

Woodville Recharge Basin Aquifer Protection Study

BC-07-19-02-29

Final Report

Friday, September 29, 2006
(peer reviewed version, 01/28/07)

by

McGlynn Laboratories Inc.

MACTEC

Tallahassee-Leon County GIS

Ardaman and Associates

Prepared for the
*The Board of Leon County
Commissioners*

French Spring, Leon County Florida



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Executive Summary

The Woodville Recharge Basin Aquifer Protection Study was commissioned by the Leon County Board of County Commissioners and funded by a grant from the U.S. Environmental Protection Agency (USEPA). This study assessed the vulnerability of the Floridan Aquifer, which is unconfined in most of the watershed. This is an aquifer recharge area. Water flows through about 20 feet of sandy soil into the underlying lime rock where it mixes into the Floridan Aquifer. The world-class springs here require a healthy aquifer. This is vital for the preservation of Wakulla Springs, Spring Creek, the St. Marks Rise, French Spring, Chicken Branch Spring and Horn Spring. It is also a source of drinking water.

The Woodville Recharge Basin (WRB) is experiencing rapid growth. The endless forests that covered the WRB are being replaced by homes and businesses. The water quality of the aquifer is deteriorating. The Watershed Analysis and Management Model (WAM) shows that if current zoning regulations are followed, once the WRB is fully developed, the water quality of the aquifer will be severely impaired regarding human health and our springs will no longer be a tourist attraction. WAM identified the areas that are suited for development. This study investigated the sources and concentrations of groundwater contaminants and proposes options to remedy the degradation of the Floridan Aquifer and preserve our bountiful springs.

As people move into the WRB, associated sewage and management practices cause increasing degradation of the Floridan Aquifer. The thin veneer of sandy soils is not suited for cleansing the surface water that filters through it to the aquifer. The WRB should be designated an Aquifer Protection Zone. To protect and preserve the quality of our groundwater and preserve our springs the following actions are recommended:

- Aquifer friendly water quality standards are recommended;
- A state of the art sewer system on major roads is recommended;
- Adjusting the density of septic systems to aquifer vulnerability, cave systems and sinkholes is recommended;
- Performance based septic systems are recommended;
- Aquifer friendly fertilizers are recommended;
- Aquifer friendly stormwater regulations are recommended;
- Permit based trust funds are recommended;
- Aquifer friendly public education programs are recommended;
- Purchasing sensitive features and habitat restoration are recommended;
- The WAMview Model (run by Leon County staff) should be utilized as a planning tool for sustainable growth.

Project / Task Organization

The Woodville Recharge Basin Study was implemented by Leon County, Florida, with funding from USEPA. Thomas Ballentine, P.E. (Leon County) is the project manager for Leon County, Florida.

Leon County contracted with McGlynn Laboratories Inc. (MLI) to complete the study. Sean McGlynn, Ph.D., (MLI) is the Project Director for MLI. Kathleen McGlynn is the Project QA Manager. Greg Mauldin, Leon County GIS, is responsible for GIS and modeling aspects of this project with support from McGlynn Laboratories GIS department. Dell Bottcher, Ph.D., P.E., Soil and Water Engineering Technology wrote the WAMview model and are providing technical support for the modeling. Frank Lesesne, PG., from MACTEC is the head geologist on this project and was particularly involved with modeling, dye study analysis and geological interpretation. He is responsible for geological interpretation. Steven Reecy, PE., of Ardaman and Associates assisted with hydrogeological components of the study, particularly the placement septic and atmospheric deposition studies. Ken Campbell, PG., and Bridget CoaneBrigit, PG., both of the Florida Geological Society were responsible for the installation and analysis of lithographies for the deep wells. JD Kemp, PG., is responsible for the installation of shallow wells for septic and background studies.

The data generated by this project will be very useful to Leon County in making future planning decisions regarding the WRB. McGlynn Labs used the Tallahassee-Leon County GIS Department for principal GIS support they will automatically acquire all of the data layers generated in this study as well as a functional geospatial surface and groundwater quality model. This watershed model will then be in their possession for future use. They will also be able to apply the expertise acquired during this project and the EPA watershed model, WAMview to other watersheds. Since this model is validated for TMDL usage, it will be a very valuable tool for Leon County. Fundamentally, the hydrology, particularly surface-groundwater interactions within the WRB are poorly understood. The water quality and geospatial analysis that will result from this study will be available to Leon County to promote more sensitive development that will protect the unconfined aquifer and water quality of our valuable water resources.

Problem Definition / Background

The Woodville Recharge Basin (WRB) is a closed surface water drainage basin located in southeastern Leon County, Florida encompassing approximately 60 square miles (Figure A.1). The basin encompasses most of the Woodville Karst Plain located directly north of several 1st order magnitude springs, including the St. Marks Rise, Wakulla Springs and Spring Creek. Within the WRB the shallow Floridan Limestone Aquifer is largely unconfined because of the highly permeability soils and numerous sinks (Figures A.1 through A.4). The aquifer within the WRB is highly vulnerable to a wide range of anthropogenic activities and has witnessed a 10-fold increase in nitrate concentrations at Wakulla Springs over the past 25 years. Since this region is largely undeveloped and has been identified as one of the fastest developing regions of the United States it is likely to experience considerable growth and development in the future. Protecting the Aquifer is necessary to maintain and improve the water quality in three first order magnitude springs.

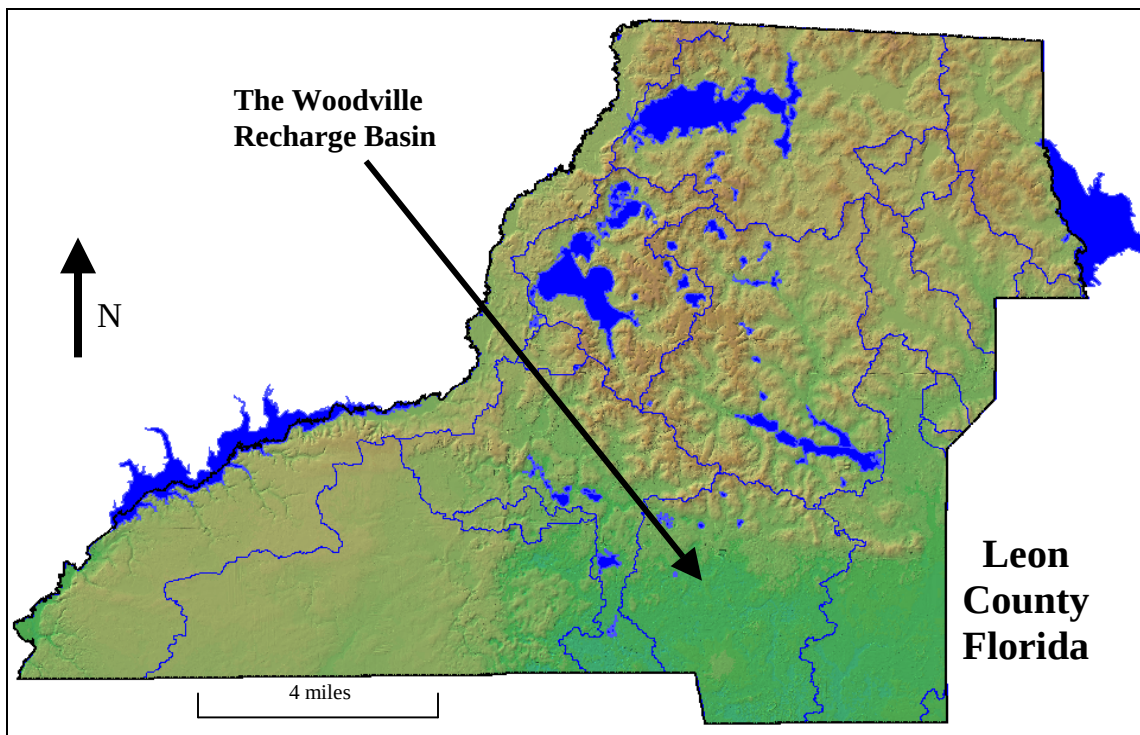


Figure A.1: The Woodville Recharge Basin is a closed watershed in southeastern Leon County. Map by Greg Mauldin, Tallahassee-Leon County GIS.

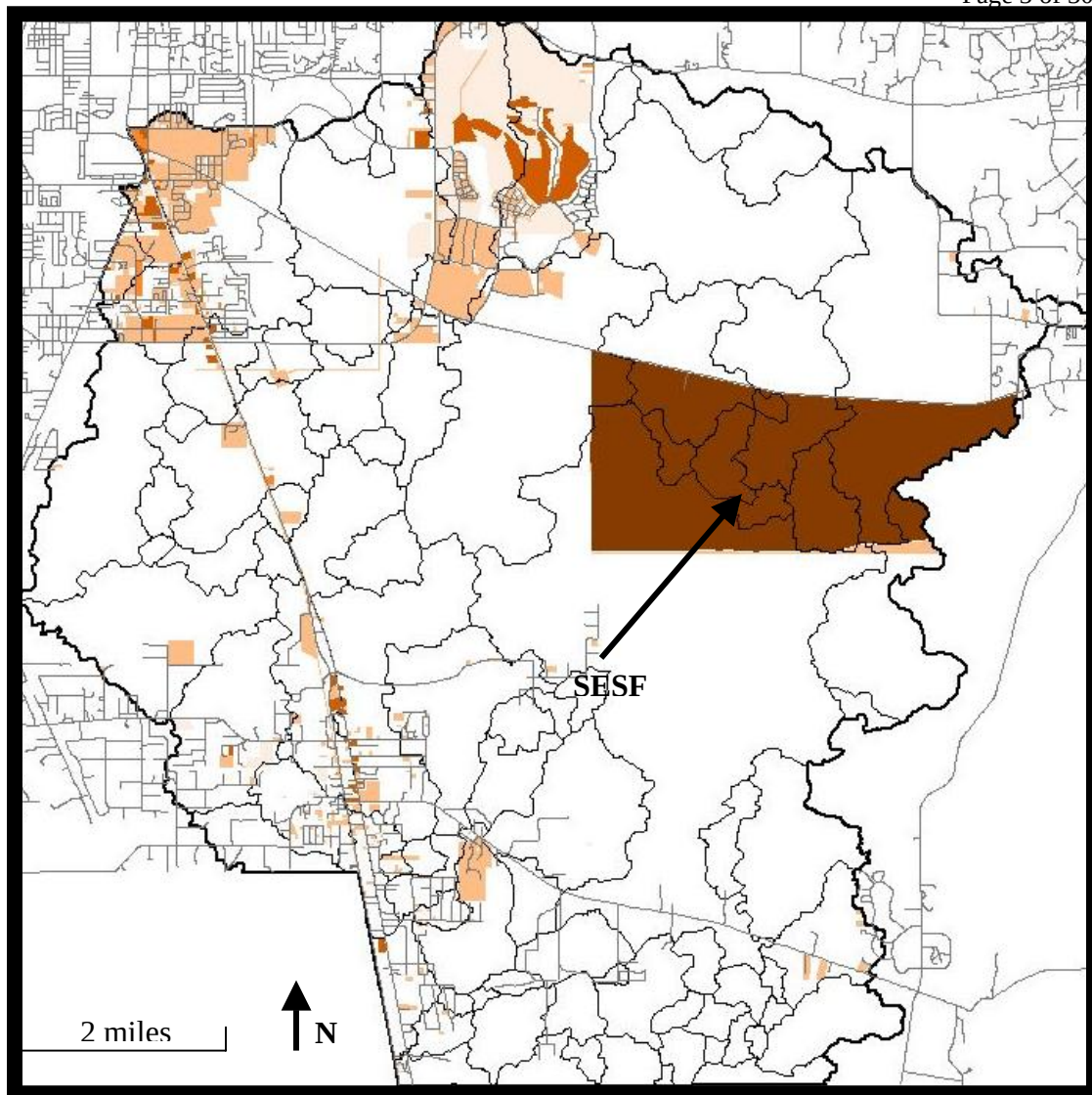


Figure A.2: Potential point sources of pollution within the WRB include residential development, agriculture and industrial sources. Map by Greg Mauldin, Tallahassee-Leon County GIS.

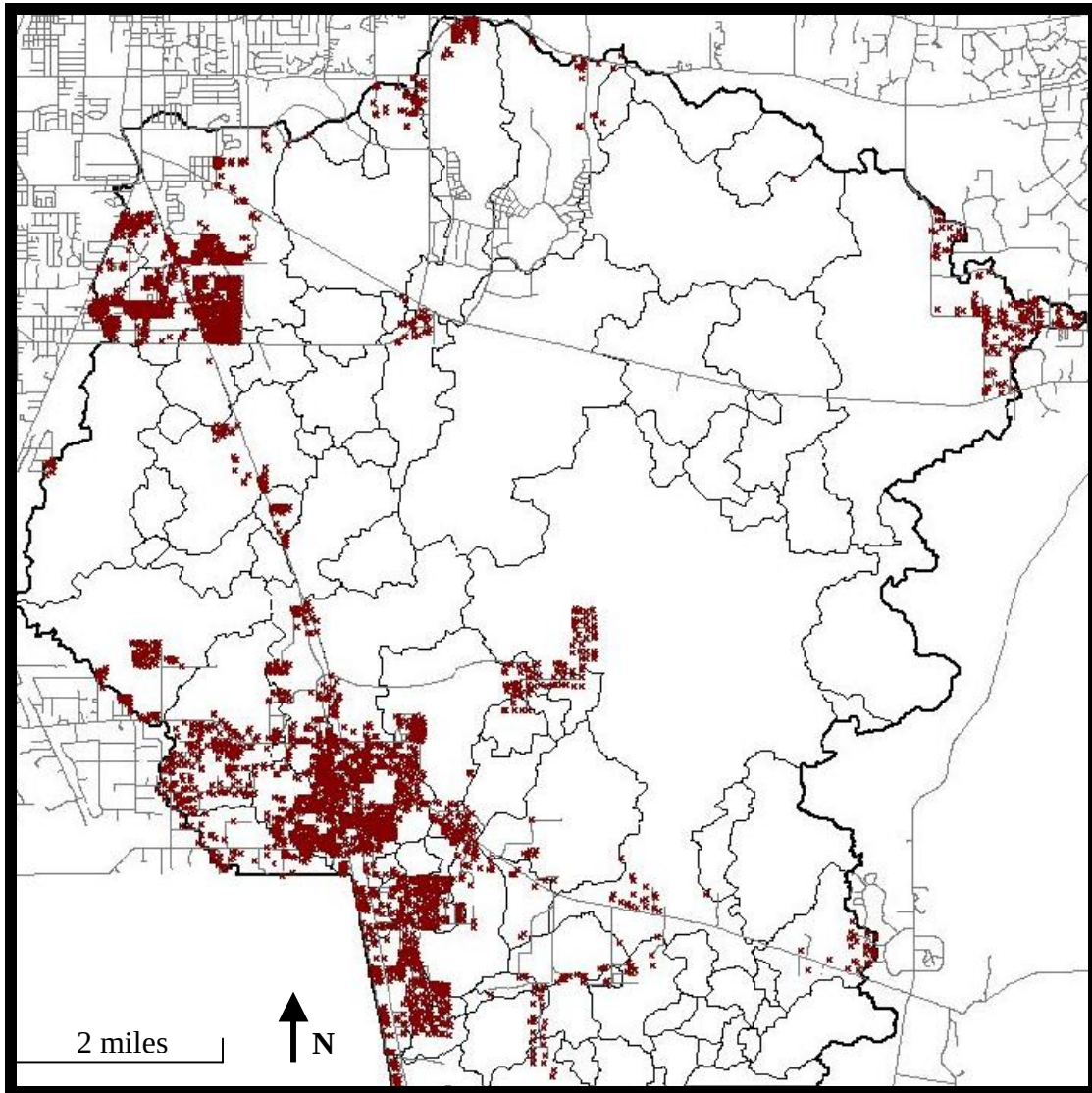


Figure A.3: The locations of approximately 700 domestic septic systems within the WRB. Map by Greg Mauldin, Tallahassee-Leon County GIS.

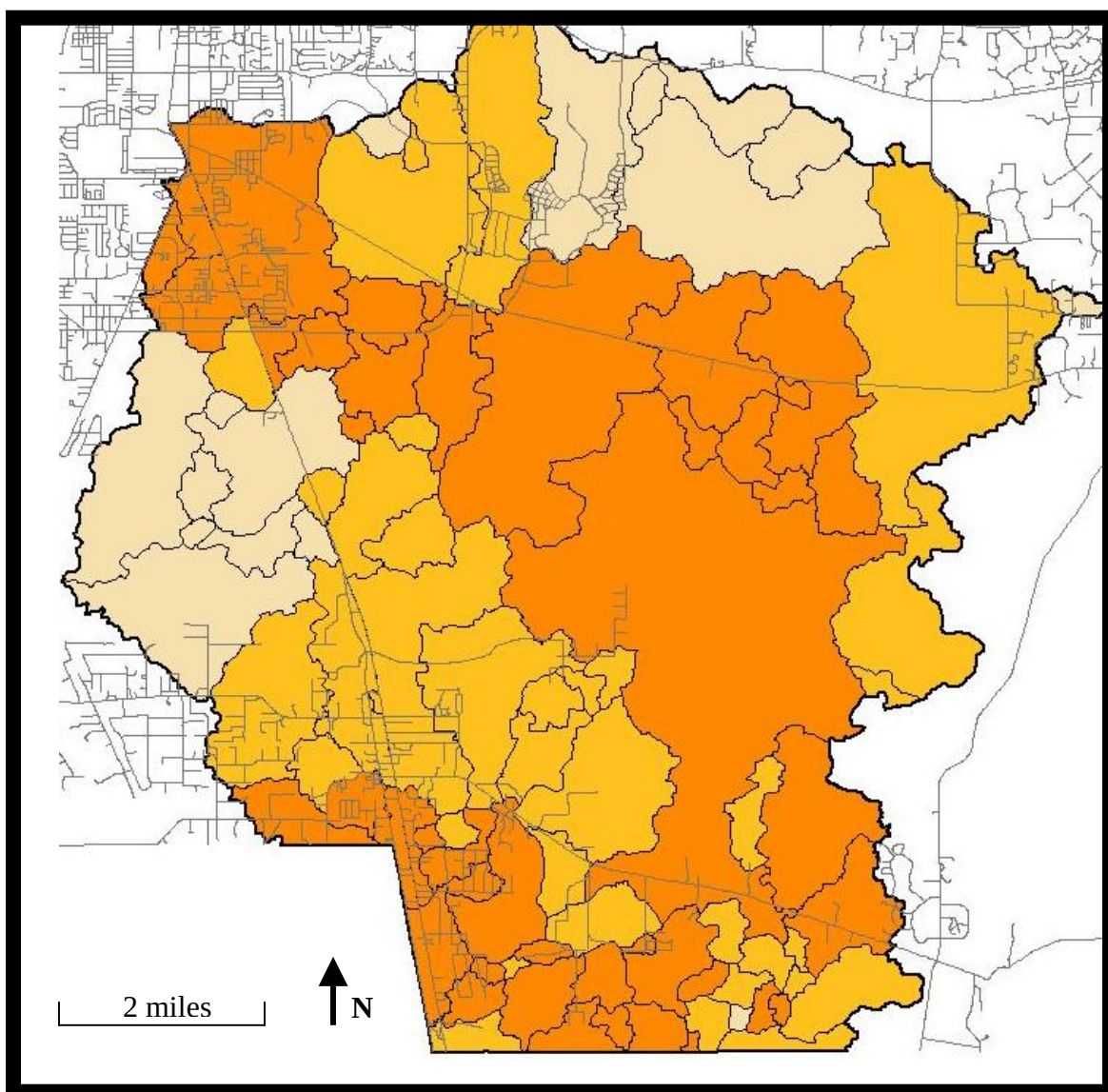


Figure A.4: Sub-basins within the WRB prioritized according to the Raster GRID Analysis Model. Darker colors indicate areas of greatest concern regarding aquifer water quality. Map by Greg Mauldin, Tallahassee Leon County GIS.

The WRB is situated on the Woodville Karst Plain between Tallahassee and Wakulla Springs. Topographically the WRB is rather flat and punctuated by thousands of small sub-basins or karst depressions. Stormwater pooling in the basin is eventually conducted to the aquifer through the highly permeable overlying sediments and numerous sinkholes. The impact of high-density housing, a likely consequence of future development, is not known. The impact of domestic septic systems located in poor soils types with high water tables is not well understood. Pollution sources have been identified that may contribute to rising nitrate concentrations in the aquifer, these include: atmospheric deposition; the City of Tallahassee's Southeast Sprayfield Farm (SESF); numerous domestic septic systems; commercial fertilizers; livestock; and urban stormwater runoff (Figure A.2).

Approximately half the basin is owned by the St. Joe/Arvida Corporation and is largely undeveloped and under lease to hunt clubs. Another 12% of the basin includes the SESF. Private parcels on the remaining 22% of the basin include approximately 700 domestic septic tanks (figure A.3).

Wakulla Springs is an international attraction approximately 5 miles southwest of the WRB. Wakulla Springs is the best long-term data source for water quality in the Woodville Karst Plain. Groundwater nitrate concentrations in Wakulla Springs have dramatically increased over the past 25 years. This spring has a problem with ever increasing nutrient concentrations, particularly nitrates. While most attention focuses on nitrates, data indicates that Wakulla Springs is phosphate limited and is also impacted by phosphorus pulses. Nutrient enrichment is causing nuisance growth of submerged aquatic plants (SAV) and macrophytic algae. Herbicide treatments are necessary, and regularly applied at the spring to maintain recreational activities.

A5.1 The Identification of Vulnerable Portions of the Aquifer

A systematic scientific identification of areas within the WRB where the aquifer is most vulnerable to contamination was performed utilizing existing data. The primary data elements contributing to groundwater contamination were prioritized and analyzed. The sub-basins were used as the base geographic unit for prioritizing areas within the WRB where the aquifer is most vulnerable to contamination.

A model was generated through a raster GRID analysis process. The 7 primary input data layers to the model used for sub-basin prioritization were as follows:

1) KARSTIC: A Northwest Florida Water Management District data layer. This layer was then assigned a weight of 3 in the output model.

2) Septic Tank Locations: The Septic Tank point data was generated from Tallahassee-Leon County GIS utilizing the centroids of inhabited buildings. This data was compared for accuracy with the City of Tallahassee's existing septic tank database, which overlapped some of the study area. This data layer was converted to raster GRID data. The pixel value for each septic tank was assigned a value of 1. This layer was assigned a weight of 4.

3) Septic Tank Density: The number of septic tanks per acre was computed from the Septic Tank Location data layer in order to model the cumulative impact of pollution loading from multiple septic tanks. This layer was assigned a weight of 2. The weight was relatively low to prevent introducing spatial autocorrelation with the previous layer.

4) Location of Karst Windows: A GIS algorithm ground truthed was run on the Tallahassee-Leon County GIS's LIDAR data to locate potential Karst features. Ground truthing revealed 43 potential karst windows located within the Woodville Basin. These 43 features were converted to a raster GRID. Due to the fact that these features are direct conduits to the groundwater, this layer was assigned a weight of 10.

5) Existing Landuse: The existing landuse polygon data from the Tallahassee-Leon County Planning Department was rescaled according to landuse intensity. Values were assigned to the 20 generalized landuse categories according to the intensity of landuse and are as follows:

<u>Landuse</u>	<u>Value</u>	<u>Landuse</u>	<u>Value</u>
Single Family Residential	2	Multi-Family Residential	4
Vacant Residential	0	Commercial	5
Vacant Commercial	1	Industrial	6
Vacant Industrial	2	Institutional	3
Warehousing	2	Government	3
Office	3	Golf Courses	5

Right-of-Way	1	Churches	2
Cemeteries	1	Agriculture	1
Silviculture	0	Vacant	0
Public Land	0	COT Sprayfield	8

The vacant commercial and vacant industrial areas were assigned values greater than 0 because most had landuse in the past. Most vacant residential areas are open land and have yet been built upon. The sprayfield was assigned a high value due to the large nutrient volumes. The reclassified landuse data was converted to a raster GRID and given a weight of 2 in the overall model.

6) Future Landuse: The Tallahassee-Leon County Planning Department generated this data for allowable areas land use. The values found within the WRB are as follows:

<u>Landuse</u>	<u>Value</u>	<u>Landuse</u>	<u>Value</u>
Rural	0	Mixed Use	4
Activity Center	4	Institutional Government	3
Urban Fringe	2	Open Space	0
Residential Preservation	3	Institutional Education	2
Open Space Stormwater	2	Industrial	5
Rural Community	2		

The reclassified future landuse data was converted to a raster GRID and given a weight of 2 in the overall model.

7) Soil Permeability: Soil permeability data was obtained from the Leon County Soil Survey, Table 15, Physical and Chemical Properties of Soils. This data was linked to soil polygon data and reclassified into 6 classes:

<u>Permeability (Inches / hour)</u>	<u>Class</u>
0.2 – 0.6	1
0.6 – 2.0	2
2.0 – 6.0	3
6.0 – 20.0	4
Greater than 20	5

Soil polygons coded as water were assigned a value of 0. The reclassified permeability data was converted to a raster GRID and assigned a weight of 7 in the overall model.

The resulting model is as follows: $\text{rank} = (\text{karstic} * 3) + (\text{septic} * 4) + (\text{septic density} * 2) + (\text{window} * 10) + (\text{landuse} * 2) + (\text{future landuse} * 2) + (\text{soil permeability} * 7)$

This equation produced a raster GRID with values ranging from 21 – 156. A zonalmean function using the sub-basin data as the zone grid and the output from the model as the

value grid was used to assign each sub-basin a priority ranking relative to the level of further study needed in Phase 2 of this project. After this stage was completed, the area of the Apalachicola National Forest was assigned a value of 50 and subtracted from the previous result due to the lack of development potential within the National Forest. Study activities may well take place in this area, especially if karst window features are found to exist there. Please see the prioritization map (Figure A.4).

A5.2 HYDROLOGY OF WOODVILLE RECHARGE BASIN

Groundwater flows from higher elevations to lower elevations. In southeastern Leon County this is generally from the north (Tallahassee Hills) to the south (Coastal Lowlands), where groundwater discharges directly into rivers, creeks, springs and the Gulf of Mexico. A piezometric mapping effort using LIDAR data, found that groundwater generally flows southwest through the WRB. This finding is in general agreement with the NFWFMD's earlier study. Piezometric mapping does not show or represent cavernous conduit flow.

Two recent sources of water table elevations have been used to infer the direction of groundwater flow within the WRB. The sources of data include:

- 1) PIEZOMETRIC MAP OF THE FLORIDAN AQUIFER PREPARED BY NFWFMD (CHELLETTE *ET. AL.*, 2002) FOR SOUTHERN LEON AND WAKULLA COUNTIES, FIGURE A5-5. AT THE TIME OF INVESTIGATION, THIS MAP IS THE MOST RECENT AND COMPLETE FLORIDAN WATER TABLE ELEVATIONS AVAILABLE FOR THE WRB AND NORTHERN WAKULLA COUNTY.
- 2) The second source of water level data is a new piezometric map constructed utilizing LIDAR data (land and water table elevation obtained from satellite data, Figure A5-6). This data relies on the assumption that the water levels in sinkholes, south of the Cody Scarp, are representative of the water levels in Floridan wells in this area. The accuracy of the water level data provided by LIDAR data is approximately ± 0.4 feet, which is adequate to obtain water table elevation trends across this area. Elevations range from approximately 19 feet at the SESF to 8 feet above land surface south of Woodville.

Although the water table data on these two maps were collected concurrently by two entirely different methods, the data agree remarkably well across the WRB. Piezometric contours are plotted on Figures A.5 and A.6 for the water level data and LIDAR data, respectively.

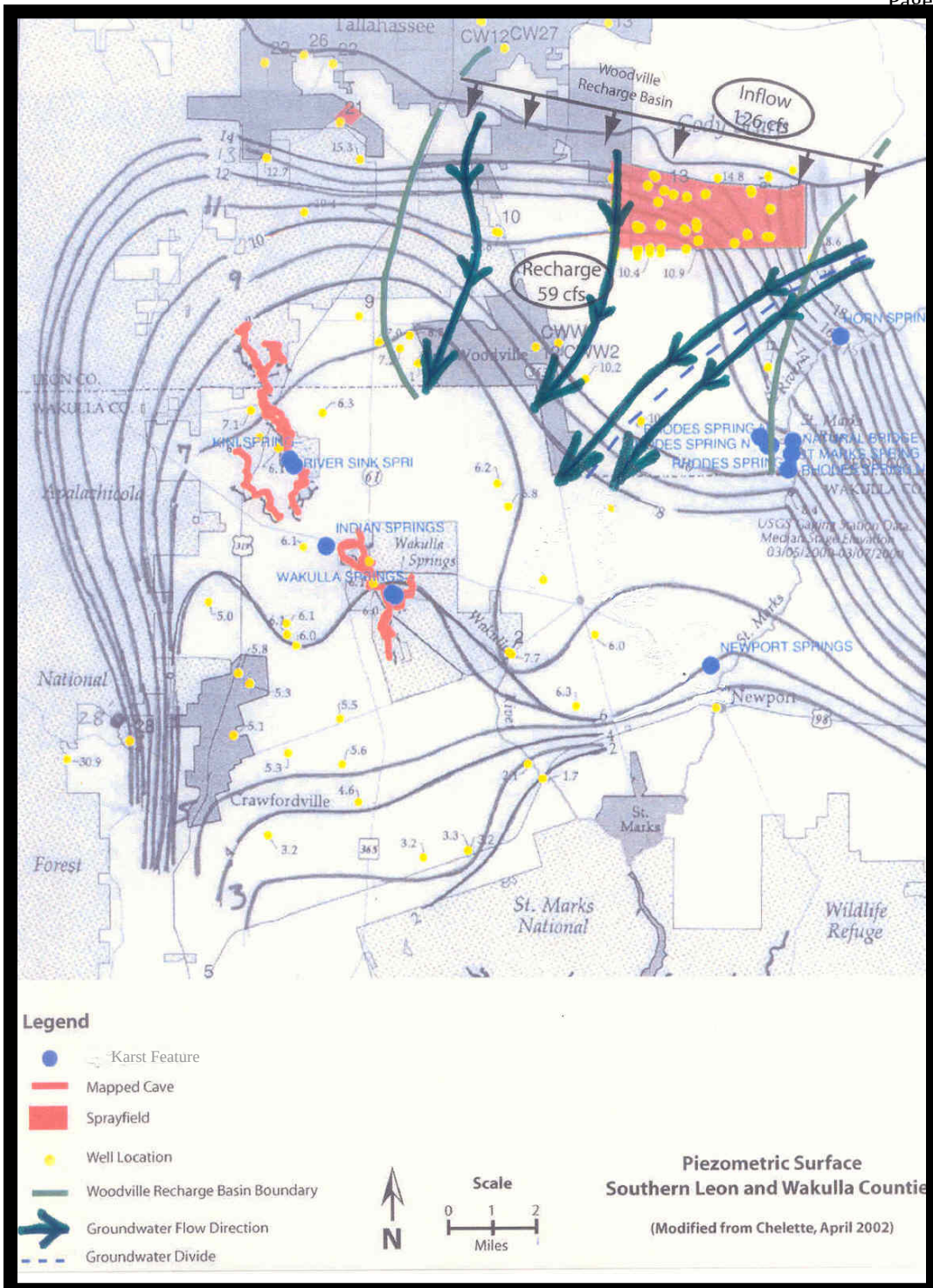


Figure A.5: Piezometric Surface, Southern Leon and Wakulla Counties (NFWFMD data). Arrows indicate the direction of groundwater flow.

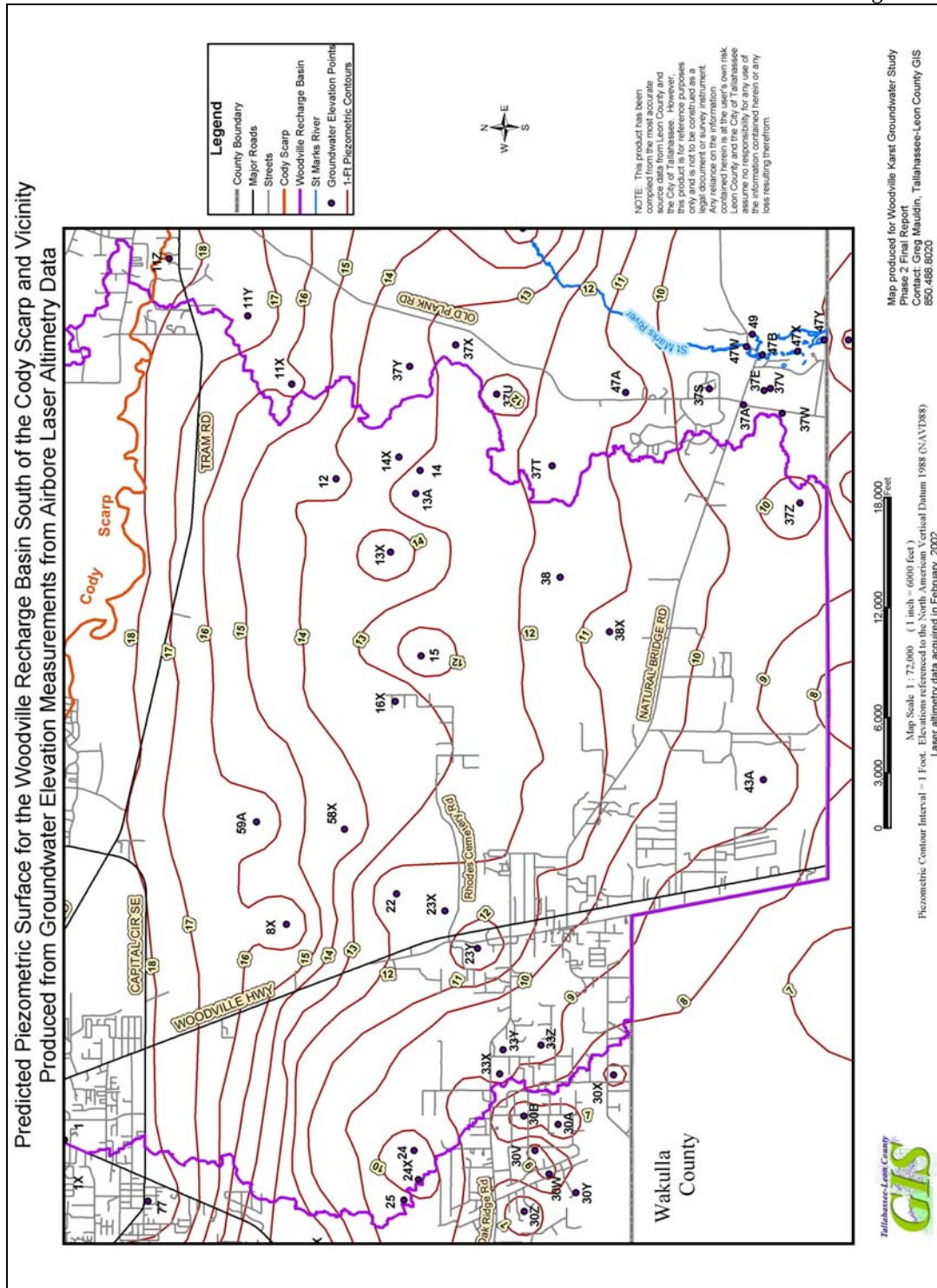


Figure A.6: Piezometric Surface Southern Leon and Wakulla Counties, Leon County GIS from LIDAR data, Greg Mauldin

Based on the topographic and physiographic data, it appears at the first impression is that groundwater flow from the SESF would take the shortest route to a discharge area, which would be the St. Marks River, located only about 2.5 miles southeast of the SESF; However, preliminary hydraulic and water quality data does not indicate that water from the SESF discharges into the upper reaches of the St. Marks River. Piezometric contours do not curve towards the river, nor does the discharge of the St. Marks River appear to increase in flow above Natural Bridge. In addition, geochemical data supports this conclusion. The nitrate concentrations appear to remain consistently low in the upper portion of the St. Marks River.

Two physiographic features account for the apparent lack of groundwater contribution to the St. Marks River from the SESF. First, the upper portion of the St. Marks River appears to be “perched” or elevated above the Floridan aquifer; therefore, the bed of the river is not truly “downhill” from the SESF (Figure A.6). Second, there appears to be “confining material” (i.e., clay or dolomite) on top of the Floridan aquifer from the headwaters of the Floridan aquifer downstream to the Natural Bridge area that effectively seals the riverbed. In addition, the flow of the St. Marks River increases over 10 fold at the St. Marks River Rise (from 30 cubic feet per second [cfs] to 345 cfs, indicating a different source of water (Figure A.6).

Groundwater flow from the vicinity of the SESF, as illustrated on Figures A.5 and A.6, is to the south and gradually towards the southwest through Woodville and into Wakulla County towards Wakulla Springs. The direction of groundwater flow trends with water quality data indicating elevated nitrate levels from the SESF continuing through the Woodville area. Very little, if any groundwater from the SESF travels to the upper reaches of the St. Marks River based on the groundwater water level elevation maps and the nitrate levels measured in surface waters above the St. Marks Rise.

In order to calculate the effect of dilution upon the irrigation water at the SESF, a number of assumptions must be made. During Phase II a search of data available pertaining to soil infiltration rates, soil/lithologic descriptions of the subsurface material and pump test data revealed that little published data. For instance, Florida Geological Survey well cuttings and core library revealed 23 sets of cuttings with descriptions exist in and adjacent to the WRB, however the soil/geologic descriptions were not detailed, the sampling interval was too broad (10 to 20 feet) to determine precise depth intervals of geologic/hydrogeologic changes, and most often the cuttings were collected but not described by a knowledgeable geologist.

The following assumptions are made for the current calculated values.

- Size and Shape of Basin - approximately 60 square miles, approximately 8 miles by 8 miles, Figure A.1. Determined by Leon County/GEM.

- Direction of Groundwater Flow - piezometric map of southern Leon County and Wakulla County, (Figure A.5) from the NFWFMD report “Nitrate Loadings as an Indication of Non-Point Source Pollution in the Lower St. Marks-Wakulla Rivers Watershed”, Northwest Florida Water Management District, Water Resources Special Report 02-1, 2002, which has been recently updated (Chelette, April 2002, unpublished). The second map is a recent piezometric map generated by the Leon County GIS Section from February 2002 LIDAR data, Figure A.6.
- Water budget – From the NFWFMD report “Nitrate Loadings as an Indication of Non-Point Source Pollution in the Lower St. Marks-Wakulla Rivers Watershed”, Northwest Florida Water Management District, Water Resources Special Report 02-1, 2002. Figure 56 “Water Budget from Wakulla Springs Contributory Area” from that report.
 - o Rainfall average – 55 inches per year
 - o Groundwater recharge – south of Cody Scarp, 12 inches per year
 - o Application rate at SESF – 160 inches per year
 - o Size of Area applied – 1500 acres
 - o Portion of 160 inches applied recharging groundwater – 50% (or 80 inches per year)
- Application of nitrates at SESF is known to vary widely, but averages are assumed based on available data.

Based on the average amounts of precipitation, groundwater inflow and average SESF application rates, the volume of water sprayed is diluted about 6:1 (16%) by groundwater flowing into the SESF and precipitation on the SESF (see Table A.1). It should be noted that groundwater leaving the SESF is diluted further beyond the SESF by precipitation at an approximate rate of an additional 2 percent per mile towards the southwest. A two percent dilution rate is indicative of isotropic porous media. A review of recent nitrate data indicates groundwater is diluted from the SESF through Woodville and southwestwards towards Wakulla Springs. It appears that nitrates leaving the SESF at 10 mg/L are diluted 10%/mile or after 10 miles, at Wakulla Springs the nitrates are about 1 mg/L, indicating conduit flow dilution between the SESF and Wakulla Springs (Figures A.20, A.23 and A.24). The higher actual dilution rate shows that there is additional water from some source diluting the nitrate plume.

Table A.1: Woodville Recharge Basin Recharge Assumptions

Natural, Average	WRB mgd, (cfs)¹	SESF mgd, (cfs)
Groundwater Inflow, (GWI)	82 (126)	37 (58)
Recharge Precipitation (R)	38 (59)	22 (34)
Total Outflow	120 (185)	59 (92)
SESF Recharge		
Application Rate (daily average)	Yearly	160 inches
	Daily	0.44 inches
Size of SESF application area		1500 acres
Percent of sprayed water infiltrated		50% (80 inches)
Percent of water evapotranspired		50% (80 inches)
Gallons of water recharged per day from spraying	9.5 mgd (14.7 cfs)	
Dilution factor ² spray/GWI + R	9.5/59	16% or 6:1
Velocity of groundwater flow		3 ft per day ³

¹ One cubic foot per second (cfs) = 0.646 million gallons per day (mgd).

² Assumes nitrates are lost with evapotranspiring water, plant nitrate uptake is not considered.

³ Tentative average, ranges widely depending on solution features will evaluate further in Phase III. This is non-fracture flow, fracture flow would be much higher.

The identification of karst features in the WRB.

The consensus among local hydrogeologists was that the sandy soils of the WRB would fill in caverns and prevent conduit flow. Approximately half the basin is under private ownership by the St. Joe/Arvida and public access is prohibited. Potential karst features were identified by the County's GIS Division utilizing the LIDAR data and a GIS algorithm. These features were then located and evaluated in the field after obtaining permission from St. Joe/Arvida. Numerous karst features open to the aquifer were identified. Some karst features contained submerged caverns. The cavern system seems to underlie much of the WRB, but it may not be continuous through the basin.

Most of the surface waters within the WRB had adequate water quality. Domestic wells tended to be less than 100 feet deep. Contaminated wells showed no discernable pattern. Contamination was often traceable to near by surface impacts, such as OSTDS or agricultural activities. Examination of the SESF monitoring well data revealed that the effluent sinks rapidly into deeper limestone units. The nitrate plume is at a depth of approximately 125 feet at the southern boundary of the SESF. A recent septic tank study in Karst by the Florida Department of Health (Roeder, 11/24/04) showed that septic tanks behaved similarly. Effluent sank rapidly in Karst to the level of cavernous flow (Figures A.8, 9 and 10). Nutrients (both nitrogen and phosphorus) as well as Fluorescent dyes injected into the septic systems turned up in the monitoring wells within days. There are several possible reasons for this behavior: effluent is more dense and sinks; continued application of effluent pushes it down; or conduit flow exerts a negative hydrolic pressure and draw available water down.

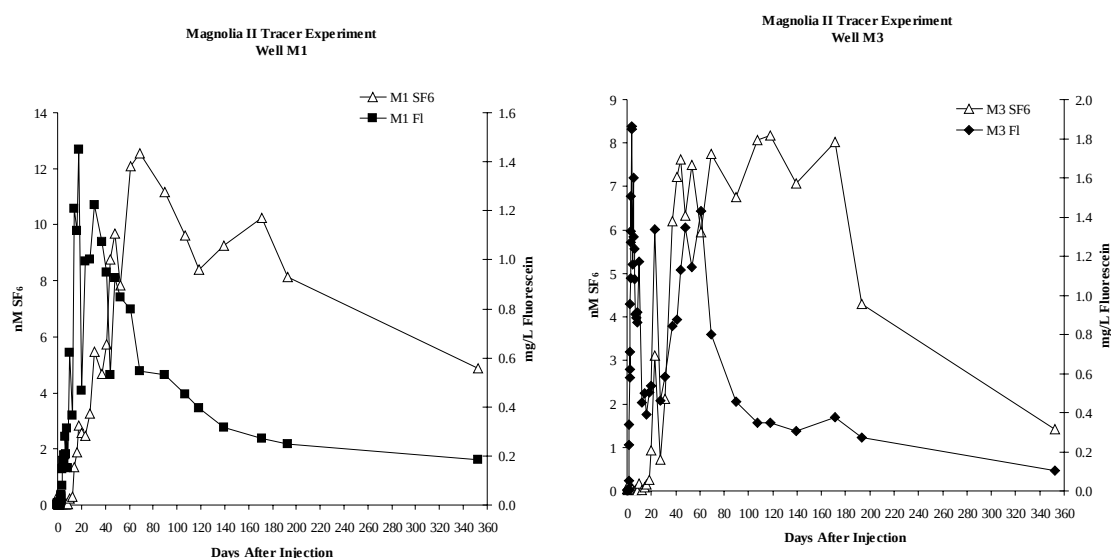


Figure A.8: In the DoH Karst OSTDS study, Well M1 (first graph), the dye traveled 75 feet in 2.5 days and in Well M3 (second graph) the Dye traveled 135 feet in 1.4 days

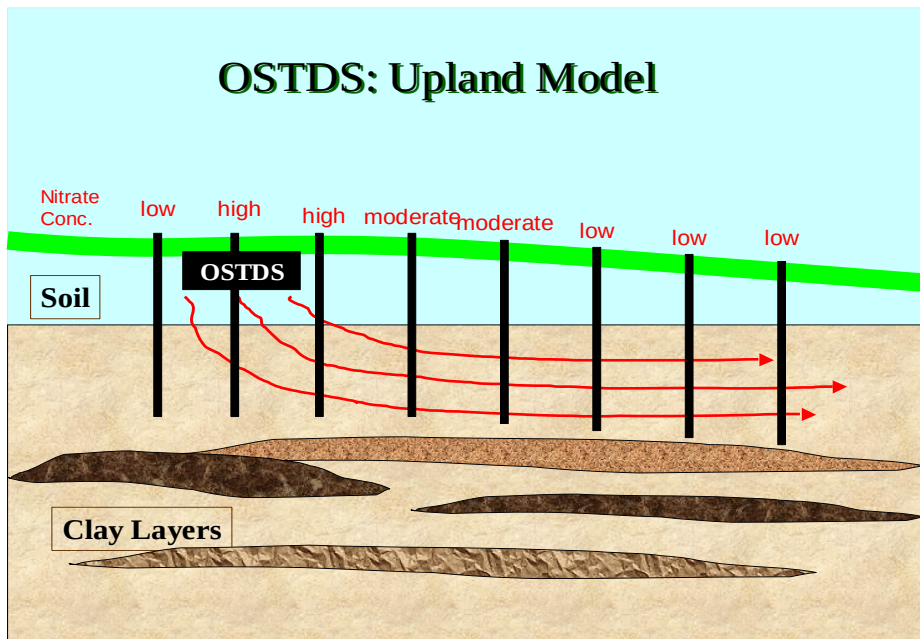


Figure A.9: Model for a septic system in normal soils. The treatment of the effluent is rather good with favorable removal of nutrients. DoH Karst OSTDS study.

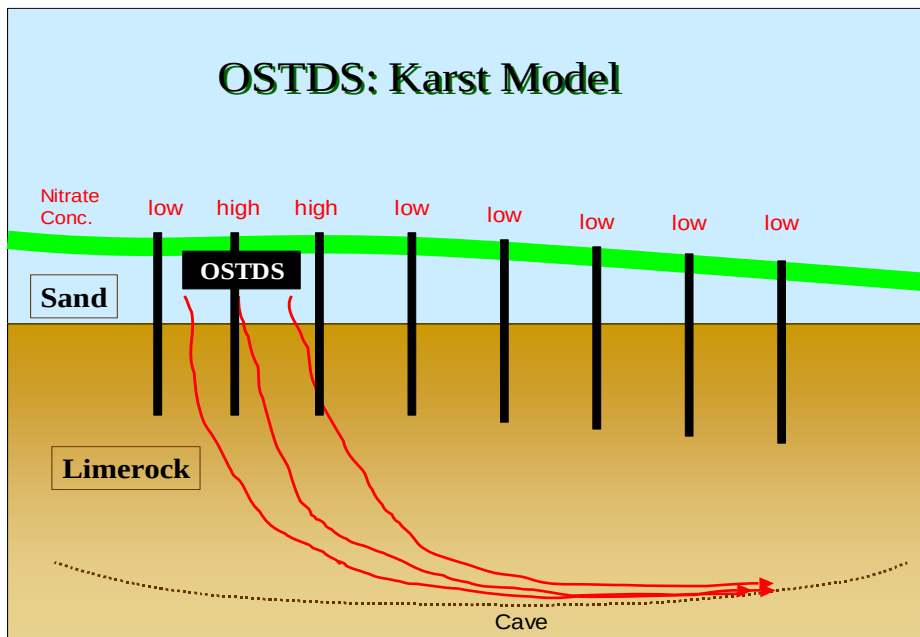


Figure A.10: Model for a septic system in Karst. The treatment of the effluent is rather poor with minimal removal of nutrients. DoH Karst OSTDS study.

A5-4: The impact of the SESF on Wakulla Springs.

The shallow surficial sand aquifer is elevated in nitrate on the SESF property and areas immediately thereto. In the rest of the WRB the shallow surficial sand aquifer is not contaminated. Karst features, open to the aquifer, between the SESF and Wakulla Springs had nitrate concentrations significantly elevated above background levels. These karst features were open into the aquifer. When nitrate concentrations in these karst features are plotted, a dilution factor of approximately 10 percent per mile was calculated. This preliminary data indicates conduit flow. This, together with the Piezometric map and the lack of nitrates in the St. Marks Rise indicates that the direction of groundwater flow from the SESF is probably towards Wakulla Springs. Wakulla Springs is enriched with nitrates. Nitrogen/Phosphorus ratios indicate that Wakulla Springs may be phosphate limited. While nitrates derive from wastewater inputs to the aquifer (SESF and OSTDS), phosphates could originate from urban storm water entering open karst features. The soils of northern Leon County are phosphate rich deposits of clay called the Hawthorn Formation. Phosphates are transported through sinks via subterranean conduits from the clay upland regions of Leon County to the springs. Lake Lafayette, Lake Jackson, Lake Munson and the Eastern Sinks, which contain open karst features, are likely sources of phosphate loading.

A5-4.1: MONITORING AND PERMIT DATA REVIEWED

Data obtained from the SESF monitoring wells shows that the nitrates are occurring primarily in deeper wells near the southern boundary of the SESF. Well depth for these deeper wells is between 100 and 125 feet. The soils at the SESF are very permeable. The SESF effluent descends rather than mounds and may travel south at even greater depths. Two of the wells on the southern boundary of the SESF average over 6 mg/L nitrate over the last 4 years (Figure A.5).

Select historical graphs of the SESF well data for nitrates, all with rather high nitrate concentrations (Figures A.11, 12, 13 and 14) show maximum nitrate concentrations occurring in 1989. This appears to be due to fertilizers applied to the SESF through the center pivot irrigation system. The subsequent reduction in nitrate concentrations occurred when the farmer switched to a time-release fertilizer. After 1989 monitoring well nitrate concentrations dropped several mg/L and have remained rather constant except for a few incidents of elevated nitrate levels caused by problems with the SESF effluent quality when the SESF was holding back residuals in 2002.

The contribution of sinking streams to the semi-confined and unconfined portions of the Floridan Aquifer is 10.5% (Figure A5-18). There is little or no treatment of the stormwater entering these lakes. Direct surface to aquifer transport of stormwater to the aquifer is significant.

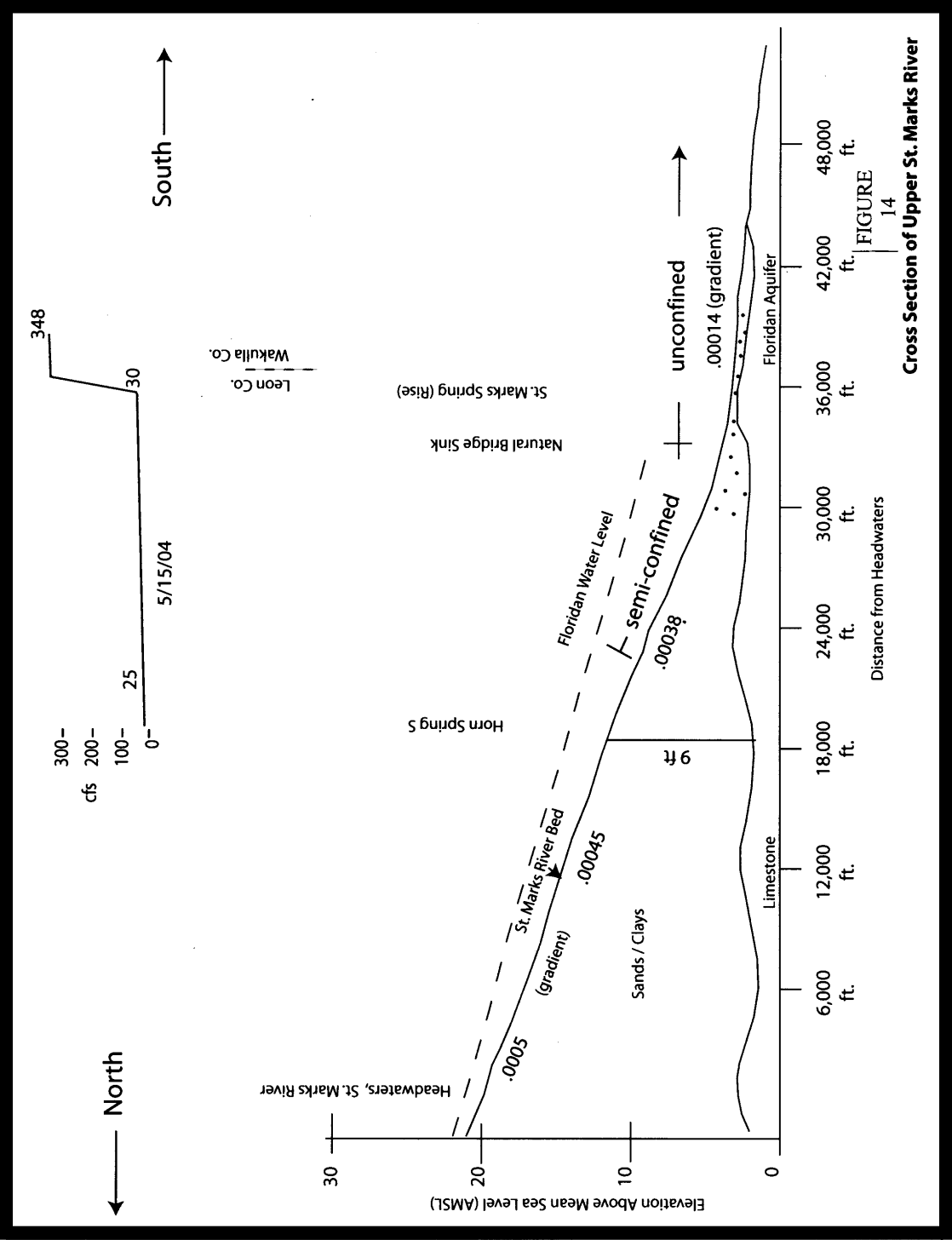


Figure A.7: Cross section of the upper St. Marks River (URS data)

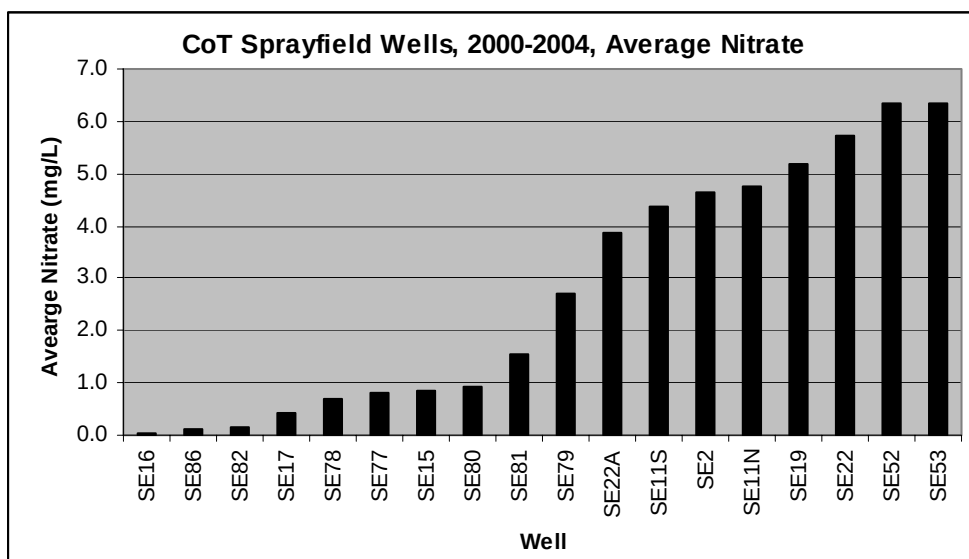


Figure A.11: Average nitrate concentrations in groundwater sampled from the SESF monitoring wells. Nitrates analyzed by the City of Tallahassee Water Quality Laboratory. Graphics produced and analyzed by MLI.

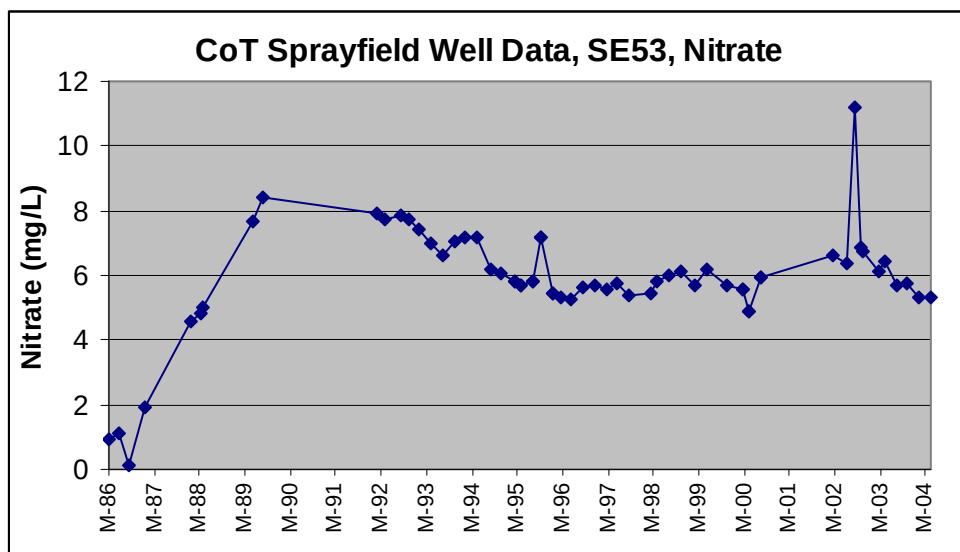


Figure A.12: Historical data from the SESF well with the highest average nitrate concentrations. This well is on the southern boundary of the SESF and is about 100 ft deep. Nitrate concentrations in August 2002 exceeded 10 mg/L in one instance. Nitrates analyzed by the City of Tallahassee Water Quality Laboratory. Graphics produced and analyzed by MLI.

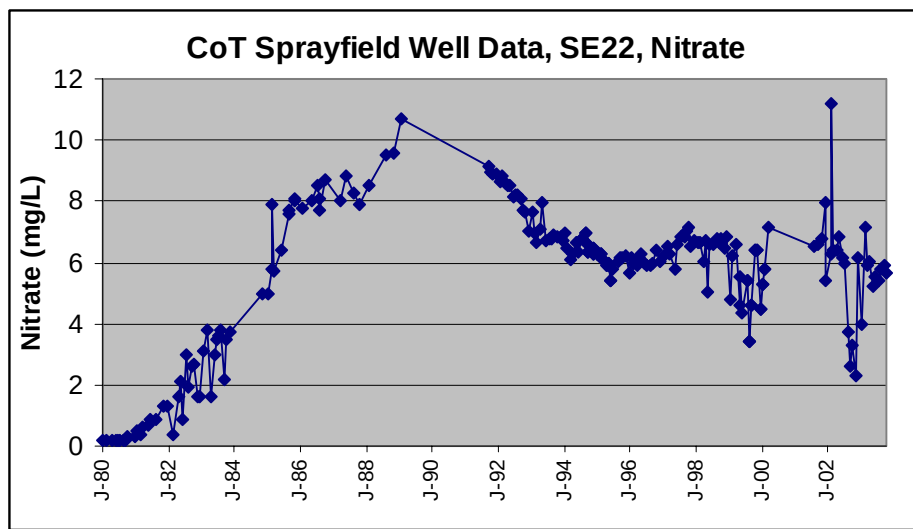


Figure A.13: The third highest nitrate concentrations occurred in well SE22. This is a deep well; approximately 125 feet deep near the southern boundary of the SESF. Nitrate concentrations in August 2002 exceeded 10 mg/L. Nitrates analyzed by the City of Tallahassee Water Quality Laboratory. Graphics produced and analyzed by MLI.

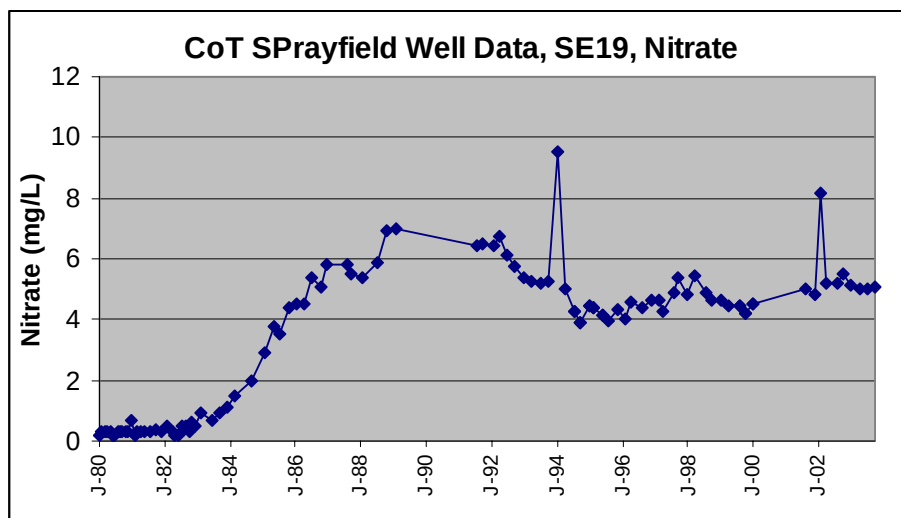


Figure A.14: this mid depth well (approx. 75 feet deep) towards the center of the SESF had the fourth highest nitrate concentrations. Nitrates analyzed by the City of Tallahassee Water Quality Laboratory. Graphics produced and analyzed by MLI.

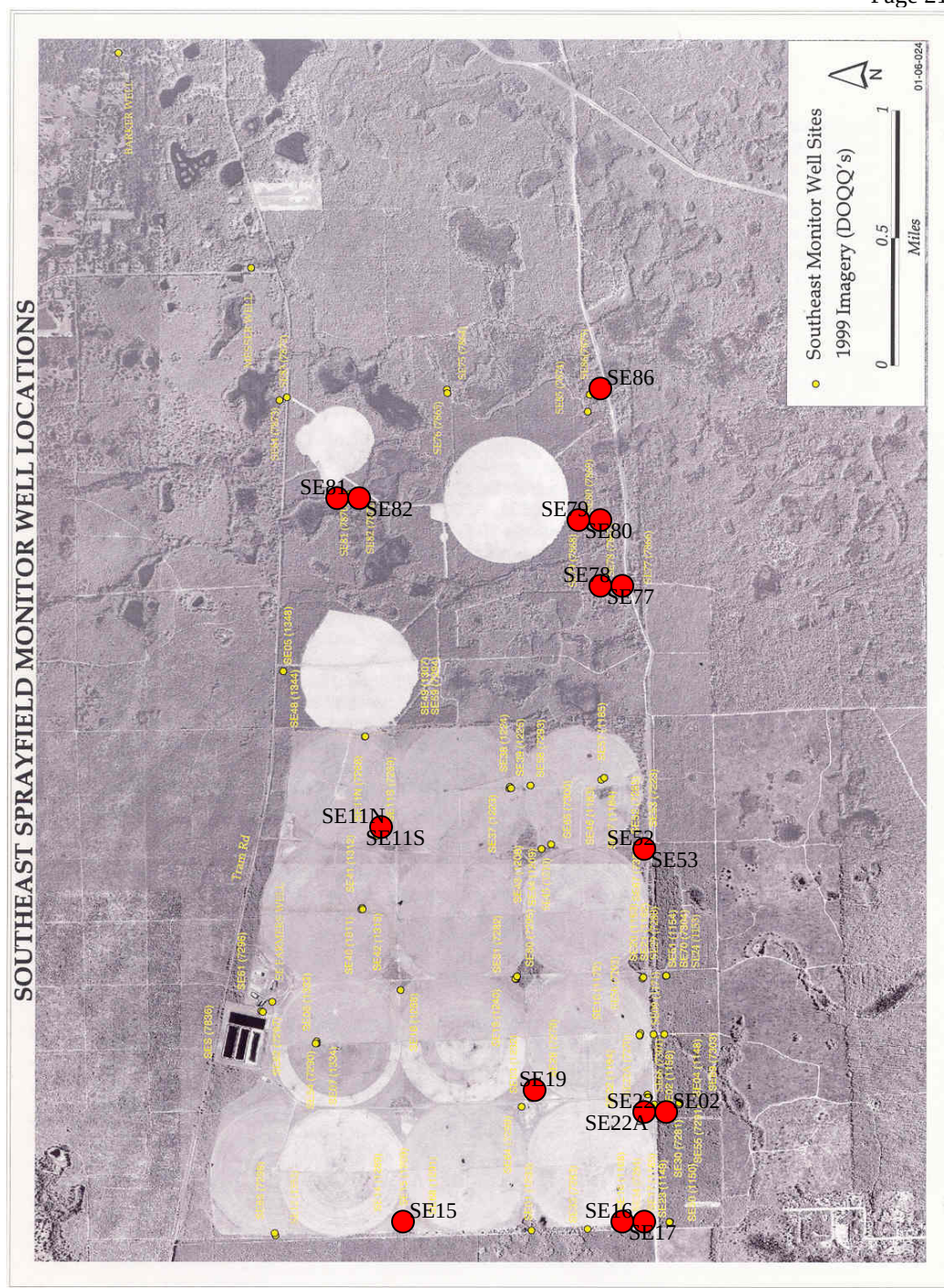


Figure A.15: Well locations on the SESF. From Chellette, Angela, Pratt, Thomas and Katz, Brian G., “Nitrate Loadings as an Indication of Non-Point Source Pollution in the Lower St. Marks-Wakulla Rivers Watershed”, Northwest Florida Water Management District, Water Resources Special Report 02-1, April 2002, 138 pp

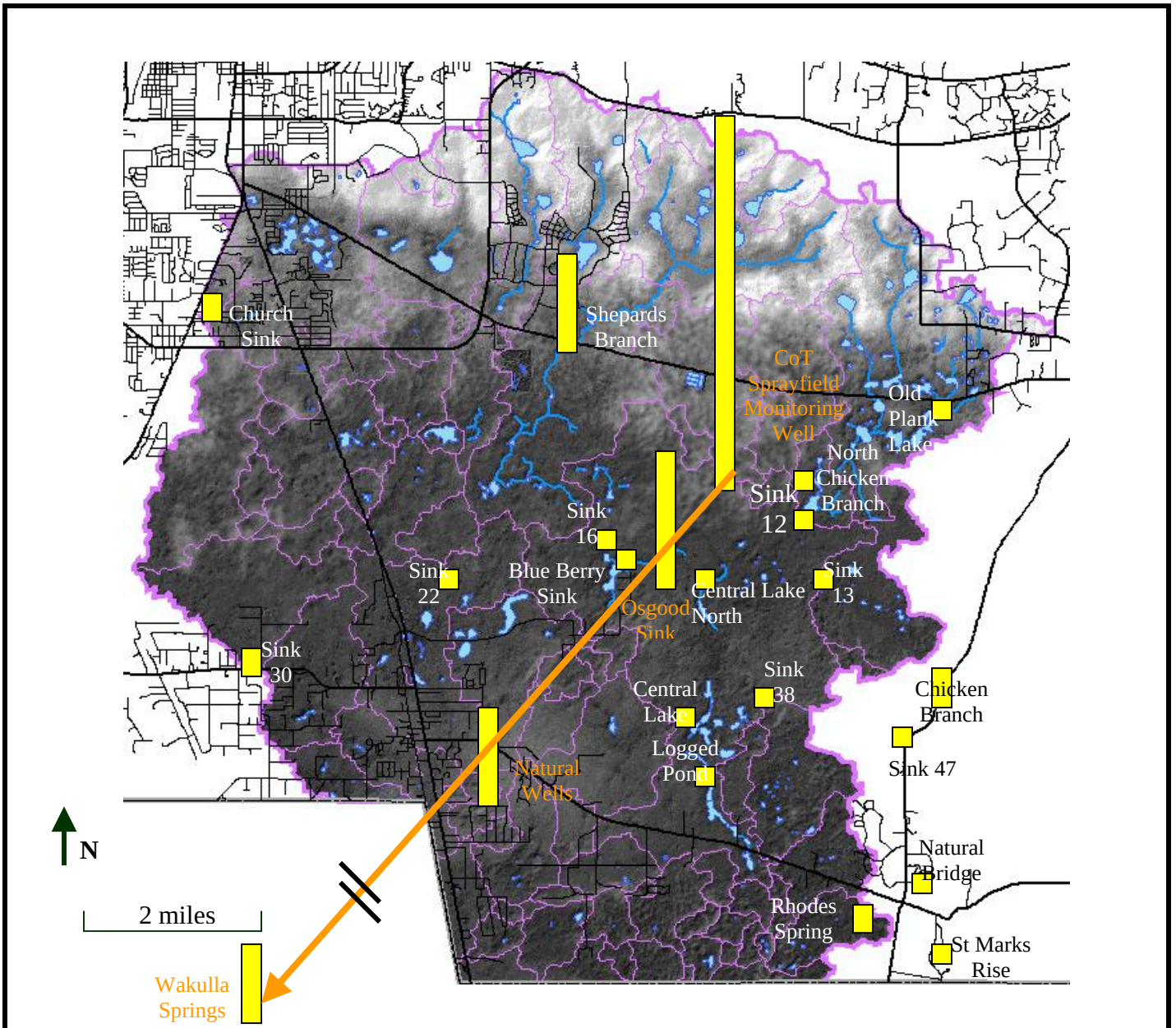


Figure A.16: Nitrate concentrations in the Woodville Recharge Basin surface waters. The column height is proportional to nitrate concentration; 1.0 cm equals 1.0 mg/L nitrate. Numbers associated with the columns indicate well numbers (Table 4).

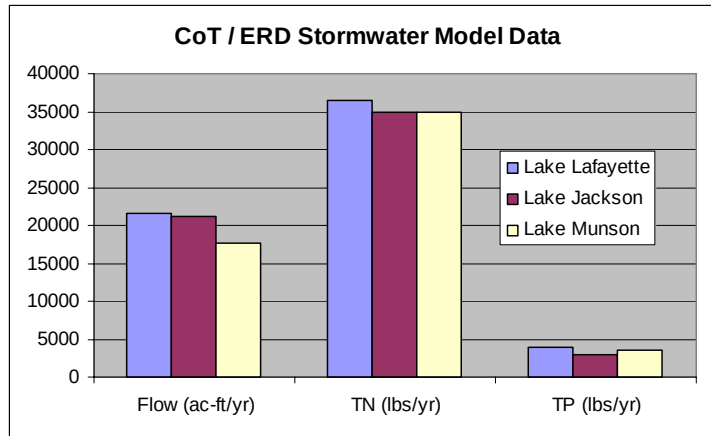


Figure A.17: Graphic from CoT Stormwater Model for flow, nitrogen and phosphorus loading to Lakes Lafayette, Jackson and Munson, all of which drain into sinkholes (Harvey Harper).

Nitrate concentrations within the CoT Sprayfield Monitoring wells, Osgood Sink, Natural Wells and Wakulla Springs had a very interesting relationship (Figure A.16). When these nitrate concentrations are plotted against the distance from the SESF in miles an exponential relationship explains 99.7% of the variability (Figure A.19). If the SESF well represents the nitrate plume diffusing through the soil matrix and the other data points represent conduit flow and the SESF well is then eliminated a linear relationship that has a coefficient of correlation that accounts for 88.7% of the variability results (Figure A.20). When the dilution rate of 2% (theoretical dilution per mile for isotropic porous medium) is plotted (Figure A.21) it is obvious that the actual dilution rate is almost 10% per mile (Figure A.22). Water from other areas must be converging to dilute the SESF nitrate plume. The dilutions of the nitrate plume exceed normal recharge by precipitation and diffuse groundwater flow indicating that conduit flow probably occurs in the portion of the WRB between the SESF and Wakulla Springs.

Water quality data in the Woodville Karst Plain has historically concentrated on nitrate concentrations in the aquifer, not on phosphates. Phosphorus does not normally penetrate the soil matrix and become a concern in the aquifer. If we examine the historical databases for the Leon County Lakes Ecology Program and Wakulla Springs (Figure A.23), we find elevated phosphate in the very lakes impacted by urban stormwater that contain active sinkholes. Note the elevated phosphorus concentrations for Lakes Lafayette and Munson and Jackson. If we examine the nitrates in Leon County surface water (Figure A.24), we notice that the concentrations of nitrates in the same lakes are not elevated. The Ochlockonee River and Lake Talquin are elevated due to sewage inputs from Georgia, though this river is considered perched by geologists. These lakes are directly connected to the aquifer with active open sinkholes. These are karst lakes that

disappear into the aquifer periodically. Leon Counties karst lakes could be a source of phosphorus in the aquifer, not nitrogen.

Wakulla Springs was sampled for a one month during a period of significant rainfall (June to July 2003). The daily readings of phosphate in Wakulla Springs (MLI data) displayed a rather flashy behavior (Figure A.25). This was unlike the daily readings of Nitrate in Wakulla Springs that showed a rather constant nature (Figure A.26). The divergent behavior of these ions implies that they probably derived from different sources. Total Nitrogen (TN, LAKEWATCH data) was plotted against the discharge at Wakulla Springs (NFWFMD). The variation had a significant negative correlation, which could imply dilution of a constant source. Total Phosphorus (TP, LAKEWATCH data) evidenced no significant relationship, which could imply a different source. If phosphorus in the aquifer were derived from urban stormwater flowing into karst features it would derive from a different source. Urban stormwater, elevated in phosphorus, could be communicated into the aquifer without treatment by the soil matrix. This could account for the variability. The phosphorus in stormwater would be highest in the first runoff in the storm; a phenomenon usually termed the first flush. Nitrate, probably derived from a more constant source like septic and sprayfield effluent would constantly percolates through the soil matrix and would be diluted by additional flow in the aquifer.]

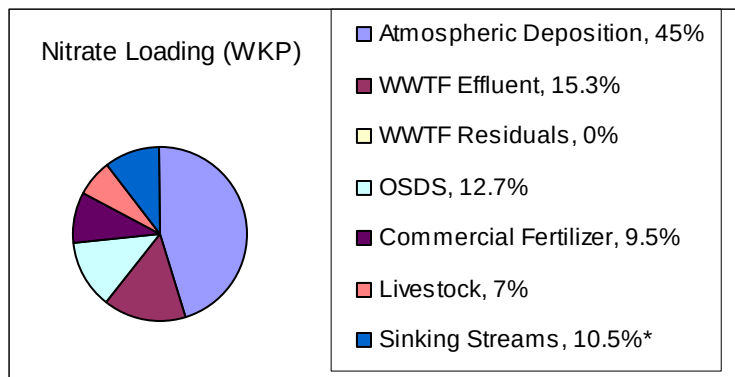


Figure A.18: Nitrogen contribution of sinking streams to the semi-confined and unconfined portions of the Woodville Karst Plain increases from 3% to 10.5% when the loading within the Lafayette, Munson and Jackson watersheds is considered.

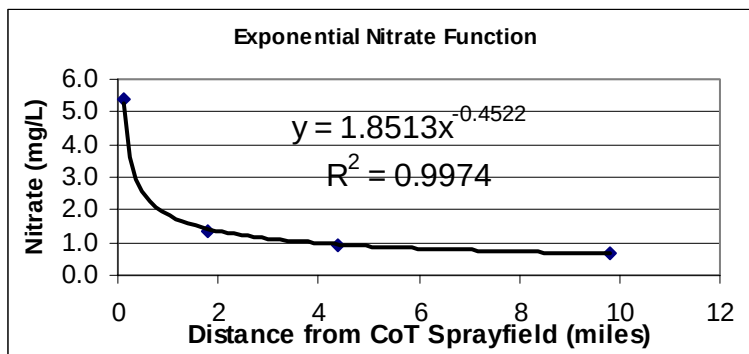


Figure A.19: Nitrate concentrations (CoT Sprayfield Monitoring wells, Osgood Sink, Natural Wells and Wakulla Springs) are plotted against the distance from the SESF in miles an exponential relationship explains 99.7% of the variability.

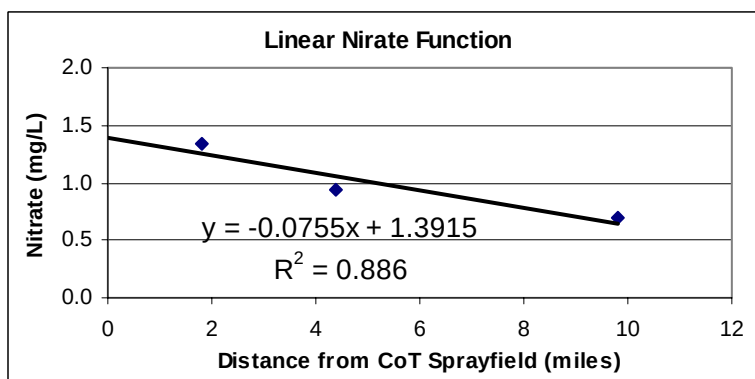


Figure A.20: A linear relationship explains 88.7% of the variability.

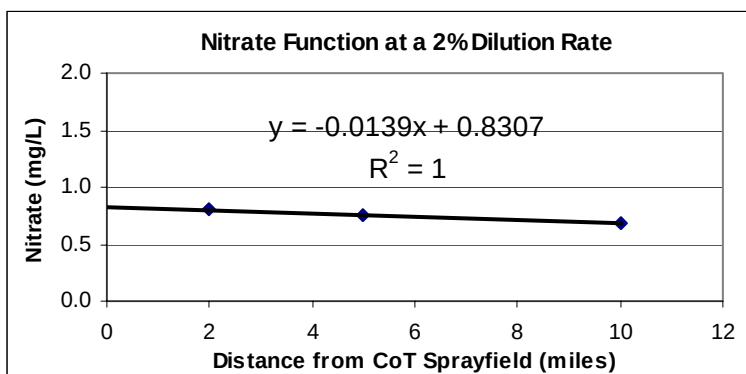


Figure A.21: Dilution rate of 2%, the theoretical dilution per mile for isotropic porous medium.

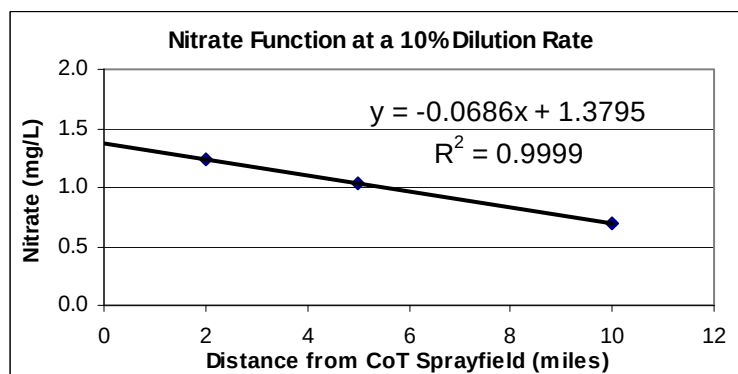


Figure A.22: Dilution rate of 10% per mile.

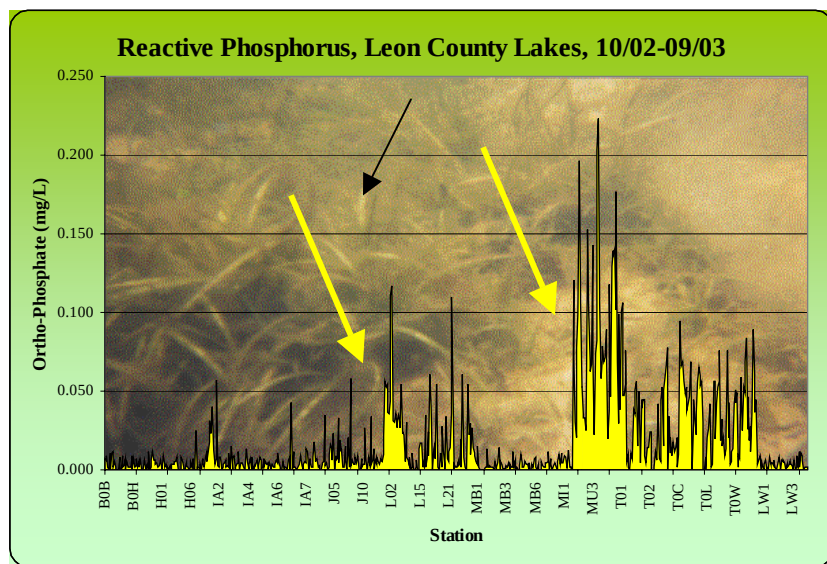


Figure A.23: Phosphate in Leon County surface water. Note high values for Lafayette and Munson. Jackson was dry.

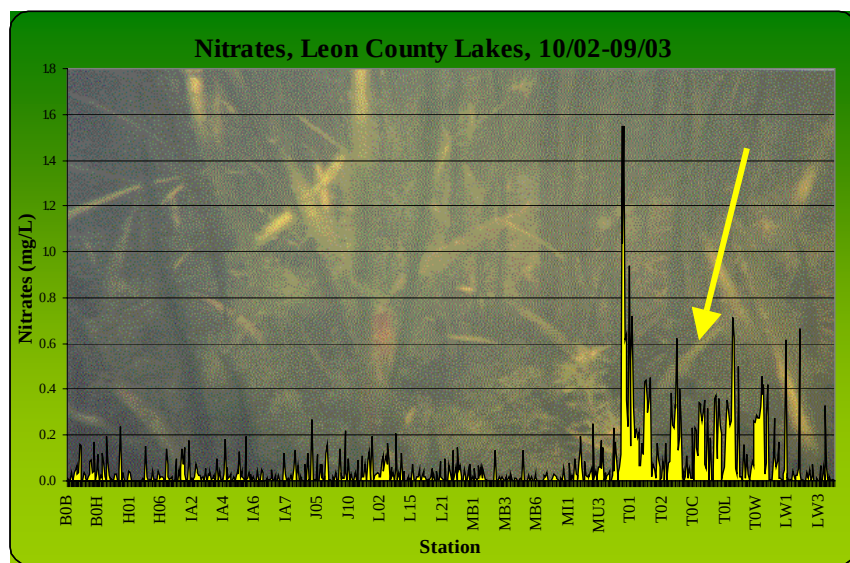


Figure A.24: Nitrate in Leon County surface water. Note lower values for Lafayette and Munson (Jackson was dry). The Ochlockonee River and Lake Talquin are elevated due to sewage inputs from Georgia.

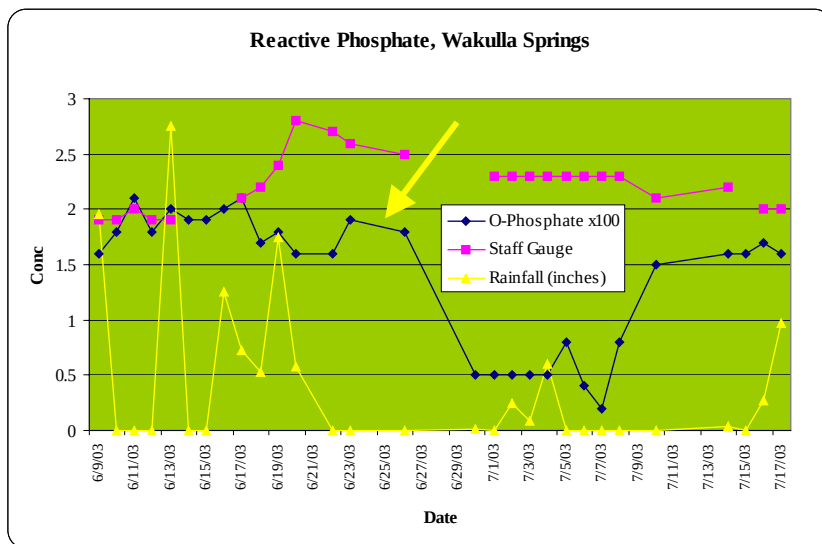


Figure A.25: Phosphate daily readings in Wakulla Springs. Note the flashy nature of concentration swings. Phosphate is in mg/L multiplied by 100 for graphical presentation.

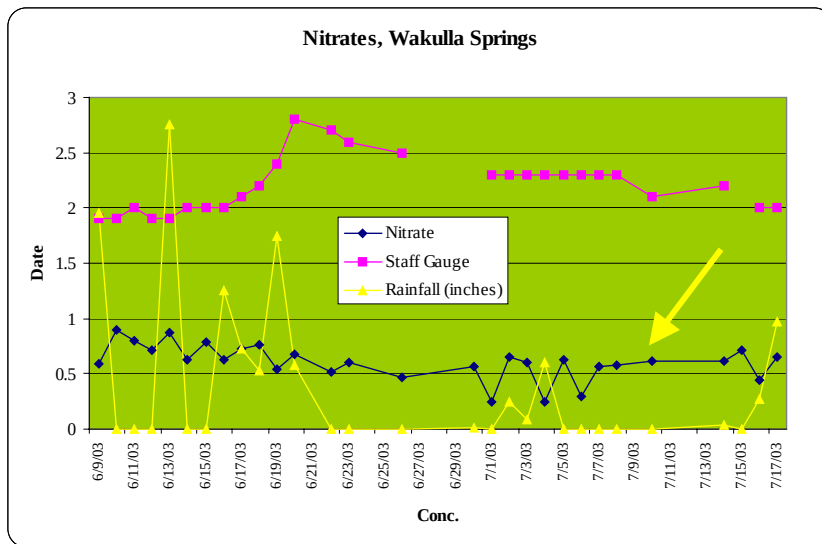


Figure A.26: Nitrate daily readings in Wakulla Springs. Note the rather constant nature of the nitrate concentrations. Nitrate in mg/L.

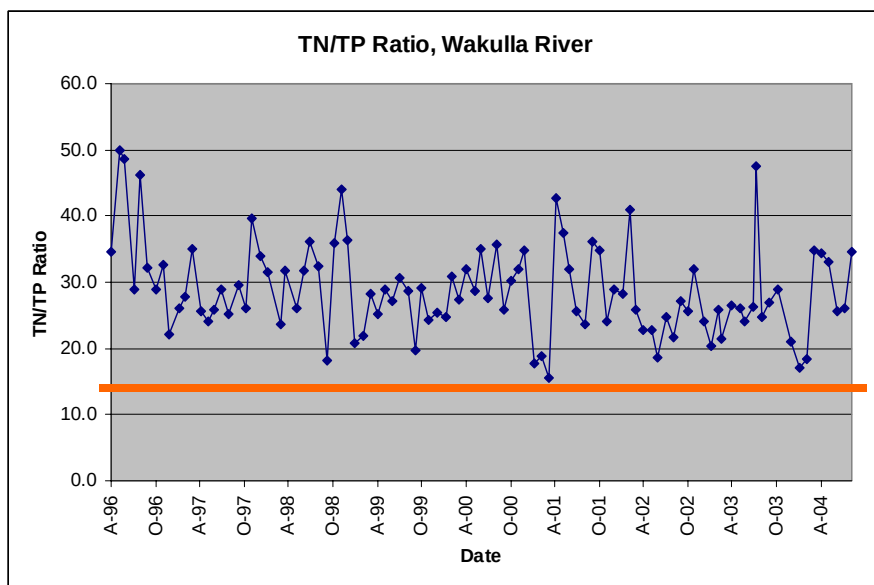


Figure A.27: TN/TP ratios at Wakulla Springs since 1996 have been above 15 (LAKEWATCH Data).

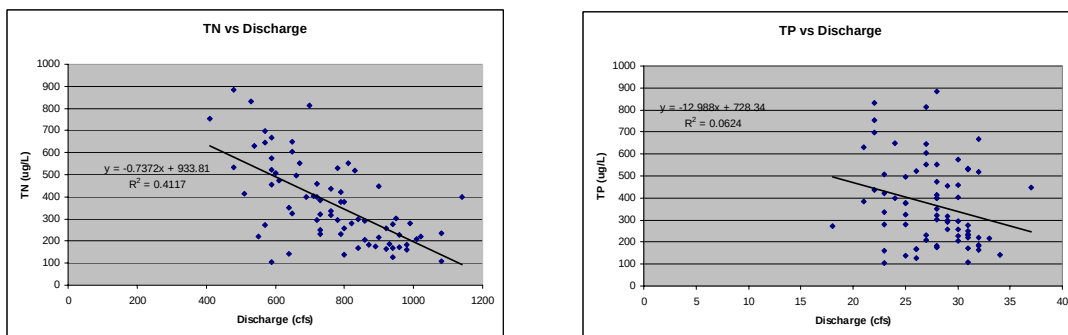


Figure A.28: The relationship with TN and TP to discharge at Wakulla Springs. TN shows an inverse relationship; typically this indicated a dilution factor. TP showed no relationship (LAKEWATCH Data).

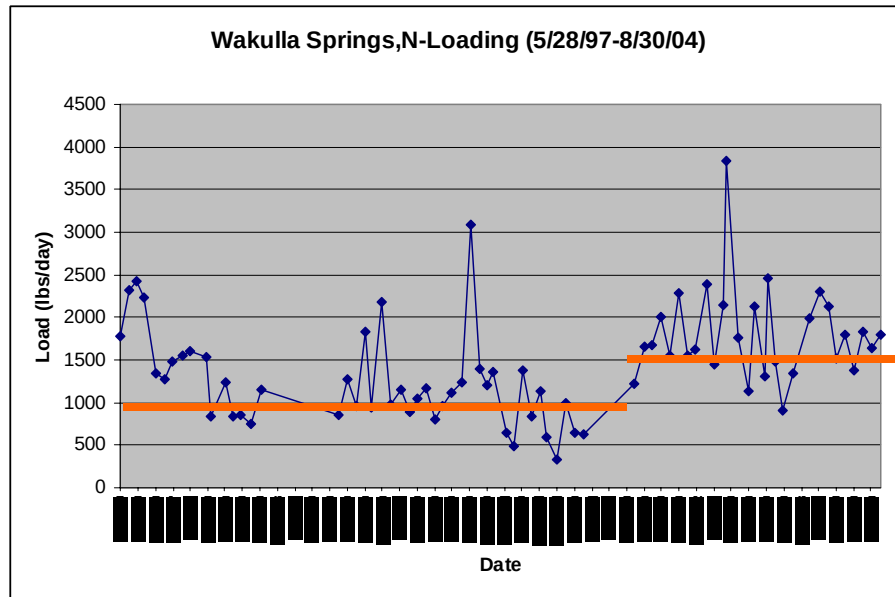


Figure A.29: TN arithmetic average 5/28/97- 4/26/02 = 1239.3 lbs/day
 TN arithmetic average 4/26/02-8/30/04 = 1829.5 lbs/day
 Representing a 47% increase in TN (LAKEWATCH Data)

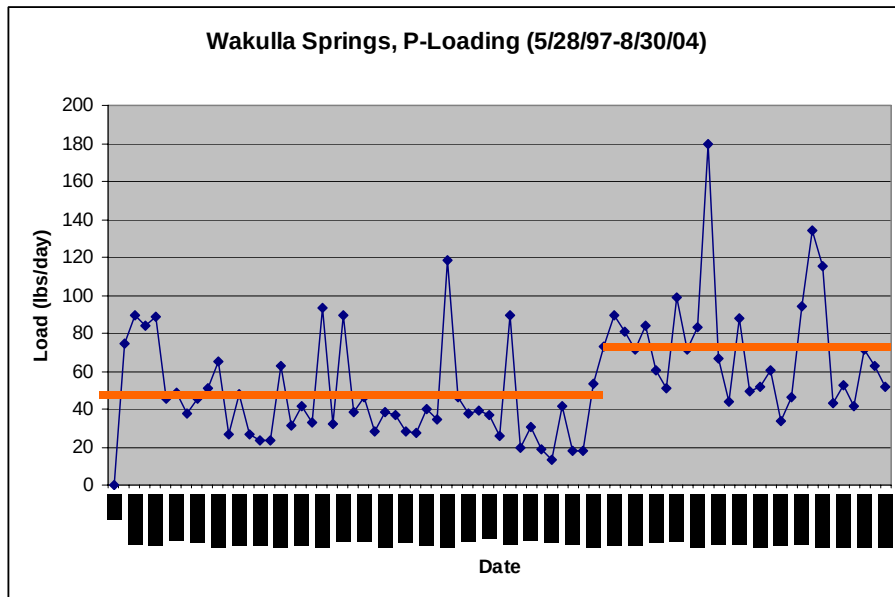


Figure A.30: TP arithmetic average 5/28/97- 4/26/02 = 45.4 lbs/day
 TP arithmetic average 4/26/02-8/30/04 = 73.2 lbs/day
 Representing a 61% increase in TP (LAKEWATCH Data)

Chapter 1

Hydrological Investigations



Ardaman & Associates, Inc.



Section 1.1: Atmospheric Deposition, Water Quality Data

Summary of Results (rainwater)

- The WRB has relatively low atmospheric deposition rates.
- Nutrients in rainwater are too high for healthy springs.
- Nitrogen deposition was higher in the winter months.
- Phosphorus deposition was highest in the summer months.
- Nitrate concentration in the rainwater decreased while passing through the soil.
- Phosphorus concentrations increased as it passed through the soil, this was probably due to soil/water equilibrium.
- Background nutrient concentrations in the WRB reflect the nutrients in our native soils.
- There was a surge in groundwater nutrients following the first rain after an extended dry period.

Conclusions

- Atmospheric deposition of oxidized nitrogen does not seem to have a major effect on groundwater nitrate nutrient concentrations. Phosphate deposition may be more significant but even the sandy soils of the WRB contain enough clay that the soil water equilibrium concentrations of phosphate may play a role.

Methods: Atmospheric Deposition Studies

Three shallow piezometric wells were drilled into the top of the limerock of the surficial aquifer by vibracore along the pipeline corridor in the national forest, an unpopulated area northwest of Woodville (figures 1.1.1-1.1.3). A permit was obtained from the US Forestry Service. These sites were located sufficiently distant from roadways, septic and STP influences. These wells were advanced to a depth of approximately 12-feet on top of a limestone layer. Steve Reese prepared the following account of the lithography from Ardaman and Associates. Only one core was collected for lithography due to budget constraints. At well location PL2, located in the National Forest, we observed a white to tan sand to a depth of 7 feet underlain by a thin layer of tan to brown clayey sand terminating at 8 feet below land surface. Underlying the clayey sand was a tan to brown sand to a depth of 10 feet and finally, underlying this layer was a tan to brown silty slightly clayey sand to a depth of 12 feet. Following advancement of the borings, monitor wells were installed at each location (figures 1.1.11 – 1.1.12).

These wells were monitored utilizing FDEP groundwater sampling protocols (DEP-SOP-001/02, FS 2200 Groundwater Sampling). The wells were sampled monthly and analyzed

for Nitrate+Nitrite, Chloride and Total Phosphorus. NELAC analytical protocols were followed. Due to concerns of possible impacts from the SESF the background wells were moved slightly outside of the WRB to an area in the National Forrest where influence was unlikely. The atmospheric deposition station was located at the middle background monitoring well, PL2. They are located off a gated and locked sand access road near the powerline easement. This access road has little or no traffic. Wet deposition samples were retrieved immediately following rain events (which were not very numerous as this study was conducted during a rather dry time period).

Wet-deposition samples were collected in ultra-trace metal free polyethylene funnels and 1-liter Teflon bottles mounted in a vertical PVC pipe (as illustrated). As shown, the bottle is enclosed in the PVC tube to minimize any photochemical reactions and external contamination of the sampler. The funnel and 1 liter bottle combination allow for a maximum of 16 cm of rain per event to be collected. Sampling stations were located in the national Forrest less than 15 minutes from the laboratory. Samples were collected immediately after the rainfall event and preserved and analyzed according to NELAC protocols. Rainfall events were scarce during the study period but time ranges for the samples were added. Dry deposition samples were not collected as experts cited insurmountable contamination problems.

Precipitation Water Quality Data

The WRB is located in a region of relatively low atmospheric deposition rates. Local data was in agreement with this, but the wet deposition concentrations of nitrogen and phosphorus exceeded the concentrations of these nutrients that are necessary to maintain healthy waterbodies in our region (McGlynn, 2005). The average oxidized nitrogen concentrations exceeded what is thought to be necessary for a healthy spring (0.4 mg/L NO_x, Joe Hand, FDEP). Phosphorus concentrations exceeded the TMDL targets for Lake Okeechobee (0.01 mg/L, FDEP; table 1.1.1 and figure 1.1.6). Oxidized nitrogen deposition was higher in the winter months while phosphorus deposition was highest in the summer months (table 1.1.1 and figure 1.1.5).

Greg Mauldin ran the model the first time before the sampling was over and took an average of an early portion of the data. This is close enough considering experimental error and the inherent error in the model. Future runs can incorporate the updated average. Leon County is in full possession of the WAM Model and all the data. The Tallahassee-Leon County GIS Department can run it any time. Rainfall data from the Counties New Storm Warning System run by the NFWFMD could not be used in this study. There were too many data gaps (not zeros but missing data). While this is probably adequate for a storm warning system it caused grave problems with the WAM model. Rainfall data from the nearby Tallahassee Municipal Airport were used. The WAM model calculates loadings by multiplying volume of rainfall times the concentration of nutrients. Evapotranspiration, due to surface temperature and wind speed were also applied to this calculation by the WAM model.

Concerning the spike in rainfall TP concentrations that occurred in July and August of 2006, heavy rains in the high summer heat are different from winter rains. In the summer high temperatures accelerate desiccation. During the sampling period an extended drought occurred at about this time. Dust from the atmosphere was prevalent and could be observed coating the surface of area lakes at this time. Dust derived from the native soils contains phosphate. This dust was a natural constituent in the local rainfall at that time. Dust being removed by rainfall can also be noted in the relief felt by those suffering from allergies after a good rain. This was not contamination. These particular storms were anticipated and the collection apparatus was serviced before and after the events.

Background Well Water Quality Data

Ninety-five% of the nitrogen in the rainwater was removed as it passed through the soil matrix to reach the water table and our monitoring wells (figure 1.1.10). Phosphorus tended to increase in concentration as it passed through the soil matrix possibly due to soil/water equilibrium (soils contain phosphorus). Atmospheric deposition may not seem have a major effect ground water nutrient concentrations. There were some surprising results that merit further investigation.

The NO_x, TP, and chloride concentrations found in the three wells during the sampling period, are a number of elevated values. On 4/3/06 and 7/17/06 very high values of chloride were posted for well PL2. Chloride is a common constituent of seawater. The salt in the sea is due to the Sodium Chloride content. Chloride derived from atmospheric deposition usually comes from oceanic sources. Wastewater Sprayfields can also affect atmospheric chloride concentrations. The chloride deposition is affected by storm systems from the coast. The WRB is close enough to the coast as to be periodically affected by elevated chlorides of a marine origin. These depositions are probably derived from a marine origin.

PL2 also had high TP values on 5/31/06 and 8/14/06. Well PL1 had high TP values on 12/28/05, 5/31/06, and 8/14/06. It is likely elevated groundwater readings for phosphorus from high TP readings in PL1 and PL2 (PL3 was dry) on 8/14/06 correlate with elevated phosphorus in the rainfall. It is unlikely that there were any spills or dumped effluents in the national forest with gated access roads. These samplings occurred following major isolated rainstorms in an extended dry period in the region. Phosphorus may have been elevated in the rain samples due to atmospheric dust wash out. These karst soils may have less capacity to absorb phosphorus than previously thought or perhaps the dry conditions have an effect on the soil chemistry. However, from a loading perspective this event driven loadings may be rather insignificant. This needs further investigation.

Nutrients and other factors are included in the total attenuation such as soil properties (i.e. soil affinity absorption) evapotranspiration, delayed uptake by the root zone (time

dependant) etc. in the WAM model. The calculations in the model do not have a 20% total attenuation. This factor is only part of the attenuation, the Base Attenuation Coefficient for Subsurface Nutrients.

On a “global” perspective, we are fortunate that the WRB is located in an area of very low deposition rates of nutrients. While the deposition of nitrates is well documented the deposition of phosphorus lacks significant data. Researchers who collect data for phosphorus deposition in Florida told me that they use the data more for QA purposes to see if their sampler was contaminated. The collection of phosphorus data in an automatic sampler, as used by other researchers in Florida, does not seem to be amenable to the protocols for the analysis of phosphate, which requires immediate field filtration and refrigeration. We were able to collect samples immediately after events because of the proximity of our lab to the field stations. Also, since as a lab we did not have to send the samples out for analysis but were able to collect them and analyze them at any time of the day or night and during holidays. While the levels of nutrients in our atmosphere are low by national standards this can change as we burn more fossil fuels and build coal plants. Also, as we burn more fossil fuels the amount of acid deposition will increase. In a fragile karst area where sinkholes form frequently by dissolution processes any increase in acid deposition will only aggravate the situation. There is a need for continued monitoring of these wells since few studies couple background aquifer wells with atmospheric deposition sampling. I hope more research is accomplished.

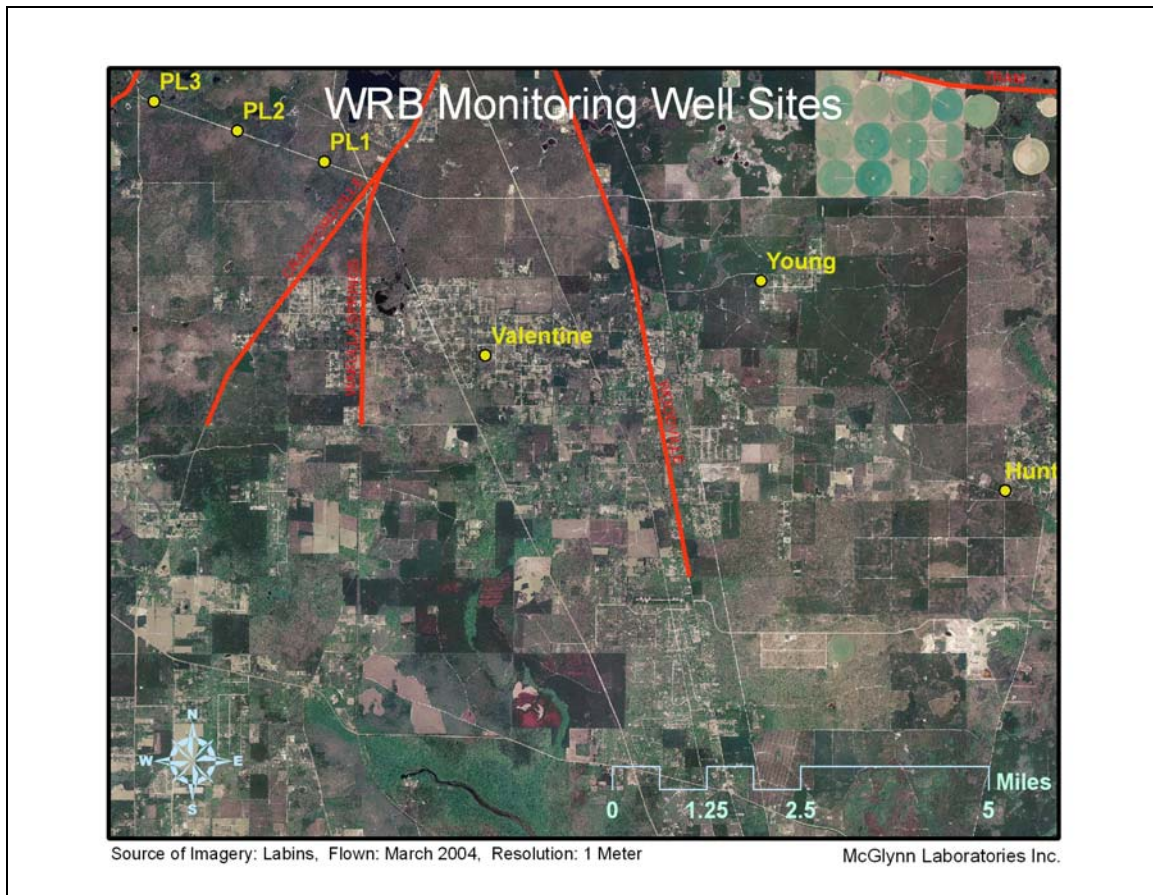


Figure 1.1.1: The location of groundwater wells PL1, PL2 and PL3 and the well's general location in the Woodville Recharge Basin Watershed.

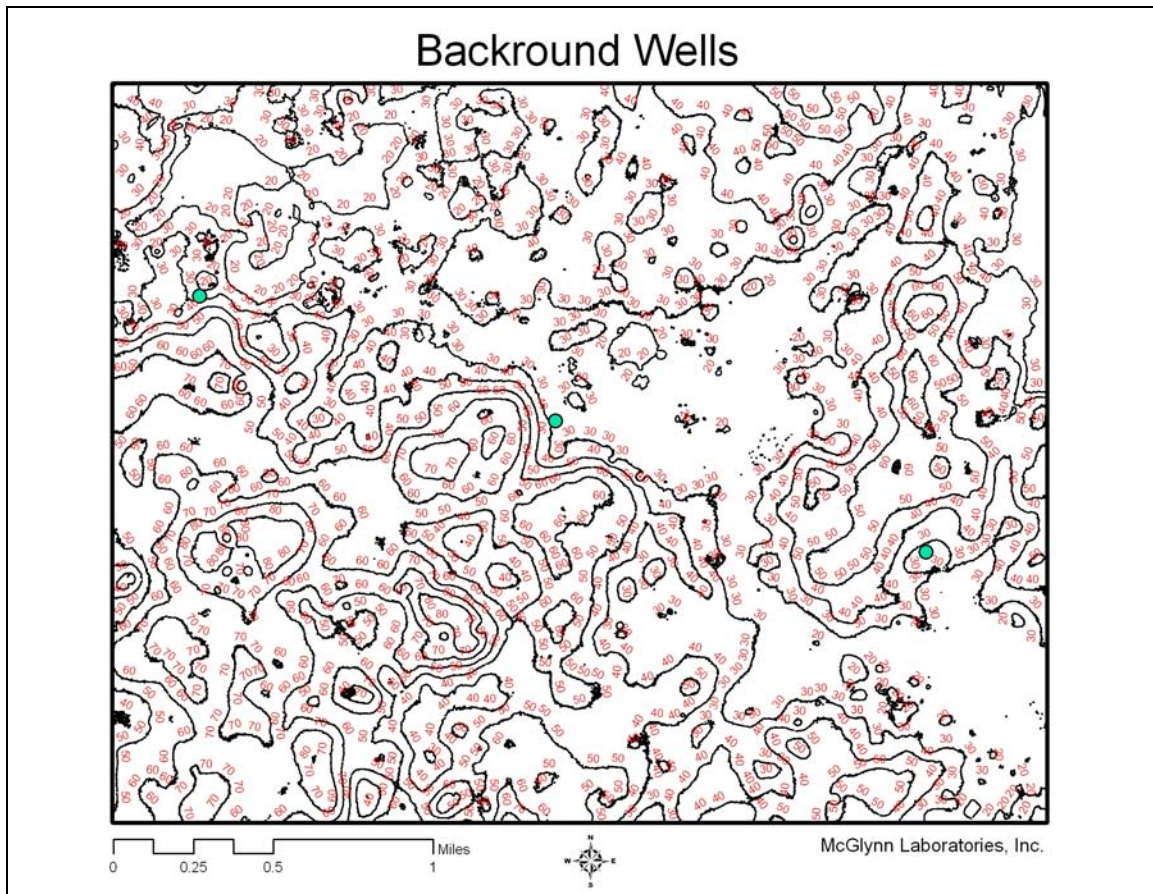


Figure 1.1.2: This detailed schematic diagrams of each of the three groundwater sampling wells with their relative location with respect to each other.

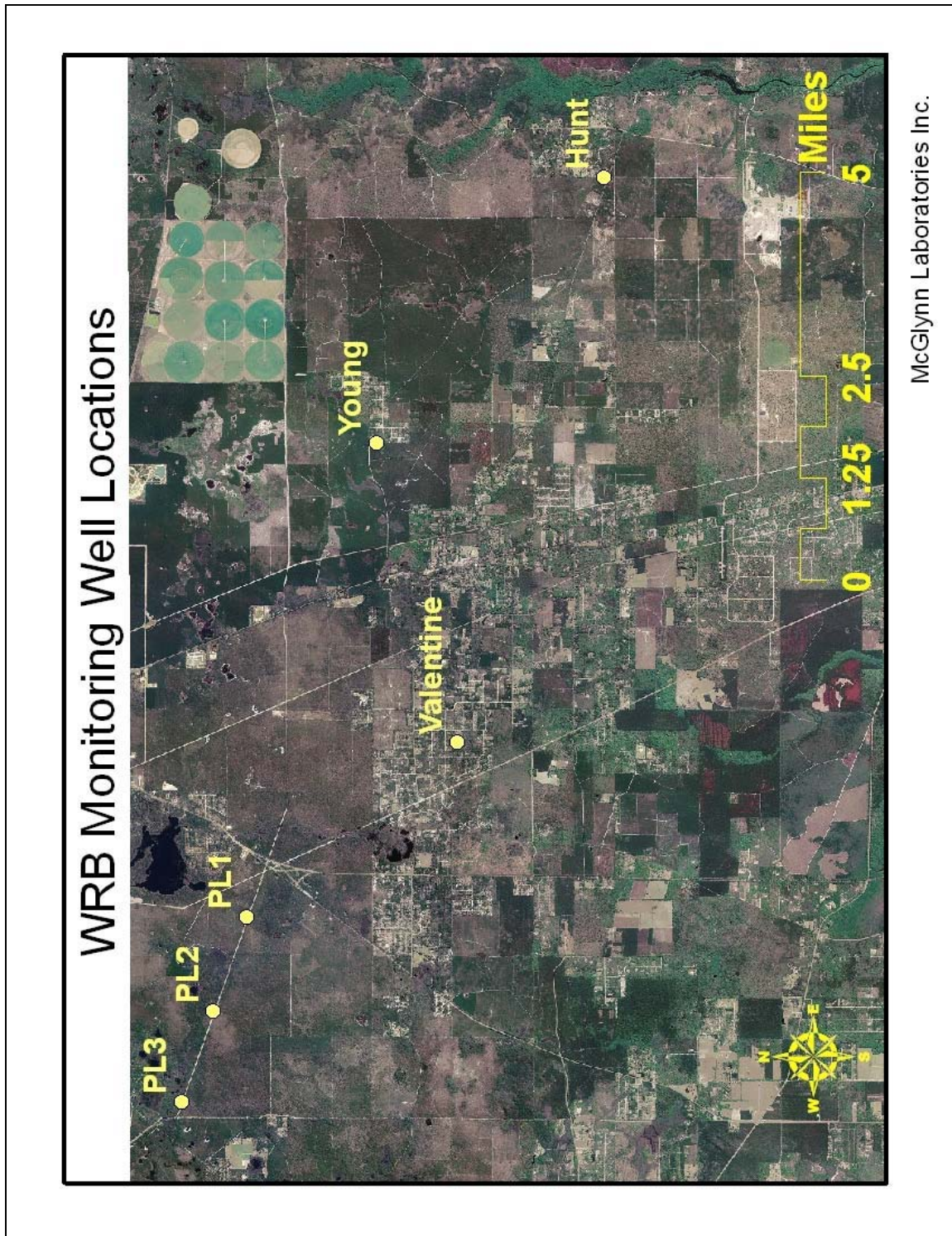


Figure 1.1.3: Locations of the three background wells in the national forest, PL1, PL2 and PL3. The three septic tank monitoring locations are also depicted (Valentine, Young and Hunt).

Table 1.1.1: Experimental results of the monthly rainfall nutrient data in the WRB. Rainfall data was collected from the first day to the last day each month during the study period. Data represents a monthly average concentration based on the total volume of rainfall for that month.

WRB Precipitation	Nitrate+Nitrite	Total P
	EPA	EPA
	353.3	365.2
Date	<i>mdl=0.01</i>	<i>mdl=0.006</i>
Sample	<i>pql=0.04</i>	<i>pql=0.024</i>
Collected	mg/L	mg/L
Oct-05	0.42	0.007
Nov-05	0.44	0.014
Dec-05	0.89	0.020
Jan-06	0.77	0.019
Feb-06	0.53	0.009
Mar-06	0.52	0.010
Apr-06	0.64	0.009
May-06	0.51	0.007
Jun-06	0.25	0.008
Jul-06	0.46	0.021
Jul-06	0.39	0.036
Aug-06	0.38	0.088
Average	0.52	0.021
Minimum	0.25	0.007
Maximum	0.89	0.088
Median	0.48	0.012



Figure 1.1.4: The atmospheric deposition sampling device.

Table 1.1.2: Experimental results for background well nutrient data in the WRB

Task: Woodville Recharge Basin									
Client: Leon County									
Data Set Id.: WRB Summary Background Wells							Nitrate+Nitrite	Chloride	Total P
		Page: 1				EPA	EPA	EPA	
Field Identification Information						353.3	325.3	365.2	
			Date		Date	mdl=0.01	mdl=0.73	mdl=0.006	
	Collection		received at	Repetition	received at	pql=0.04	pql=2.92	pql=0.024	
Station	Date	Time	Laboratory		Laboratory	mg/L	mg/L	mg/L	
PL1	12/28/05	15:45	12/28/05	1	12/28/05	0.03	2.7	0.039	
PL2	12/28/05	14:56	12/28/05	1	12/28/05	0	4.4	0.007	
PL3	12/28/06	dry	dry	dry	dry	dry	dry	dry	
PL1	01/12/06	10:21	2/24/06	1	2/24/06	0.01	2.1	0.002	
PL2	01/12/06	9:12	2/24/06	1	2/24/06	0	2.4	0.003	
PL3	01/12/06	8:15	2/24/06	1	2/24/06	0.03	4.6	0.007	
PL1	02/24/06	12:00	2/24/06	1	2/24/06	0	1.8	0.002	
PL2	02/24/06	11:13	2/24/06	1	2/24/06	0	3.5	0.002	
PL3	02/24/06	10:13	2/24/06	1	2/24/06	0.05	5.3	0.014	
PL1	03/17/06	11:23	4/3/06	1	4/3/06	0.04	4.1	0.017	
PL2	03/17/06	10:15	4/3/06	1	4/3/06	0.03	5.6	0.014	
PL3	03/17/06	9:34	4/3/06	1	4/3/06	0.06	4.7	0.021	
PL1	04/03/06	12:28	4/3/06	1	4/3/06	0.05	3.5	0.022	
PL2	04/03/06	11:36	4/3/06	1	4/3/06	0.02	35.5	0.015	
PL3	04/03/06	10:27	4/3/06	1	4/3/06	0.14	70.9	0.076	
PL1	05/31/06	14:18	5/31/06	1	5/31/06	0.02	4.4	0.031	
PL2	05/31/06	13:45	5/31/06	1	5/31/06	0	5.3	0.042	
PL3	05/31/06	dry	dry	dry	dry	dry	dry	dry	
PL1	07/17/06	13:14	7/17/06	1	7/17/06	0.02	5.3	0.012	
PL2	07/17/06	12:29	7/17/06	1	7/17/06	0.01	16	0.017	
PL3	07/17/06	dry	dry	dry	dry	dry	dry	dry	
PL1	08/14/06	13:14	8/14/06	1	8/14/06	0.03	2.7	0.096	
PL2	08/14/06	12:29	8/14/06	1	8/14/06	0.02	6.2	0.148	
PL3	08/14/06	dry	dry	dry	dry	dry	dry	dry	

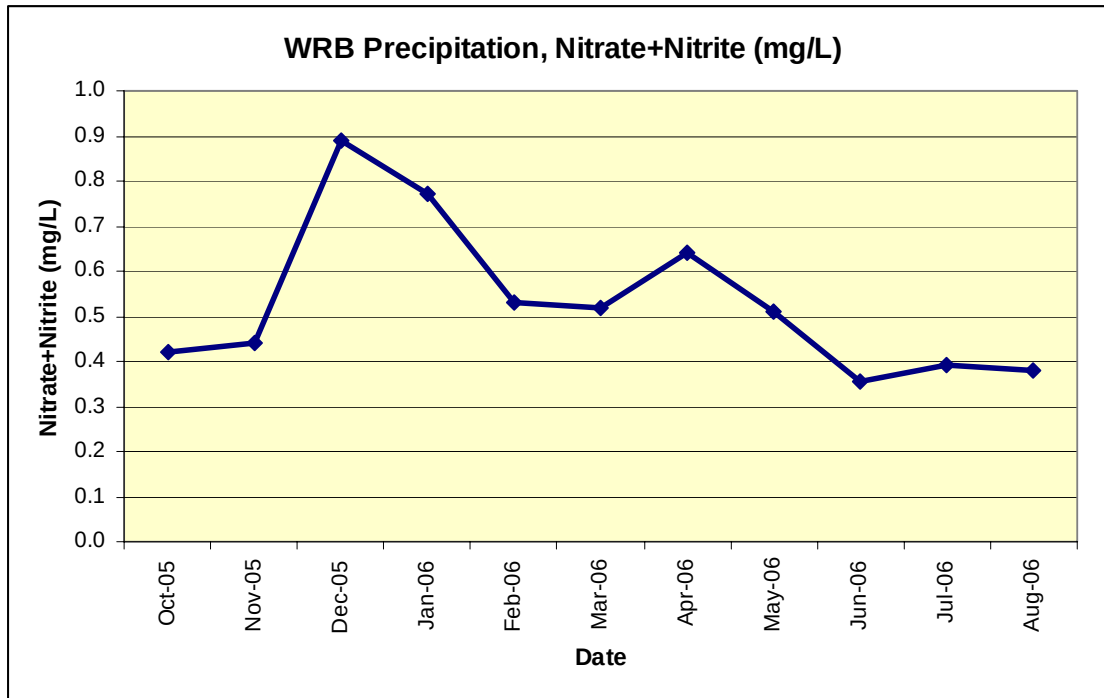


Figure 1.1.5: Wet deposition, oxidized nitrogen.

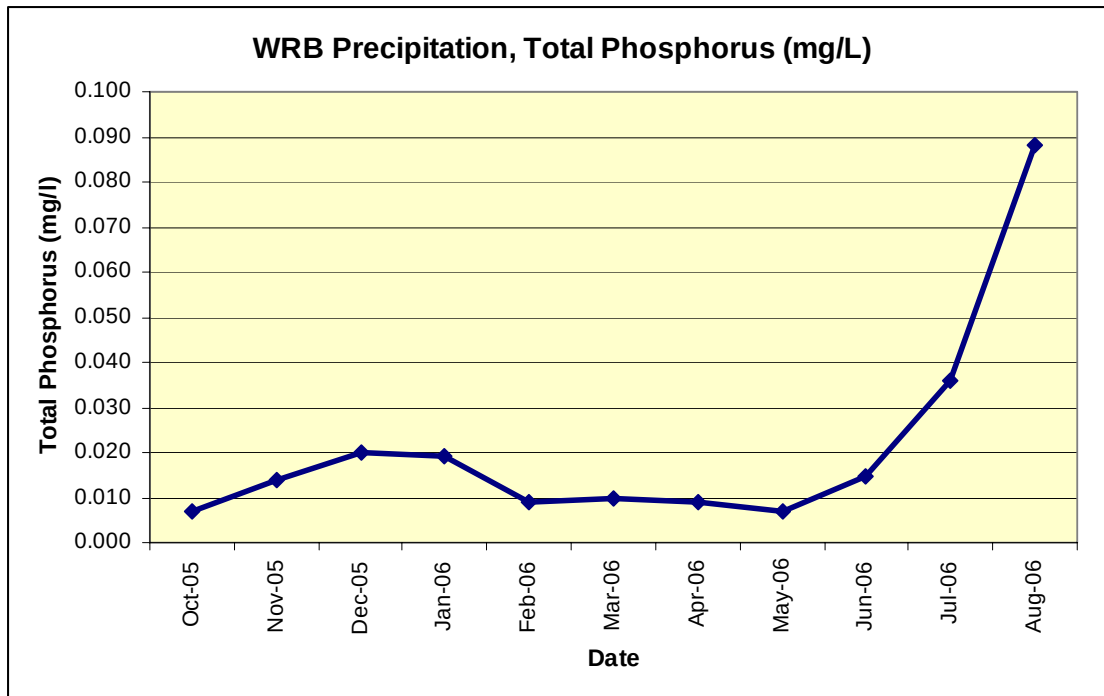


Figure 1.1.6: Wet deposition, total phosphorus.

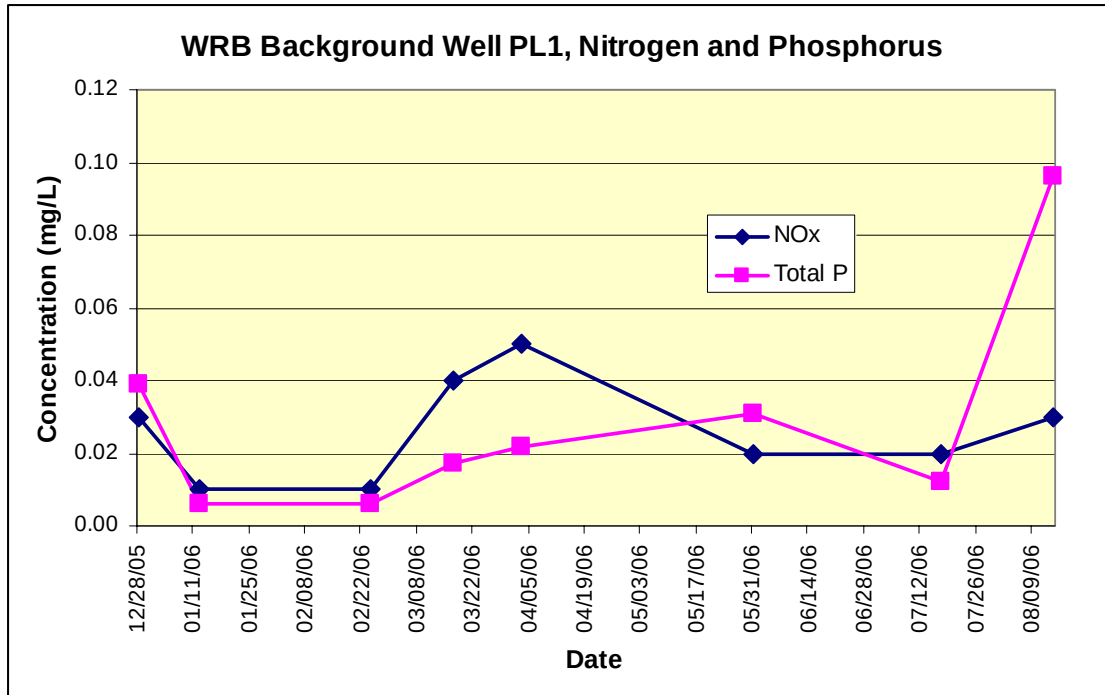


Figure 1.1.7: Oxidized nitrogen and phosphorus in background well 1. There was a surge in groundwater nutrients following extended dry periods.

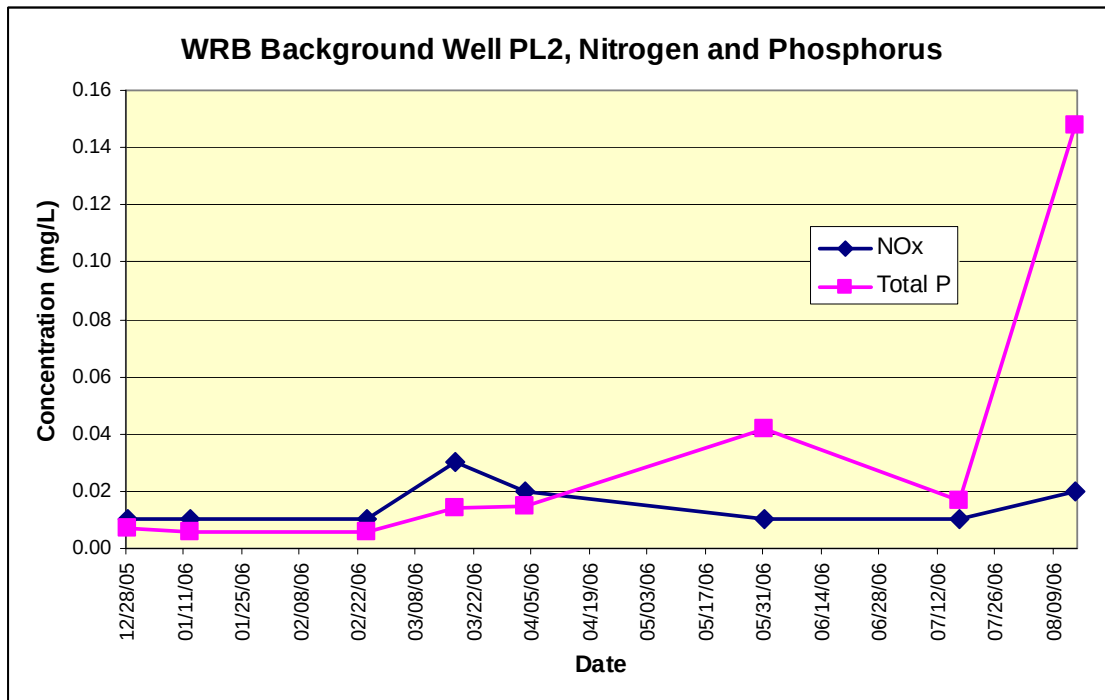


Figure 1.1.8: Oxidized nitrogen and phosphorus in background well 2. There was a surge in groundwater nutrients following extended dry periods.

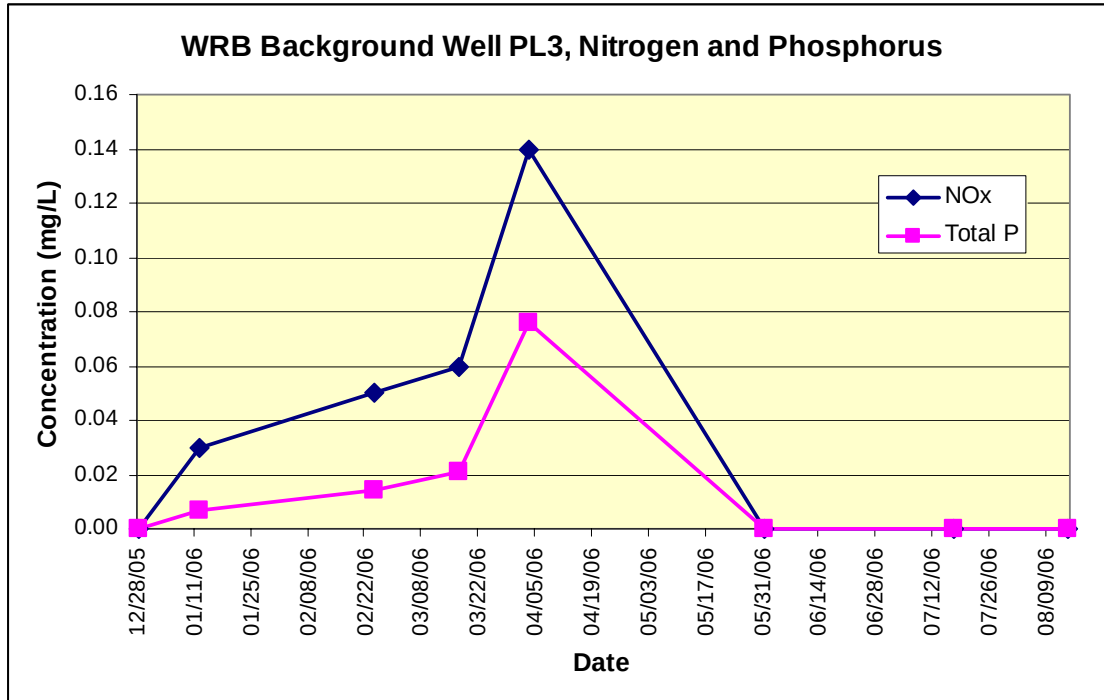


Figure 1.19: Oxidized nitrogen and phosphorus in background well 3. This well was dry during the summer of 2006 because of drought conditions.

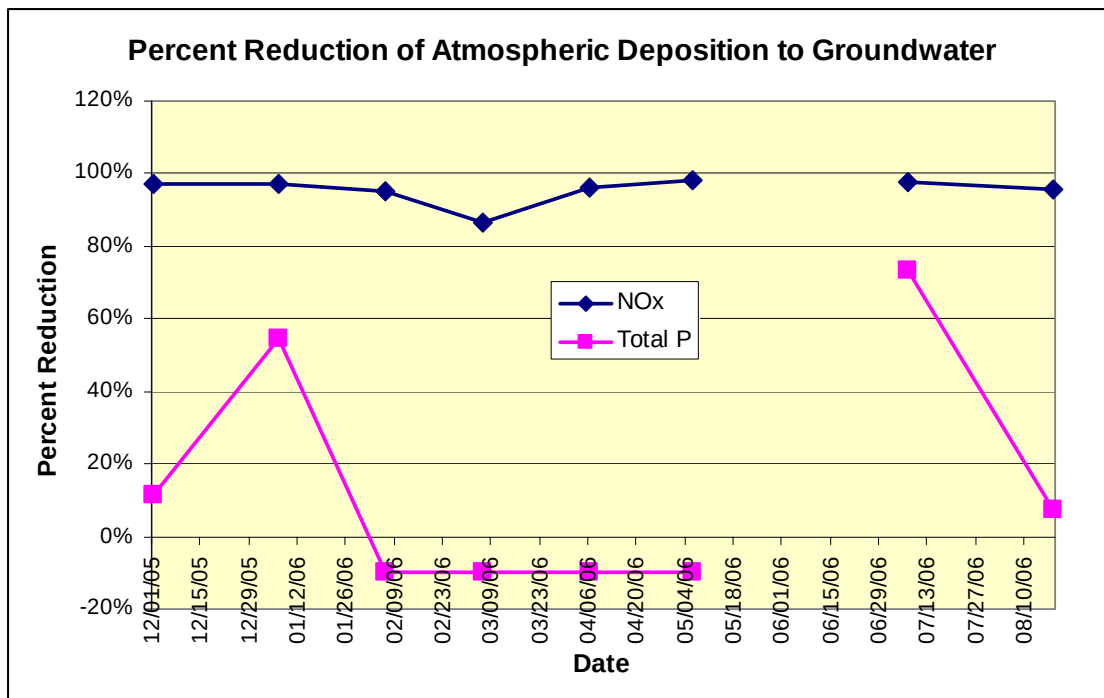


Figure 1.1.10: 95% of the nitrogen in the rainwater was removed and did not interact with the aquifer. Phosphorus tended to increase in concentration as it passed through the ground probably due to soil/water equilibrium. Atmospheric deposition does not seem to affect ground water nutrient concentrations.



Figure 1.1.11: Coring into the top of the aquifer. Steve Reece of Ardaman and Associates sampled the cores. JD Kemp Geological Investigations installed the wells.



Figure 1.1.12: WRB background monitoring well number 2.

Section 1.2: Septic Tank Study

Summary of Results (wastewater)

- The septic tank systems tested in this study did not have dramatic effects on the surficial aquifer
- Approximately 50% of the high dose nitrogen treatments were attenuated in mesocosms and this calibrates the WAM model's predictions.
- Phosphorus was completely attenuated in mesocosms.

Conclusions

Mesocosm experiments indicate that nitrogen from wastewater likely has a greater effect on the aquifer than phosphorus.

The surficial white sandy soils collected in this experiment did not contain the sparse clays found at depth in the atmospheric deposition monitoring wells. Clays often have high phosphorus content. The phosphorus from the sparse clays may have desorbed into the water in the atmospheric deposition monitoring wells. Since clays were absent from the mesocosm cores attenuation rates for phosphorus were improved. The attenuation rates from the experimental section agreed very well with the model results. The WAM model calculates the attenuation rates based on many factors that change with soil temperature and moisture content as well as the soil type.

Methods: Septic System Studies

Septic tank systems were monitored quarterly. Three sites had four quarterly sampling events (figure 1.2.1). Three monitoring wells were placed around each septic tank site using a vibrocore to install the well screen into the top of the surficial aquifer system under the personal supervision of a geotechnical engineer, Steven Reecy of Ardaman and Associates. The sites were selected for the following characteristics as well as for the necessary willingness of the resident to have their septic system probed.

- 1) Good soil, high OSDS density (Rhodes Cemetery, Young Residence)
- 2) Poor soil, low OSDS density (Natural Bridge Road near the St. Marks Rise, Hunt Residence)
- 3) Poor soil, high OSDS density (Spiral Garden off Woodville Highway, Valentine Residence)

It was very kind of the local residents to allow us to invade their property to study their septic systems. The maps included in this section contain roadways, topos and the condition of the sites depicted as digital orthoquads (figures 1.2.1-1.2.10). Well lithography and descriptions follow. The young well core contained the most clay but had the worst treatment.

Three separate septic tank systems were monitored during this study to observe the changes in groundwater concentrations of oxidized nitrogen, chloride, and total phosphorus as a function of proximity to septic tanks and population centers. In addition, the concentrations of these constituents within the shallow and deep aquifers were compared. The data set obtained is too limited to identify the mechanisms involved or provide definitive proof of the relationships observed. However, this study does provide anecdotal evidence of the effect of septic systems on the shallow and deep aquifer in the Woodville area that may provide direction for a more detailed study.

In this study, a truck-mounted geoprobe was utilized to advance continuous soil probes at the locations outlined in Figure 1.2.1. Borings were advanced at the Hunt site, the Valentine Site, and the Young Site. Specifically, borings were advanced at well locations, HW-1, VW-2, and YW-1. In general, we observed the following strata:

The lithology at the Hunt site, the Valentine site and the Young site, were relatively similar. At the Hunt site a brown to tan silty sand was observed at HW-1 to a depth of 4.5 feet. This soil was underlain by a fine white sand to a depth of 6 feet. Underlying this layer was an orange and gray sand mottled with fat clay (locally known as “pipe clay”) to a depth of 12 feet. Below this fat clay layer was a tan, calcareous, sandy clay to the termination of the boring at 14 feet. In the location of the Valentine well (VW-2), a brown to tan silty sand was observed to a depth of 6 feet. This soil was underlain by a white fine sand to a depth of 11 feet. Underlying the fine sand was a tan to brown slightly clayey sand to a depth of 16 feet. Finally an orange and gray mottled fat clay was observed to the termination of the boring at a depth of 20 feet below land surface. At the Young site, at Well YW-1, a brown to tan silty sand was observed to a depth of 3.5 feet underlain by a tan to brown clayey sand to a depth of 4.5 feet. Underlying these sand layers was an orange and gray sandy fat pipe clay to a depth of 11 feet and a tan clayey sand to a depth of 12 feet. A tan calcareous clayey sand (lime silt) was observed underlying the tan clayey sand to a depth of 14 feet. These lime silts were underlain by a limestone layer to the termination of the boring at 15 feet. Following advancement of the borings, monitor wells were installed at each location.

Septic Tank Data Summary

At the Hunt site (figures 1.2.1, 1.2.2-1.2.4), a source well was installed next to a residential septic tank to a depth of 14-feet on top of a limestone layer at HW-1. A background well, HW-3, was also installed at a location believed to be beyond the influence of the septic tank to the same depth. Sample points HW-3 and HW-2 are the

locations of a potable drinking water well and a sink hole. The Hunt site is considered to be located in a moderately populated area in Woodville.

At the Valentine site (figures 1.2.1, 1.2.5-1.2.7), a source well was installed next to a residential septic tank to a depth of 20-feet at VW-2. A background well, VW-1, was also installed at a location believed to be beyond the influence of the septic tank to the same depth. Sample points VW-3 and VW-4 are the locations of water spigots associated with a water well. The Valentine site is considered to be located in a relatively heavily populated area in Woodville.

At the Young site (figures 1.2.1, 1.2.8-1.2.10), a source well was installed next to a residential septic tank to a depth of 14-feet on top of a limestone layer at YW-1. A background well, YW-2, was also installed at a location believed to be beyond the influence of the septic tank to the same depth. Sample point YW-3 is the location of a potable drinking water well. The Young site is considered to be located in a relatively lightly populated area in Woodville.

Following installation, the wells were sampled quarterly and analyzed for oxidized nitrogen by EPA method 353.3, Chloride by EPA method 325.3, and Total Phosphorus by EPA method 365.2 (analytical results, table 1.2.3).

Following the compilation of the analytical results, a table was then generated which compares the average of the constituent concentrations analyzed from source wells located adjacent to the septic tanks to the average background well concentrations from wells believed to be beyond the influence of the septic tanks. The results are tabulated in Table A.

The raw effluent data from table 1.2.2 cannot be used to generate a loading as sewage concentrations are variable with time. Flow volumes were impossible measure within the budget of this study. It does however give an idea of the initial and final water quality.

Table 1.2.1: TABLE A

Location	Average Shallow Background Well Concentration (mg/l)			Average Shallow Background Well Concentration (mg/l)		
	NOx	Chloride	Total P	NOx	Chloride	Total P
Hunt HW-3/HW-4 (Moderate Population)	0.905	24.35	0.032	0.063	7.1	0.0075
Valentine VW-1/VW-4 (Heavy Population)	0.057	7.975	0.00675	0.165	8.0	0.0035
Young YW-2/YW-3 (Low Population)	1.577	15.725	0.00575	0.095	5.75	0.01825
Average Populated Areas	0.846	16.02	0.015	0.107	6.95	0.00975
PL2 Background (Unpopulated)				0.01	9.862	0.031

Though the data set is limited, the data suggests the following:

- The concentrations of oxidized nitrogen appears to be significantly higher, perhaps by a factor of 10, in the shallow aquifer adjacent to the septic tanks when compared to points more distance located on the same parcel. This appears to indicate that oxidized nitrogen concentrations decrease relatively rapidly within the shallow aquifer as a function of distance due to either dilution or natural processes.
- The concentrations of chloride and total phosphorus appear to be slightly elevated, perhaps by a factor of 2, near the septic tank area. These concentrations also appear to decrease relatively rapidly within the shallow aquifer as a function of distance due to either dilution or natural processes.
- Based upon the proximity of well locations within heavily populated areas, moderately populated areas, lightly populated areas, and unpopulated areas, there appears to be some correlation between the concentration of oxidized nitrogen and population density (based on adjacent developed area) in the shallow aquifer. However, there is no, or possibly even inverse correlation between concentrations of Chloride and Phosphorus relative to population density (based on adjacent developed area).

A second table was then generated, which compares the average of the constituent concentrations analyzed background well samples to constituent concentrations analyzed in deep well samples. The results are provided in Table B (below).

Table 1.2.2: TABLE B

Location	Average Shallow Background Well Concentration (mg/l)			Average Deep Well Concentration (mg/l)		
	NOx	Chloride	Total P	NOx	Chloride	Total P
Hunt HW-3/HW-4 (Moderate Population)	0.063	7.1	0.0075	0.12	7.1	0.014
Valentine VW-1/VW-4 (Heavy Population)	0.165	8.0	0.0035	0.276	7.1	0.013
Young YW-2/YW-3 (Low Population)	0.095	5.75	0.01825	0.64	9.075	0.00625
Average	0.107	6.95	0.00975	0.345	7.758	0.03325

Though the data set is limited, the data suggests the following:

Shallow aquifer concentrations of oxidized nitrogen, chloride, and total phosphorus are roughly less than or equal to those concentrations found in the deep aquifers samples.

- Provided that these constituents are not removed during a drinking water purification process, this implies that septic tank activity is not elevating the deep aquifer concentrations. The observed background concentrations of these constituents observed in the shallow water table would dilute the concentrations found in the deeper aquifer in the event that the two aquifers intermixed.

Methods: Mesocosm Studies

Invitro mesocosms consisted of an ANOVA array of 8 inch diameter cores taken in the study area (4 x 4 matrix). The mesocosm tests focused on pollutants found to be significant in the Atmospheric Monitoring experiments, phosphorus and nitrogen (McGlynn and Kwader, 2005). Two invitro mesocosm experiments were run each month, one for phosphorus and another for nitrogen. Concentrations of nitrogen and phosphorus were designed to create treatments that would simulate the effects of sprayfield and septic tank effluent. A series of treatments differing in concentrations of nitrate and soluble reactive phosphorus were arranged in a standard bioassay (Rand and Petrocelli, 1985). Four treatments of nitrate were used in this study and consisted of approximately: blank; 0.15 mg/L; 1.5 mg/L; and 15 mg/L. Four treatments of phosphate were used in this study and consisted of approximately: blank; 0.3 mg/L; 1.0 mg/L; and 2.0 mg/L. The treatments were made from commercial ACS grade reagents. Bioassays were arranged for an ANOVA. Four replicates for each of the four treatments were assayed separately

twice a month for phosphorus and nitrogen. The treatments and replicates were randomly and equally interspersed (data analysis, figures 1.2.5-1.2.19).

Cores were taken randomly in the Apalachicola National Forrest near the background well MW-2 where the rainfall station was also set. We determined that the predominant groundcover was Long Leaf Pine forest and the cores were taken in this habitat. Cores were taken in the WRB and consisted of the typical surficial soil in the basin, white sand (figure 1.2.11). These soils lacked clay particles but were infused with some black organic matter. These soils were not hydric. Cores were 18 inches deep, including vegetative cover, the root zone and local sediment underlying the root zone. Fresh cores were taken in the WRB for each mesocosm experiment. Cores were open on the top and screened on the bottom. Native grasses predominated in the cores. Grasses are difficult to identify without an inflorescence but included wiregrass (*Aristida stricta*), immature gallberry, sweetbay (*Magnolia virginiana*), swamp cyrilla (*Cyrilla racemiflora*), blueberries, and blackberries. Each core had a liter of water applied through a sprinkler system to simulate a gentle rainfall. All 16 cores were 18 inches high and 6 inches wide and accommodated 12 inches of native soil.

The greenhouse was located 3 miles from the study site at our laboratory in Tallahassee. Weather conditions at our laboratory are very similar to that in the field site. The greenhouse was under a tree canopy of Loblolly Pine, Water Oak and Live Oak. This has similar optical characteristics to the longleaf pine habitat where the cores were taken. Sunlight, shade, humidity, and temperature regimes were similar to the conditions from where the vegetation/soil samples were taken. Rainfall was the variable and the cores were not subjected to rainfall but were watered with nutrient free water at a natural rate to mimic the WRB. During much of this study there was little rainfall. Cores were maintained at normal seasonal temperatures, solar radiation intensity and photoperiod in a greenhouse 2 miles from study site in Tallahassee, Florida. Experiments were performed quarterly (to account for seasonality). Treatments were applied to the top of the cores as simulated rainwater. Exuded pore water was collected at the base in a specially designed siphon apparatus. The difference between the initial and final concentrations of the rainwater represent uptake.

The use of an ANOVA array facilitated the calculation and interpretation of statistically significant results from the experiment (Remington and Schork, 1970). These experiments evaluated the effects of WRB soil on both rainfall and spray field effluent. An ANOVA array is a very standard statistically based experimental setup. Unfortunately the apparatus has already been disassembled and was not very interesting to look at in the first place. It was constructed from PVC pipe with a siphon from the bottom of the core to draw water off for analysis after it passed through the core. In an ANOVA analysis there is no difference in the experimental setup. All the cores were identically and randomly selected at the study site. In a 4x4 ANOVA Array there are 16 cores and 4 different treatments each with four replicates. In an ANOVA Array the difference is in the treatments. In this manner the statistically the relevant differences between the variables (Nitrogen and Phosphorus treatments) were elucidated.

Mesocosm Data Summary

Mesocosm results showed highly significant results for the nitrite treatments (low p-values and high f-values. Results for the phosphorus mesocosms were not statistically significant. Approximately 50% of the nitrogen treatments were attenuated as it passed through the mesocosms. Phosphorus was almost completely attenuated as it passed through the mesocosms. After passing through the mesocosm experiment the final concentration of phosphorus was probably due to soil/water equilibrium values since the soils in the WRB contain phosphorus. The equilibrium value of phosphorus seems to be about 0.016 mg/L phosphate.

There is significant nutrient uptake in the WRBs sandy soils. The WAM model calculates uptake in a complex manner utilizing numerous factors and conditions. Experimental values were used to calibrate the WAM model. Initial runs did not agree with the experimental data. When good data was inputted into the model and all the variables were accounted for the model outputs agreed with the experimental results. There was not a single factor, or rather in the WAM model there was not just one calculation that is responsible for uptake. There are multiple factors. These experimental results showed that factors observed in the mesocosms, like nitrate pulses were also included and predicted by the model. The uptake of nutrients predicted by the model was confirmed by these field studies.

Soil moisture and seasonality seem to affect nutrient uptake and release. From the results of this experiment soil moisture seems to be the most important. Temperature, which is quite variable also seems to have played a role. This investigation should be continued because with the number of variables involved one year of quarterly data is not enough analyze seasonal trends. In addition the physical disturbance of the soil has an effect on nutrient uptake and release. This could account for some of the nutrient release noted when the septic tank at the young site was replaced with a more advanced system. It should be noted that the released nutrient seem to have shown up at a sinkhole on the property,

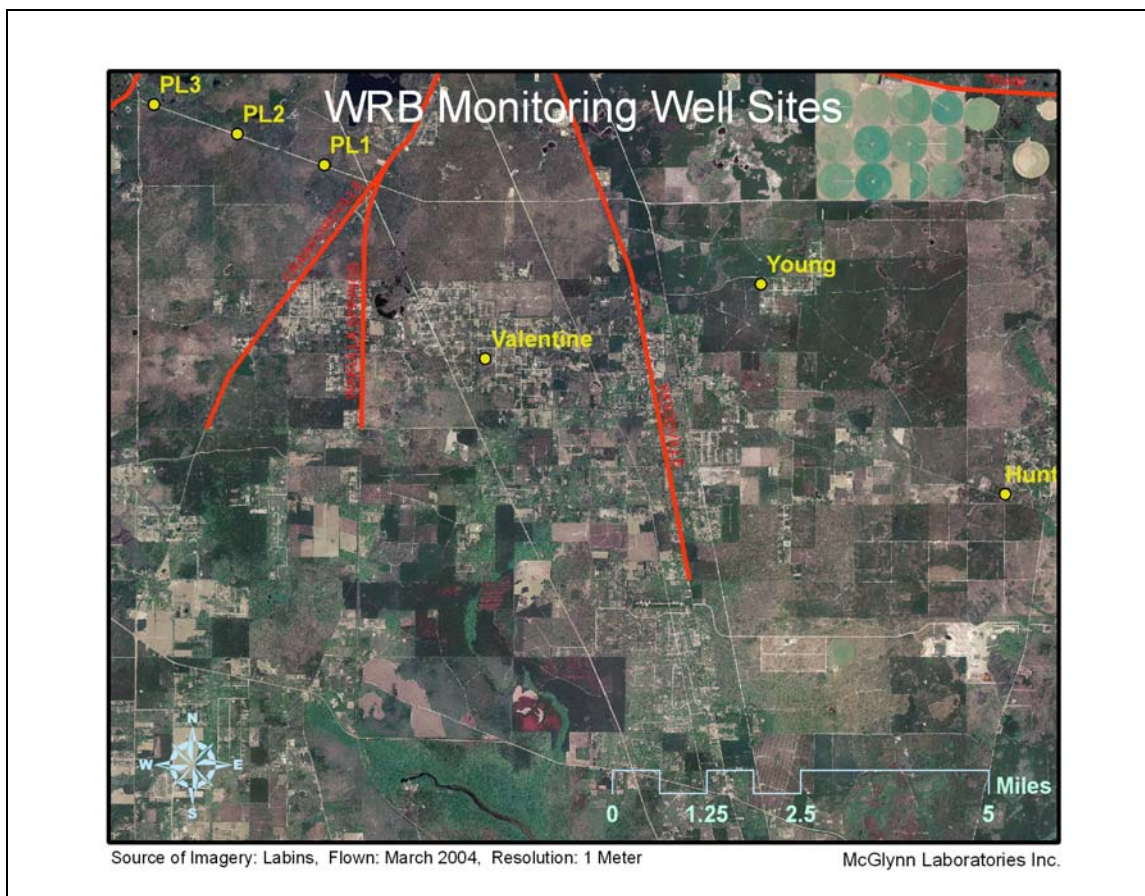


Figure 1.2.1: Septic tank study sites in the WRB, These sites are spread throughout the WRB.

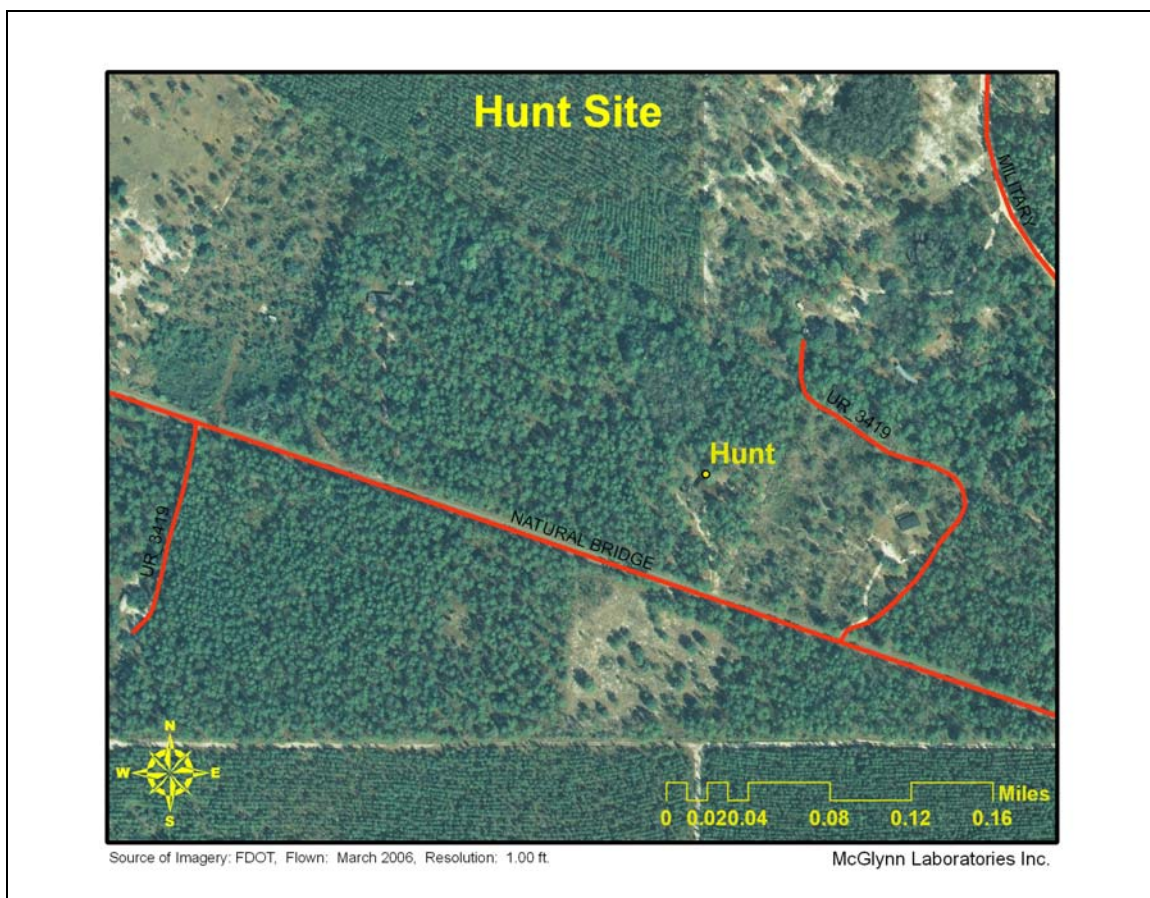


Figure 1.2.2: Septic tank study site, the Hunt Site

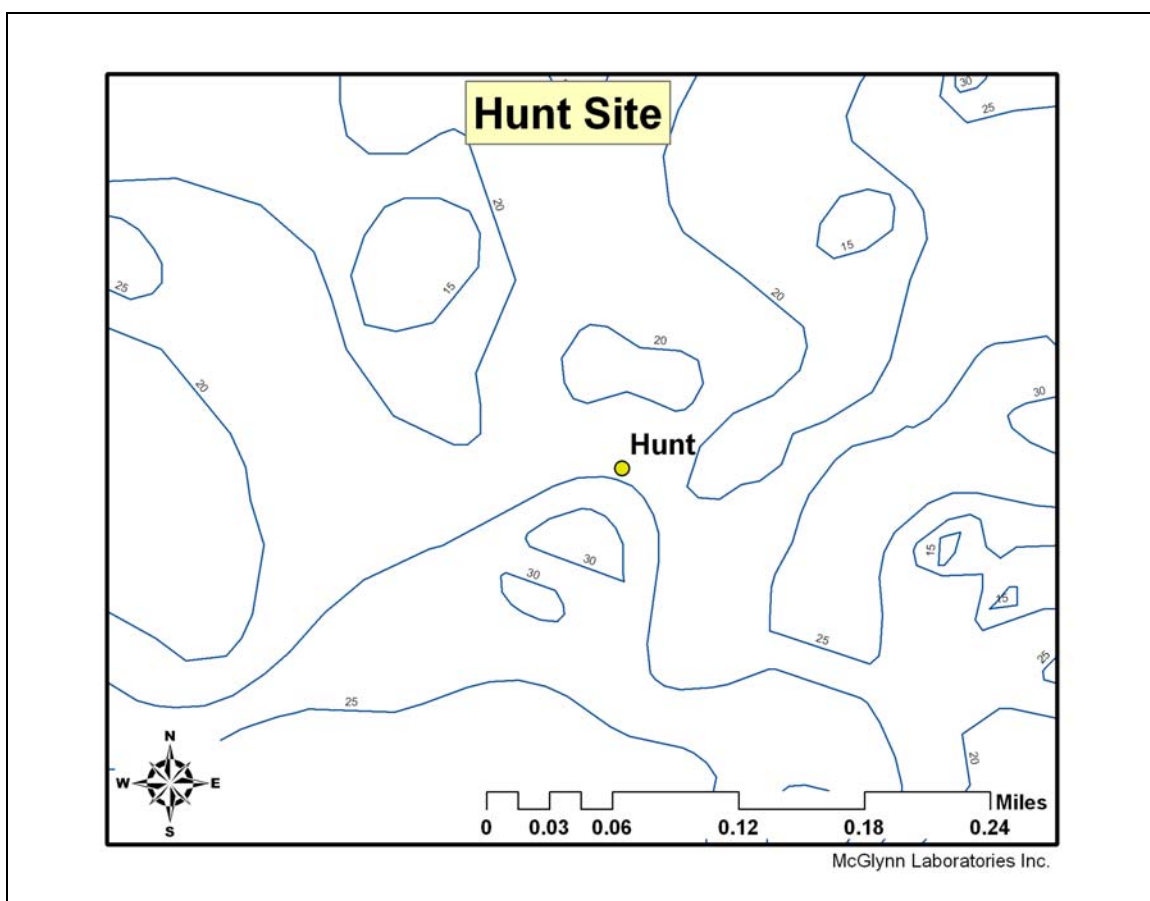
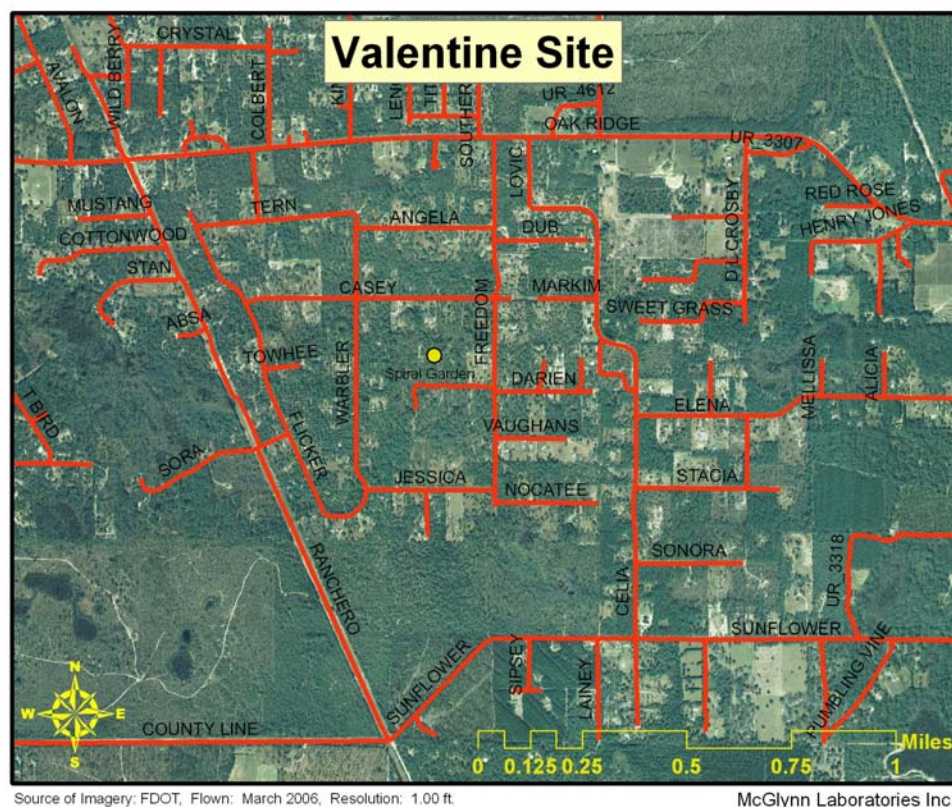


Figure 1.2.3: Septic tank study site, the Hunt Site



Figure 1.2.4: Septic tank study site, the Hunt Site



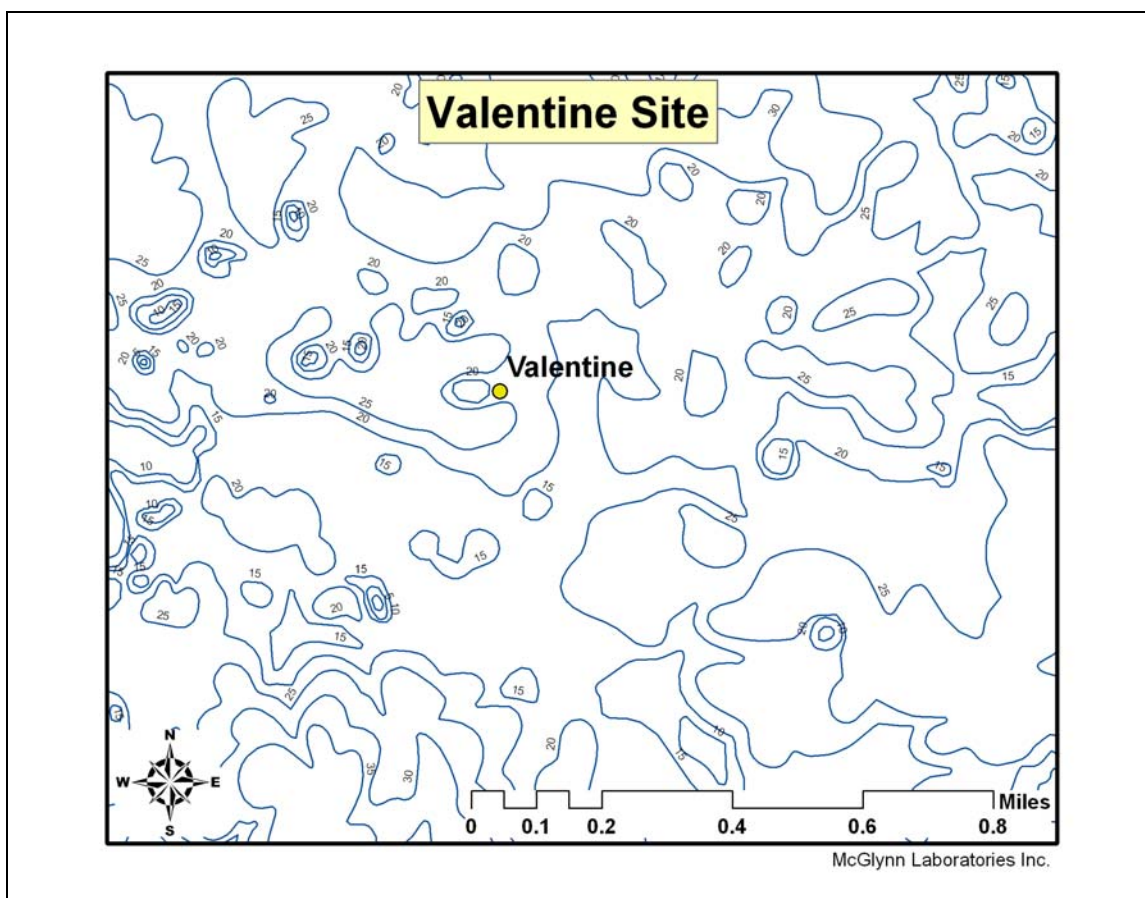


Figure 1.2.6: Septic tank study site, the Valentine Site

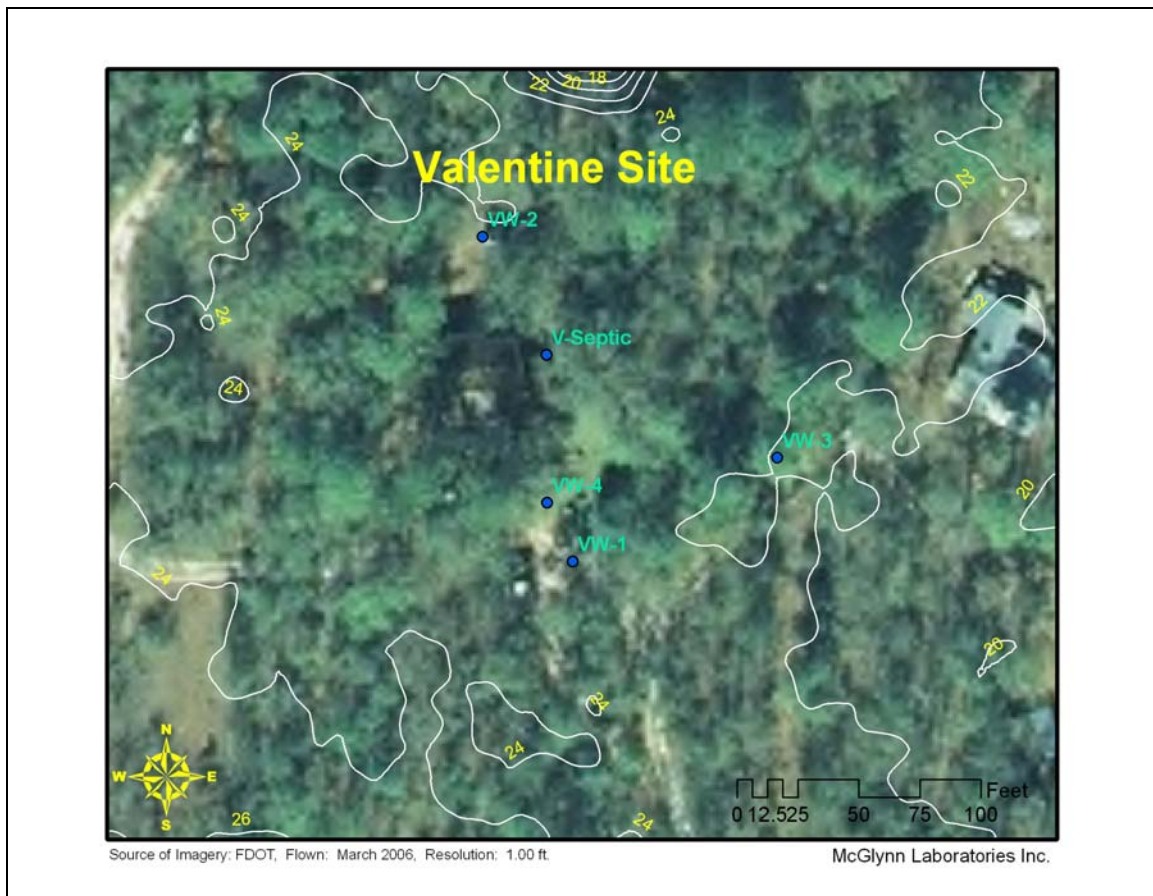


Figure 1.2.7: Septic tank study site, the Valentine Site

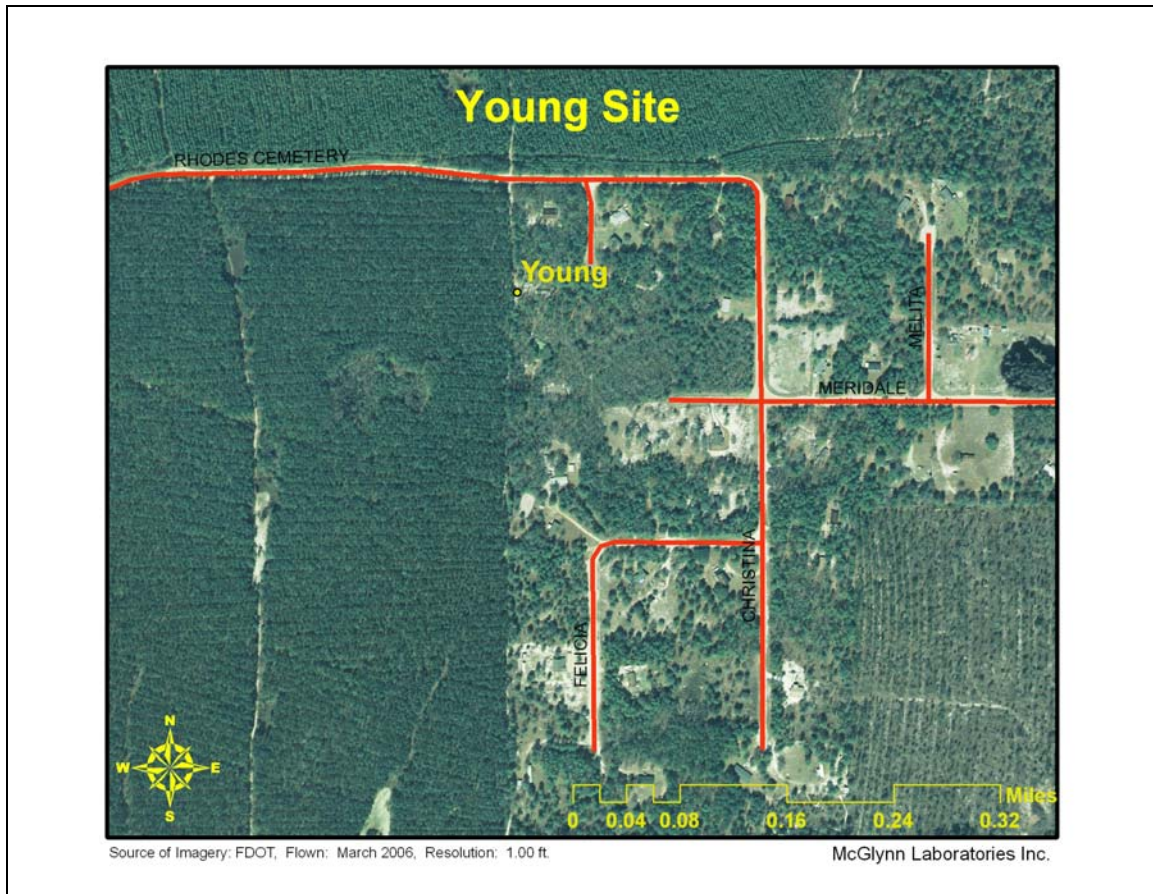


Figure 1.2.8: Septic tank study site, the Young Site

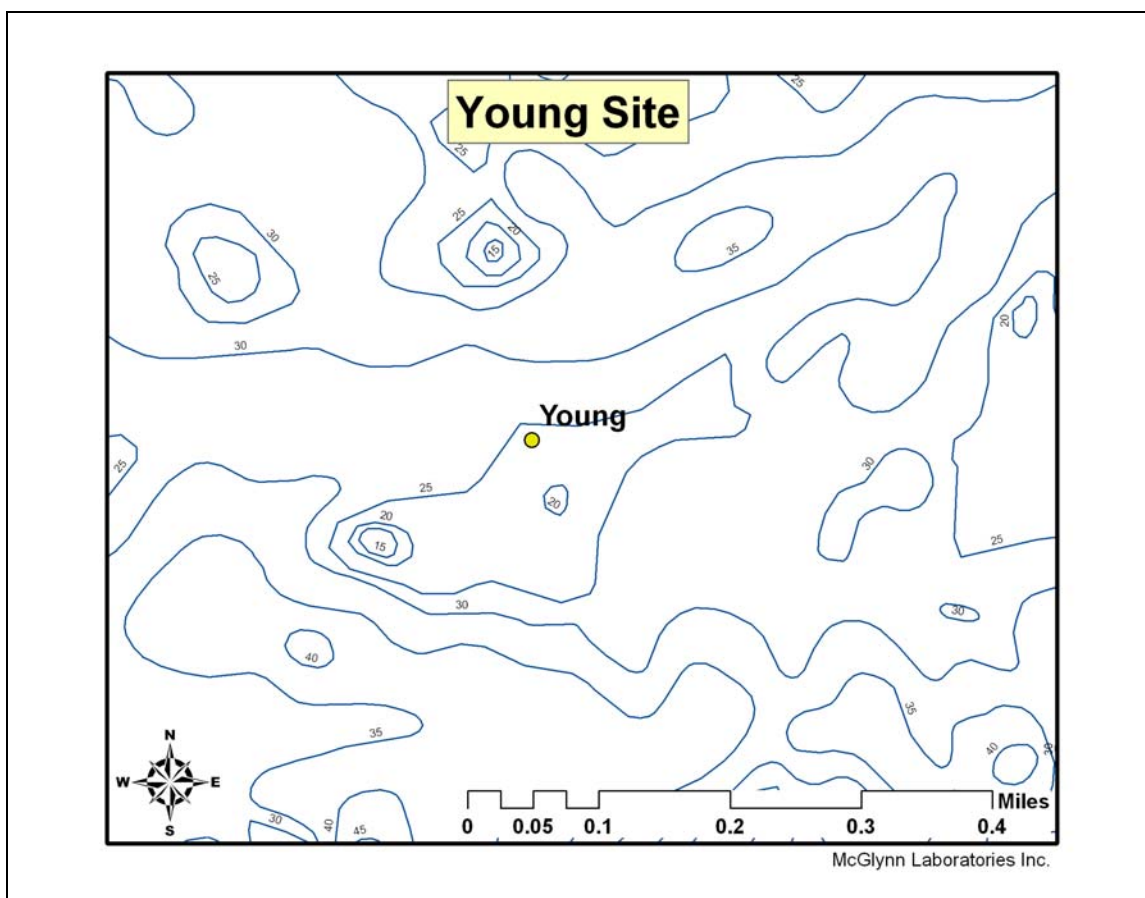


Figure 1.2.9: Septic tank study site, the Young Site

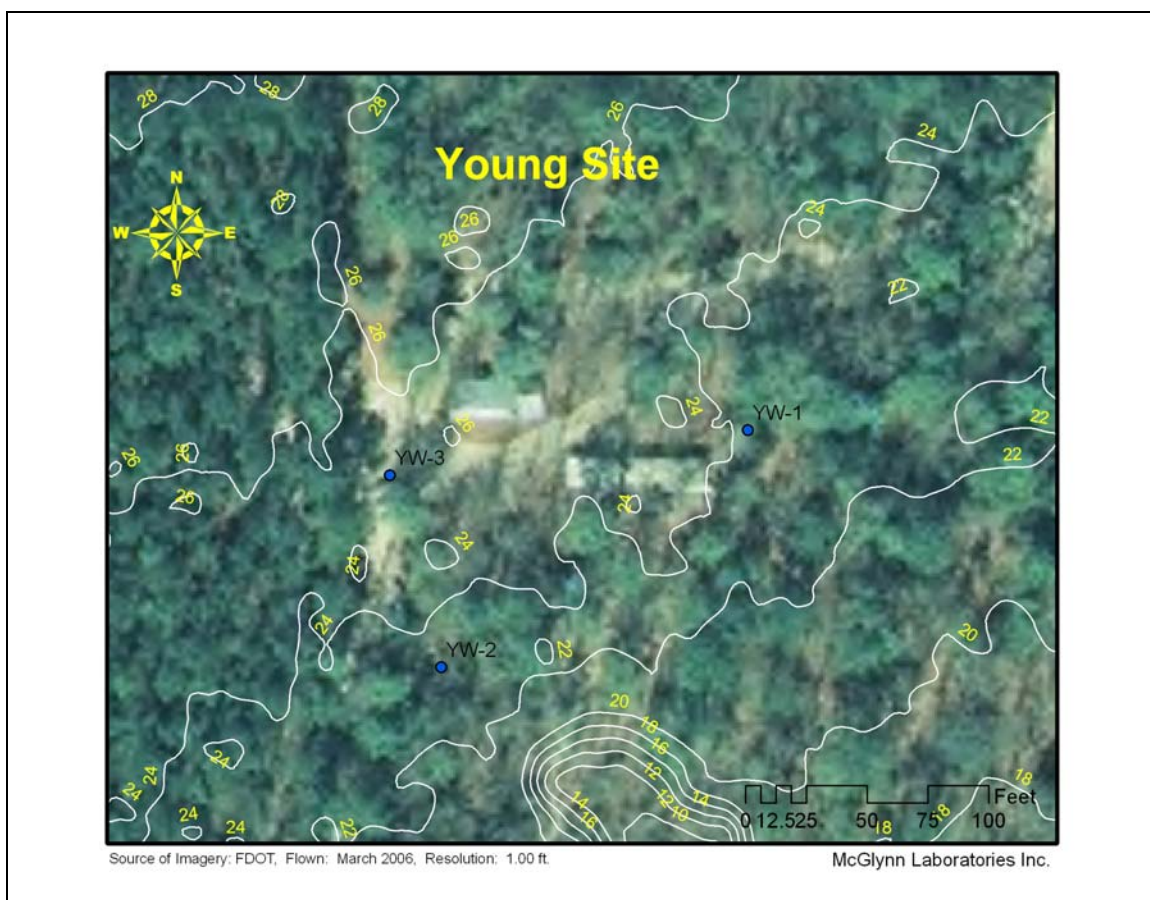


Figure 1.2.10: Septic tank study site, the Young Site

Table 1.2.3: Nitrate + Nitrite (oxidized nitrogen, chloride and total phosphorus data from the WRB septic tank studies.

Task: Woodville Recharge Basin Client: Leon County Data Set Id.: WRB122805 Page: 1								
Field Identification Information						NOx EPA 353.3 <i>mdl=0.01</i> <i>pql=0.04</i> mg/L	Chloride EPA 325.3 <i>mdl=0.73</i> <i>pql=2.92</i> mg/L	Total P EPA 365.2 <i>mdl=0.006</i> <i>pql=0.024</i> mg/L
Station	Collection Date	Time	Depth Code	Rep	Date received at Laboratory			
Hunt Well 1	12/29/05	14:30	n/a	1	12/29/05	1.62	26.6	0.020
Hunt Well 1	02/24/06	17:14	n/a	1	02/24/06	1.03	12.4	0.014
Hunt Well 1	05/31/06	15:54	n/a	1	05/31/06	0.69	29.2	0.040
Hunt Well 1	07/17/06	16:53	n/a	1	07/17/06	0.28	29.2	0.052
Hunt Well 2	12/29/05	14:45	n/a	1	12/29/05	0.04	6.2	0.005
Hunt Well 2	02/24/06	17:44	n/a	1	02/24/06	0.09	8.9	0.004
Hunt Well 2	05/31/06	16:21	n/a	1	05/31/06	0.12	5.3	0.014
Hunt Well 2	07/17/06	17:12	n/a	1	07/17/06	0.00	8.0	0.007
Hunt Well 3	12/29/05	14:22	n/a	1	12/29/05	1.49	31.0	0.015
Hunt Well 3	02/24/06	18:00	n/a	1	02/24/06	0.62	8.9	0.004
Hunt Well 3	02/24/06	18:00	n/a	F2	02/24/06	0.65	8.0	0.004
Hunt Well 3	05/31/06	16:08	n/a	1	05/31/06	0.42	10.6	0.013
Hunt Well 3	07/17/06	16:25	n/a	1	07/17/06	0.13	7.1	0.017
Hunt Well 4	07/17/06	16:36	n/a	1	07/17/06	0.12	7.1	0.014
Valentine Well 1	12/29/05	11:17	n/a	1	12/29/05	0.21	8.9	0.005
Valentine Well 1	02/24/06	13:30	n/a	1	02/24/06	0.00	7.1	0.002
Valentine Well 2	12/29/05	11:36	n/a	1	12/29/05	0.11	8.9	0.012
Valentine Well 2	02/24/06	13:03	n/a	1	02/24/06	0.00	12.4	0.004
Valentine Well 2	05/31/06	17:34	n/a	1	05/31/06	0.06	5.3	0.004
Valentine Well 2	07/17/06	14:27	n/a	1	07/17/06	0.11	5.3	0.007
Valentine Well 3	12/29/05	10:24	n/a	1	12/29/05	0.31	7.1	0.005
Valentine Well 3	12/29/05	10:24	n/a	F2	12/29/05	0.31	7.1	0.005
Valentine Well 3	02/24/06	13:17	n/a	1	02/24/06	0.11	7.1	0.002
Valentine Well 3	05/31/06	17:49	n/a	1	05/31/06	0.39	6.2	0.005
Valentine Well 3	07/17/06	14:40	n/a	1	07/17/06	0.45	7.1	0.014
Valentine Well 4	02/24/06	13:24	n/a	1	02/24/06	0.13	8.0	0.002
Valentine Well 4	05/31/06	17:45	n/a	1	05/31/06	0.32	7.1	0.008
Valentine Well 4	07/17/06	14:36	n/a	1	07/17/06	0.38	6.2	0.003
Young Well 1	12/29/05	13:42	n/a	1	12/29/05	1.60	10.6	0.000
Young Well 1	02/24/06	15:45	n/a	1	02/24/06	0.89	14.2	0.002
Young Well 1	05/31/06	18:38	n/a	1	05/31/06	0.66	15.1	0.005
Young Well 1	07/17/06	15:50	n/a	1	07/17/06	3.16	23.0	0.016
Young Well 2	12/29/05	13:21	M	1	12/29/05	0.35	6.2	0.015
Young Well 2	02/24/06	15:49	S	1	02/24/06	0.01	4.4	0.012
Young Well 2	05/31/06	18:20	n/a	1	05/31/06	0.02	6.2	0.020

Young Well 2	07/17/06	15:19	n/a	1	07/17/06	0.00	6.2	0.026
Young Well 2	07/17/06	15:19	n/a	L2	07/17/06	0.00	6.2	0.024
Young Well 3	12/29/05	13:18	n/a	1	12/29/05	0.69	8.0	0.000
Young Well 3	02/24/06	16:04	n/a	1	02/24/06	0.65	16.8	0.002
Young Well 3	05/31/06	18:22	n/a	1	05/31/06	0.68	8.0	0.007
Young Well 3	07/17/06	15:25	n/a	1	07/17/06	0.54	3.5	0.016

Table 1.2.4: Sewage effluent collected before the septic system.

	DataSetID:	WRB:SE PEFF	TNN EPA	Total P EPA
	SET/PAGE: 1/1		351.4	365.2
			MDL	MDL
		Collection	0.1	0.0
	Station	Date	mg/L	mg/L
	Station	Date	mg/L	(abs)
1	Hunt Effluent	12/29/05	35.2	2.6
2	Young Effluent	12/29/05	10.5	0.6
3	Valentine Effluent	12/29/05	46.2	6.4
4	Hunt Effluent	02/24/06	22.9	3.8
5	Young Effluent	02/24/06	15.9	3.9
6	Valentine Effluent	02/24/06	35.1	7.6
1	Hunt Effluent	05/31/06	1.3	0.1
2	Young Effluent	05/31/06	9.6	0.2
3	Valentine Effluent	05/31/06	22.9	2.2
4	Hunt Effluent	07/17/06	36.7	4.6
5	Young Effluent	07/17/06	25.9	2.3
6	Valentine Effluent	07/17/06	10.9	2.1



Figure 1.2.11: Native soils in the WRB are paleolithic beach sand mixed with clay.

Table 1.2.5: Statistical results of the Phosphorus Mesocosm Experiment, 1st Quarter

	Treatment Conc. (ppm)	Exp Conc (ppm)	% Rec.
A	0	-0.002	NA
A1	0	0.003	NA
A2	0	0.002	NA
A3	0	0.005	NA
A4	0	0.008	NA
B	0.639	0.639	100.0%
B1	0.639	0.111	17.4%
B2	0.639	0.063	9.9%
B3	0.639	0.038	5.9%
B4	0.639	0.022	3.5%
C	1.943	1.943	100.0%
C1	1.943	0.145	7.5%
C2	1.943	0.077	4.0%
C3	1.943	0.068	3.5%
C4	1.943	0.055	2.8%
D	2.433	2.433	100.0%
D1	2.433	0.137	5.6%
D2	2.433	0.091	3.7%
D3	2.433	0.092	3.8%
D4	2.433	0.053	2.2%

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
A	4	0.018316	0.004579	8.55E-06
B	4	0.234071	0.058518	0.00152
C	4	0.345373	0.086343	0.001635
D	4	0.37277	0.093193	0.001178

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.019471	3	0.00649	5.980412	0.009841	3.4903
Within Groups	0.013023	12	0.001085			
Total	0.032494	15				

Table 1.2.6: Statistical results of the Nitrogen Mesocosm Experiment, 1st Quarter

	Treatment Conc. (ppm)	Exp Conc (ppm)	% Rec.
A	0	-0.062	NA
A1	0	-0.067	NA
A2	0	-0.029	NA
A3	0	-0.023	NA
A4	0	-0.068	NA
B	3.403	3.403	100.0%
B1	3.403	0.859	25.2%
B2	3.403	1.145	33.6%
B3	3.403	1.721	50.6%
B4	3.403	1.552	45.6%
C	16.155	16.155	100.0%
C1	16.155	6.846	42.4%
C2	16.155	7.736	47.9%
C3	16.155	9.033	55.9%
C4	16.155	7.111	44.0%
D	29.410	29.410	100.0%
D1	29.410	11.604	39.5%
D2	29.410	6.137	20.9%
D3	29.410	5.669	19.3%
D4	29.410	8.324	28.3%

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
A	4	-0.18717	-0.04679	0.000578
B	4	5.277035	1.319259	0.152738
C	4	30.72603	7.681508	0.950571
D	4	31.73414	7.933535	7.327099

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	209.5687	3	69.85623	33.14262	4.36E-06	3.4903
Within Groups	25.29296	12	2.107747			
Total	234.8617	15				

Table 1.2.7: Statistical results of the Statistical results of the Phosphorus Mesocosm Experiment, 2nd Quarter

	Treatment Conc. (ppm)	Exp Conc (ppm)	% Rec.
A	0	0.003	NA
A1	0	0.021	NA
A2	0	0.027	NA
A3	0	0.017	NA
A4	0	0.021	NA
B	0.346	0.346	100.0%
B1	0.346	0.024	6.9%
B2	0.346	0.014	4.1%
B3	0.346	0.019	5.5%
B4	0.346	0.017	5.1%
C	1.269	1.269	100.0%
C1	1.269	0.027	2.1%
C2	1.269	0.016	1.2%
C3	1.269	0.027	2.1%
C4	1.269	0.014	1.1%
D	1.958	1.958	100.0%
D1	1.958	0.039	2.0%
D2	1.958	0.016	0.8%
D3	1.958	0.021	1.1%
D4	1.958	0.009	0.5%

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
A	4	0.086086	0.021521	1.66E-05
B	4	0.074753	0.018688	1.64E-05
C	4	0.084467	0.021117	4.96E-05
D	4	0.084467	0.021117	0.000156

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	2.01E-05	3	6.72E-06	0.112534	0.951094	3.4903
Within Groups	0.000716	12	5.97E-05			
Total	0.000736	15				

Table 1.2.8: Statistical results of the Nitrogen Mesocosm Experiment, 2nd Quarter

	Treatment Conc. (ppm)	Exp Conc (ppm)	% Rec.
A	0	-0.064	NA
A1	0	1.149	NA
A2	0	0.994	NA
A3	0	0.939	NA
A4	0	1.227	NA
B	0.019	0.019	100.0%
B1	0.019	1.601	100.0%
B2	0.019	1.028	100.0%
B3	0.019	1.015	100.0%
B4	0.019	1.216	100.0%
C	1.462	1.462	100.0%
C1	1.462	2.569	97.0%
C2	1.462	2.585	98.2%
C3	1.462	2.651	102.6%
C4	1.462	2.179	70.3%
D	14.949	14.949	100.0%
D1	14.949	8.439	48.8%
D2	14.949	5.998	32.4%
D3	14.949	7.137	40.0%
D4	14.949	6.811	37.9%

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
A	4	4.308887	1.077222	0.01786
B	4	4.859324	1.214831	0.074636
C	4	9.983611	2.495903	0.046005
D	4	28.38473	7.096182	1.030927

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	95.65348	3	31.88449	109.0601	5.66E-09	3.4903
Within Groups	3.508286	12	0.292357			
Total	99.16177	15				

Table 1.2.9: Statistical results of the Phosphorus Mesocosm Experiment, 3rd Quarter

	Treatment Conc. (ppm)	Exp Conc (ppm)	% Rec.
A	0	0.001	NA
A1	0	0.026	NA
A2	0	0.018	NA
A3	0	0.012	NA
A4	0	0.009	NA
B	0.334	0.334	100.0%
B1	0.334	0.008	2.3%
B2	0.334	0.008	2.3%
B3	0.334	0.012	3.6%
B4	0.334	0.008	2.3%
C	1.307	1.307	100.0%
C1	1.307	0.015	1.2%
C2	1.307	0.011	0.8%
C3	1.307	0.023	1.8%
C4	1.307	0.006	0.5%
D	1.939	1.939	100.0%
D1	1.939	0.015	0.8%
D2	1.939	0.009	0.5%
D3	1.939	0.011	0.5%
D4	1.939	0.004	0.2%

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
A	4	0.065438	0.016359	5.55E-05
B	4	0.034755	0.008689	5.3E-06
C	4	0.054699	0.013675	5.18E-05
D	4	0.039357	0.009839	1.96E-05

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	0.000149	3	4.98E-05	1.507418	0.262768	3.4903
Within Groups	0.000397	12	3.3E-05			
Total	0.000546	15				

Table 1.2.10: Statistical results of the Nitrogen Mesocosm Experiment, 3rd Quarter

	Treatment Conc. (ppm)	Exp Conc (ppm)	% Rec.
A	0	-0.072	NA
A1	0	0.670	NA
A2	0	0.450	NA
A3	0	0.190	NA
A4	0	0.303	NA
B	0	-0.131	NA
B1	0	0.196	NA
B2	0	-0.010	NA
B3	0	0.250	NA
B4	0	0.208	NA
C	1.382	1.382	100.0%
C1	1.382	1.472	106.6%
C2	1.382	1.427	103.3%
C3	1.382	1.336	96.7%
C4	1.382	1.351	97.8%
D	12.001	12.001	100.0%
D1	12.001	10.943	91.2%
D2	12.001	7.315	60.9%
D3	12.001	12.152	101.3%
D4	12.001	12.606	105.0%

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
A	4	1.612378	0.403094	0.043064
B	4	0.644261	0.161065	0.013515
C	4	5.586643	1.396661	0.004114
D	4	43.01627	10.75407	5.749914

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	309.4879	3	103.1626	71.01677	6.58E-08	3.4903
Within Groups	17.43182	12	1.452652			
Total	326.9197	15				

Table 1.2.11: Statistical results of the Phosphorus Mesocosm Experiment, 4th Quarter

	Treatment Conc. (ppm)	Exp Conc (ppm)	% Rec.
A	0	0.002	NA
A1	0	0.014	NA
A2	0	0.007	NA
A3	0	0.003	NA
A4	0	0.013	NA
B	0.343	0.343	100.0%
B1	0.343	0.011	3.3%
B2	0.343	0.005	1.5%
B3	0.343	0.008	2.4%
B4	0.343	0.005	1.5%
C	1.202	1.202	100.0%
C1	1.202	0.010	0.8%
C2	1.202	0.007	0.5%
C3	1.202	0.007	0.5%
C4	1.202	0.010	0.8%
D	2.045	2.045	100.0%
D1	2.045	0.005	0.2%
D2	2.045	0.007	0.3%
D3	2.045	0.007	0.3%
D4	2.045	0.007	0.3%

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
A	4	0.03736	0.00934	2.7E-05
B	4	0.029498	0.007375	9.06E-06
C	4	0.032643	0.008161	3.3E-06
D	4	0.024782	0.006195	6.18E-07

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	2.1E-05	3	7E-06	0.701031	0.569336	3.4903
Within Groups	0.00012	12	9.99E-06			
Total	0.000141	15				

Table 1.2.12: Statistical results of the Nitrogen Mesocosm Experiment, 4th Quarter

	Treatment Conc. (ppm)	Exp Conc (ppm)	% Rec.
A	0	-0.007	NA
A1	0	1.354	NA
A2	0	1.169	NA
A3	0	1.279	NA
A4	0	1.241	NA
B	0.145	0.145	100.0%
B1	0.145	1.778	1227.8%
B2	0.145	1.089	752.0%
B3	0.145	1.407	971.6%
B4	0.145	1.441	994.9%
C	1.482	1.482	100.0%
C1	1.482	2.036	137.4%
C2	1.482	1.783	120.3%
C3	1.482	2.060	139.0%
C4	1.482	1.904	128.4%
D	16.630	16.630	100.0%
D1	16.630	13.016	78.3%
D2	16.630	12.775	76.8%
D3	16.630	10.607	63.8%
D4	16.630	11.932	71.8%

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
A	4	5.04276	1.26069	0.005983
B	4	5.715464	1.428866	0.079339
C	4	7.784169	1.946042	0.016492
D	4	48.33057	12.08264	1.183697

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	334.1337	3	111.3779	346.5635	6.44E-12	3.4903
Within Groups	3.856536	12	0.321378			
Total	337.9902	15				

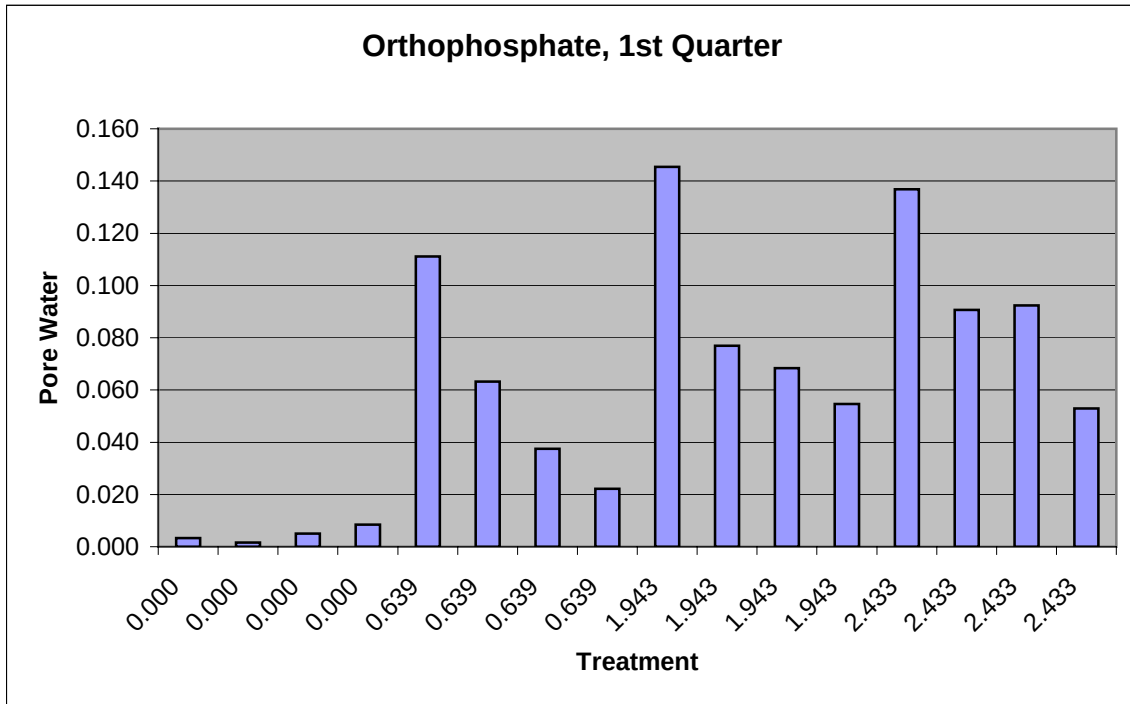


Figure 1.2.12: Graphical depiction of the 1st quarter phosphorus mesocosm.

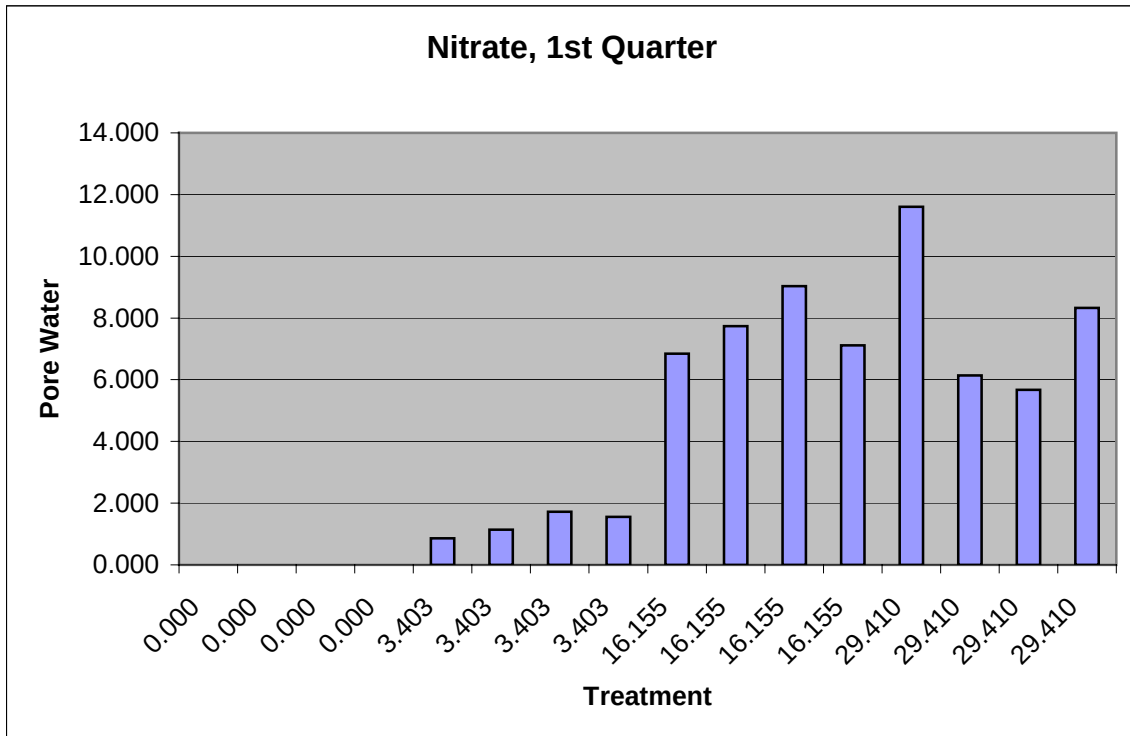


Figure 1.2.13: Graphical depiction of the 1st quarter nitrogen mesocosm.

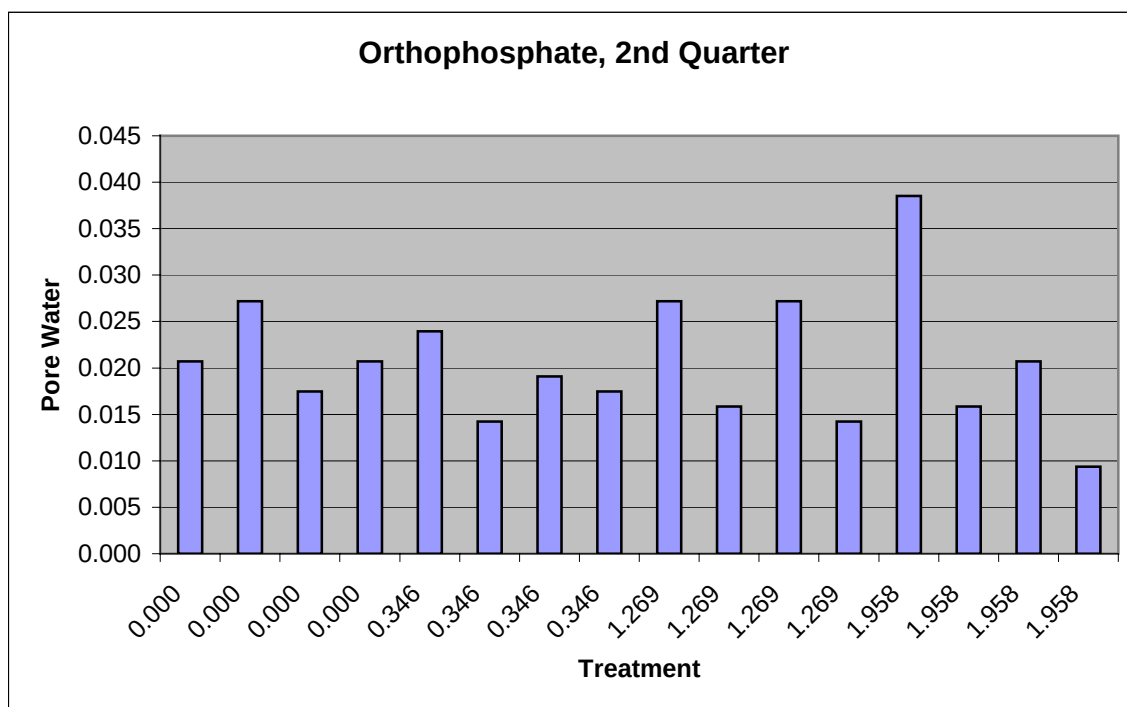


Figure 1.2.14: Graphical depiction of the 2nd quarter phosphorus mesocosm.

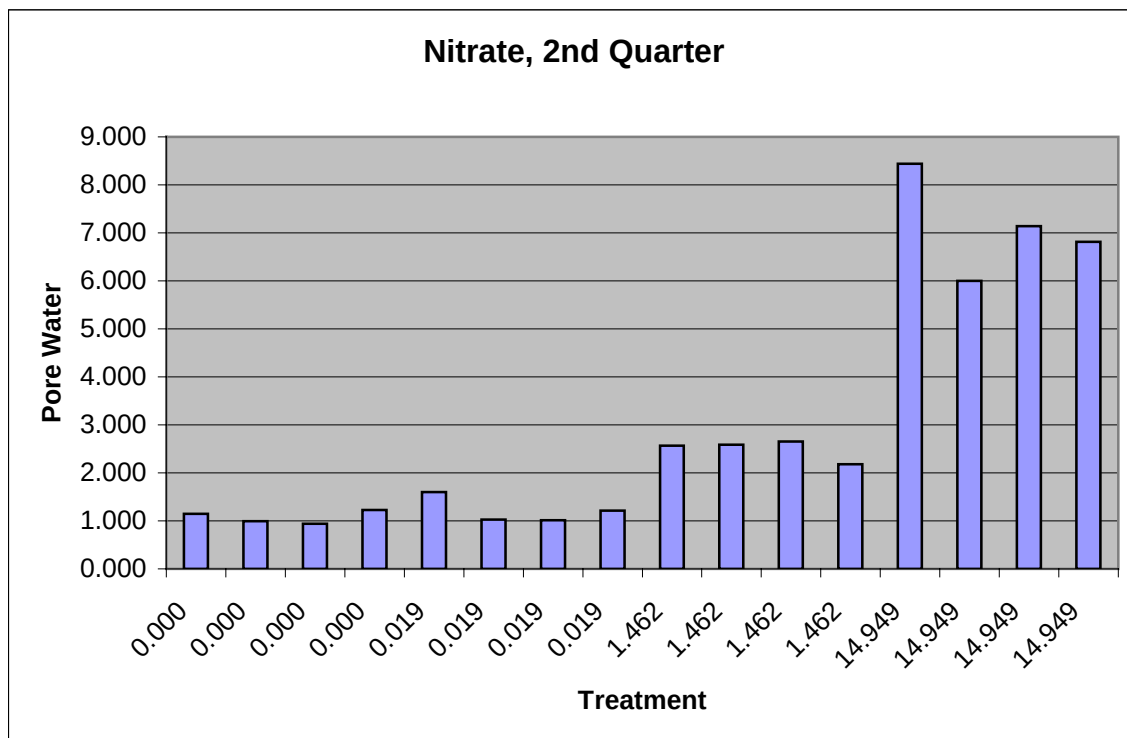


Figure 1.2.15: Graphical depiction of the 2nd quarter nitrogen mesocosm.

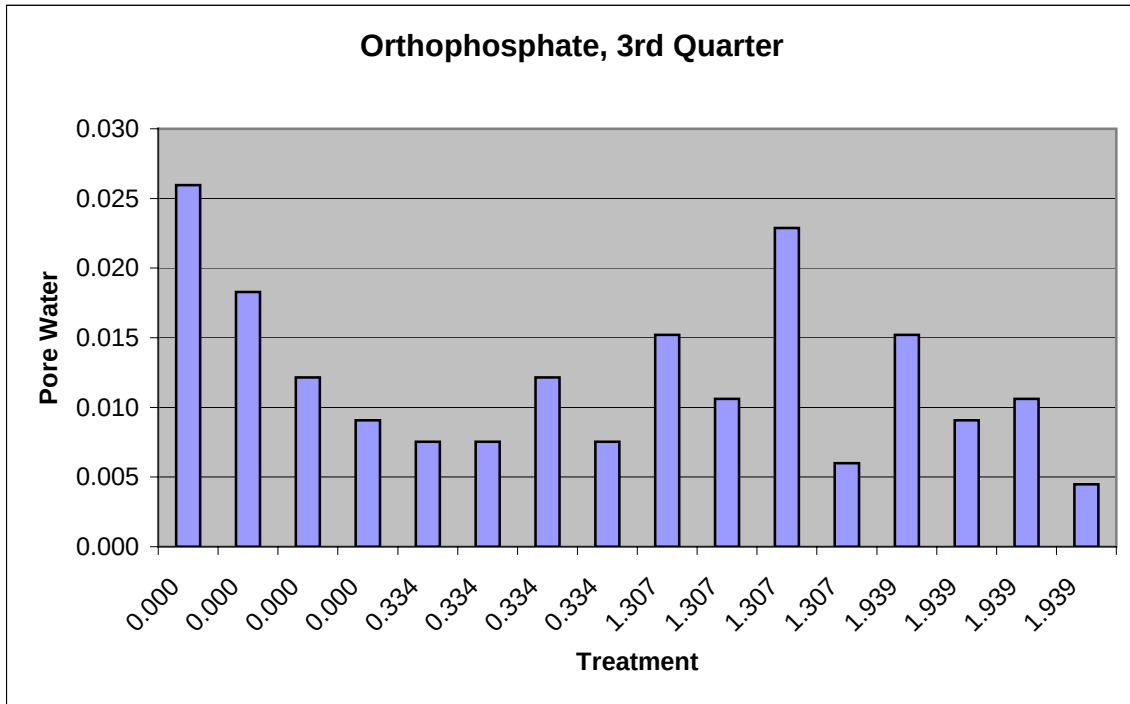


Figure 1.2.16: Graphical depiction of the 3rd quarter phosphorus mesocosm.

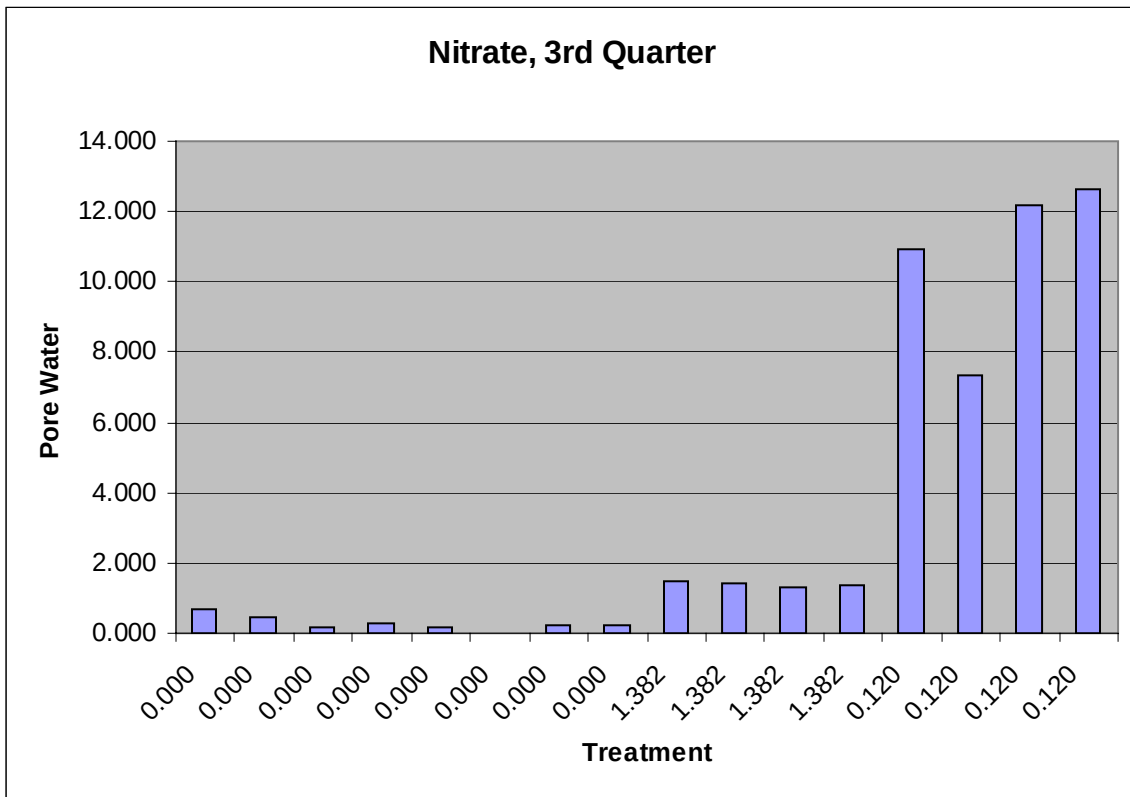


Figure 1.2.17: Graphical depiction of the 3rd quarter nitrogen mesocosm.

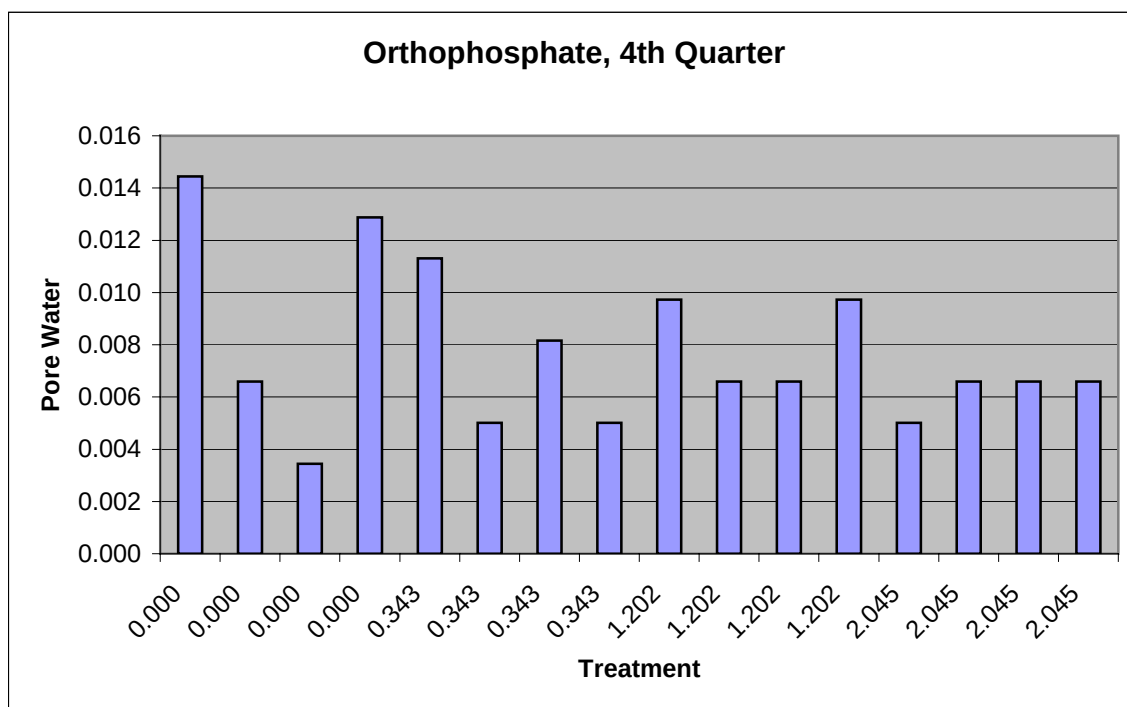


Figure 1.2.18: Graphical depiction of the 4th quarter phosphorus mesocosm.

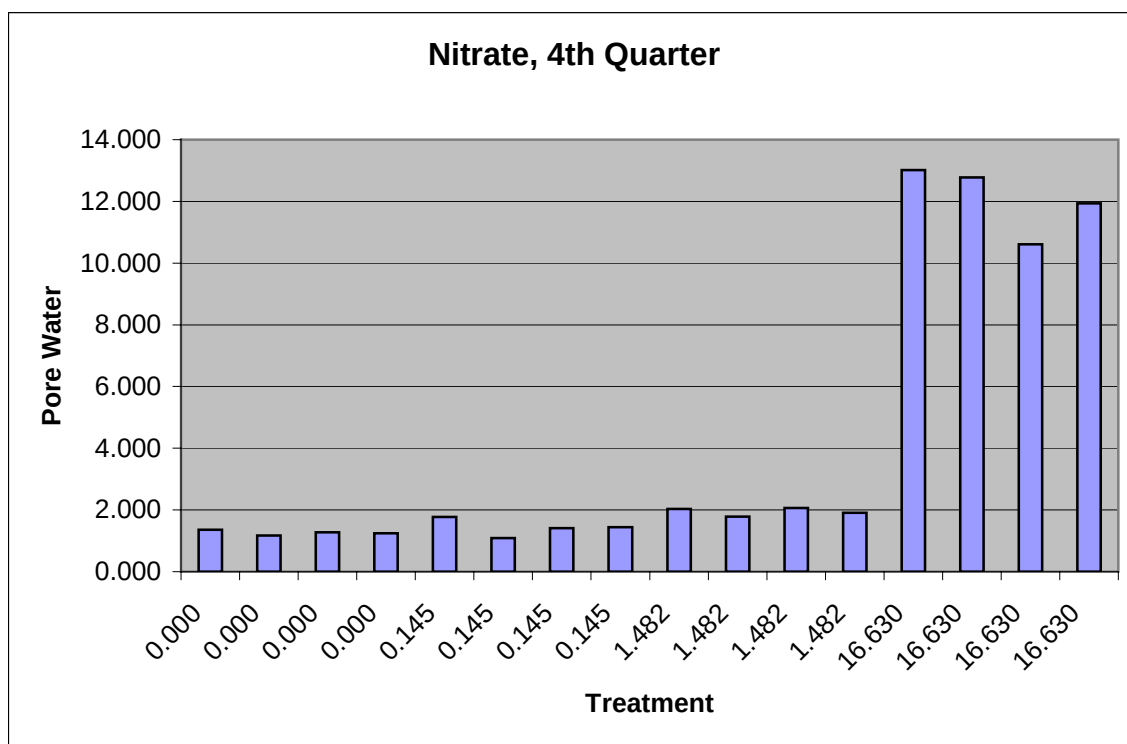


Figure 1.2.19: Graphical depiction of the 4th quarter nitrogen mesocosm.

Section 1.3: Conduit Flow, Dye Studies

Summary of Results

This investigation documented and proved for the first time that sinks from the 'Eastern Sinks Region' flow to the St. Marks Rise. These sinking streams in northern Leon County and Jefferson County were shown to flow to the St. Marks Rise by specific dye studies. It is hoped that this will help to define the Springshed of the St. Marks Rise. The dye trace from Bird Sink covered a distance of 16 miles and is the longest distance covered in a dye study in this area.

1. Dye study from the Western Cavern at Natural Bridge to the St. Marks Rise. This cavern appears to have no flow and there was no dye detected at the St. Marks Rise.
2. Dye study from the Eastern Cavern at Natural Bridge to the St. Marks Rise. The dye trace showed connection to the St. Marks Rise (0.62 miles) with a flow velocity of 0.08 miles per hour. The time of travel was 7 hours 29 minutes.
3. Dye study from the Rhodes Springs to the St. Marks Rise. The Rhodes Springs are swallet where there is a spring run that sinks back into the ground. No dye was detected in Rhodes Sinks #1 and #4. Therefore, it is assumed that Rhodes Sinks #1 and #4 do not receive flow from Rhodes Springs #2. However, there was a definite connection between Rhodes Springs #2 and the St. Marks Rise with a flow velocity of 0.067 miles per hour. The time of travel was 14 hours 55 minutes for the 1.0 mile approximate distance underground.
4. Dye study from Burnt Mill Creek (Dead Indian Sink) to the St. Marks Rise where it disappears into the aquifer at Dead Indian Sink on Wood Sink Plantation in Jefferson County. There was a definite connection between Burnt Mill Creek and the St. Marks Rise with a flow velocity of 0.018 miles per hour. The time of travel was 22 days for the 10 miles approximate distance.
5. Dye study from Black Creek (Bird Sink) to the St. Marks Rise where it disappears into the aquifer at Bird Sink near Interstate 10 in Leon County.. There was a definite connection between Black Creek and the St. Marks Rise with a flow velocity of 0.023 miles per hour. The time of travel was 28 days for the 16 miles approximate distance.
6. Dye study from Lake Miccosukee to the St. Marks Rise. In progress.

Methods

Water flowing out of two major discharge areas, or springs flows through the WRB. In the WRB much of the aquifer is unconfined. Dye studies are used to define cavernous underground conduit flow. Diffuse groundwater flow, measured with Piezometric wells (please see Phase II), does not adequately address conduit flow. Conduit flow is much more rapid than diffuse groundwater flow. Water flowing in conduits does not get much water quality improving treatment as it flows through its limestone channels. Conduits, or underground water filled caverns are common within the WRB. Open karst features connecting the surface of the WRB with underground conduits have been identified. Dye trace studies are necessary to characterize where the water is coming from and/or discharging to in a karst aquifer.

There are several options that can be utilized for dye tracing. SF6 can be used when there are no conduits. In this study we utilized the fluorescent dye, Rhodamine WT. Most dye studies that have been conducted in this area were performed using integrated samplers and laboratory fluorometers. The detection limit can get to 1 part per billion (ppb), but a discrete sampling interval can miss the detection of the maximum concentration of the dye pulse. There are also problems with cross contamination since sample bottles and tubing are reused. Insitu fluorometers offer continuous monitoring. The dye pulse can be more easily caught at its maximum concentration. Since sample containers and tubing are not reused there is minimal possibility of cross contamination. We used computerized Hydrolab insitu Rhodamine WT Fluorometers by Turner Designs. The accuracy is +/- 3% for signal equivalents of 1ppb Rhodamine WT dye. The resolution is 0.01 ppb. The dynamic range at high sensitivity settings is 0 – 10 ppb. The typical battery life is 313 days and the memory can store up to 120,000 measurements. Procedures for the dye tracing experiments (Wilson et al,1986; McGlynn and Kwader, 2003; McGlynn et al, 2005).

It should be noted that previous dye studies conducted by FDEP and FGS (Dr. Rhodney Dehan) have demonstrated that Ames Sink, located to the west of the WRB and the SESF, located in the center of the WRB both flow to the aquifer discharge point at Wakulla Springs. Flow to the St. Marks Rise, a larger spring than the Wakulla, has not been previously investigated. This dye study, funded by EPA and Leon County demonstrates that flow to the St. Marks is from the Eastern Sinks region of Leon County that lies to the north east of the WRB and western Jefferson County. Spring Creek, an even larger first order spring for the Floridan Aquifer, discharges in the marine environment and has not been investigated.

The Hydrolab dye sensors were placed on weighted lines, underwater, at the center of the discharge point of the St. Marks Rise. Weather conditions are noted in the text. It was very dry during the dye studies. All of the dye studies were conducted after a pulse of rain cause flow down the various sinks. The St. Marks Rise was flowing strongly and

there was no discernable variation in flow during the study. It was notable how exceptionally clear the water was since rainfall was scarce.

The diameter of the caverns is difficult to determine without diving. Chris Brown produced an underwater video of Bird Sink and its cavern system, about 10 years ago. The average cavern width seems to be about 20 feet. Dead Indian Sink seems to have an opening about 10 feet wide but this is difficult to verify. Chris Werner recently mapped the caverns in the St Marks River. He should be consulted for details concerning that cavern system. The caverns there seem to be very large and in excess of 20 feet in diameter.

Maps depicting the route of the dye study, local topography, access routes to the site, pictures of the site with the dye study in progress, breakout curves and charts are presented for each dye of the 5 dye studies in the following pages.

Note on the Toxicity of Rhodamine WT: Rhodamine WT is not to be confused with Rhodamine B that is considered rather toxic. Rhodamine WT was developed for use in dye studies and is approved by EPA. It is considered safe at the levels used in this dye study and there is valid toxicological data to support this. All fluorescent substances are inherently mutagenic because of the delocalized electrons that cause the fluorescence. There does not appear to be any data on the toxicity of Fluorescence dyes so it is not certain how safe they are. The following letter from EPA approved the use of Rhodamine WT for use in dye studies. More recent data have actually allowed higher concentrations.

United States Environmental Protection Agency
Washington, D.C. 20460

Aug 2 1988

Office of Water
Ms. Janice Warnquist
Chemical Safety Manager
Crompton and Knowles Corporation
P.O. Box 341 (500 Pear Street)
Reading, Pennsylvania 19603

Dear Ms. Warnquist:

The Criteria and Standards Division (Office of Drinking Water) has reviewed the available data on chemistry and toxicity of Rhodamine dyes. We would not anticipate any adverse health effects resulting from the use of Rhodamine WT as a fluorescent tracer in water flow studies when used with the following guidelines.

A maximum concentration of 100 micrograms/liter Rhodamine WT is recommended for addition to raw water in hydrological studies involving surface and ground waters.

Dye concentration should be limited to 10 micrograms/liter in raw water when used as a tracer in or around drinking water intakes.

Concentration in drinking water should not exceed 0.1 micrograms/liter. Studies which result in actual human exposure to the dye via drinking water must be brief and infrequent. This level is not acceptable for chronic human exposure. In all of the above cases, the actual concentration used should not exceed the amount required for reasonably certain detection of the dye as required to accomplish the intended purpose of the study.

The Criteria and Standards Division recommends that Rhodamine B not be used as a tracer dye in water flow studies. This advisory supersedes all earlier advisories issued by EPA on the use of fluorescent dyes as tracers in water flow studies. This advisory is granted on a temporary basis only.

EPA is terminating its voluntary additives advisory program as announced in the Federal Register (53 FR, 25586, July 7, 1988). A copy of the Federal Register Notice is enclosed for your convenience. All EPA advisory opinions issued within the framework of the additives program will expire on April 7, 1990.

Our opinion concerning the safety of this tracer dye does not constitute an endorsement, nor does it relate to its effectiveness for the intended use. If this letter is to be used in any way, we require it to be quoted in its entirety.

Sincerely,

Arthur H. Perler, Chief
Science and Technology Branch
Criteria and Standards Division

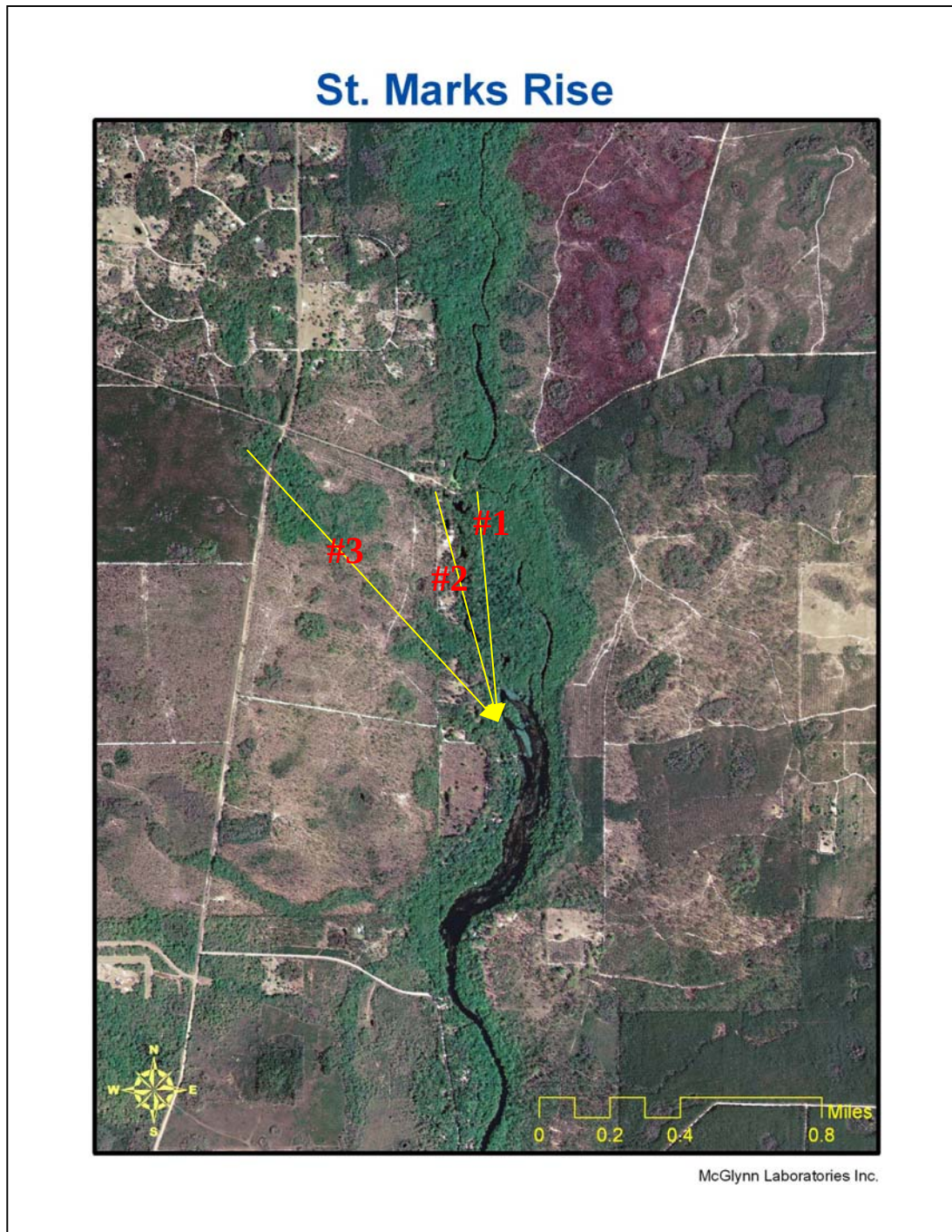
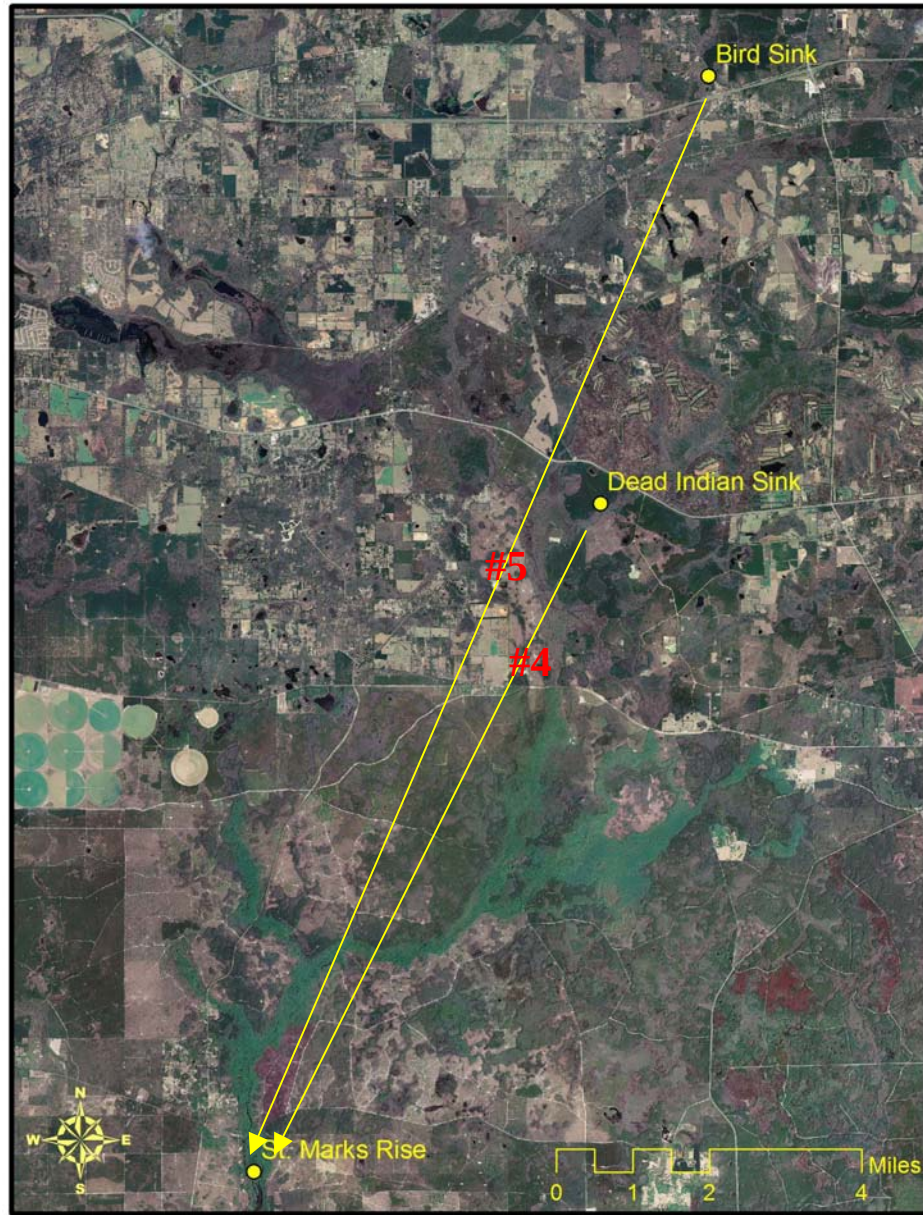


Figure 1.3.1: Natural Bridge and the St. Marks Rise were investigated with the first three dye studies. The arrows depict: #1, the Eastern Cavern; #2, the Western Cavern; and #3 the Rhodes Springs. All these studies were monitored at the St. Marks Rise.

Bird Sink and Dead Indian Sink to St. Marks Rise



McGlynn Laboratories Inc.

Figure 1.3.2: Dye studies were also conducted between two disappearing streams in Leon and Jefferson Counties and the St. Marks Rise. The arrows depict: #4, Dead Indian Sink where Burnt Mill Creek sinks into the aquifer; #5, and Bird Sink where Black Creek sinks into the aquifer. These traced the dye to the St. Marks Rise.

Dye Study #1 (10/16/05)

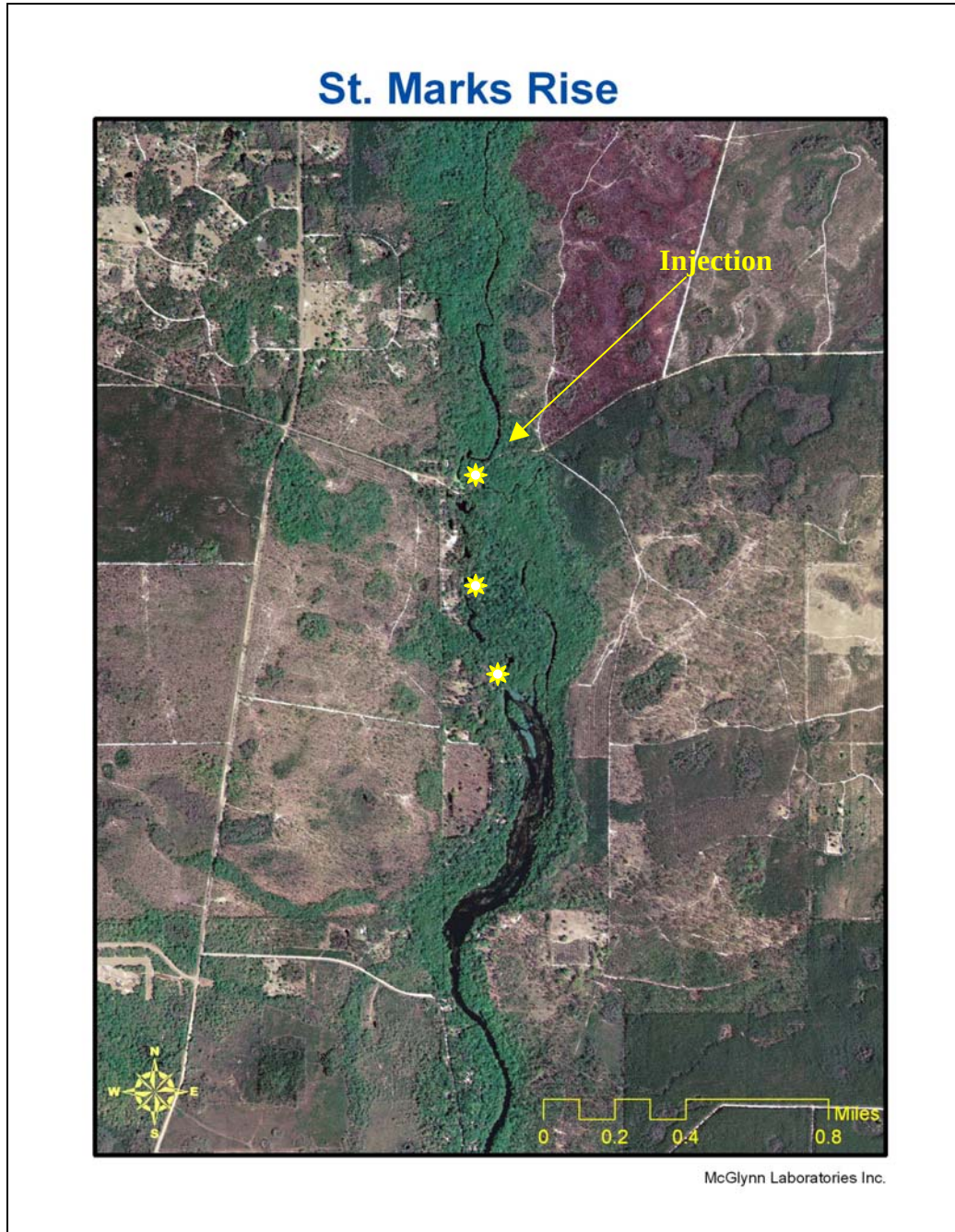


Figure 1.3.3: The location of the dye injection and sensor placement for the first dye study from Eastern Cavern at Natural Bridge to the St. Marks Rise.

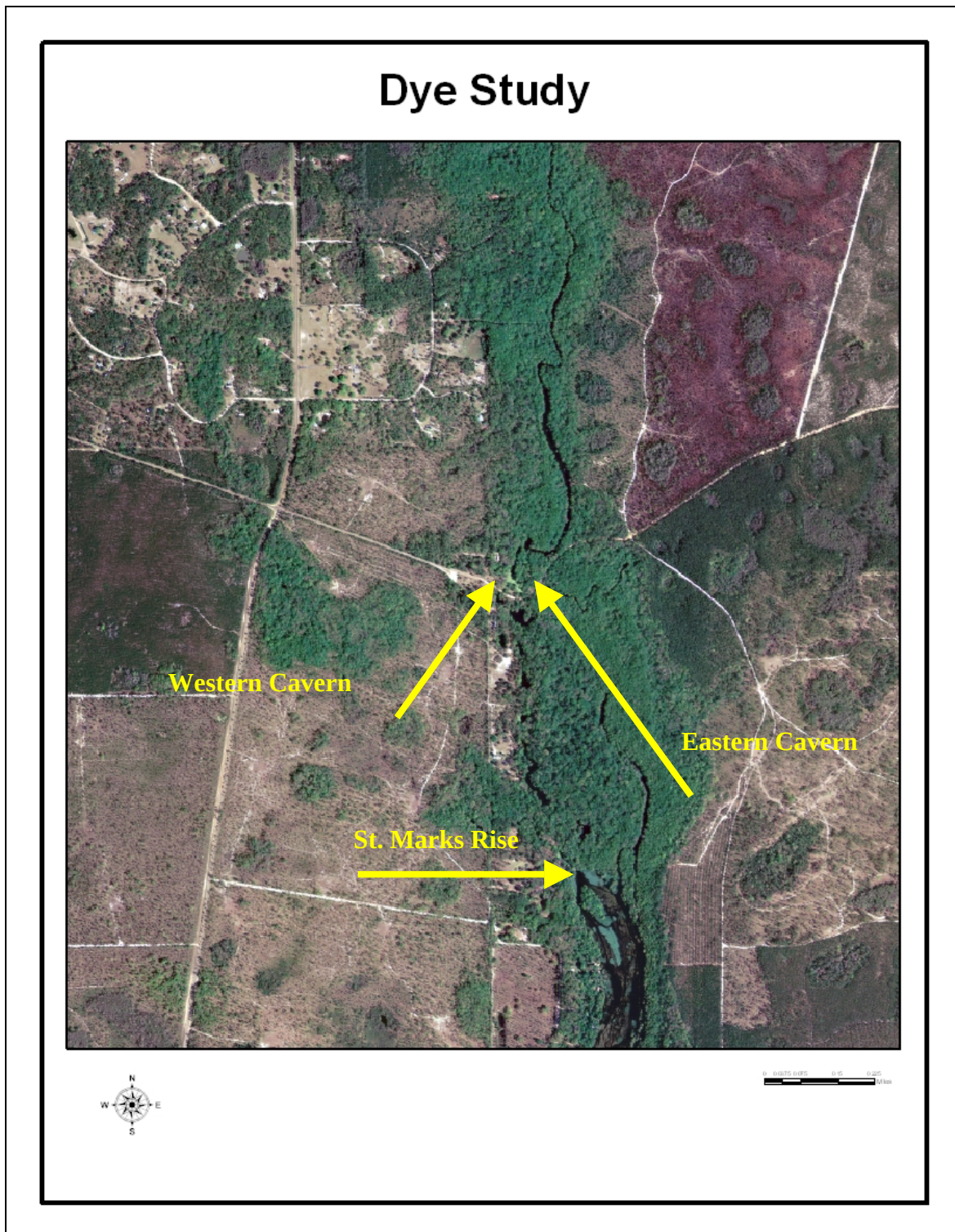


Figure 1.3.4: This map depicts the eastern and the western cavern at Natural Bridge on the Upper St. Marks River and the St. Marks Rise the source of the Lower St. Marks River.

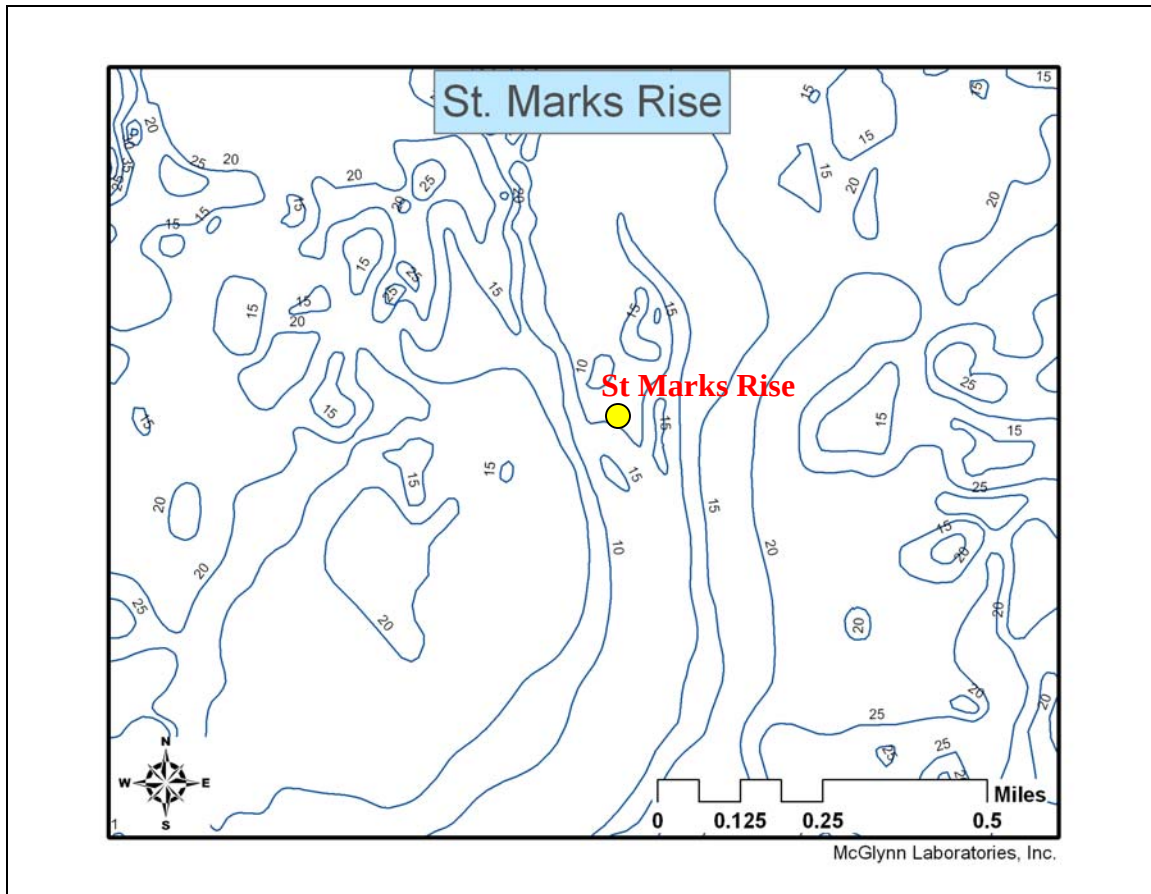


Figure 1.3.5: This map depicts the topography of the St. Marks Rise the source of the Lower St. Marks River.

Dye Study #1

Results

Dye Injected at 12:30 in Easternmost Cavern, Natural Bridge

Amount of Rhodamine: 250g

Upper St. Marks Flow: 58.6 cfs

Lower St. Marks Flow: Lower St. Marks: 560 cfs

location	date	time	timing	max	distance (miles)	Speed (miles/hr)
Natural Bridge	10/16/2005	12:30	0 min	247g	0.00	
Gate Sink	10/16/2005	xxx	no response	0ppb	0.03	none
Middle Sink	10/16/2005	xxx	no response	0ppb	0.10	none
St. Marks Rise	10/16/2005	xxx	no response	0ppb	0.62	none

Dye Study #2
10/21/05

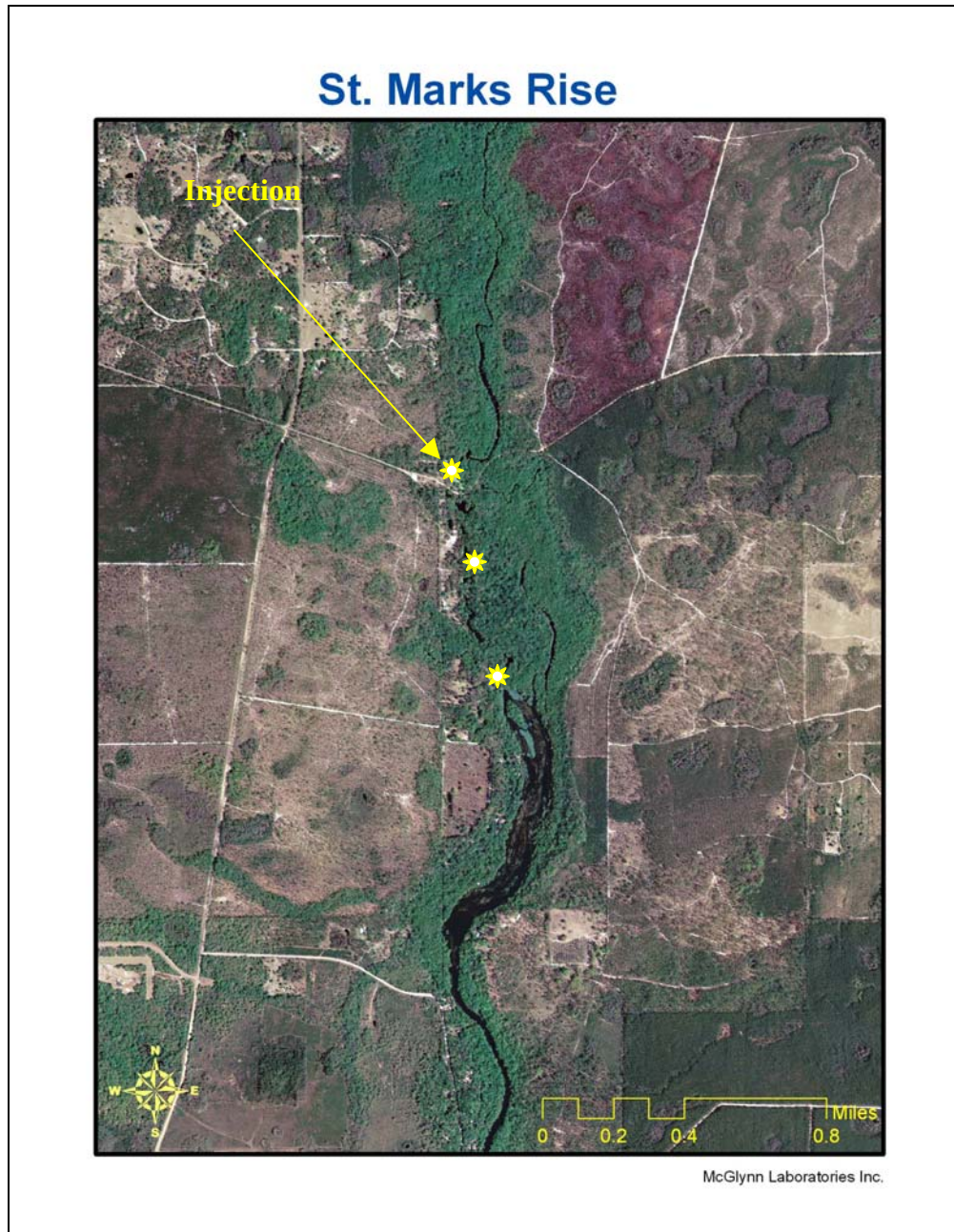


Figure 1.3.6: The location of the dye injection and sensor placement for the second dye study from Western Cavern at Natural Bridge to the St. Marks Rise.

Dye Study #2 Results

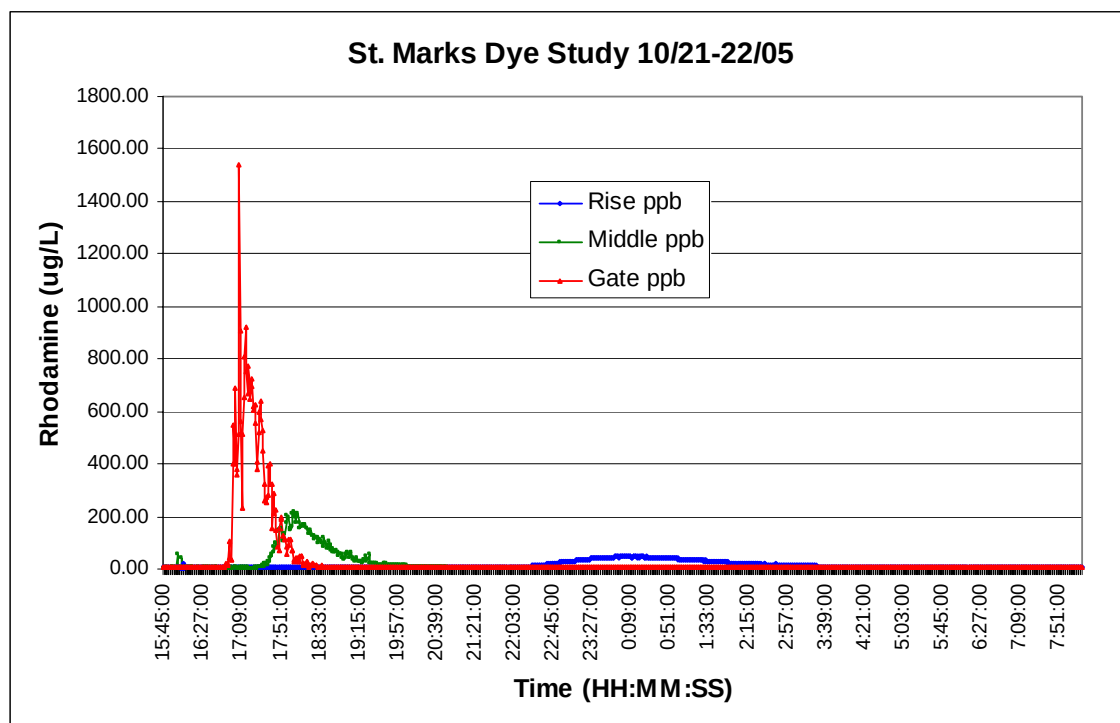


Figure 1.3.7: This graph depicts the breakout curves from the second dye study from Natural Bridge to the St. Marks Rise.

Dye Injected at 16:30 in Westernmost Cavern, Natural Bridge
Amount of Rhodamine: 249g
Upper St. Marks Flow: 58.6 cfs
Lower St. Marks Flow: Lower St. Marks: 560 cfs

location	date	time	timing	max	distance (miles)	Speed (miles/hr)
Natural Bridge	10/21/2005	16:30	0 min	247g	0.00	
Gate Sink	10/21/2005	17:05	35 min	1536ppb	0.03	0.05
Middle Sink	10/21/2005	18:06	1 hr 36 min	215ppb	0.10	0.06
St. Marks Rise	10/21/2005	23:59	7 hr 29 min	47ppb	0.62	0.08



Figure 1.3.8: Front sink (a swallet spring)



Figure 1.3.9: Injecting dye and pumping it to the cavern.



Figure 1.3.10: Injecting more dye (James McClean, dye master)



Figure 1.3.11: Hydrolab DSIV insite Rhodamine sensor.

Dye study #3,
11/05/05

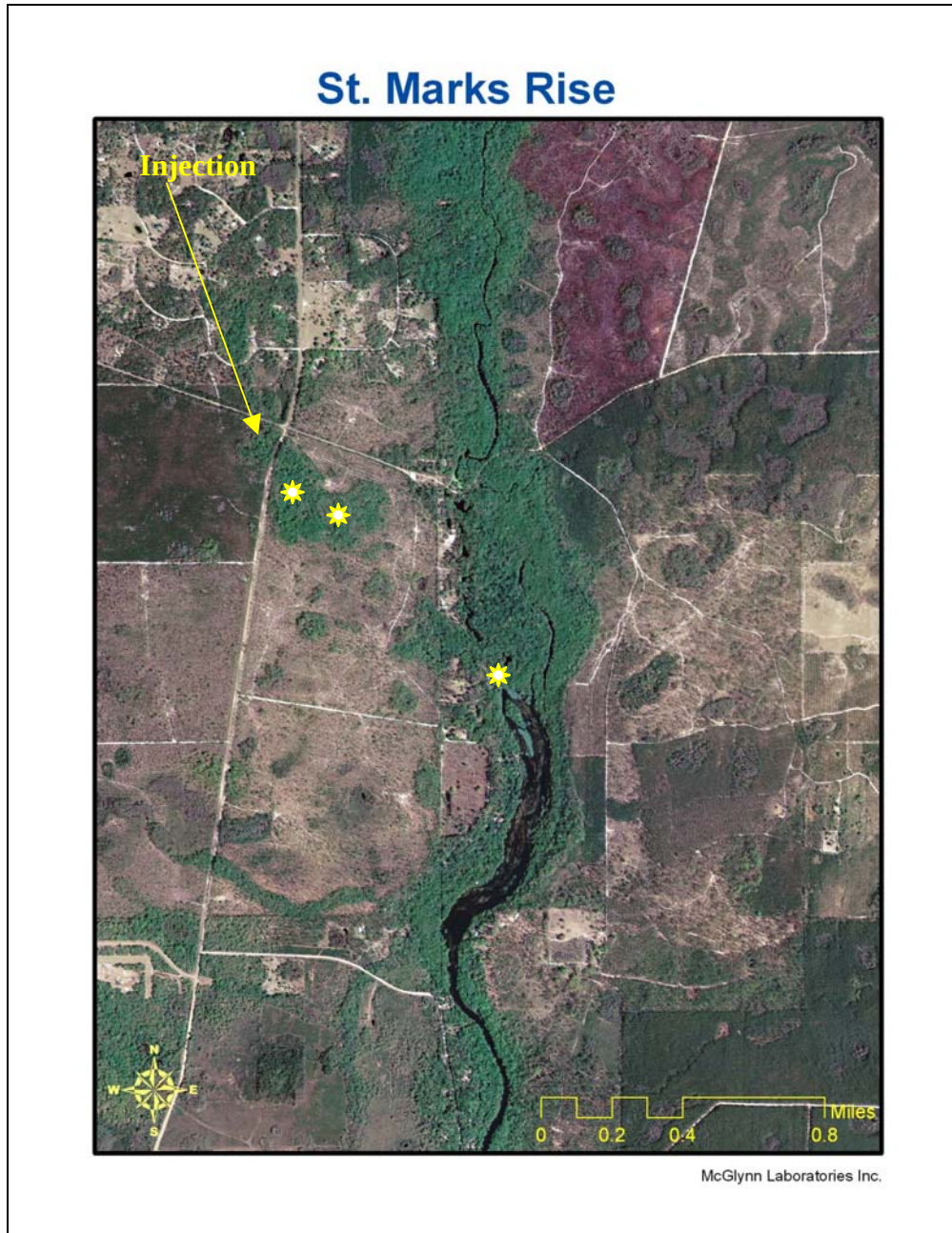


Figure 1.3.12: The location of the dye injection and sensor placement for the third dye study from Rhodes Spring to the St. Marks Rise.

Dye Study #3 Results

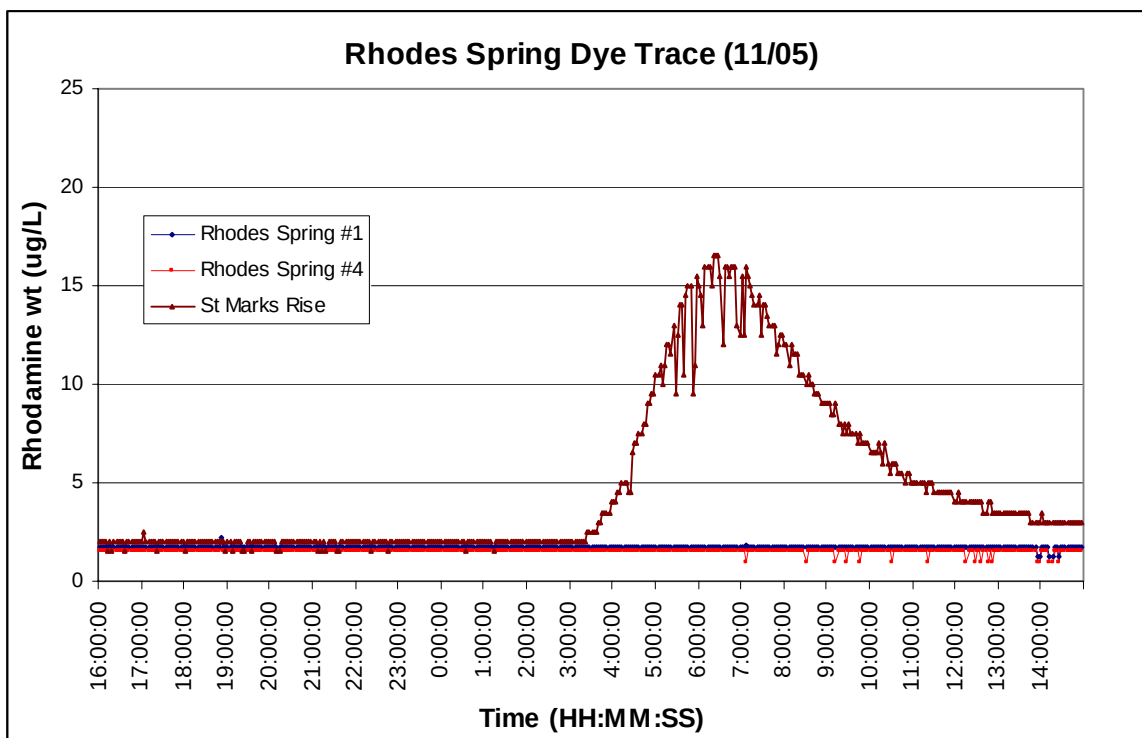


Figure 1.3.13: This graph depicts the breakout curves from the third dye study from Rhodes Spring to the St. Marks Rise.

Dye Injected at Rhodes Spring #2 @15:30 on 11/5/05

Rhodes Spring #2 is located right off Old Plank Road (just south of Natural Bridge Road)

Amount of Rhodamine: 250g

location	date	time	timing	max	distance (miles)	Speed (miles/hr)
Rhodes Spring #2	11/05/2005	15:30	0 min	250g	0.00	
Rhodes Spring #1	11/06/2005	xxx	no response	0ppb	0.34	none
Rhodes Spring #4	11/06/2005	xxx	no response	0ppb	0.37	none
St. Marks Rise	11/06/2005	06:25	14 hr 55 min	17ppb	1.00	0.067



Figure 1.3.14: Injecting the dye in the sink at Rhodes Spring #2



Figure 1.3.15: Dye going down the sink at Rhodes Spring #2



Figure 1.3.16: Dye was not detected in Rhodes Spring #4



Figure 1.3.17: Dye in the sink at Rhodes Spring #2 (James and his helpers)

Dye Study #4



Figure 1.3.18: The location of the dye injection and sensor placement for the fourth dye study from Dead Indian Sink where Burnt Mill Creek sinks into the aquifer to the St. Marks Rise. Dead Indian Sink is approximately 10 miles from the St. Marks Rise.

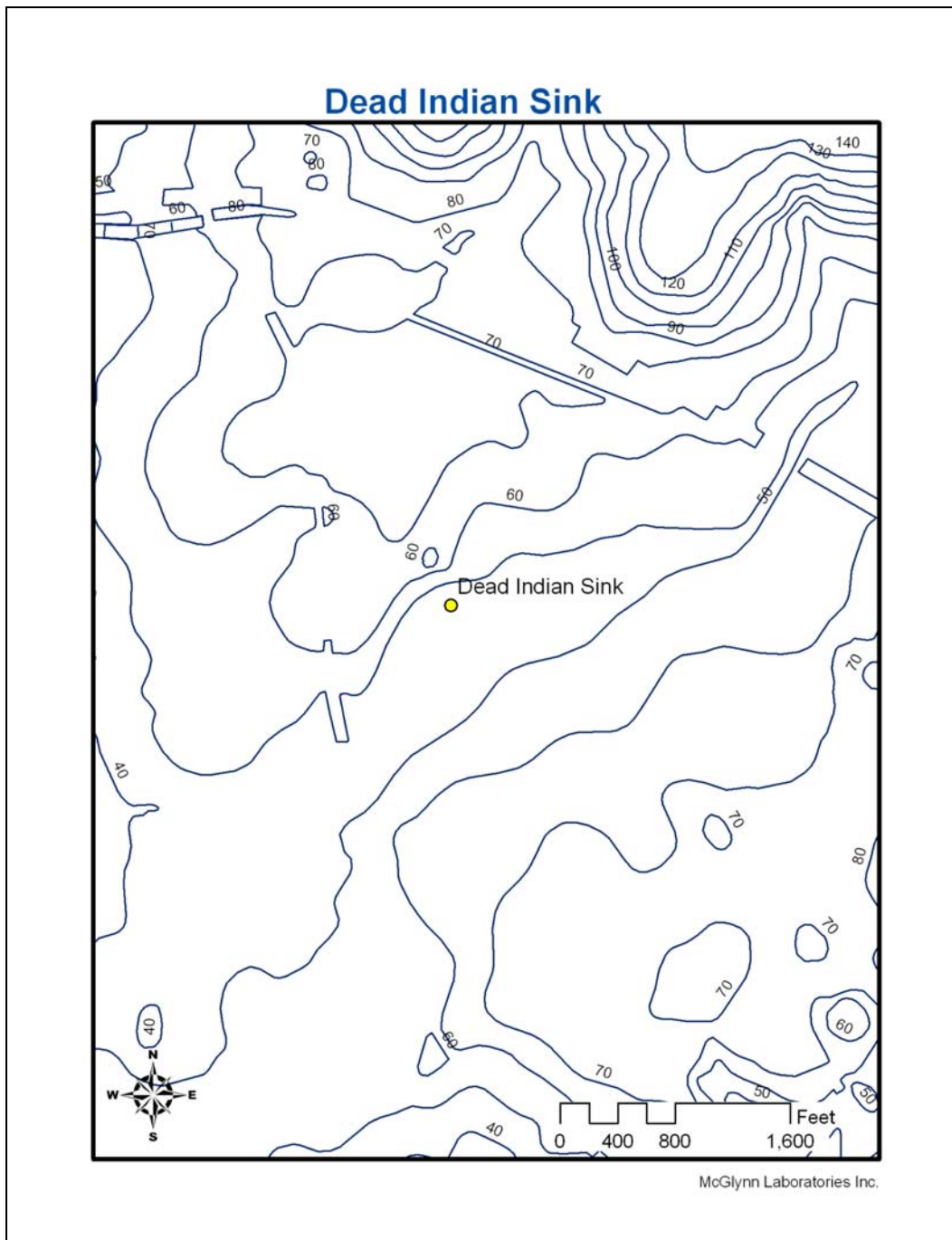


Figure 1.3.19: This map depicts the topography at Bird Sink.

Dye Study #4: Results

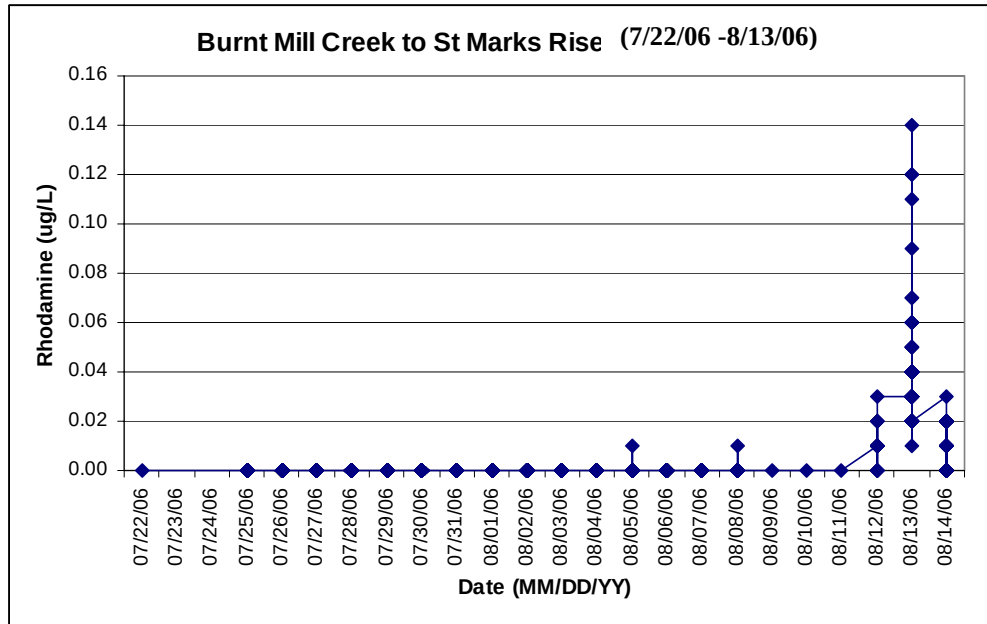


Figure 1.3.20: This graph depicts the daily dye concentrations from the fourth dye study from Burnt Mill Creek to the St. Marks Rise, at the St. Marks Rise.

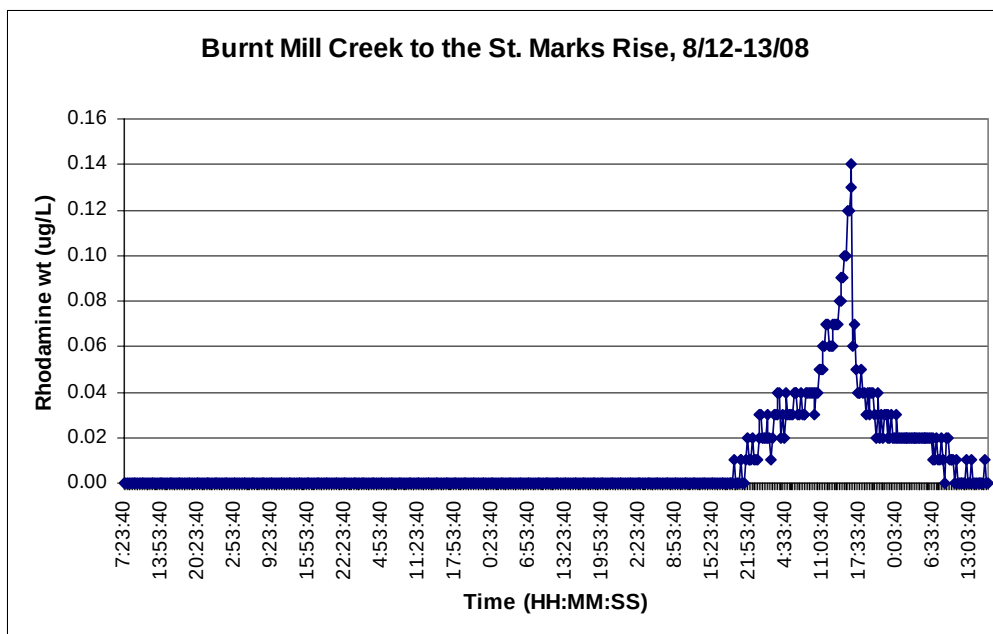


Figure 1.3.21: This graph depicts the breakout curves from the fourth dye study from Burnt Mill Creek to the St. Marks Rise, at the St. Marks Rise.

Dye Injected at Dead Indian Sink where Burnt Mill Creek goes underground @15:30 on 07/22/06.

Dead Indian Sink is located south of US 27 in Jefferson County in Wood Sink Plantation.

Amount of Rhodamine: 1000g

GPS Coordinates: 30 24.305N; 84 04.307W

location	date	timing	max	distance (miles)	Speed (miles/hour)
Waccissa River	7/22-8/14/06	no response	0ppb	6.24	none
Chicken Branch	7/22-8/14/06	no response	0ppb	6.83	none
St. Marks Rise	7/22-8/14/06	22 days 30 min	0.14ppb	9.99	0.018

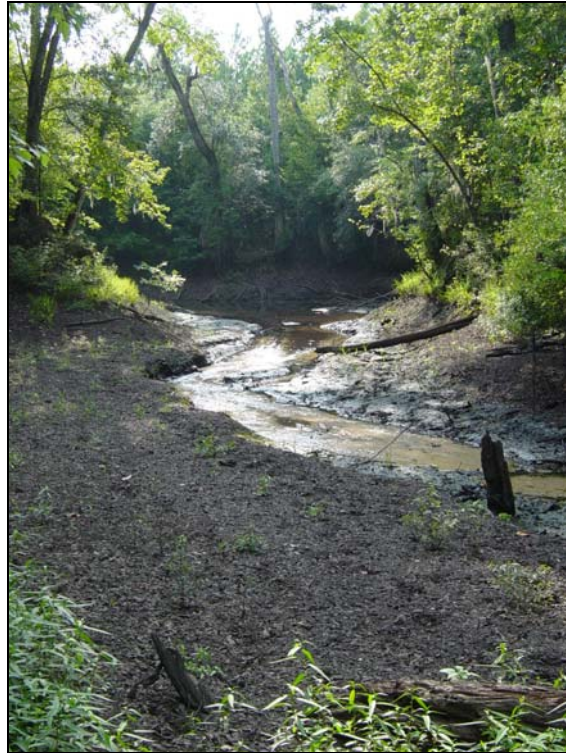


Figure 1.3.22: Burnt Mill Creek is a sinking spring that descends into the aquifer at Dead Indian Sink. Dye was poured into the creek and allowed to disappear with the water



Figure 1.3.23: Rhodamine wt dye, 1 kg, was poured into Burnt Mill Creek on July 22, 2006 at 17:20



Figure 1.3.24: The dye was disappearing into the sink by 17:30.

Dye Study #5



Figure 1.3.25: The location of the dye injection and sensor placement for the fifth dye study from Bird Sink where Black Creek sinks into the aquifer to the St. Marks Rise. Bird Sink is approximately 16 miles from the St. Marks Rise.

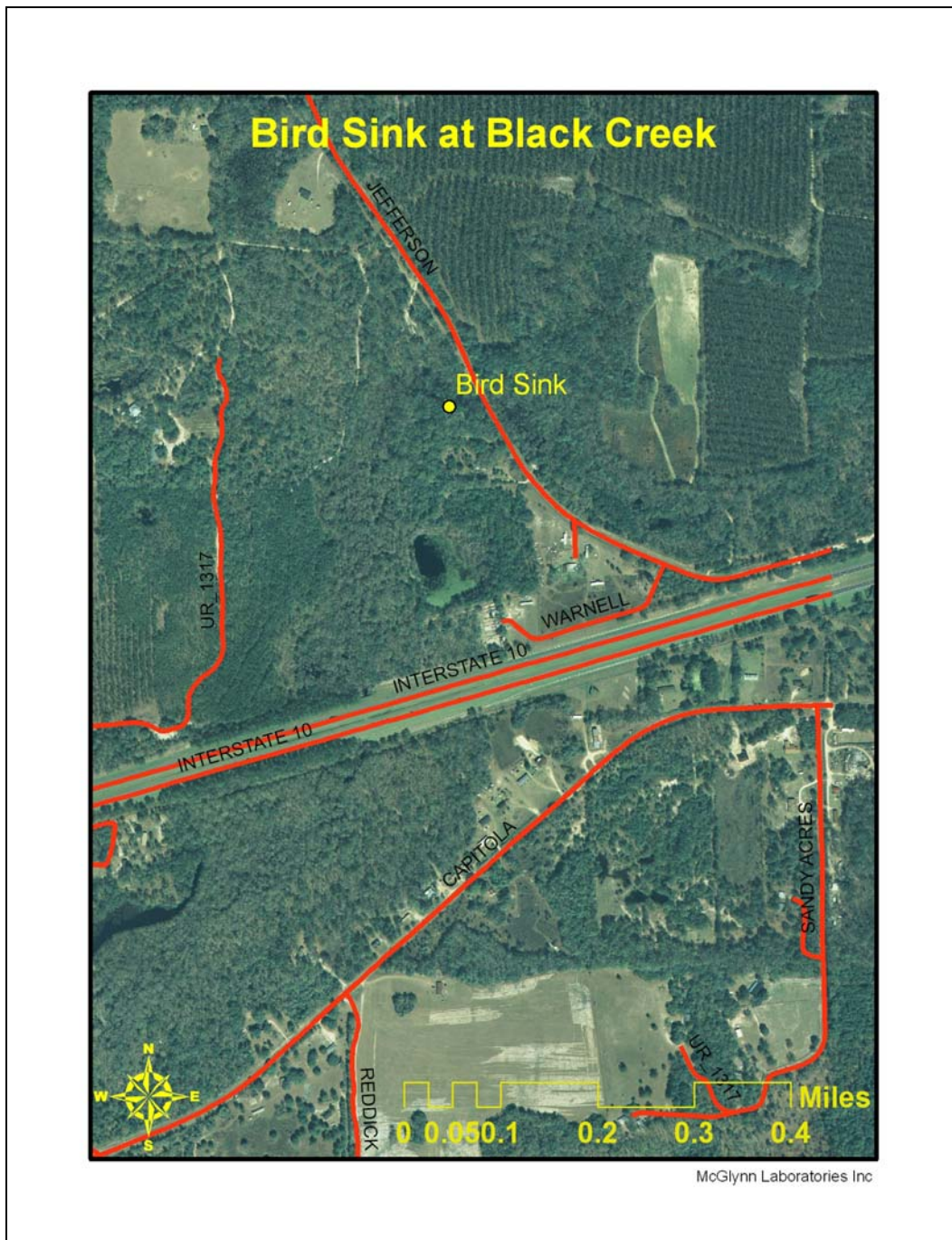


Figure 1.3.26: This map depicts the road to Bird Sink. Dead Indian Sink is not located near any road but can be accessed at the bridge on US 27 over Burnt Mill Creek. This sink is in Jefferson County and we do not have GIS coverage for their roads. The St. Marks Rise is accessed from Natural Bridge Road (see previous map). Go downstream to the Sink located in a Cypress and Black Gum Swamp.

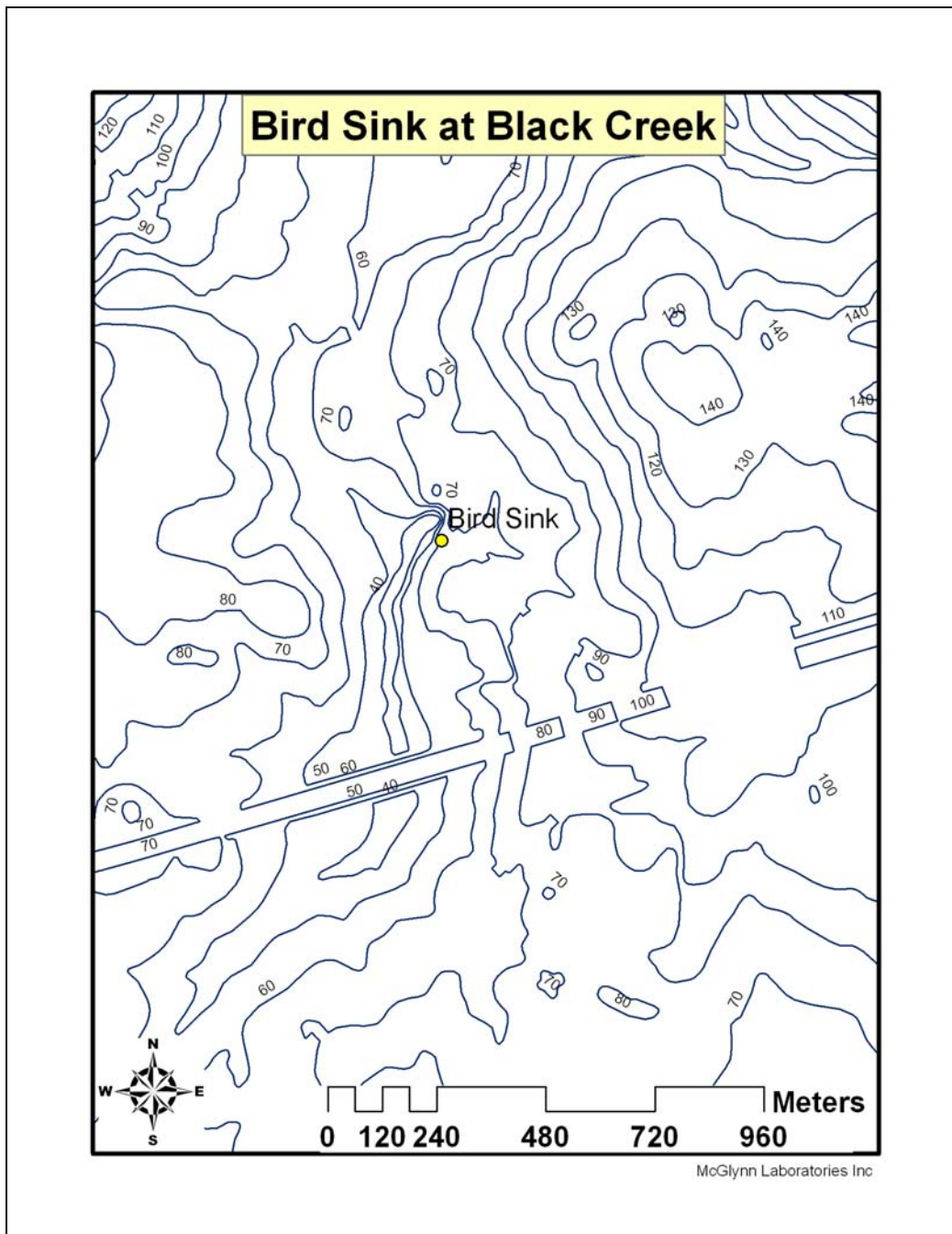


Figure 1.3.27: This map depicts the topography at Bird Sink.

Dye Study #5: Results

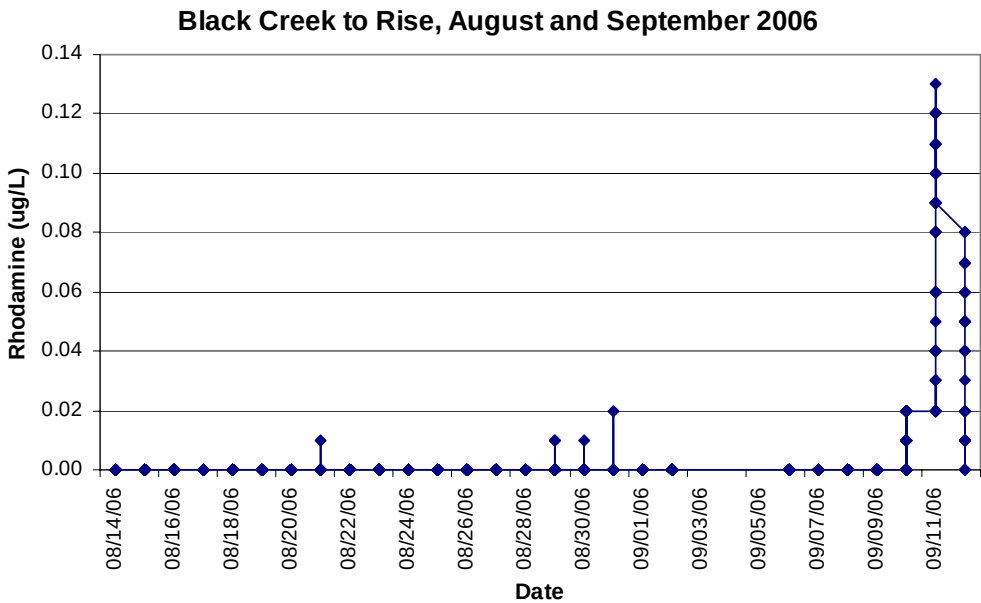


Figure 1.3.28: This graph depicts the daily dye concentrations at the St. Marks Rise from the fifth dye study from Black Creek to the St. Marks Rise.

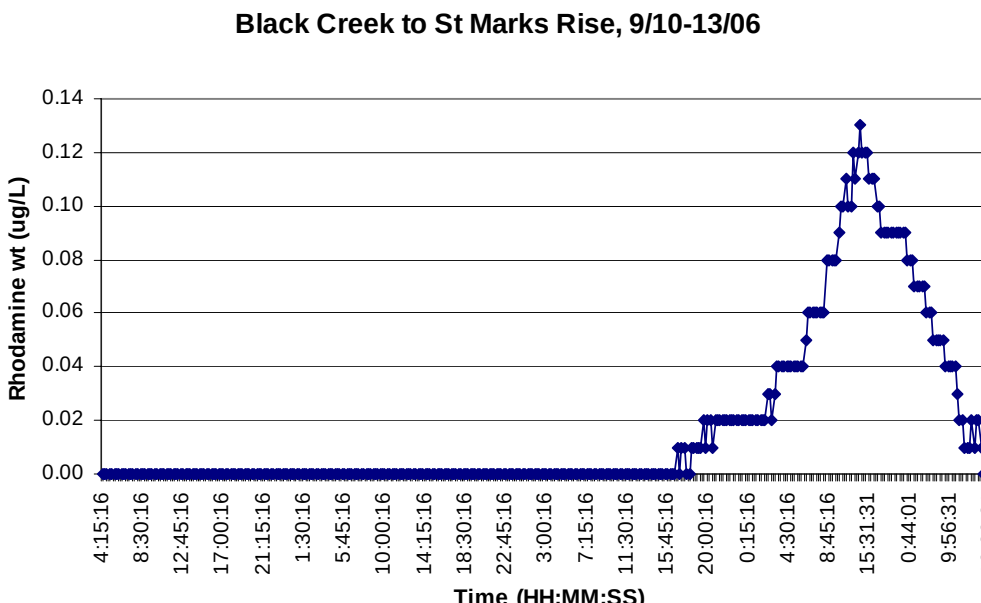


Figure 1.3.29: This graph depicts the breakout curves from the fifth dye study at the St. Marks Rise from Black Creek to the St. Marks Rise.

Dye Injected at Bird Sink: 8/13/06 at 14:30
 Dye detected at St. Marks Rise: 9/10/06 at 16:45
 Dye Maximum at St. Marks Rise: 9/11/06 at 13:45
 Bird Sink just north of I-10 off Jefferson Road
 Amount of Rhodamine: 1500g

location	date	timing	max	distance (miles)	Speed (miles/hour)
Waccissa River	8/13-9/10/06	no response	0ppb	10.46	none
Chicken Branch	8/13-9/10/06	no response	0ppb	12.22	none
St. Marks Rise	8/13-9/10/06	28 days 2 hrs and 15 min	0.13ppb	15.62	0.023



Figure 1.3.30: Black Creek is a sinking blackwater stream



Figure 1.3.31: Black Creek flowing into cavern at Bird Sink



Figure 1.3.32: Scenic Black Creek with Cypress knees as it flows through private property.



Figure 1.3.33: Dye going down Bird Sink. Note the floating trash in Bird Sink. It flows to the sink with each storm.

Section 1.4: Deep Aquifer Water Quality Analysis

Conclusions

Nitrogen and phosphorus are the pollutants of concern in this study. However, in this study they do not pose a human health threat. These nutrients were shown to be above concentrations considered safe for springs (0.2 mg/L Nitrate, Wekiva Study, FDEP 2004). These wells contained waters at levels that are considered detrimental to our springs.

This data coupled with other dye studies (FDEP's study, unpublished) have show that there are extensive conduit systems on either side of the WRB. Conduits and flows in the central and western WRB carry nutrient rich water to Wakulla Springs. Conduits to the east carry the waters of sinking streams and lakes that are low in nutrients from relatively undeveloped parts of Eastern Leon and Western Jefferson Counties to the St. Marks Rise. In Leon County some of this water comes from across the Georgia border.

These deep wells, and the information from the lithographies indicate that groundwater flow may be facilitated in the WRB by a dipping impervious dolomite layer between 100 and 200 feet depth. A rubble zone above the dolomite behaves as a pseudo conduit also facilitating groundwater flow. In addition saline waters were encountered at depths of 300 feet within the WRB. The municipal supply well in Woodville may not be able to be deepened because of this. We do not know if this is salt water intrusion or a stagnant saline layer. More research, and more deep wells need to be investigated.

Summary of Results

Dye studies conducted by the FGS have shown a connection between the SESF and Ames Sink to Wakulla Springs (figure 1.4.1). The dye took 42 days to reach Wakulla Springs from the SESF and 6 days to reach Wakulla Springs from Ames Sink. Dye studies performed during this study showed a direct connection between Natural Bridge, Rhodes Springs, Dead Indian Sink (Gadsden County) and Bird Sink to the St. Marks Rise (for details concerning the MLI dye studies (section 1.3). The dye study from Bird Sink to the St. Marks Rise spanned the longest distance of all these dye studies, over 16 miles. Each of these dye studies, except for the run between the SESF and Wakulla Springs demonstrated conduit flow. The SESF dye run demonstrated facilitated diffuse porous flow indicating that there is no direct conduit but that the dye passed rather readily through the ground.

The geology of the WRB is complex. The installation of a grid of monitoring wells has allowed some generalizations. Dolomite is traceable throughout Southeastern Leon County, including the WRB. The deposits appear to be extensive. The pervasive dolomite deposits are similar in Alachua County where the Hawthorn Formation thins out and

vanishes as it does in the WRB. The erosion of the Hawthorn possibly released magnesium, which can cause dolomitization. The formation of dolomite has never been reproduced in the laboratory. Dolomitization does occur at static groundwater levels. Dolomitization is catalyzed by fresh/salt interaction. The dolomite layer in the WRB is tabular or plainer in shape. The dolomite layer also dips; it gets deeper in the strata to the south. This could be explained by changing sea levels during its formation. The dolomite zone occurs at about 117 feet below the land surface at the northern end of the WRB near the SESF and at about 191 feet below the land surface at the southern end of the WRB at Natural Wells.

The layer of dolomite underlying the WRB is significant because it appears to be impermeable, e.g., groundwater does not easily pass through it. The dolomite is not a considered a confining layer since it is very brittle and contains many fractures. The dolomite layer does cause the groundwater in the WRB to move laterally. Just above the dolomite layer is weathered lime rock, essentially a rubble zone that contains clays, organic material and cavity fill. This is not necessarily a cavity but it behaves as one throughout the WRB. Groundwater flows laterally above the dolomite zone very readily. Since the dolomite zone is dipping towards the south, lateral ground water flow is facilitated.

There are clay layers throughout the geologic strata in the WRB. Typically, the clay layers are rather thin causing water to move laterally. The clay layers are not continuous over large areas, therefore, they do not represent a confining layer. There are numerous sinkholes punctuating the surface of the WRB. These sinks effectively pierce the clay layers rendering them rather ineffectual. The Floridan Aquifer flows through the limestone materials above and below the dolomite and either discharges at the Coast or continue to flow to other discharge areas in the Gulf. The aquifer south of the Cody Scarp in the WRB is unconfined and vulnerable to the effects of pollutants.

Concentrations of chlorides have been observed to rise in the borings and monitoring wells installed by FGS at 250 feet beneath the land surface. By 320 feet beneath the land surface, the chloride level was observed to increase even more. Chlorides are an indicator of salt water. Historical data does not exist to allow us to assess whether or not this is a natural boundary, a result of saltwater intrusion or ancient underground seawater. If salt water is rising in the WRB it could indicate that fresh water withdrawals and/or the first order springs are having an effect on the boundary between the freshwater and salt water, however we do not know if this is the case. These findings do suggest that the municipal water supply wells in the Woodville area cannot be drilled deeper to produce better water.

There was no available current data that identified water quality violations of state or federal water quality regulations for groundwater occurring in the Floridan Aquifer in the WRB. All three wells were sampled and analyzed for EPA priority organic contaminants for two quarters during this study and were found to be below laboratory detection levels. Data from the City of Tallahassee's 6 other well sites also had no hits. This data was

provided to us by the City of Tallahassee and analyzed by the USGS Laboratory. Previous studies have determined that heavy metals are not a matter of concern (NFWFMD, 2002). Nitrogen and phosphorus have not been found at concentrations that pose a risk for human consumption. The water quality of the Floridan Aquifer is high.

The concentrations of nutrients in the Floridan Aquifer appear to be rising based on current long term at Wakulla Springs monitoring data and this is a major concern (NFWFMD, 2002; FDEP, 2004; Peer Review Committee, 2005). There appears to be a gradient in the concentrations of nutrients from the SESF to Wakulla Springs (figure 2). Monitoring well data from the SESF provide evidence of nitrate concentrations at approximately 6 mg/L in certain monitoring wells at the SESF at a depth of 100 feet beneath the land surface (McGlynn et al 2003). Deep wells installed by FGS south of the sprayfield have nitrate concentrations of approximately 2 mg/L (well SJ1, USGS, unpublished). Other deep wells further south had concentrations of 1.5 mg/L nitrate (well SJ4, USGS, unpublished). A deep well at Natural Wells showed a similar concentration of nitrate at 150 foot depth. The long term monitoring data suggest that nutrients, although at concentrations below human health criteria, are increasing in the Floridan Aquifer waters to levels that threaten the ecological health of our numerous springs. These springs are being choked with aquatic plants and algae. Algal toxins have been showing up at some of our springs.

Methods

Deep Floridan Aquifer monitoring wells for water quality sampling were expensive compared to the other wells installed in this project, approximately 250 feet deep and costing approximately \$10,000 each. The wells were drilled and installed by the Florida Geological Society (FGS). Ken Campbell and Brie Coane, both Professional Geologists installed these wells.

Well sampling locations were chosen in consultation with the USGS and Florida Geological Society (FGS) to augment the grid of wells they are placing south of the SESF in the WRB. This strategy of placing the monitoring wells was adopted due to information gathered in Phase I and Phase II of this study (KARSTIC Aquifer Vulnerability Model for the Woodville Recharge Drainage Basin in Leon County, Florida, Point and Non-Point Pollution Sources with the KARSTIC Aquifer Vulnerability Model for the Woodville Recharge Basin, Leon County, Florida; Potential Karst Windows within the Woodville Recharge Drainage Basin in Leon County, Florida; Septic Tank Locations and Soil Suitability within the Woodville Recharge Drainage Basin, Leon County, Florida; Piezometric Maps of Groundwater Flow).

Monitoring wells were sampled according to FDEP's Standard Operating Procedures, 2001 (DEP-SOP-001/02, FS 2200 Groundwater Sampling). Groundwater samples were collected at the monitoring wells on a quarterly basis. All nine wells were supposed to be sampled in this study but the City of Tallahassee would not allow us to sample their

wells. The City of Tallahassee had previously agreed to cooperate with us. Both the City and County Commissions passed resolutions that we were to share the well fields and not duplicate efforts and waste money by drilling duplicate wells. The FGS was not able to complete the well drilling until half way through this project because of the difficult lithology. We were able to sample only three wells for two quarters. 5 additional samples will be analyzed for organics (Caffeine and the 8270 scan run on selected wells. Organic parameters of concern, chemicals that the USGS found in over 10% of impacted groundwater samples, were examined (Brown et al, 1998).

Monitoring wells were sampled according to FDEP's Standard Operating Procedures, 2001 (DEP-SOP-001/02, FS 2200 Groundwater Sampling). Groundwater samples were collected at the monitoring wells on a quarterly basis. All nine wells were supposed to be sampled in this study but the City of Tallahassee would not allow us to sample their wells. The City of Tallahassee had previously agreed to cooperate with us. Both the City and County Commissions passed resolutions that we were to share the well fields and not duplicate efforts and waste money by drilling duplicate wells. The FGS was not able to complete the well drilling until half way through this project because of the difficult lithology. Nobody from Leon County Staff helped in this matter or communicated this difficulty to the Commission. We were able to sample only three wells for two quarters. 5 additional samples will be analyzed for organics (Caffeine and the 8270 scan run on selected wells. Organic parameters of concern, chemicals that the USGS found in over 10% of impacted groundwater samples, were examined (Brown et al, 1998).

*Lithographies and well construction details as well as site maps and data are presented in the next few pages.

*A photographic lithology of the deep wells is available on our web site:
www.mcglynnlabs.com

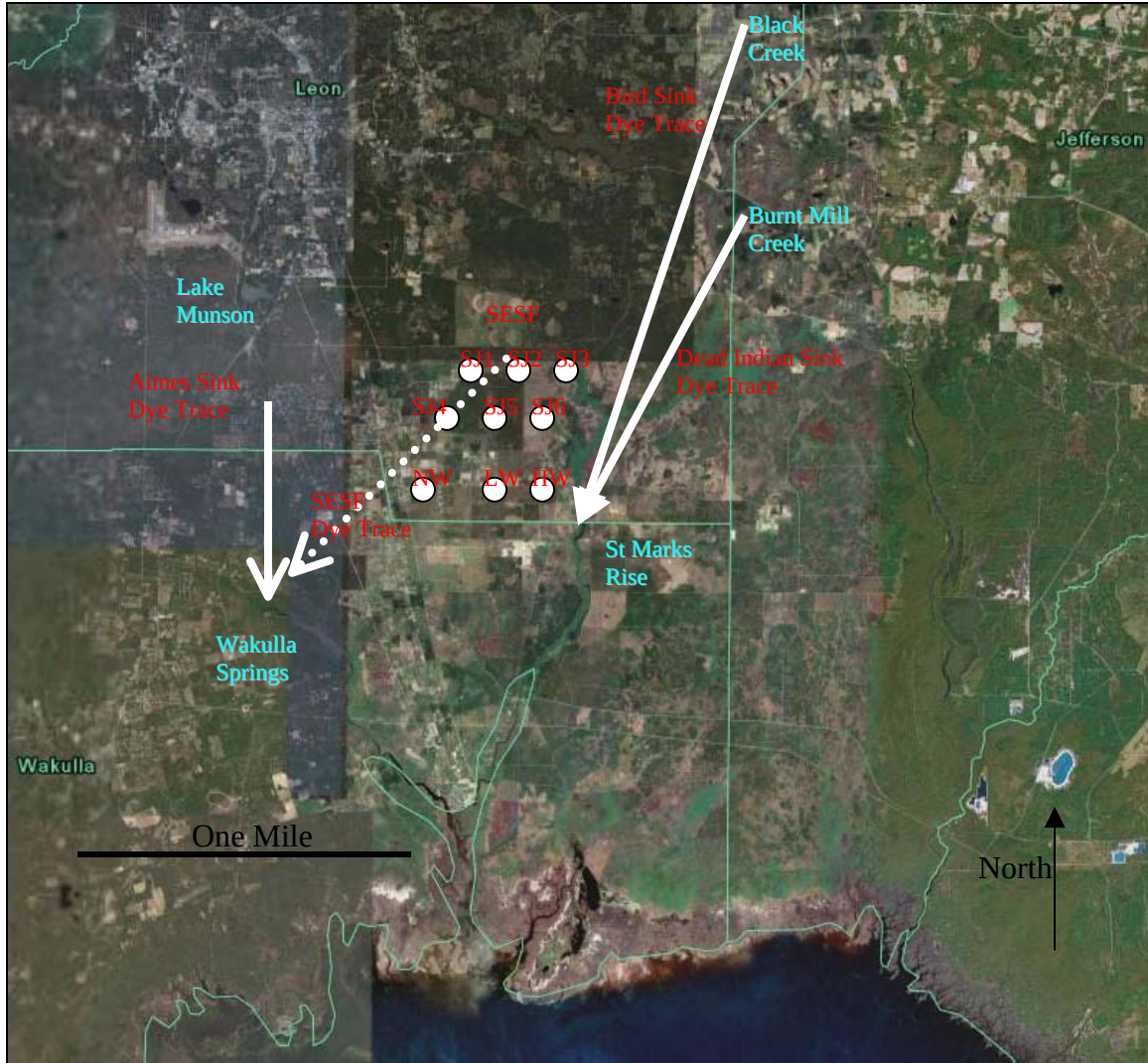


Figure 1.4.1: Schematic Map of the Deep Wells installed by FGS. SJ1-SJ6 were funded by the City of Tallahassee. NW (Natural Wells), LW (Lewis Well) and HW (Hunt Well) were funded by Leon County. Dye Trace Studies are depicted with arrows.

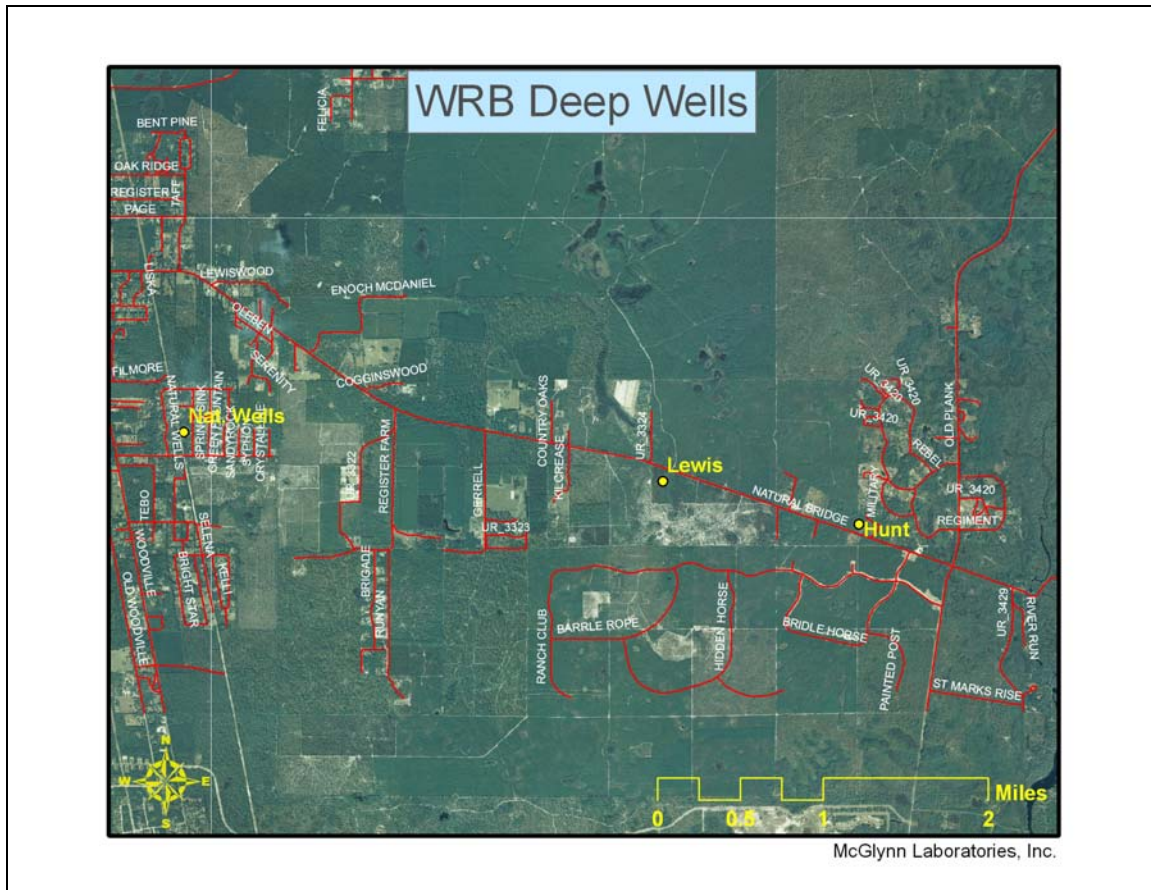


Figure 1.4.2: Roads in the vicinity of the deep wells funded by Leon County.

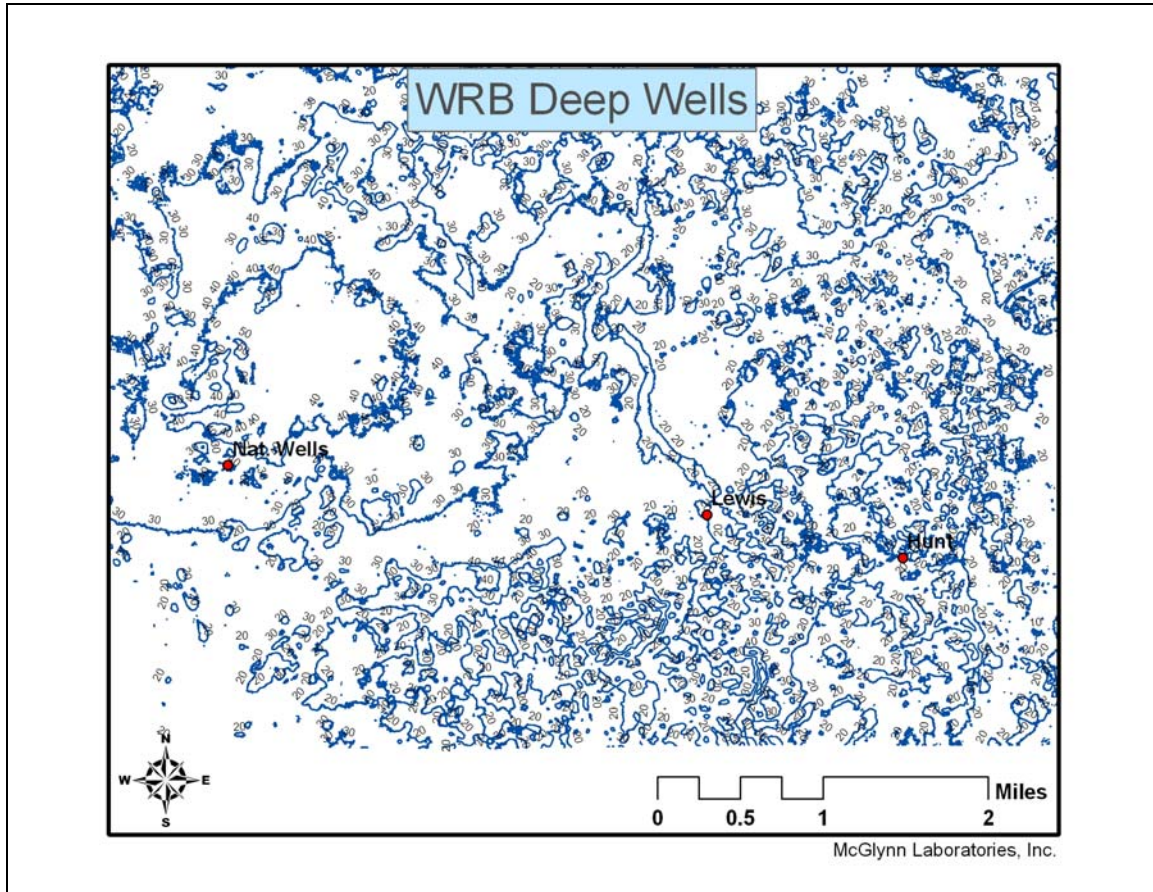


Figure 1.4.3: Topography in the vicinity of the deep wells funded by Leon County.

Table 1.4.1: Nitrates at different well depths. This sampling was performed to locate the depth at which contamination was most likely. After the well is finished this kind of sampling cannot be performed because it is in a sealed pipe. We needed to locate the screen in a plume, if there was one. We found the plume at the Natural well and the Lewis well and without doing this we would have never been able to do this. The USGS did it in their wells too.

Preliminary Data McGlynn Laboratories Inc				Nitrate+Nitrite as N	Chloride	Total P
				EPA 353.3 <i>mdl=0.008</i> <i>pql=0.032</i> mg/L	EPA 325.3 <i>mdl=1.08</i> <i>pql=4.32</i> mg/L	EPA 365.2 <i>mdl=0.003</i> <i>pql=0.012</i> mg/L
			Well Depth ft			
WRB-HuntWell	05/30/06	10:40	50			
WRB-HuntWell	05/31/06	15:35	100			
WRB-HuntWell	06/07/06	15:30	150			
WRB-HuntWell	06/15/06	15:30	200			
WRB-HuntWell	06/19/06	13:15	250			

Preliminary Data McGlynn Laboratories Inc				Nitrate+Nitrite as N	Chloride	Total P
				EPA 353.3 <i>mdl=0.008</i> <i>pql=0.032</i> mg/L	EPA 325.3 <i>mdl=1.08</i> <i>pql=4.32</i> mg/L	EPA 365.2 <i>mdl=0.003</i> <i>pql=0.012</i> mg/L
			Well Depth ft			
WRB-Natural Well	08/17/06	13:00	50			
WRB-Natural Well	08/23/06	12:59	100			
WRB-Natural Well	08/28/06	15:00	150			
WRB-Natural Well	08/31/06	16:15	200			
WRB-Natural Well	09/15/06	14:15	250			

Preliminary Data McGlynn Laboratories Inc				Nitrate+Nitrite as N	Chloride	Total P
				EPA 353.3 <i>mdl=0.008</i> <i>pql=0.032</i> mg/L	EPA 325.3 <i>mdl=1.08</i> <i>pql=4.32</i> mg/L	EPA 365.2 <i>mdl=0.003</i> <i>pql=0.012</i> mg/L
			Well Depth ft			
WRB-Lewis Well	09/18/06	13:00	55			
WRB-Lewis Well	09/21/06	14:00	100			
WRB-Lewis Well	10/17/06	12:26	149			
WRB-Lewis Well	10/26/06	10:49	199			
WRB-Lewis Well	11/14/06	15:53	354			

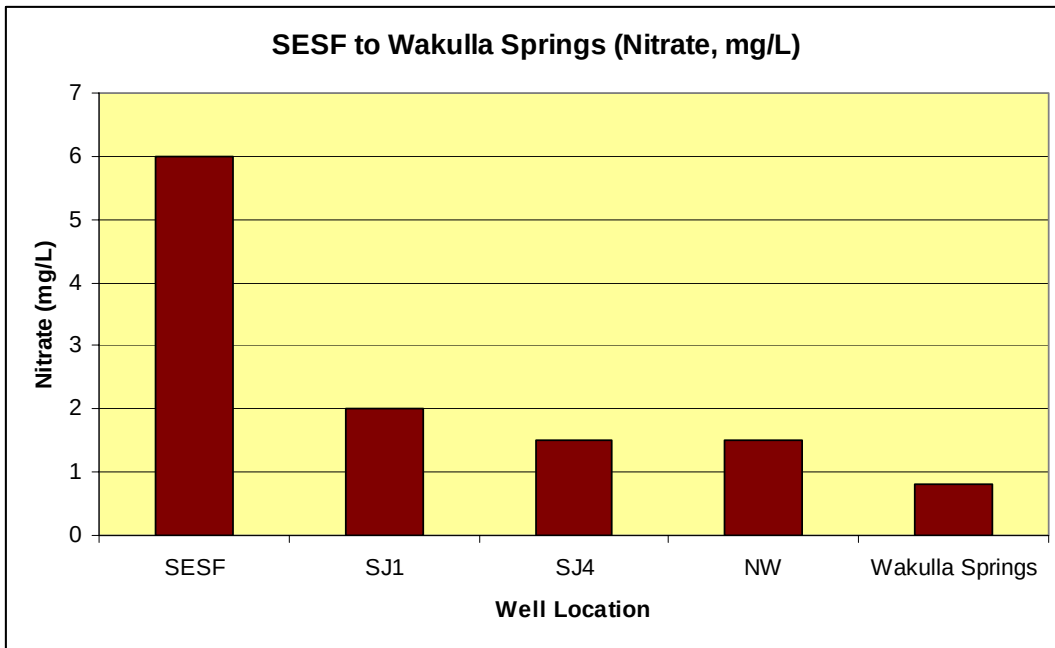


Figure 1.4.1: Nitrate concentrations in wells from the SESF to Wakulla Springs.

Table 1.4.2: USGS data

Deep wells sampled south of the SESF by USGS: SJ 1; SJ 2; SJ 3; SJ 4; SJ 5 and SJ 6
Dates: 1/11/05 and 7/11/06
Results: all below detection limit (except one benzene hit that seems to be contamination)

Compounds Sampled (EPA 8151)

1,1,1,2-Tetrachloroethane; 1,1,1-Trichloroethane; 1,1,2,2-Tetrachloroethane; 1,1,2-Trichloroethane; 1,1-Dichloroethane; 1,1-Dichloroethylene; 1,1-Dichloropropene; 1,2,3-Trichlorobenzene; 1,2,3-Trichloropropane; 1,2,4-Trichlorobenzene; 1,2,4-Trichlorobenzene; 1,2,4-Trimethylbenzene; 1,2-Dibromo-3-chloropropane; 1,2-Dibromoethane; 1,2-Dichlorobenzene; 1,2-Dichlorobenzene; 1,2-Dichloroethane; 1,2-Dichloropropane; 1,3,5-Trimethylbenzene; 1,3-Dichlorobenzene; 1,3-Dichlorobenzene; 1,3-Dichloropropane; 1,4-Dichlorobenzene; 1,4-Dichlorobenzene; 2,2-Dichloropropane; 2,4,5-TP(Silvex); 2,4,6-Trichlorophenol; 2,4-D; 2,4-Dichlorophenol; 2,4-Dimethylphenol; 2,4-Dinitrophenol; 2,6-Dinitrotoluene; 2-Chloronaphthalene; 2-Chlorophenol; 2-Chlorotoluene; 2-Methyl-4,6-dinitrophenol; 2-Nitrophenol; 3,3-Dichlorobenzidine; 4,4-DDD; 4,4-DDE; 4,4-DDT; 4-Chloro-3-methylphenol; 4-Chlorophenylphenyl ether; 4-Chlorotoluene; 4-Nitrophenol; a-BHC; Acenaphthene; Acenaphthylene; Aldrin; Anthracene; b-BHC; Benzene; Benzidine; Benzo(a)anthracene; Benzo(a)pyrene; Benzo(b)fluoranthene; Benzo(ghi)perylene; Benzo(k)fluoranthene; Bis(2-chloroethoxy)methane; Bis(2-chloroethyl)ether; Bis(2-chloroisopropyl)ether; Bis(2-ethylhexyl)phthalate; Bromobenzene; Bromochloromethane; Bromodichloromethane; Bromoform; Bromomethane; Butylbenzylphthalate; Caffeine; Carbon tetrachloride; Chlorobenzene; Chloroethane; Chloroform; Chloromethane; Chrysene; cis-1,2-Dichloroethylene; cis-1,3-Dichloropropylene; Dalapon; D-BHC; DCPA (Dacthal); Dibenzo(ah)anthracene; Dibromochloromethane; Dibromomethane; Dicamba; Dichlorodifluoromethane; Dieldrin; Diethylphthalate; Dimethylphthalate; Di-n-butylphthalate; Di-n-octylphthalate; Dinoseb; Endosulfan I; Endosulfan II; Endosulfan; Sulfate; Endrin; Endrin ketone; Ethylbenzene; Fluoranthene; Fluorene; G-BHC(lindane); Heptachlor; Heptachlor epoxide; Hexachlorobenzene; Hexachlorobutadiene; Hexachlorobutadiene; Hexachlorocyclopentadiene; Hexachloroethane; Indeno(123cd)pyrene; Isophorone; Isopropylbenzene; Methoxychlor; Methylenechloride; MTBE; Naphthalene; Naphthalene; n-Butylbenzene; Nitrobenzene; N-nitrosodimethylamine; N-nitroso-di-n-propylamine; N-nitrosodiphenylamine; n-Propylbenzene; Pentachlorophenol; Pentachlorophenol; Phenanthrene; Phenol; Picloram; p-Isopropyltoluene; Pyrene; sec-Butylbenzene; Styrene; t-Butylbenzene; Tetrachloroethylene; Toluene; Total Xylenes; trans-1,2-Dichloroethylene; trans-1,3-Dichloropropylene; Trichloroethylene; Trichlorofluoromethane and Vinyl chloride



Figure 1.4.3: Cores from Natural Wells ready for the core library at FGS



Figure 1.4.4: FGS drilling the well (Brie Coane and Ken Campbell)

WELL CONSTRUCTION DATA					
Well Number: 18746		Site Name: Woodville Recharge Basin		FDEP Facility I.D. Number: N/A	
Well Location and Type (check appropriate boxes): ☐ On-Site ☐ Right-of-Way ☐ Off-Site Private Property ☒ Above Grade (AG) ☐ Flush-to-Grade		Well Purpose: ☐ Perched Monitoring ☐ Shallow (Water-Table) Monitoring ☒ Intermediate or Deep Monitoring ☐ Remediation or Other (describe)		Well Install Date(s): December 6, 2006	
If AG, list feet of riser above land surface: 2.65				Well Install Method: Rotary with mud	
Borehole Depth (feet): 250		Well Depth (feet): 194.1	Borehole Diameter (inches): 4	Manhole Diameter (inches): N/A	Well Pad Size: 2 feet by 2 feet
Riser Diameter and Material: 2-Inch PVC		Riser/Screen Connections: ☒ Flush-Threaded ☐ Other (describe)	Riser Length: 154.75 feet from 0 feet to 154.75 feet		
Screen Diameter and Material: 3-Inch Diameter, Open Hole		Screen Slot Size: Open Hole	Screen Length: N/A feet from 154.75 feet to 194.1 feet		
1 st Surface Casing Material: PVC also check: ☒ Permanent ☐ Temporary		1 st Surface Casing I.D. (inches): 6	1 st Surface Casing Length: 20 feet from 0 feet to 20 feet		
2 nd Surface Casing Material: also check: ☐ Permanent ☐ Temporary		2 nd Surface Casing I.D. (inches): N/A	2 nd Surface Casing Length: N/A feet from N/A feet to N/A feet		
3 rd Surface Casing Material: also check: ☐ Permanent ☐ Temporary		3 rd Surface Casing I.D. (inches): N/A	3 rd Surface Casing Length: _____ feet from N/A feet to N/A feet		
Filter Pack Material and Size: Open Hole		Prepacked Filter Around Screen (check one): ☐ Yes ☒ No		Filter Pack Length: N/A feet from N/A feet to N/A feet	
Filter Pack Seal Material and Size:		Open Hole Completion		Filter Pack Seal Length: N/A feet from N/A feet to N/A feet	
Surface Seal Material:		Neat Cement		Surface Seal Length: 150.60 feet from 0 feet to 150.6 feet	

WELL DEVELOPMENT DATA			
Well Development Date:		Well Development Method (check one): ☐ Surge/Pump ☐ Pump ☐ Compressed Air ☒ Other (describe) Wells were developed with air, as the borehole was reamed	
Development Pump Type (check): ☐ Submersible ☒ Other (describe) Airlift		Depth to Groundwater (before developing in feet):	
Pumping Rate (gallons per minute): 18	Maximum Drawdown of Groundwater During Development (feet):		Well Purged Dry (check one): ☐ Yes ☒ No
Pumping Condition (check one): ☒ Continuous ☐ Intermittent	Total Development Water Removed (gallons):	Development Duration (minutes):	Development Water Drummed (check one): ☐ Yes ☐ No
Water Appearance (color and odor) At Start of Development:		Water Appearance (color and odor) At End of Development:	

WELL CONSTRUCTION OR DEVELOPMENT REMARKS
Well is located on private property at 5831 Natural Bridge Road, Woodville, Leon County, Florida. Borehole caved in during reaming for well installation from 273.6 to 211.7 feet below the landsurface.

Figure 1.4.5: Well Construction Data, Natural Wells (typical of the three wells)

Boring/Well Number: W-18744		Permit Number: T200603124		FDEP Facility Identification Number: N/A	
Site Name: Woodville Recharge Basin		Borehole Start Date: 05/25/06	Borehole Start Time: ☐ AM ☐ PM		
		End Date: 08/21/06	End Time: ☐ AM ☐ PM		
Environmental Contractor: Florida Geological Survey		Geologist's Name: Ken Campbell		Environmental Technician's Name: Jake Halfhill	
Drilling Company: Florida Geological Survey		Pavement Thickness (inches): N/A	Borehole Diameter (inches): 3		Borehole Depth (feet): 249.5
Drilling Method(s): Rotary with mud		Measured Well DTW (in feet after water recharges in well): 10.45		OVA (list model and check type): N/A ☐ FID ☐ PID	
Disposition of Drill Cuttings [check method(s)]: ☐ Drum ☒ Spread ☐ Backfill ☐ Stockpile ☐ Other					
(describe if other or multiple items are checked):					
Borehole Completion (check one): ☒ Well ☐ Grout ☐ Bentonite ☐ Backfill ☒ Other (describe)					
Lithologic Description Interval (feet beneath the land surface)				Sample Description (include grain size based on USCS, odors, staining, and other remarks)	
0	to	7		Sand, Fine to Coarse, Gray and Brown	
7	to	11.5		Clay, grey and brown	
11.5	to	15.5		Limestone	
15.5	to	17.5		Cavity	
17.5	to	39		Limestone	
39	to	67		Limestone, fossiliferous	
67	to	92		Limestone, grannular	
92	to	102		Limestone, calcitic	
102	to	122		Limestone, grannular, fossiliferous	
122	to	123		Limestone, grannular	
133	to	139		Limestone	
139	to	147		Dolomite	

Figure 1.4.6: Well Completion Report, Natural Well

Boring/Well Number: W-18745			Permit Number: T200603646			FDEP Facility Identification Number: N/A		
Site Name: Woodville Recharge Basin			Borehole Start Date: 08/07/06		Borehole Start Time: ☐ AM ☐ PM		End Date: 09/29/06	
			End Time: ☐ AM ☐ PM					
Environmental Contractor: Florida Geological Survey			Geologist's Name: Ken Campbell			Environmental Technician's Name: Jake Halfhill		
Drilling Company: Florida Geological Survey			Pavement Thickness (inches): N/A		Borehole Diameter (inches): 3		Borehole Depth (feet): 253.5	
Drilling Method(s): Rotary with mud		soil moisture content		Measured Well DTW (in feet after water recharges in well): 30		OVA (list model and check type): N/A ☐ FID ☐ PID		
Disposition of Drill Cuttings [check method(s)]: ☐ Drum ☒ Spread ☐ Backfill ☐ Stockpile ☒ Other								
(describe if other or multiple items are checked):								
Borehole Completion (check one): ☒ Well ☐ Grout ☐ Bentonite ☐ Backfill ☒ Other (describe)								
Lithologic Description Interval (feet beneath the land surface)				Sample Description (include grain size based on USCS, odors, staining, and other remarks)				
0	to	5						Sand, fine, white
5	to	13.5						Clayey Sand, yellow
13.5	to	20.25						Sand, fine, white
20.25	to	25.25						Clay, blue with limestone
25.25	to	30.25						Limestone, white, dolostone rip clast
30.25	to	31.75						Limestone, with blue clay
31.75	to	87.5						Limestone, cream with fossils and rip clast
87.5	to	91.5						Clay, green
91.5	to	101.5						Limestone, cream
101.5	to	106.5						Limestone, cream, with clayey laminates
106.5	to	108						Limestone, clayey
108	to	111.5						Clay, blue green

Figure 1.4.7: Well Completion Report, Lewis Well

Boring/Well Number: W-18746				Permit Number: T200604106				FDEP Facility Identification Number: N/A			
Site Name: Woodville Recharge Basin				Borehole Start Date: 09/14/06		Borehole Start Time: ☐ AM ☐ PM		End Date: 12/06/06		End Time: ☐ AM ☐ PM	
Environmental Contractor: Florida Geological Survey				Geologist's Name: Ken Campbell				Environmental Technician's Name: Jake Halfhill			
Drilling Company: Florida Geological Survey				Pavement Thickness (inches): N/A		Borehole Diameter (inches): 3		Borehole Depth (feet): 273.6			
Drilling Method(s): Rotary with mud		soil moisture content		Measured Well DTW (in feet after water recharges in well): 14		OVA (list model and check type): N/A ☐ FID ☐ PID					
Disposition of Drill Cuttings [check method(s)]: ☐ Drum ☒ Spread ☐ Backfill ☐ Stockpile ☐ Other (describe if other or multiple items are checked):											
Borehole Completion (check one): ☒ Well ☐ Grout ☐ Bentonite ☐ Backfill ☒ Other (describe)											
Lithologic Description Interval (feet beneath the land surface)				Sample Description (include grain size based on USCS, odors, staining, and other remarks)							
0 to 2.5				Sand, medium, light brown							
2.5 to 5.0				Sand, fine, tan and gray							
5 to 7.5				Clayey Sand, mottled red							
7.5 to 10				Clayey Sand, mottled red and gray							
10 to 15				Sandy Clay, mottled gray							
15 to 20				Clay, brown and yellow, grading to Limestone, white							
20 to 25				Limestone, cream and light brown							
25 to 30				Limestone, white, light gray, calcitic							
30 to 40				Limestone, cream and tan, moldic, some laminites							
40 to 45				Limestone, cream and tan, micro moldic							
45 to 50				Clay, blue							
50 to 55				Limestone, cream							

Figure 1.4.8: Well Completion Report, Hunt Well

Section 1.5: Analysis of Discharges to Karst Features

Introduction

This study on discharges to Karst Features was undertaken because stormwater can flow into Sinkholes and pass directly to the aquifer without being attenuated. This has been termed a short circuit to the aquifer. Many compounds like phosphorus, pesticides, herbicides and petroleum hydrocarbons are hydrophobic and thus absorb onto soils rapidly. These compounds are unlikely to filter through the soil into the aquifer but they can easily flow into a sinkhole and enter the aquifer.

Compounds like Nitrate and Chloride behave differently, they are hydrophilic and pass through the soils easily. They can enter the aquifer without the aid of a sinkhole but they too will pass through a sinkhole into the aquifer. Sinkholes or Open Karst features are a good means for aquifer recharge but if stormwater or other human contaminants are present they can be the most highly vulnerable point in the aquifer. Here the aquifer is not protected from contamination.

This section investigates the nature of sinkholes in the WRB during storm events and their vulnerability. Ames Sink was chosen for monitoring, even though it was outside the WRB, because it is nearby and drains a large urban watershed within the City of Tallahassee. Blueberry Sink was chosen as a site because it is a sink located in a typical Woodville Suburb. Chicken Branch was chosen because it receives the most flow of all the sinks in the WRB. It also contains a significant spring not located on any county or state map. Ames Sink is located in a rural trailer community on sandy unpaved roads but its watershed encompasses most of downtown Tallahassee, Florida State University and about a third of the City of Tallahassee. Chicken Branch is heavily forested with cypress trees. It is a continuation of the drainage from off the Cody Scarp through the CoT Sprayfield buffer and the Hidden Lakes. It contains both karst features and springs.

Methods

Four storm events were sampled at 3 different karst features that receive stormwater surface flows. Flows will be measured with a Marsh McBurney 201D portable current flow meter (DEP-SOP-001/02, FT 1800, Field Measurement of Water Flow and Velocity). Samples were collected with automated samplers according to NELAC protocols. Base flow samplers were taken as a grab sample. The standard stormwater parameters analyzed include temperature, dissolved oxygen, pH, specific conductivity, alkalinity, chlorides, fecal coliforms, ammonia, nitrite + nitrate, total nitrogen, reactive phosphate, total phosphate, total suspended solids, turbidity, copper, iron, chromium, lead and zinc.

Summary of Results

The WRB has few large karst features.

The WRB has numerous small karst features.

Karst features in the WRB represent fractures in the clay layers. Significant flow from the surficial aquifer enters these sinks draining nearby septic systems.

There were statutory violations of copper, iron and fecal coliforms in the stormwater flowing into sinks.

There were possible violations of nitrogen and phosphorus in the stormwater flowing into sinks. The major sink studied here, Ames Sink, which flows from Lake Munson is a much more significant avenue of contamination to the aquifer than any karst feature in the WRB since the amount of flow that goes down it is so great. Ames Sink concentrations were much higher than those at Blueberry Sink and Chicken Branch. Ames sink drains a large urban area. The other sinks do not.

Algal toxins, in violation of drinking water standards, also enter the aquifer at Ames Sink (see data below).

None of the areas sampled were at typical pristine levels of contaminants. Chicken Branch was the best but had some issues. Fecal Coliform levels were just below the State Water Quality Criteria of 900 counts per 100ml (Florida Statutes). Nitrate and Ammonia were at elevated levels, far above those considered safe for a spring (0.3 mg/L, Wakiva Study)

Blue berry Sink may have been affected by the replacement of a nearby septic system with a high performance unit during the course of this study. TN was elevated during the 7/25/06 sampling. This was probably due to the septic system at the residence being replaced with an aerobic system. Disturbing an old drainfield releases many of the bound nutrients that probably seeped into the sinkhole. There was also a noticeable decline in water quality and excessive algal growth in the sink. It also appears that new septic systems may require as much as a year before their drainfields develop bacterial mats capable of metabolizing wastewater.

The concentrations of contaminants in Ames Sink were higher than those at Blueberry Sink and Chicken Branch because. Ames sink drains a large urban area. The other sinks do not. Ames Sink was had extremely poor water quality. According to one of the peer reviewers, it was shown to carry up to 1600 lbs/day of nitrogen to Wakulla Spring in four days. How does this one feature affect nitrate concentration at spring? Since one pound of nitrate will contaminate approximately 120,000 gallons (assumes 8.3 #/gal) of water to 1 mg/L (ppm) then 1600 pounds will contaminate 192,000,000 gallons of water to 1 ppm.

Since the spring discharges about 1,000,000,000 (billion) gallons of water a day, Ames sink could account for approximately $\frac{1}{4}$ of the nitrates contaminated to 0.8 mg/L (or 0.2 of the 0.8 mg/L observed from Ames sink alone). This is significant (tom Kwader, PG).

Phosphorus may be the primary pollutant of concern in the stormwater flowing into sinks holes. Phosphorus is absorbed in the soils. It needs an open karst feature to enter the aquifer and it was found to be elevated in stormwater in the WRB and Ames Sink. Algal toxins were also detected in the water flowing into Ames Sink at levels above the WHO Drinking Water Standard. Fecal Coliform bacteria and copper were also entering most of the sinkholes investigated at elevated concentrations.

The loading of Nitrogen, and Phosphorus in the stormwater flowing into Ames sink was found to be much more significant than any of the loadings from the individual WRB features. If loading is considered the aquifer in the WRB does not seem to be threatened by Stormwater runoff to sinkholes within the WRB at the current time. The water quality in the aquifer is threatened by the loading of pollutants from Ames Sink that is close to the WRB. Leon County Staff requested that Ames Sink be analyzed in this study even though it is outside the Watershed.

Conclusions

Phosphorus may be the primary pollutant of concern in the stormwater flowing into sinks holes. Phosphorus is absorbed in the soils. It needs an open karst feature to enter the aquifer and it was found to be elevated in stormwater in the WRB and Ames Sink. Algal toxins were also detected in the water flowing into Ames Sink at levels above the WHO Drinking Water Standard. Fecal Coliform bacteria and copper were also entering most of the sinkholes investigated at elevated concentrations.

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As a side note, TN was elevated during the 7/25/06 sampling at Blueberry Sink. This was probably due to the septic system at the residence being replaced with an aerobic system. Disturbing an old drainfield seems to release bound nutrients that probably seeped into the sinkhole. There was a noticeable decline in water quality and excessive algal growth in the sink at this time. It also appears that new septic systems, even advanced ones, may require as much as a year before their drainfields develop bacterial mats capable of metabolizing wastewater.

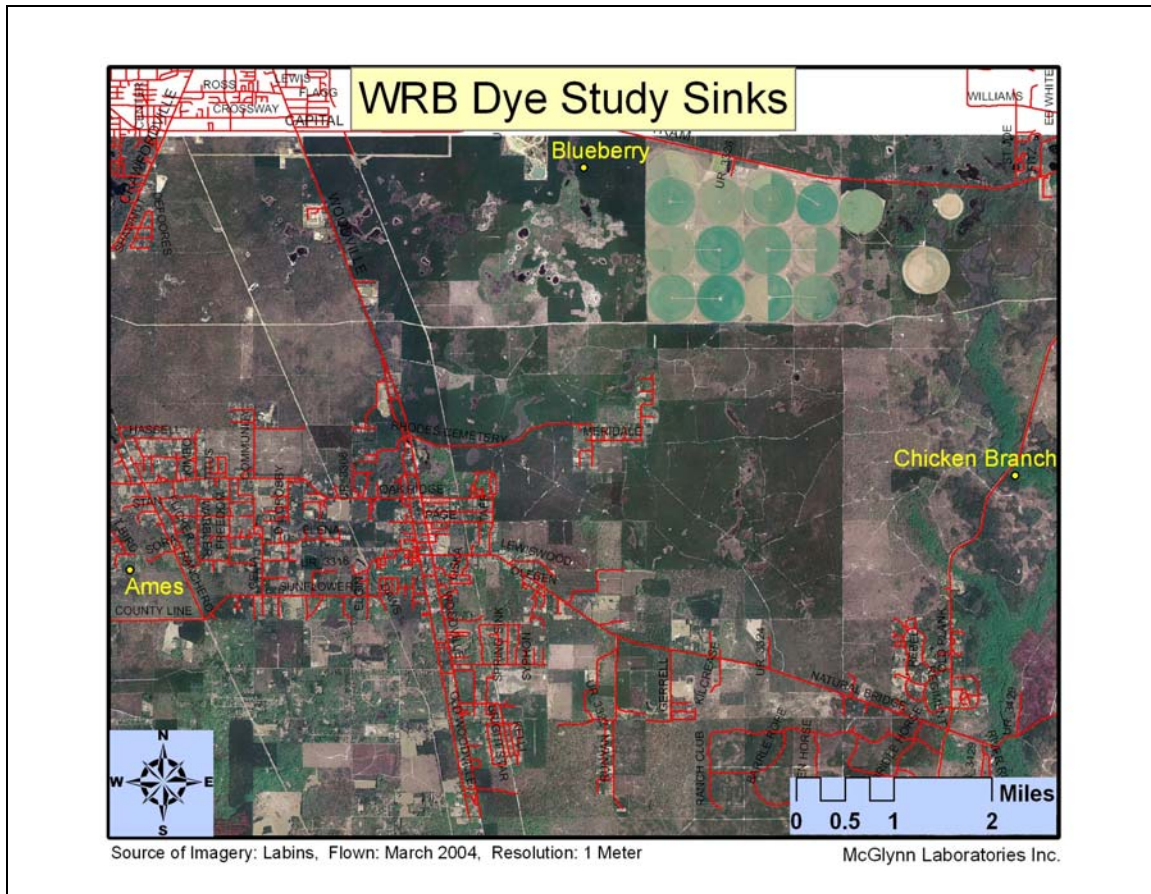


Figure 1.5.1: Map of the WRB Karst Features sampled for stormwater and base flow.

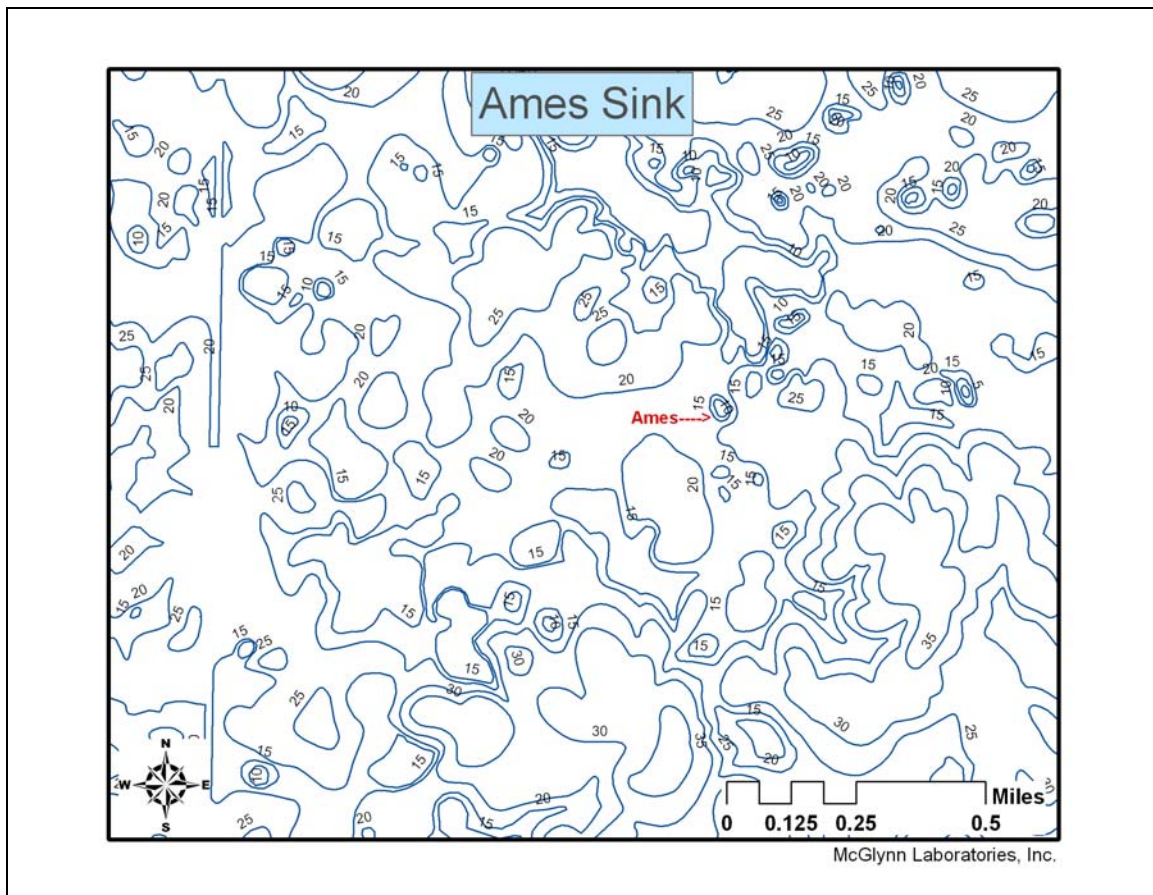


Figure 1.5.2: Map of Ames Sink contours. The sink was sampled at the inflow.

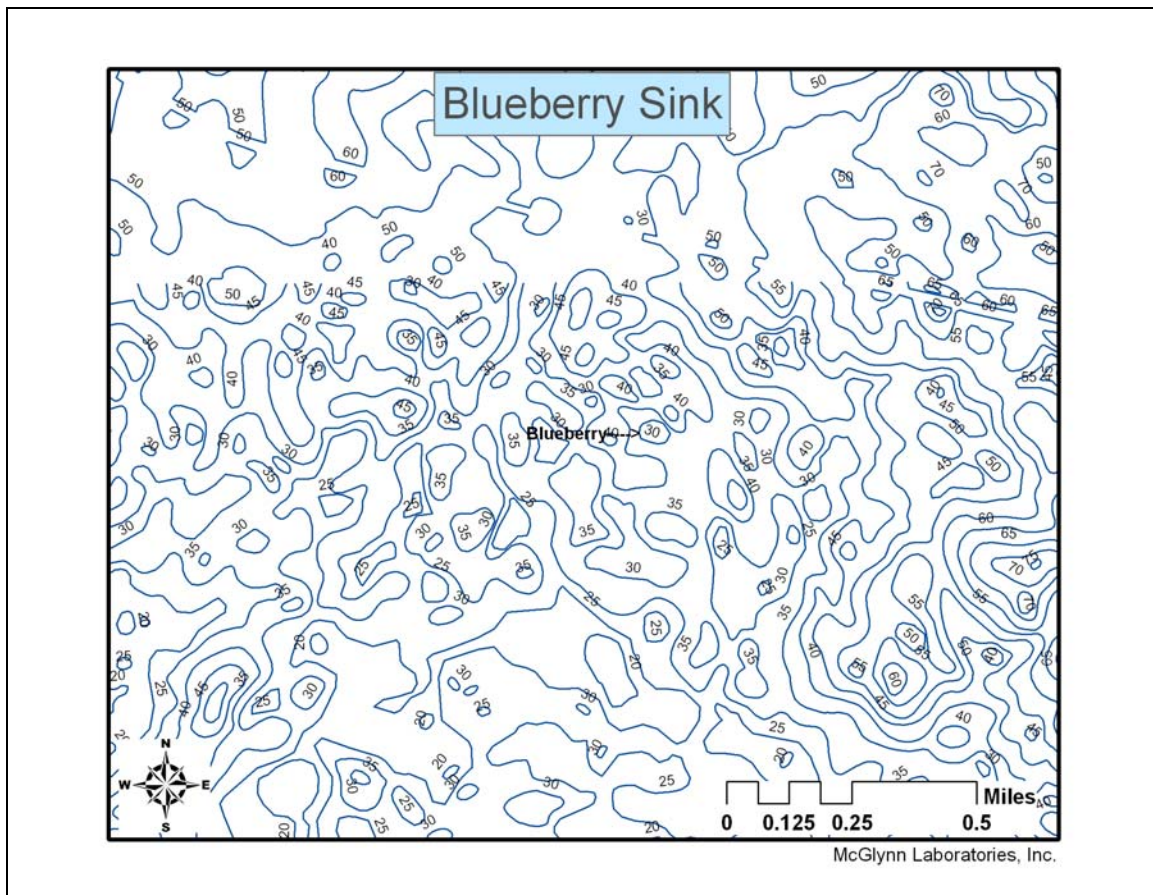


Figure 1.5.3: Map of Blueberry Sink contours. The sink was sampled at the inflow.

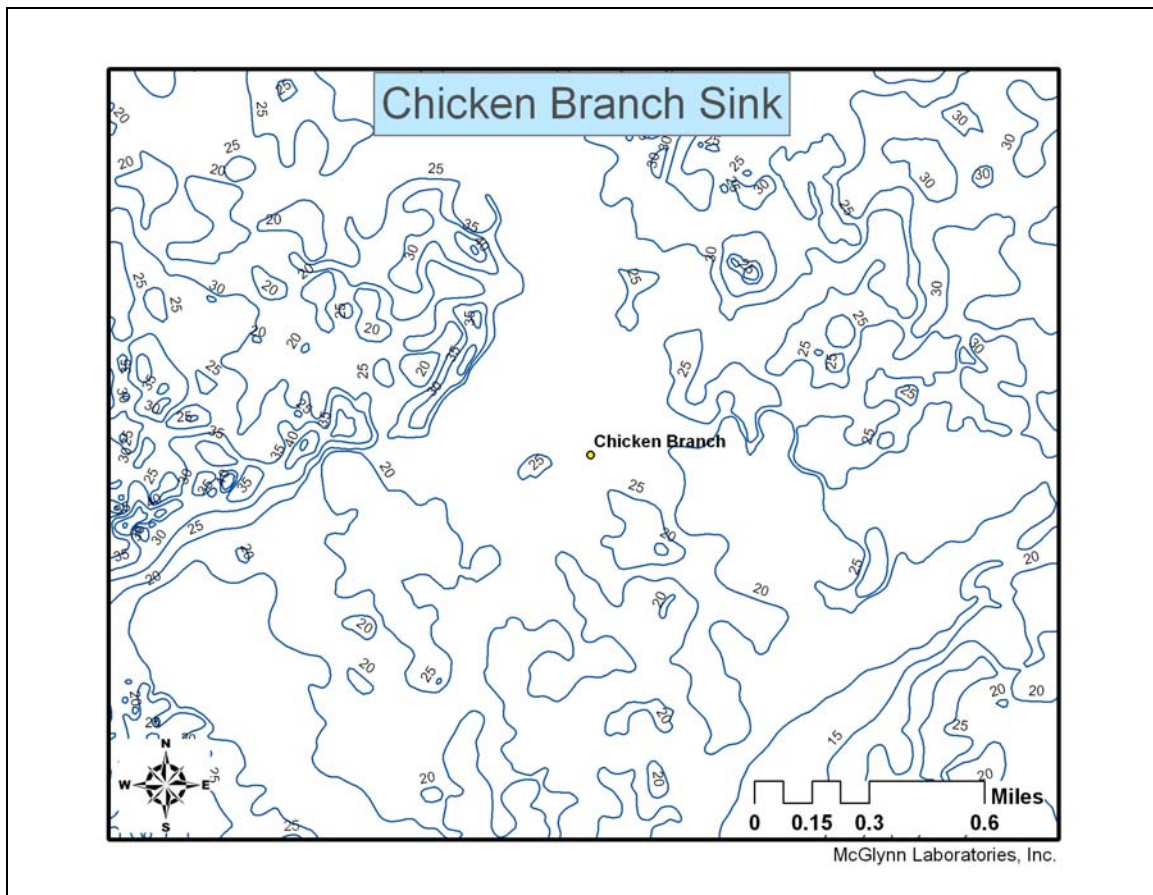


Figure 1.5.4: Map of Chicken Branch contours. This site was sampled at Plank Road.

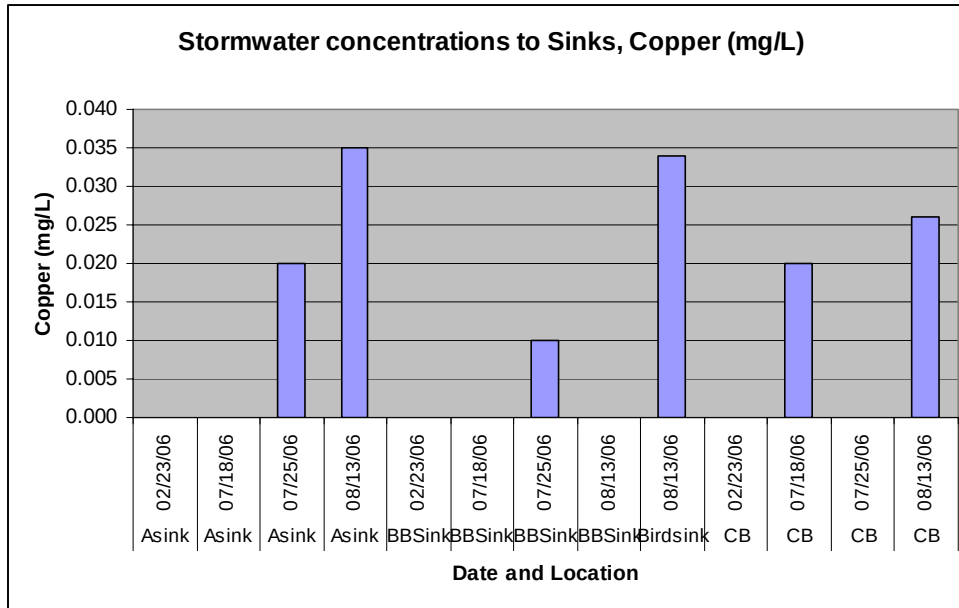


Figure 1.5.5: Almost half the stormwater samples exceeded the dissolved metals criteria for copper (62-302.500(2)(d), FAC

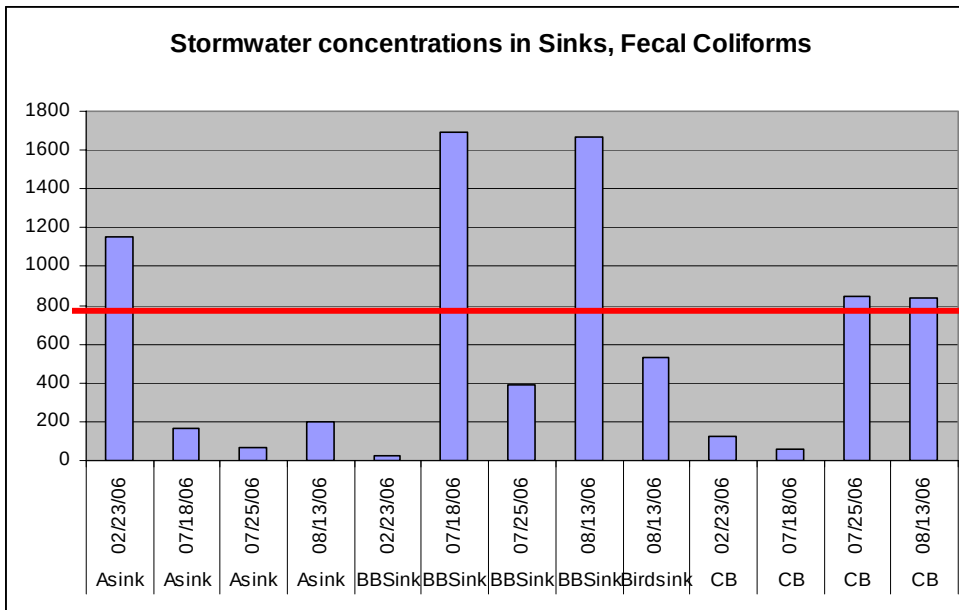


Figure 1.5.6: Four the stormwater samples exceeded the bacterialological criteria for fecal coliforms (62-302.500(2)(d), FAC

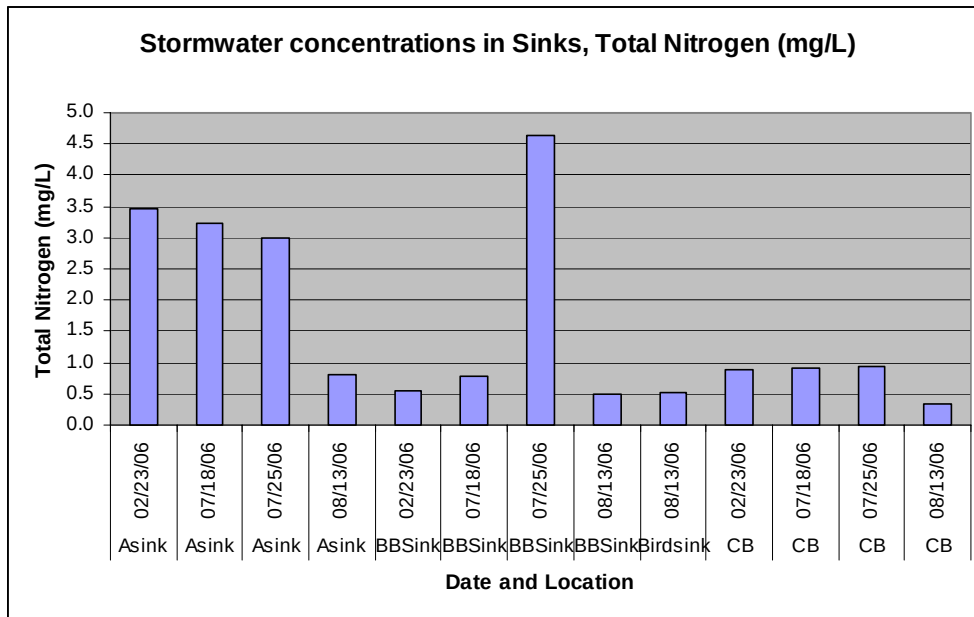


Figure 1.5.7: Nitrogen concentrations in Ames Sink may be sufficient to create a biological imbalance and could constitute a violation of Florida Statutes (62-302.500(2)(d), FAC).

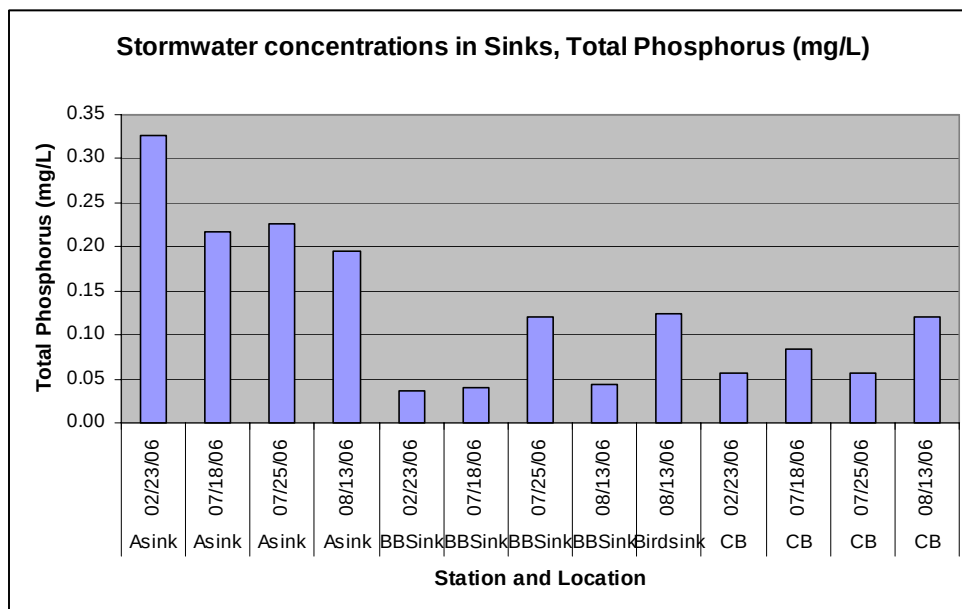


Figure 1.5.8: Phosphorus concentrations in Ames Sink may be sufficient to create a biological imbalance and could constitute a violation of Florida Statutes (62-302.500(2)(d), FAC).

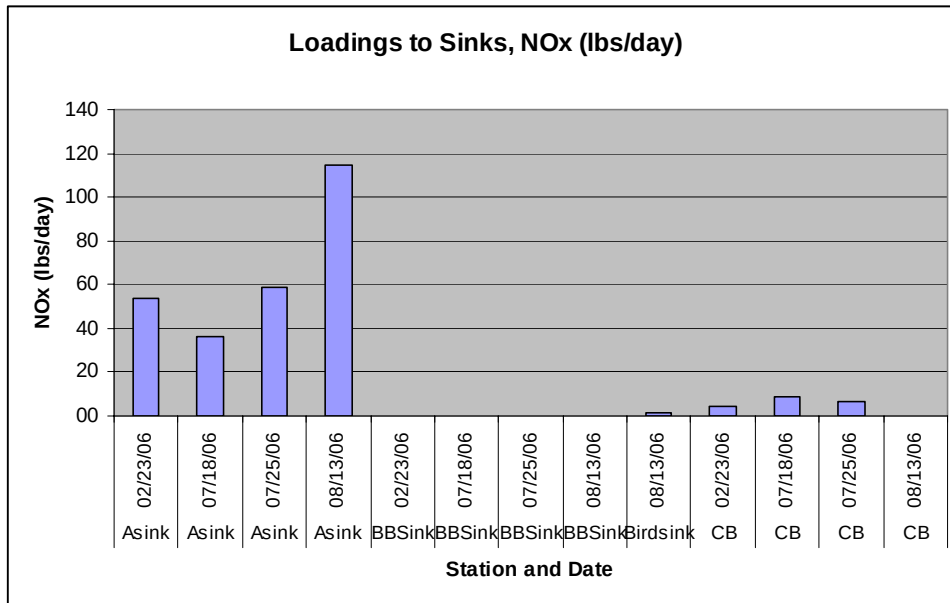


Figure 1.5.9: Loadings of nitrates to Ames Sink is greater than the loadings from the other sinks to the aquifer.

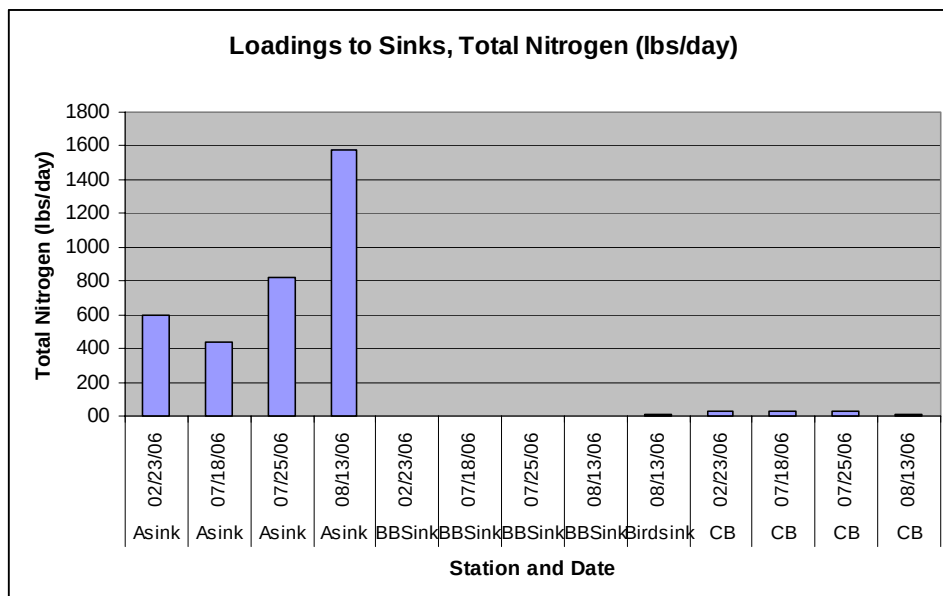


Figure 1.5.10: Loadings of nitrogen to Ames Sink is greater than the loadings from the other sinks to the aquifer.

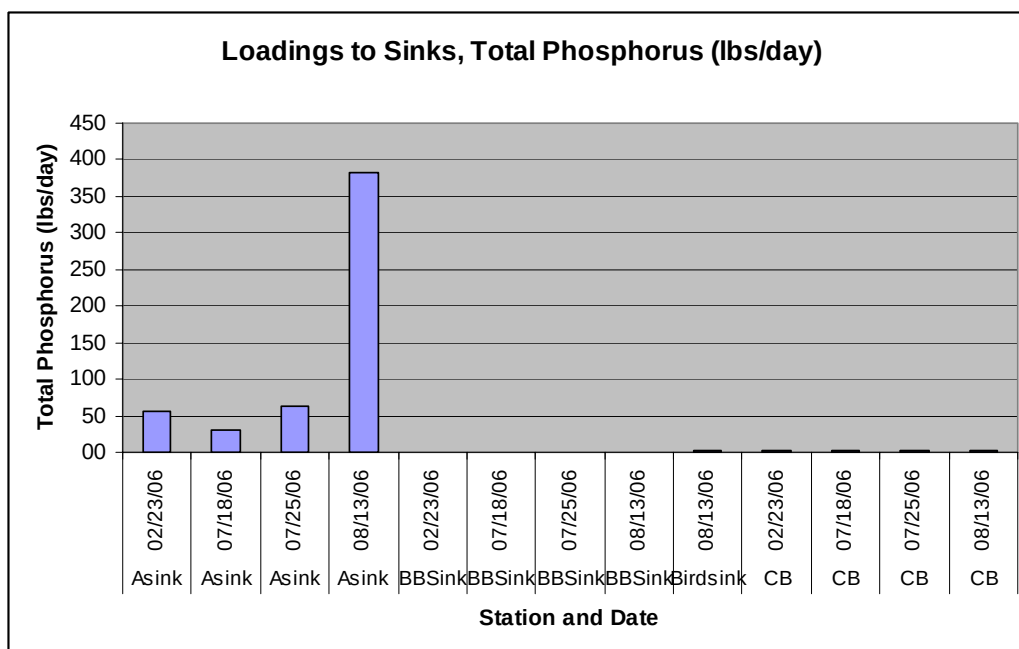


Figure 1.5.11: Loadings of Phosphorus to Ames Sink is greater than the loadings from the other sinks to the aquifer.

Microcystin Analysis Report (Lake Munson)

Analytical Methodology – A microcystins enzyme linked immunosorbent assay (ELISA) was utilized for the quantitative and sensitive congener-independent detection of MCs. Toxins analyzed by Greenwater Labs in Palatka, Florida.

****The drinking water threshold effects the level for the toxin microcystin is 1.0 µg/L MCLR (World Health Organization).**

Table 1.5.1: Microcystin toxins in Ames Sink and Lake Munson

<u>Sample</u>	<u>Date of Collection</u>	<u>MC levels (µg/L)</u>
Munson Bloom	09/23/05	54
Munson Bloom	05/01/06	26
Munson Bloom	05/22/06	20
Munson Bloom dup	05/22/06	20
Munson (Munson Slough)	08/13/06	46
Munson (Munson Slough) dup	08/13/06	14

*The loading of this toxin to the aquifer at Ames Sink on 8/13/06 was 0.16 lbs per day.

Table 1.5.2: WRB stormwater data. CB is Chicken Branch. BBSink is Blueberry Sink. Asink is Ames Sink at Lake Munson. Bird Sink is just that.

	WRB Data				NOx	Ammonia	TN	ORTHO-P	Total P
	Storm Sampling Data Summary				EPA	EPA	EPA	EPA	EPA
	Field Identification Information				353.3	350.3	351.4	365.200	365.2
					<i>mdl=0.01</i>	<i>mdl=0.049</i>	<i>mdl=0.081</i>	<i>mdl=0.004</i>	<i>mdl=0.006</i>
	Collection				<i>pql=0.04</i>	<i>pql=0.196</i>	<i>pql=0.128</i>	<i>pql=0.016</i>	<i>pql=0.024</i>
	Station	Date	Time	Depth Code	mg/L	mg/L	mg/L	mg/L	mg/L
Storm Sample	CB	02/23/06	18:11	C	0.156	0.125	0.881	0.036	0.056
Storm Sample	BBSink	02/23/06	18:54	C	0.024	0.045	0.548	BDL	0.036
Storm Sample	Asink	02/23/06	19:23	C	0.312	0.311	3.464	0.018	0.326
Storm Sample	CB	07/18/06	18:40	C	0.269	0.145	0.904	0.042	0.084
Storm Sample	BBSink	07/18/06	19:05	C	0.081	0.056	0.779	BDL	0.040
Storm Sample	Asink	07/18/06	19:44	C	0.267	0.307	3.219	0.013	0.217
Storm Sample	CB	07/25/06	15:44	C	0.189	0.113	0.940	0.040	0.056
Storm Sample	BBSink	07/25/06	15:07	C	BDL	0.120	4.640	0.007	0.121
Storm Sample	Asink	07/25/06	16:38	C	0.213	0.182	2.993	0.014	0.225
Storm Sample	BBSink	08/13/06	11:00	C	0.014	0.121	0.507	0.005	0.044
Storm Sample	CB	08/13/06	11:30	C	0.018	0.126	0.347	0.047	0.120
Storm Sample	Asink	08/13/06	12:50	C	0.058	0.125	0.804	0.009	0.196
Storm Sample	Birdsink	08/13/06	14:00	C	0.095	0.119	0.533	0.055	0.124
Base Flow	CB	01/23/06	8:22	M	0.055	0.049	0.367	0.006	0.025
Base Flow	BBSink	01/23/06	9:05	M	0.035	0.052	0.300	0.004	0.011
Base Flow	Asink	01/23/06	9:40	M	BDL	0.044	0.735	0.021	0.132
Base Flow	CB	03/09/06	15:31	M	0.068	0.062	0.462	0.012	0.028
Base Flow	BBSink	03/09/06	16:21	M	0.044	0.057	0.466	0.003	0.031
Base Flow	Asink	03/09/06	15:14	M	0.027	0.061	0.655	0.032	0.187
Base Flow	CB	05/22/06	17:46	M	0.042	0.055	0.553	0.008	0.028
Base Flow	BBSink	05/22/06	18:02	M	0.061	0.061	0.473	BDL	0.011
Base Flow	Asink	05/22/06	17:22	M	0.011	0.057	1.005	0.017	0.143

Table 1.5.2: Continued.

WRB Data Storm Sampling Data Summary					F Coli	Turbidity	Alkalinity	Chloride	TSS
Field Identification Information					EPA FC <i>mdl=1</i>	EPA 180.1 <i>mdl=0.25</i>	EPA 310.1 <i>mdl=0.73</i>	EPA 325.3 <i>mdl=0.15</i>	EPA 160.2 <i>mdl=7.314</i>
Collection					<i>pql=4</i> Cts/100ml	<i>pql=1.0</i> (NTU)	<i>pql=2.92</i> mg/L	<i>pql=0.60</i> mg/L	<i>pql=29.256</i> mgTSS/L
Station	Date	Time	Dep th Cod e						
Storm Sample	CB	02/23/06	18:11	C	123	5	105	9.2	15.2
Storm Sample	BBSink	02/23/06	18:54	C	23	5	95.5	6.2	14.6
Storm Sample	Asink	02/23/06	19:23	C	1153	12	33	9.8	21.7
Storm Sample	CB	07/18/06	18:40	C	60	6.0	111.0	6.2	15.5
Storm Sample	BBSink	07/18/06	19:05	C	1690	5.0	100.0	5.3	14.1
Storm Sample	Asink	07/18/06	19:44	C	170	13.0	36.0	7.1	12.8
Storm Sample	CB	07/25/06	15:44	C	850	5.0	104.0	10.6	13.9
Storm Sample	BBSink	07/25/06	15:07	C	393	57.0	92.0	7.1	650.8
Storm Sample	Asink	07/25/06	16:38	C	63	14.0	30.5	10.6	12.0
Storm Sample	BBSink	08/13/06	11:00	C	1667	3.0	16.0	67.0	BDL
Storm Sample	CB	08/13/06	11:30	C	840	5.0	42.5	72.0	10.2
Storm Sample	Asink	08/13/06	12:50	C	200	7.0	29.2	6.0	11.5
Storm Sample	Birdsink	08/13/06	14:00	C	533	5.0	47.9	0.0	BDL
Base Flow	CB	01/23/06	8:22	M	13	0	95.3	7.3	BDL
Base Flow	BBSink	01/23/06	9:05	M	2	0	102	8.2	BDL
Base Flow	Asink	01/23/06	9:40	M	125	4.0	25.1	8.9	BDL
Base Flow	CB	03/09/06	15:31	M	6	1.0	105.0	6.8	BDL
Base Flow	BBSink	03/09/06	16:21	M	6	0.0	99.7	7.1	BDL
Base Flow	Asink	03/09/06	15:14	M	13	5.0	29.2	7.1	7.6
Base Flow	CB	05/22/06	17:46	M	7	0.0	102.3	8.9	BDL
Base Flow	BBSink	05/22/06	18:02	M	2	0.0	95.2	7.5	BDL
Base Flow	Asink	05/22/06	17:22	M	562	7.0	38.4	8.9	BDL

Table 1.5.2: Continued.

	WRB Data				Chromium	Copper	Iron	Lead	Zinc
	Storm Sampling Data Summary				EPA	EPA	EPA	EPA	EPA
	Field Identification Information				218.1	220.1	236.1	239.1	289.1
	Dep th Cod e				<i>mdl=0.027</i>	<i>mdl=0.01</i>	<i>mdl=0.175</i>	<i>mdl=0.088</i>	<i>mdl=0.039</i>
	Collection				<i>pql=0.108</i>	<i>pql=0.10</i>	<i>pql=0.688</i>	<i>pql=0.352</i>	<i>pql=0.156</i>
	Station	Date	Time		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Storm Sample	CB	02/23/06	18:11	C	BDL	BDL	0.325	BDL	BDL
Storm Sample	BBSink	02/23/06	18:54	C	BDL	BDL	0.226	BDL	BDL
Storm Sample	Asink	02/23/06	19:23	C	BDL	BDL	0.523	BDL	BDL
Storm Sample	CB	07/18/06	18:40	C	BDL	0.020	0.237	BDL	BDL
Storm Sample	BBSink	07/18/06	19:05	C	BDL	BDL	0.221	BDL	BDL
Storm Sample	Asink	07/18/06	19:44	C	BDL	BDL	0.435	BDL	BDL
Storm Sample	CB	07/25/06	15:44	C	BDL	BDL	0.182	BDL	BDL
Storm Sample	BBSink	07/25/06	15:07	C	BDL	0.010	3.766	BDL	BDL
Storm Sample	Asink	07/25/06	16:38	C	BDL	0.020	0.427	BDL	BDL
Storm Sample	BBSink	08/13/06	11:00	C	BDL	BDL	BDL	BDL	BDL
Storm Sample	CB	08/13/06	11:30	C	BDL	0.026	0.185	BDL	BDL
Storm Sample	Asink	08/13/06	12:50	C	BDL	0.035	0.377	BDL	BDL
Storm Sample	Birdsink	08/13/06	14:00	C	BDL	0.034	0.736	BDL	BDL
Base Flow	CB	01/23/06	8:22	M	BDL	BDL	BDL	BDL	BDL
Base Flow	BBSink	01/23/06	9:05	M	BDL	BDL	0.195	BDL	BDL
Base Flow	Asink	01/23/06	9:40	M	BDL	BDL	0.512	BDL	BDL
Base Flow	CB	03/09/06	15:31	M	BDL	BDL	0.217	BDL	BDL
Base Flow	BBSink	03/09/06	16:21	M	BDL	BDL	0.311	BDL	BDL
Base Flow	Asink	03/09/06	15:14	M	BDL	0.015	0.349	BDL	BDL
Base Flow	CB	05/22/06	17:46	M	BDL	BDL	0.195	BDL	BDL
Base Flow	BBSink	05/22/06	18:02	M	BDL	BDL	BDL	BDL	BDL
Base Flow	Asink	05/22/06	17:22	M	BDL	BDL	0.394	BDL	BDL

Table 1.5.2: Continued.

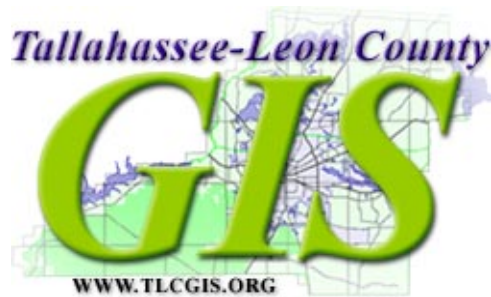
	WRB Data				FLOW
	Storm Sampling Data Summary				
	Field Identification Information				
	Depth Code				
	Collection				
	Station	Date	Time		CFS
Storm Sample	CB	02/23/06	18:11	C	5.1
Storm Sample	BBSink	02/23/06	18:54	C	0.01
Storm Sample	Asink	02/23/06	19:23	C	32.0
Storm Sample	CB	07/18/06	18:40	C	6.0
Storm Sample	BBSink	07/18/06	19:05	C	0.09
Storm Sample	Asink	07/18/06	19:44	C	25.0
Storm Sample	CB	07/25/06	15:44	C	6.4
Storm Sample	BBSink	07/25/06	15:07	C	0.07
Storm Sample	Asink	07/25/06	16:38	C	51.0
Storm Sample	BBSink	08/13/06	11:00	C	0.02
Storm Sample	CB	08/13/06	11:30	C	3.13
Storm Sample	Asink	08/13/06	12:50	C	363
Storm Sample	Birdsink	08/13/06	14:00	C	3.3
Base Flow	CB	01/23/06	8:22	M	2.1
Base Flow	BBSink	01/23/06	9:05	M	0
Base Flow	Asink	01/23/06	9:40	M	22.1
Base Flow	CB	03/09/06	15:31	M	1.2
Base Flow	BBSink	03/09/06	16:21	M	0
Base Flow	Asink	03/09/06	15:14	M	12.3
Base Flow	CB	05/22/06	17:46	M	2.2
Base Flow	BBSink	05/22/06	18:02	M	0
Base Flow	Asink	05/22/06	17:22	M	13.4

Chapter 2

GIS Analysis Portion

Pollutant Loadings Modeling using WAM View

Part 1



Ardaman and Associates

Part 1: Physiography

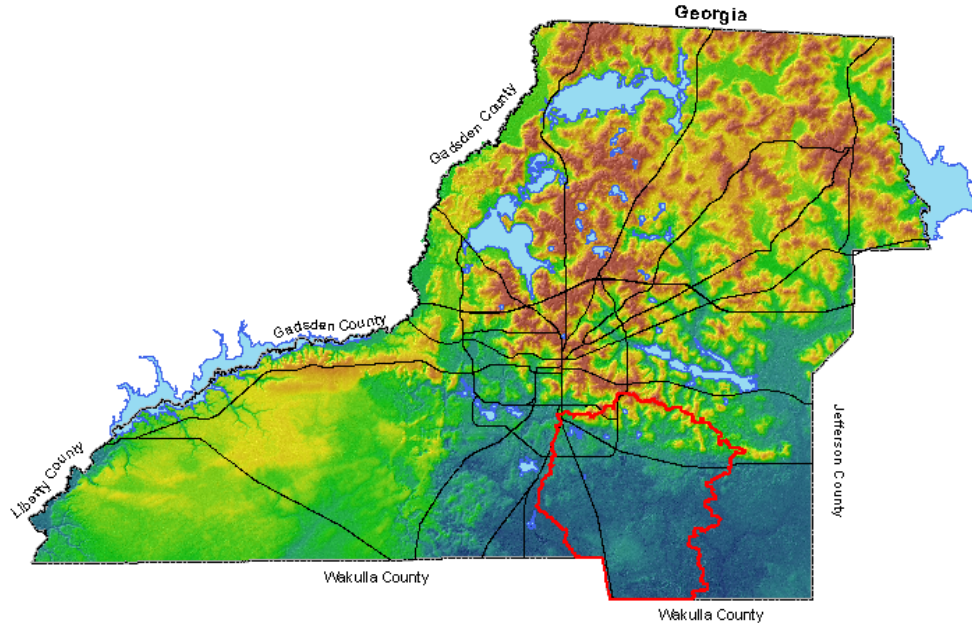


Figure 2.1.1: Shaded relief map of Leon County showing the location of the Woodville Recharge Basin shows the location of the Woodville Recharge Basin, (shown in red) in Leon County, Florida. The basin covers approximately 83 square miles in the southeastern part of the county. As can be seen, it is an area of relatively low relief. The elevations range from approximately 5 feet to approximately 220 feet above sea level, with the majority of the basin lying less than 40 feet above sea level. The highest elevations occur along the northern tier of the basin.

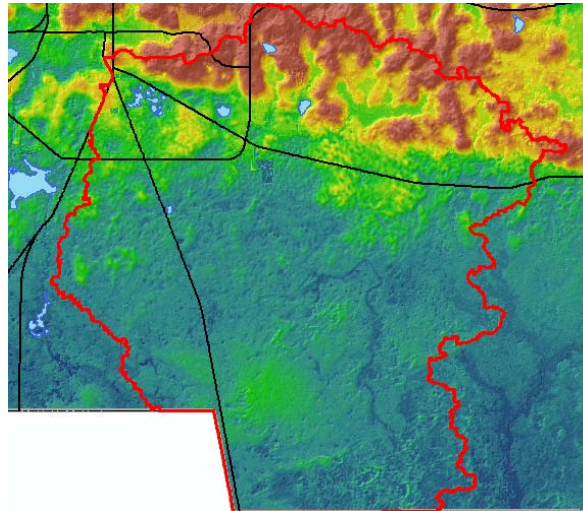


Figure 2.1.2: Shaded Relief map of Woodville Recharge Basin shows a more detailed view of the relief within the Basin. The higher elevations in the northern portion contrast sharply with the low-lying topography of the majority of the Basin. The east-west oriented feature dividing the high and low elevation regions is known as the Cody Scarp. This feature forms an important boundary between hydrogeologic

sensitivity relative to groundwater contamination and in the concentration and distribution of associated karst landforms. This shaded relief view shows the wide distribution of karst depressions south of the Cody Scarp and a number of paleo-stream courses.

Physiographic Provinces within the Woodville Recharge Basin

The Woodville Recharge Basin falls within 5 physiographic provinces within Leon County; namely the Tallahassee Red Hills, the Lake Munson Sandhills, the Cody Sandhills, the Woodville Karst Plain, and the Wakulla Sandhills, (please see Figure 3). This results in a complex geomorphology and has a strong influence on the movement of surface water and on the potential for groundwater contamination. A description of the physiographic characteristics for each province is given below, (Swanson, etal, 1992).

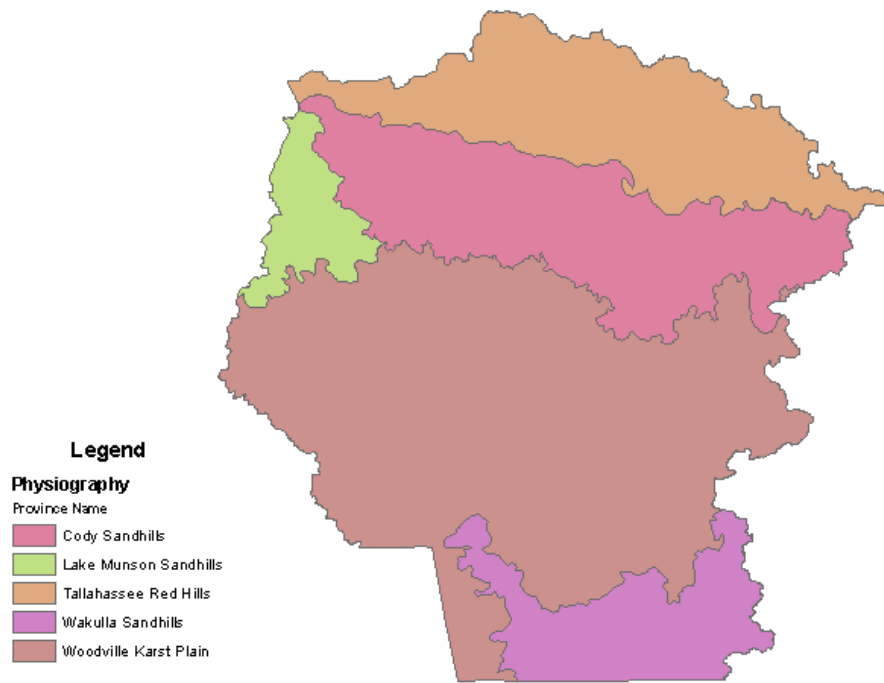


Figure 2.1.3: Physiographic Provinces within the Woodville Recharge Basin

The Tallahassee Red Hills is part of a Miocene-Pliocene river delta composed of clay, silt and sand deposited over limestone bedrock. The surface sediments have been significantly eroded and dissected by surface runoff, resulting in many hills and ravines. Along with many deep ravines, the region is characterized by gentle hills separated by shallow swales. There has been significant subsurface solution of the underlying limestone bedrock resulting in numerous karst depressions of varying sizes. Many of these depressions contain clayhill lakes. Due to the clay/silt overburden, which ranges from 20 – 80 feet in thickness, groundwater is rarely visible in the depressions. In fact, the clay sediments provide a barrier to pollutant migration and, as a result, groundwater vulnerability is relatively low in this region, except in the proximity of several large karst sinkhole depressions which provide a direct connection between groundwater and surface water runoff. This province is characterized by numerous streams.

The Cody Sandhills border the Tallahassee Red Hills to the south. They run east-west along a Pleistocene shoreline known as the Cody Scarp. This province marks a 100 – 150 foot drop in elevation from the Red Hills to the Woodville Karst Plain. This regions consists of numerous low sand hills deposited over limestone bedrock with a thin layer of clay in between. Due to the high permeability of the soils, most of the surface drainage percolates into the ground resulting in few streams. There are 2 intermittent

watercourses, including Shepard's Branch. High soil permeability and associated dissolution of the underlying limestone, result in numerous karst depressions. Many contain sandhill lakes, particularly on the eastern end. This is a high aquifer recharge area and an area where the aquifer is highly vulnerable to pollution.

The Lake Munson Sandhills are a large region of dry hills and deep sand ridges with areas of subsurface silt and clay. This results in a number of small to large natural lakes, the largest of which is Lake Bradford. Most of the drainage is subsurface and the landscape is heavily pocked with hundreds of karst depressions. Due to the high permeability of the soils, this region is an area of high aquifer recharge. There are only two surface stream systems: Bradford Brook and Fisher Creek, though much of the surface drainage feeding these two systems comes from surrounding physiographic provinces. Many of the lakes have a direct connection to the Floridan aquifer, (namely the Bradford Chain-of-Lakes) and Fisher Creek terminates in a swallet in the Apalachicola national Forest.

Only a small portion of the Munson Sandhills lies within the Woodville Recharge Basin. Most of this area has significant urban land use. The topography in this region is characterized by low sand hills interspersed with temporary ponds. There is one large karst window, a sinkhole with a direct groundwater connection, (Church Sink). This feature receives significant stormwater runoff.

The majority of the Woodville Recharge Basin falls within the Woodville Karst Plain. This region is a low, flat plain consisting of sand several feet thick deposited over limestone bedrock. Almost all of the drainage is subsurface and the area is characterized by sinkholes and karst depressions creating a patchwork of thousands of small closed basins. Many of the depressions have clay sediments in the bottoms which hold perched surface water bodies. In the eastern portion of the province, many of the depressions intersect the Floridan aquifer, exposing visible groundwater. This area is a high aquifer recharge area and most of the area exhibits a high vulnerability to groundwater pollution. This region is the area of greatest focus for the study.

The remaining portion of the Woodville Recharge Basin falls within the Wakulla Sandhills province. The topography in this is made up of numerous small hills which sharply contrast with the flat topography of the Woodville Karst Plain. These hills are dune deposits associated with a former Pleistocene shoreline. There is no evident surface drainage in this region. The large inter-dune swales form large floodzones during wet periods due to clay hardpan deposits.

Part 2

WAM Model Approach and Algorithms

There are main components to WAM:

- WAM View GIS interface
- BUCSHELL sub program
- The field models (GLEAMS and EAAMOD)
- BlasRoute model

WAM (Watershed Assessment Model), was primarily developed by Del Bottcher and Barry Jacobsen of Soil & Water Engineering Technologies, Inc. (SWET) in Gainesville Florida. WAM integrates a number of non-spatial water resource models and links these models to spatial datasets in a GIS environment.

WAM View is a raster-based Geographic Information System (GIS) application designed by Jeff Hiscock of JGH Engineering in Palm Beach Gardens, Florida. It is written in Avenue and designed to run under ESRI's ArcView 3x generation of GIS software. WAM is currently being migrated to ArcGIS 9.x. It is currently in the public domain and will remain so in the ArcGIS environment.

WAM View allows the spatial data layers to be overlaid and accessed by the component sub programs in WAM which generate the predicted flow, stage, and nutrient values. WAM computations are based on an overlay of the input grid data layer. WAM utilizes GIS functions to perform a cell-by cell overlay of raster wastewater utility service areas, rainfall zone, land use, and soils data layers to create a list of unique combinations that are used by the model to produce the output results.

A FORTRAN subprogram called the Basin Unique Cell Shell model, BUCSHELL, is executed by WAM to simulate each of the unique cell combinations. Before actual simulation can take place BUCSHELL generates the input parameters files needed by the field-scale sub-model to compute loadings for each specific unique combination. BUCSHELL selects one of four separate field-scale sub-models to simulate each unique cell combination. The currently available field models are the GLEAMS model (Knisel, 1993), EAAMOD (SWET, 2000), and two sub-models written specifically for WAM to handle wetland and urban landscapes. BUCSHELL determines which submodel to use by comparing the land use and/or soil codes, (Bottcher, Jacobson, 2006). The field models generate daily time series files, (called day files) for every unique combination.

The Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model was developed by Knisel et al to simulate edge-of-field and bottom-of-root-zone loadings of water, sediment, pesticides, and plant nutrients from the complex climate-soil-management interactions. It has evolved through several versions from its inception in 1984 to the present, and has been evaluated in numerous climatic and soil regions of the world.

The Everglades Agriculture Area model (EAAMOD) was developed by SWET and is a farm-scale hydrologic and water quality model is desired for use within the Okeechobee basin to assess the South Florida Water Management District (SFWMD) in accessing the effectiveness of various management strategies, including BMPs, that will reduce P loads from beef pastures and other agricultural activities in the Lake Okeechobee basin and surrounding areas.

For most soil in the Woodville region WAM applies the GLEAMS field model to generate the water quality data. WAM uses EEAAMOD is high water table and muck soil conditions.

Basin Land Stream Routing (BLASRoute) model is used for routing the surface and groundwater. The stream reaches are routed to the outlet by solving the continuity equation and Manning's equation for

uniform channel flow with a variable time step of approximately 15 minutes, based upon the stream velocity. Manning's equation was chosen for two reasons: First, the slowly-varying and sub-critical stream conditions commonly found in Florida are appropriate for approximation with Manning's equation. Secondly, there are relatively few required inputs (slope, roughness, cross-sectional area, and hydraulic radius) as they are easily obtained or estimated.

The groundwater routing is accomplished by two methods. Surface streams that end in closed depressions are routed to the outflow boundary using groundwater reach features in the reach GIS shapefile. For the second condition, the version of WAM used for the Woodville study routes water that flows into closed depressions to the outflow reach by using Euclidean distance to identify the nearest outflow reach.

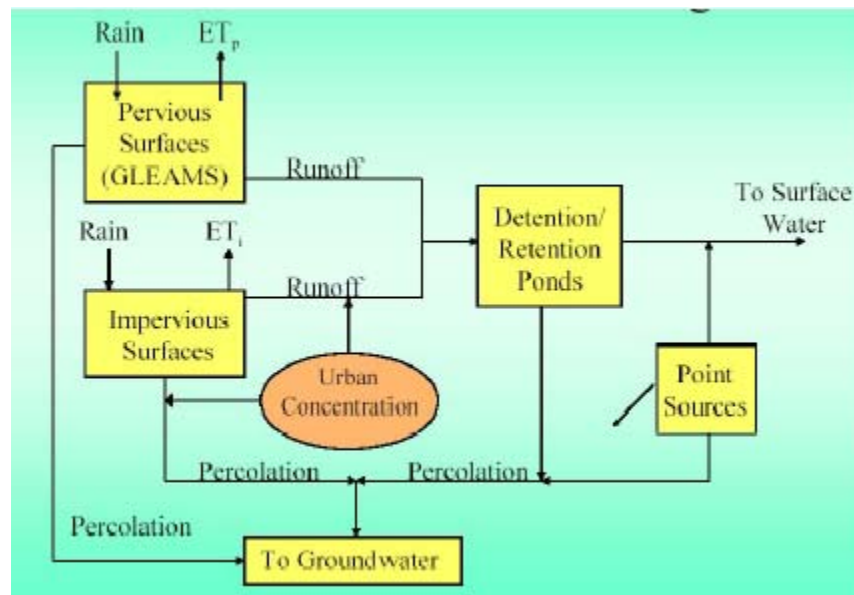


Figure 2.2.1: Flowchart of BUCShell post processing by BLASRoute, (Mytyk and Kaplan, 2005)

Nutrient Attenuation

WAMView calculates nutrient loadings by modeling the balance of accumulation and attenuation on a cell-by-cell basis. Once runoff has left the source cell, attenuation to the streams is calculated based on flow rate, characteristics of flow path, distance of the flow path, and land use types, (see the attenuate.in in Section 4.1.2). This includes Euclidean distance from a stream reach and the length of the reach, (see distance grid data sets in Section 4.1.1). Separate coefficients for different wetland types are stored by the system in a text file. The first order decay formula for land and stream attenuation is shown in Equation 1. The attenuation and distances are calculated using the ArcView Spatial Analyst watershed and distance functions (Bottcher and Jacobson, 2006).

Equation 1

$$dC = (C - C_b) * e^{(-a * q - b * d)}$$

where:

dC = change in concentration (ppm)

C = current concentration (ppm)

C_b = background concentration (ppm)

a = attenuation multiplier

b = attenuation exponent

q = flow rate (m³/s)

d = flow distance (m)

Stream Routing: BLASRoute**Manning's Equation**

WAM View routes runoff through the stream reaches to the watershed outlet by solving the continuity equation and Manning's equation for uniform channel flow using a variable time step of approximately 15 minutes, based on stream velocity. Manning's equation was chosen for its proven ability to predict uniform stream flow with minimal inputs; namely slope, roughness, cross-sectional area, and hydraulic radius. All can be easily measured or estimated. Manning's equation computes velocity of water movement through a conveyance based on roughness, hydraulic radius and gradient and is shown in Equation 2.

Equation 2

$$v = 1/n \times R^{2/3} \times S^{1/2}$$

Where :

n = [coefficient of roughness](#) (typically 0.3; varies by stream roughness conditions)

v = Water velocity down the channel (m / sec) = flow (m³sec⁻¹) / cross sectional area (m²)

R = Hydraulic radius (m) = cross sectional area (m²) / [wetted perimeter](#) (m)

S = Gradient of channel (m / 100m)

Wetted Perimeter = sum of length of sides and bottom of channel; used to calculate friction loss.

A numeric solution of Manning's flow and continuity equations using a modified time-varying linear-reservoir routing technique is used within each time step. The continuity of mass equation used in WAM is shown in Equation 3, which sets the net flow of a reach equal to the sum of the adjacent reach flows and the land inflows at that time. The stream network is assumed to have slowly varying flow and depth (i.e., that the water surface

represents the energy grade line). Flow rates *between* reaches are found by Manning's equation (Equations 4 and 5), (Bottcher and Jacobson, 2003 and Mytyk and Kaplan, 2005).

Equation 3

$$\frac{dV_i}{dt} = Q_i = \sum_{j=1}^n q_{ij} + q_{iLand}$$

where

n = number of tributary reaches

q_{ij} = flow rate between reaches “i” and “j”

q_{iLand} = flow rate from surrounding land into reach “i”

Equation 4

$$\text{for } s > 0, \quad q_{i,j} = -\frac{A_i \cdot R_i^{2/3} \cdot s^{1/2}}{n}$$

Equation 5

$$\text{for } s < 0, \quad q_{i,j} = \frac{A_i \cdot R_i^{2/3} \cdot (-s)^{1/2}}{n}$$

where

$q_{i,j}$ = stream reach flow rate between reaches “i” and “j” (m³/s)

A_i = stream cross-sectional area (m²)

R_i = stream hydraulic radius (m)

$s_{i,j}$ = water surface slope between reach “i” and “j”

n = Manning’s n

Finite Difference Integration

The new volume for each reach at the end of a time step is calculated as the sum of the volume of the reach at the start of the time step and the change in volume during the time step:

Equation 6

$$V_{i,t_0+\Delta t} = V_{i,t_0} + \Delta V_{i,t_0+\Delta t}$$

where

V_{i,t_0} = volume in reach "i" at time t_0

$\Delta V_{i,t_0+\Delta t}$ = change in volume during time step $t_0 + \Delta t$

t_0 = time at the beginning of a time step (min)

Δt = length of time step (min)

i = reach identification number

Integrating the net flow for a reach, Q_i , over the time step gives the change in volume during the time step:

Equation 7

$$\Delta V_{i,t_0+\Delta t} = \int_{t_0}^{t_0+\Delta t} Q_{i,t} dt$$

A finite difference approximation of this integration can be performed using the Euler method:

Equation 8

$$\Delta V_{i,t_0} = Q_{i,t_0} \cdot \Delta t$$

Initial testing of this integration showed that the approximation is good only for very small time steps (i.e., less than 10 seconds). Using larger time steps, the simulation quickly became unstable because the assumption that Q is constant throughout the time step is not valid for large time steps.

A better estimation of the integration can be derived using the additional information that flow is always trying to go to equilibrium conditions. An exponential approximation of the change in flow rate over time produced far more stable and better estimates of integration than the Euler method. This exponential approximation implies a first order relationship between Q and V . Consequently, the ratio (k) between dQ and dV is assumed constant during each time step, but may vary between time steps:

Equation 9

$$k_{i,t_0} \equiv \frac{dQ_{i,t}}{dV_{i,t}}$$

where

$dQ_{i,t}$ = the derivative of Q for reach “i” at time “t”

$dV_{i,t}$ = the derivative of V for reach “i” at time “t”

t = any time during the time step (i.e., between t_0 and $t_0 + \Delta t$)

k_{i,t_0} = ratio of $dQ_{i,t}$ and $dV_{i,t}$ during the time step from “ t_0 ” to “ $t_0 + \Delta t$ ”

Equations 10 through 13 are used to calculate k_{i,t_0} . In order to calculate the constant k_{i,t_0} for each time step and reach, the derivative of Q_i with respect to V_i is taken at the beginning of the time step as seen in equation 10.

Equation 10

$$k_{i,t_0} = \frac{dQ_{i,t_0}}{dV_{i,t_0}} = \sum_{j=1}^n \frac{dq_{i,j}}{dV_i} + \frac{dq_{i,Land}}{dV_i}$$

Taking the derivative of Manning’s equations 11 and 12:

Equation 11

$$\frac{dq_{i,j}}{dV_i} = q_{i,j} \left[\frac{2}{3 \cdot R_i} \cdot \frac{dR_i}{dV_i} + \frac{1}{2 \cdot s} \cdot \frac{ds_i}{dV_i} + \frac{1}{A_i} \cdot \frac{dA_i}{dV_i} \right]$$

where

$\frac{dq_{i,j}}{dV_i}$ = change in flow rate between reaches "i" and "j" per unit change in volume in reach "i"

(1/s)

$\frac{dR_i}{dV_i}$ = change in average hydraulic radius per unit change in volume in reach "i" (1/m²)

$\frac{ds_{i,j}}{dV_i}$ = change in slope between reaches "i" and "j" per unit change in volume in reach "i"

(1/m³)

$\frac{dA_i}{dV_i}$ = change in average area per unit change in volume in reach "i" (1/m)

and

$$\frac{dR_i}{dV_i} = \frac{w_i \cdot P_i - 2 \cdot A_i}{l_i \cdot w_i \cdot P_i^2} \quad \text{Equation 12}$$

$$\frac{ds_{i,j}}{dV_i} = \frac{\frac{1}{l_i \cdot w_i} - \left(\frac{Q_j}{Q_i}\right) \cdot \frac{1}{l_j \cdot w_j}}{(l_i + l_j)/2}$$

$$\frac{dA_i}{dV_i} = \frac{1}{l_i}$$

where

w_i = stream width at water surface (m)

l_i = reach length (m)

P_i = wetted perimeter (m)

A_i = reach cross-sectional area

Once k_{i,t_0} has been calculated, the assumption of a first order relationship between V and Q can be used to calculate the change in volume during the next time step.

Combining equations 3 – 9 gives

$$k_{i,t_0} \cdot Q_{i,t} = \frac{dQ_{i,t}}{dt} \quad \text{Equation 13}$$

Rearranging gives

$$k_{i,t_0} \cdot dt = \frac{dQ_{i,t}}{Q_{i,t}} \quad \text{Equation 14}$$

Integrating both sides from time 0 to t:

$$\int_0^{t_1} k_{i,t_0} \cdot t \cdot dt = \int_0^{Q_{i,t_1}} \frac{dQ_{i,t}}{Q_{i,t}} \quad \text{Equation 15}$$

$$k_{i,t_0} \cdot t \Big|_0^{t_1} = \ln(Q_{i,t}) \Big|_{Q_{i,t_0}}^{Q_{i,t_1}} \quad \text{Equation 16}$$

$$k_{i,t_0} \cdot t_1 = \ln(Q_{i,t_1}) - \ln(Q_{i,t_0}) = \ln\left(\frac{Q_{i,t_1}}{Q_{i,t_0}}\right) \quad \text{Equation 17}$$

Taking the exponent of both sides gives:

$$e^{k_{i,t_0} \cdot t_1} = \frac{Q_{i,t_1}}{Q_{i,t_0}} \quad \text{Equation 18}$$

Rearranging gives:

$$Q_{i,t_1} = Q_{i,t_0} \cdot e^{k_{i,t_0} \cdot t_1} \quad \text{Equation 19}$$

Integrating the equation with respect to “t” gives the change in volume between time “0” and “Δt” gives:

$$\Delta V_i \equiv \int_0^{\Delta t} Q_{i,t} dt = \int_0^{\Delta t} Q_{i,t_0} \cdot e^{k_{i,t_0} \cdot t} dt = \frac{Q_{i,t_0}}{k_{i,t_0}} \cdot e^{k_{i,t_0} \cdot t} \Big|_0^{\Delta t} \quad \text{Equation 20}$$

$$\Delta V_i = \frac{Q_{i,t_0}}{k_{i,t_0}} \cdot (e^{k_{i,t_0} \cdot \Delta t} - 1) \quad \text{Equation 21}$$

Equation 12 works best for the common case of $k_{i,t_0} < 0$ and $k_{i,t_0} \cdot \Delta t < -13$. The value -13 was chosen because it is approximately $\ln(10^{-6})$, below which is when the term

$$(e^{k_{i,t_0} \cdot \Delta t} - 1)$$

approaches -1.

For the case where k_{i,t_0} is near zero or greater than zero, Q_{i,t_0} is assumed to be constant. This assumption is made because k_{i,t_0} greater than 0 happens rarely and only for short periods of time. Using equation 12 causes large overestimates of ΔV_i . For the case when $k_{i,t_0} \cdot \Delta t$ becomes a large negative number, equation 14 is used because the results will closely approximate equation 12, but will not cause the software to produce an underflow warning message.

for $|k_{i,t_0}| \approx 0$ or $k_{i,t_0} > 0$, $\Delta V_i = Q_{i,t_0} \cdot \Delta t$

for $k_{i,t_0} \cdot \Delta t < \ln(10^{-6})$, $\Delta V_i = -\frac{Q_{i,t_0}}{k_{i,t_0}}$

(Bottcher and Jacobson, 2003)

To verify the BLASRoute (continuity and Manning's) equations used in WAM, the Bottcher and Jacobson compared the approach with the more complex DuFlow model, developed in the Netherlands, and gauging station results. The algorithms for stage and flow used in BLASRoute were able to simulate the flows and stages of water through the stream network. They produced results similar to the DuFlow model and also closely matched gauging values. For more discussion on the verification of the model, see Bottcher and Jacobson, 2005.

Part 3

Section 3.1 Input Data Sources (Woodville WAM Model)

3.1.1 Geospatial Data Summary

The geospatial datasets used as input for the WAM model were collected from a variety of sources and were initially published at a variety of scales. The largest scale datasets were produced at a base scale of 1:1200. The smallest scale datasets were produced at a scale of 1:24000. Some of the data sources were mapped as raster data (topography) and some were mapped as vector data (land use, streams, drainage units, soils, etc). WAM requires raster data for input, except for the drainage basins, watersheds, and stream reaches. Except for these three data sources, all of the vector data had to be converted to raster and all of the raster data sources had to have a common spatial resolution. Because the spatial accuracy of the overall model cannot exceed the spatial accuracy of the smallest scale layer, the base scale of the WAM spatial data is 1: 24000. WAM used the metric system for all units. The spatial definitions for the WAM datasets (input and output) are given below:

Cell Size = 10 Meters (0.01 Hectares)
 Number of Rows = 1626
 Number of Columns = 1638

BOUNDARY STATISTICS

Xmin =	619108.674	Minimum Elevation =	2.4 Meters
Xmax =	635488.674	Maximum Elevation =	67.2 Meters
Ymin =	141232.918		
Ymax =	157492.918		

COORDINATE SYSTEM DESCRIPTION

Projection: Lambert Conformal Conic
 Datum: NAD83/99
 Units: Meter
 Spheroid: GRS1980
 1st standard parallel: 29 35 0.000 Latitude
 2nd standard parallel: 30 45 0.000 Latitude
 Central Meridian: -84 30 0.000 Longitude
 Latitude of projection's origin: 29 0 0.000
 False easting (meters): 600000.00000
 False northing (meters): 0.00000

Data Layers

Topography and Drainage

The most specific spatial data sets available were provided by Tallahassee-Leon County GIS (TLCGIS). These data sets were topography, drainage basins and watersheds, and stream reaches. These data sets have a base scale of 1:1200. The topographic data was produced from a combination of LIDAR and photogrammetrically compiled breaklines. These data sources were assembled to produce a digital elevation model (DEM) mosaic with a spatial resolution of 5 feet. Elevations are referenced to the North American Vertical Datum 1988 (NAVD88).

The accuracy assessment of the digital elevation surface produced a Root Mean Square Error (RMSE) of 0.36 feet. Since LiDAR data is not normally distributed due to the behavior of filtering algorithms in different vegetation regimes, National Digital Elevation Program guidelines specify computing a Consolidated Vertical Accuracy (CVA) at a 95% confidence interval. This value is derived by multiplying the RMSE by 1.96, (95% of the normal bell curve), for all land cover types. The CVA for the elevation data is 0.63 feet. The CVA standard for 2-foot contour data is 1.19 feet.

The drainage basins and watersheds were produced from the raster DEM data. The DEM was processed to eliminate spurious “pits” and “peaks” resulting from noise in the data. This was necessary to derive a coherent data set of flow direction and valid closed depressions. The flow direction surface was used to delineate the smallest units of consistent drainage called catchments. These catchments were then aggregated first into the watershed and closed basin units, and secondly into the larger drainage basin units. This was done for the entirety of Leon County.

The stream reaches were used for the WAM study are a subset of a countywide water course data set mapped using the DEM. Because of the high sampling rate of Lidar, very detailed DEMs are produced, often even in relatively dense vegetation. Stream courses are frequently clearly discernible in the DEM data. The water courses were mapped for each drainage basin in Leon County using the DEM for control. The water course features identified in the Woodville Recharge Basin were selected and used as the stream reaches for the WAM model.

The topography-related data sets are shown on the following pages.

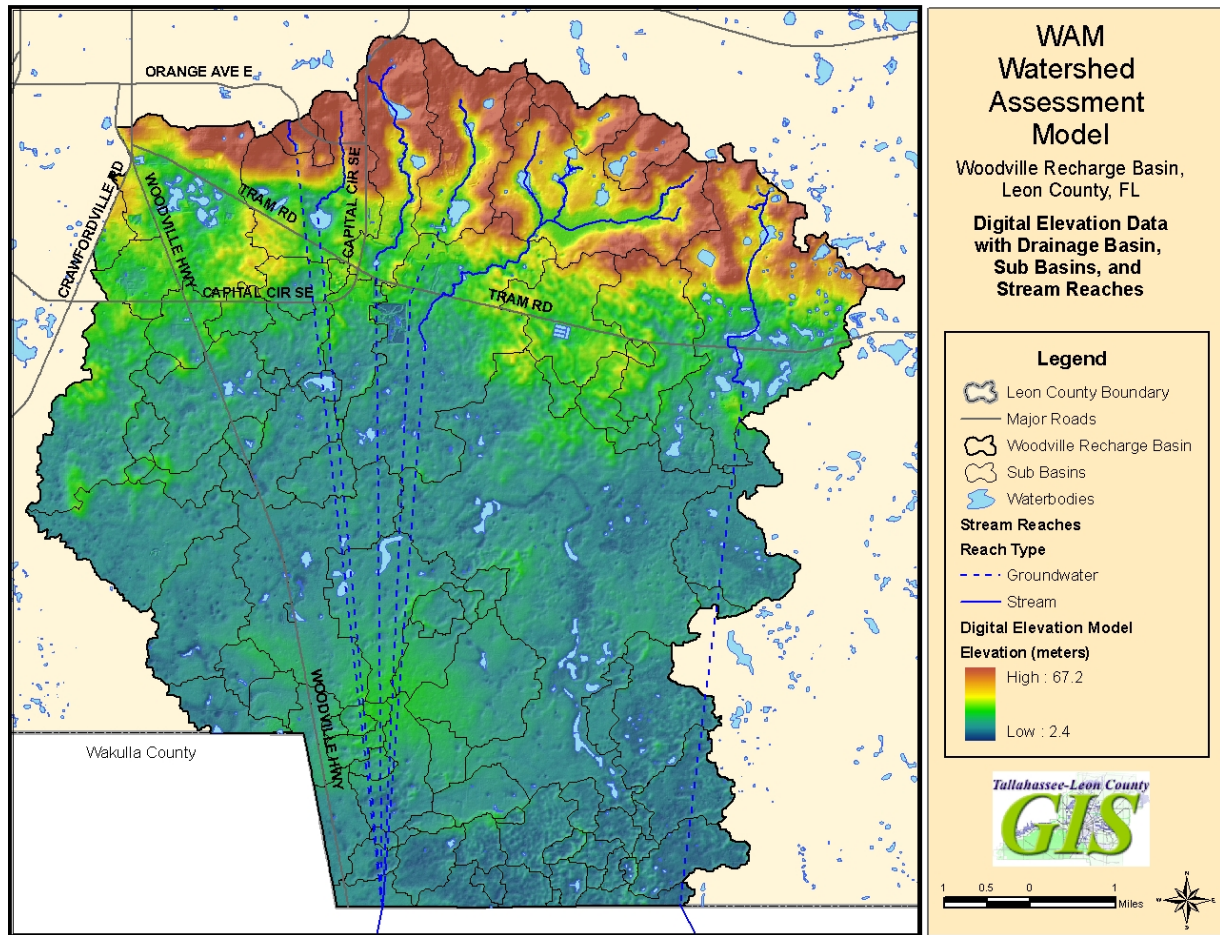


Figure 2.3.1.1: Topography, Drainage Units and Stream Reaches

Stream reach segments must be connected. This hierarchical connectivity is assigned by the user. During this process, the user specifies the reach as a stream, canal, slough, groundwater, or shoreline reach. This attribute, along with drainage area specifies the profile used for the hydraulic modeling parameters applied in the WAM water flow calculations.

As seen in Figure 2.3.1.1, stream reaches are defined for the ephemeral and permanent streams rising in the northern part of the Basin. All of these features terminate into depressions or sloughs, where the surface flow enters the ground. In order to route the flow of these streams to the groundwater, groundwater reaches were used to connect these streams to the Basin outflow. The aquifer flow continues beyond the boundaries of the Woodville Basin. However, since this was designated as the study area, it was necessary to use a stream reach feature to simulate an outflow boundary condition in order for WAM to properly accumulate water flow variables, as well as nutrient concentrations within the groundwater. In this regard, two such reaches were defined due to two different groundwater drainage zones. One reach simulates the Wakulla groundwater zones and the other simulates the St. Marks groundwater zones. This will be further discussed in a later section pertaining to the groundwater zones.

Water flow into a surface stream is modeled initially based on Euclidean distance to stream. As mentioned above, the stream reach type and the sub basin area define the width, depth, and shape of the profile. The accumulation and attenuation of water is influenced by the distance from the stream. Once in

the stream, Manning's equation is applied to account for the friction and conveyance hydraulics and the water volumes and nutrient loadings are accumulated and attenuated through a series of iterative integrations applied until the reach terminates. Daily volume, stage, depth values and nutrient concentrations are stored in spreadsheets.

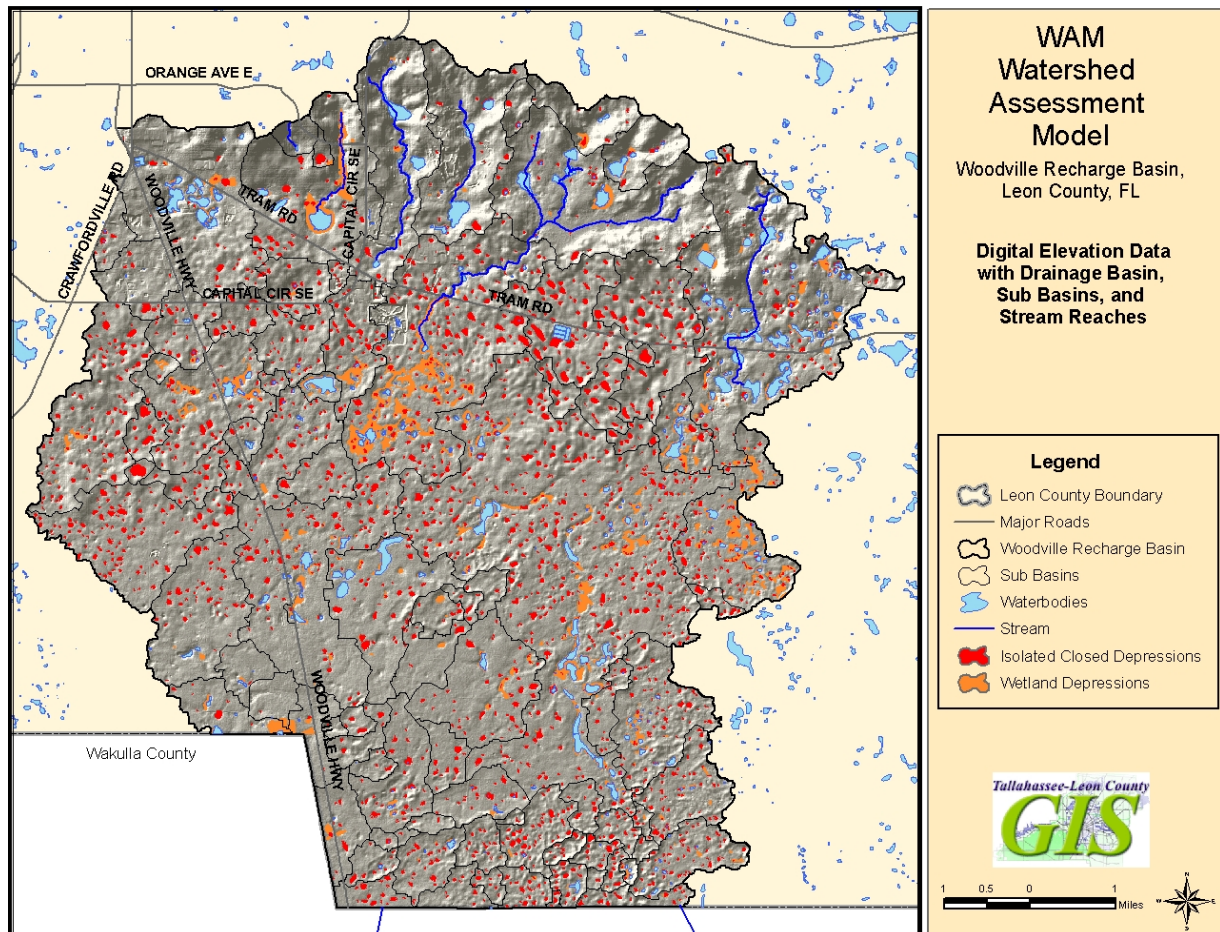


Figure 2.3.1.2: Closed depressions in The Woodville Recharge Basin

WAM was originally designed to accumulate water flow, including groundwater flow through stream reaches. Based on this design, WAM was designed to model groundwater flow using attributed reach segments. This was applied for occasions where a surface reach went underground, then reappeared, or for spring rises. The hydrogeology of the Woodville Recharge Basin is such that virtually all the flow is subsurface, Figure 2.3.1.2. Only about 10% of the Woodville Basin is drained by surface stream conveyance. The surface streams that rise in the Tallahassee Red Hills, flow off the Cody Scarp and into karst depressions. For the remainder of the Basin, drainage either percolates directly or runs off into depressions, where it then percolates. SWET and JGH Engineering (the authors of the WAM model) modified the WAM code to accommodate this unique hydrologic regime. This very important modification allows a cell-by-cell flow of water across the surface if the area is not drained directly by a stream reach and allows for cell-by-cell flow in the groundwater. More importantly, it provides a superior method for calculating groundwater nutrient loadings from the land cell. The water is routed to the nearest depression, then to the nearest outflow reach. This calculation is accomplished by raster Euclidean distance data. A time delay coefficient is applied to deliver the water to the outflow reach. This method allows all the

groundwater flow to be accounted for at the Basin outflow. However, while it allows for a cell-by-cell nutrient loading and water accumulation, it does not allow the user to retrieve predicted cell-by-cell nutrient concentration values because the surface flow accumulation by BLASRoute is routed by groundwater reaches to the outflow reach. Modifying this implementation would require extensive programming because as the surface streams terminate into a depression, the flow and concentration values from BLASRoute would have to be dispersed by integration the surface stream load into the overall background of the groundwater in order to avoid “hot spikes” in the flow and loadings.

Distance Grids used by WAM

The following series of maps shows the Euclidean distance data sets used for routing water flow and nutrients.

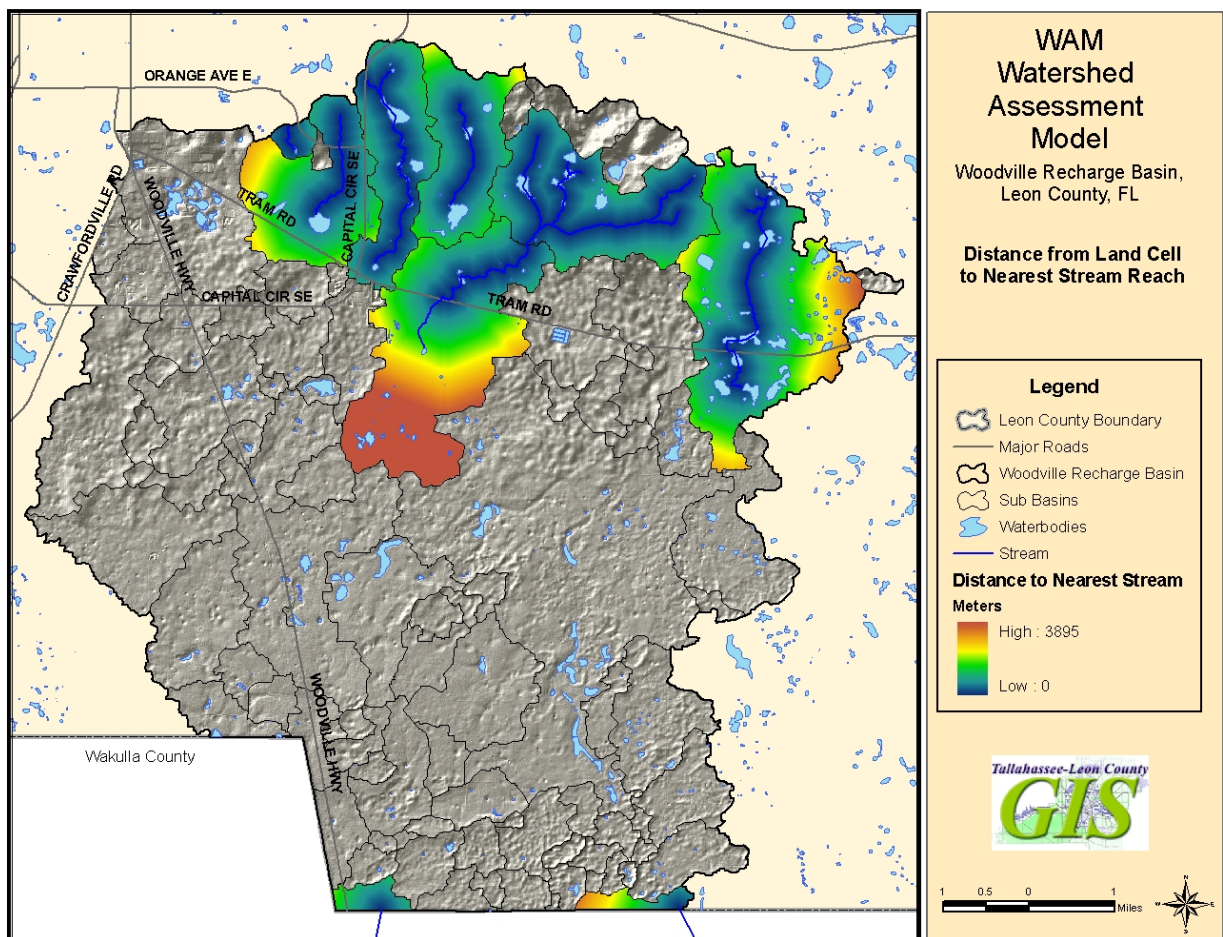


Figure 2.3.1.3: Distance from Land Cell to nearest Stream Reach

The grid data set shown in Figure 2.3.1.3 is calculated for each sub basin containing a stream reach. If a land cell drains to a stream reach, this value is applied for the time delay and flow accumulation into the stream. However, as shown in Figure 2.3.1.2, these sub basins also contain numerous depressions. If the flow from a cell in these sub basins is directly to one of these depressions rather than the stream reach, the distance measure shown in Figure 2.3.1.4 below applies. The flow accumulation is based on percolation,

time delay and distance to the outflow stream reach. There is no hydraulic modeling component to this situation.

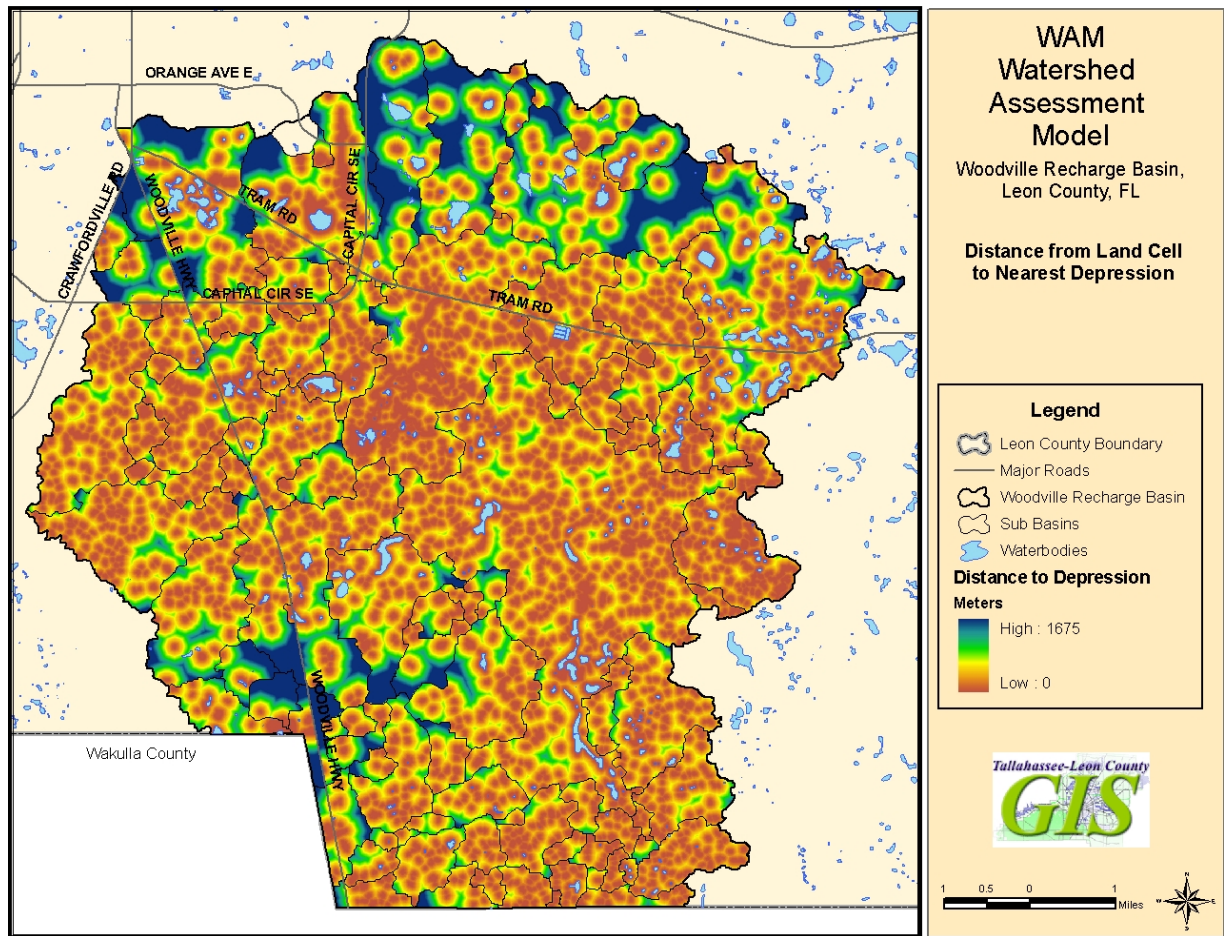


Figure 2.3.1.4: Distance from Land Cell to Nearest Depression

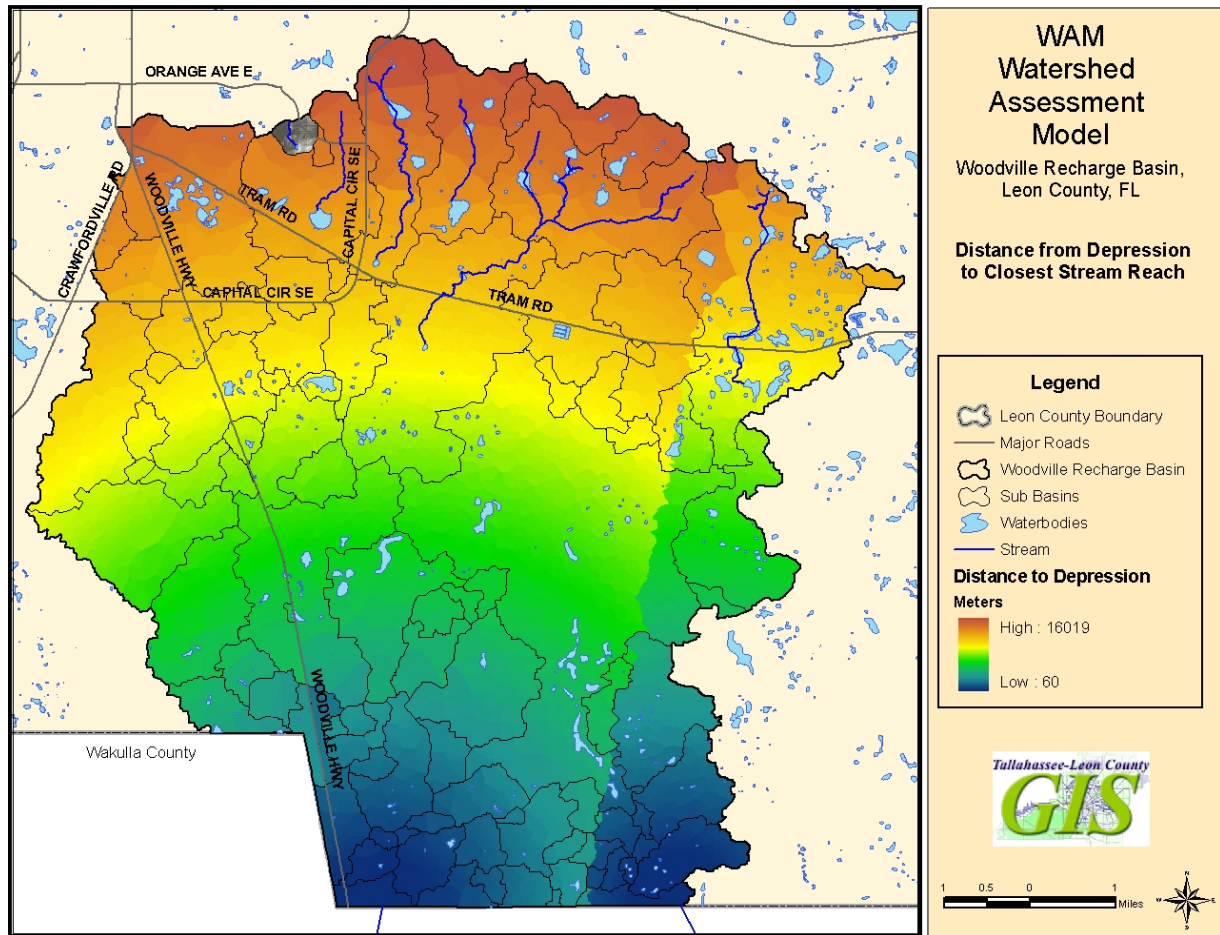


Figure 2.3.1.5 Distance from Depression to Closest Stream Reach

This distance grid is used to route the groundwater to the outflow stream reaches. The surface flow may flow into a stream, then into a depression or it may flow directly into a depression. Once the flow ends up in a depression, the depression is intersected with this data to identify the nearest reach. The flow is then routed there. A WAM parameter controls the velocity of the groundwater. For the Woodville WAM the subsurface velocity is set to 60 meters per day.

The northeast-southwest trend in this data shows the interface between the Wakulla groundwater zone and the St. Marks groundwater zone. The flow from all cells east of the line is routed to the stream reach denoting the St. Marks boundary. The flow from all cells west of the line is routed to the stream reach denoting the Wakulla boundary. WAM also tracks the distance from each groundwater zone cell to the closest stream reach.

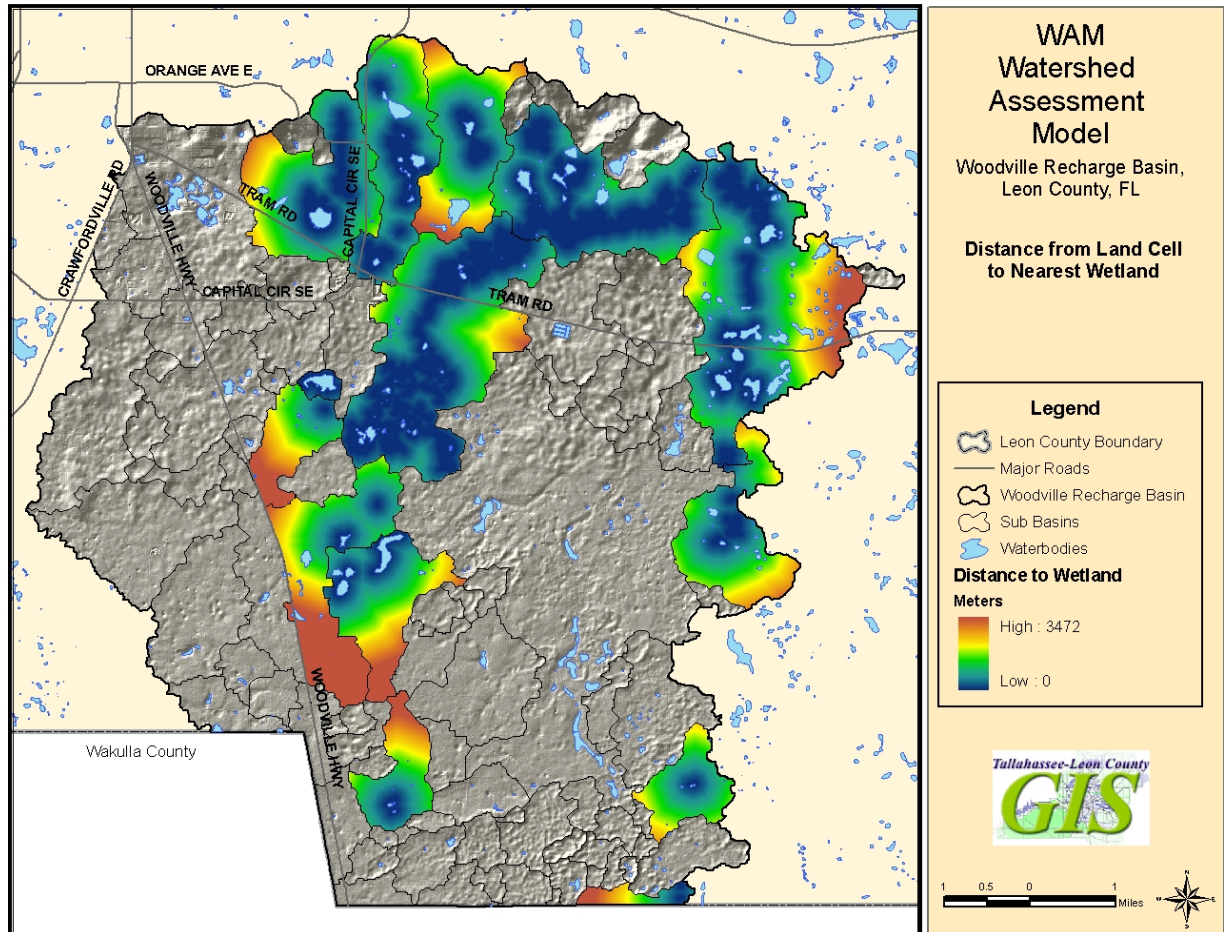


Figure 2.3.1.6: Distance from land cell to nearest wetland

Wetlands are delineated by WAM based on soils data. WAM uses wetland for surface flow attenuation. This is based on Euclidean distance. Figure 2.3.1.6 shows the distance from the land cell to the nearest wetland. Figure 2.3.1.7 shows the distance from the nearest wetland to the nearest stream reach. By comparing attenuated and unattenuated output nutrient data from WAM, it is possible to evaluate the nutrient storage capacity of wetland systems.

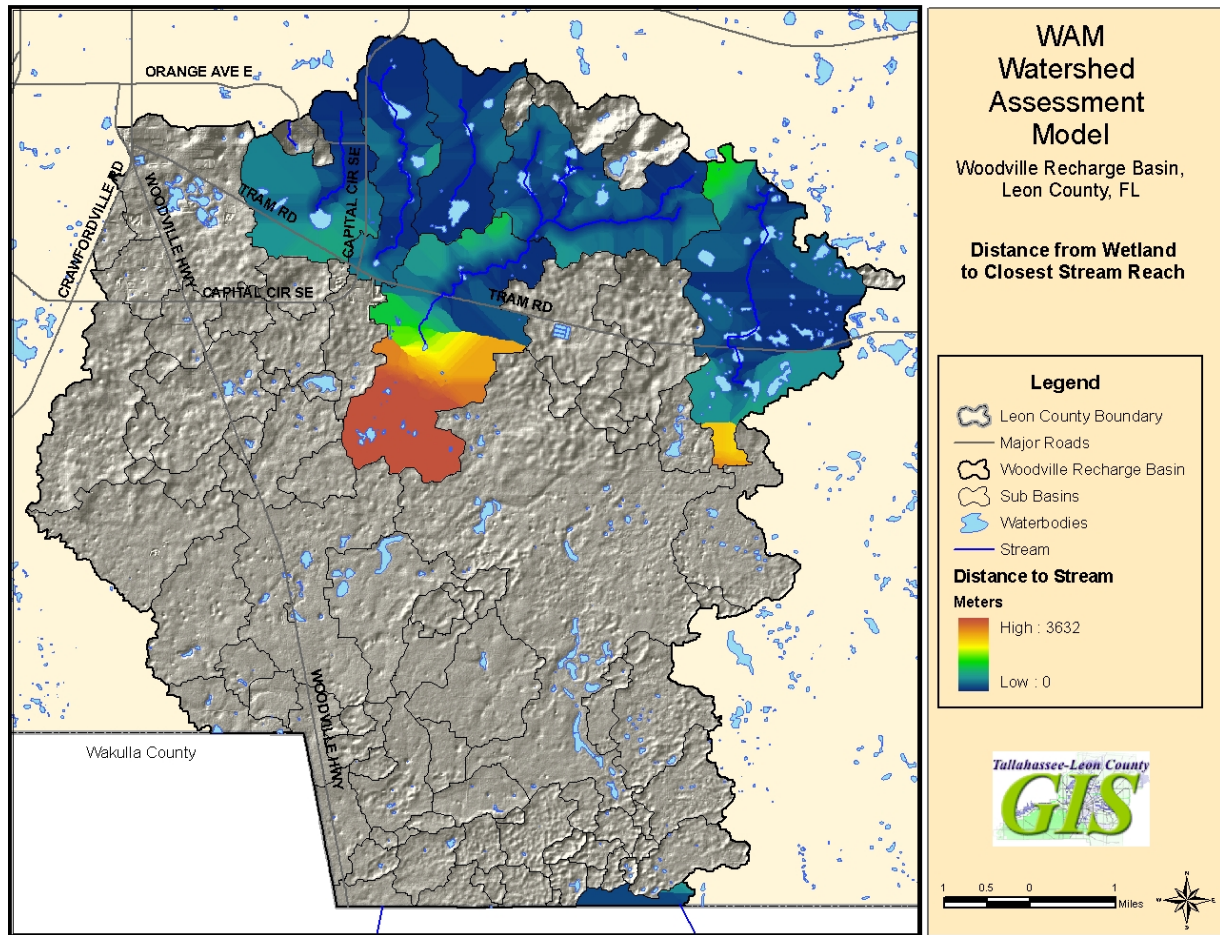


Figure 2.3.1.7: Distance from wetland to closest stream reach

Land Use Data

The land use layer is the primary input geospatial data layer for computing the nutrient loadings. The land use data used for the Woodville WAM model was originally a polygon data set produced in 1995 through air photo interpretation. This data produced by Greenhorne and Omara under contract with the State of Florida. The classification system used for the land use data is the Florida Land Use and Land Cover Classification System, (FLUCCS). The nominal scale of the original data is 1:24000.

For the Woodville WAM study, the land use data was clipped to the basin limits and updated using 1-meter resolution color orthoimagery (dated 2004) as a spatial and attribute reference. The revised land use data has a nominal scale of 1:6000. In addition to the general update of the land use, the City of Tallahassee Southeast Sprayfield (SESF) pivots were digitized into the land use data so that the SESF could be included in the WAM model. The polygon data was converted to raster data for model input. The land use data for the Woodville Recharge Basin is shown in Figure 2.3.1.8. A summary of the land use categories occurring within the Woodville basin is shown in Table 2.3.1.8.

The model parameters related to land use are applied globally to the default output for the basin. The user can specify parameters associated with a particular land use category, such as population density, crop planting and harvesting, slope, drainage area, erosion factors, fertilizer application events for nitrate, ammonia and phosphorous, organic waste applications, storm water retention pond treatment, and nutrient fractions for soluble, sediment and ground water nitrogen.

The land use parameters file also contains entries for Best Management Practices (BMPs). These are secondary land use entries related to the parent entry, but with modified parameters. For instance, there may be an entry for medium density residential on septic without retention. The BMP entry might be medium density residential with secondary treatment and storm retention.

Table 2.3.1.8: Land Use Categories Occurring in the Woodville Recharge Basin, Associated Nutrient Loadings, (Kg / Ha), and the Number of Applications per Year

Land Use	Area (Ha)	Fertilizer N	Fertilizer NH	Fertilizer P	Fertilizer Events	Source	
Cemeteries	5.03	0	0	6.7	3	SWET	
Commercial and Services	197.81	25	0	0	1	SWET	
Community Recreational Facilities	80.11	25	0	0	1	SWET	
Coniferous Plantations	7231.87	20	0	5	1	SWET	
Correctional	11.60	25	0	5	1	SWET	
Cropland and Pastureland	249.06	30	0	5	1	SWET	
Cypress	251.43	0	0	0	0	SWET	
Disturbed Land	22.88	0	0	0	0	SWET	
Educational facilities	55.85	25	0	0	1	SWET	
Electrical Power Facilities	0.61	0	0	0	0	SWET	
Electrical Power Transmission Lines	149.90	0	0	0	0	SWET	
Emergent Aquatic Vegetation	46.44	0	0	0	0	SWET	
Extractive	77.18	0	0	0	0	SWET	
Forest Regeneration Areas	1333.75	20	0	5	1	SWET	
Freshwater Marshes	61.61	0	0	0	0	SWET	
Golf Courses	93.89	0	0	6.7	3	SWET	
Governmental	7.56	25	0	0	1	SWET	
Improved Pastures	76.79	80	80	0	1	SWET	
Industrial	75.28	0	0	0	0	SWET	
Intermittent Ponds	73.90	0	0	0	0	SWET	
Lakes	115.65	0	0	0	0	SWET	
Mixed Coniferous/Hardwood	815.97	0	0	0	0	SWET	
Mixed Rangeland	1.32	0	0	0	0	SWET	
Mobile home units, medium density	4.39	50	0	30	1	SWET	
Municipal Sprayfield	705.43	9	9	5.2	20	COT	
Oil, Water, or Gas Transmission Lines	20.57	25	0	0	1	SWET	
Open Land	74.68	0	0	0	0	SWET	
Other Recreational	5.53	25	0	0	1	SWET	
Recreational	11.01	25	0	0	1	SWET	
Religious	3.46	25	0	0	1	SWET	
Reservoirs	70.30	0	0	0	0	SWET	
Residential, high density	510.92	70	0	30	1	SWET	
Residential, low density	554.63	25	0	20	1	SWET	
Residential, medium density	920.28	50	0	30	1	SWET	
Sand and Gravel pits	8.72	0	0	0	0	SWET	
Shrub and Brushland	266.94	0	0	0	0	SWET	
Strip Mines	6.68	0	0	0	0	SWET	
Unimproved Pasture	101.70	45	45	0	1	SWET	
Upland Coniferous Forests	2151.76	0	0	0	0	SWET	
Wetland Coniferous Forests	41.39	0	0	0	0	SWET	
Wetland Forested Mixed	633.72	0	0	0	0	SWET	
Wetland Scrub Shrub	98.95	0	0	0	0	SWET	

Note: Some land uses may carry additional loadings not documented in this table, such as nutrient loadings from septic tanks for residential land uses outside the wastewater utility service zone.

Land Use / Land Cover Categories

Cemeteries	Freshwater Marshes	Other Recreational
Commercial and Services	Golf Courses	Recreational
Communications Facilities	Governmental	Religious
Community Recreational Facilities	Holding ponds	Reservoirs
Coniferous Plantations	Improved Pastures	Residential, high density
Correctional	Industrial	Residential, low density
Cropland and Pastureland	Intermittent Ponds	Residential, medium density
Cypress	Lakes	Sand and Gravel pits
Disturbed Land	Mixed Coniferous/Hardwood	Shrub and Brushland
Educational facilities	Mixed Rangeland	Strip Mines
Electrical Power Facilities	Mobile home units, medium density	Unimproved Pasture
Electrical Power Transmission Lines	Municipal Sprayfield	Upland Coniferous Forests
Emergent Aquatic Vegetation	Oil, Water, or Gas Transmission Lines	Wetland Coniferous Forests
Extractive	Open Land	Wetland Forested Mixed
Forest Regeneration Areas	Open Land (Urban)	Wetland Scrub Shrub

Land Use / Land Cover Classification Legend (see Figure 2.3.1.8 below)

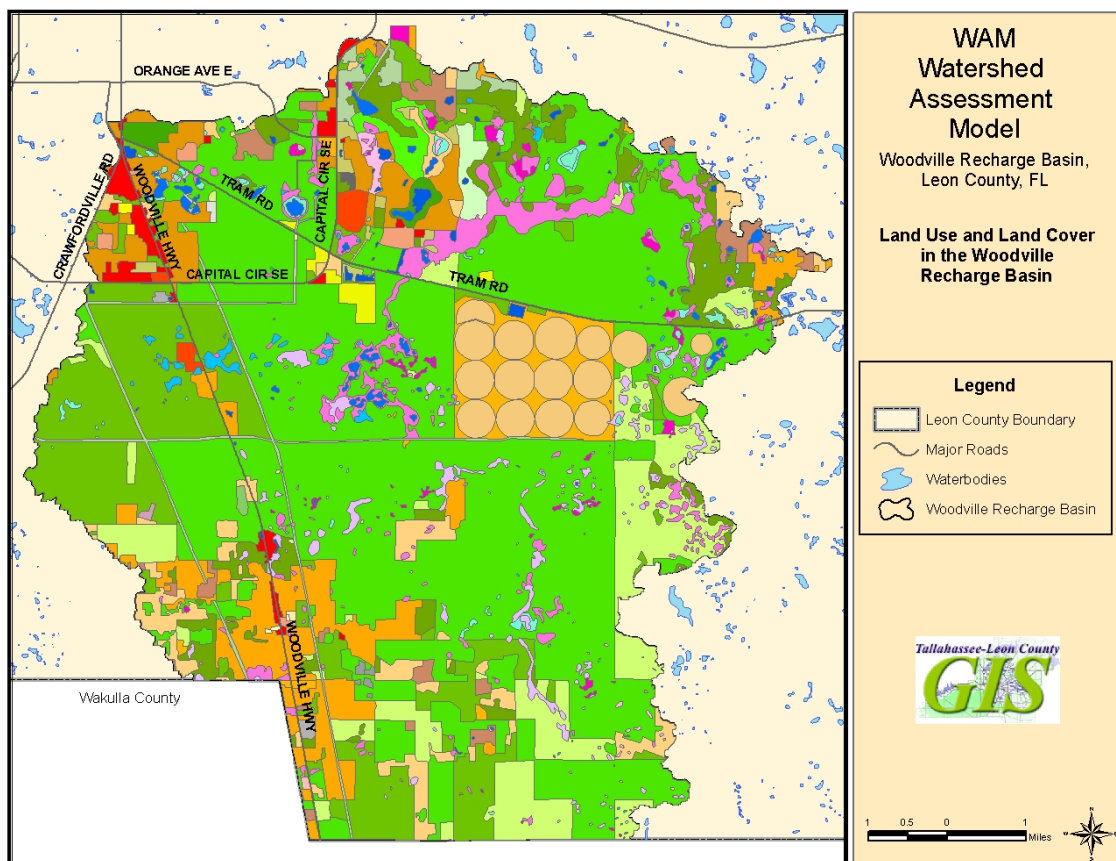


Figure 2.3.1.8: Land Use and Land Cover in the Woodville Recharge Basin, (data from 2004)

Soils Data

The soils data used for the Woodville WAM model is 1:20000 scale Natural Resources Conservation Service (NRCS) data. The soils data was clipped to the basin boundary and joined with the soilnames.dbf file in WAM to verify that all the soils are listed in the WAM tables and to relate the WAM codes to NRCS soil codes. The WAM soil code values are used to produce the raster soils data. The soils data is used to model water and nutrient percolation, absorption and nutrient mineralization. WAM uses the soil class to reference the soils.bnz file which stores parameters defining the NRCS soil group, soil evaporation, hydraulic slope, phosphorous absorption, root zone conductivity, erosion K-factor, specific surface area for clay particles, clay and silt content, the number of soil horizons, and the organic content, pH and calcium carbonate concentration of each soil horizon. The soil class is also used by the BUCSHELL sub program to determine whether to use the GLEAMS field model or the EAAMOD field model. The soils data is shown in Figure 2.3.1.9.

WAM calculates the movement of water through the soil to the groundwater by means of a subsurface hydrograph to estimate what fraction of the water leave each land cell each day. The physical properties of the soil horizon are integrated with an assumed velocity of water to produce the daily output fro water movement. Additionally, there are some elements of evapotranspiration, namely soil evaporation, included in the soil parameters file. WAM uses the Priestly-Taylor equation to calculate evapotranspiration.

The soils data is where denitrification occurs within WAM once the water begins to percolate. The denitrification process occurs within the plant root zone. WAM keeps track of all nitrogen sources (fertilizer, organic waste, atmospheric deposition) and forms, (pools), as part of the daily totals files. Based on the physical and chemical properties of the soil profiles, and the volume of available water (rainfall, irrigation) the field model (GLEAMS) tracks the nitrogen pools (fast acting, slow acting, soluble, particulate, gaseous, etc), the transformation of nitrogen from one pool to another and whether the denitrification processes are occurring in aerobic and anerobic conditions. The parameters in soils.bnz determine the length of time that water and nutrients remain within the root zone. Once the water/nutrient loads have left the root zone, the model applies the 0.8 attenuation coefficient to the groundwater loadings.

Soils in the Woodville Recharge Basin

Soils	
Soil Name	
 ALBANY LOAMY SAND, 0 TO 2 PERCENT SLOPES	 OCILLA FINE SAND
 ALBANY-URBAN LAND COMPLEX, 0 TO 2 PERCENT SLOPES	 ORANGEBURG FINE SANDY LOAM, 2 TO 5 PERCENT SLOPES
 ALPIN SAND, 0 TO 5 PERCENT SLOPES	 ORANGEBURG FINE SANDY LOAM, 5 TO 8 PERCENT SLOPES
 BLANTON FINE SAND, 0 TO 5 PERCENT SLOPES	 ORANGEBURG FINE SANDY LOAM, 8 TO 12 PERCENT SLOPES
 CHAIRES FINE SAND	 ORANGEBURG-URBAN LAND COMPLEX, 2 TO 12 PERCENT SLOPES
 CHIPLEY FINE SAND, 0 TO 2 PERCENT SLOPES	 ORTEGA SAND, 0 TO 5 PERCENT SLOPES
 FACEVILLE SANDY LOAM, 2 TO 5 PERCENT SLOPES	 PAMLICO-DOROVAN COMPLEX
 KERSHAW SAND, 0 TO 5 PERCENT SLOPES	 PELHAM FINE SAND
 KERSHAW SAND, 5 TO 8 PERCENT SLOPES	 PITS
 KERSHAW-URBAN LAND COMPLEX, 0 TO 5 PERCENT SLOPES	 PLUMMER FINE SAND
 LAKELAND SAND, 0 TO 5 PERCENT SLOPES	 PLUMMER MUCKY FINE SAND, DEPRESSIONAL
 LEON SAND	 RUTLEGE LOAMY FINE SAND
 LUCY FINE SAND, 0 TO 5 PERCENT SLOPES	 RUTLEGE SOIL, OCCASIONALLY FLOODED
 LUCY FINE SAND, 5 TO 8 PERCENT SLOPES	 SAPELO FINE SAND
 LUTTERLOH FINE SAND, 0 TO 5 PERCENT SLOPES	 SUBMERGED
 LYNCHBURG FINE SANDY LOAM	 TALQUIN FINE SAND
 NORFOLK LOAMY FINE SAND, 2 TO 5 PERCENT SLOPES	 TROUP FINE SAND, 0 TO 5 PERCENT SLOPES
 NORFOLK LOAMY SAND, CLAYEY SUBSTRATUM, 5 TO 8 PERCENT SLOPES	 WAGRAM LOAMY FINE SAND, 0 TO 5 PERCENT SLOPES
	 WAGRAM LOAMY FINE SAND, 5 TO 8 PERCENT SLOPES
	 YONGES FINE SANDY LOAM

Soils Classification Legend (See Figure 2.3.1.9 below)

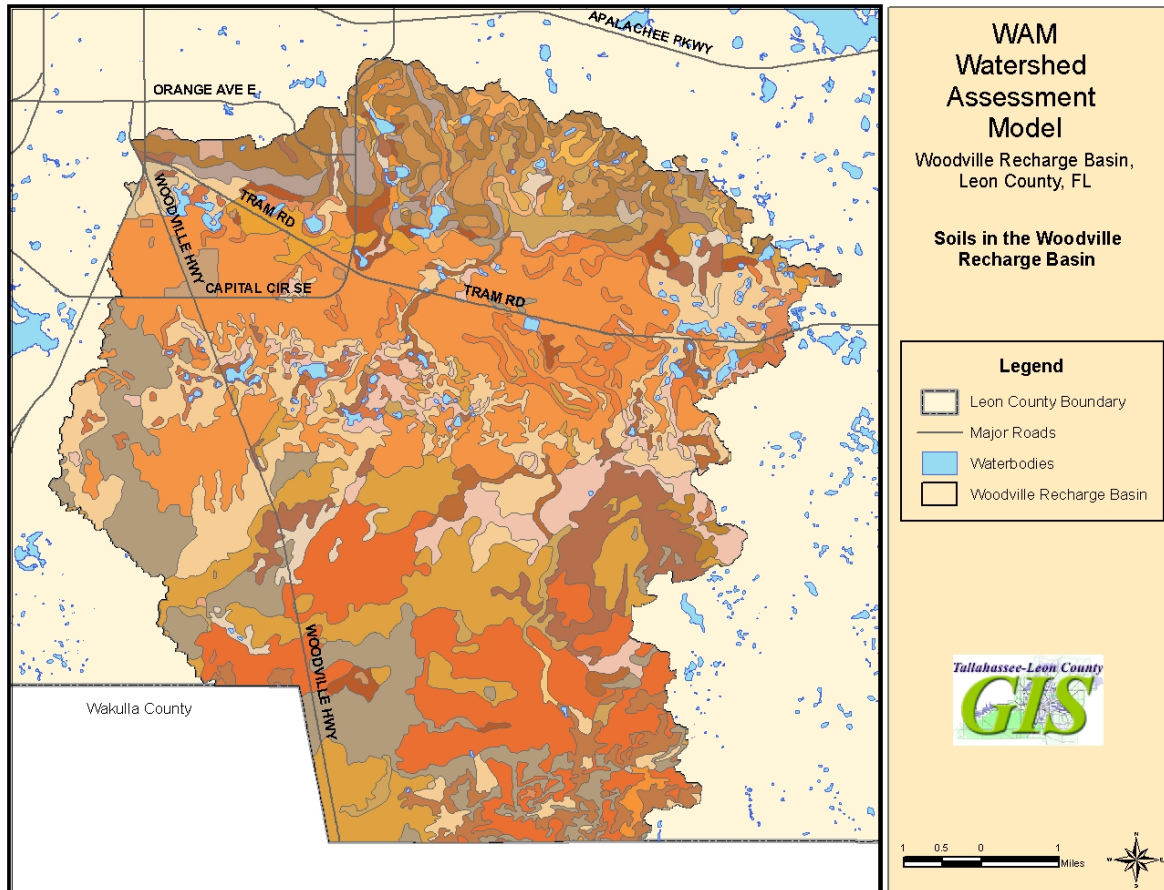


Figure 2.3.1.9: Soils within the Woodville Recharge Basin

Rainfall Zones

The rainfall zone data is a raster grid covering the extent of the basin and for which the cell value points to a number in the WAM rainfall input file (rainfiles.in). The entries in this file in turn relate the rain zone cell value to an ASCII file of daily rainfall totals organized by year. There is one daily rainfall file for each rain zone. The daily rainfall file must have entries covering the duration of the WAM run. The rainfall totals are in centimeters. Two rain zones were used for the Woodville study, one to apply to the basin as a whole and the other to accommodate the SESF effluent applications. The rainfall zones are shown in Figure 2.3.1.10.

Thirty years of daily rainfall data (ranging from January 1, 1977 – December 31, 2006) was obtained from the National Climatic Data Center (NCDC) for the Tallahassee Regional Airport. There are a number of rain gauges distributed around Leon County and an attempt was made to use data from these gauges in order to better represent the variations in rainfall. Unfortunately, many of these stations have not been operating long enough to be useful in the study and there are often missing values. The NCDC data was intact except for the month of April, 1996. In order to recover this month, it was necessary to calculate a mean daily total for all the other years of April observations and use those values for April, 1996.

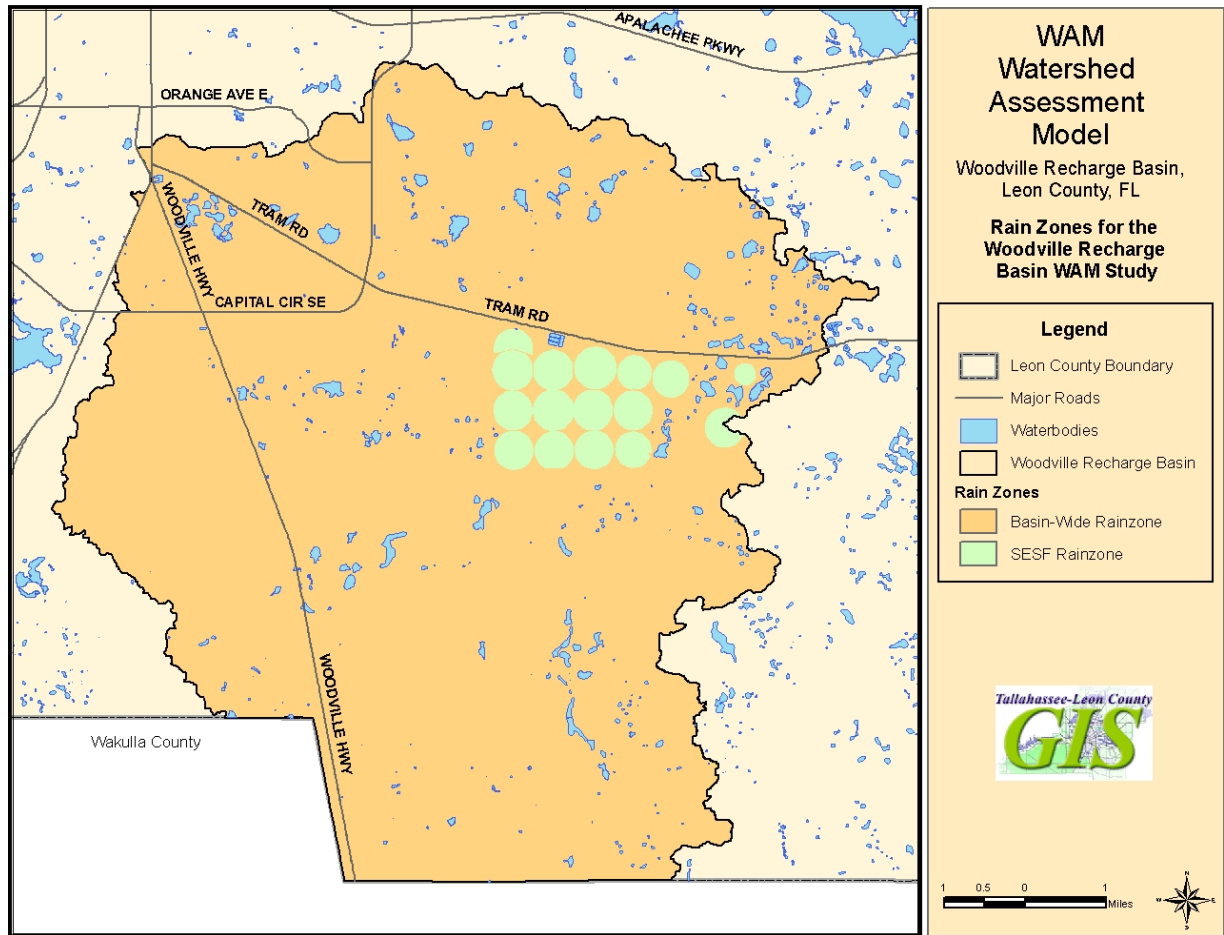


Figure 2.3.1.10: Rain Zone Data for Woodville Recharge Basin WAM Study

Due to the presence of the SESF in the Basin, the impacts of this facility had to be included in the model. It was decided to assign the SESF its own rain zone to accommodate the application of wastewater. The application rate for each year (in million gallons per day) was converted to cubic centimeters per hectare per day and a rainfall file for the SESF was built by adding these values shown in Table 2.3.1.10 below to the daily totals from the NCDC data.

Table 2.3.1.10: Average Yearly Application Rates for the City of Tallahassee SESF

Year	Rate (cm/day)	Area (Ha)	Total N (mg/l)
1987	0.88	862.27	14.51
1988	0.76	862.27	17.84
1989	0.72	862.27	16.80
1990	0.69	862.27	16.35
1991	0.77	862.27	15.86
1992	0.75	862.27	14.97
1993	0.75	862.27	12.99
1994	0.90	862.27	11.30
1995	0.73	862.27	13.23
1996	0.75	862.27	12.83
1997	0.83	862.27	14.25
1998	0.94	862.27	13.94
1999	0.75	983.18	13.41
2000	0.73	983.18	13.04
2001	0.78	983.18	16.21
2002	0.82	983.18	11.02
2003	0.89	983.18	12.32
2004	0.82	983.18	11.71

Data for application rates, facility area, and Total nitrogen concentrations were provided by the City of Tallahassee Water Quality Division. Area data from COT may differ somewhat from GIS calculated area.

Utility Service Zones

This data set is optional, but WAM uses the utility service zone layer to differentiate land uses which are serviced by wastewater treatment service areas from those land uses serviced by septic tanks. The cell values in this data set equal 1 for the areas in the utility zone and are otherwise null. This data set is included in the BUCSHELL process of creating unique combinations of cells. The waste loading from people is not included in the daily loading files if the cell falls in the utility zone. The loading for wastewater treatment facilities is added as fertilizer events in the land use definition file (landuse.bnz) for that land use. If the utility zone cell value is null, a daily total of 0.0565 kg of total nitrogen and 0.01865 kg of phosphorous per person per day is added to the percolation variables for each nutrient as a septic tank loading. This is multiplied by the population density variable for each land use class affected.

This is a crucial factor in the Basin due to the large number of septic tanks in the Basin. In addition, the SESF receives a largest portion of the wastewater from the population served by the City of Tallahassee Sewer Utility.

Part of this study is directed to evaluate whether or not increased land use density in the Basin and whether or not that land use is serviced by central sewer or by septic will affect the nutrient levels found in the groundwater.

The utility zone data is shown in Figure 2.3.1.11 below:

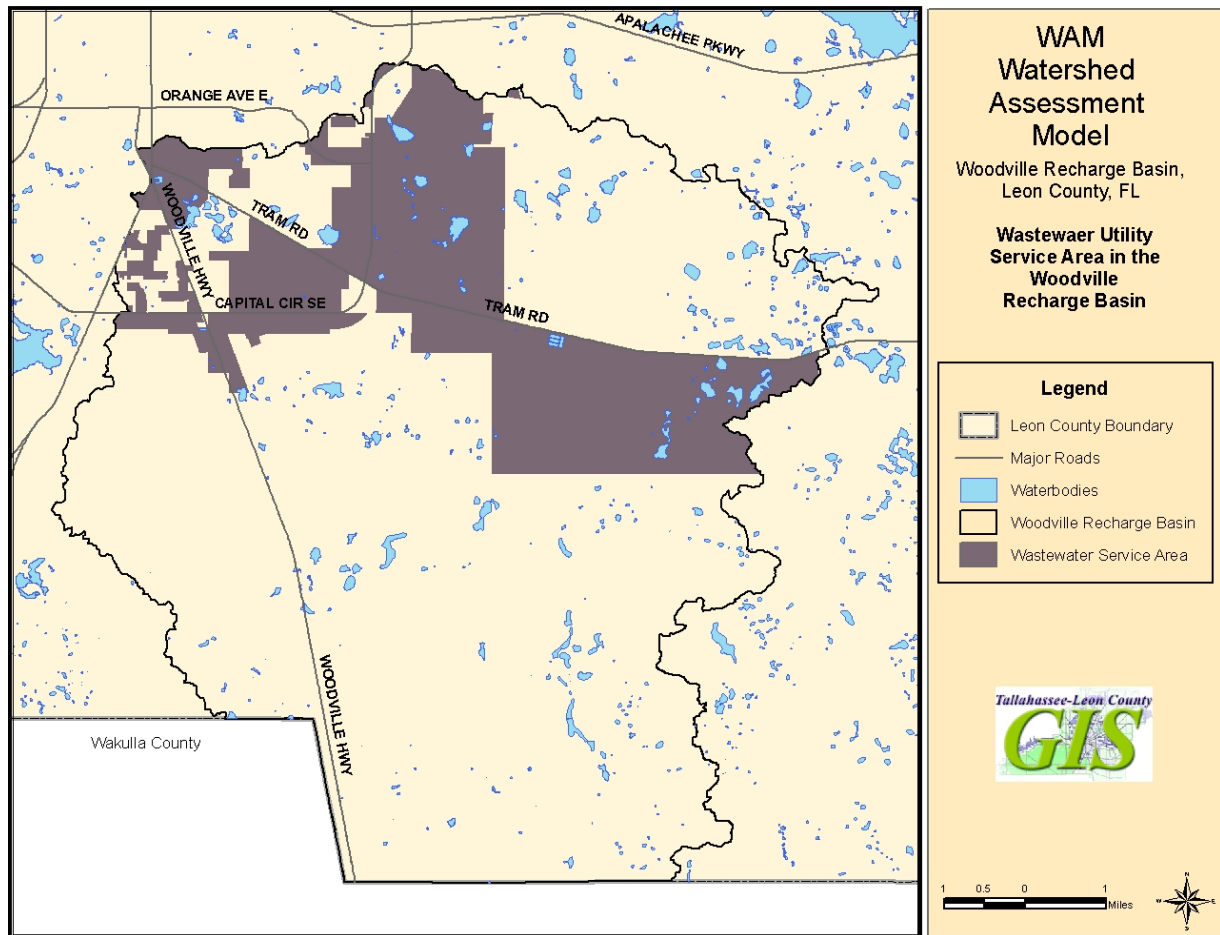


Figure 2.3.1.11 Wastewater Utility Service Area in the Woodville Recharge Basin

3.1.2: Non Spatial Tabular Data

Global Input Files

The global input files are text files containing model input parameters which are used for model runs for all basins. Some of the global input files most relevant for understanding the Woodville WAM scenario are described here. A full description of all WAM input files is given in Bottcher and Jacobson, 2005. All WAM parameters are accessible to the user, but user-modification requires expert knowledge. The parameters that the user is most likely to change are those for controlling crop planting, harvesting, fertilization, wastewater effluent application rates, animal waste applications, etc. Often the user can obtain specific data from the land owner or the wastewater treatment operator.

The discussion of the non-spatial component of WAM is given to provide an understanding of where data is stored and accessed by WAM. This is useful for those readers interested in the WAM modeling processes. Those readers interested in understanding the application of WAM to the Woodville Study may not find this section of interest.

$$dC = (C - C_b) * e^{-(a * q - b * d)}$$

where:

- dC = change in concentration (ppm)
- C = current concentration (ppm)
- Cb = background concentration (ppm)
- a = attenuation multiplier
- b = attenuation exponent
- q = flow rate (m³/s)
- d = flow distance (m)

PO4	Use	Surface Water Attenuation												
		<u>BOD</u>			<u>SolNO3</u>			<u>SolNH4</u>			<u>SolOrgN</u>			<u>Sol.</u>
	Code	a	b	Cb	a	b	Cb	a	b	Cb	a	b	Cb	a
b Cb Stream 0.7 0.05	5100	0.000	0.8	0.5	0.000	0.7	0.02	0.000	0.7	0.015	0.000	0.7	0.2	0.000
Wet land 0.65 0.10 Retention	5350	0.00001	0.8	0.5	0.00004	0.7	0.02	0.00004	0.7	0.015	0.00004	0.7	1.4	0.0010
Wetland 0.65 0.05 Coniferous Forest	6200	0.00025	0.5	0.5	0.00012	0.6	0.02	0.00012	0.6	0.015	0.00012	0.6	1.6	0.00004

Stream	Use Code	Sub Surface Attenuation											
		<u>SolNO3</u>			<u>SolNH4</u>			<u>SolOrgN</u>			<u>Sol. PO4</u>		
		a	b	Cb	a	b	Cb	a	b	Cb	a	b	Cb
	5100	0.8	0.0	-99	0.8	0.0	-99	0.8	0.0	-99	0.0	0.0	-99
Wetland Retention	5350	0.8	0.0	-99	0.8	0.0	-99	0.8	0.0	-99	0.0	0.0	-99
Wetland Coniferous Forest	6200	0.8	0.0	-99	0.8	0.0	-99	0.8	0.0	-99	0.0	0.0	-99

For the surface water, the attenuation coefficients vary with land use type. For most the water uses, except for lakes, the attenuation multiplier is 0. An attenuation multiplier is applied for all wetland land uses. This coefficient is not used for other non-wetland land uses. For the surface water scenario, the attenuation exponent and back ground concentration variables are set specifically for each land use.

No background concentration is applied for the sub-surface attenuation scenario. The attenuation multiplier is 0.8 and the attenuation exponent is 0.0 for all land uses.

Default.bnz:

This is the primary simulation control file. It controls the simulation period (number of years), the number of simulation years to skip before computing daily totals, and evapotranspiration factors. The Woodville WAM scenario was set to run from 1987 – 2005, skipping the first 5 years. This yielded 19 years of daily totals. It is important to skip the first few years of the simulation to allow the model to come to equilibrium, otherwise, the flow output levels and nutrient concentration levels will be inaccurate. Default.bnz also contains crop definition parameters which influence nutrient uptake, such as estimations of crop nitrogen, rooting depth, dry matter ratio, carbon-to-nitrogen ratio, harvestable yield, nitrogen-to-phosphorous ratio, and leaf-area index. These parameters are set for the vegetated land uses and are used by the GLEAMS sub program for nutrient simulation.

Default.bnz stores several parameters related to potential evapotranspiration. WAM uses the Priestly-Taylor equation to calculate potential evapotranspiration.

Default.bnz also contains other components. There are parameters related to overland flow erosion. These parameters are mostly used for agricultural model scenarios. There also are parameters defining waste definitions for specific nutrient sources. The table below shows the nutrient content settings for the Woodville WAM model. The most relevant entries are those for septic tanks and for secondary sewage treatment for the SESF. These percentage-based parameters are used in daily total calculations. These values allow nutrient loading to be calculated from weight-based waste application data.

Table 2.3.2.1: Global Default Parameters: Percent Nutrient Content for Animal and Human Waste

Nutrient Source	Total N Content (%)	Org N Content (%)	NH4 Content (%)	P Content (%)	Org P Content (%)
Beef Operation	2.88	1.94	0.92	1.6	1.52
Dairy Operation	2.2	1.66	0.53	0.82	0.79
Horse Farm	1.74	1.2	0.54	0.5	0.498
Poultry Farm	3.1	2.06	1.03	2.9	2.85
Sheep	2.7	1.83	0.86	0.79	0.785
Swine	4.5	2.57	1.92	2.5	2.495
Septic Tank	0.0052	0.004	0.001	0.001	0.0003
Raw Sewage	0.0057	0.0018	0.0039	0.0021	0.0004
Secondary Treatment	0.0013	0.0004	0.00085	0.0006	0.0001
Tertiary Treatment	0.0003	0.0001	0.0002	0.0001	0
Bad Septic Tank	0.0052	0	0	0.001	0.0003

Bottcher and Jacobson, 2006

WAM does not model stormwater runoff toxins, default.bnz contains parameters for nutrient concentrations (ppm) in stormwater runoff for biological oxygen demand, sediment and soluble nitrate, ammonia, and phosphorous. Stormwater retention pond parameters for the ratio of pond volume to unit land area, and the fraction of sediment materials passing through the pond.

An important section of the default.bnz file controls weather/climate parameters and background concentrations of nitrate and phosphorous in rainfall. The climate parameters are mean elevation, latitude,

mean monthly temperature, mean monthly radiation, and mean monthly dewpoint. The mean elevation set for the Woodville WAM model was set to 9.14 meters. The latitude was set to 30.5 degrees.

Table 2.3.2.2 below shows the monthly mean climatic parameter settings for the Woodville WAM model.

Table 2.3.2.2: Global Default Climate parameters

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	VARIABLE
17.8	19.4	23.3	26.7	30.6	32.7	33.3	33.3	31.7	27.2	22.8	18.9	MAX TEMP (C)
4.4	5.6	8.9	11.7	16.7	21.1	22.8	22.8	20.6	13.9	8.9	5.6	MIN TEMP (C)
16.37	17.01	16.05	20.99	27.72	21.63	19.67	27.16	26.67	21.74	15.88	18.92	RADIATION (LANGLEYS)
98	114	123	118	99	89	82	79	92	104	100	96	WIND (KM/DAY)
11.06	9.44	12.22	15.44	17.94	20.5	20.72	20.78	20.22	18.5	13.61	12.83	DEW POINT

NOAA, 2006

For the Woodville WAM model, the rainfall concentration of nitrogen was set to 0.61 ppm and the rainfall concentration of phosphorous was set to 0.014 ppm, (McGlynn, 2006).

Landuse.bnz:

Landuse.bnz is one of the important of the global input files. This file controls the specific parameter settings for each land use and best management practice (BMP) entry. The landuse polygon data set starts with a Florida Land Use Land Cover Classification System (FLUCCS) attribute. This field is joined with the table landuse.dbf in WAM to relate the FLUCCS code to the WAM Land Use Code. If all local land uses are not in the WAM table, it must be updated by the user to include them. Once the WAM codes have been added to the polygon attributes, a raster land use grid is produced using the WAM code and the cell value. These WAM codes are used to reference each cell in the land use grid to the land use entry in landuse.bnz. Below is an entry from landuse.bnz used in the Woodville WAM model for the low density residential landuse (WAM code = 2). The most relevant parameters are shown in red and described below. If the value is -999, the parameter is not used.

*NAME 2 Low Density Residential

Description

Mobile homes, 95% pervious with grass, harvested, non-irrigated, 25/20 kg/ha/yr N/P, 4.1 people/ha septic, no retention pond

Simulation Control

1 1 0 IROT FLGSEQ FLGSOL

Population Density

4.1 47 HDEN HTYPE

0 0 ADEN ATYPE

Initial Conditions

1 0 -999 -999 BST RESDW ORGNW ORGPW

-999 -999 -999 -999 -999 CLAB CNIT POTMN TN TP

Crop

1 0.95 0.5 NCROP FCROP FPERC

10 1001 1365 -999 -999 -999 0 ICROP DPLANT DHRVST DTRUNC BEGGRO ENDGRO IROPT

Hydrology

25.2 600 2 1.5 3 XOVT XSLPT DAREA WLW DITCH

36 60 73 79 CN2

Erosion

1 0 NXF NXC

1 XFACT()

1 1 LROT NDATES()

1 CDATE()

1 0.1 0.5 0.03 LXF CFACT PFACT NFACT

Fertilizer

1 NF

1032 0 0 25 0 20 -999 DF METHAI DEPINI FN FNH FP FTRWAT


```

Organic Waste
0                               NW
Tillage
0                               NTIL
Retention Pond
0   0   S                       PRTIME PAREA PONDTYPE
Point Source
0   0                           PSCODE STRTCLN
N Fractions
0.10 0.05 0.85                 Surface Soluble NO3 NH4 OrgN
-99 -99                       Surface Sediment NH4 OrgN
0.81 0.003 0.19               Groundwater NO3 NH4 OrgN
BMP Factors      Non-Represented BMP Multipliers
1   1   1 1.8         TSS TN TP BOD (Surface parameters)
1   1                   TN TP      (Groundwater parameters)

```

The parameter definitions are as follows:

ADEN Animal density (number/hectare)
 ATYPE Animal waste type (GLEAMS definitions)
 DF Day of fertilizer event (1001 = January 1; 1365 = December 31)
 DPLANT Day crop planted (1001 = January 1; 1365 = December 31)
 DHARVST Day crop harvested (1001 = January 1; 1365 = December 31)
 FN Fertilizer nitrate (Kg/Hectare)
 FNH Fertilizer ammonia (Kg/Hectare)
 FP Fertilizer phosphate (Kg/Hectare)
 HDEN Human density (persons/hectare)
 HTYPE Human waste type (from default.bnz, 47 = septic, 48 = raw, 49 = secondary, 50 = tertiary, 51 = 0 discharge)
 ICROP Crop Identification code (10 = Bermuda grass)
 NCROP Number of crops
 NF Number of fertilizer events

Entries for some additional land uses follow. The same parameters are highlighted to assist in comparison.

*NAME 19 Medium Density Residential

Description

Houses, 75% pervious with grass, harvested, nonirrigated, 50/30 kg/ha/yr N/P, 14.4 people/ha septic, no retention pond

Simulation Control

```

1   1   0                       IROT FLGSEQ FLGSOL

```

Population Density

```

14.4 47                       HDEN HTYPE
0   0                       ADEN ATYPE

```

Initial Conditions

```

1   0 -999 -999               BST RESDW ORGNW ORGPW
-999 -999 -999 -999 -999     CLAB CNIT POTMN TN TP

```

Crop

```

1 0.75 0.25                   NCROP FCROP FPERC
10 1001 1365 -999 -999 -999 0 ICROP DPLANT DHRVST DTRUNC BEGGRO ENDGRO IROPT

```

Hydrology

```

25.2 600 1 1.5 3             XOVT XSLPT DAREA WLW DITCH
30 58 71 78                  CN2

```

Erosion

```

1   0                       NXF NXC
1                       XFACT()
1   1                       LROT NDATES()
1                       CDATE()
1 0.1 0.5 0.03             LXF CFACT PFACT NFACT

```

Fertilizer

```

1                               NF

```

```

1091  0  0  50  0  30 -999 DF  METHAI  DEPINI  FN  FNH  FP  FTRWAT
Organic Waste
0
Tillage
0
Retention Pond
0  0  S
Point Source
0  0
N Fractions
0.10 0.05 0.85
-99 -99
0.81 0.003 0.19
BMP Factors      Non-Represented BMP Multipliers
1  1  1  1.8      TSS TN TP BOD (Surface parameters)
1  1              TN TP      (Groundwater parameters)

```

*NAME 26 Improved Pasture

Description

Managed, 100% pervious with grass, harvested, nonirrigated, 160/0 kg/ha/yr N/P, 1.2 beef cows/ha, no retention pond

Simulation Control

```

1  1  0
Population Density
0  0
1.2 17

```

```

IROT  FLGSEQ  FLGSOL

```

```

HDEN  HTYPE

```

```

ADEN  ATYPE

```

Initial Conditions

```

1  0 -999 -999
-999 -999 -999 -999 -999
BST  RESDW  ORGNW  ORGPW
CLAB  CNIT  POTMN  TN  TP

```

Crop

```

1  1  0
10 1001 1365 -999 -999 -999 0
NCROP  FCROP  FPERC
ICROP  DPLANT  DHRVST  DTRUNC  BEGGRO  ENDGRO  IROPT

```

Hydrology

```

35.2 600
50 67 79 87
XOVT  XSLPT  DAREA  WLW  DITCH
CN2

```

Erosion

```

1  0
1
1  1
1
1  0.1 0.5 0.03
NXF  NXC
XFACT()
LROT  NDATES()
CDATE()
LXF  CFACT  PFACT  NFACT

```

Fertilizer

```

1
1045  0  0  80  80  0 -999 NF
DF  METHAI  DEPINI  FN  FNH  FP  FTRWAT

```

Organic Waste

```

12
1001  0  0  1
1032  0  0  1
1060  0  0  1
1091  0  0  1
1121  0  0  1
1152  0  0  1
1182  0  0  1
1213  0  0  1
1244  0  0  1
1274  0  0  1
1305  0  0  1
1335  0  0  1
NW
DW  METHAO  DEPINO  MFRAC
DW  METHAO  DEPINO  MFRAC
DW  METHAO  DEPINO  MFRAC
DW  METHAO  DEPINO  MFRAC
DW  METHAO  DEPINO  MFRAC
DW  METHAO  DEPINO  MFRAC
DW  METHAO  DEPINO  MFRAC
DW  METHAO  DEPINO  MFRAC
DW  METHAO  DEPINO  MFRAC
DW  METHAO  DEPINO  MFRAC
DW  METHAO  DEPINO  MFRAC
DW  METHAO  DEPINO  MFRAC

```

Tillage

```

0
NTIL

```

Retention Pond

```

0  0  S
PRTIME  PAREA  PONDTYPE

```

```

Point Source
0 0
N Fractions
0.08 0.01 0.91
-99 -99
0.81 0.003 0.19
BMP Factors
1 1 1 1.8
1 1
PSCODE STRTCLN
Surface Soluble NO3 NH4 OrgN
Surface Sediment NH4 OrgN
Groundwater NO3 NH4 OrgN
Non-Represented BMP Multipliers
TSS TN TP BOD (Surface parameters)
TN TP (Groundwater parameters)

```

Note that there is no human density or waste and the animal density is assigned as 1.2 animals per hectare.

Also note

12 organic water application events (one per month) have been added to this land use.

Below is the entry used in the Woodville WAM model for the SESF.

*NAME 990 User Defined 0 - Municipal Sprayfield

Description

Managed - N based, 100% pervious with forage crops, harvested, fertigated (8.0286 cm/wk), 11 ppm Total Nitrogen application, 2 ppm phosphate application

Simulation Control

```

1 1 0
Population Density
0 0
0 0
IROT FLGSEQ FLGSOL
HDEN HTYPE
ADEN ATYPE

```

Initial Conditions

```

1 0 -999 -999
-999 -999 -999 -999 -999
BST RESDW ORGNW ORGPW
CLAB CNIT POTMN TN TP

```

Crop

```

2 1 0
10 1091 1305 -999 -999 -999 0 ICROP DPLANT DHRVST DTRUNC BEGGRO ENDGRO IROPT
52 1306 2090 -999 -999 -999 0 ICROP DPLANT DHRVST DTRUNC BEGGRO ENDGRO IROPT

```

Hydrology

```

35.2 600 10 1.5 3
20 67 79 87
XOVT XSLPT DAREA WLW DITCH
CN2

```

Erosion

```

1 0
1
1 4
1
1 0.2 0.5 0.03
90
1 0.6 0.5 0.03
110
1 0.2 0.5 0.03
340
1 0.4 0.5 0.03
NXF NXC
XFACT()
LROT NDATES()
CDATE()
LXF CFACT PFACT NFACT
CDATE()
LXF CFACT PFACT NFACT
CDATE()
LXF CFACT PFACT NFACT
LXF CFACT P

```

FACT NFACT

Fertilizer

```

20 NF
1018 0 0 10 0 5.2 -999 DF METHAI DEPINI FN FNH FP FTRWAT
1036 0 0 10 0 5.2 -999 DF METHAI DEPINI FN FNH FP FTRWAT
1054 0 0 10 0 5.2 -999 DF METHAI DEPINI FN FNH FP FTRWAT
1072 0 0 10 0 5.2 -999 DF METHAI DEPINI FN FNH FP FTRWAT
1090 0 0 10 0 5.2 -999 DF METHAI DEPINI FN FNH FP FTRWAT
1108 0 0 10 0 5.2 -999 DF METHAI DEPINI FN FNH FP FTRWAT
1126 0 0 10 0 5.2 -999 DF METHAI DEPINI FN FNH FP FTRWAT
1144 0 0 10 0 5.2 -999 DF METHAI DEPINI FN FNH FP FTRWAT
1162 0 0 10 0 5.2 -999 DF METHAI DEPINI FN FNH FP FTRWAT
1180 0 0 10 0 5.2 -999 DF METHAI DEPINI FN FNH FP FTRWAT

```

1198	0	0	10	0	5.2	-999	DF	METHAI	DEPINI	FN	FNH	FP	FTRWAT
1216	0	0	10	0	5.2	-999	DF	METHAI	DEPINI	FN	FNH	FP	FTRWAT
1234	0	0	10	0	5.2	-999	DF	METHAI	DEPINI	FN	FNH	FP	FTRWAT
1252	0	0	10	0	5.2	-999	DF	METHAI	DEPINI	FN	FNH	FP	FTRWAT
1270	0	0	10	0	5.2	-999	DF	METHAI	DEPINI	FN	FNH	FP	FTRWAT
1288	0	0	10	0	5.2	-999	DF	METHAI	DEPINI	FN	FNH	FP	FTRWAT
1306	0	0	10	0	5.2	-999	DF	METHAI	DEPINI	FN	FNH	FP	FTRWAT
1324	0	0	10	0	5.2	-999	DF	METHAI	DEPINI	FN	FNH	FP	FTRWAT
1342	0	0	10	0	5.2	-999	DF	METHAI	DEPINI	FN	FNH	FP	FTRWAT
1360	0	0	10	0	.52	-999	DF	METHAI	DEPINI	FN	FNH	FP	FTRWAT
Organic Waste													
0							NW						
Tillage													
0							NTIL						
Retention Pond													
0	0	S					PRTIME	PAREA	PONDTYPE				
Point Source													
0	0						PSCODE	STRCLN					
N Fractions													
0.07	0.02	0.91					Surface Soluble	NO3	NH4	OrgN			
-99	-99						Surface Sediment	NH4	OrgN				
0.81	0.003	0.19					Groundwater	NO3	NH4	OrgN			
BMP Factors													
1	1	1	1.8				Non-Represented BMP Multipliers						
							TSS	TN	TP	BOD	(Surface parameters)		

Note that for the SESF 20 fertilizer events have been added to model the addition of the wastewater nutrient load. In order to calculate the loadings from the SESF, the average annual applications of water, in million gallons per day, were compared with the average annual loading of nitrogen in pounds per acre. The units were converted to metric giving mean application of 18 Kg per hectare application rate for total nitrogen per fertilizer event. The all of the landuse.bnz entries were provided by Bottcher and Jacobson, 2005, except for the total nitrogen loadings and the irrigation volumes for the SESF were provided by the City of Tallahassee Water Quality Division. The nutrient loadings represent effluent only. The detailed fertilizer data was unavailable and during the most of the model run period, fertilizer applications had been dramatically reduced.

Soils.bnz

WAM uses the soil class to reference the soils.bnz file which stores parameters defining the NRCS soil group, soil evaporation, hydraulic slope, phosphorous absorption, root zone conductivity, erosion K-factor, specific surface area for clay particles, clay and silt content, the number of soil horizons, and the organic content, pH and calcium carbonate concentration of each soil horizon. The soil class is also used by the BUCSHELL sub program to determine whether to use the GLEAMS field model or the EAAMOD field model. All soils entries were kept at defaults as provided by Bottcher, etal.

Example of soils.bnz:

*NAME	4	ALBANY											
0.0125	3	3.3	3			CHS	SGROUP	CONA	ISOIL				
0.9	150	20	0.1			RC	RD	SSCLY	KSOILO				
4						NOSOHZ							
18	61	104	150			BOTHOR							
0.022	0.012	0.009	0.105			BR15							
0.122	0.092	0.069	0.265			FC							
0.45	0.4	0.41	0.35			POR							
1.9	1.9	2.2	15.9			CLAY							
1.6	2.5	2.2	2.6			SILT							
22	25.7	30.8	0.6			SATK							
1.7	0.4	0.2	0			OM							

4.3	4.4	4.4	4.1	PH
5	4	3	4	BSAT
0	0	0	0	CACO3

Rainfall Files

Below is a sample of the rainfall data used for the Woodville WAM model. This data is a portion of daily totals for 1987. The daily rainfall data used in the model ranged from January 1, 1987 – December 31, 2005.

STN99987cm	1.14	0.00	0.00	2.84	0.01	0.00	0.00	0.00	0.00	1.52	1
STN99987cm	0.00	0.00	0.00	0.00	1.52	4.62	0.15	0.05	1.27	0.01	2
STN99987cm	0.69	1.04	0.00	0.00	1.27	0.00	0.00	0.00	0.01	0.25	3
STN99987cm	0.00	0.00	0.86	0.00	0.00	0.81	0.25	0.66	0.00	0.00	4
STN99987cm	0.00	0.00	0.00	0.00	0.00	1.09	3.91	0.01	0.01	0.00	5
STN99987cm	0.25	1.47	4.24	0.00	0.23	0.03	0.18	0.00	1.63	0.00	6
STN99987cm	0.00	0.00	0.00	0.00	0.00	3.00	0.03	0.03	0.00	0.38	7
STN99987cm	0.25	0.00	0.00	0.00	0.00	0.00	5.92	0.00	0.00	0.00	8
STN99987cm	0.00	0.00	0.30	0.01	2.13	2.41	0.00	5.36	4.22	0.00	9
STN99987cm	0.00	0.00	0.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10
STN99987cm	0.00	0.00	0.00	0.13	0.00	0.00	0.03	0.00	0.00	0.00	11
STN99987cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12
STN99987cm	0.00	0.00	0.00	0.01	0.00	0.00	1.14	0.00	0.00	0.10	13
STN99987cm	0.00	2.29	8.00	0.01	2.74	0.76	0.01	0.01	0.00	0.00	14
STN99987cm	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15
STN99987cm	0.00	0.00	0.00	0.66	1.93	0.01	0.00	0.00	0.00	0.00	16
STN99987cm	0.00	0.01	0.05	0.41	4.57	3.78	6.76	0.13	0.01	0.01	17
STN99987cm	4.29	1.32	0.13	5.00	0.25	0.99	1.32	0.00	0.00	0.00	18
STN99987cm	0.25	0.00	0.00	2.54	0.01	4.67	0.01	1.32	0.81	0.00	19
STN99987cm	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.01	0.13	20
STN99987cm	0.13	0.00	0.00	0.00	1.65	0.00	3.05	0.05	0.08	0.00	21
STN99987cm	0.01	1.27	0.01	0.08	0.53	0.43	0.97	0.18	0.00	0.00	22
STN99987cm	0.00	0.00	0.00	5.66	4.65	6.17	0.51	0.01	2.97	0.05	23
STN99987cm	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	24

The full list of global input text files is given below:

GlobalInputs

Attenuate.in - table of attenuation coefficients for each land use and water type [BLASRoute]

Control.# - control file for EAAMOD [BUCShell]

Default.bnz - default information used by models including years of simulation

Defaultn.in - default information used by models including rates

Eaamod.inp - list of files and sensitivity run control for EAAMOD [BUCShell]

Files.fin - list of input files and unit numbers for EAAMOD [BUCShell]

Files.in - lists I/O files that are used by GLEAMS [BUCShell]

Field.# - field geometry and conditions for EAAMOD [BUCShell]

FldCtrFiles.in - list of field and control files for EAAMOD [BUCShell]

Hydsurf.in - unit hydrograph for delivery of surface water to stream reaches [BLASRoute]

Hydssurf.in - unit hydrograph for delivery of subsurface water to stream reaches [BLASRoute]

Landuse.bnz - land use specific model parameters for GLEAMS [BUCShell]

Lu-eea.bnz - land use specific model parameters for EAAMOD [BUCShell]

Lumodel.bnz - list of land uses that are to be run using EAAMOD [BUCShell]

Luspec.bnz - information for land uses simulated by the special case model [BUCShell]

Outlet.in - water quality and stage conditions in time series at the outlet [BLASRoute]

Rainfiles.in - list of rain stations and corresponding zone numbers [BUCShell]
 Route.inp - lists other input files and input parameters [BLASRoute]
 Soil-eaa.bnz - soil specific model parameters for EAAMOD [BUCShell]
 Soils.bnz - soil specific model parameters for GLEAMS [BUCShell]
 Sspec.bnz - information for soils simulated by the special case model [BUCShell]
 StationName.ran - daily rainfall information [BUCShell]
 StreamEros.in - stream erosion input file [BLASRoute]
 StreamProfileDefs.in - default definitions for reach type x-sections and mannings n [BLASRoute]
 Temp.tem - temperature information for EAAMOD [BUCShell]
 Timedelay.in - time delay coefficients for surface and subsurface flow based on land use [BLASRoute]
 Wtfield.wtf - field water table file used by EAAMOD [BUCShell]
 (Mytyk and Kaplan, 2005)

Local Input Tabular Files

StreamPointSource.in

This file defines point source input parameters for additional water volume and nutrient inputs. This is the file that was used to account for the background flow and nutrient content in the aquifer. WAM currently has no facility to incorporate this type of data in a spatial data set. This file was linked to the outflow reach so that the flow and loadings from rainfall, land uses and aquifer background would all be accounted for at the outflow. This was necessary to for the model to accurately predict groundwater flow and nutrient concentration in the aquifer at the boundary of the study area.

Reach number 2 is the outflow reach for the Wakulla groundwater zone and reach number 3 is the outflow reach for the St. Marks groundwater zone. Since the purpose was to establish a background condition, the nutrient source is expressed in concentration. This file begins on January 1, 1987 and applies to the full duration of the model run. The flow rate is set at 3.5926 cubic meters per second, the soluble nitrate concentration is 0.4 ppm and soluble phosphate concentration is 0.07 ppm , (McGlynn, 2006).

```

ReachNum Interpolate Conc/Load (ppm | kg/d) Stream/Groundwater - - - Wakulla Groundwater Zone
2      No      Conc      Stream
TSS,SolNO3,SolNH4,SolOrgN,SolP,SedNH4,SedOrgN,SedP,BOD, Minimum point source removal
concentration (ppm)

```

```

*****
Daily Date,Flow (cms),TSS,SolNO3,SolNH4,SolOrgN,SolP,SedNH4,SedOrgN,SedP,BOD
1/01/1987,3.5926,0.0,0.4,0.0,0.0,0.07,0.0,0.0,0.0,0.0

```

```

ReachNum Interpolate Conc/Load (ppm | kg/d) Stream/Groundwater - - - St.Marks Groundwater Zone
3      No      Conc      Stream
TSS,SolNO3,SolNH4,SolOrgN,SolP,SedNH4,SedOrgN,SedP,BOD, Minimum point source removal
concentration (ppm)

```

```

*****
Daily Date,Flow (cms),TSS,SolNO3,SolNH4,SolOrgN,SolP,SedNH4,SedOrgN,SedP,BOD
1/01/1987,3.5926,0.0,0.4,0.0,0.0,0.07,0.0,0.0,0.0,0.0

```

Unique.bnz

This file is a tabular result of BUCSHELL. BUCSHELL evaluates all of the input spatial layers that contribute to WAM model parameters and records all of the unique combinations of Soil, Land Use, Wastewater utility zone and Rainfall zone. The last number for each record in the file is the number of

raster cells which conform to a particular unique combination of data inputs. BUCSHELL references this file to create a Day File for each unique occurrence.

```
"soildesc","Grid2","ludesc","Grid3","Grid4","Grid5","Count"
'CHAIRES',70,'LOW DENSITY RESIDENTIAL ',2,10,0,3464
'CHIPLEY',74,'LOW DENSITY RESIDENTIAL ',2,10,0,2467
'RUTLEGE',337,'COMMERCIAL AND SERVICES ',3,10,1,318
'TALQUIN',370,'COMMERCIAL AND SERVICES ',3,10,1,8
'TROUP',388,'COMMERCIAL AND SERVICES ',3,10,1,285
'WATER',408,'COMMERCIAL AND SERVICES ',3,10,1,210
'ALBANY',4,'RURAL LAND IN TRANSITION ',4,10,0,2
'ALPIN',6,'RURAL LAND IN TRANSITION ',4,10,0,2364
'BLANTON',38,'RURAL LAND IN TRANSITION ',4,10,0,5961
'FACEVILLE',126,'RURAL LAND IN TRANSITION ',4,10,0,42
```

The full list of local input tabular files and the associated WAM modules are given below:

LocalInputs

Boundary.in - list of boundary conditions [BLASRoute]

Psources.bnz - point source water quality and flow time series data [BUCShell]

StreamProfile.in - reach cross-section data (vertical distance from bottom vs. width) [BLASRoute]

Streams.in - reach data including to_reach, length, type, manning n, etc. [BLASRoute]

Structures.in - type, dimensions, elevations and operating parameters for water control structures [BLASRoute]

Unique.bnz - unique soil/land use combinations [BUCShell]

StreamPointSource.in - point source water quality and flow time series data [BLASRoute]

lucode.asc - grid of land use codes [BLASRoute]

soilgrid.asc - grid of soil codes [BLASRoute]

rainzone.asc - grid of Thiessen rainfall zones [BLASRoute]

utilzone.asc - grid of wastewater treatment utility areas [BLASRoute]

unique.asc - grid of unique soil/land use combinations (used in older versions) [BLASRoute]

cellDist1.asc - grid of distance from land cell to closest stream reach [BLASRoute]

cellDist2.asc - grid of distance from land cell to closest wetland [BLASRoute]

cellDist3.asc - grid of distance from land cell to closest depression [BLASRoute]

cellDist5.asc - grid of distance from wetland to closest stream reach [BLASRoute]

cellDist6.asc - grid of distance from depression to closest stream reach [BLASRoute]

cellDist7.asc - grid of distance from groundwater cell to closest stream reach [BLASRoute]

landusecode.asc - grid of land use codes for calculating attenuation of surface flow [BLASRoute]

WetLandUsecode.asc - grid of land use codes for wetlands for calculating attenuation of surface flow [BLASRoute]

DepressUsecode.asc - grid of land use codes for depressions for calculating attenuation of surface flow [BLASRoute]

StreamNode.asc - grid of stream reach closest to land cell [BLASRoute]

WetlandNode.asc - grid of wetland closest to land cell [BLASRoute]

DepressNode.asc - grid of depression closest to land cell [BLASRoute]

GWNode.asc - grid of stream reach closest to groundwater cell [BLASRoute]

(Mytyk and Kaplan, 2005)

Day Files

A day file is created by BUCSHELL for every unique combination of soil, wastewater utility zone, land use and rainfall zone. There is a record for every day for which the model is run. The file is populated with loadings in kilograms per hectare for all nutrients for both runoff and percolation. In addition, the amount of runoff and percolation in centimeters is recorded. The day files are populated with flow and nutrient data based on the field model results. The field model uses the values from the parameters defined in all of the input parameter files to produce the model results. The day files are used by another sub program, BLASRoute to accumulate the flow and nutrient variables for the reaches and the flow moving through the depressions. This information is then output into the various spatial data and spreadsheets.

Day files can also be used to calculate specific sources of particular nutrients. For, instance, this file is for a low density residential land use on septic. For days with no runoff, the nitrogen loadings could only come from septic tank loadings. In order to calculate the loading of total N from septic tanks, the sum of Perc NO₃, Perc NH₄, and Perc Org N for one record, multiplied by the number of hectares for the land use, divided by the number of people (human density * area) yields a very good estimate of Total N from septic tanks for that land use.

The naming convention for the day files is Day_utilzone#_rainzone#_lucode#_soil#.csv , and represents the daily output for each unique combination

Part 4 Model Output

4.1.1 Default Model Output

WAM output comes in 2 forms: raster grids and Excel spreadsheets. The raster grid output is stored as both binary grid data sets that can be viewed and analyzed in a GIS system and as ASCII grid data sets that are used by WAM for running scenario modifications through the WAM View interface. In addition grid data sets for percolation and runoff (in average centimeters per year) are written out as floating point ASCII grid data sets. The user can restore these data outputs to binary grids using GIS software. The spatial data output by WAM is given below. The .asc file name extension indicate the ASCII grids. The binary grids do not have this extension.

- Runoff leaving each land cell
- Percolate leaving each land cell
- Soluble N leaving each land cell
- Sediment N leaving each land cell
- Soluble P leaving each land cell
- Sediment P leaving each land cell
- Soluble N from land cell reaching stream.
- Sediment N from land cell reaching stream.
- Soluble P from land cell reaching stream.
- Sediment P from land cell reaching stream.
- Soluble N from land cell removed by wetlands.
- Soluble P from land cell removed by wetlands.
- Sediment N from land cell removed by wetlands.
- Sediment P from land cell removed by wetlands.
- Total suspended solids leaving each land cell.
- Total suspended solids from land cell reaching stream.
- Subsurface soluble N from land cell.

Two spreadsheet files are output for each stream reach. The first type is named Reach#####.csv, where ##### is the reach connectivity numbers assigned by the user during setup. These files contain daily outputs for stage (in meters), depth (in meters), velocity (meters per second), flow (cubic meters), total suspended solids (ppm), soluble nitrate (ppm) soluble ammonia (ppm), soluble organic nitrate (ppm), soluble phosphorous (ppm), sediment ammonia (ppm), sediment organic nitrate (ppm), sediment phosphorous (ppm), and biological oxygen demand (ppm). There is a record in the spreadsheet for each day

The second spreadsheet file is named Reach#####NPS.csv where ##### is the reach connectivity numbers assigned by the user during setup and NPD is non point source. These files contain daily outputs for surface flow (cubic meters per day), total suspended solids (grams per day), surface soluble nitrate (grams per day), surface soluble ammonia (grams per day), surface soluble organic nitrate (grams per day), surface soluble phosphorous (grams per day), surface sediment ammonia (grams per day), surface sediment organic nitrate (grams per day), surface sediment phosphorous (grams per day), surface biological oxygen demand (grams per day), groundwater flow (cubic meters), groundwater soluble nitrate (grams per day), groundwater soluble ammonia (grams per day), groundwater soluble organic nitrate (grams per day), and groundwater soluble phosphorous (grams per day).

Maps of the spatial output and examples of the spreadsheet output are provided below. Data showing actual groundwater loadings from the land surface and rainfall is calculated only for soluble nitrate, (grid data set GwNcel). SWET is planning to add groundwater loadings for additional nutrients in the ArcGIS release (Jacobson, 2006).

4.1.2 Geospatial Output Data

The geospatial datasets provide the most important model output for the Woodville Study. This data shows the spatial distribution of nutrient loadings from the land surface and the model computes the estimated groundwater loadings of soluble nitrate from the land cell. In this regard, the model provides the capability to evaluate the impact of land use on groundwater quality.

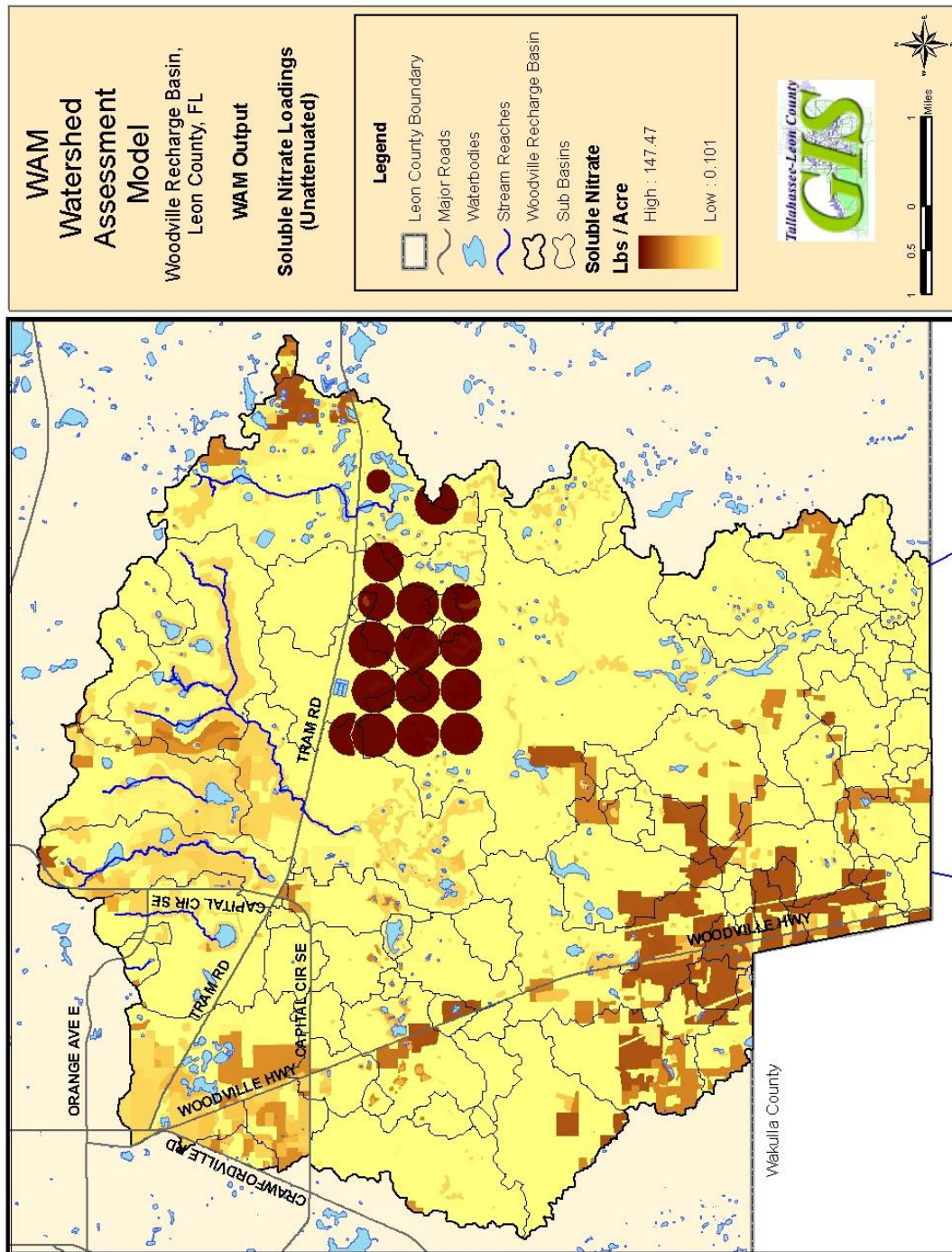


Figure 4.1.2.1: Soluble Nitrate leaving land cell (Lbs/Acre/Yr)

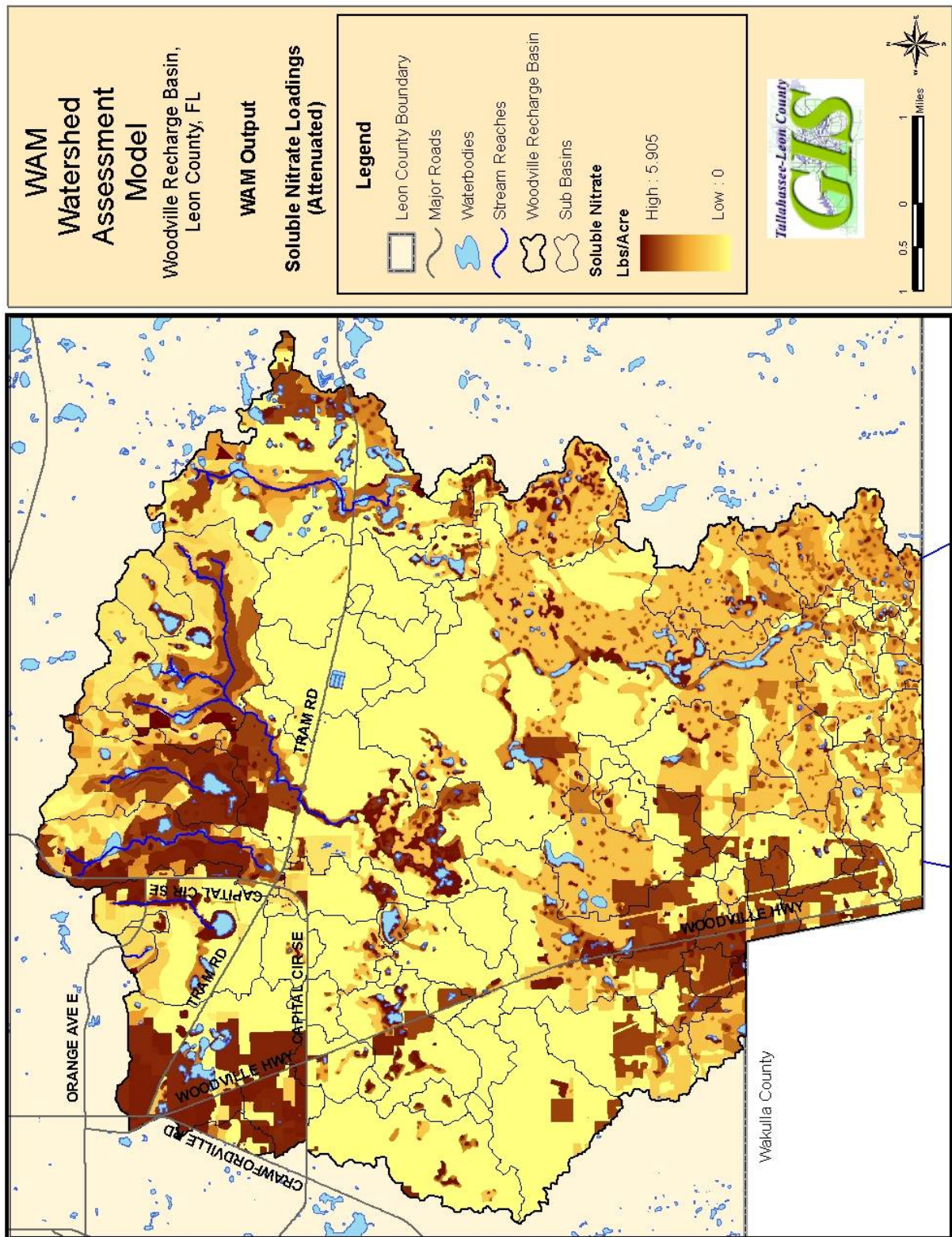


Figure 4.1.2.2: Soluble Nitrate reaching stream (Lbs/Acre/Yr)

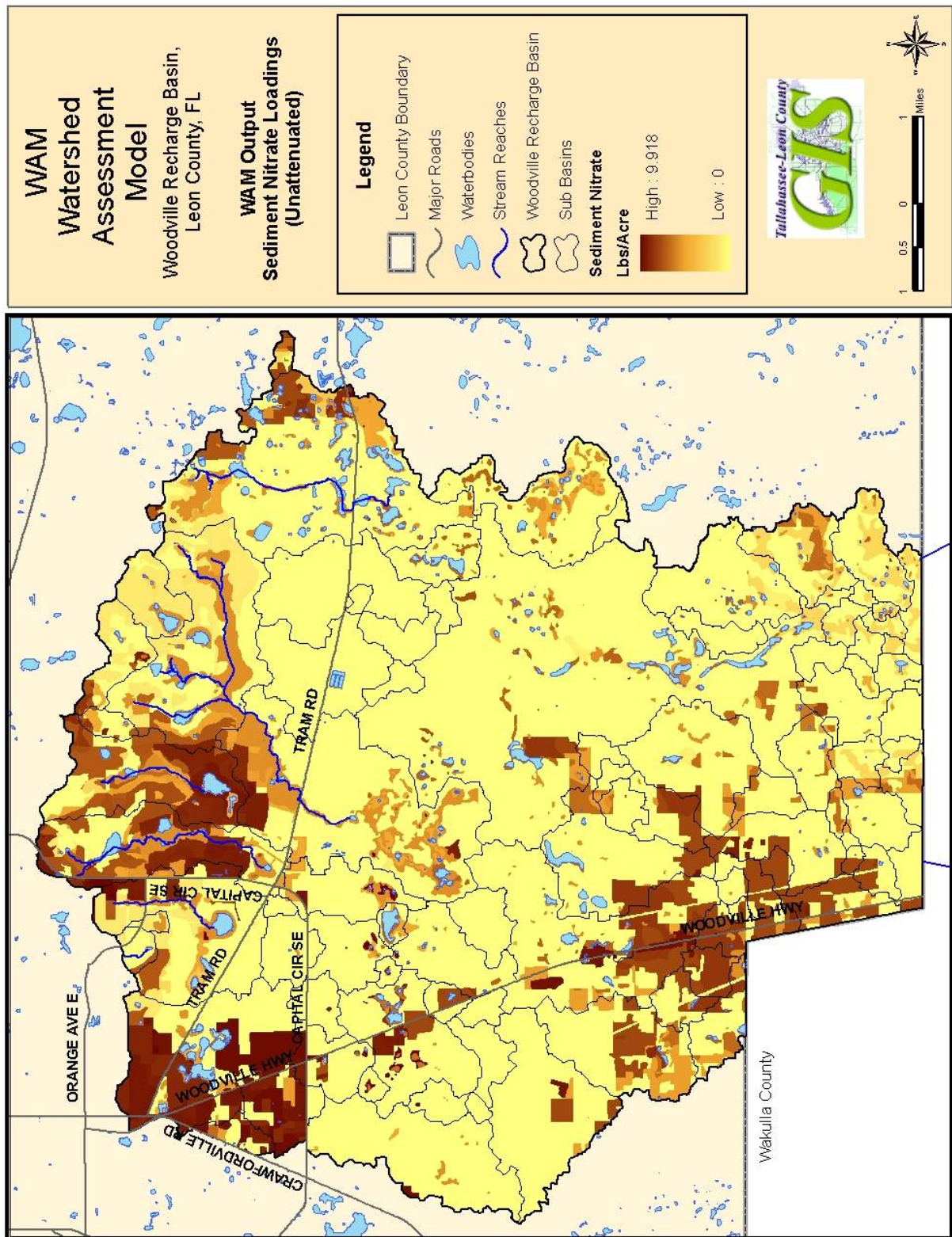


Figure 4.1.2.3: Sediment Nitrate leaving land cell (Lbs/Acre/Yr)

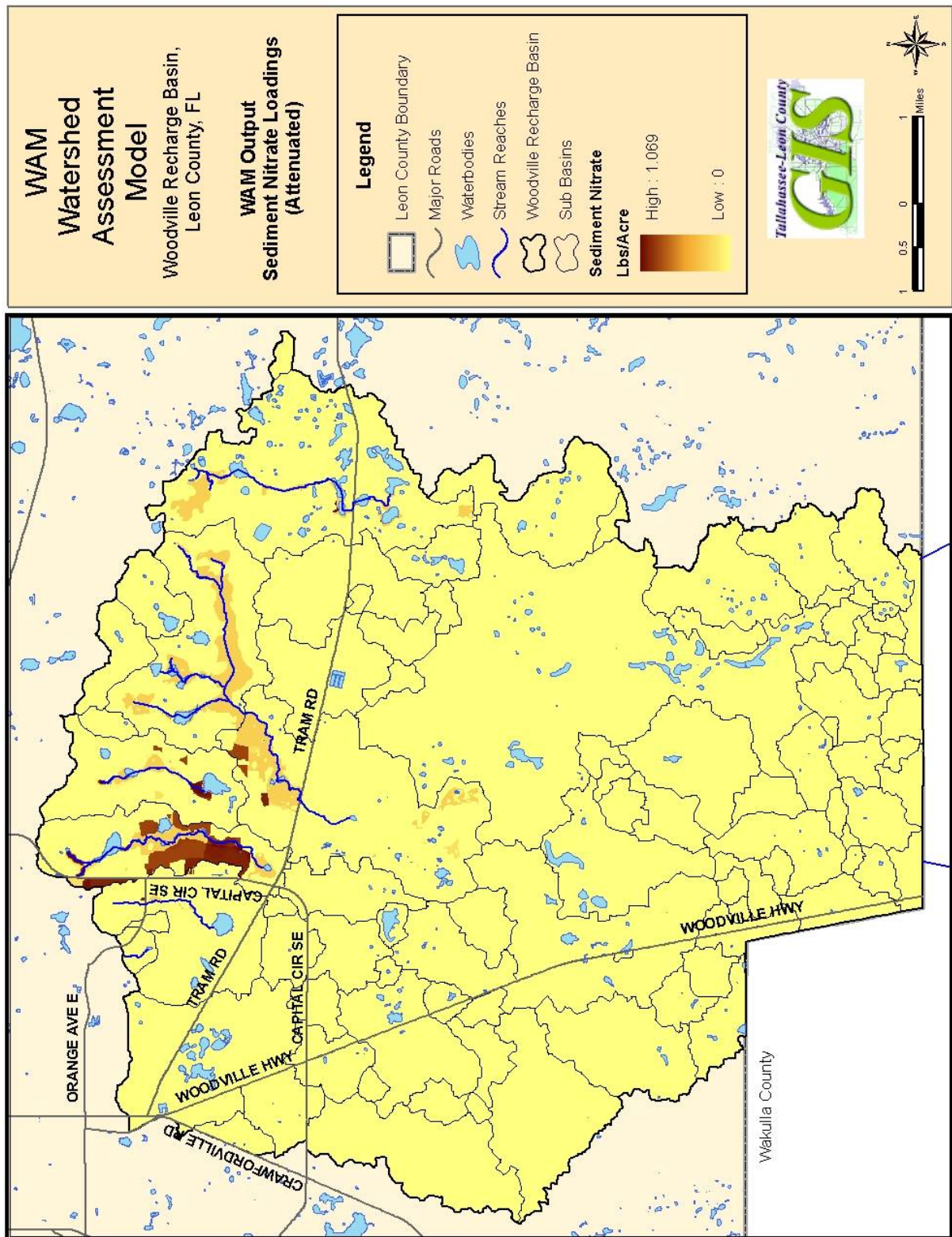


Figure 4.1.2.4: Sediment Nitrate reaching stream (Lbs/Acre/Yr)

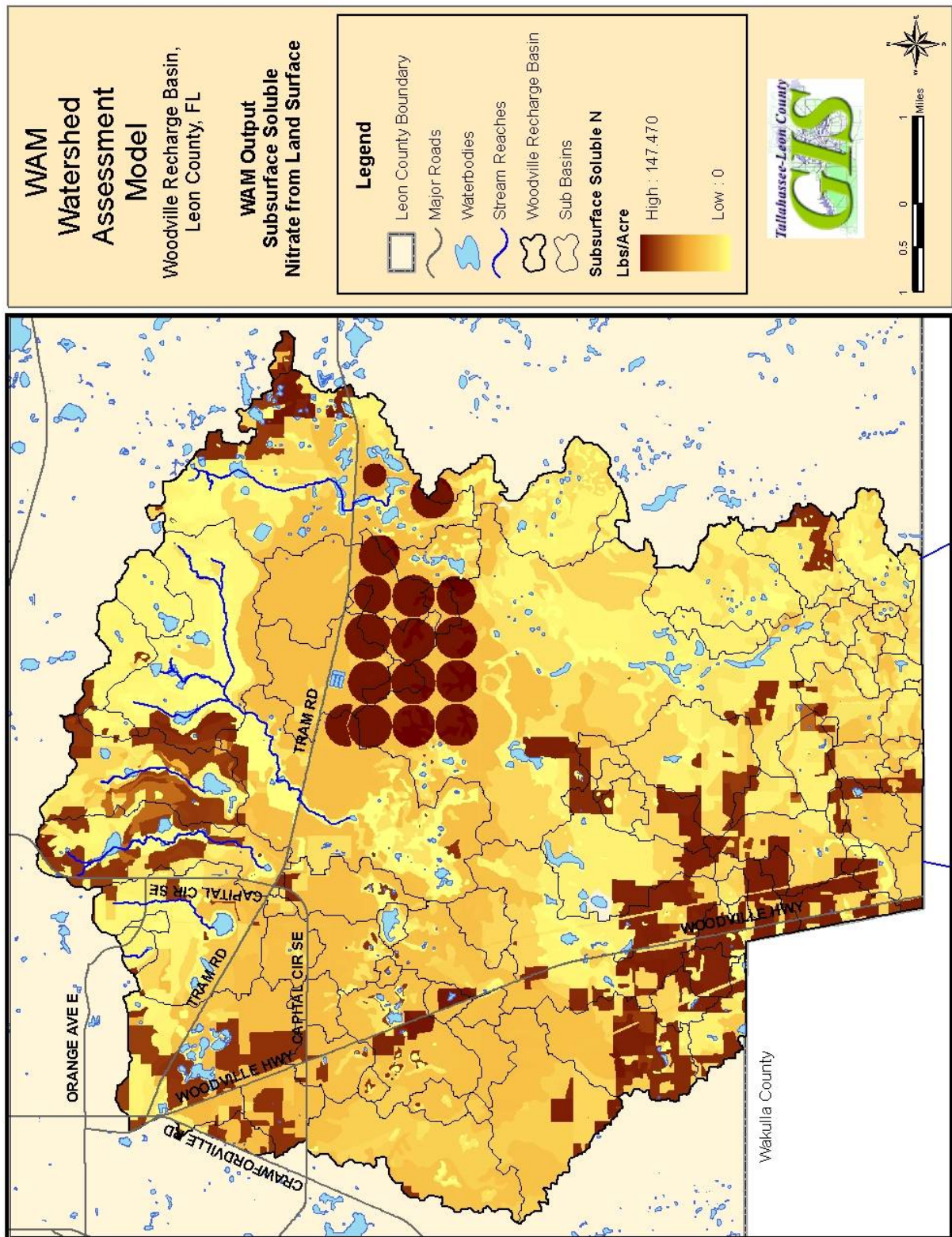


Figure 4.1.2.5: Subsurface soluble nitrate from land cell (Lbs/Acre/Yr)

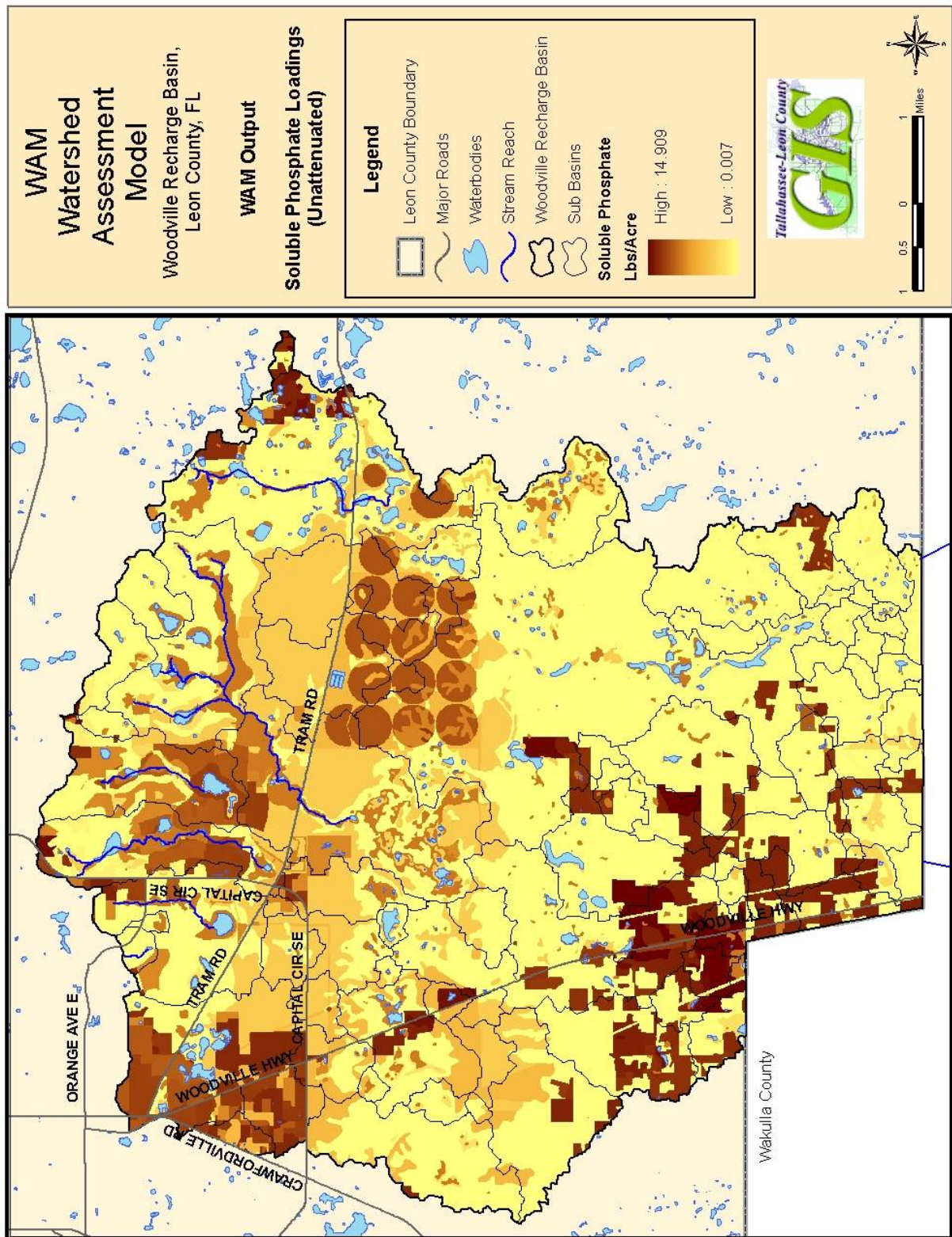


Figure 4.1.2.6: Soluble Phosphorous leaving land cell (Lbs/Acre/Yr)

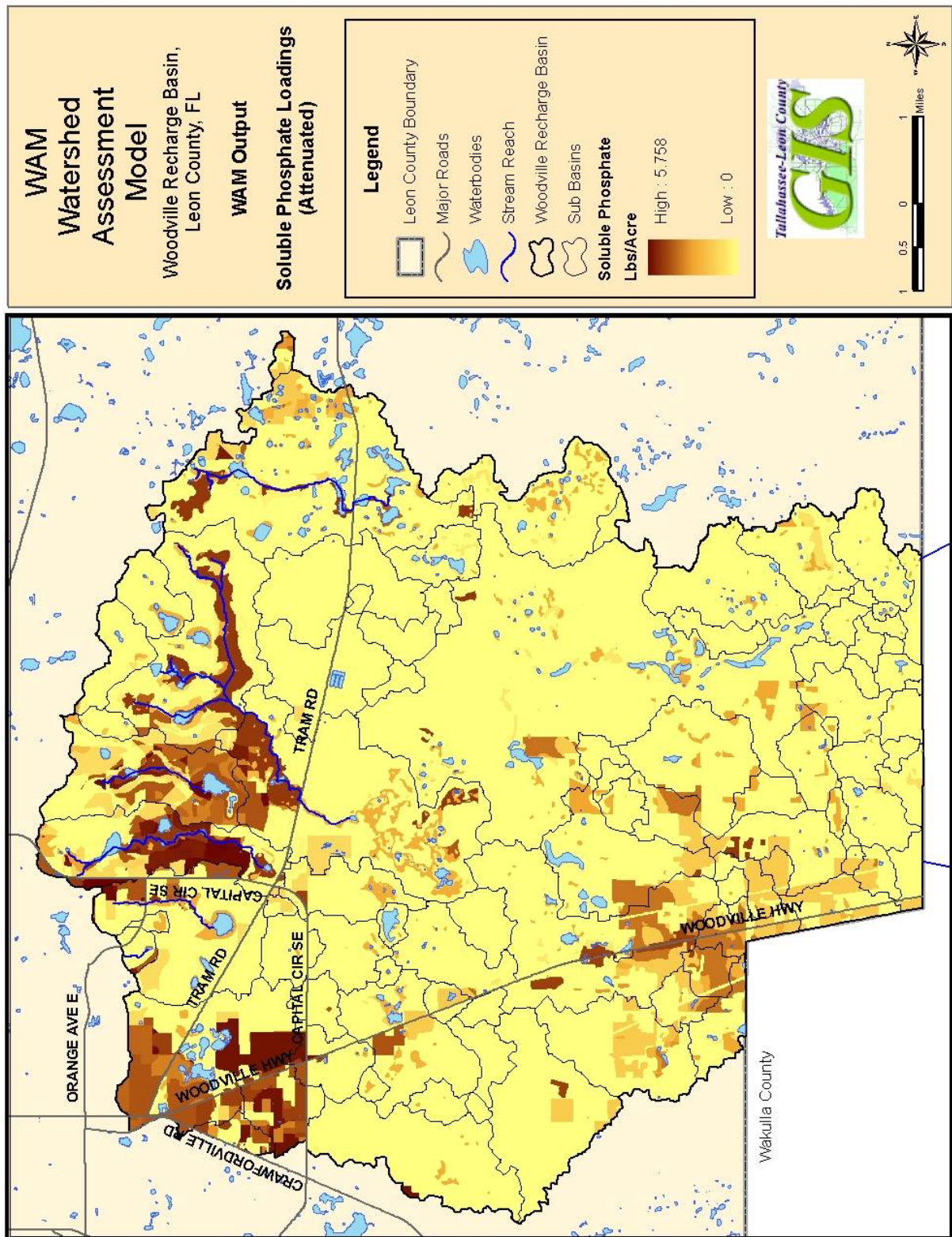
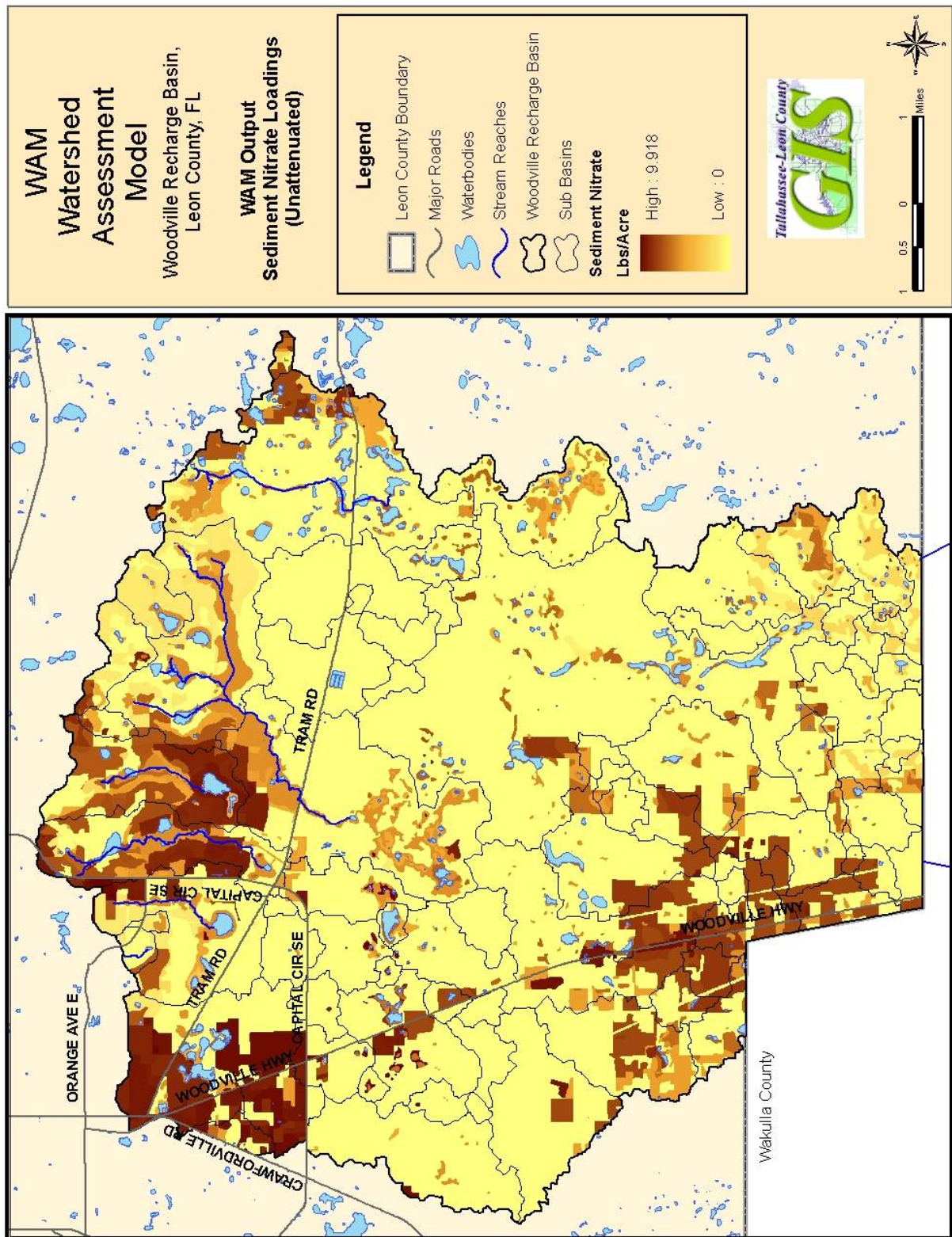


Figure 4.1.2.7: Soluble Phosphorous reaching stream (Lbs/Acre/Yr)



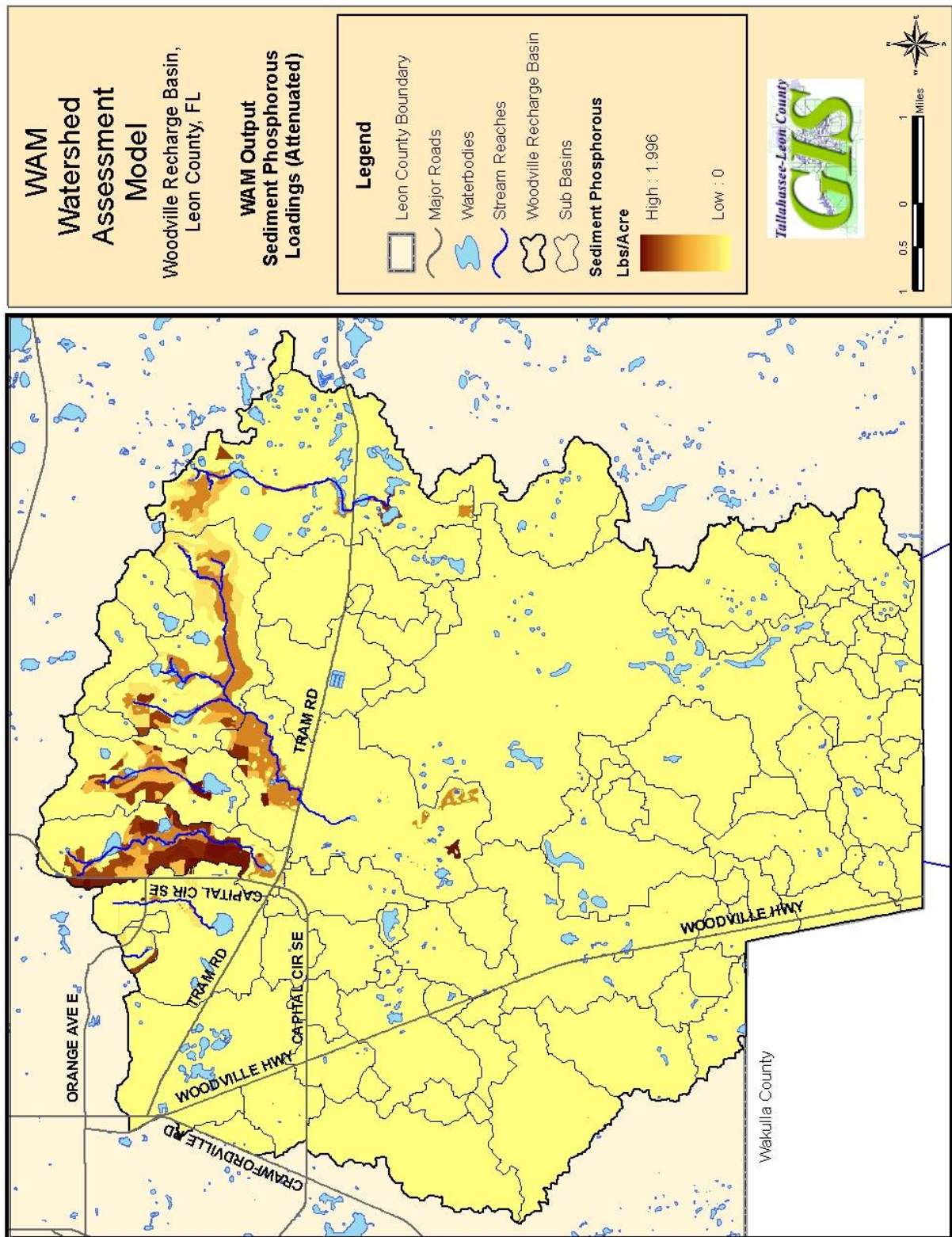
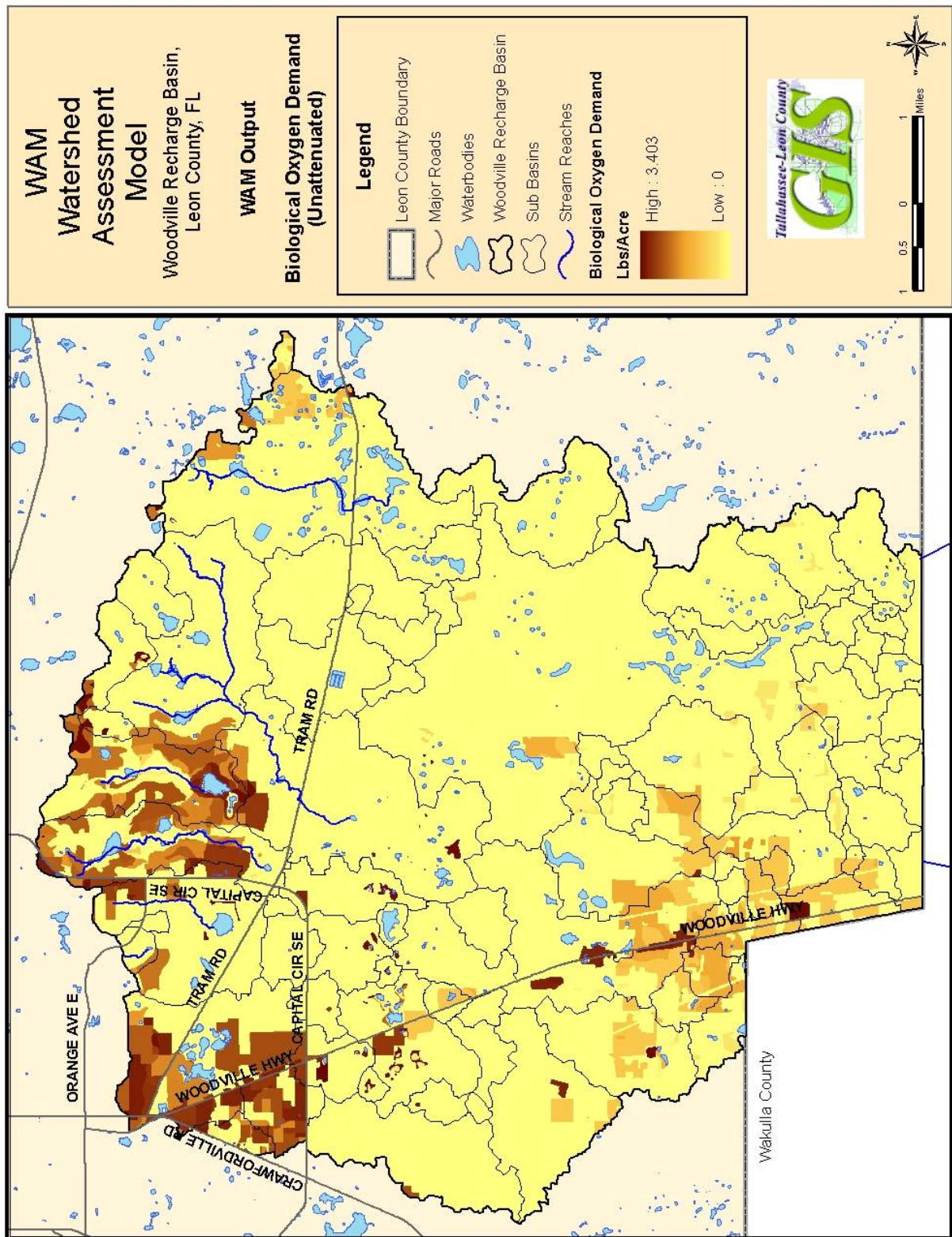


Figure 4.1.2.9: Sediment Phosphorous reaching stream (Lbs/Acre/Yr)



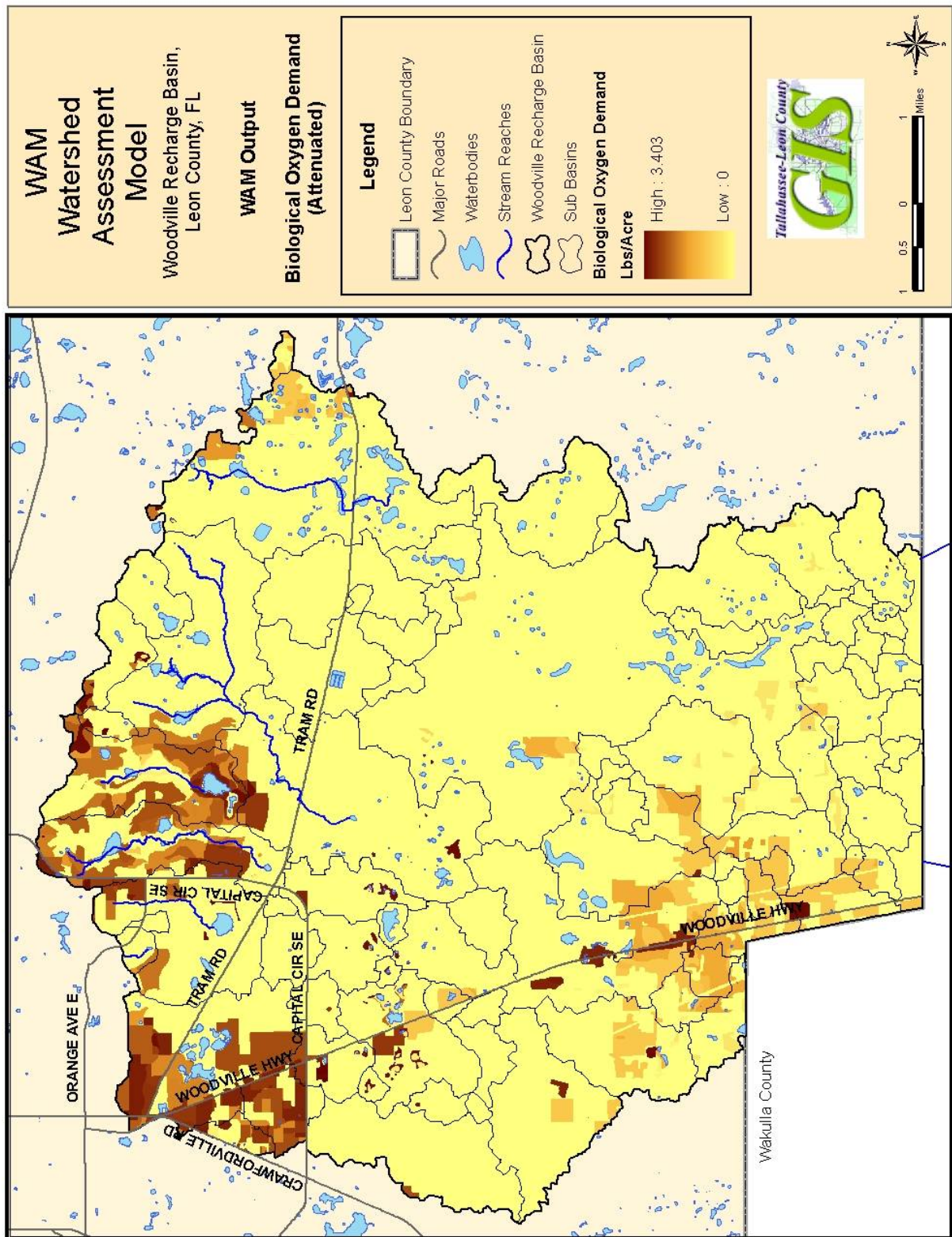


Figure 4.1.2.11: Biological Oxygen Demand reaching stream (Lbs/Acre/Yr)

Part 5 Deliverables

Deliverable 7.1 Groundwater soluble nitrate from the SESF

The rainzone for the SESF covers the pivots for the facility. This rainzone was used to clip the groundwater soluble nitrate grid. The deliverables include a location map of the sprayfield and a zoomed-in map of the groundwater nitrate loadings and a WAM spreadsheet of summary loadings by land use.

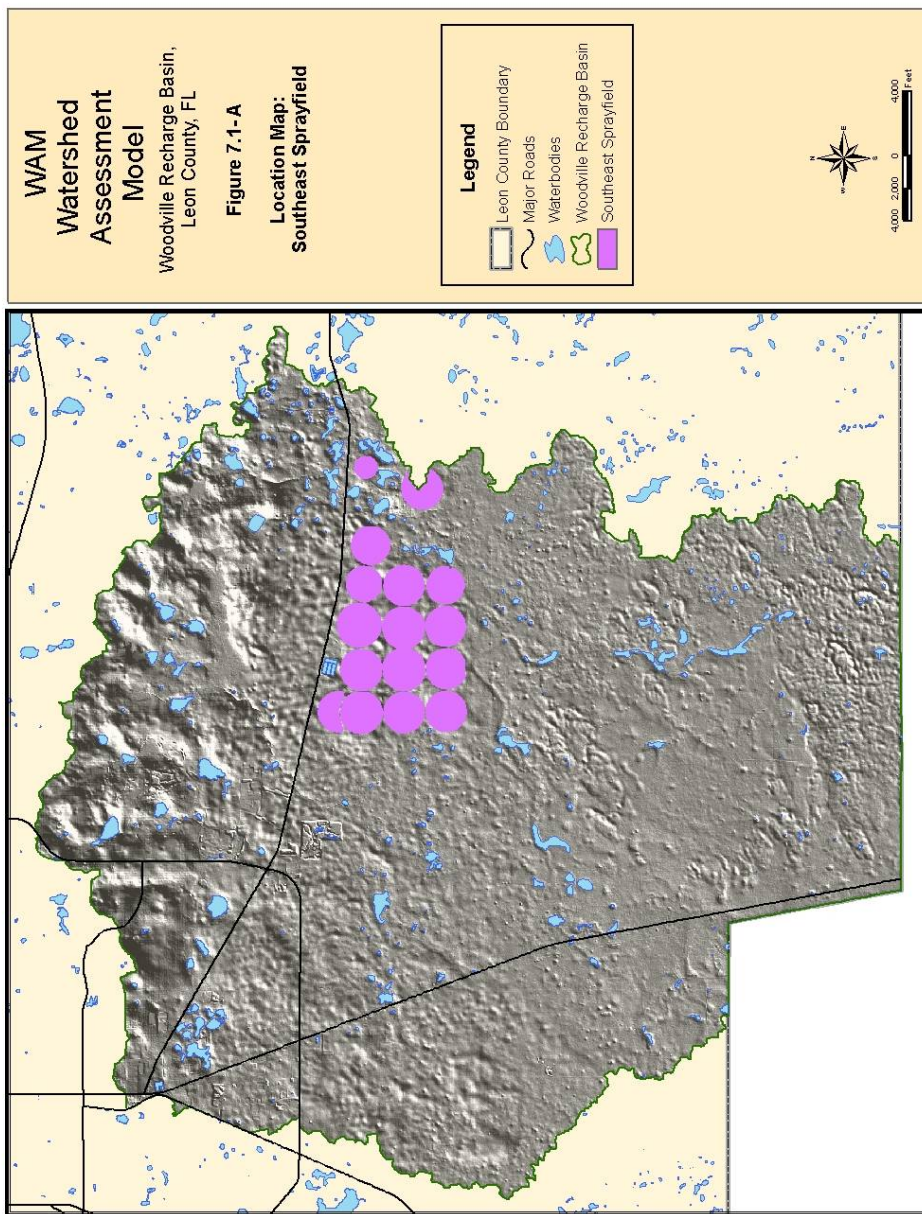


Figure 5.1: Location map of the City of Tallahassee Southeast Sprayfield

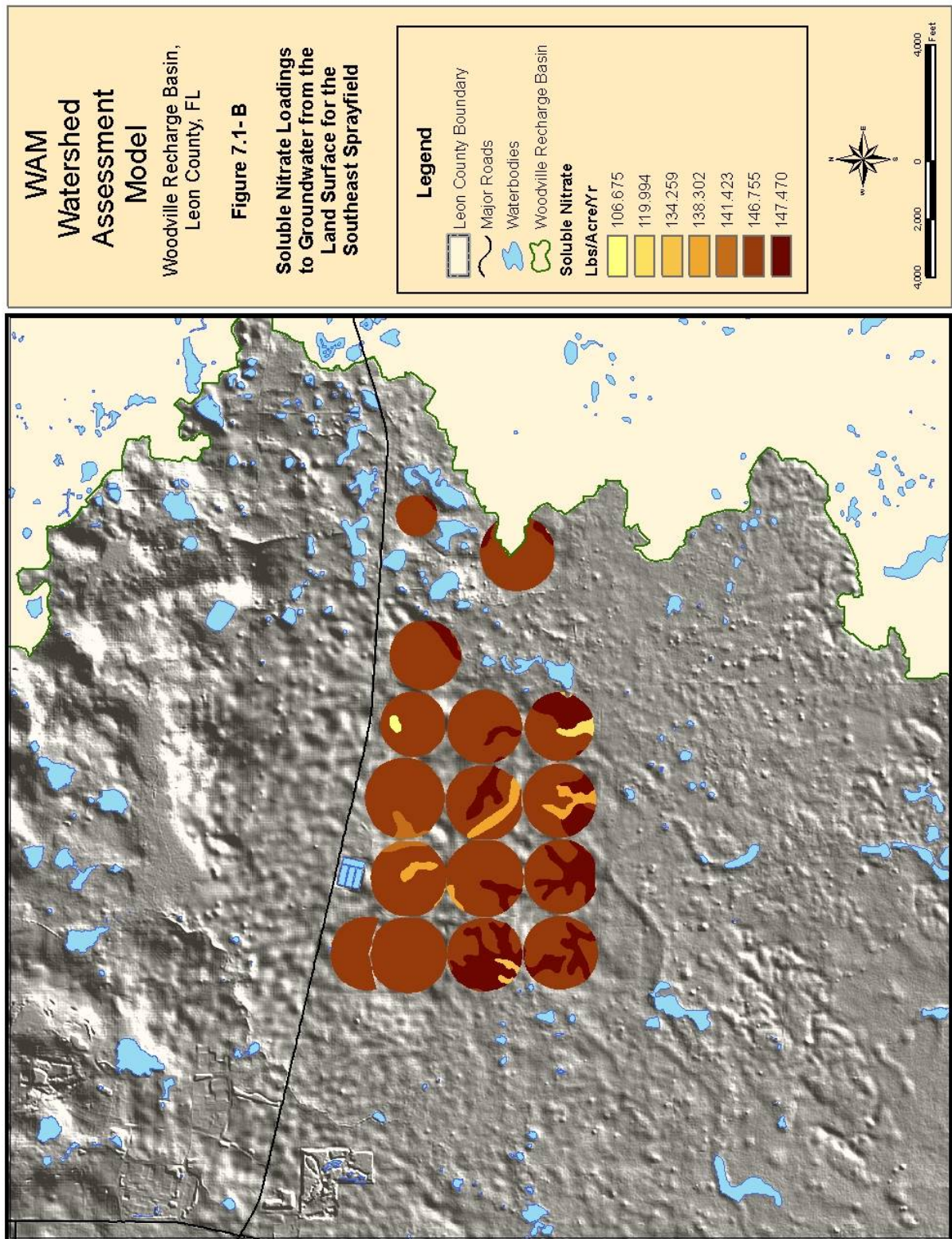


Figure 5.2: Soluble nitrate loadings to groundwater from the land surface for the SESF

Table 5.1 Groundwater nitrate from the land surface by land use

Land Use	Area (Ha)	GW NO3 (Kg/Ha/Yr)	Total GW NO3 (Kg/Yr)
Low Density Residential	552	20.961	11560.2
Commercial and Services	361	0.331	119.8
Rural Land in Transition	249	1.137	283.4
Scrub and Brushland	2585	0.412	1066.4
Hardwood Conifer Mixed	816	0.143	117.0
Coniferous Plantations	8548	0.312	2667.1
Open Water	186	0.000	0.0
Cypress	246	0.000	0.0
Wetland Forested Mixed	763	0.000	0.0
Freshwater Marshes	108	0.000	0.0
Barren Land	97	8.249	796.4
Medium Density Residential	917	75.117	68871.2
High Density Residential	511	4.621	2360.2
Industrial	76	15.926	1213.7
Managed Landscape	99	1.839	181.7
Improved Pasture	77	21.726	1671.8
Unimproved Pasture	102	5.145	523.6
Undeveloped Urban Land	74	0.302	22.5
Prisons	12	2.656	30.6
Mining	93	0.250	23.1
Municipal Sprayfield	705	146.279	103186.7

Soluble Nitrate Loadings to the Land Surface at the SESF: 937.2 Kg / Yr

Soluble Nitrate Loadings Attenuated at the SESF: 255.8 Kg / Yr

Percent Attenuation at the SESF: 27.3 %

Deliverable 7.2 Impacts to Groundwater due to Treatment Plant Residuals

There are no residuals disposed of in the Woodville Recharge Basin. 30 sites were investigated where the application of residuals were reported in the WRB but all proved to be false.

Deliverable 7.3 Soluble Nitrate to Groundwater from Residential Septic Tanks

The utility zone data was used to erase all the land uses from the land use grid that fall inside the wastewater service area. The residential land uses were extracted from the remaining data and copied to a separate grid. Using the day file from low density residential on septic, the records for which there was no runoff were selected. For those days there was a nominal perc rate (in kilograms per day) of 0.002173 for soluble NO₃, 0.010865 for soluble ammonia, and 0.04346 for soluble organic nitrate. Adding these three figures gives a total daily load of 0.056498 (kg/day) for this land use. The population density for this land use is 4.1. Dividing 0.056498 / 4.1 = 0.01378 kg /person/day of total N. Total N is used because of nitrification in the soil, (Bottcher, 2006). The total population for each land use category was computed by multiplying population density by the load per person per day. The total loading was computed by multiplying this figure for each land use by the area (hectares) for each land use and summing them. This result was multiplied by 365 days per year to get an annual total for each land use. The results are presented in the table below. The low value for mobile homes is an artifact of the land use classification. Most of the low and medium density

residential is mobile homes.

Septic Tank Loadings (Total N)

Landuse	Loading (Person/Day)	Density	Hectares	Population	TNPerDay (KG)	TNPerYr (KG)	
Residential, low density	0.01378	4.1	504.16	2067	28.484	10396.672	
Residential, medium density	0.01378	14.4	905.36	13037	179.652	65573.124	
Mobile home units, medium density	0.01378	14.4	4.38	63	0.869	317.233	
Residential, high density	0.01378	49.0	172.54	8454	116.502	42523.397	
							118810.427 Total N (Unattenuated)
							95048.341 Total N (Attenuated)

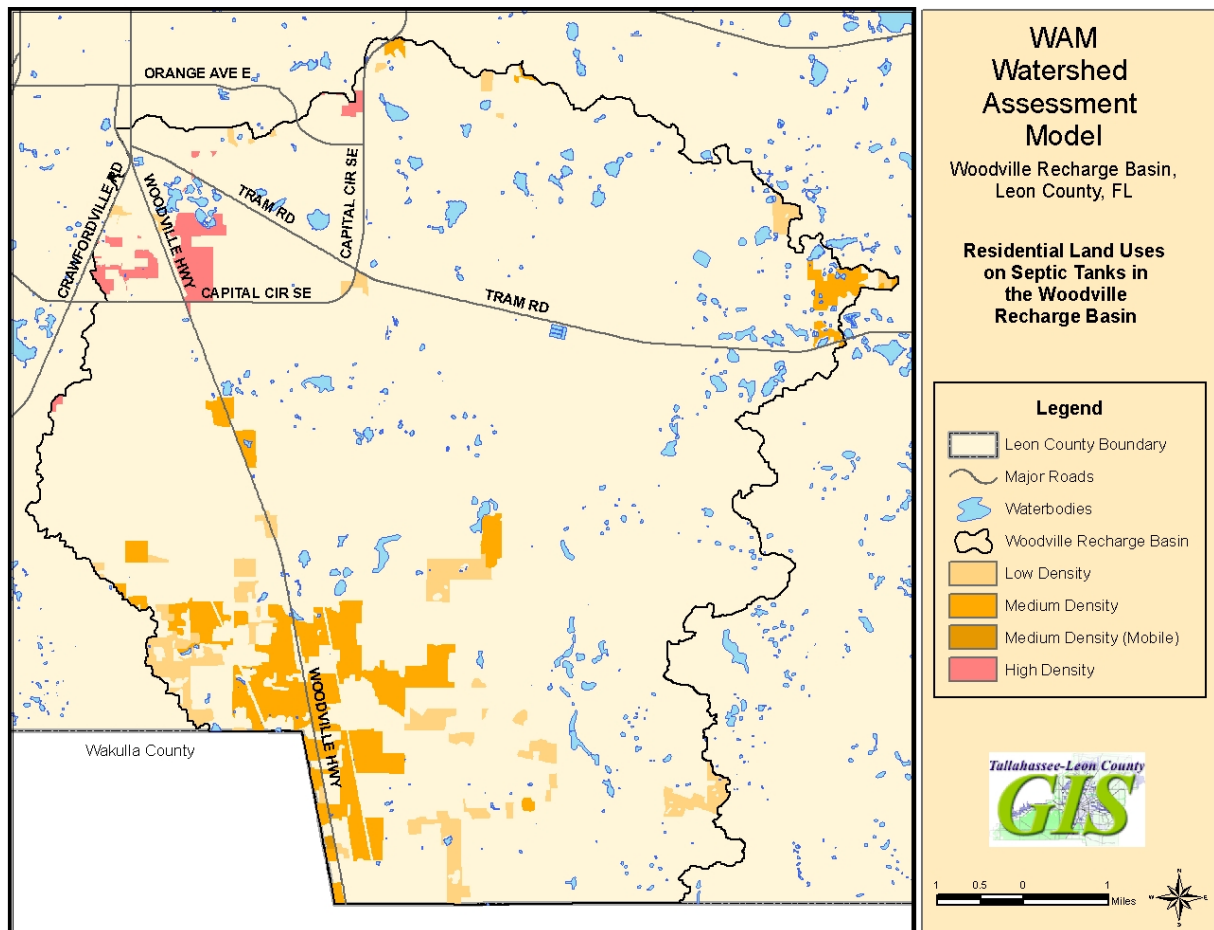


Figure 5.3 Residential Land Uses in the Woodville Recharge Basin on Septic Tanks

Deliverable 7.4: Soluble Nitrate Percolation to the Aquifer

WAM calculates percolation (annual average in centimeters) and outputs a grid. Since the cell size is 10 meters, each cell is 0.01 hectares. The area in hectares was computed by # Cells / 100. The rainfall concentration of soluble nitrate (0.61 ppm) was used to estimate the runoff concentration.

Soluble N by Percolation (kg/yr) = (perc (cm) * area (ha)) * 0.61 ppm / 10

The loading to the groundwater basin-wide of soluble nitrate by direct percolation is 54445.3 Kg/Yr).

Table 5.2: Stormwater pollutants to the aquifer due to direct groundwater percolation

PERC (CM/YR)	NUMBER OF CELLS	AREA (HA)	NO3 (KG/YR)
0	135312	1353.1	0.00
4	3198	32.0	7.80
5	15764	157.6	48.08
7	455	4.6	1.94
9	899	9.0	4.94
10	17217	172.2	105.02
11	22475	224.8	150.81
12	614	6.1	4.49
13	6494	64.9	51.50
14	44	0.4	0.38
15	12794	127.9	117.07
17	5190	51.9	53.82
18	12094	120.9	132.79
20	32417	324.2	395.49
21	3527	35.3	45.18
22	5220	52.2	70.05
23	52702	527.0	739.41
24	2903	29.0	42.50
25	122923	1229.2	1874.58
26	67382	673.8	1068.68
27	3976	39.8	65.48
28	251	2.5	4.29
29	632	6.3	11.18
30	1987	19.9	36.36
31	4760	47.6	90.01
32	279	2.8	5.45
33	817	8.2	16.45
34	2625	26.3	54.44
35	14526	145.3	310.13
36	69338	693.4	1522.66
37	149204	1492.0	3367.53
38	18103	181.0	419.63
39	6031	60.3	143.48
40	29605	296.1	722.36
41	60095	601.0	1502.98
42	20491	204.9	524.98
43	51	0.5	1.34
44	451	4.5	12.10
45	6116	61.2	167.88

Table 5.2 Continued

PERC (CM/YR)	NUMBER OF CELLS	AREA (HA)	NO3 (KG/YR)
46	3751	37.5	105.25
47	21847	218.5	626.35
48	5015	50.2	146.84
49	33119	331.2	989.93
50	120218	1202.2	3666.65
53	58818	588.2	1901.59
55	188204	1882.0	6314.24
56	8765	87.7	299.41
57	7559	75.6	262.83
58	7047	70.5	249.32
59	4002	40.0	144.03
60	74137	741.4	2713.41
61	1828	18.3	68.02
62	501	5.0	18.95
63	3211	32.1	123.40
64	75051	750.5	2929.99
65	24135	241.4	956.95
66	1491	14.9	60.03
67	27149	271.5	1109.58
68	119	1.2	4.94
69	264	2.6	11.11
70	2119	21.2	90.48
71	10984	109.8	475.72
72	5634	56.3	247.45
73	6481	64.8	288.60
74	11393	113.9	514.28
75	795	8.0	36.37
76	634	6.3	29.39
77	106	1.1	4.98
78	21553	215.5	1025.49
81	4711	47.1	232.77
82	2117	21.2	105.89
83	1474	14.7	74.63
86	2569	25.7	134.77
87	341	3.4	18.10
88	3020	30.2	162.11
315	389	3.9	74.75
317	272	2.7	52.60
334	161	1.6	32.80
335	69719	697.2	14247.08

Deliverable 7.5: Soluble Nitrate to Groundwater via Runoff into Open Sinks versus Soil-filled Depressions

WAM calculates runoff (annual average in centimeters) and outputs a grid. The drainage catchments for the open sinks were identified and converted to a grid. This data was used as a mask to isolate the runoff cell that fell within the catchments. The drainage area for sinkholes is usually small. Also there is no runoff value for open water surface. Consequently, only 26.25 hectares drain into open sinks. 17170 hectares drains into soil-filled depressions.

For drainage to open sinks

Groundwater soluble N by runoff (kg/yr) = (runoff (cm) * area (ha)) * 0.61 ppm / 10

Groundwater soluble N by runoff (kg/yr) to opens sinks = 4.52 kg/yr

**** Note:** Since the catchments for the sinks have steep slopes, attenuation should not be a factor. Thus the unattenuated loading was used.

For drainage to soil-filled depressions

Groundwater soluble N by runoff (kg/yr) = ((runoff (cm) * area (ha)) * 0.61 ppm / 10) * 0.8 (GW attenuation)

Groundwater soluble N by runoff (kg/yr) to soil-filled depressions: 9739.1 kg/yr

The results are given in Tables 5.3 and 5.4

Table 5.3: stormwater pollutants flowing to open karst features

RUNOFF (CM/YR)	AREA (HA/100)	AREA (HA)	NO3 (KG/YR)
0	1976	19.76	0.00
3	481	4.81	0.88
9	7	0.07	0.04
25	64	0.64	0.98
42	94	0.94	2.41
116	3	0.03	0.21

Table 5.4: stormwater pollutants flowing to closed karst depressions

RUNOFF (CM/YR)	AREA (HA/100)	AREA (HA)	NO3 (KG/YR)
0	806900	8069.00	0.00
1	84205	842.05	51.37
2	9535	95.35	11.63
3	321450	3214.50	588.25
4	18912	189.12	46.15
5	17128	171.28	52.24
6	15930	159.30	58.30
7	45092	450.92	192.54
8	15877	158.77	77.48
9	24866	248.66	136.51
10	4447	44.47	27.13
11	9800	98.00	65.76
12	729	7.29	5.34
13	4537	45.37	35.98
14	548	5.48	4.68
15	347	3.47	3.18
16	389	3.89	3.80
21	9303	93.03	119.17
22	312	3.12	4.19
25	59079	590.79	900.95
27	4985	49.85	82.10
28	1387	13.87	23.69
29	26070	260.70	461.18
30	25	0.25	0.46
31	19522	195.22	369.16
32	63	0.63	1.23
35	132	1.32	2.82
39	1169	11.69	27.81
40	61	0.61	1.49
41	587	5.87	14.68
42	111567	1115.67	2858.35
45	2462	24.62	67.58
55	14941	149.41	501.27
56	13729	137.29	468.98
57	223	2.23	7.75
58	4019	40.19	142.19

Table 5.4: continued

RUNOFF (CM/YR)	AREA (HA/100)	AREA (HA)	NO3 (KG/YR)
59	817	8.17	29.40
102	15521	155.21	965.72
103	1700	17.00	106.81
116	14023	140.23	992.27
117	10580	105.80	755.09
118	4219	42.19	303.68
126	12091	120.91	929.31
127	2633	26.33	203.98
131	92	0.92	7.35
139	220	2.20	18.65
140	113	1.13	9.65
148	4	0.04	0.36
152	4666	46.66	432.63
178	33	0.33	3.58

Deliverable 7.6: Soluble Nitrate to Groundwater by Land Use

This is one of the default tables output by WAM. Table 5.5 shows the land uses in the Woodville Recharge Basin in ascending order. The surface loadings results are given in Table 5.6. Table 5.7 shows loadings to the groundwater from the land.

Table 5.5: Landuse in the WRB in ascending order

LAND_USE	AREA (HECTARES)
Coniferous Plantations	8548
Scrub and Brushland	2585
Medium Density Residential	917
Hardwood Conifer Mixed	816
Wetland Forested Mixed	763
Municipal Sprayfield	705
Low Density Residential	552
High Density Residential	511
Commercial and Services	361
Rural Land in Transition	249
Cypress	246
Open Water	186
Freshwater Marshes	108
Unimproved Pasture	102
Managed Landscape	99
Barren Land	97
Mining	93
Improved Pasture	77
Industrial	76
Undeveloped Urban Land	74
Prisons	12

Table 5.6: Nitrate loading to the surface in the WRB by Landuse.

LAND USE (surface-	AREA	MEAN Surface	TOTAL Surface
Coniferous Plantations	8563	0.493	4222.9
Scrub and Brushland	2586	0.506	1308.2
Medium Density Residential	917	76.519	70156.6
Hardwood Conifer Mixed	816	0.531	433.0
Wetland Forested Mixed	763	6.121	4668.1
Municipal Sprayfield	705	146.290	103194.4
Low Density Residential	552	21.323	11759.9
High Density Residential	511	10.656	5442.7
Commercial and Services	361	7.005	2532.1
Cypress	251	6.002	1509.0
Rural Land in Transition	249	1.398	348.4
Open Water	186	3.187	593.7
Freshwater Marshes	108	6.122	659.9
Unimproved Pasture	102	5.865	596.9
Managed Landscape	99	2.240	222.0
Barren Land	97	13.228	1277.2
Mining	93	1.309	121.1
Improved Pasture	77	22.162	1705.4
Industrial	76	21.795	1661.0
Undeveloped Urban Land	74	0.545	40.6
Prisons	12	8.572	98.7

Table 5.7: Soluble Nitrate to Groundwater by Land Use

Land Use	Area (Ha)	Mean GW NO3 (Kg/Ha/Yr)	Total GW NO3 (Kg/Yr)
Barren Land	97	8.249	796.4
Commercial and Services	361	0.331	119.8
Coniferous Plantations	8548	0.312	2667.1
Cypress	246	0.000	0.0
Freshwater Marshes	108	0.000	0.0
Hardwood Conifer Mixed	816	0.143	117.0
High Density Residential	511	4.621	2360.2
Improved Pasture	77	21.726	1671.8
Industrial	76	15.926	1213.7
Low Density Residential	552	20.961	11560.2
Managed Landscape	99	1.839	181.7
Medium Density Residential	917	75.117	68871.2
Mining	93	0.250	23.1
Municipal Sprayfield	705	146.279	103186.7
Open Water	186	0.000	0.0
Prisons	12	2.656	30.6
Rural Land in Transition	249	1.137	283.4
Scrub and Brushland	2585	0.412	1066.4
Undeveloped Urban Land	74	0.302	22.5
Unimproved Pasture	102	5.145	523.6
Wetland Forested Mixed	763	0.000	0.0

Table 5.8: The present removal of Nitrates by Landuse. The efficiency of removal of pollutants applied to the surface of a given Landuse.

LAND_USE (surface-nitrate)	Removal Efficiency
Wetland Forested Mixed	100.0%
Rural Land in Transition	100.0%
Open Water	100.0%
Freshwater Marshes	100.0%
Commercial and Services	95.3%
Cypress	81.2%
Mining	80.9%
Hardwood Conifer Mixed	73.0%
Prisons	69.0%
High Density Residential	56.6%
Undeveloped Urban Land	44.6%
Barren Land	37.6%
Coniferous Plantations	36.8%
Industrial	26.9%
Scrub and Brushland	18.5%
Managed Landscape	18.2%
Unimproved Pasture	12.3%
Improved Pasture	2.0%
Medium Density Residential	1.8%
Low Density Residential	1.7%
Municipal Sprayfield	0.0%

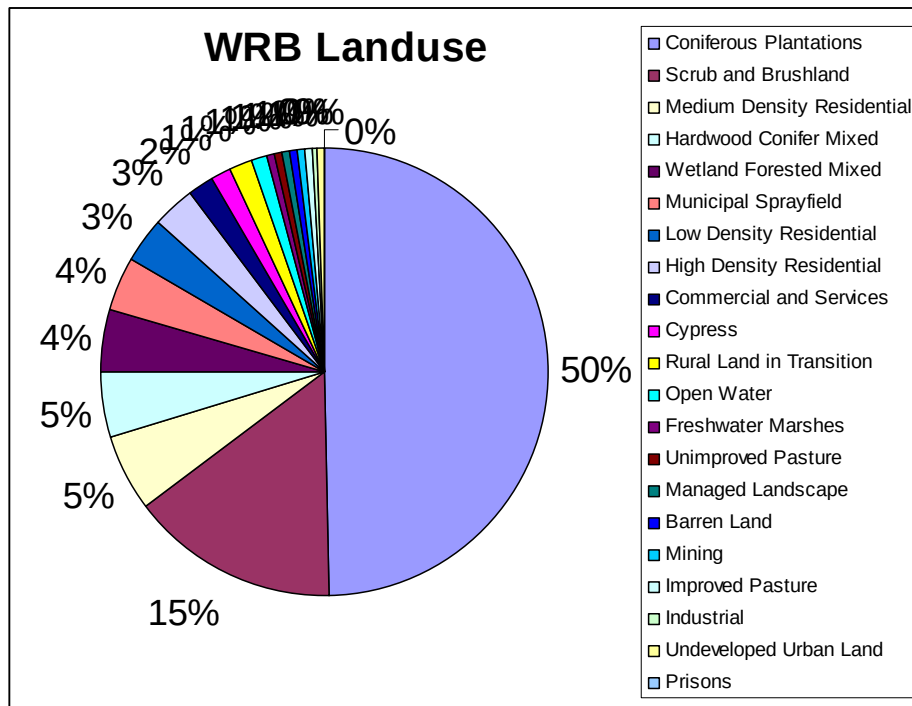


Figure 5.4: WRB Landuse (by Area)

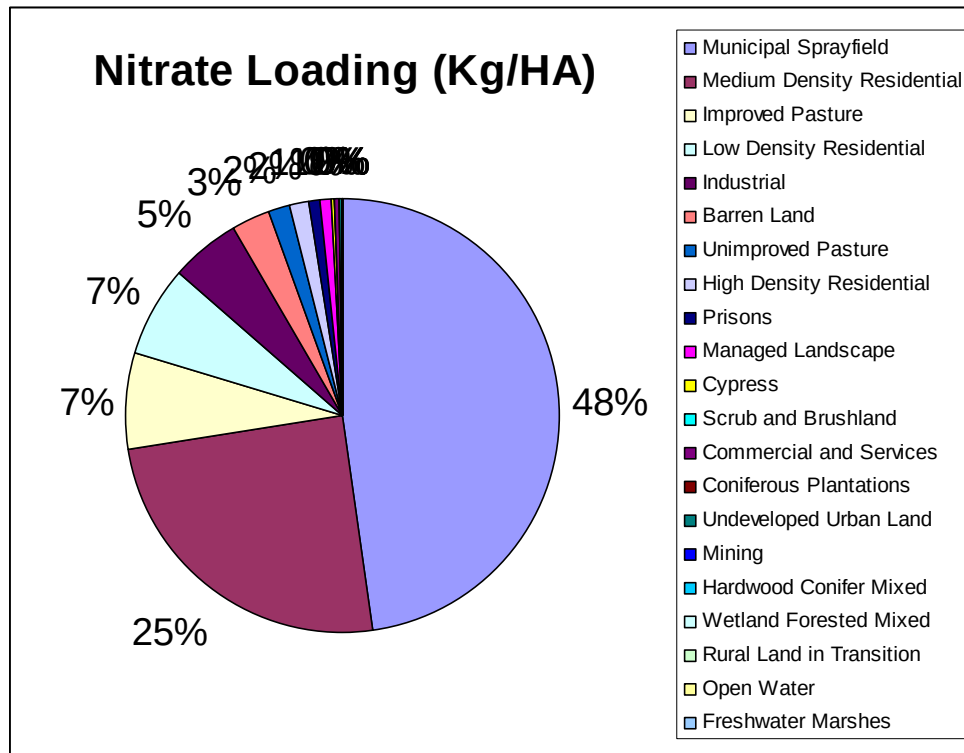


Figure 5.5: WRB Nitrate loadings per unit area

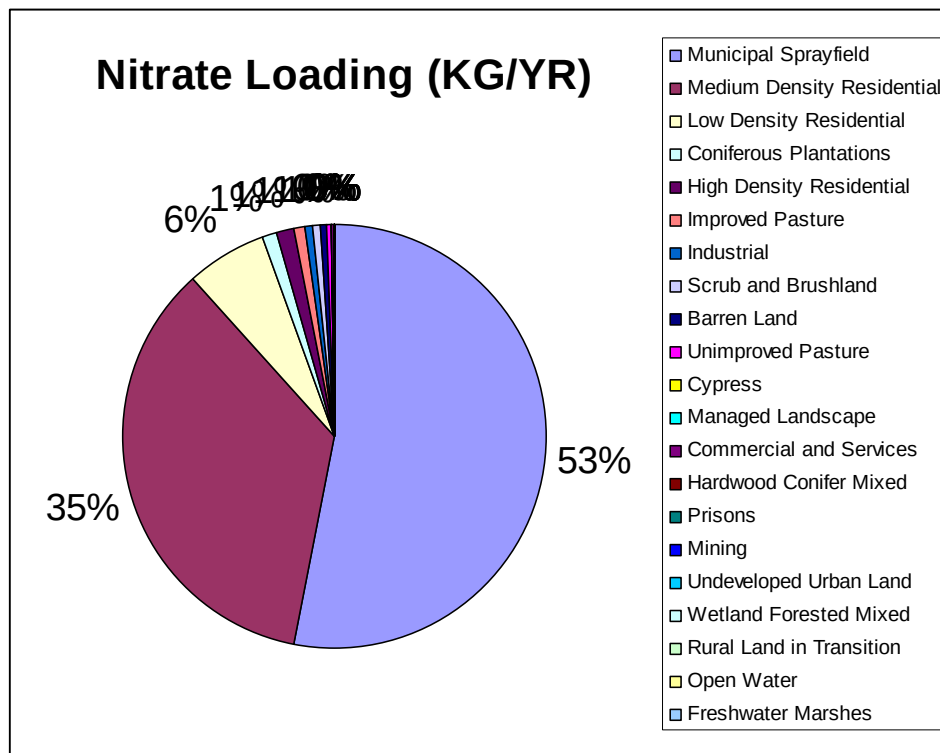


Figure 5.6: Total loadings of nitrate

Deliverable 7.7: Soluble Nitrate to Groundwater by Atmospheric Deposition

The soluble nitrate concentration in rainfall is 0.61ppm. The total rainfall over the 19 year study period was 1157.117cm

There are 17218 hectares in the basin. The attenuation coefficient for percolated ground is 0.8 (Bottcher, etal)

$(2939.077 \text{ cm} * 17218\text{Ha} * 0.61 \text{ ppm}) / 10 = 3086906.88 \text{ Kg}$ for the 19 year period

$3086906.88 \text{ Kg} / 19 = 162468.78 \text{ Kg/Yr}$

$162468.78 \text{ Kg/Yr} * 0.8 \text{ (GW Attenuation)} = 129975 \text{ Kg}$ of nitrate loading to the groundwater per year basin wide

Deliverable 7.8, 7.9, and 7.10: Ratio of Runoff to Percolation in the Woodville Recharge Basin

Using the sub basin data as a zone grid, a zonal sum function was run to compute the total runoff and perc by sub basin. Ratio was computed by: $\text{Ratio} = \text{Runoff} / \text{Perc}$. The data was normalized from 1 – 10 by:

$\text{Normal} = \text{Ratio} * 10 / 4.97$. The results are given in Table 5.9 (shown on the following pages). The same data is shown in map form in Figures 5.7 and 5.8.

Table 5.8: Ratio of Runoff to Percolation in the Woodville Recharge Basin (Part 1)

Sub Basin Name	Acres	Hectares	Runoff (cm/yr)	Perc (cm/yr)	Ratio	Normal
BAR-ONE CB	415	168	41724	734857	0.06	0.11
BATTLEBRIDGE CB	1016	411	150701	1381085	0.11	0.22
BATTLEFIELD #1 CB	561	227	109623	747126	0.15	0.29
BATTLEFIELD #2 CB	487	197	99027	428958	0.23	0.46
BIG SANDHILL #1 CB	193	78	18345	363772	0.05	0.10
BIG SANDHILL #2 CB	74	30	10793	99518	0.11	0.22
BIG SANDHILL #3 CB	175	71	21526	231500	0.09	0.19
BIG SANDHILL #4 CB	17	7	1389	17807	0.08	0.16
BIRD CB	96	39	79410	66362	1.20	2.41
BRYAN CB	909	368	164243	843073	0.19	0.39
CAMPBELL POND CB	1628	659	2808400	2125156	1.32	2.66
CLAUSE CB	544	220	177180	901815	0.20	0.39
DISC VILLAGE EAST CB	598	242	160250	1022029	0.16	0.32
DISC VILLAGE WEST CB	74	30	9351	117889	0.08	0.16
EAGLE LAKE CB	3163	1280	1279329	5591844	0.23	0.46
EAGLES BEAK CB	69	28	34915	156976	0.22	0.45
EAST WOODVILLE CB	6595	2669	1121449	16650646	0.07	0.14
FILMORE ROAD CB	37	15	19735	68109	0.29	0.58
FIVE LAKES WS	1270	514	1163431	1839920	0.63	1.27
FOREST GROVE WS	193	78	186112	386104	0.48	0.97
GEORGE CB	301	122	0	515012	0.00	0.00
GORBY CB	361	146	94800	907639	0.10	0.21
GREEN CB	52	21	4224	97228	0.04	0.09
HOGAN POND CB	381	154	98825	282515	0.35	0.70
HOMESTEAD CB	346	140	50260	415593	0.12	0.24
JONES CB	116	47	21770	148852	0.15	0.29
JUNKYARD CB	168	68	566964	113970	4.97	10.00
KAREN CB	215	87	25747	203580	0.13	0.25
KAY CB	1092	442	343563	1539622	0.22	0.45
KOREAN BAPTIST CB	156	63	288392	269554	1.07	2.15
LEENA # 1 CB	319	129	6578	605868	0.01	0.02
LEENA # 2 CB	52	21	17012	63595	0.27	0.54
LEWISWOOD CB	316	128	143899	545977	0.26	0.53
LITTLE CB	383	155	52968	436566	0.12	0.24
LITTLE LAKE CB	64	26	16843	124709	0.14	0.27
LONG DROP CB	49	20	23000	34389	0.67	1.34
LONGVIEW CB	124	50	11303	165271	0.07	0.14
LUTTERLOH POND CB	2903	1175	1697808	4535918	0.37	0.75
MIDDLE RHODES WS	72	29	4104	108093	0.04	0.08
NATIONAL FOREST #1 CB	1347	545	91420	2618497	0.03	0.07
NATIONAL FOREST #2 CB	44	18	0	92597	0.00	0.00
NATIONAL FOREST #3 CB	161	65	6563	328414	0.02	0.04
NATIONAL FOREST #4 CB	240	97	0	507302	0.00	0.00
NATIONAL FOREST #5 CB	109	44	465	221777	0.00	0.00
NATURAL WELLS #1 CB	188	76	100232	397126	0.25	0.51
NATURAL WELLS #2 CB	91	37	75225	216719	0.35	0.70
NEDSTER CB	213	86	100835	347416	0.29	0.58
NORTH WOODVILLE CB	684	277	511423	1171247	0.44	0.88
OAK RIDGE SCHOOL CB	415	168	1132730	592507	1.91	3.84

Table 5.8: Ratio of Runoff to Percolation in the Woodville Recharge Basin (Part 2)

Sub Basin Name	Acres	Hectares	Runoff (Cm/Yr)	Perc (CmYr)	Ratio	Normal
OAKS AT WOODVILLE CB	138	56	98175	304053	0.32	0.65
REGISTER CB	222	90	26013	326221	0.08	0.16
RHODES # 1 CB	166	67	16986	225090	0.08	0.15
RHODES # 2 CB	121	49	5323	217128	0.02	0.05
RHODES CEMETARY WS	1087	440	345927	1329902	0.26	0.52
SANDHILL #1 CB	331	134	34163	595899	0.06	0.12
SANDHILL #10 CB	96	39	7086	121015	0.06	0.12
SANDHILL #11 CB	126	51	16918	147839	0.11	0.23
SANDHILL #12 CB	32	13	5754	30490	0.19	0.38
SANDHILL #13 CB	67	27	7938	79773	0.10	0.20
SANDHILL #14 CB	170	69	26749	170484	0.16	0.32
SANDHILL #15 CB	40	16	3737	45211	0.08	0.17
SANDHILL #16 CB	35	14	12075	30893	0.39	0.79
SANDHILL #2 CB	69	28	12188	136647	0.09	0.18
SANDHILL #3 CB	190	77	21370	288346	0.07	0.15
SANDHILL #4 CB	27	11	2334	60522	0.04	0.08
SANDHILL #5 CB	385	156	39744	609549	0.07	0.13
SANDHILL #6 CB	138	56	11835	145759	0.08	0.16
SANDHILL #7 CB	79	32	7485	85102	0.09	0.18
SANDHILL #8 CB	128	52	15878	147508	0.11	0.22
SANDHILL #9 CB	42	17	5017	50504	0.10	0.20
SANDY #1 CB	42	17	26025	78914	0.33	0.66
SANDY #2 CB	153	62	69318	237356	0.29	0.59
SANDY #3 CB	175	71	18425	286096	0.06	0.13
SANDY #4 CB	22	9	5421	35737	0.15	0.30
SEA BOARD CB	124	50	40923	295308	0.14	0.28
SEVEN MILE POND CB	588	238	45460	1012119	0.04	0.09
SHEPHERD BRANCH WS	2011	814	1027097	1596048	0.64	1.29
SIX MILE POND CB	1016	411	670821	1918037	0.35	0.70
SOUTH WOODVILLE CB	346	140	175292	717234	0.24	0.49
SPRAY FIELD #1 CB	932	377	43559	3869421	0.01	0.02
SPRAY FIELD #2 CB	1070	433	982	4814900	0.00	0.00
SPRAY FIELD #3 CB	250	101	0	2612289	0.00	0.00
SPRAY FIELD #4 CB	47	19	0	408975	0.00	0.00
SPRAY FIELD #5 CB	109	44	0	1104722	0.00	0.00
SPRAY FIELD #6 CB	114	46	0	1307488	0.00	0.00
SUB CB	215	87	7967	433965	0.02	0.04
SUMMERHAVEN CB	143	58	150307	253766	0.59	1.19
THREE PUDDLES EAST CB	136	55	163116	258700	0.63	1.27
THREE PUDDLES WEST CB	272	110	155494	539005	0.29	0.58
TRAM ROAD CB	1537	622	821544	1822404	0.45	0.91
VICKERS CB	1334	540	142265	2642854	0.05	0.11
WAKULLA CB	351	142	129416	529947	0.24	0.49
WEST WOODVILLE CB	1048	424	214947	2153126	0.10	0.20
WILD DOG CB	1339	542	1464380	1721703	0.85	1.71
WILLIAM CB	84	34	8811	89838	0.10	0.20
WOODVILLE ELEMENTARY CB	1413	572	716445	1983021	0.36	0.73

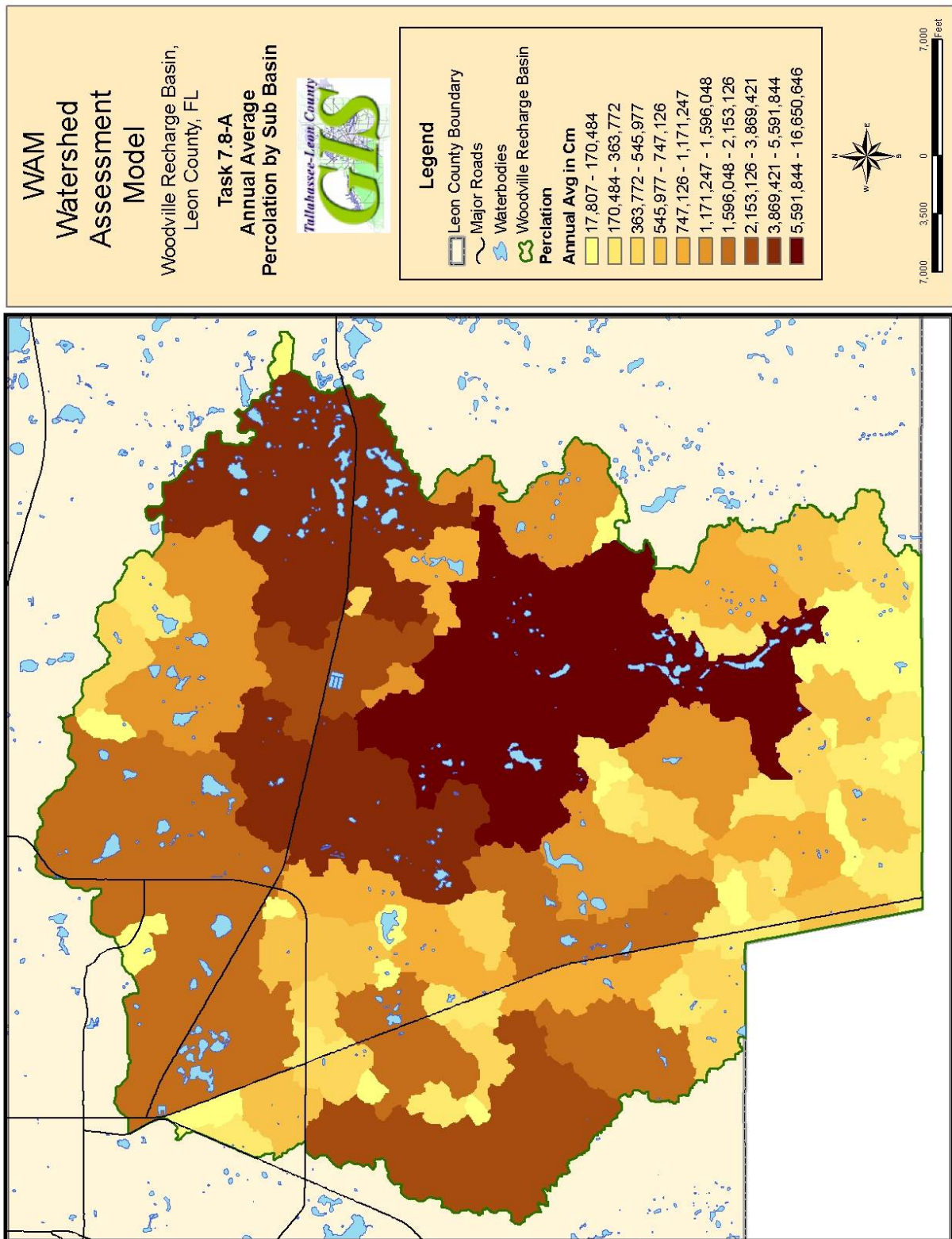


Figure 5.7: Average Annual Percolation by Sub Basin, (percolation expressed in centimeters)

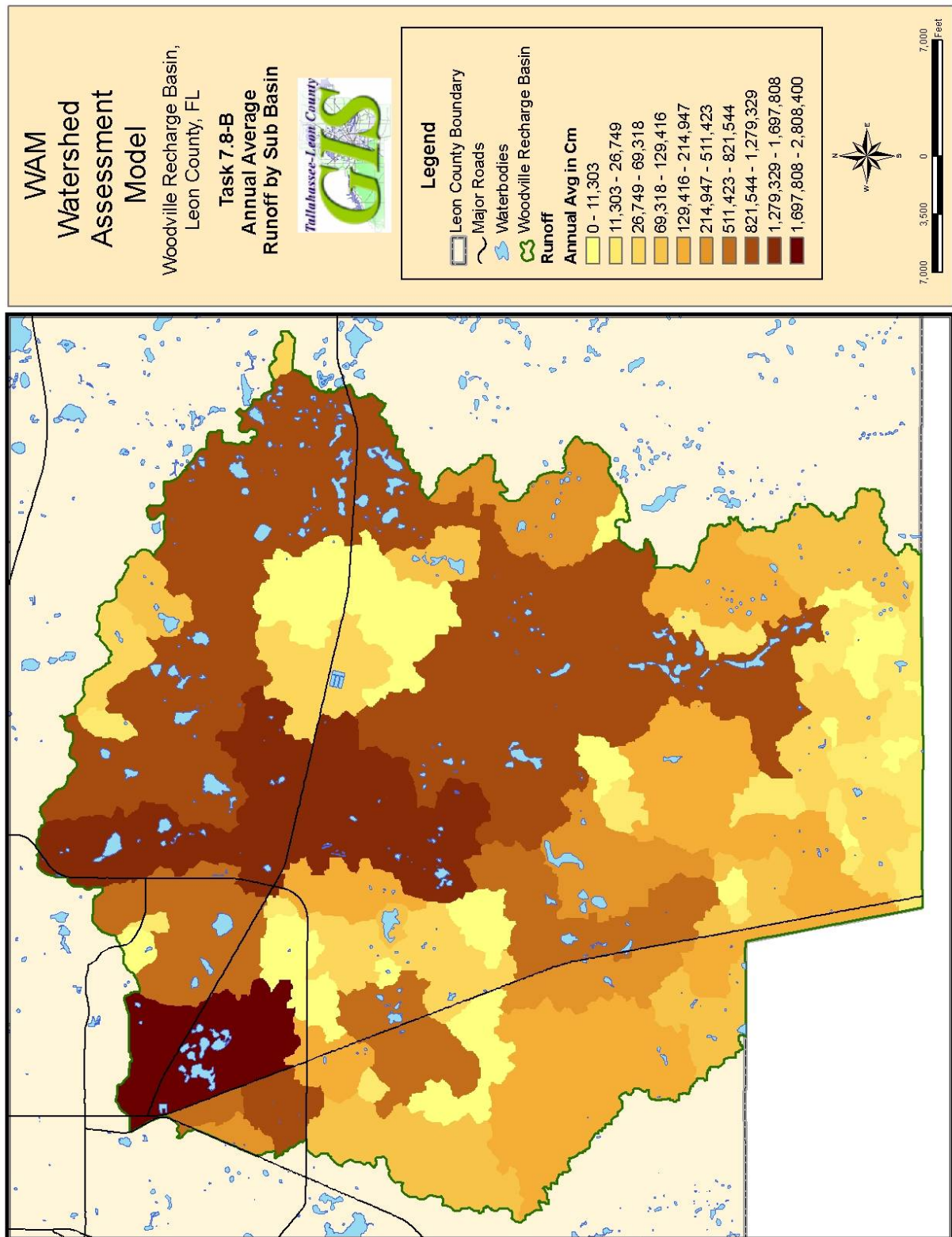


Figure 5.8: Annual Average Runoff by Sub Basin, (runoff expressed in centimeters)

Deliverables 8.1, 8.2, 9.2.4, and 9.3.3

These deliverables are all components of the WAM model. The software and all associated data layers are a deliverable to the County. Tallahassee-Leon County GIS provides staff support for the use of GIS in the County in general, The WAM model is included in this support.

Deliverable 9.1: Soluble Nitrate to Land Surface by Parcel

Current parcel data was intersected with the soluble nitrate to the land surface data and then the result was summed by parcel number to produce a table. Since the table is 6000 records, it is not included here but delivered as a digital file. A small scale basin-wide map and four larger scale quadrant maps are shown in Figures 5.8 – 5.12.

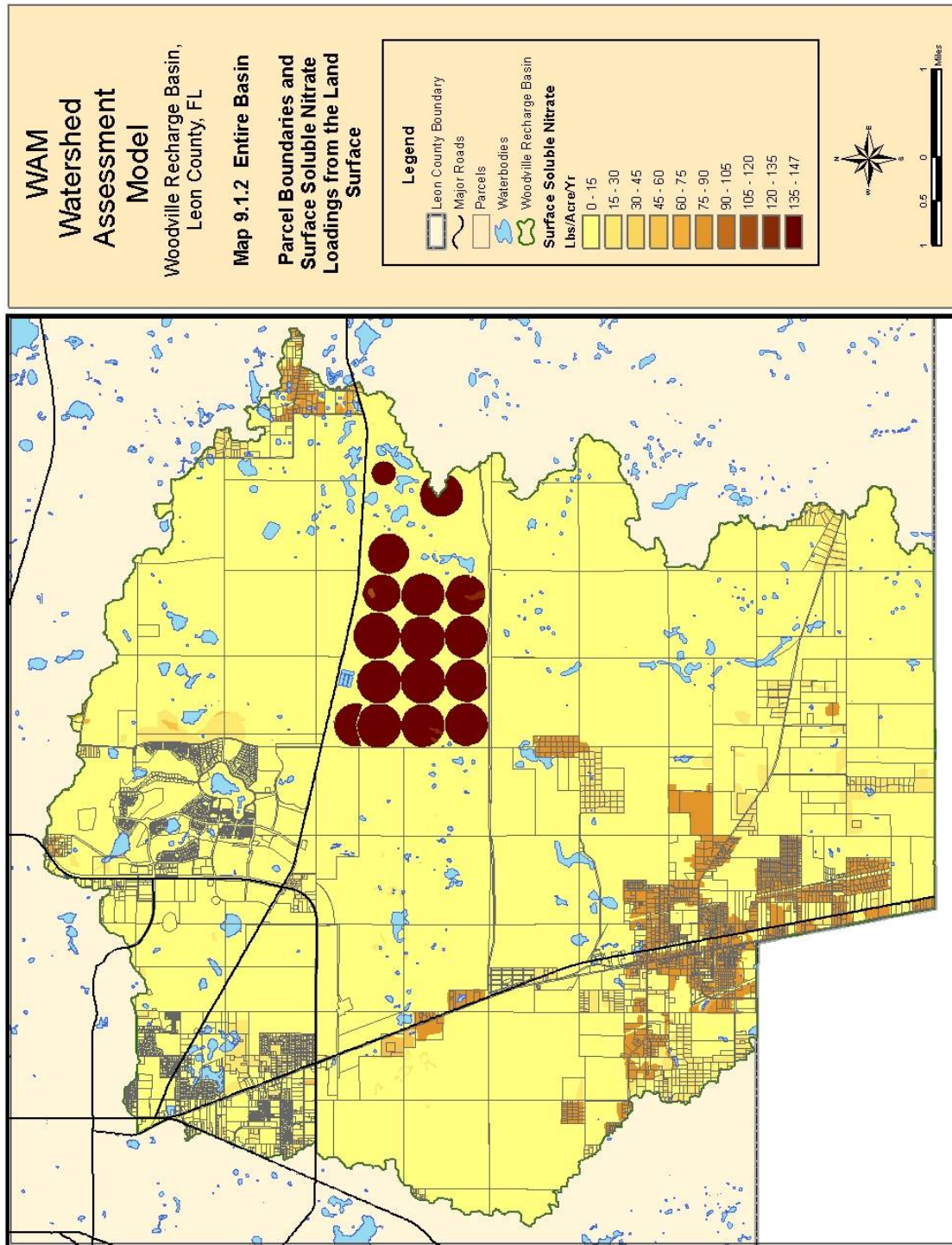


Figure 5.8: Parcel Boundaries and Soluble Nitrate Loadings from the Land Surface

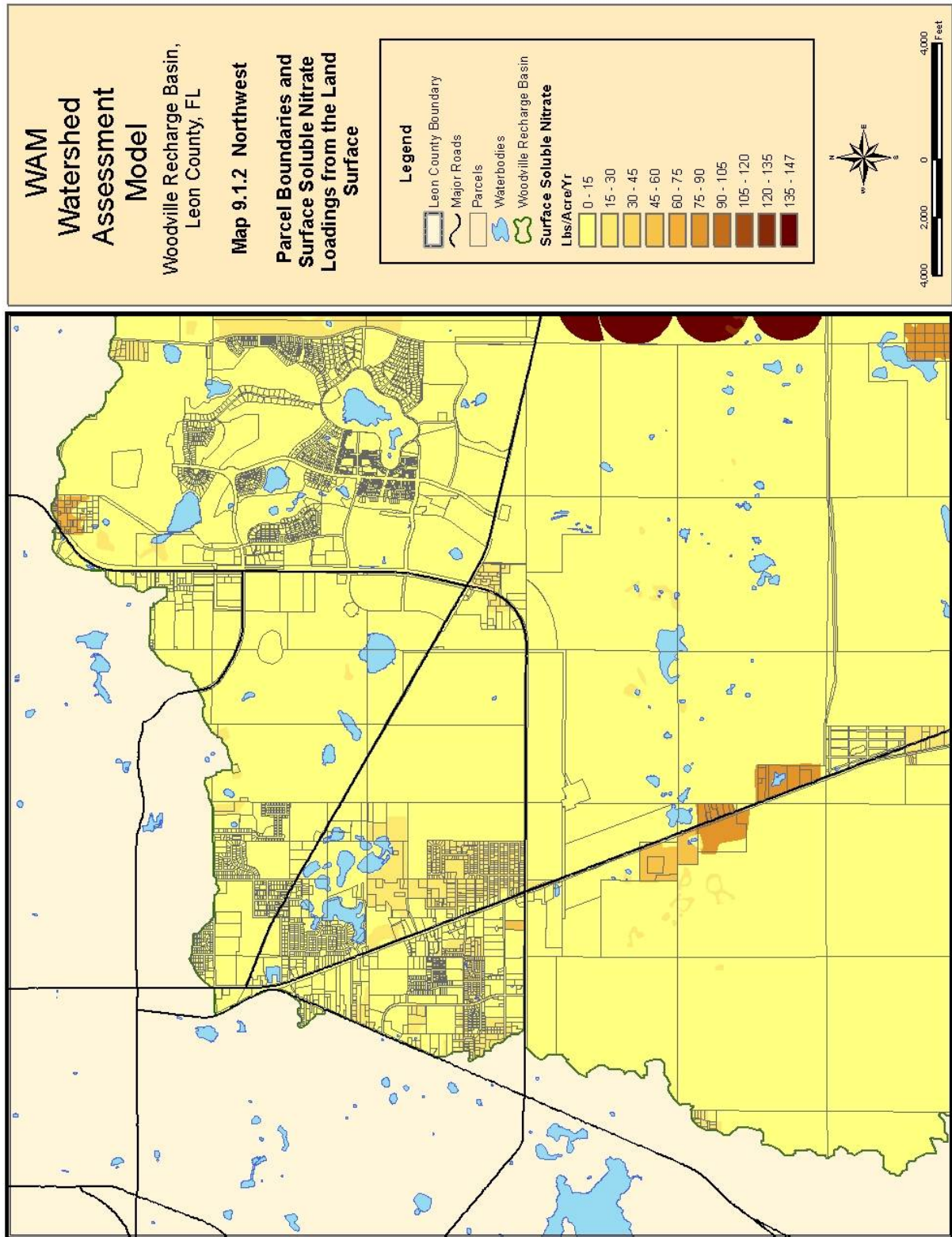


Figure 5.9: Parcel Boundaries and Soluble Nitrate Loadings to the Land Surface (NW Quadrant)

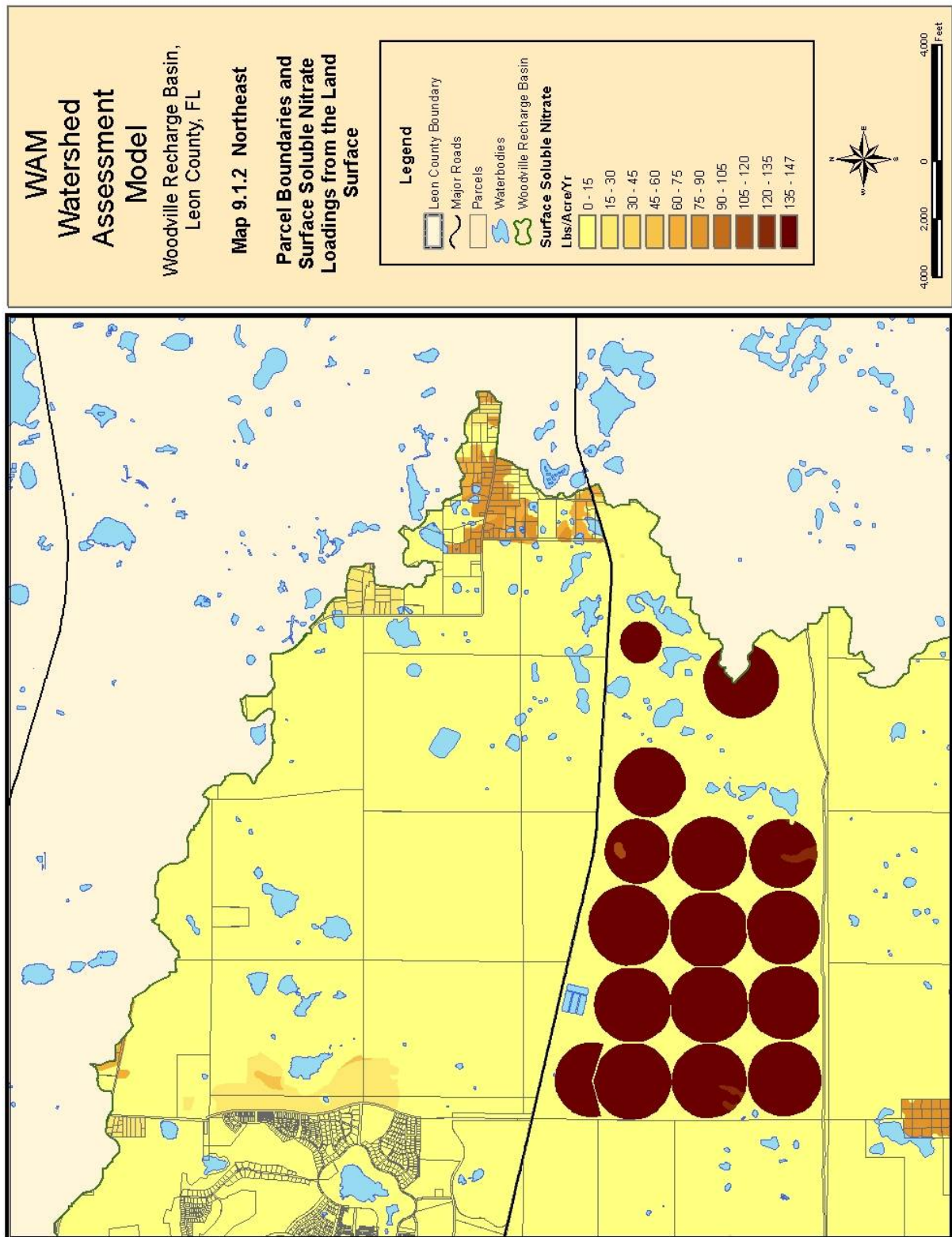


Figure 5.10: Parcel Boundaries and Soluble Nitrate Loadings to the Land Surface (NE Quadrant)

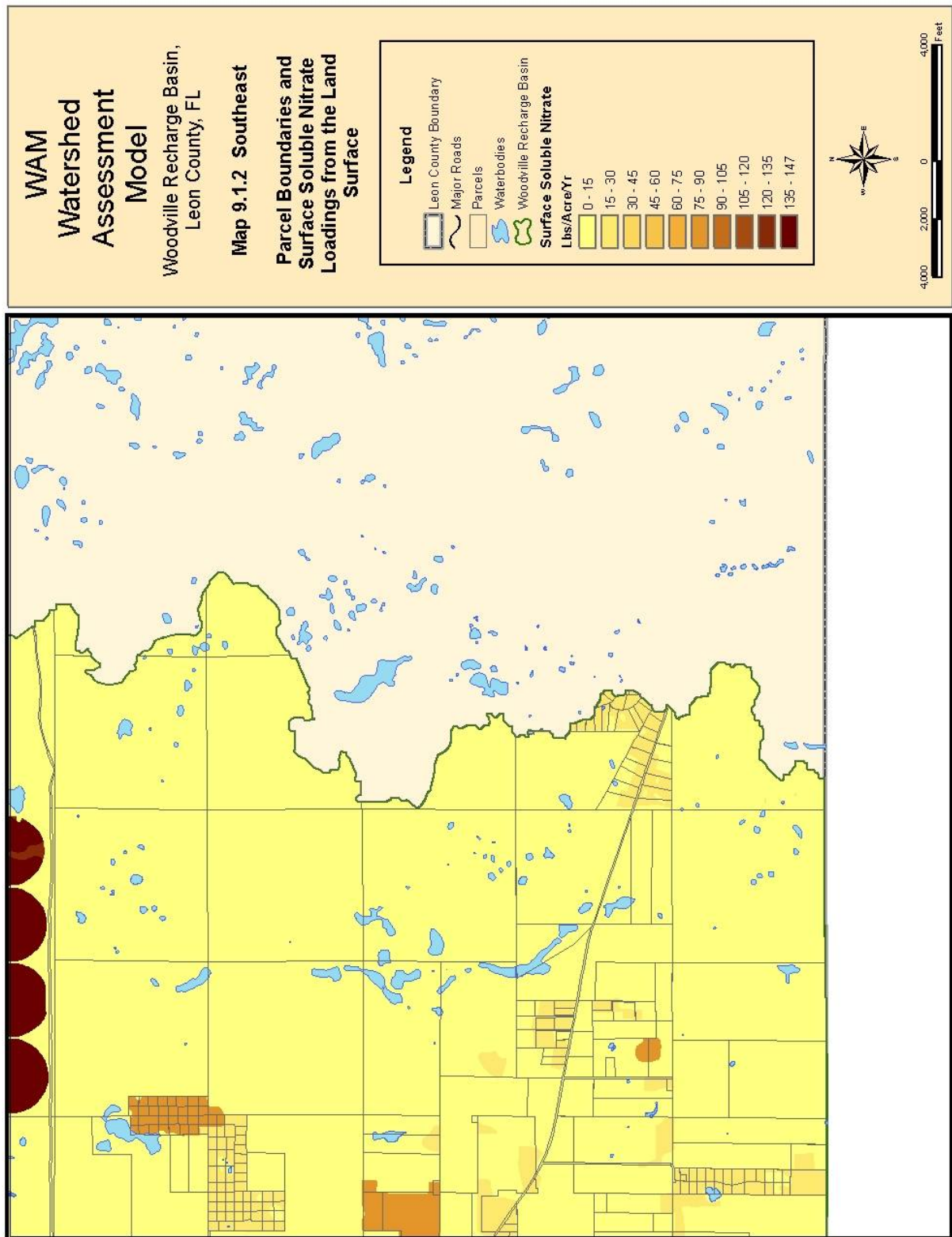


Figure 5.11: Parcel Boundaries and Soluble Nitrate Loadings to the Land Surface (SE Quadrant)

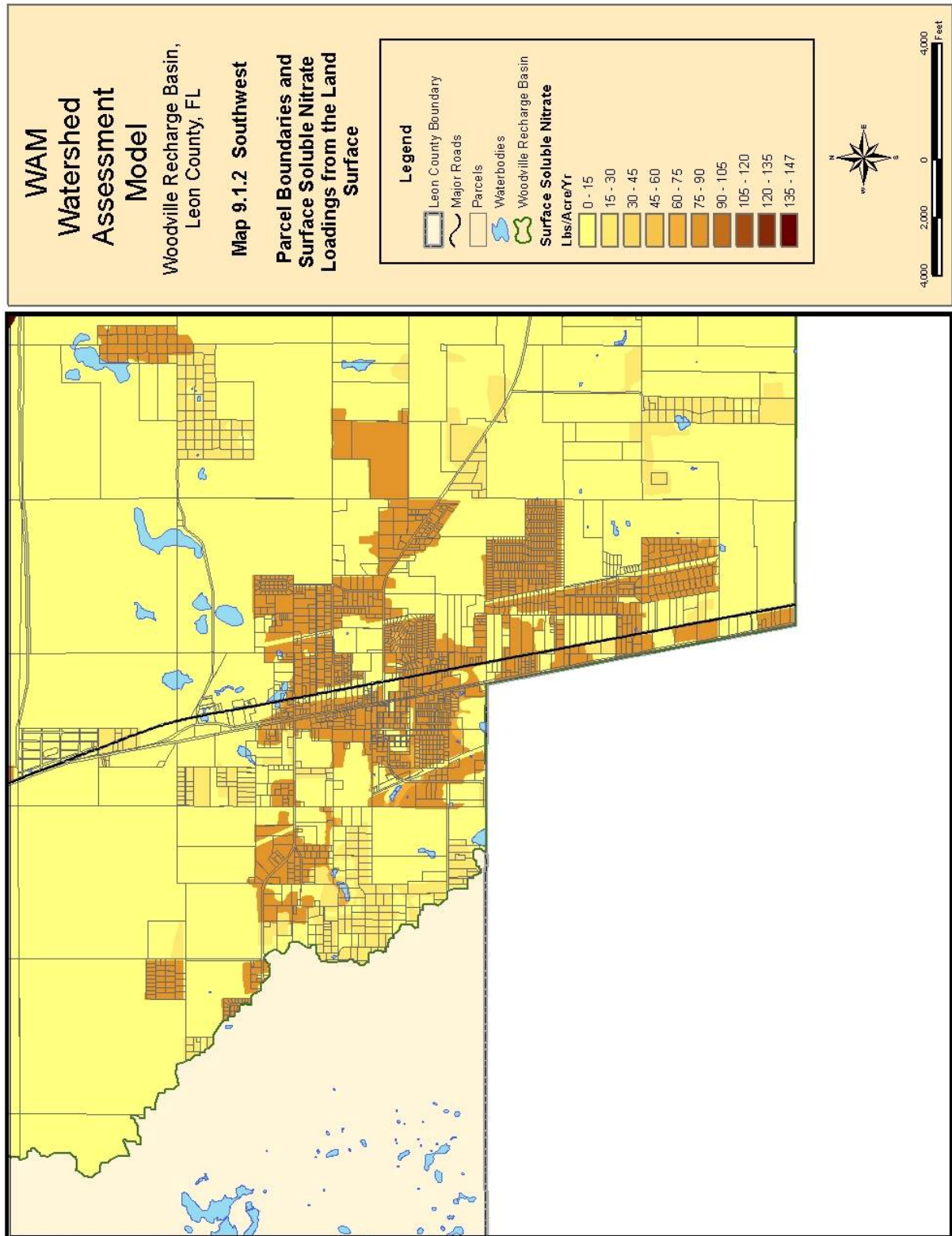


Figure 5.12: Parcel Boundaries and Soluble Nitrate Loadings to the Land Surface (SW Quadrant)

Deliverable 9.2: Results from Task 7 by Sub Basin

9.2.1.7.1 Soluble Nitrate to Groundwater from the SESF by Sub Basin

Figure 5.13 shows the sub basin boundaries in conjunction with the ground water soluble nitrate loadings from the SESF pivots. Table 5.9 provided the summary loadings by sub basin.

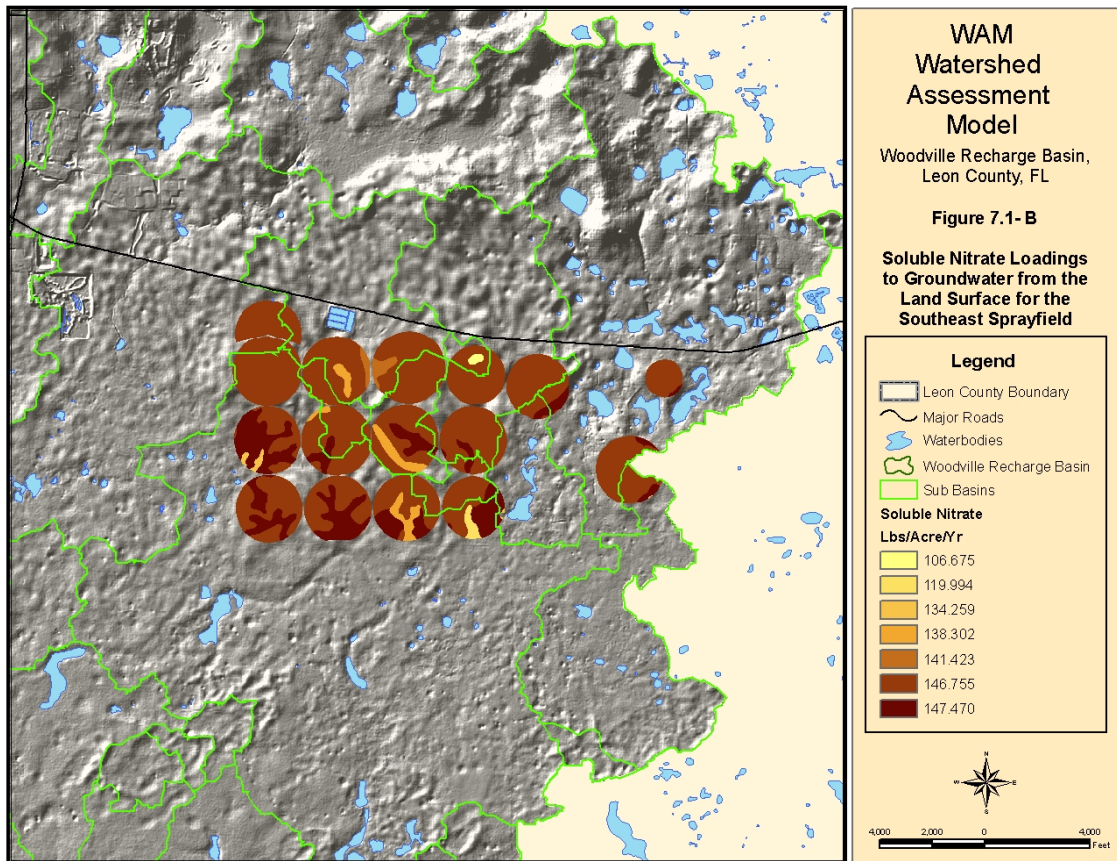


Figure 5.13: Soluble Nitrate to Groundwater from the SESF by Sub Basin

Table 5.9: Soluble Nitrate to Groundwater from the SESF by Sub Basin

Sub Basin Name	Area (HA)	SumSolNO3 (g/Ha/Yr)	Sum SolNO3 (Kg/Ha/Yr)	Total Loading (Kg/Yr)
SPRAY FIELD #6 CB	38.36	144175.67	144.18	5530.578573
SPRAY FIELD #3 CB	75.22	144175.67	144.18	10844.89365
SPRAY FIELD #4 CB	11.04	126715.00	126.72	1398.9336
SPRAY FIELD #5 CB	31.42	147112.50	147.11	4622.27475
GORBY CB	13.13	142828.00	142.83	1875.33164
EAST WOODVILLE CB	273.25	137356.00	137.36	37532.527
SPRAY FIELD #1 CB	73.9	142160.00	142.16	10505.624
LUTTERLOH POND CB	30.05	146755.00	146.76	4409.98775
SPRAY FIELD #2 CB	95.35	147112.50	147.11	14027.17688
KAY CB	14.45	142828.00	142.83	2063.8646
EAGLE LAKE CB	49.24	147112.50	147.11	7243.8195

9.2.1.7.3 Soluble Nitrate to Groundwater from Residential Septic Tanks by Sub Basin

The results from deliverable 7.3 are shown summarized by sub basin in Table 5.10. Figure 5.14 shows the location of the residential land uses in the basin in conjunction with sub basin boundaries.

Table 5.10: Soluble Nitrate to Groundwater from Residential Septic Tanks by Sub Basin

Sub Basin Name	Total N (Kg/Yr)
BATTLEBRIDGE CB	1484.18
BATTLEFIELD #1 CB	1040.57
BATTLEFIELD #2 CB	1.03
BIG SANDHILL #1 CB	447.08
CAMPBELL POND CB	23484.35
CLAUSE CB	193.23
DISC VILLAGE EAST CB	2722.02
DISC VILLAGE WEST CB	112.26
EAGLE LAKE CB	5157.27
EAGLES BEAK CB	806.31
EAST WOODVILLE CB	3321.51
FILMORE ROAD CB	459.92
FIVE LAKES WS	355.38
FOREST GROVE WS	4158.80
HOMESTEAD CB	189.63
JONES CB	44.85
JUNKYARD CB	99.50
KOREAN BAPTIST CB	2174.33
LEENA # 2 CB	8.87
LEWISWOOD CB	3634.42
LITTLE CB	155.00
LONGVIEW CB	32.17
MIDDLE RHODES WS	72.38
NATIONAL FOREST #1 CB	1096.73
NATURAL WELLS #1 CB	2845.68
NATURAL WELLS #2 CB	2179.35
NEDSTER CB	1888.58
NORTH WOODVILLE CB	4437.08
OAK RIDGE SCHOOL CB	9069.56
OAKS AT WOODVILLE CB	2593.64
REGISTER CB	314.89
RHODES # 1 CB	156.52
RHODES # 2 CB	239.80
RHODES CEMETARY WS	4411.16
SANDHILL #1 CB	349.54
SANDHILL #2 CB	266.43
SANDHILL #3 CB	235.29
SANDHILL #4 CB	56.09
SANDHILL #5 CB	453.23
SANDY #1 CB	631.57
SANDY #2 CB	1372.88
SANDY #3 CB	533.79
SANDY #4 CB	34.85
SEA BOARD CB	1088.59
SEVEN MILE POND CB	326.65
SIX MILE POND CB	1568.06
SOUTH WOODVILLE CB	4585.16
SUMMERHAVEN CB	2795.71
THREE PUDDLES EAST CB	3292.64
THREE PUDDLES WEST CB	64.08
TRAM ROAD CB	1899.43
VICKERS CB	2215.59
WAKULLA CB	1464.73
WEST WOODVILLE CB	6487.10
WILD DOG CB	2566.69
WOODVILLE ELEMENTARY CB	7134.28

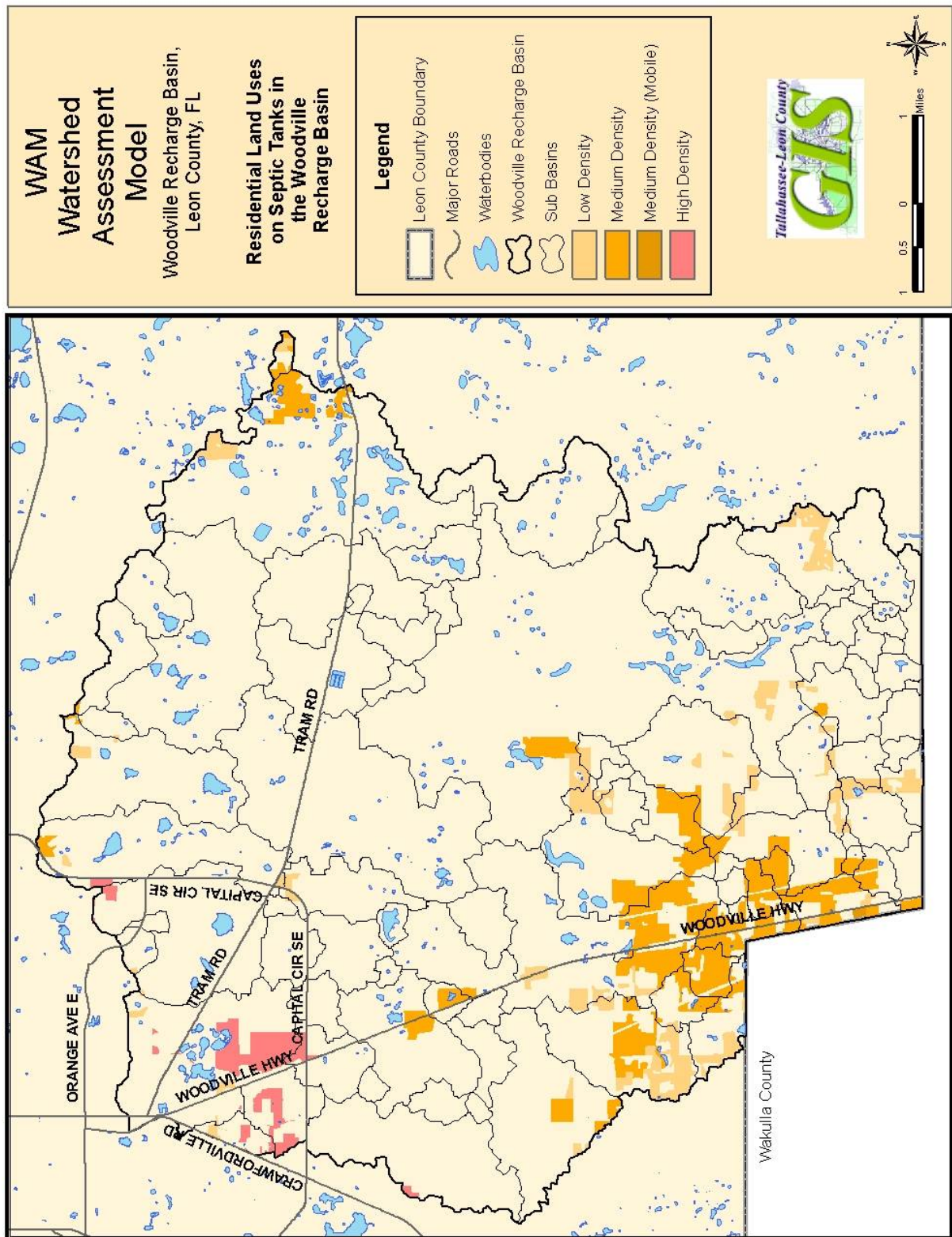


Figure 5.14: Soluble Nitrate to Groundwater from Residential Septic Tanks by Sub Basin

9.2.1.7.4: Annual Average Percolation by Sub Basin

Figure 5.15 shows the distribution of average annual percolation (in centimeters) in conjunction with the sub basin boundaries. Table 5.11 provides the summary results.

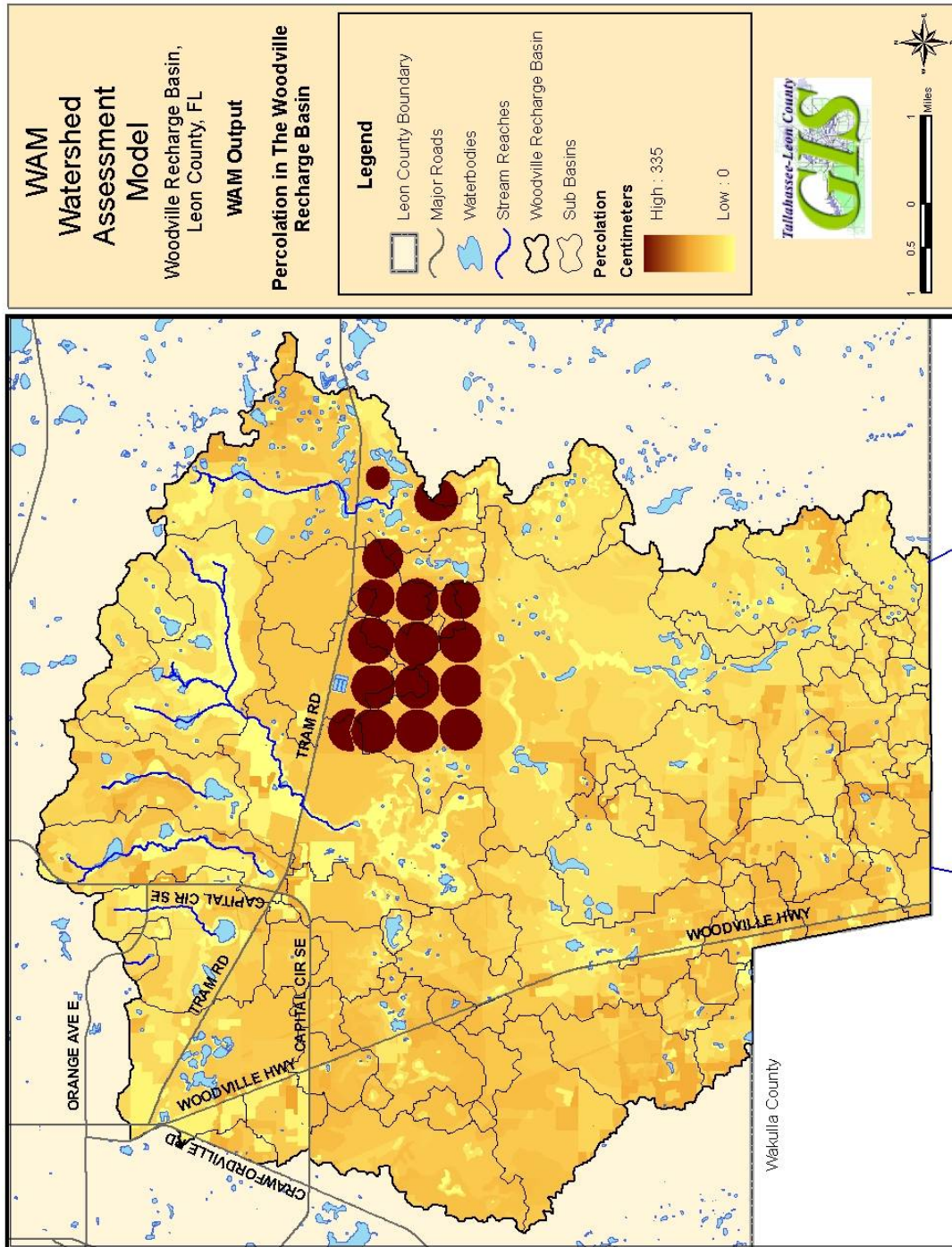


Figure 5.15: Annual Average Percolation by Sub Basin

Table 5.11 Annual Average Percolation by Sub Basin (Part 1)

Sub Basin Name	Total Perc By Sub Basin (Cm)
BAR-ONE CB	550110
BATTLEBRIDGE CB	1711830.316
BATTLEFIELD #1 CB	913525.8462
BATTLEFIELD #2 CB	718531.2
BIG SANDHILL #1 CB	344025.6667
BIG SANDHILL #2 CB	115007.8571
BIG SANDHILL #3 CB	177208.8
BIG SANDHILL #4 CB	20295
BIRD CB	84989.8
BRYAN CB	845053.2
CAMPBELL POND CB	2364727.75
CLAUSE CB	844778
DISC VILLAGE EAST CB	1028997
DISC VILLAGE WEST CB	109800
EAGLE LAKE CB	5655375.909
EAGLES BEAK CB	150479.3333
EAST WOODVILLE CB	15019480
FILMORE ROAD CB	64759.5
FIVE LAKES WS	2054335.216
FOREST GROVE WS	275828.5
GEORGE CB	558489.5
GORBY CB	1142451.5
GREEN CB	93551.25
HOGAN POND CB	321897.125
HOMESTEAD CB	604764
JONES CB	153754.3571
JUNKYARD CB	271116.0714
KAREN CB	185049.6667
KAY CB	2473254
KOREAN BAPTIST CB	307450.5
LEENA # 1 CB	515087.5
LEENA # 2 CB	87839.2
LEWISWOOD CB	476398.125
LITTLE CB	532370.4545
LITTLE LAKE CB	113681.25
LONG DROP CB	44888
LONGVIEW CB	178879.25
LUTTERLOH POND CB	5584274.559
MIDDLE RHODES WS	116211.2
NATIONAL FOREST #1 CB	1914555.462
NATIONAL FOREST #2 CB	86584.5
NATIONAL FOREST #3 CB	258174.4286
NATIONAL FOREST #4 CB	456042
NATIONAL FOREST #5 CB	200532
NATURAL WELLS #1 CB	358102.4615
NATURAL WELLS #2 CB	189885.5
NEDSTER CB	351032.5
NORTH WOODVILLE CB	1125212
OAK RIDGE SCHOOL CB	549288.5

Table 5.11: Annual Average Percolation by Sub Basin (Part 2)

Sub Basin Name	Total Perc By Sub Basin (Cm)
OAKS AT WOODVILLE CB	236974
REGISTER CB	408033.8889
RHODES # 1 CB	251723
RHODES # 2 CB	266797.125
RHODES CEMETARY WS	1705542
SANDHILL #1 CB	579627.25
SANDHILL #10 CB	119782
SANDHILL #11 CB	125065.6
SANDHILL #12 CB	40732
SANDHILL #13 CB	68514.75
SANDHILL #14 CB	176923.1429
SANDHILL #15 CB	42885.33333
SANDHILL #16 CB	25782.66667
SANDHILL #2 CB	118277.5
SANDHILL #3 CB	335012
SANDHILL #4 CB	64205.71429
SANDHILL #5 CB	595469
SANDHILL #6 CB	179634.6667
SANDHILL #7 CB	78084
SANDHILL #8 CB	136957.3333
SANDHILL #9 CB	34400
SANDY #1 CB	67159.33333
SANDY #2 CB	243100
SANDY #3 CB	326563.2
SANDY #4 CB	43143
SEA BOARD CB	243324
SEVEN MILE POND CB	899814.3158
SHEPHERD BRANCH WS	2375845.467
SIX MILE POND CB	1542580
SOUTH WOODVILLE CB	629349.2308
SPRAY FIELD #1 CB	2639528.571
SPRAY FIELD #2 CB	3731906.286
SPRAY FIELD #3 CB	1345194.667
SPRAY FIELD #4 CB	419764.6667
SPRAY FIELD #5 CB	605421
SPRAY FIELD #6 CB	626154.6667
SUB CB	301397.875
SUMMERHAVEN CB	235060
THREE PUDDLES EAST CB	231833.4
THREE PUDDLES WEST CB	439819.875
TRAM ROAD CB	2244462.5
VICKERS CB	2566310.636
WAKULLA CB	575226.6667
WEST WOODVILLE CB	1810430.621
WILD DOG CB	2280778.6
WILLIAM CB	101079
WOODVILLE ELEMENTARY CB	2217660.185

9.2.1.7.6: Summary Land Use Loadings by Sub Basin

This deliverable is poorly represented in printed tabular form. The length and complexity make the results difficult to interpret. This product has been provided as a digital data set in the GIS system specified in the Task 8 deliverables. The spatial distribution of land use by sub basin is easily retrieved in a digital environment. Figure 5.16 shows land use in conjunction with the sub basin boundaries.

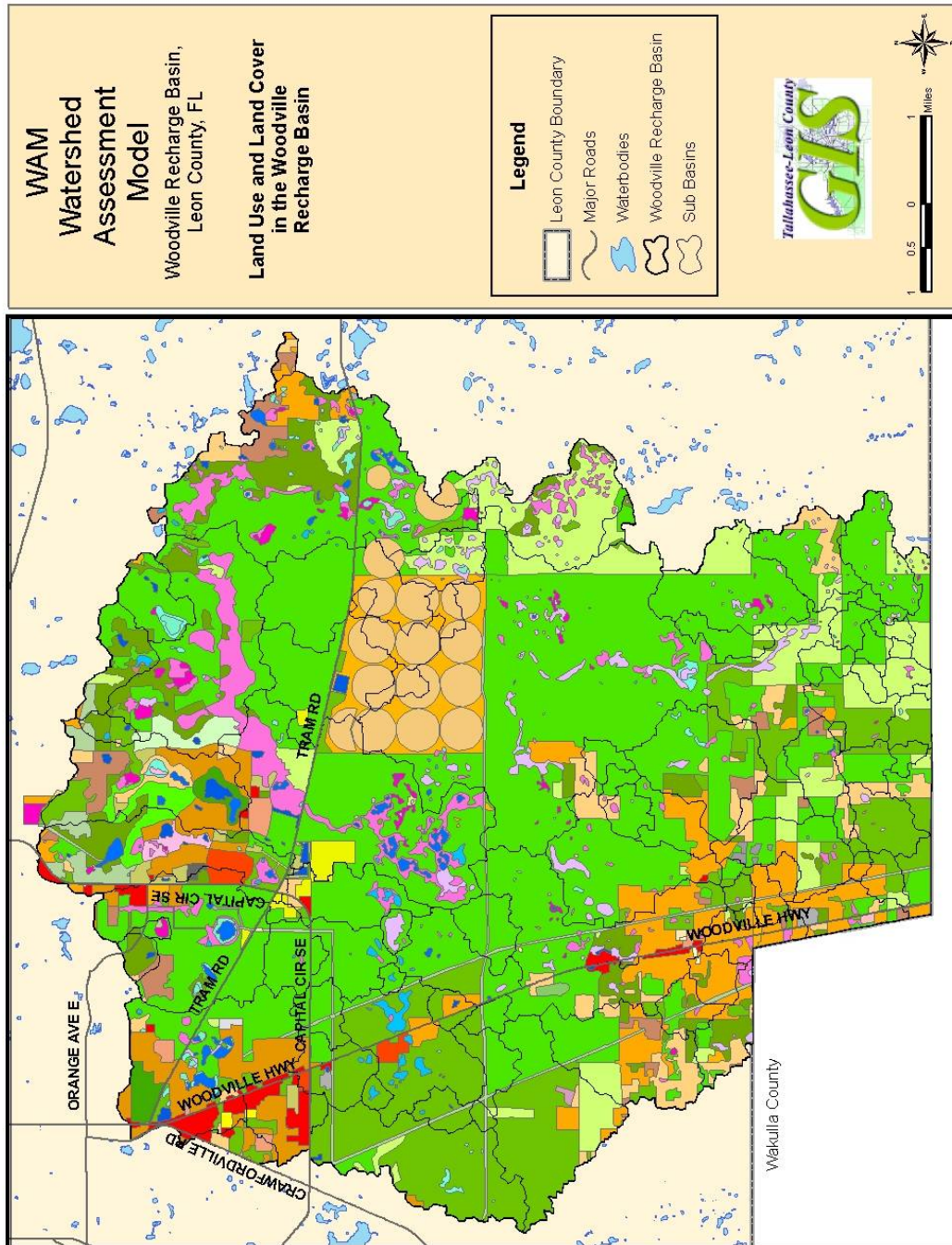


Figure 5.16: Land Use with Sub Basin Boundaries

9.2.1.7.7: Soluble Nitrate from Atmospheric Deposition by Sub Basin

Atmospheric deposition is constant over the region, thus the sub basin summary is a function of area. The soluble nitrate concentration of rainfall is given as 0.61 ppm, (McGlynn, 2006). The data is summarized in Table 5.12.

Table 5.12: Atmospheric deposition of soluble nitrate by Sub Basin (part 1)

Sub Basin Name	Area (Ha)	NO3 Atmospheric Deposition (Kg/Yr)
BAR-ONE CB	150.03	557.66
BATTLEBRIDGE CB	366.27	1361.42
BATTLEFIELD #1 CB	202.5	750.72
BATTLEFIELD #2 CB	176.06	653
BIG SANDHILL #1 CB	70	256.17
BIG SANDHILL #2 CB	27.29	101.43
BIG SANDHILL #3 CB	63.32	233.57
BIG SANDHILL #4 CB	6.2	22.85
BIRD CB	35.71	132.73
BRYAN CB	328.05	1217.46
CAMPBELL POND CB	587.68	2183.77
CLAUSE CB	196.46	730.24
DISC VILLAGE EAST CB	215.41	800.67
DISC VILLAGE WEST CB	26.84	99.76
EAGLE LAKE CB	1140.21	4233.06
EAGLES BEAK CB	25.35	93.74
EAST WOODVILLE CB	2376.79	8833.45
FILMORE ROAD CB	14.04	52.18
FIVE LAKES WS	458.47	1703.01
FOREST GROVE WS	69.83	259.55
GEORGE CB	109.24	406.04
GORBY CB	130.94	486.7
GREEN CB	19.19	71.32
HOGAN POND CB	137.93	511.86
HOMESTEAD CB	125.19	465.33
JONES CB	42.29	157.19
JUNKYARD CB	60.74	225.73
KAREN CB	78.19	290.63
KAY CB	393.68	1459.21
KOREAN BAPTIST CB	56.11	208.41
LEENA # 1 CB	115.75	430.24
LEENA # 2 CB	18.61	69.17
LEWISWOOD CB	114.45	425.41
LITTLE CB	138.04	512.16
LITTLE LAKE CB	23.5	87.34
LONG DROP CB	18.1	67.27
LONGVIEW CB	44.91	166.74
LUTTERLOH POND CB	1046.09	3888.31
MIDDLE RHODES WS	25.94	96.41
NATIONAL FOREST #1 CB	485.4	1803.37
NATIONAL FOREST #2 CB	16.26	60.43
NATIONAL FOREST #3 CB	58.11	215.99
NATIONAL FOREST #4 CB	86.7	322.26
NATIONAL FOREST #5 CB	39.32	146.15
NATURAL WELLS #1 CB	68.26	253.72
NATURAL WELLS #2 CB	33.46	124.37
NEDSTER CB	77.15	286.76
NORTH WOODVILLE CB	247.17	918.73
OAK RIDGE SCHOOL CB	150.52	559.37

Table 5.12: Atmospheric deposition of soluble nitrate by Sub Basin (part 2)

Sub Basin Name	Area (Ha)	NO3 Atmospheric Deposition (Kg/Yr)
OAKS AT WOODVILLE CB	50.42	187.41
REGISTER CB	80.71	299.99
RHODES # 1 CB	59.65	221.71
RHODES # 2 CB	44.19	164.25
RHODES CEMETARY WS	392.58	1459.21
SANDHILL #1 CB	120.13	446.52
SANDHILL #10 CB	35.23	130.94
SANDHILL #11 CB	45.98	170.9
SANDHILL #12 CB	11.98	44.52
SANDHILL #13 CB	24.69	91.77
SANDHILL #14 CB	61.63	227.88
SANDHILL #15 CB	14.96	55.6
SANDHILL #16 CB	12.68	47.13
SANDHILL #2 CB	25.3	94.04
SANDHILL #3 CB	68.65	255.17
SANDHILL #4 CB	10.6	39.4
SANDHILL #5 CB	139.02	516.73
SANDHILL #6 CB	50.84	188.97
SANDHILL #7 CB	28.92	107.49
SANDHILL #8 CB	46.69	173.54
SANDHILL #9 CB	16	59.47
SANDY #1 CB	15.38	57.16
SANDY #2 CB	55.25	205.36
SANDY #3 CB	63.37	232.53
SANDY #4 CB	8.76	32.56
SEA BOARD CB	45.06	167.48
SEVEN MILE POND CB	211.59	786.48
SHEPHERD BRANCH WS	725.1	2695.12
SIX MILE POND CB	366.45	1362.09
SOUTH WOODVILLE CB	125.36	464.99
SPRAY FIELD #1 CB	335.94	1248.68
SPRAY FIELD #2 CB	386.44	1436.39
SPRAY FIELD #3 CB	90.08	334.82
SPRAY FIELD #4 CB	17.18	63.85
SPRAY FIELD #5 CB	39.57	147.08
SPRAY FIELD #6 CB	41.93	155.85
SUB CB	77.53	288.17
SUMMERHAVEN CB	52.52	191.49
THREE PUDDLES EAST CB	48.91	181.79
THREE PUDDLES WEST CB	98.01	364.3
TRAM ROAD CB	553.8	2058.1
VICKERS CB	481.05	1787.54
WAKULLA CB	127.35	472.8
WEST WOODVILLE CB	378.33	1405.99
WILD DOG CB	483.1	1795.16
WILLIAM CB	30.74	113.85
WOODVILLE ELEMENTARY CB	509.59	1894.14

Deliverable 9.3: Areal Distribution of Nutrients in the Woodville Recharge Basin

The products called for in this section have been shown in Section 4.1.2 and above in Section 4.1.3. All of the data elements described in this section are also delivered as live data. The WAM model, input data sets, output data sets are deliverables to Leon County.

Task 9.3.2 asks that a hypothetical buildout scenario be developed and the impacts to the groundwater be analyzed by the model. All of the pine plantation and forest regeneration land uses were converted to medium density residential (99% of which is served by septic tanks). The model was re run and the results are shown below. Table 5.13 shows the existing soluble nitrate loadings to groundwater by land use. The modified results are shown in Table 5.14.

Table 5.13: Existing soluble nitrate loadings to groundwater by land use

Land Use	Area (Ha)	Mean GW NO3 (Kg/Ha/Yr)	Total GW NO3 (Kg/Yr)
Barren Land	97	8.249	796.4
Commercial and Services	361	0.331	119.8
Coniferous Plantations	8548	0.312	2667.1
Cypress	246	0.000	0.0
Freshwater Marshes	108	0.000	0.0
Hardwood Conifer Mixed	816	0.143	117.0
High Density Residential	511	4.621	2360.2
Improved Pasture	77	21.726	1671.8
Industrial	76	15.926	1213.7
Low Density Residential	552	20.961	11560.2
Managed Landscape	99	1.839	181.7
Medium Density Residential	917	75.117	68871.2
Mining	93	0.250	23.1
Municipal Sprayfield	705	146.279	103186.7
Open Water	186	0.000	0.0
Prisons	12	2.656	30.6
Rural Land in Transition	249	1.137	283.4
Scrub and Brushland	2585	0.412	1066.4
Undeveloped Urban Land	74	0.302	22.5
Unimproved Pasture	102	5.145	523.6
Wetland Forested Mixed	763	0.000	0.0

Table 5.14: Modified soluble nitrate loadings to groundwater by land use

Land Use	Area (Ha)	Mean GW NO3 (Kg/Ha/Yr)	Total GW NO3 (Kg/Yr)	Difference (Kg/Yr)
Low Density Residential	552	20.961	11560.2	0.0
Commercial and Services	361	0.331	119.8	0.0
Rural Land in Transition	249	1.137	283.4	0.0
Scrub and Brushland	2585	0.412	1066.4	0.0
Hardwood Conifer Mixed	816	0.143	117.0	0.0
Coniferous Plantations	0	0.000	0.0	2668.9
Open Water	186	0.000	0.0	0.0
Cypress	246	0.000	0.0	0.7
Wetland Forested Mixed	763	0.000	0.0	0.0
Freshwater Marshes	108	0.000	0.0	0.0
Barren Land	97	8.249	796.4	0.0
Medium Density Residential	9465	67.282	636838.6	567967.0
High Density Residential	511	4.621	2360.2	0.0
Industrial	76	15.926	1213.7	0.0
Managed Landscape	99	1.839	181.7	0.1
Improved Pasture	77	21.726	1671.8	0.0
Unimproved Pasture	102	5.145	523.6	0.0
Undeveloped Urban Land	74	0.302	22.5	0.0
Prisons	12	2.656	30.6	0.0
Mining	93	0.250	23.1	0.0
Municipal Sprayfield	705	146.279	103186.7	0.0

The WAM interface allows the user to develop scenarios by making land use modifications and applying BMPs and regenerating the model results to analyze changes in nutrient loadings. This is a very powerful tool for land use planning or to evaluate the predicted impact of planned development activities. The interface presents the results to the users with a split-screen to show the original and modified results side-by-side. Figure 5.17 shows the land use modifications. Figure 5.18 shows the impact of the land use modification to groundwater soluble nitrate loadings.



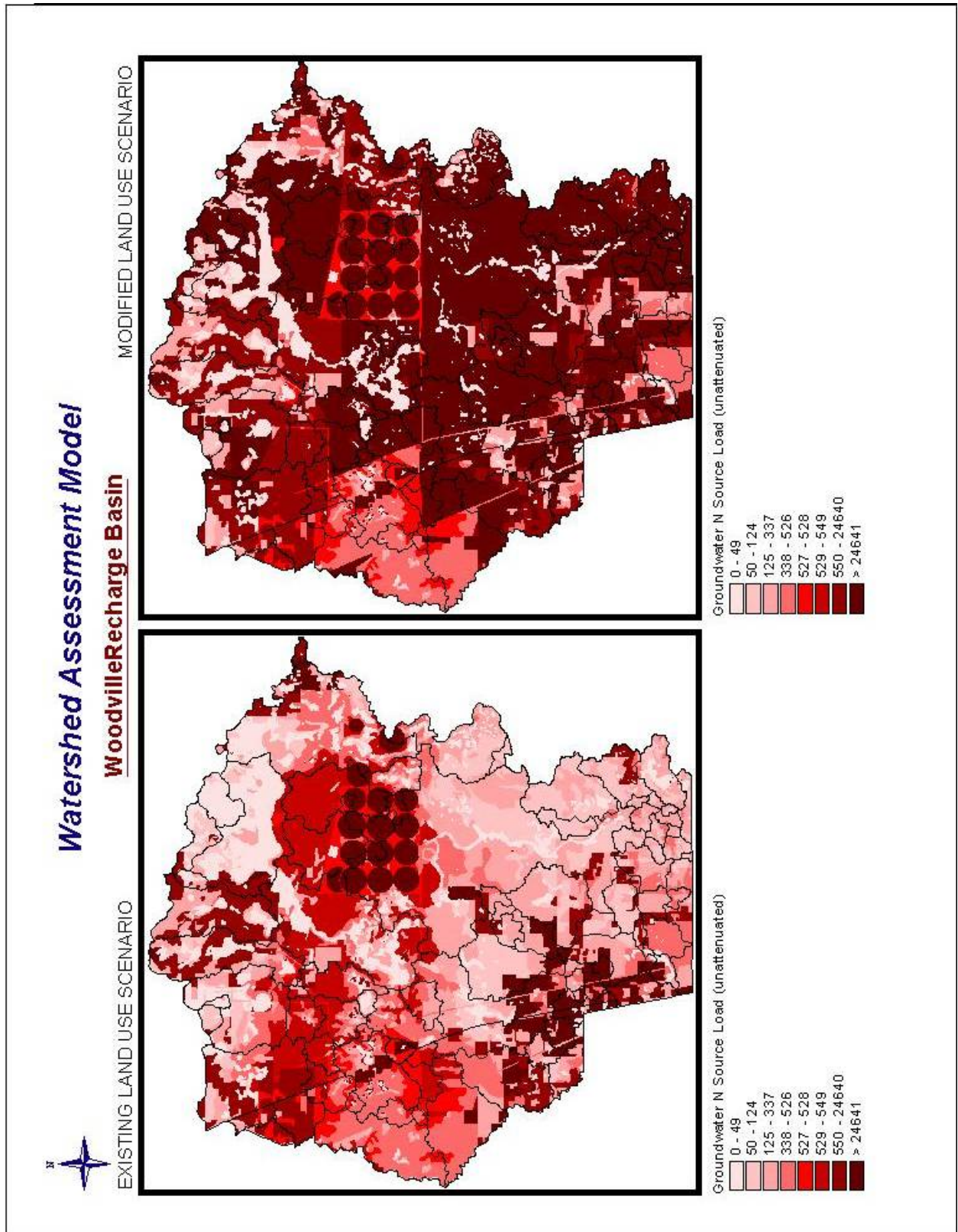


Figure 5.18 Existing and Hypothetical Buildout Impacts to Groundwater Nitrate in the Woodville Recharge Basin

The soluble nitrate loadings to the groundwater for medium density residential land use increases by 567967 kilograms per year. This hypothetical loading now surpasses the annual loadings from the SESF by more than 6 times. Under the existing land use distribution, medium density residential contributes slightly more than half the annual loadings of the SESF. The SESF is currently the largest single loading by land use in the basin. In order to answer the question regarding FDEP drinking water standards, the amount of water in the aquifer would have to be known, along with the background concentration of the water in the aquifer, in order to appropriately dilute the loadings from the land surface. This cannot be accomplished unless the entire “springshed” was modeled. The WRB represents only a small piece of the puzzle.

However, additional GIS analysis can provide some insight into the impact of increased land use densities within the WRB on groundwater quality by using WAM output in conjunction with KARSTIC aquifer vulnerability data. The grid of soluble nitrate loadings from the land surface was divided by the grid of the unattenuated soluble nitrate loadings to compute a dataset indicating the percentage of the soluble nitrate that makes it into the aquifer. This data was intersected with the KARSTIC aquifer vulnerability data. The areas where greater than 50% of the land surface loadings enters the ground water and where the KARSTIC score is greater than 150 were extracted and presented in Figure 5.19 (on the next page). This shows area where increased land use densities are likely to have an adverse effect on groundwater quality.

Discontiguous areas less than 1 hectare were removed to eliminate noise resulting from the data processing. The areas shown in lavender are areas where the soils are highly drained, there is a high concentration of karst features and natural denitrification processes remove half or less of the initial land-surface nitrate loadings. This map does not attempt to quantify the threshold at which adverse impact would occur. It simply identifies the areas where the groundwater is relatively unprotected.

Based on this study, there are some recommendations which may be beneficial to the long-term analysis of the impacts of land use on groundwater quality:

1. Install WAM at Leon County Growth and Environmental Management. Existing GIS staff can provide the support needed for implementation and use. SWET is due to release a new version of WAM designed to run in ESRI's ArcGIS environment. Enhancements will include surface-to-groundwater loadings for phosphorous in addition to nitrate, and possibly other nutrients as well. It will also include a more robust groundwater component. Best of all, WAM is no cost to the County.
2. Fine-tune the model with more specific data (beyond the scope of this study) and conduct scenario-based analyses of the impacts of proposed developments. This include applying best management practices to proposed (and existing) land uses and evaluate the cost-benefit of such best management practices for use in possible changes to the land development regulations.
3. Integrate WAM output data with the new Leon County Aquifer Vulnerability (LAVA) data to identify the areas most sensitive to groundwater impact.
4. Use WAM, the information contained in the final report, and other GIS datasets (primarily utility data, ESA data, existing and future land use, and LAVA) to conduct a more detailed GIS analysis to make specific location-based policy recommendations LCGEM management
5. Rather than approach land development regulation from a surface-drainage sub basin perspective, regulation should be evaluated on a location-based approach. The influence of surface hydrology is far less than subsurface hydrology in this region.

The power of this tool is much more than a one-time study and this report. WAM as a working model with live data has the capability to greatly assist in long-term policy decisions for aquifer protection.

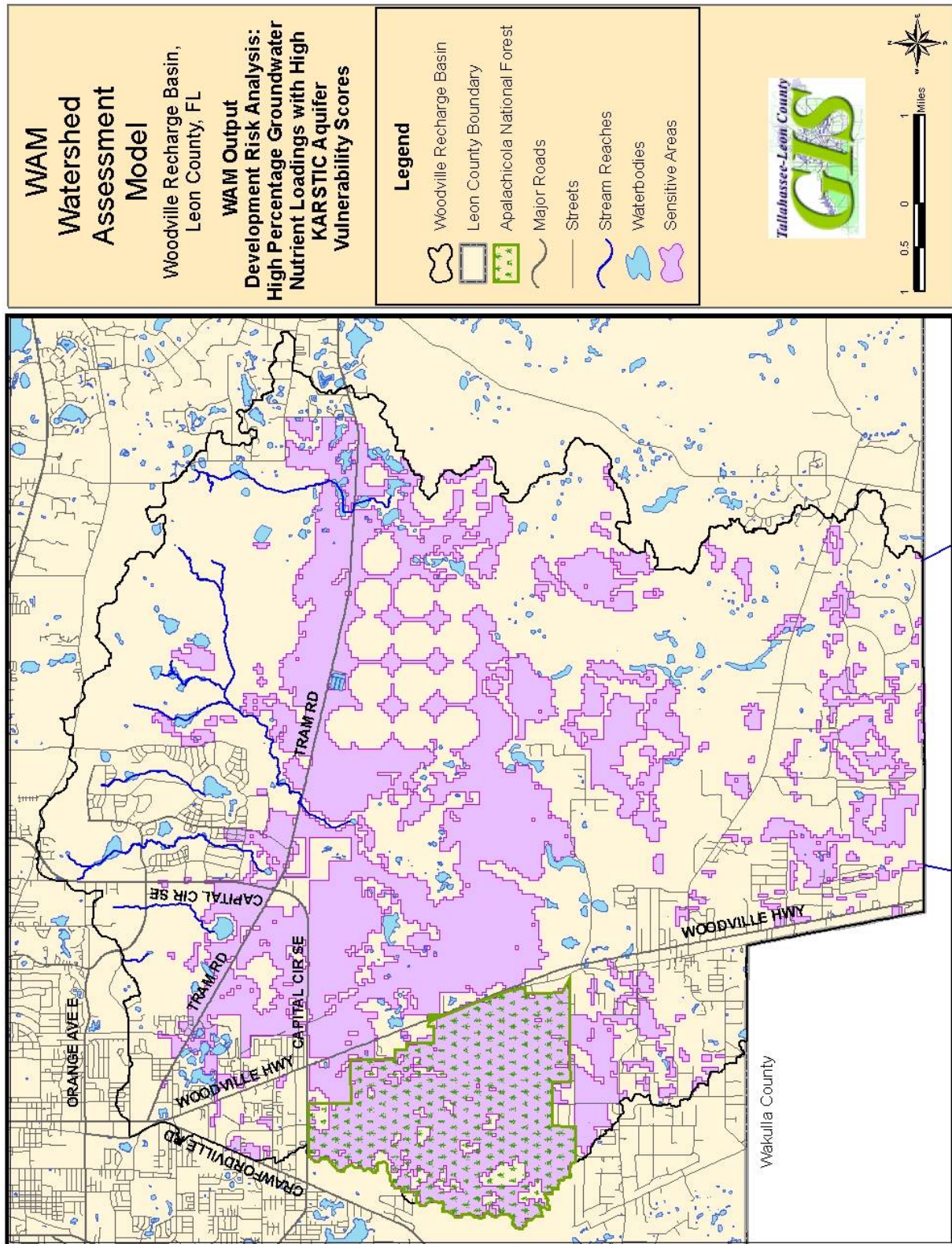


Figure 5.19 Areas Where Increased Land use Density is Likely to Adversely Impact Groundwater Quality

Chapter 3

Mitigations Options



Ardaman & Associates, Inc.

Chapter 3: Mitigation Options

Nutrients are the primary water quality concern in the Floridan Aquifer within the WRB. Drinking water quality standards violations were rare in the WRB. However, the WAM model indicates that, at build out and under current zoning regulations, drinking water quality violations would become widespread throughout the WRB. There are currently isolated areas within the WRB where the drinking water is becoming tainted by wastewater or livestock. The decline of our spring systems, most notably Wakulla Springs, has received considerable attention lately among the populace, regulatory and professional personnel, caused by deteriorating groundwater quality within the WRB. The improvement of groundwater quality is necessary to preserve a healthy aquatic system at area springs.

Surface water and groundwater are one and the same in the WRB. The confining layers that protect the deep Floridan Aquifer do not exist in most of the WRB. The attenuation, treatment or removal of pollutants is minimal in the karst soils. If we are to maintain a healthy springshed the inputs of nutrients must be reduced.

The most important action that could be implemented to protect Wakulla Springs, the St. Marks Rise, the Spring Creek Springs, Horn Springs, Chicken Branch Spring and all the other springs that receive waters from the Woodville Recharge Basin would be to implement an aquifer protection status that would provide for more stringent groundwater quality standards. Protective groundwater quality standards should be implemented by Leon County in the WRB to protect our area springs if we want them to be preserved for future generations. Groundwater quality standards need to meet acceptable surface water quality criteria. Best management practices for stormwater should also be reevaluated to ensure that nutrients enter the Floridan Aquifer at concentrations that would meet surface water quality standards at Karst features.

Nitrate groundwater standards need to be lowered to 3 mg/L from the standard of 10 mg/L. Phosphorus (SRP) need to be below 0.05 mg/L. The current iron standard of 0.3 mg/L is satisfactory. Additional research needs to be performed on the effects of nutrients on our springs so that we can be sure that these suggested levels will provide the necessary level of protection.

According to the Wekiva Study (FDEP, 2004) freshwater springs need to have a nitrate concentration of 0.2 mg/L to be healthy. Independently another group has proposed that the nitrate concentration needs to be 0.3 mg/L (Joe Hand personal communication). Several geologists recommended that the groundwater standard in Woodville needs to be at these levels. These levels are not attainable by current technology. Using the WAM model results, mass balance and experimental results in this study we have proposed the above treatment standards based on dilution rates as well as soil treatment capacity and the requirements that groundwater, when it emerges at a spring, be at a concentration that can support a healthy ecosystem. These standards will also insure good drinking water

quality for well water. State regulatory officials contacted in the course of this study were in favor.

Leon County can implement ground quality water standards that exceed State and Federal standards. For example, the current minimum design standards for stormwater treatment in the Florida are 0.5 inches. The City of Tallahassee's stormwater standards exceed the state criteria. They require treatment of the first 1.125 inches. Leon County's variable stormwater standards also exceed the state criteria in some areas. The Lake Jackson watershed has a stormwater standard that requires the retention of a 50 year storm and Bradfordville a 4 inch standard. Thus water quality standards in our area already exceed state and federal guidelines. Our groundwater quality standards could be further strengthened and this would be the easiest and most cost effective way to protect our springs.

Implementing appropriate standards for groundwater nutrients would allow healthy springs and appropriate targets for wastewater treatment. However, it is difficult from an infrastructure standpoint to achieve this level of wastewater treatment in the low-density rural sprawl developments typical in the WRB. Infrastructure costs associated with the complexity of operating advanced water treatment WWTPs and performance based septic systems could be lessened with clustered development bolstered by tax incentives and conservation easements.

***It is very important that the use of inorganic fertilizers be restricted in the unconfined parts of the WRB. The use of inorganic fertilizer is rather ineffective here since it tends to wash out to the aquifer before the plants can absorb it. Rather mulching and time released fertilizers should be encouraged.**

3.1: Appropriate Basin Specific Mitigation Measures:

****Restricting the use of septic tanks in aquifer-vulnerable areas.***

Private septic systems currently serve more homes in the WRB than sanitary sewer. The aquifer within the WRB is vulnerable to contamination from septic tanks. Some parts of the WRB have adequate clay layers that slow the vertical migration of nutrients, however the presence of numerous sinkholes and karst depressions pierce these clay lenses. The earth slumps into these karst features causing a sloping of the subterranean strata to these karst features. Septic tank effluent flows down gradient through the porous strata, over the clay layers and into the aquifer without much water quality treatment. Performance based septic systems need to be required in the WRB as well as assessed and monitored for nutrient removal efficiency.

The town of Woodville should be serviced with a municipal sewer system because of the vulnerability of the aquifer. Where the sewer goes should be driven more by where it is affordable, where it is practical to put it and where it would mesh with the cities master plan. Septic tank use should be eliminated in a buffer zone off of the major roads like Woodville Highway, Capitol Circle and Natural Bridge Road. One consideration would be where gravity or pumps would be necessary to move the effluent in the pipe system. This is more of a utilities question beyond the scope of this study. It should be noted that most of the Tram Road area is ill suited for septic tank usage because of the soil characteristics. Existing homes in this area should be on sewer too.

This study provides part of the information necessary to integrate into the sewer master plan. This consideration has to be predicated on the cost and ability to integrate portions of the WRB into the master plan. Location based loadings are more significant than the subbasins which are defined by the flow of surface waters, for these considerations. Location specific mitigation options that Leon County can be implemented as policy initiatives to protect the groundwater. The following map shows the areas where land use densities could be increased or decreased. This data needs to be further refined through GIS analysis to come up with board recommendations. A science-based study quantifies the problem but further work must be accomplished to formulate specific policy decisions.

A local revision of the groundwater standard for nitrate would be a tremendous benefit to the ecology of this area where groundwater and surface water are interchangeable. This study is recommending a revision of the nitrate standard to 3 mg/L nitrate regulated with monitoring wells installed with every system. A high ranking FDEP official thought that 5 mg/L for nitrate would suffice. The science in this report, the WAM Model and the experiments performed in this study (Septic Tank Monitoring, Mesocosm Experiments and Background Analysis) suggest that a 3 mg/L nitrate standard is achievable. Enforcement of this standard can be achieved by requiring the installation of monitoring

wells in the top of the aquifer. A monitoring well should be located at property line or 100 feet down-gradient from each new septic system; whatever is less (FDEP standard monitoring well policy). These wells, if installed by push core, could cost from \$200 to \$500.00. This monitoring system would allow us to protect the aquifer and preserve our springs for posterity because not every system will work as planned.

This study recommends the use of restrictive densities. New septic tank systems with enhanced nutrient reduction coupled with drip irrigation can achieve the 3 mg/L proposed for the regional groundwater standard. Alternative wastewater treatment is necessary for environmentally sensitive remote areas such as parts of the WRB where the aquifer is unconfined and susceptible to contamination. The Health Department has regulations for septic tanks at one per a quarter acre, or quarter acre lots for septic systems. The Wekiva Springshed has been studied extensively, it is plagued with similar nutrient problems and investigators have found that septic systems should be limited to lots of one acre or greater. Septic systems should be located at least $\frac{1}{2}$ mile from cave systems and at least 1 mile from a sinkhole with buffer. This standard is adequate to protect the less sensitive areas of the WRB where the aquifer is unconfined. Mass balances for the WRB indicate that one septic tank system per 5 acres is necessary to protect environmentally sensitive areas. Environmentally sensitive areas are defined as those where 50% of the nitrate loaded onto the surface reaches the aquifer. Environmentally sensitive areas are depicted in violet within the map below.

All septic systems in areas where the aquifer is unconfined should be performance based. The level of treatment required should be 3 mg/L nitrate to correspond with the regional groundwater standard of 3 mg/L nitrate. These systems cost more than the traditional septic systems. For example a recirculating aerobic system with carbon additives costs about \$10,000 per system.

Restrictive densities could be lessened if septic systems go to a 1 mg/L nitrate performance standard. This is achievable with drip irrigation coupled with advanced secondary treatment that costs about \$20,000 per system. With this kind of treatment 3 residences could be placed on 1 acre of land in the less vulnerable areas where the aquifer is unconfined. 3 residences could be placed on 5 acre of land in the vulnerable areas where the aquifer is unconfined. These treatment levels need to be verified with monitoring.

To decrease costs, clustered septic tank systems can be used. This would significantly lower the costs of performance based septic systems. As an example, on St. George Island a clustered system has the houses grouped together with zero lot lines. This minimizes the cost of piping and infrastructure. It minimizes infrastructure and maximizes households for septic systems with aerobic level treatment. Clustered systems typically have 4 to 12 lots per system. Variances could be requested to increase density.

There is a regulatory limit for the number of residences that can be placed on a clustered septic system. If a system has a capacity of over 10,000 gallons per day regulation under the DoH would no longer be available. FDEP does not regulate septic systems. For any type of clustered units no more than 28 units are possible (e.g., 350 gpd per household). For example, The Chaires Public School is on septic system at 12,000 gpd. Here FDEP declined jurisdiction but DoH permitted.

In areas of the WRB where the aquifer is unconfined and less vulnerable (less than 50% of the nitrate loading to the surface gets to the aquifer, figure 3.1) clustered housing is recommended as a cost saving alternative. Preliminary data indicates that one aerobic septic system that can achieve the 3 mg/L nitrate standard, per 1 acre, would protect the aquifer in the less vulnerable areas. If a clustered system is installed at 1 mg/L three times the density should be adequate to protect the aquifer. Then a twenty-acre parcel could support 36 clustered homes. Homes should be clustered on a minimum area of the property to minimize cost. Zero lot lines also help in minimizing impervious surfaces.

In areas of the WRB where the aquifer is unconfined and vulnerable (greater than 50% of the nitrate loading to the surface gets to the aquifer, figure 3.1) clustered housing is recommended as a cost saving alternative. Preliminary data indicates that one aerobic septic system that can achieve the 3 mg/L nitrate standard, per 5 acres, would protect the aquifer in the vulnerable areas. If a clustered system is installed at 1 mg/L three times the density should be adequate to protect the aquifer. Then a twenty-acre parcel could support 12 clustered homes. Homes should be clustered on a minimum area of the property to minimize cost. Zero lot lines also minimize impervious surfaces.

The regulation and management of these systems is very important. Monitoring wells should be required on all systems in order to evaluate their performance. Penalties and fines should be imposed on the systems that fail to perform as required by their permit. Level-2 management requires that a responsible party manage the system. Level-5 management requires ownership of unit by management company that managements it. The formation of a Government Utility Authority is recommended with Capitol Outlay and User Fees. The selection of the management level requires a planning and budget evaluation that is not within the scope of this study.

Management and Monitoring are recommended because these systems can fail and a failing system could have serious aquifer water quality consequences in areas where the aquifer is unconfined. Septic Systems fail when sludge fill pores in the drain field, biomat buildup inhibits percolation rates, root intrusion inhibits percolation rates, or physical damage to the system (such as driving a vehicle over the drainfield).

It should be noted that older systems have developed extensive Biomat in their drainfields. Biomat contains microorganisms that reduce nutrient loading to the aquifer. Newer systems need time to develop these, often as much as a year. The older systems tested in this study were performing adequately to meet the water quality standards

proposed herein. A newly installed system tested did not perform well because the biomat takes time to develop and disruption and digging in the old drainfield released the nutrients that had been bound up in it.

There is a need for further WAMview model runs and engineering analysis to fully evaluate the nutrient loading to the aquifer from all of these different types of systems. For example, we need to evaluate whether the concentrated loading of a decentralized sewer system is really as efficient as the diffuse loading of scattered aerobic septic systems.

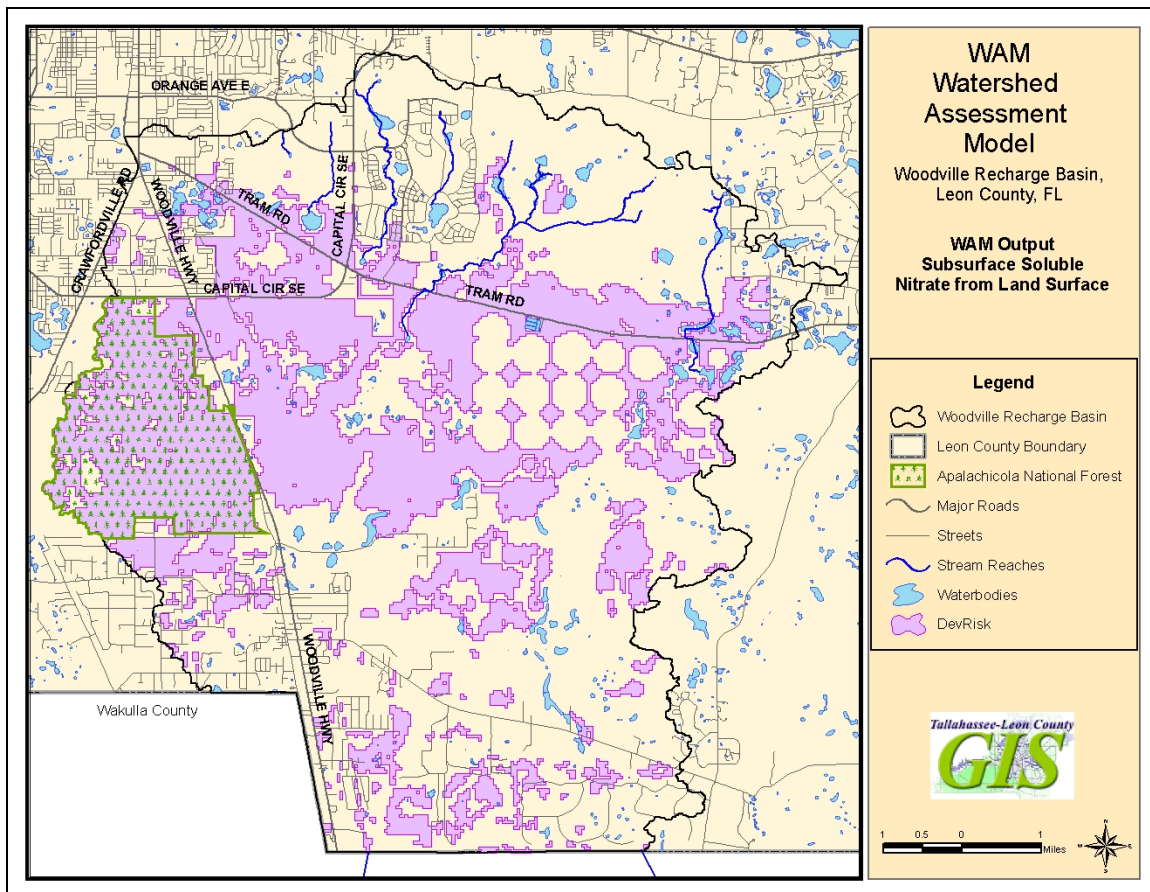


Figure 3.1: This map depicts aquifer vulnerable areas within the WRB. The areas shaded in violet are vulnerable to aquifer pollution. In these areas more than 50% of the Nitrate loading to the lands surface reached the aquifer.

High tech performance based septic systems are available. These provide additional water quality treatment and are an improvement over the traditional septic tank systems. They are much more expensive, with costs approaching or exceeding \$10,000 per system. They are also more difficult to operate. The variation of treatment schemes is complex. If the 3 mg/L groundwater nitrate standard is implemented with monitoring it does not matter what kind of system is installed because we can check its performance. Clustered systems

are available that could be used to route the wastewater from multiple residences to lessen the financial burden.

Unlike Waste Water Treatment Plants (WWTPs) septic systems (individual or clustered) are required to obtain permits for installation but are not regulated or required to have regular maintenance or to meet treatment standards. Septic systems are buried and are difficult to inspect and test. In the clay soils of northern Leon County failed septic systems pond and are self-evident. In the sandy soils of the WRB ponding does not occur and failed septic systems can continue to appear to be operating indefinitely while they load the aquifer with nutrient pollution. There are no requirements for monitoring wells and chemical analysis to assure that these systems are actually performing efficiently or are actually working at all. Numerous problems can cause the failure of septic systems and the release of nutrients into the environment: drainfield problems, leachfield problems, cesspool problems, and drywell problems.

Septic systems must be properly designed and installed to function properly in the soil and conditions peculiar to each individual parcel. Septic systems can fail from rather benign causes:

- A household water leak or excess water use that overloads the system.
- Changes in landscaping that paves over, crushes, or damages a portion of the system.
- Changes in position of downspouts, rain gutters, and paved areas that drain excess water into the area of the yard with the septic system.
- Failure to pump the septic tank to remove excess sludge and scum.

Natural solids break down well but certain solids and household chemicals (lint, greases, detergents) do not break down well at all. It is necessary to pump these accrued solids from septic tanks periodically to keep them from leaching into the septic system drain field to avoid a systemic failure. The following items can cause premature failure of septic systems:

- **Chemicals:** photo chemicals, paints, thinners, oils, varnishes, pesticides, used motor oil, unwanted cooking oil
- **Cigarette butts**
- **Coffee grounds**
- Diapers, cloth, disposable, cotton, paper, plastic
- **Dirt:** such as from people who clean their flower pots in the bath tub
- **Paper towels**
- **Plastic bags or other plastic scrap:** or trash of any kind
- **Sanitary napkins**
- **Food scraps:** which increase the solids load in the tank and so may be slow to settle into the sludge layer or scum layer.

- **Ground food from a garbage disposer:** which adds to the solids load in the septic tank and increases the needed pumping frequency.
- **Tampons:** which are not biodegradable cotton. Although a couple of tampons are not going to clog up a drain line nor ruin the septic tank, however they'll still be there years later when the tank is pumped. In a large household where many of these items may need to be disposed-of, wrapping them in toilet tissue and placing them in the garbage is a better destination.
- **Cotton swabs:** (Q-tips(R)) have been known to clog a drain or two.
- **Condoms:** won't clog a pipe but like some other debris, they are (mostly) not biodegradable.
- **Cooking oil, cleaners:** and the like should not be emptied down drains.
- **Trash and scrap:** such as dental floss
- **Toys:** this may seem odd, but little kids may toss a toy car, doll, or other object into the john where it's at risk of causing a costly clog.
- **Antibiotics:** the normal use of antibiotics by occupants in a one or two family residence with a septic system will not harm the septic tank or fields. High levels of discharge of antibiotics in urine and body waste from many building occupants using such drugs, such as at a nursing home with 50 residents and an onsite septic system, can kill bacteria in the septic tank and leach field and thus may indeed be a problem for such facilities.
- **Pesticides and Septic Systems:** people who need to dispose of un-used pesticides should not put them in building drains or toilets. In the U.S. contact state department of environment or local health department to find the nearest local, hazardous waste disposal station where they accept unwanted chemicals, paint, etc., often at no charge.
- **Illegal Drug Manufacturing and Septic Systems:** A septic system in New York was connected to house where illegal drugs were manufactured. So much contaminant was flushed down house drains that the workers contaminated their own well and poisoned themselves.
- **Water softeners:** if improperly adjusted, or if it is not working properly, excessive salt or softener backwash discharge, when sent into the septic tank and leach fields, can damage or reduce the life of the septic system.

The above problems can alter and severely affect the efficiency of nutrient removal by even the most advanced septic system. Septic systems in the WRB need to be monitored for efficiency of nutrient removal. We need to require that Septic Systems operating in the WRB maintain a service contract with a licensed septic tank company for annual service including pump out.

The monitoring of nutrients coupled with stricter groundwater quality standards for nutrients could allow for continued utilization of septic tank and drainfield technology for wastewater treatment and protect the Florida Aquifer. It is not necessary to perform expensive monitoring for toxic compounds. Toxic substances in septic systems will

decrease the efficiency of nutrient removal and the failure of the nutrient removal capacity of the septic sample will be evident from nutrient monitoring.

Septic tank maintenance contracts, monitoring wells and water quality monitoring should be required for new construction. These aquifer protection policies could also be implemented for existing business and residential properties when they are sold and purchased in the WRB.

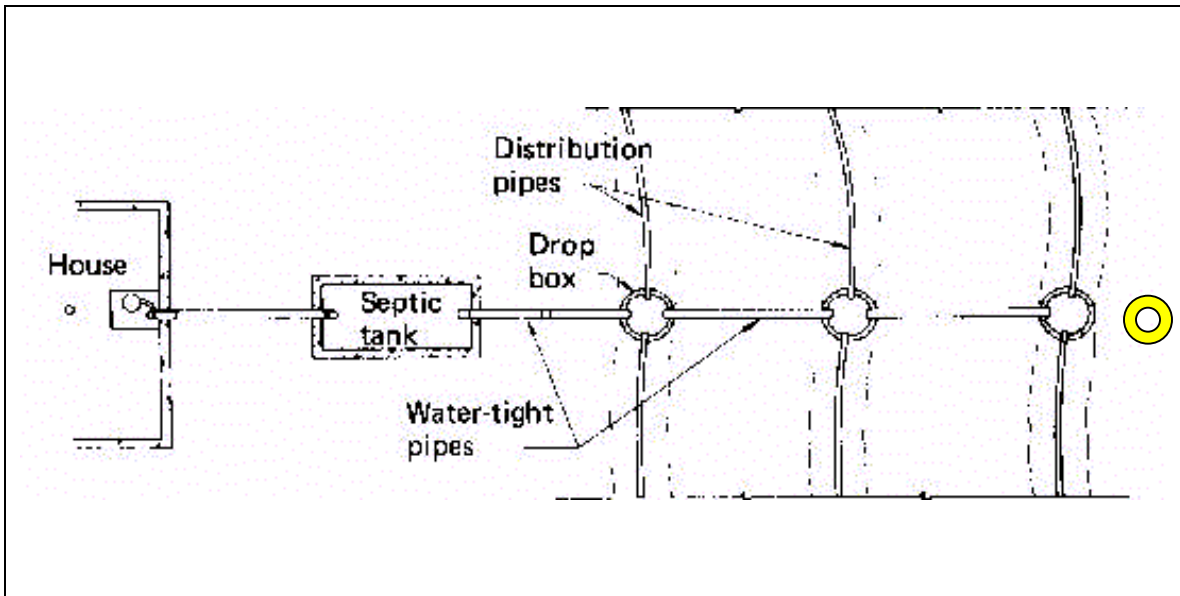


Figure 3.2: locations of shallow surficial aquifer monitoring wells for septic systems.

*It should be noted that the costs of advanced septic systems would increase the cost of the average septic system installation by about \$5000. The installation of monitoring wells will cost about \$200 - \$500. Monitoring wells should be installed down gradient into the top of the surficial aquifer. This can be accomplished with easily with a push core. The monitoring well should be 100 ft from the system or at the property line, whichever is less.

****Modifications to the current CoT Sprayfield Farm.***

There are many options and strategies that can be employed to dispose of the wastewater to protect our springs. These options should be coordinated with Wakulla County for a possible multijurisdictional solution. A multijurisdictional wastewater treatment option could solve regional problems and protect the springshed. It would be easier to acquire federal funding to solve a multijurisdictional problem.

The SESF has agreed to implement Advanced Wastewater Treatment (AWT). Plans included regional sprayfields located outside of Capitol Circle in proximity to the urban areas they services.

The old SESF was a fine wastewater sprayfield. It is well run and managed with state of the art techniques. It complied with state and federal groundwater standards. Unfortunately these standards offered little protection for our springs. The wastewater applied at the SESF percolated into the ground so rapidly that had little water quality treatment. The water applied to the SESF sinks rapidly to over 100 feet depth on site and then hits the dolomite strata and heads for Wakulla Springs through extremely porous media that also offers minimal water quality treatment.

New research shows that highly organic effluents, such as the SESF discharge to groundwater, can have adverse effects on the subsurface soil geochemistry in karst topography. The high BOD of this organic effluent causes changes in the subsurface oxidation/reduction potential and can cause diverse chemical reactions to occur. Highly organic effluents can cause the mineralization of soil bound iron and sulfurous compounds.

The City of Tallahassee has pledged to fix the Sprayfield and go to AWT. They will spend almost 200 million dollars upgrading the system. They will treat their effluent to the same 3 mg/L standard proposed in this study. The opinion that the SESF is returning the water back to the springshed is true and will be beneficial as far as spring recharge is concerned once the upgrade is performed. However, this is misleading because the wastewater at the SESF is collected from numerous areas within Tallahassee and Leon County that are in different springsheds. It should be noted that an effort should be made to return the purified wastewater into the proper springshed.

Table 3.1: Modifications to the current SESF.

Solution	Description	Pros	Cons
Domestic Reuse: Hopkins Plant	Cool Hopkins plant with Waste Water	5mgd Replace groundwater	Expense of pipeline and pumping
Advanced Wastewater Treatment (AWT)	Tertiary treatment of effluent at the SESF with hyacinth ponds and algal turf scrubbers	Tertiary treatment Waste Water Produces useful products	Any additional treatment costs some money
Domestic Access Reuse Piping	Residents could water with treated wastewater	This would lessen withdrawals from the aquifer	Water would need to be pumped north to Tallahassee
Domestic Reuse: Northside Miniplant	Irrigate with Waste Water, north side	Irrigate with Waste Water	Expense of new mini plant
Domestic Reuse: Capital Cascade Greenway	Irrigate with Waste Water, Capital Cascade greenway	Irrigate with Waste Water Provide base flow	Expense of new mini plant
Discharge to Ochlockonee River	SW Discharge	Could cleanse Ochlockonee	Possible effects on Ochlockonee Bay Difficult Permitting
New Sprayfield: Highway 20	New WWTP	Aquifer confined Replace septic systems	Need land, Mounding, National Forest
New Sprayfield: Joint System with Crawfordville	New WWTP	Good funding opportunity Replace septic systems	2 municipalities Possibly in Spring Recharge Area
Deep Well Injection GW Discharge	Deep well injection	No surface water discharge	Possible effects on aquifer Permitting
Pipeline to the Gulf	Pipe the sewage to Apalachee Bay	None	Marine Pollution Impossible Permitting Issues

Since the City of Tallahassee has agreed to go to AWT much of the problem has been solved. Three actions described below could be evaluated for cost benefit and implemented in the near future.

First: A pipeline could be constructed to the Hopkins Plant and cooling water drawn from the aquifer could be replaced with wastewater from the SESF. This would decrease the amount of water withdrawn and pumped from the Floridan Aquifer as well as utilize at least 4 mgd of wastewater that would be volatilized in the cooling process at the plant and not go to Wakulla Springs.

Second: Miniplants could be constructed at several locations in northern Leon County so that the City of Tallahassee and Leon County have the opportunity to practice domestic

reuse. Currently, water treated for domestic reuse has to be pumped to the WP Smith Plant for treatment and then pumped back to the northside of town. This is expensive and impractical. With local miniplants in operation highly purified gray water could be used for irrigation on golf courses, road medians, college campuses and even individual residences. Reused water could even be used to provide the increased base flow in the Capitol Cascade Greenway. Domestic Reuse of wastewater should be encouraged. Obviously the flow of reuse water can be controlled and if it is to provide only base flow it could be turned off prior to anticipated flood events. Adequate base flow improves the flushing of a system and with all the ponds proposed for this drainage, the Capitol Cascade Greenway there is ample opportunity to make sure that no flooding occurs.

Third: Coordinate with Wakulla County to develop regional solution to protect our springs. Wakulla County is closer to Wakulla Springs and because of that proximity they will have to implement higher treatment standards than Leon County.

The above suggestions will need additional cost benefit evaluation before implementation. Environmental benefit for the reduction in nutrient pollutants can be evaluated using the WAMview model to simulate loadings to the aquifer. These model runs are beyond the current scope of this study and should be performed as part of a cost benefit analysis to evaluate and select design and engineering options.

A new sprayfield could be constructed outside of the WRB in western Leon County, Gadsden or Liberty County where the geologic conditions may be more suited to a sprayfield. These areas, and the area along Highway 20 West, in Leon County have a confined deep aquifer and a surficial aquifer. These areas have soils suitable for wastewater treatment. There are fewer sinkholes in these areas but have a lower percolation rate that would require more surface area than the current sprayfield.

The option of a new sprayfield in that area should be explored, possibly in conjunction with Wakulla County. Areas in Gadsden County that are within the Gulf Trough and the Apalachicola Embayment have very thick clay layers (this is where attapulgite is found). The clays in the Apalachicola Embayment can make it very difficult to obtain ground water in these areas. Perhaps treated wastewater could be a boon for agriculture in the area. We also discussed the availability of land, particularly in regard to the National Forest. That land should be avoided. This option has some intriguing possibilities but will require an engineering and political analysis that is beyond the scope of this investigation.

Deep well injection of the wastewater also needs investigation. The finding that highly saline waters underlie the WRB at depths of 300 feet and greater implies that there is not mixing between the Floridan Aquifer and this deep saline layer. This water does not discharge at Wakulla Springs. Little is known concerning this deep saline layer as it was just discovered. This possibility of deep well injection needs investigation.

From a regulatory standpoint this may it is commonly thought that the Floridan Aquifer is undifferentiated in our area. If wastewater were injected into the Floridan Aquifer at depth it could change the hydraulics of the aquifer. There are no definitive confining layers that would act as a barrier with the Upper Floridan and insure that the wastewater injected into the aquifer would stay in lower levels of the aquifer. Injecting effluent could disrupt density gradients. The Floridan Aquifer does not well seem to be well suited for injection into the lower aquifer. However the presence of saline waters below 300 feet in Leon County and the newly observed dolomite layers that may behave as a confining layer imply there may be some differentiation of aquifer units. This shows how little we know about the Floridan Aquifer in our area. At least FGS should sink some more deep test wells because if there is a stagnant saline layer at depth in the aquifer this could work. Officials at FDEP and the NFWFMD believe that this option does not merit further investigation because advanced treatment is a much better option.

Also, it is very important to note that several cities in Georgia near the Ochlockonee River discharges minimally treated wastewater into the Ochlockonee River. The base flow of the Ochlockonee River is mostly WWTP effluent from Cairo, Moultrie, and Thomasville, etc. During high river stages the Ochlockonee River flows into Lake Iamonia. The high river stages causes the springs to reverse flow thereby allowing the introduction of additional water containing nutrients into the Floridan Aquifer adding to the background concentrations that are observed at hydraulically down-gradient areas. Tallahassee could discharge tertiary treated wastewater into the Ochlockonee River. This needs further investigation and is not a preferred solution.

One of the peer reviewers asked us to consider a pipeline to Apalachee Bay (south of St. Marks) is a possibility rather than tertiary treatment. They claim that the freshwater (20 MGD) would be a small amount compared to freshwater already discharging to Apalachee Bay. We feel that piping is not a good option for disposal into another area. There would be no benefit of recharge to the other aquifer. According to state regulatory officials this amounts to putting the problem somewhere else, not fixing it. Instead they recommended public access reuse piping throughout the County.

****Sewer Systems for the WRB.***

Decentralized sewer systems have a higher level of treatment. Here the effluent is pumped to treatment plant. Decentralized sewer systems can service 20 to 50 lots, sometimes as many as 100 lots per unit. These would have to be AWT (FDEP), with percolation ponds or a small sprayfield. This could allow higher density developments. Statewide, the number of decentralized sewer systems is decreasing. For example the Fallschase WWTP is being integrated into a larger municipal system. As growth continues the large systems expand into these areas. The people that own them generally do not want to be in the business. It is estimated that these systems will cost a third to a half of the cost of sewer in the remote and ecologically sensitive portions of the WRB.

The regulation and management of these systems is very important. Monitoring wells should be required on all systems in order to evaluate their performance. Penalties and fines should be imposed on the systems that fail to perform as required by their permit. Level-2 management requires that a responsible party manage the system. Level 5 management requires ownership of unit by management company that managements it. The formation of a Government Utility Authority is recommended with Capitol Outlay and User Fees. The selection of the management level requires a planning and budget evaluation that is not within the scope of this study.

There is a need for further WAMview model runs and engineering analysis to fully evaluate the nutrient loading to the aquifer from all of these different types of systems. For example, we need to evaluate weather the concentrated loading of a decentralized sewer system is really as efficient as the diffuse loading of scattered aerobic septic systems.

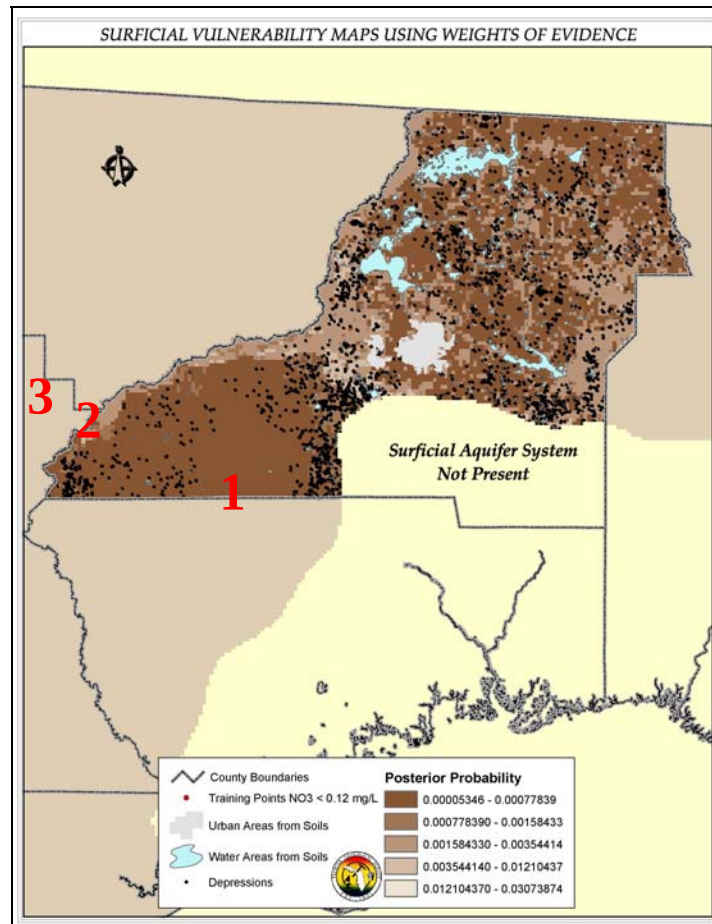


Figure 3.3: the following is an aquifer vulnerability profile for Leon County by FGS. The WRB lacks a surficial aquifer and confining layers. Three areas have suitable soils for wastewater disposal over a protected aquifer: 1 - Highway 20 west of the WRB; 2 - the Ochlockonee River; 3 - Gadsden County and Liberty Counties.

Based on the WAMview model results, the Woodville Community would benefit from being served by a sewer system. The WAMview model demonstrates that high density developments on a sewer system have lower nutrient loading rates than low density developments on conventional septic tank systems. New developments in the WRB should be encouraged to be on sanitary sewer. Medium and low density developments should be encouraged to cluster, such as shown in figure 4.3 in a beehive manner, so that infrastructure costs and logistics would be minimized. The associated lands in the cluster could be maintained as open space under conservation easement or utilized for low impact activities. This could help preserve the natural attenuation of stormwater runoff and associated nutrients. The WRB is relatively flat and most types of wastewater disposal will require pumping and pipes. Clustered lots and housing helps maintain zoning densities, and minimize infrastructure costs and urban sprawl, while it maximizes open space

could be maintained as open space under conservation easement or utilized for low impact activities. This could help preserve the natural attenuation of stormwater runoff and associated nutrients. The WRB is relatively flat and most types of wastewater disposal will require pumping and pipes. Clustered lots and housing helps maintain zoning densities, and minimize infrastructure costs and urban sprawl, while it maximizes open space.

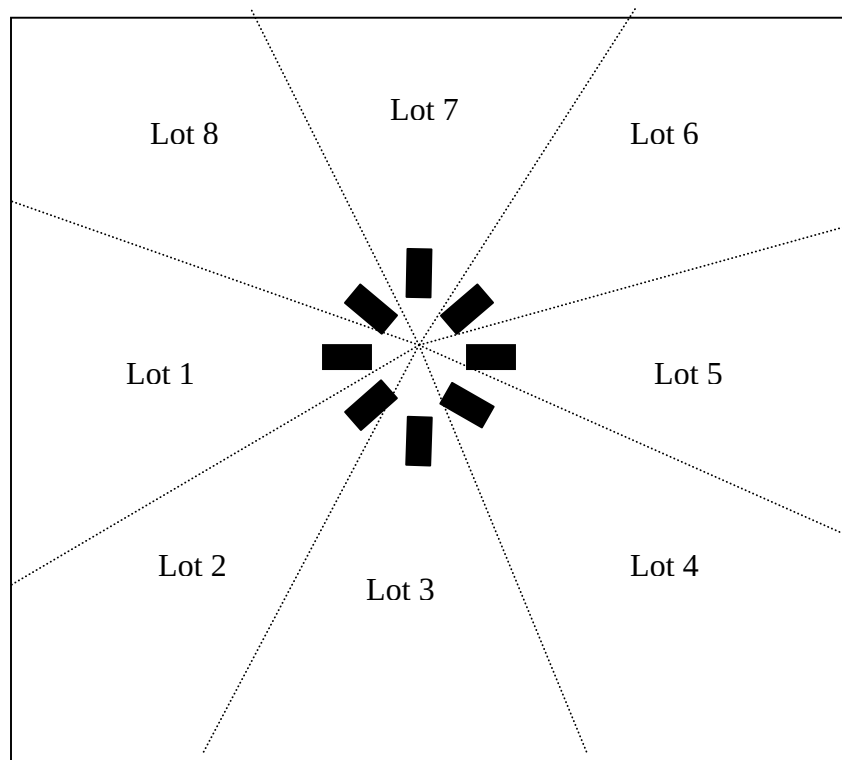


Figure 3.4: A clustered low density single family home unit. This maintains zoning densities, minimizes infrastructure costs and maximizes open space. This would minimize the impact of development where the Floridan Aquifer is vulnerable.

****Better water quality treatment regulations for stormwater runoff.***

Currently, the WRB is not known to have a problem with urban stormwater. Very few surface water features (lakes or streams) exist within the WRB in urban areas. Most of those that do exist are either above the Cody Scarp where there are thick clay layers of the Hawthorn formation or where it runs off the Cody Scarp into the lowlands of the central WRB. In some areas eroded sediment carried by surface water has been deposited in low areas of the WRB and has formed low permeability layers in some of the basins in the unconfined WRB. Here water briefly accumulates in lakes before it percolates into the aquifer and disappears. These lakes are found to the west and east of the SESF and need protection as land on the Cody Scarp is developed.

The St. Joe Corporation is currently developing the area north of the Cody Scarp, as a development called Southwood. A series of ponds are utilized in the Southwood development to treat the stormwater before it evaporates or percolates into the unconsolidated sands and clay sediments above the Floridan Aquifer in this part of the WRB.

However, the unconfined portion of the WRB is poorly suited for traditional stormwater ponds. The lime rock foundation of the WRB is so close to the land surface that storm water ponds are likely to provide a direct connection to the Floridan Aquifer. These storm water ponds could have the potential to develop sinkholes if the unconsolidated sediments above the limestone are eroded and enter voids in the limestone formation. These ponds could allow nutrient polluted stormwater and sludge to flow directly into the Floridan Aquifer, adding to the current pollutant loading. Traditional storm water retention ponds should be discouraged in the WRB in favor of constructed marsh systems that provide treatment of nutrient pollutants by natural organic process before it flows into the aquifer.

Recently sinkholes have formed in a new holding pond near SESF. These ponds were built by St. Joe Corporation in November 2005 to treat the stormwater from the developments in Southwood, which is located above the Cody Scarp in the WRB. Even the clays used to construct the bottom of these ponds are relatively foreign to the WRB. These clays have high phosphate content and in the phosphorus poor sands of the WRB this is a pollutant. The use of phosphoric clays in the WRB should be discouraged, as they themselves are a pollutant.

It is recommended that synthetic liners be utilized if stormwater retention ponds have to be built in the unconfined WRB. Furthermore, the use of highly pigmented clays, which are very common north of the Cody Scarp, should be prohibited in the WRB. Pigments from these clays could slowly leach into the aquifer and affect the clarity of our springs.

Although stormwater ponds may not be a desirable feature in the unconfined WRB, they are required by current regulations to control and treat storm water flow from developments. The collection of stormwater concentrates it at one location and the soils of the WRB do not have the capacity to treat it. The soils can handle diffuse loadings very well but not a concentrated loading. Smaller developments in the WRB should be exempted from current stormwater treatment requirements and more innovative best management practices should be examined to provide a means to disperse the stormwater over a larger area to gain the desired treatment. This matter needs further study. The NPDS requirements are designed to protect receiving waterbodies and there are very few of these receiving waters in the WRB.

Stormwater can be treated by phyto-remediation, which absorb most of the nutrients. Disney has used this technology for a long time at Reedy Creek. Final tertiary treatment of the wastewater could then be accomplished with algal turf scrubbers. Stormwater would then meet the improved groundwater quality standards. The periodic harvesting of the plants produces a product that can be used as livestock feed, biofuel or mulch. From an ecological standpoint this 'green' solution is attractive. Dr. McGlynn visited plants plant at Disney and on Lake Okeechobee (SFWMD) and found them to be quite impressive (Appendix 2).

This report simply noted that percolation ponds in areas where the aquifer is unconfined and where there is less than 40 feet of sand (which has little treatment capacity) over the aquifer are rather ineffective and that they tend to develop sinkholes. Sinkholes short-circuit the treatment capacity of the aquifer. Plugging the sinkholes is very expensive and runs the risk of blocking significant conduits that carry water to discharge points. The intent of this report was to point out that it would be more efficient from both water quality and economic perspectives to not concentrate the percolation of water in one place but to attempt to spread out the percolation over a larger area as would occur, in a natural setting.

Not all clays have the same phosphorus content. Hawthorn deposits, such as we have in northern Leon County have very high phosphorus content, often 30% to 50% phosphorus. This is why these deposits are often mined for phosphorus. Hawthorn deposits should not be used as liners. Clay deposits that are low in phosphorus could be used. The analysis of the phosphorus content of clay is rather inexpensive, usually less than \$50 per sample. It would be wise to measure the phosphorus content of the clays and require low phosphorus content in the WRB. This is infinitely cheaper than cleaning out the phosphorus after it gets into the aquifer before it damages sensitive resources, like springs. Regarding Hawthorn Clays and other clay soils containing elevated phosphorus. There is a chemical equilibrium between absorption and desorption with the interstitial water. Hawthorn clay can actually release phosphorus to the water. This is basic chemistry and in this study we actually measured to equilibrium concentrations. Which are presented in the table below. Samples were run in triplicate and results clearly show

that Hawthorn Clay sampled in central Leon County had soil/ water phosphorus equilibrium concentrations of 0.048 mg/L total phosphorus. This is the concentration of phosphorus found in nutrient free water that was placed in contact with the clay. This result can be called leachable phosphorus. This phosphorus concentration is elevated from a surface water quality perspective. The Hawthorn also released nitrate to the water. Sand and Lime rock did not leach significant concentrations of nutrients.

Table 3.2: Leachable nutrients from soils in the WRB.

Soil Sample (September 2006)	Nitrate as N EPA 353.3 mdl=0.008 pql=0.032 mg/L	Total P as P EPA 365.2 mdl=0.003 pql=0.012 mg/L
WRB Lime Rock	0.019	BDL
WRB Lime Rock	BDL	BDL
WRB Lime Rock	0.011	BDL
Tallahassee Hawthorn Clay	0.171	0.043
Tallahassee Hawthorn Clay	0.162	0.059
Tallahassee Hawthorn Clay	0.140	0.041
WRB Sand 1	BDL	BDL
WRB Sand 1	BDL	BDL
WRB Sand 1	BDL	BDL
WRB Sand 2	BDL	BDL
WRB Sand 2	BDL	BDL
WRB Sand 2	BDL	BDL

A clay material that does not contain phosphate would still be an appropriate material. Phosphate content of clays varies considerably. Hawthorn can be 30% to 50% phosphate. Grain to pebble size inclusions are common. A certified chemical analysis should be obtained that shows that the clays do not contain phosphate.

Filter fabric with fine sandy soil layer above it (fine mesh) could do this. The sandy soil overlaying it would decrease the maintenance necessary.

This study was not a stormwater study but I am pleased to offer a little help here. In its natural condition, the WRB does not produce any stormwater. The perk rates of the sandy soils are so high that surface water does not leave the basin. Surface water perks so rapidly that none of the sinkholes in the WRB actually receive significant amounts of stormwater runoff. These kinds of sinkholes, the ones that receive significant stormwater runoff, are all located where there are significant clays to slow the perk rate and the

stormwater flows in channels to the sinkholes (Porter Hole, Lafayette Sink, Bird Sink, Ames Sink etc.).

The only reason that there is stormwater in the WRB is that current engineering practices collect it and concentrate it at certain points such as stormwater treatment ponds). The soils of the WRB have little capacity to handle this concentrated amount of stormwater and may form sinkholes in these ponds. It might be more efficient from both water quality standpoints and economic standpoints to try to adapt our stormwater engineering to the natural condition of the WRB and design more systems which allow a diffuse runoff flow to percolate naturally into the sandy soils by minimizing impervious surfaces as well as employing thoughtful placements of berms and swales to create a diffuse flow. By not collecting so much stormwater there would be less flooding and greater treatment of the water.

In instances where the amount of runoff is too great, like at a large commercial shopping mall in an urban setting, it would be better to locate such facilities where soils are better suited to treat by an appropriate technology by using stormwater treatment systems that use filter marshes or littoral benches to convey water to a pond that provides retention, detention, percolation and evapotranspiration to meet the treatment goal. (IE. Such as areas where soils have significant clayey sand layers, and adequate elevations above the aquifer, and where the aquifer exists below a clay confining unit).

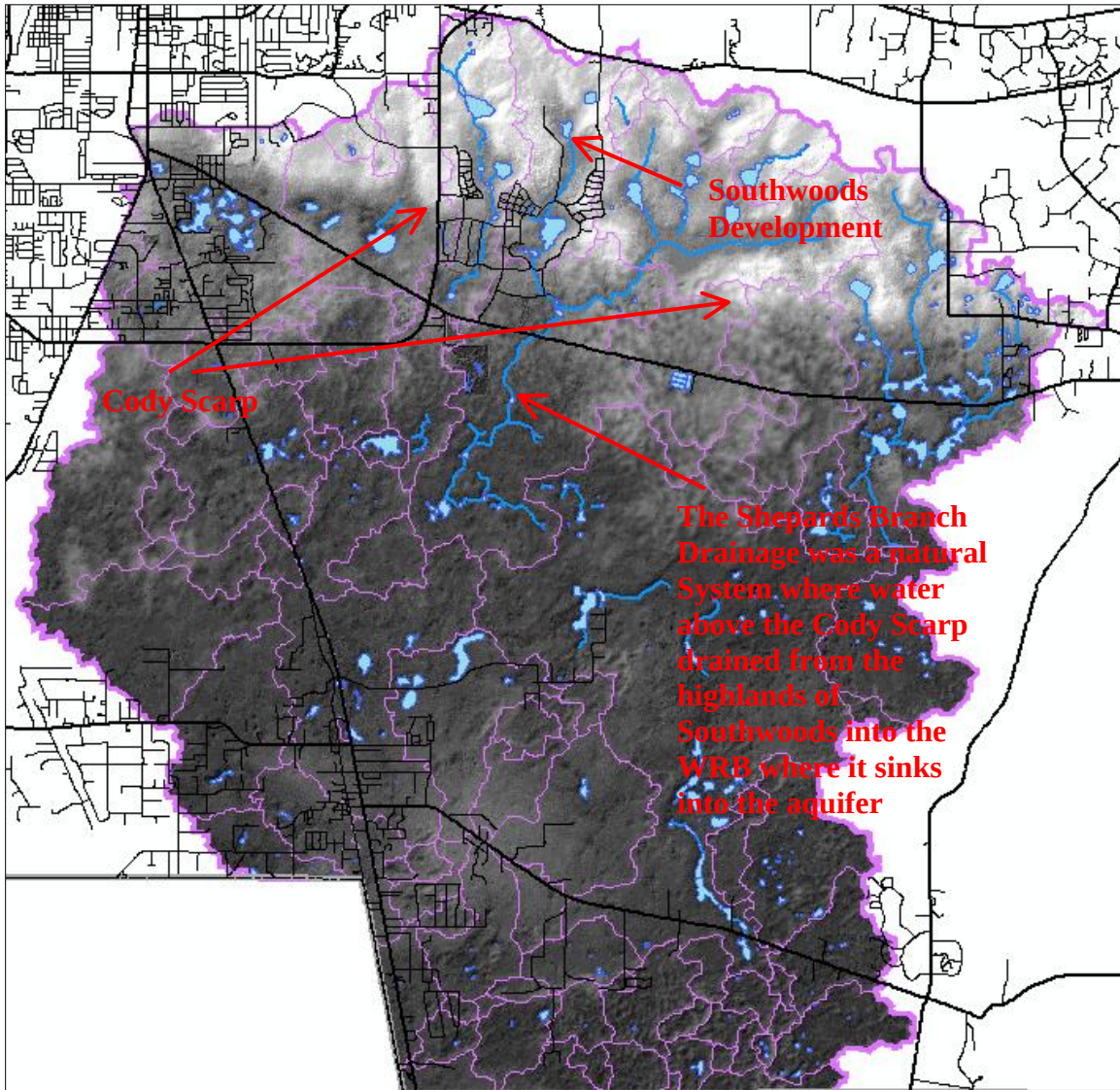


Figure 3.5: Drainages in the Woodville Basin. The Shepard's Branch drainage begins on the hills of Southwoods and runs under a bridge on Highway 259. The drainage sinks into the sands of northeast of Woodville.



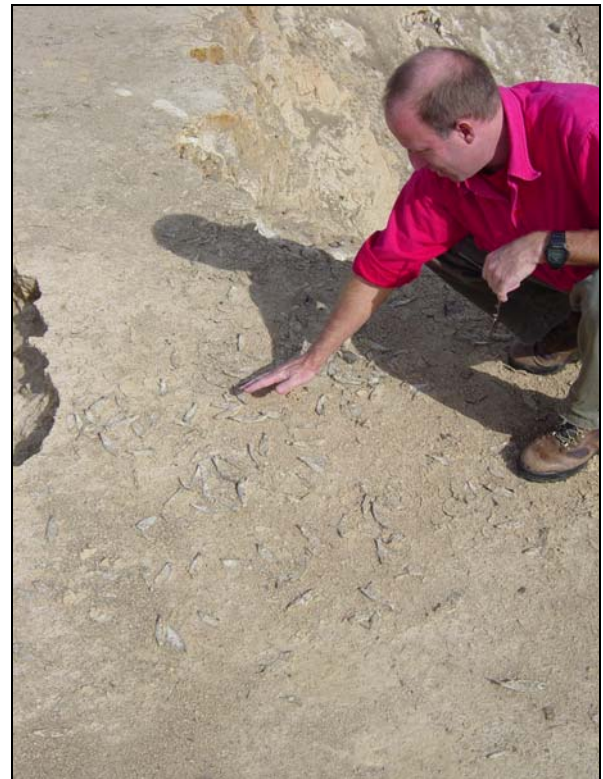
Figure 3.6: map depicting the sites shown in the following pictures. Site 2 was where the new sinkholes formed. Sites 1, 3 and 4 are altered natural features, mostly karst in nature, that are part of the Shepards Branch Drainage.



Site 1: Pond in Southwoods dry



Site 2: Sink in Eastern pond.



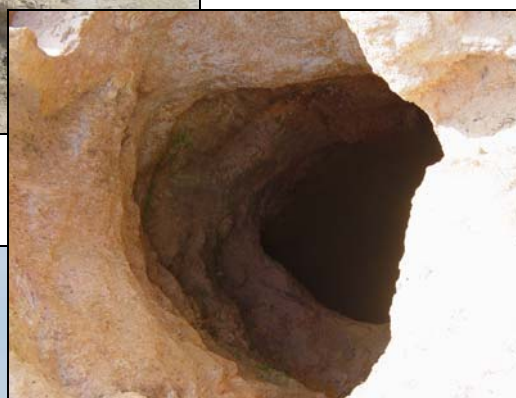
Site 2: Sink in Eastern pond, dead fish at rim of sink. This shows that this pond had been holding water for enough time for it to develop a fish population.



Site 2: Additional sinks forming in Eastern Pond



Site 2: Sink in Western Pond



Site 2: Sink in Western Pond.



Site 2: Additional depressions forming in Eastern Pond



Site 2: Sink in Western Pond.



Site 3: Live Oak Orchard Pond where the drainage ends and the waters from the Cody Scarp sink into the aquifer.



Site 4: Lutterloh Pond another dead end where the waters from the Cody Scarp sink into the aquifer.

****Specific Stormwater retrofit projects to provide stormwater treatment prior to discharge.***

The WAM model results demonstrate that the WRB does not generate large amounts of storm water runoff at this time. The rural nature of the basin coupled with the high percolation rate causes water to infiltrate into the ground rapidly and generates minimal volumes of stormwater. However, stormwater from more urbanized areas enters the WRB from other drainage basins such as the adjacent Lake Munson Watershed and the Southwoods Development, which is located above the Cody Scarp within the WRB.

We propose two stormwater projects and two habitat restorations. The most important stormwater project for the Basin is the Blueprint 2000 retrofits to the Capitol Cascade Greenway, all improvements along the historic St. Augustine Branch, which drains into Lake Munson. Phase IV of the Blueprint 2000 project, the Springhill Road segment, offers the greatest opportunity to improve water quality. The second stormwater project involves improvements associated with the ponds associated with the Southwoods Development in the WRB (previous section). The two habitat restorations deal with the central wetland, an archaic river course which runs through the center of the WRB and the wetland just north of the Woodville Community.

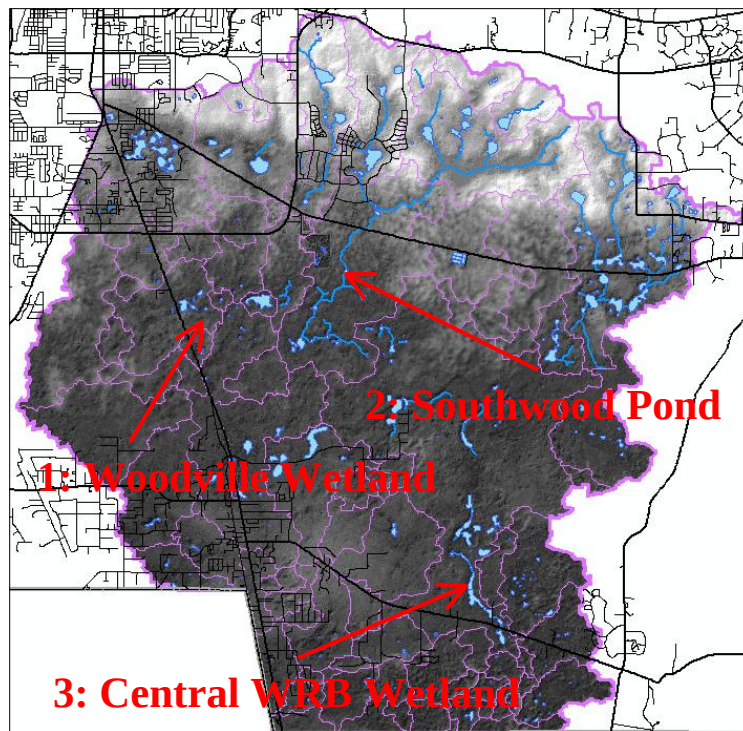


Figure 3.7: Stormwater projects suggested for the WRB

Lake Munson and Ames Sink

The Lake Munson Watershed receives stormwater from just over 30% of the City of Tallahassee including Florida State University and Downtown Tallahassee. Stormwater of impaired quality flows down the St. Augustine Branch into Lake Munson and eventually drains into Ames Sink where it sinks in that open karst feature directly into the Floridan Aquifer. The waters from Ames sink flow underground through caverns to Wakulla Springs in about 7 days.

When Ames Sink is overwhelmed, water stages up and pops off into neighboring closed basins and floods parts of the WRB. Two stormwater ponds have already been constructed in the drainage, Elberta Crate and Henrietta. These offer scant water quality improvements since they are bypassed in major storm events. The Lake Munson Restoration adequately addressed flooding concerns near the FSU Stadium and Lake Bradford Road, but the straightening of Munson Slough as well as the creation of trapezoidal sides and the removal of the willow covered shallow mud flats in Lake Munson has allowed stormwater volumes in Lake Munson to increase.

The results of this study show that Ames sink delivers up to 1600 lbs/day of nitrogen to Wakulla Springs in four days. How does this one feature affect nitrate concentration at spring? Since one pound of nitrate will contaminate approximately 120,000 gallons (assumes 8.3 #/gal) of water to 1 mg/L (ppm) then 1600 pounds will contaminate 192,000,000 gallons of water to 1 ppm. Since the spring discharges about 1,000,000,000 (billion) gallons of water a day, Ames sink could account for approximately $\frac{1}{4}$ of the nitrates contaminated to 0.8 mg/L (or 0.2 of the 0.8 mg/L observed from Ames sink alone). This is significant (peer review comment from Tom Kwader, PG).

The Elberta Crate facility was designed to capture the first flush of an isolated storm event. There are control structures that direct the first inch of rainfall or stormwater runoff into the facility. Anything over an inch bypasses the facility. This is an offline pond; a diversion dike is in the middle of the channel. When the dike is overtopped all subsequent stormwater goes into the stream. The captured water, which is supposed to represent the first flush, theoretically the dirtiest stormwater gets 100% retention in the pond. This helps with water quality but it is not enough and this fact is well recognized. Additional funds are being allocated to further addressing this water quality problem through BLUEPRINT 2000, which has already designed 4 different options for a series on ponds along Springhill Road to address this water quality issue. These ponds are not deficient but are helpful in addressing the stormwater issues on the Capitol cascades Greenway. All of this water flows into Lake Munson and then through sinkholes eventually reaches Wakulla Springs. These ponds although inadequate, have been recognized as part of the solution, to address the water quality issues in the Lake Munson Watershed that have caused the collapse of the Lake Munson ecosystem (McGlynn 2007, <http://www.mcglynnlabs.com/LakeMunsonFishKill0107.pdf>).

These facilities were never thought to adequately address the water quality issues concerning the stormwater that flows into Lake Munson, which has been experiencing ammonia toxicity, toxic algal blooms, oxygen toxicity and the mass mortality of aquatic plants and juvenile fish for the past two years. Furthermore, more funding is already being allocated by BLUEPRINT 2000 to address this issue. It is also the opinion of many scientists and non-scientists in Leon and Wakulla Counties that the stormwater in Lake Munson also affects water quality in the springs.

The water quality of the Lake Munson and the water that discharges into Ames Sink has deteriorated. This is evidenced by persistent algal blooms in Lake Munson that have resulted in elevated levels of algal toxins in Ames Sink. Blueprint 2000 has the ability to implement best management practices that would improve the quality of the stormwater discharging into Ames Sink. The marshes and ponds planned along the St. Augustine Branch could alleviate this problem if they are properly designed. Algal turf scrubbers should be included in the design of the marsh to polish the stormwater before it enters Lake Munson.

A lot of the sediment removed from Munson Slough was very degraded. Much of it was litter. This was a good activity but in doing so blockages were removed that slowed down the flow of the water. These blockages, while composed of unnatural material, should be removed, but their physical effect was actually to increase the treatment capacity of the slough by increasing the residence time of the water in it. Straightening the slough and reducing friction by smoothing and grading the banks also has the same effect. While the irregular banks, curves and debris piles in the slough mimic conditions none of the natural marshlands that once existed in the slough were restored to buffer the increased velocity of the water.

The Lake Munson Ecosystem has become severely degraded since the work was performed on the slough and more work is planned to finish improving the water quality of the water that enters Lake Munson through Munson Slough. This is subjected to a TMDL by FDEP. It is unreasonable to blame the restoration for this situation since this project was only a small part of the work planned to mitigate the flooding and improve water quality in the watershed. Once the ponds in the Capitol Cascades Greenway are complete (if properly designed) these water quality in Lake Munson should greatly improve. Camp, Dresser and McKee, Inc. took the first step to bring Lake Munson back but unless we further improve water quality in the Lake Munson Watershed it will be a wasted effort. These projects are planned as part of BLUEPRINT 2000's Capitol Cascade Greenway. We need to make sure that they happen.

Southwoods Ponds

The Southwoods Ponds (previous section) are rectangular. They need to be rendered more curvilinear and expanded to include the desolate sand mines just to their south. The sand mines should be converted into a shallow marsh system to allow additional

treatment of the stormwater. Algal turf scrubbers should be included in the design of the marsh to polish the discharge before it enters Lakes Lutterloh and Live Oak Orchard Pond. There is a similar drainage on the eastern side of the SESF, the hidden lakes drainage. Both these areas south of the Cody Scarp hold water most likely because of the erosion and redeposition of clay sediments. This area may need similar attention as Southwoods continues to develop. It is important that the lakes south of the Cody Scarp be preserved.

The two wetland areas designated for restoration in the WRB include wetland areas on both sides of the Woodville Highway just north of the town and the Central Wetland, a long narrow wetland ribbon extending north to south through the WRB.

This pond is a percolation pond. There are considerable problems with these ponds and the development has been seriously considering abandoning them and may already have abandoned them (personal communication from an anonymous engineer). The comments is engineering related and beyond the scope of the WRB study. However, other ponds like Elberta Crate and Henrietta have had similar problems with sinkholes that cost hundreds of thousands of dollars to fix.

The Community Development District owns these ponds (CDD). So the county can have as much effect as the city on their operation. As stated in the text of this report, this area, as well as the area on the other side of the CoT Sprayfield is natural drainages from the upland Cody Scarp. These two areas naturally contain marshes and lakes because of the clays that have eroded off the Cody Scarp and deposited there by the drainages. The drainage on the other side of the CoT Sprayfield is likely to need similar stormwater treatment as the previously mentioned Shepard Branch Drainage. The science needed to do this adequately is being presented here. Use the natural system to help preserve water quality and surficial flow. By percolating and retaining the natural flow from the Cody Scarp we cause the natural lakes and wetlands in this area to desiccate, particularly during dry periods. We must preserve the natural hydrology. Holding Ponds are a bad idea since they seem to inevitable form sinkholes and pollute the aquifer. A marsh system would function better. This marsh system could be augmented by phyto-remediation techniques like algal turf scrubbers if additional water quality treatment is desired. The marsh system should be designed to improve water quality and the natural hydrology. These areas will only develop flooding problems if impervious surfaces are increased on the Cody Scarp. I hope that we do not sacrifice these wetlands and lakes in the future. If the uplands cannot adequately address these issues in the uplands where there are adequate clay lenses to allow stormwater retention ponds then further development there should be avoided.

It should be noted that the drainage from the Cody Scarp on the east side of the CoT Sprayfield Farm is similar to the Southwood Drainage. When development occurs in the St. Joe properties above the Cody Scarp that drain into this region a similar situation may arise. This drainage flows into the Sprayfield buffer and the Hidden Lakes. These lakes

are similar to those that receive water from the Southwood Drainage. An enhanced wetland may be preferable to another large holding pond. The lakes below the drainage need the water from the scarp to maintain water levels. Allowing the water to flow and receive treatment from wetlands is a more natural solution. If an enhanced marsh should become inadequate for water quality treatment the system could be augmented with phyto-remediation (Appendix 2).

Central Wetlands

The central wetland was once a river; probably Paleolithic, and clay deposited by that alluvial flow have sealed the basin which now holds water. The entire region is degraded from heavy logging and needs to be replanted and aquascaped. Ditching and the drainage of the wetlands in areas for logging activities have altered the hydrology. As the WRB develops this area, it will become increasingly important to treat the surface water that flows into it. As a wetland, this area does not contain karst features that connect it with the aquifer. The preservation and restoration of this wetland is of vital importance to the future health of the WRB.

The Central Wetlands is a dominant feature of the landscape in the WRB. As mentioned earlier the natural condition in the WRB is that not much stormwater collects on the highly permeable forest soils that surround the central wetlands. These central wetlands seem to collect only the rainfall that falls on to it and seepage from the aquifer. A hydrology study of the Central Wetland would be useful.

There is no visible expression of a sinkhole in the Central Wetlands. LIDAR did not find a sinkhole. The area is currently leased to hunters. These hunters know the Central Wetlands very well and during the drought walked all over it while it was dry. They never found a sinkhole. Chris Werner, PG. surveyed the area too. He did not find an open karst feature in the Central Wetland. Alluvial deposits from an ancient river course seem to have sealed this area. Other sinking streams in Leon County have visible features where they disappear. There are no visible features that indicate that this is a sinking stream.

The Central Wetlands exists contrary to the data on our percolation Charts. The Central Wetland is a narrow but long feature in the WRB. It is on land owned by the St. Joe Corporation and is leased to Hunt Clubs. Access to this area is very difficult to get. There are numerous locked gates. There are no good roads. The area contains a lot of hunters that become very annoyed when disturbed. It has probably never been properly surveyed. It is obvious that the Percolation Charts we have missed this feature, which does not percolate but holds water very well. I have already had the sub basins in the WRB modified because they did not account for this feature. This feature is there.

- (1) The Central Wetland is currently in a very natural state. We should study its hydrology so that it is not disrupted by development. The hydrology does not currently need to be restored it need to be preserved.
- (2) Exotic plants and animals have not yet invaded the wetland,
- (3) The native vegetation in the wetland needs to be restored in the Central Wetlands. This should be performed as a habitat enhancement. This entire Central Wetland seems to have been clear-cut within the past ten years. Larger cypress trees are nonexistent but there are numerous stumps. Juvenile cypress trees are coming up in the wetland. Many of these are growing much too profusely. The natural condition would be that few seedlings would survive beneath the canopy of mature cypress. When all the cypress is all of the seedlings come up at once. In pine plantations they thin out the trees so that there is healthy growth. This needs to be done in some places. In other places the planting certain types of vegetation would be helpful.
- (4) There does not appear to be any pollution in the Central Wetlands since it is in the middle of a huge tract of timber. There do appear to have been two oil wells in the area. These need to be investigated but I do not anticipate any problem since the one I found was adequately sealed and the hunters had removed most of the superstructure for their hunting stands.
- (5) This area is so flat that the surrounding uplands are not very high. The depth of the clay deposits should be investigated as well as the bathymetry of the wetlands. Some of these wetlands may actually be lakes. If there are adequate clay layers the lakes could be deepened to improve habitat. If the surrounding uplands are not highly vulnerable to aquifer pollution

Woodville Wetlands

The Woodville Wetlands need to be improved and could provide a natural gateway into the Woodville community since it is on both sides of the highway just north of the town. The lake is artificial and was dredged in the past. The floating dock in it is partially submerged and needs to be removed. The wetlands appear to be in good shape and could benefit from a nature walk that would give people access.

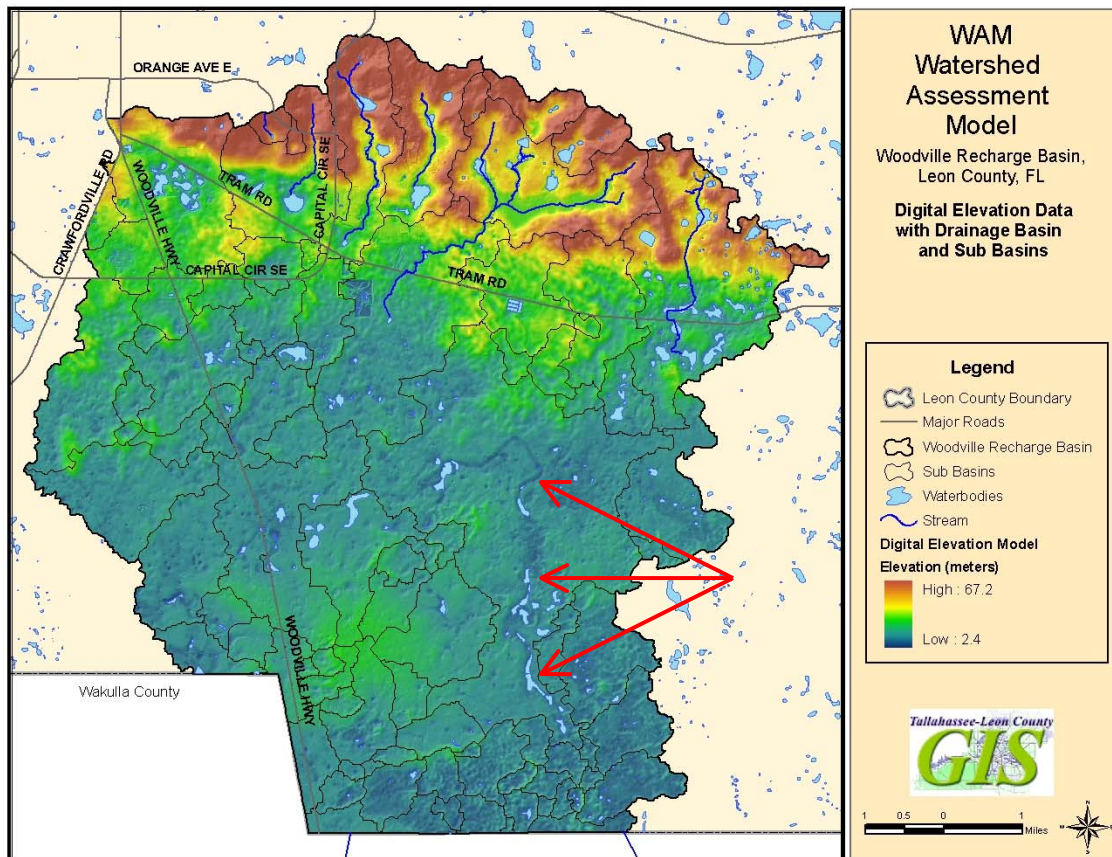


Figure 3.8: This digital elevation map shows the central wetland



Figure 3.9: hypereutrophic Lake Munson



Figure 3.10: Aerial view of the central swamp



Figure 3.11: Selected close up views of the heavily logged Central Wetlands running through the WRB.



Figure 3.12: sand mine in foreground with the Southwoods pond just above.



Figure 3.13: lakes at the terminus of the Shepards Branch drainage.



Figure 3.14: The sand mine and the Southwoods pond.

****Restrict certain land uses or the density of development in aquifer vulnerable areas.***

Leon County is very fortunate that the historical usage of the WRB was silviculture. There are very few developments or almost no industry in this region. We can thank St. Joe for having good land management practices that have assisted in maintaining the aquifer quality and magnificent springs. The WRB just south of the Cody Scarp is particularly vulnerable to surficial pollutants since it represents an ancient coastline where the ancient rise and fall of sea levels has eroded clay layers that could protect the aquifer. It would be nice if we could fence it all off to keep it natural and protected but that is not realistic. The WRB will be developed and Leon County has a chance to implement design standards and regulations that will protect this invaluable resource for future generations.

Wastewater disposal should be restricted in this region. As much of this region as possible should be served by a sewer system that does not contribute to the degradation of surface and groundwater quality. Septic systems need to be monitored and serviced by licensed providers. The use of fertilizers in residential areas should be discouraged. Xeric landscaping should be promoted. Residential low impact and carefully sewered developments are the preferred Landuse. Agriculture, which requires extensive fertilization, should be discouraged. Industrial Landuse should be discouraged if it can not be designed and constructed in a manner that does not adversely impact surface and groundwater quality.

The entire Woodville Recharge Basin south of the Cody Scarp is an aquifer vulnerable area. Here the aquifer is unconfined. There should not be any heavy industrial activities that involve chemicals that could be released into the environment. Landuse that require high degrees of inorganic fertilizers should be restricted. If farming is performed they should be tree farms or organic farms that do not use fertilizers or pesticides. If the land is too low, like marginal wetlands development should also be avoided.

****Purchase specific aquifer vulnerable lands by government.***

It would be nice if Leon County could purchase the most vulnerable aquifer recharge areas in the WRB since this would protect the aquifer and ground water quality. This would amount to almost 30% of the WRB. Perhaps this is unrealistic.

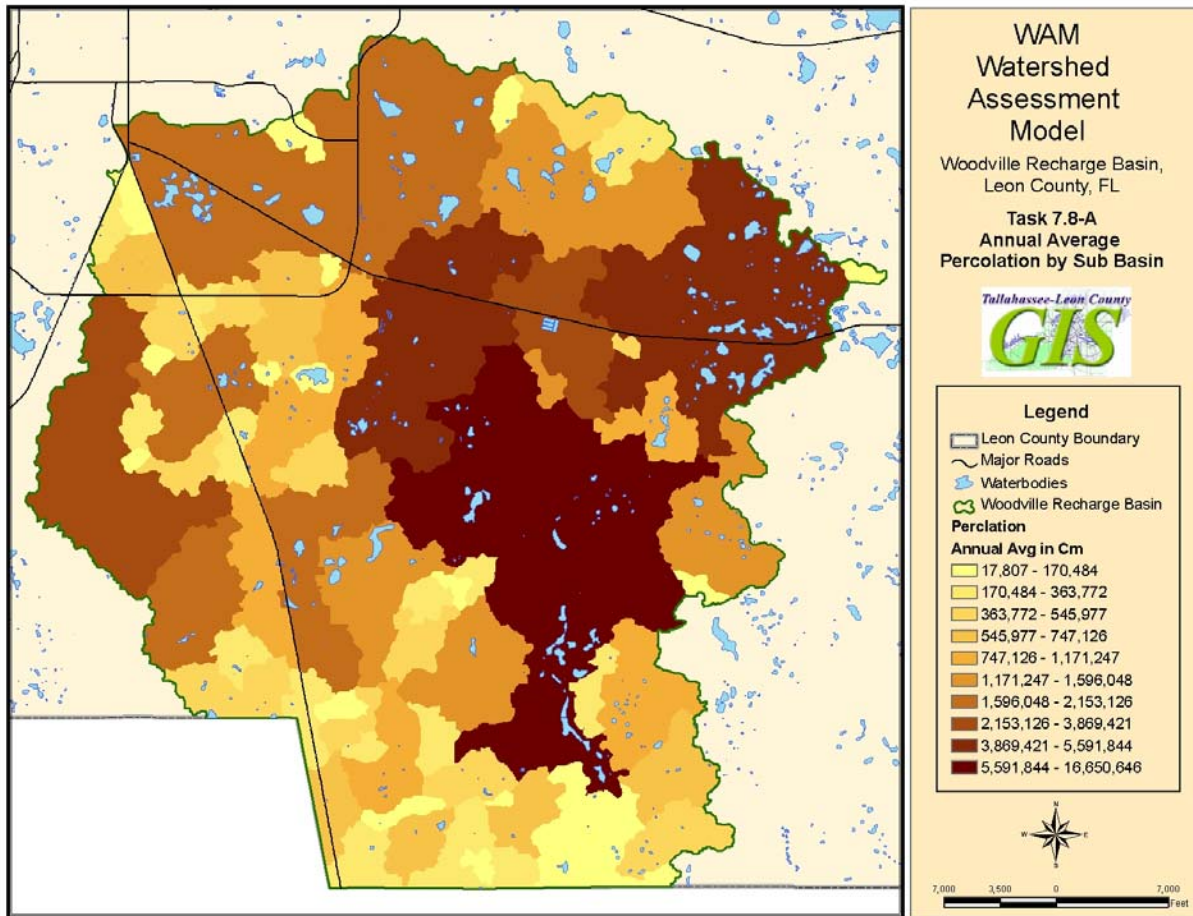


Figure 3.15: the darkest brown areas in this map depict areas of maximum perk rates in the WRB; they are the most sensitive to surficial pollutants.

There are three areas in the WRB of significance that should be purchased. One area is important for cultural, the other two are exceptional karst features and points of vulnerability to the aquifer. These are Verdura, the St. Marks Rise and Natural Wells (Appendix 3).

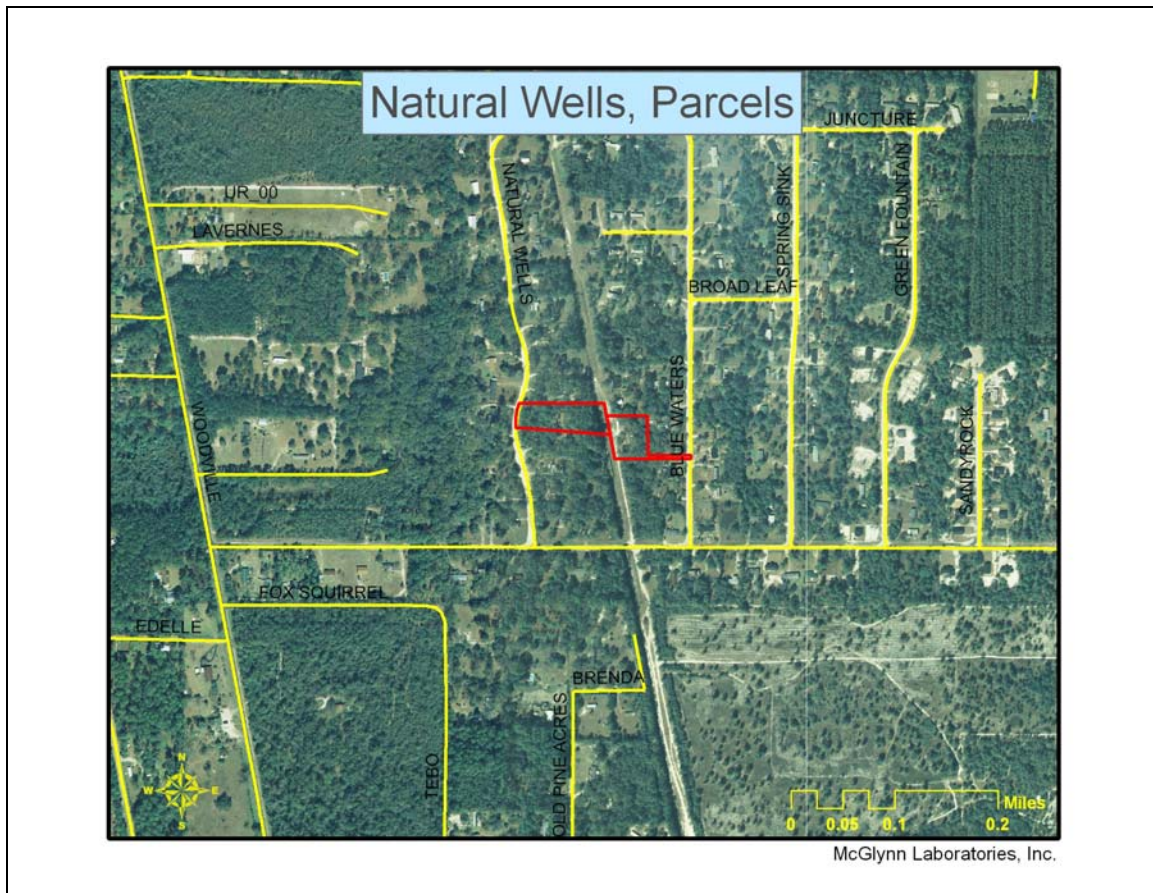


Figure 3.16: The Natural Wells parcels have a certified value of \$62,684.00

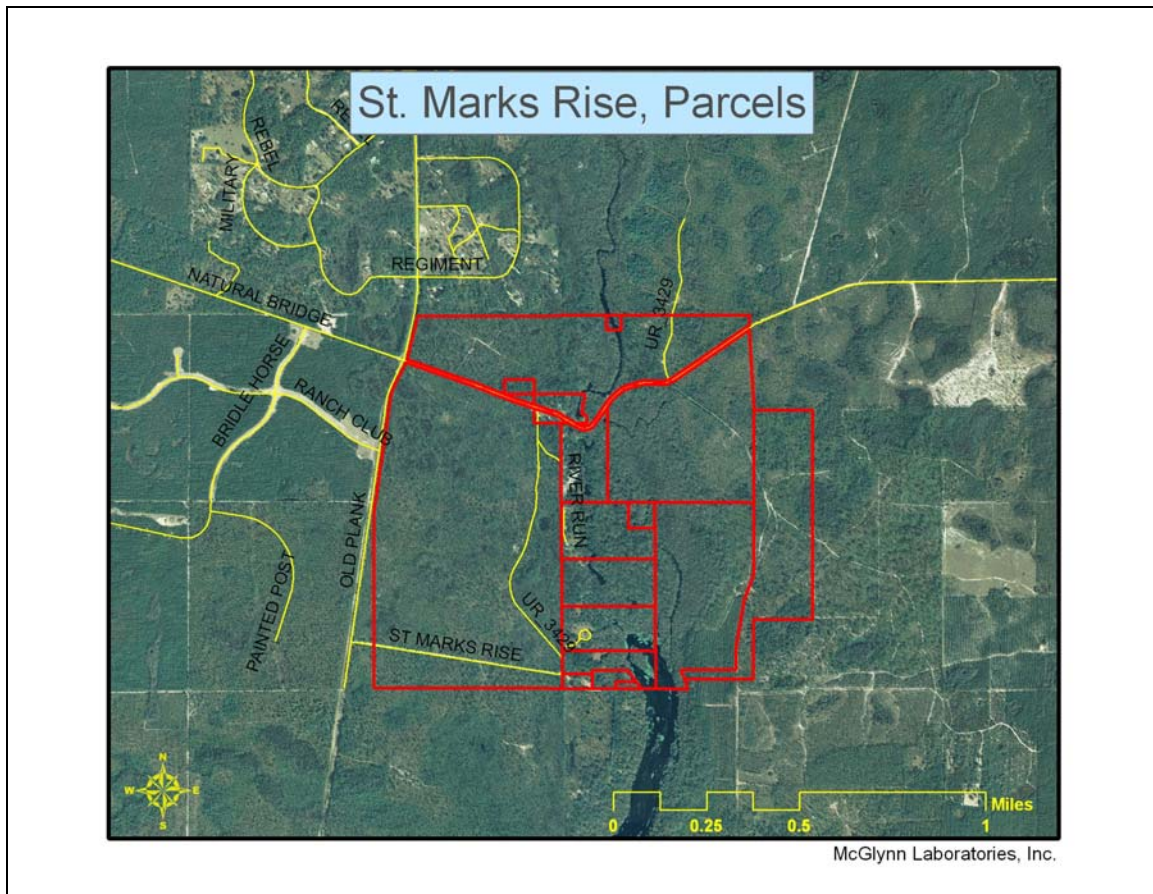


Figure 3.17: The St. Marks Rise parcels have a certified value of \$1,409,004.00

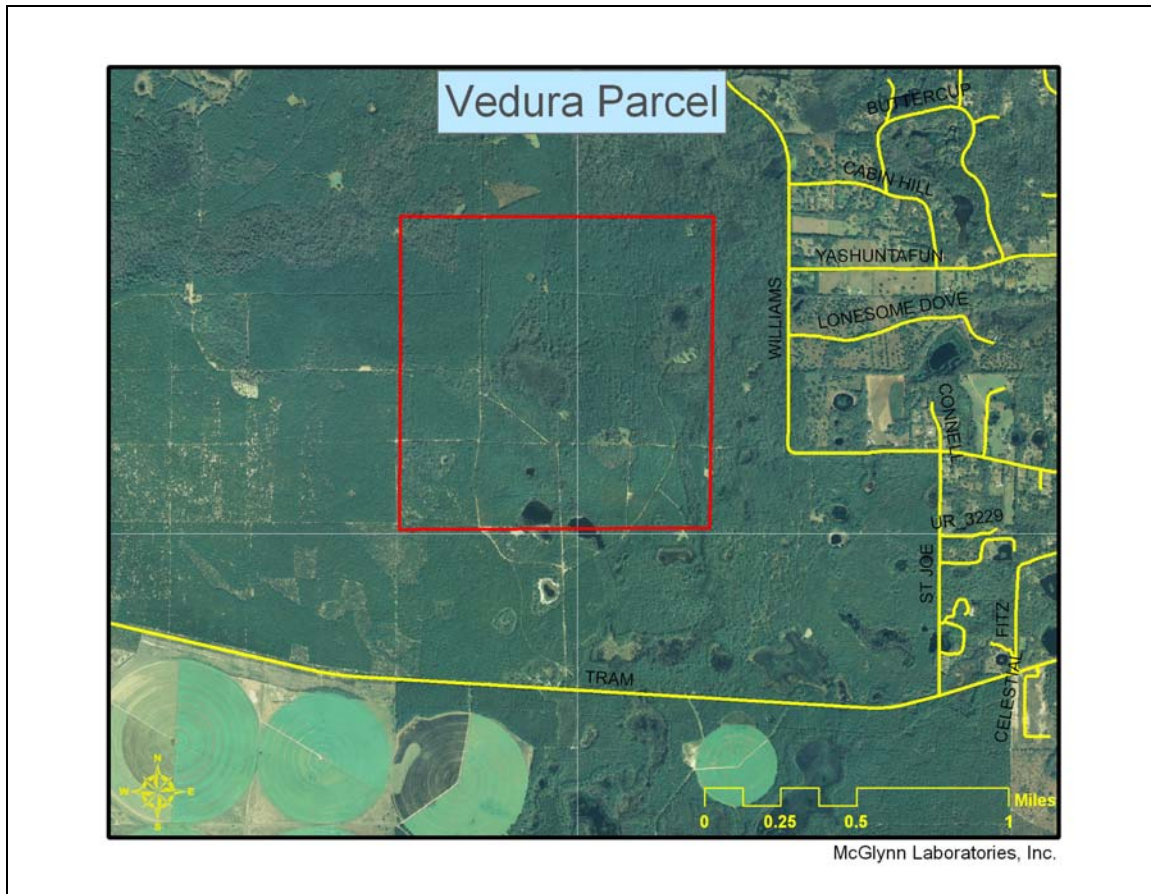


Figure 3.18: The Verdura parcel has a certified value of \$29,352,393.36 but this is for a square mile. Less of the property is needed to preserve the site.

****Offer tax incentives for placing conservation easements on aquifer vulnerable areas.***

Tax incentives should be offered for placing conservation easements on any area in the WRB. Conservation easements should be used to promote clustered low density developments that would be amenable to efficient wastewater treatment while maintaining open spaces under conservation easement.

A map is included 3 defining these areas (figure 3.1). These areas are designated as a GIS layer, which Leon County has. It is possible for the Tallahassee Leon County GIS Department to easily map these parcels but it is impossible for us to display such details in a map and will can be accomplished by the County in the future for each parcel in the WRB. Adequate sewer technology as defined in the text needs to be implemented according to the vulnerability of each parcel.

****Encourage via incentives, zoning, etc. and the development of land parcels that are less likely to cause pollution of the aquifer.***

The development of land parcels that are less likely to cause pollution to the aquifer should be encouraged in any manner possible.

****Establish a permit based trust fund to provide the monies to accomplish land and conservation easement purchases.***

A permit-based trust fund should be established to accomplish land purchases and establishing conservation easements. Every type of permit in the WRB should devote 20% of its cost to the trust.

****Establish an educational outreach to educate residents on low nutrient impacts.***

An educational outreach program should be established for the WRB. The primary objective of this public education program is to reduce the amount of nutrients entering the aquifer and lakes of the WRB. The foundation of the multi-media education campaign, aimed at the citizens of Leon, Gadsden, Jefferson, and Wakulla Counties, is to:

- Raise the awareness of the unique geologic and hydrologic features in the WRB.
- Advance an understanding of the interaction of the watersheds' soil and water resources.
- Create a sense of "belonging to a special place," thereby promoting a feeling of personal responsibility in caring for the health of the natural system.

- Educate the public about specific actions they could adopt in their daily lives to improve water quality and reduce nutrient loads to the aquifer.
- Reduce pollution from neighborhood yards impacting the aquifer through a targeted community outreach program.
- Promote effective septic tank usage and management.

****Regulate the usage of fertilizers in the unconfined aquifer portions of the WRB.***

It is very important that the use of inorganic fertilizers be restricted in the unconfined parts of the WRB. The use of inorganic fertilizer is rather ineffective here since it tends to wash out to the aquifer before the plants can absorb it. Rather mulching and time released fertilizers should be used exclusively. The example of the nutrient reduction that occurred with the removal of inorganic fertilizers at the CoT Sprayfield Farm should be enough evidence that inorganic fertilizers are ineffective and extremely harmful to the water quality in the aquifer.

3.2: Preliminary cost estimates for implementing the land purchase and capital improvement options.

Priority of actions by their relative importance (all of these are very important)

1. Improve CoT Sprayfield Farm
 2. Sewer major roads in the WRB
 3. Establish an educational outreach to educate residents.
 4. Require Performance Based Septic Systems
 5. Require time release fertilizers
 6. Stormwater retrofit projects and restorations
 7. Purchasing of specific aquifer vulnerable lands
- ❖ Modifications to the current TP Smith WRF management plan
 - AWT treatment at SESF
 - \$200,000,000
 - Pipeline to Hopkins plant from the SESF
 - \$100,000
 - Regional Miniplants
 - \$1,500,000
 - New Sprayfield (3x land area)
 - \$200,000,000
 - ❖ Performance Based Septic Systems (cost burden on private sector)
 - ❖ Proposing sewer systems for specific areas of the Woodville Recharge Basin.
 - Infrastructure
 - \$40,000,000
 - ❖ Proposing specific stormwater retrofit projects to provide stormwater treatment prior to discharge.
 - Southwood Ponds
 - Could St Joe do this?
 - Central Wetlands
 - Could St Joe do this?
 - Woodville Wetlands
 - Maybe \$200,000
 - ❖ Purchasing of specific aquifer vulnerable lands by government.
 - St Marks Rise
 - \$10,000,000 (for one parcel the other is owned by the Munroe's of Quincy)
 - Verdura Plantation
 - \$500,000 (parcel is not subdivided, an estimate of price is difficult)
 - Natural Bridge
 - \$200,000 (certified value)
 - ❖ Establish an educational outreach to educate residents on low nutrient impacts.
 - \$50,000 per year

REFERENCES

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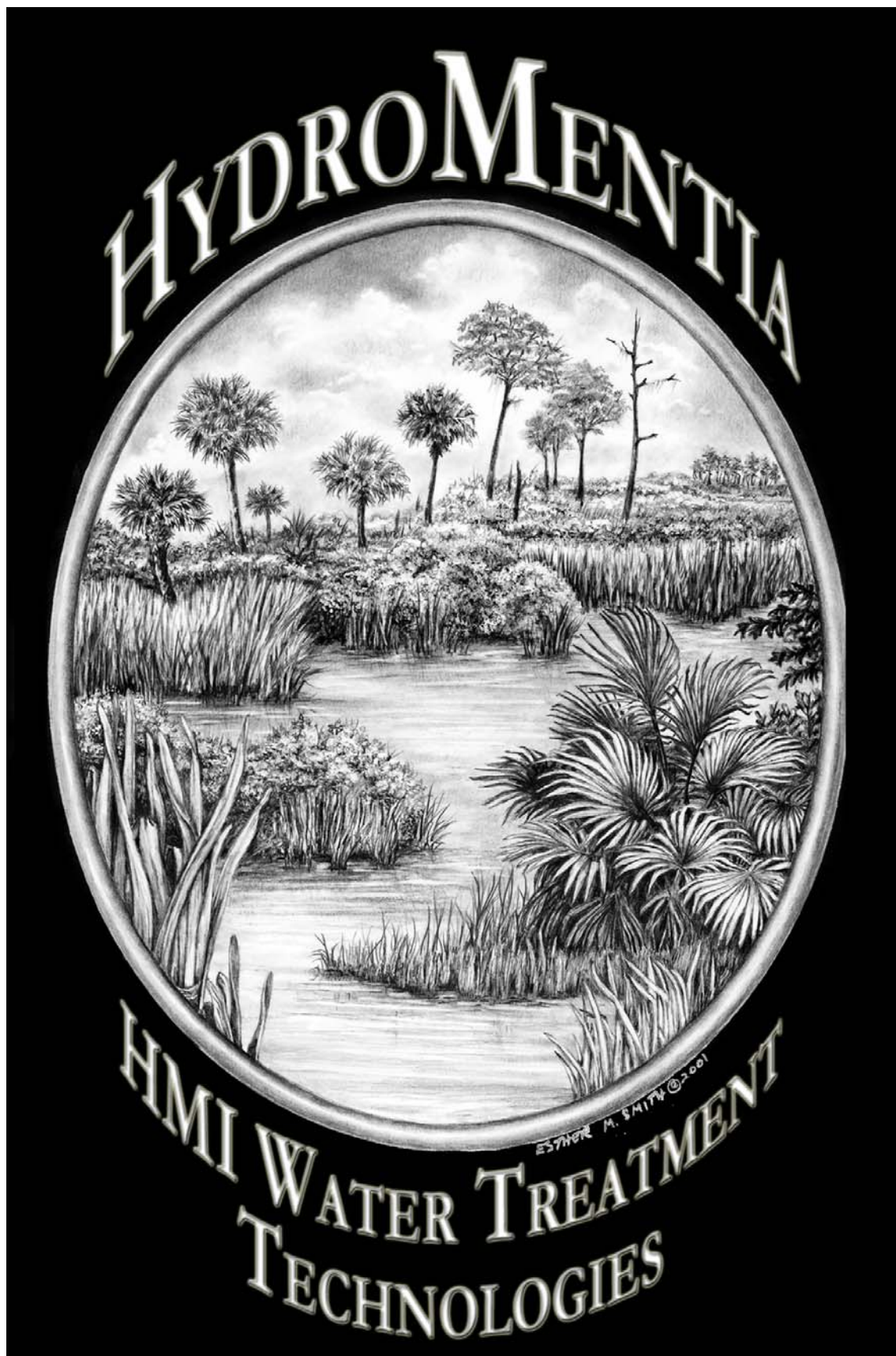
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Algal Turf Scrubber Technology

This technology is presented here as an example of technology currently available to improve water quality using natural phyto-remediation. Plants can be used to naturally cleanse degraded water. We do not endorse the use of Water Hyacinths but they have been demonstrated to work remarkably well at cleansing surface waters. Water Hyacinths are invasive exotics and do not perform as well in North Florida as they do in South Florida. Our harsher winters cause them to be inactive for three months of the year. We need to explore these techniques with native plants more suited to our climate. The water hyacinth is a preliminary treatment step. The algal turf scrubbers are the water polisher. They can reduce the level of nutrients to pristine levels. The algae used are typically harvested from local water bodies and are native. This water treatment process produces good water quality and a commercially viable product, mulch or animal feed (after the plants have removed the nutrients from the water). Dr McGlynn visited these plants in South Florida where they were used in the Everglades Cleanup and was quite impressed.



1.0 BACKGROUND

1.1 WATER POLLUTION CONTROL

Prior to about 1972 it was a generally accepted strategy in Florida to manage stormwater within developed and developing watersheds by accommodating the need for flood control through the accelerated collection and conveyance of runoff into the closest downstream surface waterbody—typically a lake, river or estuary. Alternatively, it was not uncommon for groundwater to be the receiving resource through sinks or drainage wells. While agriculture was the early beneficiary of such wholesale drainage efforts, by the second quarter of the 20th century urban expansion demanded further refinement of stormwater infrastructure, with the demand that runoff be removed even more expeditiously to the receiving water. In addition, it was not unusual during these times to manipulate the morphometry of the receiving surface waterbody through perimeter berming, control structures, dredging and filling, and drainage wells in an expanded effort to manage flooding; lower shallow groundwaters; retain water for potable and agricultural uses; and to control mosquito breeding.

This strategy was challenged with the implementation of the Federal Clean Water Act (CWA)—PL92-500—in 1972, which may be seen as the first unanimous institutional recognition that the disruption of pre-development water quality was attributable not only to discharged wastewaters (point sources), but also to the extent and nature of pollutant loading, and scheduling and timing of flows, attendant with stormwater flows associated with a disrupted watershed (non-point sources). During the early years of this implementation, while only point source management received any sizable funding for construction projects, there were a number of parallel efforts to quantify the extent of stormwater impacts. The collection of programs targeted at non-point source pollution were called “208 plans”, from Section 208 of the CWA. Typically these plans resulted in the delineation of watersheds and the extent of land uses and land-use loading rates, and a general assessment of pollutant and hydraulic loads associated with stormwaters. From the “208” efforts; the EPA National Pollution Discharge Elimination System (NPDES) program; Florida’s Surface Water Improvement and Management (SWIM) plans; and regional and local programs, a series of best management practices (BMP), and passive structural technologies have been developed and incorporated into regional stormwater programs, regulations and development codes. Stormwater utilities have also been developed in many counties, which provide a funding mechanism for more aggressive stormwater treatment programs.

While the increased awareness of the deleterious impacts of non-point source pollution upon regional water resources has resulted in a general reduction in pollutant loading and adjustments of flow scheduling to be more emulative of pre-development patterns, in many cases these efforts have not been sufficient to allow these resources to recover to acceptable water quality conditions. These “impaired” water resources accordingly became an issue as the courts attempted to determine the intent of the CWA and the nature and extent of the remaining responsibilities related to reclamation and sustained management of these resources. From these discussions has emerged a mandate to not only identify these “impaired” resources and the critical pollutants responsible for these impairments, but also to establish load allowances, known as Total Maximum Daily Load or TMDL, for these pollutants.

It is the responsibility of the Florida Department of Environmental Protection (FDEP) to establish TMDL’s, and to inform the impacted public of the TMDL program. However, outside of a few exceptions, such as with the joint Federal/State funded Comprehensive Everglades Restoration Program (CERP), the fiscal responsibility for satisfying the TMDL requirements remains largely with local governments. The TMDL program then may be seen as an un-funded mandate.

It is not only the TMDL program however that is soliciting action from local entities to seriously confront the challenges of comprehensive treatment and management of stormwaters. Loss of recreational opportunities, imposition upon property values, and major ecological impacts associated with excessive pollutant and hydraulic loading attendant with stormwater runoff are all serious quality of life factors that erode the general economic and social welfare of a community. While in the recent

past such issues may have not been viewed by many as serious impediments to economic development, it is now recognized that poor surface water quality can result in loss of aesthetic and recreational appeal; continuous fish kills; overgrowth by exotic and nuisance aquatic plant species; red tide blooms and sea grass loss in coastal areas; increased mosquito populations; human health issues; toxic blue-green algae blooms; serious degradation of springs and groundwater; and loss of fisheries and wading bird populations, and that each of these can directly and profoundly impact the socio-economic health of a region.

Recognizing the need for serious, effective treatment and management of stormwaters however is only one requirement for resolving the present problem. The next phase—implementation-- is presently hindered by a paucity of administrative and technical tools to develop and initiate successful programs, and consequently the social demands to protect the resources typically outpace the ability of the state-of-the-art to meet these demands. This is particularly true in urbanized areas that are under heavy development pressure. Ironically, these regions are typically those with an abundance of critical water resources. For example the lake region of Florida's central ridge is under extraordinary development pressure (Orange, Seminole, Polk, Lake and Osceola counties), as are the counties contiguous to the coastal estuaries on both the east and west coast of the peninsula as well as the gulf coast of the panhandle, and northern inland regions, such as Alachua, Marion and Leon counties associated with large lake systems, surrounded by major springs and spring runs.

From a technical perspective, the primary challenges in treating and managing stormwater are 1) management of flows and allocating those flows to the receiving waters in a manner emulative of pre-development conditions, and 2) treating the collected and retained stormwaters prior to release to the receiving waters, with treatment, as a minimum, usually involving the reduction of floatable solids, oils, suspended solids, biodegradable organics, and nutrients. In addition, if full restoration of the receiving water is desired, the program should include a mechanism for restoring, to the extent practical, the original morphometry of the resource, as well as removal of accumulated solids and nutrients. Such efforts often need to include restoration of littoral zones; reclaiming buffer areas; establishing native submerged aquatic vegetation; removal or stabilization of organic sediments; elimination or reduction of septic tanks; and removal of exotic and nuisance species.

Stormwater flow and sediment management can be effectively accomplished through the use of detention areas and reservoirs, assisted with proper infrastructure sizing and upstream BMP's such as baffles, screens, grassed swales, road paving, etc. New developments are typically required to provide these levels of treatment, with older systems usually in need of upgrading. For large watersheds, major downstream impoundments may be needed, such as the large reservoir systems planned for the Lake Okeechobee Watershed (LOW) and the Everglades Protection Area, both part of CERP, or alternatively, Aquifer Storage and Recovery (ASR). In many urban and sub-urban areas, land area may not be available to provide the required storage, and therefore it may not be practical or possible to prevent heavy loads from being discharged directly to the receiving water resource. In such cases, mechanical methods can be used to reduce sediment loads (e.g. tangential separators), chemical addition can help to immobilize and settle solids and labile phosphorus, and continuous "kidney" type facilities can serve to remove nutrients prior to or even after they have been discharged into the receiving water resource.

1.2 MAPS WATER TREATMENT TECHNOLOGIES

Technologies for nutrient removal from stormwaters have been slow in development, and those which have been developed, such as large regional stormwater wetland treatment areas (STA) and marsh flowways require extensive land areas, and are not often practical in urban and sub-urban watersheds, or regions in which land costs are escalating rapidly. In addition, these "passive" type wetland approaches rely not upon actual removal of nutrients, but rather upon finite storage within the treatment units themselves. Therefore long term management of these stored nutrients is an issue of concern—the cost of which can be quite extensive.¹ Chemical treatment units have been noted to be

¹ The City of Orlando just recently had to remove over 500,000 cubic yard of organic sediment after 15 years of operation of

effective for reduction of phosphorus, and capable of removals to concentrations at 10 ppb total phosphorus.² However, chemical costs and sludge disposal can be problematic. Nonetheless, engineered chemical treatment units do result in actual removals of phosphorus, rather than in-process storage. Managed Aquatic Plant System (MAPS)³ have been developed, and are now commercially available, which rely upon direct nutrient uptake by cultivated aquatic plants and the subsequent frequent removal and recovery through harvesting and processing of the targeted crop. This approach offers reduced land area requirements when compared to “passive” wetland treatment, while providing quantifiable removal, recovery and reuse of captured nutrients. HydroMentia, Inc. has developed two MAPS technologies—the water hyacinth scrubber or WHS™ and the Algal Turf Scrubber® or ATS™.

The WHS™ involves the cultivation of the floating aquatic plant, water hyacinths, within an engineered treatment cells, including specialized harvesting and processing equipment. Water hyacinths have been used for successfully treating nutrient laden waters for over three decades. The WHS™ technology offers the advantage of establishing the management of these plants for purposes of water pollution control as sustainable and cost effective. Harvested hyacinths can be processed into compost, livestock feed and other marketable products, which can either be sold outside the watershed, or recycled within the watershed, thereby reducing the net import of nutrients. The WHS™ provides high rates of nutrient removal with the additional advantage of providing relatively long hydraulic retention times, which permits both settling and flow attenuation. The WHS™ relies upon atmospheric CO₂ as a carbon source, and hence does not depend upon bicarbonate and carbonate levels in the water, thereby avoiding increased daytime pH levels in the effluent. Because of the shading provided by the hyacinth crop, phytoplankton blooms are typically repressed, and effluent suspended solids concentrations are usually quite low. Effluents from WHS™ units however are normally low in dissolved oxygen, and may require aeration before being released into the receiving waters. WHS™ facilities require permitting through FDEP Aquatic Plant Management, as the water hyacinth is an exotic plant of concern. Provision must be included in the design and operation of WHS™ to ensure there is no release of water hyacinth tissue that could propagate in native waters.

WHS™ units quite often serve as an appropriate pre-treatment unit prior to a final treatment by an Algal Turf Scrubber® or ATS™. The WHS™ technology does not provide the high areal nutrient removal rates associated with ATS™ when nutrient concentrations are comparatively low. As a general rule, WHS™ is applicable when influent nutrient concentrations are greater than 300 ppb total phosphorus and 2.00 mg/l total nitrogen. WHS™ is ideally suited for treatment of runoff associated with heavy agricultural activity, or conditions influenced by point source discharges. Quite often suburban watersheds are characterized by somewhat lower concentrations, and accordingly WHS™ application may be less practical.

The Algal Turf Scrubber® or ATS™ relies upon the sustained cultivation of a community of attached algae within an engineered system. This cultivation requires that the rate of flow and nutrient allocation be such that high levels of productivity are maintained. Nutrient removal accordingly results primarily from the frequent removal of excess productivity. As with the WHS™, harvested material can be processed into viable products, such as compost or livestock feed. The ATS™ offers the advantage of very high areal removal rates for both nitrogen and phosphorus, and hence reduced land area requirements.⁴ In addition, the ATS™ effluent is highly oxygenated, often exceeding

the Orlando Easterly Wetland.

² The South Florida Water Management District (SFWMD) conducted a pilot project and a Supplemental Technology Standard of Comparison (STSOC) on chemical (alum) treatment in the Everglades, and found the technology to be cost effective when compared to STA technology.

³ MAPS is an acronym first used by HydroMentia to define the family of processes involving the actual cultivation of aquatic plants within an engineered unit for the purposes of providing general water quality improvements and removing and recovering nutrients from polluted waters.

⁴ For example, STA systems may achieve phosphorus removal rates of 1-4 g-P/m²-yr or less than 0.10 lb-P/acre-day; WHS™ units at high nutrient concentrations may achieve as high as 25 g-P/m²-yr removal or about 0.62 lb-P/acre-day; ATS™ systems at comparatively low nutrient concentrations have been documented as achieving well over 50 g-P/m²-yr or 1.24 lb-P/acre-day. The implication is that an ATS™ unit may provide treatment in 1 acre equivalent to 50 acres of STA or treatment wetlands.

saturation during the daytime, and well above 5 mg/l dissolved oxygen (DO) during the nighttime. ATS™ units provide no substantial hydraulic detention, and little storage for heavy sediment loads. As the producing algae relies heavily upon dissolved bicarbonate, carbon dioxide and carbonate as a carbon source, pH levels within the effluent can increase during the daytime as alkalinity shifts towards hydroxyl alkalinity. ATS™, like WHS™, can be effective at removing metals and select organic compounds. Typically ATS™ applications are associated with comparatively low influent nutrient concentrations, following reduction of suspended solids and biodegradable organics (e.g. BOD). The ATS™ technology was specifically developed for lower nutrient conditions, and is well suited for many stormwater management applications. Provided within the next section is a more detailed review of ATS™.

2.0 ATS™ TECHNICAL REVIEW

Periphytic and epiphytic (attached) algal communities⁵ are seen throughout nature, being particularly prevalent in highly energetic situations such as tidal areas, coral reefs, and freshwater rivers and streams. These algae serve not only as part of the primary producing community, dominated typically by photosynthetic organisms, but they also sequester and allocate nutrients in a manner that protects the function and diversity of the larger ecosystem. For example, it has been documented that within coral reefs⁶, whose sustenance relies upon very low levels of nutrients, periphytic algae can achieve relatively high levels of production at very low nutrient levels, thereby gaining a selective advantage over suspended algae (phytoplankton). Odum⁷ in his classic study on Silver Springs found epiphytic algae had a similar role in stabilizing the nutrient dynamics within the spring run. Both of these examples involve high levels of water movement, and it has been noted that such movement assists in nutrient accessibility in low nutrient environments.^{8,9} However, within the Everglades, a much less energized environment, periphyton has also been identified as important in retaining oligotrophic conditions.¹⁰

Considering this evolved function of nutrient management it is logical that an engineered emulation of these attached algae communities would serve as a means of managing nutrients within nutrient laden stormwaters, just as the emulation of heterotrophic communities through activated sludge technology serves to manage biodegradable organics and reduced nitrogen within wastewaters. The first engineered attached algae systems involved the use of a sloped bed over which recycled seawater was delivered in surges at a rate that ensured shallow laminar flows at comparatively high velocities.¹¹ These systems, labeled Algal Turf Scrubber® or ATS™¹² were ancillary to aquaria used in the cultivation of reef corals. The surging was used to simulate the effects of oscillatory waves, which stimulated the productivity of the attached algae community. Larger scale systems followed in California and Florida in an effort to apply the system as a large-scale pollution control technology^{13,14,15}. In 2001, the possible application of ATS™ as a means of providing cost effective phosphorus management within the LOW resulted in the issuance of a Grant¹⁶ to HydroMentia for a 0.50-1.0 MGD Prototype Facility within the S-154 Basin - one of the more problematic watersheds in terms of phosphorus loading. This project was a jointly funded public-private endeavor by the South Florida Water Management District (SFWMD), the Florida Department of Environmental Protection (FDEP), the Florida Department of Agriculture and Consumer Services (FDACS) with private contributions from HydroMentia, Inc. During the first year the MAPS system was operated as a two-

⁵ Periphytic refers to algae attached to inanimate substrates, such as rocks and soil particles. Epiphytic refers to algae attached to other organisms, such as other algae, vascular plants, and animals (e.g. turtle shells).

⁶ Work conducted by Dr. Walter Adey and others associated with the Smithsonian Institutes in establishing methods for cultivating corals reef communities.

⁷ Odum, H.T. (1955) "Trophic Structure and Productivity of Silver Springs, Florida" *Ecol. Monographs*, **27**, 55-112

⁸ Carpenter, R.C., J.H. Hackney and W.H. Adey (1991) "Measurement of primary producer and nitrogenase activity of coral reef algae in a chamber incorporating oscillatory flow" *Limnol. Oceanogr.* **36**(1): 40-49

⁹ Brezonik, P.L. (1994) *Chemical Kinetics and Process Dynamics in Aquatic Systems*, 505-525, Lewis Publishers, Boca Raton, FL, USA ISBN 0-87371-431-8

¹⁰ Thomas, S, E.E. Gaiser, M. Gantar, A. Pinowska, L.J. Scinto and R.D. Jones (2002) "Growth of calcareous epilithic mats in the margin of natural and polluted hydrosystems: phosphorus removal implications in the C-111 basin Florida Everglades, USA" *Lake and Reservoir Management* **18**(4):324-330

¹¹ Adey, W.H. and J. Hackney (1989) "Harvest production of coral reef algal turfs." In *The Biology, Ecology and Mariculture of Mithrax spinosissimus Utilizing Cultured Algal Turfs*. W.H. Adey (Ed.) Mariculture Institute, Washington, DC

¹² Adey, W.H. and T. Goertmiller (1987) "Coral reef algal turfs: master producers in nutrient poor seas" *Phycologia* **26**: 374-386.

¹³ Craggs, R.J., W.H. Adey, K.R. Jensen, M. St. John, F. B. Green, and W. J. Oswald (1994) Evaluation of the ATS™/UV System for Tertiary Wastewater Treatment at Patterson, California. EEHSL Report No. 94-1. University of California, Berkeley, CA

¹⁴ Adey, W.H., C. Luckett and K. Jensen (1993) "Phosphorus removal from natural waters using controlled algal production." *Restor. Ecol.* **1**: 29-39

¹⁵ HydroMentia, Inc. (2004) S-154 Pilot ATS™-WHS™ Aquatic Plant Treatment System Q3 Report. Submitted to South Florida Water Management District

¹⁶ Stewart, E.A. (2000) *Estimates of Phosphorus and Nitrogen treatment Efficiency Aquatic Plant Based Wastewater Treatment System Phase 1A HydroMentia's Recirculating Aquaculture System, Okeechobee, FL*. Prepared for HydroMentia, Inc. Ocala, FL, USA

process unit, with the WHS™ providing initial treatment and the ATS™ providing polishing. In an extended investigation, the ATS™ was used as the sole treatment unit, and hydraulic and pollutant loadings were increased to optimize areal removal rates.

Typically, an ATS™ engineered for handling sizable hydraulic loads are composed of the following:

1. Influent flow delivery system, which may be a low head, high flow pumping system (e.g. axial flow pumps), or a gravity conveyance system in association with a natural or structural drop in water level, (e.g. control structure, locks)
2. An influent flume designed to distribute water equitably along the width of the ATS™ floway, and from which intermittent release control devices are placed to deliver flow to receiving surger boxes.
3. Flow delivery surgers, designed to pulse flows in a manner emulative of oscillatory waves. These devices are automatic siphon mechanisms placed on a surger box. The intermittent surging of water helps disrupt the boundary layer, which develops around the algal cell wall, which can impair the rate of diffusion of nutrients, particularly at low concentrations.
4. A sloped ATS™ floway that includes a compacted soil sub-base upon which is laid an HDPE geomembrane, and over which is installed a geotextile mesh, which serves as an attachment matrix for the algae. Floway length is typically no less than 250 feet, with the actual length being determined by treatment requirements and influent characteristics.
5. An effluent and harvest flume that runs the full width of the ATS™ floway. Typically this flume is triangular in cross section, with a variable cross sectional area, increasing as flows accumulate. The slope is designed to ensure at least 1.5 fps velocity throughout the flume, which ensures conveyance of the harvested material. The flume serves both as a means to move effluent, and, during harvest, to transport harvested algae to a pick-up rake.
6. An automatic Flex-Rake, typically as manufactured by Duperon Corporation of Saginaw Michigan. The Flex-Rake not only facilitates capture and removal of harvested algae filaments, but also the continuous removal of sloughed algae and any incidental rogue solids.
7. Harvesting vehicles and attachments for dislodging and moving excess production into the effluent flume

A general plan and section schematic of a typical ATS™ system is noted in Figure A. As noted, optional ancillary components are also shown. These include a microscreen unit to remove residual fine solids (<10 ppb) and a diversion mechanism and diversion pond to avoid discharge of flows which may be high in algae solids, such as during harvesting or during heavy rainfall. Both of these options would be included if very high levels of treatment and low nutrient concentrations are required, such as in the Everglades where there is a 10 ppb total phosphorus limit.

Also noted in Figure A is the option to pull influent upstream of, or directly from the receiving water. This ensures the system functions on a continuous basis, even during the dry season when stormwater runoff is negligible, and detention ponds and tributaries may be dry.

While there are a number of processing options available for the harvested algae, the easiest to implement and operate is windrow composting. This would require construction of a compost pad, and would require loading and mixing equipment.

Operational demands are oriented around 1) the O&M of the mechanical equipment (pumps, rakes, screens) and vehicles 2) harvesting and processing of the algae crop and 3) performance and process monitoring and operations. While overall performance and process oversight should be by a trained process engineer or biologist, the dynamics of the ATS™ are similar to other biological processes, and could be managed on a daily basis by a certified wastewater operator. As with wastewater facilities, the larger and more complex the facility, the higher the level of certification needed, and the greater the frequency of necessary visitation.

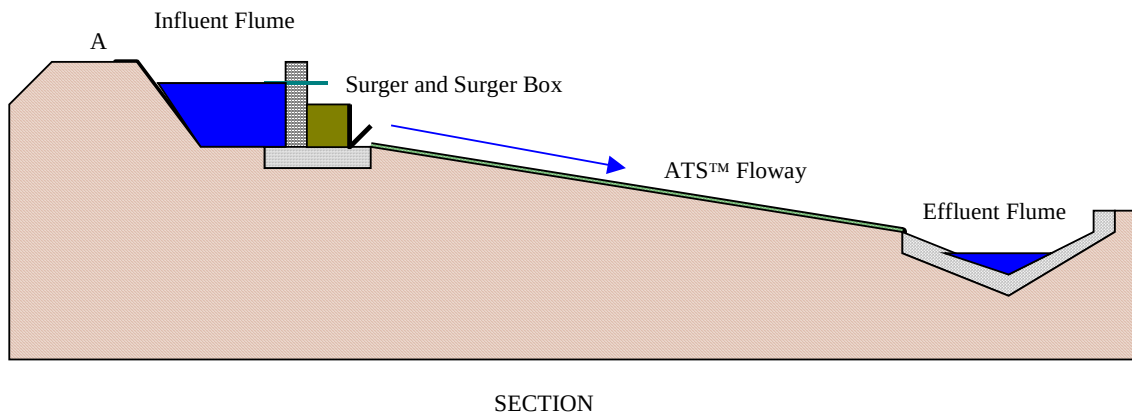
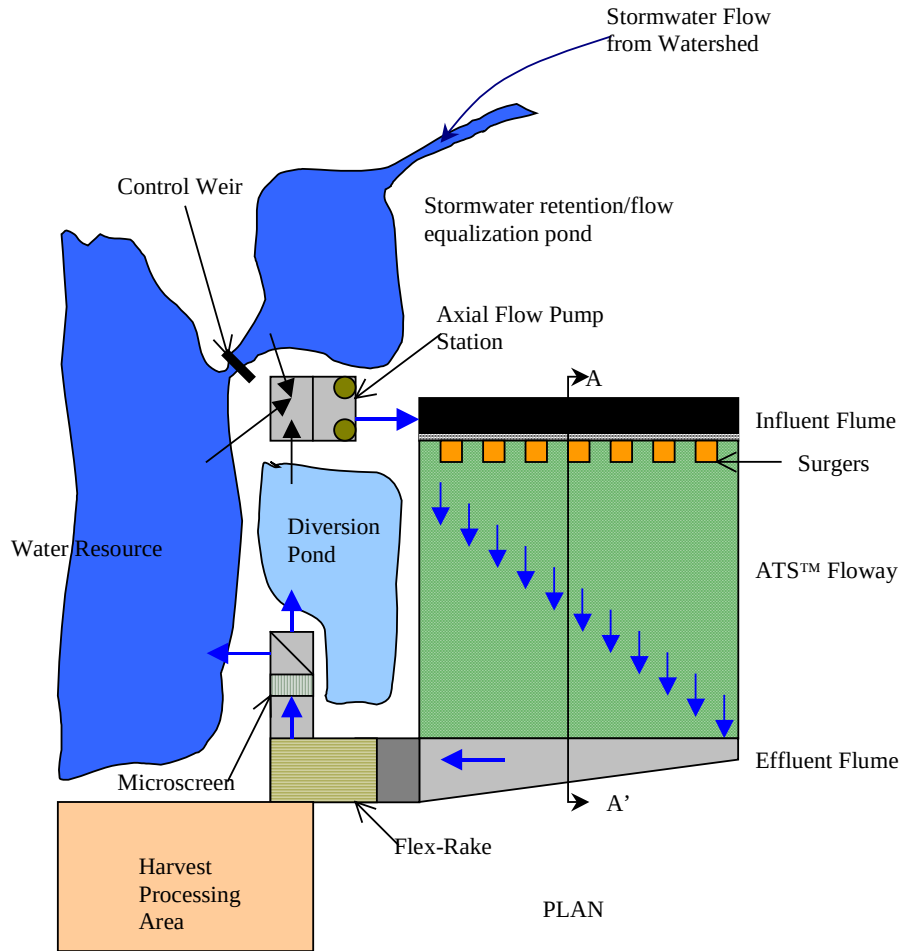


Figure A: Typical ATSTM Layout Schematic (NTS)

3.0 ATS™ PROCESS DYNAMICS AND MODEL

As with many biological water treatment processes, the dynamics associated with the ATS™ can be described through a first-order reaction—that being that the rate of reduction is a function of the concentration of the targeted substrate (nutrient). This can be expressed through Equations 1 through 3.

$$dS/dt = -kS \quad \text{Equation 1}$$

or

$$dS/S = -kdt \quad \text{Equation 2}$$

Integrated between $t = 0$ to $t = i$ as

$$\ln(S_i/S_0) = -kt \quad \text{or} \quad S_i = S_0 e^{-kt} \quad \text{Equation 3}$$

Where S is the nutrient concentration, t is time, and k is the rate constant

This general expression was initially applied to enzymatic reactions as described by Michaelis-Menten¹⁷. While the value “ k ” within the laboratory was initially applied to a specific substrate and a specific enzyme, the “ k ” value has come to be identified within more complex biological treatment processes with the cumulative effect of a broad and fluctuating collection of reactions and organisms. For example, within treatment wetlands, the value of “ k ” is identified as the rate coefficient associated with the accretion of phosphorus into the sediments and standing crop of biomass, without any attempt to identify and segregate the specific processes involved, such as chemical precipitation, adsorption, immigration and direct plant uptake.¹⁸ While repetitive experimentation in such cases can strengthen confidence in establishing values for “ k ” on a short-term basis, it cannot determine the rate of change in “ k ” as environmental conditions change within the wetland itself—i.e. as accretion begins to change to chemical and physical complexation of the process.

Within sustainable biological processes, in which biomass removal allows long-term stabilization of the chemical and physical environment, it is possible to orient the first-order reaction around the principle mechanism involved in nutrient removal—that being actual biomass productivity. In some cases, modeling of this productivity can target a dominant species, such as with the WHS™ technology. However, in most cases, the application of growth models is applied to a set community of involved organisms, such as with activated sludge, fixed film technology, and ATS™.

The MAPS technologies differ from activated sludge and fixed film processes such as trickling filters and Rotating Biological Contactors (RBC), in that the targeted biological community is a photoautotrophic, carbon fixing community, instead of a heterotrophic, carbon respiring community. In ecological terms, the MAPS would represent the primary production trophic level, while the heterotroph based processes would represent the detritivorous trophic level.

When a biological unit process is oriented around sustainable community production, the first order kinetics are generally applied through the Monod¹⁹ relationship.

$$Z_t = Z_0 e^{mt} \quad \text{Equation 4}$$

¹⁷ Michaelis, L. and M/L/ Menten, (1913) *Biochem. Z.*, **49**, 333

¹⁸ Walker, W.W. (1995) “Design basis for Everglades stormwater treatment areas” Water Resource Bulletin American Water Resources Association Vol 31 No. 4

¹⁹ Monod, J. (1942) *Recherches sur la Croissance des Cultures Bacteriennes*, Herman et Cie, Paris

Where Z is the biomass weight and m is the specific growth rate (1/time) when:

$$m = m_{\max} S / (K_s + S) \quad \text{Equation 5}$$

Where $m_{\max}$ is the maximum potential growth rate and K_s is the half-saturation constant for growth limited by nutrient S , or the concentration of S when $m = \frac{1}{2} m_{\max}$.

Considering the flow dynamic of the ATS™ as noted in Figure A, the system may be viewed as a plug flow system. Recognizing that the average biomass at any one time on the ATS™ is assumed stable (Z_{ave}), and relatively constant when harvesting is done frequently, and the reduction rate at steady state of S is also a function of the concentration of S within the tissue or S_t , then S_{y1} at a sufficiently small increment “ y ” down the ATS™ may be expressed as:

$$S_{y1} = S_{y0} - \{Z_{ave} e^{[m_{\max} S_{y0} / (K_s + S_{y0})] [(y_1 - y_0) / V]} - Z_{ave}\} / [q(y_1 - y_0) / V] \quad \text{Equation 6}$$

Where “ v ” is the flow velocity down the ATS™ at unit flow rate “ q ”.

The conditions required for Equation 6 are that the temperature is optimal for growth, that solar intensity is relatively constant, that the process is irreversible, and that there is no inhibitory effects related to S within the ranges contemplated, and that the difference between S_{y1} and S_{y0} is sufficiently small as to not influence m . If temperature impacts are considered, then the classical V'ant Hoff-Arrhenius²⁰ equation (Equation 7) may be incorporated as noted in Equations 8.

$$m_{opt} / m_1 = Q^{(T_{opt} - T_1)} \quad \text{or} \quad m_1 = m_{opt} / Q^{(T_{opt} - T_1)} \quad \text{Equation 7}$$

Where m_{opt} is the growth rate for given S at the optimal growing temperature °C, T_{opt} , and m_1 is the growth rate for the same given S at some temperature °C, T_1 , when $T_1 < T_{opt}$, and Q is an empirical constant ranging from 1.03 to 1.10.

$$S_{y1} = S_{y0} - \{Z_{ave} e^{[m_{\max} S_{y0} / (K_s + S_{y0})] [(y_1 - y_0) / V] [1 / Q^{(T_{opt} - T_1)}]} - Z_{ave}\} / [q(y_1 - y_0) / V] \quad \text{Equation 8}$$

In more northern applications, adjustments might need to be made for light intensity as well. While there are seasonal fluctuations in Florida for both solar intensity and photoperiod, the impacts are assumed to be minimal when compared to temperature influences, and can be incorporated into the empirical determination of Q .

Estimation of $m_{\max}$ and K_s can be done by applying field data as described by Lineweaver-Burke²¹. A Lineweaver-Burke review of S-154 data is noted within Figure B. As is often done with individual wastewaters in which activated sludge is to be applied, it is quite often helpful to conduct a bench level analysis with an ATS™ unit to establish these values in the field, and to identify the limiting nutrient. A bench study is suggested for the applications discussed within this proposal. The nature and costs for these studies are included in a later section of the text.

²⁰ As described by Brezonik, P.L.(1994) *Chemical kinetics and process dynamics in aquatic systems*, CRC Press, Boca Raton, FL pp 114-117

²¹ Lineweaver, H and D. Burke (1934) “The determination of enzyme dissociation constants” *J.Am.Chem.Soc.* **56**, 568

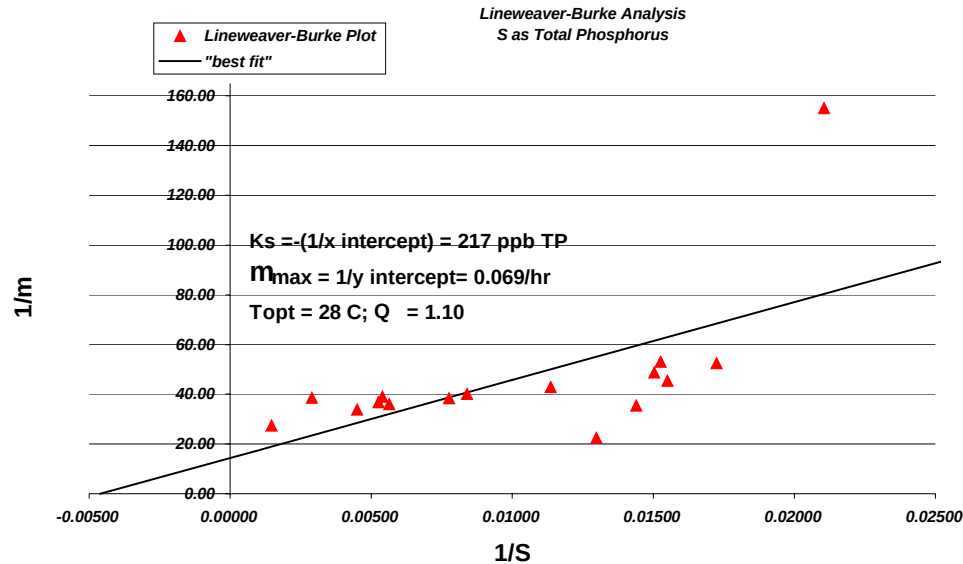


Figure B: Lineweaver-Burke Plot for S-154 single stage ATSTM floway; S as total phosphorus

The plot noted as Figure B is for a floway hydraulically loaded at a rate of about 21 gallons/minute for each foot of floway width, a parameter called linear hydraulic loading rate or LHLR. From the LHLR and the slope of the floway it is possible to use the Manning's equation to estimate average velocity, "v". This requires assignment of Manning's coefficient –"n"—which can be estimated based upon field velocity measurements.

The model that is developed for estimating performance is based upon a composite average condition for the entire floway. For example an average standing biomass, Z_{ave} represents the standing crop at anytime as dry-g/m² averaged over the whole ATSTM area. It is a function of the frequency of harvesting, and can be estimated through Equation 9.

$$Z_{\text{ave}} = \left(\sum_{m=1}^n S_{Z_0} e^{24mm} \right) / n$$

Equation 9

It is recognized that any one section of the ATSTM may be providing better or less treatment than the model projection, but as an average, the model effluent estimate and actual composite effluent can be expected to be similar. This applies to any time period during the operation. While photosynthesis occurs only during the daytime, productivity projections are based upon a 24-hour period. While there may be some concern that nocturnal performance is below diurnal performance, experience on Florida stormwater indicates that nutrient uptake does continue with the loss of sunlight, even if carbon fixation is discontinued.

While the model is based upon the assumption that direct nutrient uptake within the plant biomass is the sole removal mechanism, under certain conditions other phenomenon may also contribute—including chemical precipitation, both within the water column directly, and upon the surface of the algal cell wall, luxury uptake, adsorption and emigration through invertebrate pupae emergence and predation. Some evidence of these factors is noted with the change in tissue phosphorus concentration with change in water column total phosphorus concentration, as noted within Figure C. By incorporating the change in phosphorus concentration within the tissue, the Monod based model can be considered to incorporate the influence of these other phosphorus removal mechanisms.

APPENDIX A

Algal Turf Scrubber® (ATS™)

Patent No. 4,333,263 – Algal Turf Scrubber®

Patent No. 4,966,096 - Water Purification System and Apparatus

Patent No. 5,097,795 - Water Purification System and Apparatus

Patent No. 5,527,456 - Apparatus for Water Purification by Culturing and Harvesting Attached Algal Communities (License Rights Granted to ABES)

Patent No. 5,573,669 - Method and System for Water Purification by Culturing and Harvesting Attached Algal Communities (License Rights Granted to ABES)

Patent No. 5,715,774 - Animal feedstocks comprising harvested algal turf and a method of preparing and using the same

Patent No. 5,778,823 - Method of raising fish by use of algal turf

Patent No. 5,851,398 – Algal turf water purification method

Patent No. 6,572,770 – Apparatus and Method for Harvesting and Collecting Attached Algal Communities

Water Hyacinth Scrubber (WHS™)

Patent No. 5,811,007 - Vascular Plant Aquaculture and Bioremediation System and Method

Patent No. 5,820,759 – Integrated aquaculture and bioremediation system and method

Patent No. 6,393,812 – Method and apparatus for gathering, transporting and processing aquatic plants.

Patent No. 6,732,499 – Method and apparatus for gathering, transporting and processing aquatic plants.

Appendix 3: Natural Features in the WRB that need Protection: the St. Marks Rise; Natural Wells and Verdura

St. Marks Rise

The St. Marks Rise is the in Leon County is a first order magnitude spring with greater flow than Wakulla Springs. It is difficult to measure the absolute flow because multiple vents feed it. The St. Marks River goes underground at Natural Bridge and emerges from the ground, a mile to the south, at the St. Marks Rise. The flow at the Rise is 90% greater than at Natural Bridge. Most of the water in the St. Marks Rise is springfed. Water quality is generally better than that of the Wakulla. The area between Natural Bridge and the Rise is punctuated by numerous swallets. This area is privately owned and there is no public access. Few people in Leon County have actually seen the St. Marks Rise. It is an unbelievable dynamic karst feature. This area is very vulnerable to contamination.



Figure 1: Battle Field Monumant at natural Bridge



Figure 2: French Spring

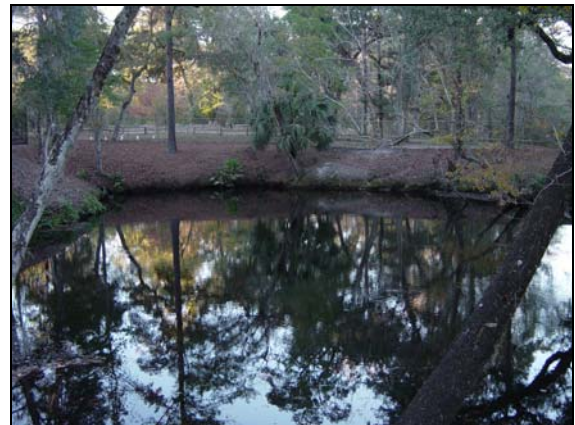


Figure 3: Front Swallet



Figure 4: Eastern with Daryll Spring Swallet



Figure 5: Small Swallet



Figure 6: another Swallet



Figure 7: another Swallet



Figure 8: the last Swallet



Figure 9: another Swallet



Figure 10: the St. Marks Rise

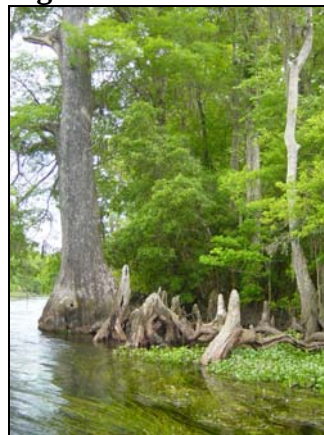


Figure 11: the St. Marks Rise and native Vallisneria. There are Limpkins here.

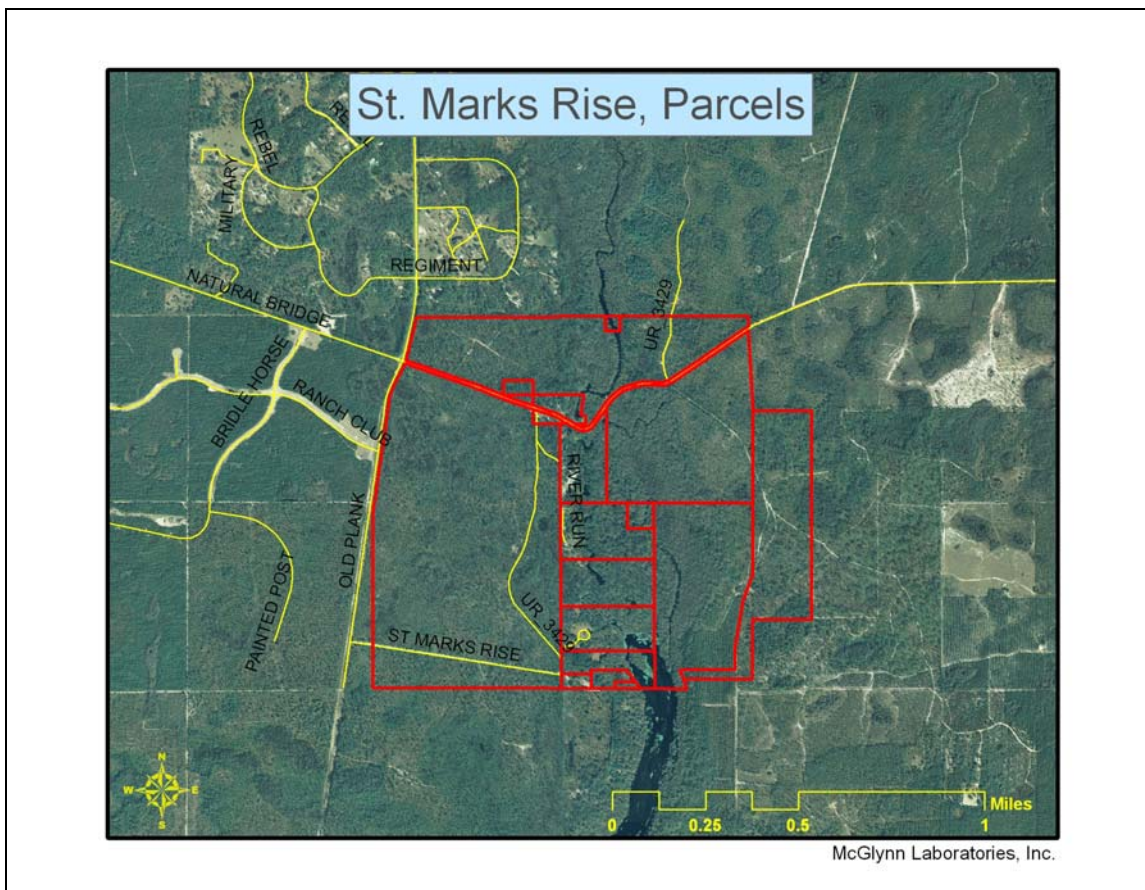


Figure 12: The St. Marks Rise parcels have a certified value of \$1,409,004.00

Natural Wells

Natural Wells is located near the powerlines south of Natural Bridge Road in the southern portion of the WRB. It is not a large karst feature. Natural Wells is an open cavern that is partially submerged. The portion of the cavern open to the air is a remarkably beautiful grotto. This is an open karst feature of exceptional beauty. It needs protection, as the aquifer is vulnerable to contamination. If it were open to the public it would help with ecotourism and education.



Figure 13: Looking down at the entrance to Natural Wells



Figure 14: Looking up at the entrance to Natural Wells

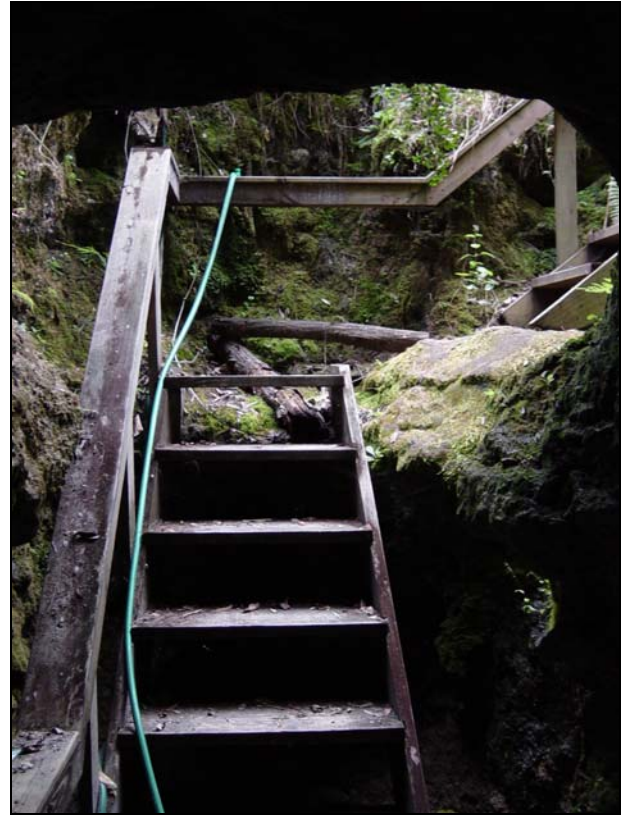


Figure 15: Stairs leading to Natural Wells



Figure 16: Stairs leading to Natural Wells

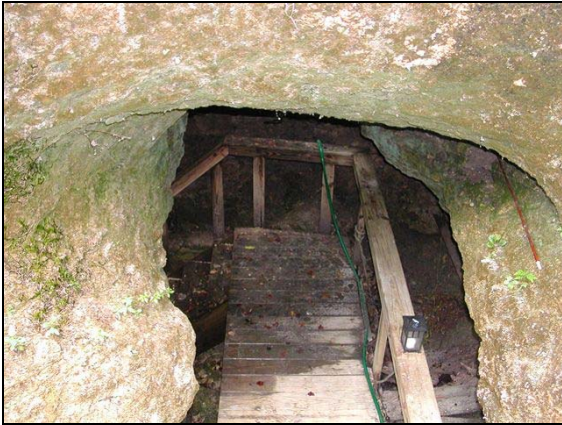


Figure 17: Stairs leading to Natural Wells



Figure 19: Amanda Kubes sampling water from the submerged cavern in Natural Wells



Figure 18: Submerged cavern in Natural Wells

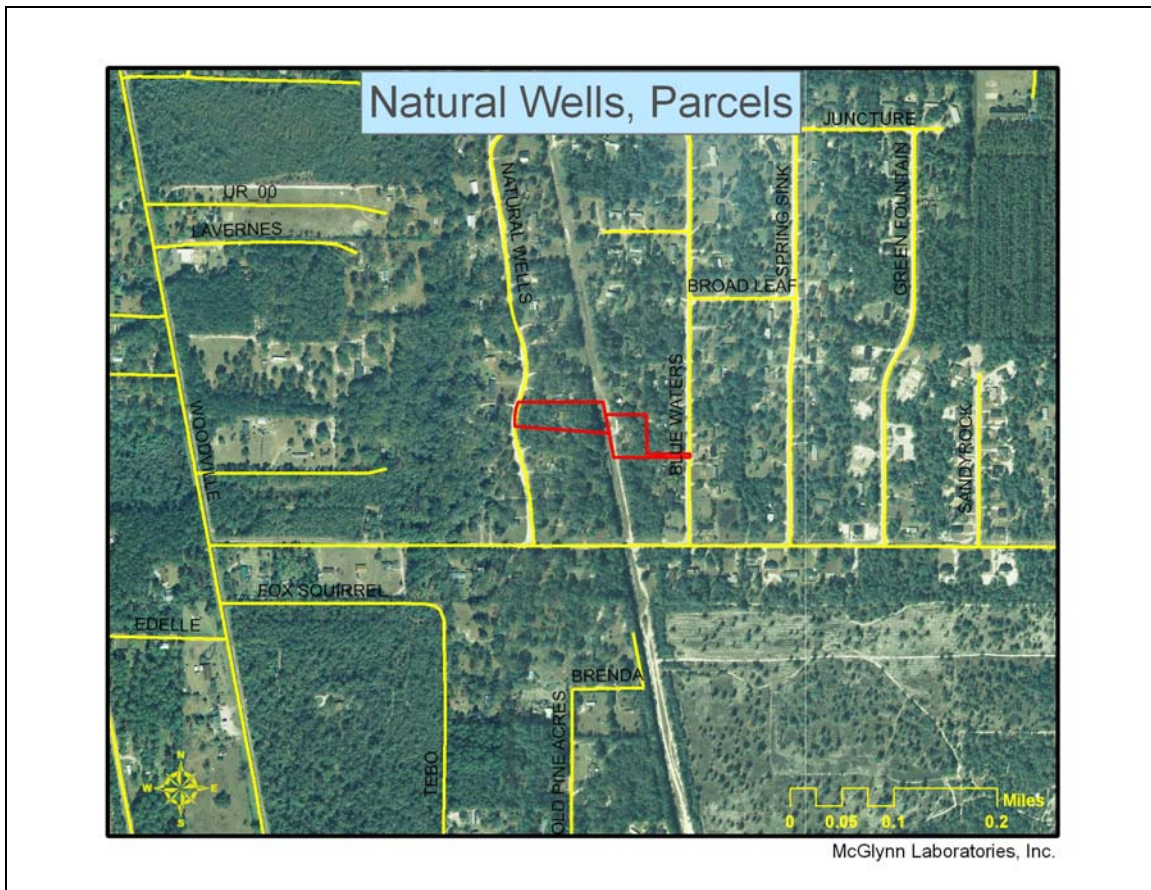


Figure 20: The Natural Wells parcels have a certified value of \$62,684.00

Verdura Plantation

Within the Woodville Aquifer Basin study area exists a little-known historic site of the grandest scale; one of inestimable scientific value and cultural importance. On a high promontory, commanding a panoramic view of the entire region, stand ten towering columns of imposing size and marvelous craftsmanship. These columns are the dramatic remains of the Verdura Plantation mansion, built in the 1830s and destroyed by fire in approximately 1890. One of the largest examples of the early antebellum plantation style, it was home to the family of pre-statehood businessman, banker and planter Benjamin Chaires. He came to Tallahassee after pioneering the laying out of Jacksonville. He established the first bank and brought the railroad to Tallahassee, but he was primarily a planter. Verdura was the largest and most elegant plantation in the area, 13 rooms, and three story brick on 9000 acres 7 miles south on Tallahassee. He was the first millionaire ever to reside in the state of Florida. Nearby stand the crumbling crypts and monuments of the Chaires family cemetery, where Benjamin Chaires himself was interred.

Despite its rather remote location, this important historic site is being plundered and vandalized. Excavations and graffiti are evident among the columns and within the cemetery itself. The burial vault of Martha Chaires, wife of Benjamin, has been thoroughly desecrated; the remains of the deceased completely removed. The ruins are on private property, the exact location of which is by tradition not revealed, and thus not here identified to prevent wider knowledge of its whereabouts (and thus further looting). Clearing and plowing to create broader hunting vistas further disturbs the site, turning up pottery shards by the thousands, diminishing their scientific and historical value.

Very little scientific study has taken place at this critically important site. The precise location of the slave cemetery, known to have existed on the grounds, has not been identified. The locations of the slave quarters, cotton gin, and other outbuildings, have not been charted. The exact site of a Seminole Indian encampment, known to have existed on the property during the Second Seminole War, has not been found. The remains of a Spanish colonial-era mission have been identified, but little studied. Evidence of occupation by Apalachee Indians and earlier aboriginal peoples have not been studied or properly documented.

This site, unique in Florida due to its diverse historical influences, is a geographic intersection point of Leon County's richly textured history. Yet its most prominent features are deteriorating due to vandalism, looting, and the elements -- tree falls slowly destroying what remains of the mansion house and cemetery. The Columns of Verdura dwarf the well-known columns currently located at the Chamber of Commerce building in Tallahassee, also designed and constructed by Benjamin Chaires. Like the ruins of an ancient Greek temple, these forgotten giants stand silent sentinel over Florida's Big Bend region; unseen, uninterpreted and unprotected.

The Ruins of Verdura truly are Florida's Parthenon, and remain the region's most spectacular hidden historical wonder.



Figure 21: Verdura Plantation, eastern facade.



Figure 23: Verdura Plantation, western facade.

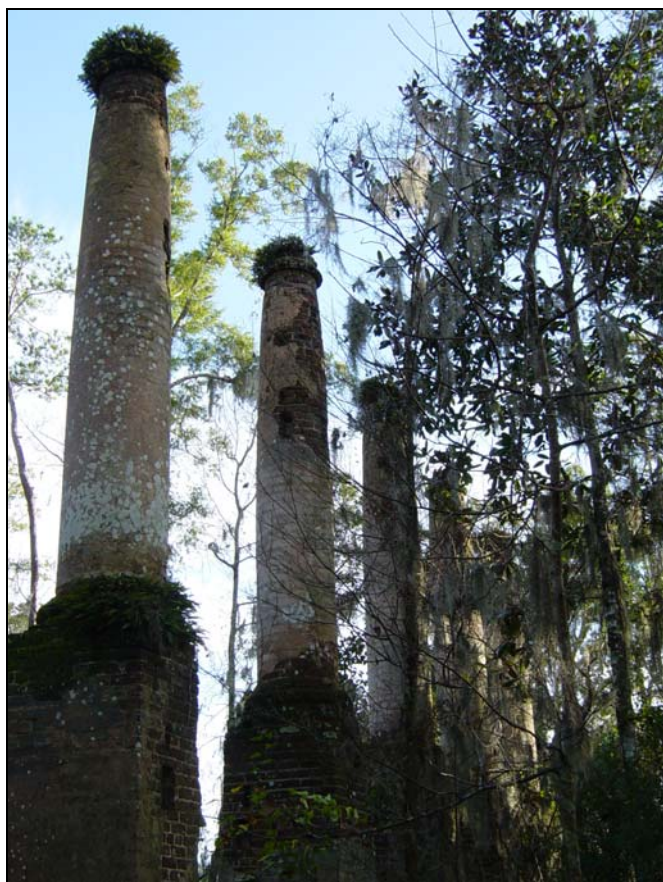


Figure 22: Verdura Plantation, eastern facade.



Figure 24: Verdura Plantation, creek separation the plantation from the cemetery.



Figure 25: Verdura Plantation Cemetery, cemetery entrance with the tomb of Benjamin Chaires (capped with an urn).



Figure 27: Verdura Plantation Cemetery, desecrated tomb of Benjamin Chaires wife.

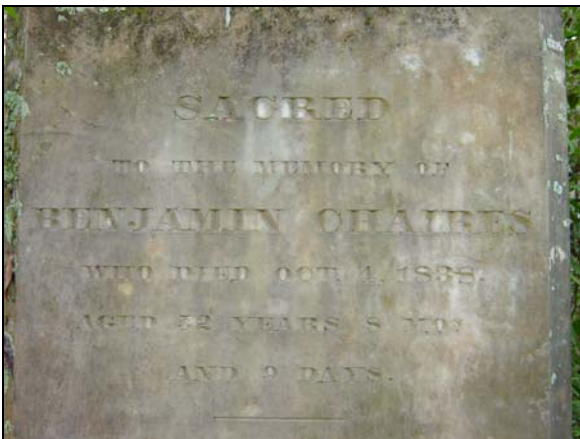


Figure 26: Verdura Plantation Cemetery, inscription on the tomb of Benjamin Chaires.



Figure 28: Verdura Plantation Cemetery.

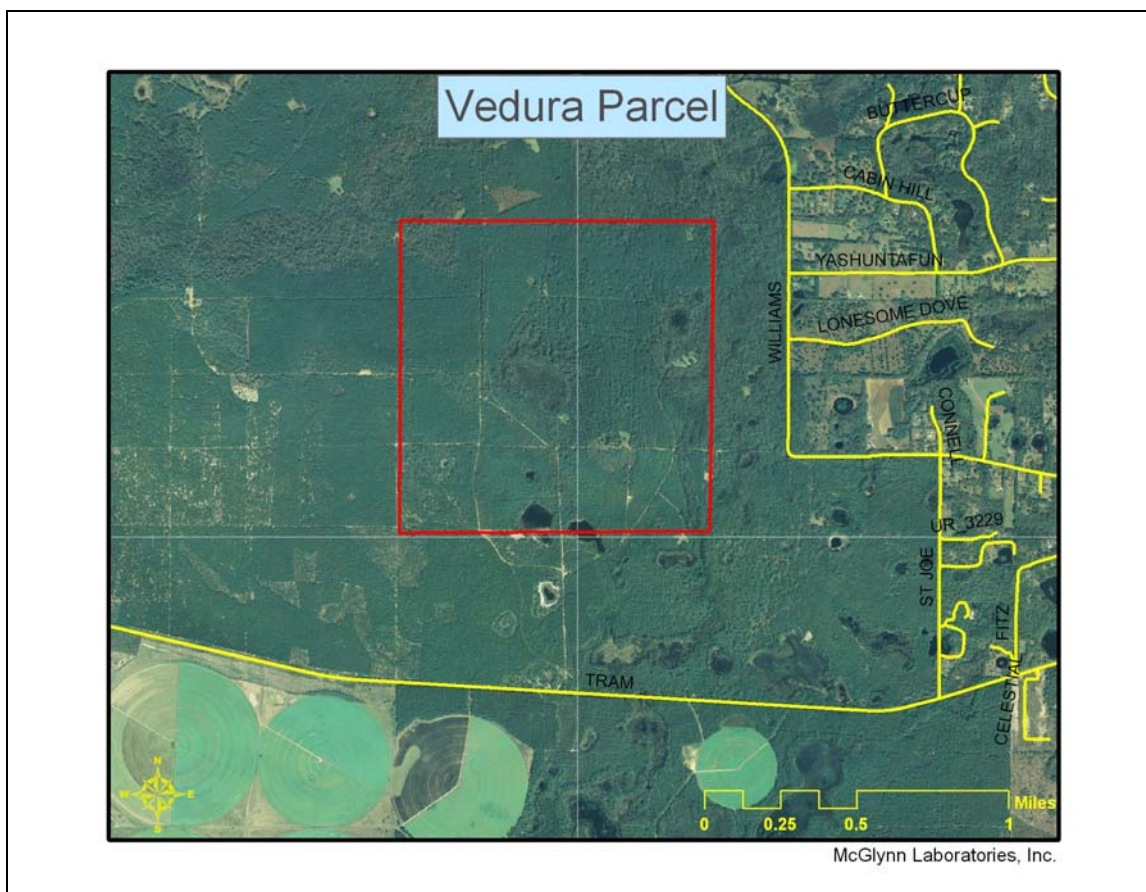


Figure 29: The Verdura parcel has a certified value of \$29,352,393.36 but this is for a square mile. Less of the property may be acquired to preserve the site.

WRB
Karst Feature Inventory

Site #	Coordinates	Type	Wet/Dry	Size (ft)
1	Lat: 30 23.2770 N; Lon: 84 17.1550 W	KW	W	150' x 100'
2	Lat: 30 23.1760 N; Lon: 84 17.1788 W	D	D	60' x 60'
3	Lat: 30 23.6978 N; Lon: 84 14.3853 W	MM	N/A	200' x 60'
4	Lat: 30 22.3421 N; Lon: 84 09.4480 W	D	D	20' x 20'
5	Lat: 30 22.3590 N; Lon: 84 10.1091 W	KL	W	150' x 200'
6	Lat: 30 22.2130 N; Lon: 84 12.7991 W	D	D	20' x 25'
7	Lat: 30 21.2851 N; Lon: 84 16.8078 W	D	D	40' x 40'
7A	Lat: 30 21.159 N; Lon: 84 16.673 W	KL	W	300' x 100'
8	Lat: 30 20.8388 N; Lon: 84 15.2092 W	D	D	10' x 10'
9	Lat: 30 21.5446 N; Lon: 84 09.9567 W	D	D	50' x 50'
9A	Lat: 30 21.577 N; Lon: 84 10.013 W	S	W	12' x 12'
9B	Lat: 30 21.585 N; Lon: 84 10.013 W	S	W	25' x 25'
10	Lat: 30 21.4804 N; Lon: 84 09.9400 W	D	D	50' x 50'
11	Lat: 30 21.6513 N; Lon: 84 09.7968 W	D	W	25' x 25'
11A	Lat: 30 21.595 N; Lon: 84 09.858 W	D	D	85' x 45'
11B	Lat: 30 21.662 N; Lon: 84 09.136 W	S	W	10' x 10'
12	Lat: 30 20.8330 N; Lon: 84 10.3210 W	S	W	15' x 30'
12A	Lat: 30 20.956 N; Lon: 84 09.920 W	S	W	15' x 15'
12B	Lat: 30 20.908 N; Lon: 84 09.562 W	SP	W	N/A
13	Lat: 30 20.1998 N; Lon: 84 10.4334	KW	W	30' x 30'
13A	Lat: 30 20.109 N; Lon: 84 10.471 W	S	W	25' x 25'
14	Lat: 30 20.0788 N; Lon: 84 10.2358 W	S	W	15' x 45'
15	Lat: 30 20.0735 N; Lon: 84 12.1527 W	KW	W	60' x 60'
15A	Lat: 30 19.782 N; Lon: 84 12.121 W	D	W	8' x 8'
16A	Lat: 30 20.375 N; Lon: 84 12.671 W	KW	W	25' x 25'
16B	Lat: 30 20.548 N; Lon: 84 12.607 W	S	W	150' x 150'
17	Lat: 30 20.2418 N; Lon: 84 12.2000 W	D	D	50' x 50'
18	Lat: 30 20.1553 N; Lon: 84 12.0387 W	D	D	25' x 25'
19	Lat: 30 20.2116 N; Lon: 84 11.9204	D	W	25' x 25'
21	Lat: 30 20.1292 N; Lon: 84 13.4631 W	D	D	15' x 15'
22	Lat: 30 20.3030 N; Lon: 84 14.6186 W	KW	W	25' x 25'
23	Lat: 30 20.0245 N; Lon: 84 14.7094 W	D	D	15' x 20'
24	Lat: 30 20.1511 N; Lon: 84 17.2749 W	D	W	25' x 25'
25	Lat: 30 20.2411 N; Lon: 84 17.7860 W	D	W	30' x 35'
26	Lat: 30 20.2177 N; Lon: 84 17.8106 W	D	W	50' x 50'
27	Lat: 30 20.4558 N; Lon: 84 17.8618 W	D	D	40' x 40'
28	Lat: 30 20.3747 N; Lon: 84 17.8410 W	D	W	25' x 25'
29	Lat: 30 19.7608 N; Lon: 84 16.8685 W	D	D	40' x 40'
30	Lat: 30 19.4905 N; Lon: 84 16.6979 W	D	D	30' x 30'
30A	Lat: 30 18.867 N; Lon: 84 17.008 W	KW	W	40' x 40'
30B	Lat: 30 19.170 N; Lon: 84 16.922 W	KW	W	35' x 35'
32	Lat: 30 19.835 N; Lon: 84 13.344 W	KW	W	40' x 40'
32A	Lat: 30 19.833 N; Lon: 84 13.325 W	D	D	30' x 30'
33	Lat: 30 19.4905 N; Lon: 84 16.6979 W	N/A	N/A	N/A
34	Lat: 30 19.5458 N; Lon: 84 12.8754 W	D	D	30' x 30'
35	Lat: 30 19.6828 N; Lon: 84 10.8285 W	D	W	15' x 15'
36	Lat: 30 19.7881 N; Lon: 84 10.7143 W	D	W	45' x 45'
37	Lat: 30 18.4066 N; Lon: 84 10.4505 W	N/A	N/A	N/A
37A	Lat: 30 17.180 N; Lon: 84 09.558 W	SS	W	15' x 15'

Site #	Coordinates	Type	Wet/Dry	Size (ft)
37B	Lat: 30 17.191 N; Lon: 84 09.601 W	SP	W	25' x 25'
37C	Lat: 30 17.197 N; Lon: 84 09.591 W	SP	W	15' x 15'
37D	Lat: 30 17.009 N; Lon: 84 09.435 W	SP	W	15' x 15'
37E	Lat: 30 17.006 N; Lon: 84 09.416 W	SS	W	25' x 25'
38	Lat: 30 18.8275 N; Lon: 84 11.3430 W	D	W	30' x 20'
47A	Lat: 30 18.268 N; Lon: 84 09.508 W	S	W	15' x 15'
47B	Lat: 30 16.830 N; Lon: 84 09.651 W	KW	W	60' x 60'
48	Lat: 30 16.998 N; Lon: 84 09.049 W	SS	W	65' x 65'
49	Lat: 30 17.096 N; Lon: 84 08.827 W	SP	W	60' x 50'
57	Lat: 30 19.089 N; Lon: 84 07.751 W	SP	W	40' x 40'
58	Lat: 30 21.210 N; Lon: 84 13.601 W	KL	W	Acres
58A	Lat: 30 21.267 N; Lon: 84 13.871 W	KL	W	Acres
59	Lat: 30 21.705 N; Lon: 84 13.889 W	KL	W	Acres
59A	Lat: 30 21.550 N; Lon: 84 13.870 W	S	W	30' x 30'
Chicken Branch	Lat: 30 19.991 N; Lon: 84 08.920 W	Sp	W	
Southwood 1	Lat: 30 22.932 N; Lon: 84 14.031 W	KW	W	
Southwood 2	Lat: 30 23.017 N; Lon: 84 14.064 W	S	D	
Shepard Branch Pond	Lat: 30 22.115 N; Lon: 84 13.423 W	KW	W	
Blue Sink	Lat: 30 20.164 N; Lon: 84 08.847 W	KW	W	
Natural Wells	Lat: 30 17.898 N; Lon: 84 14.279 W	KW	W	

Abbreviations
KW: karst window
D: Depression
KL: Karst Lake
S: Sinkhole
SP: Spring
SS: Sinking Stream
MM: Man-made
W: wet
D: Dry
N/A: not applicable
H: historical site

Woodville Basin Karst Feature Inventory

Site Name:	Sink 1 -- Church Sink
Investigator:	C. Werner
Date:	13-Apr-04
Time:	11:15
Location (Lat/Lon):	Lat: 30 23.2770 N; Lon: 84 17.1550 W
Directions:	Woodville Hwy approx. 2 miles north of Capital Circle South
	Just North of Korean Baptist Church
Weather Conditions:	Clear to partly cloudy, 60 F.
Feature Type:	Karst window with cave system
Size Estimate (Area):	150' x 100'
GL to Btm (or H2O):	30 - 40 ft
Depth Estimate:	Basin is 15 - 20 ft deep known from cave mapping.
H2O Visibility (Secchi):	Brackish to green in color ~8 ft. At other times very clear blue.
	Following precipitation events runoff from steep sand sides creates dark
	muddy water. Inside cave visibility has been up to 50 ft when clear on surface.
Description:	Large circular sink with fairly steep sides. Extensive erosional storm water
	features in NE corner of sink. Feature was used as a drainage culvert for
	drainage from Woodville Hwy at one time. Drainage pipe still remains, but is no
	longer in use.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 1 -- Church Sink
Investigator:	C. Werner
Date:	13-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 2
Investigator:	C. Werner
Date:	13-Apr-04
Time:	11:20
Location (Lat/Lon):	Lat: 30 23.1760 N; Lon: 84 17.1788 W
Directions:	Woodville Hwy approx. 2 miles north of Capital Circle South
	South of Korean Baptist Church
Weather Conditions:	Clear to partly cloudy, 60 F.
Feature Type:	Dry Depression
Size Estimate (Area):	60' x 60' circular.
GL to Btm (or H2O):	15 - 20 ft below surrounding topography.
Depth Estimate:	No water present.
H2O Visibility (Secchi):	N/A
Description:	Gently sloping sides, especially from NE corner south toward the feature.
	Small cement building in center of sink was used as a pumphouse to pump
	water up from aquifer to create a swimming hole for local residents. Not used
	today. No sign of visible water from large precipitation events present.
Additional Information:	

Karst Feature Inventory Images

Site Name: Sink 2

Investigator: C. Werner

Date: 13-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 3 -- C & C Landfill
Investigator:	C. Werner
Date:	13-Apr-04
Time:	11:05
Location (Lat/Lon):	Lat: 30 23.6978 N; Lon: 84 14.3853 W
Directions:	Off Capital Circle SE
Weather Conditions:	Clear to partly cloudy, 60 F.
Feature Type:	Manmade
Size Estimate (Area):	200' x 60' rectangular
GL to Btm (or H2O):	25 - 35 ft with extremely steep graded sides
Depth Estimate:	No water.
H2O Visibility (Secchi):	N/A
Description:	Large landfill. Manmade using dozers. Not a karst feature.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 3 -- C & C Landfill
Investigator:	C. Werner
Date:	13-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 4
Investigator:	C. Werner
Date:	25-Apr-04
Time:	9:10
Location (Lat/Lon):	Lat: 30 22.3421 N; Lon: 84 09.4480 W
Directions:	
Weather Conditions:	Partly cloudy, 60 F
Feature Type:	Dry Depression
Size Estimate (Area):	20' x 20'
GL to Btm (or H2O):	5 - 10 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Dry sink that appears to sometimes hold water. Most likely following large precipitation events. Slumping features seen in sand on sides.
Additional Information:	

Karst Feature Inventory Images

Site Name: Sink 4

Investigator: C. Werner

Date: 25-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 5
Investigator:	C. Werner
Date:	25-Apr-04
Time:	9:07
Location (Lat/Lon):	Lat: 30 22.3590 N; Lon: 84 10.1091 W
Directions:	
Weather Conditions:	Partly cloudy, 60 F
Feature Type:	Karst Lake
Size Estimate (Area):	150' x 200'
GL to Btm (or H2O):	5 - 8 ft
Depth Estimate:	~ 2 - 3 ft
H2O Visibility (Secchi):	Greenish tannic water, somewhat clear with ~5 - 8 ft visibility.
Description:	Large oval shaped Sinkhole Pond. Grass growing in center of water, likely low water conditions due to lack of rainfall. Gently sloping sides with lots of quartz sand along edge of water. Most likely no cave present.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 5
Investigator:	C. Werner
Date:	25-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 6
Investigator:	C. Werner
Date:	25-Apr-04
Time:	9:20
Location (Lat/Lon):	Lat: 30 22.2130 N; Lon: 84 12.7991 W
Directions:	
Weather Conditions:	Partly cloudy, 60 F
Feature Type:	Dry Depression
Size Estimate (Area):	20' x 25'
GL to Btm (or H2O):	10 - 15 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Gently to moderately sloping sides. Dry sandy bottom seen in karst feature.
Additional Information:	

Karst Feature Inventory Images

Site Name: Sink 6

Investigator: C. Werner

Date: 25-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 7
Investigator:	C. Werner
Date:	14-Apr-04
Time:	10:05
Location (Lat/Lon):	Lat: 30 21.2851 N; Lon: 84 16.8078 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Dry Depression
Size Estimate (Area):	40' x 40' circular
GL to Btm (or H2O):	5 - 8 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Large gently sloping sides with grass in center on feature. No water present.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 7
Investigator:	C. Werner
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 7A
Investigator:	C. Werner
Date:	14-Apr-04
Time:	10:15
Location (Lat/Lon):	Lat: 30 21.159 N; Lon: 84 16.673 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Karst Lake
Size Estimate (Area):	300' x 100' oval
GL to Btm (or H2O):	5 ft
Depth Estimate:	2 - 5 ft
H2O Visibility (Secchi):	Dark tannic water.
Description:	Large recharge wetland area. No cave evident. Retains water better part of year.
	Only likley to go dry during extended periods of drought.
Additional Information:	

Karst Feature Inventory Images

Site Name: Sink 7A

Investigator: C. Werner

Date: 14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 8
Investigator:	C. Werner
Date:	14-Apr-04
Time:	11:05
Location (Lat/Lon):	Lat: 30 20.8388 N; Lon: 84 15.2092 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Dry Depression
Size Estimate (Area):	10' x 10'
GL to Btm (or H2O):	15 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Very steep sided sink, sand sides with large pine trees surrounding sink.
	No water present.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 8
Investigator:	C. Werner
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 9
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04
Time:	16:42
Location (Lat/Lon):	Lat: 30 21.5446 N; Lon: 84 09.9567 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Dry Depression
Size Estimate (Area):	50' x 50' circular
GL to Btm (or H2O):	20 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Large dry sink with steep sides. No water present.
	Very similar to Sink 10.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 9
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 9A
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04
Time:	16:25
Location (Lat/Lon):	Lat: 30 21.577 N; Lon: 84 10.013 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Sinkhole
Size Estimate (Area):	12' x 12' circular
GL to Btm (or H2O):	10 - 12 ft
Depth Estimate:	1 - 3 ft
H2O Visibility (Secchi):	Dark tannic water.
Description:	Small sink with perennial stream running to it. In line with several E - W trending sinks.
	No cave.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 9A
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 9B
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04
Time:	16:30
Location (Lat/Lon):	Lat: 30 21.585 N; Lon: 84 10.013 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Sinkhole
Size Estimate (Area):	25' x 25' circular
GL to Btm (or H2O):	15 ft
Depth Estimate:	A few inches
H2O Visibility (Secchi):	Dark tannic shallow water.
Description:	Medium round sink with little water in bottom. Steep sides with sand sides.
	Small creek near this comes from Bonnet Pond.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 9B
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 10
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04
Time:	16:35
Location (Lat/Lon):	Lat: 30 21.4804 N; Lon: 84 09.9400 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Dry Depression
Size Estimate (Area):	50' x 50' circular
GL to Btm (or H2O):	20 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Large dry sink with very steep sides. Supported by large pine roots growing on sides of sink.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 10
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 11
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04
Time:	16:50
Location (Lat/Lon):	Lat: 30 21.6513 N; Lon: 84 09.7968 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Depression
Size Estimate (Area):	25' x 25' circular
GL to Btm (or H2O):	15 - 20 ft
Depth Estimate:	Several inches
H2O Visibility (Secchi):	Dark tannic
Description:	Circular sink with moderately sloping sides. Large pines and oaks surrounding sink. Just E of Bonnet Lake.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 11
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 11A
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04
Time:	16:50
Location (Lat/Lon):	Lat: 30 21.595 N; Lon: 84 09.858 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Dry Depression
Size Estimate (Area):	85' x 45' oval shaped sink
GL to Btm (or H2O):	35 - 40 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Large oval shaped sink with very steep walls. Sides of clay and sand.
	Sand ridge slump features in bottom of feature.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 11A
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 11B
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04
Time:	17:00
Location (Lat/Lon):	Lat: 30 21.662 N; Lon: 84 09.136 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Sinkhole
Size Estimate (Area):	10' x 10'
GL to Btm (or H2O):	15 ft
Depth Estimate:	~2 - 5 ft
H2O Visibility (Secchi):	Dark tannic water.
Description:	Small sink located farthest E on the sprayfield. Sand slumping on sides with steep walls.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 11B
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 12
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04
Time:	18:05
Location (Lat/Lon):	Lat: 30 20.8330 N; Lon: 84 10.3210 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Sinkhole
Size Estimate (Area):	15' x 30' dual sink feature
GL to Btm (or H2O):	8 - 12 ft
Depth Estimate:	5 - 10 ft
H2O Visibility (Secchi):	Dark tannic water
Description:	Sink has never been seen dry by Sprayfield employees. At peak precipitation events, sink will drain morthern depressions and water will flow into sink.
	Large oaks surround sink.
	Possible cave, needs to be investigated.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 12
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 12A
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04
Time:	17:44
Location (Lat/Lon):	Lat: 30 20.956 N; Lon: 84 09.920 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Sinkhole
Size Estimate (Area):	15' x 15'
GL to Btm (or H2O):	5 ft
Depth Estimate:	~ 12 ft
H2O Visibility (Secchi):	Dark tannic water.
	Usually clear.
Description:	Feature is usually always wet with clear blue water. Possible cave.
	This feature was excavated during construction of the St. Joe culvert. Steep
	sand sides, with obvious slumping and mass wasting features.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 12A
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 12B -- Chicken Branch headwaters
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04
Time:	17:27
Location (Lat/Lon):	Lat: 30 20.908 N; Lon: 84 09.562 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Stream headwaters
Size Estimate (Area):	N/A
GL to Btm (or H2O):	N/A
Depth Estimate:	N/A
H2O Visibility (Secchi):	N/A
Description:	Near the boundary of the southern end of the sprayfield at the gas line.
	Culvert put in by St. Joe ~40 years ago, used to drain sprayfield land in order
	to plant and havest trees. Currently drains lakes ~20 - 30 ft higher in elevation
	about 1 mile north. Culvert run N - S direction and starts as Eagle Lake.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 12B -- Chicken Branch headwaters
Investigator:	C. Werner, S. McGlynn, H. Davis
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 13
Investigator:	C. Werner
Date:	10-Apr-04
Time:	11:15
Location (Lat/Lon):	Lat: 30 20.1998 N; Lon: 84 10.4334
Directions:	Enter St. Joe property on north side of Natural Bridge Rd. Located on Dim 4 Rd.
Weather Conditions:	Clear day, 70 F
Feature Type:	Karst Window
Size Estimate (Area):	30' x 30' circular
GL to Btm (or H2O):	12 - 15 ft below sink sides
Depth Estimate:	15 ft
H2O Visibility (Secchi):	Greenish-brown water with large limestone blocks at bottom.
	Assesment on 14-Apr-2004 found water to be bluish-green with 20 ft visibility.
Description:	Definite cave potential, Large circular sink. Large tree overturned in basin.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 13
Investigator:	C. Werner
Date:	10-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 13A
Investigator:	C. Werner
Date:	10-Apr-04
Time:	11:00
Location (Lat/Lon):	Lat: 30 20.109 N; Lon: 84 10.471 W
Directions:	Enter St. Joe property on north side of Natural Bridge Rd. Located on Dim 4 Rd.
Weather Conditions:	Clear day, 70 F
Feature Type:	Sinkhole
Size Estimate (Area):	25' x 25' circular
GL to Btm (or H2O):	10 ft
Depth Estimate:	Several feet
H2O Visibility (Secchi):	Dark tannic water appears to be shallow
Description:	Small sink with shallow water, lots of small trees in center of sink.
	Located south of Sink 13.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 13A
Investigator:	C. Werner
Date:	10-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 14
Investigator:	C. Werner
Date:	26-Feb-04
Time:	12:40
Location (Lat/Lon):	Lat: 30 20.0788 N; Lon: 84 10.2358 W
Directions:	Enter St. Joe property on north side of Natural Bridge Rd. Located on Dim 4 Rd.
Weather Conditions:	Overcast with light to moderate rain, 45 - 50 F
Feature Type:	Sinkhole
Size Estimate (Area):	15' x 45' ft oval shaped
GL to Btm (or H2O):	8 - 10 ft
Depth Estimate:	Several feet deep.
H2O Visibility (Secchi):	Dark tannic red water.
Description:	Large oaks surrounding sink, not likely to have cave. Check back in order to determine if water visibility improves.
Additional Information:	Second check on 10-Apr-2004 confirms that there is likely no cave present.
	Water level is approximately 2 - 3 ft lower than when previously inventoried.
	Several developing sinks just west of Sink 14 and south of Sink 13.

Karst Feature Inventory Images

Site Name:	Sink 14
Investigator:	C. Werner
Date:	26-Feb-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 15 -- Osgood Sink
Investigator:	C. Werner
Date:	10-Apr-04
Time:	11:50
Location (Lat/Lon):	Lat: 30 20.0735 N; Lon: 84 12.1527 W
Directions:	Located on St. Joe company south of SW corner of COT sprayfield.
Weather Conditions:	Clear day, 70 F
Feature Type:	Karst Window
Size Estimate (Area):	60' x 60' circular
GL to Btm (or H2O):	20 - 25 feet
Depth Estimate:	60 - 90 feet in cavern zone.
H2O Visibility (Secchi):	Duckweed on surface. Greenish tannic color. At times color is crystal clear
	cobalt in color with 200 ft visibility.
Description:	Very large circular sink with steep sides. Mapped cavern zone but no
	entrance to cave. No clear water movement can be detected at depth.
Additional Information:	Visibility change is indicative of active flow. This site may be a possible
	tracing or injection point for tracing study.

Karst Feature Inventory Images

Site Name:	Sink 15 -- Osgood Sink
Investigator:	C. Werner
Date:	10-Apr-04



Woodville Basin Karst Feature Inventory

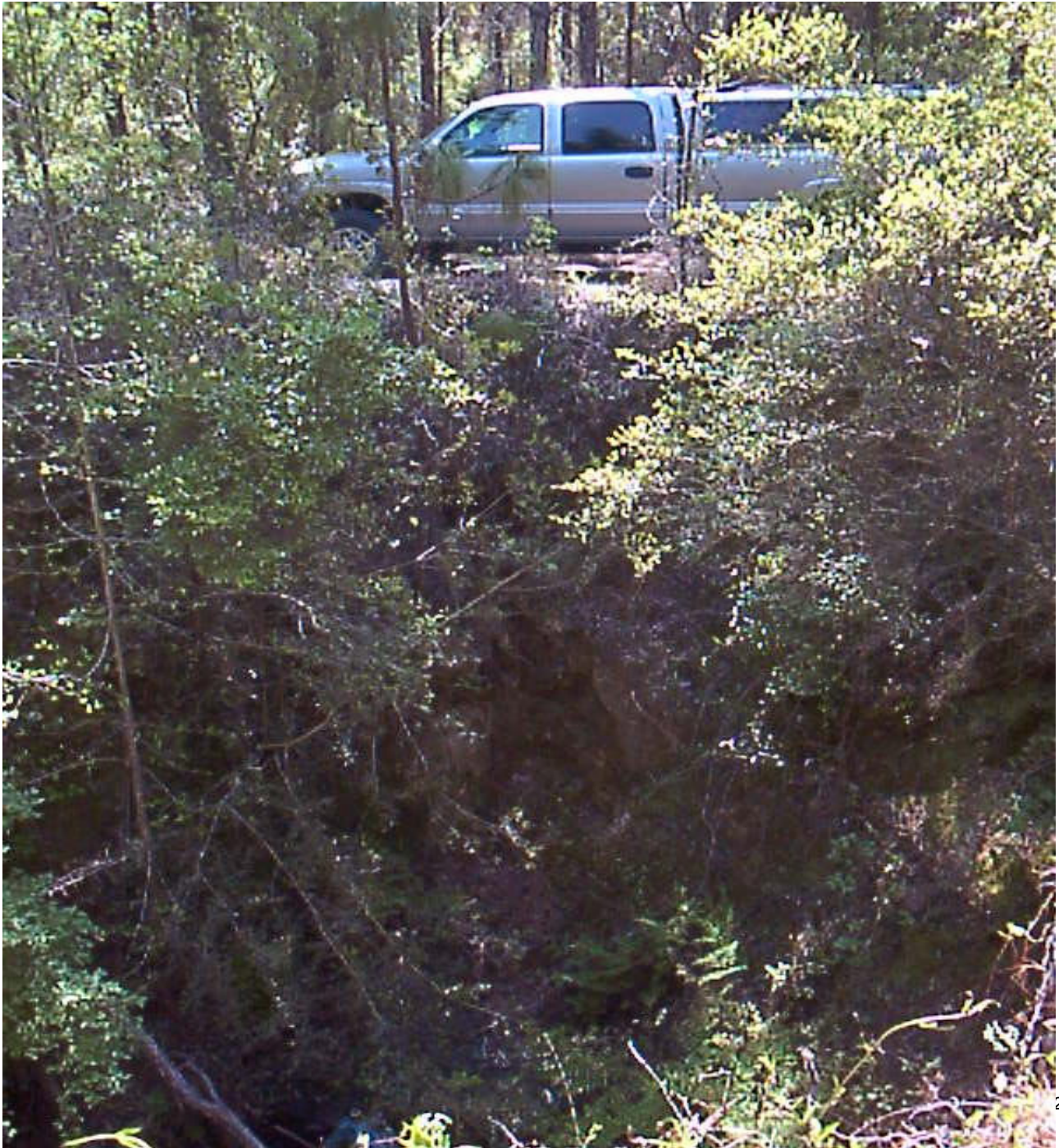
Site Name:	Sink 15A
Investigator:	C. Werner
Date:	10-Apr-04
Time:	11:45
Location (Lat/Lon):	Lat: 30 19.782 N; Lon: 84 12.121 W
Directions:	St. Joe property on cutoff between Upper Rd and Osgood Rd. Just south of
	Osgood Sink (15).
Weather Conditions:	Clear day, 70 F
Feature Type:	Depression
Size Estimate (Area):	8' x 8'
GL to Btm (or H2O):	30 - 35 ft
Depth Estimate:	1 - 2 ft
H2O Visibility (Secchi):	Dark brown to tannic water on bottom.
Description:	Deep narrow sink newly forming. Very steep sided with unstable sides.
Additional Information:	

Karst Feature Inventory Images

Site Name: Sink 15A

Investigator: C. Werner

Date: 10-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 16A -- Hideaway Sink
Investigator:	C. Werner
Date:	10-Apr-04
Time:	15:55
Location (Lat/Lon):	Lat: 30 20.375 N; Lon: 84 12.671 W
Directions:	Take Rhodes Cemetary Rd. off Woodville Hwy to Lorinda Ct. Turn right into last driveway, sink straight ahead.
Weather Conditions:	Clear day, 70 F
Feature Type:	Karst Window
Size Estimate (Area):	25' x 25' circular
GL to Btm (or H2O):	12 - 15 ft
Depth Estimate:	30 ft
H2O Visibility (Secchi):	Tannic water but appears to be clearing.
Description:	Definite cave was explored but not mapped. Future work should include mapping the cave.
Additional Information:	Excellent potential as an injection / monitoring site for dye tracing.

Site Name:	Sink 16A -- Hideaway Sink
Investigator:	C. Werner
Date:	10-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 16B
Investigator:	C. Werner
Date:	14-Apr-04
Time:	14:30
Location (Lat/Lon):	Lat: 30 20.548 N; Lon: 84 12.607 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Sinkhole
Size Estimate (Area):	150' x 150'
GL to Btm (or H2O):	15 - 20 ft from surrounding topography
Depth Estimate:	4 - 5 ft likely shallower in places
H2O Visibility (Secchi):	Dark tannic water.
Description:	Large recharge area with standing tannic water. LIDAR data shows this as a sink near the end of a paleo-surface drainage channel.
	More investigation warranted.
Additional Information:	Possible sinke here, must be investigated with weighted line and sampling.

Karst Feature Inventory Images

Site Name: Sink 16B

Investigator: C. Werner

Date: 14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 17
Investigator:	C. Werner
Date:	10-Apr-04
Time:	12:10
Location (Lat/Lon):	Lat: 30 20.2418 N; Lon: 84 12.2000 W
Directions:	
Weather Conditions:	Clear day, 70 F
Feature Type:	Depression
Size Estimate (Area):	50' x 50' circular
GL to Btm (or H2O):	5 - 8 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Large recharge area, tall grass growing in bottom. Feature may have water present following large precipitation events. No cave entrance or standing water present at time of inventory.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 17
Investigator:	C. Werner
Date:	10-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 18
Investigator:	C. Werner
Date:	10-Apr-04
Time:	12:26
Location (Lat/Lon):	Lat: 30 20.1553 N; Lon: 84 12.0387 W
Directions:	
Weather Conditions:	Clear day, 70 F
Feature Type:	Depression
Size Estimate (Area):	25' x 25' circular
GL to Btm (or H2O):	5 - 8 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Dry depression, possible recharge area. Not a typical subsidence feature.
	No evidence of water present.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 18
Investigator:	C. Werner
Date:	10-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 19
Investigator:	C. Werner
Date:	10-Apr-04
Time:	12:33
Location (Lat/Lon):	Lat: 30 20.2116 N; Lon: 84 11.9204
Directions:	
Weather Conditions:	Clear day, 70 F
Feature Type:	Depression
Size Estimate (Area):	25' x 25' circular
GL to Btm (or H2O):	8 - 10 ft
Depth Estimate:	1 -2 ft
H2O Visibility (Secchi):	Greenish-tannic water with 1 - 2 ft of visibility.
Description:	Smaller gently sloping sides leading to center of depression. Water in bottom with no cave entrance. Most likely a recharge area that is partially filled with water part of the year. Grass and small shrubs growing in bottom.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 19
Investigator:	C. Werner
Date:	10-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 21
Investigator:	C. Werner
Date:	14-Apr-04
Time:	11:40
Location (Lat/Lon):	Lat: 30 20.1292 N; Lon: 84 13.4631 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Depression
Size Estimate (Area):	15' x 15' circular
GL to Btm (or H2O):	5 - 8 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Dry bottom with sand in center of depression. No water present except likely at large precipitation events. In early stages of sink formation.
Additional Information:	

Karst Feature Inventory Images

Site Name: Sink 21

Investigator: C. Werner

Date: 14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 22
Investigator:	C. Werner
Date:	14-Apr-04
Time:	11:25
Location (Lat/Lon):	Lat: 30 20.3030 N; Lon: 84 14.6186 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Karst window
Size Estimate (Area):	30' x 30' circular
GL to Btm (or H2O):	12 - 15 ft
Depth Estimate:	15 ft
H2O Visibility (Secchi):	Greenish water slightly tannic in color.
Description:	Large steeply sided sink. Definite relief in sink below water. Likely has cave.
Additional Information:	Definite possibility as a tracing injection / monitoring site.

Karst Feature Inventory Images

Site Name:	Sink 22
Investigator:	C. Werner
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 23
Investigator:	C. Werner
Date:	14-Apr-04
Time:	10:50
Location (Lat/Lon):	Lat: 30 20.0245 N; Lon: 84 14.7094 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Depression
Size Estimate (Area):	15' x 20'
GL to Btm (or H2O):	10 - 12 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Sink located directly underneath powerlines. Filled with debris and trash.
	No water present.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 23
Investigator:	C. Werner
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 24
Investigator:	C. Werner
Date:	13-Apr-04
Time:	12:00
Location (Lat/Lon):	Lat: 30 20.1511 N; Lon: 84 17.2749 W
Directions:	
Weather Conditions:	Partly cloudy to sunny, 75 F
Feature Type:	Depression
Size Estimate (Area):	25' x 25' circular
GL to Btm (or H2O):	8 - 10 ft
Depth Estimate:	1 - 2 ft
H2O Visibility (Secchi):	Dark tannic water in center of feature
Description:	Gently sloping sides with small trees growing in center. No cave entrance likely.
	Appears to be a perennially active as a recharge area.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 24
Investigator:	C. Werner
Date:	13-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 25
Investigator:	C. Werner
Date:	13-Apr-04
Time:	12:35
Location (Lat/Lon):	Lat: 30 20.2411 N; Lon: 84 17.7860 W
Directions:	
Weather Conditions:	Partly cloudy to sunny, 75 F
Feature Type:	Depression
Size Estimate (Area):	30' x 35' circular
GL to Btm (or H2O):	8 - 10 ft
Depth Estimate:	1 - 2 ft
H2O Visibility (Secchi):	Dark tannic water, less than 2 ft visibility.
Description:	Large circular sink with shallow water in bottom. Gently sloping sides.
	Likely no cave present in this feature.
Additional Information:	

Karst Feature Inventory Images

Site Name: Sink 25

Investigator: C. Werner

Date: 13-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 26
Investigator:	C. Werner
Date:	13-Apr-04
Time:	12:40
Location (Lat/Lon):	Lat: 30 20.2177 N; Lon: 84 17.8106 W
Directions:	
Weather Conditions:	Partly cloudy to sunny, 75 F
Feature Type:	Depression
Size Estimate (Area):	40' x 50' circular
GL to Btm (or H2O):	12 - 15 ft
Depth Estimate:	3 ft
H2O Visibility (Secchi):	Dark tannic water.
Description:	Large sink with distinctive slumping features surrounding the center in a circular pattern. Large sand wall on W side of sink. Most evidence of recent subsidence seen in WKP near a sink.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 26
Investigator:	C. Werner
Date:	13-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 27
Investigator:	C. Werner
Date:	13-Apr-04
Time:	12:25
Location (Lat/Lon):	Lat: 30 20.4558 N; Lon: 84 17.8618 W
Directions:	
Weather Conditions:	Partly cloudy to sunny, 75 F
Feature Type:	Depression
Size Estimate (Area):	40' x 40' circular
GL to Btm (or H2O):	12 - 15 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Large circular sink, no water present. This is a large depression that is in the early sink formation stage. Most likely contains water following large precipitation event, but likely dry most of the year. Small growing in bottom.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 27
Investigator:	C. Werner
Date:	13-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 28
Investigator:	C. Werner
Date:	13-Apr-04
Time:	12:10
Location (Lat/Lon):	Lat: 30 20.3747 N; Lon: 84 17.8410 W
Directions:	
Weather Conditions:	Partly cloudy to sunny, 75 F
Feature Type:	Depression
Size Estimate (Area):	25' x 25' circular
GL to Btm (or H2O):	15 ft
Depth Estimate:	1 ft
H2O Visibility (Secchi):	Dark water
Description:	Steep sided depression with some water at bottom. Lots of trash present.
	No cave entrance likely.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 28
Investigator:	C. Werner
Date:	13-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 29
Investigator:	C. Werner
Date:	14-Apr-04
Time:	9:30
Location (Lat/Lon):	Lat: 30 19.7608 N; Lon: 84 16.8685 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Depression
Size Estimate (Area):	40' x 40' circular
GL to Btm (or H2O):	10 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Large circular sink with gently sloping sides. No water present.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 29
Investigator:	C. Werner
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 30
Investigator:	C. Werner
Date:	14-Apr-04
Time:	9:40
Location (Lat/Lon):	Lat: 30 19.4905 N; Lon: 84 16.6979 W
Directions:	
Weather Conditions:	Clear 75 F
Feature Type:	Depression
Size Estimate (Area):	30' x 30' circular
GL to Btm (or H2O):	No water
Depth Estimate:	N/A
H2O Visibility (Secchi):	N/A
Description:	Gently sloping sides with a large oak growing in the center of the depression.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 30
Investigator:	C. Werner
Date:	14-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 30A
Investigator:	C. Werner, D. Young, S. McGlynn
Date:	09-May-04
Time:	11:38
Location (Lat/Lon):	Lat: 30 18.867 N; Lon: 84 17.008 W
Directions:	
Weather Conditions:	Clear, warm
Feature Type:	Karst Window
Size Estimate (Area):	40' x 40'
GL to Btm (or H2O):	12'
Depth Estimate:	20' +
H2O Visibility (Secchi):	Dark tannic water
Description:	Large feature with significant depth. Likely a karst window, while at least a sinkhole through which water can infiltrate quickly to aquifer.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 30A
Investigator:	C. Werner, D. Young, S. McGlynn
Date:	09-May-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 30B
Investigator:	C. Werner, D. Young, S. McGlynn
Date:	09-May-04
Time:	11:53
Location (Lat/Lon):	Lat: 30 19.170 N; Lon: 84 16.922 W
Directions:	
Weather Conditions:	
Feature Type:	Karst Window
Size Estimate (Area):	35' x 35'
GL to Btm (or H2O):	12'
Depth Estimate:	20' +
H2O Visibility (Secchi):	Moderately clear, ~10 ft visibility
Description:	Small cave know to be here from personal communication with D. Young.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 30B
Investigator:	C. Werner, D. Young, S. McGlynn
Date:	09-May-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 32 Blueberry Sink
Investigator:	C. Werner, D. Young, S. McGlynn
Date:	09-May-04
Time:	10:00
Location (Lat/Lon):	Lat: 30 19.835 N; Lon: 84 13.344 W
Directions:	
Weather Conditions:	Clear
Feature Type:	Karst Window
Size Estimate (Area):	40' x 40'
GL to Btm (or H2O):	10 - 12 ft
Depth Estimate:	15'
H2O Visibility (Secchi):	~12 ft
Description:	Moderate sized karst window. Used to have access to small cavern according to owner, but through years of slumping, sand has now obstructed the entrance. This KW provides direct access to the aquifer.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 32 Blueberry Sink
Investigator:	C. Werner, D. Young, S. McGlynn
Date:	09-May-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 32A
Investigator:	C. Werner, D. Young, S. McGlynn
Date:	09-May-04
Time:	10:15
Location (Lat/Lon):	Lat: 30 19.833 N; Lon: 84 13.325 W
Directions:	
Weather Conditions:	Clear
Feature Type:	Depression
Size Estimate (Area):	30' x 30'
GL to Btm (or H2O):	4' - 8'
Depth Estimate:	
H2O Visibility (Secchi):	Dry.
Description:	
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 32A
Investigator:	C. Werner, D. Young, S. McGlynn
Date:	09-May-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 33
Investigator:	C. Werner
Date:	10-Apr-04
Time:	13:43
Location (Lat/Lon):	Lat: 30 19.4905 N: Lon: 84 16.6979 W
Directions:	
Weather Conditions:	Clear day, 70 F
Feature Type:	No Feature
Size Estimate (Area):	N/A
GL to Btm (or H2O):	N/A
Depth Estimate:	N/A
H2O Visibility (Secchi):	N/A
Description:	
Additional Information:	

<i>Karst Feature Inventory Images</i>	
Site Name:	Sink 33
Investigator:	C. Werner
Date:	10-Apr-04

Woodville Basin Karst Feature Inventory

Site Name:	Sink 34
Investigator:	C. Werner
Date:	10-Apr-04
Time:	13:55
Location (Lat/Lon):	Lat: 30 19.5458 N; Lon: 84 12.8754 W
Directions:	
Weather Conditions:	Clear day, 70 F
Feature Type:	Depression
Size Estimate (Area):	30' x 30' circular
GL to Btm (or H2O):	8 - 10 ft
Depth Estimate:	No water
H2O Visibility (Secchi):	N/A
Description:	Large depression with no water in bottom of feature. Grass growing in bottom.
	Gently sloping sides with no cave present.
	Likely to serves as a recharge area following large precipitation events.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 34
Investigator:	C. Werner
Date:	10-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 35
Investigator:	C. Werner
Date:	26-Feb-04
Time:	12:15
Location (Lat/Lon):	Lat: 30 19.6828 N; Lon: 84 10.8285 W
Directions:	
Weather Conditions:	Overcast with light to moderate rain, 45 - 50 F
Feature Type:	Depression
Size Estimate (Area):	15' x 15' circular
GL to Btm (or H2O):	10 ft
Depth Estimate:	1 ft
H2O Visibility (Secchi):	Dark tannic water only a foot deep.
Description:	Small sink with some water in bottom. Most likely dry for the better part of the year. Only contains water during large precipitation events. Sink is in early stages of formation. Two trees appear to have recently fallen over in response to the recent subsidence.
Additional Information:	

Karst Feature Inventory Images

Site Name: Sink 35

Investigator: C. Werner

Date: 26-Feb-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 36
Investigator:	C. Werner
Date:	26-Feb-04
Time:	11:45
Location (Lat/Lon):	Lat: 30 19.7881 N; Lon: 84 10.7143 W
Directions:	St. Joe property north side of Natural Bridge Rd.
Weather Conditions:	Overcast with light to moderate rain, 45 - 50 F
Feature Type:	Depression
Size Estimate (Area):	45' x 45' bowl shaped
GL to Btm (or H2O):	10 - 12 ft below surrounding topography
Depth Estimate:	1 - 3 ft.
H2O Visibility (Secchi):	Ligh brown muddy water, clearly due to surrounding runoff.
Description:	Steep side on SE side of sink. A few samll trees in water. Water level is obviously higher than normal due to precipitation. No flow detected. A few large pines and oaks surrounding bowl. Horseshoe shaped.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 36
Investigator:	C. Werner
Date:	26-Feb-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 37
Investigator:	C. Werner
Date:	10-Apr-04
Time:	15:15
Location (Lat/Lon):	Lat: 30 18.4066 N; Lon: 84 10.4505 W
Directions:	
Weather Conditions:	Clear day, 70 F
Feature Type:	No Feature
Size Estimate (Area):	N/A
GL to Btm (or H2O):	N/A
Depth Estimate:	N/A
H2O Visibility (Secchi):	N/A
Description:	Appears to be an inverse sink. Large mound with the surrounding topography about 8 - 10 ft lower. Large trees at center of elevated feature.
Additional Information:	

<i>Karst Feature Inventory Images</i>	
Site Name:	Sink 37
Investigator:	C. Werner
Date:	10-Apr-04

Woodville Basin Karst Feature Inventory

Site Name:	Sink 37A - Rhodes Springs
Investigator:	C.Werner, S. McGlynn, D. Young
Date:	09-May-04
Time:	
Location (Lat/Lon):	Lat: 30 17.180 N; Lon: 84 09.558 W
Directions:	
Weather Conditions:	
Feature Type:	Sinking Stream
Size Estimate (Area):	15' x 15'
GL to Btm (or H2O):	
Depth Estimate:	12 ft
H2O Visibility (Secchi):	Clear ~35 ft
Description:	Sinking stream of water in run from Feature 37A and 37B
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 37A - Rhodes Springs
Investigator:	C.Werner, S. McGlynn, D. Young
Date:	09-May-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 37B - Rhodes Springs
Investigator:	C. Werner, S. McGlynn, D. Young
Date:	09-May-04
Time:	
Location (Lat/Lon):	Lat: 30 17.191 N; Lon: 84 09.601 W
Directions:	
Weather Conditions:	
Feature Type:	Spring
Size Estimate (Area):	25' x 25'
GL to Btm (or H2O):	
Depth Estimate:	10 ft
H2O Visibility (Secchi):	35 ft visibility
Description:	Spring
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 37B - Rhodes Springs
Investigator:	C. Werner, S. McGlynn, D. Young
Date:	09-May-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 37C - Rhodes Springs
Investigator:	C. Werner, S. McGlynn, D. Young
Date:	09-May-04
Time:	
Location (Lat/Lon):	Lat: 30 17.197 N; Lon: 84 09.591 W
Directions:	
Weather Conditions:	
Feature Type:	Spring
Size Estimate (Area):	15' x 15'
GL to Btm (or H2O):	
Depth Estimate:	10 ft
H2O Visibility (Secchi):	35 ft visibility
Description:	Spring
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 37C - Rhodes Springs
Investigator:	C. Werner, S. McGlynn, D. Young
Date:	09-May-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 37D - Rhodes Springs
Investigator:	C. Werner, S. McGlynn, D. Young
Date:	09-May-04
Time:	
Location (Lat/Lon):	Lat: 30 17.009 N; Lon: 84 09.435 W
Directions:	
Weather Conditions:	
Feature Type:	Spring
Size Estimate (Area):	15' x 15'
GL to Btm (or H2O):	
Depth Estimate:	10 ft
H2O Visibility (Secchi):	35 ft visibility
Description:	Spring
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 37D - Rhodes Springs
Investigator:	C. Werner, S. McGlynn, D. Young
Date:	09-May-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 37E - Rhodes Springs
Investigator:	C. Werner, S. McGlynn, D. Young
Date:	09-May-04
Time:	
Location (Lat/Lon):	Lat: 30 17.006 N; Lon: 84 09.416 W
Directions:	
Weather Conditions:	
Feature Type:	Sinking Stream
Size Estimate (Area):	25' x 25'
GL to Btm (or H2O):	
Depth Estimate:	10 ft
H2O Visibility (Secchi):	35 ft visibility
Description:	Sinking stream. Features appear in nearly straight line heading toward
	St. Marks River Rise. Water flow is from NW to SE toward River Rise.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 37E - Rhodes Springs
Investigator:	C. Werner, S. McGlynn, D. Young
Date:	09-May-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 38
Investigator:	C. Werner
Date:	26-Feb-04
Time:	11:20
Location (Lat/Lon):	Lat: 30 18.8275 N; Lon: 84 11.3430 W
Directions:	Enter St. Joe property off of Natural Bridge Rd.
Weather Conditions:	Overcast with light to moderate rain, 45 - 50 F
Feature Type:	Depression
Size Estimate (Area):	30' x 20' oval shaped
GL to Btm (or H2O):	10 -15 ft
Depth Estimate:	Likely only a few feet deep.
H2O Visibility (Secchi):	Dark shallow water filling most of sink.
Description:	Steep sides on SW side, many small tress throughout bottom of sink.
	Not likely to have a cave entrance unless it is sanded in in theSW deeper corner.
Additional Information:	Second check on 9-Mar-2004 shows much lower water level. No cave present. Only leaves and detrital debris from subsiding sink sides on bottom.
	Water is still tannic but feature is clearly not a karst window.

Karst Feature Inventory Images

Site Name:	Sink 38
Investigator:	C. Werner
Date:	26-Feb-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 48 - Natural Bridge Sink
Investigator:	C. Werner
Date:	10-Apr-04
Time:	
Location (Lat/Lon):	Lat: 30 16.998 N; Lon: 84 09.049 W
Directions:	
Weather Conditions:	
Feature Type:	Sinking Stream
Size Estimate (Area):	65' x 65'
GL to Btm (or H2O):	10 ft
Depth Estimate:	Unknown
H2O Visibility (Secchi):	Less than 2 ft, dark tannic water
Description:	Large sink where St. Marks River diverts underground. Several features in the immediate area, unclear which are main contributory to sinking of St. Marks.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 48 - Natural Bridge Sink
Investigator:	C. Werner
Date:	10-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 49 - Natural Bridge Spring
Investigator:	C. Werner
Date:	10-Apr-04
Time:	
Location (Lat/Lon):	Lat: 30 17.096 N; Lon: 84 08.827 W
Directions:	
Weather Conditions:	
Feature Type:	Spring
Size Estimate (Area):	60' x 60'
GL to Btm (or H2O):	5-8 ft
Depth Estimate:	Unknown
H2O Visibility (Secchi):	2 ft, dark tannic water
Description:	Large spring of the St. Marks River. Several features in this area appear to work together to capture flow and divert it underground to the St. Marks Rise. More detailed mapping will be needed along with tracing to determine sources and sinks of actual water. Some features appear to be active while others are not.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 49 - Natural Bridge Spring
Investigator:	C. Werner
Date:	10-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 57 - Horn Spring
Investigator:	C. Werner, S. McGlynn
Date:	09-May-04
Time:	
Location (Lat/Lon):	Lat: 30 19.089 N; Lon: 84 07.751 W
Directions:	
Weather Conditions:	Clear
Feature Type:	Spring
Size Estimate (Area):	40' x 40'
GL to Btm (or H2O):	5 ft
Depth Estimate:	15 ft
H2O Visibility (Secchi):	10 - 15 ft
Description:	Sand bottom spring showing percolation of water from sandy bottom. Small spring run toward St. Marks River.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 57 - Horn Spring
Investigator:	C. Werner, S. McGlynn
Date:	09-May-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 58 -- Lutterloh Pond
Investigator:	C. Werner
Date:	26-Apr-04
Time:	10:20
Location (Lat/Lon):	Lat: 30 21.210 N; Lon: 84 13.601 W
Directions:	
Weather Conditions:	Partly cloudy, 60 F
Feature Type:	Karst Lake
Size Estimate (Area):	Several acres
GL to Btm (or H2O):	5 - 8 ft
Depth Estimate:	
H2O Visibility (Secchi):	Dark tannic area.
Description:	Large recharge area with shallow water. Sand and grass along the gently sloping sides. No cave likely.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 58 -- Lutterloh Pond
Investigator:	C. Werner
Date:	26-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 58A
Investigator:	C. Werner
Date:	26-Apr-04
Time:	10:10
Location (Lat/Lon):	Lat: 30 21.267 N; Lon: 84 13.871 W
Directions:	
Weather Conditions:	Partly cloudy, 60 F
Feature Type:	Karst Lake
Size Estimate (Area):	Several acres
GL to Btm (or H2O):	5 - 8 ft
Depth Estimate:	
H2O Visibility (Secchi):	Dark tannic water.
Description:	Large cypress swamp directly south of Live Oak Orchard. Best possibility for having a cave in this area.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 58A
Investigator:	C. Werner
Date:	26-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 59 -- Live Oak Orchard Pond
Investigator:	C. Werner
Date:	26-Apr-04
Time:	9:45
Location (Lat/Lon):	Lat: 30 21.705 N; Lon: 84 13.889 W
Directions:	
Weather Conditions:	Partly cloudy, 60 F
Feature Type:	Karst Lake
Size Estimate (Area):	Several square acres
GL to Btm (or H2O):	~ 5 ft
Depth Estimate:	3 - 8 ft
H2O Visibility (Secchi):	Dark tannic water.
Description:	Large gently sloping sides of lake. Sand and grass surrounding water.
	Approximately 3 ft low. Large oaks surrounding lake with fish and birds present.
Additional Information:	

<i>Karst Feature Inventory Images</i>	
Site Name:	Sink 59 -- Live Oak Orchard Pond
Investigator:	C. Werner
Date:	26-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Sink 59A -- Live Oak Orchard Sink
Investigator:	C. Werner
Date:	26-Apr-04
Time:	9:55
Location (Lat/Lon):	Lat: 30 21.550 N; Lon: 84 13.870 W
Directions:	
Weather Conditions:	Partly cloudy, 60 F
Feature Type:	Sinkhole
Size Estimate (Area):	30' x 30'
GL to Btm (or H2O):	5 - 8 ft
Depth Estimate:	8 - 15 ft
H2O Visibility (Secchi):	Dark tannic water, with no detectable flow.
Description:	Sink has steeper sides than most in the area. It is in line with several dry sinks running N - S direction. Possible cave but unlikely (most likely sanded in).
Additional Information:	

Karst Feature Inventory Images

Site Name:	Sink 59A -- Live Oak Orchard Sink
Investigator:	C. Werner
Date:	26-Apr-04



Woodville Basin Karst Feature Inventory

Site Name:	Chicken Branch
Investigator:	
Date:	22-Jun-03
Time:	14:55
Location (Lat/Lon):	Lat: 30 19.991 N; Lon: 84 08.920 W
Directions:	
Weather Conditions:	
Feature Type:	Spring
Size Estimate (Area):	
GL to Btm (or H2O):	
Depth Estimate:	
H2O Visibility (Secchi):	
Description:	Spring
Additional Information:	

Karst Feature Inventory Images

Site Name: Chicken Branch

Investigator: 0

Date: 22-Jun-03



Woodville Basin Karst Feature Inventory

Site Name:	Southwood 1
Investigator:	Sean McGlynmn
Date:	05-Oct-04
Time:	16:00
Location (Lat/Lon):	Lat: 30 22.932 N; Lon: 84 14.031 W
Directions:	
Weather Conditions:	
Feature Type:	
Size Estimate (Area):	
GL to Btm (or H2O):	
Depth Estimate:	
H2O Visibility (Secchi):	
Description:	Large feature with significant depth. Probably an area of high permeability through which water can infiltrate quickly to aquifer. No open Karst feature found when dry Receives continuous drainage from Southwoods
Additional Information:	

Karst Feature Inventory Images

Site Name:	Southwood 1
Investigator:	Sean McGlymn
Date:	05-Oct-04



Woodville Basin Karst Feature Inventory

Site Name:	Southwood 2
Investigator:	Sean McGlymn
Date:	05-Oct-04
Time:	16:00
Location (Lat/Lon):	Lat: 30 23.017 N; Lon: 84 14.064 W
Directions:	
Weather Conditions:	
Feature Type:	Large dry feature. Dry Karst Depression
Size Estimate (Area):	
GL to Btm (or H2O):	
Depth Estimate:	
H2O Visibility (Secchi):	
Description:	Large dry feature. Dry Karst Depression
Additional Information:	

Karst Feature Inventory Images

Site Name:	Southwood 2
Investigator:	Sean McGlymn
Date:	05-Oct-04



Woodville Basin Karst Feature Inventory

Site Name:	Shepard's Branch Pond
Investigator:	
Date:	
Time:	
Location (Lat/Lon):	Lat: 30 22.115 N; Lon: 84 13.423 W
Directions:	South of Tram road from Shepard's Branch
Weather Conditions:	
Feature Type:	
Size Estimate (Area):	
GL to Btm (or H2O):	
Depth Estimate:	
H2O Visibility (Secchi):	
Description:	Possibly a large feature with significant depth. Likely a karst window
Additional Information:	Several other features on the run
	Shepard's Branch at Tram Road Lat: 30 22.620 N; Lon: 84 13.220 W
	1st dry depression Lat: 30 22.450 N; Lon: 84 13.375 W
	Southern End of Pond Lat: 30 22.055 N; Lon: 84 13.456 W

<i>Karst Feature Inventory Images</i>	
Site Name:	Shepard's Branch Pond
Investigator:	Sean McGlynn
Date:	00-Jan-00



Woodville Basin Karst Feature Inventory

Site Name:	Blue Sink
Investigator:	Sean McGlynn
Date:	06-Jan-04
Time:	1:00
Location (Lat/Lon):	Lat: 30 20.164 N; Lon: 84 08.847 W
Directions:	
Weather Conditions:	
Feature Type:	
Size Estimate (Area):	
GL to Btm (or H2O):	
Depth Estimate:	
H2O Visibility (Secchi):	
Description:	Large feature with significant depth. Likely a karst window, while at least a sinkhole through which water can infiltrate quickly to aquifer.
Additional Information:	

Karst Feature Inventory Images

Site Name:	Blue Sink
Investigator:	Sean McGlynn
Date:	06-Jan-04



Woodville Basin Karst Feature Inventory

Site Name:	Natural Wells
Investigator:	Sean McGlynn
Date:	
Time:	
Location (Lat/Lon):	Lat: 30 17.898 N; Lon: 84 14.279 W
Directions:	
Weather Conditions:	
Feature Type:	Possible Open Karst Window
Size Estimate (Area):	
GL to Btm (or H2O):	
Depth Estimate:	
H2O Visibility (Secchi):	
Description:	Cavern Entrance to submerged chambers
	Explored by divers and no swimmable passage
Additional Information:	

Karst Feature Inventory Images

Site Name:	Natural Wells
Investigator:	Sean McGlynn
Date:	00-Jan-00



