A Challenging Site for Aquifer Recharge: Keystone Heights Rapid Infiltration Basins Feasibility Study

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The Florida Department of Environmental Protection, Suwannee River Water Management District, and St. Johns River Water Management District (SJRWMD) initiated the North Florida Regional Water Supply Partnership (NFRWSP) in 2011 (Figure 1). The NFRWSP consists of state agency partners, as well as local governments and stakeholders in north Florida. The goal of NFRWSP is to form collaborative solutions that ensure sustainable water supplies for north Florida, while protecting waterways and natural systems. Aquifer recharge is one of many tools available to achieve NFRWSP's goal. The use of rapid infiltration basins (RIBs) for aquifer recharge has been successfully implemented in several areas throughout Florida. In 2013, SJRWMD funded a study to assess suitability of RIBs as a method to recharge the Upper Floridan aquifer (UFA) in the Keystone Heights area of southwest Clay County.

Study Background

An aquifer recharge investigation was conducted at three sites in the Keystone Heights area in southwest Clay County to examine the benefits of indirectly recharging the UFA and the minimum flows and levels (MFLs) lakes via RIBs. The three sites identified by SJRWMD in southwest Clay County are the South DuPont site, the North Blanding site, and the Southwest Blanding site (Figure 2).

The study area is in the Upper Etonia Creek Basin where multiple lakes have developed from collapse or subsidence sinkholes. Near the study area, water flows from the DuPont mine area via a pipe to Blue Pond, through Lowry Lake, Magnolia Lake, and into Brooklyn Lake via Alligator Creek. During extreme wet periods, Brooklyn Lake discharges to Lake Geneva through Alligator Creek and Keystone Lake; however, Brooklyn Lake is currently not discharging, and the last discharge was in 1998.

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The study area may not appear to be suitable for aquifer recharge due to the existence of a thick, low-permeability confining layer, which is contrary to a typical aquifer recharge site where recharge occurs through vertical leakage to the UFA; therefore, recharge to the UFA by means of vertical leakage at the potential RIB sites was expected to be limited. However, because most of the lakes in the study area are connected to the UFA through sinkhole features, the most efficient way to recharge the UFA was expected to be through the lakes. This makes the evaluation of

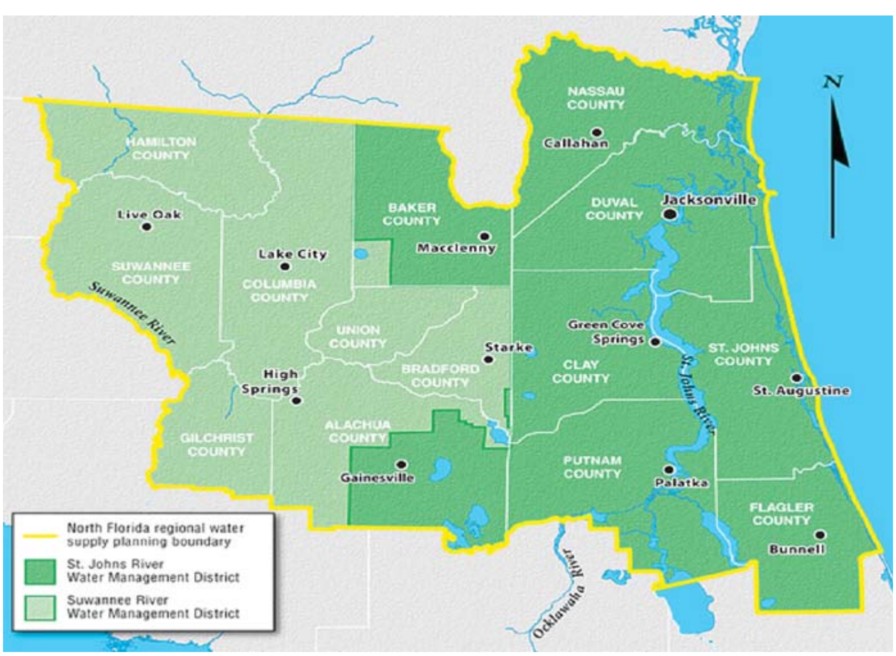

Figure 1. North Florida Regional Water Supply Planning Area

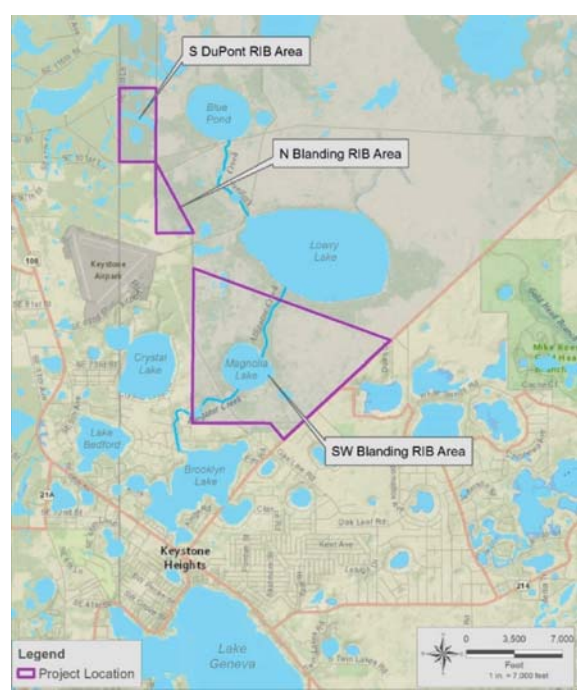

Figure 2. Study Location

the feasibility of the site for aquifer recharge and the analysis of potential benefits of indirect aquifer recharge to the UFA very challenging. A thorough and accurate understanding of not only the vertical, but also the lateral, movement of groundwater in the aquifer system and the interaction of the surface water features with the groundwater system was required. Figure 3 shows the possible movement of groundwater and the interaction between the lakes and the groundwater system in the study area.

The study included extensive data collection, desktop and field investigations, and development of a calibrated fully three-dimensional subregional groundwater model covering 65 sq mi.

The objectives of the study were:

- Preliminary evaluation of the suitability of three sites in southwest Clay County for aquifer recharge through RIBs.
- A comprehensive field investigation of the hydrogeology and suitability of RIBs at one site selected for further investigation.
- Quantification of sustainable potential recharge rate for the selected site.
- Quantification of potential benefits to the UFA and MFLs lakes.

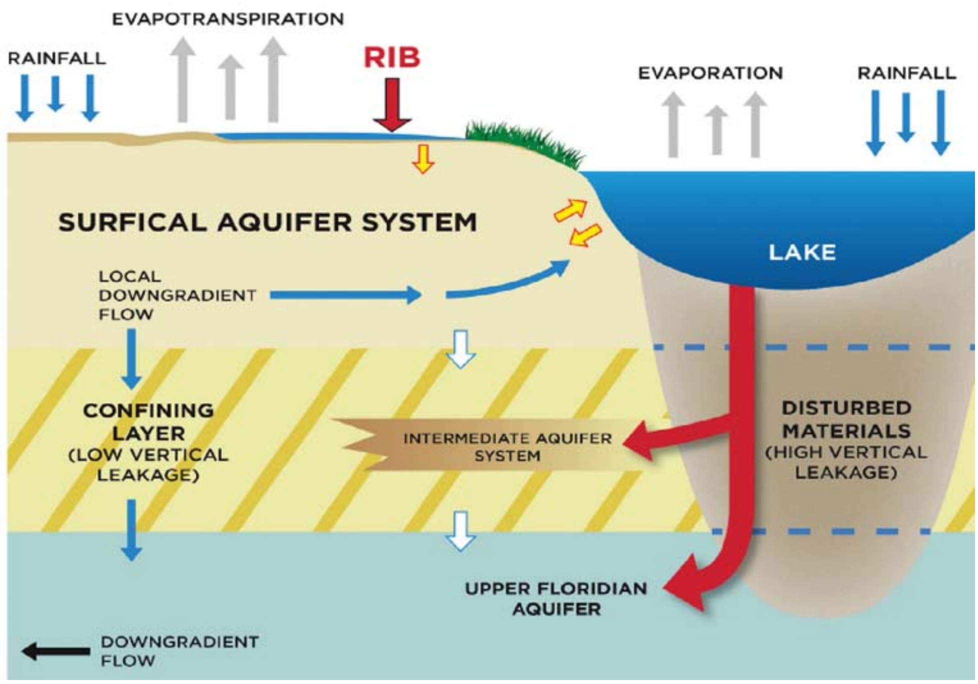

Figure 3. Possible Groundwater Movement in the Study Area (modified from Merritt, 2001)

It was important to conduct the aquifer recharge evaluations in phases. After the completion of each phase, depending on the findings of work performed, the approach to conduct the following phase was reevaluated and modified as needed.

This study was conducted in four phases; each phase was intended to build on the previous phase with regard to the technical information developed. The phases for this study were identified and are further described in the following sections.

- Phase 1 – Preliminary Site Assessment
- Phase 2 – Field Exploratory Program
- Phase 3 – Field Investigation
- Phase 4 – Sustainable Recharge Benefit Analysis

The first phase of the study included the preliminary assessment of the three potential RIB sites in the study area in southwest Clay County (Figure 2). Building on the preliminary site assessment, a detailed field exploratory program was prepared for a field investigation at the Southwest Blanding RIB area site. The field investigation included deep borings, the installation of surficial aquifer and UFA wells, geophysical surveys, multiwell aquifer performance tests, and extensive long-term groundwater level and stream flow monitoring. Using the information gathered in the preliminary site assessment and field investigation, a subregional MODFLOW groundwater model (based on the U.S. Geological Survey modular finite-difference flow model) was developed and calibrated to evaluate the potential for recharging the UFA via RIBs and the potential benefit to the MFLs lakes in the area. To better evaluate the benefit of aquifer recharge to a series of connected lakes and streams, the lakes and the streams in the study area were modeled explicitly in MODFLOW.

Phase 1: Preliminary Site Assessment

The objective of the preliminary site assessment was to summarize the available information, select the preferred site, and provide a background for preparing the field exploratory program and performing a more detailed recharge benefit analysis for the preferred site in the subsequent tasks.

A significant amount of information, including the results of previous investigations, was collected and reviewed, and a site visit was conducted. High-resolution water-table maps were developed, and a preliminary groundwater modeling analysis was performed to provide a preliminary assessment of the three potential RIB sites identified by SJRWMD.

The long-term average annual rainfall at nearby stations (Gainesville and Starke) is 51 in.; the annual average potential evapotranspiration (PET) for the period of record is 50–52 in. per year.

The preliminary site assessment evaluated the three RIB sites identified by SJRWMD in southwest Clay County: the South DuPont site, the North Blanding site, and the Southwest Blanding site.

A detailed site investigation was recommended at the Southwest Blanding site for the following reasons:

- Most of the area is covered by soils with high infiltration capacities.
- The site is close to the most critical MFLs lakes (e.g., Brooklyn Lake and Lake Geneva).
- The site surrounds Alligator Creek, the main conveyance channel in the area, which can provide the most efficient way of transmitting the additional flow to the MFLs lakes.
- Surface water inflow is the largest component of the water budget in most of the Alligator Creek chain of lakes, including Lowry, Magnolia, and Brooklyn. The water levels of lakes with high vertical seepage, such as Brooklyn Lake and Lake Geneva, drop sharply during dry years, mainly due to lack of surface inflow from upstream lakes. Providing a constant surface water inflow to these lakes, especially during dry years, will significantly benefit the lakes. Recharging the surficial aquifer system (SAS) at the Southwest Blanding site could saturate the SAS surrounding Alligator Creek and minimize the loss of surface water flow through seepage along Alligator Creek during dry years.
- An extensive SAS monitoring network is already in place.

Phase 2: Field Exploratory Program

A field exploratory program was developed to provide guidelines for a detailed field investi-

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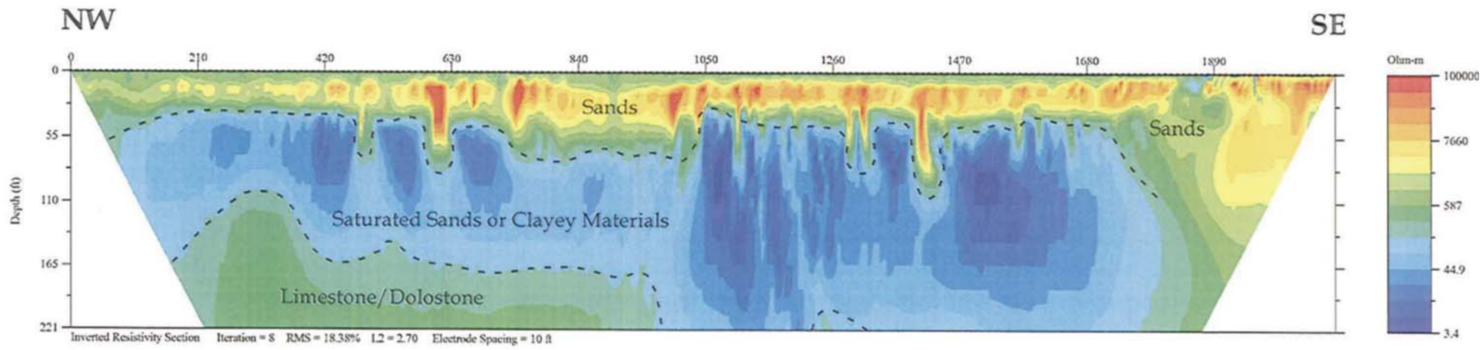

Figure 4. Two-Dimensional Electrical Resistivity Profile

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gation, including the objectives and procedures of field tests, proposed locations for additional monitoring wells and borings, and data collection plans. The field program described the proposed construction and testing activities and the methods used to analyze the data collected at the site during field investigations.

The objectives of the field exploratory program were to:

- Summarize field investigation objectives
- Develop data collection plans
- Develop field test procedures, including aquifer performance testing
- Develop groundwater modeling approach to obtain information for the recharge benefit analysis

Phase 3: Field Investigation

The purpose of the field investigation was to gather the information required to further study the subsurface conditions at the Southwest Blanding site. All data collected were processed and analyzed to support a determination of the potential suitability of the site evaluated for developing RIBs to beneficially recharge the SAS and/or the UFA.

The field investigation included installing eight surficial aquifer wells/piezometers and one UFA well. Additionally, a geophysical investigation, using electrical resistivity, was conducted and two confirmatory borings were completed to better characterize the SAS and intermediate aquifer system (IAS). Also, one surface water gauge was installed in Alligator Creek north of Magnolia Lake to collect flow and stage data for the evaluation of flow exchange between Alligator Creek and the groundwater system.

Figure 4 shows one of the two-dimensional electrical resistivity profiles developed from the electrical resistivity survey.

The review of the borings and geophysical survey results, as well as the water level data, confirmed that three distinctive aquifer systems occur in the study area: the SAS, the IAS, and the Floridan aquifer system (FAS). The SAS consists of fine-grained sand and clayey sand, with an approximate thickness of 40 to 100 ft. The IAS consists of saturated sand, clayey materials, and limestone/dolostone units associated with the Hawthorn Group. The thickness of IAS varies from approximately 150 to 200 ft in the study area. The water level data obtained from the SAS and the IAS wells indicate that SAS water levels were about 15 to 20 ft higher than the IAS water levels during the data collection period. The limestone of the UFA was encountered at 238 ft below land surface at UFA-PW-1. None of the confirmation borings, with a total depth of 200 ft, or geophysical survey traverses, with a penetration depth varying from 144 to 221 ft, showed indication of the UFA. Therefore, the top of the UFA is most likely more than 220 ft deep in the study area. The water-level data obtained from the UFA and the IAS wells indicate that the IAS water levels were more than 20 ft higher than the UFA water levels during the data collection period.

The SAS water levels are typically between 85 and 175 ft North American Vertical Datum (NAVD) 88. The depth of water at the site ranges from approximately 0–64 ft below land surface during the wet season and 11–80 ft below land surface during the dry season. Based on two continuously monitored SJRWMD well clusters completed in the SAS, IAS, and UFA near the study site, SAS levels are typically 15 to 20 ft higher than IAS levels, and the IAS levels are typically 10 to 20 ft higher than the UFA levels, indicating that the SAS recharges the UFA in this area. The long-term water level trends in the IAS wells are generally similar to the SAS trends. The study site is near the potentiometric high of the sandhill lakes. In general, groundwater in the UFA flows radially outward to the north, west, and east from the study area. UFA water levels are typically between 70 and 85 ft NAVD 88.

Slug tests and the surficial aquifer performance test (APT) were performed to estimate the SAS properties. The saturated hydraulic conductivities estimated from the slug tests were lowest in the northwest portion of the site and highest in the wells and piezometers near Alligator Creek, varying from 0.4 to 34 ft/day. A relatively low average saturated hydraulic conductivity of 1.7 ft/day was estimated from the analysis of the surficial APT. The estimated specific yield was 0.1, which is within the range of literature values for clayey fine sands.

A multiwell upper Floridan APT was conducted to obtain estimates of the transmissivity and storativity of the UFA and, if possible, the leakance of the overlying IAS. During the upper Floridan APT, water was pumped from the production well and water levels were monitored at nearby SAS, IAS, and UFA monitoring wells. An average transmissivity of approximately 32,000 sq ft per day (ft^2/day) and an average storativity of 2.3×10^{-4} were estimated for the UFA. An average leakance value of 6.5×10^{-4} day^{-1} was estimated, which is similar to the values for the leakance between Magnolia Lake and the UFA previously estimated (Watson et al, 2001 and Merritt, 2001). As a result, due to the proximity of the pumping well to Magnolia Lake, the leakance values estimated in this study most likely represent the leakance between Magnolia Lake and the UFA rather than leakance through the IAS.

A water budget analysis was also performed to better understand the interaction between Alligator Creek and the aquifer system, and to estimate streambed leakance values for the creek. Although Alligator Creek appears to be receiving water from the SAS due to the high water table elevation in the study area, it lost water along both segments during the data collection period. The flow loss occurring along the creek, similar to the lakes in the area, could be due to one or more sinkholes that may have breached the semiconfining layer between the SAS, the IAS, and possibly, the UFA under the creek. The thickness of the confining unit between the

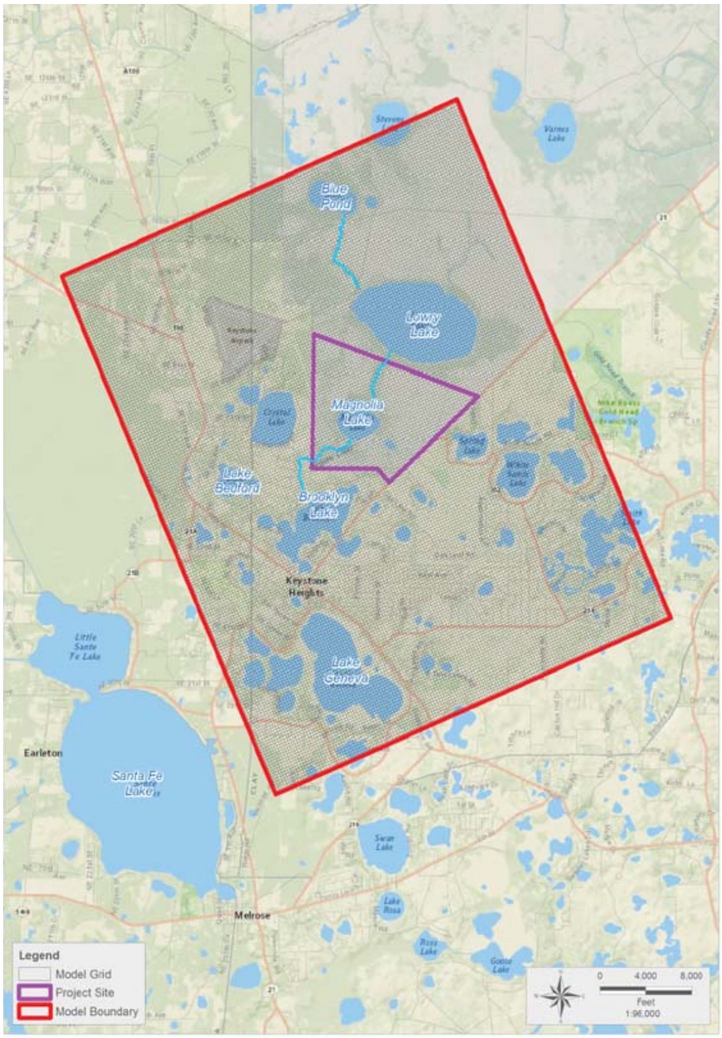

Figure 5. Groundwater Model

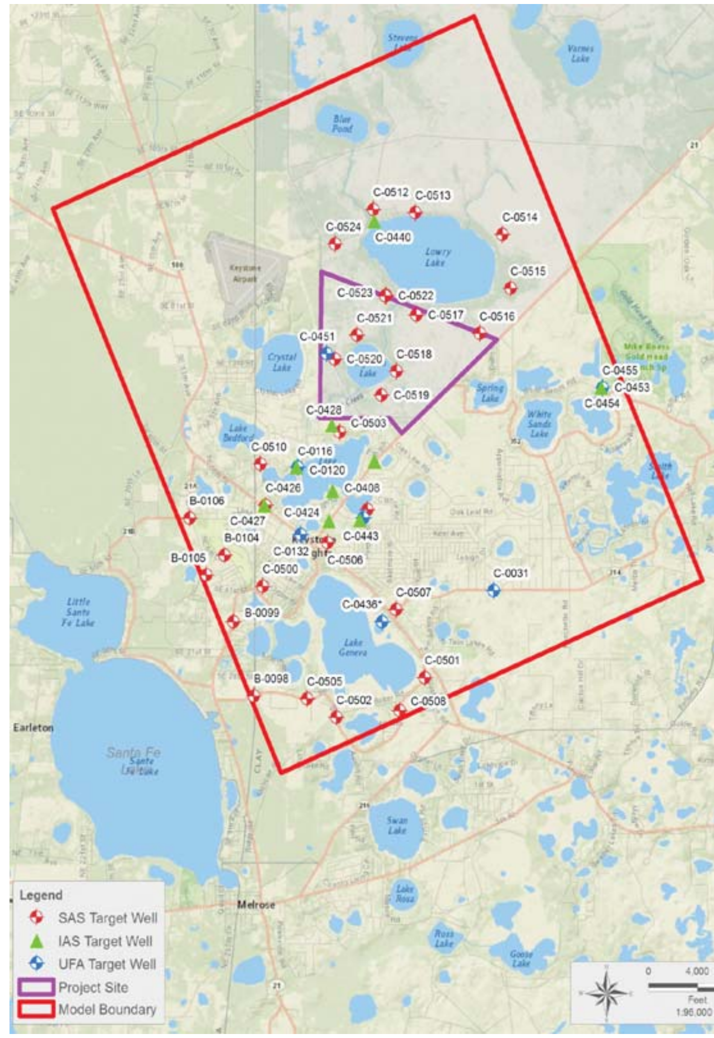

Figure 6. Target Well Locations

creek bottom and the IAS most likely becomes very thin (less than 20 ft) in some locations, which makes the creek bottom more susceptible to breaches. The connectivity could have even extended to the UFA; however, not enough information is available to determine the extent of the connectivity between the creek and the aquifer system below. Because most previous studies (Merritt, 2001) estimated leakance values for the confining unit between the lakes and the UFA, leakance values were calculated for the confining unit between the creek and the UFA using the estimated hydraulic conductivities in this study for comparison purposes. The equivalent leakance values were estimated to be 9.2×10^{-3} and 1.3×10^{-2} day^{-1} for segments 1 and 2, respectively, which are within the range of the estimated leakance values for lakes reported by Merritt (2001). The equivalent leakance values estimated beneath the lakes in this area by Merritt (2001) range from 1×10^{-3} to 3×10^{-2} day^{-1}.

The findings of the field investigation are summarized as follows:

- The estimated hydraulic conductivity values from the surficial APT and slug tests and the review of boring logs indicate that the loading capacity of the RIBs could be higher if the RIBs were located closer to Alligator Creek due to relatively higher SAS hydraulic conductivity values and steep horizontal hydraulic gradient near the creek.
- A relatively thick IAS in the study area significantly restricts the flow interaction between the SAS and the UFA.
- The flow loss occurring along Alligator Creek, similar to the lakes in the area, could be due to sinkhole(s) that may have breached the semiconfining layer among the SAS, the IAS, and possibly, the UFA under the creek. Thus, Alligator Creek may not only help with conveying the flows from the RIBs to the lakes but may also provide recharge to the UFA.
- The field investigation confirmed that most of the recharge to the UFA likely occurs through Alligator Creek and the lakes in the area.
- The results of the surficial and upper Floridan APTs, Alligator Creek water budget analysis, and previous investigations (Merritt, 2001; Watson et al, 2001) indicate that the lateral flow in the SAS that discharges into Alligator Creek and Magnolia Lake is also an important source of recharge to the UFA. In the subsequent phase of this study, lateral flows to these surface water features and vertical leakage from these features and SAS to the IAS were taken into account in evaluating the loading capacity of the RIBs and the benefits of the recharge to the UFA.

Phase 4: Sustainable Recharge Benefit Analysis

The groundwater model was developed using MODFLOW Version 2005 (Harbaugh, A.W., 2005) to evaluate the beneficial recharge potential of the Southwest Blanding site. Figure 5 shows the extent of the groundwater model domain.

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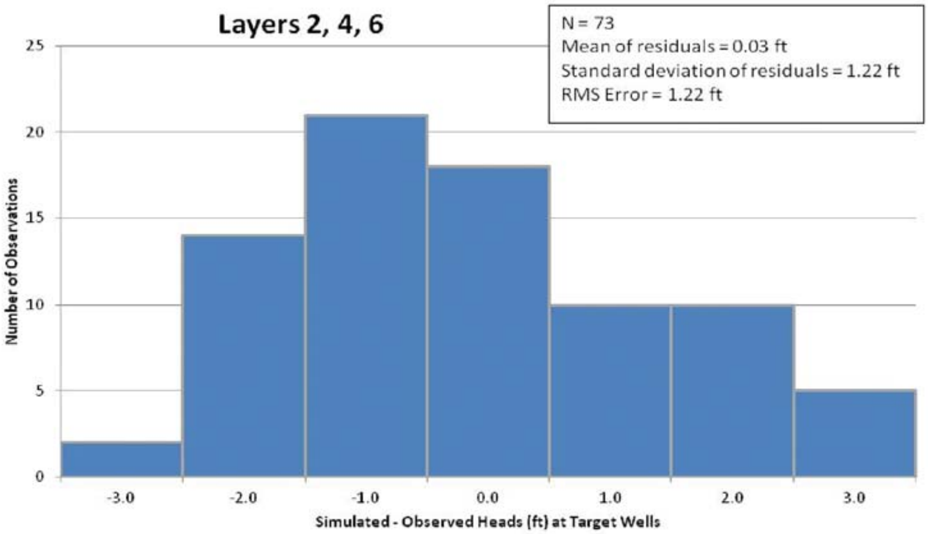

Figure 7. Residual (Simulated – Observed Water Level) Histogram

Table 1. Calibration Results for Lake Levels

Lake Station	Observed Stage (ft)	Computed Stage (ft)
Lake Lowry	130.44	130.74
Lake Magnolia	123.01	122.10
Brooklyn Lake	104.61	105.14

Table 2. Calibration Results for Vertical Water Level Differences

Site	Wells (SAS,IAS,UFA)	SAS/IAS Observed Difference	SAS/IAS Computed Difference	SAS/IAS Residual	IAS/UFA Observed Difference	IAS/UFA Computed Difference	IAS/UFA Residual
Site 1	C-0455, C-0454, C-0453	15.32	13.35	1.97	2.54	5.01	-2.47
Site 2	C-0452, C-0116, C-0120	16.23	14.72	1.51	6.15	6.86	-0.71
Site 3	C-0426, C-0427, NA	7.32	7.57	-0.25	–	–	–
Site 4	NA, C-0443, C-0442	–	–	–	10.75	11.14	-0.39

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Data collected during the preliminary site assessment and the field investigation phases were used to develop and calibrate the model. The primary objective of the model calibration was to ensure that the regional and local groundwater movement was accurately simulated and the regional and local aquifer properties were understood. The model was calibrated to average 1997 water levels, as this was the only year within the period-of-record that the water levels in the SAS, UFA, and lakes appear to be stable (not much change in water levels during the year). During this period, the average annual rainfall of 48 in. was close to the long-term average of 51 in.

The groundwater model is a fully three-dimensional model with eight layers that represent the SAS, IAS, UFA, and Lower Floridan aquifer (LFA), as well as the associated confining units. The model was developed using the lake and stream packages for the Alligator Creek segments within the study area and the connecting lakes (Lowry, Magnolia, and Brooklyn) so that water could be routed through the creek segments and water level changes in the lakes could be calculated. The observation groups for model calibration included 46 SAS well, 18 IAS wells, 9 UFA wells, stream flows, lake levels, and the vertical water level difference targets (Figure 6). The model calibration results are summarized in Figure 7 and Tables 1 and 2.

After the model was calibrated, model scenarios were set up to evaluate the recharge potential of the site during dry and wet seasons. Multiple scenarios were run to evaluate the maximum recharge potential of the site and to evaluate the benefit of additional RIB area versus RIB location.

The maximum capacity of the site was assumed to be reached when groundwater mounded within 3 ft of the ground surface. The model results indicate that the site capacity ranges from 1.75 to 2.9 mil gal per day (mgd) during the wet and dry seasons, respectively. The calibrated model agrees with previous studies (Motz et al, 2001; Watson et al, 2001; Merritt, 2001; Goodrich, 1999; and Kuniansky et al, 2012) that have shown that most leakance to the UFA occurs through the lakes within this area. Because the leakance of the IAS is low under the RIB areas, the majority of the benefit to the UFA comes from flow that reaches Alligator Creek and flows to Brooklyn Lake, which has the highest IAS leakance value and provides the majority of the benefit to the UFA. Figure 8 shows the mounding underneath Lake Brooklyn and the groundwater flow movement from artificial recharge.

The recharge to the UFA ranged from 1.1 to 2.2 mgd in the wet and dry simulations, respectively, which resulted in 0.5 to 0.9 ft of mounding

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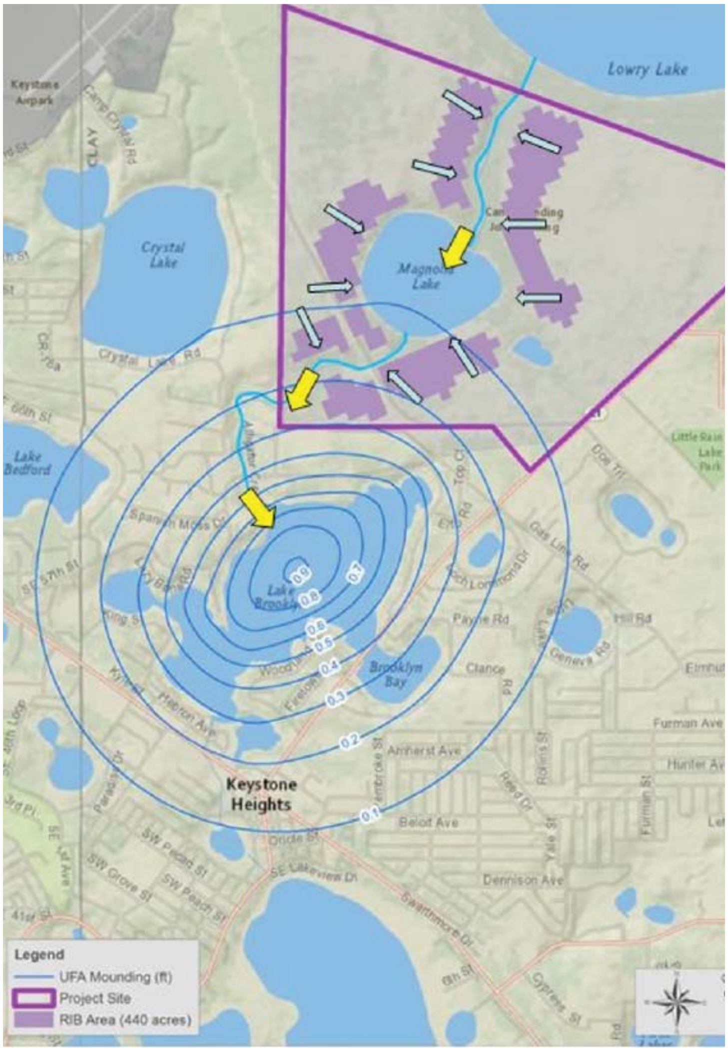

Figure 8. Groundwater Model Results

Table 3. Summary of the Results of Model Recharge Scenarios for Dry Condition

Dry Condition Scenario - A constant flow of ~ 2.9 mgd for 5 years		
Water body	**Rise in Lake Level**	**Rise in UFA Beneath Lake**
Lake Brooklyn	~3 ft	~0.9 ft

Table 4. Summary of the Results of Model Recharge Scenarios for Wet Condition

Wet Condition Scenario - A constant flow of ~ 1.75 mgd for 5 years		
Water body	**Rise in Lake Level**	**Rise in UFA Beneath Lake**
Lake Brooklyn	~2 ft	~0.5 ft

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in the UFA (Tables 3 and 4). Lake Lowry is upgradient of the recharge area and was generally not affected by the loading scenarios. Levels at Lake Magnolia also were not significantly affected because additional flow to this lake is routed to Brooklyn Lake through Alligator Creek. The water level in Brooklyn Lake increased approximately 3 ft during the dry season scenarios. The starting water level at Brooklyn Lake during the wet condition scenario is 114.9 ft, which is near the outfall elevation of 115.5 ft.

The model results indicate that the water levels will rise above this during the loading simulations and Brooklyn Lake would discharge to Alligator Creek, which flows to Lake Geneva.

Conclusions

The results of the groundwater modeling show that the areas closer to Magnolia Lake and Alligator Creek have higher recharge capacity and provide most of the flow to the lakes and benefit to UFA. The groundwater model results are consistent with previous studies that show that most of the leakage to the UFA occurs through the lakes. Because of the presence of the relatively low-permeability confining layer beneath the potential RIB sites, the majority of the benefit to the UFA would come from lateral groundwater flow that would discharge into Alligator Creek and be conveyed to Brooklyn Lake, which has the highest degree of vertical connection to the UFA in the area.

The model scenarios indicate that the potential RIB site's capacity ranges from 1.75 mgd under wet conditions to 2.9 mgd under dry conditions. The recharge to the UFA would result in 0.5 to 0.9 ft of mounding in the UFA beneath Brooklyn Lake. The model results also indicate that recharging the aquifer in the study area via RIBs would result in increased water levels in Brooklyn Lake, not only due to mounding in the UFA, but also due to increased surface water inflow from Alligator Creek and upstream Magnolia Lake. Moreover, identification of a reliable, long-term water source of sufficient magnitude (1.75-2.9 mgd) is necessary to achieve the aquifer recharge benefits estimated in this study.

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