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1.0 Introduction

The Winter Haven Chain of Lakes (WHCL) are Southwest Florida Water Management District (SWFWMD) Surface Water Improvement and Management (SWIM) priority waterbodies and consists of 24 interconnected lakes divided into the Southern and Northern Chains. Many of these lakes have been adversely impacted by historical point and non-point sources of pollution and many have been listed as impaired by the Florida Department of Environmental Protection (FDEP). FDEP has proposed Total Maximum Daily Loads (TMDLs) for impaired lakes in the Southern Chain of Lakes. FDEP did not propose TMDLs for impaired lakes in the Northern Chain of Lakes due to the uncertainty associated with pollutant loadings from atmospheric deposition, groundwater, septic tanks and lake bottom sediments.

1.1. Purpose

The purpose of this report is to provide the FDEP with additional water quality and sediment information needed to complete the TMDL for the Northern Chain of Lakes, and required by the City to address their *Winter Haven Chain of Lakes Water Quality Management Plan*. To accomplish this objective, four lakes in the Northern Chain of the Winter Haven Chain of Lakes (Haines, Rochelle, Smart, and Conine) were studied to examine the potential influence of groundwater and sediment characteristics on water budgets of the lakes. The following components were included as part of the study

- The groundwater seepage element included installing and monitoring surficial aquifer wells adjacent to each of the four lakes and measuring groundwater infiltration and water quality into the lake using groundwater seepage volume meters.
- The sediment element included collecting sediment cores from each lake, characterizing physical and chemical constituents in the sediments, and evaluating potential differences in sediments in the lakes.
- Long-term rainfall, lake levels, and groundwater data were reviewed and, in combination with field data from this study, used to evaluate the relationships among rainfall, surficial aquifer water elevations, and lake stage.

This report first presents a characterization of the physiography, topography, and soils of the WHCOL region that provides the context for the study. The second section of the report includes a description of the methods used for installing and monitoring surficial aquifer wells and seepage meters and is followed by the analyses and results used in evaluating the influence of groundwater infiltration on lake water budgets. Conclusions are presented that summarize the findings and implications of the study.

1.2. Background

Prior efforts to develop nutrient budgets for the WHCL system include the “Winter Haven Chain of Lakes PLRG Study” completed in 2005 for SWFWMD-SWIM by researchers from the University of South Florida, and the report “Nutrient TMDL for the Winter Haven Southern Chain of Lakes” completed by FDEP in 2006. In 2007, Environmental Research and Design, Inc (ERD) completed water and nutrient budget calculations for Lakes Shipp, May and Lulu as part of the “Winter Haven Chain of Lakes Sediment Removal Feasibility Study” for the City of Winter Haven.

Water and nutrient budgets can be calculated using multiple techniques: development of a “Gross Budget”, more complex modeling techniques, and direct measurement. Most budgets use a combination of these three approaches. The error that is associated with each technique can be minimized with proper evaluation and thorough review. Multiple assumptions are required when using the Gross Budget and modeling techniques (i.e., calculation through subtraction, selection of appropriate equation constants, generalization of site specific interactions, data extrapolation) which can lead to compounded and often unquantified errors. When direct measurements are made as part of an experiment, error can be increased due to faulty experimental design, inadequate site selection, or inappropriate data extrapolation.

Groundwater is considered a significant component of both water and nutrient budgets for the WHCL, although groundwater contributions to nutrient loads have not yet been adequately quantified. In the 2005 report conducted for SWFWMD-SWIM, groundwater contributions were estimated using information on groundwater elevations from two wells in the Chain of Lakes, one in the Northern Chain (near Lake Smart) and one in the Southern Chain (near Lake Lulu). While extremely limited in their geographic scope, these data indicated that groundwater elevations were higher than lake levels, thus suggesting a major influence of groundwater on water and nutrient budgets. For groundwater quality, USF (2005) noted that “There were five surficial wells in Polk County that had water-quality data. Only one of these wells is within the basin boundaries, shown in that report as the surficial well located between Lakes Eloise and Lulu. This well had three recorded data points, sampled on 3/17/1993, 3/4/1996, and 5/25/1999.” Therefore, the entire data set used for validating the assumptions in the groundwater loading portion of the Pollutant Load Reduction Goals (PLRG) study for the WHCL in the USF (2005) study seems to be limited to elevation data reported for one well location each in the Southern and Northern Chains, and one in the Southern Chain for which water quality was reported on three dates.

The FDEP (2006) TMDL report for the WHCL included the statement that “A larger proportion of the load to the Northern Chain of Lakes is derived from groundwater, which makes up 29 percent of the total load, compared with only 4 percent of the total load to the Southern Chain of Lakes”. While these conclusions may be accurate, they are based on model results from USF (2005) that contained a limited amount of data for model validation, as described above.

Therefore, current loading models and TMDL calculations are constrained by the level of information on groundwater contributions to water and nutrient budgets. Water quality data for calibrating and validating groundwater contributions appear to be limited to data collected at a

single location in the Southern Chain of Lakes, three times over a six year period. It would seem prudent to view load reduction allocations based on these data with caution until more detailed information on nutrient loadings associated with groundwater inputs can be developed.

The City of Winter Haven has recently initiated the Winter Haven Chain of Lakes Water Quality Model and Management Plan. The objective of this Plan is to identify the projects and programs necessary to ensure that the quality of water in the Northern and Southern Chain of Lakes meets the water quality objectives of the City and the regulatory requirements of FDEP. In Phase I of the City's Plan, available data related to source, volume, and pollutant load to the WHCL were reviewed. The FDEP concluded, as part of the TMDL for the southern Chain of Lakes, that additional data are needed to describe the contribution of groundwater and lake sediments in the pollutant load to the WHCL.

2.0 Watershed Characteristics

The hydrogeology, land use, physiography, topography and soil types of the Winter Haven watershed all directly affect the interaction of the surficial and Floridan aquifer with the neighboring lakes. Brief descriptions of these important factors are presented below:

2.1. Hydrogeology

The general hydrogeologic units underlying the WHCL watershed, as well as their effects on lake hydrology are discussed below; most of this information is taken from Sinclair & Reichenbaugh (1981). The principal hydrogeologic units underlying the WHCL watershed consist of the surficial aquifer system and the Floridan aquifer system. The surficial aquifer in the Winter Haven area is composed of clean, well-sorted sands that grade downward into clayey sand and sandy clay, with thickness ranging from 75 to 100 feet. It is underlain by dense, relatively impermeable clay about 100 feet thick, which is commonly phosphatic and sandy with thin layers of limestone and dolostone. This poorly permeable material forms a confining bed that retards movement of water from the surficial aquifer to the limestone of the Floridan aquifer. Limestone underlies the surficial deposits to depths of several thousand feet.

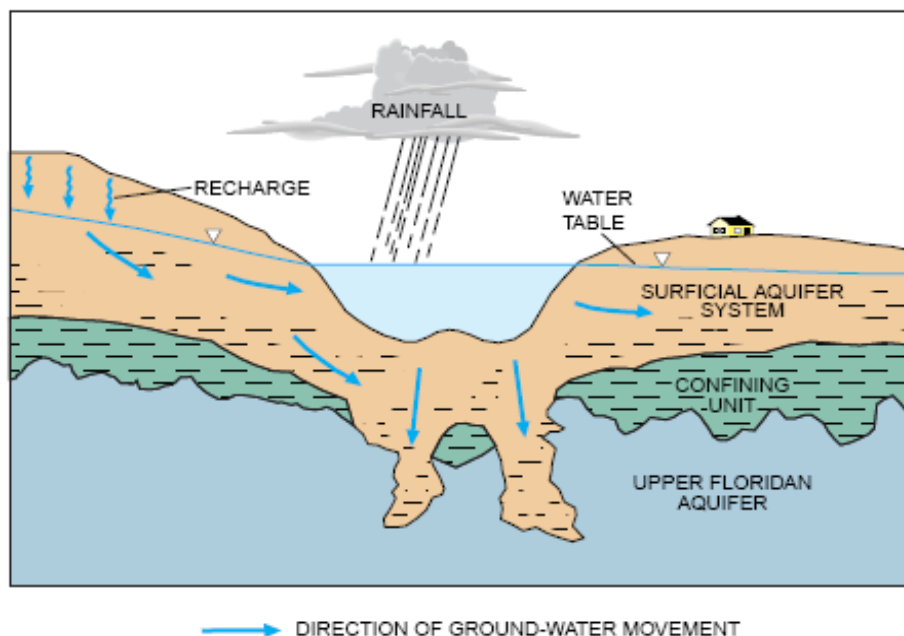
Surface drainage in the area is poorly developed because of the highly pervious nature of the sandy soils. Rain that does not fall on the lakes or is routed to the lakes via directly connected impervious surfaces can be “lost” via evaporation and/or transpiration. The remaining quantity rainfall can percolate downward through the sand. Locally this water may enter an adjacent lake as groundwater seepage, but eventually water in the surficial aquifer and lakes that is not returned to the atmosphere or released as surface flow continues downward through the sandy clay to the limestone aquifer. A generalized section of the system (Figure 1) illustrates the interactions between lake surface waters and the primary aquifer systems.

The water table generally reflects the topography of the land surface. It is highest where the land surface is high and lowest where the land surface is low. The lakes represent areas where the land surface dips beneath the water table. Lateral movement of water through the surficial aquifer is generally confined to individual lake basins because of the high water table surrounding the basins. In low-lying areas, lateral movement of water through the surficial aquifer may take place. Figure 2 illustrates six scenarios of surface and groundwater recharge and discharge.

In addition to including water from the surficial aquifer that drains to the lakes via groundwater seepage, the lakes can also be areas of downward leakage (recharge) to the Floridan aquifer (USGS 1999). The lakes occupy basins that have developed by subsidence of the surficial material into solution cavities in the Floridan aquifer. Water levels in the underlying Floridan aquifer are generally lower than the lake levels; thus, water generally moves downward from the lakes and the surficial aquifer through breaches in the confining clay layer to the Floridan aquifer (Figure 3b). In contrast, in areas where the confining layer is thin, the Florida aquifer can discharge into both the surficial aquifer and lake (Figure 3c). While a direct connection to the

Floridan aquifer may be present, the presence of mucky sediments in the center of the lakes has the potential to reduce and/or eliminate recharge and/or discharge to or from the Floridan aquifer. Lakes Haines, Rochelle, Smart and Conine all show evidence consistent with these lakes receiving groundwater inflow from the adjacent surficial aquifer. Specifically, the stage in Lake Haines fluctuates with changes in the surficial aquifer, not the Floridan aquifer, indicating a more direct interaction with the surficial aquifer (shown later in the report).

Figure 1. Generalized cross section of groundwater flow and hydrogeology through a Florida lake (source: USGS 1999)



The potentiometric surface around the study lakes was 110-120 feet NGVD, according to the May 2006 (dry season) potentiometric map for the Upper Floridan aquifer published by SWFWMD. Water level data indicate that the potentiometric surface of the Floridan aquifer declines from north to south across the WHCL watershed, resulting in an increase in the hydraulic gradient between the surficial aquifer and the Floridan aquifer as one proceeds south in the basin, and thus a corresponding increase in the potential for downward leakage.

Hydraulic conductivity (both lateral and vertical) of the surficial aquifer system is another key factor affecting groundwater flow into and out of the WHCL. Lateral hydraulic conductivities in the well-sorted sands of the surficial aquifer typically range from as little as 1 to as much as 100 feet/day (Fetter, 1980). Comparatively, a vertical hydraulic conductivity of 0.30 feet/day was assumed between the lakes and the underlying Floridan aquifer and is assumed representative of the WHCL watershed (Driscoll, 1986). Typically, surficial aquifer flows into the lakes are greatest during the late summer and early autumn months following the accumulation of rainfall during the wet season. Conversely, groundwater losses from the lakes via downward leakage to the Floridan aquifer are highest during the late spring and early summer months (April, May, and

June) of the dry season when the gradients between lake levels and the potentiometric surface are greatest.

**Figure 2. Six main classes of surface and groundwater movement in lakes
(From Boyle 1994)**

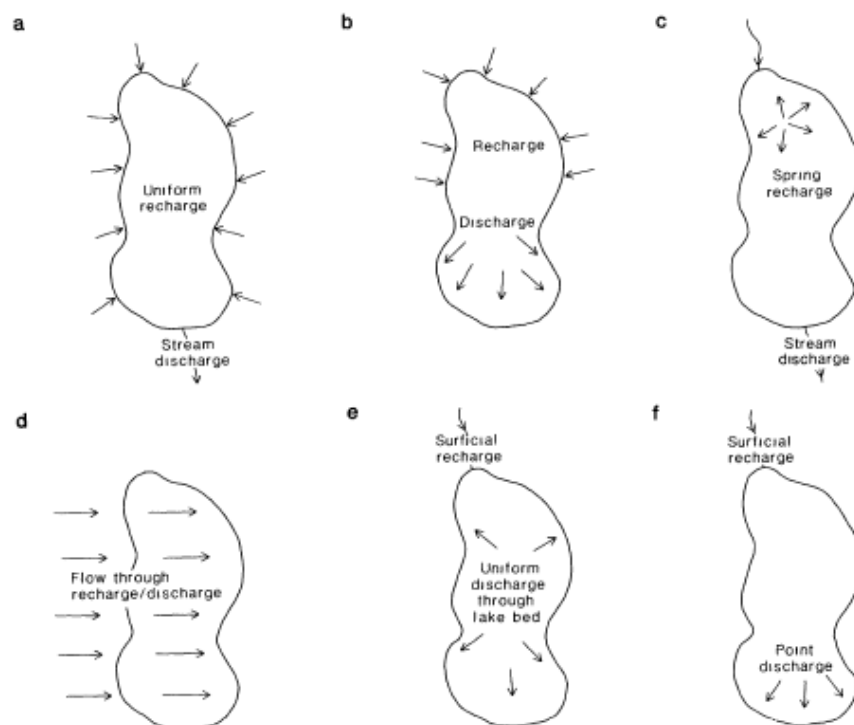
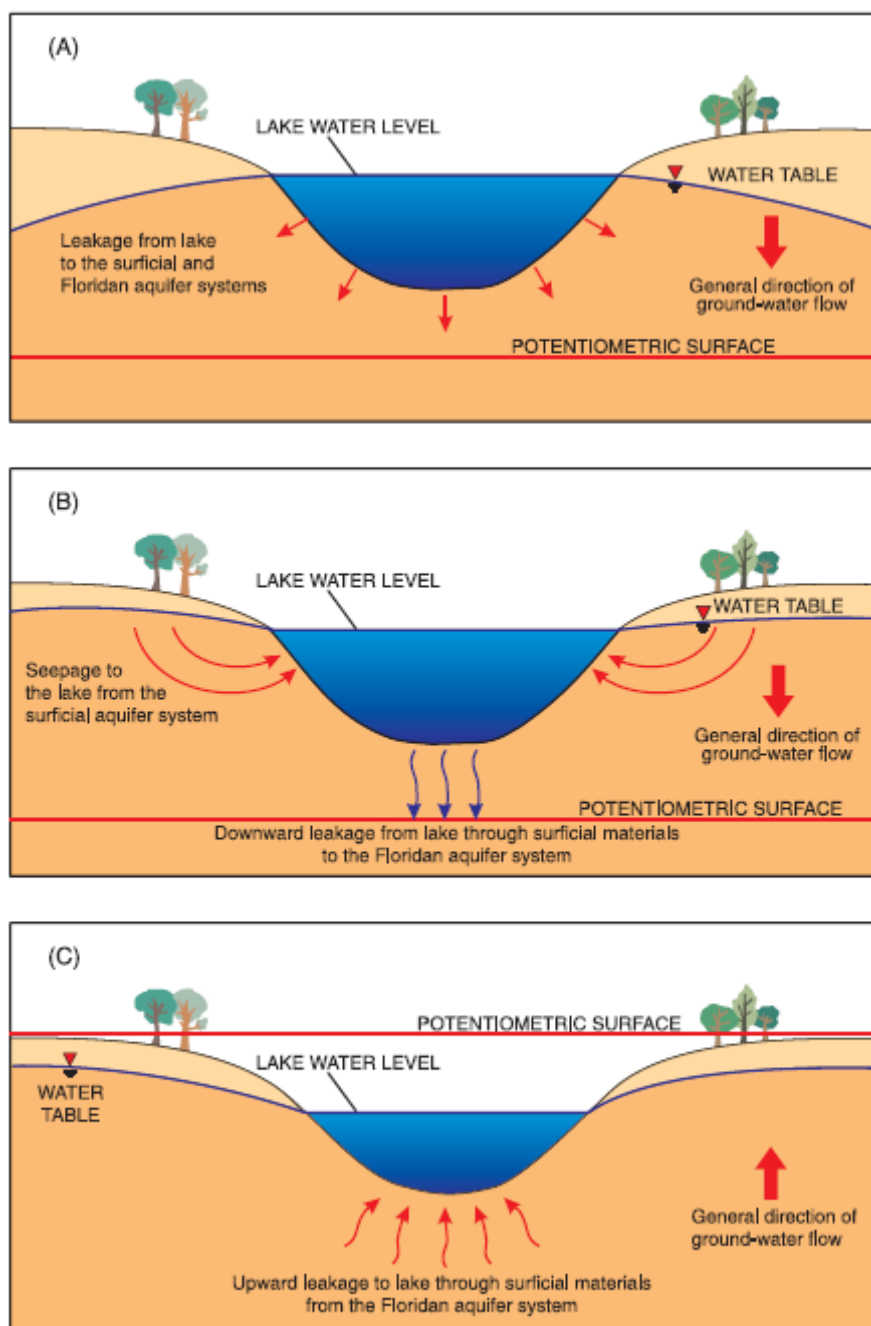


Figure 3. Interaction between groundwater and lake water levels (From Schiffer 1998)



EXPLANATION

→ FLOW PATH

2.2. Physiography, Soils and Topography

Recently, PBS&J submitted a report to the FDEP entitled “Winter Haven Chain of Lakes Pre-BMAP Assessment: An Interpretative Synthesis of Existing Information” (PBS&J 2008). This report provided a review of the physiography, topography and soils within the WHCL. An overview of this information is provided below:

Three main physiographic regions make up the WHCL region: the Lake Wales Ridge, the Winter Haven Ridge, and the Polk Uplands (Figure 4). The Lake Wales Ridge and Winter Haven Ridge are both positioned at higher elevations than the nearby Polk Uplands. Lake Haines, Rochelle, Smart and Conine are all located within the Polk Uplands region with elevations around 130 feet (NGVD). For the most part, lakes in the Polk Upland are located in a “valley” of sorts between lakes perched on the higher elevations of the Lake Wales and Winter Haven Ridges. The elevation gradient surrounding the lakes allows for an increased slope between the adjacent landscape and the lakes, permitting groundwater flow into the lakes from the surficial aquifer.

The elevations in the region of the four study lakes vary considerably based upon a digital elevation model generated from LiDAR data (Figure 5 to 7). The area of greatest elevation change in Lake Haines is located on the west side of the lake ranging from 175 to 130 feet NGVD (Figure 5). At Lake Rochelle, the highest point is found along the northern rim (170 feet NGVD) sloping to 130 NGVD along the lakes edge (Figure 6). A ridge between Lakes Conine and Smart ranges from 175 to 130 feet NGVD in elevation (Figure 7).

The soils in the region of the four lakes of interest consist of predominantly moderately to poorly drained soils (Samsula-Hontoon) with a lower mineral content and a higher organic content (Figure 8). However, lakes located within the Winter Haven Ridge physiographic region have soils that are mostly those of the Candler-Tavares-Apopka groups - well drained and sandy soils with a high mineral content and low organic content. The soils of the Winter Haven Ridge region allow for high permeability and the recharge of the surficial aquifer which in turn has the potential to move downward and laterally toward the lower-lying valley-type lakes of Lakes Haines, Rochelle, Conine and Smart.

Figure 4. Physiographic Regions within the Vicinity of the WHCL

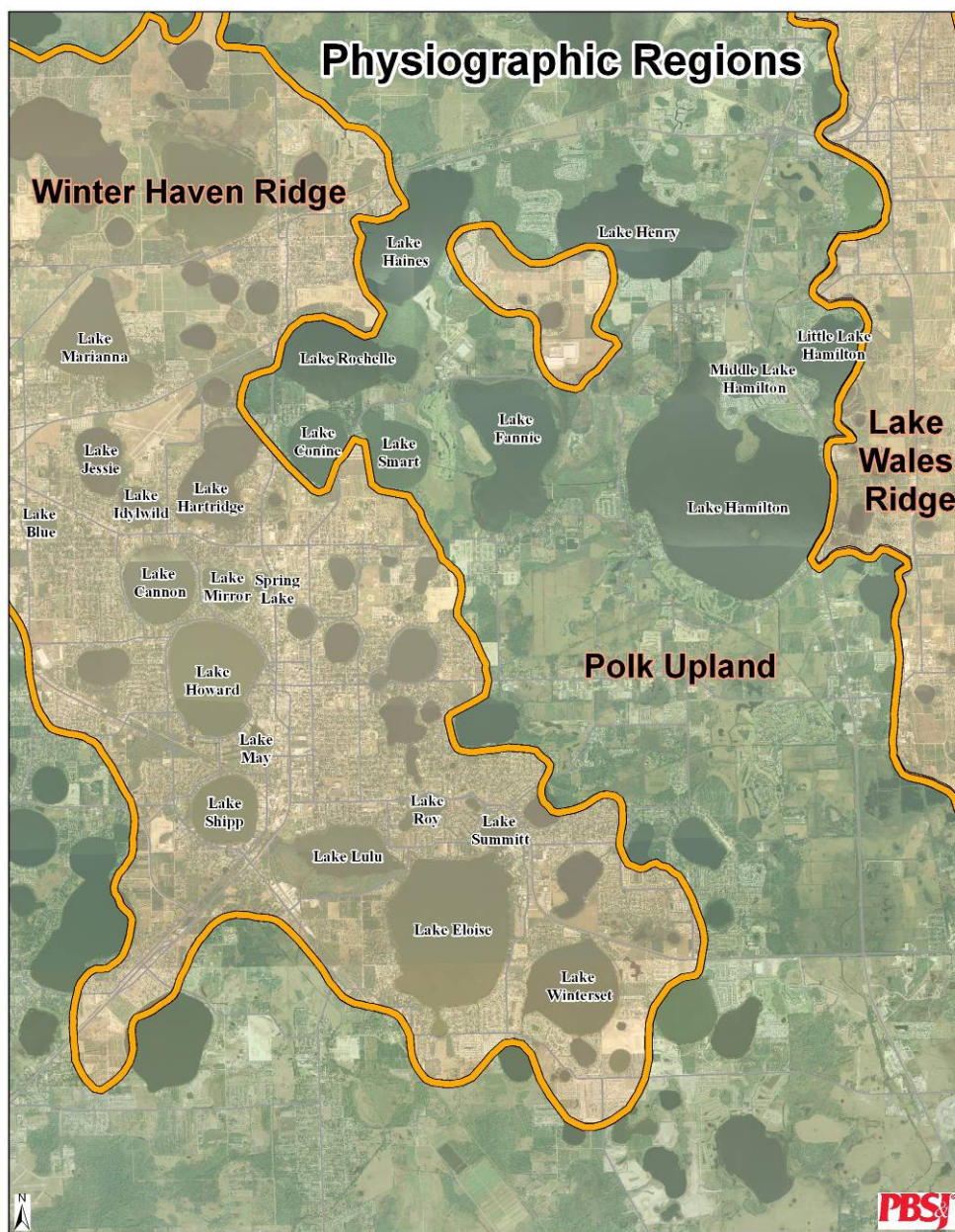


Figure 5. Lake Haines Digital Elevation Model (feet NGVD)

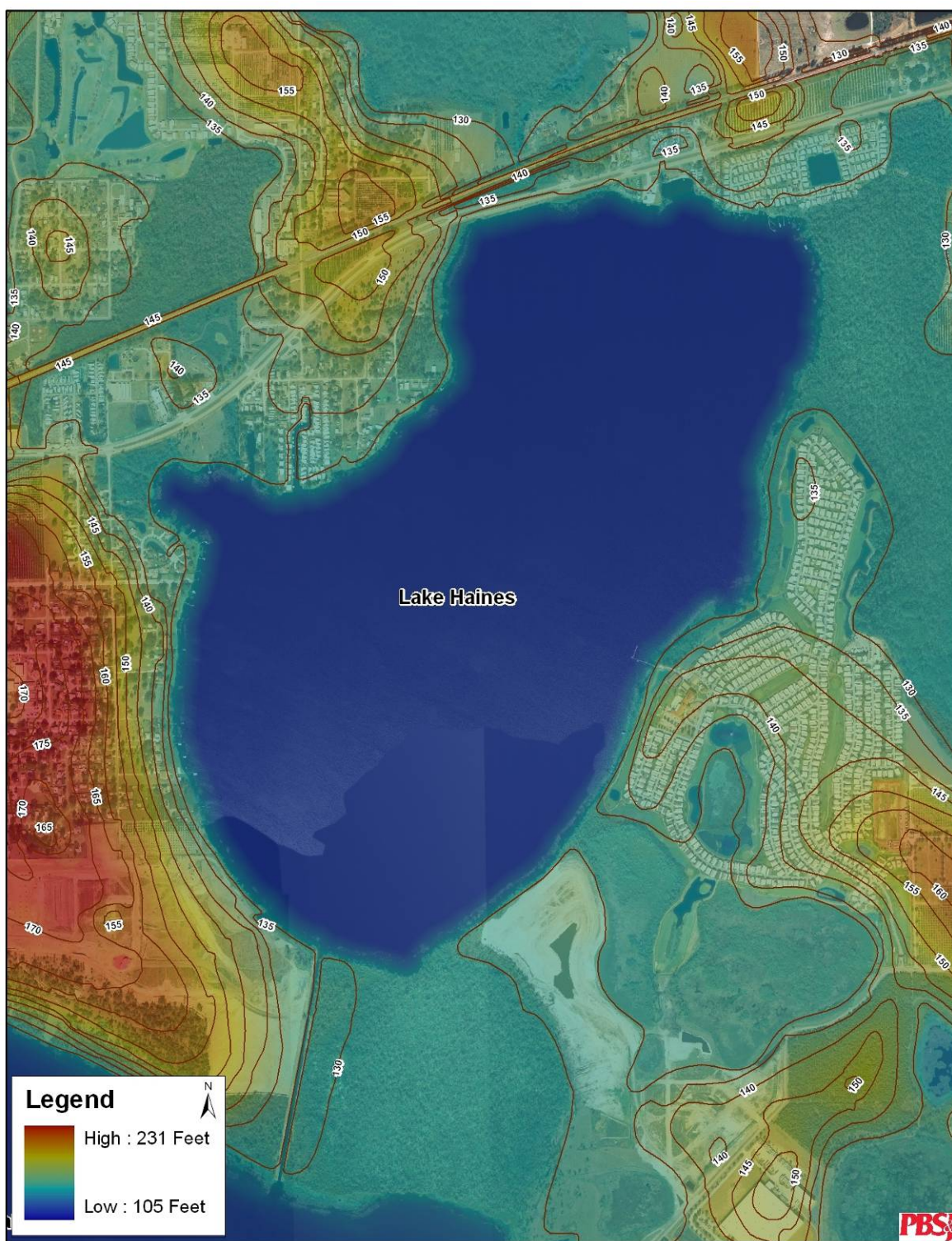


Figure 6. Lake Rochelle Digital Elevation Model (feet NGVD)

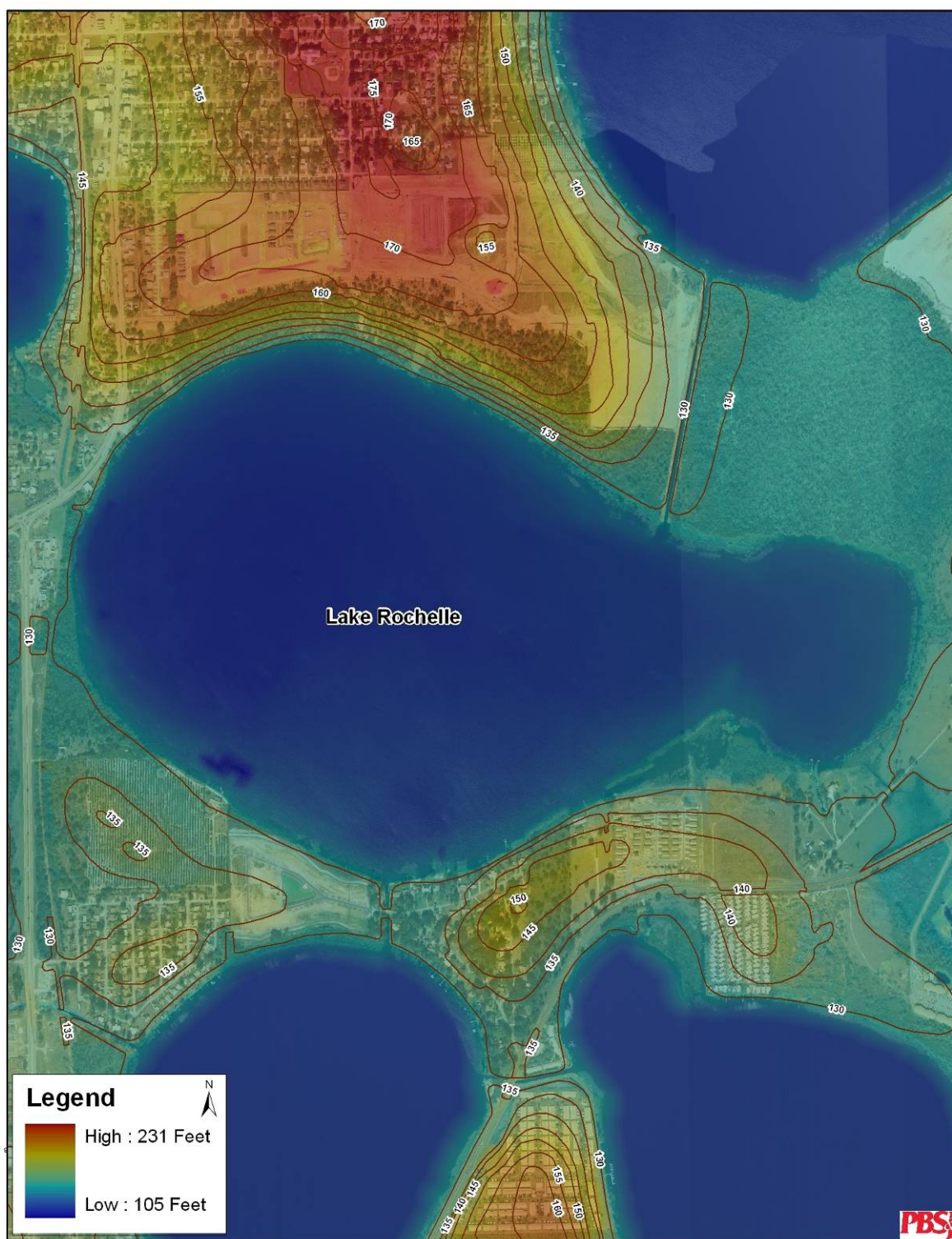


Figure 7. Lakes Conine and Smart Digital Elevation Model (feet NGVD)

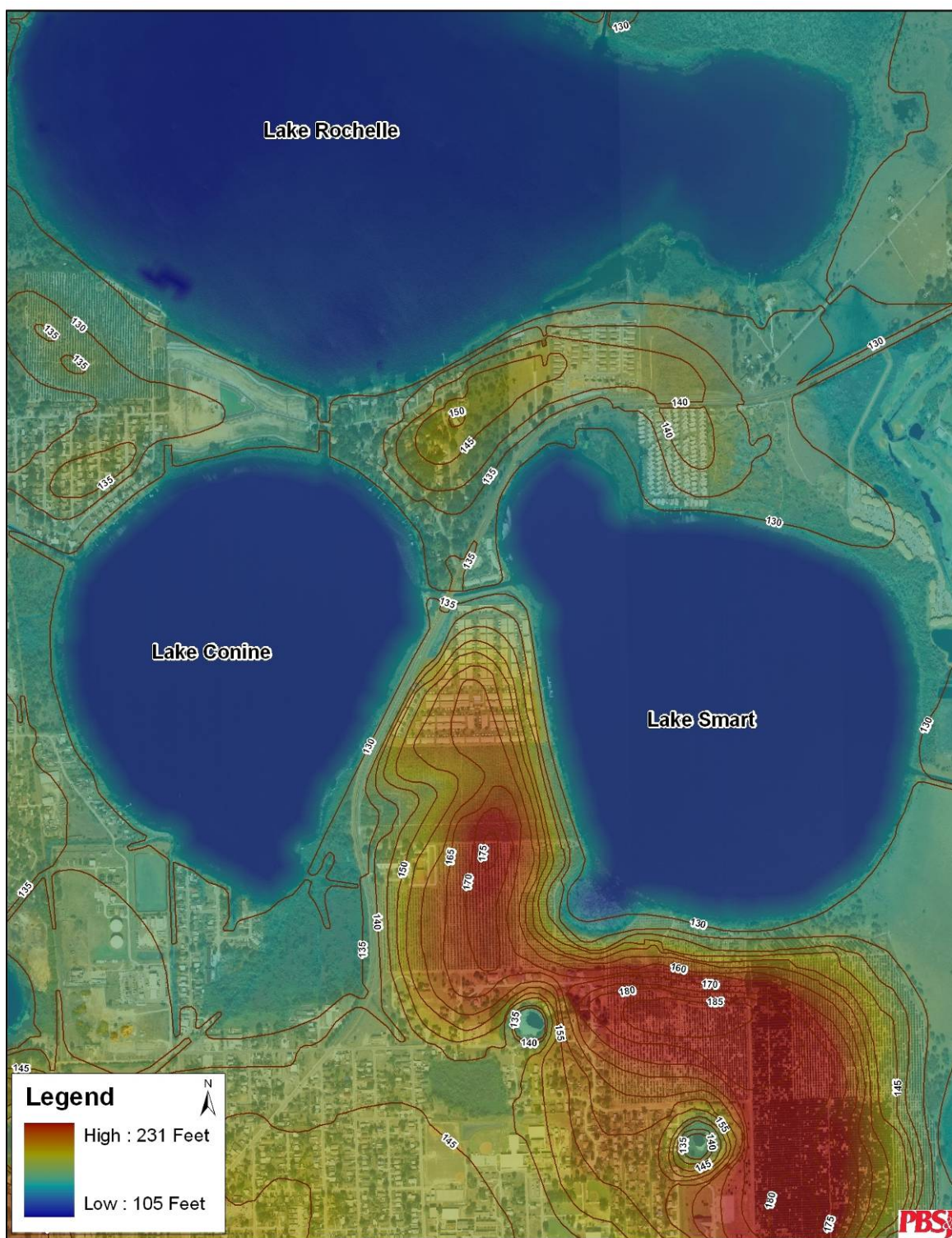
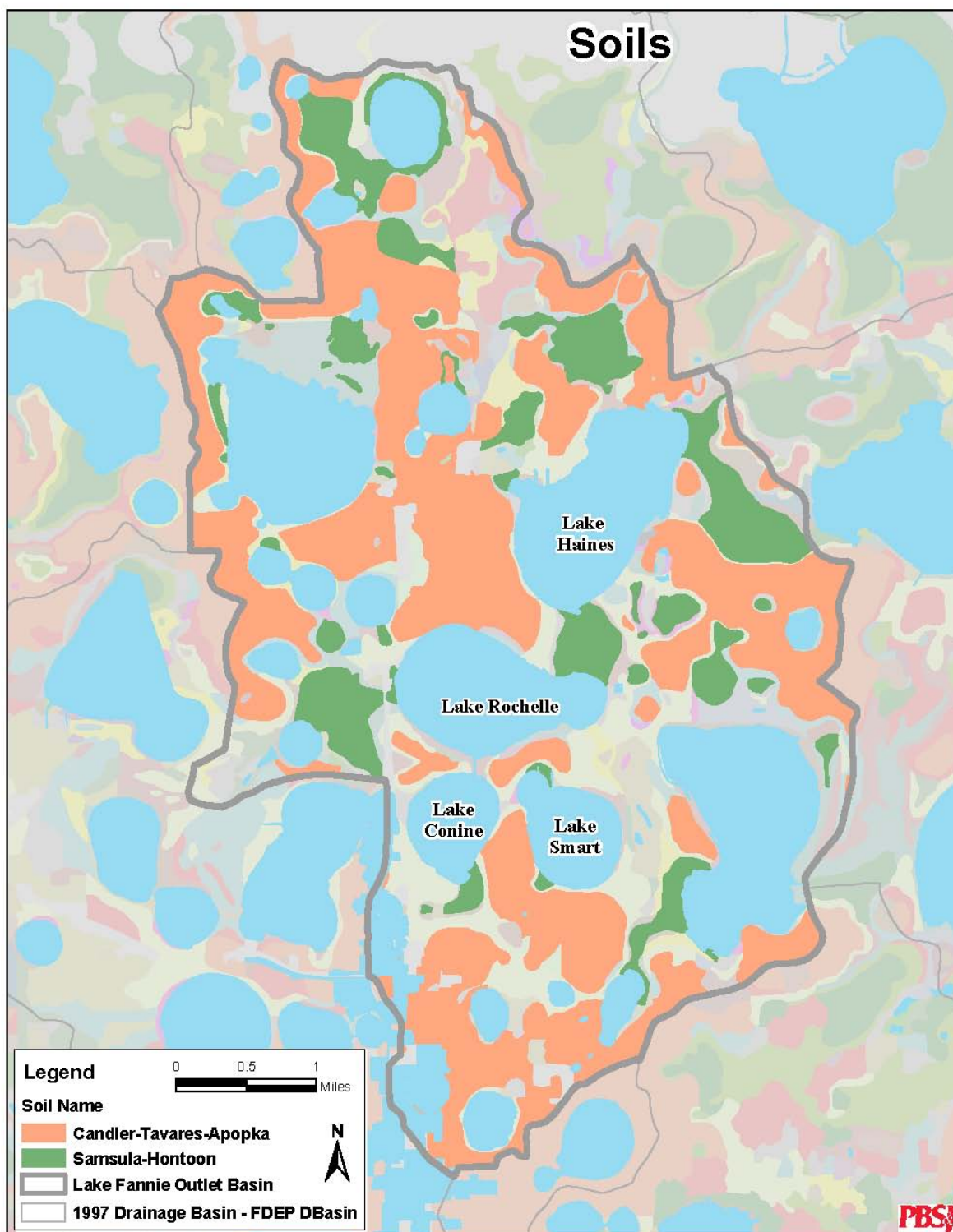


Figure 8. Surface Soils in the Lake Fannie Outlet Basin



2.3. Land Use

Land use and land cover were evaluated for 1990 and 2007 in the Lake Fannie outlet basin, which surrounds the study area. Present land use and changes from 1990 to 2007 are summarized in Table 1 and mapped in Figures 9 and 10. In the past 17 years, there has been a 15 percent increase in urbanization with a resulting 20 percent decline in agriculture. Presently, the majority of the landscape consists of a mixture of urban and agricultural land use. Approximately 4,183 acres of agricultural pastureland and uplands are present, comprising 28 percent of the watershed. These areas are largely undeveloped, and have pervious surfaces that permit infiltration of the sandy soils and potentially significant recharge to the surficial aquifer.

Table 1. Land Use in the Lake Fannie Outlet Basin

Land Use Category	1990 (acres)	2007 (acres)	Change (acres)	Change (%)
Pasture, agriculture	4,637	3,693	-944	-20
Urban, built-up	3,323	3,809	486	15
Transportation, communications, utilities	228	268	40	18
Uplands	496	490	-6	-1
Water	3,957	4,038	81	2
Wetlands	2,465	2,798	333	14
Total	15,106	15,096	-10	0

Based upon the physiography, soils, topography, and hydrogeology of the area, lakes Haines, Rochelle, Smart, and Conine are likely strongly influenced by significant groundwater seepage. The groundwater seepage and monitoring well studies described below were designed to quantify the water volume and nutrient loads to the lake explained by surficial groundwater inputs. An additional analysis of the lake bottom sediments was completed to evaluate nitrogen and phosphorus levels of lake sediments.

Figure 9. 1990 Land Use in the Lake Fannie Outlet Basin

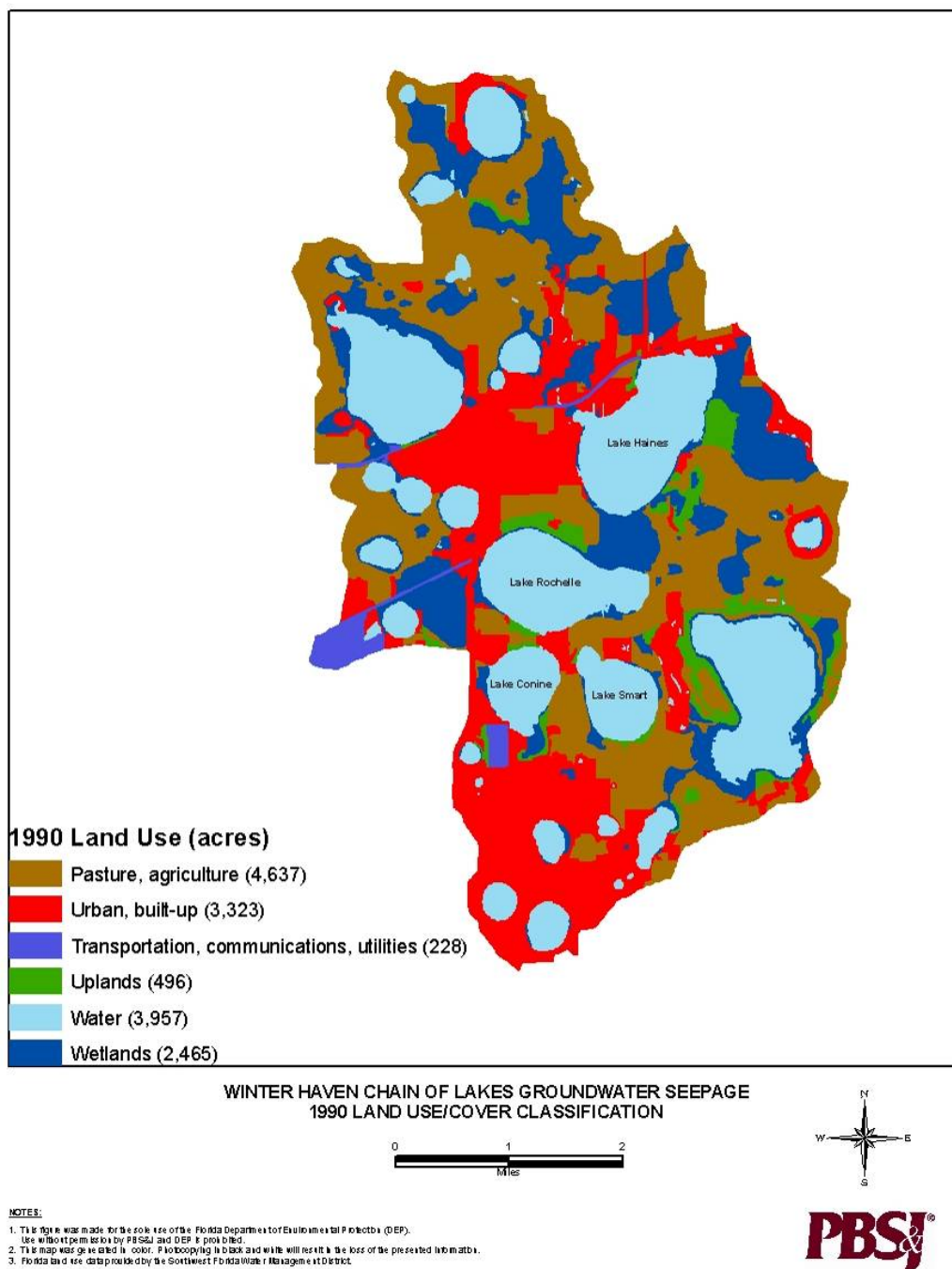
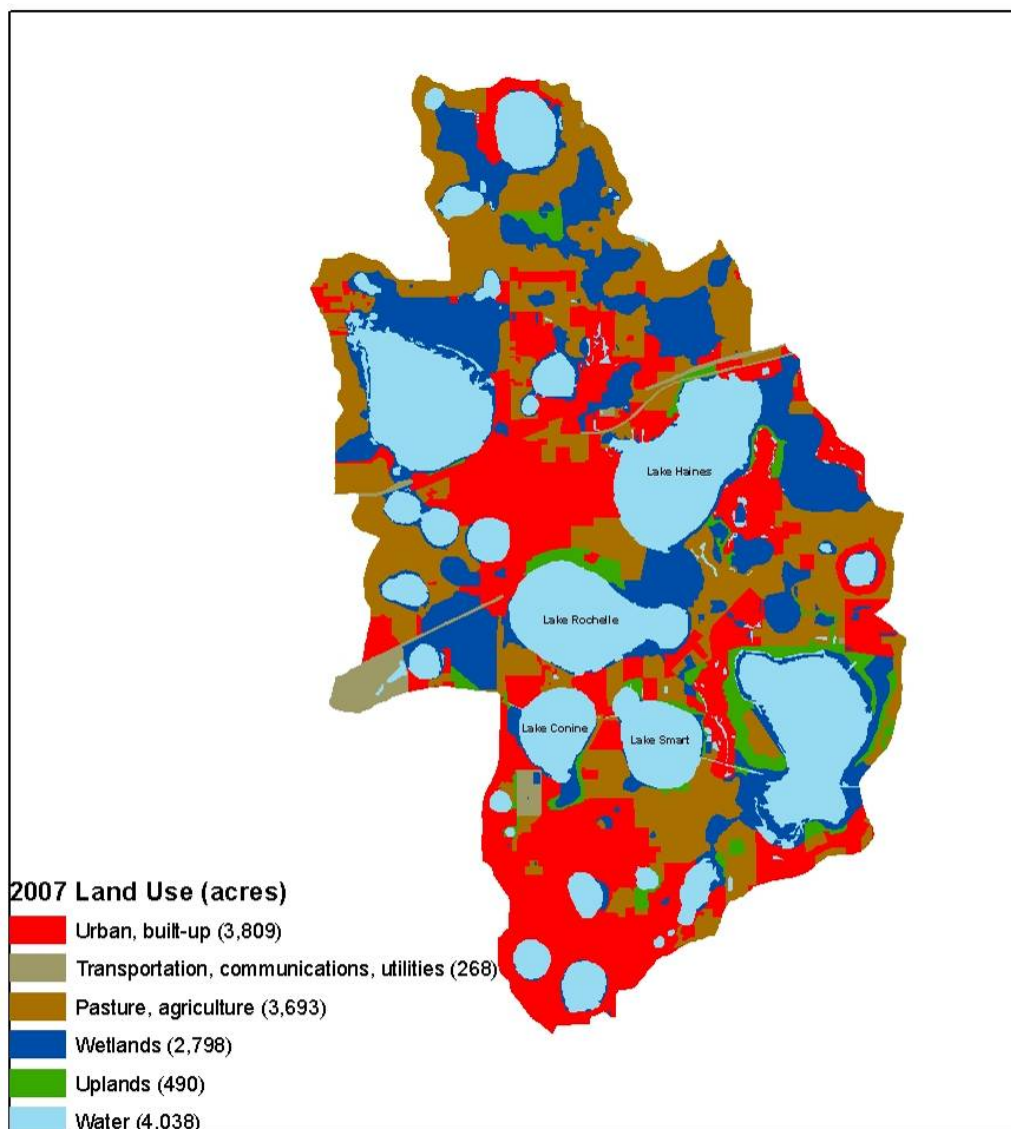
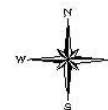


Figure 10. 2007 Land Use in the Lake Fannie Outlet Basin



WINTER HAVEN CHAIN OF LAKES GROUNDWATER SEEPAGE
2007 LAND USE/COVER CLASSIFICATION



NOTES:

1. This figure was made for the sole use of the Florida Department of Environmental Protection (DEP). Use without permission by PBS&J and DEP is prohibited.
2. This map was generated in color. Photocopying in black and white will result in the loss of the presented information.
3. Florida land use data provided by the Southwest Florida Water Management District.



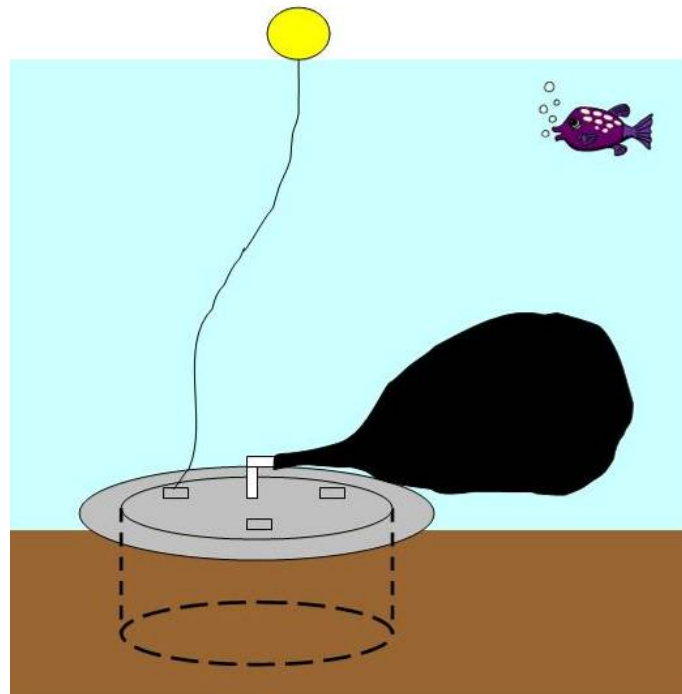
3.0 Groundwater Seepage and Monitoring Well Review

3.1. Groundwater Seepage

3.1.1. Design and Methods

In January 2008, a preliminary site visit was completed to survey the bottom sediments in lakes Smart, Rochelle, Haines, and Conine. Cores were collected with a clear, 2 inch PVC pipe at multiple locations in each lake to determine the sand/muck distribution. Limited organic/mucky sediments were present in the shallow margins investigated (i.e., < 6 feet water depth) at each lake. Based upon the results of the preliminary survey, a design for the seepage meters was developed and approved by FDEP staff. Each seepage meter was 24 inches in diameter, 10 inches tall and constructed of aluminum (Figure 11). A 6 inch flange was welded around the meter 1.5 inches from the top to prevent settling into the sediment. A 0.5 inch threaded female pipe fitting was installed on the top of the meter. The sampling port consisted of 0.5 inch PVC piping and a ball valve with a 0.5 inch male pipe fitting. A large (159 L) black sampling bag was secured to each sampling port with a zip-tie.

Figure 11. Schematic of groundwater seepage meter



Site Selection

Sixteen flanged seepage meters were installed in the four lakes (Smart, Rochelle, Haines, and Conine) in the WHCL on May 19th and 20th, 2008 (Figures 12-16). The locations of the seepage meters were selected jointly by PBS&J, FDEP, and the City of Winter Haven, based on a combination of water depth, adjacent land use characteristics and topography. Areas surrounding the lake were identified with the potential for increased groundwater seepage and nutrient loading. These were typically areas with a substantial elevation gradient or where land use categories were thought to be associated with increased nutrient loadings (i.e., citrus groves, golf courses). The final locations were chosen based on a review of the bathymetric maps (lakes Haines, Rochelle, and Conine) and expected relative groundwater seepage rates, based on surface water inflow and outflow locations for each lake. Four seepage meters were installed in each lake: three were positioned near the shoreline in less than 5 feet of water (shallow) and one was deployed with a water depth greater than 6 feet (deep) (Figure 17). The meters were inserted into the sediment until refusal by lower sediments. The distance between the flange and sediment surface was recorded to establish the initial installation height of the seepage meter.

After installation, a sample bag was deployed and the volume of seepage was measured approximately every two to three weeks for a period of six months (12 total events) beginning June 2 and 3, 2008 (Figure 18). A scientist snorkeled to each seepage meter, removed the sampling bag, and replaced it with a new sampling bag. Water quality samples were collected and analyzed once each calendar month for a period of six months (6 total events) dependent on the water volume available. Field duplicate and field blank samples were collected during each water quality sampling trip. Water quality samples were collected directly from the sample bag following FDEP protocol and immediately iced in a cooler. The water quantity was measured using graduated clear buckets. The condition of the bag (holes/no holes) and water collected (color, smell, particles) was recorded for each groundwater seepage meter site. Additionally, the distance from the flange to the sediment surface was measured on each sampling trip. The water quality samples were delivered to a courier from Benchmark Analytical and subsequently analyzed for multiple parameters (Table 2).

Twelve sampling trips were completed between June 2 and November 19, 2008 to quantify the seepage volume collected at each site and monthly water quality samples were collected from the groundwater seepage sampling bags (Table 3). Volume and water quality data collected at sites LH-ES and LH-NS on October 21, 2008 and LR-NS on July 18, 2008 were removed from analysis due to holes identified in the sampling bag. The area-normalized seepage rate (L/m^2d^{-1}) for each sampling site was calculated as follows:

$$\text{Seepage rate } (L/m^2d^{-1}) = V/(A \times T)$$

Where,

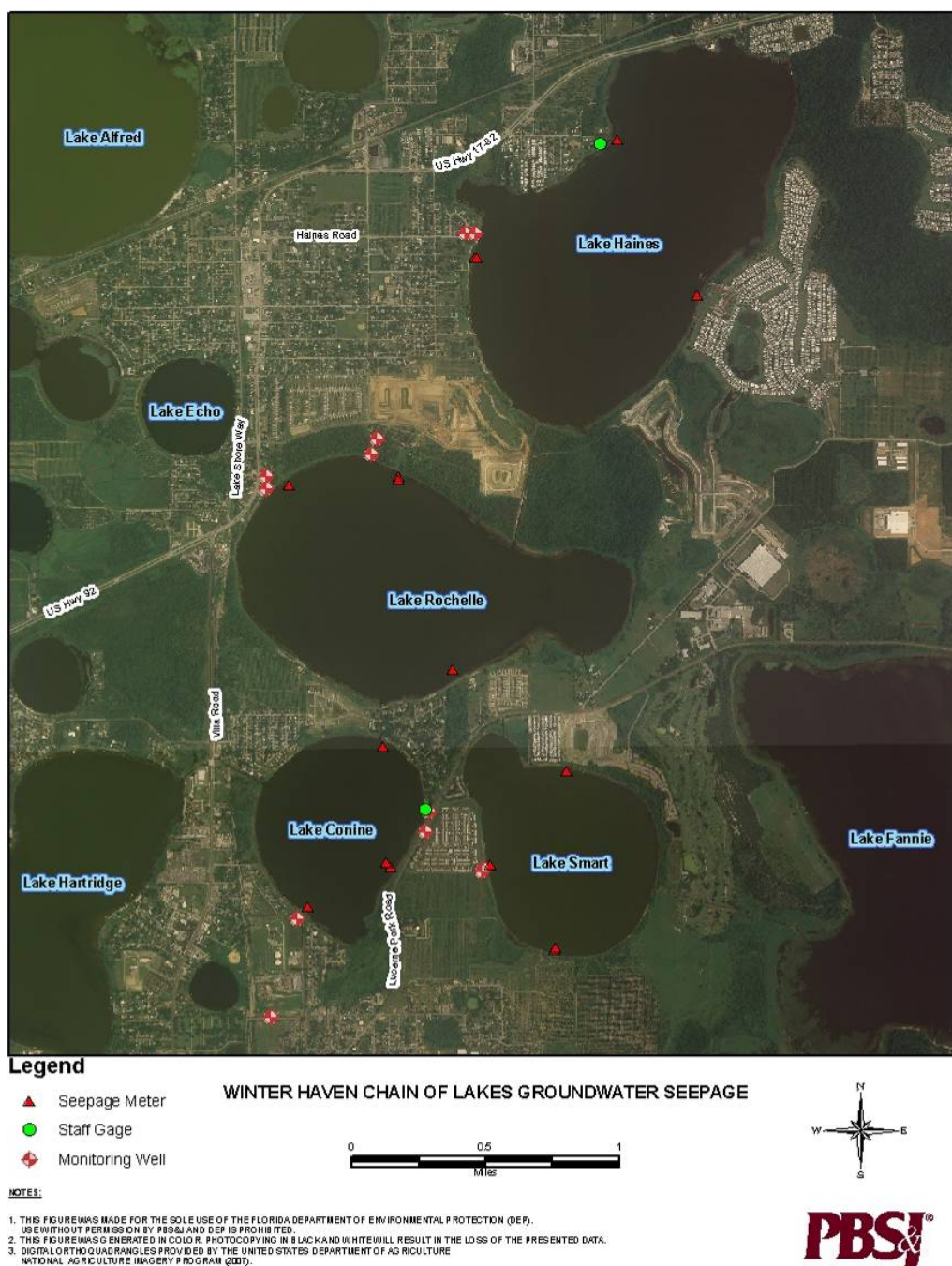
$$V = \text{volume (liters)}, A = \text{area } (m^2) \text{ and } T = \text{time (d)}$$

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The water quality samples were collected when sufficient water volume was available. The groundwater quality was compared to the 1997-2007 average and median concentrations of ambient lake water in each lake based upon data in the IWR Run 33 database (Table 4).

A YSI[®] 6250 was used for each monthly water quality trip to measure pH and conductivity of both the groundwater collected and surrounding lake water. The YSI was calibrated and post-checked each sampling day. In Lakes Haines and Conine, the stage was noted at the SWFWMD staff gauge on each sampling date. The staff gauges for Lakes Rochelle and Smart were unable to be located.

Figure 12. Location of groundwater seepage meters, surficial aquifer monitoring wells and lake staff gauges monitored during the groundwater study



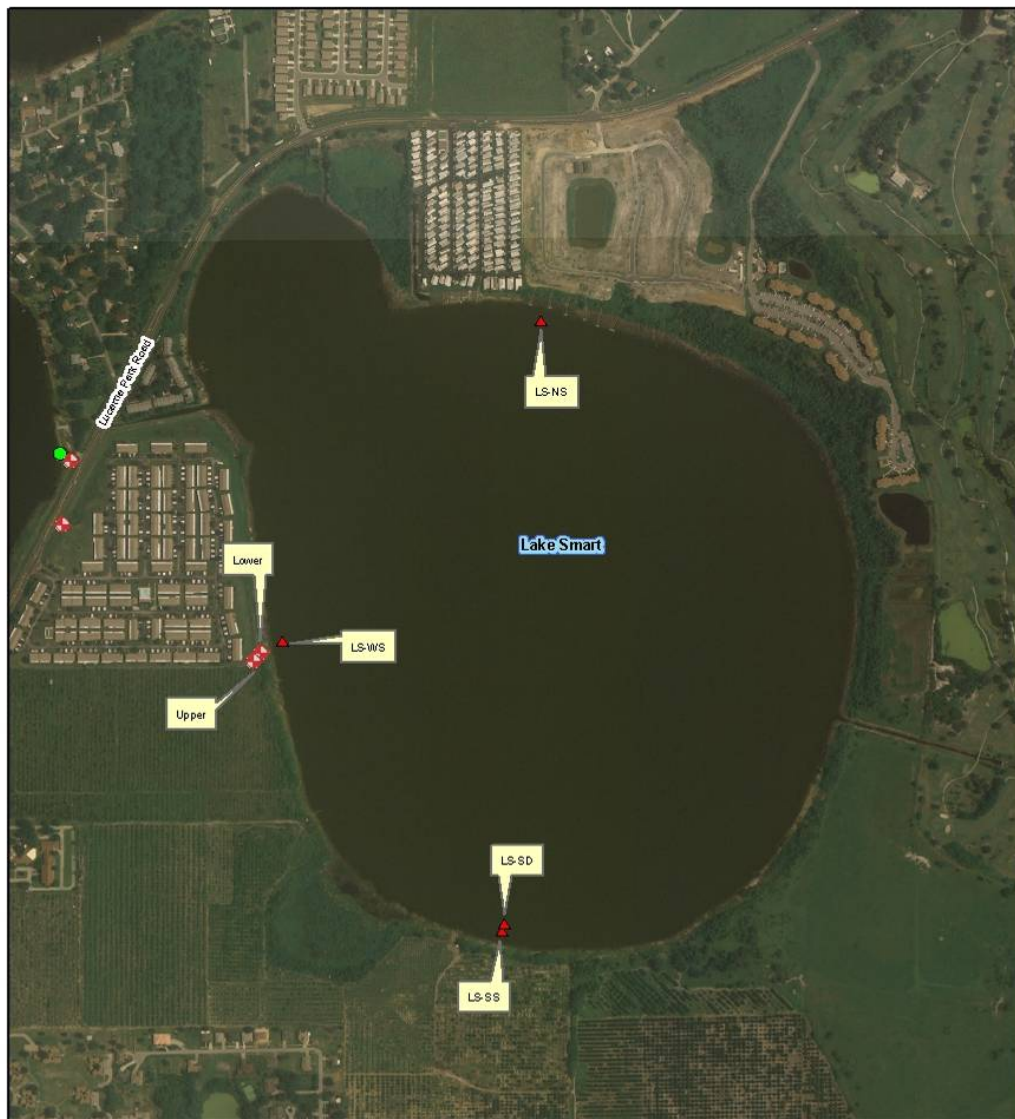
Groundwater Seepage and Monitoring Well Review

Figure 13. Location of groundwater seepage meters, surficial aquifer monitoring wells and lake staff gauges monitored during the groundwater study in Lake Haines



Groundwater Seepage and Monitoring Well Review

Figure 15. Location of groundwater seepage meters, surficial aquifer monitoring wells and lake staff gauges monitored during the groundwater study in Lake Smart



Legend

-  Monitoring Well
-  Seepage Meter
-  Staff Gage

WINTER HAVEN CHAIN OF LAKES GROUNDWATER SEEPAGE LAKE SMART



NOTES:

1. THIS FIGURE WAS MADE FOR THE SOLE USE OF THE FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION (DEP). USE WITHOUT PERMISSION BY PBS&J AND DEP IS PROHIBITED.
2. THIS FIGURE WAS GENERATED IN COLOR. PHOTOCOPYING IN BLACK AND WHITE WILL RESULT IN THE LOSS OF THE PRESENTED DATA.
3. DIGITAL ORTHO QUADRANGLES PROVIDED BY THE UNITED STATES DEPARTMENT OF AGRICULTURE NATIONAL AGRICULTURE IMAGERY PROGRAM (2007).



Groundwater Seepage and Monitoring Well Review

Figure 16. Location of groundwater seepage meters, surficial aquifer monitoring wells and lake staff gauges monitored during the groundwater study in Lake Conine

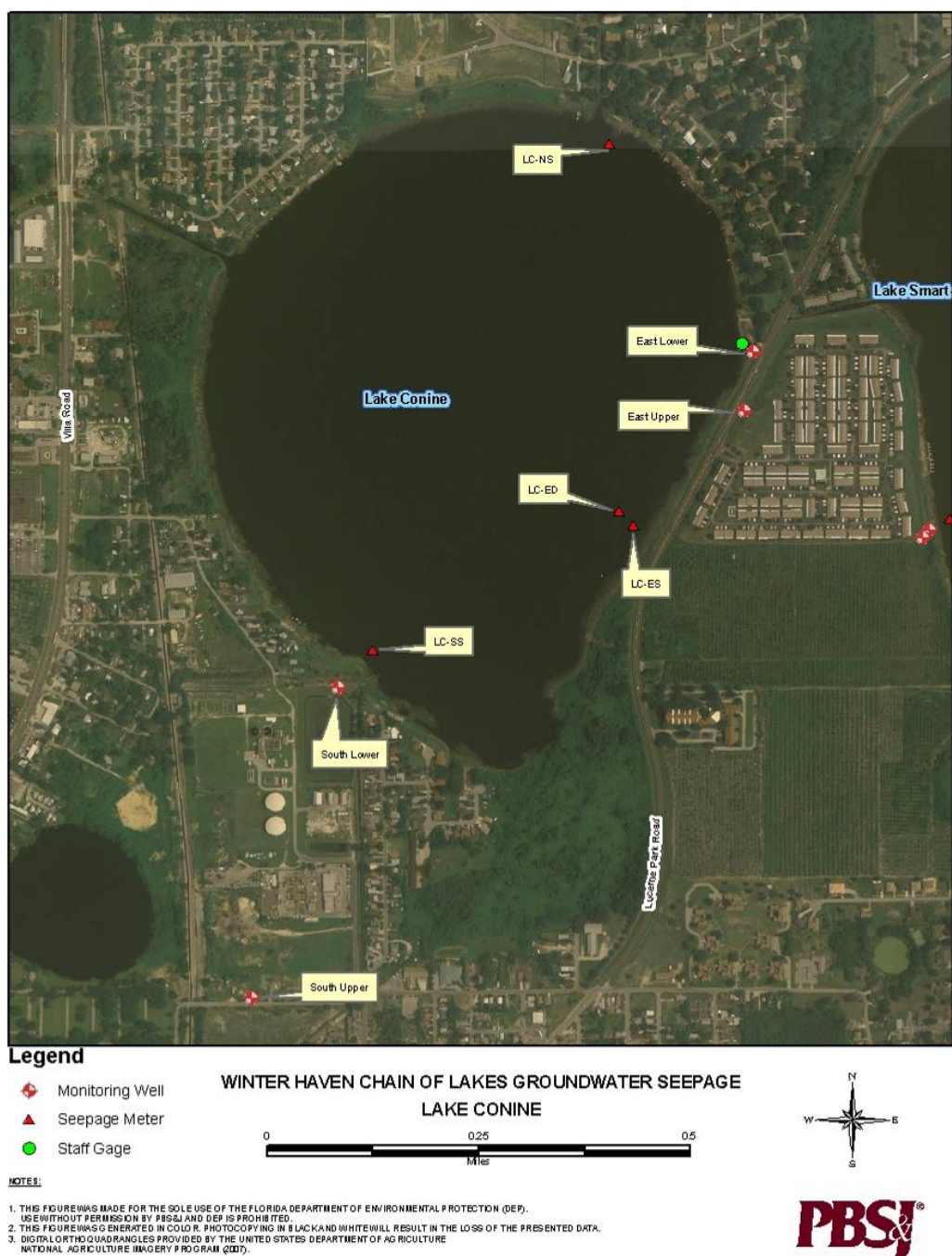


Figure 17. Installation of Groundwater seepage meters



Groundwater Seepage and Monitoring Well Review

Figure 18. Top Left: Retrieval of groundwater sampling bag. Top Right: Collection of water for water quality analysis. Bottom: Volume determination of groundwater



Groundwater Seepage and Monitoring Well Review

Table 2. List of parameters analyzed for groundwater seepage samples

Parameter	Method	Unit	MDL
pH	150.1	pH units	0.1
Specific Conductance	2510B	uhmos/cm	1.25
Alkalinity	SM 2320B	mg/l	0.594
Total Kjeldahl Nitrogen (TKN)	EPA 351.2	mg/l	0.05
Total Nitrate+Nitrite (NO _x)	EPA 353.2	mg/l	0.004
Total Ammonia (NH ₄)	EPA 350.2	mg/l	0.005
Total Nitrogen (TN)	EPA 353+351	mg/l	0.05
Total Orthophosphate (ORP)	EPA 365.3	mg/l	0.002
Total Phosphorus (TP)	EPA 365.3	mg/l	0.002
Color	110.2	PCU	5

Table 3. Groundwater Seepage completed sampling trips

Date	Analysis Completed
5/19-20	Seepage Meters Installed
6/2-3	Water Quantity
6/17 and 20	Water Quantity and Quality
7/1-2	Water Quantity
7/15-16	Water Quantity and Quality
8/4-5	Water Quantity
8/25 and 27	Water Quantity and Quality
9/11-12	Water Quantity
9/23-24	Water Quantity and Quality
10/9-10	Water Quantity
10/21-22	Water Quantity and Quality
11/6-7	Water Quantity
11/18-19	Water Quantity and Quality

Groundwater Seepage and Monitoring Well Review

Table 4. 1997-2007 Median, Mean and Sample Size of Ambient water quality for Lake Haines, Rochelle, Smart and Conine from IWR Run 33

Lake	Statistic	Conductivity (umhos/cm)	Color (PCU)	pH	Alkalinity (mg/l)	NH ₄ (mg/l)	NO _x (mg/l)	TKN (mg/l)	TN (mg/l)	TP (mg/l)
Haines	Median	218	100	7.8	55	0.011	0.008	1.4	1.3	0.07
Haines	Mean	219	95	7.9	54	0.015	0.015	1.5	1.3	0.07
Rochelle	Median	229	25	8.0	62	0.008	0.010	0.9	1.1	0.05
Rochelle	Mean	231	32	8.0	62	0.012	0.020	1.0	1.1	0.05
Smart	Median	214	46	8.4	52	0.010	0.010	1.3	1.4	0.05
Smart	Mean	221	40	8.3	53	0.011	0.052	1.3	1.4	0.06
Conine	Median	229	30	8.2	59	0.009	0.009	1.3	1.3	0.07
Conine	Mean	230	33	8.3	57	0.017	0.010	1.4	1.4	0.08
Lake	Statistic	Sample Size								
Haines	N	55	53	56	22	38	43	46	273	267
Rochelle	N	49	51	49	1	30	38	42	182	174
Smart	N	41	49	41	24	36	36	43	53	56
Conine	N	31	70	31	36	35	51	64	89	85

3.1.2. Results and Data Analysis

Results of the groundwater seepage volume study indicate that lateral groundwater infiltration into all four lakes was present. The greatest rates of seepage were measured at Lake Haines and Conine, however; there was not a significant difference in groundwater seepage rates between lakes. Additionally, a comparison between the groundwater seepage water quality samples and the ten year (1997-2007) average and median lake water concentrations was completed. Overall, the quality of the groundwater seepage samples differed from the lake concentrations. These results are presented in the following sections.

Groundwater Seepage

The groundwater seepage rates for each lake are graphed in Figures 19 to 22 and the raw data are available in Appendix A. A summary table of statistics (Minimum, Maximum and Average) is provided in Table 5. Overall, Lakes Haines, and Conine had the greatest average groundwater seepage rates (4.46 and 6.5 L/m²d⁻¹ or 0.45 and 0.65 cm/d, respectively) when compared to the seepage rates in Lakes Rochelle and Smart (2.68 and 2.29 L/m²d⁻¹ or 0.27 and 0.23 cm/d, respectively). Due to the non-normal distribution of the collected groundwater seepage data, non-parametric statistical analysis was completed for all groundwater seepage data. The Mann-Whitney W Test comparing median groundwater seepage rates at the shallow sites (N=135) to the deep sites (N=47) indicated that there was not a significant difference between measured seepage for these two depth categories (p>0.05). Additionally, there was not a significant difference in overall median seepage rate between lakes (Kruskal-Wallis, p>0.05). These results

indicate no difference in groundwater seepage among the four lakes at water depths less than 10 feet (the deepest depth for meter placement).

Table 5. Groundwater seepage summary statistics

Lake	Site	Min (L/m ² d ⁻¹)	Max (L/m ² d ⁻¹)	Average (L/m ² d ⁻¹)	Number of Samples
Haines	LH-ES	0.10	7.71	3.68	9
Haines	LH-NS	0.41	8.69	2.35	10
Haines	LH-WS	3.77	15.64	7.35	12
Haines	LH-WD	0.21	15.64	2.54	12
Haines	Shallow Average			4.46	
Rochelle	LR-WS	0.10	7.42	2.34	12
Rochelle	LR-SS	0.14	15.75	4.03	11
Rochelle	LR-NS	0.13	3.37	1.68	11
Rochelle	LR-ND	0.07	10.19	2.57	12
Rochelle	Shallow Average			2.68	
Smart	LS-NS	0.01	4.82	1.91	12
Smart	LS-WS	0.03	3.56	1.61	10
Smart	LS-SS	1.18	10.83	3.35	12
Smart	LS-SD	0.13	3.56	1.26	11
Smart	Shallow Average			2.29	
Conine	LC-SS	0.57	31.71	16.66	12
Conine	LC-NS	0.07	3.84	1.31	12
Conine	LC-ES	0.04	4.76	1.53	12
Conine	LC-ED	0.16	6.96	2.33	12
Conine	Shallow Average			6.50	

As discussed previously, site selection for the seepage meters was partially based on the adjacent topography using the premise that increased groundwater seepage would be found in areas with steeper elevational gradients. To test this assumption, an analysis comparing the adjacent land's slope and average seepage rates for each of the shallow groundwater seepage meters was completed. This analysis was calculated by identifying the elevation of the adjacent ridge (highest point) and lake shoreline (lowest point) using the digital elevation model (DEM) and the distance between the two points (Figure 19-22). A significant relationship was not evident when comparing elevational gradients and seepage rates, indicating that slope alone cannot be used to predict measured seepage rates in these lakes (Figure 23). The analysis was also completed with

the removal of the two sites with highest average seepage measurements (LH-WS and LC-SS), in case they were statistical outliers that prevented us from discerning an otherwise obvious relationship. Even with these sites removed, there was not an identified statistically significant relationship between slope and average groundwater seepage rates. An additional analysis comparing the average slope of the groundwater elevations (as measured in the monitoring wells) and groundwater seepage rates from adjacent seepage meters was completed. Consistent with the previous analyses, no significant relationship between the slope of the groundwater and the average groundwater seepage was found (Figure 24).

Figure 19. Points used for slope calculation for each seepage meter on Lake Haines

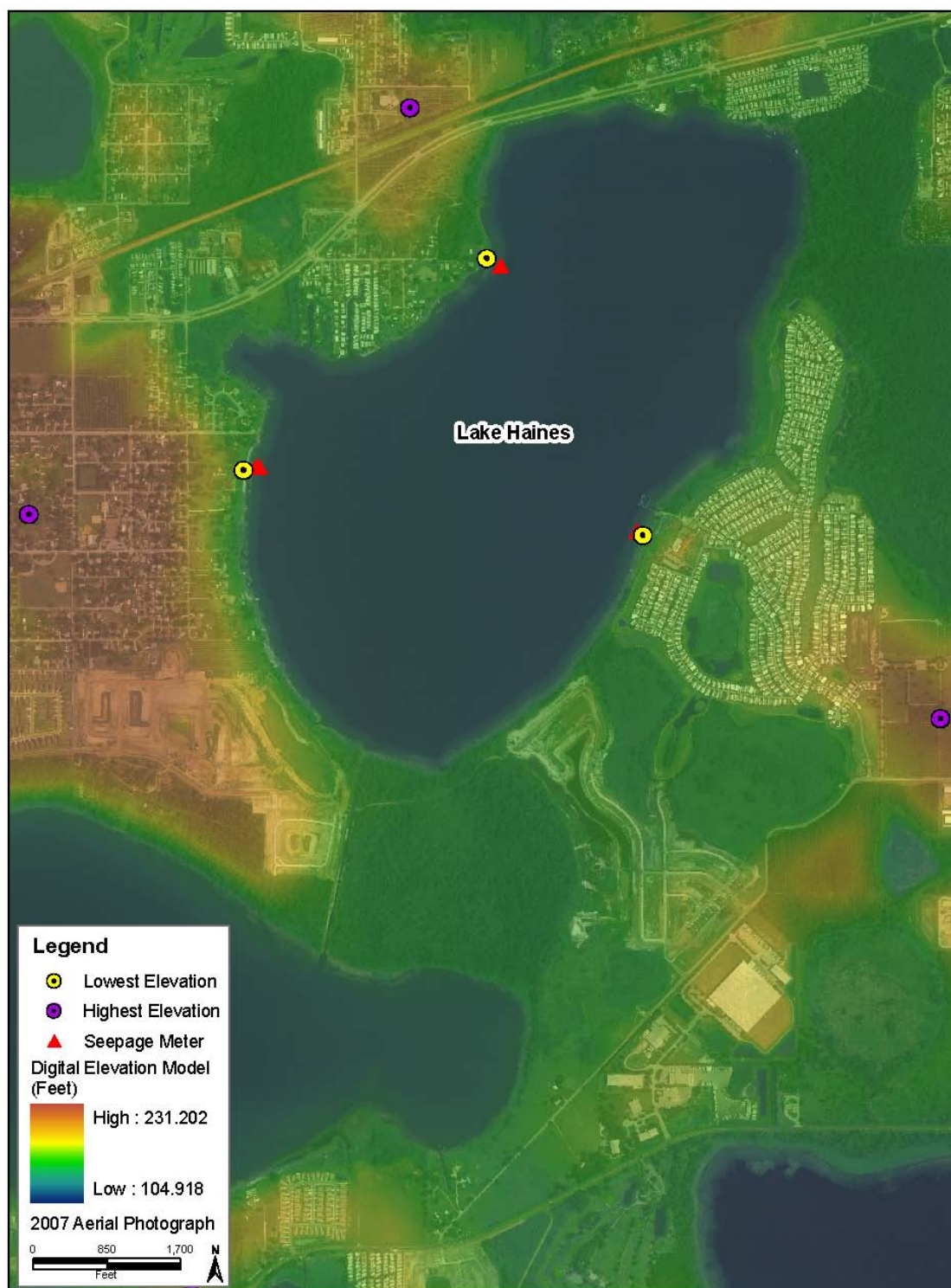


Figure 20. Points used for slope calculation for each seepage meter on Lake Rochelle

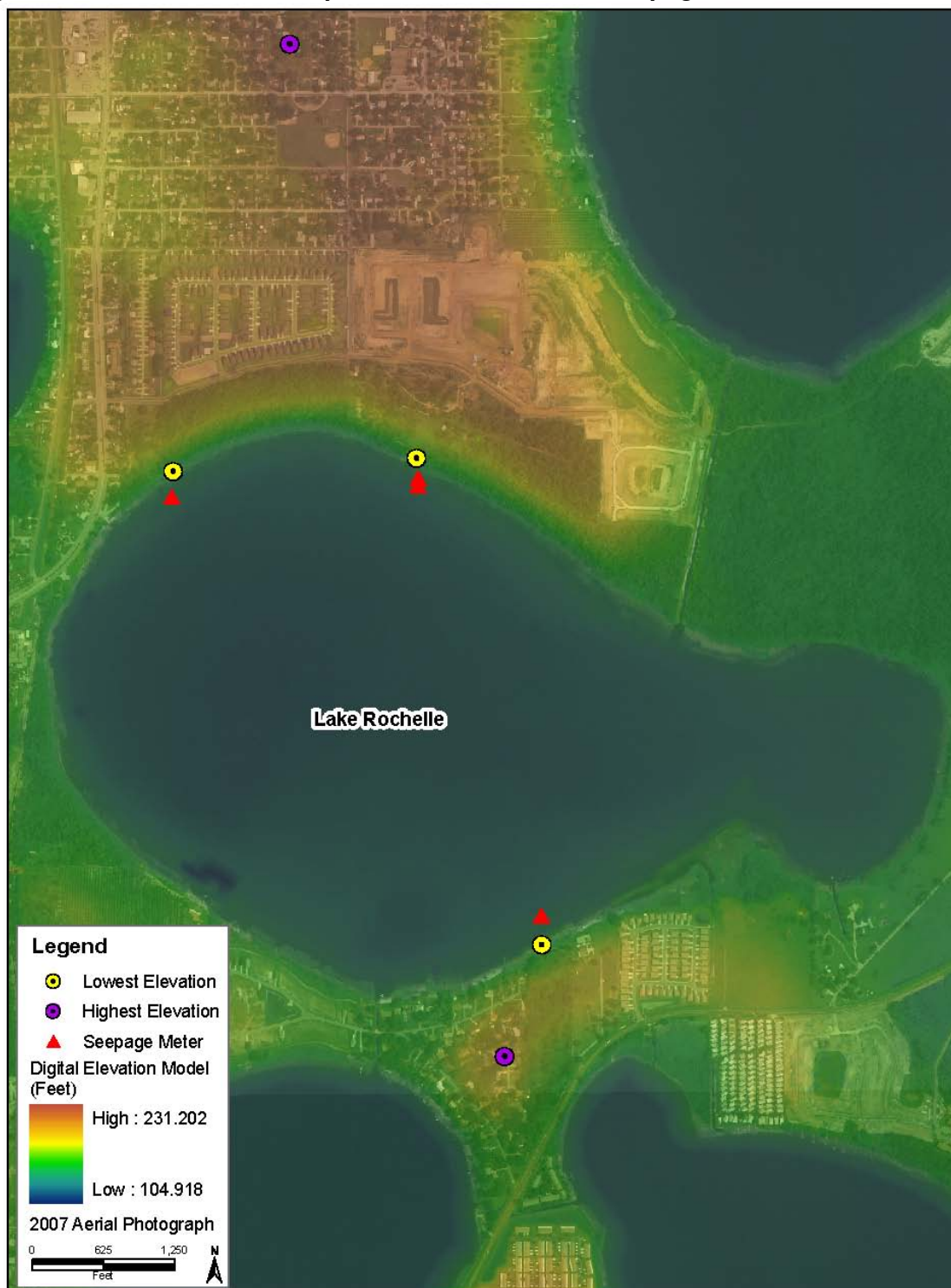


Figure 21. Points used for slope calculation for each seepage meter on Lake Smart

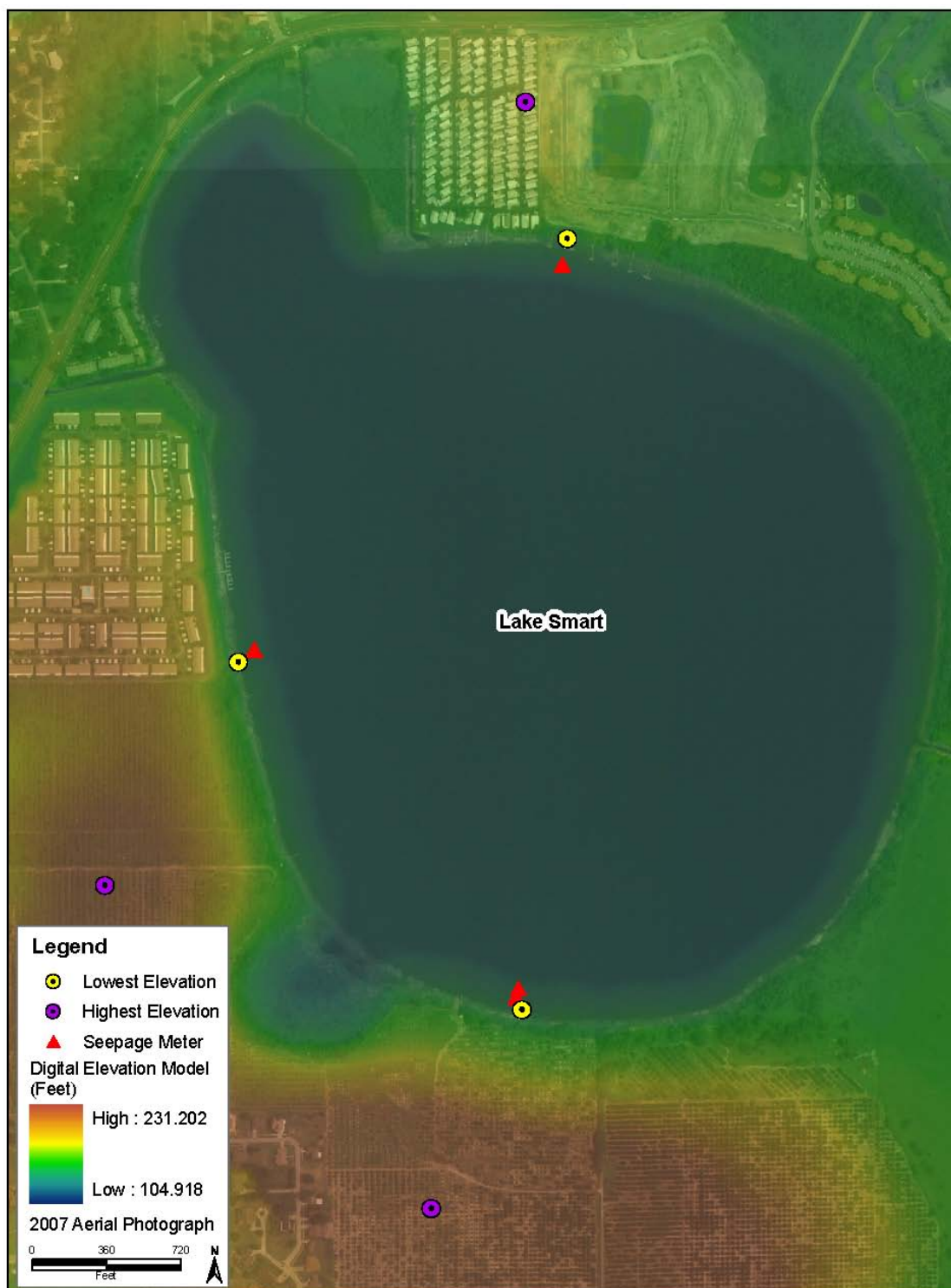


Figure 22. Points used for slope calculation for each seepage meter on Lake Conine

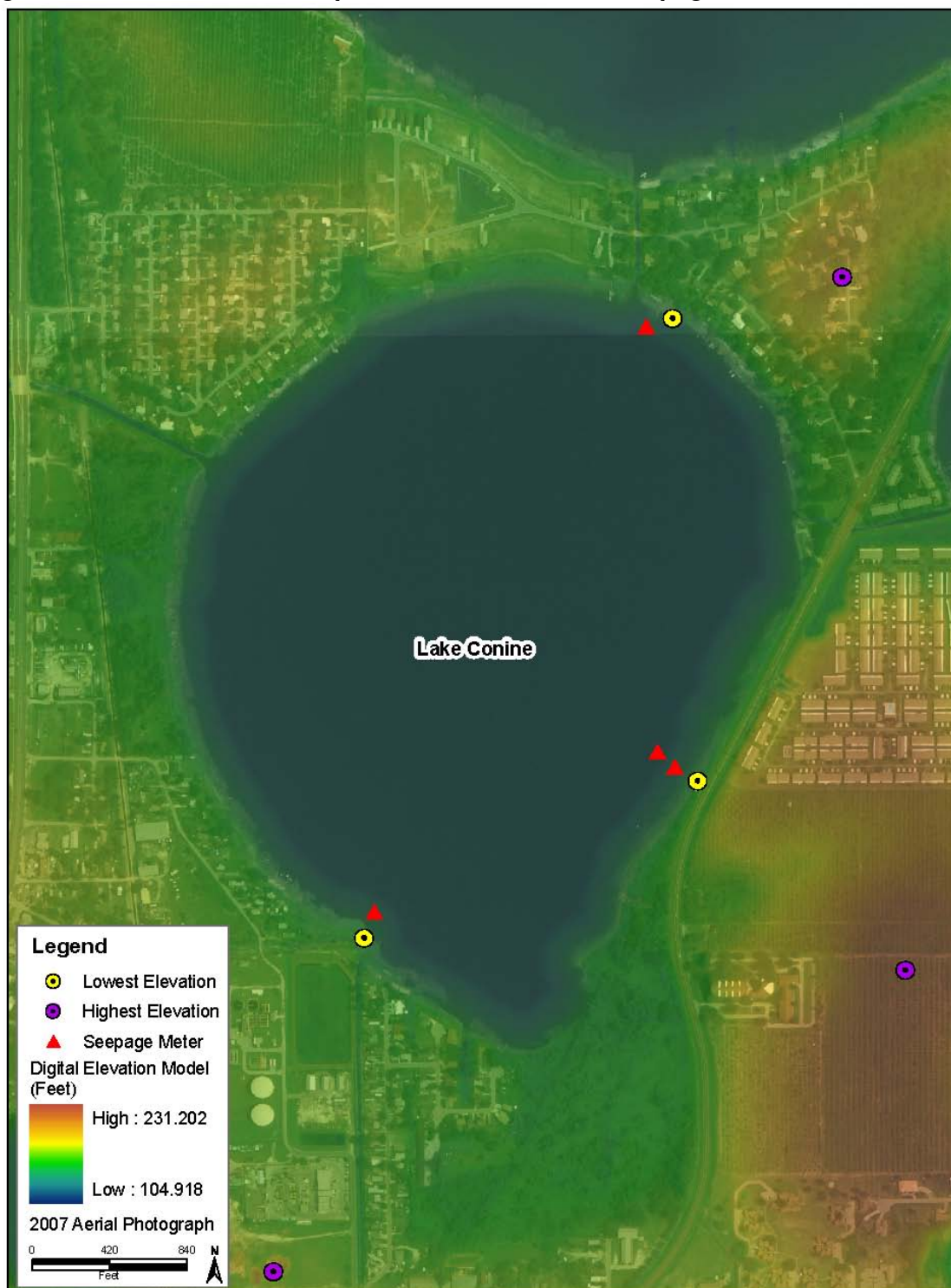


Figure 23. Evaluation of the slope of the adjacent land and seepage (red points indicate sites with highest average seepage)

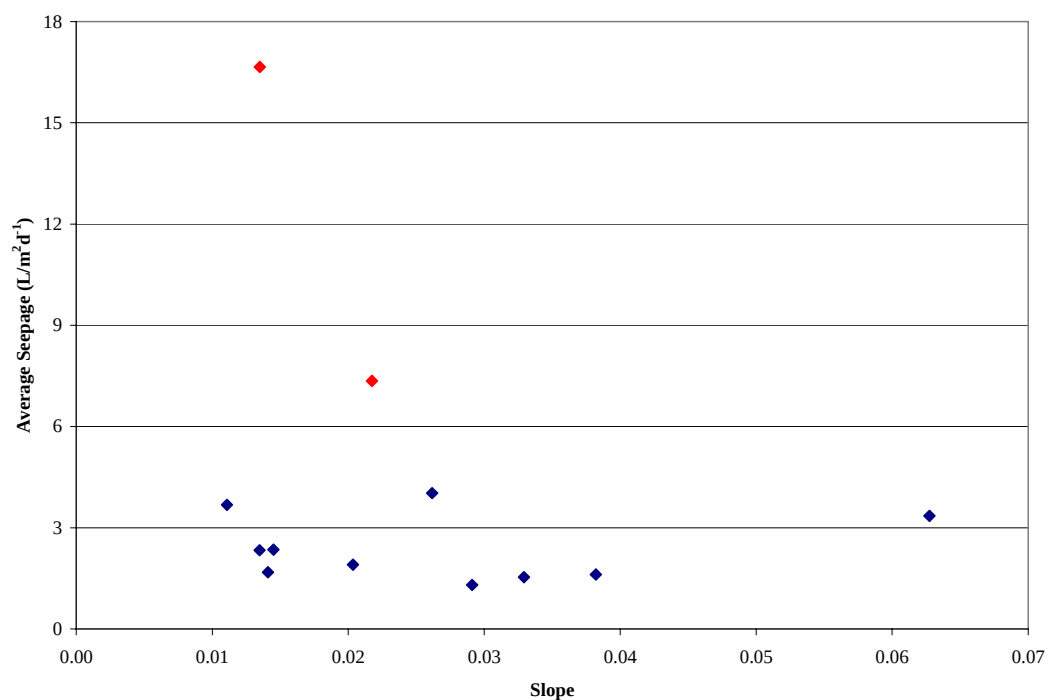
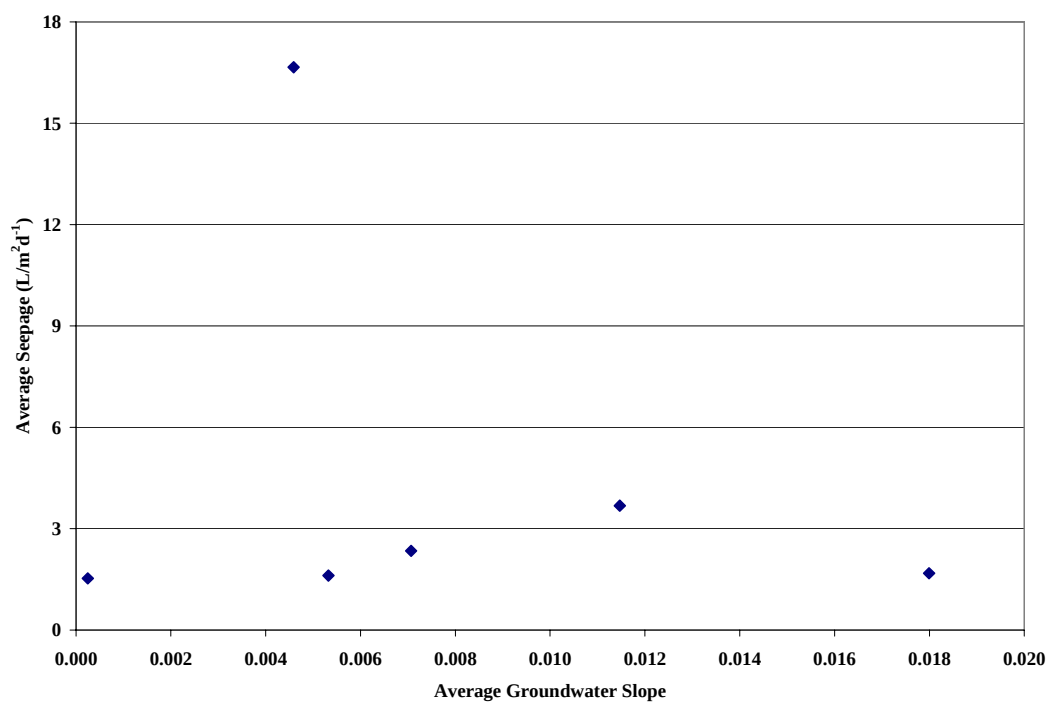


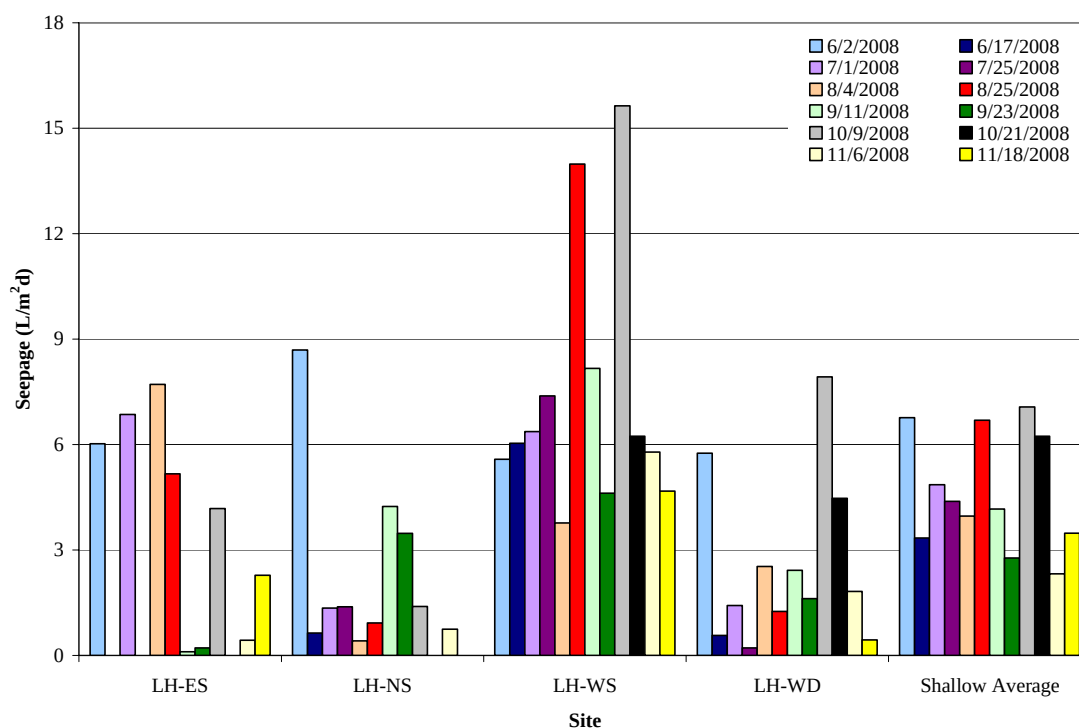
Figure 24. Evaluation of Average groundwater slope and seepage



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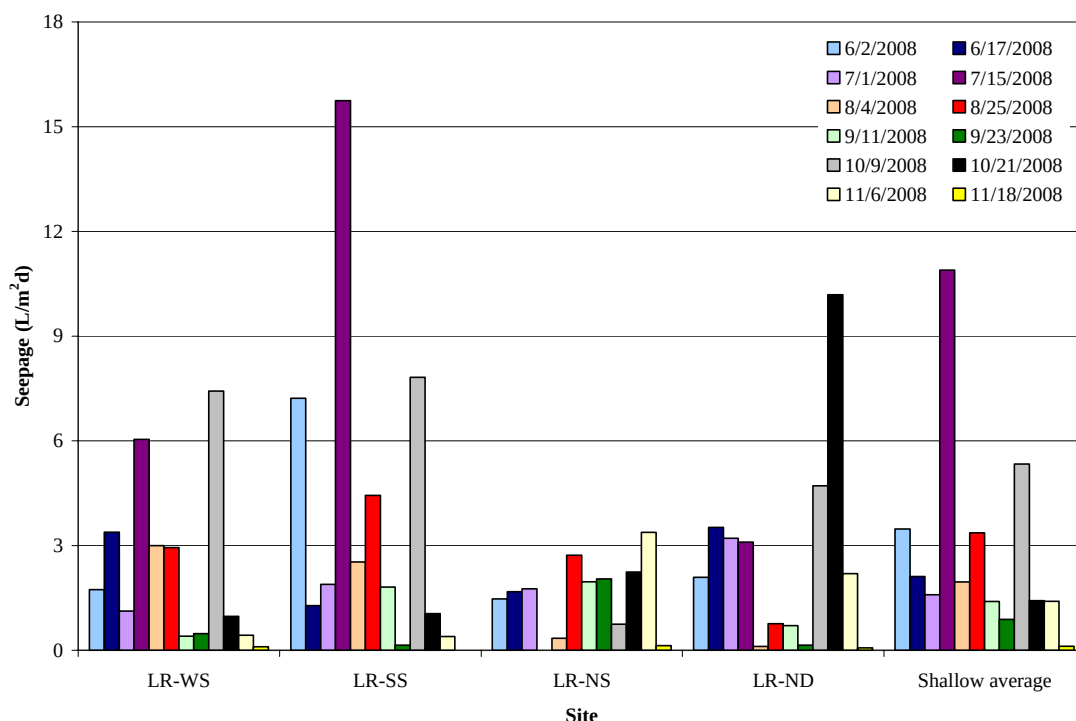
Lake Haines groundwater seepage rates ranged from 0.10 to 15.64 L/m²d⁻¹ (0.01 to 1.6 cm/d) for all four sites (Table 5; Figure 25) with the highest average rate occurring at station LH-WS on the west edge of the lake. On average, the seepage at the shallow sites was 4.46 L/m²d (0.45 cm/d) compared to 2.54 L/m²d⁻¹ (0.25 cm/d) at the deep site (LH-WD), indicating a higher rate of inflow at the shallow (<5 feet) sites. The Mann-Whitney W test was used to compare the median seepage of the shallow sites (N=31) to the deep site (N=12) in Lake Haines and results indicated no significant difference between measured seepage at the two locations (p>0.05).

Figure 25. Lake Haines groundwater seepage rates from June 2 to November 18, 2008



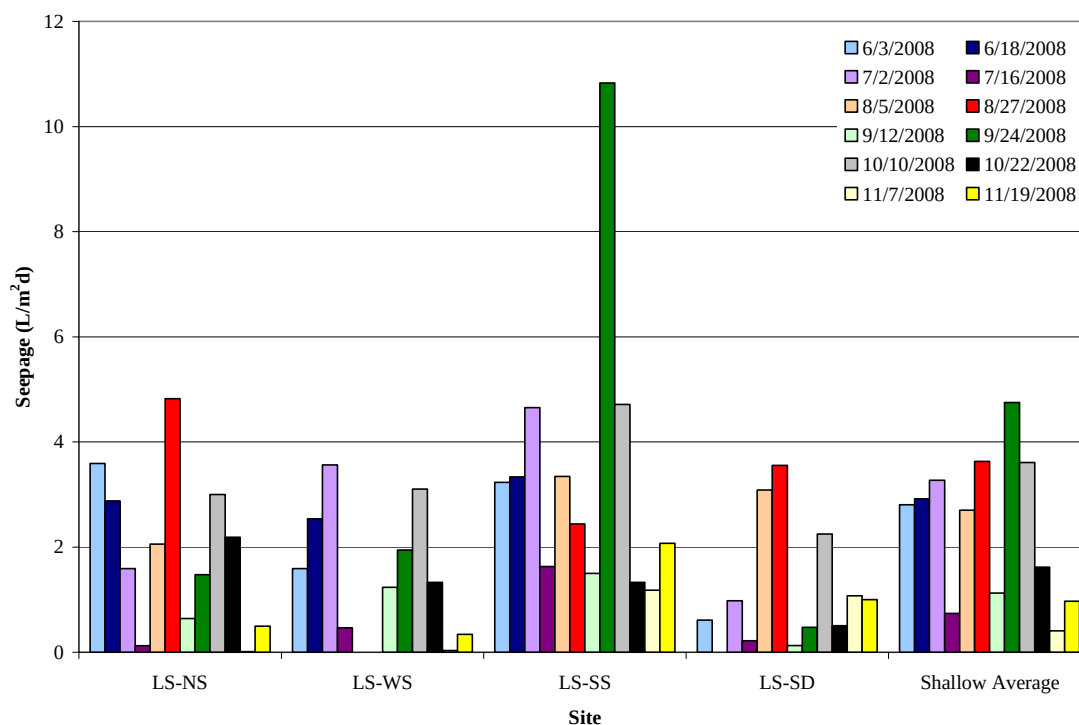
Lake Rochelle groundwater seepage ranged from 0.07 to 15.75 L/m²d (0.007 to 1.6 cm/d) for all four sites (Table 5; Figure 26) with the highest average rate occurring at station LR-SS on the south edge of the lake. On average, the seepage at the shallow sites was 2.68 L/m²d (0.27 cm/d) compared to 2.57 L/m²d (0.26 cm/d) at the deep site (LR-ND), indicating a similar rate of inflow at the shallow (<5 feet) sites compared to the deep location. Results of the Mann-Whitney W Test comparing the median groundwater seepage of the shallow sites (N=34) to the deep sites (N=12) in Lake Rochelle indicated no significant difference between measured seepage at the two locations ($p>0.05$).

Figure 26. Lake Rochelle groundwater seepage rates from June 2 to November 18, 2008



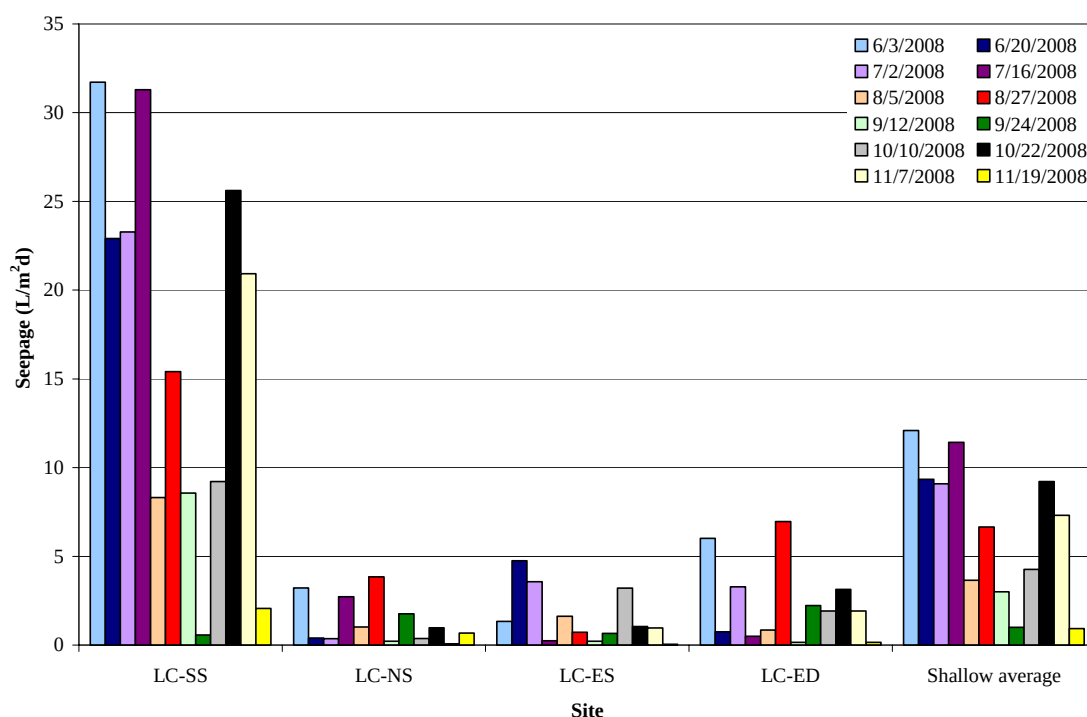
Lake Smart groundwater seepage ranged from 0.01 to 10.83 L/m²d (0.001 to 1.1 cm/d) for all four sites (Table 5; Figure 27) with the highest average rate occurring at station LS-SS on the south edge of the lake. On average, the seepage at the shallow sites was 2.29 L/m²d (0.23 cm/d) compared to 1.26 L/m²d (0.13 cm/d) at the deep site (LS-SD), indicating a higher rate of inflow at the shallow (<5 feet) sites. However, results of the Mann-Whitney W Test comparing the median seepage of the shallow sites (N=34) to the deep sites (N=11) in Lake Smart indicated that there was not a significant difference between measured seepage at the two locations ($p>0.05$).

Figure 27. Lake Smart groundwater seepage rates from June 3 to November 19, 2008



Lake Conine groundwater seepage ranged from 0.04 to 31.71 L/m²d (0.004 to 3.2 cm/d) for all four sites (Table 5; Figure 28) with the highest average rate occurring at station LC-SS on the south edge of the lake. On average, the seepage at the shallow sites was 6.50 L/m²d (0.65 cm/d) compared to 2.33 L/m²d (0.23 cm/d) at the deep site (LC-ED), indicating a higher rate of inflow at the shallow (<5 feet) sites. However, results of the Mann-Whitney W test comparing the median groundwater seepage of the shallow sites (N=36) to the deep sites (N=12) in Lake Conine indicated that there was not a significant difference between measured seepage at the two locations ($p>0.05$). The elevated groundwater seepage observed at station LC-SS could not be explained by adjacent topography.

Figure 28. Lake Conine groundwater seepage rates from June 3 to November 19, 2008



General groundwater seepage water quality statistics (minimum, maximum, average, and number of samples) for each parameter are listed in Tables 6-15. The raw water quality data are available in Appendix B and graphs for each lake are available in Appendix C. Several of the groundwater seepage meters were placed adjacent to land uses thought to be capable of having high rates of nutrient loading via groundwater seepage (i.e., citrus groves, golf courses). For example, the seepage meters located at LS-SS and LS-SD were positioned down gradient from an active citrus grove, and the seepage meter located on the east side of Lake Haines (LH-ES) was adjacent to a golf course. The water quality results from these three groundwater seepage sites were not elevated or reduced in comparison to the other sites, however.

Specific Conductivity

Conductivity of groundwater seepage water alone during this study was higher than the conductivity of the lake water, or ambient lake water, which reflects the combined influence of rainfall, overland runoff, and other factors, in addition to groundwater. The specific conductivity of groundwater measured in the seepage meters during the sampling period was greater than the median conductivity of the lake water in each of the four lakes for the period 1997-2007. The specific conductivity in seepage water collected from Lake Haines ranged from 274 to 481 $\mu\text{mhos/cm}$ and averaged 403 $\mu\text{mhos/cm}$ in the shallow well and 333 $\mu\text{mhos/cm}$ in the deep well (Table 6). In comparison, the median and mean conductivity of the lake water was 218 and 219 $\mu\text{mhos/cm}$, respectively (Table 6). In Lake Rochelle, the range of conductivity in seepage water was 267 to 479 $\mu\text{mhos/cm}$ with an average of 329 $\mu\text{mhos/cm}$ at the shallow sites and 295 $\mu\text{mhos/cm}$ at the deep site (Table 6). The median and mean conductivity of lake water was 229 and 231 $\mu\text{mhos/cm}$, respectively (Table 6). The conductivity range in Lake Smart seepage water was 284 to 474 $\mu\text{mhos/cm}$ with an average of 342 $\mu\text{mhos/cm}$ at the shallow sites and 355 $\mu\text{mhos/cm}$ at the deep site (Table 6). The median and mean conductivity of the lake water was 214 and 221 $\mu\text{mhos/cm}$, respectively (Table 6). In Lake Conine, the conductivity of the seepage water ranged from 262 to 384 $\mu\text{mhos/cm}$ with an average of 304 $\mu\text{mhos/cm}$ at the shallow sites and 290 $\mu\text{mhos/cm}$ at the deep site (Table 6). The median and mean conductivity of the lake water was 229 and 230 $\mu\text{mhos/cm}$, respectively (Table 6).

Table 6. Specific Conductance summary statistics for groundwater seepage water and ambient lake water

Lake	Site	Min ($\mu\text{mhos/cm}$)	Max ($\mu\text{mhos/cm}$)	Average ($\mu\text{mhos/cm}$)	Number of Samples
Haines	LH-ES	276	356	316	3
Haines	LH-NS	369	563	481	4
Haines	LH-WS	298	508	411	6
Haines	LH-WD	274	384	333	6
Haines	Shallow Average			403	
Rochelle	LR-WS	290	479	353	5
Rochelle	LR-SS	279	359	311	4
Rochelle	LR-NS	294	365	324	4
Rochelle	LR-ND	267	335	295	4
Rochelle	Shallow Average			329	
Smart	LS-NS	304	330	320	5
Smart	LS-WS	323	409	364	5
Smart	LS-SS	286	388	343	6
Smart	LS-SD	284	474	355	5
Smart	Shallow Average			342	
Conine	LC-SS	262	384	311	5
Conine	LC-NS	264	301	280	5
Conine	LC-ES	283	351	320	5
Conine	LC-ED	265	332	290	6

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Conine	Shallow Average			304	
Lake	IWR Run 33		Median (µmhos/cm)	Average (µmhos/cm)	Number of Samples
Haines	1997-2007 ambient lake		218	219	55
Rochelle	1997-2007 ambient lake		229	231	49
Smart	1997-2007 ambient lake		214	221	41
Conine	1997-2007 ambient lake		229	230	31

Color

The range of color values in seepage water measurements at Lake Haines was 15 to 70 PCU with an average of 51 PCU at the shallow meters and 52 PCU at the deep meters (Table 7). In comparison, the median and mean color of the ambient lake water was 100 and 95 PCU, respectively (Table 7). In Lake Rochelle, the range in color of the seepage water was 35 to 100 PCU with an average of 45 PCU at the shallow sites and 63 PCU at the deep site (Table 7). The ambient median and mean color values in the lake water were 25 and 32 PCU, respectively (Table 7). The range in color in Lake Smart seepage was 25 to 140 PCU with an average of 57 PCU at the shallow sites and 69 PCU at the deep site (Table 7). The median and mean of the color in ambient lake water was 46 to 40 PCU, respectively (Table 7). In Lake Conine, the range of color in seepage was 25 to 70 PCU with an average of 42 PCU at the shallow sites and 52 PCU at the deep site (Table 7). The median and mean of the color in ambient lake water was 30 and 33 PCU, respectively (Table 7).

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Table 7. Color summary statistics for groundwater seepage water and ambient lake water

Lake	Site	Min (PCU)	Max (PCU)	Average (PCU)	Number of Samples
Haines	LH-ES	60	60	60	3
Haines	LH-NS	45	70	55	4
Haines	LH-WS	15	70	38	6
Haines	LH-WD	35	70	52	6
Haines	Shallow Average			51	
Rochelle	LR-WS	35	50	44	5
Rochelle	LR-SS	35	60	49	4
Rochelle	LR-NS	35	50	43	4
Rochelle	LR-ND	35	100	63	4
Rochelle	Shallow Average			45	
Smart	LS-NS	40	100	67	5
Smart	LS-WS	25	50	45	5
Smart	LS-SS	40	120	60	6
Smart	LS-SD	35	140	69	5
Smart	Shallow Average			57	
Conine	LC-SS	25	50	34	6
Conine	LC-NS	40	60	48	6
Conine	LC-ES	35	50	43	5
Conine	LC-ED	35	70	52	6
Conine	Shallow Average			42	
Lake	IWR Run 33		Median (PCU)	Average (PCU)	Number of Samples
Haines	1997-2007 ambient lake		100	95	53
Rochelle	1997-2007 ambient lake		25	32	51
Smart	1997-2007 ambient lake		46	40	49
Conine	1997-2007 ambient lake		30	33	70

pH

The pH of the groundwater seepage water and median ambient lake water was similar in all four lakes. The range in seepage water pH at Lake Haines was 7.6 to 8.4 with an average of 7.9 at the shallow wells and 8.2 at the deep site (Table 8). In comparison, the median and mean pH of the ambient lake water was 7.8 and 7.9, respectively (Table 8). In Lake Rochelle, the range of seepage water pH was 7.8 to 8.5 with an average of 8.1 at the shallow sites and 8.0 at the deep site (Table 8). The ambient median and mean of the lake water pH was 8.0 (Table 8). The range of pH in Lake Smart seepage water was 7.7 to 8.8 with an average of 8.2 at the shallow sites and at the deep site (Table 8). The median and mean of the pH in ambient lake water was 8.4 and 8.3, respectively (Table 4). In Lake Conine, the range of pH in seepage water was 5.9 to 8.1 with an average of 7.3 at the shallow sites and 7.9 at the deep site (Table 8). The median and mean of the pH in ambient lake water was 8.2 and 8.3, respectively (Table 8).

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Table 8. pH summary statistics for groundwater seepage water and ambient lake water

Lake	Site	Min	Max	Average	Number of Samples
Haines	LH-ES	7.7	8.1	7.9	3
Haines	LH-NS	7.8	8.4	8.1	4
Haines	LH-WS	7.6	8.1	7.8	6
Haines	LH-WD	8.0	8.3	8.2	6
Haines	Shallow Average			7.9	
Rochelle	LR-WS	7.8	8.5	8.1	5
Rochelle	LR-SS	7.8	8.1	8.0	4
Rochelle	LR-NS	8.0	8.2	8.1	4
Rochelle	LR-ND	7.8	8.2	8.0	4
Rochelle	Shallow Average			8.1	
Smart	LS-NS	7.7	8.3	8.0	5
Smart	LS-WS	8.1	8.8	8.4	5
Smart	LS-SS	7.9	8.4	8.1	6
Smart	LS-SD	7.8	8.6	8.2	5
Smart	Shallow Average			8.2	
Conine	LC-SS	5.9	7.5	6.5	6
Conine	LC-NS	7.3	8.0	7.8	6
Conine	LC-ES	7.7	8.0	7.8	5
Conine	LC-ED	7.7	8.1	7.9	6
Conine	Shallow Average			7.3	
Lake	IWR Run 33		Median	Average	Number of Samples
Haines	1997-2007 ambient lake		7.8	7.9	56
Rochelle	1997-2007 ambient lake		8	8	49
Smart	1997-2007 ambient lake		8.4	8.3	41
Conine	1997-2007 ambient lake		8.2	8.3	31

Alkalinity

The groundwater seepage water alkalinity was greater than the median ambient lake water in Lakes Haines and Smart, while the majority of sites were greater than the lake water concentration in Lake Conine except site LC-SS. The range in seepage water alkalinity at Lake Haines was 73 to 226 mg/l with an average of 133 mg/l at the shallow sites and 116 mg/l at the deep site (Table 9). In comparison, the median and mean alkalinity of the ambient lake water was 55 and 54 mg/l, respectively (Table 9). In Lake Rochelle, the seepage water range for alkalinity was 64 to 210 mg/l with an average of 106 mg/l at the shallow sites and 83 mg/l at the deep site (Table 9). The ambient median and mean of the alkalinity in ambient lake water was 62 mg/l; however, only one lake value is available (Table 9). The range in alkalinity for Lake Smart seepage water was 66 to 186 mg/l with an average of 100 mg/l at the shallow sites and 107 mg/l at the deep site (Table 9). The median and mean of the alkalinity in ambient lake water was 52 and 53 mg/l, respectively (Table 9). In Lake Conine, the range in seepage water alkalinity was

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11 to 105 mg/l with an average of 62 mg/l at the shallow sites and 70 mg/l at the deep site (Table 9). The median and mean of the alkalinity in ambient lake water was 59 and 57 mg/l, respectively (Table 9).

Table 9. Alkalinity summary statistics for groundwater seepage water and ambient lake water

Lake	Site	Min (mg/l)	Max (mg/l)	Average (mg/l)	Number of Samples
Haines	LH-ES	79	129	103	3
Haines	LH-NS	127	226	188	4
Haines	LH-WS	78	166	108	6
Haines	LH-WD	73	154	116	6
Haines	Shallow Average			133	
Rochelle	LR-WS	73	210	118	5
Rochelle	LR-SS	66	108	86	4
Rochelle	LR-NS	87	130	115	4
Rochelle	LR-ND	64	116	83	4
Rochelle	Shallow Average			106	
Smart	LS-NS	77	97	86	5
Smart	LS-WS	82	157	122	5
Smart	LS-SS	69	131	94	6
Smart	LS-SD	66	186	107	5
Smart	Shallow Average			100	
Conine	LC-SS	11	79	34	6
Conine	LC-NS	58	71	65	6
Conine	LC-ES	71	105	87	5
Conine	LC-ED	59	91	70	6
Conine	Shallow Average			62	
Lake	IWR Run 33		Median (mg/l)	Average (mg/l)	Number of Samples
Haines	1997-2007 ambient lake		55	54	22
Rochelle	1997-2007 ambient lake		62	62	1
Smart	1997-2007 ambient lake		52	53	24
Conine	1997-2007 ambient lake		59	57	36

Ammonia

The ammonia concentration of the groundwater seepage water was greater than the 1997-2007 ambient lake water median in each of the four lakes. The range of ammonia in the seepage water at Lake Haines was 0.01 to 4.96 mg/l with an average of 0.78 mg/l at the shallow sites and 2.15 mg/l at the deep site (Table 10). In comparison, the median and mean ammonia concentration of the ambient lake water was 0.011 and 0.015 mg/l, respectively (Table 10). In Lake Rochelle, the range in ammonia concentrations of seepage water was 0.01 to 7.59 mg/l with an average of 1.32 mg/l at the shallow sites and 0.12 mg/l at the deep site (Table 10). The ambient median and mean of the lake water ammonia was 0.008 and 0.012 mg/l, respectively (Table 10). The range

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in ammonia from seepage water in Lake Smart was 0.01 to 13.2 mg/l with an average of 2.03 mg/l at the shallow sites and 4.17 mg/l at the deep site (Table 10). The median and mean of the ammonia in ambient lake water was 0.010 and 0.011 mg/l, respectively (Table 10). In Lake Conine, the range of ammonia in seepage water was 0.01 to 4.2 mg/l with an average of 0.75 mg/l at the shallow sites and 0.13 mg/l at the deep site (Table 10). The median and mean of the ammonia in ambient lake water was 0.009 and 0.017 mg/l, respectively (Table 10).

Table 10. Ammonia summary statistics for groundwater seepage water and ambient lake water

Lake	Site	Min (mg/l)	Max (mg/l)	Average (mg/l)	Number of Samples
Haines	LH-ES	0.17	1.29	0.84	3
Haines	LH-NS	0.01	4.89	1.24	4
Haines	LH-WS	0.01	0.96	0.25	6
Haines	LH-WD	0.01	4.96	2.15	6
Haines	Shallow Average			0.78	
Rochelle	LR-WS	0.02	7.59	2.19	6
Rochelle	LR-SS	0.02	2.68	0.76	5
Rochelle	LR-NS	0.03	2.29	1.01	5
Rochelle	LR-ND	0.01	0.43	0.12	6
Rochelle	Shallow Average			1.32	
Smart	LS-NS	0.02	3.71	1.55	6
Smart	LS-WS	0.01	7.58	3.25	5
Smart	LS-SS	0.01	3.19	1.30	6
Smart	LS-SD	0.03	13.20	4.17	5
Smart	Shallow Average			2.03	
Conine	LC-SS	0.01	4.20	1.25	6
Conine	LC-NS	0.03	0.32	0.15	6
Conine	LC-ES	0.03	2.33	0.87	6
Conine	LC-ED	0.05	0.22	0.13	6
Conine	Shallow Average			0.75	
Lake	IWR Run 33		Median (mg/l)	Average (mg/l)	Number of Samples
Haines	1997-2007 ambient lake		0.011	0.015	38
Rochelle	1997-2007 ambient lake		0.008	0.012	30
Smart	1997-2007 ambient lake		0.01	0.011	36
Conine	1997-2007 ambient lake		0.009	0.017	35

Nitrate + Nitrite (NO_x)

The groundwater seepage water NO_x concentration was greater than the median ambient lake water in Lakes Haines Rochelle, and Conine; however, the seepage water NO_x concentrations in Lake Smart were similar to the lake water concentration. The range in NO_x in seepage water at Lake Haines was 0.004 to 0.249 mg/l with an average of 0.036 mg/l at the shallow sites and 0.037 mg/l at the deep site (Table 11). In comparison, the median and mean NO_x of the ambient

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lake water was 0.008 and 0.015 mg/l, respectively (Table 11). In Lake Rochelle, the range of NO_x in seepage water was 0.004 to 0.303 mg/l with an average of 0.034 mg/l at the shallow sites and 0.028 mg/l at the deep site (Table 11). The ambient NO_x median and mean of the lake water was 0.010 and 0.020 mg/l, respectively (Table 11). The range in NO_x of seepage water in Lake Smart was 0.004 to 0.099 mg/l with an average of 0.010 mg/l at the shallow sites and 0.004 mg/l at the deep site (Table 11). The median and mean of the NO_x in ambient lake water was 0.010 and 0.052 mg/l, respectively (Table 11). In Lake Conine, the range of NO_x in seepage water was 0.004 to 0.496 mg/l with an average of 0.103 mg/l at the shallow sites and 0.027 mg/l at the deep site (Table 11). The median and mean of the NO_x in ambient lake water was 0.009 and 0.010 mg/l, respectively (Table 11).

Table 11. NO_x summary statistics for groundwater seepage water and ambient lake water

Lake	Site	Min (mg/l)	Max (mg/l)	Average (mg/l)	Number of Samples
Haines	LH-ES	0.004	0.017	0.010	3
Haines	LH-NS	0.017	0.033	0.022	4
Haines	LH-WS	0.004	0.249	0.075	6
Haines	LH-WD	0.004	0.108	0.037	6
Haines	Shallow Average			0.036	
Rochelle	LR-WS	0.009	0.303	0.080	6
Rochelle	LR-SS	0.004	0.030	0.012	5
Rochelle	LR-NS	0.004	0.027	0.011	5
Rochelle	LR-ND	0.004	0.114	0.028	6
Rochelle	Shallow Average			0.034	
Smart	LS-NS	0.004	0.023	0.007	6
Smart	LS-WS	0.004	0.004	0.004	5
Smart	LS-SS	0.004	0.099	0.020	6
Smart	LS-SD	0.004	0.006	0.004	5
Smart	Shallow Average			0.010	
Conine	LC-SS	0.004	0.297	0.057	6
Conine	LC-NS	0.004	0.144	0.054	5
Conine	LC-ES	0.033	0.496	0.199	6
Conine	LC-ED	0.004	0.107	0.027	6
Conine	Shallow Average			0.103	
Lake	IWR Run 33		Median (mg/l)	Average (mg/l)	Number of Samples
Haines	1997-2007 ambient lake		0.008	0.015	43
Rochelle	1997-2007 ambient lake		0.01	0.02	38
Smart	1997-2007 ambient lake		0.01	0.052	36
Conine	1997-2007 ambient lake		0.009	0.01	51

Total Kjeldahl Nitrogen (TKN)

The TKN concentration in groundwater seepage water was greater than the 1997-2007 ambient lake median in each of the four lakes. The range of TKN in seepage water at Lake Haines was

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0.2 to 12.3 mg/l with an average of 4.1 mg/l at the shallow sites and 3.3 mg/l at the deep site (Table 12). In comparison, the median and mean TKN of the ambient lake water was 1.4 and 1.5 mg/l, respectively (Table 12). In Lake Rochelle, the range of TKN in seepage water was 0.8 to 9.5 mg/l with an average of 3.2 mg/l at the shallow sites and 1.9 mg/l at the deep site (Table 12). The ambient median and mean of TKN in the lake water was 0.9 and 1.0 mg/l, respectively (Table 12). The range in TKN of seepage water in Lake Smart was 2.1 to 14.3 mg/l with an average of 5.0 mg/l at the shallow sites and 5.9 mg/l at the deep site (Table 12). The median and mean of the TKN in ambient lake water was 1.3 mg/l (Table 12). In Lake Conine, the range in TKN of seepage water was 0.7 to 5.0 mg/l with an average of 2.4 mg/l at the shallow sites and 1.4 mg/l at the deep site (Table 12). The median and mean of the TKN in ambient lake water was 1.3 and 1.4 mg/l, respectively (Table 12).

Table 12. TKN summary statistics for groundwater seepage water and ambient lake water

Lake	Site	Min (mg/l)	Max (mg/l)	Average (mg/l)	Number of Samples
Haines	LH-ES	1.1	2.3	1.8	3
Haines	LH-NS	5.8	12.3	8.1	4
Haines	LH-WS	0.2	7.0	2.4	6
Haines	LH-WD	0.8	6.0	3.3	6
Haines	Shallow Average			4.1	
Rochelle	LR-WS	1.6	9.5	4.5	6
Rochelle	LR-SS	0.9	4.2	2.4	5
Rochelle	LR-NS	1.3	4.9	2.7	5
Rochelle	LR-ND	0.8	4.2	1.9	6
Rochelle	Shallow Average			3.2	
Smart	LS-NS	2.9	6.4	4.4	6
Smart	LS-WS	3.0	9.2	6.7	5
Smart	LS-SS	2.3	5.8	4.0	6
Smart	LS-SD	2.1	14.3	5.9	5
Smart	Shallow Average			5.0	
Conine	LC-SS	1.1	4.6	3.6	6
Conine	LC-NS	0.9	1.6	1.2	6
Conine	LC-ES	1.0	5.0	2.4	6
Conine	LC-ED	0.7	2.2	1.4	6
Conine	Shallow Average			2.4	
Lake	IWR Run 33		Median (mg/l)	Average (mg/l)	Number of Samples
Haines	1997-2007 ambient lake		1.4	1.5	46
Rochelle	1997-2007 ambient lake		0.9	1	42
Smart	1997-2007 ambient lake		1.3	1.3	43
Conine	1997-2007 ambient lake		1.3	1.4	64

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Total Nitrogen (TN)

The TN concentration in groundwater seepage water was greater than the 1997-2007 ambient lake median in each of the four lakes. The groundwater TN concentrations were very similar to the reported TKN concentrations, indicating that the majority of nitrogen input into the lake via groundwater is either organic nitrogen or ammonia. The range of TN in seepage water at Lake Haines was 0.4 to 12.3 mg/l with an average of 4.1 mg/l at the shallow sites and 3.4 mg/l at the deep site (Table 13). In comparison, the median and mean TN of the ambient lake water was 1.3 mg/l (Table 13). In Lake Rochelle, the range of TN in seepage water was 0.8 to 9.5 mg/l with an average of 3.3 mg/l at the shallow sites and 1.9 mg/l at the deep site (Table 13). The ambient median and mean of the TN in lake water was 1.1 mg/l (Table 13). The range of TN in seepage water for Lake Smart was 2.1 to 14.3 mg/l with an average of 5.0 mg/l at the shallow sites and 5.9 mg/l at the deep site (Table 13). The median and mean of the TN in ambient lake water was 1.4 mg/l (Table 13). In Lake Conine, the range of TN in seepage water was 0.7 to 5.0 mg/l with an average of 2.5 mg/l at the shallow sites and 1.4 mg/l at the deep site (Table 13). The median and mean of the TN in ambient lake water was 1.3 and 1.4 mg/l, respectively (Table 13).

Table 13. TN summary statistics for groundwater seepage water and ambient lake water

Lake	Site	Min (mg/l)	Max (mg/l)	Average (mg/l)	Number of Samples
Haines	LH-ES	1.2	2.3	1.8	3
Haines	LH-NS	5.8	12.3	8.1	4
Haines	LH-WS	0.4	7.1	2.5	6
Haines	LH-WD	0.8	6.1	3.4	6
Haines	Shallow Average			4.1	
Rochelle	LR-WS	1.6	9.5	4.6	6
Rochelle	LR-SS	0.9	4.2	2.4	5
Rochelle	LR-NS	1.3	4.9	2.7	5
Rochelle	LR-ND	0.8	4.2	1.9	6
Rochelle	Shallow Average			3.3	
Smart	LS-NS	2.9	6.4	4.4	6
Smart	LS-WS	3.0	9.2	6.7	5
Smart	LS-SS	2.3	5.8	4.0	6
Smart	LS-SD	2.1	14.3	5.9	5
Smart	Shallow Average			5.0	
Conine	LC-SS	1.1	4.6	3.6	6
Conine	LC-NS	0.9	1.7	1.2	5
Conine	LC-ES	1.0	5.0	2.6	6
Conine	LC-ED	0.7	2.3	1.4	6
Conine	Shallow Average			2.5	
Lake	IWR Run 33		Median (mg/l)	Average (mg/l)	Number of Samples
Haines	1997-2007 ambient lake		1.3	1.3	273
Rochelle	1997-2007 ambient lake		1.1	1.1	182
Smart	1997-2007 ambient lake		1.4	1.4	53
Conine	1997-2007 ambient lake		1.3	1.4	89

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Orthophosphate (ORP)

Sufficient data to provide a median concentration of ambient lake water was not available for the lakes; therefore, a comparison between groundwater seepage water and lake water concentrations was not completed. The range of ORP concentration in groundwater seepage water at Lake Haines was 0.007 to 0.298 mg/l with an average of 0.091 mg/l at the shallow sites and 0.118 mg/l at the deep site (Table 14). In Lake Rochelle, the range of ORP in seepage water was 0.002 to 0.302 mg/l with and average of 0.064 mg/l at the shallow sites and 0.034 mg/l at the deep site (Table 14). The range of ORP in seepage water at Lake Smart was 0.002 to 0.007 mg/l with an average of 0.003 mg/l at the shallow sites and 0.004 mg/l at the deep site (Table 14). In Lake Conine, the range of ORP in seepage water was 0.002 to 0.057 mg/l with an average of 0.013 mg/l at the shallow sites and 0.007 mg/l at the deep site (Table 14).

Table 14. ORP summary statistics for groundwater seepage water

Lake	Site	Min (mg/l)	Max (mg/l)	Average (mg/l)	Number of Samples
Haines	LH-ES	0.007	0.104	0.058	3
Haines	LH-NS	0.014	0.228	0.095	4
Haines	LH-WS	0.011	0.248	0.121	6
Haines	LH-WD	0.007	0.298	0.118	5
Haines	Shallow Average			0.091	
Rochelle	LR-WS	0.002	0.302	0.104	5
Rochelle	LR-SS	0.002	0.028	0.010	4
Rochelle	LR-NS	0.005	0.149	0.079	5
Rochelle	LR-ND	0.002	0.122	0.034	4
Rochelle	Shallow Average			0.064	
Smart	LS-NS	0.002	0.005	0.004	5
Smart	LS-WS	0.002	0.005	0.003	5
Smart	LS-SS	0.002	0.006	0.004	6
Smart	LS-SD	0.002	0.007	0.004	5
Smart	Shallow Average			0.003	
Conine	LC-SS	0.003	0.036	0.018	6
Conine	LC-NS	0.002	0.007	0.004	6
Conine	LC-ES	0.002	0.057	0.016	5
Conine	LC-ED	0.002	0.014	0.007	6
Conine	Shallow Average			0.013	

Total Phosphorus (TP)

The TP concentration of groundwater seepage water was greater than the 1997-2007 ambient lake median in Lakes Haines and Rochelle but less than the lake median in Lakes Smart and Conine. The range of TP in seepage water at Lake Haines was 0.004 to 0.373 mg/l with an average of 0.131 mg/l at the shallow sites and 0.165 mg/l at the deep site (Table 15). In comparison, the median and mean TP of the ambient lake water was 0.07 mg/l (Table 15). In Lake Rochelle, the range of TP in seepage water was 0.012 to 0.334 mg/l with and average of

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0.101 mg/l at the shallow sites and 0.09 mg/l at the deep site (Table 15). The ambient median and mean of the TP in lake water was 0.05 mg/l (Table 15). The range of TP in seepage water at Lake Smart was 0.002 to 0.082 mg/l with an average of 0.023 mg/l at the shallow sites and 0.041 mg/l at the deep site (Table 15). The median and mean of the TP in ambient lake water was 0.05 and 0.06 mg/l, respectively (Table 15). In Lake Conine, the range of TP in seepage water was 0.002 to 0.348 mg/l with an average of 0.055 mg/l at the shallow sites and 0.043 mg/l at the deep site (Table 15). The median and mean of the TP in ambient lake water was 0.07 and 0.08 mg/l, respectively (Table 15).

Table 15. TP summary statistics for groundwater seepage water and ambient lake water

Lake	Site	Min (mg/l)	Max (mg/l)	Average (mg/l)	Number of Samples
Haines	LH-ES	0.035	0.133	0.099	3
Haines	LH-NS	0.053	0.285	0.136	4
Haines	LH-WS	0.088	0.289	0.159	6
Haines	LH-WD	0.004	0.373	0.165	6
Haines	Shallow Average			0.131	
Rochelle	LR-WS	0.015	0.334	0.162	6
Rochelle	LR-SS	0.012	0.106	0.040	5
Rochelle	LR-NS	0.033	0.168	0.101	5
Rochelle	LR-ND	0.014	0.286	0.090	6
Rochelle	Shallow Average			0.101	
Smart	LS-NS	0.002	0.053	0.026	6
Smart	LS-WS	0.002	0.051	0.021	5
Smart	LS-SS	0.002	0.042	0.021	6
Smart	LS-SD	0.002	0.082	0.041	5
Smart	Shallow Average			0.023	
Conine	LC-SS	0.026	0.083	0.044	6
Conine	LC-NS	0.019	0.054	0.032	6
Conine	LC-ES	0.002	0.348	0.088	6
Conine	LC-ED	0.023	0.060	0.043	6
Conine	Shallow Average			0.055	
Lake	IWR Run 33		Median (mg/l)	Average (mg/l)	Number of Samples
Haines	1997-2007 ambient lake		0.07	0.07	267
Rochelle	1997-2007 ambient lake		0.05	0.05	174
Smart	1997-2007 ambient lake		0.05	0.06	56
Conine	1997-2007 ambient lake		0.07	0.08	85

TN and TP Groundwater Loading Rates

The groundwater seepage rates and nutrient concentrations measured for the shallow (<5 feet water depth) and deep (<10 feet water depth) wells for each lake were used to calculate the TN and TP groundwater loading rates (Figures 29 and 30). Since no significant difference in seepage rates were identified between shallow and deep seepage meters, the average groundwater

seepage rate for each sampling trip was calculated combining the shallow and deep sites. From average trip seepage rates per lake, the average groundwater seepage for the study period was calculated (Table 16). The average groundwater seepage TN and TP concentrations for the duration of the study were calculated using the same technique that was utilized for the groundwater seepage rate (Table 16). The experimental average groundwater TN and TP concentrations were applied to the average groundwater seepage rate to determine the loading rates for each lake (Figures 29 and 30). Lake Haines had the highest groundwater loading rate for both TN and TP. The groundwater loading rates from Lakes Haines, Rochelle, Smart, and Conine were within an order of magnitude of the loading rates based on data collected and reported by ERD for lakes May, Lulu, and Shipp (ERD 2007).

Table 16. Average groundwater seepage rates, TN and TP concentrations over the experiment.

Lake	Average Groundwater Seepage (L/m ² d ⁻¹)	Average TN (mg/l)	Average TP (mg/l)
Haines	4.04	3.77	0.14
Rochelle	2.71	2.94	0.10
Conine	5.46	2.27	0.05
Smart	2.14	5.01	0.03

Figure 29. TN groundwater loading rate ($\text{mg}/\text{m}^2\text{d}^{-1}$) for the shallow and deep sites compared to rates calculated for lakes May, Lulu and Shipp based upon ERD data

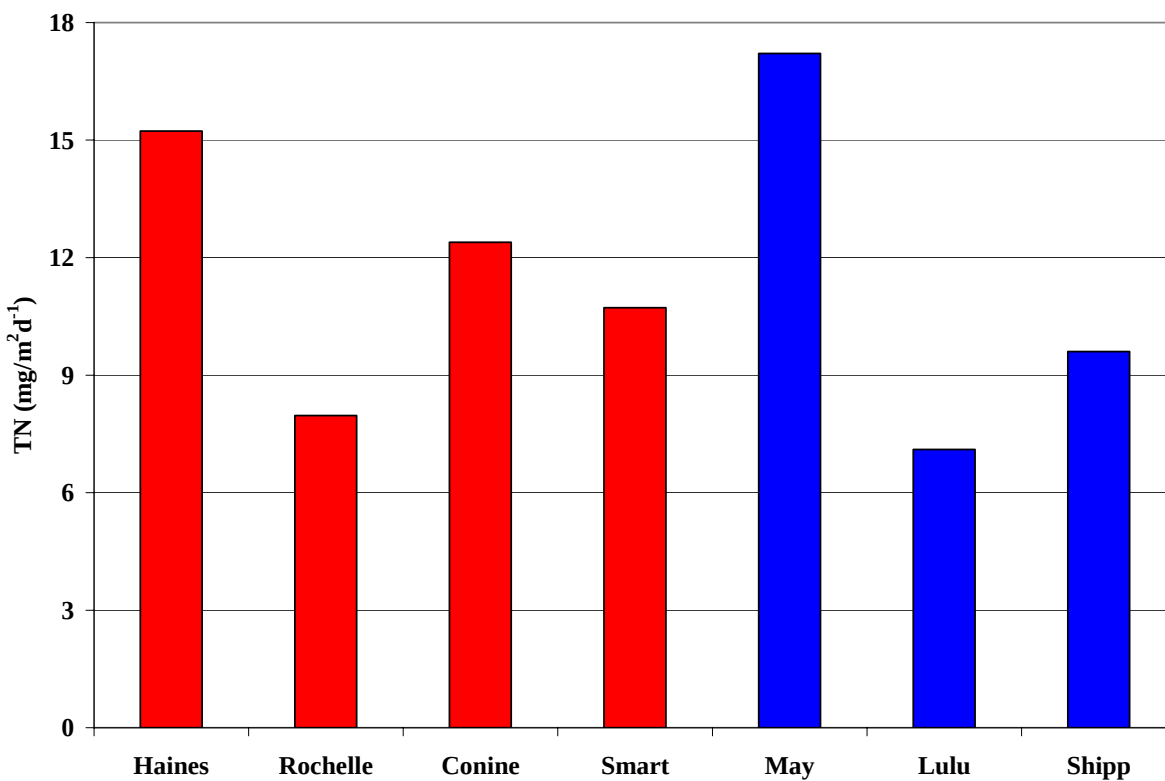
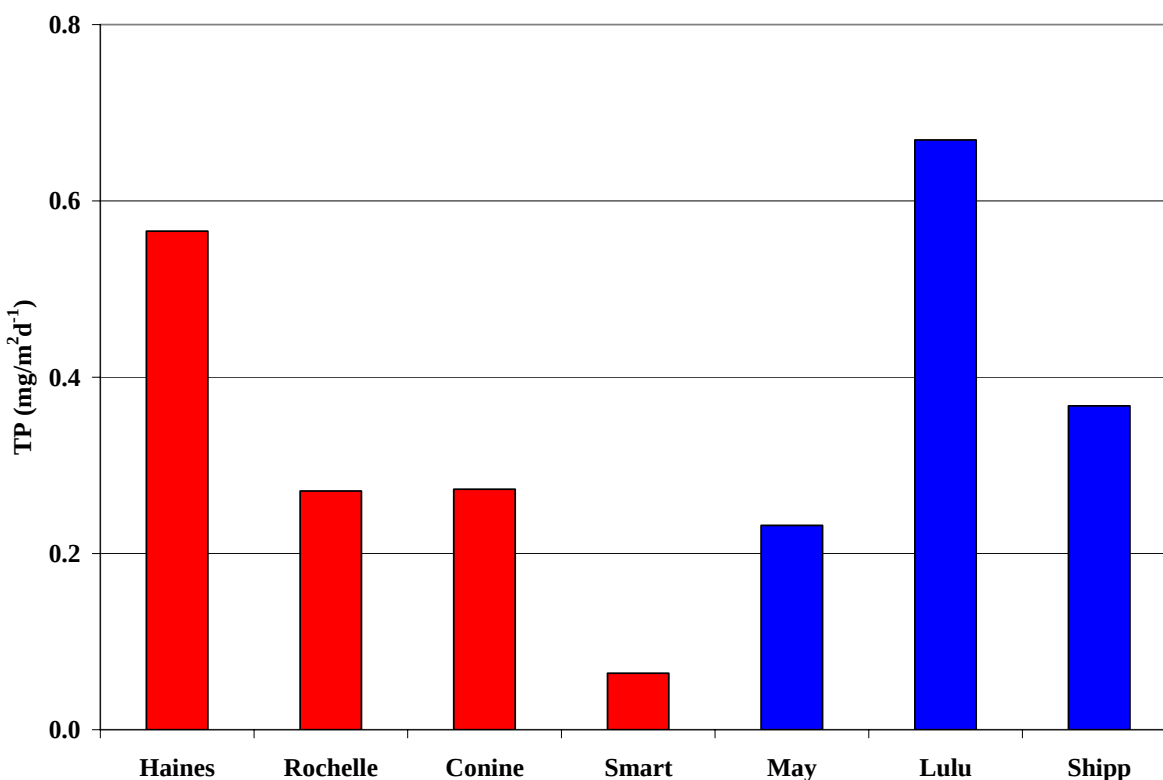


Figure 30. TP groundwater loading rate ($\text{mg}/\text{m}^2\text{d}^{-1}$) for the shallow and deep sites compared to rates calculated for lakes May, Lulu and Shipp based upon ERD data



3.2. Surficial Groundwater Monitoring Wells

3.2.1. Design and Methods

This section presents the results of surficial groundwater monitoring activities associated with the monitor well installation. The objective of the monitoring was to measure groundwater levels and evaluate the influence of groundwater infiltration into the WHCL. Well construction was conducted on July 28-30, 2008 by Huss Drilling (Huss) of Dade City, Florida and was overseen by a PBS&J environmental scientist.

The locations for the ground water monitoring wells were based on several factors including: proximity to the study lake, appropriate elevation change between the upper and lower wells, permission to access the property, and the ability to access the site with drilling equipment. The documentation to provide permission to access and install the ground water monitoring wells on the property took longer than anticipated resulting in delayed installation. All 12 monitoring wells were constructed using hollow stem auger (HSA) techniques with a high torque truck-mounted HSA drill. This drilling method uses a series of continuous flight augers (CFA)

approximately five feet long. The CFA method is a non-displacement system, i.e., the volume of material excavated is designed to equal to the volume of the augers inserted into the ground. This results in no net displacement of the soil surrounding the well. Another type of screw auger could excavate less material, but would displace the soil adjacent to the well for its entire depth, and thus possibly affect the permeability of the soil around the well screen.

During drilling, water was forced into the auger to keep drill cuttings from filling the hollow center of the auger series. The series of augers kept the borehole open during drilling and well installation. The screen, casing, and sand pack for the well were emplaced inside the augers. The augers were raised and removed one at a time as the sand pack was installed. All of the wells were constructed of PVC well casing and well screen with a conical silt trap. While casing and screen lengths varied based on the depth to the water table, the silt traps used were six inches in length. Silt traps allow for fine sediments to settle below the screened portion of the well without impacting the hydraulics of the well. The well screens were surrounded by filter packs consisting of silica sand. A filter pack is coarse sand or fine gravel that is placed between the borehole wall and screen. Filter packs are used to settle out fine-grained particles that may otherwise enter the well and are installed to increase the effective hydraulic diameter of the well.

Cement was installed on top of the filter pack to hold into place a metal frame for the manhole cover, or in the case of two wells, an aluminum protective casing, and to prevent downward percolation of overlying waters.

Ten of the wells were installed flush to the ground to minimize their visibility and to reduce interference with landscaping maintenance. These wells were capped with a locking plug, although in most cases these caps were left loose (not air-tight) to prevent potential effects of pressure differences between the inside and outside of the casing. In some wells, the seal was kept tight and locked to prevent the possibility of tampering. In all the flush-mount wells, a hole was drilled in the casing below the cap for additional ventilation. The manhole frames and covers were eight inches in diameter and secured by cement within a two-foot square wooden frame (Figure 31). The two wells at Lake Rochelle North were built with above-ground aluminum protective casings instead of being cut at ground level. The protective casings used were 4X4 inches in width and 5 feet in length. Casing approximately two-feet in length was installed with cement into the borehole leaving the top of the casing about three feet above ground. The plugs in these wells were kept very loose for ventilation. No additional holes were drilled into the casing. The protective casing provided a flip-top locked lid to prevent tampering (Figure 31). Once installed, the wells were developed using a small diameter submersible pump powered by a car battery. Wells were developed until water appeared to be free of sediment. This typically took between 15 and 30 minutes.

After installation of the monitoring wells, the latitude, longitude and elevations were acquired by PBS&J surveyors. Table 17 lists the coordinates, elevations, and depths of the monitoring wells. Detailed monitor well schematics for each well are provided in Appendix D. The wells designated as “upper wells” are farthest and at a higher elevation compared to the lake. The wells designated as “lower wells” are closest to the lake and at a lower elevation compared to the upper well.

Figure 31. Left- Flush mount groundwater monitoring well. Right- Above-ground groundwater monitoring well



Groundwater Seepage and Monitoring Well Review

Table 17. Coordinates, Elevations, and Depths of the Monitoring Wells

Monitoring Well Site	Total Depth (feet) of Well	Casing Length / Screen length (feet)	Elevation* of Top of Casing	Elevation* of Ground Adjacent to Well	Northing**	Easting**	Latitude***	Longitude***
Lake Haines - upper	15	5 / 10	131.87	132.20	1366267.1567	747383.2653	28.09203	81.71708
Lake Haines - lower	15	5 / 10	128.33	128.70	1366267.9753	747594.1693	28.09203	81.71643
Lake Rochelle North - upper	25	10 / 15	156.69	153.09	1362194.7255	745633.3999	28.08084	81.72254
Lake Rochelle North - lower	15	5 / 10	135.78	131.59	1361898.5955	745534.9423	28.08002	81.72285
Lake Rochelle Northwest - upper	15	5 / 10	140.74	140.99	1361466.5786	743459.0680	28.07885	81.72929
Lake Rochelle Northwest - lower	15	5 / 10	129.47	129.69	1361206.9932	743460.2735	28.07813	81.72929
Lake Smart - upper	25	10 / 15	138.65	138.70	1353676.5935	747766.7596	28.05739	81.71599
Lake Smart - lower	15	5 / 10	129.25	129.50	1353628.8140	747725.2874	28.05726	81.71611
Lake Conine East - upper	25	10 / 15	136.62	137.00	1354422.8791	746609.4870	28.05945	81.71957
Lake Conine East - lower	15	5 / 10	129.54	129.70	1354795.7181	746663.7737	28.06048	81.71940
Lake Conine South - upper	15	5 / 10	141.82	142.20	1350743.3431	743530.4632	28.04935	81.72914
Lake Conine South - lower	15	5 / 10	133.87	134.20	1352693.0735	744067.5057	28.05471	81.72746
* Elevations are in feet NGVD29.								
** US State Plane - Florida West (feet)								
*** NAD 1983 (2007)								

3.2.2. General Local Surficial Geology Encountered

The stratigraphy of the monitoring well sites is not described in detail here, as soils were solely observed as drill cuttings pushed to the surface during excavation. The stratigraphic units encountered consisted of organic deposits overlying marine deposits. These are very generally described below.

Organic Deposits

Organic deposits generally consisted of brown fibrous organic debris and detritus. Maximum particle size was less than 1 inch and had no apparent structure or odor. All organic deposits were dry at the time of drilling and typically were not deeper than two feet. The only well dug into soils that could be classified as “wetland” soils was the lower well at Lake Haines. The soil near the surface at this site was mucky sand and contained small organic bodies.

Marine Deposits

The observed marine deposits fall into two categories: clay and sand. Clay deposits were encountered in some well explorations. They varied in thickness but all were gray with traces of fine sand and were typically moist to wet. Due to the use of HSA drilling, the presence of clay had no adverse effect on the construction or depth of any well.

The sand deposits consisted mainly of gray to yellow to dark brown sand. Table 18 lists the soils series and descriptions of the soils found where the monitoring wells were installed.

Table 18. Soils Encountered during Monitoring Well Installation

Lake	Well Location	Soil Series	Drainage	Permeability
Haines	Upper	Smyrna & Myakka Fine Sands	Poor to very poor	Rapid to moderate
Haines	Lower	Smyrna & Myakka Fine Sands	Poor to very poor	Rapid to moderate
Rochelle	North - upper	Candler Sand	Excessive	Rapid
Rochelle	North - lower	Candler Sand	Excessive	Rapid
Rochelle	Northwest - upper	Tavares	Moderate	Rapid or very rapid
Rochelle	Northwest - lower	Adamsville Fine Sand	Somewhat poor	Rapid
Conine	East - upper	Adamsville Fine Sand	Somewhat poor	Rapid
Conine	East - lower	Adamsville Fine Sand	Somewhat poor	Rapid
Conine	South - upper	Adamsville Fine Sand	Somewhat poor	Rapid
Conine	South - lower	Adamsville Fine Sand	Somewhat poor	Rapid
Smart	Upper	Candler Sand	Excessive	Rapid
Smart	Lower	Candler Sand	Excessive	Rapid
Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions. USDA-NRCS, Lincoln, NE.				

3.2.3. Results and Data Analysis

The elevation of the groundwater in each monitoring well was measured 16 times between August 5, 2008 and November 26, 2008, the raw data are available in Appendix E. It was the intent of the study to monitor the groundwater elevations every two weeks for six months providing 12 groundwater elevation readings. Due to delays associated with obtaining permission to access the private property for the installation of the monitoring wells, the monitoring wells were installed in August 2008. To compensate for this delay, groundwater elevation measurements were made on a weekly basis for the latter time period of the study, resulting in 16 groundwater elevation readings per site. This greater temporal frequency allowed for greater resolution for the analyses outlined below. The installation and sampling of the groundwater seepage meters in the lake was not delayed due to the ground water monitoring wells. Results indicate that, in general, the groundwater level followed the topography of the land surface. Additionally, the groundwater levels for the corresponding lake were greater than the lake levels, evidence of the hydraulic gradient needed for groundwater inflows to occur. Detailed results are presented below.

The distance from the north side of the top of the well casing to the water table was measured with a Solinst Model 101 Water Level Meter (Solinst Canada Ltd., Ontario, Canada). This distance was subtracted from the surveyed elevation of the top of well casing to determine the elevation of the water level. To eliminate the possibility of inconsistent readings due to uneven cutting of the top of casing, the north side was surveyed and was the only side of the casing used for measurements.

Rainfall data recorded at the Southwest Florida Water Management District's (SWFWMD) rainfall collection site ID# 25167 (ROMP73 Winter Haven) were retrieved from SWFWMD's website (<http://www8.swfwmd.state.fl.us/WMIS/ResourceData/ExtDefault.aspx>). This rainfall site was chosen because of its proximity to the study area and the availability of daily rainfall data. This collection site is located just east of Lake Howard and approximately five miles south of the monitoring wells at Lake Haines and approximately two miles south of the south monitoring wells at Lake Conine.

The lake elevation data were compiled from available staff gage data and the SWFWMD website. The data for Lake Haines (SWFWMD site ID# 25228), Lake Smart (ID# 25381), and Lake Rochelle (ID# 25391) were retrieved from the SWFWMD website. The water elevations for Lake Conine (ID# 25389) from the website were supplemented with the staff gage data recorded when the seepage meters were measured. The staff gage at Lake Haines was read on the days the volume from the in-lake seepage meters were measured, but the SWFWMD data were available for each day, so SWFWMD's measurements were used. The locations of the staff gages in Lake Haines and Lake Conine are mapped in Figures 13 and 16.

For each lake, groundwater elevations, weekly cumulative rainfall and lake stage were evaluated and graphed in Figures 32 to 37. While the depths to the water table differed between paired (upper and lower) wells, the elevation of the groundwater was always higher (with the exception of one pair) in the upper wells than in their associated lower wells (Figures 32 to 37). This shows that the surficial aquifer tends to follow the contour of the landscape. The exception to

this was the pair of wells on the east side of Lake Conine. The elevation of wells differed by seven feet, but the elevation of the groundwater was nearly the same for both wells during the entire study period. Generally, the surficial aquifer water elevation represents the topography with highest water levels observed at greatest land elevations. However, at any one location, water level elevation is not dependent on topographical elevation.

An analysis of the normalized change in groundwater depth was evaluated for each pair of wells. The normalized data were calculated by subtracting the lowest water elevation for each well from each measurement at that well to establish water level changes relative to zero. At lakes Smart, Haines, Rochelle Northwest, and Conine South, there were no differences in the changes in water elevation between wells ($p > 0.05$), indicating that the groundwater elevation in the upper and lower wells have the same response to surface water infiltration. At the Lake Conine East well sites, a significant difference in groundwater elevation change ($p < 0.03$) was observed. Additionally, the wells at Lake Rochelle North also had a significant difference in groundwater level fluctuations ($p < 0.007$). The upper well at this site had the greatest change in topography in comparison to the paired lower well; based on the elevation increase the water table was located further below the land surface. A visual evaluation of the groundwater well data for Lake Rochelle North location indicates a similar response in water elevation at the upper and lower wells (Figure 34).

A review of the cumulative weekly rainfall data indicates that the rainy season began in the middle of June and ended in early September (Figures 32-37). For the purpose of this study, the groundwater elevation in the monitoring wells were measured every two weeks initially and then every week. Due to the period between measurements at the monitoring wells, the groundwater elevation (approximately weekly) did not correspond to the rainfall (daily) reporting intervals and therefore precluded an evaluation of direct relationships. Based upon the sandy, permeable, soils in the region, a relatively rapid response due to rainfall (few days) would be expected showing an increase in the groundwater elevation during periods of rain and a decrease in the groundwater elevation during periods without rain. Typically, higher groundwater elevations occur at the end of the rainy season. Overall, this trend was observed from the surficial aquifer monitoring well data, an increase in groundwater levels was observed in the wells during the middle of August, with peak elevations observed between 8/21 and 9/18 (28 days), with two exceptions. The highest water level in the lower well on the south side of Lake Conine was on the first day of monitoring (8/5). The highest water level in the lower well at Lake Haines was on 10/22.

Due to a decrease in rainfall at the onset of the dry season, a decline in surficial aquifer water elevations was observed beginning in early September. If the groundwater elevations are examined beginning with the readings on 9/11, it is seen that the groundwater levels fall slowly and at a relatively constant rate. The water levels in the upper wells fell more rapidly (average slope = -0.02 feet / day) than the levels in the lower wells (average slope = -0.01 feet / day). The lower well at Lake Haines was omitted from this calculation due to its unusual fluctuations. The basis for the variability in this well's groundwater levels is not apparent to us.

Figure 32. Lake Haines Surficial Aquifer Water Elevations, Stage and Weekly Rainfall

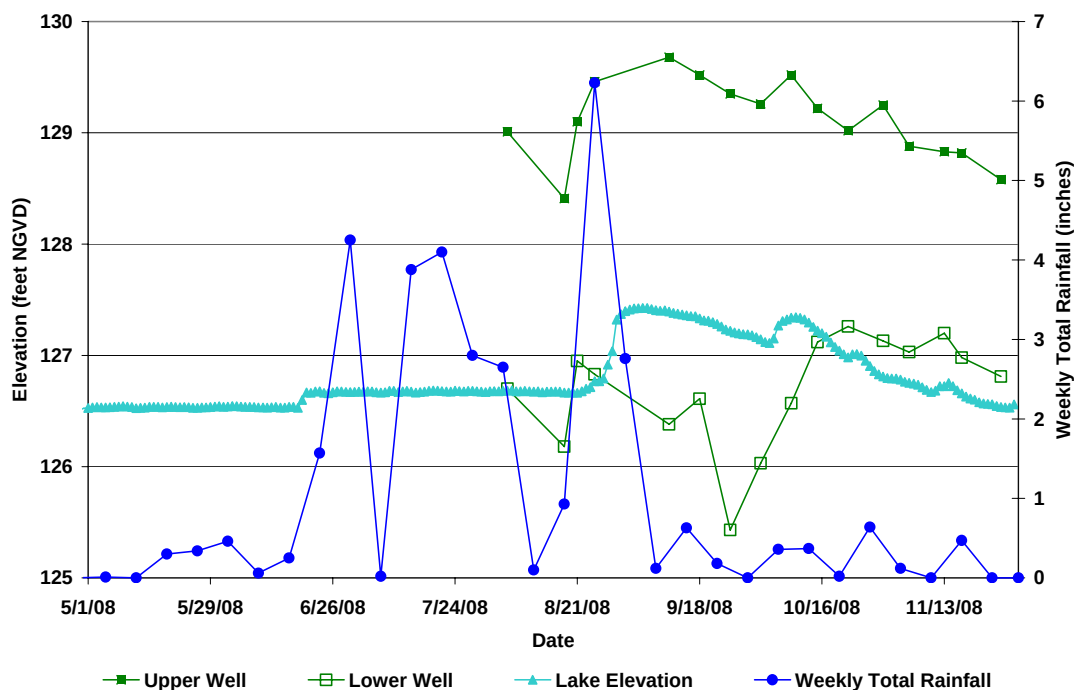


Figure 33. Lake Rochelle Northwest Surficial Aquifer Water Elevations, Stage and Weekly Rainfall

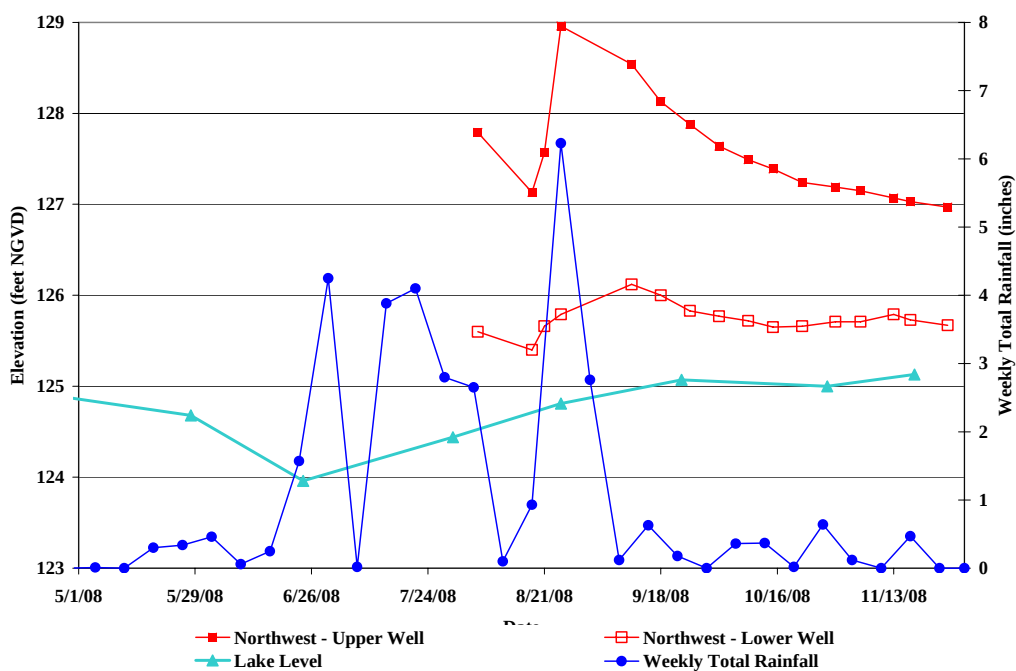


Figure 34. Lake Rochelle North Surficial Aquifer Water Elevations, Stage and Weekly Rainfall

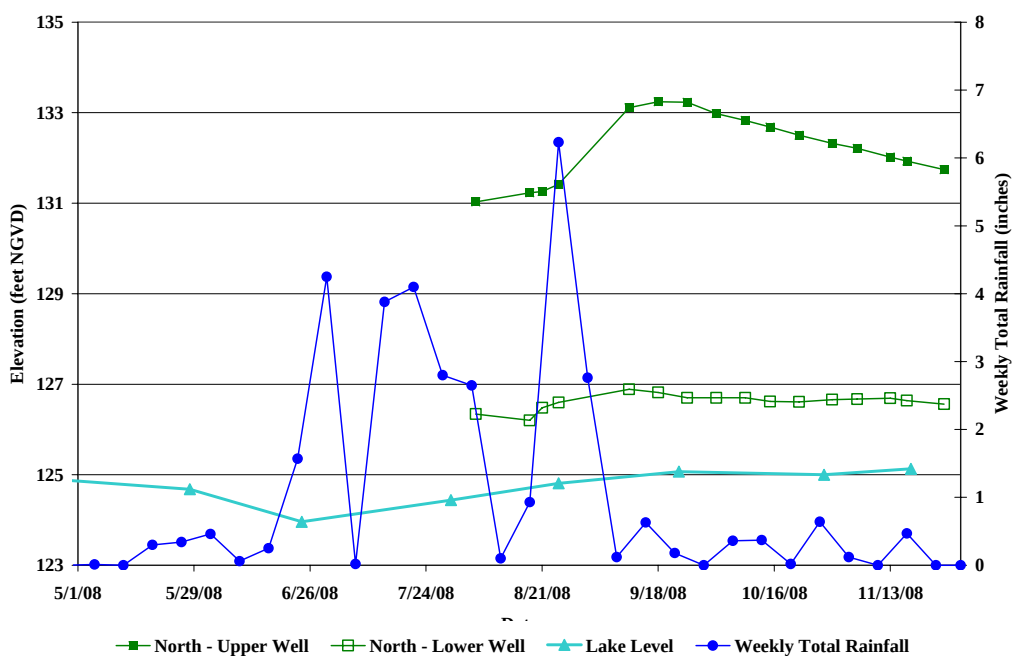


Figure 35. Lake Conine Water East Surficial Aquifer Water Elevations, Stage and Weekly Rainfall

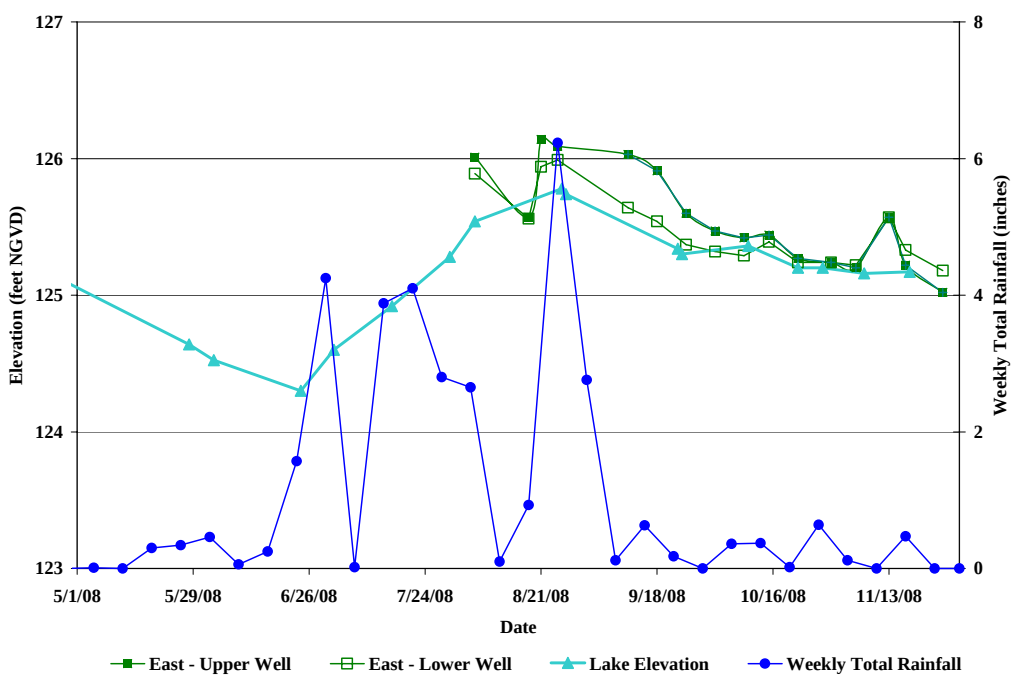


Figure 36. Lake Conine Water South Surficial Aquifer Water Elevations, Stage and Weekly Rainfall

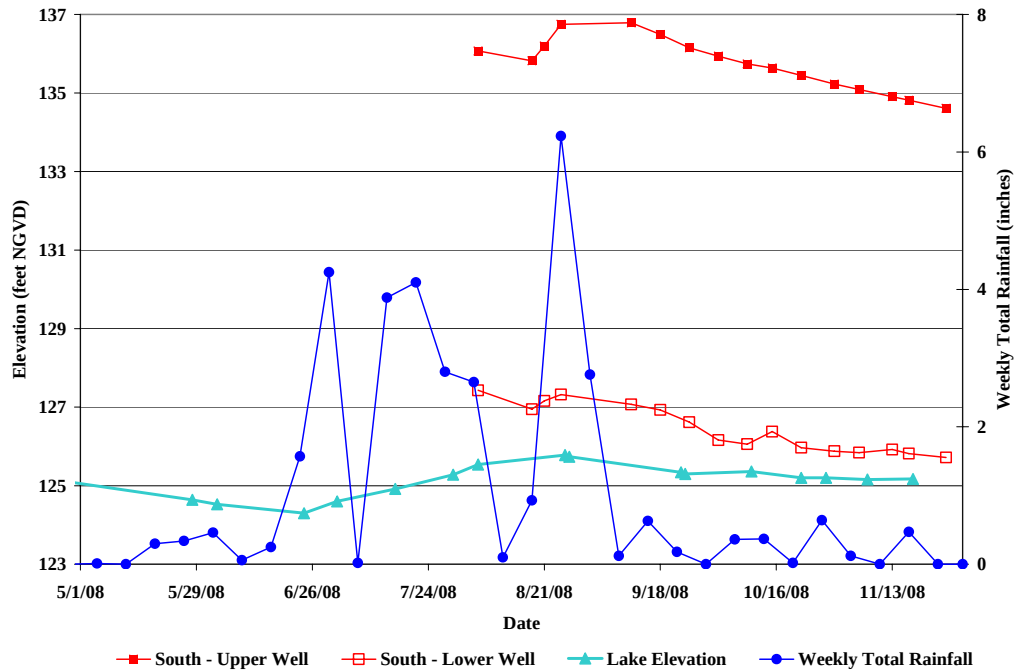
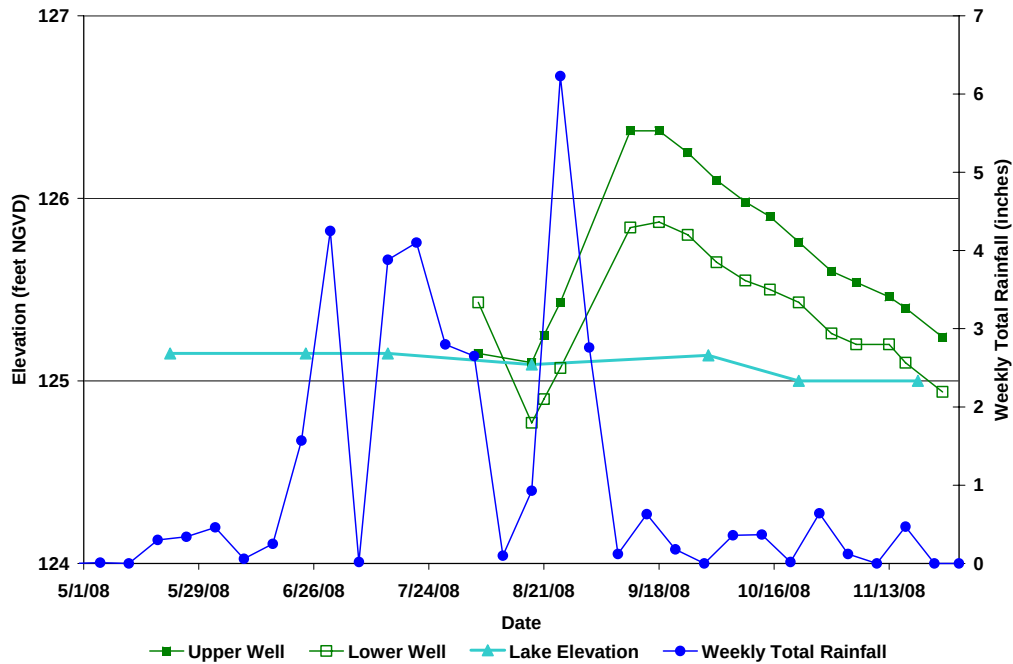


Figure 37. Lake Smart Surficial Aquifer Water Elevations, Stage and Weekly Rainfall



4.0 Potential Groundwater Influence

In Florida, lakes are classified as either seepage lakes or drainage lakes based upon the absence or presence of a surface water outflow (Schiffer 1998). Two-thirds of Florida lakes are seepage lakes that lack a confined surface inflow or outflow (Lee and Swancar 1997). Historically, the WHCL were likely seepage lakes. However, the lakes have canals which were constructed connecting the lakes in series. Presently, all four lakes part of this study are drainage lakes and have surface water outflows (discharge canal). However, and due to fluctuations in seasonal water levels, connectivity to these canals is not permanent. At low water levels, when there is a disconnect of the lakes from their potential recharge and discharge canals, the water levels in these lakes are likely more influenced by groundwater input and rainfall than surface water inflows and outflows. Throughout this groundwater study, the lake water levels were low due to an extended drought, thereby; removing the connection between lakes.

In order to validate the influence of groundwater and rainfall on lake levels, the data from the groundwater seepage and well monitoring experiment were reviewed to determine evidence for any correlations between lake levels, rainfall and surficial aquifer levels. Due to limitations in sample size, relationships were not evident with daily rainfall but a seasonal effect was apparent. Therefore, a review of nearby monitoring stations for daily rainfall, daily surficial aquifer levels and Lake Haines daily stage were evaluated for the period of November 28, 2007 to January 8, 2009 (Figure 38 and 39). Due to limited stage data for Lake Smart, Rochelle and Conine (these lakes are monitored on a monthly basis by SWFWMD); only Lake Haines was evaluated. Rainfall data were retrieved from nearby Lake Henry using the SWFWMD water management information system (WMIS) website (station 25170, <http://www8.swfwmd.state.fl.us/WMIS/ResourceData/ExtDefault.aspx>). Similarly, the daily stage data from Lake Haines was retrieved from WMIS (station 25228). The daily surficial aquifer data were obtained from a USGS monitored groundwater well near Lake Alfred (site number 28100808144184, http://groundwaterwatch.usgs.gov/countymaps/FL_105.html).

Figure 38. Location of Lake Henry rainfall gauge, Lake Haines stage gauge and surficial aquifer well

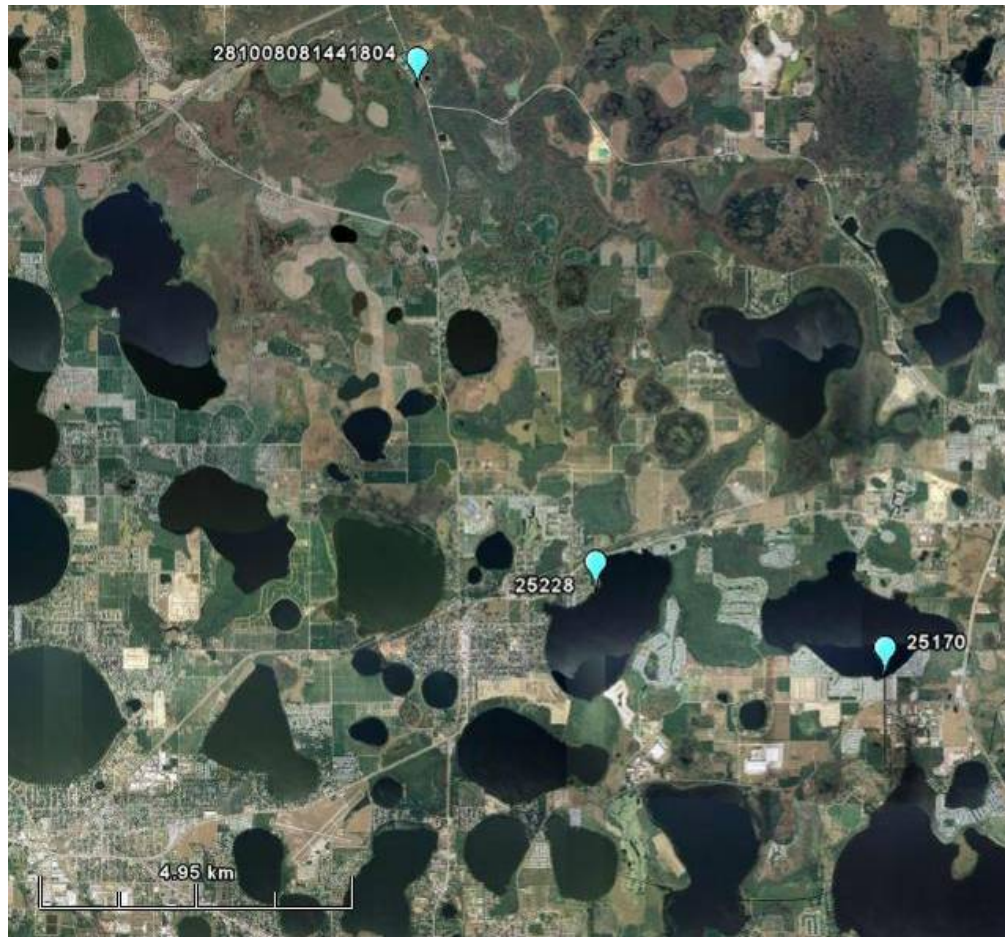
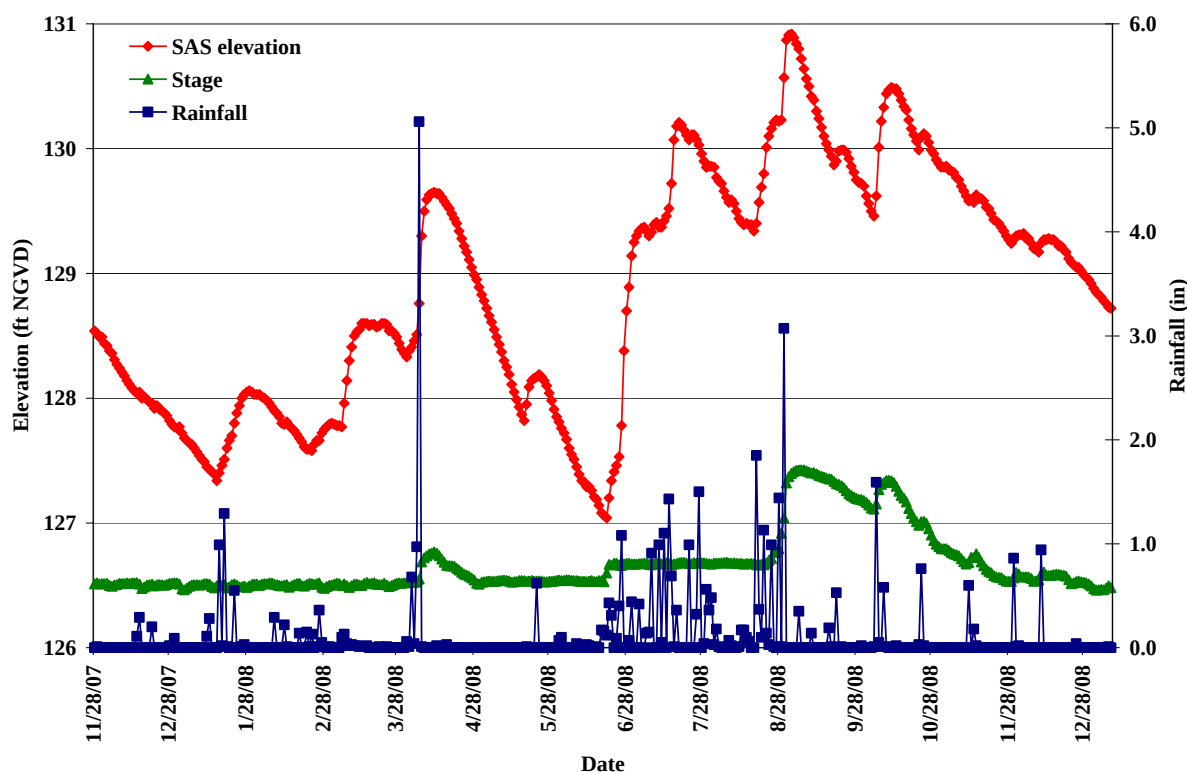


Figure 39. Daily rainfall, Lake Haines stage and surficial aquifer water level elevation data



The majority of all groundwater in Florida originates from rainfall (Fernald and Purdum 1998). Rainfall on the watershed reaches the shallow aquifer through multiple pathways: 1) direct infiltration through the pervious surface, 3) runoff of impervious surfaces to permeable soils, and 3) saturation of less-permeable soils leading to increased infiltration. Factors affecting recharge of the surficial aquifer by rainfall include soil permeability and porosity, and the thickness of the unsaturated zone (Spechler and Kroening 2007). Therefore, the time period between rainfall events and a response in surficial water levels can be variable and delayed. Intuitively, there is a relationship between rainfall and surficial aquifer water elevations and lake stage which can be observed immediately and seasonally.

A statistical evaluation of the relationship between daily rainfall and daily surficial aquifer and lake elevations provided limited information based on the sporadic nature of rain events, and the consequentially non-normal distribution of rainfall data. However, a review of the change in surficial aquifer water elevation and daily rainfall indicates a significant direct linear relationship ($p=0.0000$; $r^2=0.322$; Figure 40) indicating that a lack in rainfall results in a decline in surficial aquifer water elevations, and that (as expected) rainfall events correspond to an increase in groundwater elevations. A similar response was observed at Lake Round in Hillsborough County between rainfall and the surficial and Upper Floridan aquifers (Metz and Sacks 2002). A similar relationship was observed between daily rainfall and the change in Lake stage ($p=0.0000$; $r^2=0.296$; Figure 41). While an immediate response to rainfall in the surficial aquifer water

elevation and lake stage is apparent, the impact is short lived. In general, most rainfall events less than one inch do not affect surficial aquifer water level elevations or lake stage. An immediate change in the surficial aquifer water elevation due to daily rainfall appears to account for approximately one-third of the variability in the surficial aquifer water elevation.

Figure 40. Relationship between daily rainfall and the change in surficial aquifer water elevation ($p=0.0000$; $r^2=0.322$)

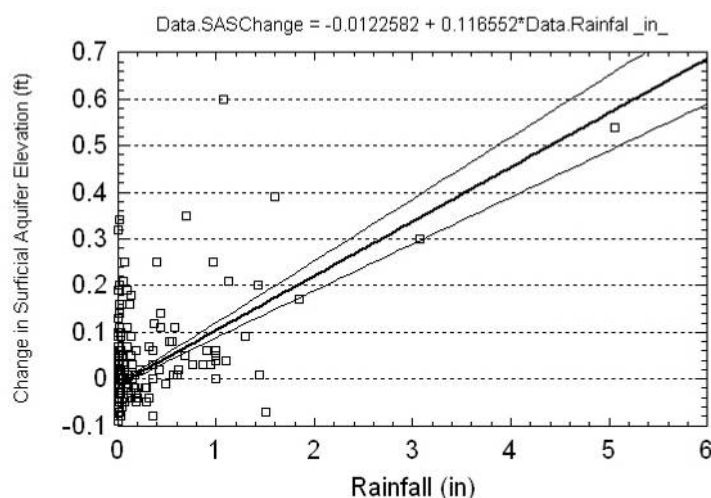
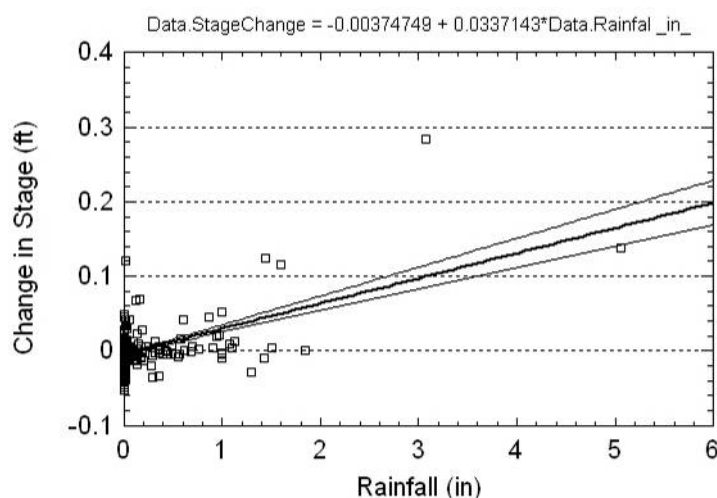


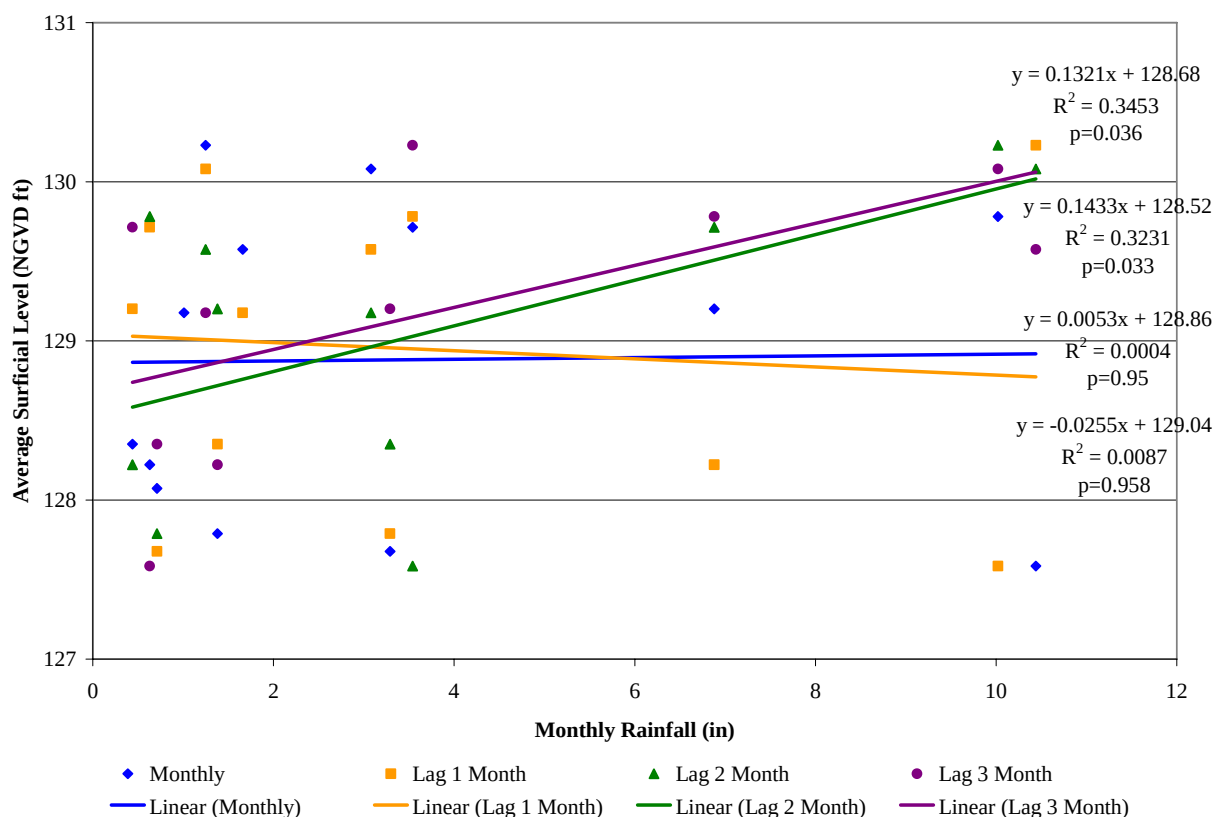
Figure 41. Relationship between daily rainfall and the change in lake stage ($p=0.0000$; $r^2=0.296$).



An additional evaluation of the average monthly surficial aquifer water level and cumulative monthly rainfall was completed to determine if a seasonal relationship was evident (apparent in PBS&J monitoring data). The analysis indicated a significant relationship after applying a two month lag and improves with a three month lag (Figure 42). The evaluation of the data over a longer time period removes some of the variability associated with rainfall and the time lag

allows for infiltration from multiple groundwater recharge pathways. Overall, and as expected, it is likely that the surficial aquifer water level is directly affected by the antecedent aquifer conditions and rainfall.

Figure 42. Relationship between monthly rainfall and average surficial aquifer water levels with different lag periods.



Changes in the surficial aquifer water elevation are explained by daily rainfall, seasonal conditions, and the antecedent aquifer elevation. Based on the above-described relationship between the change in surficial aquifer water levels and daily rainfall, the following empirical relationship was derived:

$$\text{Change in Surficial Aquifer Water Elevation (feet)} = -0.0122582 + 0.116552 * \text{Daily Rainfall(in)}$$

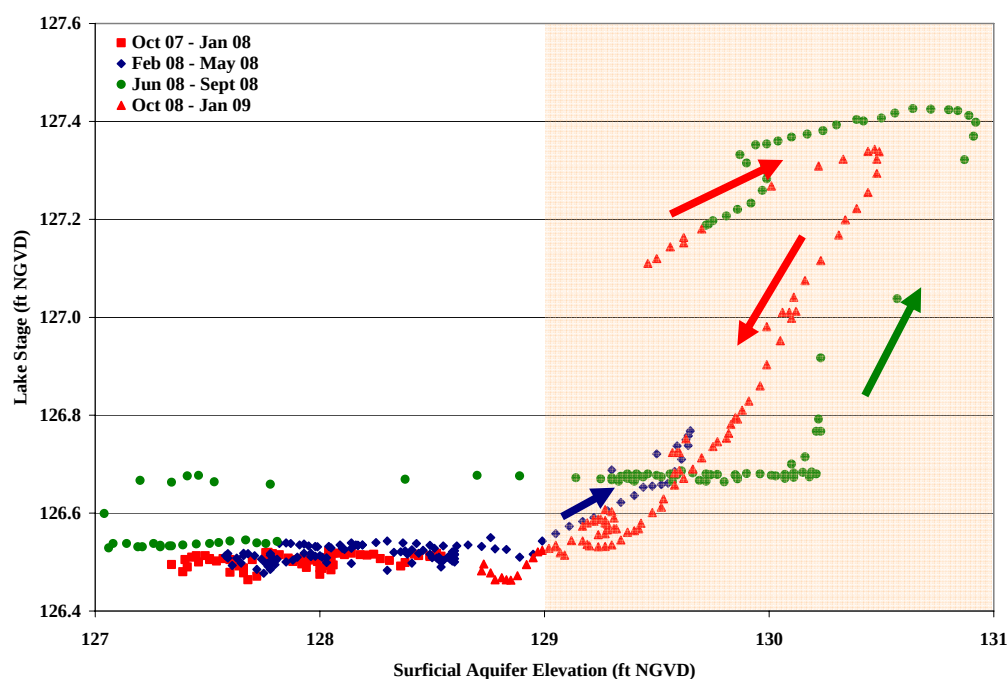
Based upon this equation, the expected change in water elevation during periods of rainfall or drought can be predicted. For example, a five inch rainfall should result in a 0.57 feet increase in aquifer water elevation. However, a 100-day drought would result in a 1.23 feet decline in the aquifer water elevation.

The higher surficial aquifer water elevations, compared with lake stage, observed in the 2007-2009 data are consistent with a hydraulic gradient that favors groundwater infiltration to the lake. The same trend was observed in the surficial aquifer wells monitored by PBS&J during this

study. In a previous water and nutrient budget completed for Lake Haines (submitted to the SWFWMD by PBS&J in 2004), groundwater was also identified as the primary component of the lake water budget. The results of our study and others consistently point to groundwater as the primary component influencing lake levels (volume) in the study lakes.

The data reviewed for Lake Haines (2007 to 2008) was divided into four time blocks: October 2007 to January 2008 (Dry-dry season), February 2008 to May 2008 (Dry season), June 2008 to September 2008 (Wet Season) and October 2008 to January 2009 (Dry-dry season; Figure 43). Based upon the data from November 28, 2007 to January 8, 2008, changes in the surficial aquifer water elevation and lake stage were dependent upon the prior wet season. For example, the water elevation in the surficial aquifer was steadily declining in October 2007- January 2008 due to a lack of rain but the lake stage remained relatively constant at about 126.5 feet (NGVD). However, surficial aquifer water elevations and lake stage both declined during the October 2008- January 2009 season, perhaps because the starting lake elevation was greater. Both the aquifer and lake responded to the wet conditions of June 2008 to September 2008. Overall, it appears that lake levels remain constant until the surficial aquifer water elevation is greater than 129 feet NGVD at this surficial aquifer well location. At surficial aquifer water level elevations greater than 129 feet NGVD, lake stage increases which is attributed to increased groundwater infiltration.

Figure 43. Relationship between the surficial aquifer water elevation and Lake Haines stage ($r^2=0.53$)



5.0 Groundwater Quantification Limitations

Groundwater seepage can be determined through the calculation of a Gross Water Budget, modeling effort or direct measurement. The modeling of groundwater flow and Gross Water Budget development require multiple assumptions which can result in compounded errors leading to an over or under estimate of flow. While groundwater modeling can be a valuable tool when field verified data is not available, seepage meters are widely used as an acceptable measure of groundwater flow in and out of freshwater and marine systems. Below is a discussion of some of the limitations for several of the techniques available to quantify groundwater seepage.

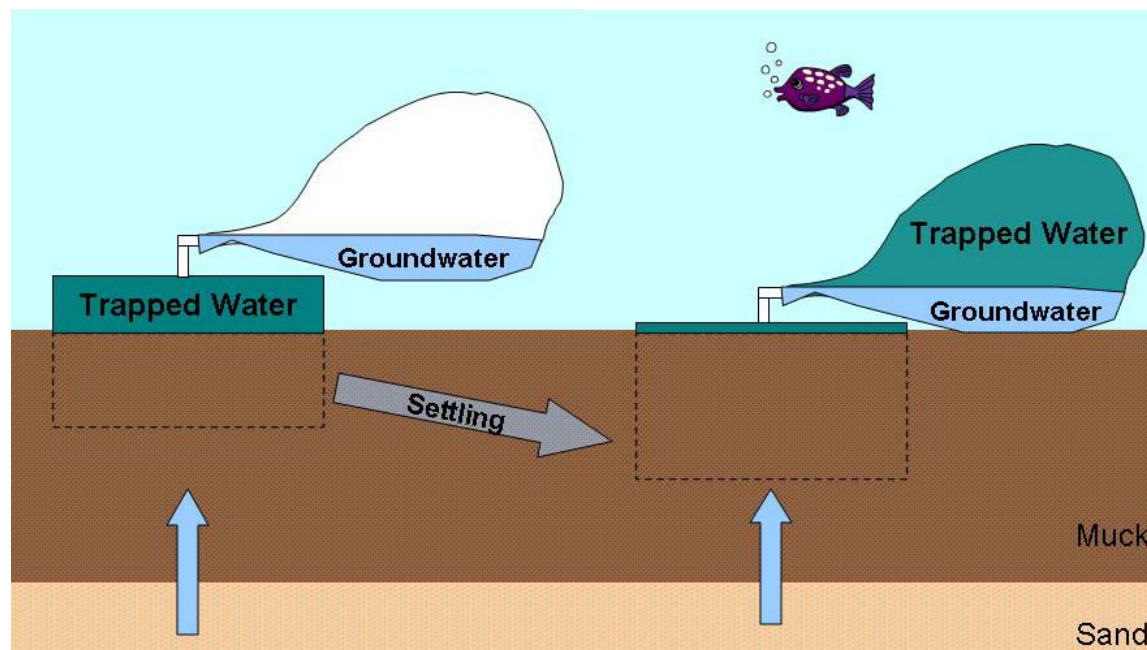
5.1. Direct Measurement Review

Groundwater seepage studies have been completed in several lakes throughout central Florida (ex. lakes Hancock, Shipp, May, Lulu). For each of these studies, direct groundwater input to the lake was measured using a groundwater seepage meter. Generally, the meter design consists of a cylindrical barrel with one open end. The open end is driven into the sediment isolating a small portion of the bottom. The closed end of the barrel has a hole and a means to connect a sampling bag in order to capture all water which transfers through the bottom into the water column. The bag is removed and replaced over a given time scale in order to quantify the water collected. The deployment and sampling techniques used can be subject to error.

5.1.1. Settlement of Seepage Meters

The structure of the lake bottom sediments (i.e., percent organic, percent moisture, percent solid) can provide insight into the regions of the lake where seepage is likely to occur. Isiorho et al. (1996) reported that seepage rates are higher in sandy substrates compared to muck and silt dominated sediments. Additionally, the installation of seepage meters in mucky sediments can lead to artificial seepage readings through the settling of the meter into the muck (Figure 44).

Figure 44. Schematic of settling groundwater seepage meter in mucky substrate



The flange around the seepage meters installed in Lakes Haines, Rochelle, Smart and Conine was included in order to prevent the settling of the seepage meter into the substrate, and it also allowed for the measurement of the meter in relation to the sediment surface. Sufficient water volume within the “head space” of these meters is present so that the settling of non-flanged seepage meter can result in elevated seepage rates due to water within the head space of the meter entering into collection bags via settling of the meter, rather than “true” groundwater seepage (Boyle 1994). Although measurements of the distance between the flange and the sediment surface did not suggest seepage meter settlement occurred in this study (Table 19), a mathematical exercise to determine if the water within the head space of a settling seepage meter could be responsible for a significant amount of “seepage” volumes estimated was undertaken, and is discussed in greater detail below.

Table 19. Initial and Final measurement of distance from the seepage meter to the lake bottom for each site

Lake	Site	Flange to Sediment Surface (in)	
		Initial	Final
Haines	LH-ES	flush	flush
Haines	LH-NS	flush	0.5
Haines	LH-WS	3	2
Haines	LH-WD	3	4
Rochelle	LR-WS	3	4
Rochelle	LR-SS	3.5	4
Rochelle	LR-NS	2	2
Rochelle	LR-ND	4	5
Smart	LS-NS	4	2
Smart	LS-WS	4	3
Smart	LS-SS	3	3
Smart	LS-SD	5	4
Conine	LC-SS	flush	0.5
Conine	LC-NS	2	2
Conine	LC-ES	flush	0.5
Conine	LC-ED	3	2

For this study, the average seepage rate for all meters located in 5 feet of water or less was $4.07 \text{ L/m}^2\text{d}^{-1}$ (0.41 cm/d) compared to $2.19 \text{ L/m}^2\text{d}^{-1}$ (0.22 cm/d) at the deep sites (> 5 feet deep). The first sampling effort was removed from the dataset for all of the seepage meter deployments to account for any potential initial settling which could lead to inflated seepage rates. At the shallow sites, the average seepage rate decreased by 5 percent ($3.85 \text{ L/m}^2\text{d}^{-1}$ or 0.39 cm/d) with a 6 percent reduction at the deep sites ($2.06 \text{ L/m}^2\text{d}^{-1}$ or 0.21 cm/d). This small change in seepage rate estimates suggests that potential settling of the seepage meters did not account for a significant influx of water from within the meter's head space into the sampling bags. However, these seepage meters were installed in a sandy substrate, which was determined prior to the initiation of the study by the use of sediment cores. Settling of the seepage meters would not be likely to occur due to the sediment structure.

PBS&J completed a similar data review based upon a study recently completed by Environmental Research and Design, Inc (ERD) on lakes Lulu, May and Shipp titled "Winter Haven Chain-of-Lakes Sediment Removal Feasibility Study". The ERD (2007) study included a sediment quantification and characterization and groundwater seepage component for each lake. The sediment characterization component completed by ERD reported that Lakes Lulu, Shipp

and May have an extensive muck layer of sediment on the bottom. In Lake May, approximately 50 percent of the lake bottom is covered by 7 feet or more of muck. The majority of the northern portion of Lake Shipp is covered by 3-5 feet of muck. Lake Lulu is covered by 1-2 feet of muck with as much as 5-10 feet of muck in the northern area. In these lakes, seepage rate estimates **could** be complicated by settling issues described above, at least in deeper areas of the lakes.

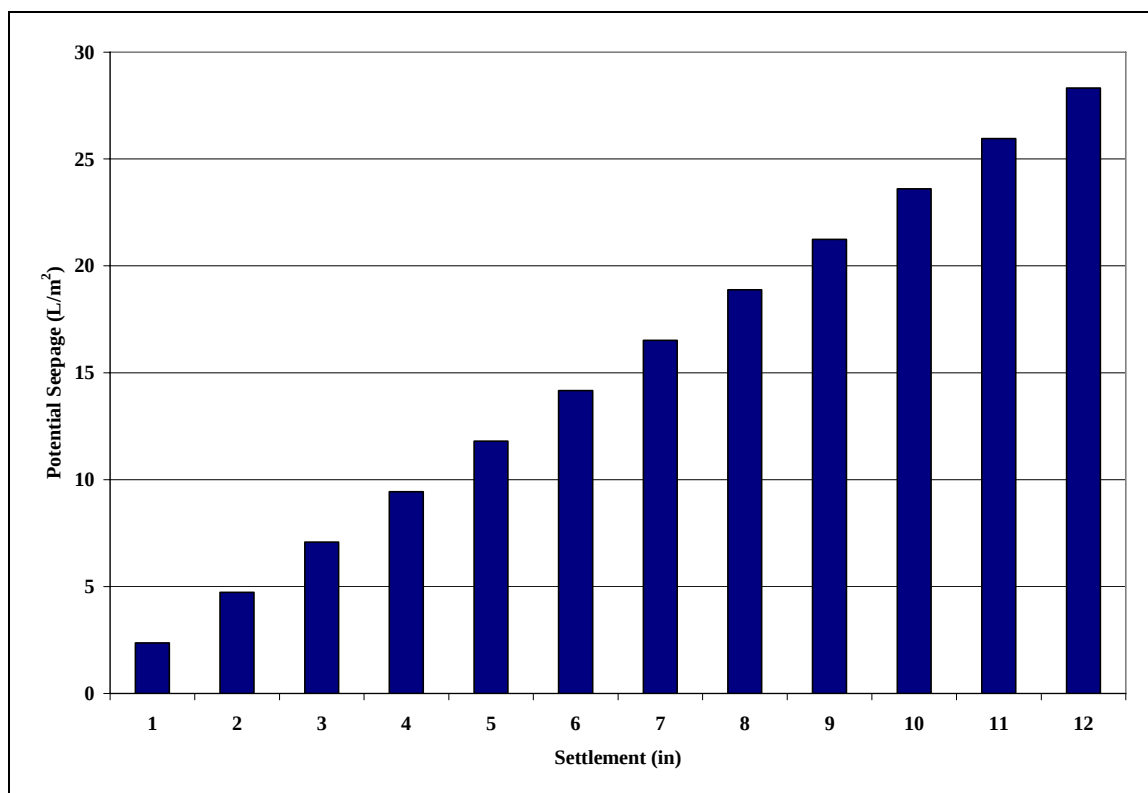
For their study, ERD (2007) installed a total of twenty-six seepage meters: five in Lake May, 10 in Lake Shipp and 11 in Lake Lulu. The majority of the seepage meters were installed along the littoral zone of the lake in approximately 5 feet of water. The remaining meters were installed in the deepest areas of the lakes ranging from approximately 9 to 13 feet deep. The seepage meters were not constructed with a flange to reduce/eliminate settling and measurements were not completed to determine if settling occurred. Due to the extensive and deep coverage of muck in all three lakes, settling of the seepage meters into the bottom sediments could have affected the reported seepage rates.

After initial installation, collection bags were installed after the established equilibration of one month, a technique expected to minimize (but perhaps not eliminate) potential settling artifacts. The overall range in seepage inflow for all sites was 0.24 to 15.35 L/m²d⁻¹ (0.024 to 1.54 cm/d). A similar mathematical simulation to establish if settling of the seepage meters may have increased groundwater seepage rates was completed by PBS&J using the ERD data. The average seepage rate for all meters located in 5 feet of water was 2.59 L/m²d⁻¹ (0.26 cm/d) compared to 2.05 L/m²d⁻¹ (0.21 cm/d) at the deep sites (>9 feet deep). The first sampling effort was removed from the dataset for all of the seepage meters deployed in the ERD experiment to account for potential settling leading to inflated seepage rates. At the shallow sites, and upon removing the first sampling trip values, the average seepage rate decreased by 8 percent (2.37 L/m²d⁻¹ or 0.24 cm/d). In contrast, after removing the first sampling trip values the rate at the deep sites decreased by 48 percent (1.07 L/m²d⁻¹ or 0.11 cm/d) indicating a substantial decrease in seepage rate estimates after the initial sampling event. This suggests that it is possible that seepage meters settled into the mucky sediments in the deepest locations, thus increasing the seepage volumes collected in that study.

Assuming that settling of seepage meters can lead to inflated groundwater seepage rate estimates, an analysis to determine the quantity of displaced pore water that could be produced was calculated. Based upon the design of the un-flanged seepage meters, and assuming approximately 3 inches of head space (ERD 2007) remained above the sediment surface, and also using a 0.27 m² area for the meter itself (ERD 2007), settling associated with 3 inches of head space would equate to approximately 7.1 L/m² of seepage (Figure 45). This calculation extrapolates the amount of seepage that would occur with 3 inches of settling within a 0.27 m² area to a 1 m² area.

It is recommended that in order to reduce/eliminate the probability of seepage meter settling, the depth of muck should be addressed during seepage meter construction, and the addition of a flange around the seepage meter should be incorporated to minimize settling. Additionally, monitoring of the vertical movement (settling) of the meter is important. The implementation of these components could provide sufficient information to address settling within mucky substrates.

Figure 45. Potential seepage attributed to the settling of seepage meters into the mucky substrate



5.1.2. Aquifer Connectivity

While groundwater seepage from the surficial aquifer and/or Floridan aquifer into lakes is a generally accepted mechanism for the changes in the water budget for the majority of lakes throughout central Florida, a review of local potentiometric pressure and lake bottom sediments can assist in determining the likelihood of seepage being probable in the first place. A groundwater seepage study was completed for Lake Hancock in 1998/1999 by ERD (1999) which estimated that 5.3 percent of the hydrologic input to the lake was from groundwater inflow. They also concluded that 38 percent of the total nitrogen load to the lake could be explained by groundwater seepage into the lake (the second largest contributor). While the overall estimated groundwater input into the lake is relatively small, the impact of groundwater on the nitrogen budget, due to high concentrations of nitrogen in seepage meter bags, was substantial.

Water level data available for Lake Hancock and groundwater data from a nearby surficial aquifer well were reviewed to determine if adequate hydraulic head was present to allow for groundwater seepage into Lake Hancock during the period of April 2005 to September 2006. These data are not from the same time period as that covered in the ERD (1999) report; they are not meant to suggest that finding in the ERD (1999) report are erroneous, simply that an exercise such as that outlined below should perhaps be incorporated into future groundwater seepage

estimates. Water level information for Lake Hancock was retrieved from the SWFWMD website (www.wattermatters.org; SID 24532) and the surficial aquifer data (www.usgs.gov; site number: 275336081484403) was obtained from the USGS (Figure 46).

Figure 46. Location of staff gauge and surficial aquifer well at Lake Hancock



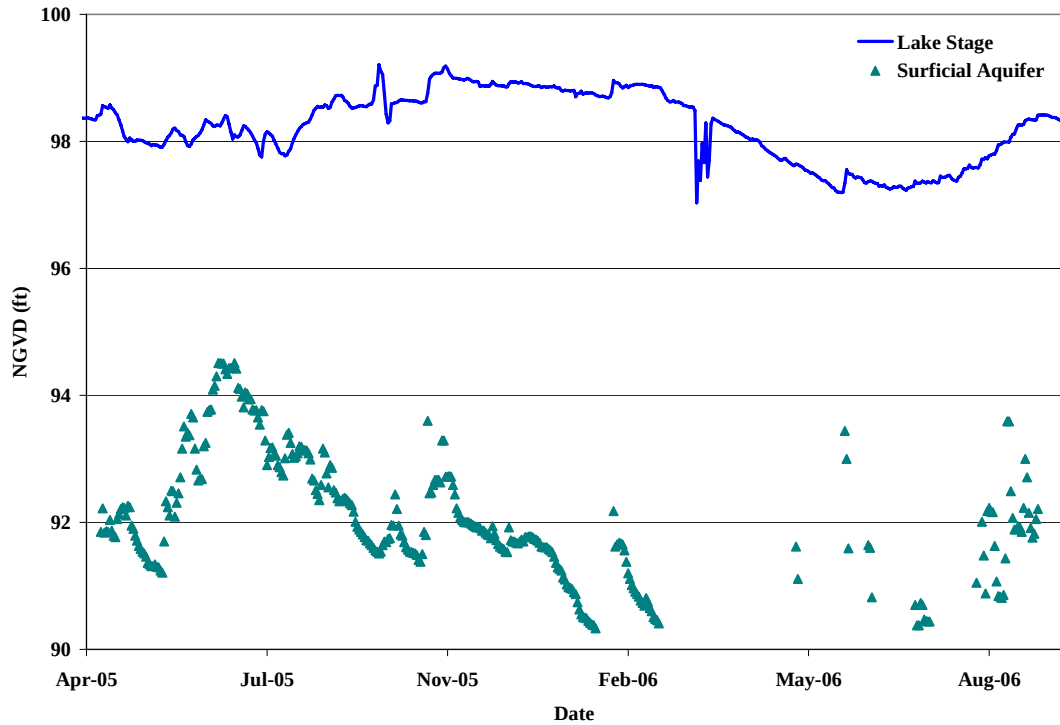
During 2005 to 2006, water levels in Lake Hancock ranged between 97 and 99 feet NGVD. In contrast, surficial aquifer groundwater levels ranged between 90 and 94.5 feet NGVD, levels that were consistently below the surface of the lake (Figure 47). Generally, in order to have groundwater inputs into the lake from the surficial aquifer, a gradient from the aquifer to the lake is required. However, over this time period the gradient found suggests the movement of water from the lake into the surficial aquifer was more likely to occur than vice versa. This information suggests that Lake Hancock may be “perched” above the surficial aquifer, without the hydraulic head necessary to allow for groundwater seepage into the lake.

If this is true, then how is it possible that groundwater input of nitrogen was measured in Lake Hancock? It could be that lake level and surficial aquifer levels in 1997 to 1998 displayed an opposite pattern as that found in 2005 to 2006.

Alternatively and as previously discussed, mucky lake bottom sediments and the potential settling of meters could be an important factor to be considered when successfully estimating groundwater seepage rates. Lake Hancock has muck 1 to 4 feet thick on the bottom of the entire lake (PBS&J 2007 and others). Similar to lakes May, Shipp and Lulu, the settling of the seepage meters into this muck layer could have provided an artifact of groundwater input to the lake. The implications of accurately quantifying groundwater seepage and the resulting nutrient input is

important when attempting to develop basin management action plans in response to the TMDL to reduce nutrient loads. If 38 percent of the nitrogen load to Lake Hancock might not actually be due to groundwater input, then what is the source of the now not fully-explained load?

Figure 47. Comparison of Lake Hancock stage and nearby surficial aquifer water levels



6.0 Lake Bottom Sediments

6.1. Design and Methods

Lake bottom sediment samples were collected in all four lakes. Seven samples were collected in October 2008 from each lake (Figures 48 to 51). Samples were collected at each groundwater seepage meter site and additional sediment samples were collected at three locations near the center of the lake. Triplicate sediment samples were collected at each sampling site with a Ponar. Visual characteristics of each sediment core were recorded and a composite sediment core sample was collected from the 0-10 cm layer and placed into two sampling containers. The samples were submitted to the MOTE laboratory, and analyzed for the following parameters:

- Moisture Content
- Organic Content
- Total Phosphorus
- Total Kjeldahl Nitrogen

MOTE Marine Laboratory analyzed the samples for moisture and organic content. The total phosphorus and total Kjeldahl nitrogen (TKN) analysis was subcontracted to TestAmerica in Mobile, Alabama. A total nitrogen analysis of the lake bottom sediments was not completed, as NO_x within sediment samples is mostly restricted to sandy, porous substrates not fine-grained (mucky) substrates. However, NO_x content is included within the groundwater seepage volumes that include waters percolating through the interstitial spaces between sediment particles. The raw data from the sediment analysis are available in Appendix F. Field parameters of lake water pH, temperature, conductivity, dissolved oxygen, and secchi depth, were measured at the water surface (0.2 m) and at 0.5 m intervals to the bottom at each sediment core location using a YSI 6250 (Appendix F).

The results of the sediment core analyses were used to determine the physical and chemical characteristics of the lake bottom sediments. This information can be incorporated into whole-lake nutrient budgets via incorporation of estimates of bottom resuspension frequencies, as outlined by Bachmann et al. (2000).

Figure 48. Location of collected sediment samples and bathymetry in Lake Haines

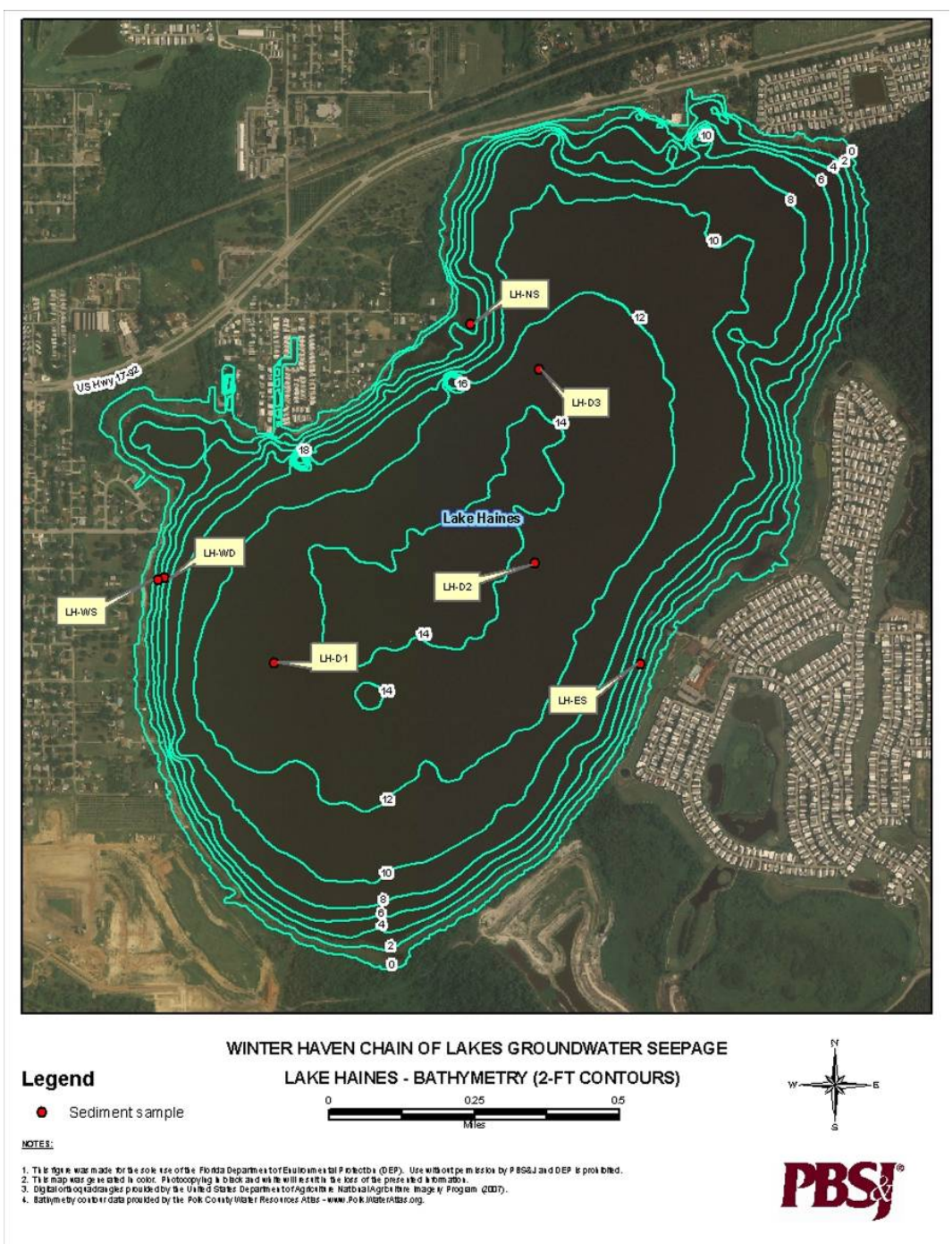


Figure 49. Location of collected sediment samples and bathymetry in Lake Rochelle

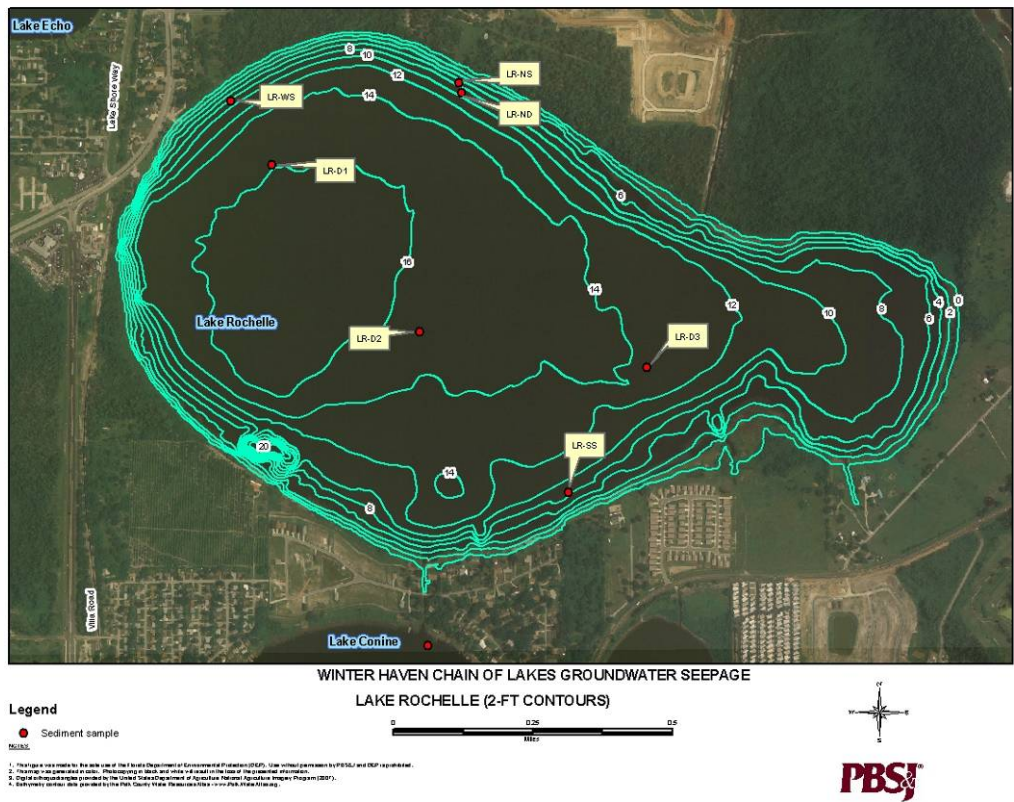


Figure 50. Location of collected sediment samples in Lake Smart

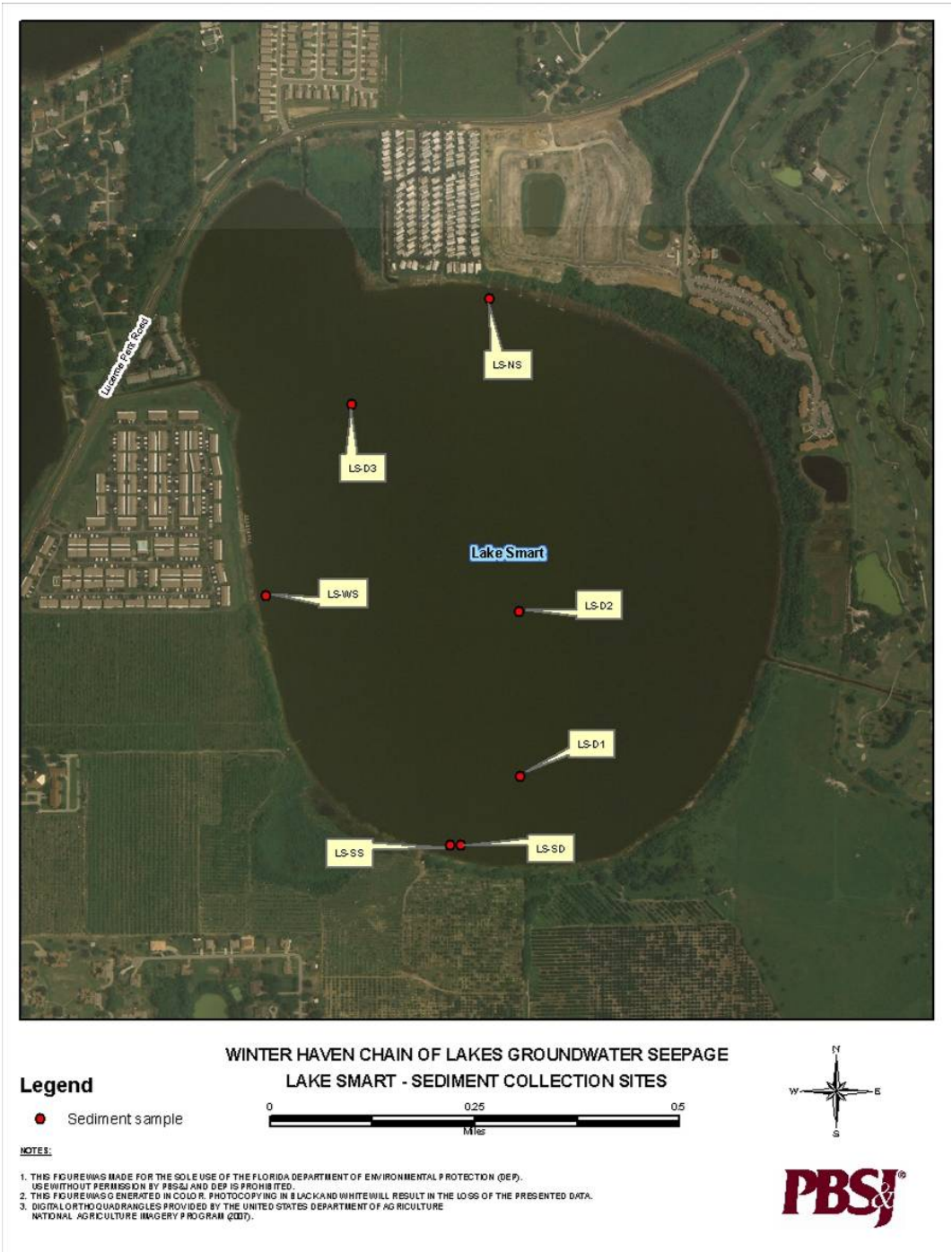
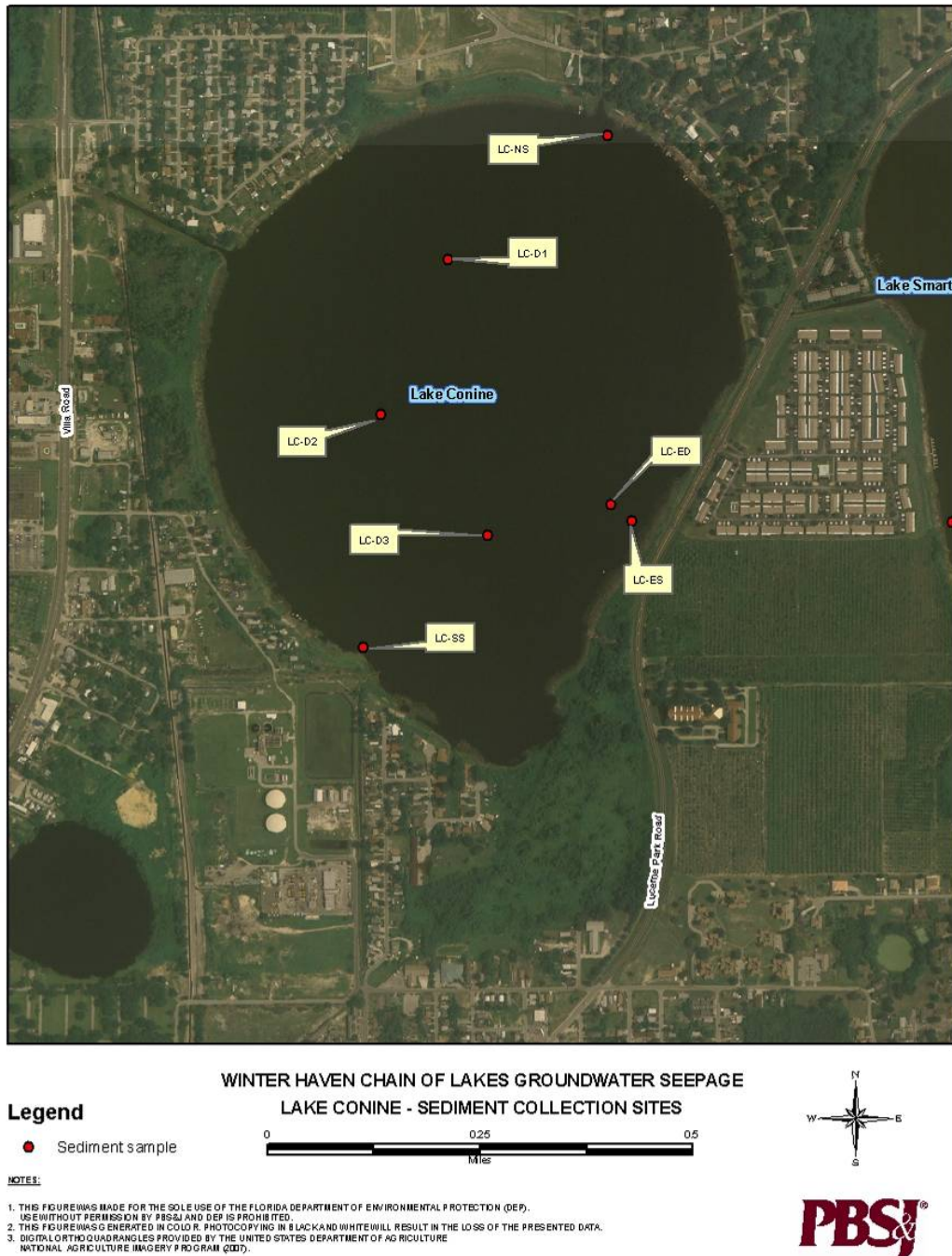


Figure 51. Location of collected sediment samples in Lake Conine



6.2. Results and Data Analysis

The results of the seven composite sediment samples for each lake including moisture and organic content and total phosphorus and nitrogen concentration are presented in Table 20. In general, the results indicated that the shallower portions of all four lakes were dominated by sand and had little organic content. In contrast, the deep water depth sites reported the greatest silt and

clay components with increased TN and TP concentrations. A more detailed review of the sediment analysis is presented below.

Lakes Haines, Rochelle and Smart all had similar average solid contents from 62-63 percent while Lake Conine had an average solid content of 54 percent (Table 20; Figure 52). Similarly, the average moisture content of Haines, Rochelle and Smart was 37-38 percent and 46 percent in Lake Conine. The average organic content was highest in Lake Conine (16 percent) and lowest in Lake Haines (6 percent). When evaluating the sediment samples based upon water depth, in all four lakes the sediment samples collected near the seepage meters (water depths <10 feet) had a greater than 75 percent solid content and less than 25 percent moisture content (Figure 52). In contrast, the samples taken in the middle of the lake at the greatest water depths had higher moisture content. A similar trend was observed in the organic content data.

The sediment composition of the solid component was predominantly sand at the seepage meter sites with minimal clay and silt (Table 20, Figure 53). However, the deeper sites in each lake had increased silt and clay composition. The difference between the shallow (<10 feet) and the deep sites can be related to the accumulation of organic material in the center of the lakes. The results of these samples confirmed the preliminary site visit indicating that a sandy substrate with little organic material was present near the shoreline of the lakes and supports the hypothesis that groundwater seepage rates are likely to be greatest in the shallow peripheral areas of the lake. The centers of the lakes have sediments with a greater organic material. The composition of the lake bottom is important when considering seepage rates, as Isiorho et al (1996) reported that seepage rates in sandy sites are statistically higher than those in mucky areas.

Lake Haines reported the lowest average TP and TKN sediment concentrations, 233 and 2,066 mg/kg, respectively (Table 20). The highest average TP and TKN concentrations were reported in Lake Conine, 1,250 and 5,499 mg/kg, respectively. The average TP and TKN concentrations in Lake Rochelle are 288 and 2,696 mg/kg, respectively. In Lake Smart, the average TP is 236 mg/kg and average TKN is 3,780 mg/kg. Similar to the sediment composition results, the sediment sites at deeper water depths had a greater average TP concentration (1,159 mg/kg) compared to the shallower sites (9 mg/kg) (Figure 54). The average TKN concentration at the deeper sites was 7,640 mg/kg, while the average at the shallower sites was 413 mg/kg (Figure 55).

When compared to the average sediment TP and TN concentrations in Lake Hancock (229 and 1,335 mg/kg, respectively), the deeper sites in Lakes Haines, Rochelle, Smart and Conine have a higher concentration. However, the majority of the lake bottom sediments have TP and TKN concentrations below the Lake Hancock average (CDM 2002). The average TP concentration of sediments in Lakes May, Shipp and Lulu were 2,549, 669, and 1,151 mg/kg, respectively (ERD 2007). The average sediment TN concentration in Lakes May, Shipp and Lulu were 17,847, 6,092 and 17,357 mg/kg, respectively. Lakes Haines, Rochelle, Smart and Conine had sediment nutrient concentrations similar to Lake Shipp but were substantially less than Lakes May and Lulu.

Table 20. Percent organic, solid and moisture content of each composite sediment sample and total phosphorus and TKN concentrations

Lake	Site	Organic Content (%)	Solid Content (%)	Moisture Content (%)	Nutrients (mg/kg)	
					Total Phosphorus	TKN
Haines	LHD1	7	54	46	350	3300
Haines	LHD2	4.4	59.7	40.3	170	990
Haines	LHD3	28.9	24.3	75.7	1000	8600
Haines	LHES	0.9	75.3	24.7	0.35	310
Haines	LHNS	0.6	77.2	22.8	0.36	350
Haines	LHWD	0.9	77.8	22.2	54	370
Haines	LHWS	1.4	73	27	56	540
Haines	Average	6.3	63.0	37.0	233	2066
Rochelle	LRD1	29.9	21.6	78.4	1000	9000
Rochelle	LRD2	0.6	80.5	19.5	21	760
Rochelle	LRD3	30.5	22.4	77.6	990	7700
Rochelle	LRND	0.8	77.7	22.3	0.37	520
Rochelle	LRNS	0.7	80	20	5.7	240
Rochelle	LRSS	1.2	81.7	18.3	0.36	390
Rochelle	LRWS	0.5	80.1	19.9	0.34	260
Rochelle	Average	9.2	63.4	36.6	288	2696
Smart	LSD1	47.7	14.3	85.7	1000	12000
Smart	LSD2	45	11.9	88.1	630	12000
Smart	LSD3	0.4	82.5	17.5	2.3	330
Smart	LSNS	0.6	80.9	19.1	0.37	1000
Smart	LSSD	0.5	81.2	18.8	0.36	290
Smart	LSSS	0.6	79.9	20.1	11	500
Smart	LSWS	0.6	80.5	19.5	7.8	340
Smart	Average	13.6	61.6	38.4	236	3780
Conine	LCD1	47.8	9.6	90.4	2800	15000
Conine	LCD2	50.1	9.9	90.1	5600	20000
Conine	LCD3	8.8	41.3	58.7	350	2000
Conine	LCED	0.7	82	18	0.33	300
Conine	LCES	0.7	82.1	17.9	0.36	400
Conine	LCNS	1.7	78.3	21.7	0.39	500
Conine	LCSS	1.2	76.5	23.5	0.38	290
Conine	Average	15.9	54.2	45.8	1250	5499

Figure 52. Percent Solid, Moisture and Organic content of each sediment sample

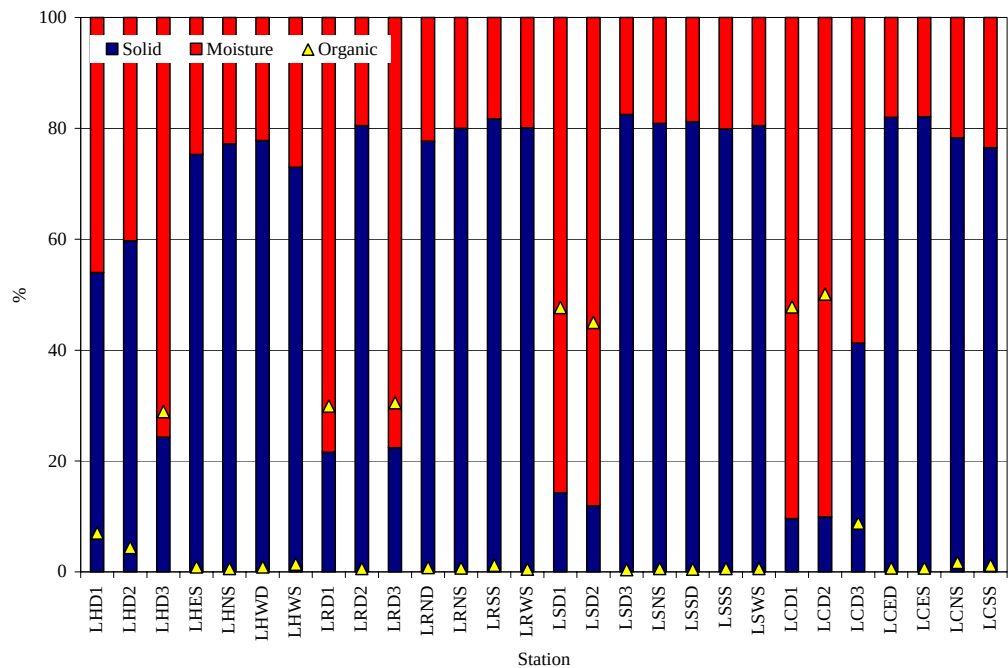


Figure 53. Percent sediment composition of clay, silt and sand for each site

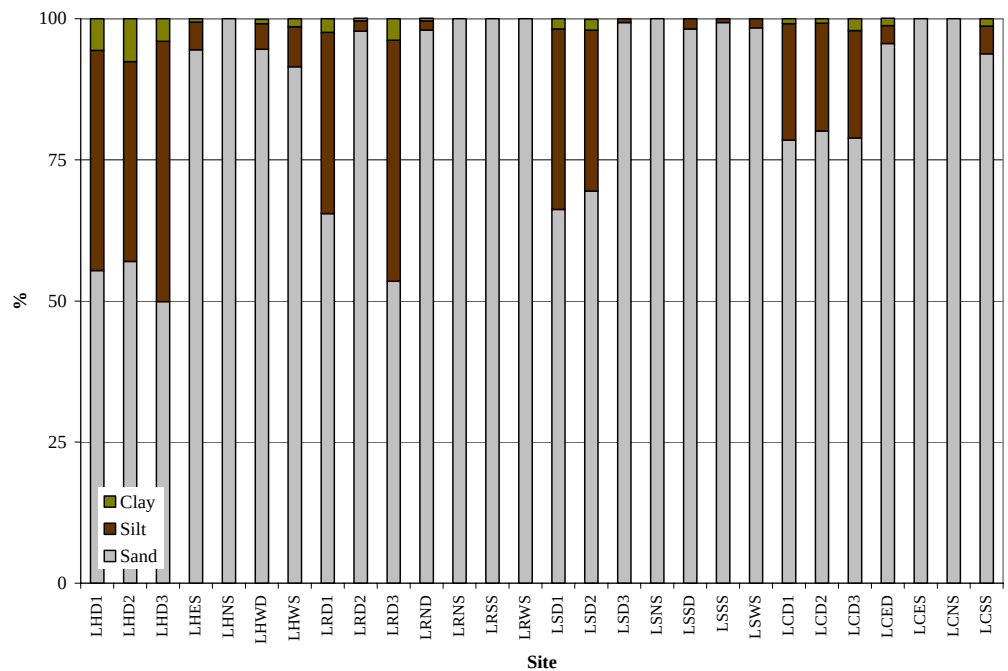
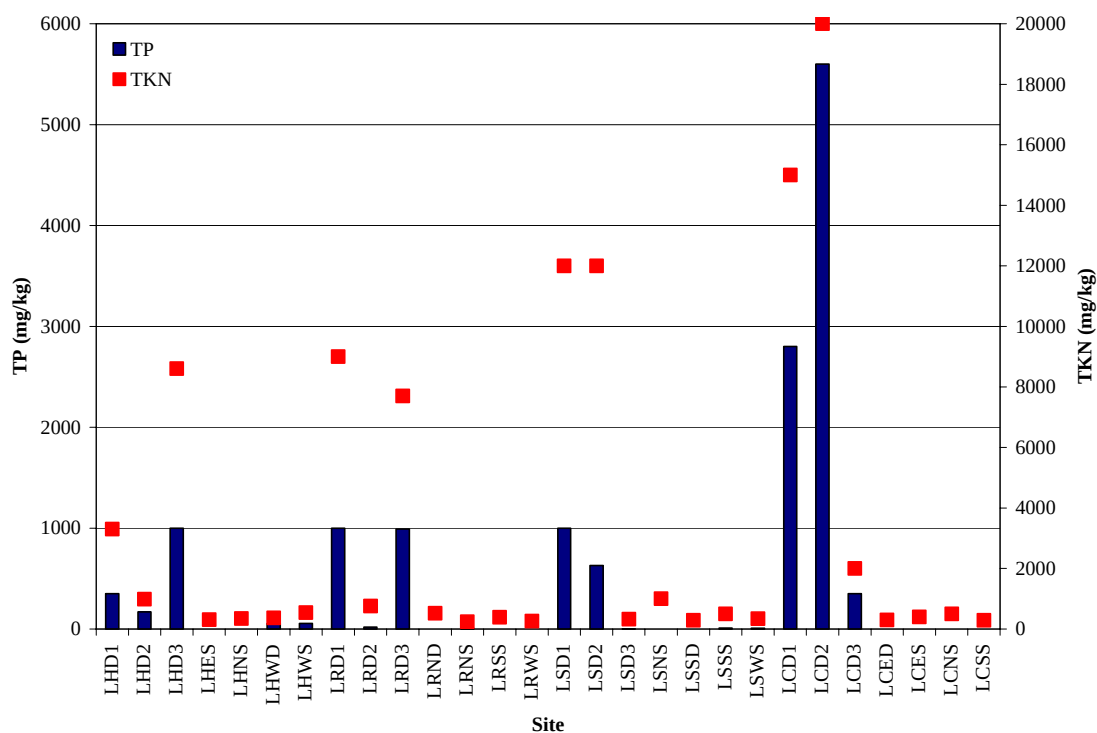


Figure 54. Total Phosphorus and Total Kjeldahl Nitrogen concentration at each sediment site



7.0 Groundwater Inflow and Nutrient Loading

Groundwater is considered a significant component of both water and nutrient budgets for the WHCL, although groundwater contributions to nutrient loads have not yet been adequately quantified. In the 2005 report conducted for SWFWMD-SWIM, USF researchers modeled groundwater contributions using information on groundwater elevations from two wells in the Chain of Lakes, one in the Northern Chain (near Lake Smart) and one in the Southern Chain (near Lake Lulu). While extremely limited in their spatially-appropriate "inference space", these data indicated that groundwater elevations were higher than adjacent lake levels, thus suggesting a major influence of groundwater on water and nutrient budgets. For groundwater quality, USF (2005) noted that "There were five surficial wells in Polk County that had water-quality data. Only one of these wells is within the basin boundaries, shown in that report as the surficial well located between Lakes Eloise and Lulu. This well had three recorded data points, sampled on 3/17/1993, 3/4/1996, and 5/25/1999." Therefore, the entire data set used for validating the groundwater quality assumptions in the groundwater loading portion of the PLRG study for the WHCL in the USF (2005) study seems to be limited to elevation data reported for one well location each in the Southern and Northern Chains, and one location in the Southern Chain for which water quality was available.

For this study, groundwater inflow and nutrient loadings to Lakes Haines, Rochelle and Conine were calculated based upon the data acquired from the in-lake seepage experiments and compared to the PLRG/TMDL modeled results. All of the groundwater seepage meters for the in-lake study completed by PBS&J were installed in water depths at or shallower than 10 feet. Therefore, groundwater inflow, TN and TP loadings were calculated over the area of the lake with water depths equal to or less than 10 feet deep. A whole lake groundwater loading calculation was not completed due to the uncertainty related to groundwater seepage rates at deeper water depths (> 10 feet deep). The sediment characterization results (presented in Section 6.0) indicate that mucky sediments are present in the deeper sections of all four lakes and available literature indicates that groundwater seepage is reduced and/or eliminated in mucky substrates (Isiorho et al. 1996), an additional reason why groundwater inflow estimates might best be conducted without including potentially artifact-driven rates (see section 5.1.1) in the deepest muck-rich portions of these lakes.

The calculation of the groundwater inflow, TN and TP loading within each lake at depths up to 10 feet was determined using the available bathymetric information. Bathymetry information was available for Lakes Haines, Rochelle and Conine but not for Lake Smart. For Lakes Haines and Rochelle, digital bathymetry data was available from the Polk County Wateratlas website (www.polk.wateratlas.usf.edu) from 2005 and 2006, respectively. Approximately 40% of Lake Haines has a water depth shallower than 10 feet, 297 of 736 total acres. In Lake Rochelle, 176 of 583 total acres (30%) less than 10 feet in depth. The 1989 Florida Fish and Wildlife Conservation Commission bathymetric survey for Lake Conine was used to determine the area at or less than 10 feet in water depth. Using gridded graph paper, approximately 86 of the 233 total acres in Lake Conine had a water depth shallower than 10 feet (37%). The average groundwater

seepage rates (Table 16) derived for Lakes Haines, Rochelle and Conine were then applied over the area below the 10 foot contour and extrapolated to a year.

The annual groundwater inflow calculated from the PBS&J groundwater seepage experiment was compared to the modeled technique reported in the TMDL (FDEP 2007) and the groundwater component calculated using Darcy's Law by a previous PBS&J study for Lake Haines (PBSJ 2004). Although different techniques were utilized for all three reports (Table 21), similar results were found (Figure 55). The groundwater inflow volume calculated for the TMDL report was determined using a groundwater model (MODFLOW) run annually for a ten year period (1990-1999). Annual lake elevations for each lake and surficial aquifer elevation at a well located south of Lake Rochelle were used to calculate the head gradient for each lake. Constants were decided for the multiple parameters using either the parameter estimation program (PEST) or based on literature values. A recharge zone was determined for the Northern Chain of Lakes and used to determine the annual groundwater contribution for each year over the ten year modeling period for Lakes Haines, Rochelle, Conine and Smart. The water budget completed by PBSJ in 2004 for Lake Haines determined the net groundwater input by solving the water balance equation. Both of these approaches (FDEP 2007 and PBSJ 2004) used a whole-lake approach to calculate groundwater inflow contributions.

Figure 55. Estimated annual groundwater inflow (m³/yr) in Lakes Haines, Conine and Rochelle shallower than 10 feet in water depth compared to values from the TMDL and PBS&J 2004 Water and Nutrient Budget report.

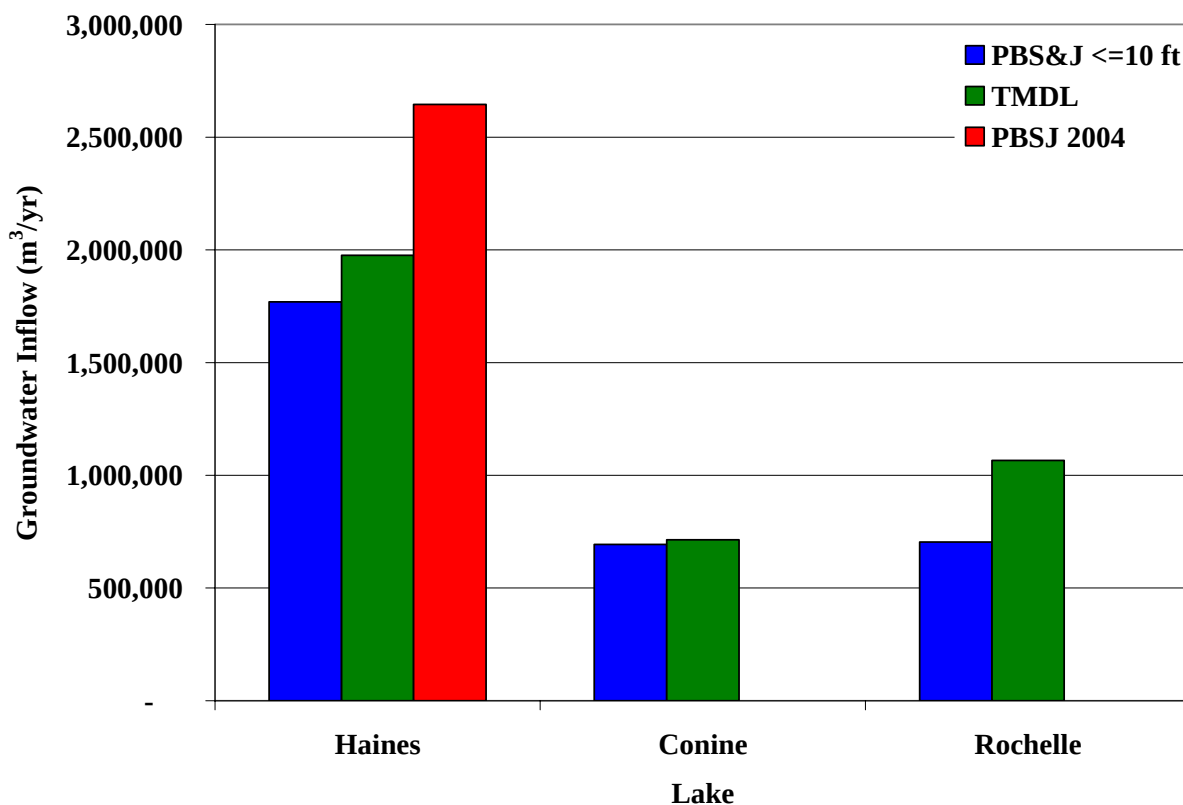


Table 21. Comparison of Groundwater inflow and Nutrient loading calculation techniques.

	PBSJ 2009	PLRG/TMDL	PBSJ 2004
Geographic Scale	Lakes Haines, Rochelle, and Conine	All lakes in the Winter Haven Chain of Lakes	Lake Haines and Shipp
Method	direct measurement	Modeled (Groundwater model)	Balance Equation and Darcy's Law
Groundwater seepage	direct measurement	Lake Rochelle surficial aquifer well and lake stage	Lake Haines surficial aquifer well and lake stage
Water Quality Data	direct measurement	Lake Eloise surficial aquifer well	Lake Haines surficial aquifer well
Loading calculation	water depths ≤10 ft	whole lake	whole lake

The groundwater inflow estimates for each technique were similar when compared (Figure 55). In Lake Haines, approximately 1.77 million m³/yr of groundwater was calculated to flow into the lake each year. The groundwater inflow was 10% less than that modeled for the TMDL and 33% less than that calculated by PBSJ in 2004. For Lake Rochelle, 700,000 m³/yr of groundwater was calculated to enter the lake, which was 34% less than that reported in the PLRG/TMDL. Finally, Lake Conine had 690,000 m³/yr of groundwater inflow using the direct measurement which was 3% less than the modeled results in the TMDL. The differences in techniques could be explained by the PBSJ 2009 estimate utilizing a higher inflow rate that was applied to a smaller area (<=10 feet water depth). In contrast, the TMDL inflow volumes are from a lower (modeled) rate applied to the entire lake bottom (including the deep mucky areas). To reiterate, the PBSJ 2009 calculations were based upon in-lake direct measurements of groundwater seepage. The TMDL groundwater inflow estimate was derived from a model using estimated parameters driven by regional surficial aquifer level data.

Using the average TN and TP groundwater seepage concentrations (Table 16) from the in-lake seepage measurements, annual TN and TP groundwater loads were calculated for each lake at water depths less than 10 feet. These loads were also compared to the TMDL (FDEP 2007) modeled results and the Lake Haines nutrient budget completed by PBSJ (2004; Figures 56 and 57). The TP annual groundwater load calculated for the TMDL was completed using the average of three total phosphorus water quality measurements over six years at a surficial aquifer well adjacent to Lake Eloise in the Southern Winter Haven Chain of Lakes (0.021 mg/l). The annual TN groundwater load was not reported in the TMDL; however, the TN concentrations from the same well (adjacent to Lake Eloise) were provided by SWFWMD and the average TN concentration (4.03 mg/l) was applied to the annual groundwater inflow as calculated for the TMDL. The annual TN and TP loads reported by PBS&J (2004) for Lake Haines were calculated using the annual groundwater inflow and the annual geometric mean of TN and TP at two surficial aquifer wells adjacent to Lake Haines.

Figure 56. Estimated annual groundwater TN load (kg/yr) to Lakes Haines, Conine and Rochelle shallower than 10 feet in water depth compared to values calculated similar to the TMDL modeling technique and PBS&J 2004 Water and Nutrient Budget report.

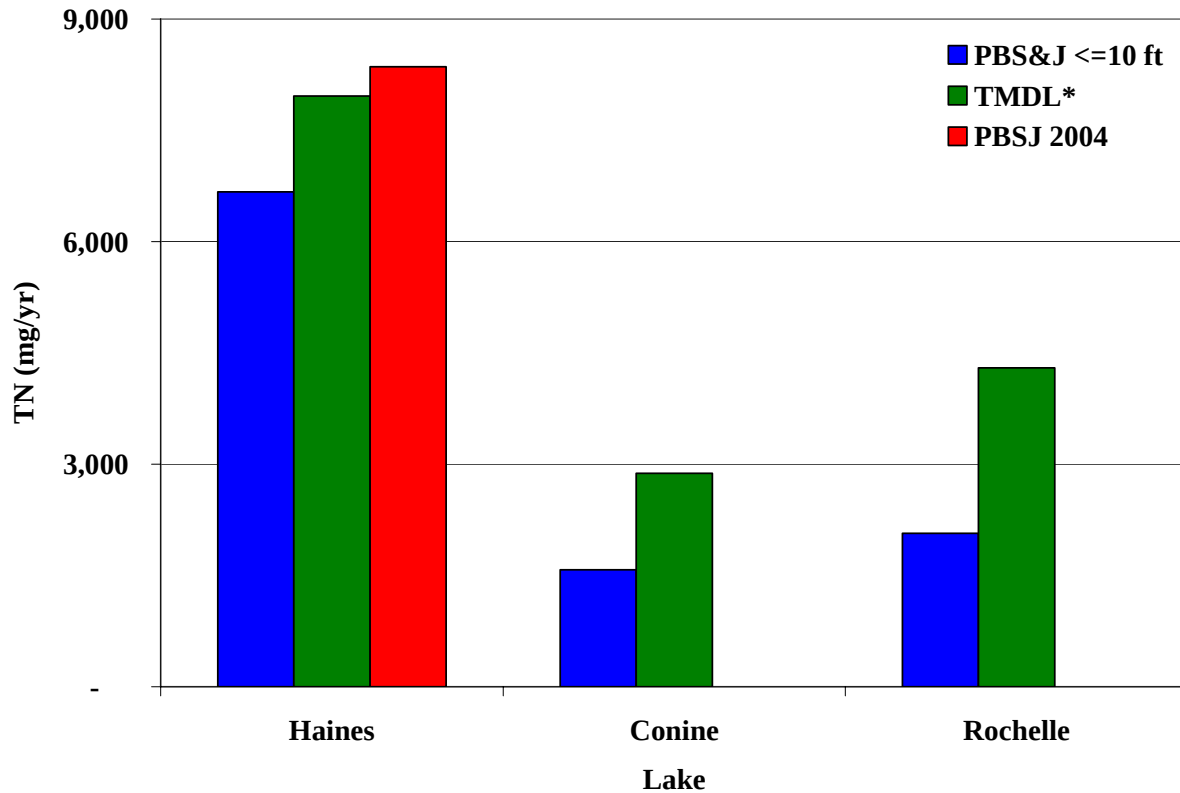
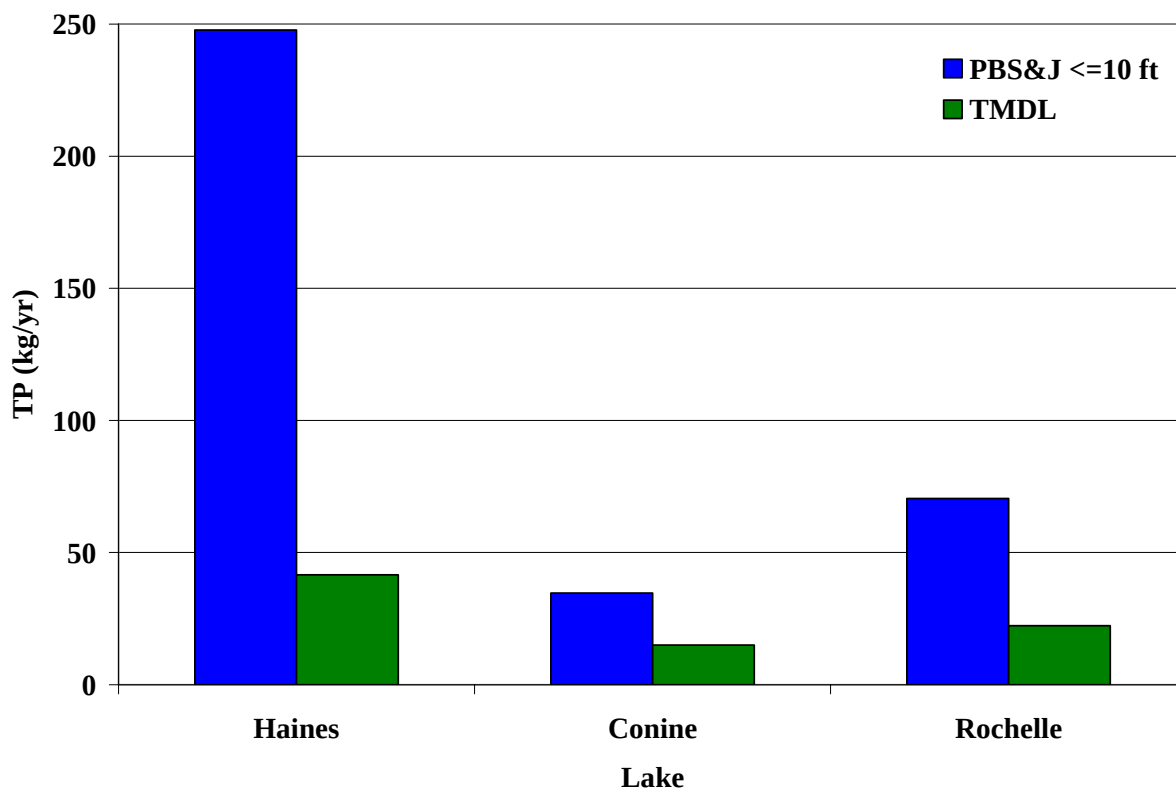


Figure 57. Estimated annual groundwater TP load (kg/yr) to Lakes Haines, Conine and Rochelle shallower than 10 feet in water depth compared to values from the TMDL and PBS&J 2004 Water and Nutrient Budget report.



The annual groundwater TN loads are similar in Lake Haines when comparing these three techniques (direct measurement vs. modeling) as was found for the results from the water budgets (Figure 56). Overall, the TN concentrations applied to the annual groundwater inflow were similar between techniques, resulting in similar loading estimates at Lake Haines. The Lake Haines estimated groundwater TN load was 6,700 kg/yr using direct measurement; this load is 16% and 20% less than values reported in the TMDL (FDEP 2007) and PBSJ (2004) nutrient budgets, respectively. The annual groundwater TN loads for Lake Conine and Rochelle (1,600 and 2,100 kg/yr, respectively) were 45% and 52% less than that calculated using the TMDL (FDEP 2007) method, respectively. The substantial difference in load calculations is likely due to the TN concentrations applied to the groundwater inflow, as water inflow estimates were not as divergent between different techniques. Using direct measurements, the average concentration of TN in the groundwater in Lakes Haines, Conine and Rochelle is 3.77, 2.27 and 2.94 mg/l, respectively. In contrast, the average TN concentration measured in the surficial aquifer well adjacent to Lake Eloise was 4.03 mg/l. The average TN concentration reported by ERD for Lakes May, Shipp and Lulu for water depths less than 10 feet deep, and where muck depths were less than one foot were 5.4, 6.9, and 5.2 mg/l (ERD 2007). The disparity between TN groundwater load calculations reported in the TMDL report and this study can be attributed

to the combination of differences in groundwater inflow volumes, differences in TN concentrations applied to these volumes, and differences in the area over which these estimates were applied (i.e., whole-lake vs. shallower than 10 feet in water depth).

In contrast to the roughly similar rates of TN loads from groundwater, the annual groundwater TP loads measured by PBSJ through direct measurement were substantially higher than the TMDL results for all three lakes (Figure 57). The annual groundwater TP load to Lakes Haines, Conine and Rochelle were 83, 57 and 68% greater than the loads modeled for the TMDL, respectively. For the TMDL report (FDEP 2007), the TP concentrations for groundwater inflow were derived from one well (in the southern chain of lakes) with 3 water quality samples over a 6-year period. In contrast, a total of 19, 24, and 22 direct TP measurements were used to calculate the average groundwater TP concentration associated with seepage into Lakes Haines, Conine and Rochelle. The average TP concentrations calculated by direct measurement were 0.14, 0.05 and 0.10 mg/l for Lakes Haines, Conine and Rochelle, respectively. In contrast, the average TP concentration from the surficial aquifer well at Lake Eloise was 0.021 mg/l. The average TP concentrations for groundwater seepage calculated by ERD for Lakes May, Shipp and Lulu through direct measurement water levels for sites less than 10 feet deep and where muck levels were less than one foot deep were 0.08, 0.50 and 0.30 mg/l, respectively. Thus, the average TP concentration from the surficial aquifer well used for the TMDL study (FDEP 2007) is considerably lower than values directly measured from groundwater seeping through the bottom sediments of all six lakes examined here (ERD 2007 and this study).

In their TMDL report, FDEP (2007) reports that groundwater inflow accounts for 24, 21 and 9% of the TP input to Lakes Rochelle, Haines and Conine, respectively (FDEP 2007). However, the direct measurement technique completed here suggest that groundwater seepage into the lakes is a more significant route for TP loading than was noted in the PLRG / TMDL studies. This conclusion is further supported when comparing the results from this study with prior efforts in Lakes May, Shipp and Lulu (ERD 2007). Groundwater TP concentrations measured using the seepage meters were 50-85% greater than those reported in the surficial aquifer well located adjacent to Lake Eloise. It is our conclusion that the groundwater TP concentration from the Lake Eloise surficial aquifer well is not representative of the TP concentration associated with groundwater inflows into Lakes Haines, Conine, Rochelle and Smart, as elevated levels of sediment TP concentrations provide a larger source of TP that can be loaded into the water column via either seepage itself, or sediment resuspension. Groundwater loading of TP into these lakes is likely to be more substantial than the rates used in the TMDL report (FDEP 2007), with surface runoff perhaps becoming less important than is currently estimated. This should be considered during the development and implementation of the BMAP created in response to the TMDL.

8.0 Summary and Conclusions

8.1. Summary

Groundwater is considered a significant component of both water and nutrient budgets of the Winter Haven Chain of Lakes (WHCL), although estimates of groundwater contributions to nutrient loads are limited due to the paucity of data available for calibrating and validating groundwater contributions. The present study included 16 groundwater seepage meters in four lakes and 12 surficial aquifer meters adjacent to the same four lakes for a period of 6 months. Water level and chemistry data from the present study, as well as available long term rainfall and surficial aquifer data, were reviewed and analyzed in an effort to better characterize nutrient loadings associated with groundwater inputs in the Winter Haven Northern Chain of Lakes. This information will provide the FDEP with additional water quality and sediment information necessary to complete the TMDL for the Northern Chain of Lakes, and required by the City to address their *Winter Haven Chain of Lakes Water Quality Management Plan*.

The lakes in the WHCL have poorly developed surface drainage due to the highly pervious nature of the sandy soils that characterize the underlying surficial aquifer that ranges from 75 to 100 feet thick. The water table generally reflects the topography of the land surface and lakes occur where the land surface falls beneath the water table. Lateral movement of water through the surficial aquifer is generally confined to individual lake basins because of the high water table associated with the basins. It is for these reasons that it is important to evaluate the influence of groundwater on water and nutrient budgets in the WHCL.

8.1.1. Groundwater Monitoring Wells

Differences in groundwater elevations in surficial monitoring wells during the four month sampling period (August 5, 2008 to November 26, 2008) followed the topography of the land surface and groundwater levels adjacent to lakes were higher than corresponding surface water levels in the lakes. Groundwater levels increased within a few days following rainfall events, and increased during the middle of August, with peak elevations observed between 8/21 and 9/18 (28 days). Groundwater levels declined more slowly and at a relatively constant rate during periods of no rain and water levels in the upper wells (farther from the lake) declined more rapidly than the levels in the lower wells (closer to the lake).

In this study, results of groundwater seepage experiments indicated that lateral groundwater infiltration occurred in all four lakes examined and there was no difference in the infiltration volumes measured between lakes. Differences in concentrations of water quality parameters measured (e.g. conductivity, color, nutrients) from groundwater seepage meters and the ten year (1997-2007) average concentrations in the lake were consistent with differences anticipated between groundwater chemistry and the ambient lake water chemistry.

8.1.2. Rainfall, Groundwater, and Lake Level Relationships

The influence of groundwater and rainfall on lake levels was examined using data from the groundwater seepage meters and the surficial groundwater monitoring wells. Due to the small sample size of our field data for this study (N=8) and the sporadic nature of rain events, relationships were not evident using daily rainfall, although a seasonal effect of wet and dry season rainfall on the surficial aquifer and lake water levels was apparent.

Further analyses included data from nearby daily rainfall, daily surficial aquifer wells, and Lake Haines daily stage stations for the period from November 28, 2007 to January 8, 2009. An analysis of the relationship between the change in surficial aquifer water elevation and daily rainfall was significant ($p=0.0000$; $R^2=0.322$) using the 2007-2009 data and illustrated the increase and decline in surficial aquifer water elevations associated with periods of rainfall and periods of no rainfall, respectively. The R^2 value (0.322) indicates that rainfall accounts for about one-third of the variability in the surficial aquifer water level. Using lag times that increase the time over which the surficial aquifer responds to rainfall, the effect of some of the variation in rainfall is removed and the effects of multiple groundwater recharge pathways are included (albeit indirectly) in the relationship.

These results are consistent with surficial aquifer water level responses that are driven by rainfall and antecedent aquifer water levels (which in turn reflect rainfall). The following empirical relationship describing water levels in the surficial aquifer as a function of rainfall was subsequently developed that can predict the change in surficial aquifer water elevation during periods of rainfall or drought:

Change in surficial aquifer water level (feet) = $-0.0122582 + 0.116552 * \text{daily rainfall (inches)}$

For example, a five inch rainfall should result in a 0.57 foot increase in aquifer water elevation. However, a 100-day drought would result in a 1.23 feet decline in the aquifer water elevation. The higher surficial aquifer water elevations, compared with lake stage, observed in the 2007-2009 data are consistent with a hydraulic gradient that favors groundwater infiltration to the lake. The same trend was observed in the surficial aquifer wells monitored by PBS&J during this study. In a previous water and nutrient budget completed for Lake Haines (submitted to the SWFWMD by PBS&J in 2004), groundwater was also identified as the primary component of the lake water budget. The results of our study and others consistently point to groundwater as the primary component influencing lake levels (volume) in the study lakes.

The 2007-2009 data for Lake Haines provided an opportunity to pursue further analysis of changes in surficial aquifer water levels. Results of these analyses indicated that changes in the surficial aquifer water elevations and lake stage were dependent upon the prior wet season. For example, the water elevation in the surficial aquifer was steadily declining in October 2007-January 2008 (dry season) due to absence of rain, but the lake stage remained relatively constant at about 126.5 feet (NGVD). However, surficial aquifer water elevations and lake stage both

declined during the October 2008- January 2009 dry season, perhaps because the elevation at the beginning of the dry season was higher. Both the aquifer and lake responded to the wet season conditions of June 2008 to September 2008.

The direct relationship between rainfall and surficial aquifer water levels is quantifiable over a long time period of time given adequate data. However, in the absence of long term data, a direct relationship between rainfall and groundwater under localized conditions is difficult to quantify because of the extremely high variability in rain events and the complexity of the influences of direct rainfall, runoff, evaporation, transpiration, and percolation, and aquifer recharge on groundwater levels.

It should be noted that lake levels in Lake Haines remained constant until the surficial aquifer water elevation exceeded 129 feet NGVD at a land surface elevation of 137.5 feet NGVD. An explanation for this “threshold effect” is that the hydraulic gradient is not sufficient at aquifer levels below 129 feet NGVD (at this monitoring well location) and the interaction between the lake and surficial aquifer is limited. At higher surficial aquifer water elevations, hydraulic head increases and is sufficient to result in groundwater infiltration to the lake.

8.1.3. Lake Groundwater Seepage

Groundwater seepage into a lake can be estimated by developing a Gross Water Budget, groundwater modeling, or direct measurement. While groundwater modeling can be a valuable tool when field verified data are not available, seepage meters are a widely accepted means of measuring groundwater in-flows and out-flows of a system.

The average seepage rate measured at shallow meters during this study (meters in 5 feet of water or less) was $4.07 \text{ L/m}^2\text{d}^{-1}$ (0.41 cm/d) compared to $2.19 \text{ L/m}^2\text{d}^{-1}$ (0.22 cm/d) at the deep meters (> 5 feet deep). Average seepage rates decreased by 5 percent at the shallow meters ($3.85 \text{ L/m}^2\text{d}^{-1}$ or 0.39 cm/d) and by 6 percent at the deep meters ($2.06 \text{ L/m}^2\text{d}^{-1}$ or 0.21 cm/d) when the first sampling event values were removed. This small change in seepage rate changes over time suggests that settling or shifting of the seepage meters was negligible due to placement of the meters in sand (as opposed to muck) and the inclusion of a flange that limited movement of the meter in the lake sediments. In a previous lake seepage study (ERD 2007), un-flanged seepage meters were installed in muck sediments up to 7 feet deep that may have complicated groundwater seepage measures.

8.1.4. Lake Sediments

The results of the sediment core analyses were used to determine the physical and chemical characteristics of the lake bottom sediments. This information can be incorporated into whole-lake nutrient budgets via incorporation of estimates of bottom resuspension frequencies, as outlined by Bachmann et al. (2000).

Seven composite sediment samples from each lake were analyzed for moisture and organic content and total phosphorus and nitrogen concentration. The average organic content was highest in Lake Conine (16 percent) and lowest in Lake Haines (6 percent). Sediment samples collected near seepage meters (water depths <10 feet) in all four lakes were greater than 75 percent solid content and less than 25 percent moisture content, while sediments from the deeper portions of the lake had a higher moisture content. Similarly, shallower portions of the lake had less organic content when compared with the deeper portions, which had higher silt and clay composition. These differences in sediments between the shallow and the deep portions of the lake are typical and can be attributed to the accumulation of organic material in the center of the lakes. The composition of the lake bottom is important when considering seepage rates because rates in sandy sites are greater than those in mucky sites (Isiorho et al 1996).

Soil chemistry differences between deep and shallow portions of the lake were similar to those described for physical soil characteristics. Average TP concentrations were substantially higher at the deeper lake sites (1,159 mg/kg) when compared to the shallower sites (9 mg/kg). Average TKN concentration at the deeper sites was 7,640 mg/kg, compared with 413 mg/kg at the shallower sites. For comparison, average sediment TP and TN concentrations in Lake Hancock (229 and 1,335 mg/kg, respectively) are lower, although the majority of the lake bottom sediments in the WHCL study lakes have TP and TKN concentrations below the Lake Hancock average (CDM 2002).

8.2. Conclusions

Results of this study are consistent with previous studies that identify groundwater seepage as the primary component influencing water budgets in lakes. Data collected as part of this study will provide additional data for development of the TMDL and *Winter Haven Chain of Lakes Water Quality Management Plan*. However, groundwater is a function of both antecedent groundwater conditions and rainfall and the relationships between lake levels, groundwater, rainfall, and nutrients can be difficult to quantify. Field data collected for this study proved somewhat limited due to the short (15 weeks) sampling period, although longer term data for surficial aquifer water levels, and lake levels, were available for a single lake, Lake Haines, and these data were used for comparison with our short term field data. Seepage meters were successful in intercepting and measuring groundwater into the lake and water chemistry analyses provided further evidence of groundwater seepage into the study lakes. Sediment analyses indicated greater muck at deeper lake depths, as expected, and we found that the integrity of the groundwater seepage meters may be affected in muck sediments.

Continued monitoring of site-specific surficial groundwater levels, lake levels, and groundwater seepage into lakes may be necessary to adequately address the needs of FDEP and the City of Winter Haven.

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