THREE DIMENSIONAL MODELING OF WEKIVA SPRINGSHED WITH WASH123D

by

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ABSTRACT

This thesis presents a three-dimensional groundwater modeling of Wekia springshed in central Florida using a numerical model, WASH123D. Springs have historically played an important role in Florida’s history. The Wekiva River is a spring-fed system associated with about 19 springs connected to the Floridan aquifer. With increased urbanization and population growth in this region, there has been an increased strain on the water levels of Floridan aquifer which is a major source of potable water. Maintaining groundwater recharge to the aquifer is a key factor of the viability of the regional water supply as well as Wekiva ecosystem.

Hence, the first-principle, physics-based watershed model WASH123D has been applied to conduct the study of Wekiva “springshed”, which is the recharge area and watershed contributing groundwater and surface water to the spring. In this work, the hydrogeologic conditions of the Wekiva springshed are discussed followed by the modeling details such as mathematical background, domain discretization and initial and boundary conditions considered. Finally, the results from the model are discussed.

The Wekiva WASH123D model was run to evaluate the average, steady state 1995 hydrological conditions. The distribution of simulated Floridan aquifer system groundwater levels using WASH123D shows very good agreement with the field observations at corresponding locations.

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1. INTRODUCTION

As Florida's population continues to grow, the underlying Floridan aquifer and connected springs are facing increasing pressures. This growth brings an inevitable rise in water use, as well as extensive land use changes. Water shortages could become a controlling factor in the location and timing of new development. Each year, lands within springsheds are developed, altering the quality and quantity of water flowing to the springs. Springs serve as windows into the quality of our groundwater, which continues to decline as development pressures increase.

The spring-fed system, Wekiva River and its tributaries, along with the St. Johns River and associated lands in Central Florida have long been recognized as one of the most valuable natural assets of the state. These areas, which include most of the Central Florida portion of St. Johns River Water Management District (SJRWMD), were designated based upon the likelihood of future water resource problems due to projected 2010 groundwater withdrawals.

The purpose of this thesis is to develop a numerical modeling tool that will be capable of estimating the hydrologic characteristics of the fresh groundwater flow system in the Wekiva springshed region.

The Wekiva springshed region is centered upon Orange and Seminole counties but includes most of Brevard, Lake, and Osceola counties plus parts of Marion, Polk, Sumter, and Volusia counties (see Figure 1-1). The region includes areas located within the jurisdiction of three water management districts: the St. Johns River Water Management District, the Southwest Florida Water Management District (SWFWMD), and the South Florida Water Management District (SFWMD).

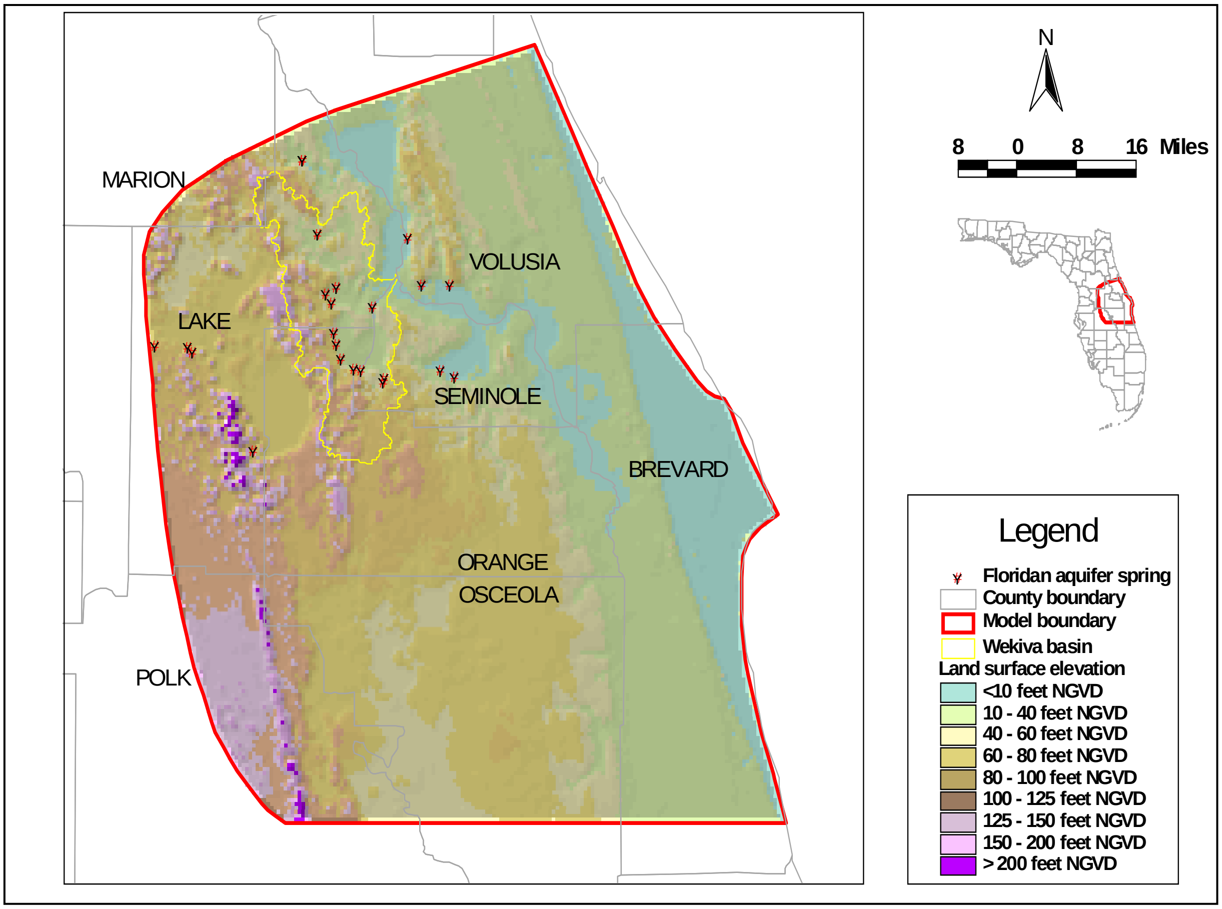


Figure 1-1 Land Surface Elevations and Floridan Aquifer Springs in Modeling Area

The Wekiva River springshed is modeled using WASH123D to simulate the three dimensional groundwater flows to predict potential steady-state changes in the groundwater flow system in the area due to projected average 2020 withdrawals.

WASH123D (A Numerical Model Simulating Water Flow and Contaminant and Sediment Transport in WAterSHed Systems of 1-D Stream/River Network, 2-D Overland Regime, and 3-D Subsurface Media, Yeh, et al., 1998) is a watershed model that can be used to simulate flows, sediment and reactive chemical transport, all separately or simultaneously. This model can read flow fields computed from either its flow module or other flow models to proceed to transport simulations. When both flow and transport are simulated, the flow fields are computed first. Then the transport is calculated using the computed flow fields at respective times. The feedback of transport on flow is not considered (e.g., no density effect is considered) in this model.

There may be three approaches to model surface flow in a watershed system: the kinematic, diffusive, and dynamic wave models. The dynamic wave models completely describe water flow but they are very difficult to solve under some conditions (e.g., when the slope of ground surface is steep), regardless of what numerical approach is employed. On the other hand, the diffusion and/or kinematic models can handle a wide range of flow problems but are inaccurate when the inertial terms play significant roles (e.g., when the slope of groundwater surface is small). Thus, three options are provided in this report: the kinematic wave model, the diffusion wave model, and the dynamic wave model to accurately compute water flow over a wide range of conditions. The diffusion/kinematic wave models were numerically approximated with the Lagrangian method. The dynamic model was first mathematically transformed into characteristic wave equations. Then it was numerically solved with the Lagrangian-Eulerian method.

The subsurface flow governing equations are discretized with the Gelarkin finite element method. The surface/subsurface interface boundary is treated as a variable boundary as described in the FEMWATER model.

The principles of mass balance were employed to derive the transport equations governing the temporal-spatial distribution of chemicals, suspended sediment, and bed sediment. Chemical kinetics based on the collision theory was used to present the relationship between reactant and product species in all chemical reactions and volatilization. The predictor-corrector numerical scheme was used to solve the transport equations. In the predictor step, the Lagrangian-Eulerian method was employed to solve the advection-dispersion transport equation with the source/sink term evaluated at the previous time. In the corrector step, the implicit finite difference was used to solve the system of ordinary equations governing the chemical kinetic reactions. The nonlinearity in flow and sediment transport equations is handled with the Picard method, while the nonlinear chemical system is solved by using the Newton-Raphson method.

In chapter 2, an overview of all the literature researched during the course of the thesis is provided. In chapter 3, the model region- the geologic and hydrologic properties are described in detail. In chapter 4, the methodology followed to model the Wekiva Springshed- computer code selection, mathematical basis, discretization, applied boundary conditions are discussed in detail. In chapter 5, the simulation results are analyzed, followed by the conclusions.

2. LITERATURE REVIEW

2.1 Springs of Florida

With over 600 freshwater springs, Florida is blessed with perhaps the largest concentration of these natural features in the world. They are supplied by the Floridan aquifer, the source of drinking water for most of Florida. Most of Florida’s springs are located in the region stretching from Hillsborough, Orange, Seminole and Volusia counties north and west to Walton County. Many studies have been carried out focusing on this region’s springsheds— the land areas that feed water to the springs.

2.1.1 Springs Geology

Florida rests on a bed of limestone. The carbon dioxide in the atmosphere makes rainwater slightly acidic and when this rainwater works its way through the limestone dissolving channels and caves, it form an underground drainage system. Where larger cavities are created, the overlying rock sometimes collapses, forming a sinkhole or spring. Most Florida springs exist where the limestone of the Floridan Aquifer is exposed at the land surface and ground water is forced out from underground. This type of landscape is commonly referred to as “karst.” The soils within this very porous topography are often sandy. Water passes through rapidly and is poorly filtered, so pollution from the land passes quickly into the underlying aquifer. Additionally, sinkholes, streams, and lakes act as conduits, further polluting the aquifer. These pollutants then emerge in the spring water (FDCAEP, 2002).

The entire state of Florida is a karst region, resting on a limestone plateau formed millions of years ago when the area was a shallow sea. These karst features are mostly visible in those areas where there is little to no clay and sandy soils on top of the limestone, and where the ground water is near the surface. Areas with well-developed karst terrain and the location of major springs are strongly correlated. Springs are classified by their rate of discharge. Springs discharging 100 cubic feet per second or more are First magnitude and springs producing less than one pint per minute are Eighth magnitude (see Table 2-1).

Table 2-1 Spring discharges and corresponding magnitude values

Magnitude	**Average Flow (Discharge)**
1	100 ft3/s (cubic feet per second) or more
2	10 to 100 ft3/s
3	1 to 10 ft3/s
4	100 gal/min (gallons per minute) to 1 ft3/s(448 gal/min)
5	10 to 100 gal/min
6	1 to 10 gal/min
7	1 pint to 1 gal/min
8	Less than 1 pint/min

2.1.2 Springs Connectivity

The area of land that feeds a spring (recharge area) is identified as a springshed. The extent of a springshed is influenced by topography, the presence of cave systems, fissures and other karst features as well as hydrological or water pressure.

Water falling miles away seeps into the ground water, eventually enters the cave system and emerges through a spring. A stream disappears underground, but can travel through the karst landscape and reemerge through a spring (FDCAEP, 2002). Sinkholes can also be connected to a spring. Pollutants entering any of these apparently unrelated systems can travel underground to the spring. This movement can be relatively quick or can take years. Thus, in a karst landscape, what can not be seen is as important as what can be seen. Understanding the hydrology and geology of these landscapes is important to developing effective strategies for spring's protection.

2.1.3 Negative Impact of Land Use on Springs

The ground water that feeds springs is recharged by seepage from the surface and through direct conduits such as sinkholes. Numerous studies by Florida's water management districts and the United States Geological Survey clearly demonstrate contamination attributable to changes in land use in springsheds. An activity on land directly and indirectly affects the quality of water moving through the subsurface karst matrix. Contamination is a major threat. Water can carry contaminants from the land surface into springs. Stormwater runoff can carry oil, fertilizer, pesticides, and bacteria. Septic tanks and underground storage tanks can contribute nutrients, bacteria and chemicals via seepage. This contamination seeps to the ground water and travels to the spring. Increased nutrients, including soluble forms of nitrogen, essentially fertilize the water in springsheds. The quantity of water feeding a spring and its corresponding discharge can also be dramatically affected by land use. The natural flow of water to springs is controlled by complex interactions. These include the amount and frequency of rainfall, the porosity and permeability of the aquifer, the hydrostatic head within the aquifer, and the hydraulic gradient of the land. Flows can be reduced or eliminated by over-pumping water from the aquifer for irrigation or potable water needs. These negative impacts are unlikely to remain confined to a spring. Springs drain large amounts of ground water from the Floridan Aquifer, contributing to the relatively constant temperature and steady flow rate of many of Florida's spring runs—rivers that stem from the outflow of a spring. Other rivers receive significant portions of their flow from seeps— water table springs that issue from the riverbank. Thus, contaminated spring water is carried directly into the ensuing rivers and can dramatically impact the health of this riverine environment as well. Reducing the amount of water discharged from a spring also reduces the flow in the river, creating additional impacts (FDCAEP, 2002).

2.1.4 Springs Protection and Remediation

Steps to plan for springshed protection include:

- Use Florida's Comprehensive Planning Process Effectively
- Establish a Working Group
- Adopt a Resolution of Support for Springshed Protection
- Collect Data and Map the Resources
- Establish Springshed Protection Zones
- Create an Overlay Protection District
- Use Other Appropriate Land Use Planning Tools
- Use Acquisition and Easement Strategies to Protect the Most Sensitive Areas
- Establish Voluntary Stewardship Programs
- Adopt Comprehensive Plan Policies for Springshed Protection

These steps are discussed in detail in the report of the Florida Departments of Community Affairs and Environmental Protection (FDCAEP, 2002).

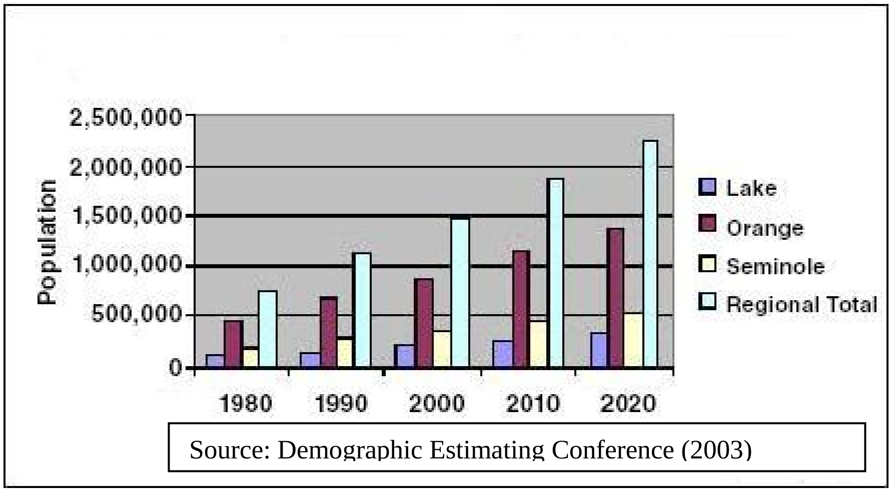
As part of the data collection and resource mapping, a variety of useful federal, state local and private sources of data for mapping a springshed are available, including Aquifer Vulnerability Models. Both the U.S. Environmental Protection Agency and the Florida Department of Environmental Protection use models to determine aquifer vulnerability to pollution. Such modeling can provide valuable guidance when identifying the types of land uses appropriate for areas within a springshed.

2.2 Preserving the Wekiva River Basin Ecosystem

2.2.1 Background

The Wekiva Basin ecosystem is an outstanding natural resource: the Wekiva River and its tributaries have been designated an Outstanding Florida Water, a National Wild and Scenic River, a Florida Wild and Scenic River, and a Florida Aquatic Preserve.

The viability of the Wekiva ecosystem and regional water supply are dependent on maintaining groundwater recharge to the aquifer. Since the early 1980s, the central Florida region has continued to experience tremendous growth that has resulted in increasing demands on the region’s transportation system and rising development pressures on the land surrounding the Wekiva River Protection Area. In the decade between 1980 and 1990, the growth rate in the three-county area exceeded 30 percent (see Figure 2-1). While the rate of growth has slowed, it is projected to exceed 20 percent through 2010 (six percent higher than the state rate) and slow only slightly to 17 percent by the year 2020 (compared to the projected state rate of 13 percent) (WBATF, 2003).



Source: Demographic Estimating Conference (2003)

Figure 2-1 Population Growth in the Wekiva Basin Area

In order to balance the protection of the Wekiva Basin Area with the new growth and the future transportation needs of the region, a Wekiva Basin Area Task Force was created. The Task Force was charged with considering, evaluating, and making recommendations concerning the following issues:

1. The most appropriate location for a highway route that connects State Road 429 to Interstate 4, and which causes the least disruption and provides the greatest protection to the Wekiva Basin ecosystem, while also achieving the goal of connecting the two routes.

2. A transportation plan that evaluates the diverse considerations associated with the potential expansion of roads or corridors within the Wekiva Basin Area. The plan should address, but need not be limited to, the subjects of land acquisition, springshed protection, innovative road design, protection of rural character, protection of habitat, utilization of financial resources, and the adequacy of local government plans as they relate to growth related impacts of transportation corridors.

2.2.2 The Wekiva Springshed

The Wekiva River is a spring-fed system associated with 19 springs connected to the Florida Aquifer. Of these, 11 are known to be second and third magnitude springs. The Wekiva Basin Area comprises two elements: surface water and ground water. The geographic area of the Wekiva River surface water basin, combined with the geographic area of the recharge basin – or "springshed" – (see Figure 2-2) form the Wekiva Basin Area referred to in this discussion.

Potable water in central Florida is supplied almost exclusively by groundwater from the Floridan aquifer. The abundance of public lands and significant large tracts of privately owned lands create large blocks of contiguous wildlife habitat for numerous species.

In 1988, the Florida Legislature enacted the Wekiva River Protection Act, codified as Chapter 369, Part II, Florida Statutes, to protect the resources of the Wekiva River Basin. The Act declared the Wekiva River to be a natural resource of state and regional importance, and delineated an area comprising portions of Lake, Seminole and Orange Counties as the Wekiva River Protection Area (WBATF, 2003).

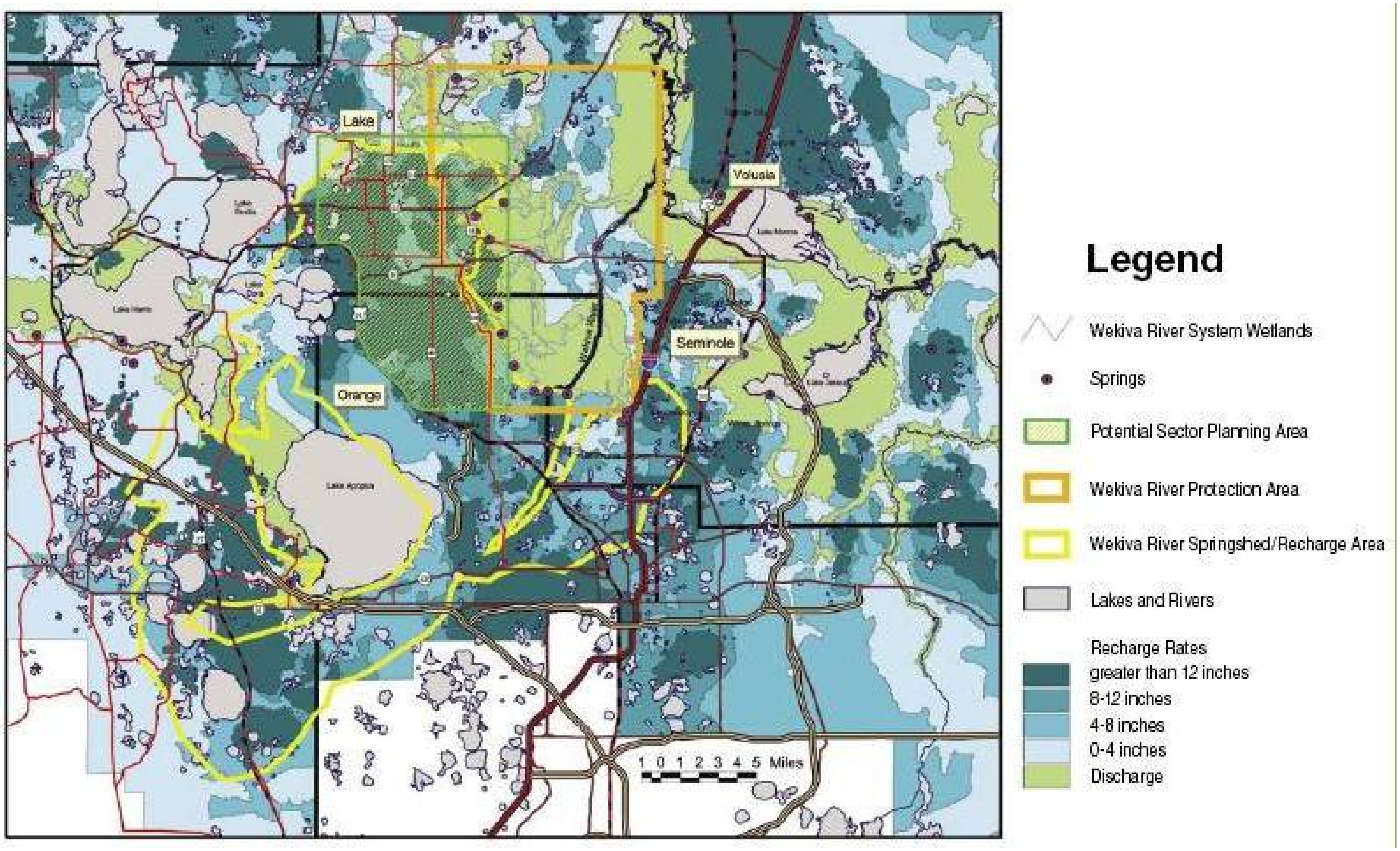


Figure 2-2 Wekiva River Springshed/Recharge Area

Source: Department of Commnity affairs and SJRWMD, December 2003

2.2.3 Task Force Recommendations

After various considerations and evaluations, the Task Force provided recommendations which are grouped based on the issues addressed: recommendations related to achieving the connection of SR 429 to Interstate 4, including corridor selection and roadway design, as well as a future plans for transportation improvements in the Wekiva Basin Area; and recommendations related to protecting the Wekiva Basin Area ecosystem, including land acquisition, protection of wildlife and habitat and the springshed/recharge areas, and preserving rural character.

The recommendations related achieving the roadway connection and its improvements are discussed in detail in the Wekiva Basin Area Task Force report (WBATF, 2003).

The recommendations related to enhanced local government comprehensive planning procedures, implementing refinements to the water resources regulatory framework and protecting wildlife are provided below.

2.2.3.1 Enhancing Local Government Comprehensive Planning Procedures

According to the final report of the Florida Springs Task Force, “A spring is only as healthy as its recharge basin...The groundwater that feeds springs is recharged by seepage from the surface and through direct conduits such as sinkholes. Because of this, the health of spring systems is directly influenced by activities and land uses within the spring recharge basin.” During the deliberations of the Wekiva Basin Area Task Force, it became clear that protection of groundwater recharge to Wekiva Springs, Rock Springs, and the many other springs that feed the Wekiva River is crucial to the long-term health of the Wekiva Basin Ecosystem. Because the primary groundwater recharge area lies to the west and outside of the Wekiva River Protection

Area no special statutory protection presently exists for critical groundwater recharge lands. The volume of groundwater moving toward discharge to form the Wekiva Basin spring systems has diminished over time given withdrawals of water for consumptive use and loss of recharge due to land development. Land uses within the Wekiva River Springshed dictate the health of the spring system; therefore, the assignment of appropriate types of land use and density and intensity of development is crucial. Low-impact land uses should be located near the springs and in areas of high or moderate recharge. Protecting Florida Springs: Land Use Strategies and Best Management Practices manual recommends low-impact land uses, including preservation, conservation, recreation, open space, unimproved rangeland, long-crop rotation, silviculture and very low density rural residential (generally no more than one unit per 10 acres) be located in springshed recharge areas. High-impact land use such as mining, industrial, heavy commercial and urban uses with extensive impervious surfaces should be avoided. The fragile nature of the Wekiva River Springshed requires land use development standards to protect the quality and quantity of recharge that replenish the aquifer and maintain springs flows. Development standards are best management practices (BMP) that help to mitigate land use impacts and protect the health of the recharge basin. The following best management practices are recommended to mitigate impacts in the Wekiva River Springshed:

- Reduce impervious surface (streets and parking areas) to reduce runoff and retain recharge;
- Maintain open space and natural recharge areas to protect groundwater resources and wildlife habitat;
- Manage storm water impacts to reduce runoff and maintain water quality of recharge;

- Provide enhanced wastewater treatment for septic tanks, and central treatment systems, and a septic tank maintenance and inspection program; and
- Landscape design and maintenance to reduce impacts from chemicals and conserve water resources.

The U.S. Geological Survey has defined “Most Effective Recharge Areas” as areas having greater than 10 inches of recharge per year. Essentially, recharge is considered as the amount of rainfall that percolates through soils and reaches the aquifer. Figure 2-2, which is derived from data provided by the St. Johns River Water Management District, documents the recharge areas and recharge rates within the Wekiva River Springshed, and shows that most of the land in the springshed has a recharge rate greater than 12 inches. Figure 2-2 also shows an area with high potential for designation as a Wekiva River Springshed Sector Planning Area. The area includes about 55,000 acres located outside of the boundary of the Wekiva River Protection Area, and comprises land located within the jurisdictions of Orange County, City of Apopka, Lake County, the City of Eustis, and the City Mount Dora. There are also high and moderate recharge areas that extend farther south and west and also to the east within Seminole County. It has been recommended that these sensitive recharge areas must be protected through appropriate land use planning techniques, such as sector planning. “Sector planning” refers to preparation of a more detailed land use plan for a specific geographic area. A sector plan provides more specific information and guidance than is provided under the general comprehensive plan. Such information typically includes area-specific information on population trends, economic forecasts, existing and future land use, development standards and best management practices, protection of natural resources including groundwater recharge, transportation and infrastructure, and community design features applicable to the specific area of study. The same Floridan aquifer which feeds the Wekiva River and its spring system is the primary source of potable water for central Florida. The Task Force recognized that the proposed Wekiva Parkway, associated interchanges and other roadways in the area will improve access and thereby increase development pressure in the critical recharge area for the Floridan Aquifer and Wekiva River spring system. The Task Force recommendations to address these issues are:

- "The Florida Legislature should amend Florida Statutes to establish a Wekiva River Springshed Protection Area to complement the existing Wekiva River Protection Area. A Wekiva River Springshed Sector Planning Area will be established by the Administration Commission. Within the Wekiva River Springshed Sector Planning Area, the legislation should preclude local governments with jurisdiction from amending their comprehensive plans within the area to increase the types, intensities and densities of land uses, or to identify or schedule new road improvements, until such time as a springshed sector plan as an amendment to the local government comprehensive plan is adopted pursuant to Chapter 163, Part II, Florida Statutes, consistent with Wekiva River Springshed Protection Area legislation, except for the necessary comprehensive plan amendments needed to plan, design, engineer, and acquire the right of way for the Wekiva Parkway and the US 441 Bypass. Permitting and construction of the Wekiva Parkway and the US 441 Bypass shall not occur until the completion of springshed sector plan. The Task Force recommends that the springshed sector plan be a cooperative, coordinated effort with the objectives of maintaining rural character and protecting groundwater recharge resulting in a no net loss of recharge potential. The legislation should direct the local governments to adopt their respective portions of the springshed sector plan by May 30, 2004. Plan amendments related to the implementation of the Wekiva Parkway and the US 441 Bypass, and the springshed sector plan shall not be counted toward the twice per year limit on the adoption of plan amendments”.

- “The legislation to create the Wekiva River Springshed Protection Area should include the following content requirements for the springshed sector plan:
    - A detailed land use plan that does not exceed the overall types, intensities and densities of development now permitted by the applicable local comprehensive plan within the springshed area. However, flexibility is available to convert between future land use categories, provided that provisions to protect rural character and groundwater recharge are equal to or greater than existing levels. The springshed sector plan may include innovative and flexible planning techniques such as performance standards for open space and impervious surface coverage, clustering, transfer of development rights, and land acquisition for the purposes of conservation, recreation and open space.
    - A detailed transportation plan which addresses as applicable the Wekiva Parkway alignment, interchange locations, and the need for any additional or expanded regional or local roadways including alignment and design and construction features consistent with the Task Force recommendations. The transportation plan should include an evaluation of any programmed road improvements within or which might affect the Springshed Protection Area and eliminate any improvements that are

> inconsistent with maintaining rural character and protecting groundwater recharge or which are made unnecessary by the Wekiva Parkway".

2.2.3.2 Protecting Rural Character in the Wekiva River Springshed

The Wekiva River Protection Act did not define "rural character" yet directed that within the designated protection area, rural character be preserved through appropriate local government comprehensive plan provisions to control development density and intensity. In the Wekiva River Protection Area and the Wekiva River Springshed, rural character includes recognizing current limits on the types, densities, and intensities of land use on an overall basis as approved through local comprehensive plans.

Municipalities in the Wekiva River Springshed are increasing annexation of rural lands in Orange and Lake Counties near the Wekiva River Protection Area. As municipal boundaries expand into the Wekiva Basin Area, cities will play an important role in preserving the rural landscape through planning efforts that give due consideration to the Wekiva River Protection Act's directive to maintain rural character.

Another factor important to preserving rural character is placing limits on the number of interchanges on the Wekiva Parkway and assuring that any development that may occur near potential interchanges is consistent with the sector plan for maintaining the area's rural character and protecting the springshed.

The Executive Order required the Task Force to address the rural character of the Wekiva Basin Area. In response, the Task Force made the following recommendation:

- “The Task Force recommends that legislation to implement its recommendation related to creation of a Wekiva River Springshed Protection Area and the related sector planning process should include provisions for land use planning requirements for each potential interchange recommended for the Wekiva Parkway. The interchange land use plans should address appropriate land uses and compatible development, secondary road access, access management, right-of-way protection, vegetative protection and landscaping, signage, and the height and appearance of structures. The interchange land use plans will also direct appropriate changes to land development regulations. The interchange land use plans should be adopted as an amendment to the local government comprehensive plans pursuant to Chapter 163, Part II, Florida Statutes, by May 30, 2004.”
- “The Task Force recommends that “rural character,” be defined as patterns of land use:
    - Where open space, agricultural and silvicultural lands, the natural landscape, and vegetation predominate over the built environment;
    - That foster traditional rural lifestyles, support rural-based economies such as agriculture, timber, eco- tourism, aquaculture, and provide opportunities to both live and work in rural areas;
    - That provide visual landscapes associated with rural areas and rural communities;
    - Those are compatible with the use of the land by wildlife and are consistent with the protection of the quality and quantity of water resources including natural surface water flows and groundwater recharge and discharge areas.”

2.2.3.3 Strengthening the Water Resources Regulatory Framework

The St. Johns River Water Management District presented model results indicating that by the year 2020 Wekiva groundwater recharge areas will decline from predevelopment levels due primarily to water withdrawals to supply the region’s water demands.

In addition, the District has conducted the Water Supply Needs and Sources Assessment and the Wekiva Basin is located in a Priority Water Resource Caution Area. The District indicates that water supply problems have become critical or are projected to become critical by the year 2010. This assessment indicates that projected water use may result in unacceptable impacts to natural systems and groundwater quality. This assessment further indicates that harm to native vegetation potentially could occur as a result of a decline in the water table, primarily effecting wetland vegetation.

Continued reductions in the spring flows of both Rock Springs and Wekiwa Springs, indicated by the assessment, would also be problematic. Flow in the Wekiva River is dependent upon the flow from Wekiva Springs. Furthermore, District staff testified that the regional water supply plan developed for the region because anticipated sources of water are inadequate to meet 2020 projected demands did not take into account further urbanization and growth in the Wekiva River Springs recharge area. Determining sustainable yields for water resources will continue to present challenges until the establishment of minimum flows and levels in the Wekiva River Basin is completed. The following recommendation has been provided:

- “The Task Force recommends that legislation to implement its recommendation related to creation of Wekiva River Springshed Protection Area will result in new permitting criteria to be applied by the St. Johns River Water Management District through its existing permit programs governing Management and Storage of Surface Waters and Environmental Resource Permits under Chapter 373, Part IV, Florida Statutes, and Consumptive Uses of Water, under Chapter 373, Part II, Florida Statutes. The District should review its existing rules to determine the appropriateness of adding specific criteria to achieve the following goals:

- Pre-development and post-development recharge rates for each permitted system shall be equalized so that no loss of recharge occurs.
- Retention/detention systems are constructed so as to minimize losses of water due to evapotranspiration.
- Impervious surfaces are limited to a density and spatial distribution within each permitted project necessary to maximize recharge rates.
- Projects involving the redevelopment of existing developed sites will include features to re- establish recharge at rates which, as nearly as practicable, match the recharge rates at the site existing prior to disturbance by any development.
- Projects which involve landscaping use landscape components, such as xeriscape, which minimize the need for irrigation.
- Reclaimed water use is required to the greatest extent practicable for irrigation purposes.
- New consumptive uses of water within the protection area do not increase in aggregate volume within the protection area. Additional consumptive uses which are permitted must be offset by additional recharge provided, retirement of other existing consumptive uses, or net reductions in water use achieved due to the implementation of water conservation methods.

    - Best Management Practices shall be required limiting the impacts of nitrate fertilizers.
    - Thresholds for Surface Water Management Permits shall be appropriately lowered, as necessary to achieve the other goals established above.
    - Concurrent approval of Environmental Resource Permits/Surface Water Management Permits and any related Consumptive Use Permits shall be required.”

2.2.3.4 Protecting Wildlife and Habitat

As noted in the introduction, the Wekiva River Basin Area is a resource of state significance, largely due to its natural resource value. The Task Force’s recommendations related to the selection of the proposed corridor and the design and construction of the roadway have given careful consideration to minimizing the impacts of the expanded transportation system on wildlife and the connectivity of habitat. The Task Force also recognized that the optimum means for protected wildlife is bringing important habitat areas into public ownership and thus made the following recommendation:

- “The State of Florida shall use all means at its disposal to complete the acquisition of the Wekiva-Ocala Greenway Florida Forever Project. The highest priority shall be given to completing the acquisition of the following specific parcels prior to construction associated with the Wekiva Parkway and US 441 Bypass:
    - Neighborhood Lakes (1,507 acres)
    - Seminole Woods/Swamp (approx. 5,500 acres)

    - New Garden Coal (1,643 acres)
    - Pine plantation (approx. 700 acres)

  In addition, effort should be made to identify and acquire additional lands located within the Wekiva River Springs recharge area. To the maximum extent feasible, these lands shall be managed as part of the Florida State Park System or by another appropriate state land management agency."

2.2.3.5 Implementation Plan

The Task Force recommended a two-step implementation process: First, a working group of all affected local governments and interest groups represented on the Task Force be formed to provide input related to proposed legislation. Second, legislation is recommended to ensure that the springshed areas are protected consistent with the recommendations of this report.

- The Task Force recommended the following proposed implementation steps:
    - "Wekiva Basin Area Task Force completes its recommendations.
    - The Department of Community Affairs with the assistance of the East Central Florida Regional Planning Council meets with each affected local government (either individually or in small groups).
    - Local governments are asked to review their existing plans and regulations in relation to the Task force recommendations and subsequently submit a summary report regarding consistency of their plans and regulations with the Task Force recommendations.

- The Department of Community Affairs receives and reviews the reports submitted by each local government and prepares a summary report regarding consistency of local plans and land development regulations with Task Force recommendations.
- The Department of Community Affairs with the assistance of the East Central Florida Regional Planning Council convenes a meeting of all affected local governments and interest groups represented on the Task Force, and other state and federal agencies with land management or oversight responsibilities in the Wekiva Basin Area to:
    - i. Review the Department of Community Affairs' summary report;
    - ii. Consider any potential local government issues; and
    - iii. Review and provide input regarding proposed legislative changes.
- The Florida Senate and the Florida House of Representatives convene at least one field hearing in the Wekiva River Springshed area.
- Draft legislation is submitted for consideration by the Legislature— completed by February 28, 2003."

2.3 A Numerical Model Simulating Water Flow and Contaminant and Sediment Transport in Watershed Systems of 1-D Stream-River Network, 2-D Overland Regime, and 3-D Subsurface Media

This technical report, CHL-98-19, presented the development of a numerical model, WASH123D, simulating water flow, contaminant transport, and sediment transport in watershed systems (Yeh et al., 1998). A watershed system is defined and the modules of WASH123D, its capabilities and shortcomings are discussed. The three options studied in modeling the flow in river/stream network and overland regime: the kinematic wave approach, diffusion wave approach, and dynamic wave approach are explained in detail. A heuristic derivation is provided for the governing equations for flow in river/stream network, surface runoff in the overland regime, flow in the subsurface sediment and chemical transport in river/stream network, sediment and chemical transport in the overland regime, and chemical transport in the subsurface. This report also provided the numerical approaches to solve governing equations for flows in the river/stream network, overland, and subsurface systems. Dynamic wave and kinematic/diffusion wave models are both given for solving flow on ground surface. The kinematic and diffusion wave approaches are known to be numerically robust in terms of numerical convergency and stability, i.e., they can generate convergent and stable simulations over a wide range of ground surface slopes in the entire watershed. The question is the accuracy of these simulations. The kinematic wave approach usually produces accurate solutions only over the region of steep slopes. The diffusion wave approach normally gives accurate solutions over the region of mild to steep slopes. However, neither approach has the ability to yield accurate solutions over the region of small slopes, in which the inertial forces are no longer negligible compared to the gravitational forces. The kinematic wave approach cannot even address the problems of backwater effects. On the other hand, a dynamic wave approach, having included all forces, can theoretically have the potential to generate accurate simulations over all ranges of slopes in a watershed. Unfortunately, the dynamic wave approaches are not numerically robust in terms of numerical convergency and stability. Even with the physically natural method of characteristics, not mention the conventional finite difference and finite element methods, it is very difficult to have a convergent and stable solution over the region of steep to mild slopes. This is perhaps the reason that no fully dynamic wave models have been developed for applications to watersheds in which the ground surface slopes range from steep and mild to small. The dilemma is that: kinematic/diffusion wave approaches are numerically robust over all ranges of slopes but produce inaccurate solutions over the region of small slopes; the dynamic wave approaches can deliver accurate solutions over all ranges of slopes but are not numerically robust over the region of steep to mild slopes. Therefore, it is desirable to develop a hybrid model, in which an adaptive selection of kinematic, diffusive, or dynamic wave approaches can be made over various regions of different slopes. Such a model should deliver both numerical robustness and accuracy over all ranges of slopes in a watershed. The remaining research problem is the adaptive mechanisms: under what slopes a dynamic wave approach should be employed and under what slopes a kinematic or diffusion wave approach should be adapted automatically by the code. The subsurface flow is described by Richard’s equation where water flow through saturated-unsaturated porous media is accounted for. The numerical approximation to solve both sediment and chemical transport in river/stream network and overland regimes, and chemical transport in the subsurface are discussed as well. There are 15 groups of example problems to illustrate the capability of the model. The unique capabilities of WASH123D and its mathematical basis are discussed in detail in the Methodology section of this thesis report.

2.4 Numerical Prediction Experiment of a Watershed Modeling System

A numerical prediction experiment of a watershed modeling system was conducted by Dr.G Huang, Dr.H.Wang and Dr.G.T.Yeh. WASH123D, a physically-based watershed modeling system was applied to a real watershed for flooding simulation during a storm event (Huang et al., 2002).

The watershed modeling system, WASH123D, simulates coupled water flow and transport in one-dimensional channel network, two-dimensional overland and three-dimensional subsurface porous media. The governing equations for surface flow are based on the shallow water equations or their approximate forms (diffusion wave and kinematic wave models). The modified Richards equation is applied for subsurface flow. Developed for generic application, hydraulic structures, such as weirs/gates, culverts, pumping, retention ponds, and levees/dikes, are incorporated into the model. In the surface flow components, the numerical solution for both one-dimensional (channels) and two-dimensional (overland) full shallow water equations is based on the Lagrangian-Eulerian finite element method. The method of characteristics (MOC) is applied for the advection terms. The Galerkin finite element method is used for the turbulent diffusion terms. Parabolic type governing equations of the diffusion wave model are solved by the Galerkin finite element method. The pure advection kinematic wave models are solved by Lagrangian method. In the subsurface flow component, Galerkin finite element method is used to solve the modified Richards equation. Internal coupling among overland and channel flow, overland and subsurface flow, and channel and subsurface flow is also considered.

The model was applied to the South Fork Broad (SFB) River watershed in Georgia. The surface area of the watershed considered was about 453 square kilometers. The watershed was divided into 5567 triangular elements with 10,943 nodes.

The rainfall prediction was provided by a high resolution mesoscale model. The storm event was chosen during the extra-tropical transitional period (3-5 Sept 1998) of Hurricane Earl (1998). The initial and boundary conditions of MM5 were prepared from the NCEP Global

Analyses on 2.5 degree grids with 12 hour intervals. Four nesting domains were used in the MM5 forecast. The grid size on Mercator projection were 135, 45, 15, and 5~km, respectively. The 5~km domain rainfall forecasts at 10-minutes intervals were used in the watershed modeling.

Only surface runoff was considered and the diffusion wave approximation is used. A simple infiltration model was used to compute the infiltration loss from rainfall. A Manning's roughness of 0.015 was used.

The forecasted rainfall data provided spatially and temporally varied rainfall time series for each triangular element and are used for flood runoff modeling. Since the rainfall rate during the first 20 hours is less than the assumed saturated soil conductivity, 5.0E-7 m/s, it is assumed that all rainfall during this period was absorbed into soil. Then a three-hour simulation during the heavy rainfall period with a rainfall rate greater than 1.0E-6 m/s is conducted.

Preliminary results indicate that flooding processes and flooded area are reasonably simulated with rainfall forecast from a mesoscale atmospheric model, Penn State/NCAR MM5.

3. DESCRIPTION OF STUDY AREA

3.1 Introduction

Springs have historically played an important role in Florida's history and the Wekiva River is a spring-fed system associated with many, possibly 19 springs connected to the Floridan aquifer. Maintaining groundwater recharge to the aquifer is a key factor of the viability of the regional water supply as well as Wekiva ecosystem. A first principle, physics-based watershed model WASH123D- A Numerical Model Simulating Water Flow and Contaminant and Sediment Transport in WAterSHed Systems of 1-D Stream/River Network, 2-D Overland Regime, and 3-D Subsurface Media (Yeh et al., 1998) has been applied to conduct the study of Wekiva "springshed", which is the recharge area and watershed contributing groundwater and surface water to the spring.

The basic hydrogeologic characteristics of the study area are discussed in this chapter. The Wekiva WASH123D model was run to evaluate the average, steady state 1995 hydrological conditions. The distribution of simulated Floridan aquifer system groundwater levels using WASH123D shows very good agreement with the field observations at corresponding locations. Also identified are the areas of recharge to and discharge from the Floridan aquifer system. Decreases of the spring discharge due to the urbanization are discussed, and the relationship between distance and percentage of groundwater flow contribution to Rock Spring discharge is analyzed.

3.2 Description of the Hydrogeologic System

The region of study is essentially the same as the East Central Florida (ECF) model developed by the St. Johns River Water Management District (SJRWMD). Hydrologic data utilized in this thesis were obtained mainly from the input files for running the SJRWMD ECF (East-Central Florida) regional groundwater flow model. Documentation for the model can be found in the SJRWMD Technical Report SJ2002-3 (Boniol, et al., 1993).

It is centered upon Seminole and Orange counties and also includes most of Brevard, Lake, and Osceola counties plus parts of the Marion, Polk, and Volusia counties. The important climatic, topographic, and hydrogeologic characteristics of the ECF region, organized in a hydrogeologic framework, are discussed in this section.

3.2.1 Climate

The study area climate is humid and subtropical, with warm, relatively wet summers and mild, relatively dry winters (Tibbals, 1990). Most years have at least several days when the temperature drops below freezing, but minimum temperatures are rarely below 20ºF and maximum temperatures are rarely above 100ºF. Rainfall represents the largest input of water to the hydrologic system, and it is unevenly distributed. Approximately 60% of the annual rainfall occurs from June through October (Rao et al., 1997). Normal annual rainfall amounts measured within the region range from around 46 in/yr (inches per year) to 56 in/yr approximately.

Although evapotranspiration (ET) represents the largest water loss from the hydrologic system, there are few data available that represent direct ET measurements. Estimates of the upper and lower limits of average annual ET rates in the region have been made by Tibbals

(1990) and Visher and Hughes (1975). The upper limit is approximately equal to the rate at which water can evaporate from an open body of water. This limit ranges from 46 in/yr in the Northeastern part of the ECF region to 49 in/yr in the southwestern part (Tibbals, 1990). Estimates of minimum annual ET rate vary from 25 in/yr to 35 in/yr (Knochenmus and Hughes, 1976; Tibbals, 1990; Sumner, 1996).

3.2.2 Topography and Surface Water Features

Topographic relief and the nature of surface water features affect the distribution of recharge and discharge within the groundwater flow system. They are briefly described in this section.

The area of the study region is approximately 10,000 square miles (Figure 1-1). Land surface elevations range from sea level at the coast to greater than 200 ft above the National Geodetic Vertical Datum of 1929 (NGVD, formerly called mean sea level) at hilltops in Lake and Polk counties. In general, the topography increases in elevation in a step-wise fashion westward from the coast to highland areas in Lake, Polk, and western Orange counties (Boniol, et al., 1993) Generally, the major topographic features are oriented in a coast-parallel or northwest to southeast direction.

The major surface water bodies within this area include rivers and their tributaries, canals, coastal lagoons, large lakes, numerous small storage ponds, 23 Floridan aquifer springs and over 5,000 wells. Long term flow measurements records indicate that the St. Johns, Ocklawaha, and Kissimmee rivers account for approximately 85% of the total surface water discharge within the region (USGS, 1998).

There are hundreds of lakes that are not connected to the major surface water drainage systems and have no surface streams or canals flowing in or out of them. These seepage lakes are most numerous in the highland areas of Lake County, eastern Marion County, western Orange and Seminole counties, eastern Polk County, and western Volusia County. They range in size from less than 1 acre to approximately several hundred acres and receive water from direct rainfall, overland runoff, and discharge from the surficial aquifer system. Seepage lakes are often sinkhole depressions that have filled with water. Water level fluctuations tend to be greater in seepage lakes located in upland areas than in other lakes because inflow from runoff and groundwater is relatively less constant (Schiffer, 1996a).

3.3 Groundwater Flow

The Clastic and Carbonate sediments beneath the area can be grouped into three aquifers (Surficial aquifer system, Upper Floridan aquifer, Lower Floridan aquifer) bounded by three confining layers (Intermediate confining unit, Middle semi confining unit, Lower confining unit). These hydrostratigraphic units apply throughout the domain (see Figure 3-2) and their characteristics are described in this section.

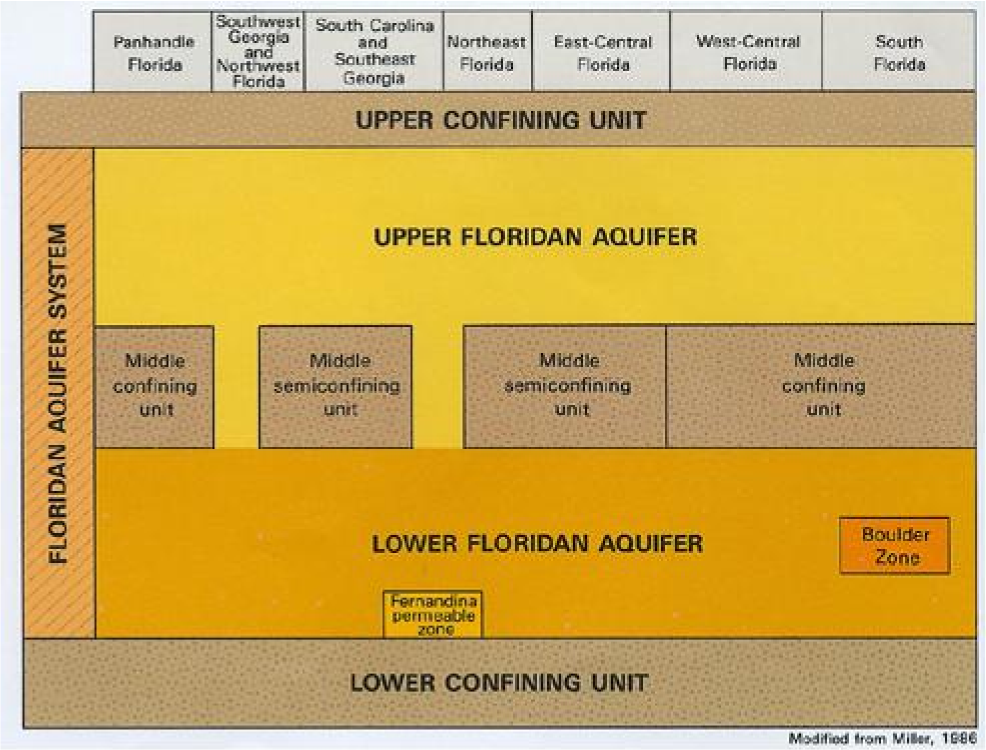


Figure 3-1 The Floridan Aquifer System

3.3.1 Surficial Aquifer System

The uppermost unit is the surficial aquifer system with the thickness ranging from less than 20 ft to as much as 150 ft. The top of this unit (the water table) is located from within a few feet to several tens of feet below land surface. The surficial aquifer system receives recharge mainly from rainfall, irrigation water, and the Floridan aquifer while the discharge occurs mainly due to the evapotranspiration from the water table, seepage to surface water bodies and pumpage. Reported horizontal hydraulic conductivity of the surficial aquifer system sediments varies from 0.03 ft/day to 200 ft/day. This layer consists of Pleistocene to Recent (Holocene) age sand, silt, clayey sand, and shell beds.

3.3.2 Intermediate Confining Unit

The intermediate confining unit separates the surficial aquifer system from the underlying Floridan aquifer system. The generalized thickness of the intermediate confining unit is from less than 50 ft to over 200 ft, increasing from north to south. This unit is believed to receive recharge from the surficial layers and discharge to the Floridan aquifer where the water table is higher than Floridan aquifer potentiometric surface. The estimated leakance (ratio of vertical conductivity to thickness of the intermediate confining unit) derived from aquifer tests ranges from 10-6/day to 0.8/day. This layer consists of unconsolidated sand, silt, clay, and shell and consolidated beds of shell, limestone, and dolomite of Pliocene and Miocene age.

3.3.3 Floridan Aquifer System

The Floridan aquifer system contains the thickest and most extensive aquifer layers in Florida. Estimation of changes in regional-scale groundwater flow patterns due to widespread pumping increases in the Floridan aquifer system is the focus of this study.

The Floridan aquifer system is composed of permeable Paleocene-age and Eocene-age carbonate rocks. The geologic formations that comprise the Floridan aquifer system are, from bottom to top: the Cedar Keys Formation, the Oldsmar Formation, the Avon Park Formation, and the Ocala Limestone (Table 3-1). These formations consist of interbedded limestone, dolomite, and dolomitic limestone in which the amount of primary porosity, secondary porosity, and secondary infilling of pores or fractures is highly variable with depth. Throughout the ECF region, the Floridan aquifer system has been subdivided into three hydrostratigraphic subunits on the basis of relative hydraulic conductivity (Miller 1986; Tibbals 1990): the Upper Floridan aquifer, the middle semiconfining unit, and the Lower Floridan aquifer.

Total thickness of the Upper Floridan aquifer ranges from less than 200 ft to more than 650 ft in the study area, generally increasing from the northwest to the southeast. Reported transmissivities of Upper Floridan aquifer are between 1200 ft^2/day and 530,000 ft^2/day. It consists of the Ocala Limestone and approximately the upper one-third of the Avon Park Formation (Table 3-1).

Total thickness of the Lower Floridan aquifer ranges from approximately 1,000 ft to greater than 2,000 ft and gradually increases in a southward direction. Reported transmissivities of Lower Floridan aquifer are between 200,000 ft^2/day and 670,000 ft^2/day. Estimated rates of natural recharge range from less than 4 in/yr to greater than 12 in/yr through the Floridan aquifer system. Natural discharge occurs as diffuse upward leakage to the surficial aquifer system and as spring flow, approximate 42% of which comes from the springs of Wekiva River Basin. The geologic units comprising the Lower Floridan aquifer are the lower part of the Avon Park Formation, the Eocene Oldsmar Formation, and the upper part of the Paleocene Cedar Keys Formation.

Total thickness of the revised middle semiconfining unit ranges from approximately 150 ft to 650 ft and also generally increases in a southward direction. The leakances of the middle semiconfining unit range from less than 0.00005/day to more than 0.001/day. This layer consists of relatively soft, micritic limestone and dense, dolomitic limestone with little secondary porosity compared to the aquifer units above and below.

Table 3-1 Geologic and Hydrostratigraphic Units within the Model Area

<table>
<tr><th>SYSTEM</th><th>SERIES</th><th colspan="2">STRATIGRAPHIC UNIT</th><th colspan="2">HYDROGEOLOGIC UNIT</th></tr>
<tr><td>QUATERNARY</td><td>HOLOCENE
PLEISTOCENE</td><td colspan="2" rowspan="2">UNDIFFERENTIATED SAND AND CLAY DEPOSITS</td><td colspan="2" rowspan="2">SURFICIAL AQUIFER SYSTEM</td></tr>
<tr><td rowspan="12">TERTIARY</td><td rowspan="2">PLIOCENE</td></tr>
<tr><td rowspan="4">HAWTHORN GROUP</td><td rowspan="2">PEACE RIVER FORMATION</td><td colspan="2" rowspan="3">INTERMEDIATE AQUIFER SYSTEM OR INTERMEDIATE CONFINING UNIT</td></tr>
<tr><td rowspan="3">MIOCENE</td></tr>
<tr><td rowspan="2">ARCADIA FORMATION</td></tr>
<tr><td rowspan="8">FLORIDAN AQUIFER SYSTEM</td><td rowspan="4">UPPER FLORIDAN AQUIFER</td></tr>
<tr><td>OLIGOCENE</td><td colspan="2">SUWANNEE LIMESTONE</td></tr>
<tr><td rowspan="5">EOCENE</td><td colspan="2">OCALA LIMESTONE</td></tr>
<tr><td colspan="2" rowspan="2">AVON PARK FORMATION</td></tr>
<tr><td rowspan="2">MIDDLE CONFINING UNIT</td></tr>
<tr><td colspan="2" rowspan="3">OLDSMAR AND CEDAR KEYS FORMATIONS</td></tr>
<tr><td rowspan="2">LOWER FLORIDAN AQUIFER</td></tr>
<tr><td>PALEOCENE</td></tr>
</table>

3.3.4 Recharge and Discharge

Recharge to the Floridan aquifer system is derived almost exclusively from downward leakage from the surficial aquifer system. A relatively small amount flows laterally into the study region from recharge areas along the Highlands Ridge to the south. Estimated rates of natural recharge range from less than 4 in/yr to greater than 12 in/yr (Figure 3-3). Low rates of recharge occur where the water levels in the surficial aquifer system are only slightly above the potentiometric surface of the Upper Floridan aquifer, or where the intermediate confining unit is sufficiently thick or of low enough permeability to significantly retard the downward movement of water. Low-rate recharge areas coincide with topographically low or flat areas where the water table is consistently near land surface, enhancing ET from the saturated zone. High rates of recharge occurs where the vertical gradient between the surficial aquifer system and the Upper Floridan aquifer is the greatest and where the intermediate confining layer is thinnest or the most permeable. High-rate recharge areas coincide with highlands characterized by sandy ridges with deep water table soils and karst topography and where there are few perennial streams to collect overland runoff. The highest rates of recharge occur where sinkhole depressions collect overland runoff and surficial aquifer system base flow. An example of one such location is Wolf Sink in northeastern Lake County near Mount Dora, where a small stream (Wolf Branch) drains a nearly 5-square-mile (mi^2) area and ends at the sink, providing a nearly direct connection to the Upper Floridan aquifer (Schiffer, 1996b).

In the Orlando metropolitan area, drainage wells provide a significant manmade source of recharge to the Floridan aquifer system. Approximately 479 drainage wells have been completed to the Upper Floridan aquifer in and around Orlando (Figure 3-4), mainly for storm runoff removal and lake-level control. Total average daily flow into the Upper Floridan aquifer from these wells has been estimated at between 33 million gallons per day (mgd) and 52 mgd (Tibbals 1990; CH2M HILL, 1997). The status of approximately 265 of the wells inventoried by CH2M HILL (1997) is unknown, but many may have been capped, plugged, or clogged with debris and no longer operate.

Discharge from the Floridan aquifer system occurs, naturally, as diffuse upward leakage to the surficial aquifer system and as spring flow. Water leaks upward to the surficial aquifer system through the intermediate confining unit wherever the Floridan aquifer potentiometric surface is greater than that of the surficial aquifer system (delineated as discharge areas on Figure 3-3). The rate of upward leakage depends upon the thickness and vertical hydraulic conductivity of the intermediate confining unit. Most of the natural discharge from the Floridan aquifer system occurs from springs. There are 23 documented springs in the study region that discharged at an average rate of approximately 601 cubic feet per second (cfs) (388 mgd) in 1995. Average discharge rates for 1995 measured at individual springs ranged from less than 1 cfs at Sulphur and Droty springs to 150 cfs at Blue Spring in southwestern Volusia County. Approximately 42% of the total spring flow discharges from springs in the Wekiva River Basin. Most of the base flow to the Wekiva River is derived from Floridan aquifer springs.

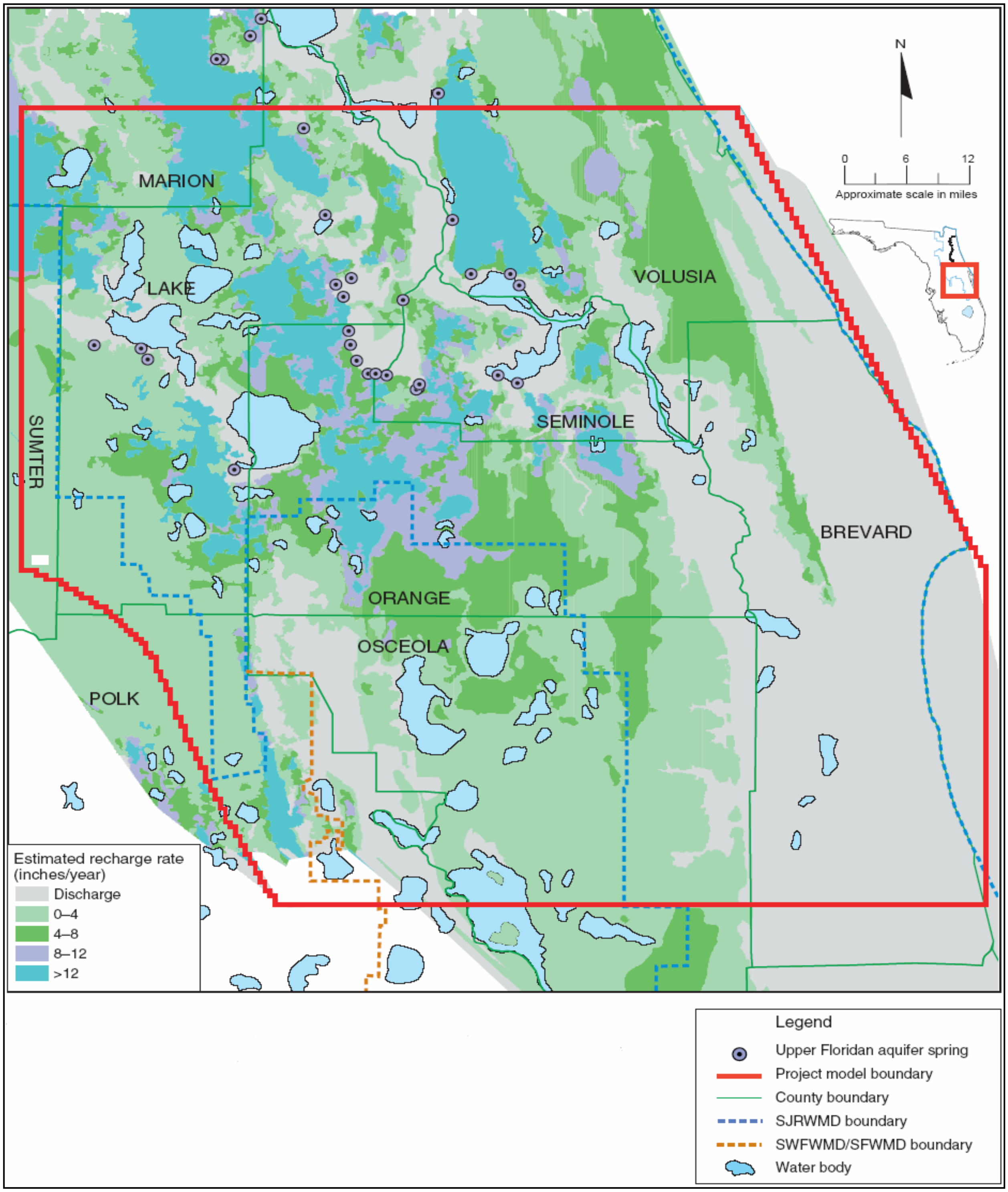


Figure 3-2 Areas of Recharge to and Discharge from the Floridan Aquifer System

(Source: Technical Publication –SJ2002-3; SJRWMD)

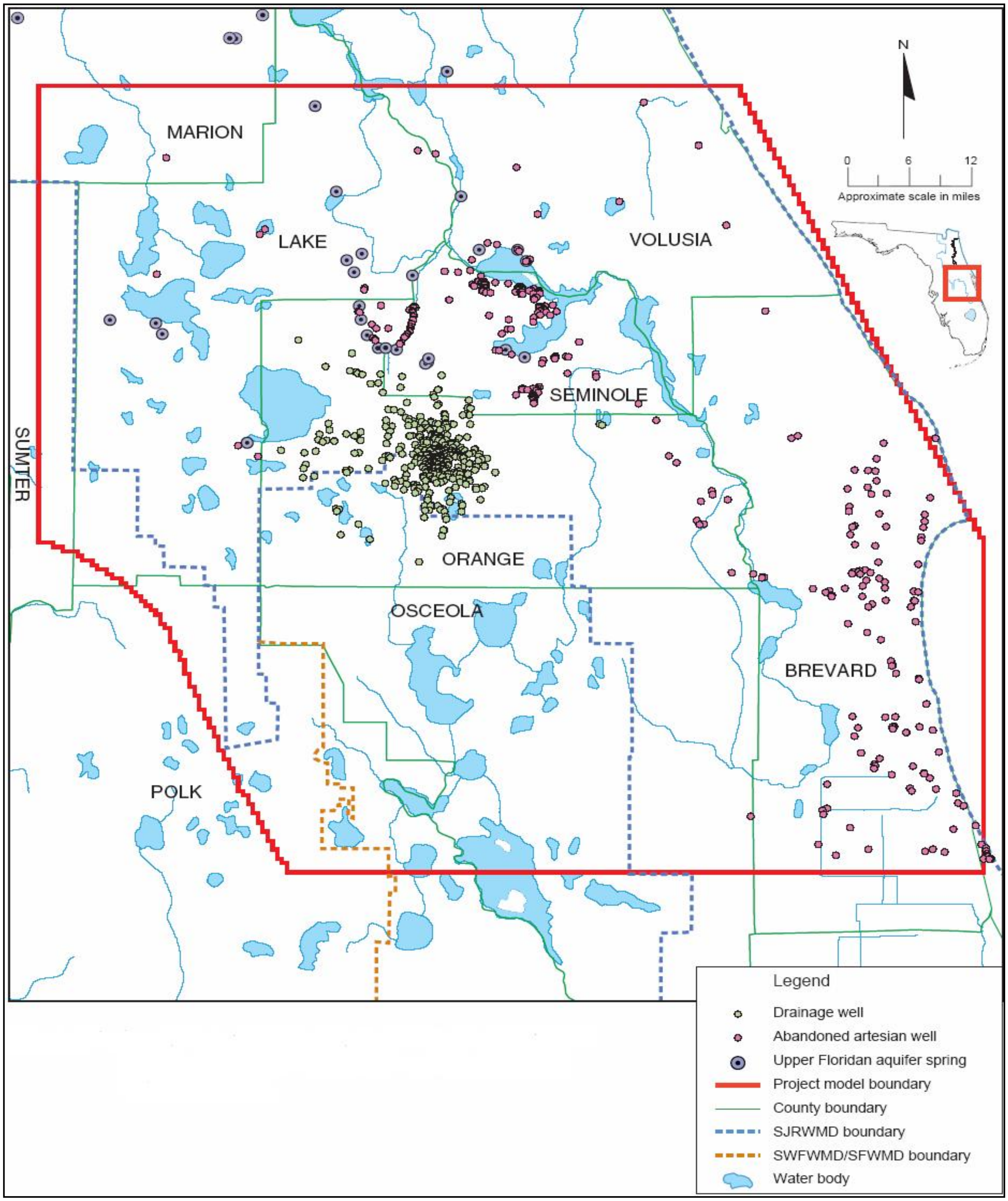


Figure 3-3 Locations of Drainage Wells that Recharge the Floridan Aquifer System and of Abandoned Artesian Wells

(Source: Technical Publication –SJ2002-3; SJRWMD)

3.3.5 Hydraulic Characteristics

The data available concerning Floridan aquifer system aquifer hydraulic characteristics derived from aquifer tests include information on Upper and Lower Floridan aquifer transmissivities and specific-capacity and normalized well yield data. Reported transmissivity of the Upper Floridan aquifer ranges from approximately 1,200 ft^2/day to 530,000 ft^2/day from 84 tests (Table 3-2). Lower Floridan aquifer transmissivity estimates ranged 200,000 ft^2/day to 670,000 ft^2/day based on 10 aquifer performance tests. The relatively few Lower Floridan tests that have been conducted to date were located within or near the Orlando area. Field estimates of vertical hydraulic conductivity of the middle semiconfining unit have been made at two sites. At the Bull Creek Wildlife Management Area in eastern Osceola County, estimates ranged from 0.005 ft/day to 2 ft/day (PBS&J, 1990).

Table 3-2 Ranges of Aquifer Parameter Values Reported from Aquifer Performance Tests Conducted in the East-Central Florida Region

Hydrostratigraphic unit	Parameter	Minimum Reported Value	Maximum Reported Value	Approximate Number of Tests	Sources*
Surficial aquifer system	Horizontal hydraulic conductivity	0.03 ft/day	200 ft/day	50	1,2,4,6
Surficial aquifer system	Transmissivity	90 ft^2/day	20,000 ft^2/day	30	2,5,6
Intermediate confining unit	Leakance	$1 * 10^{-6}$/day	0.8/day	38	5
Upper Floridan aquifer	Transmissivity	1,217 ft^2/day	530,000 ft^2/day	84	3,5
Lower Floridan aquifer	Transmissivity	200,535 ft^2/day	688,450 ft^2/day	10	5,7

*1=McGurk et al. (1989); 2=Phelps (1990); 3=Shaw and Trost (1984); 4=Spechler and Halford (2001); 5=Szell (1993); 6=Williams (1995); 7=St. Johns River Water Management District consumptive use permitting files
(Source: Technical Publication –SJ2002-3; SJRWMD)

3.3.6 Potentiometric Levels

Throughout nearly the entire study region, the Floridan aquifer system is sufficiently confined so that water levels in wells completed within it are above the top of the aquifer. The Floridan aquifer system is unconfined only in small, isolated areas in the immediate vicinity of several springs (e.g., Rock Springs and Wekiva Spring), where limestone is at or within a few feet of land surface. Johnston et al. (1980) constructed a map of the estimated average predevelopment potentiometric surface of the Upper Floridan aquifer throughout Florida. In the model region (Figure 3-5), elevations of the estimated average predevelopment potentiometric surface ranged from less than 10 ft NGVD along the coast and along the St. Johns River in western Volusia County to approximately 130 ft NGVD in northern Polk County.

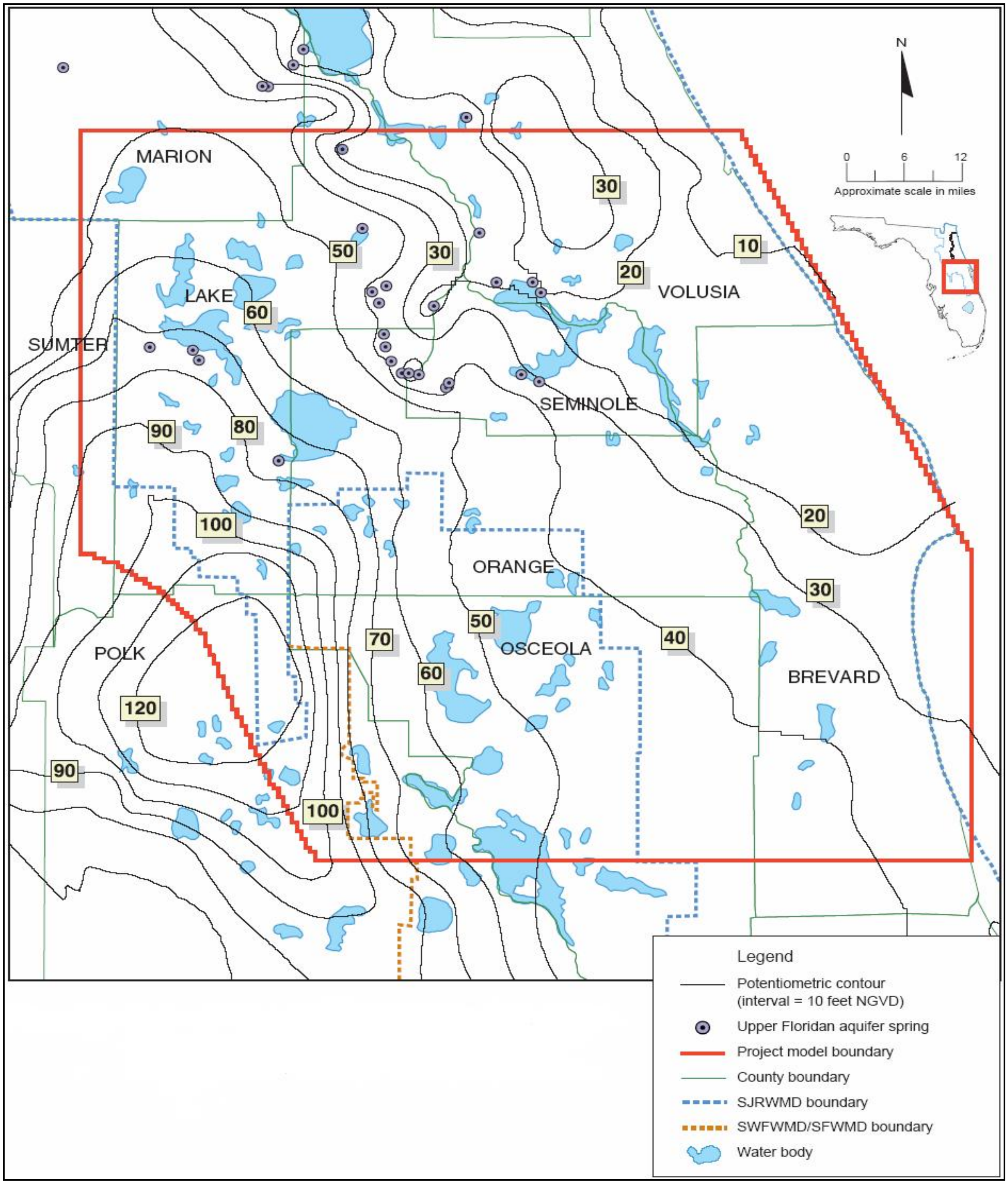


Figure 3-4 Estimated average 1995 potentiometric surface of the Upper Floridan aquifer

(Adapted from Knowles et al. 1995 and O'Reilly et al. 1996)

3.3.7 Historic and Projected Water Use

Most of the water used in the study region is withdrawn from the Floridan aquifer system (Florence and Moore, 1997; SFWMD, 2000; Marella, 1999). The groundwater withdrawn from the Floridan aquifer system has been used for agricultural irrigation, commercial/industrial, recreational, and domestic (household) uses. Domestic uses are both self-supplied and derived from public-water supplies. In some areas, agricultural irrigation has historically been the largest user of water from the Floridan aquifer system. For example, Stubbs (1937) documented potentiometric declines of several feet between 1913 and 1937 in northern and central Seminole County due to extensive use of approximately 2,000 artesian wells to irrigate truck farms. Over the past several decades, however, public-water supply withdrawals have surpassed agricultural withdrawals in Orange, Seminole, and Volusia counties (Table 3-3). The average annual withdrawal rates that have been projected for 2020 indicate that this trend will continue. Significant portions of the projected increases in irrigation withdrawals in Lake and Seminole counties between 1995 and 2020 are for recreational (golf course) irrigation. In terms of spatial patterns, public water supply use is centralized, with well fields located within and around populated areas. In contrast, agricultural wells are more diffuse and are spread throughout the entire model domain.

Table 3-3 Historic and Projected Average Annual Groundwater Withdrawals from Selected Counties within the Model Region (in million gallons per day)

County	1970	1985	1995	2020
Agricultural and Recreational Irrigation				
Brevard	47.9	100.3	90.7	84.4
Lake	13.4	28.8	53.2	79.6
Orange	11.2	47.9	30.5	37.8
Osceola	8	40	41.6	44.8*
Seminole	3.4	23.2	9.5	15.6
Volusia	6.9	36.6	27.7	32.5
Total	90.8	276.8	253.2	294.7
Public Supply				
Brevard	3.5	9.2	15	16
Lake	10	15.3	22.6	70.6
Orange	65.8	122.6	165	328.2
Osceola	2.7	5.7	19.2	38.0*
Seminole	6.3	34.9	50.7	94.8
Volusia	19.2	36.4	48.8	90.9
Total	107.5	224.1	321.3	638.5
Self-Supplied, Commercial, Industrial, and Power Generation				
Brevard	0.4	0.5	2.1	0.9
Lake	19.4	12.2	10.2	13.6
Orange	7	15.2	20.1	6.9
Osceola	0.2	3.2	0.8	1.5*
Seminole	0.5	5	0.1	0.2
Volusia	1	0.8	1.1	1
Total	28.5	36.9	34.4	24.1
Self-Supplied Domestic				
Brevard	3.4	5.6	5.2	2.1
Lake	3.3	8.5	6	1.3
Orange	7.6	6.1	12.9	10.5
Osceola	2	4.8	6.8	5.5*
Seminole	2.7	3.6	8.6	2.1
Volusia	3.7	5.3	3.6	12
Total	22.7	33.9	43.1	33.5
Total for all uses	249.5	571.7	652	946

*East-central Florida model portion only.
Source: Marella 1995, 1999; Vergara 1998; SFWMD 1998

4. SIMULATION OF GROUNDWATER FLOW

The conceptual model discussed in this section and the hydrologic data discussed in previous sections were used to construct a numerical model of groundwater flow within the fresh groundwater flow system. The model simulates 1995 average, steady-state conditions. The data of year 1995 is used due to the availability of published data (USGS, 1998).

4.1 Conceptual Model of Groundwater Flow

In order to construct a numerical model that can adequately simulate groundwater flow in the Wekiva springshed region, the details of the hydrogeologic framework have been simplified into a conceptual model that incorporates the important regional-scale features of the groundwater flow system.

The conceptual model consists of three aquifers separated by two semiconfining units and underlain by a confining unit. Groundwater flow has been conceptualized as quasi-three-dimensional. That is, horizontal flow occurs only within the aquifer layers and vertical flow occurs only between the aquifer layers. Horizontal flow within the semiconfining units is not simulated. These units act as membranes to transmit flow vertically between the aquifer layers above and below. No flow occurs between the Lower Floridan aquifer and the lower confining unit. There is also no vertical exchange of flow between the freshwater flow system and those portions of the aquifer layers containing saline water. The surficial aquifer system is conceptualized as an unconfined aquifer. This means that simulated layer 1 water levels represent the elevation of the regional water table surface. The surficial aquifer system is recharged by infiltration of water derived from rainfall through the unsaturated zone. Although horizontal flow within the surficial aquifer system is simulated, it is recognized that the direction and magnitude of the surficial aquifer system horizontal gradient is, in many places, more detailed than can be simulated by a regional-scale model. Detailed simulation of the shape of the water table surface is beyond the scope of this thesis. ET occurs from both the unsaturated zone above the surficial aquifer system and the saturated zone within the surficial aquifer system. The model can simulate ET from the groundwater flow system only. Therefore, total ET is the sum of that amount simulated by the model from the saturated zone plus an estimated amount from the unsaturated zone. Total annual ET should not, on the average, exceed the average annual free-water surface evaporation. The Floridan aquifer system is recharged by downward movement of water from the surficial aquifer system wherever the elevation of the water table is higher than the potentiometric surface of the Upper Floridan aquifer. Similarly, water discharges from the Floridan aquifer system wherever the potentiometric surface of the Upper Floridan aquifer is greater than the water table elevation.

Discharge from model layer 2 within the Upper Floridan aquifer is concentrated at springs. Permeability is assumed to be higher in model layer 2 than in model layer 3 in the vicinity of the larger (first- and second-magnitude) springs. The base of the freshwater flow system occurs at the top of the lower confining unit of the Floridan aquifer system or at the elevation of the 5,000 mg/L chloride isosurface, where it is present within the aquifer system.

4.2 Computer Code Selection

A first principle, physics-based watershed model WASH123D (A Numerical Model Simulating Water Flow and Contaminant and Sediment Transport in WAterSHed Systems of 1-

D Stream/River Network, 2-D Overland Regime, and 3-D Subsurface Media, Yeh et al., 1998) has been applied to conduct the Wekiva springshed study. WASH123D was first developed by Gour-Tsyh (George) Yeh in 1994 for EPA (Athens) and U.S. Army Corps to study the groundwater, overland and river hydraulics. It was modified in 1998 to couple the contaminant, sediment, salinity, and thermal transport. The 3-D groundwater module of WASH123D is employed in the Wekiva springshed study and the mathematical basis is stated as follows.

4.2.1 Mathematical Basis

The flow of groundwater is governed by the principles of conservation of mass and momentum. WASH123D applies Darcy's law as the general equation of the motion for groundwater so that the linear laminar flow is assumed during the investigation. The governing equation of subsurface flow through variably saturated media can be derived as (Yeh, 1987):

$$\frac{\partial \theta}{\partial t} + \nabla \cdot \mathbf{V} = F\frac{\partial h}{\partial t} + \nabla \cdot \left[-\mathbf{K} \cdot \left(\nabla h + \nabla z \right) \right] = q \tag{1}$$

where θ is the effective moisture content [L^3/L^3]; h is the pressure head [L]; t is time [T]; **K** is the hydraulic conductivity tensor [L/T]; z is the potential head [L]; q is the source and/or sink representing the artificial injection or withdraw of fluid [L^3/L^3]; and F is the water capacity [$L^3/L^3/T$] given by

$$F = \frac{d\theta}{dt} \tag{2}$$

And the Darcy's velocity (L/T) can be calculated as:

$$V = -\mathbf{K} \cdot \left(\nabla h + \nabla z \right) \tag{3}$$

Equations (1) through (3) and the constitutive relationships among the pressure head, degree of saturation, and hydraulic conductivity tensor, together with associated initial and boundary conditions, can be used to compute the temporal-spatial distributions of the hydrological variables, such as total head, pressure head, and Darcy's velocity.

Five types of boundary conditions are taken into account as follows.

Dirichlet conditions:

This boundary condition is used when pressure head can be prescribed on the boundary. It can be expressed as

$$h = h_d(x_{b,} y_{b,} z_b, t) \qquad on \qquad B_d \tag{4}$$

Neumann conditions:

This boundary condition is employed when the flux results from pressure-head gradient is known as a function of time. It is written as

$$-\mathbf{n} \cdot \mathbf{K} \cdot \nabla h = q_n(x_{b,} y_{b,} z_b, t) \qquad on \qquad B_n \tag{5}$$

Cauchy conditions:

This boundary condition is employed when the flux results from total-head gradient is known as a function of time. It can be written as

$$-\mathbf{n} \cdot \mathbf{K} \cdot (\nabla h + \nabla z) = q_c(x_{b,} y_{b,} z_b, t) \qquad on \qquad B_c \tag{6}$$

River Boundary Conditions:

$$-\mathbf{n} \cdot \mathbf{K} \cdot (\nabla h + \nabla z) = -(K_R / b_R)(h_R - h) \qquad on \qquad B_r \tag{7}$$

Variable conditions:

This boundary condition is usually used for the ground surface boundary when the coupling of surface and subsurface systems is not taken into account.

(1) During precipitation periods:

$$h = h_p(x_{b,} y_{b,} z_b, t) \qquad on \qquad B_v \tag{8}$$

$$-\mathbf{n} \cdot \mathbf{K} \cdot (\nabla h + \nabla z) = q_p(x_{b,} y_{b,} z_b, t) \qquad on \qquad B_v \tag{9}$$

(2) During non-precipitation periods

$$h = h_p(x_{b,} y_{b,} z_b, t) \qquad on \qquad B_v \tag{10}$$

or

$$h = h_m(x_{b,} y_{b,} z_b, t) \qquad on \qquad B_v \tag{11}$$

or

$$-\mathbf{n} \cdot \mathbf{K} \cdot (\nabla h + \nabla z) = q_e(x_{b,} y_{b,} z_b, t) \qquad on \qquad B_e \tag{12}$$

where (x_b,y_b,z_b) is the spatial coordinate on the boundary; **n** is an outward unit vector normal to the boundary; h_d, q_n, and q_c are the prescribed Dirichlet functional value [L], Neumann flux [$L^3/L^2/T$], and Cauchy flux [$L^3/L^2/T$], respectively; B_d, B_n, and B_c are the Dirichlet, Neumann, and Cauchy boundary, respectively; B_v is the variable boundary; h_p is the allowed ponding depth [L] and q_p is the throughfall of precipitation [L/T], respectively, on the variable boundary; h_m is the allowed minimum pressure head [L] on the variable boundary; q_e is the allowed maximum evaporation rate [$L^3/L^2/T$] on the variable boundary, which is the potential evaporation; K_R is the hydraulic conductivity of the river bottom sediment layer [L/T], b_R is the thickness of the river bottom sediment layer [L], h_R is the depth of the river bottom measured from the river surface to the top of the bottom sediment layer [L], and B_r is the river boundary segment. Only one of the Equations (8) through (12) is used at any point on the variable boundary at any time.

4.2.2 Unique Features of WASH123D

WASH123D has the following main features that make it flexible and versatile in modeling a wide range of real-world problems.

(a) “True” rather than “quasi” three-dimensional subsurface problems can be simulated;

(b) Irregular elements facilitate the representation of complex geometry;

(c) Both heterogeneous and anisotropic media, as many as desired, can be taken into account;

(d) On the ground surface, infiltration rates are determined by the WASH123D model rather than imposed as an input parameter by users of MODFLOW;

(e) Vadose zone can be incorporated to more realistically simulate the infiltration;

(f) Density dependent flow is available to more realistically model coastal aquifers;

(g) Many options are available to both compose and solve matrix equations.

The FORTRAN code WASH123D iteratively solves the three-dimensional groundwater flow equations. Input to the program includes the geometry of the system, the properties of the media, and the initial and boundary conditions. Output includes the spatial distribution of pressure head, total head, velocity fields, moisture contents, as a function of time.

4.3 Finite Element Discretization

The use of WASH123D requires the modeling domain divided into discrete elements. The numerical equations of groundwater flow are solved iteratively for each node to produce simulated water levels, or head values and Darcy's velocity field. As shown in Equation (1), the groundwater flow between elements depends on the head gradient as well as the conductivities assigned to each element. The model domain was discretized as shown in Figure 4-1. The discretization is coinciding with the ECF model except that the intermediate confining unit and the middle semiconfining unit were incorporated in the simulation.

The domain profile was divided into six layers along the vertical direction (Figure 4-1). The discretization is coinciding with the ECF model except that the intermediate confining unit and the middle semiconfining unit were incorporated in the simulation. The six layers are stated as following:

(1) ECF Layer 1, known as the surficial layer (indicated as yellow in Figure 4-1);

(2) The intermediate confining unit (indicated as upper red layer in Figure 4-1);

(3) ECF Layer 2, known as the upper zone of the Upper Floridan aquifer (indicated as blue in Figure 4-1);

(4) ECF Layer 3, known as the lower zone of the Upper Floridan aquifer (indicated as gray in Figure 4-1);

(5) The middle semiconfining unit (indicated as lower red layer in Figure 4-1);

(6) ECF Layer 4, known as the Lower Floridan aquifer (indicated as green in Figure 4-1).

Numerically, the modeling domain was totally discretized into 437,576 Triangular Prism Elements (see upper left of Figure 4-1) connected at 249,057 nodes. The interior elements have the equal size 3,125,000 square feet while the boundary elements have the approximate size of one-eighth square mile due to the irregularity. Furthermore, considering the large depth of ECF Layer 2 and Layer 4, each was divided into two sub-layers of elements with the same media parameters. Therefore, eight numerical layers are included in the simulation. The interconnection of Triangular Prism Elements of the 3-D Mesh is shown in Figure 4-2.

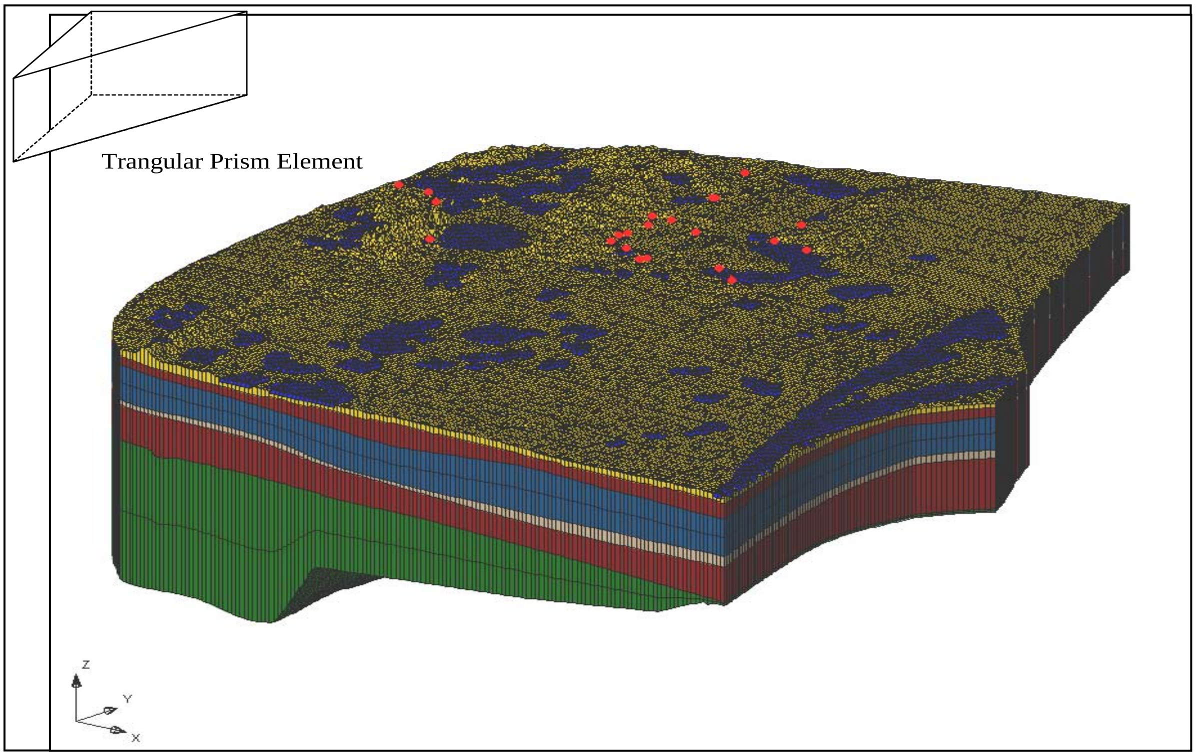


Figure 4-1 Three Dimensional Finite Element Mesh of the Modeling Domain

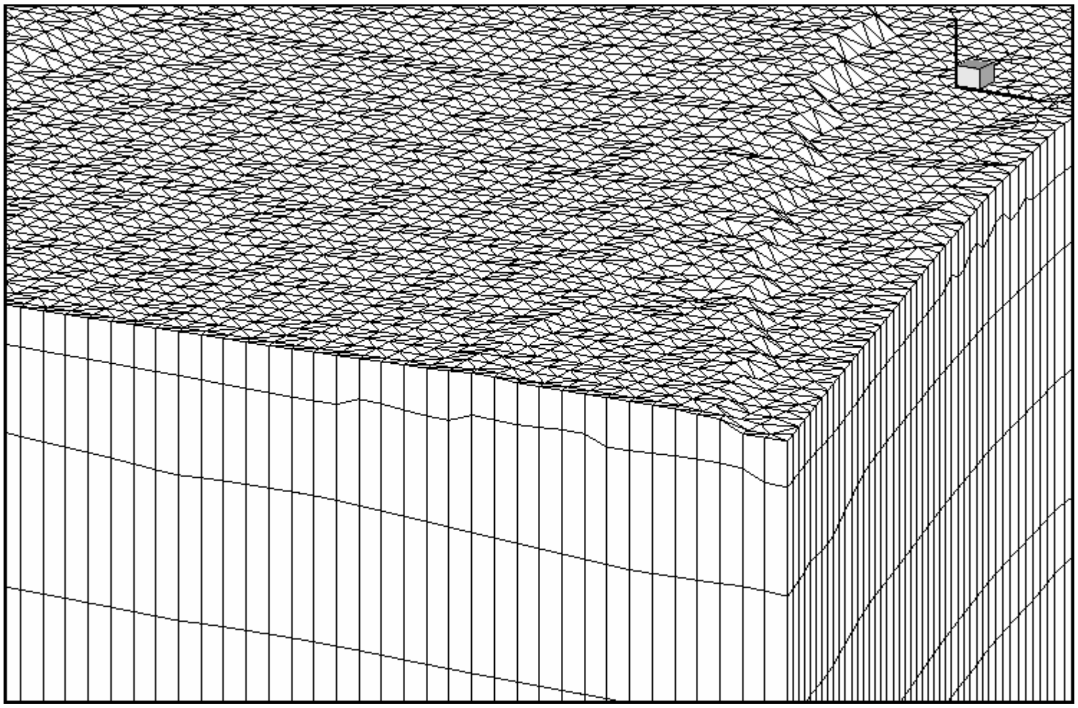


Figure 4-2 Interconnection of Triangular Prism Elements of the 3-D Mesh

4.4 Hydrologic Data Input

The model requires the user to provide all the relevant data to simulate the subsurface flows. Two input files are required, one providing the model geometry data and the other providing several types of hydrologic data to assign boundary conditions, applied stresses, and properties of each numerical layer. Due to the large size of input and output files, only partial input files are shown in Appendix-A. Various types of hydrologic data considered for the model simulation are discussed below.

4.4.1 Boundary Conditions

The model domain was assigned different boundary conditions for the Floridan aquifer system layers and confining units, at springs, at water bodies such as lakes, and at the air-media interface. The boundary conditions assigned can be classified into three types: (1) prescribed potentiometric levels (heads), (2) prescribed flow rates, and (3) head-dependent flux.

The bottom of the model is a zero-prescribed flux boundary. As the modeling domain do not have clearly defined hydrogeologic boundaries within the Floridan aquifer system, realistic conditions are set up and applied along the lateral sides of the domain to represent flow that occurs across these artificial boundaries. Potentiometric surface map of the Upper Floridan aquifer (Figure 3-5) was used to locate the model boundaries and to help in defining these conditions. Flow directions within the Upper Floridan aquifer will be perpendicular to the potentiometric contours shown in Figure 3-5. Hence, the northern, southwestern, and western sides of the domain are prescribed as zero-flux boundary conditions, while the head values are defined along the southern and the seaward boundary. These head values are mainly from the input for general-head boundary (GHB) package of the ECF model. Constant elevations were assumed at springs and lakes, and their boundary conditions were assigned as prescribed levels (heads), which are also from the ECF model input.

Because several stresses were applied to the model, including well withdrawals from different depths within the Floridan aquifer system, recharge to the Upper Floridan aquifer through drainage wells and recharge to the surficial aquifer system caused by rainfall and evapotranspiration, the air-media interface is usually a boundary on which the subsurface flow direction is not predetermined and needs to be set up so that consistent computational results can be obtained. WASH123D is such designed as: when a boundary is flux-type for the rainfall period, a complete adsorption of throughfall water is assumed subject to the constraint that the simulated pressure head thereon is not greater than the allowed ponding depth, while a potential evapotranspiration is simulated subject to the constraint that the simulated pressure head thereon is greater than the allowed miminum pressure (which is usually the wilting point) if it is for the evaporation period. The ponding-type boundary is to simulate the accumulation of water above ground surface subject to the constraint that the simulated inward flux thereon is less than the rainfall rate while the minimum pressure-type boundary is to describe the allowed minimum pressure associated with the soil being considered as long as the simulated evapotranspiration thereon is less than the potential evapotranspiration. The ECF model input dataset for the evapotranspiration (EVT) package provides such parameters, such as rainfall rate, ponding depth, potential evapotranspiration, and minimum pressure.

4.4.2 Applied Stresses

One of the important input stress to the model is the recharge applied to the surficial aquifer system, including precipitation, flow to rapid infiltration basins, septic tank effluent, the evapotranspiration from the unsaturated zone, applied irrigation as well as the overland runoff. The recharge rates were previously estimated by developing an algorithm that incorporates the appropriate portions of the steady state water budget for the surficial layer in the ECF model and these values are used as air-media boundary condition input as discussed above and are considered from the ECF model input for the recharge (RCH) package.

A total of 5,097 wells are applied to different depth of the modeling domain. These wells are classified as four types: (1) withdraw wells; (2) drainage wells; (3) self-supplied domestic wells; and (4) free-flowing wells. The withdraw wells introduces the majority of the water consumed. Much of the information used to prescribe well rates is from the ECF model's well (WEL) package input. For the present simulation, these wells were treated as point sources or sinks as indicated by the q term in Equation (1). Withdraw wells, self-supplied domestic wells, and free-flowing wells have the negative rates and each of these kind of wells is treated as a point of sink, while each of the drainage well as a point of source in WASH123D.

4.4.3 Aquifer and Confining Unit Characteristics

The model geometry or hydrostratigraphy data defining aquifer layers and confining units top and bottom elevations, were obtained from the calibration data of the ECF model.

Horizontal isotropy was assumed for all the eight numerical layers, i.e., the horizontal hydraulic conductivity was assumed to be equal along the x- and y- directions. The calibrated vertical conductivities and leakance of the intermediate confining and semiconfining units of ECF model were employed to estimate the hydraulic characteristics of the model layers represented by the material types input of WASH123D. Due to the scarcity of large-scale hydraulic conductivities estimates for the surficial layer, a homogenous horizontal hydraulic conductivity equaled 20 ft/day is assumed throughout this system. While all the other seven numerical layers have unique material type defined at each element. Moreover, the media within the vicinity of the springs usually have large conductivities to drive the groundwater upward; a particular material type was given for each element of the 23 springs in the modeling domain. Totally 154,684 unique material types each with 9 properties were defined in the simulation.

5. RESULTS

The Wekiva WASH123D model was run to evaluate the average, steady state 1995 hydrological conditions. The model provides output file that consists of the spatial distribution of pressure head, velocity fields, and moisture contents, as a function of time. It also generates other output files that could be directly read into post-processing tool such as GMS and plotting tool such as Tecplot. Appendix-B shows partial output. Figure 5-1 and 5-2 shows the spatial distribution of total head and pressure heads obtained after the simulation. The results are validated using previously verified models' (ECF and FEMWATER) output and field/observation data. The WASH123D model results show very good agreement with the previously verified model results and field observations.

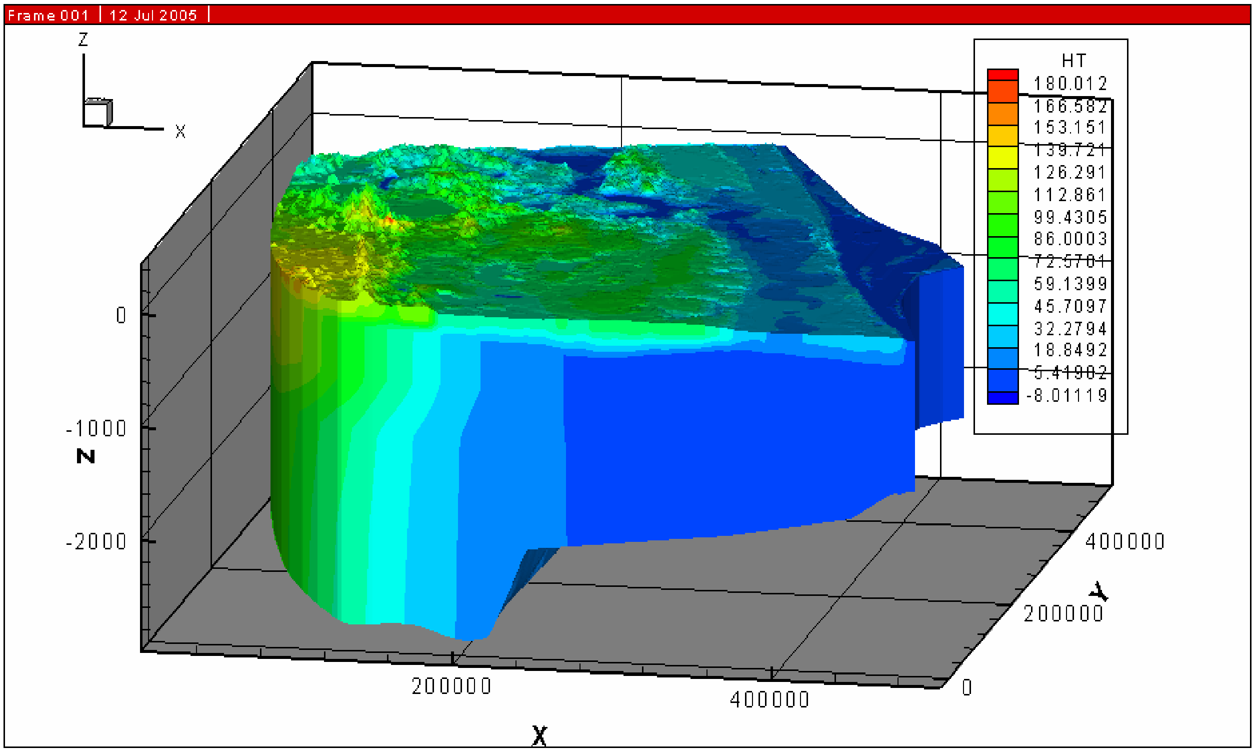


Figure 5-1 Total Head across the Wekiva Springshed after the Simulation

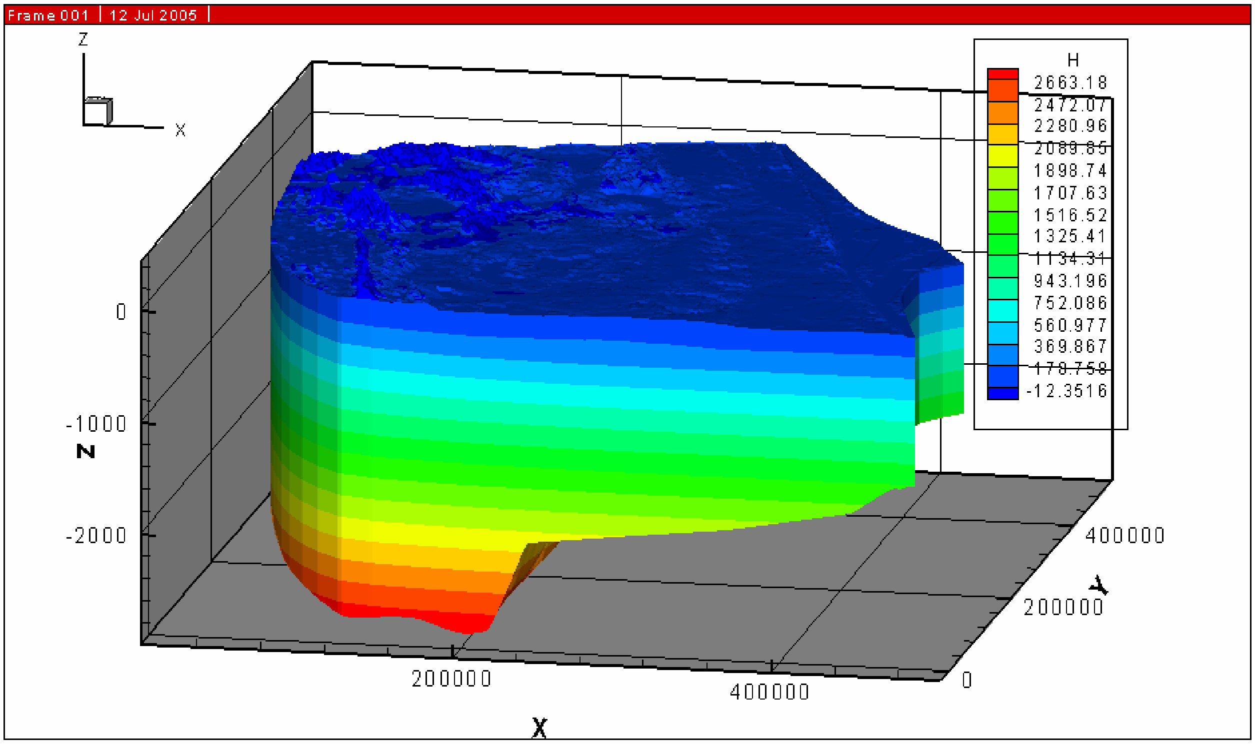


Figure 5-2 Pressure Head across the Wekiva Springshed after the Simulation

5.1 Potentiometric Levels

The distribution of simulated Floridan aquifer system groundwater levels using WASH123D shows good agreement with the field observations at corresponding locations. One can also observe that the simulated 1995 water levels mimic the topography on a regional scale.

Figure 5-3 shows the WASH123D model simulated surficial aquifer system (layer 1) water levels. These water levels are very close to those of the ECF model simulated surficial aquifer system water levels (Figure 5-4). A minimal difference might set in due to the difference in the conceptual model where the bounding layers (intermediate confining unit and middle semi confining unit) are not modeled in ECF model whereas they are modeled in WASH123D model.

Figure 5-5 shows the WASH123D model simulated 1995 potentiometric surface of all the layers. Figure 5-6 shows the average 1995 Upper Floridan aquifer (layer 2) potentiometric surface. The simulated potentiometric contours also verify the zero-flux boundaries having been set for the western, southwestern, and northern sides of the modeling domain.

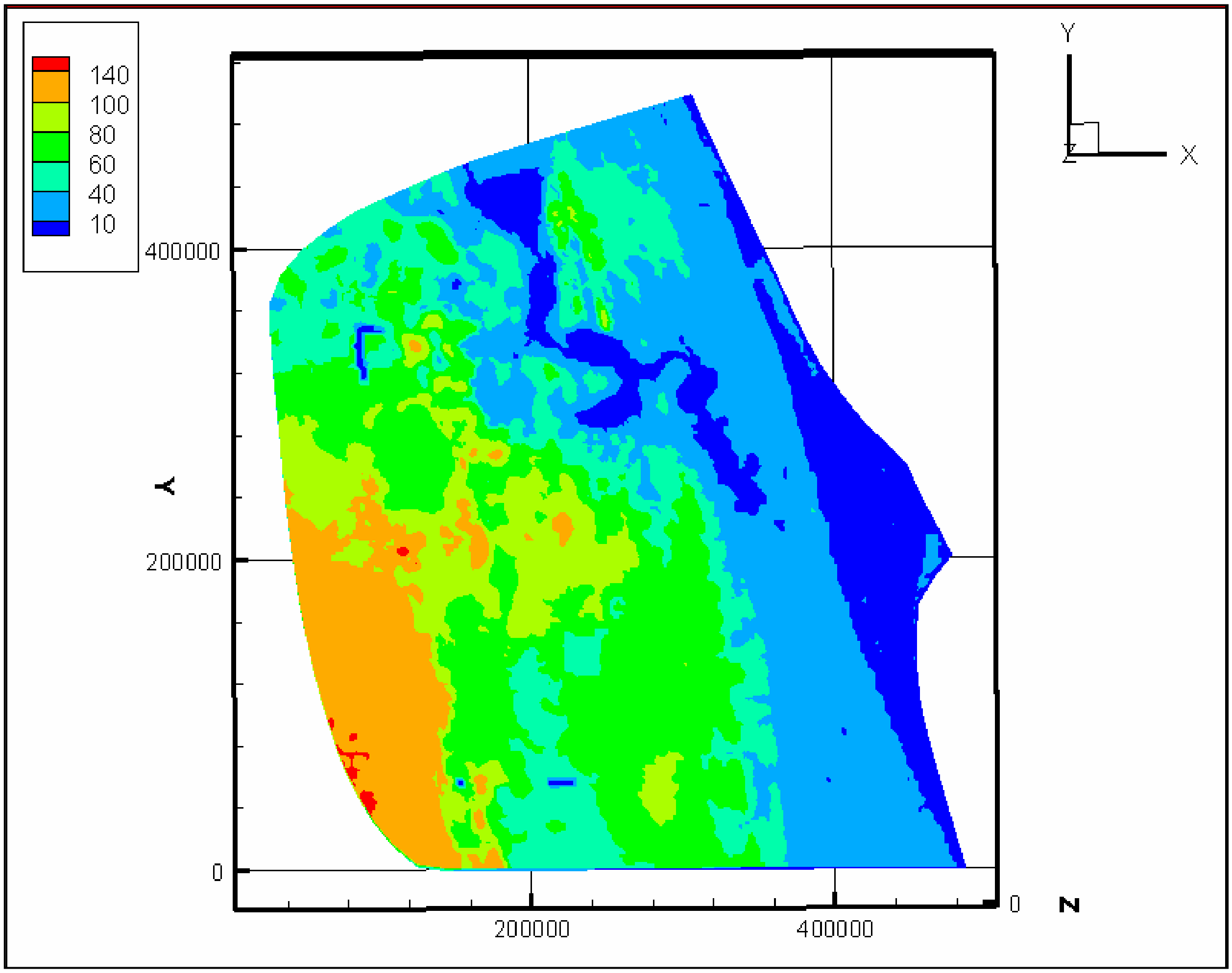


Figure 5-3 WASH123D Model Simulated Surficial Aquifer System (layer 1) Water Levels for Average 1995 Conditions

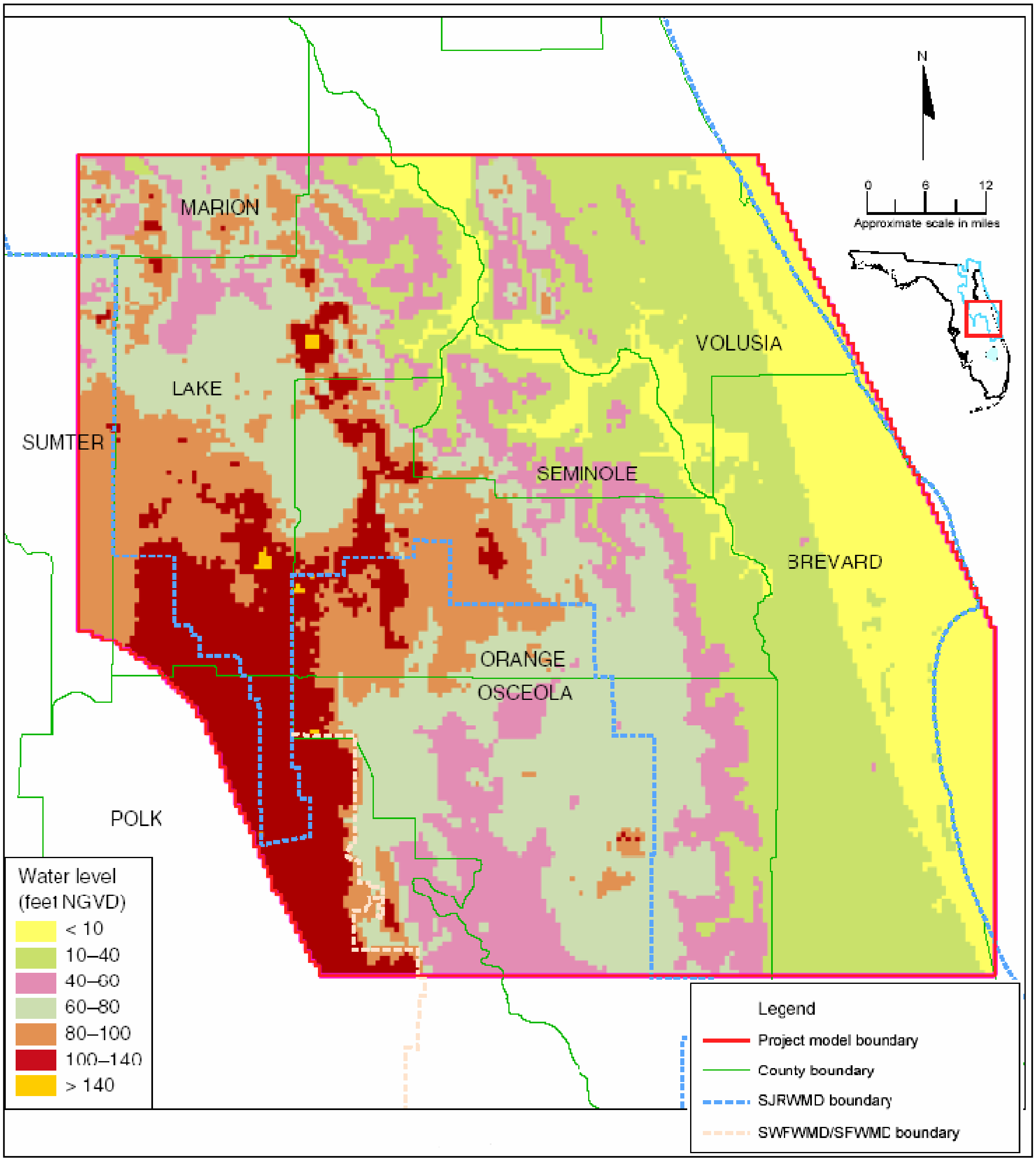


Figure 5-4 ECF Model Simulated Surficial Aquifer System (layer 1) Water Levels for Average 1995 Conditions

(Source: Technical Publication –SJ2002-3; SJRWMD)

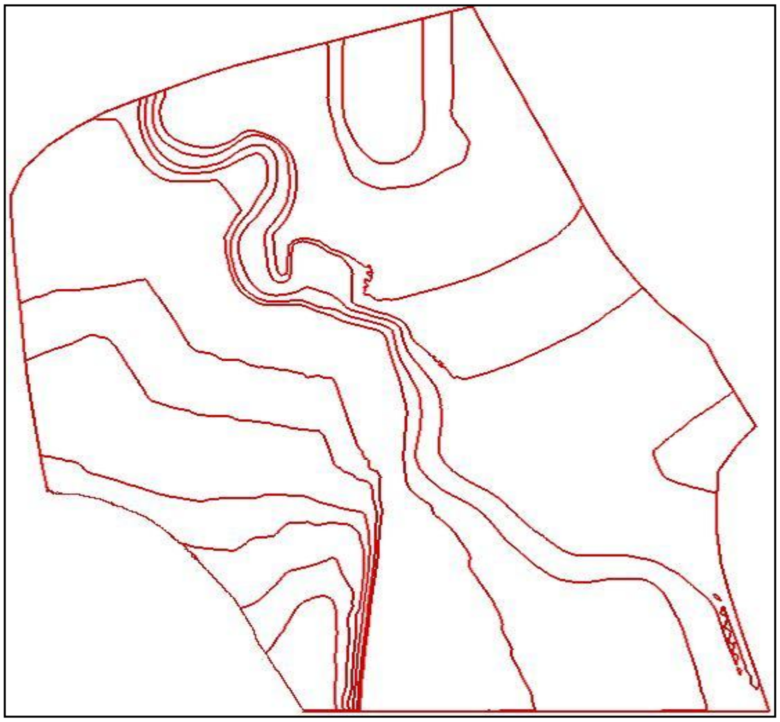


Figure 5-5 Simulated 1995 UFA (layer 2) Potentiometric Surface

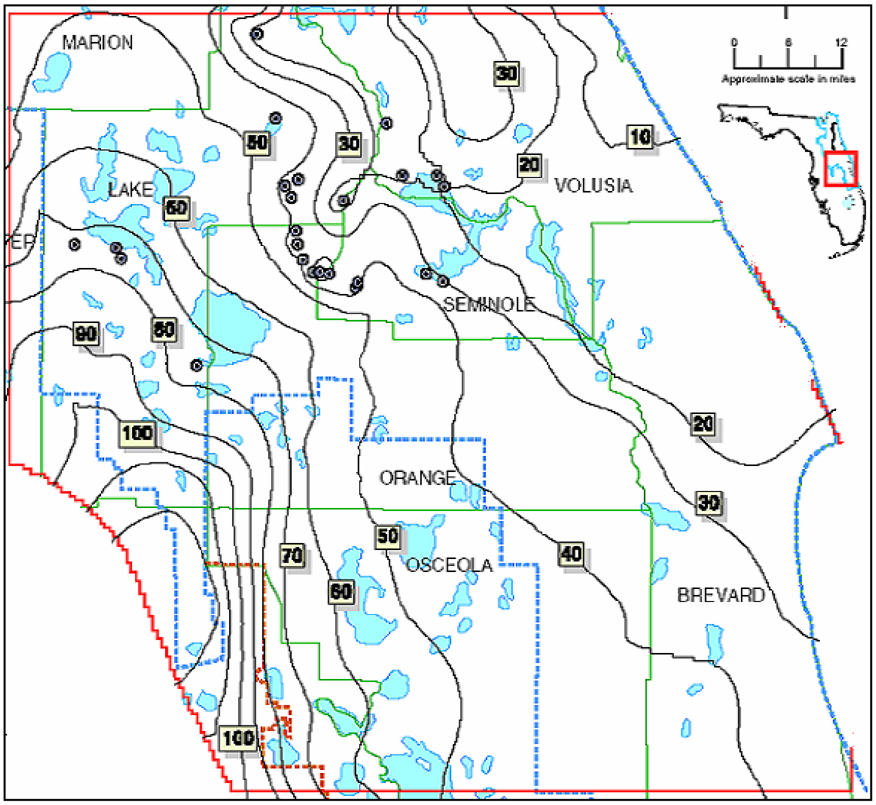


Figure 5-6 Average 1995 UFA (layer 2) Potentiometric Surface

5.2 Groundwater Flow

The groundwater flow patterns can be observed based on the simulated velocity fields as well as the potentiometric surfaces. The groundwater flow within the subsurface aquifer system is caused due to the potentiometric head difference. In a regional scale, the velocities are perpendicular to the head contours. Figure 5-7 shows the velocity vectors in the model domain.

Hydraulic conductivity is high within the vicinity of the spring due to which the Darcy’s velocities are high upwards resulting in spring discharge (Figure 5-8). It can be noticed that most of the groundwater recharge to spring flow is from the relatively shallow aquifer within the vicinity of the spring, where the velocities are relatively high hence taking less time for the groundwater to move to the spring. However, it can also be observed that part of the recharge is also from deeper aquifer as well as seepage from the surface.

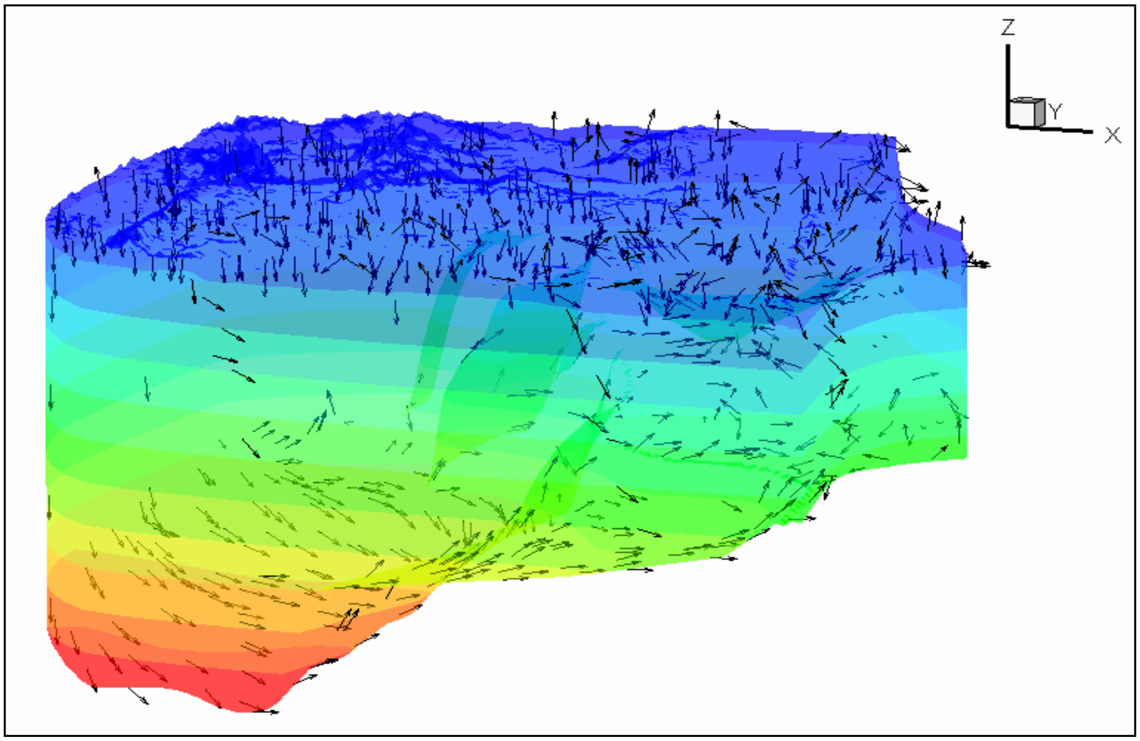


Figure 5-7 Simulated Wekiva Basin Groundwater Velocity Vectors

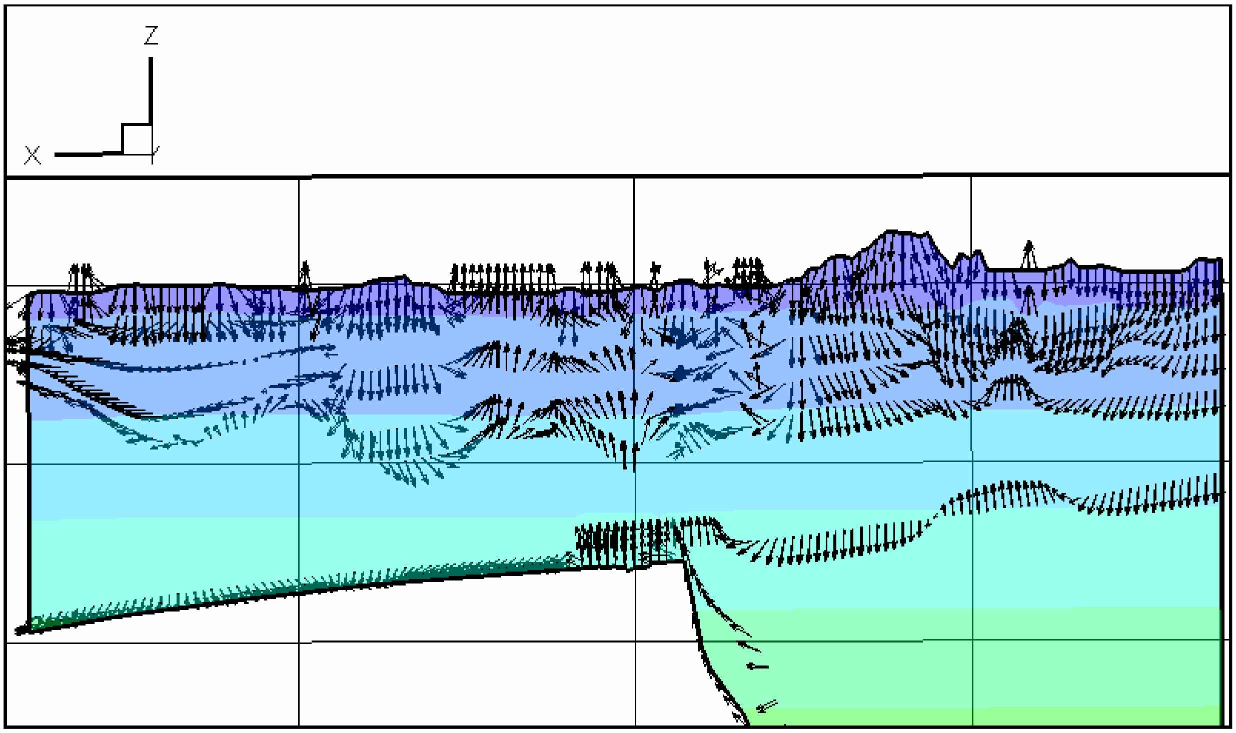


Figure 5-8 Simulated Groundwater Flow across X-Z slice at a specific Y (336000) Unit

6. Conclusions

The numerical, first principle, physics-based watershed model WASH123D has been used to model the Wekiva springshed. This model simulates three dimensional subsurface flows with in the study area. The area of study is centered upon Seminole and Orange counties but includes most of Brevard, Lake, and Osceola counties plus parts of the Marion, Polk, and Volusia counties. The modeling domain was discretized into 437,576 Triangular Prism Elements connected at 249,057 nodes. It has been sub categorized into eight numerical layers according to the regional geometry or hydrostratigraphy. Input hydrologic data consists of incorporated boundary conditions, applied stresses, and properties of each numerical layer.

The Wekiva WASH123D model was run to evaluate the average, steady state 1995 hydrological conditions. The distribution of simulated Floridan aquifer system groundwater levels using WASH123D shows very good agreement with the field observations at corresponding locations.

Though the Wekiva WASH123D model shows good simulation results compared with the observation data even without calibration, there will always be some limitations to the extent of approximation of the real field situations. This is because the numerical model is based on the extent of simplification of the conceptual model. Other factors include the element size, the inaccuracies of measurement data, and incomplete knowledge of the spatial variability of input parameters. For example, laminar flow is not assumed throughout the subsurface, especially within the vicinity of the springs. Also, the elevations of the lakes are not treated as a function of time. Interaction between water bodies such as lakes and the subsurface flows need to be considered to ensure mass conservation. And, appropriate element refinement is required near springs, wells, and lakes to increase the accuracy of the simulation.

All stresses input in this study represented average, steady state conditions. A Wekiva WASH123D model capable of transient simulations with sources/sinks and all types of boundary conditions considered spatially and/or temporally dependent, based on the appropriate initial conditions, can be further developed. Such a Wekiva WASH123D model could be further applied to examine the potential long-term, transient impact due to changes of stresses.

APPENDIX

Table A-1 Partial Model Geometry Input File (*.3DM)

```
WMS3DM
T1
T2 Wekiva Model Geometry Input Data
T3
GE6   1       28320   27674   28319   647     1       646     1
GE6   2       28319   27674   28321   646     1       648     1
GE6   3       27675   28321   27674   2       648     1       1
GE6   4       28322   28321   27675   649     648     2       1
GE6   5       28322   27675   27676   649     2       3       1
.
.
.
GE6   437572  221376  221382  221375  249049  249055  249048  273482
GE6   437573  221376  221381  221382  249049  249054  249055  273483
GE6   437574  221376  221377  221381  249049  249050  249054  273484
GE6   437575  221381  221377  221378  249054  249050  249051  273485
GE6   437576  221378  221379  221380  249051  249052  249053  273486
GN    1       303432.2243     497216.2359     5.373794556
GN    2       301035.2298     496514.9718     5.118711948
GN    3       298638.2353     495813.7077     14.01131153
GN    4       296241.2409     495112.4437     19.56216049
.
.
.
GN    249054  243750  198750  -1551.5
GN    249055  243750  201250  -1548.5
GN    249056  243750  203750  -1544.5
GN    249057  243750  206250  -1540.5
END
```

Table A-2 Partial Model Flow Input File (*.3BC)

```
WMS3BC
T1
T2 Wekiva Model Flow Input Data
T3
OP1       1
OP2       0         0         1         12        1
OP3       1.0d0     1.0D0     1.0d0
OP4       0
OT3       5         17        2005      0         0
IP1       200       3000      300       1.0D-1    1.0D-1    1.0D-1
TC1       2.4D+6    1.2d0     0.0       2.4d0
OC1       1         1         0         1
OC2       3         1         2         3
OC3       0         0         1
OC4       3         1         2         3
OC5       1         1
MP1       0
MP2       1         8.333E-01           8.333E-01           4.167E-03           0.0E+00   0.0E+00   0.0E+00   0.0E+00   4.0E-01
MP2       2         0.000E+00           0.000E+00           7.694E-05           0.0E+00   0.0E+00   0.0E+00   0.0E+00   4.0E-01
MP2       3         0.000E+00           0.000E+00           7.695E-05           0.0E+00   0.0E+00   0.0E+00   0.0E+00   4.0E-01
.
.
.
MP2       273508    2.968E+01           2.968E+01           2.968E+01           0.0E+00   0.0E+00   0.0E+00   0.0E+00   4.0E-01
MP2       273509    6.399E+01           6.399E+01           6.399E+01           0.0E+00   0.0E+00   0.0E+00   0.0E+00   4.0E-01
MP3       3         2         2.8317D11.09729D0
SP1       1         2         4         6         0         7         0.0       -6.0D0
SP1       2         2         4         6         0         7         0.0       -6.0D0
SP1       3         2         4         6         0         7         0.0       -6.0D0
.
.
.
SP1       273507    2         4         6         0         7         0.0E+00   -6.0E+00
SP1       273508    2         4         6         0         7         0.0E+00   -6.0E+00
SP1       273509    2         4         6         0         7         0.0E+00   -6.0E+00
PS1       90508     2248
PS1       90507     767
PS1       90505     549
.
.
.
PS1       194630    1201
PS1       194631    803
PS1       194637    298
DB1       306       6000      1
DB1       307       6000      1
DB1       308       6000      1
.
.
.
DB1       111337    6003      1
DB1       111338    6003      1
DB1       111339    6003      1
RS1       1         2         6060
RS1       2         2         6061
RS1       3         2         6062
.
```

```
.
.
RS1       54695     2         55291
RS1       54696     2         55292
RS1       54697     2         55293
ICS       0
ICH       0         1         0.0
ICM       0         4.5D0
ICF       0         0         0
XY1 2 2 0 0 0 0   MOISTURE CONTENT VS. PRESSURE HEAD
-4000     0.4
2000      0.4
XY1 4 2 0 0 0 0   RELATIVE CONDUCTIVITY VS. PRESSURE HEAD
-4000     1
2000      1
XY1 6 2 0 0 0 0   WATER CAPACITY VS. PRESSURE HEAD
-4000     0
2000      0
XY1       7         2         0         0         0         0         ponding depth  vs time series
0         0
1.0D38  0
XY1       20        2         0         0         0         0         PSS
0.0d0     -65928.33333
1.00D+38            -65928.33333
.
.
.
XY1       2573      2         0         0         0         0         PSS
0.0d0     6799.625
1.00D+38            6799.625
XY1       6000      2         0         0         0         0         Dirichlet head
0.0d0     53
1.0D38    53
.
.
.
XY1       6058      2         0         0         0         0         Dirichlet head
0.0d0     83.1
1.0D38    83.1
XY1       6059      2         0         0         0         0         Dirichlet head
0.0d0     86.4
1.0D38    86.4
XY1       6060      2         0         0         0         0         VAR
0.0d0     1.06E-04
1.00E+381.06E-04
XY1       6061      2         0         0         0         0         VAR
0.0d0     1.06E-04
1.00E+381.06E-04
.
.
.
XY1       55292     2         0         0         0         0         VAR
0.0d0     4.82E-05
1.00E+384.82E-05
XY1       55293     2         0         0         0         0         VAR
0.0d0     6.96E-05
1.00E+386.96E-05
END
```

Table A-3 Partial Model Output File

```
1 TABLE OF SYSTEM-FLOW PARAMETERS  .. AT TIME =  0.0000D+00
 (DELT =  0.0000D+00) ITIM=  -1

  TYPE OF FLOW                         RATE       INC. FLOW    TOTAL FLOW
1. FLOW THROUGH DIRICHLET NODES ..  -3.1271D+09    0.0000D+00    0.0000D+00
2. FLOW THROUGH CAUCHY NODES . . .   0.0000D+00    0.0000D+00    0.0000D+00
3. FLOW THROUGH NEUMANN NODES .  .   0.0000D+00    0.0000D+00    0.0000D+00
4. FLOW THROUGH SEEPAGE NODES .. .   8.6882D+00    0.0000D+00    0.0000D+00
5. FLOW THROUGH INFILTRATION NODES  -3.1136D+09    0.0000D+00    0.0000D+00
6. FLOW THROUGH UNSPECIFIED NODES    3.1074D+09    0.0000D+00    0.0000D+00
7. NET FLOW THROUGH ENTIRE BOUNDARY -3.1333D+09    0.0000D+00    0.0000D+00
8. ARTIFICIAL SOURCES/SINKS . . . .  2.9624D+06    0.0000D+00    0.0000D+00
9. INCREASE IN WATER CONTENT . . .   3.1303D+09    0.0000D+00    1.1215D+14
A. FLOW THROUGH RIVER NODES  . . .   0.0000D+00    0.0000D+00    0.0000D+00
 *** NOTE: (+) = OUT FROM, (-) = INTO THE REGION.
.
.
.
..  PRESSURE HEAD (L) AT TIME =  0.0000D+00  (DELT =  0.0000D+00)  IT =   -1

 INPUT OVERLAND INITIAL CONDITIONS
  NODE I      PRESSURE HEAD (L) OF NODES I,I+1,..,I+4
     1 -5.3737946D+00 -5.1187119D+00 -1.4011312D+01 -1.9562160D+01 -2.4228950D+01
     6 -1.5549961D+01 -1.8366678D+01 -1.8913569D+01 -1.9935926D+01 -2.3832150D+01
    11 -2.1270958D+01 -1.8325798D+01 -1.8826117D+01 -2.3451946D+01 -2.4971565D+01
   .
   .
   .
249046  1.5400000D+03  1.5435000D+03  1.5475000D+03  1.5510000D+03  1.5540000D+03
249051  1.5550000D+03  1.5585000D+03  1.5565000D+03  1.5515000D+03  1.5485000D+03
249056  1.5445000D+03  1.5405000D+03
..  VELOCITY (L/T) AT TIME =  0.0000D+00  (DELT =  0.0000D+00)  IT =   -1

 INPUT OVERLAND INITIAL CONDITION
  NODE    X-VELOC.     Y-VELOC.     Z-VELOC.
  ----    --------     --------     --------
      1   6.8725D-19   1.0631D-18   3.8733D-18
      2  -1.9267D-19  -7.4105D-21   3.5842D-18
      3   2.1771D-18   2.0779D-18   4.1969D-18
.
.
.
 249055   1.7433D-16  -2.5500D-16   6.7108D-17
 249056   2.1630D-16  -3.2075D-16   5.8304D-17
 249057   2.6736D-16  -5.0424D-16   6.1811D-17
...
.
.
1 TABLE OF SYSTEM-FLOW PARAMETERS  .. AT TIME =  0.0000D+00
 (DELT =  0.0000D+00) ITIM=   0

  TYPE OF FLOW                         RATE       INC. FLOW    TOTAL FLOW
1. FLOW THROUGH DIRICHLET NODES ..  -3.1271D+09    0.0000D+00    0.0000D+00
2. FLOW THROUGH CAUCHY NODES . . .   0.0000D+00    0.0000D+00    0.0000D+00
3. FLOW THROUGH NEUMANN NODES .  .   0.0000D+00    0.0000D+00    0.0000D+00
4. FLOW THROUGH SEEPAGE NODES .. .   8.6882D+00    0.0000D+00    0.0000D+00
5. FLOW THROUGH INFILTRATION NODES  -3.1136D+09    0.0000D+00    0.0000D+00
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6. FLOW THROUGH UNSPECIFIED NODES    3.1074D+09    0.0000D+00    0.0000D+00
7. NET FLOW THROUGH ENTIRE BOUNDARY -3.1333D+09    0.0000D+00    0.0000D+00
8. ARTIFICIAL SOURCES/SINKS . . . .  2.9624D+06    0.0000D+00    0.0000D+00
9. INCREASE IN WATER CONTENT . . .   3.1303D+09    0.0000D+00    1.1215D+14
A. FLOW THROUGH RIVER NODES  . . .   0.0000D+00    0.0000D+00    0.0000D+00
 *** NOTE: (+) = OUT FROM, (-) = INTO THE REGION.

 RAINFALL-SEEPAGE NODAL FLOWS (L**3/T)
   -0.6117D+02    0.8480D+02    0.3727D+02   -0.1279D+03   -0.2567D+03
    0.1218D+03   -0.1860D+03   -0.1132D+03   -0.6741D+02   -0.2020D+03
   -0.1737D+03    0.1257D+03    0.1708D+03    0.2860D+02    0.2505D+02
   .
   .
   .
   -0.3996D+01   -0.5919D+02   -0.9808D+01   -0.8263D+02   -0.1093D+03
   -0.2140D+03   -0.4328D+02   -0.4448D+02
0 VALUES OF NPCON
          1          2          3          4          5
          6          7          8          9         10
         11         12         13         14         15
         16         17         18         19         20
         .
         .
         .
      27656      27657      27658      27659      27660
      27661      27662      27663      27664      27665
      27666      27667      27668      27669      27670
      27671      27672      27673
0 VALUES OF NPMIN
          0          0          0          0          0
          0          0          0          0          0
          0          0          0          0          0
          .
          .
          .
          0          0          0          0          0
          0          0          0          0          0
          0          0          0
0 VALUES OF NPFLX
          0          0          0          0          0
          0          0          0          0          0
          0          0          0          0          0
          0          0          0          0          0
         .
         .
         .
          0          0          0          0          0
          0          0          0          0          0
          0          0          0          0          0
          0          0          0
..  PRESSURE HEAD (L) AT TIME =  0.0000D+00  (DELT =  0.0000D+00)  IT =    0

 STEADY-STATE INITIAL CONDITIONS FOR SUBSURFAC
  NODE I      PRESSURE HEAD (L) OF NODES I,I+1,..,I+4
     1  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
     6  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
    11  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
    16  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
    21  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
    26  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
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   31  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
   36  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
   41  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
   46  0.0000000D+00 -3.2658464D+00 -1.4850181D+01 -1.1824406D+01 -6.7029671D+00
    .
    .
    .
249041  1.5577667D+03  1.5538792D+03  1.5616559D+03  1.5655505D+03  1.5656169D+03
249046  1.5662039D+03  1.5696410D+03  1.5735406D+03  1.5769773D+03  1.5799245D+03
249051  1.5805822D+03  1.5840171D+03  1.5816906D+03  1.5771369D+03  1.5741922D+03
249056  1.5702861D+03  1.5666305D+03
..  VELOCITY (L/T) AT TIME =  0.0000D+00  (DELT =  0.0000D+00)  IT =    0

 STEADY-STATE INITIAL CONDITIONS
  NODE    X-VELOC.     Y-VELOC.     Z-VELOC.
  ----    --------     --------     --------
     1   1.0690D-03   9.5021D-04  -1.6657D-05
     2   4.2063D-04   4.7655D-04   2.2503D-05
     3   2.8904D-03   1.5328D-03  -7.8351D-06
     .
     .
     .
 249055   1.7273D-03  -2.1195D-04   6.0764D-05
 249056   1.7303D-03  -2.6570D-04   8.4439D-05
 249057   1.6475D-03  -5.0059D-04   1.1687D-04
..  MOISTURE CONTENT AT TIME =  0.0000D+00  (DELT =  0.0000D+00)  IT =    0

 STEADY-STATE INITIAL CONDITIONS FOR SUBSURFAC
  NODE I      MOISTURE CONTENT OF NODES I,I+1,..,I+4
    1  4.4999999D-01  4.4999999D-01  4.4999999D-01  4.4999999D-01  4.4999999D-01
    6  4.4999999D-01  0.0000000D+00  0.0000000D+00  4.4999999D-01  4.4999999D-01
   11  4.4999999D-01  4.4999999D-01  4.4999999D-01  4.4999999D-01  0.0000000D+00
    .
    .
    .
249046  4.4999999D-01  0.0000000D+00  0.0000000D+00  4.4999999D-01  4.4999999D-01
249051  4.4999999D-01  4.4999999D-01  4.4999999D-01  4.4999999D-01  0.0000000D+00
249056  0.0000000D+00  4.4999999D-01
...
...
...
...
1 TABLE OF SYSTEM-FLOW PARAMETERS  .. AT TIME =  0.0000D+00
 (DELT =  0.0000D+00) ITIM=   0

  TYPE OF FLOW                          RATE       INC. FLOW    TOTAL FLOW
1. FLOW THROUGH DIRICHLET NODES ..  -3.1271D+09    0.0000D+00    0.0000D+00
2. FLOW THROUGH CAUCHY NODES . . .   0.0000D+00    0.0000D+00    0.0000D+00
3. FLOW THROUGH NEUMANN NODES .  .   0.0000D+00    0.0000D+00    0.0000D+00
4. FLOW THROUGH SEEPAGE NODES .. .   8.6882D+00    0.0000D+00    0.0000D+00
5. FLOW THROUGH INFILTRATION NODES  -3.1136D+09    0.0000D+00    0.0000D+00
6. FLOW THROUGH UNSPECIFIED NODES    3.1074D+09    0.0000D+00    0.0000D+00
7. NET FLOW THROUGH ENTIRE BOUNDARY -3.1333D+09    0.0000D+00    0.0000D+00
8. ARTIFICIAL SOURCES/SINKS . . . .  2.9624D+06    0.0000D+00    0.0000D+00
9. INCREASE IN WATER CONTENT . . .   3.1303D+09    0.0000D+00    1.1215D+14
A. FLOW THROUGH RIVER NODES  . . .   0.0000D+00    0.0000D+00    0.0000D+00
 *** NOTE: (+) = OUT FROM, (-) = INTO THE REGION.
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 RAINFALL-SEEPAGE NODAL FLOWS (L**3/T)
   -0.6116D+02    0.8481D+02    0.3729D+02   -0.1279D+03   -0.2567D+03
    0.1219D+03   -0.1860D+03   -0.1131D+03   -0.6733D+02   -0.2020D+03
   -0.1736D+03    0.1259D+03    0.1710D+03    0.2868D+02    0.2533D+02
   .
   .
   .
   -0.1758D+03   -0.8562D+01   -0.8702D+02   -0.1554D+03   -0.1230D+03
   -0.8886D+02   -0.3637D+02    0.5798D+02   -0.2028D+03   -0.4247D+02
    0.1655D+02   -0.3936D+02    0.1405D+02   -0.6485D+02   -0.8913D+02
   -0.1938D+03   -0.2346D+02   -0.2726D+02
0 VALUES OF NPCON
          1          2          3          4          5
          6          7          8          9         10
         11         12         13         14         15
         .
         .
         .
      27656      27657      27658      27659      27660
      27661      27662      27663      27664      27665
      27666      27667      27668      27669      27670
      27671      27672      27673
0 VALUES OF NPMIN
          0          0          0          0          0
          0          0          0          0          0
          0          0          0          0          0
          .
          .
          .
          0          0          0          0          0
          0          0          0          0          0
          0          0          0          0          0
          0          0          0
0 VALUES OF NPFLX
          0          0          0          0          0
          0          0          0          0          0
          0          0          0          0          0
          0          0          0          0          0
         .
         .
         .
          0          0          0          0          0
          0          0          0          0          0
          0          0          0          0          0
          0          0          0
..  PRESSURE HEAD (L) AT TIME =  0.0000D+00  (DELT =  0.0000D+00)  IT =    0

 STEADY-STATE INITIAL CONDITIONS FOR SUBSURFAC
  NODE I      PRESSURE HEAD (L) OF NODES I,I+1,..,I+4
    1  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
    6  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
   11  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
   16  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
   21  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
   26  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
   31  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
   36  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
   41  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00  0.0000000D+00
   46  0.0000000D+00 -2.9991921D+00 -1.4495632D+01 -1.1375898D+01 -6.1895860D+00
   .
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   .
   .
249046  1.5769183D+03  1.5805145D+03  1.5845759D+03  1.5881754D+03  1.5912871D+03
249051  1.5921350D+03  1.5957377D+03  1.5934423D+03  1.5885241D+03  1.5854142D+03
249056  1.5813440D+03  1.5775266D+03
..  VELOCITY (L/T) AT TIME =  0.0000D+00  (DELT =  0.0000D+00)  IT =    0

 STEADY-STATE INITIAL CONDITIONS
  NODE    X-VELOC.     Y-VELOC.     Z-VELOC.
  ----    --------     --------     --------
     1   1.0690D-03   9.5021D-04  -1.6655D-05
     2   4.2064D-04   4.7655D-04   2.2507D-05
     3   2.8905D-03   1.5329D-03  -7.8280D-06
     .
     .
     .
 249055   1.5988D-03   7.0605D-04   5.9451D-05
 249056   1.6083D-03   6.4443D-04   8.3565D-05
 249057   1.5333D-03   3.8199D-04   1.1641D-04
..  MOISTURE CONTENT AT TIME =  0.0000D+00  (DELT =  0.0000D+00)  IT =    0

 STEADY-STATE INITIAL CONDITIONS FOR SUBSURFAC
  NODE I      MOISTURE CONTENT OF NODES I,I+1,..,I+4
    1  4.4999999D-01  4.4999999D-01  4.4999999D-01  4.4999999D-01  4.4999999D-01
    6  4.4999999D-01  0.0000000D+00  0.0000000D+00  4.4999999D-01  4.4999999D-01
   11  4.4999999D-01  4.4999999D-01  4.4999999D-01  4.4999999D-01  0.0000000D+00
   .
   .
   .
249046  4.4999999D-01  0.0000000D+00  0.0000000D+00  4.4999999D-01  4.4999999D-01
249051  4.4999999D-01  4.4999999D-01  4.4999999D-01  4.4999999D-01  0.0000000D+00
249056  0.0000000D+00  4.4999999D-01
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