EVALUATION OF RUNOFF LOADINGS AND IMPACTS FROM UNTREATED LAKE HOLDEN DRAINAGE SUB-BASINS

Draft Final Report
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SECTION 1

INTRODUCTION

This report provides a summary of work efforts performed by Environmental Research & Design, Inc. (ERD) for the Orange County Environmental Protection Division (OCEPD) and the Lake Holden Property Owners Association (LHPOA) to evaluate water quality characteristics of runoff discharging from significant sub-basin areas to Lake Holden and provide options and recommendations for further reductions in runoff generated loadings discharging to the lake. This project has multiple objectives, including:

1. Evaluate water quality characteristics of discharges from existing stormwater treatment projects to verify that the design removal efficiencies are being achieved;

2. Provide recommendations for development of new runoff BMPs or enhancement of existing projects;

3. Evaluate historical and current water quality trends in Lake Holden to quantify impacts from previous water quality improvement projects; and

4. Evaluate hydrologic impacts of recent modifications existing drainage well structures within the lake

Monitoring of stormwater inflows to Lake Holden was conducted from December 2014-September 2015 at 10 locations within the Lake Holden watershed to identify the characteristics of inflows from significant sub-basin areas, both with and without existing stormwater BMPs. Stormwater autosamplers were installed at each of the 10 monitoring sites, and flow-weighted composite samples were collected during 77 stormwater events. This information is used to identify the operational characteristics of existing BMPs and identify significant sub-basin areas where additional BMP implementation may be appropriate.

The most recent evaluation of Lake Holden water quality and trends was conducted during 2010. The historical database was updated as part of this project, and a new series of trend analyses were conducted to evaluate current water quality trends and potential need for additional stormwater BMP. In addition, a hydraulic analysis is conducted to evaluate impacts from recent drainage well modifications on mean water elevations in Lake Holden.

This report is divided into five separate sections for presentation of the work efforts conducted by ERD. Section 1 contains an introduction to the report and a brief summary of work efforts performed by ERD. An evaluation of historic and current water quality characteristics and trends in Lake Holden is given in Section 2. Section 3 provides a discussion of the stormwater monitoring program and comparison of runoff characteristics at each of the 10 monitored sites, and includes a revised summary of runoff generated loadings of total nitrogen and total phosphorus to the lake. A review of current and proposed stormwater BMPs is provided in Section 4, and a discussion of potential hydrologic impacts from recent drainage well improvements and modifications in Lake Holden is given in Section 5. Appendices are attached which contain referenced documents and data collected by ERD during this project.

SECTION 2

WATER QUALITY CHARACTERISTICS AND TRENDS

A review of available water quality data for Lake Holden was conducted by ERD to provide a compilation of historical water quality data for the lake, evaluate ambient concentrations of significant water quality parameters, and examine long-term and short-term water quality trends. The results of these analyses and evaluations are summarized in the following sections.

2.1 Data Sources

A review of available historical water quality data for Lake Holden was conducted by ERD as part of the 2010 report titled "Evaluation of the Current Status and Potential Water Quality Improvement Options for Lake Holden". This evaluation included a search of water quality data in the possession of the City of Orlando, Orange County Environmental Protection Division (OCEPD), Florida Department of Environmental Protection (FDEP), ERD, and LAKEWATCH. Additional data were also obtained from the Orange County Water Atlas and the Florida STORET database.

Historical water quality data obtained from each of these sources was compiled into a single database. However, significant overlap and duplication in data occurred between the City of Orlando, OCEPD, and Water Atlas databases, since much of the data on the Water Atlas were obtained from these sources. Significant overlaps in data were also observed in the FDEP STORET database. The combined data set was reviewed for duplicate data entries, and the duplicate data were removed as appropriate. When overlapping data was observed between various data sources, the data were assigned to the original data source.

The water quality compilation and review conducted by ERD as part of the 2010 report included water quality data collected through much of 2009. For purposes of this current project, ERD supplemented the 2010 data set with additional water quality data collected from 2010-2015 and 2016, when available. These new data were added to the original data set to generate a revised updated database of water quality data through the end of 2015. Since the end of 2009, additional water quality monitoring has been conducted by the City of Orlando, ERD, and the LAKEWATCH monitoring program. Surface water monitoring conducted by Orange County ended in Lake Holden during 2010, and no additional monitoring has been conducted since that time.

A summary of available water quality data sources for Lake Holden is given in Table 2-1. Water quality monitoring has been conducted in Lake Holden on approximately a quarterly basis by the City of Orlando from March 2001 to the present, with separate samples collected at both north lobe and south lobe monitoring sites. Each of the collected samples was evaluated for general parameters, nutrients, and chlorophyll. A limited amount of water quality monitoring was conducted by FDEP, with five samples collected from October 2003-September 2004 as part of the state-wide monitoring effort to identify Impaired Waters, with an additional sample collected during June 2009. Each of these samples was collected near the center of the lake or lobe and evaluated for nutrients and chlorophyll.

TABLE 2-1

SUMMARY OF AVAILBLE WATER QUALITY DATA SOURCES FOR LAKE HOLDEN

DATA SOURCE	PERIOD OF RECORD	NUMBER OF SAMPLES	FREQUENCY LOCATION	PARAMETERS MEASURED
City of Orlando	3/01-Present (4/16)	120	Quarterly at N/S sites	General parameters, nutrients, chlorophyll
FDEP	10/03-9/04	5	Quarterly at center	Nutrients, chlorophyll
	6/09	1	One event at center	
LAKEWATCH	9/87-9/91	19	Monthly/quarterly at center	General parameters, nutrients, chlorophyll
	7/95-7/96	5		
	6/97-Present (4/16)	222	Monthly at center	
Orange County EPD	10/70-3/75	12	Annual at N/S sites	General parameters, nutrients, chlorophyll, microbiology, metals, demand parameters
	3/77-11/80	31	Quarterly at N/S sites	
	1/81-12/87	315	Biweekly at N/S sites	
	3/88-11/91	22	Quarterly at N/S sites	
	2/92-12/96	22	Quarterly at N/S sites	
	1/98-12/99	12	Monthly at S site	
	1/00-10/05	62	Quarterly at N/S sites	
	1/06-12/07	46	Monthly at N/S sites	
	1/08-10/10	24	Quarterly at N/S sites	
ERD	4/05-2/16	96	Monthly/quarterly	General parameters, nutrients, chlorophyll

Extensive water quality monitoring in Lake Holden has been conducted by the LAKEWATCH program, beginning in September 1987. From September 1987-September 1991, water quality monitoring was conducted at one location near the center of the lake on a monthly or quarterly basis, with the samples analyzed for general parameters, nutrients, and chlorophyll. Monitoring was resumed in July 1995 and continued until July 1996, with five samples collected over this period. Monthly monitoring was initiated by LAKEWATCH in June 1997 and has continued until the present (December 2015), with a total of 222 samples collected, with measurements conducted for general parameters, nutrients, and chlorophyll.

Extensive monitoring in Lake Holden has also been conducted by OCEPD. Monitoring was initiated in October 1970 and continued on approximately an annual basis until March 1975, with samples collected at northern and southern sites. Each of the collected samples was evaluated for general parameters, nutrients, chlorophyll, microbiological parameters, metals, and demand parameters. Monitoring was resumed again during March 1977 and conducted at the north and south lobe sites on a quarterly basis until November 1980. Beginning in January 1981 and continuing until December 1987, monitoring was conducted on a biweekly basis at the north and south lobe monitoring sites. Each of the collected samples was evaluated for the parameters listed previously. Quarterly monitoring was initiated in March 1988 and continued until November 1991, with monitoring conducted at both north and south lobe sites during most of these events. Quarterly monitoring was conducted from February 1992-December 1996 at the south lobe site only. This monitoring was continued on a monthly basis during 1997. Monthly monitoring was resumed in January 1998 and continued until December 2000. Quarterly monitoring was initiated during January 2001 and continued until October 2005. Monitoring returned to a monthly frequency during January 2006 and was continued until December 2007. Beginning in January 2008 and continuing to October 2010, monitoring was conducted on approximately a quarterly basis, with both north and south lobe monitoring sites included with each event. No additional water quality monitoring has been conducted in Lake Holden by Orange County since 2010.

All of the collected data were converted to common units to allow proper comparison of the historical data. For example, measurements of Secchi disk depth in the data sets were provided in both feet and meters, depending upon the data source. All Secchi disk depth measurements were then converted by ERD into standard units of meters. Similarly, concentrations for nutrients were provided in the historical data in both mg/l and μg/l units. All nutrient data were then converted to μg/l by ERD which is the most common current method for presentation of these data.

The historical database summarized in the 2010 report contained a variety of general parameters, multiple nutrient species, and microbiological parameters, including chlorophyll-a and fecal coliform. However, the monitoring programs conducted since 2010 have concentrated primarily on significant trophic state indicators, such as chlorophyll-a, Secchi disk depth, total nitrogen, and total phosphorus which are the most significant parameters in evaluating water quality trends. Therefore, the water quality analysis summarized in this report is limited to the trophic state parameters of chlorophyll-a, Secchi disk depth, total nitrogen, and total phosphorus.

2.2 Data Summary

A summary of the available historical water quality data for significant trophic state indicators in Lake Holden is given in Appendix A. Historical data are provided for chlorophyll-a, Secchi disk depth, total nitrogen, and total phosphorus. The complete database, included in the 2010 report, also contains extensive measurements conducted for significant cations, heavy metals, additional microbiological parameters, and miscellaneous other parameters.

A graphical summary of historical total nitrogen concentrations in Lake Holden from 1978-2015 is given in Figure 2-1. Relatively close agreement appears to exist between total nitrogen measurements conducted by the various agencies and organizations. In general, the majority of measured total nitrogen concentrations in Lake Holden have ranged from approximately 500-2500 µg/l, with a small number of measurements both above and below this range. Total nitrogen concentrations in Lake Holden appear to have peaked during the mid-1980s, followed by relatively consistent measurements until approximately 2000 when an additional peak in total nitrogen was observed. No significant differences are apparent between nitrogen concentrations measured at the north and south monitoring sites. A noticeable trend of decreasing nitrogen concentrations is apparent beginning in 2000 and continuing through 2015. This decrease in total nitrogen appears to be related to the water quality enhancement projects which have been constructed within the drainage basin. Current ambient water column concentrations of total nitrogen in Lake Holden are in the range of 500 µg/l, which is a low value for an urban lake.

A graphical summary of historical total phosphorus concentrations in Lake Holden from 1978-2010 is given in Figure 2-2. Total phosphorus concentrations in Lake Holden were highly variable over the period from 1980-1995, with the majority of measured values ranging from approximately 20-80 µg/l. Spikes in phosphorus concentrations to values in excess of 100 µg/l were observed on several occasions. In general, there appears to be relatively close agreement between phosphorus concentrations reported by the various data sources during this period. A trend of decreasing phosphorus concentrations in Lake Holden appears to occur in the late-1990s, with the lowest recorded phosphorus measurements occurring within the lake during the past several years. No significant differences in phosphorus concentrations are apparent between the north and south monitoring sites. Current ambient water column concentrations of total phosphorus in Lake Holden are near 10 mg/l, which is an extremely low value for an urban lake and similar to total phosphorus concentrations measured in pristine areas of the Butler Chain-of-Lakes.

During the period from 2000 to the present, there appears to be relatively close agreement between the phosphorus concentrations measured by LAKEWATCH, FDEP, and Orlando. However, somewhat lower total phosphorus concentrations were reported by Orange County, particularly during the period from 2000-2005. Since 2010, the Orlando and LAKEWATCH data sources appear to be more similar in value, with slightly higher total phosphorus concentrations reported by LAKEWATCH.

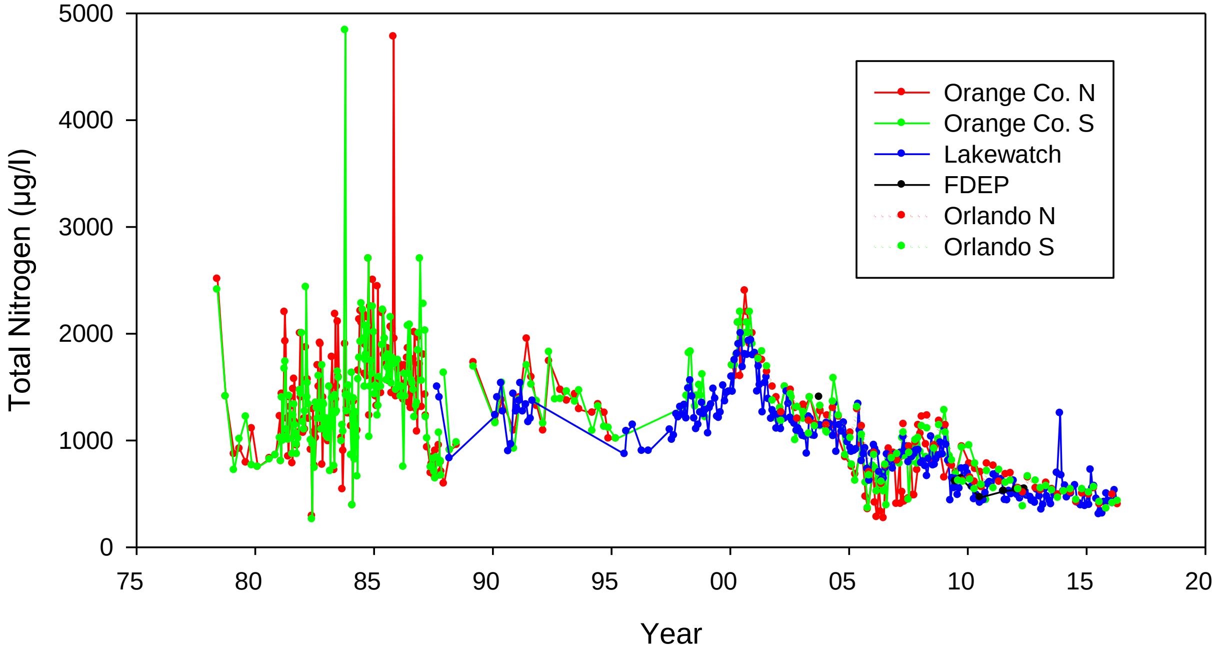


Figure 2-1. Summary of Historical Total Nitrogen Concentrations in Lake Holden from 1978-2015.

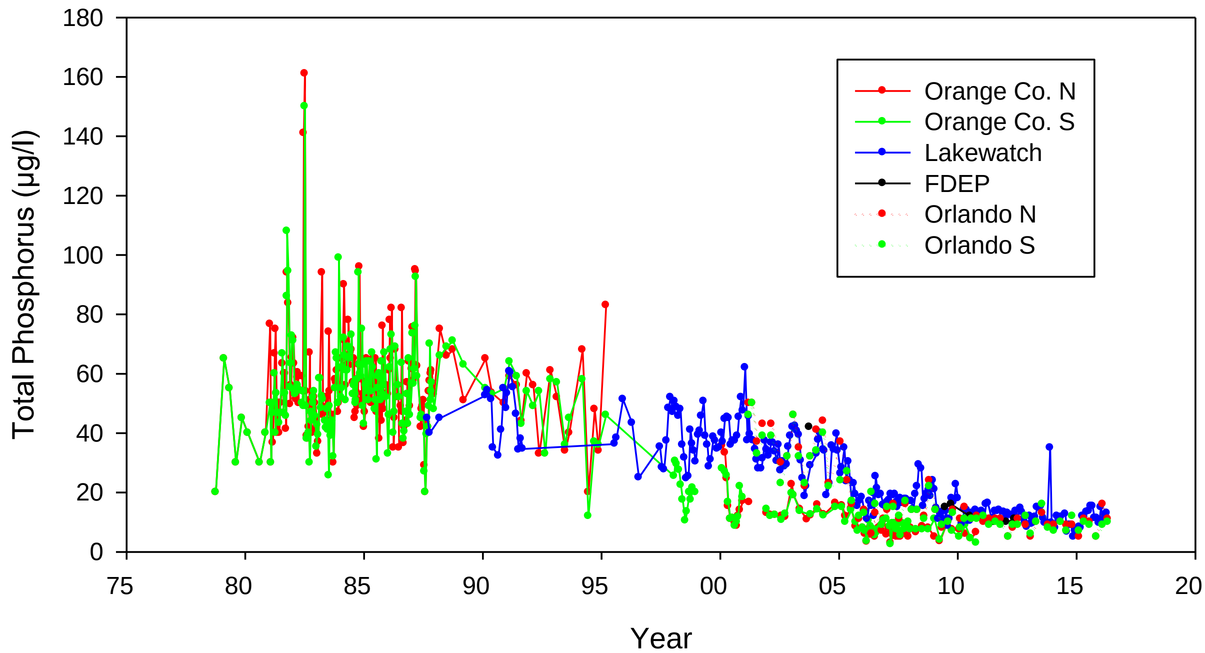


Figure 2-2. Summary of Historical Total Phosphorus Concentrations in Lake Holden from 1978-2010.

A graphical summary of historical chlorophyll-a concentrations in Lake Holden from 1987-2015 is given on Figure 2-3. Similar to the trends observed for total nitrogen and total phosphorus, chlorophyll-a concentrations have been highly variable in Lake Holden over the period of record, particularly prior to the year 2000 when chlorophyll-a concentrations ranged from approximately 20-90 mg/m^3. These rapid fluctuations in algal populations are characteristic of a highly eutrophic lake system. The highest chlorophyll-a concentrations on record in Lake Holden occurred during the mid-1980s, similar to the trends also observed for total phosphorus and total nitrogen.

Beginning in approximately 2000, a steady and rapid decrease in chlorophyll-a concentrations has occurred within the lake. The chlorophyll-a measurements conducted by Orange County and LAKEWATCH over this period appear to be relatively consistent, with no significant differences between the north and south monitoring sites. From 2005-2010, chlorophyll-a concentrations in Lake Holden ranged from approximately 5-35 mg/m^3, with some of the lowest historical chlorophyll-a concentrations measured to date during this time. Chlorophyll-a concentrations measured by the various monitoring agencies appear to be relatively similar.

However, since approximately 2010, following completion of the alum sediment inactivation project, chlorophyll-a concentrations in Lake Holden have generally been in the range of 5-6 mg/m^3 or less, with many chlorophyll-a concentrations less than 2-3 mg/m^3. Values in this range are similar to concentrations observed in some of the pristine lakes in the Butler Chain.

A graphical summary of historical Secchi disk depth measurements in Lake Holden from 1978-2015 is given in Figure 2-4. Similar to the trends previously observed for total nitrogen, total phosphorus, and chlorophyll-a, Secchi disk depth has been highly variable in Lake Holden over the past 30-40 years. Secchi disk measurements substantially less than 1 m were common in Lake Holden during the period from approximately 1980-2000. However, beginning in 2000, Secchi disk depths within the lake began to increase gradually, with rapid improvements in Secchi depth beginning in 2005. The sudden increases in Secchi disk depth illustrated on Figure 3-4 from 2005 to the present are likely related to the combination of the ongoing stormwater enhancement projects and alum sediment inactivation treatments conducted to the lake during this time. In general, Secchi disk measurements appear to be relatively similar between the various sources, although slightly lower Secchi disk depths have been reported by Orlando during the many events. Measured Secchi depth measurements over the past five years have consistently exceeded 3 m, with many Secchi disk measurements in excess of 4 m. Current Secchi disk depth in Lake Holden is also similar to some of the more pristine lakes in the Butler Chain.

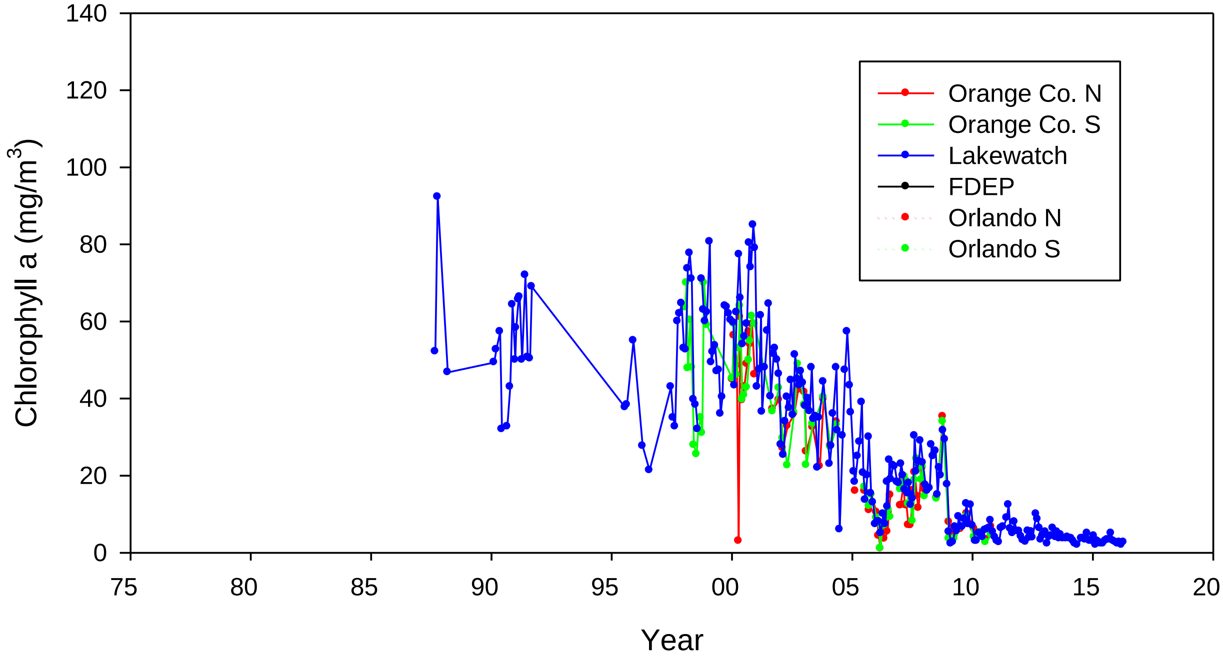


Figure 2-3. Summary of Historical Chlorophyll-a Concentrations in Lake Holden.

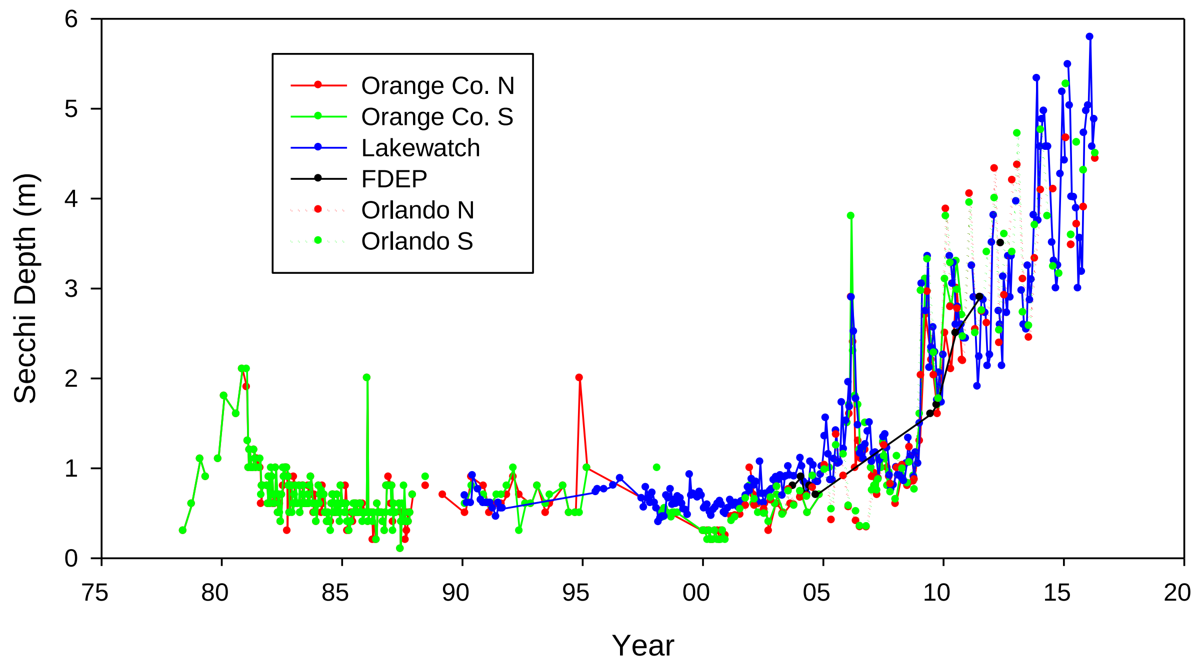


Figure 2-4. Summary of Historical Secchi Disk Depths in Lake Holden from 1978-2015.

A graphical summary of calculated trophic state index (TSI) values in Lake Holden from 1978-2015 is given in Figure 2-5. Since TSI is a measure of primary productivity, TSI values are calculated using chlorophyll-a only when chlorophyll-a data are available. If chlorophyll-a data are not available, then the TSI is estimated as the average of the TSI values for total phosphorus and Secchi depth. During the period from 1980-1990, Lake Holden was classified as a eutrophic or hypereutrophic lake system, with many calculated TSI values in excess of 80. A significant decrease in TSI values began to occur within the lake during 2000, with the TSI value gradually decreasing from hypereutrophic to eutrophic to mesotrophic, and highly oligotrophic conditions observed beginning in 2007. Over the past 10 years, calculated TSI values in Lake Holden have indicated primarily oligotrophic conditions.

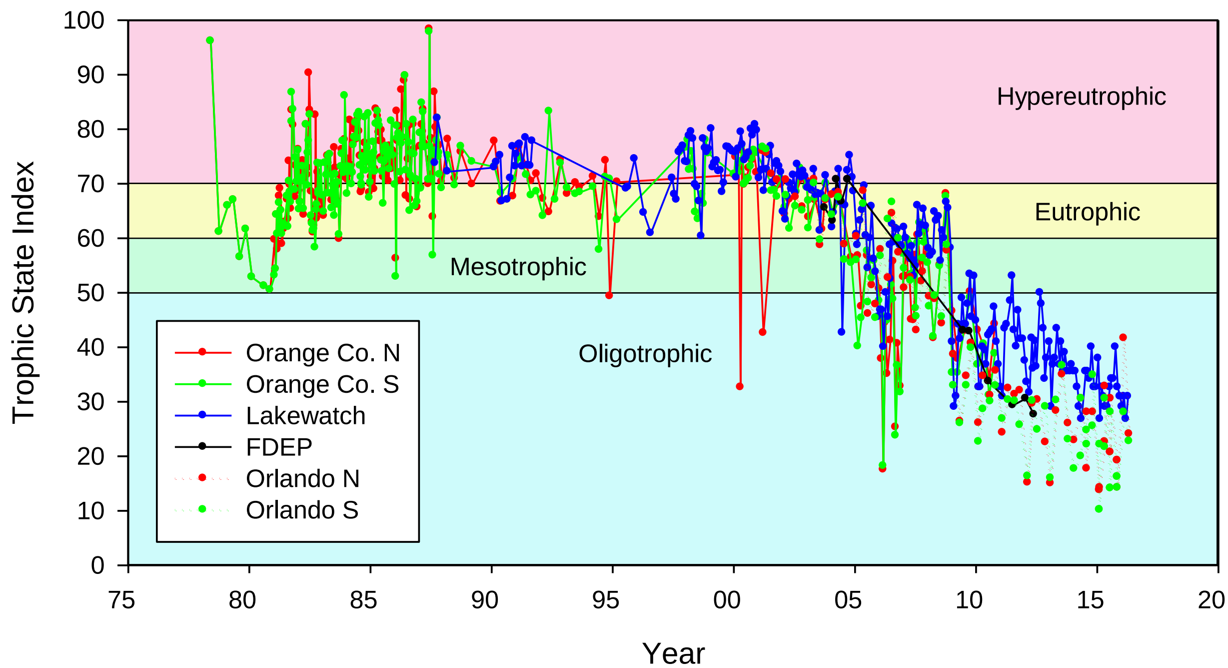


Figure 2-5. Summary of Historical Trophic State Indices (TSI) in Lake Holden from 1978-2015.

A summary of mean water quality characteristics in Lake Holden from 1985 to the present in 5-year intervals is given in Table 2-2. Mean values for significant water quality parameters are provided for each 5-year interval over the period from 1985 to the present. The mean values for each interval reflect the overall mean for all data sources for a given parameter during the evaluated interval.

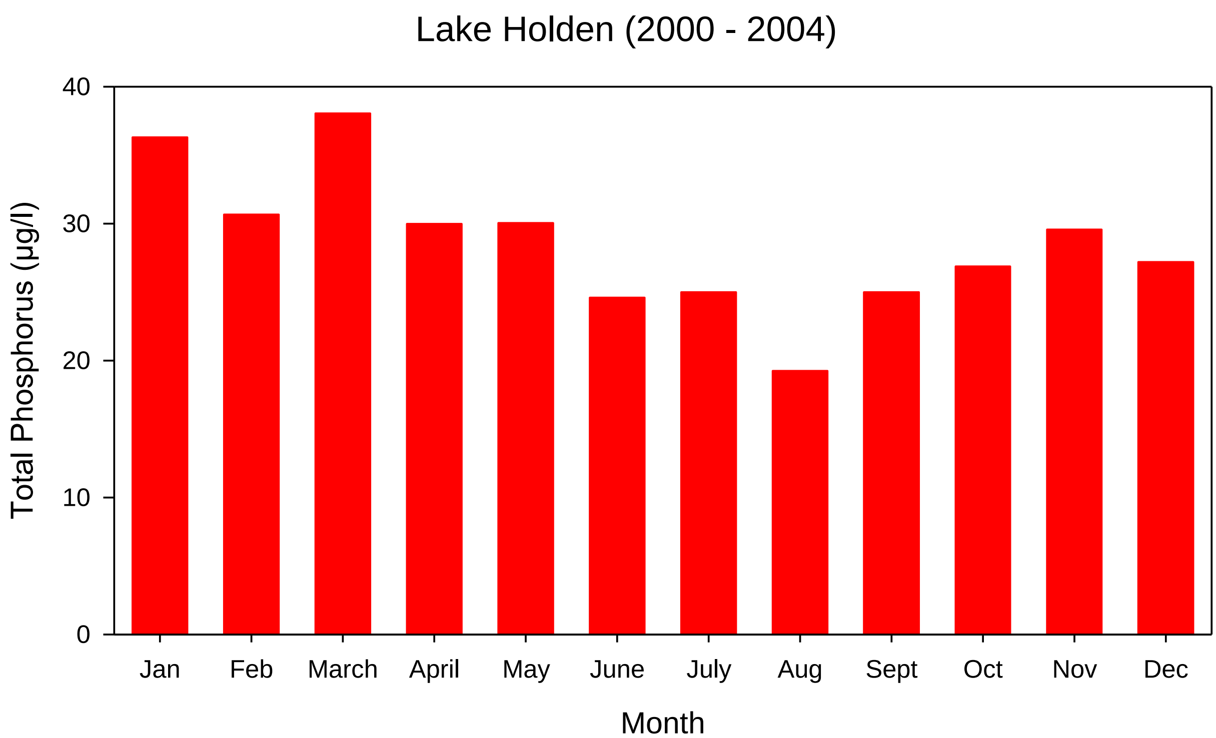
TABLE 2-2

MEAN WATER QUALITY VALUES FOR SIGNIFICANT TROPHIC STATE INDICATORS IN LAKE HOLDEN FROM 1978-2015

SAMPLE DATE	PARAMETER								
	Chlorophyll-a (mg/m3)	Secchi Disk Depth (m)	Total N (µg/l)	Total P (µg/l)	TN/TP Ratio	TSI (TP)	TSI (Chyl-a)	TSI (SD)	TSI (avg)
Pre-1985	--	0.78	1,359	55	26	70	--	70	70
1985-1989	63.7	0.54	1,493	55	29	70	76	81	75
1990-1994	54.0	0.67	1,332	48	30	67	74	73	71
1995-1999	51.0	0.65	1,285	35	43	59	73	74	72
2000-2004	44.0	0.61	1,431	29	66	53	70	77	69
2005-2009	16.3	1.25	783	13	73	34	54	56	52
2010-2015	4.2	3.39	530	10	69	27	35	24	31

As seen in Table 2-2, a gradual decrease in concentrations has been observed for most parameters from 1985 to the present. Substantial reductions in mean water column concentrations are apparent for chlorophyll-a, total nitrogen, and total phosphorus. Measured Secchi disk depths in Lake Holden have improved substantially, particularly over the past five years, with a mean Secchi disk depth of 3.39 m from 2010-2015. In general, improvements in water quality characteristics have been observed in Lake Holden since 1985 for every parameter listed in Table 2-2, with the most rapid improvements beginning in 2005 corresponding with the initiation of the sediment inactivation project. These improvements in water quality characteristics reflect the reductions in nutrient loadings as a result of the aggressive BMP implementation projects for the lake and sediment inactivation.

A comparison of mean monthly total phosphorus concentrations in Lake Holden from 2000 to the present is given in Figure 2-6. Separate plots are provided to illustrate monthly means for the period from 2000-2004, prior to the sediment inactivation project, and monthly means from 2005-2015. During the period from 2000-2004, prior to the sediment inactivation project, phosphorus concentrations in Lake Holden were lowest during the wet season months and highest during dry season conditions. This trend suggests that significant internal recycling was occurring within the lake which allowed accumulated phosphorus concentrations in lower layers of the lake to circulate throughout the entire water column during fall and winter conditions when lake circulation is most common. This circulation distributes the elevated hypolimnetic phosphorus concentrations throughout the lake and results in increased phosphorus values and a higher algal productivity during periods of circulation. The trend in mean monthly phosphorus concentrations over the period from 2000-2004 represents a classic phosphorus profile for a lake with significant internal recycling.



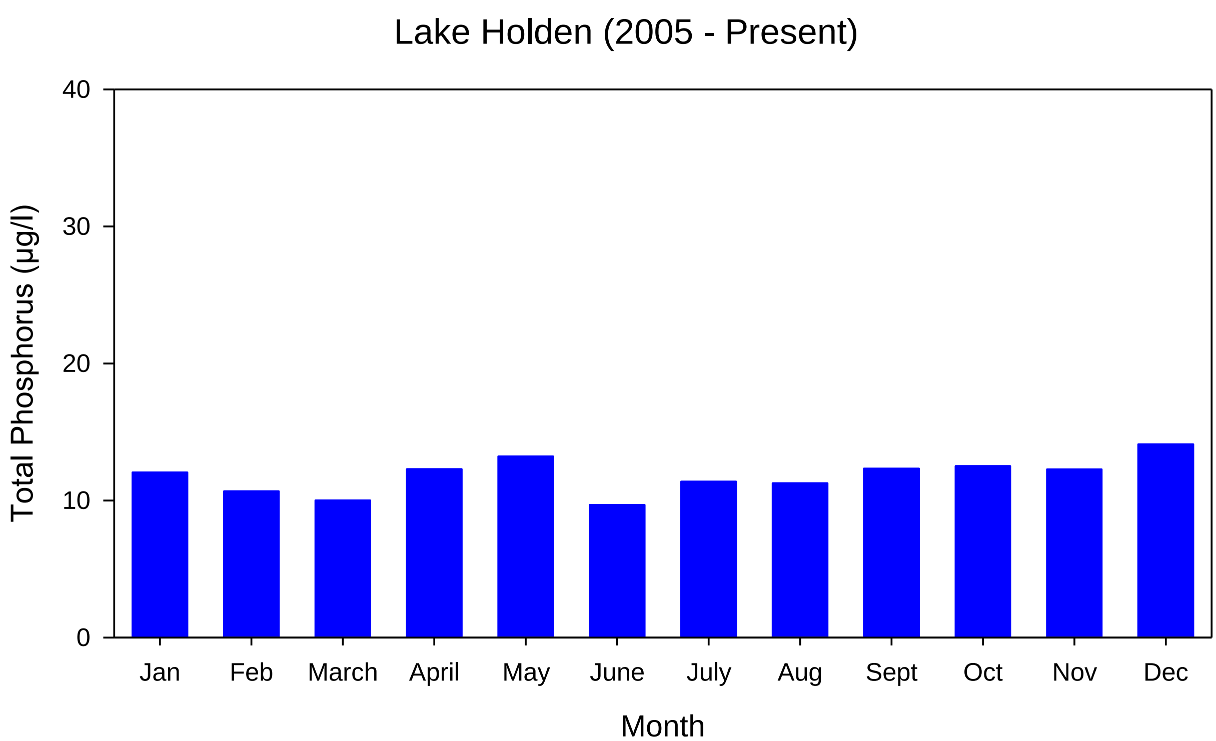


Figure 2-6. Comparison of Mean Monthly Total Phosphorus Concentrations in Lake Holden from 2000-2015.

A summary of mean monthly phosphorus concentrations in Lake Holden from 2005-2015 is given at the bottom of Figure 2-6. Two obvious patterns are apparent in phosphorus concentrations over this period. First, mean water column concentrations of total phosphorus are substantially lower throughout the year compared with phosphorus concentrations measured from 2000-2004. In addition, the elevated phosphorus concentrations observed within the lake during periods of water column circulation are absent, indicating that the project to reduce internal recycling within Lake Holden has been successful.

A comparison of mean monthly chlorophyll-a concentrations in Lake Holden from 2000-2015 is given in Figure 2-7. Similar to the trends observed for total phosphorus, the most elevated chlorophyll-a concentrations in Lake Holden during the period from 2000-2004 appear to occur during the fall and winter months in response to the elevated phosphorus concentrations which occurred during these months.

A summary of mean monthly chlorophyll-a concentrations in Lake Holden from 2005-2015 is given at the bottom of Figure 2-7. In general, chlorophyll-a concentrations within the lake are substantially lower over the last 10 years than observed from 2000-2004. In addition, the elevated chlorophyll-a concentrations observed during the fall and winter months have been eliminated, with relatively consistent chlorophyll-a concentrations throughout the year.

2.3 Water Quality Trends

A graphical summary of calculated mean annual historical concentrations of total nitrogen in Lake Holden is given in Figure 2-8. Mean annual nitrogen concentrations were calculated for each year, with data from all sources combined, to provide a mean concentration for each year. Mean annual total nitrogen concentrations in Lake Holden have ranged from approximately 500-2,000 μg/l over the historical monitoring period. Values in the upper portions of this range are typical of impacted lakes in an urban environment, while values on the low end are indicative of levels observed in pristine lakes. An apparent trend of decreasing total nitrogen concentrations appears to have begun in the year 2000, with total nitrogen concentrations ranging from approximately 500-600 μg/l since 2010.

A graphical summary of calculated mean annual historical total phosphorus concentrations in Lake Holden is given in Figure 2-9. The values summarized in this figure represent the annual mean phosphorus concentration for all combined sources available in the historical data set. Total phosphorus concentrations in Lake Holden appear to have peaked in value during the late-1980s, with an annual mean of approximately 66 μg/l. However, since that time, a gradual but steady decrease in phosphorus concentrations appears to have occurred. A more significant drop in phosphorus concentrations appears to have occurred since approximately 2004, with mean annual phosphorus concentrations over the past 3-4 years ranging from approximately 8-12 μg/l, reflecting extremely low values. These values are extremely desirable for an urban lake system, and indicate that the extensive restoration efforts which have been conducted on Lake Holden have resulted in measurable impacts on water quality.

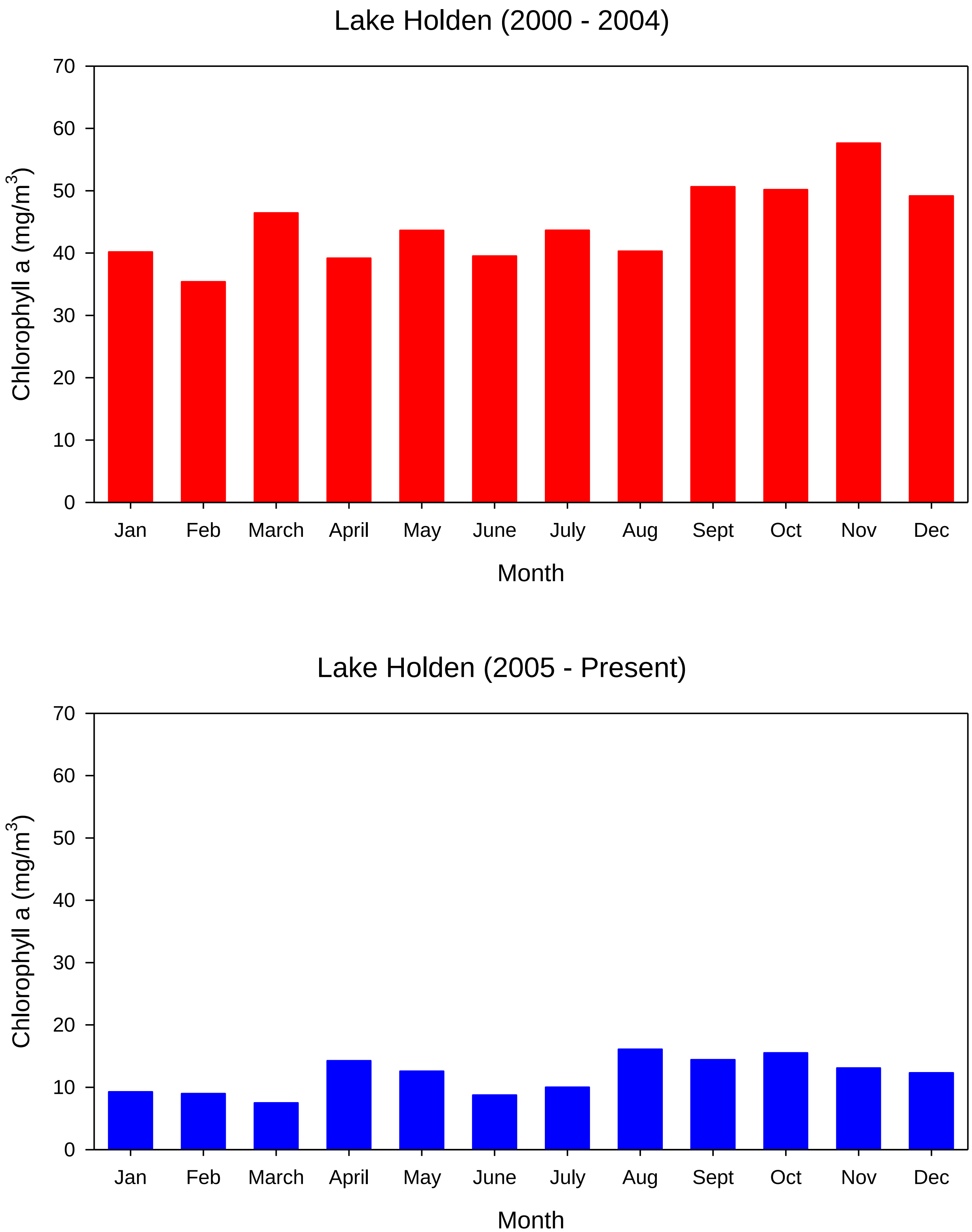


Figure 2-7. Comparison of Mean Monthly Chlorophyll-a Concentrations in Lake Holden from 2000-2015.

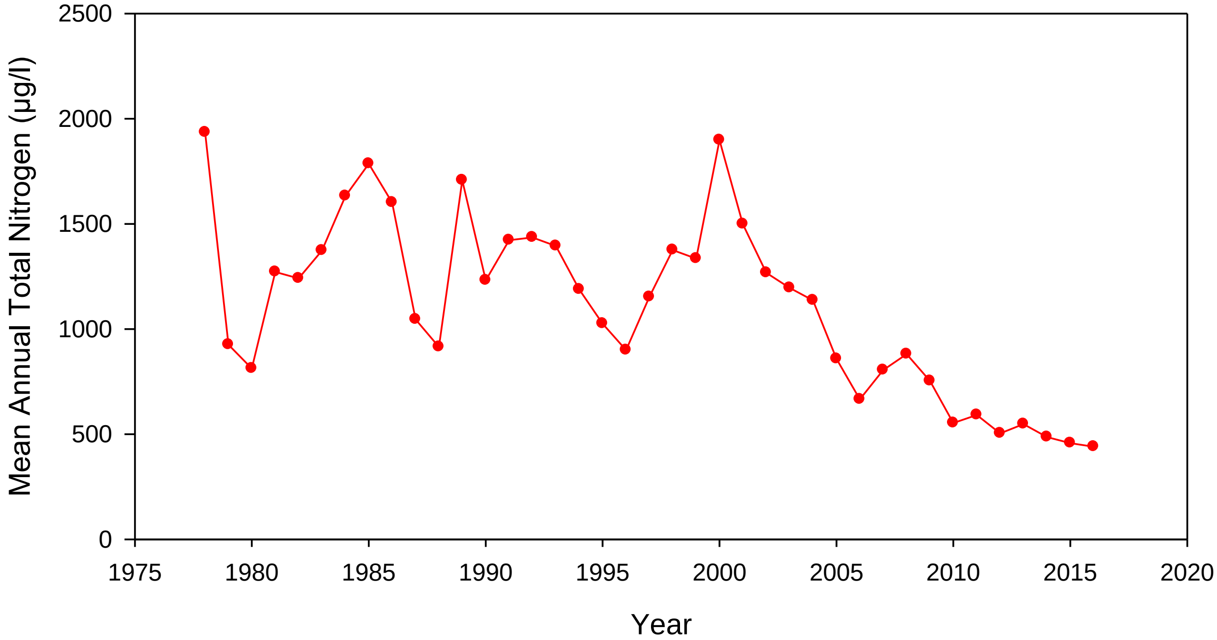


Figure 2-8. Calculated Mean Annual Historical Total Nitrogen Concentrations in Lake Holden from 1978-2015.

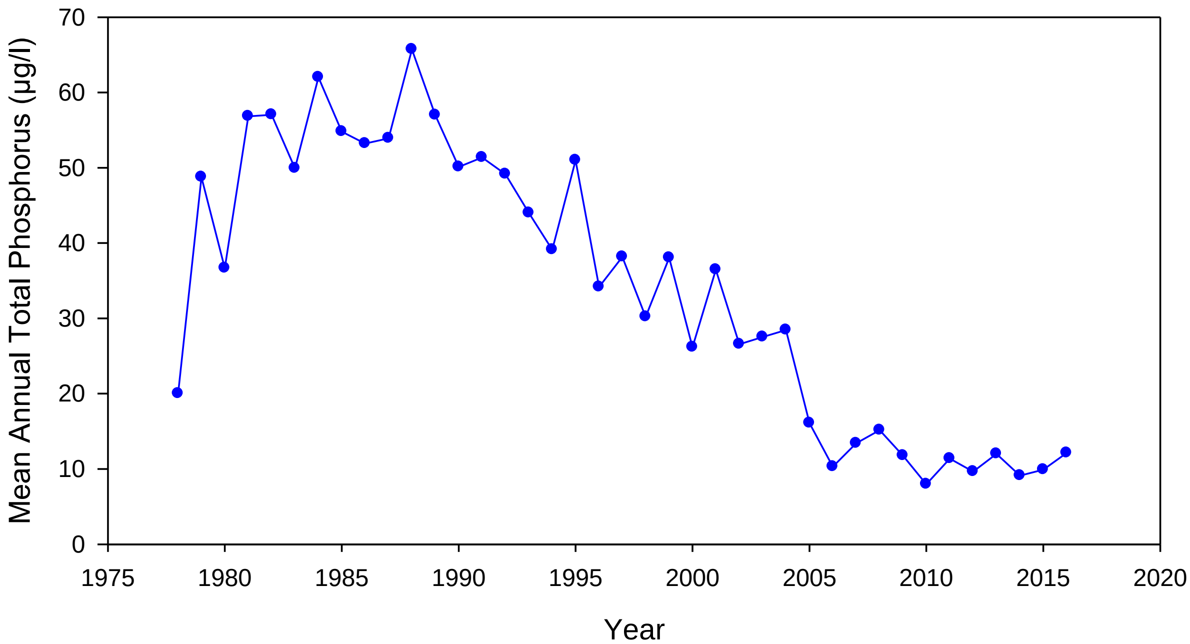


Figure 2-9. Calculated Mean Annual Historical Total Phosphorus Concentrations in Lake Holden from 1978-2015.

A graphical summary of calculated mean annual historical chlorophyll-a concentrations in Lake Holden from 1985-2015 is given in Figure 2-10. Chlorophyll-a concentrations in Lake Holden have been highly variable, with mean annual averages ranging from approximately 5-70 mg/m^3. Some of the most consistently elevated chlorophyll-a concentrations were observed within the lake during the 1980s and 1990s. Beginning in approximately 2000, a rapid decrease in annual chlorophyll-a concentrations began to occur within the lake. Over the past five years, mean annual chlorophyll-a concentrations in Lake Holden have ranged from approximately 3-4 mg/m^3, reflecting extremely good water quality and the lowest historic chlorophyll-a values measured within the lake.

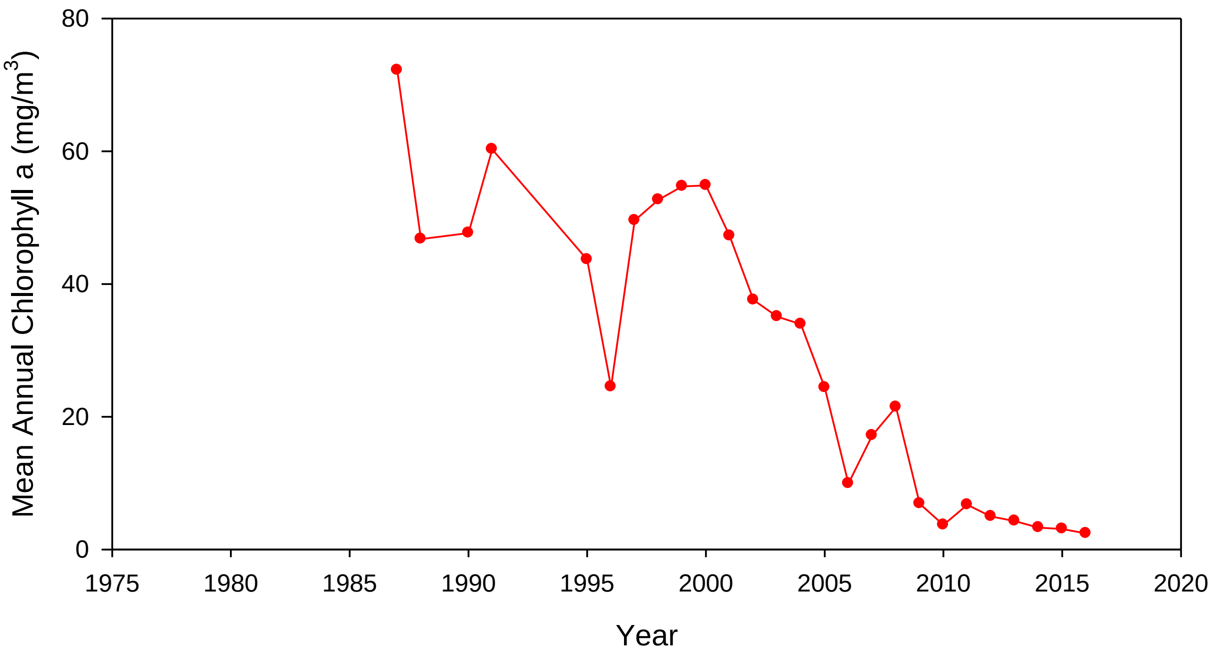


Figure 2-10. Calculated Mean Annual Historical Chlorophyll-a Concentrations in Lake Holden from 1985-2015.

A graphical comparison of calculated mean annual Secchi disk depths in Lake Holden from 1978-2015 is given on Figure 2-11. The lowest historical Secchi disk depths within the lake were observed during the period from approximately 1980-2000, with mean annual Secchi disk depths ranging from approximately 0.4-0.8 m, reflecting extremely poor water clarity. Similar to the trends observed for total nitrogen, total phosphorus, and chlorophyll-a, improvements in Secchi disk depth began to occur in the year 2000, with an increase in mean annual Secchi disk depth from 0.4 m in 2000 to approximately 3 m during 2010. Since 2010, mean annual Secchi disk depths in Lake Holden have exceeded 3.0 m.

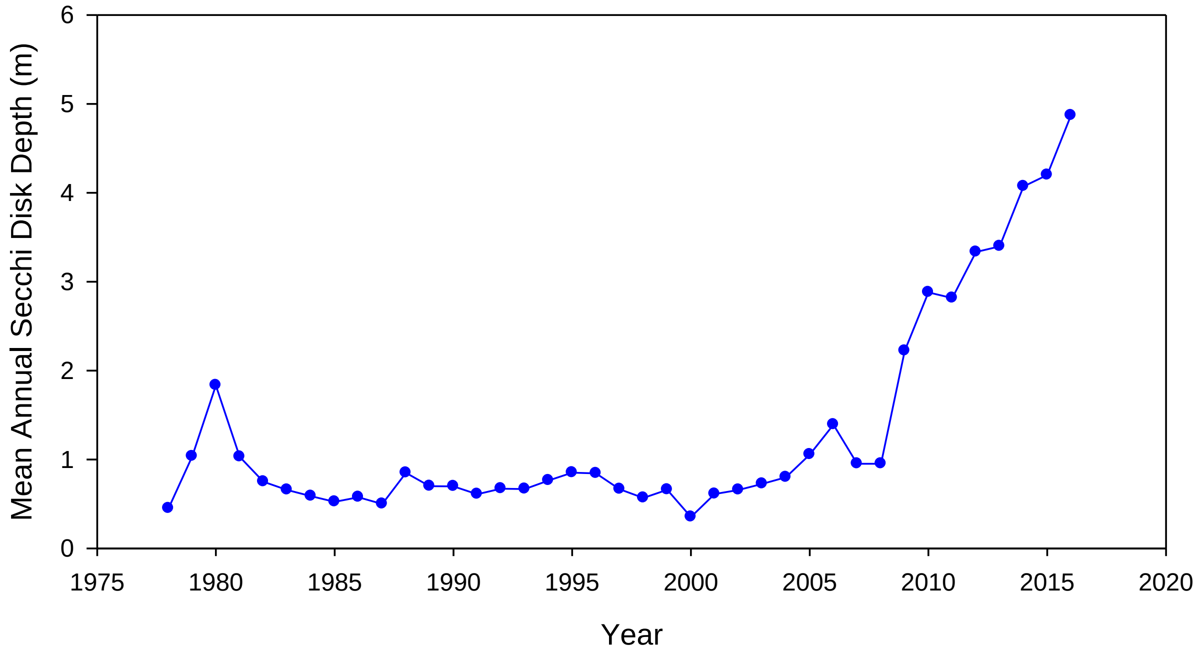


Figure 2-11. Calculated Mean Annual Historical Secchi Disk Depths in Lake Holden from 1978-2015.

A graphical comparison of calculated mean annual TSI values for Lake Holden from 1978-2015 is given on Figure 2-12. Prior to the year 2000, mean annual TSI values in Lake Holden indicated primarily eutrophic or hypereutrophic conditions. A steady decrease in TSI value began to occur in the year 2000, with mean annual TSI values falling from hypereutrophic to eutrophic to mesotrophic from the year 2000-2006. However, since 2008, Lake Holden has exhibited oligotrophic conditions, with mean annual TSI values equal to 35 or less.

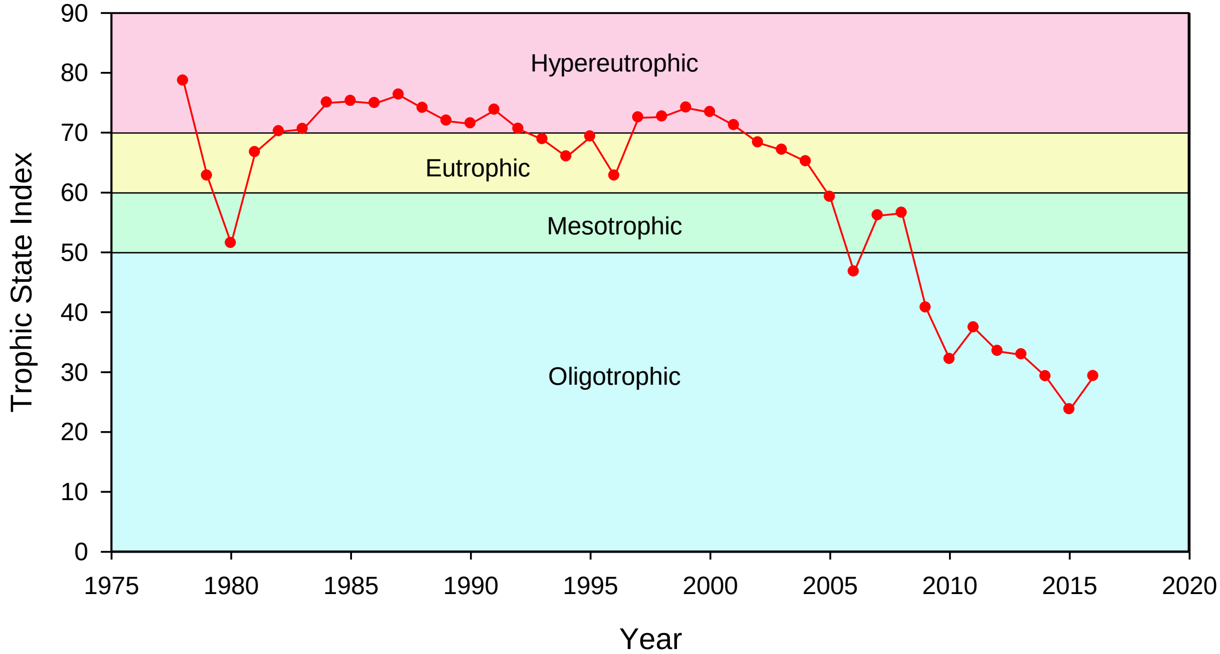


Figure 2-12. Calculated Mean Annual Historical TSI Values in Lake Holden from 1978-2015.

SECTION 3

EVALUATION OF CURRENT RUNOFF CHARACTERISTICS

This section provides a summary and discussion of stormwater monitoring and runoff characterization conducted by ERD in the Lake Holden watershed from December 2014-September 2015 to evaluate the effectiveness of existing BMPs and identify additional sub-basin areas where stormwater treatment may be needed. An overview of site selection, monitoring techniques, and runoff characteristics is given in the following sections. A discussion of drainage basin refinement is also included which addresses small changes to the sub-basin boundaries.

3.1 Watershed Refinement

The most recent formal update to the Lake Holden drainage basin was conducted by ERD during 2004 and summarized in a report titled "Lake Holden Revised Hydrologic/Nutrient Budget and Management Plan". This 2004 delineation included a total of 22 individual sub-basin areas discharging to Lake Holden, with a combined area of 769.2 acres, excluding Sub-basin 15 which is a small 4.5-acre area thought to be land-locked except under extreme flooding conditions.

While reviewing the sub-basin areas to select monitoring sites for this current study, it was decided to make two small modifications to the previous watershed delineation map. The first change involves Sub-basin B-4 which is located on the east side of the lake. The 2004 delineation divided Sub-basin B-4 into two smaller units, identified as Sub-basins B-4A and B-4B. While selecting sites for this current project, ERD field-verified that Sub-basin B-4B and northern portions of Sub-basin B-4A both discharge into the rectangular wet detention pond located on the western boundary of Sub-basin B-4A. This pond is designed to retain all runoff up to a 100-year storm event, and for all practical purposes, is essentially isolated from Lake Holden. These sub-basin areas were combined together into a revised Sub-basin B-4A.

The 2004 sub-basin delineation incorrectly included northern portions of MacArthur Drive as discharging into the large rectangular pond when these residential areas actually discharge runoff to a separate small wet detention pond located east of the northern cul-de-sac on MacArthur Drive. As a result, the residential areas discharging to the small wet detention pond on MacArthur Drive were designated as a revised Sub-basin B-4B.

The second sub-basin modification includes a linear residential area located on the southwest side of Lake Holden between Sub-basins B-11 and B-12. Runoff generated in this area is directed to an existing wet detention pond located on the north end of the residential development. This pond has no known outfall and appears to provide full retention for storm events up to a 100-year event. However, if this pond system were to overflow, the excess water volume would discharge downhill into Lake Holden, and technically, this area would potentially be a part of the Lake Holden watershed under an extreme design storm event. Therefore, this area is now included as a sub-basin area contributing to Lake Holden and is identified as Sub-basin B-11A. However, since this basin is believed to retain virtually all generated runoff, the area is assumed to be a closed basin similar to Sub-basins B-4A and B-15.

The addition of Sub-basin B-11A increases the overall drainage basin area for Lake Holden by approximately 13.4 acres to a total of 788.8 acres. However, if the closed drainage basin areas are removed from the drainage basin, including Sub-basins B-4A, B-11A, and B-15, the overall contributing drainage basin area to Lake Holden is approximately 703.0 acres. An overview of the revised sub-basin map for Lake Holden is given on Figure 3-1.

3.2 Site Selection

The sub-basin delineations indicated on Figure 3-1 were used to identify potential monitoring sites for the field monitoring program. Estimates of annual hydrologic and nutrient loadings discharging from each of the sub-basin areas to Lake Holden were developed by ERD as part of the 2004 report, and this information was also used to identify significant sub-basin areas with respect to annual loadings of total phosphorus.

A summary of annual runoff generated hydrologic and phosphorus loadings to Lake Holden, based on information provided in the 2004 report, is given on Table 3-1. Summary information is provided for each sub-basin area discharging to Lake Holden, including Sub-basin name, area, stormsewer size, annual hydrologic inputs, and annual phosphorus loadings obtained from the 2004 report. For Sub-basin 4, the estimates of basin area, runoff volume, and annual phosphorus loading were updated to reflect the revised sub-basin delineations and areas indicated on Figure 3-1. The estimated annual runoff volume discharging to Lake Holden, based upon information contained in the 2004 report, and assuming that Sub-basins B-4A, B-11A, and B-15 have zero annual inputs, is 964 ac-ft/yr. The annual runoff generated total phosphorus loading to the lake, excluding Sub-basins B-4A, B-11A, and B-15, is approximately 192 kg/yr. The calculated total phosphorus loadings summarized on Table 3-1 are based upon field monitoring of runoff inputs conducted by ERD as part of the 2004 update.

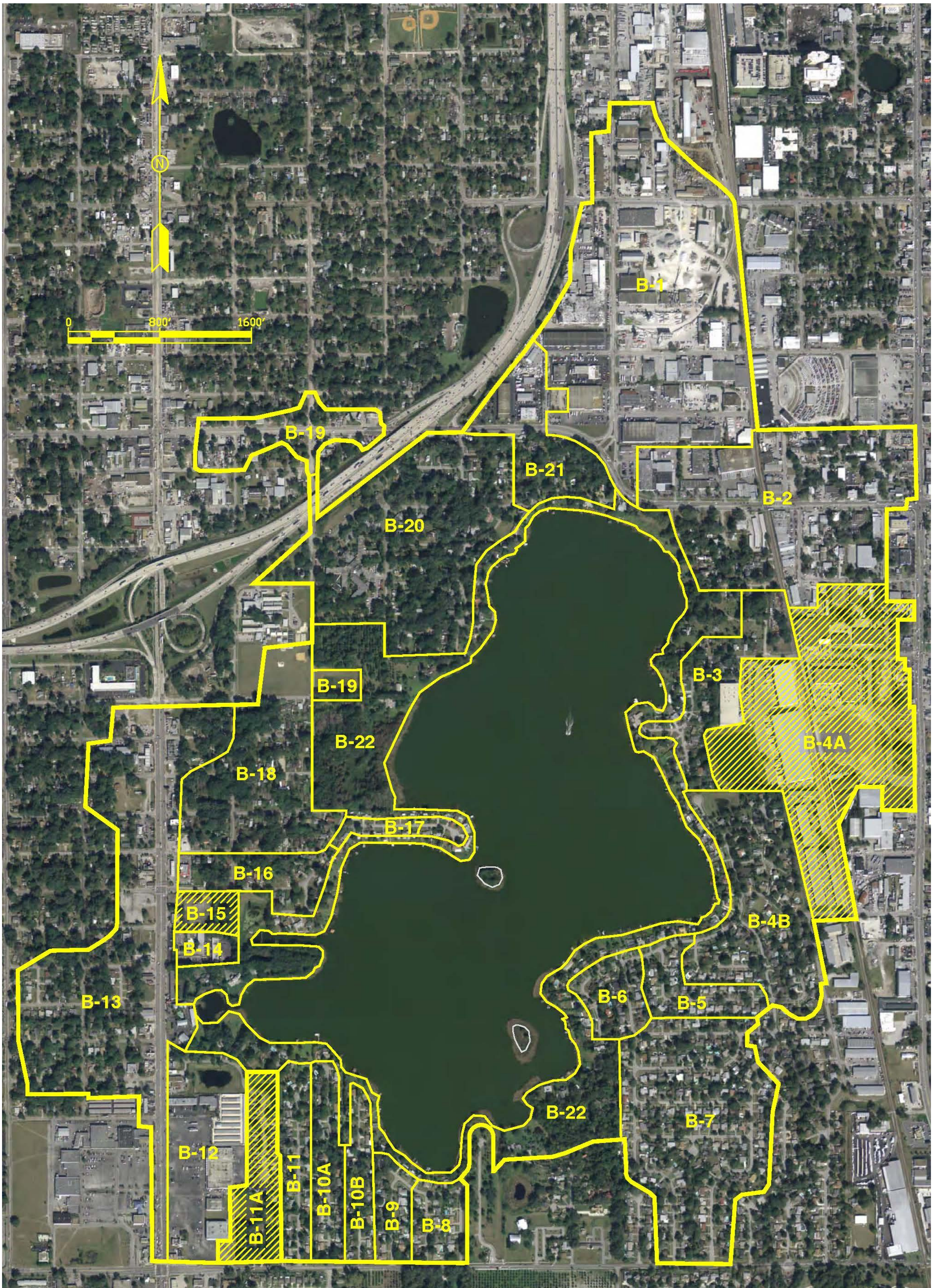


Figure 3-1. Revised Sub-basin Delineation Map for Lake Holden.

3-2

TABLE 3-1

SUMMARY OF ANNUAL HYDROLOGIC AND PHOSPHORUS LOADINGS AND SUB-BASINS SELECTED FOR STORMWATER MONITORING (Data Source: 2004 ERD Report)

SUB-BASIN NO.	BASIN AREA (acres)	BASIN NAME	STORM-SEWER	RUNOFF (ac-ft/yr)	TOTAL PHOSPHORUS LOADING (kg/yr)	BASINS RECOMMENDED FOR STORMWATER MONITORING / REASON
B-1	98.9	Division Ave.	54" RCP	261	95.1	Verify alum treatment performance
B-2	65.7	Lake Holden Terrace	48" x 76" RCP	134	8.9	Verify alum treatment performance
B-3	19.7	Pineloch Ave.	18" RCP	14.0	3.0	
B-4A	67.9	Orange Ave.-Comm/Ind..	36" RCP	0	0	All runoff retained in wet pond
B-4B	35.9	MacArthur Dr.	24" RCP	25.9	4.8	Verify FDOT pond performance for possible pond enhancement
B-5	10.4	MacArthur Dr.	24" RCP	9.8	2.2	
B-6	8.8	DeKalb Dr.	2 - 18" RCP	7.4	1.7	
B-7	52.9	Kreuger St.	48" RCP	51.0	11.4	Large untreated basin - verify runoff characteristics for possible retrofit recommendations
B-8	7.8	Holden Ave.	canal	7.0	1.6	
B-9	6.8	Springwood Dr.	24" RCP	6.6	1.5	
B-10A	10.9	South Shore Rd.	Drainage canal	11.2	2.5	
B-10B	8.0	Raymar Dr.		8.1	1.8	
B-11	10.8	Almark Dr.	24" RCP	11.2	2.5	
B-11A	13.4	--	none	0	0	All runoff retained in wet pond
B-12	26.3	OBT Shopping center	48" RCP	66.4	3.0	Large commercial basin - verify pond performance
B-13	81.5	U.S. 441 - FDOT Pond	60" RCP	135	9.8	Verify FDOT pond performance for possible pond enhancement
B-14	3.6	Old Days Inn Hotel	30" RCP	7.7	1.4	
B-15	4.5	Land Locked basin	none	0	0	
B-16	12.1	38th St.	18" RCP	12.3	2.7	
B-17	4.4	37th St.	18" RCP	5.6	1.3	
B-18	35.9	Westmoreland Dr.	overland flow	32.5	7.1	
B-19	16.8	Westmoreland Dr.	36" RCP from detention pond	22.6	2.9	Large residential basin - verify pond performance
B-20	60.9	33rd St.	36" RCP	64.0	13.9	Large untreated basin - verify runoff characteristics for possible retrofit recommendations
B-21	19.4	Paseo St.	42" RCP	35.2	4.4	Verify alum treatment performance
B-22	105.5	Lake perimeter	overland flow	27.6	10.2	
TOTAL:	**788.8**	--	--	**964**	**192**	--

Closed basin areas — Sub-basins selected for field monitoring

The information summarized on Table 3-1 was used to select monitoring sites for the current project, and sub-basins selected for monitoring are highlighted in **blue**. Sub-basins B-1, B-2, and B-21 currently receive alum stormwater treatment, and monitoring sites were selected for each of these three sub-basin areas to evaluate the effectiveness of the current injection system. Sub-basin B-4B (consisting of northern portions of MacArthur Drive) was also included in the field monitoring program to evaluate the performance of the existing wet detention pond. Sub-basins B-12 and B-13 also receive treatment in wet ponds prior to discharge to Lake Holden, and monitoring was also conducted at the pond outfalls for these sub-basins to verify the performance efficiency of each pond. Sub-basin B-19 receives treatment in a dry detention pond with underdrain filter which has been monitored by ERD on several previous occasions which indicated that discharge concentrations from this pond substantially exceed input concentrations. Additional monitoring was conducted at Sub-basin B-19 as part of this current project to verify this conclusion for possible retrofit recommendations. Sub-basins B-7 and B-20 consist of relatively large basin areas which are currently untreated, and runoff monitoring was conducted to evaluate the need and feasibility for potential retrofit projects in these areas.

Locations of runoff monitoring sites in the Lake Holden watershed are illustrated on Figure 3-2. A discussion of monitoring sites and techniques for each of the selected sites is given in the following sections.

3.2.1 Sub-basins B-1, B-2, and B-21

An overview of monitoring sites for sub-basin areas with alum stormwater treatment is given on Figure 3-3. Stormwater monitoring was conducted in each of the three sub-basins (B-1, B-2, and B-21) inside manhole structures located downstream of the point of alum addition. Stormwater monitoring at each site was conducted using an ISCO Model 3712 autosampler equipped with an integral area velocity flow meter to provide measurements of discharge rates through the stormsewer system and to collect runoff samples in a flow-weighted composite mode. The collected composite runoff samples from each site were retrieved following significant rain events and returned to the ERD Laboratory for chemical analyses. Since samples collected at these locations reflected alum treated runoff, floc within the collected samples was allowed to settle in the ERD Laboratory for approximately 24 hours to separate the alum treated runoff from the generated floc. The clear supernatant was decanted and submitted for laboratory analyses.

An overview of the runoff monitoring location for Sub-basin B-1 is given on Figure 3-4. Field monitoring was conducted inside the manhole structure where alum is added to the stormwater flow. The autosampler was suspended within the manhole to protect the equipment from vandalism. The 60-inch RCP which discharges from the Division Street sub-basin is surcharged up into the manhole structure which allows trash and debris to accumulate within the riser structure.

Photographs of the runoff monitoring location for Sub-basin B-2 are provided on Figure 3-5. This site is also located downstream from the point of alum addition, and the alum treated runoff samples were allowed to settle in the ERD Laboratory for approximately 24 hours to separate the treated runoff from the generated floc. The 48-inch x 76-inch ERCP at this location was also surcharged, allowing trash and debris to accumulate within the manhole riser.

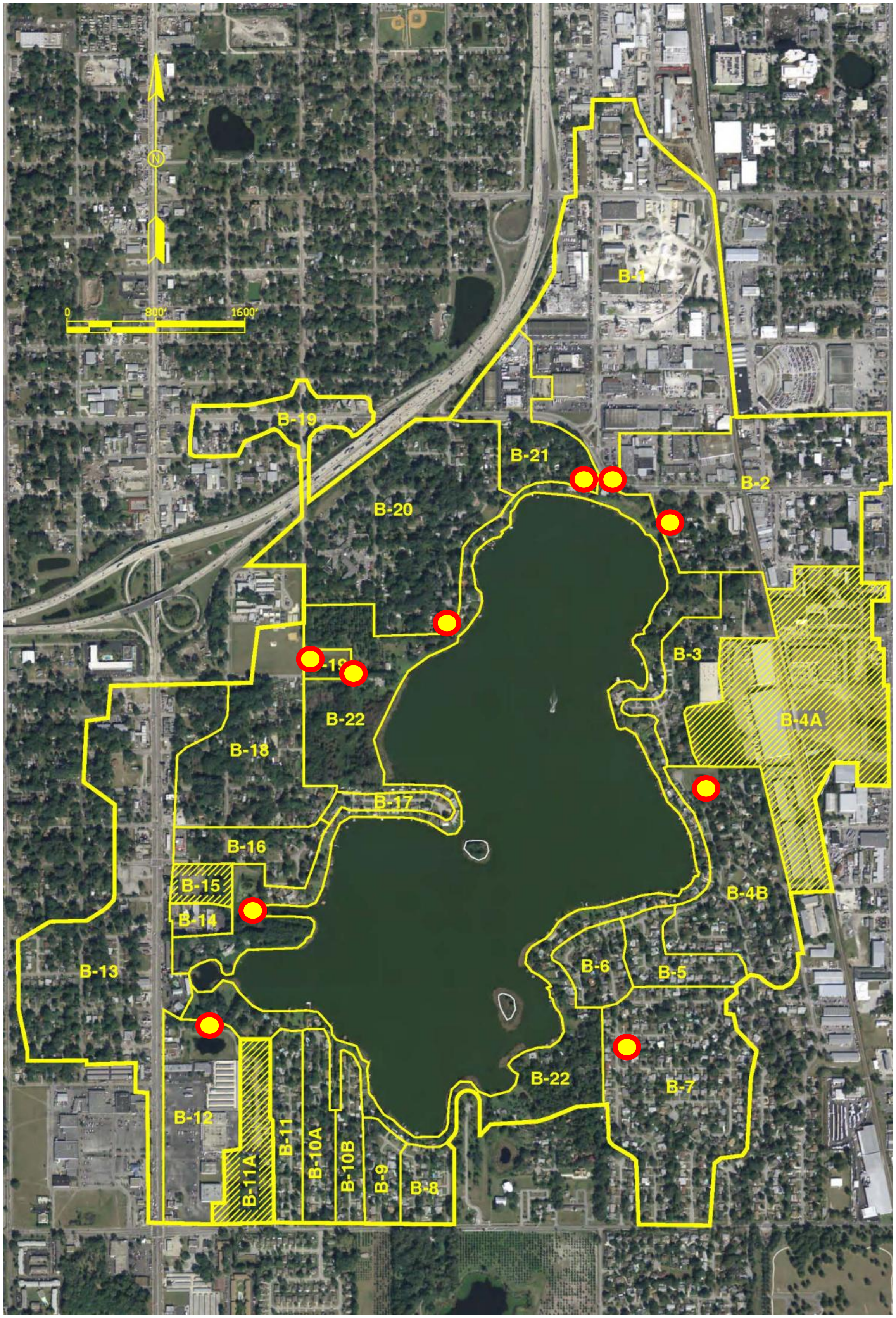


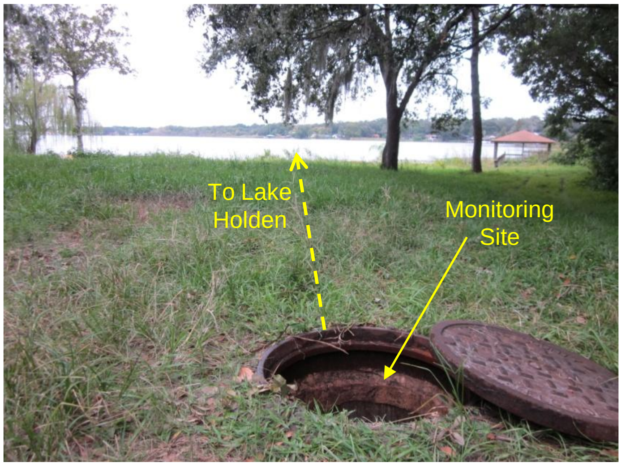
Figure 3-2. Locations of Runoff Monitoring Sites in the Lake Holden Watershed.

Figure 3-3. Overview of the Drainage System and Monitoring Sites for Alum Treated Sub-basins B-1, B-2, and B-21.

Manhole access location used for stormwater monitoring

Collected debris inside manhole

Figure 3-4. Runoff Monitoring Location for Sub-basin B-1 (Division Street).



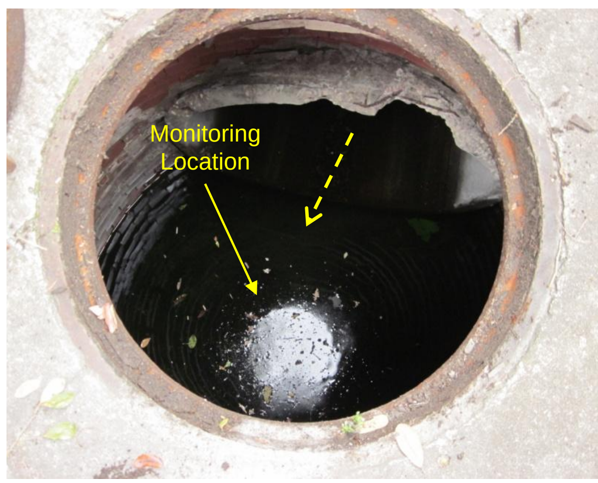
Manhole access location used for stormwater monitoring

Collected debris inside manhole

Figure 3-5. Runoff Monitoring Location for Sub-basin B-2 (Michigan Street).

An overview of the runoff monitoring location for Sub-basin B-21 is given on Figure 3-6. The monitoring site was located inside a manhole located in a private driveway which is the final point of access into the stormsewer system prior to discharging into Lake Holden. The autosampler at this location was installed inside the manhole structure and suspended using a stainless steel harness. The runoff samples collected at this site were also allowed to settle for approximately 24 hours in the ERD Laboratory to separate the treated runoff from the generated floc.

Manhole access location used for stormwater monitoring



Monitoring location inside manhole

Figure 3-6. Runoff Monitoring Location for Sub-basin B-21 (Paseo Street).

3.2.2 Sub-basin B-4B

An overview of the runoff drainage system for Sub-basin B-4B is given on Figure 3-7. Runoff generated within the residential community along MacArthur Drive and connecting roadways is collected in an underground stormsewer system and discharged into a small wet detention pond located east of the cul-de-sac at the north end of MacArthur Drive. Runoff monitoring at this site was conducted at the outfall for the wet detention pond to reflect the characteristics of discharges which actually enter Lake Holden.

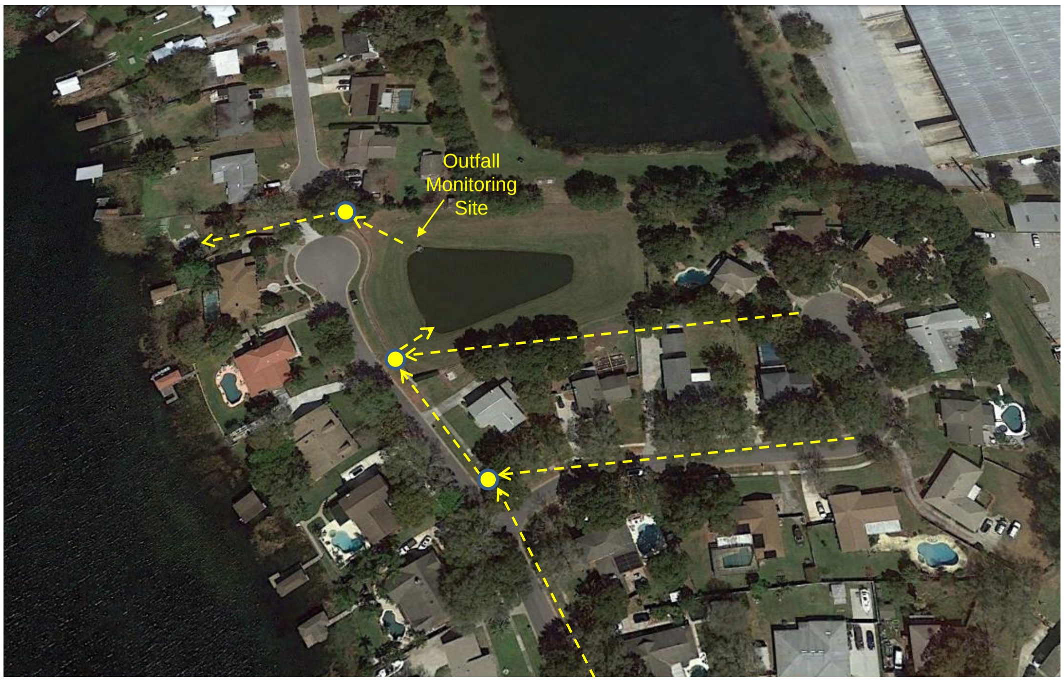


Figure 3-7. Overview of Runoff Drainage Patterns for Sub-basin B-4B (MacArthur Drive).

An overview of the runoff monitoring location and equipment for Sub-basin B-4B is given on Figure 3-8. Monitoring was conducted on the downstream side of the pond outfall structure to reflect the characteristics of water discharging from the pond to Lake Holden. An ISCO Model 3712 composite autosampler was installed inside an insulated aluminum equipment shelter and programmed to collect composite outflow samples in a flow weighted mode. Discharge measurements were conducted using the depth of water above the circular outfall orifice.

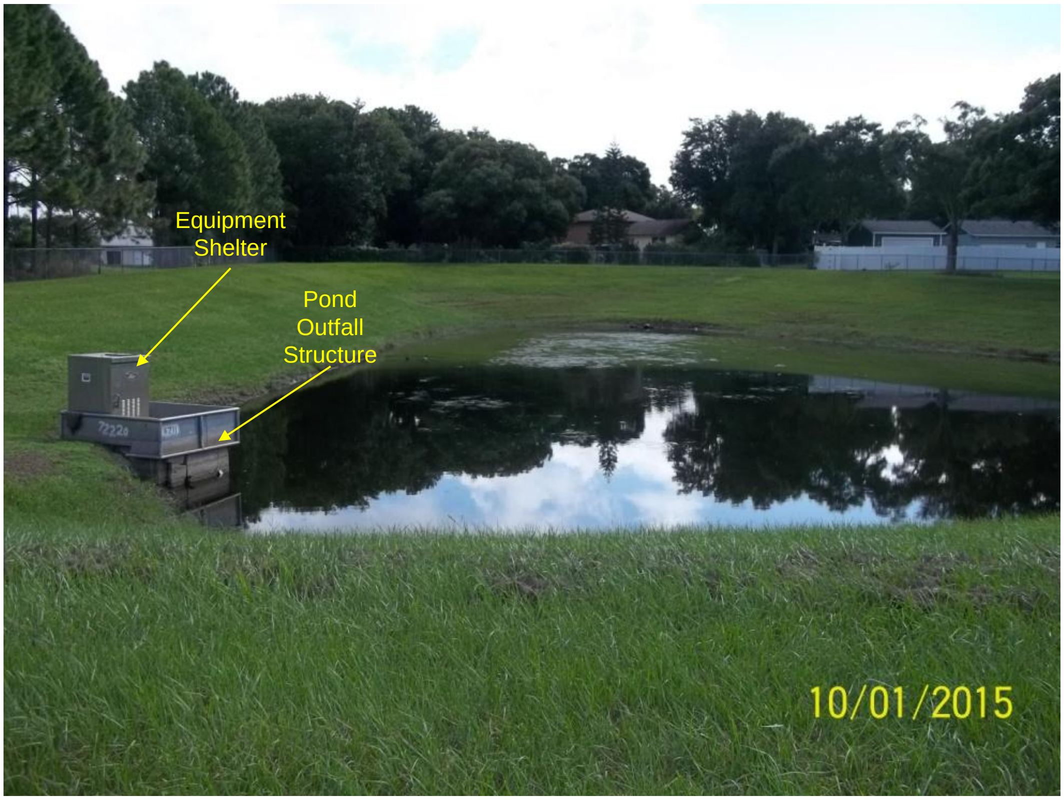


Figure 3-8. Runoff Monitoring Location and Equipment for Sub-basin B-4B (MacArthur Drive).

3.2.3 Sub-basin B-7

An overview of runoff drainage patterns for Sub-basin B-7 is given on Figure 3-9. This monitoring location is generally referred to as the Krueger Street sub-basin since runoff generated within the sub-basin area converges on the west end of Krueger Street. Runoff generated along Krueger Street, Doolittle Street, and Brandeis Avenue all enter the manhole structure indicated as the monitoring site on Figure 3-9. The combined inflows then travel through an underground stormsewer system and ultimately discharge into Lake Holden.

An overview of the monitoring location for Sub-basin B-7 is given on Figure 3-10. The location selected for the monitoring site consists of a manhole structure where flows generated along Krueger Street, Doolittle Street, and Brandeis Avenue combine together prior to discharge to Lake Holden. Runoff monitoring was conducted at this site using an ISCO Model 3712 composite autosampler with an integral area velocity flow probe to provide measurements of discharge rates through the stormsewer system and allow collection of runoff samples on a composite flow-weighted mode. Photographs of the manhole monitoring site for Sub-basin B-7 are given on Figure 3-11. The manhole consists of a deep structure with the stormsewer pipe located approximately 10 ft below the ground surface. This site maintained a constant baseflow throughout the field monitoring program.

Figure 3-9. Overview of Runoff Drainage Patterns for Sub-basin B-7 (Krueger Street).

Figure 3-10. Overview of the Monitoring Location for Sub-basin B-7 (Krueger Street).

Krueger Street site with manhole cover removed

Photo inside manhole

Figure 3-11. Photos of the Manhole Monitoring Site for Sub-basin B-7 (Krueger Street).

3.2.4 Sub-basin B-12

An overview of drainage patterns in the vicinity of Sub-basin B-12 (43rd Street) is given on Figure 3-12. Monitoring at this site was conducted at the discharge from an existing wet detention pond which provides stormwater treatment for runoff generated in the commercial/ industrial area located south of the pond. Discharges from the pond travel through an underground stormsewer system and ultimately discharge into the southwest lobe of Lake Holden.

An overview of the runoff monitoring site for Sub-basin B-12 is given on Figure 3-13. Due to security concerns, runoff monitoring was conducted at this site using manual collection methods following significant storm events. Multiple samples of discharges from the pond were collected over a 2- to 3-hour period following rain events to form a composite discharge sample for laboratory analyses.

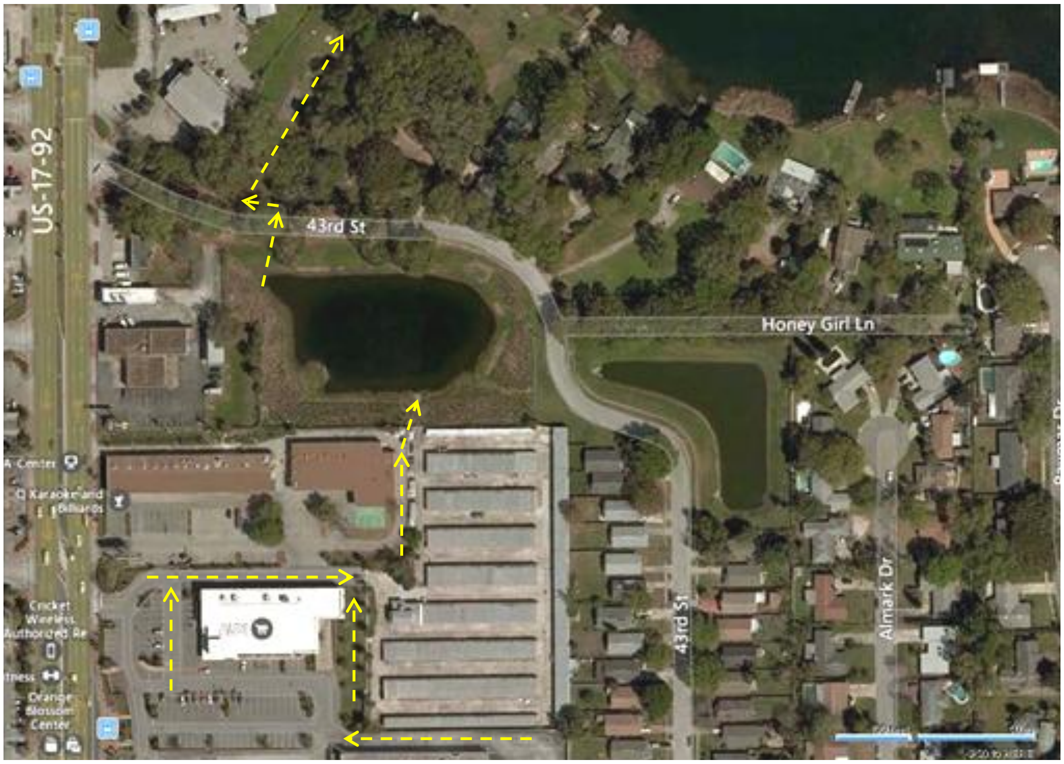


Figure 3-12. Drainage Patterns in the Vicinity of Sub-basin B-12 (43rd Street).

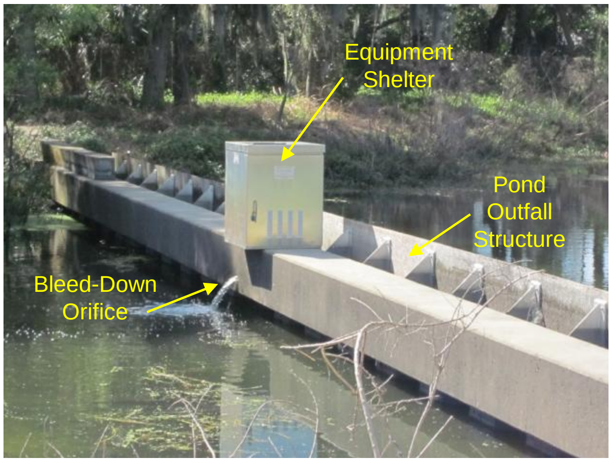
Figure 3-13. Overview of Runoff Monitoring Site for Sub-basin B-12 (43rd Street).

3.2.5 Sub-basin B-13

An overview of drainage patterns in the vicinity of Sub-basin B-13, commonly referred to as the FDOT Pond Basin, is given on Figure 3-14. With an area of 81.5 acres, this sub-basin is one of the larger individual basins discharging to Lake Holden. Runoff is generated in this area from portions of US 441 along with residential areas both west and east of the FDOT roadway. The combined runoff inflows discharge into a small wet detention pond which is substantially undersized for the area of runoff which it receives. After a relatively short residence time within the pond, the runoff discharges through an outfall structure and into a canal on the west side of Lake Holden.

Figure 3-14. Drainage Patterns in the Vicinity of Sub-basin B-13 (FDOT Pond).

Photographs of monitoring equipment used at the Sub-basin B-13 site are provided on Figure 3-15. Sample collection at this site was conducted using a Sigma Model 850 composite autosampler with an integral pressure transducer flow probe which provides measurements of discharge based upon height above the circular bleed-down orifice. The autosampler was programmed to collect discharges from the pond in a flow-weighted composite mode.



Pond outfall structure with equipment shelter

Autosampler used to collect outflow samples

Sample tubing and flow meter cables

Figure 3-15.

Photographs of Monitoring Equipment Used at the Sub-basin B-13 Site (FDOT Pond).

3.2.6 Sub-basin B-19

An overview of drainage patterns in the vicinity of Sub-basin B-19, commonly referred to as the Westmoreland Drive sub-basin, is given on Figure 3-16. Most of the actual sub-basin area for Sub-basin B-19 is located north of the photograph and includes portions of Michigan Street and Westmoreland Drive to the intersection with I-4. Runoff generated in this area is piped through an underground 24-inch RCP stormsewer into a dry detention pond at the location indicated on Figure 3-16. The dry detention pond is equipped with a perimeter underdrain system which provides filtration for the runoff inflows prior to reaching the outfall structure and discharge into Lake Holden.

Figure 3-16. Overview of Drainage Patterns in the Vicinity of Sub-basin B-19 (Westmoreland Drive).

An overview of drainage details for the Sub-basin B-19 pond is given on Figure 3-17. The water enters the pond through a 42-inch RCP stormsewer. The 6-inch perforated underdrain piping is located approximately one foot below the pond bottom and intercepts runoff inflows as well as local groundwater, carrying both to the point of discharge into the outfall structure. ERD has monitored this system on multiple previous occasions and has determined that the nutrient concentrations in discharges from the underdrain system substantially exceed the nutrient concentrations in the incoming runoff. Monitoring conducted at this site during this current project was performed to verify the concentration enhancement within the pond to evaluate possible retrofit recommendations.

Photographs of the inflow and outflow structures for the Sub-basin B-19 pond are given on Figure 3-18. Monitoring of inflows at this site were conducted using an ISCO Model 3712 autosampler equipped with a pressure transducer probe which converted measurements of water level above an installed rectangular horizontal weir into runoff discharge rates. The autosampler at this site was programmed to collect composite inflow samples on a flow-weighted basis. A similar equipment shelter was also installed on top of the pond outfall structure, with sample tubing and flow probe extended into downstream portions of the discharge pipe. The flow monitor provided a continuous record of discharge from the pond through both the underdrain and stormsewer system, with composite samples collected in a flow-proportioned mode.

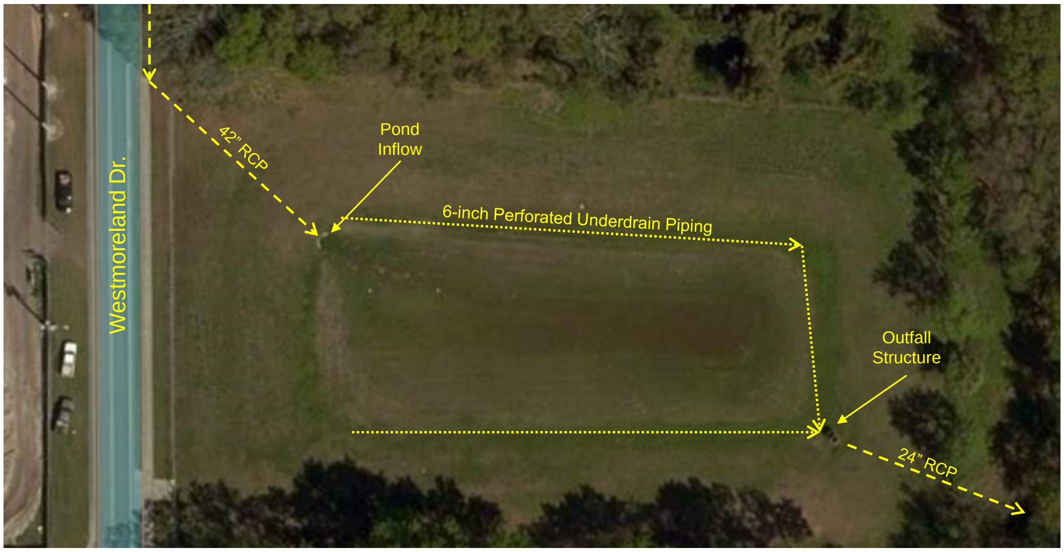
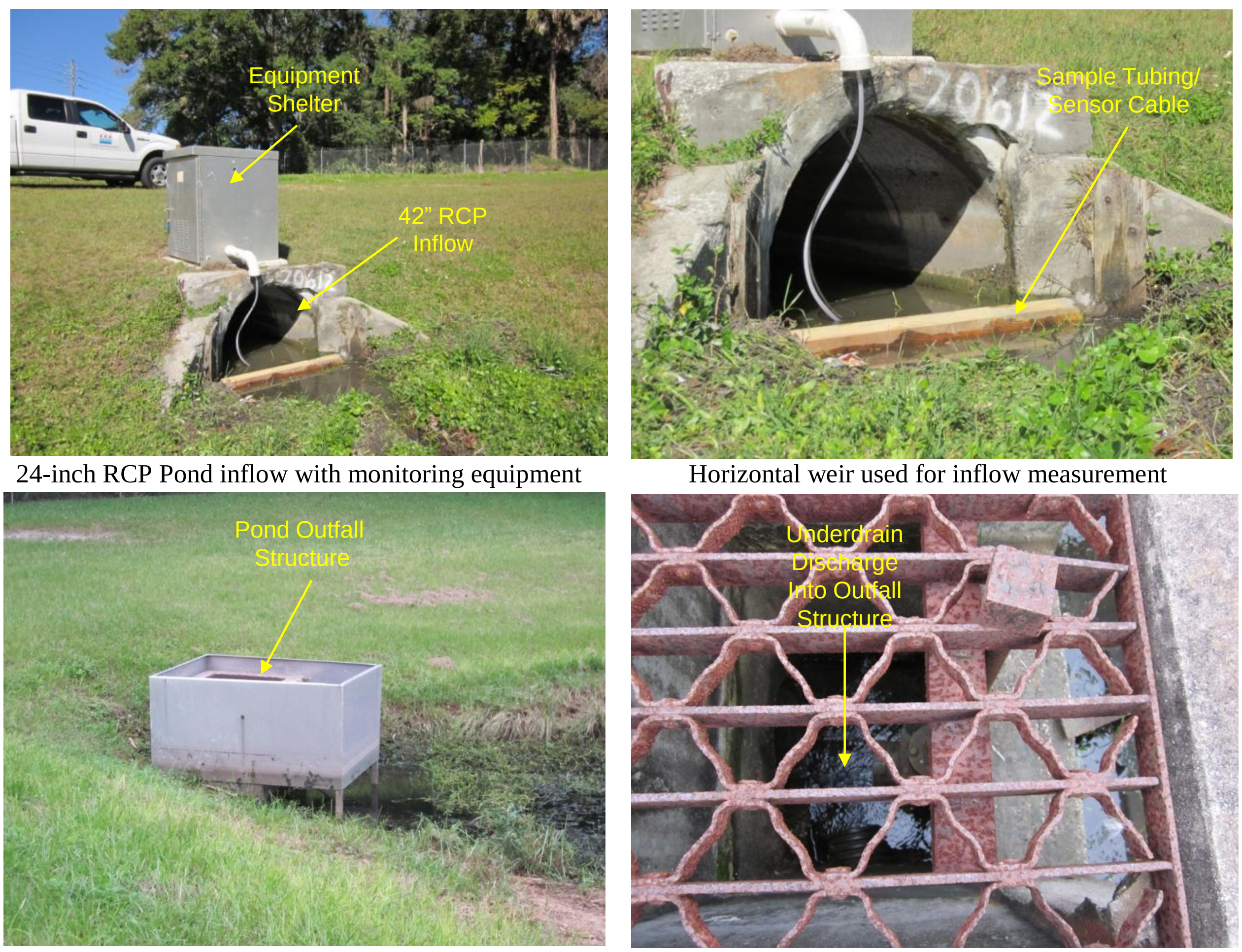


Figure 3-17. Drainage Details for the Sub-basin B-19 Pond (Westmoreland Drive).



24-inch RCP Pond inflow with monitoring equipment

Horizontal weir used for inflow measurement

Pond outflow structure

Underdrain discharge entering outflow structure

Figure 3-18. Photographs of the Inflow and Outflow Structure for the Sub-basin B-19 Pond.

3.2.7 Sub-basin B-20

An overview of general drainage patterns in the vicinity of Sub-basin B-20 is given on Figure 3-19. Runoff within this sub-basin is generated from a 60.9-acre area which consists of a combination of underground stormsewers, overland flow, and grassed swale channels. The generated runoff converges at the intersection of Alamo Drive and 33rd Street and enters a 36-inch RCP which discharges to Lake Holden. There are no significant stormwater treatment facilities located within this sub-basin.

Figure 3-19. General Drainage Patterns in the Vicinity of Sub-basin B-20 (33rd Street).

An overview of the monitoring location for Sub-basin B-20 is given on Figure 3-20. Runoff generated along Alamo Drive and 33rd Street travels primarily by overland flow and enters a cast iron grate inlet at the location indicated on Figure 3-20. An insulated aluminum equipment shelter was installed on top of the grate inlet, and an ISCO Model 3712 autosampler with integral area-velocity flow probe was used to measured runoff discharges into the inlet structure and collect composite runoff samples in a flow-proportioned mode. This inlet frequently became clogged with vegetation which required removal on a routine basis during the field monitoring program.

Figure 3-20. Overview of the Monitoring Location for Sub-basin B-20.

3.3 Field and Laboratory Methods

3.3.1 Field Monitoring

Field monitoring of runoff characteristics was conducted by ERD from December 2014-September 2015 to characterize runoff inputs into Lake Holden. Runoff monitoring was conducted at each of the 10 sites indicated on Figure 3-2. A summary of the number of runoff samples collected at the Lake Holden watershed monitoring sites from December 2014-September 2015 is given on Table 3-2. The scope of services for this project required that a total of 50 separate runoff samples be collected during the field monitoring program, with an average of 5 samples per site. However, ERD collected 6-11 composite samples per site, with a total of 77 composite samples collected during the monitoring program. Each of the composite runoff samples was analyzed for general parameters and nutrients.

3.3.2 Laboratory Analyses

A summary of laboratory methods and MDLs for analyses conducted on runoff samples collected during this project is given in Table 3-3. All laboratory analyses were conducted in the ERD Laboratory which is NELAC-certified (No. 1031026) for general parameters, nutrients, metals, and microbiological parameters. Details on field operations, laboratory procedures, and quality assurance methodologies are provided in the FDEP-approved Comprehensive Quality Assurance Plan for Environmental Research & Design, Inc. All results provided in this report comply with the requirements and/or specifications of the NELAC standard and test methods. The results presented in this report relate only to the runoff samples collected at the Lake Holden monitoring sites during the referenced time periods.

TABLE 3-2

SUMMARY OF RUNOFF SAMPLES COLLECTED AT THE LAKE HOLDEN WATERSHED MONITORING SITES FROM DECEMBER 2014 – SEPTEMBER 2015

SUB-BASIN NO.	DESCRIPTION	NUMBER OF SAMPLES COLLECTED
B-1	Division Street	7
B-2	Lake Holden Terrace	9
B-4B	MacArthur Street Pond Outfall	8
B-7	Krueger Street	7
B-12	43rd Street Pond Outfall	8
B-13	FDOT Pond Outfall	6
B-19	Westmoreland Pond Inflow Westmoreland Pond Outflow	8 6
B-20	33rd Street	7
B-21	Paseo Drive	11
	TOTAL:	**77**

TABLE 3-3

ANALYTICAL METHODS AND DETECTION LIMITS FOR LABORATORY ANALYSES CONDUCTED BY ENVIRONMENTAL RESEARCH & DESIGN, INC.

MEASUREMENT PARAMETER		METHOD[1]	METHOD DETECTION LIMITS (MDLs)[2]
General Parameters	Hydrogen Ion (pH)	SM-21, Sec. 4500-H^+ B	N/A
	Alkalinity	SM-21, Sec. 2320 B	0.5 mg/l
	TSS	SM-21, Sec. 2540 D	0.7 mg/l
	Color	SM-21, Sec. 2120 C	1 Pt-Co Unit
	Specific Conductivity	SM-21, Sec. 2510 B	0.2 μmho/cm
	Turbidity	SM-21, Sec. 2130 B	0.3 NTU
Nutrients	Ammonia-N (NH_3-N)	SM-21, Sec. 4500-NH3 G	0.005 mg/l
	Nitrate + Nitrite (NO_x-N)	SM-21, Sec. 4500-NO3 F	0.005 mg/l
	Total Nitrogen	SM-21, Sec. 4500-N C	0.025 mg/l
	Orthophosphorus	SM-21, Sec. 4500-P F	0.001 mg/l
	Total Phosphorus	SM-21, Sec. 4500-P B.5	0.001 mg/l

1. Standard Methods for the Examination of Water and Wastewater, 21st Ed., 2005.
2. MDLs are calculated based on the EPA method of determining detection limits.

3.4 Runoff Characteristics

A complete listing of the chemical characteristics of composite runoff samples collected in the Lake Holden drainage basin from December 2014-September 2015 is given in Appendix B. Laboratory data are provided for each of the 77 composite samples for each of the evaluated water quality parameters.

3.4.1 Comparison Between Sites

A statistical comparison of measured values for pH, alkalinity, TSS, and color in Lake Holden runoff samples collected from December 2014-September 2015 at each of the 10 monitoring locations is given on Figure 3-21. A graphical summary of the laboratory data 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 falling below this value. The upper line of the box represents the 75% upper quartile, with 25% of the data falling above this value. The **blue** horizontal line within the box represents the median value, with 50% of the data falling both above and below this value. The **red** horizontal line within the box represents the mean of the data points. The vertical lines, also known as "whiskers", represent the 5 and 95 percentiles for the data sets. Individual values which fall outside of the 5-95 percentile range, sometimes referred to as "outliers", are indicated as **red dots**.

The vast majority of composite runoff samples had pH values ranging from approximately 6.5-7.5 units. The non-alum treated sub-basins exhibited measured pH values which were relatively similar between the monitoring sites. However, measured pH values in the alum treated sub-basins (B-1, B-2, and B-21) exhibited a higher degree of variability, with alum treated pH values ranging from approximately 4-7 units.

Measured alkalinity values were highly variable between the 10 monitoring sites. Measured alkalinity values at the non-alum treated sites ranged from approximately 20-70 mg/l, with a higher degree of variability and a higher range of measured values observed at the three alum treated sub-basin sites (B-1, B-2, and B-21).

Measured TSS values at the runoff monitoring sites were generally low in value, particularly in comparison with TSS values commonly observed in urban and residential watersheds. The lower observed TSS concentrations observed in runoff samples collected from the Lake Holden watershed may be a reflection of the frequent street sweeping activities which occur within the overall drainage basin area. It is interesting to note that some of the highest measured TSS concentrations were observed in the discharge from the dry detention pond associated with Sub-basin B-19 which, theoretically, represents runoff filtered through core sand media.

Measured color values in runoff samples collected from the Lake Holden watershed were generally low in value, with the majority of measurements less than approximately 30 Pt-Co units. A relatively high degree of variability was observed in color values in Sub-basins B-2 and B-21, with a relatively high degree of variability in color measurements also observed at the inflow to the Sub-basin B-19 dry detention pond.

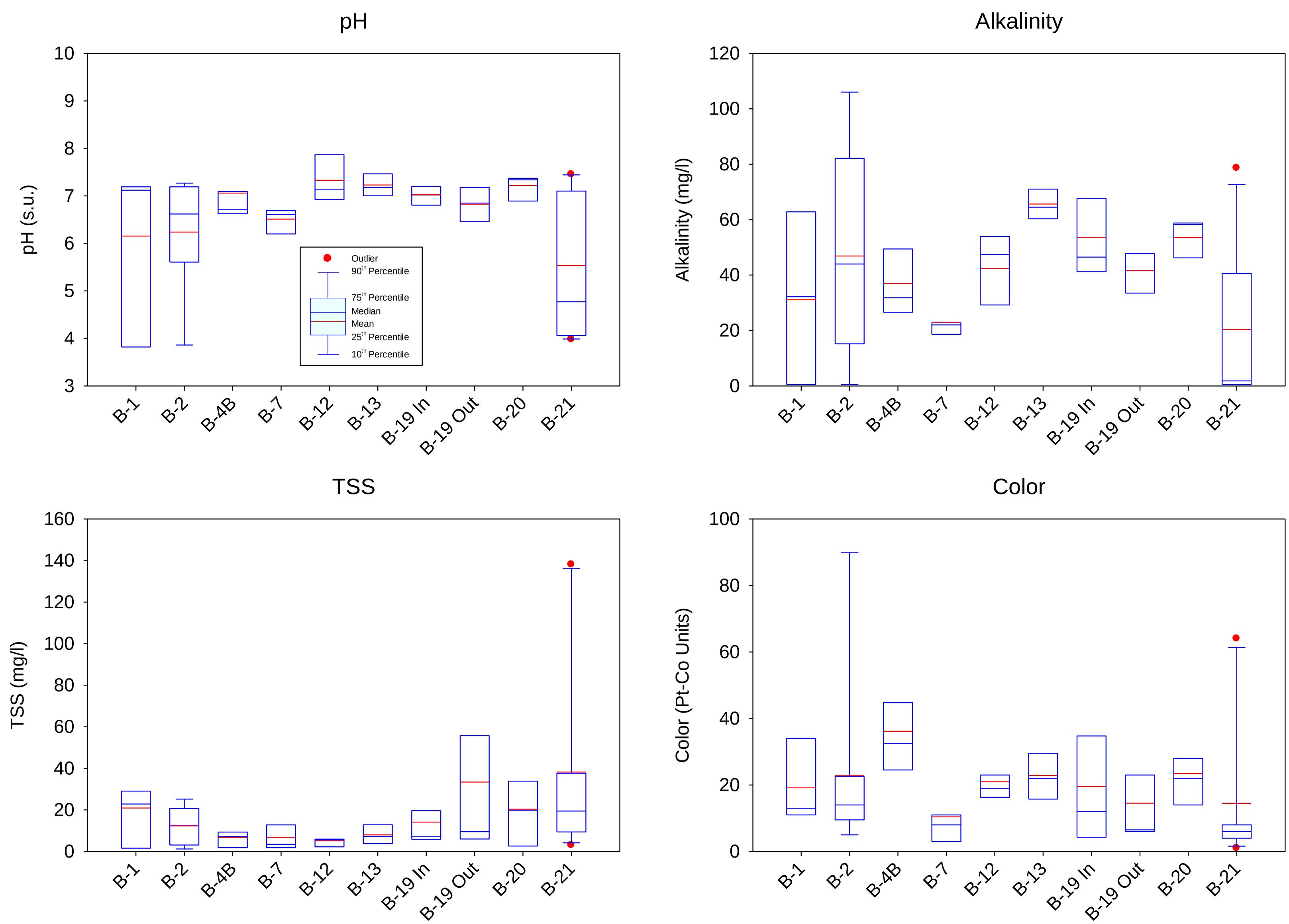


Figure 3-21. Comparison of Measured Values for pH, Alkalinity, TSS, and Color in Lake Holden Runoff Samples Collected from December 2014-September 2015.

A graphical comparison of measured concentrations of nitrogen species in Lake Holden runoff samples collected from December 2014-September 2015 is given on Figure 3-22. In general, measured concentrations of ammonia were relatively low in value at a majority of the monitoring sites, with most measurements less than 100 μg/l. However, substantially more elevated concentrations of ammonia were observed in runoff samples collected from Sub-basin B-4B (MacArthur Drive pond) and discharges from Sub-basin B-13 (FDOT pond) where measured ammonia concentrations were substantially greater than values measured at the remaining sites. The largest concentrations of ammonia by far were observed in discharges from the MacArthur Street pond, presumably due to decomposition of organic matter which had accumulated within the pond.

Measured concentrations of NO_x were low in value at 8 of the 10 monitoring locations, with a slightly more elevated concentration observed in Sub-basin B-21. However, substantially more elevated levels of NO_x were observed in discharges from Sub-basin B-7 (Krueger Street), with measured concentrations generally ranging from 5000-9500 μg/l. Elevated levels of NO_x were also observed in this sub-basin during runoff monitoring collected as part of the 2004 ERD report, and it appears that chronic levels of NO_x have been discharging from Sub-basin B-7 for many years.

A relatively high degree of variability was observed in measured concentrations of particulate nitrogen in runoff samples collected from the Lake Holden watershed. The most elevated levels of particulate nitrogen were observed in discharges from Sub-basin B-4B (MacArthur Street pond) where measured values ranged from approximately 400-800 μg/l. Particulate nitrogen concentrations at the remaining sites were generally less than 500 μg/l during most events, with concentrations less than 100-200 g/l observed in runoff collected from Sub-basins B-1 and B-7.

Overall, measured concentrations of total nitrogen were generally moderate in value, with a low degree of variability between the individual monitoring sites. The only exception to this is Sub-basin B-7 (Krueger Street) where total nitrogen concentrations were substantially elevated due to the presence of large amounts of NO_x. The measured concentrations of total nitrogen in Sub-basin B-7 were an order of magnitude greater than total nitrogen concentrations measured at many of the remaining watershed sites.

A statistical comparison of measured concentrations of phosphorus species in Lake Holden runoff samples collected from December 2014-September 2015 is given in Figure 3-23. In general, measured concentrations of SRP were low in value at many of the Lake Holden monitoring sites, particularly sites receiving alum treatment. The vast majority of measured SRP values were less than 50 μg/l, with the exceptions of Sub-basins B-2, B-4B, B-19 pond outflow, and B-20, where more elevated concentrations were observed at times.

In general, measured concentrations of dissolved organic phosphorus were low in value, with the majority of measurements less than 40 μg/l. However, more elevated concentrations were observed in discharges from Sub-basins B-2 and B-4B, although the overall observed concentrations were low to moderate in value.

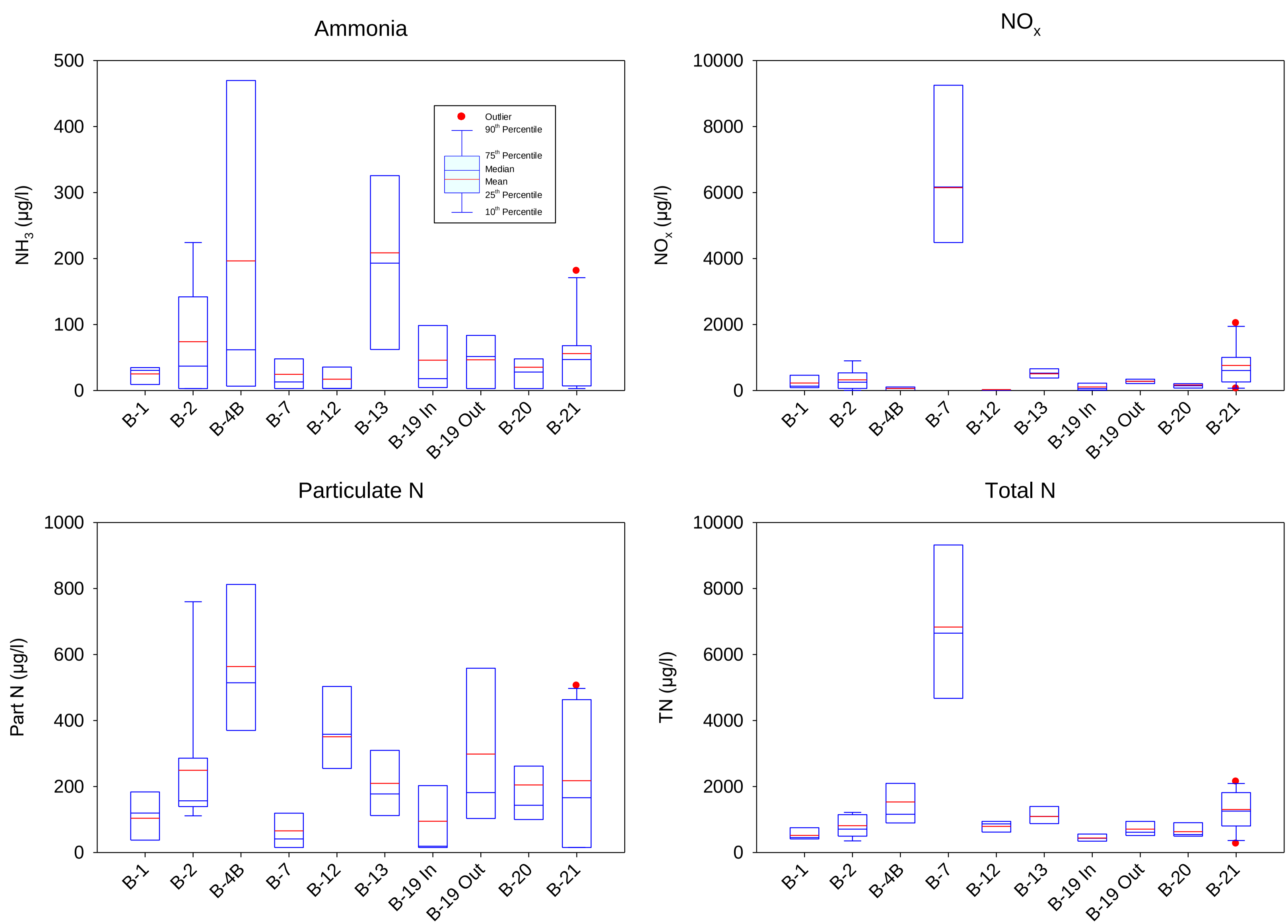


Figure 3-22. Comparison of Measured Concentrations of Nitrogen Species in Lake Holden Runoff Samples Collected from December 2014-September 2015.

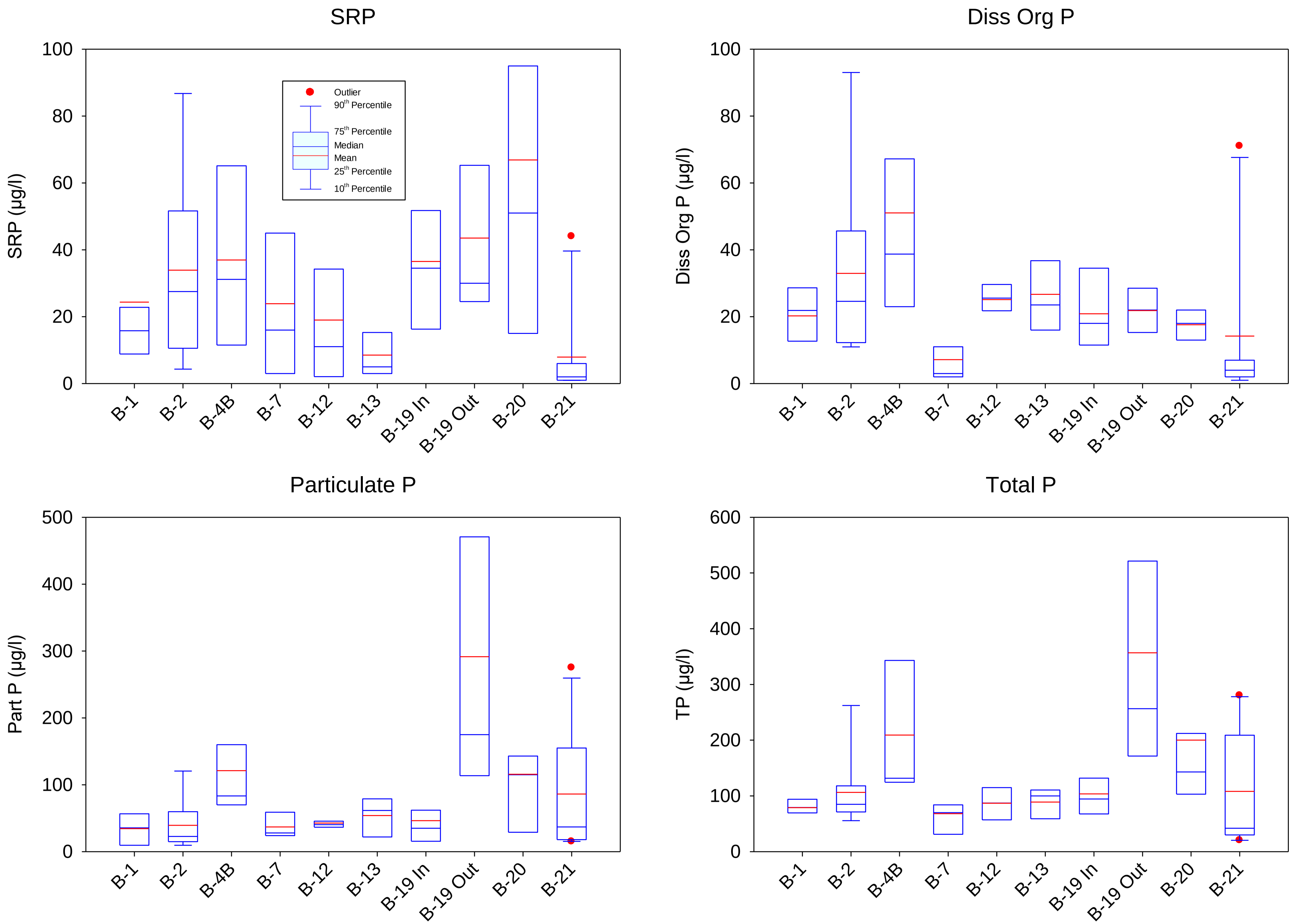


Figure 3-23. Comparison of Measured Concentrations of Phosphorus Species in Lake Holden Runoff Samples Collected from December 2014-September 2015.

Highly variable concentrations of particulate phosphorus were observed at the Lake Holden monitoring sites, with measured concentrations at 6 of the 10 sites generally less than 50 μg/l. More elevated levels of particulate phosphorus were observed in discharges from Sub-basins B-4, B-20, and B-21, with the most elevated values of particulate phosphorus observed in discharges from the Sub-basin B-19 pond. It is interesting to note that the highest concentrations of particulate phosphorus were observed in discharges from an infiltration system specifically designed to remove particulate matter from runoff.

Overall, measured concentrations of total phosphorus in runoff entering Lake Holden was generally low in value at 6 of the 10 monitoring sites, with concentrations 50% or less than runoff concentrations commonly observed in urban and residential areas. However, more elevated concentrations of total phosphorus were observed in discharges from the Sub-basin B-4B pond, the Sub-basin B-19 pond, Sub-basin B-20, and Sub-basin B-21. The observed elevated values for total phosphorus at these sites are discussed in a subsequent section which provides potential treatment options for these sub-basins.

3.4.2 Comparison by Site

A graphical comparison of event mean concentrations (emc) of total phosphorus and total nitrogen measured in individual runoff samples collected from Sub-basins B-1 and B-2 is given on Figure 3-24. Each of the individual plots contain a series of bar charts which reflect measured concentrations of total phosphorus and total nitrogen during each monitored event at the two sites. The listed event numbers reflect the order in which the samples were collected, with Event 1 reflecting the first event monitored at each site, Event 2 reflecting the second event monitored at each site, etc.

In general, a relatively high degree of variability was observed in measured concentrations of both total phosphorus and total nitrogen between individual events at each of the two monitoring sites. Each of the two sub-basins provides treatment of stormwater using alum injection. Alum treatment of stormwater runoff at the recommended coagulant dose should reduce concentrations of total phosphorus to approximately 50 μg/l (ppb) or less. One of the monitored events at Sub-basin B-1 and two of the monitored events at Sub-basin B-2 exhibited treated runoff characteristics in the range of 50 μg/l. Each of the remaining samples collected at Sub-basin B-1 (Division Street) appear to have been impacted by the alum treatment process since the observed concentrations were substantially less than typical phosphorus concentrations in raw runoff measured at this site, but the alum system appears to have been operating at less than optimum conditions during many of the Sub-basin 1 events.

A similar pattern is also exhibited at Sub-basin B-2 where two of the nine monitored events exhibited phosphorus concentrations near the target treatment goal of 50 μg/l. Five of the remaining monitored events exhibited clear signs of significant alum treatment, although at less than optimum levels. The initial monitoring event (which exhibited a total phosphorus concentration of 260 μg/l) appears to have received little or no alum addition, with Event 2 exhibiting only a partial treatment level.

Figure 3-24. Comparison of Event Mean Concentrations (emc) of Total Phosphorus and Total Nitrogen in Individual Runoff Samples Collected from Sub-basins B-1 and B-2.

A high degree of variability was also observed in measured nitrogen concentrations during each of the monitoring events conducted at Sub-basins B-1 and B-2. Since alum only provides significant removal for organic and particulate nitrogen forms, treatment levels are highly impacted by the nitrogen species present in the runoff inflows.

A comparison of event mean concentrations (emc) of total phosphorus and total nitrogen in individual runoff samples collected from Sub-basins B-4B and B-7 is given on Figure 3-25. Runoff samples from Sub-basin B-4B were collected at the discharge from the treatment pond on MacArthur Drive and reflect the characteristics of discharges from this basin into Lake Holden. Extremely elevated levels of total phosphorus were observed in discharges from the pond during the initial two monitoring events conducted during early-June 2015. Rainfall prior to these monitoring events was below normal, and runoff generated during these events reflects water which had been stored within the pond for a relatively long period. These elevated values suggest leaching of nutrients from the extensive accumulation of organic matter and leaves within the pond which is discussed in a subsequent section. The remaining samples at this site were collected during August and September and reflect characteristics of the pond under conditions of relatively continuous discharge. However, even the lowest total phosphorus concentrations measured in the pond discharge exceeded 100 μg/l, reflecting elevated values for treated runoff.

In contrast, relatively low concentrations of total phosphorus were measured in runoff collected from Sub-basin B-7 (Krueger Street) during 6 of the 7 monitoring events, with a value of approximately 150 μg/l measured during the final event. Phosphorus concentrations in raw untreated stormwater collected at the Krueger Street site were less than values measured in treated runoff from the MacArthur Drive pond outfall during 6 of the 7 monitoring events.

Highly variable concentrations of total nitrogen were measured in runoff samples collected from Sub-basin B-4B. Six of the 8 composite runoff samples exhibited total nitrogen concentrations of approximately 1,500 μg/l or less which is typical of total nitrogen concentrations measured in residential watersheds. However, somewhat more elevated concentrations of total nitrogen were observed during two of the monitoring events, with concentrations during one event approaching 3,500 μg/l.

Extremely elevated levels of total nitrogen were measured in runoff samples collected from Sub-basin B-7 (Kreuger Street), with measured nitrogen concentrations ranging from 2,600-9,900 μg/l. Values in this range are well beyond nitrogen concentrations commonly observed in urban runoff. The data suggest a significant unidentified source of nitrogen which is entering the stormsewer system, either from groundwater or other inputs, resulting in elevated nitrogen concentrations in this area.

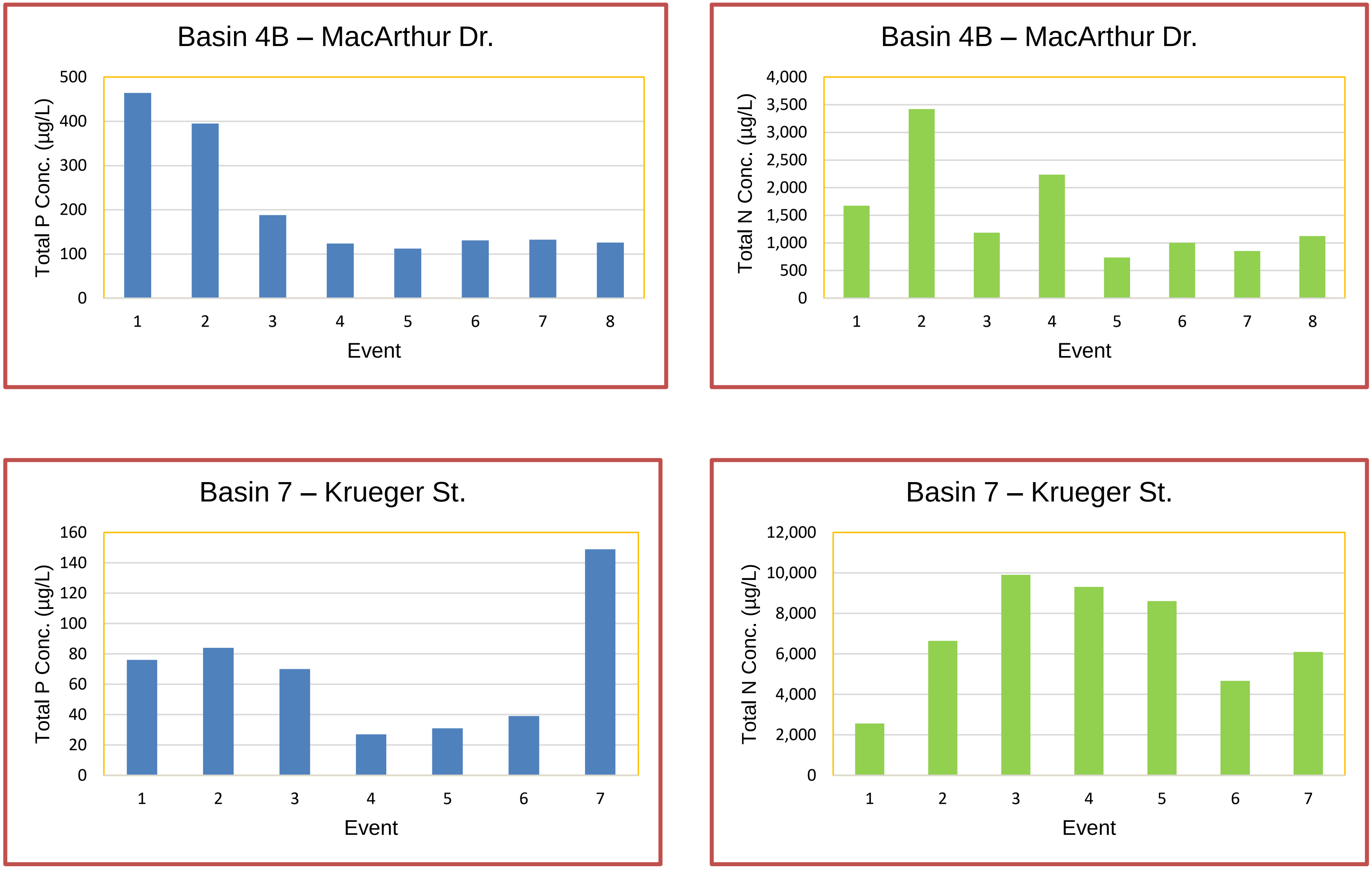


Figure 3-25. Comparison of Event Mean Concentrations (emc) of Total Phosphorus and Total Nitrogen in Individual Runoff Samples Collected from Sub-basins B-4B and B-7.

A comparison of event mean concentrations (emc) of total phosphorus and total nitrogen in runoff samples collected from Sub-basins B-12 and B-13 is given on Figure 3-26. Samples collected at each of these sites reflect discharges from wet detention systems which provide treatment for runoff generated along US 441 and adjacent commercial areas and residential roadways. Total phosphorus concentrations measured in Sub-basin B-12 were moderate in value and typical of phosphorus concentrations commonly observed in discharges from wet detention ponds with a relatively short detention time. The lower observed total phosphorus concentrations likely reflect discharges of water which have been within the pond for an extended period, while the more elevated concentrations likely reflect samples collected following large individual storm events or multiple events over a period of days. Total phosphorus concentrations exceeded 100 μg/l during 3 of the 8 monitoring events at this site.

Total phosphorus discharges from Sub-basin B-13 (FDOT Pond) also exhibited a high degree of variability, with measured concentrations ranging from approximately 50-112 μg/l, with two of the measured discharge concentrations exceeding 100 μg/l. The observed total phosphorus concentrations in discharges from the FDOT Pond are also indicative of discharges from a wet detention pond with a short residence time.

Measured concentrations of total nitrogen were highly variable in runoff samples collected at Sub-basins B-12 and B-13. Total nitrogen concentrations in each of the runoff samples collected from the discharge at the 43rd Street were less than 1000 μg/l, reflecting low to moderate concentrations. Somewhat more elevated concentrations were observed in discharges from the FDOT Pond, with 3 of the 6 samples substantially exceeding 1000 μg/l.

A comparison of event mean concentrations (emc) of total phosphorus and total nitrogen in runoff samples collected from the inflow and outflow of Sub-basin B-19 (Westmoreland Street) dry detention pond is given in Figure 3-27. Inflow samples into the pond were collected during 8 storm events, with discharge samples collected during 6 of the 8 events. Measured concentrations of total phosphorus in the pond inflows ranged from 41-197 μg/l, reflecting low to moderate concentrations for urban runoff. However, increases in phosphorus concentrations appear to occur during migration through the pond and the associated underdrain system, with outflow concentrations of total phosphorus ranging from 170-886 μg/l. The data suggest a significant increase in phosphorus concentrations within the dry detention pond. The observed increases are likely due to interception of the shallow groundwater table by the underdrain system which creates a virtually continuous discharge of runoff and local groundwater from the pond.

A similar pattern was also observed for measured concentrations of total nitrogen between the inflow and the outflow, although not to the extreme extent observed for total nitrogen. Measured concentrations of total nitrogen in the inflow ranged from 218-605 μg/l, with total nitrogen outflow concentrations ranging from 462-1133 μg/l. Concentrations of total nitrogen also appear to increase during migration through the pond system, presumably due to interception of groundwater with elevated nitrogen concentrations within the underdrain system.

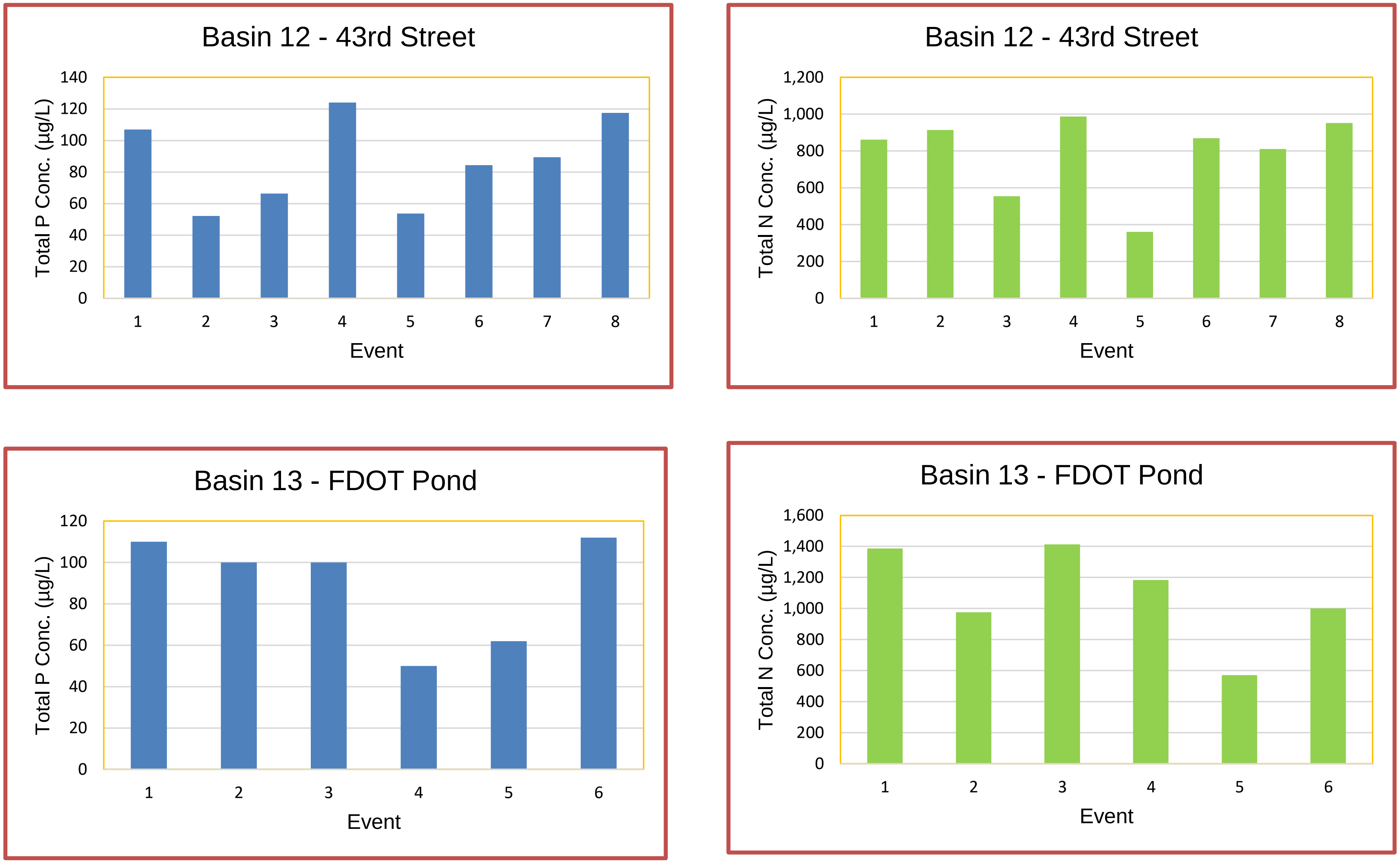
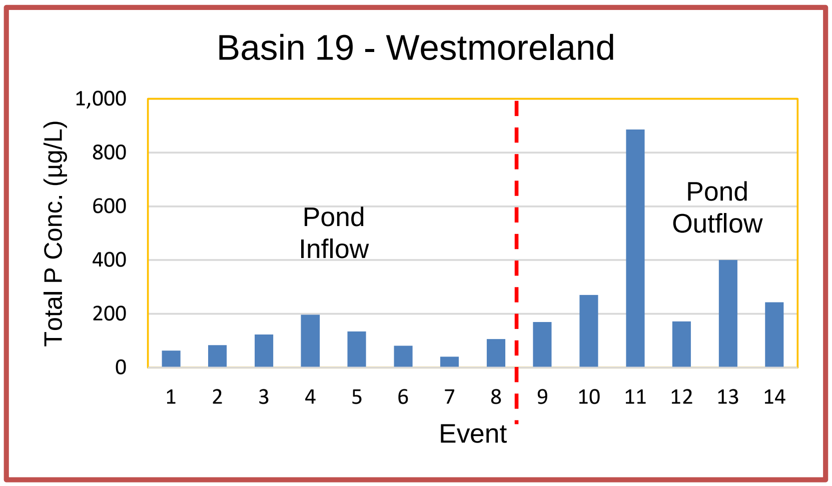


Figure 3-26. Comparison of Event Mean Concentrations (emc) of Total Phosphorus and Total Nitrogen in Individual Runoff Samples Collected from Sub-basins B-12 and B-13.



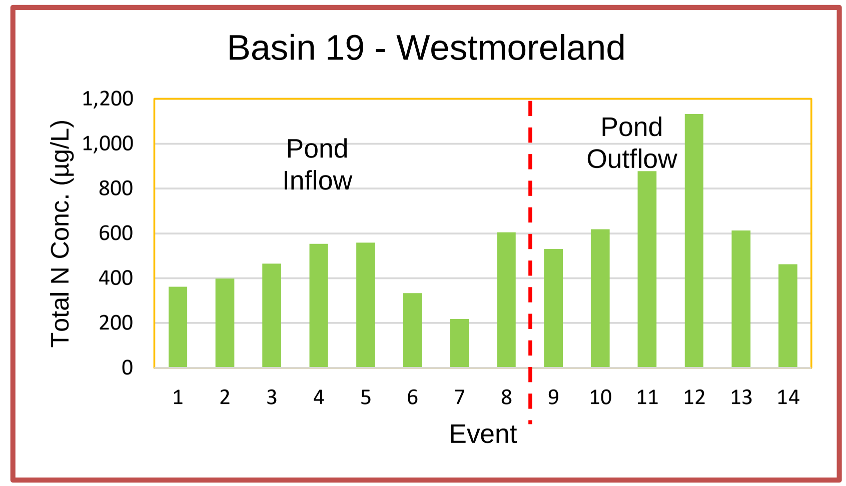


Figure 3-27. Comparison of Event Mean Concentrations (emc) of Total Phosphorus and Total Nitrogen in Individual Runoff Samples Collected from Sub-basin B-19.

A comparison of event mean concentrations (emc) of total phosphorus and total nitrogen in runoff samples collected from Sub-basins B-20 and B-21 is given in Figure 3-28. Sub-basin B-20 reflects a large drainage basin area with no significant stormwater treatment features, while the Paseo Drive site reflects runoff receiving alum treatment. Total phosphorus concentrations measured in Sub-basin B-20 (33rd Street) were highly variable, with concentrations ranging from 77-580 μg/l. The most elevated concentration of 580 μg/l was observed during late-March 2015 and was likely associated with a significant leaf-fall event. Total phosphorus concentrations for the remaining events generally ranged from 100-200 μg/l, reflecting moderate concentrations.

Measured concentrations of total phosphorus at the Paseo Drive site exhibited a wide range of values which provide a clear indication of the significance of the alum treatment system for reducing runoff concentrations. Monitoring Events 1 and 2, as well as 10 and 11, appear to have occurred when runoff discharging from the sub-basins received little or no alum addition. However, the remaining seven events all exhibit total phosphorus concentrations less than 50 μg/l, indicating significant and effective alum treatment at this location.

Measured concentrations of total nitrogen in runoff samples collected from Sub-basin B-20 were generally moderate to low in value, with measured values ranging from 396-997 μg/l. In contrast, highly variable concentrations of total nitrogen were observed at the Paseo Drive site, with measured total nitrogen concentrations ranging from 263-2,142 μg/l. The data suggests that the alum treatment system may be impacting nitrogen concentrations as well, and the more elevated concentrations of total phosphorus appear to be associated with elevated levels of NO_x which are not readily removed by alum treatment.

3.4.3 Comparison of Mean Values

A summary of overall geometric mean characteristics of runoff entering Lake Holden during the field monitoring program from December 2014-September 2015 is given on Table 3-4. Geometric mean values are provided for each measured parameter at each of the 10 field monitoring sites since the data exhibit a log-normal distribution. Mean measured pH values at the individual monitoring sites were approximately neutral in value, with slightly lower pH values observed at the sites receiving alum treatment. Runoff discharging into Lake Holden appears to be moderately well buffered, with low to moderate levels of conductivity.

In general, measured concentrations of ammonia were generally low in value at each of the monitoring sites. Concentrations of NO_x were highly variable but low to moderate in value, with the exception of the extremely elevated mean value of 4,321 μg/l observed in runoff collected at the Krueger Street site. Measured concentrations of dissolved organic nitrogen and particulate nitrogen were somewhat variable, although within the range of values commonly observed in urban runoff. Overall, measured concentrations of total nitrogen in runoff discharging to Lake Holden appear to be low to moderate in value, with the exception of the extremely elevated total nitrogen value of 6,280 μg/l observed at the Krueger Street site.

Figure 3-28. Comparison of Event Mean Concentrations (emc) of Total Phosphorus and Total Nitrogen in Individual Runoff Samples Collected from Sub-basins B-20 and B-21.

TABLE 3-4

GEOMETRIC MEAN CHARACTERISTICS OF RUNOFF ENTERING LAKE HOLDEN FROM DECEMBER 2014-SEPTEMBER 2015

SAMPLE LOCATION	DRAINAGE SUB-BASIN	PARAMETER														
		pH (s.u.)	Alk. (mg/l)	Cond. (µmho/cm)	Ammonia (µg/l)	NO_x (µg/l)	Diss. Org. N (µg/l)	Part. N (µg/l)	Total N (µg/l)	SRP (µg/l)	Diss. Org. P (µg/l)	Part. P (µg/l)	Total P (µg/l)	Turb. (NTU)	Color (Pt-Co)	TSS (mg/l)
Division Street	B-1	5.92	39.8	381	19	171	140	72	500	15	18	24	76	6.2	16	9.0
Lake Holden Terrace	B-2	6.13	36.5	141	26	118	124	206	741	23	26	28	95	5.2	16	7.9
MacArthur Drive	B-4B	7.02	34.7	127	48	25	599	521	1,347	27	40	97	179	4.8	34	4.9
Krueger Street	B-7	6.51	22.3	198	14	4,321	309	44	6,280	10	5	29	58	1.6	7	4.5
43rd Street	B-12	7.30	40.4	114	7	8	378	299	754	9	24	41	83	3.4	20	4.3
FDOT Pond	B-13	7.22	65.4	241	124	466	79	188	1,044	6	25	41	85	3.9	22	7.0
Westmoreland Inflow	B-19	7.02	51.8	129	20	42	144	40	417	29	17	51	119	2.7	12	9.3
Westmoreland Outflow	B-19	6.82	40.9	136	23	269	80	211	672	40	21	118	215	3.3	10	15.0
33rd Street	B-20	7.21	52.0	169	16	136	200	160	599	43	16	60	160	2.9	21	10.3
Paseo Street	B-21	5.34	23.6	245	29	507	189	109	1,148	3	5	51	65	10.5	7	20.7

Runoff inputs into Lake Holden generally contain low levels of both soluble reactive phosphorus (SRP) and dissolved organic phosphorus, with low to moderate concentrations of particulate phosphorus. Overall, measured concentrations of total phosphorus appear to be moderate in value, with overall geometric mean concentrations less than 100 µg/l at 6 of the 10 monitoring sites. It is interesting to note that the most elevated total phosphorus concentration observed during the field monitoring program was measured at the discharge from the Westmoreland Street dry detention pond. The overall mean concentration of 215 µg/l measured in treated runoff at this site is greater than any of the other sites which discharge untreated runoff into Lake Holden.

Runoff concentrations of both turbidity and TSS were low in value compared with concentrations commonly observed in urban areas. Runoff inflows generally exhibited low color, with a slightly more elevated value observed in the MacArthur Pond, presumably due to decomposition of the accumulated leaves and vegetation within the pond.

3.5 Revised Watershed Loadings

The most recent estimate of estimated runoff generated loadings of nitrogen and phosphorus to Lake Holden was conducted by ERD during 2004 and summarized in the report titled "Lake Holden Revised Hydrologic/Nutrient Budget and Management Plan". Runoff generated loadings were calculated based upon hydrologic modeling of the individual sub-basin areas and estimates of runoff characteristics for each sub-basin area. The estimated runoff characteristics were based upon a combination of field monitoring conducted as part of the 2004 work efforts and runoff characterization generated by ERD as a part of previous watershed studies in the Central Florida area.

Updated estimates of runoff generated loadings of total nitrogen, total phosphorus, and TSS to Lake Holden were developed as part of the current work efforts based upon runoff characteristics measured during this study and similarities between land use characteristics in monitored and un-monitored sub-basin areas. A comparison of previous and revised characteristics of stormwater runoff entering Lake Holden is given on Table 3-5. Assumed runoff concentrations are provided from the 2004 report and compared with estimated runoff characteristics for the current work efforts. Estimated runoff characteristics for Sub-basins B-1, B-2, B-4B, B-7, B-12, B-13, B-19, B-20, and B-21 are based upon direct measurements of runoff characteristics conducted as part of this study. Runoff characteristics in the remaining sub-basin areas are estimated based upon similarities between monitored and non-monitored basin areas. Estimated runoff characteristics for the commercial areas in Sub-basin B-14 are based upon recommended runoff characterization data for different land uses within the State of Florida summarized in Harper and Baker (2007).

Estimated runoff emc values for total nitrogen are lower in the current study than assumed during the 2004 evaluation for 17 of the 21 sub-basin areas which discharge runoff to Lake Holden. Much of this reduction is due to lower overall concentrations of total nitrogen at the monitored sub-basin sites for the current study compared with measurements collected during 2004, with the remaining lower emc values due to different assumptions concerning similarities between basin areas. Measured concentrations of total phosphorus are lower in value during the current study in 14 of the 21 contributing sub-basin areas compared with concentrations assumed during 2004, due to a combination of lower monitored emc values and variations in assumptions regarding similarities between sub-basin areas.

TABLE 3-5

COMPARISON OF PREVIOUS (2004) AND REVISED CHARACTERISTICS OF STORMWATER RUNOFF ENTERING LAKE HOLDEN

SUB-BASIN	LAND USE	ASSUMED 2004 RUNOFF CONCENTRATIONS			RECOMMENDED 2015 RUNOFF CONCENTRATIONS			DATA SOURCE
		Total N	Total P	TSS	Total N	Total P	TSS	
B-1	Commercial	788	296	14.2	500	76	9.0	Direct Measurement
B-2	Comm./Resid.	1,206	54	23.0	741	95	7.9	Direct Measurement
B-3	Residential	1,770	177	19.1	599	160	10.3	Similar to B-20
B-4A	Comm./Ind.	--	--	--	--	--	--	Closed Basin
B-4B	Residential	1,180	150	81.0	1,347	179	4.9	Direct Measurement
B-5	Residential	3,988	182	41.8	599	160	10.3	Similar to B-20
B-6	Residential	3,988	182	41.8	599	160	10.3	Similar to B-20
B-7	Residential	3,988	182	41.8	6,280	58	4.5	Direct Measurement
B-8	Residential	3,988	182	41.8	599	160	10.3	Similar to B-20
B-9	Residential	3,988	182	41.8	599	160	10.3	Similar to B-20
B-10A	Residential	3,988	182	41.8	599	160	10.3	Similar to B-20
B-10B	Residential	3,988	182	41.8	599	160	10.3	Similar to B-20
B-11	Residential	3,988	182	41.8	599	160	10.3	Similar to B-20
B-11A	--	--	--	--	--	--	--	Closed Basin
B-12	Commercial	506	37	4.8	754	83	4.3	Direct Measurement
B-13	Comm./Resid.	503	59	3.0	1,044	85	7.0	Direct Measurement
B-14	Commercial	1,180	150	81.0	1,070	179	47.5	Harper (2007)
B-15	Comm/Highway	--	--	--	--	--	--	Closed Basin
B-16	Residential	1,770	177	19.1	599	160	10.3	Similar to B-20
B-17	Residential	3,988	182	41.8	599	160	10.3	Similar to B-20
B-18	Residential	1,770	177	19.1	599	160	10.3	Similar to B-20
B-19	Comm./Resid.	714	105	2.8	672	215	15.0	Direct Measurement
B-20	Residential	1,770	177	19.1	599	160	10.3	Direct Measurement
B-21	Residential	1,022	102	12.0	1,148	65	20.7	Direct Measurement
B-22 (Direct)	Residential	2,290	300	27.0	599	160	10.3	Similar to B-20

Closed Basins

A summary of revised estimated annual runoff loadings of total nitrogen, total phosphorus, and TSS to Lake Holden is given on Table 3-6. This information is based upon the revised sub-basin delineations discussed in Section 3.1 and the stormwater characteristics summarized on Table 3-5. Under current conditions, runoff generated loadings of total nitrogen contribute approximately 1,264 kg/yr compared with an estimate of 1,688 kg/yr during 2004. Runoff generated loadings of total phosphorus to Lake Holden are estimated to be approximately 133 kg/yr under current conditions compared with 201 kg/yr estimated during 2004. A substantial reduction in TSS loadings appears to have occurred to Lake Holden, with a loading of approximately 20,680 kg/yr under current conditions compared with 23,651 kg/yr during 2004. Much of the difference between the current and previous loading estimates is due to reductions in measured runoff concentrations during the 2014-2015 monitoring period compared with runoff characteristics measured during 2004. The reduced runoff emc values may be related to the watershed-wide street sweeping program which has been implemented in the Lake Holden watershed and recent enhancements to the three alum runoff treatment systems.

Information on loading rates for each sub-basin is also provided as a percentage of the overall total loading to evaluate the significance of various sub-basins in terms of the annual runoff generated loadings to the lake. Sub-basin areas which contribute 5% or more of the total annual mass loading for total nitrogen, total phosphorus, and TSS are highlighted in yellow on Table 3-6. The three largest contributors of nitrogen to Lake Holden appear to be Sub-basins B-1, B-7, and B-13. Sub-basin B-1 currently receives runoff treatment by alum injection, while runoff generated in Sub-basin B-13 is treated within the FDOT pond. The apparent significance of these sub-basins in terms of nitrogen loading is due primarily to the size of the basins since these are the largest sub-basin areas outside of the direct overland flow basin. The largest loadings of total nitrogen appear to be contributed by Sub-basin B-7 which is the Krueger Street site that exhibited extremely elevated levels of total nitrogen, primarily resulting from elevated concentrations of NO_x.

Annual mass loadings of total phosphorus in excess of 5% are contributed by 6 of the 21 sub-basin areas discharging to Lake Holden. Interestingly, 5 of the 6 sub-basin areas currently have stormwater treatment systems for reduction of phosphorus loadings. Runoff generated in Sub-basins B-1 and B-2 is treated by alum injection, with Sub-basins B-4B, B-12, and B-13 providing wet detention treatment for the generated runoff. The only significant sub-basin area which does not currently have stormwater treatment is Sub-basin B-20 which is located on the northwest side of Lake Holden.

In general, the significant sub-basins with respect to loadings of TSS are similar to significant sub-basin areas for total phosphorus. TSS loadings in excess of 5% of the total are generated in 6 of the 21 sub-basin areas, all but one of which currently have stormwater treatment systems. The only sub-basin which does not currently provide stormwater treatment is Sub-basin B-20 which contributes approximately 7.6% of the annual TSS loadings to the lake.

TABLE 3-6

ESTIMATED ANNUAL RUNOFF LOADINGS OF TOTAL NITROGEN, TOTAL PHOSPHORUS, AND TSS TO LAKE HOLDEN

SUB-BASIN	BASIN AREA (acres)	OBSERVED RUNOFF VOLUME (ac-ft/yr)	MASS LOADING (kg/yr)			PERCENT OF TOTAL (%)			AREAL LOAD (kg/ac-yr)		
			Total N	Total P	TSS	Total N	Total P	TSS	Total N	Total P	TSS
B-1	98.9	262	162	24.5	2,907	12.8	18.4	27.2	1.63	0.25	29.4
B-2	65.7	137	125	16.0	1,323	9.9	12.0	12.4	1.90	0.24	20.1
B-3	19.7	12.4	9	2.5	158	0.7	1.9	1.5	0.47	0.12	8.0
B-4A	67.9	0.0	0	0	0	0	0	0	0	0	0
B-4B	35.9	73.3	122	16.2	443	9.6	12.2	4.1	3.39	0.45	12.3
B-5	10.4	9.9	7	2.0	126	0.6	1.5	1.2	0.70	0.19	12.1
B-6	8.8	7.4	5	1.5	94	0.4	1.1	0.9	0.62	0.17	10.7
B-7	52.9	51.5	399	3.7	283	31.5	2.8	2.6	7.53	0.07	5.3
B-8	7.8	7.0	5	1.4	89	0.4	1.0	0.8	0.66	0.18	11.4
B-9	6.8	6.6	5	1.3	85	0.4	1.0	0.8	0.72	0.19	12.4
B-10A	10.9	11.1	8	2.2	142	0.7	1.7	1.3	0.76	0.20	13.0
B-10B	8.0	8.1	6	1.6	103	0.5	1.2	1.0	0.75	0.20	12.9
B-11	10.8	11.2	8	2.2	143	0.7	1.7	1.3	0.77	0.21	13.2
B-11A	13.4	0.0	0	0	0	0	0	0	0	0	0
B-12	26.3	66.8	62	6.8	353	4.9	5.1	3.3	2.36	0.26	13.4
B-13	81.5	136	176	14.3	1,183	13.9	10.8	11.1	2.15	0.18	14.5
B-14	3.6	7.8	10	1.7	459	0.8	1.3	4.3	2.87	0.48	127
B-15	4.5	0.0	0	0	0	0	0	0	0	0	0
B-16	12.1	12.1	9	2.4	154	0.7	1.8	1.4	0.74	0.20	12.7
B-17	4.4	5.3	4	1.0	67	0.3	0.8	0.6	0.89	0.24	15.3
B-18	35.9	32.7	24	6.5	416	1.9	4.9	3.9	0.67	0.18	11.6
B-19	16.8	22.2	18	5.9	411	1.5	4.4	3.8	1.10	0.35	24.4
B-20	60.9	63.8	47	12.6	813	3.7	9.5	7.6	0.77	0.21	13.3
B-21	19.4	24.5	35	2.0	625	2.7	1.5	5.8	1.78	0.10	32.2
B-22 (Direct)	105.5	23.8	18	4.7	303	1.4	3.5	2.8	0.17	0.04	2.9
TOTAL:	**788.8**	**993**	**1,264**	**133**	**10,680**	**100**	**100**	**100**	**1.60**	**0.17**	**13.5**

Closed basins

Sub-basin areas which contribute 5% or more of the total annual mass loading

Sub-basins exhibiting areal loading rates in excess of 25% above the overall mean values

The observed differences between the percentage of loadings contributed by various sub-basin areas are partially due to the sizes of the different sub-basin areas, with larger sub-basins naturally contributing larger loadings than smaller sub-basins. Therefore, a subsequent analysis was conducted to evaluate the calculated loadings of nitrogen, phosphorus, and TSS on an areal basis which eliminates the impacts of watershed size. These areal loadings are expressed in terms of kg/ac-yr and reflect the loading per unit area for each sub-basin area to allow a more accurate comparison of watershed loadings and to identify "hot spots" within the sub-basins. Overall mean values for areal loading rates are provided at the bottom of Table 3-6 which were calculated by dividing the total annual mass loadings of nitrogen, phosphorus, and TSS by the total contributing sub-basin area of 703 acres. Sub-basins exhibiting areal loading rates in excess of 25% above the overall mean values are highlighted in green in Table 3-6.

Based upon this analysis, the most elevated loadings of total nitrogen appear to originate within Sub-basins B-4B, B-7, B-12, B-13, and B-14. Sub-basins with more elevated areal loadings of total phosphorus were observed in Sub-basins B-1 and B-2 (both of which receive alum stormwater treatment), Sub-basin 12 (which receives runoff treatment in a wet detention pond), and Sub-basins B-14, B-17, and B-19, with Sub-basin B-19 receiving stormwater treatment in a dry detention with filtration facility. With the exception of Sub-basin B-14, the most elevated areal loading rates for total phosphorus entering Lake Holden were observed in Sub-basins B-4B and B-19, both of which have existing stormwater management facilities. Calculated areal loading rates for TSS are somewhat similar to those observed for total phosphorus, with higher than average areal loading rates for TSS observed in Sub-basins B-1, B-2, B-14, B-19, and B-21. Each of these sub-basins, with the exception of Sub-basin B-14, currently has stormwater treatment facilities.

SECTION 4

EVALUATION OF STORMWATER TREATMENT / ENHANCEMENT OPTIONS

A discussion was provided in the previous section of existing stormwater characteristics discharging from sub-basin areas to Lake Holden based upon field monitoring conducted from December 2014-September 2015. This information is used to evaluate the effectiveness of existing BMPs and identify additional sub-basin areas where stormwater treatment may be needed. A discussion of each of the monitored sub-basin areas and potential options for stormwater treatment/enhancement is given in the following sections.

4.1 Alum Treated Sub-basins (B-1, B-2, and B-21)

Monitored phosphorus concentrations at the three alum treated sub-basin sites indicated that the alum treatment process was highly effective in reducing runoff concentrations of total phosphorus. The vast majority of alum treated runoff samples exhibited total phosphorus concentrations less than 100 μg/l, with many samples (particularly at the Paseo Avenue site) exhibiting total phosphorus concentrations less than 50 μg/l. However, evidence of partial or no alum treatment was observed during 2 of the 7 monitoring events in Sub-basin B-1, 2 of the 9 runoff events for Sub-basin B-2, and 4 of the 11 runoff events collected at the Paseo Avenue site. In addition, some of the runoff events which exhibited evidence of alum treatment, particularly in Sub-basins B-1 and B-2, appear to need a slightly higher alum treatment dose to achieve the treated total phosphorus concentration of approximately 50 μg/l for the treated runoff.

The alum treatment system was recently rehabilitated to upgrade existing equipment and replace damaged or inoperable components. However, ERD was not involved with this renovation process, and has no direct knowledge of the current dosing rate applied to each of the three sub-basins. Runoff samples collected from Sub-basin B-21 indicate that the alum treatment system easily achieves the target goal of 50 μg/l during events where alum addition occurs. However, multiple events appear to have received little or no alum addition. The alum treatment system appears to have injected alum during each of the 7 monitoring events at Sub-basin B-1, although only 1 of the 7 events achieved the target 50 μg/l goal, suggesting that the application dose may need to be increased at the Division Street site. A similar pattern was also observed for Sub-basin B-2 where it also appears that the alum addition rate should be enhanced to increase phosphorus reductions during storm events. Therefore, ERD recommends that the applied alum dose for Sub-basins B-1 and B-2 be increased by approximately 1-2 mg Al/liter to provide further reductions in treated total phosphorus concentrations at these sites.

The monitoring data also suggest that several of the runoff samples collected from Sub-basins B-2 and B-21 received little or no alum addition. Since the operation of the alum treatment process is now controlled by the City of Orlando, the Advisory Board only has limited feedback regarding the operational status of the system other than the continued assurances from the City of Orlando that the system is operating as designed, although runoff samples collected during this project suggest otherwise.

ERD recommends that the Advisory Board take a proactive approach to evaluating the performance of the alum treatment systems. The modified alum treatment system provides telemetry data for each of the three monitoring sites which contain information on monitored runoff volume and the amount of alum added to each of the three locations. The Advisory Board should provide routine verifications of alum addition volumes based upon monitored storm events within the watershed area.

A tabular summary of alum addition rates for typical storm events at Sub-basins B-1, B-2, and B-21 is given on Table 4-1. Modeled event runoff volumes are provided for each of the three sub-basin areas for a variety of rain events based upon modeling conducted by ERD as part of the 2004 report. The corresponding alum addition volumes are provided for rain events within each of the three sub-basin areas based upon alum dosage rates of 7.5 and 10 mg Al/liter. The operation of the injection system can be verified by comparing the applied alum volume for a watershed rain event based on rainfall depths measured by a City of Orlando rain gauge or gauge maintained by a homeowner on the lake. If the measured rain events falls between two of the modeled rain events listed on Table 4-1, the alum volume can be estimated using simple iteration, although the alum addition rates per rain event are not necessarily linear relationships. This exercise will at least allow the Advisory Board to conduct an independent evaluation of the system operation which may provide evidence of a system malfunction long before it would be noticed by the City.

Recommendations:

1. ERD recommends that alum addition rates be increased by approximately 1-2 mg Al/liter in Sub-basins B-1 and B-2 to attempt to reduce the treated total phosphorus concentrations to less than 50 μg/l.

2. The Advisory Board should conduct independent evaluations to verify operation of the treatment systems by comparing alum addition volumes to monitored rain events within the watershed.

TABLE 4-1

ALUM ADDITION RATES FOR TYPICAL RAIN EVENTS AT SUB-BASINS B-1, B-2, AND B-21

RAIN EVENT (inches)	EVENT RUNOFF VOLUME (ac-ft)			EVENT ALUM VOLUME (gallons)			EVENT ALUM VOLUME (gallons)		
	B-1	B-2	B-21	B-1	B-2	B-21	B-1	B-2	B-21
0.05	0	0	0	0	0	0	0	0	0
0.15	0.32	0.17	0.04	13	7	2	18	9	2
0.25	0.95	0.50	0.13	40	21	5	53	28	7
0.35	1.59	0.83	0.21	66	34	9	88	46	12
0.45	2.23	1.17	0.31	93	49	13	124	65	17
0.70	3.84	2.00	0.52	160	84	22	214	111	29
1.25	7.19	3.66	0.95	300	153	40	400	204	53
1.75	10.71	5.36	1.40	447	224	58	596	298	78
2.25	14.26	7.14	1.87	595	298	78	793	397	104
2.75	17.88	9.02	2.38	746	376	99	994	502	133
3.25	21.94	11.20	2.97	915	467	124	1,220	623	165
3.67	25.23	13.00	3.46	1,052	542	144	1,403	723	193
4.25	29.40	15.30	4.16	1,226	638	174	1,635	851	231
4.80	33.93	17.86	4.82	1,415	745	201	1,887	993	268
5.50	39.28	21.02	5.75	1,639	877	240	2,185	1,169	320
6.50	46.32	25.26	6.84	1,932	1,054	285	2,576	1,405	381
Alum Dose (mg Al/liter):				**7.5**	**7.5**	**7.5**	**10**	**10**	**10**

4.2 Sub-basin B-4B (MacArthur Drive)

Runoff monitoring for Sub-basin B-4B was conducted at the discharge from the existing wet detention pond located on the north end of MacArthur Drive. Phosphorus concentrations in runoff samples collected at this site ranged from approximately 110-470 mg/l, reflecting extremely elevated values for discharges from a wet detention facility. After observing the initial elevated total phosphorus concentrations measured at this site, ERD conducted an evaluation of the contributing watershed area and the pond to identify potential phosphorus sources. The watershed area contains a large number of mature oak trees planted along the roadway right-of-way which contribute large amounts of leaf litter and vegetation debris, particularly during leaf-fall season.

Upon inspecting the pond itself, ERD found that the design pond volume was virtually completely filled with leaves and organic matter, with only a few inches of water column above the accumulated layer of leaves. Since leaves release large quantities of soluble nutrients after entering a pond or lake, it was concluded that the elevated levels of total phosphorus measured in discharges from the Sub-basin B-4B pond were likely due to decomposition of the leaf material within the pond. The substantially reduced available water volume virtually eliminated normal physical and biological processes which occur in wet detention ponds for removal of stormwater constituents. Sub-basin B-4B receives routine weekly street sweeping activities which remove the vast majority of leaves deposited on the roadway surfaces. It is not known if the accumulated leaves within the pond consisted of excess leaf material not collected by the street sweeping program, or if the material had largely accumulated prior to initiation of the street sweeping activities. However, based upon the low level of degradation observed in the surface leaves, it appears that the leaves had entered the pond relatively recently.

ERD reported the findings of the field evaluations to the Lake Holden Water Advisory Board during the routine meeting in September 2015. This condition was noted by representatives of OCEPD present at the meeting, and the Orange County Streets and Highways Maintenance Division was informed of the current condition of the pond. Renovation activities within the pond were initiated during October 2015, and the accumulated organic material was removed, and the pond basin was re-contoured to the original design specifications. Photographs of excavation activities in the Sub-basin B-4B pond are given on Figure 4-1.

It is likely that the excavation of the Sub-basin B-4B pond has improved runoff concentrations of total phosphorus discharging from the pond into Lake Holden. However, since the runoff field monitoring was completed prior to the excavation process, all of the data collected by ERD at this site reflect the characteristics of the pond under the previous conditions. An additional runoff monitoring program is recommended for this site to verify that the pond maintenance has improved total phosphorus concentrations within the pond.

Recommendations:

1. ERD recommends that a field monitoring program be conducted to verify improvements in total phosphorus concentrations in discharges from the wet detention pond following excavation and maintenance activities.

Excavation of pond

Stockpile of dredged material

Re-contouring pond slopes

Completed project

Figure 4-1. Photographs of Excavation of the Sub-basin B-4B Pond.

4.3 <u>Sub-basin B-7 (Krueger Street)</u>

Sub-basin B-7 is a 52.9-acre area of residential single-family homes which discharges untreated stormwater runoff into Lake Holden through a 48-inch RCP on the east side of the lake. Monitored concentrations of total phosphorus collected in runoff from Sub-basin B-7 were generally low in value, with 6 of the 7 composite samples exhibiting total phosphorus concentrations of approximately 80 µg/l or less, with the most elevated total phosphorus concentration monitored at this site equal to approximately 150 µg/l. Overall, measured concentrations of total phosphorus in runoff discharging from Sub-basin B-7 are actually lower in value than several other basins with existing stormwater treatment facilities. Therefore, stormwater retrofit BMPs for reduction in total phosphorus do not appear to be necessary for Sub-basin B-7 at this time. Since this is a relatively large sub-basin area, any proposed stormwater BMP would be relatively expensive, and the anticipated reductions in total phosphorus concentrations do not appear, at this time, to be worth the large capital improvement costs.

However, Sub-basin B-7 exhibited extremely elevated levels of total nitrogen, with measured values 5-10 times greater than nitrogen concentrations measured at the remaining monitoring sites. Virtually all of the observed total nitrogen was contributed by NO_x. A relatively constant baseflow was observed at this site even during extended dry periods between rain events, suggesting a continuous source of groundwater or other input into the stormsewer system. The observed elevated concentrations of total nitrogen should be identified in an effort to reduce or eliminate these inputs. Therefore, a further monitoring program should be conducted in Sub-basin B-7 in an attempt to identify potential sources of the elevated total nitrogen concentrations. Analysis of stable isotopes of nitrogen may be useful in this effort and can assist in identifying the sources of nitrate.

Recommendations:

1. A supplemental field monitoring program should be conducted to identify the source of the substantially elevated nitrate levels observed in Sub-basin B-7.

4.4 Sub-basin B-12

Runoff discharges from Sub-basin B-12 were monitored at the discharge from the outfall structure associated with the small wet detention facility located on the north end of Sub-basin B-12. Monitored phosphorus concentrations at this site were moderate in value, with composite total phosphorus concentrations ranging from approximately 50-120 μg/l. Phosphorus values in this range are somewhat higher than concentrations commonly observed in discharges from wet detention facilities and are an indication that the pond is too small for the size of the contributing watershed. Phosphorus discharges from wet detention ponds also generally exhibit a relatively small degree of variability, and the more elevated peaks in concentrations in phosphorus concentrations observed in runoff collected from Sub-basin B-12 are another indication that the current detention time for runoff in the pond is too short to provide effective treatment. In contrast, measured concentrations of total nitrogen in discharges from the Sub-basin B-12 pond were low to moderate in value, with monitored concentrations ranging from 380-1,000 μg/l.

The ideal solution to enhancing the performance of the Sub-basin B-12 pond would be to expand both the area and volume of the pond to achieve a higher load reduction efficiency. The performance effectiveness of wet detention ponds for removal of total nitrogen and total phosphorus is primarily a function of detention time, with longer detention times resulting in higher pond removal efficiencies. Unfortunately, no additional area is available within the pond parcel to significantly enlarge the size of the pond. Much of the available land within the parcel consists of maintenance berms required by Orange County which limits the ability of the pond to expand within the existing parcel.

However, a very inexpensive method of increasing the permanent pool volume within the pond is to raise the control water elevation within the pond. A photograph of the outfall structure for the Sub-basin B-12 pond is given on Figure 3-13. Discharges from the pond are regulated primarily by a circular orifice which allows runoff inputs to bleed-down and recover the available storage volume between storm events. A simple and inexpensive method of increasing the permanent pool volume would be to raise the circular orifice within the outfall structure by approximately 1-2 ft. This change would have to be evaluated using a hydrologic model to verify that flooding conditions would not result, but this simple modification could enhance the treatment volume within the pond. Raising the water level within the pond would also force more of the water to infiltrate through the side banks rather than discharging to Lake Holden, further reducing loadings discharging to the lake, and would also assist in reducing the current encroachment of aquatic vegetation within the pond due to the existing shallow water depths.

Recommendations:

1. ERD recommends that a feasibility evaluation be conducted to evaluate raising the outfall control elevation for the Sub-basin B-12 pond to increase permanent pool storage.

4.5 Sub-basin B-13 (FDOT Pond)

Sub-basin B-13 is located on the west side of Lake Holden and receives runoff generated along portions of South Orange Blossom Trail (US 441) and interconnecting residential areas and roadways. Runoff generated within the 81.5-acre sub-basin discharges to an existing wet detention pond which was originally designed to provide a level of treatment only for the additional lanes added to the north- and south-bound portions of US 441 when the highway was expanded from 4 lanes to 6 lanes. Since the pond was designed only for a small portion of the contributing basin, it is grossly undersized for the runoff volumes which discharge to the facility. Large portions of the pond parcel are consumed by maintenance berms and pond slopes, further reducing the available area for the treatment pond.

Concentrations of total phosphorus in composite runoff samples discharging from the FDOT pond ranged from approximately 50-105 μg/l and exhibited concentrations similar to those observed for the Sub-basin B-12 outfall. The measured concentrations of total phosphorus in the pond discharges are somewhat higher than phosphorus concentrations normally observed in discharges from wet detention ponds which is a result of the small pond size and extremely short residence times for runoff inflows. Total nitrogen concentrations in discharges from the pond were moderate to low in value, ranging from approximately 590-1,400 μg/l.

Although phosphorus concentrations discharging from the FDOT pond are not extremely elevated, the observed concentrations are higher than normal for discharges from wet detention facilities, and under current conditions, contribute 10.8% of the total runoff generated phosphorus loadings to Lake Holden each year. An overview of the property appraiser's map for the FDOT pond and adjacent properties is given on Figure 4-2. Due to the unusual configuration of the pond parcel, the required maintenance berms and pond banks consume a large portion of the available area, resulting in a relatively small footprint for the pond itself. However, expansion of the pond could easily double or triple the available permanent pool volume, resulting in lower and more consistent concentrations of total phosphorus discharging from the pond into Lake Holden. The property immediately west of the pond parcel is currently vacant and is part of a larger parcel owned by New Jerusalem Enterprises, LLC. If the rear portion of the parcel west of the FDOT pond could be obtained, a substantially larger pond could be constructed at this site.

Figure 4-2. Property Appraiser's Map for the FDOT Pond and Adjacent Properties.

An overview of the proposed area for pond expansion for Sub-basin B-13 is given on Figure 4-3. This portion of the parcel is currently vacant and may be available for purchase for pond enhancement and expansion. The new expanded pond could be planted with extensive littoral zone vegetation to enhance pollutant uptake mechanisms, and the substantially larger permanent pool volume would provide a wider range of opportunities for biological uptake within the water column. The resulting discharges from the FDOT pond should be near the target goal of 50 μg/l for total phosphorus.

Figure 4-3. Proposed Area for Pond Expansion for Sub-basin B-13.

Since the pond parcel is owned by FDOT and provides relatively poor treatment for runoff inputs entering Lake Holden, FDOT may be willing to participate (either partially or fully) in a proposed expansion of the pond. Too many variables currently exist concerning the amount of land which may be available, along with the proposed pond configuration, to generate a cost estimate for pond expansion. However, ERD recommends that the Property Owners Association, in conjunction with the County, contact both the adjacent property owner and FDOT to evaluate if this is a feasible option, at least on a conceptual basis. After a potential project is better defined, a cost estimate can be developed.

Recommendations:

1. ERD recommends that the Lake Holden Property Owners Association and Orange County conduct preliminary discussions with the adjacent property owner and FDOT to evaluate the potential feasibility of expanding the FDOT pond.

4.6 Sub-basin B-19

Sub-basin B-19 is located on the west side of Lake Holden and consists of a dry detention with filtration pond which provides treatment for runoff generated in the vicinity of I-4 and Michigan Street. This sub-basin area contributes approximately 4.4% of the annual runoff generated phosphorus loadings discharging to Lake Holden. Multiple studies conducted at this site have documented a substantial increase in concentrations of total phosphorus between the inflow and outflow of the treatment system, presumably resulting from interception of shallow groundwater containing elevated phosphorus concentrations and discharging the groundwater through the outfall structure for the pond.

A quick and easy method of reducing both runoff volume and total phosphorus concentrations discharging from the pond would be to plug the drainage connections for the underdrains at the outfall control structure which would eliminate the existing groundwater related discharges from the pond. However, blocking the underdrain system would likely result in increases in water levels within the pond, causing the pond to become a shallow wetland which would be filled with emergent aquatic vegetation such as cattails and primrose willow, both of which have detrimental effects on water quality in stormwater ponds. Maintenance activities for these plants, which usually involve spraying with herbicides, would allow the vegetation to decay within the pond, causing further releases of nutrients. Therefore, to prevent this encroachment, the pond would need to be deepened and converted into a wet detention facility.

An overview of proposed pond enhancement for Sub-basin B-19 is given on Figure 4-4. This proposed option calls for the pond to be converted into a wet detention facility which will provide treatment for stormwater runoff prior to discharge to Lake Holden. The current bottom elevation of the existing pond is approximately 94 ft, and the proposed pond would extend downward from the existing pond bottom at a 2:1 slope to an elevation of 80 ft. The water control elevation within the pond would be increased from the current elevation of approximately 94 ft to approximately 96-97 ft to increase available water storage and reduce groundwater inflows into the pond. Groundwater elevations in the vicinity of the pond should be monitored during the design process to ensure that the selected control water elevation within the pond is at or above the seasonal high groundwater level to prevent significant groundwater inflows.

A summary of stage-storage relationships for the proposed Sub-basin B-19 pond enhancement is given on Table 4-2. If the pond were excavated to an elevation of 80 ft and the control elevation established at elevation 96 ft, the maximum water depth would be approximately 16 ft, with a permanent pool volume of approximately 9.8 ac-ft. As indicated on Table 3-6, Sub-basin B-19 contributes approximately 22.2 ac-ft of runoff per year to the Sub-basin B-19 pond. The proposed pond would have a detention time of 0.44 years (161 days) which should provide reductions in phosphorus concentrations of approximately 75-80% and eliminate the existing elevated phosphorus levels discharging from the pond. Construction of the pond would require excavation from the existing pond bottom at 94 ft to the proposed pond bottom at 80.0 ft, equivalent to approximately 7.7 ac-ft or 12,500 yd^3.

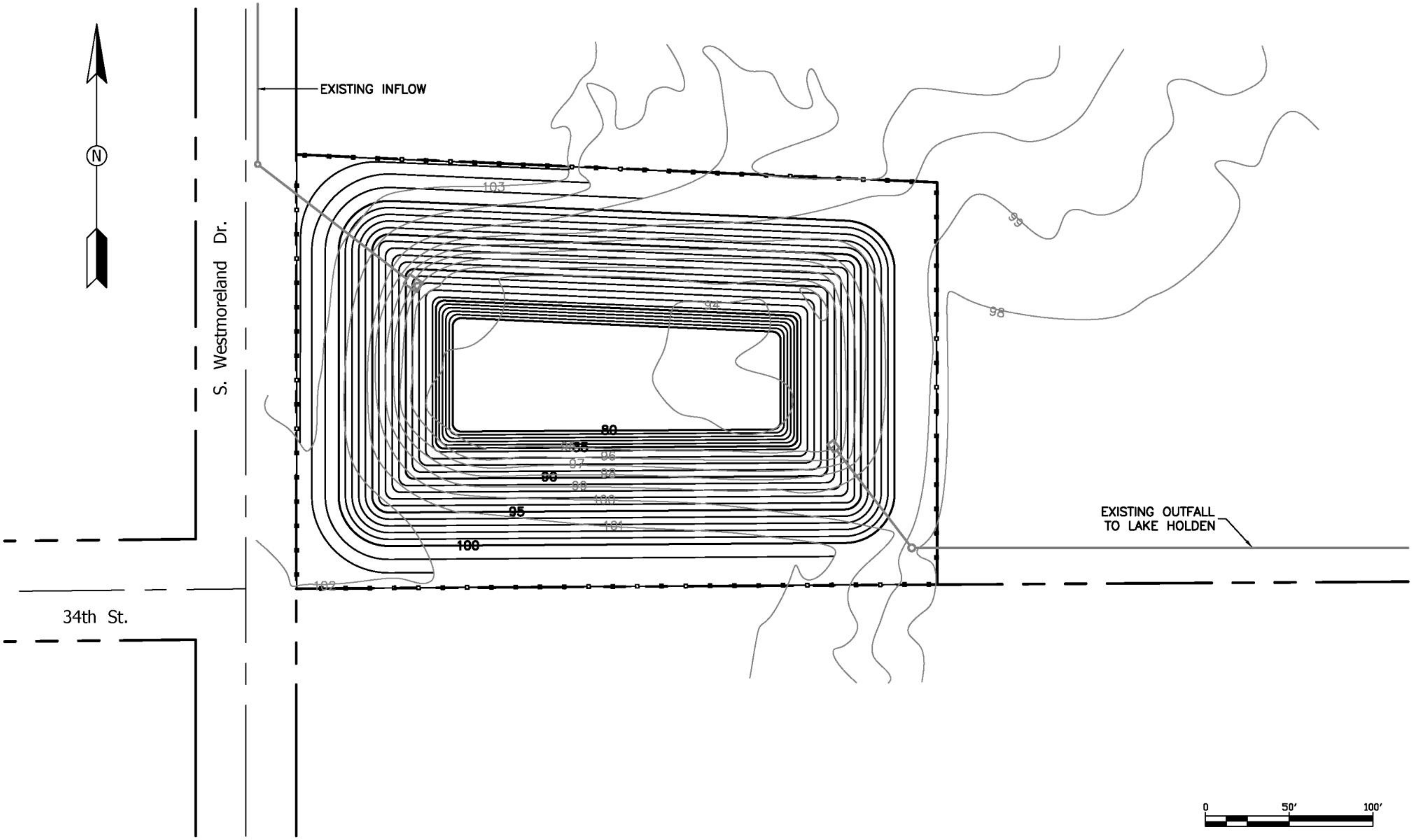


Figure 4-4. Overview of Proposed Pond Enhancement for Sub-basin B-19.

TABLE 4-2

STAGE-STORAGE RELATIONSHIPS FOR THE PROPOSED SUB-BASIN B-19 POND ENHANCEMENT

ELEVATION (ft)	AREA (ft^2)	VOLUME (ac-ft)	ELEVATION (ft)	AREA (ft^2)	VOLUME (ac-ft)
100	65,274	15.1	89	27,048	3.7
99	61,283	13.7	88	24,273	3.1
98	57,392	12.3	87	21,626	2.6
97	53,602	11.0	86	19,107	2.2
96	49,912	9.8	85	17,895	1.7
95	46,323	8.7	84	16,716	1.3
94	42,844	7.7	83	15,568	1.0
93	39,429	6.8	82	14,453	0.6
92	36,142	5.9	81	13,369	0.3
91	32,982	5.1	80	12,318	0
90	29,951	4.4			

CWL

A conceptual cost estimate for the proposed Sub-basin B-19 pond enhancements is given in Table 4-3. Cost estimates are provided for mobilization, pond excavation, outfall structure modifications, and replacement sod. The estimated conceptual cost for enhancement of the Sub-basin B-19 pond is approximately $302,500 or $363,000 with a 20% contingency.

Recommendations:

1. ERD recommends that the existing dry detention with filtration pond be converted to a wet detention facility to eliminate interception of groundwater and reduce phosphorus loadings to Lake Holden.

TABLE 4-3

CONCEPTUAL COST ESTIMATE FOR THE PROPOSED SUB-BASIN B-19 POND ENHANCEMENT

NUMBER	ITEM DESCRIPTION	UNITS	QUANTITY	UNIT PRICE ($)	COST ($)
1.	Mobilization	LS	1	20,000	$ 20,000
2.	Pond Excavation	CY	12,500	20.00	250,000
3.	Outfall Structure Modifications	LS	1	15,000	15,000
4.	Sod	SY	5,000	3.50	17,500
				Sub-Total:	$ 302,500
				Contingency (20%)	60,500
				TOTAL:	**$ 363,000**

4.7 Sub-basin B-20

Sub-basin B-20 is located on the northwest side of Lake Holden, covers approximately 60.9 acres, and contributes 9.5% of the total annual runoff generated phosphorus loadings to Lake Holden. It is the largest existing sub-basin area which does not have stormwater treatment facilities. This sub-basin is primarily residential in character with a poorly defined drainage system consisting primarily of shallow roadside swales and overland flow, with a few isolated stormsewer systems. Measured concentrations of total phosphorus in runoff samples collected from Sub-basin B-20 were generally 100 μg/l or more, although more elevated concentrations were observed during 2 of the 7 monitoring events, with one composite sample reaching almost 600 μg/l. In contrast, measured concentrations of total nitrogen in runoff samples collected from Sub-basin B-20 were low to moderate in value compared with total nitrogen concentrations commonly observed in residential areas. The fact that this basin contributes 9.5% of the annual runoff generated phosphorus loadings to the lake suggests that this sub-basin may be a candidate for implementation of a stormwater BMP since the sub-basin currently has no stormwater treatment systems.

ERD recommended previously that Sub-basin B-20 receive alum stormwater treatment by extending small diameter underground piping from the existing alum control building to the point of discharge for Sub-basin B-20 into Lake Holden. This modification was not conducted as part of the recent enhancements and renovations to the alum treatment facility. However, ERD recommends that extension of the alum treatment system into this sub-basin be given additional consideration. The extension would be relatively easy to accomplish and a conceptual design to accomplish this extension was previously provided by ERD. The estimated cost for this extension is approximately $100,000 which is relatively low capital outlay considering the significance of the sub-basin area.

Recommendations:

1. ERD recommends that the Property Owners Association reconsider implementation of an alum-based treatment system for Sub-basin B-20.

4.8 Summary of Recommendations

A summary of the proposed recommendations for additional management of stormwater within the Lake Holden basin is given in Table 4-4. Recommendations for priority of implementation are also provided for each of the recommended treatment options. The proposed activities for the alum stormwater treatment sub-basins (B-1, B-2, and B-21), along with Sub-basins B-4B and B-7, are assigned an "immediate" implementation priority since each of these proposed activities involves either activities by the Advisory Board or small field studies. The recommendation to increase the alum addition rates for Sub-basins B-1 and B-2 has the potential to impact a large percentage of the runoff generated phosphorus loading entering the lake.

The second implementation priority is assigned to Sub-basin B-19 which consists of the dry detention with filtration pond along Westmoreland Street. This sub-basin is currently discharging extremely elevated concentrations of total phosphorus to Lake Holden on a continuous basis, and implementation of the proposed wet detention facility for this site will reduce the existing discharges of total phosphorus by approximately 75% from this sub-basin.

The third implementation priority is assigned to Sub-basin B-12 which is the small detention pond located off South Orange Blossom Trail that receives runoff from a large commercial property. The proposed activities for this site are expected to have a relatively low capital cost and should increase phosphorus retention within the pond by approximately 25%.

Longer term implementation priorities were assigned to Sub-basins B-13 (FDOT Pond) and B-20. These sub-basins contribute between 12.6-14.3% of the annual runoff generated phosphorus loadings to Lake Holden and the proposed enhancements to these sub-basins have the potential to substantially reduce the existing phosphorus loadings. These recommendations may require more time for implementation and may also involve a more expensive capital cost than the previous proposed activities, with the possible exception of recommendations for Sub-basin B-19.

Combined together, the proposed recommended stormwater treatment options have the potential to substantially reduce the existing runoff generated phosphorus loadings to Lake Holden. These activities will assist in maintaining the current excellent water quality which exists within the lake.

TABLE 4-4

SUMMARY OF RECOMMENDED STORMWATER TREATMENT OPTIONS FOR LAKE HOLDEN

IMPLEMENTATION PRIORITY	SUB-BASIN	PROPOSED ACTIVITIES	PERCENT OF RUNOFF TP LOADING (%)
Immediate (#1)	B-1, B-2, B-21	ERD recommends that alum addition rates be increased by approximately 1-2 mg Al/liter in Sub-basins B-1 and B-2 to attempt to reduce the treated total phosphorus concentrations to less than 50 μg/l. The Advisory Board should conduct independent evaluations to verify operation of the treatment systems by comparing alum addition volumes for monitored rain events within the watershed.	42.5
	B-4B	ERD recommends that a field monitoring program be conducted to verify improvements in total phosphorus concentrations in discharges from the wet detention pond following excavation and maintenance activities	16.2[1]
	B-7	A supplement field monitoring program should be conducted to identify the source of the substantially elevated nitrate levels observed in this basin.	3.7
#2	B-19	ERD recommends that the existing dry detention with filtration pond be converted to a wet detention facility to eliminate interception of groundwater and reduce phosphorus loadings to Lake Holden.	5.9
#3	B-12	ERD recommends that a feasibility evaluation be conducted to evaluate raising the outfall control elevation for the Sub-basin B-12 pond to increase permanent pool storage.	6.8
#4	B-13	ERD recommends that the Lake Holden Property Owners Association and Orange County conduct preliminary discussions with the adjacent property owner and FDOT to evaluate the potential feasibility of expanding the FDOT pond.	14.3
#5	B-20	ERD recommends that the Property Owners Association reconsider implementation of an alum-based treatment system for Sub-basin B-20	12.6

1. Prior to pond maintenance

SECTION 5

EVALUATION OF DRAINAGE WELL MODIFICATIONS

Water level elevations in Lake Holden are controlled by two drainage well structures which discharge excess lake water deep into the Floridan Aquifer. Lake Holden does not have a surface outfall and is generally considered to be a closed basin. Each of the two Lake Holden drainage wells, located on the northeast and southwest portions of the lake, were inspected by the Orange County Public Works Department during September 2006, and two drainage well structures were found to be in poor condition. Each of the drainage wells also received direct inputs of untreated stormwater runoff in addition to inflows from Lake Holden and is virtually unprotected from vandalism and unauthorized access. Evaluations of the two drainage wells were conducted by Devo Engineering which recommended replacement of the wells at each site.

The drainage well located on the southwest portion of Lake Holden (designated as DW-70) was replaced by Orange County during 2007, with the northeast drainage well (designated as DW-66) replaced during 2012. Well Completion Reports for each of the two wells were prepared by Devo Engineering which included a summary of the constructed well modifications and load testing to evaluate the capacity of the new wells. A discussion of each of the modified drainage wells is given in the following sections, along with a review of potential hydrologic impacts to Lake Holden. The Well Completion Report for drainage well DW-66 is included in Appendix C.1, with the Well Completion Report for drainage well DW-70 included in Appendix C.2.

5.1 Drainage Well DW-66

The historical drainage well DW-66 is located on the northeast side of Lake Holden, adjacent to 29th Street. The original well was located within a concrete and brick structure located adjacent to 29th Street and served as a combination street inlet and lake drainage outfall well for Lake Holden. Since this injection well also received untreated runoff, it provided a conduit for runoff pollutants directly to the Floridan Aquifer.

During 2012, the drainage well structure was sealed with grout, and the drainage well was relocated approximately 2,600 ft south to the community lake lot parcel owned by the Lake Holden Property Owners Association. A location map for the original and relocated drainage well DW-66 is given on Figure 5-1. An overview of the relocated drainage well DW-66 is given on Figure 5-2. The drainage well is located approximately 26 ft east of Lake Holden and connected to the lake through a 24-inch RCP.

Figure 5-1. Location Map for the Original and Relocated Drainage Well DW-66.

Details of the relocated drainage well DW-66 are provided on Figure 5-3. The drainage well is located inside a concrete structure which is connected to Lake Holden by a 24-inch RCP. Discharges into the well are regulated by an adjustable wooden weir, with potential control elevations ranging from 87.0-89.5 ft, although the weir structure will maintain a control level of 89.5 ft except under potential flooding conditions. Inputs into the well are screened using a bar guard device which prevents large items from entering the well structure. The control elevation of 89.5 ft for the new drainage well is slightly lower than the control elevation of 89.85 ft for the original drainage well.

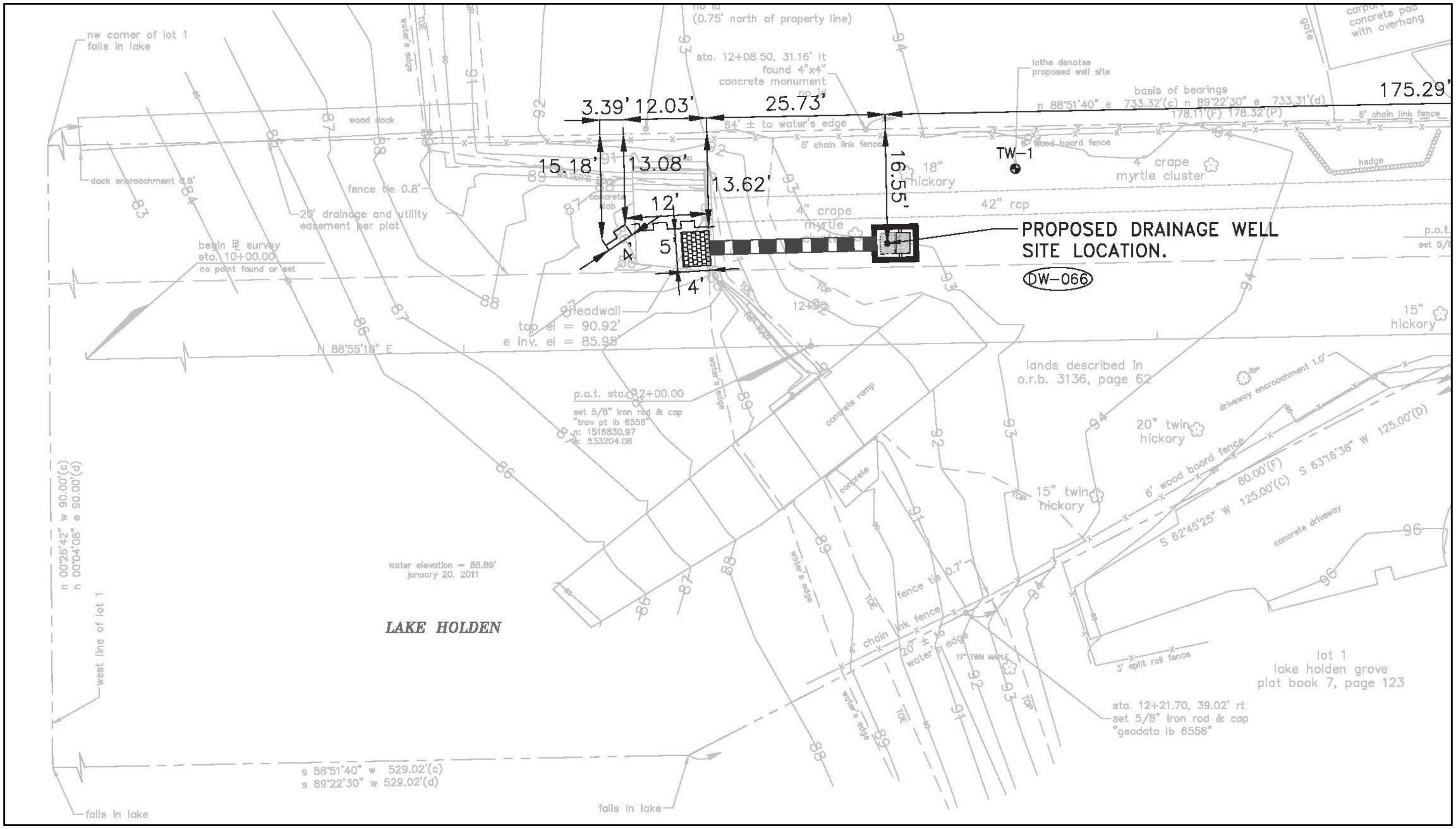
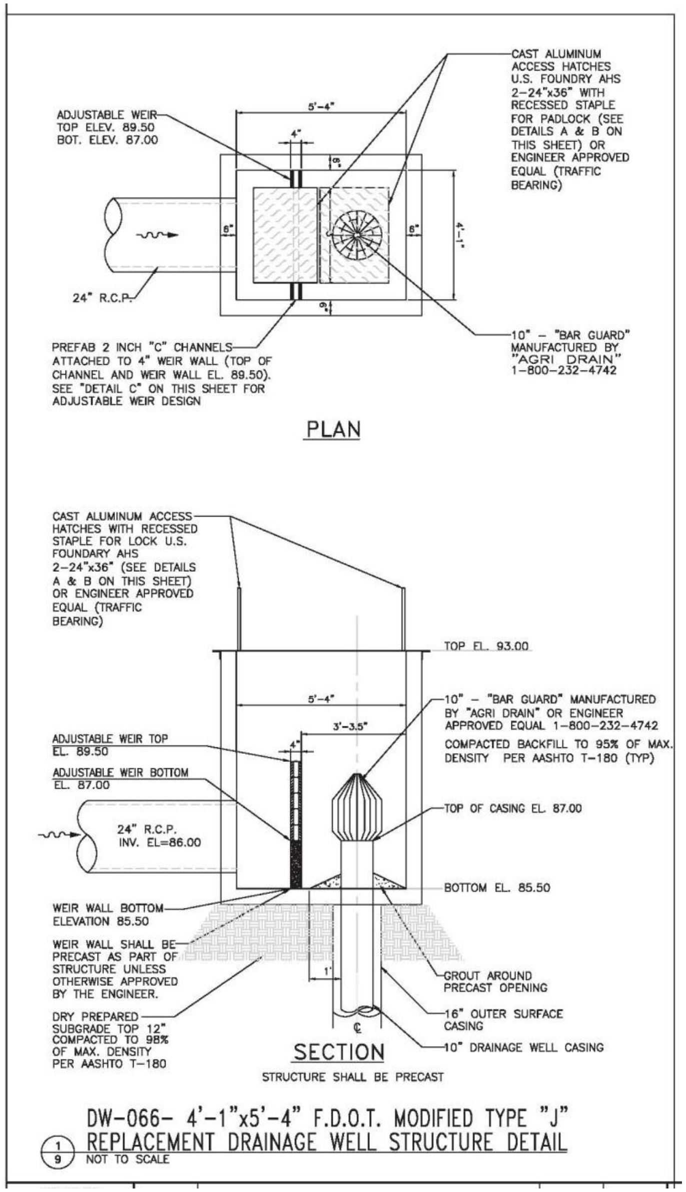


Figure 5-2. Overview of Drainage Well DW-66 Location and Lake Connection (Devo Engineering, 2012).



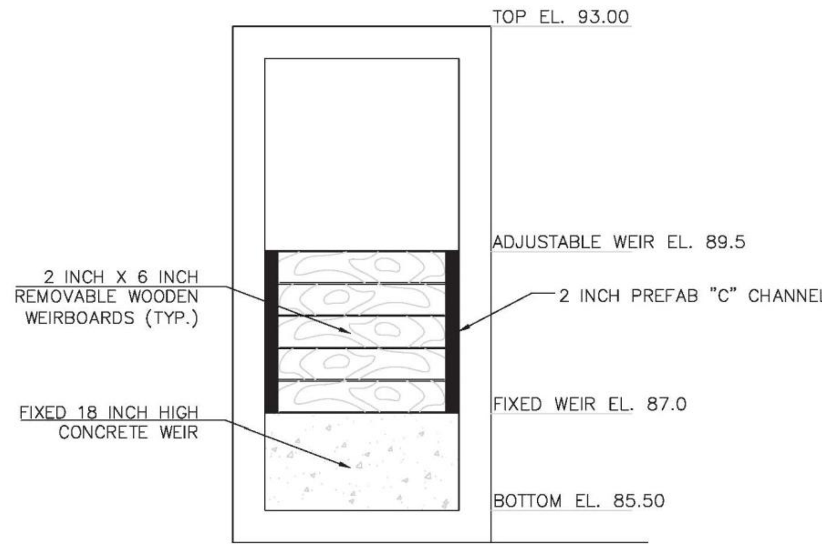


Figure 5-3. Drainage Well DW-66 Details (Devo Engineering, 2012).

A comparison of the original and renovated characteristics of drainage well DW-66 are given on Table 5-1 based upon information contained in the 2012 Devo Engineering report titled "Well Completion Report for the Construction of the 29th Street Drainage Well (DW-66)". Both the original and renovated wells consist of 10-inch diameter casing, although the original well casing extended to a depth of 129 ft, with casing extending to 100.5 ft for the renovated well. The total depth of the renovated well is less than the original well (420.5 ft vs. 236 ft), although pumping tests indicate that the geologic formation at this depth has substantial potential to receive water inflows. The control elevation for discharges through the original well were regulated by the elevation of the pipe which connects to Lake Holden which has a peak invert elevation of 89.85 ft. The renovated well provides a slight decrease in water intake elevations, with a lower control elevation of 89.5 ft. Overall, the new well provides a decrease in water level control elevation of approximately 0.35 ft in Lake Holden compared with the original well.

TABLE 5-1

COMPARISON OF ORIGINAL AND RENOVATED CHARACTERISTICS OF DRAINAGE WELL DW-66 (Source: Devo Engineering, 2012)

PARAMETER	ORIGINAL WELL	RENOVATED WELL
Diameter of Casing	10 inches	10 inches
Casing Depth	129 ft	100.5 ft
Total Depth	420.5 ft based on video log	236 ft
Elevation of Top of Casing	89.47 ft NAVD	87.0 ft
Water Control Elevation	89.85 ft	89.5 ft
Date Installed	Unknown	July 2012

Photographs of the installation of drainage well DW-66 (Devo Engineering, 2012) are given on Figure 5-4. The photographs show the intake structure and intake screen which prevents vegetation and large debris from entering the drainage well. A photograph of the weir boards used to regulate water intake level is also given on Figure 5-4, along with an overview of the completed construction site.

Attaching intake screen

Well intake structure

Weir boards used to regulate water intake level

Completed construction for DW-66

Figure 5-4. Photos of the Installation of Drainage Well DW-66 (Devo Engineering, 2012)

5.2 <u>Drainage Well DW-70</u>

Drainage well DW-70 is located on the southwest side of Lake Holden in a small cove near the intersection of 43rd Street and South Orange Blossom Trail. A location map for the original and renovated drainage well DW-70 is given on Figure 5-5. The original drainage well was evaluated during 2006 and replacement of the existing well was recommended. The original drainage well received direct stormwater inflow from a maintenance and parking area in addition to discharge from Lake Holden. Access to the drainage well structure required crossing private property. The concrete enclosure and headwall for the well were in very poor condition, and the drainage well structure was unprotected from vandalism and unauthorized access.

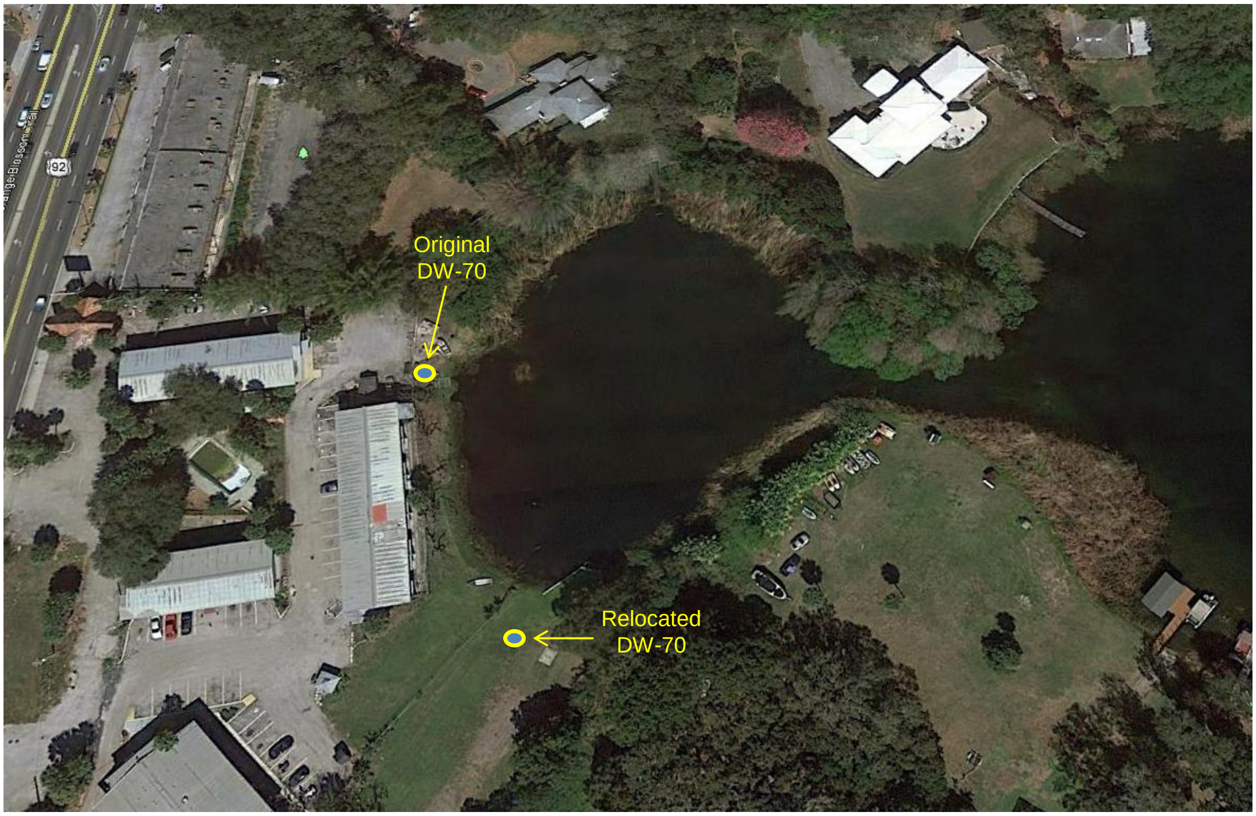


Figure 5-5. Location Map for the Original and Relocated Drainage Well DW-70.

The replacement drainage well DW-70 was relocated to a different portion of the small lobe to a parcel owned by Orange County to simplify access to the site for maintenance purposes. An overview of the location of drainage well DW-70 and the connection to Lake Holden is given on Figure 5-6 based on information contained in the 2010 Devo Engineering report titled "Well Completion Report for the Construction of Lake Holden DW-70 Drainage Well". The original drainage well consisted of a single 18-inch casing which was replaced by two 12-inch diameter wells and one 6-inch diameter well in relatively close proximity to each other. These three new wells provide the same cross-sectional area as the original historical drainage well, and are designated as drainage wells DW-70A (center), DW-70B (NW), and DW-70C (SE). The drainage wells are connected to Lake Holden through a 60-ft long, 24-inch RCP which feeds lake water into the drainage well system. Water from the lake enters a central splitter box which contains drainage well DW-70A and provides 18-inch RCP connections to drainage wells DW-70B and DW-70C.

Details for the three DW-70 drainage wells are provided on Figure 5-7. The introduction of water into the drainage well system is regulated by an adjustable weir riser, with adjustable elevations ranging from 87.5-91.0 ft. Each of the three well structures contain a bar guard to prevent vegetation and debris from discharging into the well.

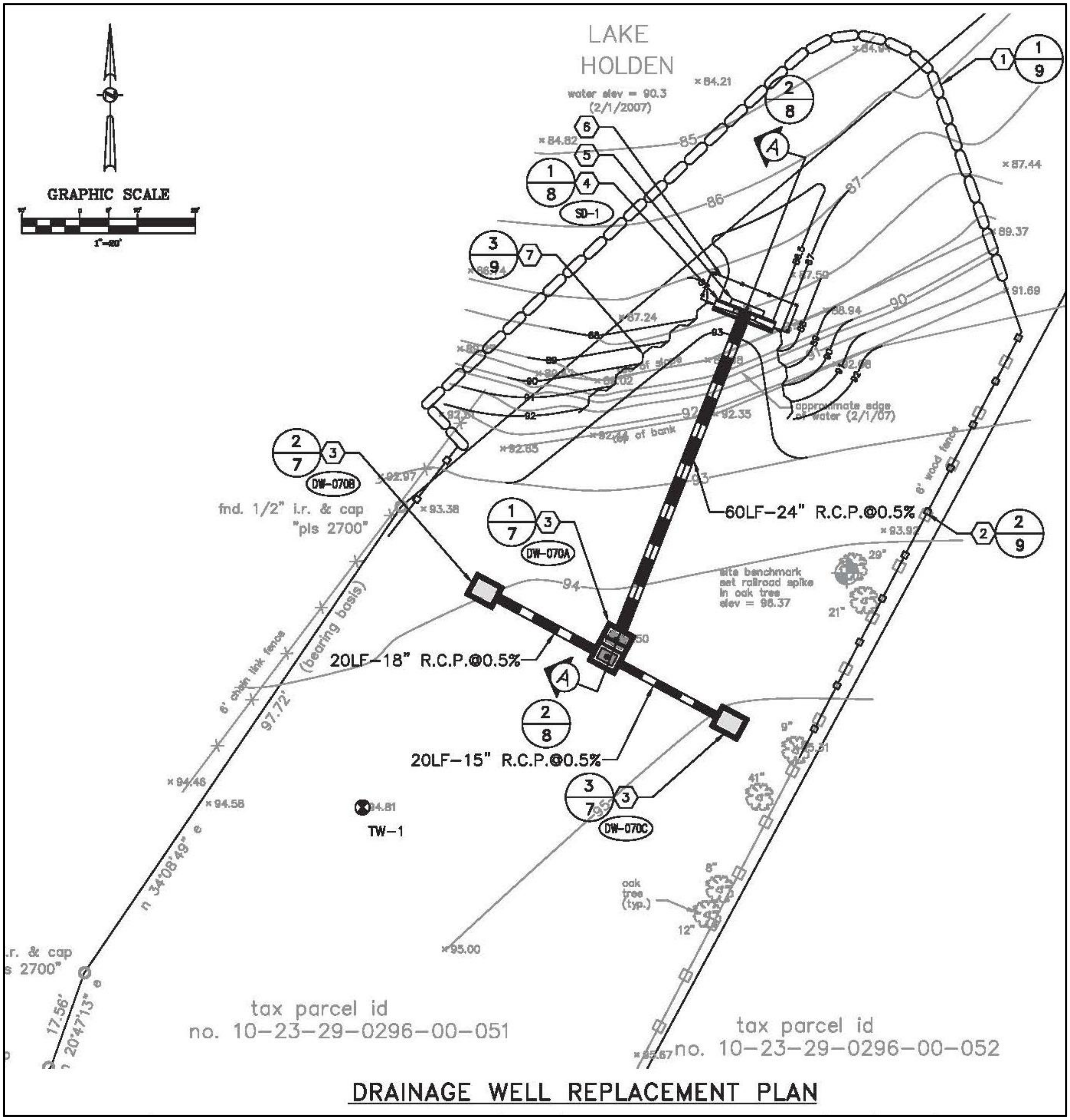


Figure 5-6. Overview of Drainage Well DW-70 Location and Lake Connection (Devo Engineering, 2010).

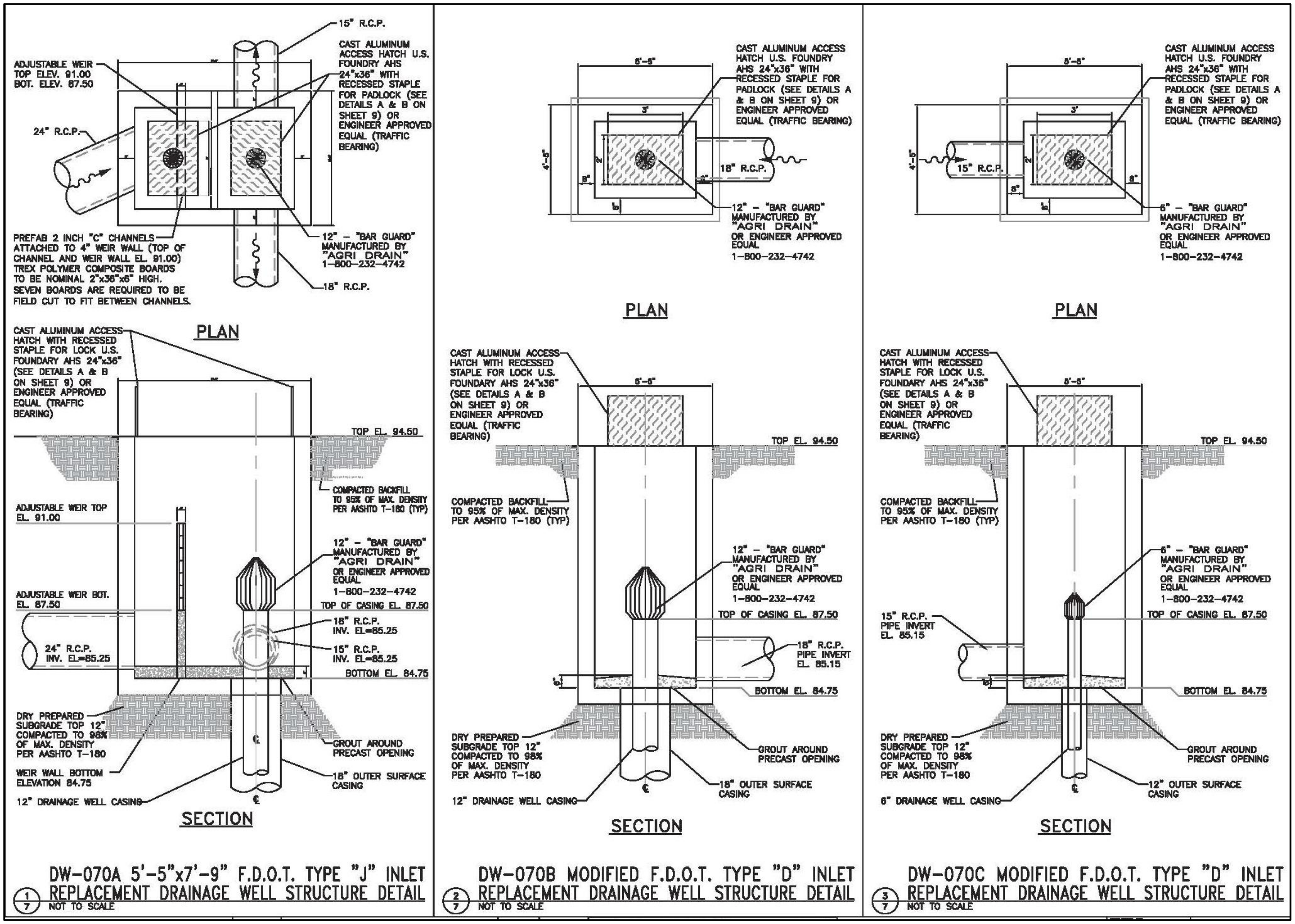


Figure 5-7. Details for the Three DW-70 Drainage Wells (Devo Engineering, 2010).

An overview of physical characteristics of the original drainage well DW-70 is given on Table 5-2. As indicated previously, the original well consisted of an 18-inch diameter casing which extended to a depth of approximately 104.5 ft below the ground surface. The total depth of the well was reported to be 600 ft, although the open bore holes subsequently collapsed at a depth of 171 ft. The elevation of the top of the casing, which regulated the level of discharges from the lake into the well, was 89.59 ft.

TABLE 5-2

ORIGINAL DRAINAGE WELL DW-70 DETAILS
(Source: Devo Engineering, 2010)

PARAMETER	ORIGINAL WELL
Diameter of Casing	18 inches
Casing Depth	104.5 ft (as measured during well inspection performed during Sept. 2006)
Total Depth	600 ft (reported in County records); well was cleaned out down to a depth of 454 ft during Sept. 2006; however, open borehole subsequently collapsed at the 171 ft depth
Elevation of Top of Casing	+89.59 ft NGVD (surveyed Feb. 2007)
Date Installed	Unknown

A summary of physical characteristics of the relocated drainage well DW-70 is given on Table 5-3. The replacement wells consist of two 12-inch and one 6-inch diameter wells which extend to depths of 108-116 ft, and have total depths ranging from 177-197 ft. The well elevations at the top of the casing range from 87.50-87.62 ft. However, discharges to the drainage wells at this site do not begin until the water level in Lake Holden exceeds the top of the adjustable weir at elevation 91.00 ft. Photographs of installation and construction of drainage well DW-70 are given on Figure 5-8.

Shortly after installation of the three DW-70 drainage wells, a geysering effect was noted on drainage well DW-70A. To correct the geysering problem, removable PVC sleeves were placed on drainage wells DW-70A and DW-70B. The sleeve on the top of drainage well DW-70A was equipped with a vertical slot, measuring 4 inches tall and 6 inches wide, with the invert elevation set at the top of the casing. The sleeve on drainage well DW-70B was equipped with a slot measuring 4 inches tall and 14 inches wide, with the invert elevation also set at the top of the casing elevation. These modifications appear to have corrected the observed geysering activities.

TABLE 5-3

RELOCATED DRAINAGE WELL DW-70 DETAILS
(Source: Devo Engineering, 2010)

PARAMETER	DW-70A	DW-70B	DW-70C
Outer Casing Diameter	18 inches	18 inches	14 inches
Depth of Outer Casing	105 ft	108 ft	105 ft
Well Casing Diameter	12 inches	12 inches	6 inches
Depth of Well Casing	108 ft	116 ft	116 ft
Open Bore Hole Diameter	12 inches	12 inches	6 inches
Depth of Open Bore Hole	177 ft	193 ft	197 ft
Elevation at Top of Casing	87.57 ft NGVD	87.62 ft NGVD	87.5 ft NGVD
Weir Elevation	Adjustable: 87.6-91.0 ft NGVD		

Wellhead structure for DW-70A

Intake structure with skimmer and trash screen

Weir boards used to regulate water intake level

Completed construction for DW-70A

Figure 5-8. Photos of the Installation of Drainage Well DW-70 (Dev, 2010)

5.3 Evaluation of Hydrologic Impacts from the Modified Drainage Well Structures

Concerns were raised by members of the Lake Holden POA concerning potential impacts to water level elevations in Lake Holden from the revised drainage well structures. To address this issue, an analysis was conducted by ERD to evaluate mean annual discharges to the drainage well structures under the original and revised drainage well systems. Available historical water level elevation for Lake Holden was obtained from the Lake Holden POA website over the period from 1958-2008. The available water level information for each year was averaged together to obtain an estimate of the mean annual water level elevation for each year of record. Hydrologic models were then developed to estimate the mean annual discharge rates into the drainage well structures under the original and revised conditions.

The model reflecting the original historical drainage well system used an assumed inflow invert elevation of 89.85 ft for drainage well DW-66 and an inflow invert elevation of 89.59 ft for drainage well DW-70. This analysis resulted in an estimate of the annual average inflow rate to each of the two wells for each annual period based upon the mean annual water surface elevation. A summary of this analysis is given in Table 5-4. Over the available period of record, the average discharge to the historical drainage well DW-66 was 1.12 cfs, with an average discharge of 2.99 cfs into drainage well DW-70. Overall, approximately 813 ac-ft of water discharged to drainage well DW-66 each year, with 2,164 ac-ft of lake water discharging to drainage well DW-70, with a combined inflow for the two original drainage wells of approximately 2,977 ac-ft/yr.

An additional hydrologic model was developed to evaluate discharges into the revised weir structures based upon the constructed designs. This analysis assumes that inflows into drainage well DW-66 occur when lake water exceeds the inflow weir elevation of 89.5 ft, while discharges into drainage well DW-70 are not initiated until the water level elevation reaches 91.0 ft. Under these conditions, the majority of discharges from the lake occur through the DW-66 structure, with only a small annual discharge into the DW-70 structure. Estimates of mean annual inflows into drainage well DW-66 were calculated for each of the years with available water level data to estimate what the drainage well inflow volumes would have been if the revised weir structures had been in place since 1958. Over this period of record, the mean annual inflow to drainage well DW-66 would have been approximately 4.12 cfs, with an annual inflow to drainage well DW-70 of only 0.24 cfs. The mean annual discharge to drainage well DW-66 would have been 2,986 ac-ft/yr, with an annual inflow of 170 ac-ft/yr to drainage well DW-70. Overall, the two combined wells would have discharged approximately 3,156 ac-ft/yr which is approximately 6% greater than the estimated annual discharge of 2,977 ac-ft/yr through the original drainage well structures.

The previous analysis suggests that the revised drainage well structures will have little impact on overall hydrology of water levels in Lake Holden. However, as indicated on Table 5-4, mean annual discharges to drainage well DW-66 at an invert elevation of 89.5 ft ranged from 0-16.46 cfs. The specific capacity of the drainage wells was not evaluated as part of the study conducted by Devo Engineering, so it is not known if the drainage well system is capable of accepting some of the more elevated discharge values, particularly those in excess of 10 cfs. Therefore, although the hydraulic analysis indicates that the intake volumes would be approximately equal between the original and modified weir structures, drainage well DW-66 may not be acceptable of accepting all of the estimated inflows, and water level elevations in Lake Holden may be slightly higher under the revised drainage well system compared with the original design.

TABLE 5-4

COMPARISON OF MEAN ANNUAL INFLOW RATES TO LAKE HOLDEN DRAINAGE WELLS UNDER ORIGINAL AND REVISED CONDITIONS

YEAR	MEAN ELEVATION (ft)	DRAINAGE WELL FLOW RATES (cfs)			
		Original Drainage Wells		Revised Drainage Wells (Weirs @ 89.5 and 91.0 ft)	
		DW-66	DW-70	DW-66	DW-70
1958	90.53	2.03	5.25	7.42	0.00
1959	90.64	2.13	6.25	8.59	0.00
1960	91.05	4.83	7.42	11.41	2.19
1961	89.95	0.72	2.63	3.47	0.00
1962	88.69	0.00	0.00	0.00	0.00
1963	89.70	0.56	1.48	2.06	0.00
1964	90.56	2.14	5.56	7.74	0.37
1965	89.67	0.03	1.43	1.65	0.00
1966	89.68	0.83	2.60	3.53	0.00
1967	90.28	1.59	4.28	5.93	0.06
1968	90.20	1.56	3.80	5.38	0.00
1969	90.64	2.37	6.03	8.41	0.29
1970	90.78	3.32	6.43	9.40	1.05
1971	90.16	1.43	3.53	4.99	0.00
1972	90.75	2.78	6.60	9.41	0.12
1973	90.98	4.19	7.28	10.90	1.47
1974	90.53	2.90	5.49	8.06	1.17
1975	90.70	3.27	5.87	8.78	1.00
1976	90.37	1.35	4.68	6.25	0.00
1977	89.94	0.54	2.77	3.50	0.00
1978	90.23	1.27	4.03	5.44	0.00
1979	90.31	1.08	4.33	5.66	0.00
1980	89.90	0.33	2.37	2.95	0.00
1981	88.40	0.00	0.00	0.00	0.00
1982	90.04	1.65	3.61	5.21	0.20
1983	90.82	3.33	6.62	9.75	0.58
1984	90.66	2.43	6.20	8.68	0.05
1985	90.22	1.31	3.80	5.19	0.05
1986	90.83	3.31	6.74	9.87	0.50
1987	90.79	3.25	6.52	9.56	0.57
1988	91.13	4.83	7.90	12.18	0.82
1989	90.51	2.03	5.27	7.34	0.16
1990	89.90	0.36	2.42	2.95	0.00
1994	91.84	8.88	9.95	16.46	6.15
1995	91.67	8.31	9.53	15.64	5.08
1996	90.47	1.72	5.20	7.09	0.01
1997	89.79	0.35	1.60	2.05	0.03
1998	90.18	1.21	3.62	4.95	0.02
1999	89.52	0.09	1.15	1.37	0.00
2000	88.42	0.00	0.15	0.17	0.00
2001	87.92	0.00	0.02	0.03	0.00
2002	89.86	1.61	3.45	5.00	0.18
2003	90.50	1.73	5.40	7.31	0.07
2004	90.70	3.31	5.73	8.52	1.61
2005	90.52	1.86	5.52	7.51	0.15
2006	89.52	0.18	1.53	1.85	0.00
2007	89.54	0.09	1.20	1.42	0.00
2008	90.13	1.53	2.94	4.25	0.88
Average	**89.79**	**1.12**	**2.99**	**4.12**	**0.24**
Mean Inflow (ac-ft/yr)		**813**	**2,164**	**2,986**	**170**
Total Inflow (ac-ft/yr)		**2,977**		**3,156**	