

Ground Water Study Report

GROUND WATER–SURFACE WATER
INTERACTION STUDY,
LAKE LOCHLOOSA AREA,
ALACHUA AND MARION COUNTIES, FLORIDA

Florida Department of Environmental Protection
Division of Water Resource Management
Bureau of Watershed Management
Ground Water Protection Section

January 2008

EXECUTIVE SUMMARY

Nutrients are known to cause the impairment of many lakes in Florida, but it is often difficult to identify the sources of the contamination. Detailed modeling is only as good as the information available, and sufficient data rarely exist for identifying ground water flows to lakes.

The 2000 Verified List of impaired surface waters for the Ocklawaha River Basin identified Lake Lochloosa and several lakes in the Orange Creek watershed as impaired by nutrients (phosphorus and nitrogen). However, the Florida Department of Environmental Protection's (FDEP) draft total maximum daily load (TMDL) for nutrients in Lake Lochloosa was not finalized because of uncertainties about how these contaminants enter the lake. The draft TMDL report recommends load reductions for nitrogen and phosphorus, and the Basin Management Action Plan (BMAP) for the Orange Creek watershed includes specific measures to address nutrient impairment in surface waters, but the source(s) of the nutrients and the routes by which they enter Lake Lochloosa had not been explored.

Lake Lochloosa and adjacent Orange Lake are located in a well-developed karst plain. Both lakes are perched on a confining unit (part of a large geological formation called the Hawthorn Group) containing abundant natural phosphate and varying in its consistency and effectiveness. Three aquifer systems have the potential to interact with these lakes. In the immediate area of Lake Lochloosa, the surficial and intermediate aquifers provide seepage to the lake, and the underlying Floridan aquifer also has an influence. Farther to the south, at Orange Lake, the confining unit is not effective, and this lake loses water to the Floridan.

This study examined the ground water pathways through which nutrients enter Lake Lochloosa and evaluated the effects of natural and human sources on the lake's nutrient levels. It also explored the physical and chemical characteristics of the surrounding area's ground water and surface water. Carried out in the spring and summer of 2006, the study was conducted by FDEP's Ground Water Protection Section, with assistance from FDEP's Watershed Monitoring Section, Florida State University's Oceanography Department, and the St. Johns River Water Management District.

Relatively shallow ground water samples were collected from 16 locations representing typical land uses near the two lakes. Elevated phosphorus (measured as orthophosphate) was detected in samples from most locations. For the most part, orthophosphate concentrations were several times higher than total phosphorus levels in Lake Lochloosa, because of the natural phosphate present in the Hawthorn Group. Elevated nitrate was detected at only 2 locations on the west side of Orange Lake, where ground water would not be expected to discharge to the lake.

When the chemistry of ground water from the surficial and intermediate aquifers was compared with that of pore water (water filling the spaces between grains of sediment) collected from immediately beneath the lake bed, the results indicated that both aquifers are sources of the pore water beneath Lake Lochloosa.

An FSU survey showed elevated radon-222 levels, indicative of higher ground water seepage, along the northern and northwestern edges of the lake. FSU's model calculated an average ground water advection rate of approximately 0.58 centimeters per day. Based on this rate, the daily discharge of ground water into the lake during this

measurement period was approximately 132,000 cubic meters per day. This method does not account for ground water seepage out of the lake, which also likely occurred in certain areas.

The study results indicate that potential phosphorus loading via ground water to the lake under this scenario could be as high as 100 pounds per day. This could occur during high ground water discharge periods, as reflected by higher lake stage. Measurements should be made during lower lake stage to establish ground water discharge rates during those periods. At that time an estimate of loading can be made that considers seasonal fluctuations.

This report recommends that the draft phosphorus TMDL for Lake Lochloosa be revised to account for ground water contributions in the nutrient budget. The techniques used in this analysis should also be refined and used to support future TMDL modeling in other lakes where there are uncertainties about nutrient loading through ground water.

ACKNOWLEDGMENTS

This report was prepared by the Ground Water Protection Section of the Bureau of Watershed Management, Florida Department of Environmental Protection (FDEP). Study participants include the following:

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We would like to acknowledge the assistance provided by many individuals during the course of this study. Margaret Murray, Natasha Dimova, and Ben Mwashote of Florida State University's Oceanography Department conducted radon assessment work and seepage measurements under Drs. Bill Burnett and Jeff Chanton (with special thanks to Margaret for her efforts). Dr. Rodney DeHan of the Florida Geological Survey provided contract funding for the radon work. Jeff Davis of the St. Johns River Water Management District (SJRWMD) coordinated a thermographic survey of Lake Lochloosa, coordinated the borehole geophysical logging, and provided invaluable information on the hydrogeologic setting. Jian Di and Erich Marzolf of SJRWMD and Dr. Bob Kelly of SAIC provided timely and excellent review comments. Tom Biernacki and his staff in FDEP's Watershed Monitoring Section provided the resources, boats, and equipment to conduct the surface water sampling and radon surveys. We also want to acknowledge the fine services provided by Jim Stidham and Associates, Inc., and particularly the efforts of Scott Sigler, who ran the direct-push sampling program, obtained permits and property access, and surveyed historical land uses in the area. Finally, we want to thank Linda Lord for applying her expert editing skills to this document.

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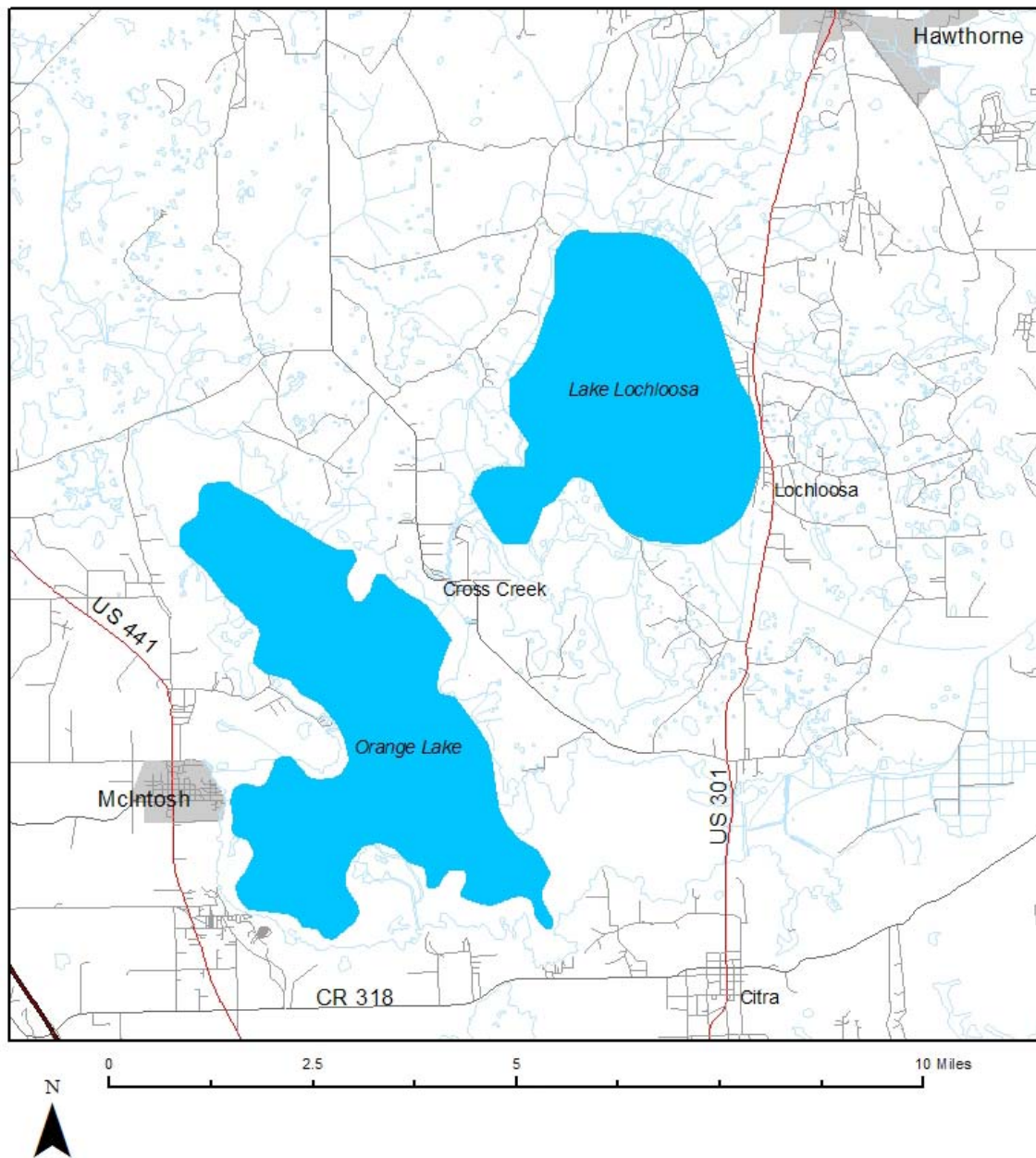
INTRODUCTION

The 2000 Verified List of impaired surface waters for the Ocklawaha River Basin identified several lakes in the Orange Creek watershed, including Lake Lochloosa, as impaired by nutrients (phosphorus and nitrogen). The Florida Department of Environmental Protection (FDEP) submitted a draft total maximum daily load (TMDL) for nutrients in Lake Lochloosa, and recommended reductions in nitrogen and phosphorus loading. However, the nutrient TMDL for Lake Lochloosa was not finalized because of uncertainties about the hydrologic inputs, sources, and origin of the nutrients in the lake. The Basin Management Action Plan (BMAP) for the Orange Creek watershed includes measures to address nutrient impairment in surface waters, but until now the source (or sources) of the nutrient enrichment and the routes by which nutrients enter Lake Lochloosa have been relatively unexplored.

This study examines the ground water pathways that allow nutrients to enter Lake Lochloosa and evaluates how naturally occurring phosphorus in the aquifer matrix and anthropogenic sources of phosphorus and nitrogen may be affecting nutrient levels in the lake. It also explores the physical and chemical characteristics of the surrounding area's ground water and surface water. The study analyzed land use data to determine potential sources of nutrients in ground water, estimated overall ground water contributions using chemical and radon tracers, identified ground water discharge "hot spots" based on a radon survey, and calculated ground water seepage and potential phosphorus loading based on an advection-diffusion model developed by Florida State University (FSU) that uses average radon values.

The study was conducted in the spring and summer of 2006 by FDEP's Ground Water Protection Section, with assistance by FDEP's Watershed Monitoring Section, FSU's Oceanography Department, and the St. Johns River Water Management District (SJRWMD). Jim Stidham and Associates, Inc. (JSA) provided contracted drilling and sampling services. Activities included the collection and analysis of ground water, pore water (water filling the spaces between grains of sediment), and surface water samples for chemical parameters, as well as the estimation of ground water seepage and potential nutrient inputs using a combination of techniques. A subsequent section discusses the specific project tasks and agency involvement.

Figure 1 shows the study area and the principal waterbodies of interest.

Figure 1. Study Area and Principal Waterbodies

SETTING

Physiography and Soils

Lake Lochloosa and Orange Lake lie within the physiographic division known as the Alachua Prairies. In this region of advanced karst development, subsidence has created numerous solution features that form loosely connected prairies and lakes (Kindlinger et al., 2000). The study area also includes a portion of the Northern Highlands to the north and a small portion of the Fairfield Hills to the southwest. Topography slopes from the north to the south, and also slopes eastward from the Fairfield Hills region in the southwest corner. In the area north of Lake Lochloosa, the elevation is approximately 100 feet above national geodetic vertical datum (NGVD). The elevation at the Lake Lochloosa and Orange Lake shorelines is less than 60 feet NGVD. The crest of the Fairfield Hills at McIntosh to the west is approximately 100 feet NGVD. **Figure 2** shows these physiographic regions and elevations.

The predominant soils in the Alachua Prairies portion of the study area are Spodosols, which are poorly drained, acidic soils with a leached sandy surface horizon and an underlying organic hardpan layer (or spodic horizon) that creates perched water zones during wet-weather periods. In general, the soils surrounding the lakes are low in slope and as a result have a low runoff potential. In the marshes and wetland areas along lake margins, the soils are Histosols—organic-rich muck or peat soils that form in decomposed plant matter. Aflisols, occurring in the Fairfield Hills area, are moderately well drained, highly arable, and have clayey subsoils. Entisols which, consist of deep, sandy soils with a low clay and organic content, occur in a portion of the study area to the south of the lakes. A later section of this report evaluates soil chemistry.

Surface Water

Lake Lochloosa is somewhat typical of lakes in the Alachua Prairies, being generally shallow (5-foot average depth) and formed as the result of limestone dissolution. It is large, with a surface area of approximately 5,600 acres, and has a watershed of approximately 52,000 acres. According to the SJRWMD, the lake stage in Lochloosa from January 1991 to April 2006 ranged between 54.12 and 61.01 feet above mean sea level (msl), with the median stage being at 56.7 feet msl. In March 2006, when the study began, the lake stage was approximately 58 feet msl, somewhat higher than the median.

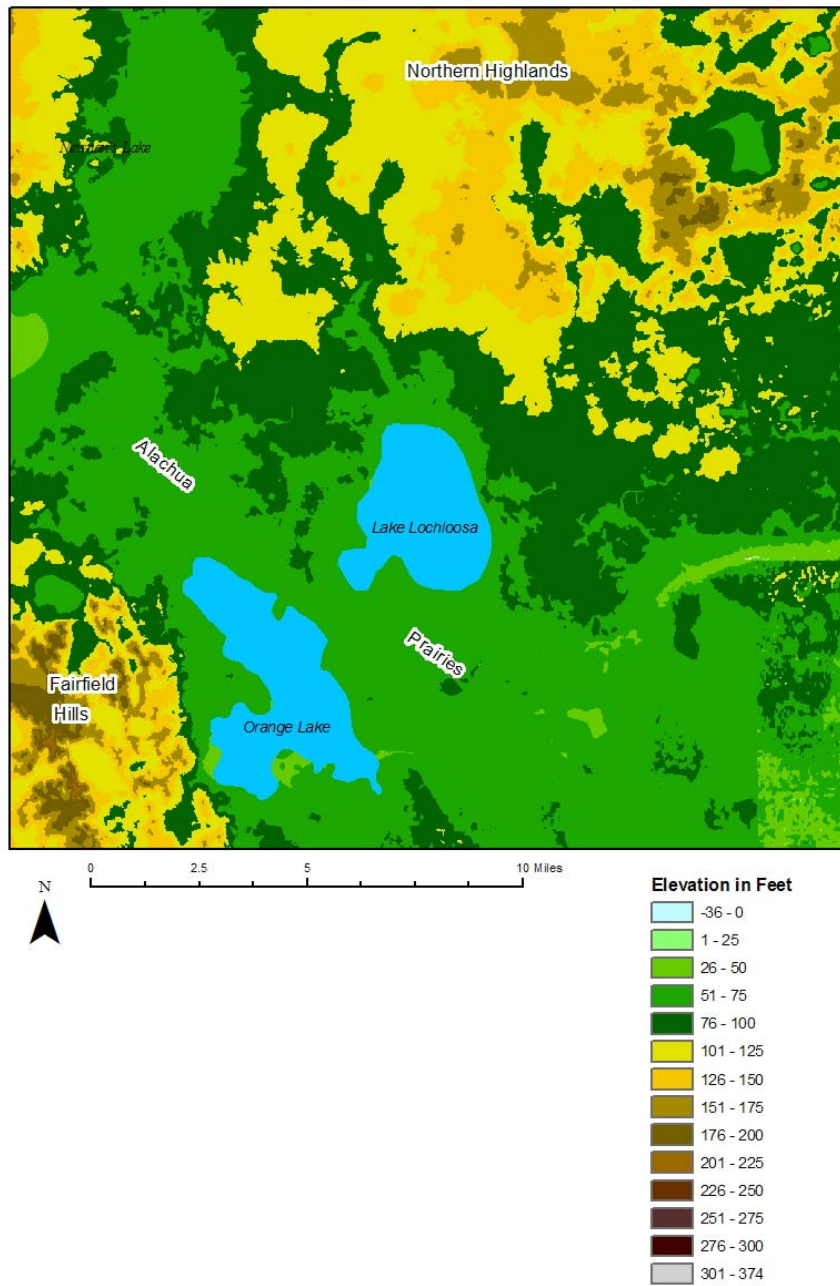
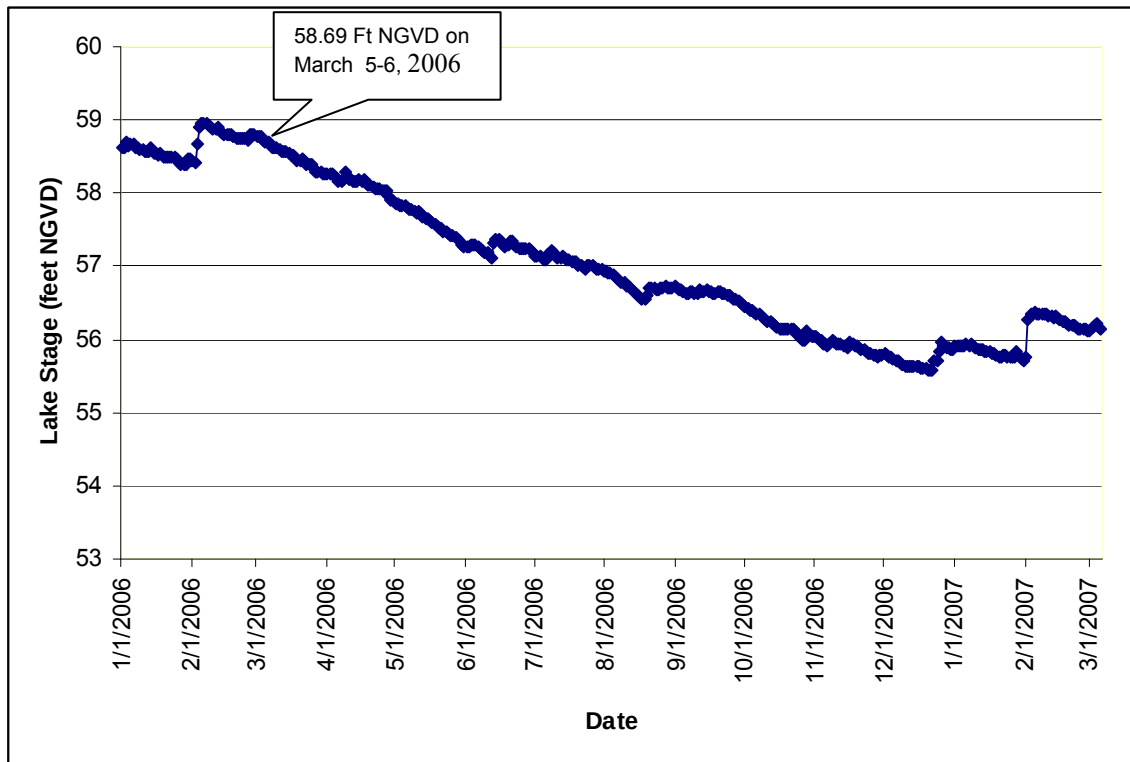
Figure 2. Physiography and Elevations in the Study Area

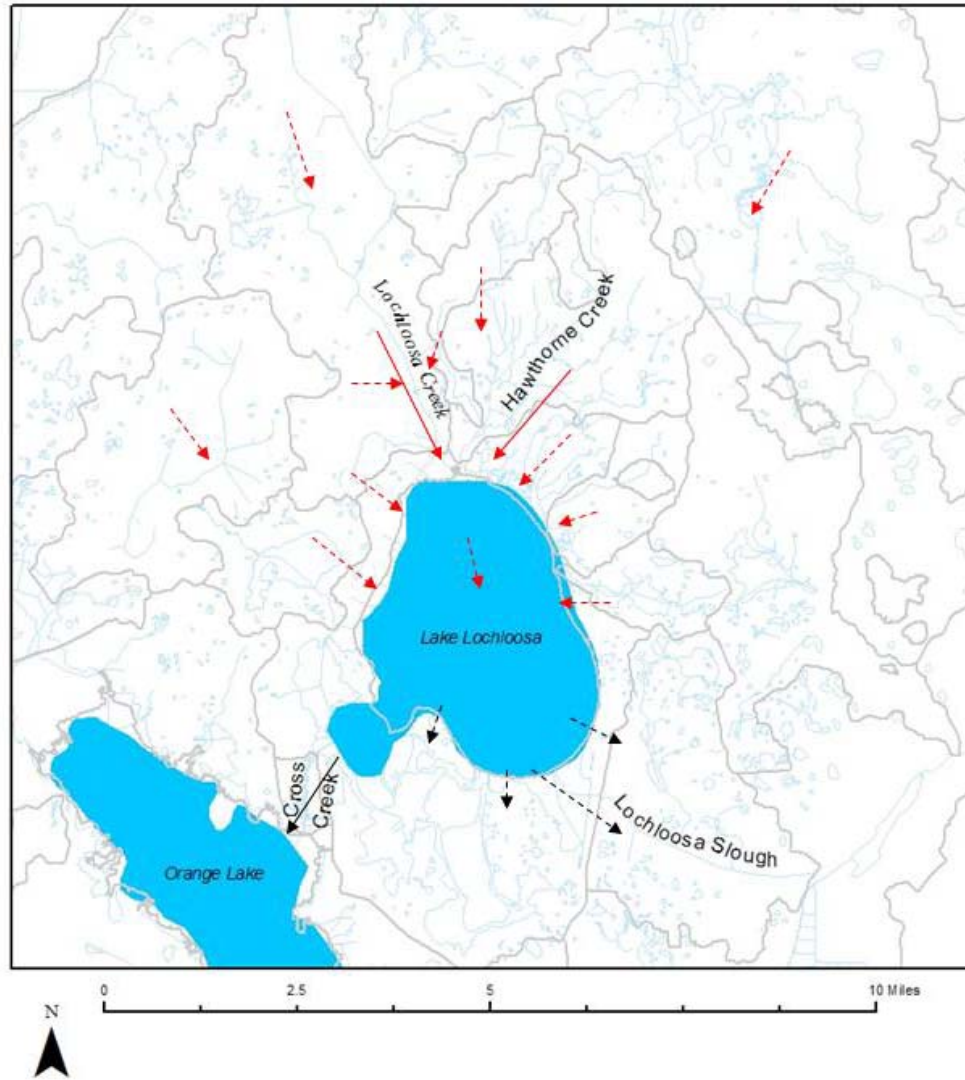
Figure 3. Lake Lochloosa Stage, 1991-2006

Source: SJRWMD web site

The water budget for Lake Lochloosa is complex and, except for rainfall and evapotranspiration, inputs and outputs have not been consistently measured. The sources of water to the lake include direct rainfall, surface flow, and subsurface flow from ground water. A drainage area to the north supplies surface water inflow through Lochloosa and Hawthorne Creeks, both of which flow to the lake intermittently during periods of wet weather. It is thought that the area to the north is also the source of much of the ground water seepage to the lake. Lochloosa Creek, the main tributary, has several years of flow data measured by the U.S. Geological Survey and frequently does not flow during dry periods. Otherwise, stream and runoff inputs have not been quantified. Ground water seepage, which may come from the surficial aquifer, unconfined intermediate-aquifer material, and/or the Floridan aquifer, contributes water to the lake but has not previously been measured.

Surface water outflow from Lochloosa occurs via Cross Creek (to Orange Lake) and through Lochloosa Slough in the southeastern corner of the lake. The SJRWMD recently began measuring flow in Cross Creek, but the outflow to Lochloosa Slough has not been quantified. Subsurface outflow from the lake into ground water is also not defined; some of it possibly occurs as seepage via the surficial aquifer system into Lochloosa Slough to the south. **Figure 4** shows likely flow paths to and from Lake Lochloosa. A water budget developed by SJRWMD for a portion of 2005 through 2006 estimated a net loss of water from the lake during that time, which was accounted for by evaporation and negative ground water seepage exceeding runoff, rainfall and positive ground water seepage over the measurement period (Di and Marzolf, 2007).

FDEP (2001) listed Lake Lochloosa as impaired by nutrients because it had elevated Trophic State Index (TSI) values, which are derived from a calculation using phosphorus, nitrogen, and chlorophyll concentrations. Based on the TMDL document, the long-term (1988–2001) average concentrations of total phosphorus (TP), total nitrogen (TN), and chlorophyll *a* (chl_a) were 0.062 milligrams per liter (mg/L), 2.18 mg/L, and 82.0 micrograms per liter (µg/L), respectively. The long-term average TSI calculated from these data according to the procedures adopted in the IWR is 76.9 (ranging from 54.8 to 89.5). Although nutrient levels in the water column have fluctuated, they have remained high in recent years.

Figure 4. Lake Lochloosa Surface and Subsurface Flow Paths

Notes: Red arrows indicate inflows, black arrows indicate outflows. The dashed lines indicate likely ground water flow pathways.

Geology and Ground Water

The geologic material in the study area consists of shallow sands and clays of Pleistocene age that lie on top of phosphatic sands, clays, dolosilts, and dolostone of the Miocene-age Hawthorn Group. The Hawthorn Group material (occurring throughout much of Florida) overlies limestone of the Ocala Group, which is of Eocene age. The study area lies within a transitional area where the Hawthorn Group material changes in composition and decreases in thickness southwest of Lake Lochloosa, in the vicinity of Orange Lake. The upper sequences of the Hawthorn Group are eroded and reworked, and it is difficult to determine the exact boundary between them and the overlying Pleistocene sands. In some areas, the residual material of the Hawthorn Group is at the land surface.

REFERENCES USED IN THIS SECTION

Several references were used for this section of the report. They include Kindlinger et al., 2000; Green et al., 1989; Macesich, 1988; Scott et al., 2001; Scott, 1988; Clark et al., 1964; Campbell and Scott, 1991; and SJRWMD Watershed Maps Online.

Aquifer Systems

Ground water in the study area is found in three aquifer systems: surficial, intermediate, and Floridan. In the Orange Creek Basin, the surficial aquifer occurs in sands and clays wherever underlying clay layers provide an effective basal confining unit. It is not present as a discrete aquifer in the southern part of the study area, where the confining unit is not continuous. This aquifer exists under water-table conditions, and rainfall is its main source of recharge. The water table fluctuates seasonally, and the depth at which it occurs varies seasonally with rainfall and with elevation and proximity to waterbodies and wetlands. The surficial aquifer is a source of water for lakes and streams, but it can also receive water from them. Topography dictates ground water flow in the surficial aquifer, with ground water flowing from areas of higher to lower elevation. According to a SJRWMD geographic information system (GIS) coverage showing estimated ground water elevations in the surficial aquifer, flow is mainly from the elevated area north of Lake Lochloosa toward the lake.

The intermediate aquifer system occurs in the Hawthorn Group material, which in the study area consists of clays, sandy clays, sandy silts, thin calcareous lenses, and zones of dolostone that occur near its base. In some areas the intermediate system is a significant source of water to wells, but in the study area it functions as a confining unit where the clay layers are extensive and continuous. Both Lake Lochloosa and Orange Lake are perched on this clayey material. The confining unit (along with a distinct surficial aquifer) loses its integrity to the south and west of the lakes, because the Hawthorn Group material thins and clay layers are not continuous. Lithologic data collected during the June 2006 direct-push sampling indicates that the water-bearing zones within the clayey material of the intermediate system (where they are present) are

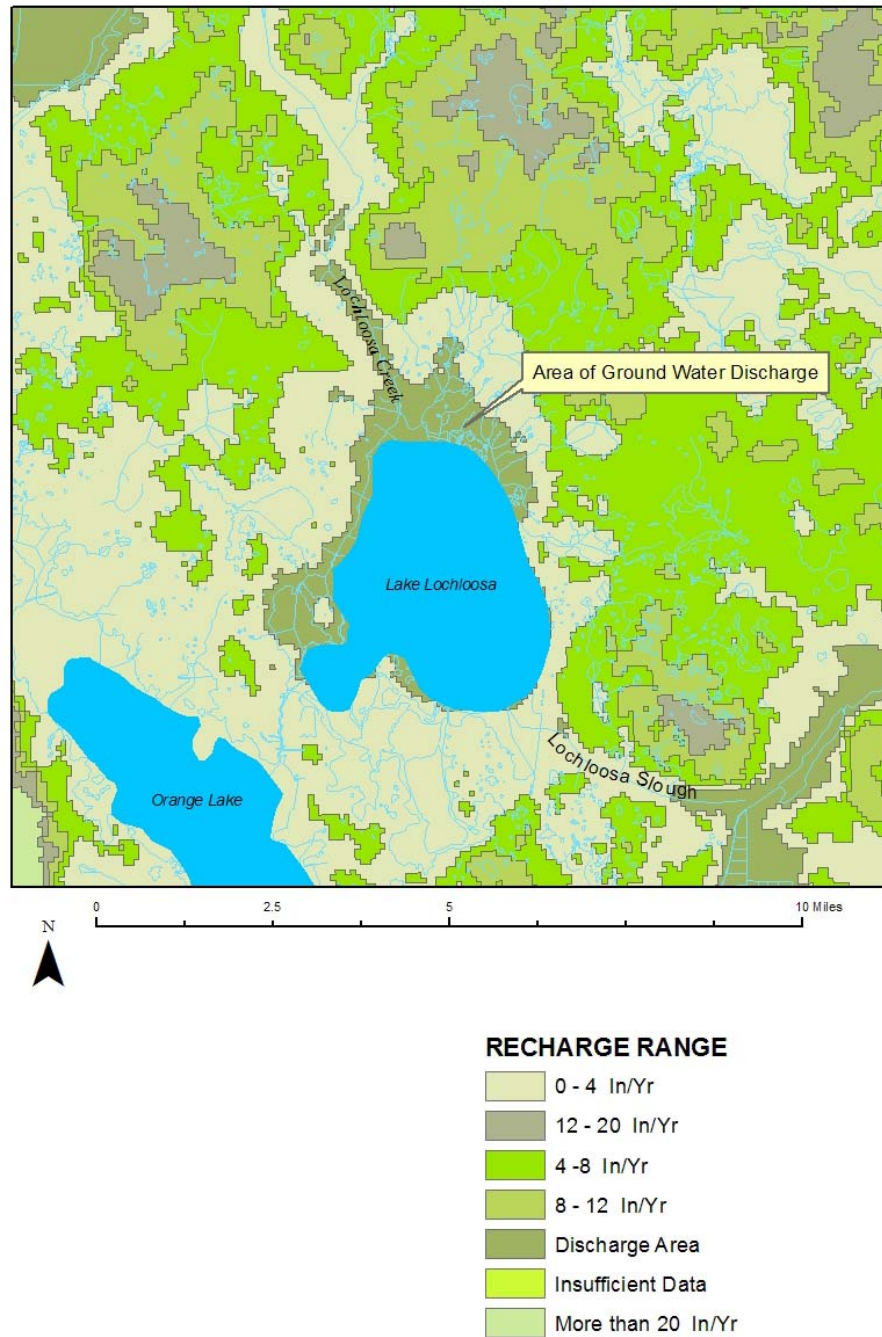
not extensive. It was observed that units that contain and yield water consist of thin silty sand layers and narrow bands of brittle dolostone that occur between zones of clay.

The Floridan aquifer is a vast resource and provides water to all the potable wells in the study area. It is found in the Ocala Group, which consists of thick sequences of Eocene-age carbonate rocks that are hundreds of feet in thickness. In the northern and eastern parts of the study area, the Floridan is confined beneath the Hawthorn Group material and exists under artesian pressure. In fact, in a portion of the study area, the pressure is high enough that flowing artesian conditions are present. A third-magnitude spring, Magnesia Spring, and several artesian wells are found in this area, which roughly includes Lochloosa Creek, Lake Lochloosa, and Lochloosa Slough to the southeast.

Figure 5 shows this area of discharge from the Floridan aquifer. Farther to the south and west, where the Hawthorn Group material is thinner and less continuous, the Floridan is not confined by the clayey material and occurs under water table conditions. In these areas, overlying sand deposits function as part of the Floridan aquifer.

Ground Water–Surface Water Interactions

Ground water elevations relative to surface water and the extent of the confining unit dictate the most likely scenarios for ground-water-to-surface-water discharge, or vice versa. Based on topographic map data, ground water elevations in the surficial and intermediate aquifers in the areas of higher elevation surrounding Lake Lochloosa to the north, northwest, and northeast are somewhat higher than the lake stage. According to potentiometric surface contour maps provided by the SJRWMD, the potentiometric surface of the Floridan aquifer is also higher than the lake stage in areas to the north and beneath Lake Lochloosa (the area of Floridan aquifer discharge). Farther to the south, where there is no longer a continuous confining unit, the potentiometric surface of the Floridan drops and is lower than the lake stage for Orange Lake. Orange Lake discharges to the Floridan aquifer, while the potential exists for Lake Lochloosa to receive water from the Floridan and also discharge to it, depending on aquifer head.

Figure 5. Areas of Ground Water Recharge and Discharge, Floridan Aquifer

Source: SJRWMD GIS files.

STUDY METHODS

Shallow ground water quality sampling and the collection of lithologic samples were performed in June 2006, using a direct-push sampling system at strategic locations near Lake Lochloosa and Orange Lake. Samples were collected at 16 spatially representative locations that reflected the principal land uses/land coverages near the lakes, with the main focus on Lochloosa (**Figure 6**). Direct-push ground water samples were collected at depths ranging from 7 to 40 feet below land surface. Surface soil samples were also collected at these locations. JSA conducted this sampling and analytical work, under the direction of FDEP's Ground Water Protection Section. The SJRWMD also geophysically logged representative boreholes, which was helpful in defining clay layers and phosphate-enriched zones. **Appendix A** provides the geophysical logs and lithologic descriptions.

In March 2006, FDEP samplers collected surface water samples at several locations in Lake Lochloosa and one location in Lochloosa Creek (**Figure 7**). At most of these same locations, shallow ground water (pore water) samples were also collected from native material beneath the lake bed and muck layer using a hand-driven wellpoint sampler. Surface water and pore water samples were analyzed for nutrients and indicator parameters, as were the direct-push ground water samples.

At the same time, FSU Oceanography Department researchers collected samples for radon measurement in surface water (Lake Lochloosa and Lochloosa Creek) and ground water (shallow pore water samples from push-point samplers driven into the lake bed). FSU also used a continuous radon monitor in the lake to identify potential areas of high ground water seepage. The selection of surface water and pore water sampling locations was in part guided by thermography maps for the lake provided by the SJRWMD. FSU also deployed a seepage meter array at a location off the eastern shore of Lake Lochloosa to assist in understanding seepage rates at one location in the lake.

Radon-222 (^{222}Rn) is an excellent tracer of ground water discharge to surface waters, and various radon tracer approaches have been used in recent years as tools in estimating the submarine discharge of ground water to coastal waterbodies. However, this method has been applied to lakes in only a few instances (Corbett et al., 1999, Stinger, 2004). The method employed by FSU researchers involved the collection of radon data and the use of a radon flux model to estimate a seepage rate. **Appendix B** contains the report on FSU's radon survey and seepage measurement activities. **Appendix C** contains an excerpt from Stringer (2004) that describes the radon model in greater detail.

To help establish water quality in the Floridan aquifer, FDEP also sampled one Floridan-aquifer-depth potable well that provides water to a fish camp on the east side of Lake Lochloosa.

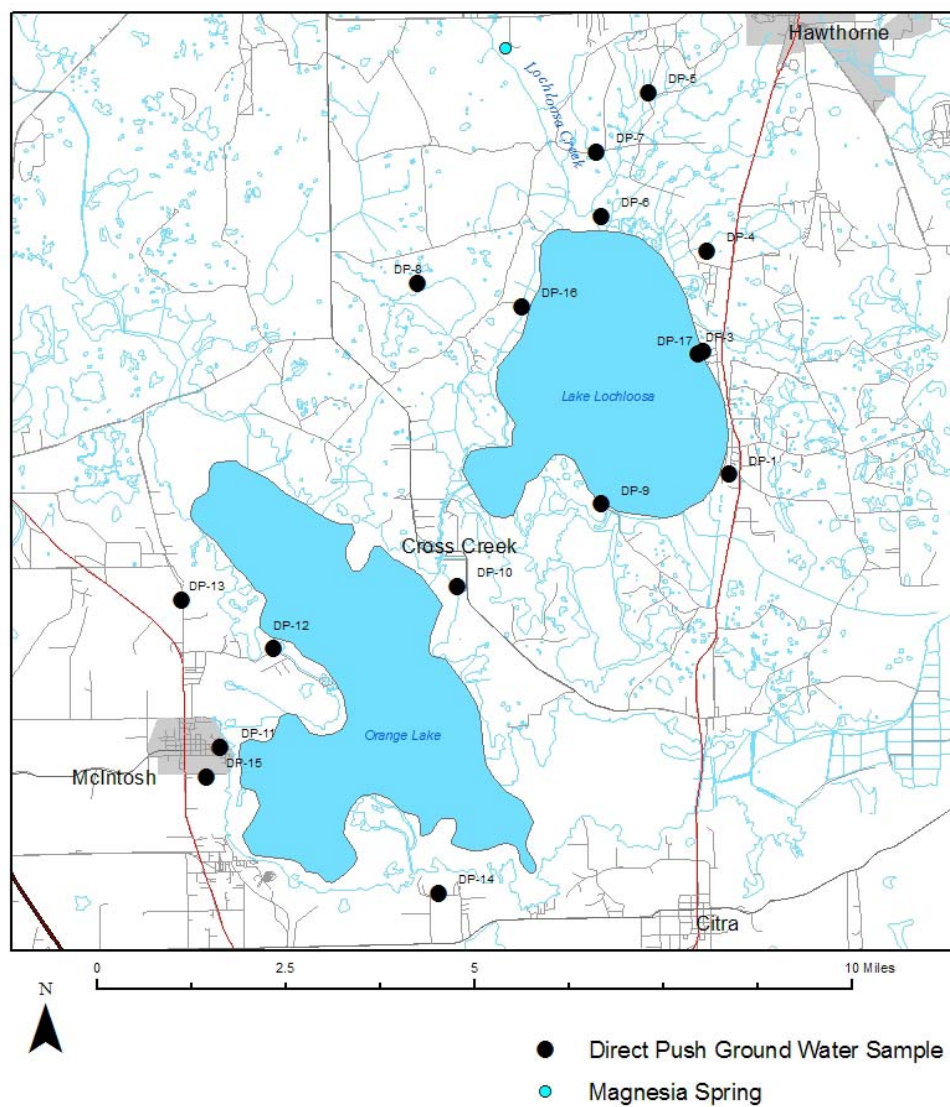
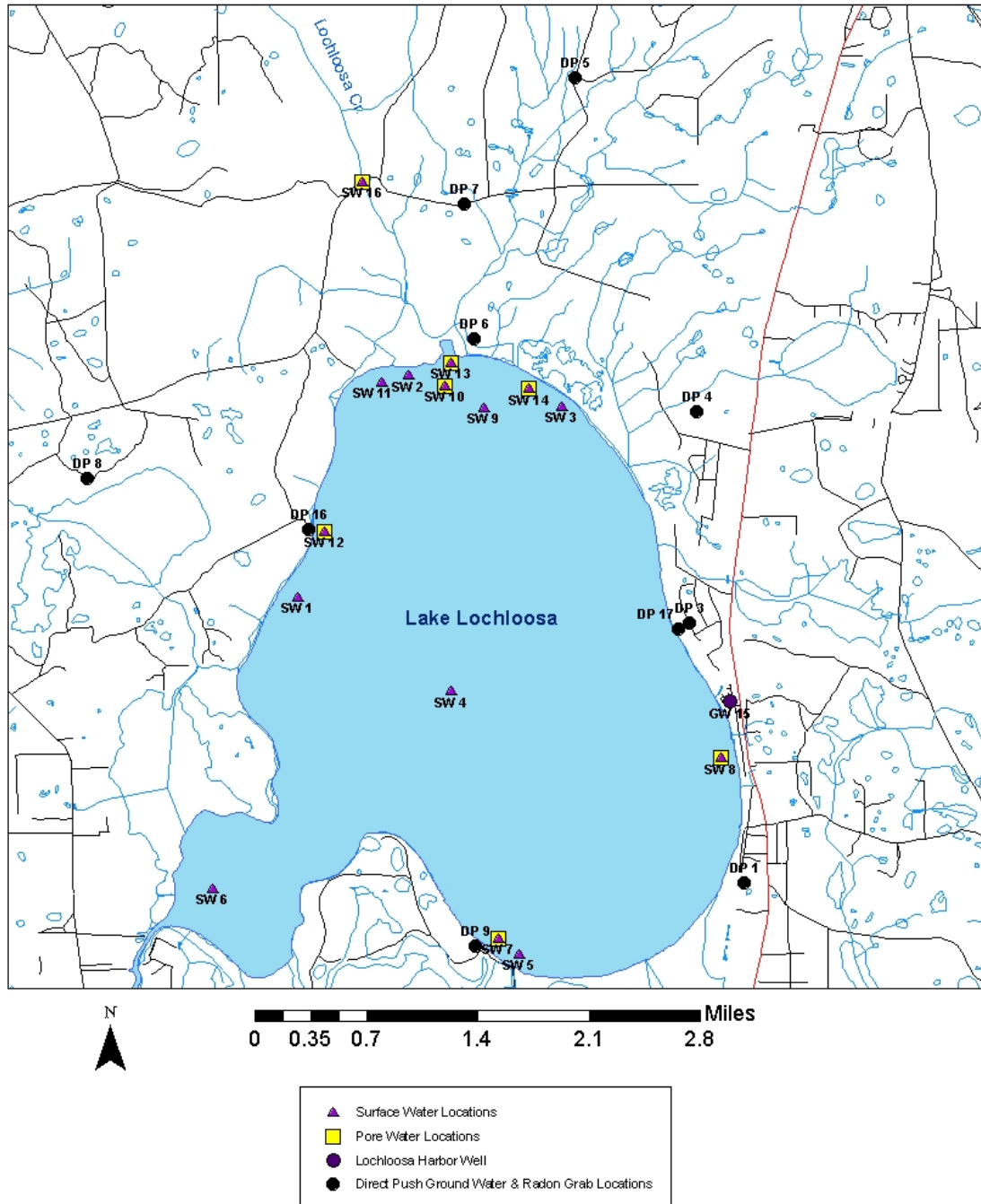
Figure 6. Direct-push Ground Water Sampling Locations

Figure 7. Surface Water and Pore Water Sampling Locations

NUTRIENT SOURCE ASSESSMENT

One objective of the study was to assess ground water quality beneath land use areas with the potential to contribute nutrients to lakes via ground-water-to-surface-water discharge. Natural ground water quality characteristics were also assessed.

Ground water samples were collected from the upper one or two ground water–bearing zones encountered through temporary monitoring wells installed with a direct-push rig. Samples were collected from the surficial and intermediate aquifers at locations north and east of Lake Lochloosa, and from the Floridan aquifer from locations south of Lochloosa and surrounding Orange Lake. The sampling locations were selected to evaluate the potential ground water influences of the following land use/land cover types:

- *Silviculture/pine forest,*
- *Beef cattle pasture,*
- *High-density residential using septic tanks,*
- *Low-density residential using septic tanks and with livestock, and*
- *Agriculture/former citrus groves.*

Land Use and Ground Water Quality

Because silviculture is the predominant land use in the study area, ground water samples were collected at locations adjacent to pine trees of various ages in the SJRWMD and Plum Creek property north of Lake Lochloosa, so that the effects of fertilization practices, if any, would be observed in ground water samples. The potential impacts of several pastures occupied by beef cattle were evaluated, one to the northeast of Lake Lochloosa and two areas on the western shore of Orange Lake. Many of the open fields and agricultural areas on the west side of Orange Lake that were sampled were once citrus groves, and the two pastures west of Orange Lake were previously citrus areas, according to historical aerial photographs.

Ground water samples were also collected in the Lochloosa Shores subdivision, in the older, high-density village of Lochloosa on the southeastern shore of the lake, in the Cross Creek community between the lakes, in the town of McIntosh on the western shore of Orange Lake, and in a less-densely developed residential area of 5- to 10-acre tracts south of Orange Lake. Samples were collected in these residential areas to evaluate the impacts of septic tank drainfields and residential lawn fertilizers on ground water quality. The area containing the 5- to 10-acre ranchettes was also sampled to evaluate the potential influence of livestock wastes, mainly equine.

Figure 8 shows the ground water sampling locations and land uses in the study area. **Table 1** summarizes the ground water sampling locations, sampling depth intervals, depths to ground water, aquifers represented by the samples, and detected concentrations of nitrate-nitrogen, ammonia-nitrogen, dissolved phosphorus, and dissolved orthophosphate.

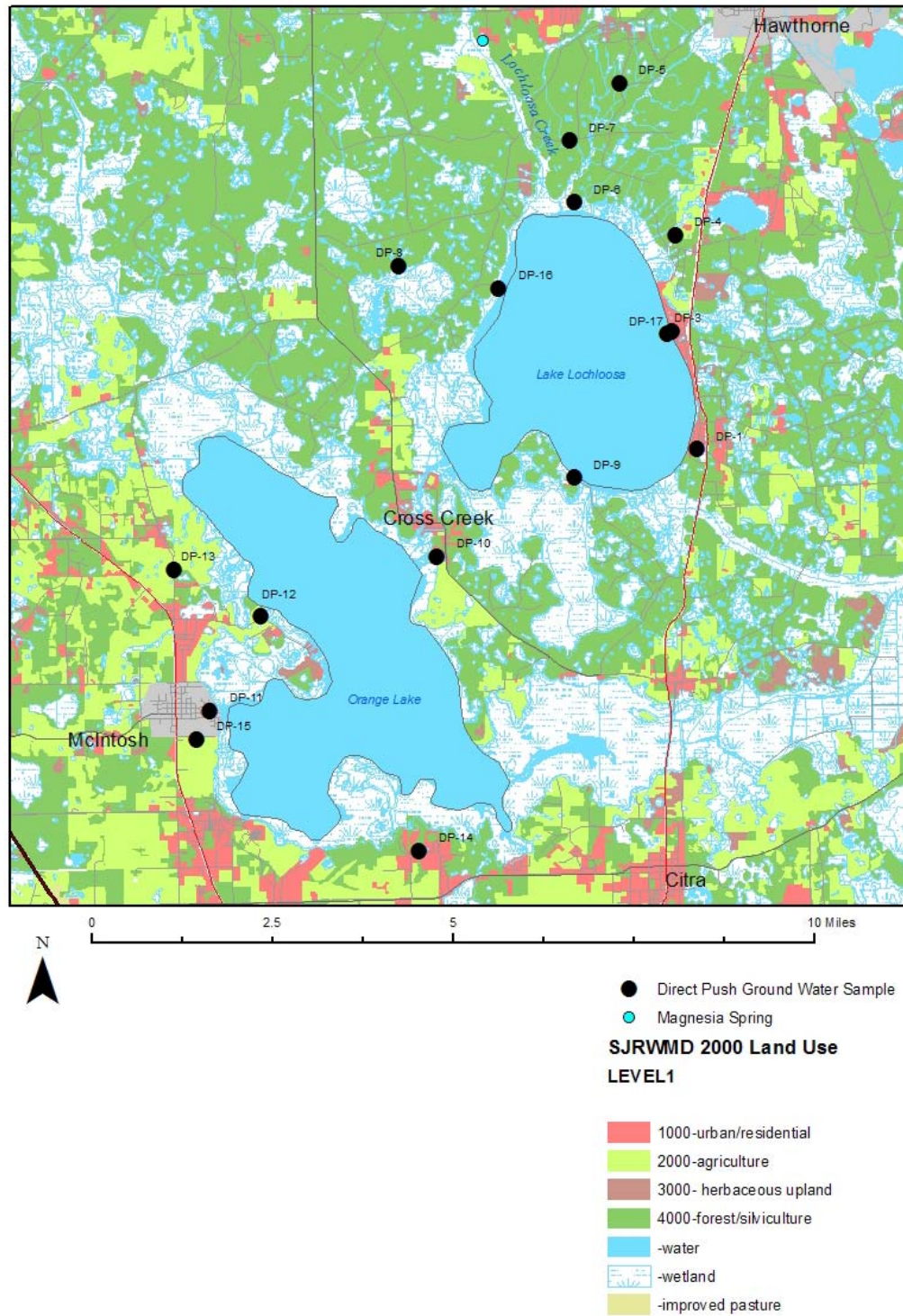
Figure 8. Direct-push Sampling Locations and Land Uses

Table 1. Direct-push Sampling Results for Nutrients in Ground Water with Land Use Setting

Location	Aquifer ¹	Sample Depth (ft)	Depth to Water (ft)	Chloride (mg/L)	Nitrate-N (mg/L) ²	Ammonia-N (mg/L) ²	Phosphorus (mg/L) ²	Orthophosphate (mg/L) ²
Urban/residential (High- to medium-density residential/septic tanks, lawn fertilizers)								
DP-1A	S	8	5	425	0.008U	2	0.1	0.1
DP-1B	I	16	5.45	525	0.008U	1	0.2	0.2
DP-3A	S	8	3.7	25.2	0.008U	0.2	0.5	0.5
DP-3B	I	27	10.85	14.3	0.181	0.2	0.08	0.08
DP-10A	S	7	4.1	25.8	0.211	0.4	0.9	0.6
DP-10B	I	40	11.8	43.7	0.183	0.1	2	0.7
DP-11B	I	32	10.9	46	0.008U	0.003U	0.06	0.03U
DP-17B	I	20	10.6	14.4	0.008U	0.3	1	1
Urban/residential (Low-density residential, hobby farms/fertilizer, animal waste)								
DP-14B	F	28	9.9	6.73	0.008U	0.1	0.08	0.07
Silviculture/ natural conditions, potential fertilizer								
DP-5A	S	9	6.2	46.3	0.207	0.04	0.4	0.4
DP5-B	S	19	5.5	41.7	0.008U	0.07	0.5	0.4
DP-6A	S	14	5.9	11.6	0.008U	0.08	0.08	0.02
DP-6B	I	30	2.8	7.38	0.008U	0.1	0.02 I	0.02
DP-7A	S	18	5.25	23.3	0.008U	0.04	0.5	0.3
DP-8B	I	36	4.65	5.92	0.18	0.003U	1.0	1.0
DP-16A	S	12	7.85	9.44	0.008U	0.03	0.6	0.5
DP-16B	I	38	7.2	7.98	0.008U	0.03	0.02 I	0.01
Forest/silviculture adjacent to improved pature (Silviculture, pasture/fertilizer, animal waste)								
DP-4A	S	20	5.7	15.6	0.008U	0.02	0.1	0.1
Improved pasture (Pasture/hayfield, former citrus/fertilizer, animal waste)								
DP-12B	I	39	11.5	19.1	4.95	0.09	0.5	0.5
DP-13A	S	10	7.8	12.8	0.008U	0.003U	0.09	0.09
DP-13B	I or F	27	8.55	11	4.25	0.003U	0.1	0.05
DP-15B	F	27	21.4	14.8	0.215	0.03	0.3	0.3
Wetland (Lake influence/natural conditions)								
DP-9B	I	18	4.85	19.3	0.008U	0.05	0.04	0.02

Notes:

Samples collected May 30 to June 8, 2006.

¹ S = surficial; I = intermediate; F = Floridan² Dissolved

Nitrate, chloride, and ammonia were the most useful indicators of anthropogenic sources of nutrients in ground water samples collected in this study. Nitrate is the most typical indicator of nutrient contamination from such sources as fertilizers, animal waste, and human wastewater, and occurs naturally only in minute concentrations. Chloride is also a good indicator of contamination from the same sources, as well as others. Ammonia occurs naturally in some areas at moderate concentrations but is often an indicator of wastewater and animal waste. Ammonia readily converts to nitrate in the presence of oxygen, and so elevated ammonia concentrations in ground water often occur

where the water table is high. Other indicators can be useful in conjunction with one or more of these contaminants.

Nitrate

Nitrate concentrations above detection levels indicate anthropogenic influences, but many shallow wells in the Orange Creek Basin have detectable nitrate levels. From the FDEP Background Monitoring Network Database, the median nitrate value for unconfined aquifers in the basin is 0.25 mg/L. Nitrate concentrations were detected at 6 of the 16 locations in the study. The highest nitrate concentrations (4.95 and 4.25 mg/L at DP-12 and -13, respectively) were detected in unconfined Floridan aquifer samples in an agricultural area on the west side of Orange Lake (**Figure 8**). Based on current and historical land uses, the sources could have been fertilizers used on orange groves or pastures/hayfields. Lower concentrations were detected at 2 locations in residential areas and 2 other locations where the land use is silviculture. These detections did not exceed 0.211 mg/L. Nitrate discharge to Orange Lake from DP-12 and -13 is unlikely, since the Floridan aquifer does not discharge to the lake in that area, based on potentiometric surface data for the aquifer and lake stage data.

Chloride

The median chloride concentration for unconfined aquifers in the Orange Creek Basin is 16 mg/L. Elevated chloride was detected at 4 locations, at concentrations ranging from 41.7 to 525 mg/L. The highest concentrations (525 and 425 mg/L in the intermediate- and surficial-zone wells, respectively) were detected at DP-1, which was installed in Lochloosa, an older, high-density residential community on the southeastern shore of the lake (**Figure 8**). Elevated ammonia, sodium, and specific conductance correspond with the high chloride at DP-1. The sodium concentration in the surficial-zone well (202 mg/L) exceeds its primary ground water maximum contaminant level (MCL). Both chloride concentrations exceed the secondary MCL for chloride.

Ammonia

The median for ammonia in unconfined aquifers in the basin is very low (0.022 mg/L). Ammonia can be produced during the decomposition of plant material and is not always associated with a pollutant source. Considering the wetlands in this area, somewhat higher ammonia concentrations near swampy areas could represent local ambient levels. However, the highest ammonia levels detected in the study are definitely not naturally occurring. As mentioned previously, these were detected at DP-1 (2 mg/L in the surficial zone and 1 mg/L in the intermediate zone) in the community of Lochloosa. The ammonia detected at DP-1 is approximately 2 orders of magnitude higher than the median for unconfined aquifers in the basin, and its detection may be significant in light of its relationship to the other constituents found at this location. The cause of the contamination at DP-1 is not known, but ground water in this area is a potential source of nitrogen to the lake.

Phosphorus

Phosphorus and orthophosphate were also included in the suite of analytes, because nutrient enrichment by phosphorus is a cause of impairment in the lakes. Total phosphorus is a non-selective analysis that can include phosphorus derived from both organic and inorganic sources (organic from decomposed plant matter, inorganic from fertilizers and natural geologic material), whereas orthophosphate analysis measures only inorganic phosphorus content. Due to the natural abundance of phosphorus in the geologic material, however by these analyses alone, neither could be linked to land use. The basinwide median for phosphorus in unconfined aquifers in the basin is 0.099 mg/L. It was expected that in the study area—where many of the ground water samples collected were from aquifers in contact with phosphorus-containing material—phosphorus levels would be high and most likely reflective of orthophosphate content in the native material. Comparable results for analyses of phosphorus and orthophosphate in the direct-push sampling show that the source of phosphorus in the ground water in this area is inorganic (Table 1). Depending on location, depth, and proximity to phosphatic material, the concentrations of phosphorus (total) orthophosphate ranged from as low as 0.02 mg/L to as high as 1 mg/L, with most concentrations exceeding 0.1 mg/L. Median orthophosphate concentrations for the Floridan, intermediate, and surficial aquifers were 0.17, 0.54, and 0.35 mg/L, respectively, in the immediate vicinity of Lake Lochloosa.

Phosphorus was evaluated because of its potential to enter the lakes from soil runoff and leaching. The median value for phosphorus (total) in the Spodosols surrounding Lake Lochloosa was 131 milligrams per kilogram (mg/kg). For the Aflisols on the western shore of Orange Lake, phosphorus values ranged from 305 to 490 mg/kg. Both of these fall within the statewide ranges for their soil orders, as measured by Chen and Ma (2001). One sample collected from south of Orange Lake, from Entisols (126 mg/kg), also fell within the statewide ranges. Ramnarine (2003), in his study of phosphatic soil distribution in Alachua County, found this area to be one of generally low phosphorus occurrence in surface soils. Based on the chemistry and runoff characteristics of the soils surrounding the lakes, it is unlikely that phosphorus from eroded surface soils is a significant input. **Table 2** presents phosphorus results for the soil samples collected at the locations shown in **Figure 8**.

Table 2. Phosphorus Concentrations in Surface Soil Samples

Location	Soil Order	Total Phosphorus (mg/kg)	Median Value for Soil Order
DP-1	Spodosols	924	
DP-3		36	
DP-4		131	
DP-5		43	
DP-6		4.00	
DP-7		39.0	
DP-8		237	
DP-9		47.0	
DP-10		317	
DP-16		168	
DP-17		251	131
DP-11	Aflisols	309	
DP-12		490	
DP-13		305	
DP-15		309	309
DP-14	Entisols	126	126

ASSESSMENT OF GROUND WATER INPUTS

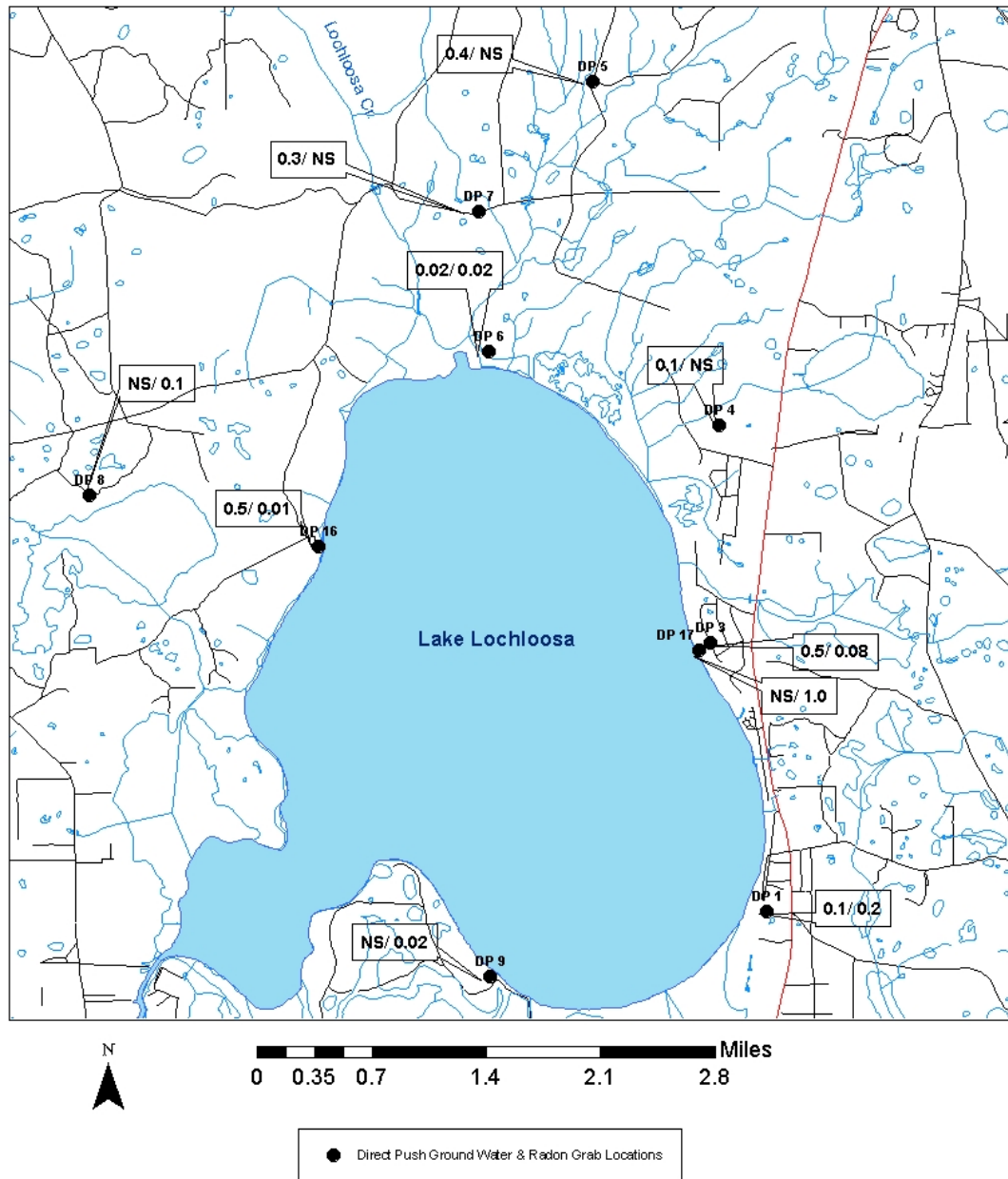
In assessing ground water inputs, the study objectives were to (1) quantify ground water nutrient concentrations in ground water around and beneath the lake; (2) identify tracers for use in estimating the magnitude of the ground water contribution to the lake; (3) estimate an overall ground water seepage rate; and (4) provide a range of potential nutrient loadings to the lake associated with ground water discharge.

A number of techniques were used to help understand and quantify ground water inputs into Lake Lochloosa. Ground water samples from areas surrounding the lake and immediately beneath the lake bed (pore water) were collected to better understand the levels of nitrogen and phosphorus available to the lake via ground water seepage, and the potential contributions of the different aquifers. Several chemical tracer concentrations and field parameters were also measured to assist in defining relative contributions and the overall ground water contribution to the lake. FSU's radon survey then provided information on the areas of greatest seepage in the lake and the estimated seepage rate.

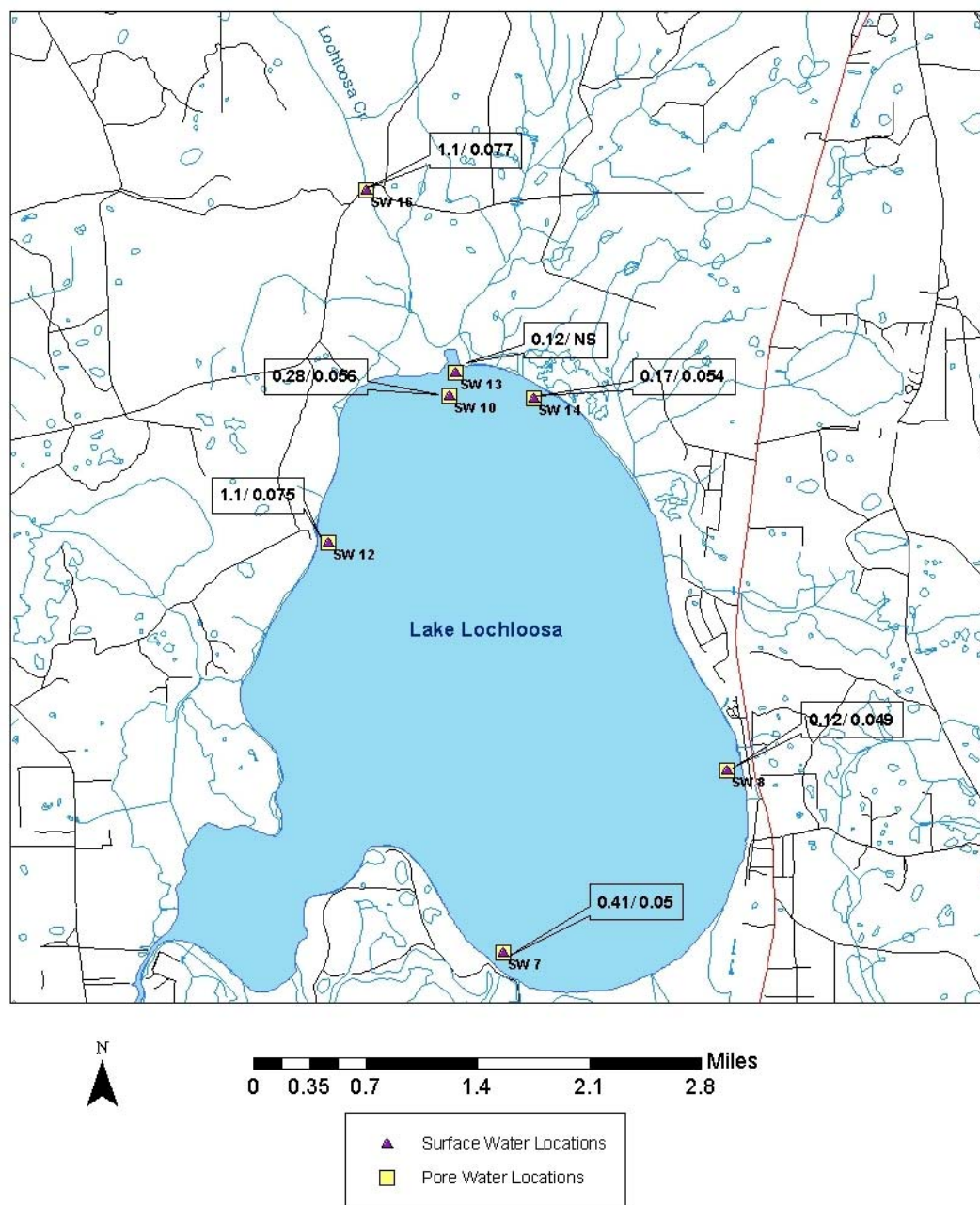
Ground Water–Pore Water Comparison

Direct-push ground water samples were collected from both the surficial and intermediate aquifers near Lake Lochloosa. **Table 3** presents the analytical results. Nitrate is below detection limits in all but 3 of the samples near the lake and is relatively low at other locations, but as discussed previously, ammonia-nitrogen was elevated at 1 location on the southeast side of the lake. Phosphorus is the nutrient of greatest significance as a ground-water-to-surface-water constituent, and dissolved phosphorus and dissolved orthophosphate concentrations were above 0.1 mg/L in most samples from both the surficial and intermediate zones. Orthophosphate concentrations represent phosphorus from the Hawthorn Group matrix. **Figure 9** shows the distribution of dissolved orthophosphate in the direct-push ground water samples near the lake. In the surficial aquifer, dissolved orthophosphate ranged from 0.02 to 0.5 mg/L, and in the intermediate aquifer it ranged from 0.02 to 1.0 mg/L. Median orthophosphate concentrations were 0.54 and 0.35 mg/L for the surficial and intermediate zones, respectively.

The 5 pore water samples represent ground water just below the ground water–surface water interface in the lake or creek. Nutrient concentrations in the samples were similar to the direct-push samples, with nitrate results at below or near detection limits and orthophosphate concentrations ranging between 0.12 and 1.1 mg/L. The median orthophosphate concentration in pore water samples from beneath the lake was 0.345 mg/L. **Figure 10** shows orthophosphate concentrations in the pore water samples and total phosphorus concentrations in the surface water samples; these are summarized in **Table 4** along with the surface water sampling results. In all cases where paired samples were collected, orthophosphate concentrations in pore water samples exceeded both orthophosphate (inorganic) and total phosphorus concentrations in corresponding surface water samples.

Figure 9. Orthophosphate Concentrations in Ground Water

NS = Not sampled.

Figure 10. Orthophosphate Concentrations in Pore Water and Surface Water

Note: Ratio Shown = Ortho-P in Pore Water vs. Surface Water in mg/L

Table 3. Chemistry Results for Ground Water Samples from Direct-push Wells and a Supply Well near Lake Lochloosa (May 30–June 8, 2006)

Location	Zone ¹	Sample Depth (ft BLS) ²	Depth to Ground Water (ft BLS) ²	Analyte									
				Chloride (mg/L)	Nitrate-N (mg/L)	Ammonia-N (mg/L)	Phosphorus (mg/L)	Ortho-phosphate (mg/L)	Calcium (mg/L)	Magnesium	Sodium (mg/L)	pH (std units)	Specific Conductance (umho/cm)
DP-1 ³	S	8	5	425	0.008U	2	0.1	0.1	27.7	20.6	202	6.08	1,494
	I	16	5.45	525	0.008U	1	0.2	0.2	118	80.1	31	5.98	1,738
DP-3 ³	S	8	3.7	25.2	0.008U	0.2	0.5	0.5	5.84	3.51	12.4	5.74	148
	I	27	10.85	14.3	0.181	0.2	0.08	0.08	63.3	34.5	9.42	6.84	575
DP-4 ³	S	20	5.7	15.6	0.008U	0.02	0.1	0.1	4.1	2.09	8.47	5.17	97.6
DP-5 ³	S	9	6.2	46.3	0.207	0.04	0.4	0.4	6.14	5.56	20.1	4.93	209
	I	19	5.5	41.7	0.008U	0.07	0.5	0.4	11.8	6.37	14.2	5.5	212
DP-6 ³	S	14	5.9	11.6	0.008U	0.08	0.08	0.02	54.5	14.9	7.86	7.3	371
	I	30	2.8	7.38	0.008U	0.1	0.02 I	0.02	47.6	11.7	7.04	7.73	319
DP-7 ³	S	18	5.25	23.3	0.008U	0.04	0.5	0.3	8.19	7.41	12.2	5.73	176
DP-8 ³	I	36	4.65	5.92	0.18	0.003U	1.0	1.0	4.76	2.7	7.37	5.77	82.4
DP-9 ³	I	18	4.85	19.3	0.008U	0.05	0.04	0.02	65.8	45.4	41.7	7.13	782
DP-16 ³	S	12	7.85	9.44	0.008U	0.03	0.6	0.5	3.37	2.04	5.44	4.99	77.23
	I	38	7.2	7.98	0.008U	0.03	0.02 I	0.01	35.8	14.1	10.4	6.98	320
DP-17 ³	I	20	10.6	14.4	0.008U	0.3	1	1	19.2	8.87	9.83	5.85	216
Lochloosa Harbor well	F	N/A ⁴	N/A ⁴	N/A ⁴	0.004	N/A ⁴	0.21	0.17	56.2	11.9	N/A ⁴	7.28	364

Notes:¹ S = surficial aquifer; I = intermediate aquifer; F = Floridan aquifer.² BLS = Below land surface.³ All samples filtered; results for all analytes except for pH and specific conductance represent dissolved concentrations.⁴ N/A = For well information, not available; for analytes, not analyzed.

Table 4. Chemistry Results for Pore Water and Surface Water Samples from Lake Lochloosa and Lochloosa Creek (3/2006)

Location	Type ¹	Analyte							
		Nitrate+Nitrite-N (mg/L)	Phosphorus (mg/L)	Ortho- phosphate (mg/L)	Alkalinity (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	pH (std units)	Specific Conductance (umho/cm)
SW-7	PW	0.004U	0.4	0.41	99	34.1	10.5	6.91	243
	SW	0.12	0.1	0.05	21	9.7	2.5	7.29	88
SW-8	PW	0.012	0.15	0.12	31A	10.6	3.5	6.70	106
	SW	0.13	0.11	0.049	21	9.7	2.5	7.24	89
SW-10	PW	0.004U	0.33	0.28	131	37.3A	11.5A	6.19	302
	SW	0.096	0.1	0.056	17	9.4	2.5	7.03	87
SW-12	PW	0.004U	1.4	1.1	7.5	2.6	2.7	4.91	117
	SW	0.13	0.17	0.075	20	9.3	2.4	6.85	86
SW-13	SW	0.004U	0.19	0.12	23	12.5	2.1	6.18	86
SW-14	PW	N/A	N/A	N/A	N/A	N/A	N/A	5.34	259
	SW	0.084	0.12	0.054	16	8.9	2.4	6.34	84
SW-16	PW	0.004U	1.7	1.1	166	52	10.8	7.00	349
	SW	0.02U	0.11	0.077	15	8.7	2.8	6.44	80
	SW	0.008U	0.1	0.1		39.3	12.0	7.69	306

Notes:¹ PW = pore water; SW = surface water.

U = Analyte undetected; associated value is method detection level.

A = Value reported is the mean of two or more determinations

I = The reported value is between the laboratory method detection limit and the laboratory quantitation limit.

N/A = Not analyzed.

The source aquifer for the pore water contribution to the lake was evaluated by comparing concentrations of calcium, alkalinity, and magnesium. Specific conductance and pH were also considered in the comparison. Median values for calcium and magnesium, as well as orthophosphate, are presented in **Table 5** and graphically illustrated as scatter plots in **Figure 11**. Median pore water values from beneath the lake for calcium, magnesium, orthophosphate, pH, and specific conductance lie in between medians for the intermediate and surficial aquifers. This suggests that both aquifers combine to contribute ground water discharge to the lake. It is interesting to note that the pore water values for Lochloosa Creek nearly match alkalinity, calcium, magnesium, pH, and specific conductance for the Floridan aquifer. This may indicate the existence of small Floridan aquifer springs and seeps along the creek, which is not unreasonable considering its proximity to Magnesia Spring and the artesian flow conditions in the area.

Table 5. Comparisons between Ground Water, Pore Water, and Lake Water Median Values, Lake Lochloosa

Analyte	Median Concentrations in Water						
	Floridan Aquifer ¹	Intermediate Aquifer/ Hawthorn Matrix ²	Surficial Aquifer/ Residual Hawthorn Matrix ²	Lake-Pore Water ³	Lake-Surface Water ³	Lochloosa Creek–Pore Water ³	Lochloosa Creek–Surface Water ³
Alkalinity (mg CaCO ₃ /L)	179	N/A	N/A	65	20.5	166	15
Calcium (mg/L)	56.2	41.7	7.015	22.35	9.55	52	8.7
Magnesium (mg/L)	11.9	12.9	4.94	7	2.45	10.8	2.8
Orthophosphate (mg/L)	0.17	0.54	0.35	0.345	0.055	1.1	0.077
pH (std units)	7.28	6.91	5.615	6.45	6.94	7.00	6.44
Specific Conductance (umho/cm)	364	319.5	162	180	87	349	80

Notes:

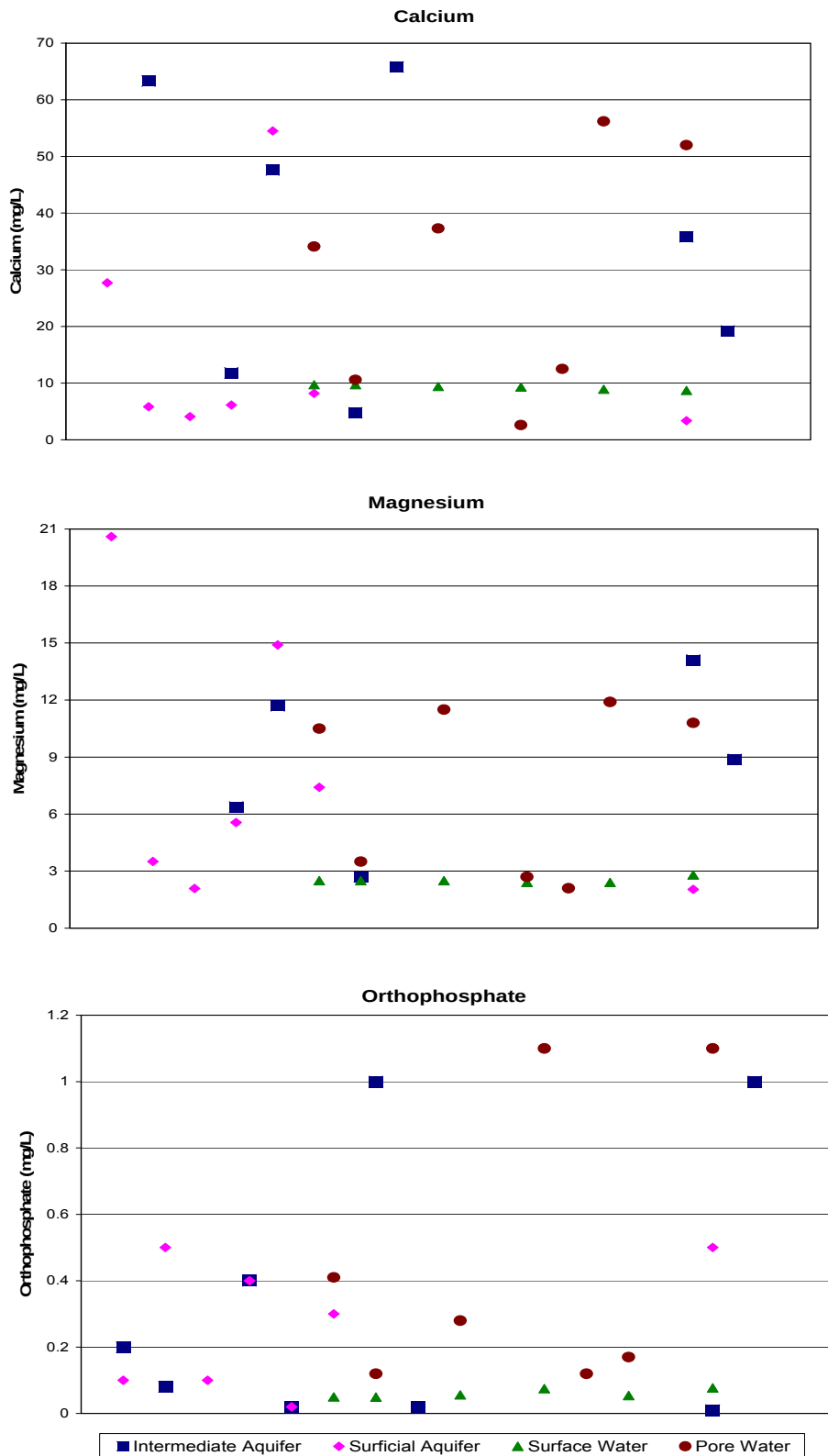
¹ Collected from potable well at Lochloosa Harbor fish camp (March 2006).

² Collected from direct-push sampling near lake (May 2006).

³ Collected March 2006.

N/A = Not analyzed.

Figure 11. Chemical Comparisons between Water Sources



Seepage Assessment

Naturally occurring ^{222}Rn makes an ideal tracer for measuring ground water seepage into a lake through bottom sediments, because it is present in enriched concentrations in ground water compared with surface water. The method employed by FSU included a continuous radon monitor survey and the collection of grab samples at locations corresponding with surface water and pore water samples. Relative radon concentrations for the continuous survey (**Figure 12**), corroborated by the grab sample results, show radon “hot spots” in the lake and in Lochloosa Creek where ground water seepage occurred at a relatively higher rate. The continuous radon survey included a traverse around the lake perimeter and one north-south transect. The grab samples were collected at locations that corresponded with the surface water–pore water samples.

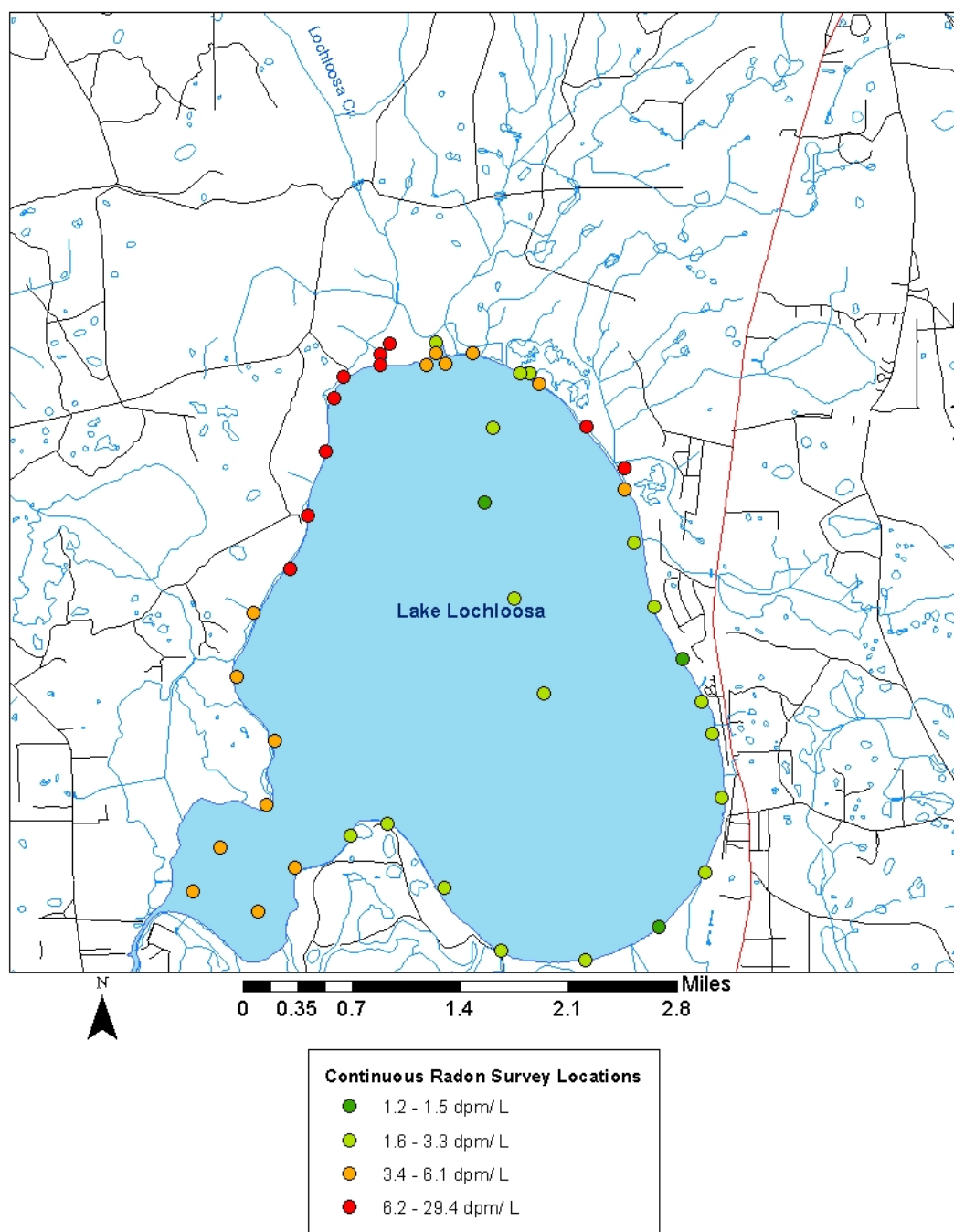
Both surveys agree, showing elevated ^{222}Rn anomalies along the north end of the lake, with the highest readings where Lochloosa and Hawthorne Creeks discharge into the lake and in Lochloosa Creek upstream of the lake. Other evidence such as topographic slope and the generalized surficial-aquifer ground water contour map prepared by the SJRWMD, coupled with the Floridan aquifer discharge potential in this area, indicate that most ground water discharge occurs in the northern part of the lake. This method does not measure negative discharge since radon’s migration pathway is upward, so areas having low-to-no radon emission in the southern part of the lake could be where there is little to no seepage or where water is actually seeping downward.

Using the simple advection-diffusion model and average radon measurements in the lake, FSU calculated a radon advection rate of 0.58 centimeters per day and a ground water discharge into the lake of approximately 132,000 cubic meters per day (m^3/day), if discharge was uniform throughout the entire lake. The radon method assumes that the lake water is relatively well mixed and so discharge takes into account localized variation in discharge. This estimate also included the radon contribution by Lochloosa Creek, which was approximately 5 percent of the total ground water discharge. This assessment is based on the results of the March 2006 sampling, and it is expected that ground water discharge would fluctuate seasonally and with rainfall.

Estimate of Potential Ground Water–related Loads

Based on the results of ground water sampling data from around and beneath Lake Lochloosa, the only nutrient of concern entering the lake through ground water is phosphorus. Nitrate concentrations in ground water in the vicinity of the lake are low, and ammonia, while of potential concern in one isolated area, does not appear to be an issue, based on pore water data. A rough estimate of the phosphorus loading was made by using the median pore water concentration of orthophosphate (0.345 mg/L) and the approximate ground water seepage rate developed using the radon advection-diffusion model (132,000 m^3/day). Using these, the potential phosphorus loading via ground water was approximately 100 lbs/day for the period of measurement. This is an average discharge rate and does not account for attenuation, if any, by lake sediments. However,

attenuation by sediments might be considered to be relatively minor, since an equilibrium state for phosphorus adsorption should have been reached.

Figure 12. Results of Continuous Radon Monitoring Survey

According to the draft TMDL document for Lake Lochloosa, the calculated total phosphorus loading to the lake was 32,563 lbs/year, and so the ground water portion estimated here would account for a significant portion of the load on a daily basis when ground water discharge is high. More detailed work using radon and seepage meters, the collection of pore water samples, and the measurement of seasonal variation is necessary to refine this estimate and establish an annualized average seepage into the lake.

SIGNIFICANT FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Significant Findings and Conclusions

- *Understanding the hydrogeological conditions in the study area is important to understanding potential ground water influences on surface waterbodies. In the northern part of the area, which includes Lake Lochloosa, three distinct aquifer systems have the potential to drain into the lake (the surficial, intermediate, and Floridan aquifers). To the south and west, in the area that includes Orange Lake, the Hawthorn Group confining layer is not effective, and the Floridan aquifer is the only aquifer that interacts with surface water. Potentiometric surface maps for this area and stage data for the lake suggest that seepage occurs from Orange Lake into the aquifer under typical conditions.*
- *Of the land use areas evaluated in the study, only two sites on the western side of Orange Lake had anomalously high nitrate levels (> 4 mg/L). Land uses for both included former citrus groves and current improved pasture/hayfields. In this area, ground water would likely not influence the lake.*
- *One location in the village of Lochloosa is an anomaly. Samples from the cluster of wells in this area contained very high concentrations of sodium and chloride and rather high levels of ammonia. The source of this contamination is not known, and without additional work, it is impossible to determine if the site influences the nearby lake.*
- *Phosphorus occurs in ground water at elevated concentrations throughout the study area due to its natural abundance in the Hawthorn Group material. Ground water in the area is a very significant potential source of phosphorus to Lake Lochloosa due to the potential for ground-water-to-surface-water discharge. Median values for orthophosphate measured in this assessment were 0.17, 0.54 and 0.35 mg/L for the Floridan, intermediate, and surficial aquifers, respectively.*
- *Chemical comparisons between ground water from the surficial and intermediate aquifers and pore water collected from immediately beneath the lake bed indicate that both aquifers are sources of pore water beneath Lake Lochloosa. Calcium, magnesium, and orthophosphate signatures suggest the relationship.*
- *The radon survey conducted by FSU in March 2006 showed elevated ^{222}Rn , indicative of higher ground water seepage, along the northern and northwestern edges of Lake Lochloosa. This observation agrees with local topography and inferred ground water flow pathways. FSU's advection-diffusion model calculated an average ground water discharge of $132,000 \text{ m}^3/\text{dy}$, using an average of all ^{222}Rn readings taken. This estimate alone cannot be extrapolated to yearly discharge since ground water discharge (and recharge) varies seasonally.*
- *With the assumed discharge rate and a ground water concentration of 0.345 mg/L (the median value for orthophosphate in all pore water samples), potential*

phosphorus loading via ground water to Lake Lochloosa could be as high as 100 lbs/dy, based on the measurements taken during the study.

Recommendations

- *The results of this study indicate that naturally occurring phosphorus constitutes a major load to Lake Lochloosa via ground water pathways. Based on this information, it is recommended that the draft TMDL be revised to account for ground water contributions in the nutrient budget. While uncertainty exists with these values, it is thought that they are reasonable estimates.*
- *The techniques used to estimate the regions of ground water discharge to a lake and to estimate ground water inputs were both rapid and effective. They should be refined and used to support future TMDL development modeling, with a focus on refining seepage and loading estimates to account for spatial and seasonal variability. This should include the strategic deployment of seepage meters, in addition to the other tools.*

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- St. Johns River Water Management District Online Watershed Map Series.
- St. Johns River Water Management District GIS files for Floridan aquifer potentiometric surface maps, and recharge and discharge maps.

St. Johns River Water Management District on-line lake stage data.

APPENDICES

***Appendix A: Direct-Push Lithologic Descriptions and
Geophysical Logs***

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-17

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
0.0		Ground Surface
		Silty Sand Tan-Orange Fine Silty Sand
2.0		
		Clayey Sand Tan-Grey Fine Clayey Sand
4.0		
6.0		
		Clayey Sand Grey-Green Fine Clayey Sand
8.0		
10.0		
		Clayey Sand Blue-Green Clay and Grey Fine Clayey Sand
12.0		
		Silty Sand Grey Fine Silty Sand - wet
14.0		
16.0		
18.0		
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/8/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-16

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
0.0		Ground Surface
		<i>Silty Sand</i> Tan-Brown Fine Silty Sand
2.0		
		<i>Silty Sand</i> Tan Fine Silty Sand - wet
4.0		
6.0		
8.0		
		<i>Clayey Sand</i> Grey-Brown Clayey Silty Sand - wet
10.0		
12.0		
		<i>Clayey Sand</i> Grey-Brown Clayey Sand - damp
14.0		
16.0		
		<i>Sandy Clay</i> Blue-White Sandy Clay
18.0		
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 5/31/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

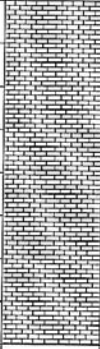
Project No.: 0384-007

Log of Borehole: DP-15

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
22.0		
24.0		
26.0		
28.0		
30.0		
32.0		
34.0		
36.0		
38.0		
40.0		

Drilled By:	Hole Size: 2"
Drill Method: Direct Push	Depth to Water (btoc):
Drill Date: 6/5/2006	

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-15

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
0.0		Ground Surface
2.0		Silty Sand Tan-Brown Fine Silty Sand
4.0		No Return - Loose Silty Sand
6.0		
8.0		Silty Clay Grey-Brown Hard Silty Clay w/ Lime Stone
10.0		
12.0		Lime Stone Chalky White Brittle Lime Stone (Shelly) - wet @ 22'
14.0		
16.0		
18.0		
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/5/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-14

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
22.0		Marl Mottled Tan-Grey Marl - wet
24.0		
26.0		Lime Stone Shelly White Lime Stone - wet
28.0		
30.0		
32.0		
34.0		
36.0		
38.0		
40.0		
Drilled By:		
Drill Method: Direct Push		Hole Size: 2"
Drill Date: 6/8/2006		Depth to Water (btoc):

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Project: Orange Lake Basin

Client: FDEP

Log of Borehole: DP-14

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
0.0		Ground Surface
		Silty Sand Tan Silt and Very Fine Sand
2.0		Silty Sand Tan-White Fine Silty Sand - damp
4.0		Clayey Sand Mottled Grey-Brown Fine Clayey Sand
6.0		Sandy Clay Grey-Green Sandy Clay
8.0		Sandy Clay Grey-Blue Sandy Clay
10.0		Clay Mottled Light Blue Clay
12.0		Silty Clay Grey-White Silty Clay and Lime Stone - wet
14.0		
16.0		
18.0		
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/8/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-13

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
22.0		Silty Sand Mottled Grey-Brown Silty Sand "Salt & Pepper" - wet
24.0		Silty Sand Grey-Brown Fine Silty Sand - wet
26.0		Clay Clayey "Salt & Pepper"
28.0		Silty Sand Grey-Brown Fine Silty Sand and Clay
30.0		
32.0		Sand Interbedded White Fine Sand
34.0		Clayey Sand Mottled Grey-White Fine Clayey Sand
36.0		Clayey Sand Mottled Tan Clayey Sand
38.0		Clay Mottled Tan Clay and Sandy Clay
40.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/7/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-13

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
0.0		Ground Surface
		<i>Silty Sand</i> Grey-Black Fine Silty Sand
2.0		<i>Silty Sand</i> Tan-Brown Fine Silty Sand
4.0		<i>Silty Sand</i> Grey-Black Fine Silty Sand - damp
6.0		<i>Silty Sand</i> Tan-White Fine Silty Sand - wet
8.0		<i>Silty Clay</i> Grey Silty Clay
10.0		<i>Silty Sand</i> Tan-Brown Fine Silty Sand - wet
12.0		
14.0		
16.0		
18.0		<i>Clayey Sand</i> Brown-Orange Clayey Sand - damp
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/7/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

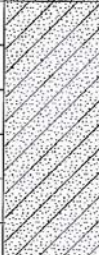
Log of Borehole: DP-12

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
22.0		Silty Sand Mottled Tan-White Silt and Fine-Medium Silty Sand
24.0		Clayey Sand Finely Bedded Blue Clays in Grey-White Fine Silty Sand
26.0		
28.0		Silty Clay Mottled Green-Orange Silty Clay
30.0		Clay Green-Orange Clay
32.0		Clay Pale Green Clay
34.0		Clay Interbedded Pale Green Clay and Grey Silty Clay
36.0		Silty Clay Blue-Green Silty Clay
38.0		Lime Stone Shelly White Lime Stone - wet
40.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/7/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Project: Orange Lake Basin

Client: FDEP

Log of Borehole: DP-12

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
0.0		Ground Surface
2.0		Silty Sand Tan-Brown Fine Silty Sand
4.0		
6.0		Clay Mottled Grey Clay and Clayey Sand
8.0		
10.0		Silty Sand Tan-White Fine Silty Sand - damp
12.0		
14.0		Clayey Sand Tan-White Fine Clayey-Silty Sand
16.0		
18.0		Silty Sand Interbedded White Silt and Fine-Medium Silty Sand
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/7/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

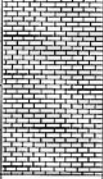
Log of Borehole: DP-11

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
22.0		Clay Grey-Blue Clay w/ Increasing Lime Stone
24.0		Clay Grey-White Clay and Lime Stone
26.0		Marl White-Orange Marl
28.0		Lime Stone Tan-White Shelly Lime Stone - wet
30.0		
32.0		
34.0		
36.0		
38.0		
40.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/7/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-11

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
0.0		Ground Surface
2.0		<i>Silty Sand</i> Grey-White Fine Silty Sand
4.0		<i>Silty Sand</i> Tan-Brown Fine Silty Sand - damp
6.0		<i>Clayey Sand</i> Mottled Grey-Brown Clayey Sand
8.0		
10.0		
12.0		<i>Clay</i> Mottled Grey-Green Clay
14.0		
16.0		<i>Clay</i> Green-Blue Clay w/ Some Lime Stone
18.0		
20.0		

Drilled By:

Drill Method: Direct Push

Drill Date: 6/7/2006

Hole Size: 2"

Depth to Water (btoc):

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-10

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
22.0		
24.0		Clayey Sand Light Grey Fine Clayey Sand, Clay, and Lime Stone - wet @ 30'
26.0		
28.0		
30.0		
32.0		Silty Sand Light Grey Fine Silty Sand "Salt & Pepper" - wet
34.0		
36.0		
38.0		
40.0		
Drilled By:		
Drill Method: Direct Push		Hole Size: 2"
Drill Date: 6/2/2006		Depth to Water (btoc):

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

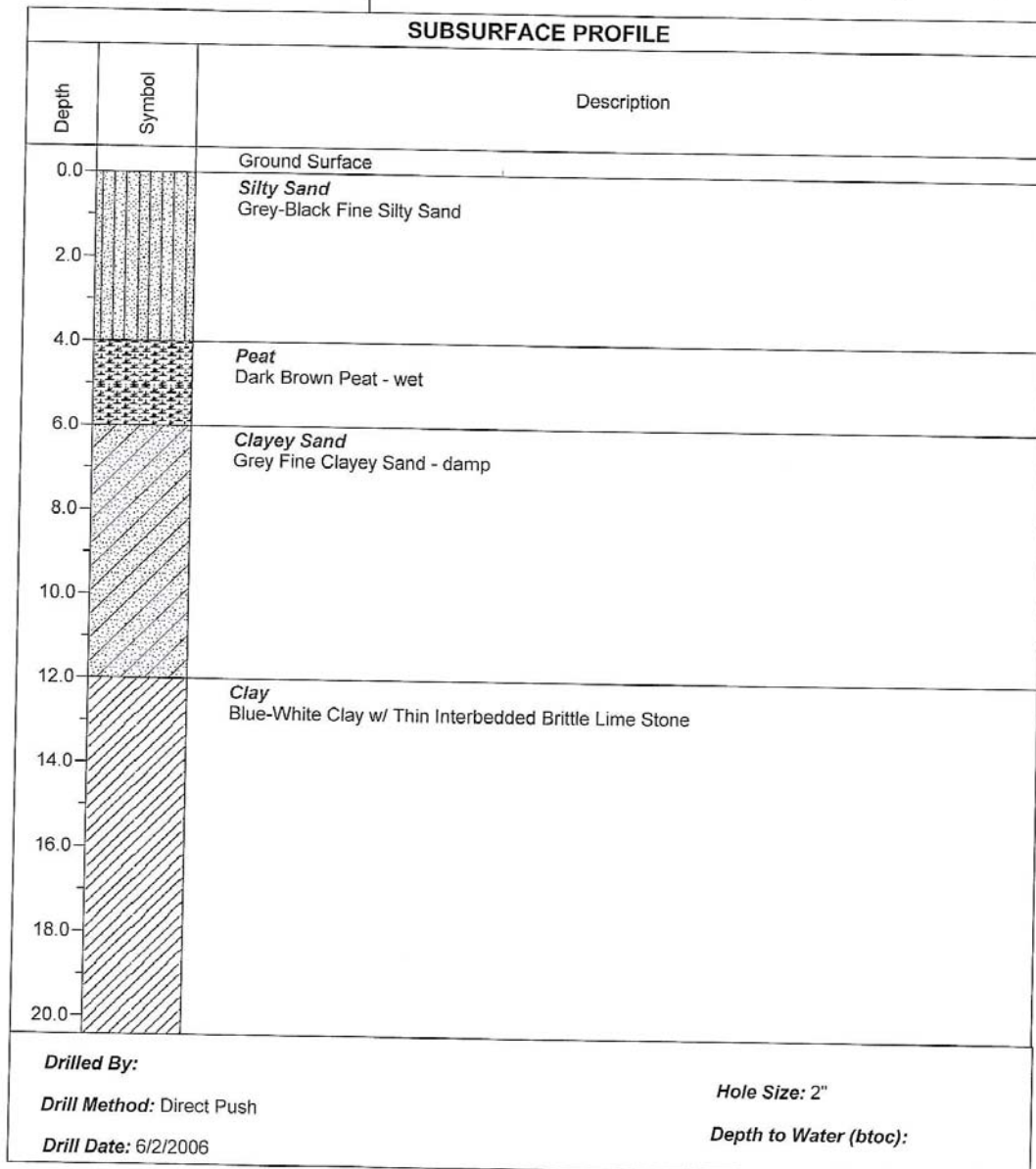
Project No.: 0384-007

Log of Borehole: DP-10

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler



Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Project: Orange Lake Basin

Client: FDEP

Log of Borehole: DP-9

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
22.0		<i>Clay</i> Grey-Orange-Green Hard Clay
24.0		<i>Clay</i> Green-Blue Clay and Lime Stone
26.0		
28.0		
30.0		
32.0		
34.0		
36.0		
38.0		
40.0		
<i>Drilled By:</i> <i>Drill Method:</i> Direct Push <i>Drill Date:</i> 6/2/2006 <i>Hole Size:</i> 2" <i>Depth to Water (btoc):</i>		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Project: Orange Lake Basin

Client: FDEP

Log of Borehole: DP-9

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
0.0		Ground Surface
		Silty Sand Grey-Black Fine Silty Sand
2.0		Silty Sand Brown Fine Silty Sand and Strongly Centered Layers (4")
4.0		Clayey Sand Dark Brown Fine Clayey Sand - damp
6.0		Clayey Sand Hard Grey Fine Clayey Sand
8.0		Clay Grey-Orange-Green Clays and Interbedded Fine Sand
10.0		
12.0		
14.0		Silty Sand Grey-White Fine Silty Sand - wet
16.0		
18.0		Sandy Clay Tan-White Sandy Clay and Brittle Lime Stone
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/2/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

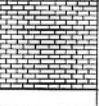
Log of Borehole: DP-8

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
22.0		Clay Mottled Green-White Clay w/ Thin Interbedded Lime Stone
24.0		Sandy Clay Green-White Silty Sandy Clay "Salt & Pepper"
26.0		
28.0		Clay Mottled Grey-White Clay and Lime Stone Marl - wet (in fractures)
30.0		
32.0		
34.0		
36.0		Clay Mottled Tan-Orange Clay
38.0		
40.0		Lime Stone Brittle Tan-White Limestone and Clay

Drilled By:

Drill Method: Direct Push

Drill Date: 6/1/2006

Hole Size: 2"

Depth to Water (btoc):

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-8

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
0.0		Ground Surface
		<i>Silty Sand</i> Brown-Blak Fine Silty Sand
2.0		<i>Clayey Sand</i> Tan-Brown Clayey Sand - damp
4.0		<i>Clayey Sand</i> Grey-White Clayey Sand
6.0		
8.0		
10.0		
12.0		
14.0		<i>Plastic Clay</i> Green-White Plastic Clay
16.0		<i>Clay</i> Green-White Clay w/ Thin Interbedded Lime Stone
18.0		
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/1/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-7

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
22.0		
24.0		Silty Sand Tan-Brown Fine Silty Sand
26.0		Clay Blue-Green to Grey Silty Clay & Lime Stone
28.0		Clay Blue-Green Hard Clay
30.0		
32.0		
34.0		
36.0		
38.0		
40.0		
Drilled By:		
Drill Method: Direct Push		Hole Size: 2"
Drill Date: 5/31/2006		Depth to Water (btoc):

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-7

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
0.0		Ground Surface
		Fine Sand Grey-Black Fine-Medium Sand
2.0		Fine Sand Grey-Brown Fine-Medium Sand
4.0		Silty Sand Light Brown Fine-Medium Silty Sand - wet
6.0		Clayey Sand Red-Orange Clayey Medium Sand
8.0		Silty Clay Grey Plastic Clay "Salt & Pepper"
10.0		
12.0		Sandy Clay Grey Silty Fine Sand and Grey Clay
14.0		Fine Sand White Fine Sand "Salt & Pepper" - wet
16.0		Flowing Sands No Data - wet
18.0		
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 5/31/2006		
Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-6

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
42.0		<i>Marl</i> Green-White Shelly Clay Marl
44.0		<i>Marl</i> Green-White Shelly Clay Marl
46.0		<i>Clay</i> Blue-Green Clay
48.0		<i>Clay</i> Blue-Green Clay
50.0		
52.0		
54.0		
56.0		
58.0		
60.0		
Drilled By: Drill Method: Direct Push Drill Date: 5/30/2006 Hole Size: 2 Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

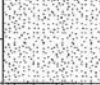
Log of Borehole: DP-6

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
22.0		Silty Sand Grey-Brown Fine Silty Sand - wet
24.0		Fine Sand Grey-White Fine Sand -wet
26.0		Fine Sand Grey-White Fine-Medium Sand - wet
28.0		Fine Sand Grey-White Fine-Medium Sand (/w phosphatic mineralogy) - wet
30.0		Clay Gray-Green Shelly Silts and Clays
32.0		Silty Clay Grey-Black Silty Clay "Salt & Pepper"
34.0		Fine Sand Grey-White Fine-Medium Sand - damp
36.0		Fine Sand Grey-White Fine-Medium Sand - damp
38.0		Fine Sand Grey-White Fine-Medium Sand - wet
40.0		Marl Blue-Green Marl "Salt & Pepper"
Drilled By: Hole Size: 2 Drill Method: Direct Push Depth to Water (btoc): Drill Date: 5/30/2006		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-6

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
0.0		Ground Surface
		Silty Sand Gray-White Fine Silty Sand
2.0		Silty Sand Tan-Orange Silty Sand
4.0		Fine Clayey Sand Gray-Orange Clayey Fine Sand
6.0		Clayey Sand and Silty Sand Gray Clayey sand and Silty Fine Sand
8.0		Clayey Sand Gray Clayey Sand
10.0		Sandy Clay Gray Clay and Silty/Clayey Sand
12.0		Medium Sand Grey-White Fine Medium Sand - wet
14.0		Silty Sand Grey-White Fine Silty Sand
16.0		Sandy Clay Brown Silty Sand and Brown Black Clay - wet
18.0		Clayey Sand Grey-Brown Clay and Clayey Sand
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 5/30/2006 Hole Size: 2 Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-5

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
22.0		Clayey Sand Blue-White Clayey Silty Sand
24.0		Silty Sand White Silty Sand
26.0		Silty Sand White Silty Sand "Salt & Pepper" - wet
28.0		Silty Clay Light Blue w/ Orange Silty Clay
30.0		
32.0		
34.0		Clay Light Blue Clay w/ Black
36.0		
38.0		
40.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/1/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-5

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
0.0		Ground Surface
		Silty Sand Grey-Black Silty Fine Sand
2.0		Silty Sand Grey-Brown Silty Sand - wet
4.0		
6.0		Fine Sand Grey-White Fine Sand - wet
8.0		Clayey Sand Grey-Brown Clayey Sand - damp
10.0		
12.0		Fine Sand Dark Grey Fine Sand - wet
14.0		
16.0		Silty Sand Brown Fine Silty Sand - wet
18.0		Silty Sand Grey-Brown Fine Silty Sand - wet
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/1/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Project: Orange Lake Basin

Client: FDEP

Log of Borehole: DP-4

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
22.0		
24.0		
26.0		
28.0		
30.0		
32.0		
34.0		
36.0		
38.0		
40.0		
Drilled By: Drill Method: Direct Push Drill Date: 5/31/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-4

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
0.0		Ground Surface
		Silty Sand Brown-Black Fine Silty Sand
2.0		Silty Sand Tan Fine Silty Sand - damp
4.0		Silty Sand Grey-Brown Fine Silty Sand - wet
6.0		Clayey Sand Orange-Brown Clayey Sand
8.0		Silty Sand Grey-Brown Fine Silty Sand - wet
10.0		Silty Sand Grey-White Fine Silty Sand - wet
12.0		
14.0		
16.0		Silty Sand Grey Fine Silty Sand - wet
18.0		
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 5/31/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Project: Orange Lake Basin

Client: FDEP

Log of Borehole: DP-3

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
22.0		
24.0		
26.0		
28.0		
30.0		
32.0		
34.0		
36.0		
38.0		
40.0		

Drilled By:

Drill Method: Direct Push

Drill Date: 6/7/2006

Hole Size: 2"

Depth to Water (btoc):

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Project: Orange Lake Basin

Client: FDEP

Log of Borehole: DP-3

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
0.0		Ground Surface
		Silty Sand Grey-White Fine Silty Sand
2.0		Peat Black-Brown Peat - wet
4.0		Silty Sand Tan-Brown Fine Silty Sand - wet
6.0		Sand Tan-White Fine-Medium Sand - wet
8.0		Clayey Sand Grey Fine Clayey Sand
10.0		Clayey Sand Grey-Green Fine Clayey Sand
12.0		Clayey Sand Blue-Green Fine Clayey Sand
14.0		
16.0		
18.0		Clay Blue-Grey Clay and Shelly Lime Stone - wet
20.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/7/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-1

Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE		
Depth	Symbol	Description
22.0		<i>Silty Sand</i> Brown Fine Silty Sand
24.0		<i>Clay</i> Light Blue Clay and Lime Stone - wet
26.0		
28.0		
30.0		
32.0		
34.0		
36.0		
38.0		
40.0		
Drilled By: Drill Method: Direct Push Drill Date: 6/6/2006 Hole Size: 2" Depth to Water (btoc):		

Jim Stidham & Associates, Inc.
547 North Monroe Street
Tallahassee, Florida 32301

Project No.: 0384-007

Log of Borehole: DP-1

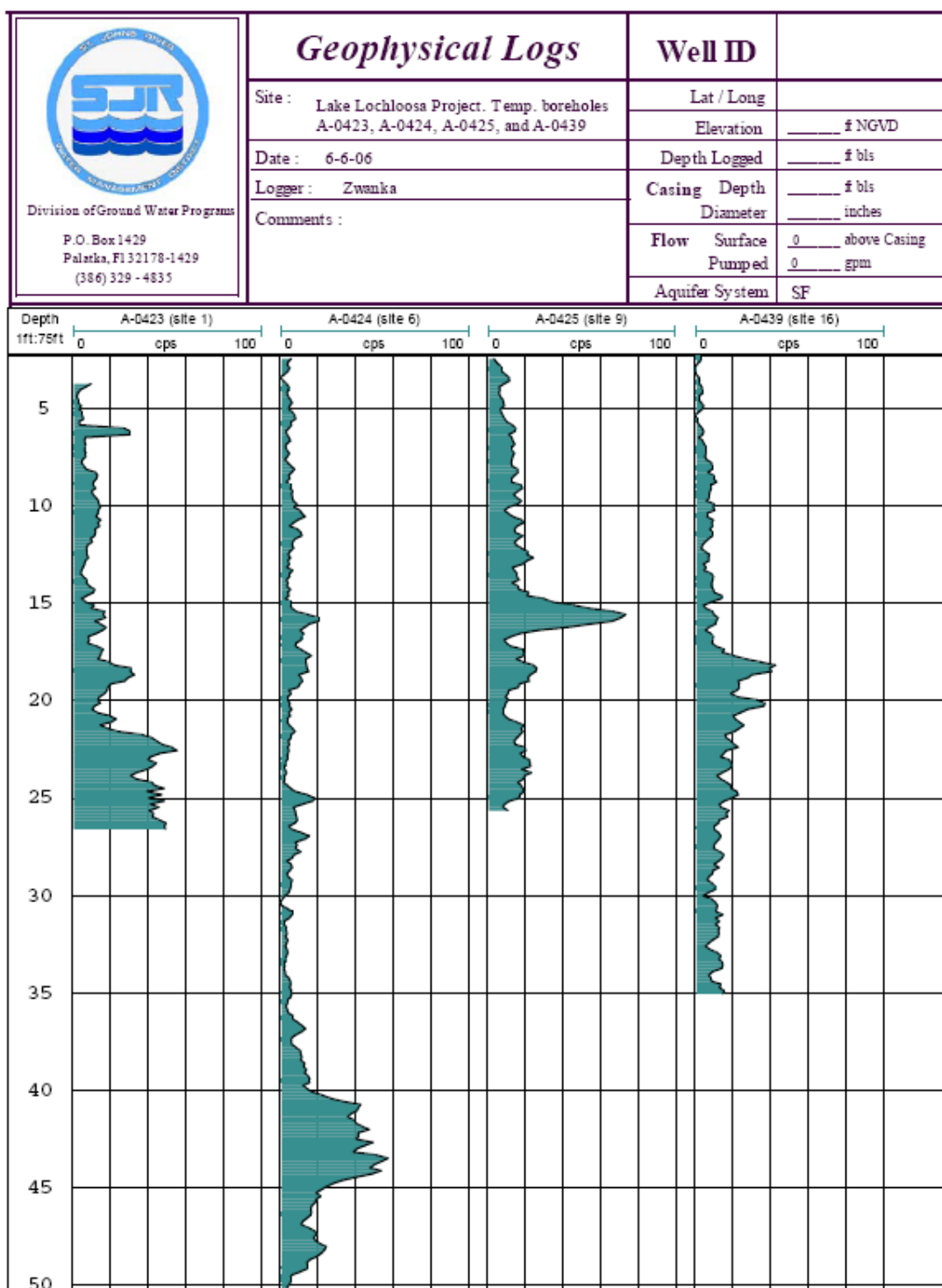
Project: Orange Lake Basin

Client: FDEP

Project Manager: Scott Sigler

SUBSURFACE PROFILE

Depth	Symbol	Description
0.0		Ground Surface
0.0		Silty Sand Grey-Black Fine Silty Sand
2.0		Silty Sand Brown Fine Silty Sand w/ Peat - wet @ 6'
4.0		
6.0		
8.0		Clayey Sand Blue-Grey Fine Clayey Sand
10.0		
12.0		
14.0		Silty Sand Blue-Grey Fine Silty Sand - wet
16.0		Clay Dark Brown Clay and Grey Silty Sand
18.0		Clay Dark Brown Clay
20.0		
Drilled By:		Hole Size: 2"
Drill Method: Direct Push		Depth to Water (btoc):
Drill Date: 6/6/2006		



Appendix B: Lake Lochloosa Radon Study

Progress Report

William C. Burnett, Jeffrey P. Chanton

March 6-9, 2006

Introduction

Six people from DEP and two people from FSU spent several days at Lake Lochloosa to evaluate the “simple radon model” for assessing groundwater seepage into lakes. The DEP participants were Rick Hicks, Professional Geologist Administrator; Pete Folland, Environmental Specialist II; Tom Biernacki, Environmental Manager; Margaret Murray, Environmental Consultant; Nicole Beirele, Environmental Specialist III; and Brooke Tweedy, Environmental Specialist I. The two FSU graduate students and research assistants were Natasha Dimova and Ben Mwashote.

Methods

Ben Mwashote deployed three seepage meters on the east side of the lake at Lochloosa Harbor fishing camp on Monday, March 6. The seepage meters were left in place for two days.

Natasha Dimova measured radon using the continuous radon monitor. She began a transect on Tuesday, March 7, from the fish camp and moved slowly counterclockwise around the lake. Depth and GPS locations were also recorded. She continued the transect on Wednesday and Thursday, including a south-to-north transect through the middle of the lake. Natasha also allowed the monitor to equilibrate for about an hour at high radon areas on the north side of the lake in the creek areas. She measured radon in air and a time series off the fish camp dock on Wednesday and Thursday. Water level was also recorded at the fish camp dock. Margaret Murray collected radon samples in bottles at several sites. She also collected pore water samples (retrieved via a push-point piezometer) for LSC analysis at various lake sites and a few wells. Four sediment samples were also collected.

Rick Hicks used a well point to measure dissolved oxygen, pH, specific conductance and temperature at eight sites in the lake and creeks. Six surface water, five pore water, and one well water samples were collected and sent to the FDEP Lab. Surface waters were sampled for chlorophyll a, enterococci, fecal coliform, alkalinity, calcium, magnesium, nitrate-nitrite, total phosphorus, and orthophosphate. Pore water and groundwater were sampled for alkalinity, calcium, magnesium, nitrate-nitrite, total phosphorus, and orthophosphate.

FDEP people assisted with deploying the seepage meters, collecting samples, navigating the boats, measuring field parameters, and recording GPS sites.

Results–Seepage Meters

During the Lake Lochloosa survey, three automatic seep meters (M4, M5 and M6) were deployed in a short transect about 50m south of the landing boat ramp. This deployment site was selected because of its logistical accessibility and security of equipment. Due to the relative abrupt steepness of lake bottom from the shoreline and the murkiness of lake water, it was only feasible to deploy the furthest seep meter (M6) at about 10m from the shore, at a depth of 1.5m. The other two seep meters (M4 and M5) were deployed next to each other (forming a duplicate set) at 5m from the shoreline. Their average depth was 0.5m. All the meters were connected to a data logger and associated accessories, which were located on the van at the shore and left to run for three days (March 6-8, 2006).

The SGD rates indicated by these meters were all very low with an average of 0.7 cm/day based on meters M4 and M5 and an average of 2.1 cm/day at site M6 (**Figure B-1**). If one assumes that this 10-meter-wide zone represents a seepage zone around the entire lake, we estimate that the total seepage around the Lake Lochloosa shoreline (length estimated at 21.6 km) would be $\sim 3000 \text{ m}^3/\text{day}$.

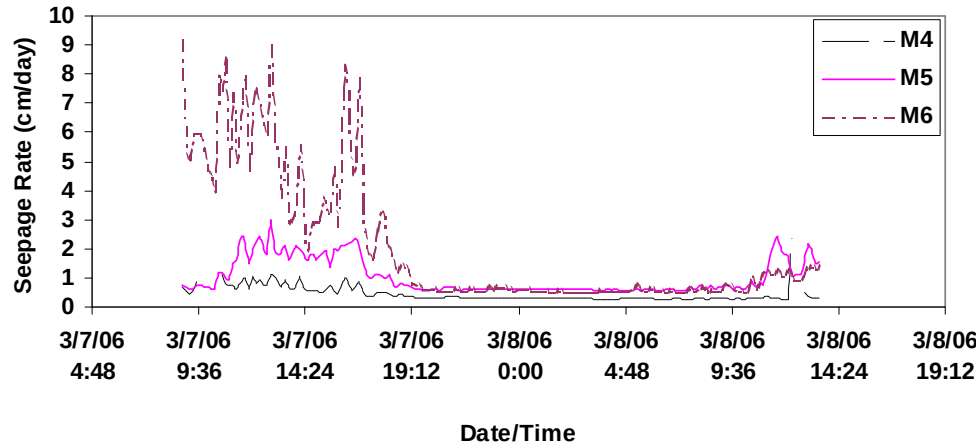


Figure B-1. Automatic seepage meter traces of three devices (M4, M5, and M6) that were deployed at 5 m (M4 and M5) and 10 m (M6) off the eastern bank of the lake.

Radon Bottle Measurements

The preliminary radon results from several sites on the lake are shown in **Figure B-2**. In general, these results are on the high side for Central Florida lakes. Lark Barco, for example, has an average radon concentration of $\sim 0.4 \text{ dpm/L}$. This may either indicate that there is, in fact, a substantial amount of groundwater inflow into the lake or the groundwater may have a higher concentration of ^{222}Rn . The bottle measurements indicate that most open water samples are in the same range, from 0.5 to 1.5 dpm/L with a few samples in the 1.5 to 3.3 dpm/L category. The highest radon was observed in samples from the creeks that drain into the northern section of the lake. These creeks are likely fed by groundwater, which explains the high concentrations.

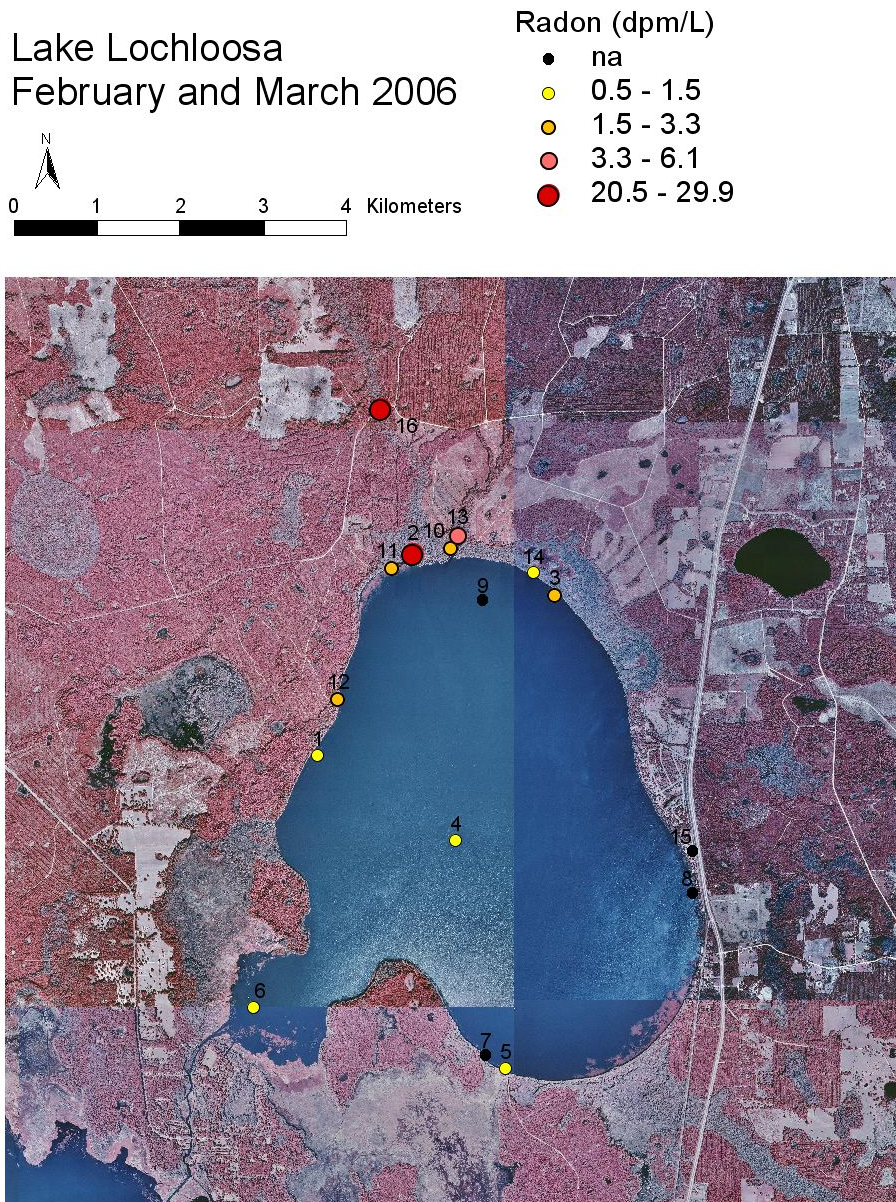


Figure B-2. Aerial view of Lake Lochloosa showing the locations and ranges of concentrations of ^{222}Rn measured from grab samples collected on the lake. Samples designated in black were lost during analysis.

Continuous Radon Measurements

We ran continuous measurements of Rn-222 from the FDEP research boat. The Rn-222 system (RAD-AQUA) has been routinely used for estimation SGD since its development a few years ago. We also established a time series experiment of the RAD-AQUA set up on the eastern shore to evaluate fluxes of groundwater discharge in the area.

We started the survey on the first day (03-07-06) at the fish camp (GPS N 29°32.011, W 82°07.383; **Figure B-3**). We continued along the shoreline in a northwest direction covering the perimeter of the lake close to the shoreline. We found elevated levels of Rn-222 , indicating a groundwater source, at two places:

(1) the smaller peak corresponds with thermo anomaly #3, GPS Long 82.112° and Lat 29.538° from the thermograph work done earlier; and (2) the larger peak was observed off a creek area at GPS Long 82.138° and Lat 29.548° (**Figure B-4**). We stayed at the 2nd location for about 30 minutes (or 3 full cycles of the counting protocol) to let the system equilibrate. We observed Rn-222 concentrations about 12 dpm/L, which are the highest we observed throughout the lake area. We finished the first day of the survey at the western side of the lake.

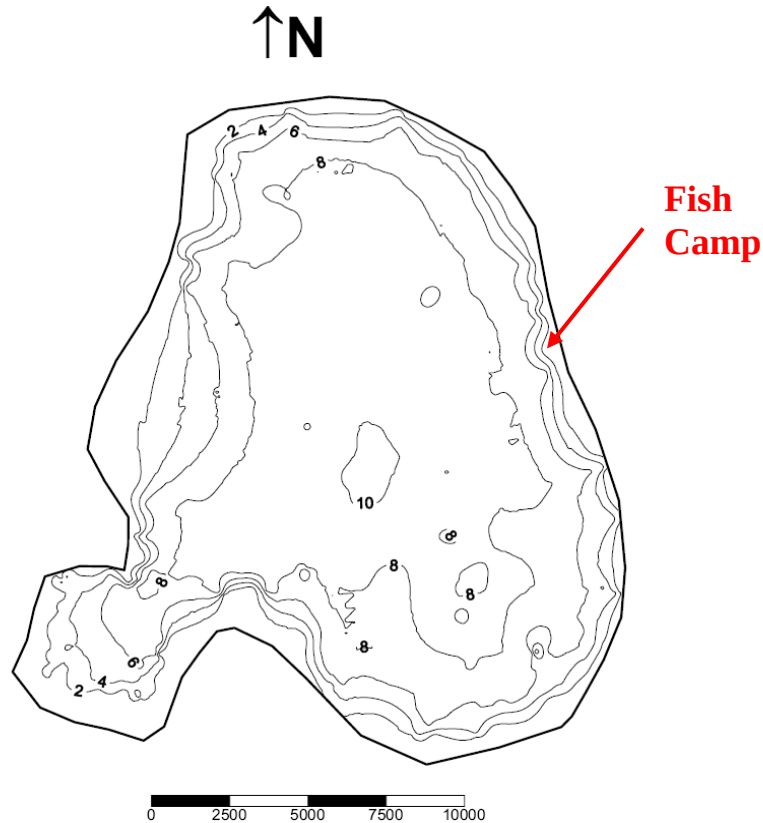


Figure B-3. Map of Lake Lochloosa and the starting point for the survey at the Fish Camp.

On the second day (03-08-06) of the survey we started at the spot where we left off the previous day. We finished the perimeter of the lake going east – southeast to the fish camp. We did not observe any areas of elevated ^{222}Rn concentrations along this track. Instead, the radon levels were quite low and uniform at about 1 dpm/L, consistent with the bottle measurements.

We also set up a stationary system at the fish camp with the aim to observe if there are any time fluctuations of the radon concentrations in the lake that may relate to variations in groundwater inputs. Based on these measurements that showed little fluctuation ($\text{av} = 1.35 \pm 0.23 \text{ dpm/L}$; $n = 12$) we calculated with our “simple advection-diffusion model” that the groundwater discharge is approximately $4 \pm 1 \text{ L/m}^2$ day. This result was calculated using an assumed groundwater concentration of 200 dpm/L (the “low” option in the model). An analysis of pore water from the push-point piezometer in the eastern section of the lake where the time-series was performed showed a similar concentration of $\sim 150 \text{ dpm/L}$. If this estimate of 4 L/m^2 day were characteristic of the entire lake, that would result in a total groundwater discharge of approximately $88,000 \text{ m}^3/\text{day}$.

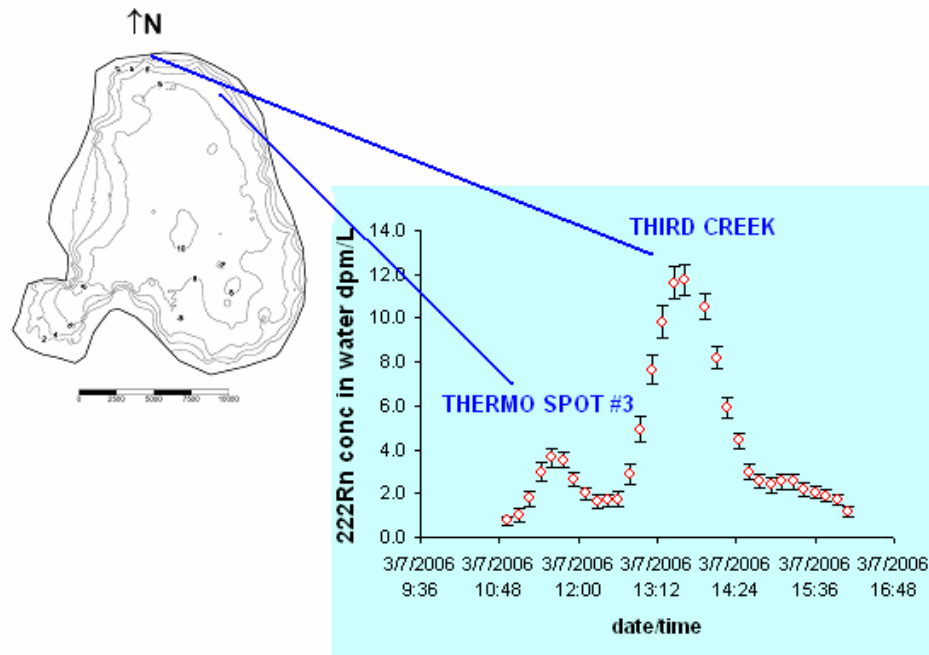


Figure B-4. Results from the automated Rn-222 survey beginning at the fish camp on the eastern shore and proceeding towards the northernmost portion of the lake. The smaller peak is in the same area as one of the thermal anomalies observed by infrared imagery and the larger peak is apparently due to groundwater discharge originating from the creeks in this area.

We started the survey on the third day (03-08-06) at the SW side of the lake and continued north. The initial reason of this transect was to try to “map” the pathway of the “Rn-222 plume” that we have already observed at the north part the first day. We did observed elevated Rn-222 concentrations as we proceeded north towards the creek.

Appendix C: Radon Model Description

Excerpt from

Assessment of Groundwater Discharge to Lake Barco via Radon Tracing

Christina Elaine Stringer
Florida State University Department of Oceanography
Master of Science Thesis
April 2004

Radon Model

General Model

Concentrations of ^{222}Rn are much greater in ground water than in surface water and this difference in activity allows the ^{222}Rn to be used as a tracer in lakes (Corbett et al., 1997) and coastal oceans (Cable et al., 1996a). Lake Barco is a small lake, with no surface water inflow or outflow. It is also relatively shallow with well-mixed waters. This allows a simple box model to be set up that allows for all inputs and outputs of ^{222}Rn in the lake setting (Figure 3.3).

Any possible source or sink of ^{222}Rn must be taken into account when assessing groundwater inputs to Lake Barco.

A one-dimensional model may be applied for a steady-state system (Corbett et al., 1997):
$$J + \lambda A_{\text{Ra}Z} - J_{\text{atm}} - \lambda A_{\text{Rn}Z} - J_{\text{GO}} = 0$$

where J is the total flux of ^{222}Rn from the lake bed to the lake waters ($\text{dpm}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$). A represents the activity of ^{226}Ra and ^{222}Rn ($\text{dpm}\cdot\text{m}^{-3}$), and λ is decay constant of ^{222}Rn . The terms λA_{Ra} and λA_{Rn} account for the production and decay of ^{222}Rn in the water column. The z term is the depth of the water column (m), J_{atm} is the radon flux lost to the atmosphere ($\text{dpm}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$), and J_{GO} is groundwater outflow ($\text{dpm}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$).

Atmospheric Flux

The total flux of ^{222}Rn across the lake surface to the atmosphere is dependent on the molecular diffusion produced by the concentration gradient across the interface and turbulent transport, which is dependent physical processes, predominantly wind speed. The total flux of radon across the interface is calculated from the following equation (MacIntyre et al., 1995):

$$J_{\text{atm}} = k(A_w - \alpha A_{\text{atm}})$$

where A_w and A_{atm} are the activities of ^{222}Rn in the surface water and air, respectively ($\text{dpm}\cdot\text{m}^{-3}$), α is Ostwald's solubility coefficient, and k is the gas transfer coefficient ($\text{m}\cdot\text{d}^{-1}$). The gas transfer coefficient is a function of the kinematic viscosity of water (ν), the molecular diffusion coefficient of ^{222}Rn (D_m), and turbulence at the air-water interface.

MacIntyre et al. (1995) present an equation in which the ratio of the kinematic viscosity to the molecular diffusion of ^{222}Rn is expressed as the Schmidt number and the turbulence is expressed as a function of wind speed:

$$k = 0.45u_{10}^{1.6}(\text{Sc} / 600)^{-n}$$

where u_{10} is the wind speed at 10m above the water surface, Sc is the Schmidt number ($\text{Sc} = \nu/D_m$), and n is a coefficient dependent upon wind speed ($n = -0.667$ for $u_{10} \leq 3.6$ m.s⁻¹ and -0.5 for $u_{10} \geq 3.6$ m.s⁻¹). Wind speed and temperature measurements at 10m were obtained from the FAWN weather station located on the preserve. A concentration of 300 dpm.m⁻³ was used as the C_{atm} term, and obtained from deployment of a continuous radon in air monitor at the center of the lake.

Benthic Flux

The flux of ^{222}Rn from advection of groundwater and diffusion through sediments on the lake bottom to the surface waters is an important source to the radon box model. Cable et al. (1996b) developed a one-dimensional, vertical advective-diffusion model by applying an equation originally developed by Craig (1969) to model ^{14}C in the water column. The flux of ^{222}Rn to the overlying water is estimated by

$$dA/dt = K_z(\partial^2 A / \partial z^2) + \omega(\partial A / \partial z) + P - \lambda A$$

where A is the ^{222}Rn activity in the sediments, z is the depth positive downwards, K_z is the vertical diffusivity, $\partial^2 A / \partial z^2$ and $\partial A / \partial z$ are the ^{222}Rn activity gradients across the sediment-water interface for diffusion and advection, respectively, ω is the vertical advective velocity (positive downward), P is the zero-order production term of radon in the pore fluids ($P = \lambda A_{\text{eq}}$, where A_{eq} is the activity of ^{222}Rn in equilibrium with ^{226}Ra in wet sediment), and λA is radioactive decay.

K_z is set equal to D_s , the wet sediment diffusion coefficient corrected for temperature and porosity. Peng et al. (1974) developed an expression for temperature dependency of molecular diffusion of radon through water, D_o

$$-\log D_o = (980/T) + 1.59$$

which is then corrected for sediment tortuosity by multiplying by porosity (ϕ), $D_s \approx \phi D_o$ (Ullman and Aller, 1982) ($D_o = 1.14 \times 10^{-5}$ cm²/sec at 18°C, (Cable et al., 1996b)). The concentration of ^{222}Rn in the advecting fluids is critical to the evaluation of the water flux through the sediments.

This may be estimated by the sediment equilibration experiments described earlier and/or by direct measurements of groundwater from monitor wells. This model allows the advective velocity (which is then converted to groundwater discharge) to be adjusted to balance the fluxes required to support the observed inventories of ^{222}Rn in the water column and the amount lost to the atmosphere.

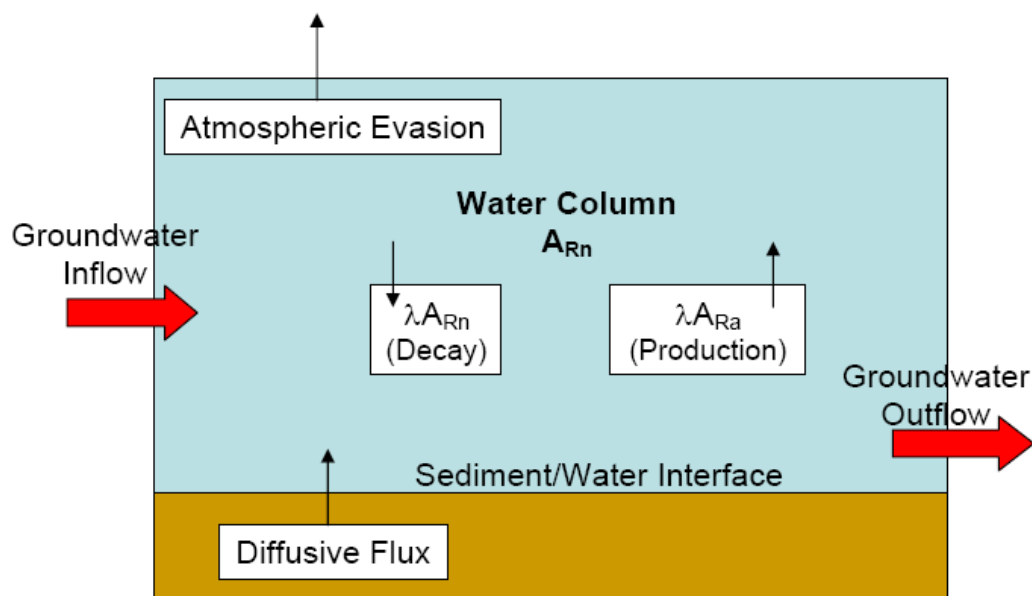


Figure 3.3. A simple box model showing the possible sources and sinks of ^{222}Rn to a lake setting. Each flux is determined and ^{222}Rn budget is created for Lake Barco. This budget is then used to estimate the actual groundwater flow rate to the lake.

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