	0.05	0.04	0.08	0.06	0.08	0.29
8.01-9.00	8.190	0.019	0.35	0.05	0.05	0.08	0.06	0.08	0.30
>9.00	10.675	0.075	2.03	0.31	0.27	0.48	0.35	0.46	1.60

	B-7	B-8	B-9	B-10A	B-10B	B-11	B-12
Generated Volume (ac-ft/yr)	51.04	6.98	6.61	11.22	8.12	11.17	66.43
Weighted Basin "C" Value	0.233	0.216	0.235	0.248	0.246	0.250	0.610

	B-7	B-8	B-9	B-10A	B-10B	B-11	B-12
TN	3988	3988	3988	3988	3988	3988	506
TP	182	182	182	182	182	182	37
BOD	17.1	17.1	17.1	17.1	17.1	17.1	3.2
TSS	41.8	41.8	41.8	41.8	41.8	41.8	4.8

Parameter	B-7	B-8	B-9	B-10A	B-10B	B-11	B-12
TN (kg/yr)	250.7	34.3	32.5	55.1	39.9	54.9	41.4
TP (kg/yr)	11.4	1.6	1.5	2.5	1.8	2.5	3.0
BOD (kg/yr)	1074.9	147.0	139.2	236.3	171.0	235.3	261.8
TSS (kg/yr)	2627.7	359.3	340.3	577.6	418.0	575.1	392.7

Parameter	B-13	B-14	B-15	B-16	B-17	B-18	B-19
Area	81.5	3.6	4.5	12.1	4.4	35.9	16.8
DCIA	48	63	39	26	26	25	34
non DCIA CN	56.3	59.7	42.8	63.7	79.1	53.9	71.5

S	7.76	6.75	13.34	5.69	2.64	8.55	3.99

Rainfall Event Range (in)	Rainfall Interval Point (in)	Number of Annual Events in Range	B-13	B-14	B-15	B-16	B-17	B-18	B-19
0.00-0.10	0.041	56.683	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11-0.20	0.152	18.866	3.16	0.18	0.14	0.26	0.09	0.73	0.46
0.21-0.30	0.252	10.590	5.25	0.30	0.24	0.43	0.15	1.21	0.76
0.31-0.40	0.353	7.312	6.00	0.35	0.27	0.49	0.17	1.39	0.87
0.41-0.50	0.456	6.325	7.33	0.42	0.34	0.60	0.21	1.69	1.06
0.51-1.00	0.713	17.102	34.10	1.97	1.56	2.79	1.04	7.87	4.95
1.01-1.50	1.221	6.733	24.55	1.42	1.12	2.01	0.97	5.67	3.81
1.51-2.00	1.726	3.145	16.68	0.97	0.76	1.49	0.80	3.84	2.92
2.01-2.50	2.217	1.470	10.40	0.60	0.46	1.01	0.55	2.43	1.97
2.51-3.00	2.704	0.726	6.53	0.37	0.28	0.68	0.37	1.59	1.31
3.01-3.50	3.246	0.391	4.41	0.25	0.18	0.49	0.26	1.13	0.92
3.51-4.00	3.667	0.260	3.44	0.19	0.14	0.40	0.21	0.91	0.73
4.01-4.50	4.216	0.149	2.35	0.13	0.10	0.28	0.14	0.65	0.51
4.51-5.00	4.796	0.056	1.04	0.06	0.04	0.13	0.06	0.30	0.23
5.01-6.00	5.454	0.167	3.69	0.20	0.15	0.47	0.23	1.10	0.81
6.01-7.00	6.470	0.019	0.51	0.03	0.02	0.07	0.03	0.16	0.11
7.01-8.00	7.900	0.019	0.66	0.03	0.03	0.09	0.04	0.22	0.15
8.01-9.00	8.190	0.019	0.69	0.04	0.03	0.09	0.04	0.23	0.15
>9.00	10.675	0.075	3.87	0.19	0.17	0.54	0.24	1.36	0.86

	B-13	B-14	B-15	B-16	B-17	B-18	B-19
Generated Volume (ac-ft/yr)	134.66	7.70	6.03	12.32	5.60	32.48	22.58
Weighted Basin "C" Value	0.400	0.520	0.322	0.247	0.311	0.219	0.326

TN	503	1180		1770	3988	1770	714
TP	59	150		177	182	177	105
BOD	2.6	8.2		4.4	17.1	4.4	2.3
TSS	3	81		19.1	41.8	19.1	2.8

Parameter	B-13	B-14	B-15	B-16	B-17	B-18	B-19
TN (kg/yr)	83.4	11.2	0.0	26.9	27.5	70.8	19.9
TP (kg/yr)	9.8	1.4	0.0	2.7	1.3	7.1	2.9
BOD (kg/yr)	431.2	77.8	0.0	66.8	117.9	176.0	64.0
TSS (kg/yr)	497.6	768.2	0.0	289.8	288.3	764.1	77.9

Parameter	B-20	B-21	B-22
Area	60.9	19.4	105.5
DCIA	28	53	1
non DCIA CN	61.5	59.4	66.3

	B-20	B-21	B-22
S	6.26	6.82	5.08

Rainfall Event Range (in)	Rainfall Interval Point (in)	Number of Annual Events in Range	B-20	B-21	B-22
0.00-0.10	0.041	56.683	0.00	0.00	0.00
0.11-0.20	0.152	18.866	1.38	0.83	0.09
0.21-0.30	0.252	10.590	2.30	1.37	0.14
0.31-0.40	0.353	7.312	2.63	1.57	0.16
0.41-0.50	0.456	6.325	3.21	1.91	0.20
0.51-1.00	0.713	17.102	14.91	8.91	0.93
1.01-1.50	1.221	6.733	10.73	6.41	1.13
1.51-2.00	1.726	3.145	7.66	4.39	2.83
2.01-2.50	2.217	1.470	5.12	2.75	3.21
2.51-3.00	2.704	0.726	3.42	1.73	2.82
3.01-3.50	3.246	0.391	2.43	1.16	2.42
3.51-4.00	3.667	0.260	1.96	0.90	2.14
4.01-4.50	4.216	0.149	1.39	0.62	1.65
4.51-5.00	4.796	0.056	0.63	0.27	0.81
5.01-6.00	5.454	0.167	2.31	0.96	3.09
6.01-7.00	6.470	0.019	0.33	0.13	0.47
7.01-8.00	7.900	0.019	0.44	0.17	0.66
8.01-9.00	8.190	0.019	0.46	0.18	0.70
>9.00	10.675	0.075	2.67	0.98	4.18

	B-20	B-21	B-22
Generated Volume (ac-ft/yr)	63.98	35.24	27.63
Weighted Basin "C" Value	0.254	0.440	0.063

	B-20	B-21	B-22
TN	1770	1022	2290
TP	177	102	300
BOD	4.4	4	7.4
TSS	19.1	12	27

Parameter	B-20	B-21	B-22	Total
TN (kg/yr)	139.5	44.4	77.9	1688
TP (kg/yr)	13.9	4.4	10.2	201
BOD (kg/yr)	346.7	173.6	251.8	7989
TSS (kg/yr)	1505.1	520.8	918.8	23651

APPENDIX F

**CHEMICAL CHARACTERISTICS OF
SHALLOW GROUNDWATER SEEPAGE
ENTERING LAKE HOLDEN FROM
APRIL-OCTOBER 2003**

Lake Holden Seepage Characteristics

Sample Location	Date	pH (s.u.)	Alkalinity (mg/l)	Conductivity (µmho/cm)	Total N (µg/l)	Total P (µg/l)
Seepage 1	4/18/03	7.63	66.1	263	657	26
Seepage 1	6/17/03	7.75	70.3	267	1014	6
Seepage 1	7/15/03	8.06	122	541	6083	1
Seepage 1	8/28/03	7.46	87.1	286	2269	1
Seepage 1	9/29/03	6.81	73.7	221	1170	10
Seepage 1	10/7/03	7.07	68.4	217	1263	4
Seepage 2	4/18/03	7.6	80	328	1997	32
Seepage 2	5/20/03	7.58	119	345	3482	9
Seepage 2	6/17/03	7.85	127	420	4285	27
Seepage 2	7/15/03	7.93	140	354	5236	54
Seepage 2	8/28/03	7.74	149	458	5035	103
Seepage 2	9/29/03	7.31	160	382	4695	149
Seepage 2	10/7/03	7.82	81	410	4111	88
Seepage 3	4/18/03	7.7	72.7	277	2238	27
Seepage 3	5/20/03	7.52	72.3	235	1700	9
Seepage 3	6/17/03	7.21	66.3	266	1313	8
Seepage 3	7/15/03	7.54	69.7	209	1156	7
Seepage 3	8/28/03	7.28	77	264	1468	7
Seepage 3	9/29/03	6.8	73.3	188	1049	6
Seepage 3	10/7/03	7.39	70.4	235	1302	6
Seepage 4	4/18/03	7.47	68.3	258	2017	36
Seepage 4	5/20/03	7.58	65.9	192	2638	17
Seepage 4	6/17/03	6.95	58.4	333	2449	20
Seepage 4	7/15/03	7.12	60.4	152	2272	21
Seepage 4	8/28/03	6.74	44.2	179	1752	20
Seepage 4	9/29/03	6.26	49.1	189	1629	14
Seepage 4	10/7/03	7.48	54	191	833	8
Seepage 5	4/18/03	7.64	77.6	285	1677	27
Seepage 5	6/17/03	8.01	109	339	5455	7
Seepage 5	10/7/03	7.74	128	293	3439	7
Seepage 6	4/18/03	7.07	55	262	1921	26
Seepage 6	5/20/03	7.46	49.9	209	2060	5
Seepage 6	6/17/03	7.25	58.6	267	2553	7
Seepage 6	7/15/03	6.97	61.4	212	2746	8
Seepage 6	8/28/03	7.1	43.9	254	2256	4
Seepage 6	9/29/03	6.66	47.5	247	3657	11
Seepage 6	10/7/03	7.13	40.6	223	1845	11
Seepage 7	4/18/03	7.56	71.5	289	2499	49
Seepage 7	5/20/03	7.58	82.4	243	2191	4
Seepage 7	6/17/03	7.08	80.2	303	3106	8
Seepage 7	7/15/03	7.45	103	270	5051	5
Seepage 7	8/28/03	6.75	111	313	4965	2
Seepage 7	9/29/03	7.08	82.2	267	10545	5
Seepage 7	10/7/03	7.55	117	370	9581	8

Lake Holden Seepage Characteristics

Sample Location	Date	pH (s.u.)	Alkalinity (mg/l)	Conductivity (µmho/cm)	Total N (µg/l)	Total P (µg/l)
Seepage 8	4/18/03	7.23	115	315	5588	285
Seepage 8	5/20/03	7.33	120	273	5723	46
Seepage 8	6/17/03	7.22	121	341	6846	33
Seepage 8	7/15/03	7.23	145	328	10723	29
Seepage 8	8/28/03	7.44	162	326	12888	37
Seepage 8	9/29/03	7.22	143	387	79	8
Seepage 8	10/7/03	7.65	118	342	8383	9
Seepage 9	4/18/03	7.67	74.05	289	1888	29
Seepage 9	5/20/03	7.54	68.9	239	2438	11
Seepage 9	6/17/03	7.48	68.3	279	2363	9
Seepage 9	7/15/03	7.48	76.8	240	3591	7
Seepage 10	4/18/03	7.23	73.06	291	1220	42
Seepage 10	5/20/03	7.49	95.6	242	2920	57
Seepage 10	6/17/03	7.56	55.4	287	2816	16
Seepage 10	7/15/03	7.18	93.1	250	4351	17
Seepage 10	8/28/03	7.28	91.9	285	4551	13

APPENDIX G

TROPHIC STATE MODELING
FOR LAKE HOLDEN

1. Current Conditions

2. Water Quality Improvement Options

1. Current Conditions

Estimated Mass Balance Vollenweider Model for Lake Holden Under Existing Conditions

Month	Initial P Conc. (mg/l)	Direct Precipitation (in)	Direct Precipitation (ac-ft)	P Inputs from Bulk Precipitation (mg/l)	P Inputs from Bulk Precipitation (kg)	P Inputs from Runoff (ac-ft)	P Inputs from Runoff (kg)	Internal Recycling (kg P)	Groundwater Seepage (ac-ft)	Groundwater Seepage (kg)	Total Inputs (ac-ft)	Total Inputs (kg)	Total Inputs (mg/l)	Surface Evaporation (in)	Surface Evaporation (ac-ft)	Outfall Losses (ac-ft)	Outfall Losses (kg)	Total Losses (ac-ft)	Total Losses (kg)	Mean Detention Time (days)	Phosphorus Retention Coefficient	Areal P Loading (g/m²)	Final Lake P Conc. (mg/l)	Chyl-a Conc. (mg/m³)	Secchi Disk Depth (m)	Florida TSI Value
January	0.031	2.51	55.7	0.045	3.09	54.3	10.2	22.5	28.6	0.6	138.5	36.3	0.213	2.43	53.9	84.6	3.3	139	3.3	719	0.879	0.031	0.032	42	0.68	75
February	0.032	2.44	54.1	0.045	3.00	52.8	9.9	20.3	27.8	0.5	134.7	33.8	0.203	2.95	65.4	69.3	2.6	135	2.6	668	0.882	0.029	0.030	39	0.74	73
March	0.030	3.59	79.6	0.045	4.42	77.6	14.5	22.5	40.9	0.8	198.1	42.3	0.173	4.38	97.2	100.9	4.0	198	4.0	502	0.835	0.035	0.035	48	0.60	77
April	0.035	2.80	62.1	0.045	3.45	60.6	11.3	21.8	31.9	0.6	154.5	37.2	0.195	5.32	118.0	36.5	1.5	155	1.5	623	0.866	0.033	0.034	46	0.63	76
May	0.034	3.79	84.1	0.045	4.67	82.0	15.3	22.5	43.1	0.8	209.2	43.4	0.168	5.93	131.5	77.7	3.3	209	3.3	476	0.827	0.037	0.036	51	0.57	78
June	0.036	7.43	164.8	0.045	9.15	160.7	30.1	21.8	84.6	1.7	410.1	62.7	0.124	5.36	118.8	291.3	13.4	410	13.4	235	0.710	0.046	0.038	55	0.53	80
July	0.038	7.55	167.5	0.045	9.29	163.3	30.6	22.5	85.9	1.7	416.7	64.1	0.125	5.30	117.5	299.1	14.2	417	14.2	239	0.706	0.046	0.039	56	0.52	80
August	0.039	6.11	135.5	0.045	7.52	132.1	24.7	22.5	69.5	1.4	337.2	56.1	0.135	5.01	111.2	226.0	10.6	337	10.6	295	0.748	0.042	0.037	53	0.54	79
September	0.037	6.22	138.0	0.045	7.66	134.5	25.2	21.8	70.8	1.4	343.3	56.0	0.132	4.40	97.5	245.8	11.2	343	11.2	281	0.745	0.042	0.036	52	0.56	79
October	0.036	2.58	57.2	0.045	3.18	55.8	10.4	22.5	29.4	0.6	142.4	36.7	0.209	3.86	85.6	56.8	2.4	142	2.4	699	0.876	0.032	0.033	44	0.65	76
November	0.033	2.59	57.5	0.045	3.19	56.0	10.5	21.8	29.5	0.6	142.9	36.0	0.204	2.79	61.8	81.1	3.2	143	3.2	674	0.875	0.030	0.031	42	0.69	74
December	0.031	2.02	44.8	0.045	2.49	43.7	8.2	22.5	23.0	0.5	111.5	33.6	0.245	2.25	50.0	61.5	2.4	111	2.4	893	0.900	0.029	0.031	40	0.71	74
Totals:		49.63	1101.0		61.10	1073.4	201.0	265.0	564.8	11.1	2739	538.2		49.97	1108.4	1630.7	72.1	2739	72.1	525	0.821	0.036	0.034	48	0.61	77

Lake Surface Area (acres): 266.2   Annual Runoff Input (ac-ft/yr): 1073.4   Annual Runoff Total P Input (kg/yr): 201   Internal Recycling P Inputs (kg/yr): 265   Lake Volume (ac-ft): 3211.5

Annual Seepage Inflow (ac-ft/yr): 564.8   Seepage Total P Load (kg/yr): 11.1

2. Water Quality Improvement Options

Estimated Mass Balance Vollenweider Model for Lake Holden With Sediment Inactivation

Month	Initial P Conc. (mg/l)	Direct Precip (in)	Direct Precip (ac-ft)	Bulk Precip (mg/l)	Bulk Precip (kg)	Runoff (ac-ft)	Runoff (kg)	Internal Recycling (kg P)	GW Seepage (ac-ft)	GW Seepage (kg)	Total Inputs (ac-ft)	Total Inputs (kg)	Total Inputs (mg/l)	Surf Evap (in)	Surf Evap (ac-ft)	Outfall (ac-ft)	Outfall (kg)	Total Loss (ac-ft)	Total Loss (kg)	Mean Detention Time (days)	P Retention Coeff	Areal P Loading (g/m²)	Final Lake P Conc. (µg/l)	Chyl-a Conc. (mg/m³)	Secchi Disk Depth (m)	Florida TSI Value
January	0.015	2.51	55.7	0.045	3.09	54.3	10.2	5.6	28.6	0.6	138.5	19.4	0.114	2.43	53.9	84.6	1.7	139	1.7	719	0.879	0.016	0.017	17	1.57	57
February	0.017	2.44	54.1	0.045	3.00	52.8	9.9	5.1	27.8	0.5	134.7	18.5	0.111	2.95	65.4	69.3	1.4	135	1.4	668	0.882	0.016	0.016	16	1.64	56
March	0.016	3.59	79.6	0.045	4.42	77.6	14.5	5.6	40.9	0.8	198.1	25.4	0.104	4.38	97.2	100.9	2.3	198	2.3	502	0.835	0.021	0.021	23	1.19	63
April	0.021	2.80	62.1	0.045	3.45	60.6	11.3	5.4	31.9	0.6	154.5	20.9	0.109	5.32	118.0	36.5	0.9	155	0.9	623	0.866	0.019	0.019	20	1.37	60
May	0.019	3.79	84.1	0.045	4.67	82.0	15.3	5.6	43.1	0.8	209.2	26.5	0.103	5.93	131.5	77.7	2.0	209	2.0	476	0.827	0.023	0.022	25	1.11	64
June	0.022	7.43	164.8	0.045	9.15	160.7	30.1	5.4	84.6	1.7	410.1	46.3	0.092	5.36	118.8	291.3	9.2	410	9.2	235	0.710	0.035	0.029	37	0.78	72
July	0.029	7.55	167.5	0.045	9.29	163.3	30.6	5.6	85.9	1.7	416.7	47.2	0.092	5.30	117.5	299.1	10.5	417	10.5	239	0.706	0.034	0.028	36	0.80	71
August	0.028	6.11	135.5	0.045	7.52	132.1	24.7	5.6	69.5	1.4	337.2	39.3	0.094	5.01	111.2	226.0	7.6	337	7.6	295	0.748	0.029	0.026	31	0.90	69
September	0.026	6.22	138.0	0.045	7.66	134.5	25.2	5.4	70.8	1.4	343.3	39.7	0.094	4.40	97.5	245.8	7.9	343	7.9	281	0.745	0.030	0.026	31	0.90	69
October	0.026	2.58	57.2	0.045	3.18	55.8	10.4	5.6	29.4	0.6	142.4	19.8	0.113	3.86	85.6	56.8	1.5	142	1.5	699	0.876	0.017	0.018	18	1.51	58
November	0.018	2.59	57.5	0.045	3.19	56.0	10.5	5.4	29.5	0.6	142.9	19.7	0.112	2.79	61.8	81.1	1.7	143	1.7	674	0.875	0.017	0.017	17	1.55	57
December	0.017	2.02	44.8	0.045	2.49	43.7	8.2	5.6	23.0	0.5	111.5	16.7	0.122	2.25	50.0	61.5	1.2	111	1.2	893	0.900	0.014	0.015	15	1.80	54
Totals:		49.63	1101.0		61.10	1073.4	201.0	66.3	564.8	11.1	2739	339.4		49.97	1108.4	1630.7	47.9	2739	47.9	525	0.821	0.023	0.021	25	1.23	63

Lake Surface Area (acres): 266.2 Annual Runoff Input (ac-ft/yr): 1073.4 Annual Runoff Total P Input (kg/y): 201 Internal Recycling P Inputs (kg/yr): 66.25 Lake Volume (ac-ft): 3211.5

Annual Seepage Inflow (ac-ft/yr): 564.8 Seepage Total P Load (kg/yr): 11.1

Estimated Mass Balance Vollenweider Model for Lake Holden With 50% Additional P Reduction in Basins 1, 7 and 20

Month	Initial P Conc. (mg/l)	Direct Precip (in)	Direct Precip (ac-ft)	Bulk Precip (mg/l)	Bulk Precip (kg)	Runoff (ac-ft)	Runoff (kg)	Internal Recycling (kg P)	GW Seepage (ac-ft)	GW Seepage (kg)	Total Inputs (ac-ft)	Total Inputs (kg)	Total Inputs (mg/l)	Surf Evap (in)	Surf Evap (ac-ft)	Outfall (ac-ft)	Outfall (kg)	Total Loss (ac-ft)	Total Loss (kg)	Mean Detention Time (days)	P Retention Coeff	Areal P Loading (g/m²)	Final Lake P Conc. (µg/l)	Chyl-a Conc. (mg/m³)	Secchi Disk Depth (m)	Florida TSI Value
January	0.029	2.51	55.7	0.045	3.09	54.3	7.1	22.5	28.6	0.6	138.5	33.3	0.195	2.43	53.9	84.6	3.0	139	3.0	719	0.879	0.028	0.029	37	0.77	72
February	0.029	2.44	54.1	0.045	3.00	52.8	6.9	20.3	27.8	0.5	134.7	30.8	0.185	2.95	65.4	69.3	2.4	135	2.4	668	0.882	0.026	0.027	34	0.84	70
March	0.027	3.59	79.6	0.045	4.42	77.6	10.2	22.5	40.9	0.8	198.1	37.9	0.155	4.38	97.2	100.9	3.6	198	3.6	502	0.835	0.032	0.031	41	0.70	74
April	0.031	2.80	62.1	0.045	3.45	60.6	7.9	21.8	31.9	0.6	154.5	33.8	0.177	5.32	118.0	36.5	1.4	155	1.4	623	0.866	0.030	0.031	40	0.71	74
May	0.031	3.79	84.1	0.045	4.67	82.0	10.8	22.5	43.1	0.8	209.2	38.8	0.150	5.93	131.5	77.7	3.0	209	3.0	476	0.827	0.033	0.032	43	0.66	75
June	0.032	7.43	164.8	0.045	9.15	160.7	21.1	21.8	84.6	1.7	410.1	53.7	0.106	5.36	118.8	291.3	11.7	410	11.7	235	0.710	0.039	0.033	44	0.66	75
July	0.033	7.55	167.5	0.045	9.29	163.3	21.4	22.5	85.9	1.7	416.7	54.9	0.107	5.30	117.5	299.1	12.1	417	12.1	239	0.706	0.040	0.033	45	0.64	76
August	0.033	6.11	135.5	0.045	7.52	132.1	17.3	22.5	69.5	1.4	337.2	48.7	0.117	5.01	111.2	226.0	9.1	337	9.1	295	0.748	0.037	0.032	43	0.66	75
September	0.032	6.22	138.0	0.045	7.66	134.5	17.6	21.8	70.8	1.4	343.3	48.5	0.114	4.40	97.5	245.8	9.7	343	9.7	281	0.745	0.036	0.032	42	0.69	74
October	0.032	2.58	57.2	0.045	3.18	55.8	7.3	22.5	29.4	0.6	142.4	33.6	0.191	3.86	85.6	56.8	2.2	142	2.2	699	0.876	0.029	0.030	39	0.73	73
November	0.030	2.59	57.5	0.045	3.19	56.0	7.3	21.8	29.5	0.6	142.9	32.9	0.187	2.79	61.8	81.1	2.9	143	2.9	674	0.875	0.028	0.029	36	0.78	72
December	0.029	2.02	44.8	0.045	2.49	43.7	5.7	22.5	23.0	0.5	111.5	31.2	0.227	2.25	50.0	61.5	2.2	111	2.2	893	0.900	0.027	0.029	36	0.79	72
Totals:		49.63	1101.0		61.10	1073.4	140.8	265.0	564.8	11.1	2739	478.0		49.97	1108.4	1630.7	63.3	2739	63.3	525	0.821	0.032	0.031	40	0.71	74

Lake Surface Area (acres): 266.2 Annual Runoff Input (ac-ft/yr): 1073.4 Annual Runoff Total P Input (kg/y): 140.8 Internal Recycling P Inputs (kg/yr): 265 Lake Volume (ac-ft): 3211.5

Annual Seepage Inflow (ac-ft/yr): 564.8 Seepage Total P Load (kg/yr): 11.1

Month	Initial P Conc. (mg/l)	Direct Precip. (in)	Direct Precip. (ac-ft)	Bulk Precip. (mg/l)	Bulk Precip. (kg)	Runoff (ac-ft)	Runoff (kg)	Internal Recycling (kg P)	GW Seepage (ac-ft)	GW Seepage (kg)	Total Inputs (ac-ft)	Total Inputs (kg)	Total Inputs (mg/l)	Surface Evap. (in)	Surface Evap. (ac-ft)	Outfall (ac-ft)	Outfall (kg)	Total Losses (ac-ft)	Total Losses (kg)	Mean Detention Time (days)	Phosphorus Retention Coefficient	Areal P Loading (g/m^2)	Final Lake P Conc. (µg/l)	Chyl-a Conc. (mg/m^3)	Secchi Disk Depth (m)	Florida TSI Value
January	0.013	2.51	55.7	0.045	3.09	54.3	7.8	5.6	28.6	0.6	138.5	17.0	0.100	2.43	53.9	84.6	1.5	139	1.5	719	0.879	0.014	0.015	14	1.85	53
February	0.015	2.44	54.1	0.045	3.00	52.8	7.5	5.1	27.8	0.5	134.7	16.2	0.097	2.95	65.4	69.3	1.3	135	1.3	668	0.882	0.014	0.014	13	1.94	52
March	0.014	3.59	79.6	0.045	4.42	77.6	11.1	5.6	40.9	0.8	198.1	21.9	0.090	4.38	97.2	100.9	2.0	198	2.0	502	0.835	0.018	0.018	19	1.44	59
April	0.018	2.80	62.1	0.045	3.45	60.6	8.7	5.4	31.9	0.6	154.5	18.2	0.095	5.32	118.0	36.5	0.8	155	0.8	623	0.866	0.016	0.016	16	1.64	56
May	0.016	3.79	84.1	0.045	4.67	82.0	11.7	5.6	43.1	0.8	209.2	22.9	0.089	5.93	131.5	77.7	1.7	209	1.7	476	0.827	0.020	0.019	20	1.35	60
June	0.019	7.43	164.8	0.045	9.15	160.7	23.0	5.4	84.6	1.7	410.1	39.2	0.078	5.36	118.8	291.3	7.8	410	7.8	235	0.710	0.024	0.024	29	0.98	67
July	0.024	7.55	167.5	0.045	9.29	163.3	23.3	5.6	85.9	1.7	416.7	40.0	0.078	5.30	117.5	299.1	8.9	417	8.9	239	0.706	0.029	0.024	28	1.00	67
August	0.024	6.11	135.5	0.045	7.52	132.1	18.9	5.6	69.5	1.4	337.2	33.4	0.080	5.01	111.2	226.0	6.4	337	6.4	295	0.748	0.025	0.022	25	1.12	64
September	0.022	6.22	138.0	0.045	7.66	134.5	19.2	5.4	70.8	1.4	343.3	33.7	0.080	4.40	97.5	245.8	6.7	343	6.7	281	0.745	0.025	0.022	25	1.12	64
October	0.022	2.58	57.2	0.045	3.18	55.8	8.0	5.6	29.4	0.6	142.4	17.4	0.099	3.86	85.6	56.8	1.3	142	1.3	699	0.876	0.015	0.015	15	1.79	54
November	0.015	2.59	57.5	0.045	3.19	56.0	8.0	5.4	29.5	0.6	142.9	17.2	0.098	2.79	61.8	81.1	1.5	143	1.5	674	0.875	0.015	0.015	14	1.84	54
December	0.015	2.02	44.8	0.045	2.49	43.7	6.2	5.6	23.0	0.5	111.5	14.8	0.108	2.25	50.0	61.5	1.1	111	1.1	893	0.900	0.013	0.013	12	2.10	51
Totals:		49.63	1101.0		61.10	1073.4	153.5	66.3	564.8	11.1	2739	291.9		49.97	1108.4	1630.7	41.0	2739	41.0	525	0.821	0.019	0.018	20	1.48	59

Lake Surface Area (acres): 266.2   Annual Runoff Input (ac-ft/yr): 1073.4   Annual Runoff Total P Input (kg/yr): 153.45   Internal Recycling P Inputs (kg/yr): 66.25   Lake Volume (ac-ft): 3211.5

Annual Seepage Inflow (ac-ft/yr): 564.8   Seepage Total P Load (kg/yr): 11.1

Estimated Mass Balance Vollenweider Model for Lake Holden With Sediment Inactivation and 50% Additional P Reduction in Basins 1, 7 and 20

Month	Initial P Conc. (mg/l)	Direct Precip. (in)	Direct Precip. (ac-ft)	Bulk Precip. (mg/l)	Bulk Precip. (kg)	Runoff (ac-ft)	Runoff (kg)	Internal Recycling (kg P)	GW Seepage (ac-ft)	GW Seepage (kg)	Total Inputs (ac-ft)	Total Inputs (kg)	Total Inputs (mg/l)	Surface Evap. (in)	Surface Evap. (ac-ft)	Outfall (ac-ft)	Outfall (kg)	Total Losses (ac-ft)	Total Losses (kg)	Mean Detention Time (days)	Phosphorus Retention Coefficient	Areal P Loading (g/m^2)	Final Lake P Conc. (µg/l)	Chyl-a Conc. (mg/m^3)	Secchi Disk Depth (m)	Florida TSI Value
January	0.013	2.51	55.7	0.045	3.09	54.3	7.1	5.6	28.6	0.6	138.5	16.4	0.096	2.43	53.9	84.6	1.4	139	1.4	719	0.879	0.014	0.015	13	1.95	52
February	0.014	2.44	54.1	0.045	3.00	52.8	6.9	5.1	27.8	0.5	134.7	15.6	0.094	2.95	65.4	69.3	1.2	135	1.2	668	0.882	0.013	0.014	13	2.04	51
March	0.014	3.59	79.6	0.045	4.42	77.6	10.2	5.6	40.9	0.8	198.1	21.0	0.086	4.38	97.2	100.9	1.9	198	1.9	502	0.835	0.017	0.017	18	1.52	58
April	0.017	2.80	62.1	0.045	3.45	60.6	7.9	5.4	31.9	0.6	154.5	17.5	0.092	5.32	118.0	36.5	0.7	155	0.7	623	0.866	0.016	0.016	15	1.72	55
May	0.016	3.79	84.1	0.045	4.67	82.0	10.8	5.6	43.1	0.8	209.2	21.9	0.085	5.93	131.5	77.7	1.6	209	1.6	476	0.827	0.019	0.018	19	1.43	59
June	0.018	7.43	164.8	0.045	9.15	160.7	21.1	5.4	84.6	1.7	410.1	37.3	0.074	5.36	118.8	291.3	7.5	410	7.5	235	0.710	0.023	0.023	27	1.05	66
July	0.023	7.55	167.5	0.045	9.29	163.3	21.4	5.6	85.9	1.7	416.7	38.0	0.074	5.30	117.5	299.1	8.5	417	8.5	239	0.706	0.027	0.023	26	1.07	65
August	0.023	6.11	135.5	0.045	7.52	132.1	17.3	5.6	69.5	1.4	337.2	31.8	0.077	5.01	111.2	226.0	6.1	337	6.1	295	0.748	0.024	0.021	23	1.19	63
September	0.021	6.22	138.0	0.045	7.66	134.5	17.6	5.4	70.8	1.4	343.3	32.1	0.076	4.40	97.5	245.8	6.4	343	6.4	281	0.745	0.024	0.021	23	1.19	63
October	0.021	2.58	57.2	0.045	3.18	55.8	7.3	5.6	29.4	0.6	142.4	16.7	0.095	3.86	85.6	56.8	1.3	142	1.3	699	0.876	0.015	0.014	14	1.88	53
November	0.015	2.59	57.5	0.045	3.19	56.0	7.3	5.4	29.5	0.6	142.9	16.6	0.094	2.79	61.8	81.1	1.5	143	1.5	674	0.875	0.014	0.014	13	1.93	52
December	0.014	2.02	44.8	0.045	2.49	43.7	5.7	5.6	23.0	0.5	111.5	14.3	0.104	2.25	50.0	61.5	1.0	111	1.0	893	0.900	0.013	0.012	12	2.20	50
Totals:		49.63	1101.0		61.10	1073.4	140.8	66.3	564.8	11.1	2739	279.2		49.97	1108.4	1630.7	39.1	2739	39.1	525	0.821	0.019	0.017	18	1.57	58

Lake Surface Area (acres): 266.2   Annual Runoff Input (ac-ft/yr): 1073.4   Annual Runoff Total P Input (kg/yr): 140.8   Internal Recycling P Inputs (kg/yr): 66.25   Lake Volume (ac-ft): 3211.5

Annual Seepage Inflow (ac-ft/yr): 564.8   Seepage Total P Load (kg/yr): 11.1