Project Summary

Title: Development of a Multi-medium Strategy of Environmental System Management of Nitrate Transport in Woodville Karst Plain, Florida

Applicant

State agency: Florida Department of Environmental Protection, Tallahassee, FL

Partner: Florida State University, Tallahassee, FL

Project Manager

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Project Abstract

The Woodville Karst Plain (WKP) hosts the Wakulla Springs, the world's largest and deepest freshwater spring and a natural treasure to the citizens of the Wakulla county and Florida State. However, water quality of the Wakulla Springs has been significantly degraded due to increase of nitrate load from lawn fertilizer, septic tanks, wastewater sprayfields, and sewage treatment plants located in the springshed. According to the stream condition index (SCI), the Wakulla Springs is consistently in the poor range. One of the obstacles of fully understanding the spring system is the complicated and largely unknown ground water flow dynamics. All the related issues, from water budget to pollutant load and from flow velocity to pollutant migration, all require a thorough and correct understanding of the groundwater system. We propose to develop a multi-medium strategy of applying the Environmental Management Systems (EMS) to the WKP for sprayfield permitting, pollution prevention, and long-term sustainability. To retain this goal, two objectives are proposed to (1) develop a mathematical/numerical model of triplet-porosity medium to simulate groundwater flow and nitrate transport in the Floridan aquifer in the WKP area and (2) employ the developed model to facilitate permitting, pollution prevention, and long-term sustainability at the WKP. The long-term objective includes use of the model as a tool for TMDLs calculations. The research results will be used to facilitate issuing permits to water and wastewater facilities, to the prevention of pollution, and to the optimized management of water resources in WKP and other sites at the southeast region with similar situations.

Statutory Authority and Flexibility

The statutory authority for conducting the proposed project starts from the federal Clean Water Act and the corresponding State laws assigned to Florida DEP. All the existing permit programs started through a problem identification stage, a management stage, and a legislation stage to mature to a permit program. At this stage, the TMDL program has already migrated into a management program. When the management program becomes mandatory, it could well develop into a permit program. The authorization has been enabled, so is the involved management polity flexibility

State Agency Support

The commissioner/Director/Secretary (as appropriate) of the state agency is aware of and endorses this proposal. If this proposal is selected, a letter of endorsement will be provided with the final work plan.

Project Narrative

1. Problem Statement

This proposal is to develop a multi-medium strategy of applying the Environmental Management Systems (EMS) to the Woodville Karst Plain (WKP) for sprayfield permitting, pollution prevention, and long-term sustainability. Figure 1 shows the study area in the WKP, bounded with the Mexico Gulf in the south, measured and model-simulated hydraulic head, identified major Karst conduits, and streams (Hazlett-Kincaid inc., 2007). The WKP hosts the Wakulla Springs (Figure 1), the world's largest and deepest freshwater spring and a natural treasure to citizens of the Leon county and Florida State. However, water quality of the Wakulla Springs has been significantly degraded due to increase of nitrate load from lawn fertilizer, septic tanks, wastewater sprayfields, and sewage treatment plants. The nitrate level in the Springs has increased from below 0.2 milligrams per liter (mg/l) in 1980 to 7 mg/l nowadays (Davis and Katz, 2007). The significant increase of nitrate level is also observed in many springs of the WKP. Although this level is still below the regulation criterion of 10 mg/l, increase of nitrate has already severely affected water quality and ecosystem of the Wakulla Springs. In 1997, hydrilla, a fast growing exotic aquatic plant, began growing out-of-control at Wakulla Springs. In recent years, thick algal mats have been growing on top of the hydrilla and other aquatic plants. According to the stream condition index (SCI), the Wakulla Springs is consistently in the poor range; biological health of the Wakulla Springs is in the lowest 20% of all rivers in Florida. Wakulla Rive is on Florida list of impaired rivers for review by the TMDL (Total Maximum Daily Load) process (to be completed in 2010) to allocate maximum nutrient loadings that a river can absorb and still be ecologically healthy.

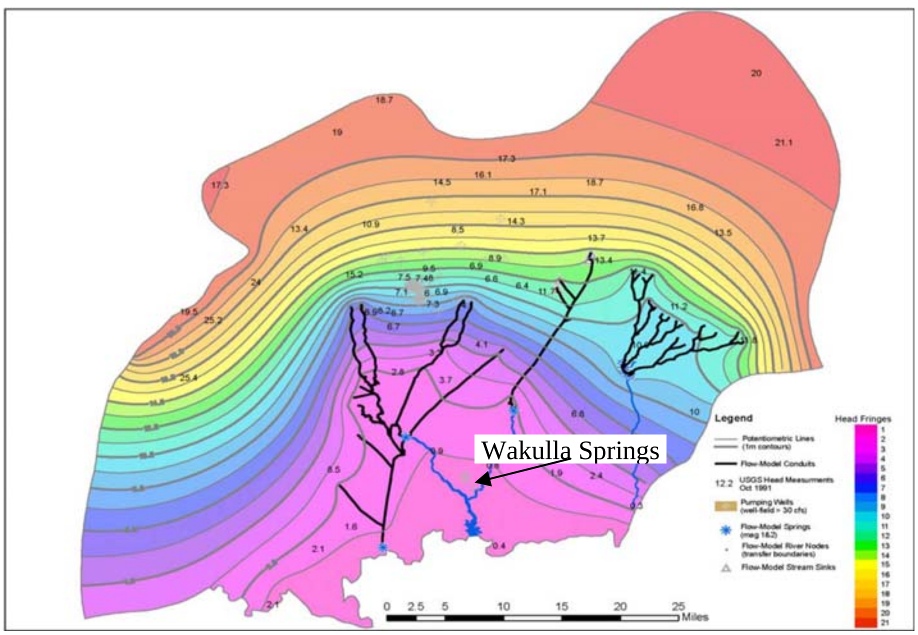

Figure 1. Map of the study area, measured and model-simulated hydraulic head, and identified major conduits (adopted from Hazzlet-Kincaid inc, 2007). Wakulla Rive is from Wakulla Springs to the Mexico Gulf bounded the WKP in the south.

One source of the nitrate pollution is from the City of Tallahassee's Smith Sewage Processing Plant where 3 tons of sludge is applied daily and the sprayfield where 20 million gallons of effluent are sprayed daily on average. Since these facilities are located upgradient to the Wakulla Springs, wastewater with nitrate enters from the facilities to groundwater and emerges from the spring. The added nitrate fertilizes the growth of hydrilla and algae, enabling them to take over the spring and river. When issuing permits to the city's facilities, it is indispensable to consider effect of the nitrate transported from the facilities on water quality and ecology at the Wakulla Springs and the WKP. In addition, with growth of the Leon County and the City of Tallahassee (population of the Leon County have increased from 150,000 in 1980 to 250,000 today), more effluent will be resulted. It is unknown whether the current protective measures included in permitting can prevent future pollution and satisfy requirements of long-term sustainability.

Study of the regional flow and transport has been conducted by state and local agencies (e.g., Lee, et al., 1995; Northwest Florida Water Management District, 2002; Davis and Katz, 2007; Hazzlet-Kincaid inc., 2007). However, these studies relied on the USGS MODFLOW (Harbaugh, 2005 of the latest version), a software insufficient to incorporate the complex Karst geologic system (Figure 1). The sprayfield and Smith plant are located at south of the Cody Scarp, where the area is riddled with sink holes and underground caves and conduits in which the nitrate transports fast. In order to simulate the fast flow in the Karst aquifer, parameters of the MODFLOW model were adjusted to unreasonable values. For example, currently used porosity value is one order of magnitude smaller than the field observations to simulate the fast flow rate of nitrate transport. The WKP area is bounded with the Mexico Gulf in the south. The ocean's tidal effect on groundwater flow is significant (Loper et al., 2006; Chicken et al., 2007). However, the current study based on MODLFLOW cannot incorporate this effect into modeling simulation. Therefore, using current model approach to implement the plan-do-check-act process of EMS is suspicious, and a new tool of multimedium strategy related to permitting is entailed.

2. Background

The major aquifer in the WKP is a Karst aquifer, the Floridan aquifer. The Floridan aquifer, which underlies all of Florida, Southern Georgia, and small parts of adjoining Alabama and South Carolina, is one of the major sources of groundwater supplies in the United States. More than 90% of Floridan domestic and public water supplies are obtained from the aquifer. The Floridan aquifer mainly consists of carbonate rocks, primarily limestone and dolomite. The Karst aquifer is manifested by sinkholes, springs, caves, disappearing streams and underground drainage channels. These features are formed due to the solution activity of acidic surface water (rich in carbon dioxide and under-saturated with respect to calcium carbonate (*Bush and Johnston*, 1988)). Many water flow conduits with various diameters and lengths are founded in the Karst aquifer and these conduits connect each other to form various nets. The existence of conduits in the limestone is the most characteristics of the Floridan aquifer, they control the groundwater flow and solute transport in subsurface in the WKP. The groundwater is also related to surface water through conduits in the forms of sinkholes, springs and others. Owing to active interaction between surface water and groundwater, the Karst aquifer is very venerable to contamination. Currently, the Floridan aquifer is contaminated by nitrite through various sources, such as the fertilizers, septic tanks, and sprayfields. The nitrite contents in many springs of the study area have been significantly increased in the last two decades. Characterization of the conduit distribution and accurate simulation of the groundwater flow and chemical transport processes in the Karst aquifer is critical to sprayfield permitting, pollution prevention, and long-term sustainability.

It has been realized that the groundwater flow in conduits is no longer a laminar flow. Therefore, Darcy law, developed from laminar flow, is no longer suitable for describe the flow process in the Karst aquifer. However, most modeling simulations for flow and transport in the Floridan aquifer are conducted through the codes (e.g., MODFLOW) developed from Darcy law, where the Karst aquifer is assumed to be porous media and the various conduits are either ignored or simply conceptualized as large conductivity areas. The predicted results for flow and transport are frequently found to significantly alleviate from the observations. This problem indicates that the current models/computer approach for groundwater flow and solute transport are not suitable to simulate the groundwater flow and solute transport in Floridan aquifer.

Here we propose to use the WKP as our study area to develop a quantitative approach for groundwater flow and solute transport in the Karst aquifer. We choose this watershed because there are many water-related environmental problems in the study area, such as the nitrite contamination. Nitrite contamination in Wakulla Springs caused by the Tallahassee sprayfield has been a legal issue in the last three years. The WKP has been studied for many years, and the investigators are familiar with the hydrology/hydrogeology conditions. A large amount of on-site data and information have been collected, especially, the largest conduct system has been well explored in the last several years by the divers. The study area is not too big, but the complicated with various Karst phenomena. The study boundaries of study area can be well defined, especially in the south where it is bounded with ocean. The study results developed in this project can be easily applied to other locations in Florida and other southeast states.

3. Project Objectives

This project is to develop a quantitative and multi-medium strategy of understanding groundwater flow and solute transport in the WKP Karst aquifer.

Objective 1. Develop a mathematical/numerical model of triplet-porosity medium to simulate groundwater flow and nitrate transport in the Floridan aquifer in the WKP area. Transport of nitrate from Tallahassee facilities (e.g., sprayfields and sewage processing plant) and nitrate distribution in the WKP will be simulated. Nitrate transport from the facilities to the Wakulla Springs is of particular interest of this project. Density dependent model will be applied to study the sea-water/groundwater interface at the south boundary of the study domain. The model will be calibrated using on-site observations of hydraulic head, groundwater discharge, and solute concentration.

Objective 2. Employ the developed model to facilitate permitting, pollution prevention, and long-term sustainability at the WKP. The long-term objective includes use of the model as a tool for MFLs and TDMLs calculations. In addition, it is expected that the model will spark interest in applying a similar modeling approach to solving problems across the Karst belt of Florida.

4. Methodology and Technical Approaches

4.1. Modeling domain, boundaries, and field data

The model area (Figure 1) encompasses 6.16×10^9 m^2 and is bounded by no-flow, constant-head, and seawater/groundwater boundaries. The constant heads are 21 m along the northern boundary. The model extends from the Ochlocknee River on the west, along the Apalachee Bay and Gulf of Mexico to the south, then north along the Aucilla River, where it then cuts across the northern boundary. The east and west boundaries are treated as no flow boundaries since they are along flow lines. For the south boundary of the Gulf of Mexico, we will use the density dependent flow model, SEAWAT (Guo et al., 2002), to determine the boundary condition with tidal waving and storm serge at extreme conditions. The model area is designed to be large enough for investigation of the Wakulla Spring system without experiencing boundary effects. It is also considered in the design that eventually the scope of the investigation may expand to the other spring cave systems in the basin, including St. Mark's Wacissa, and Spring Creek.

4.2. Conceptual model

The Floridan Karst aquifer consists of large well-studied conduits (Figure 2), many unclear small cavernous conduits, and limestone matrix. While the large conduits take a very small portion (can be neglected) of the total volume of the aquifer volume, they transport most groundwater in the system. Groundwater, recharged from precipitation and upstream flow-in, is mainly stored in the limestone matrix. The large amount of the small- and medium-size conduits connects the matrix water system with large conduit system. It should be pointed out that the limestone in the Floridan aquifer is also very conductive in comparison with other aquifers, but is much less conductive in comparison with the conduits. Owing to the dominant distribution area in comparison with conduits, precipitation and chemical compounds get into the groundwater system mainly through the matrix. How fast the recharged groundwater and chemicals can get into the major outputs, such as the Wakulla spring, mainly depends how fast they can move into the conduit system. Once they are in the large conduits, they will be discharged out the groundwater system in several days. However, from the matrix to the large conduits could be a long time process, which may take years. This explains why the water age in the Wakulla spring has a very large spectrum (Davis and Katz, 2007). The most important hydrologic control on these processes is rainfall. Dramatic fluctuations of water levels (or pressures) associated with the torrential storms and severe droughts that Florida often experiences make water flow back and forth between conduit and matrix, causing contaminants retention (sequestration) or releasing. This mechanism is described in Figure 3.

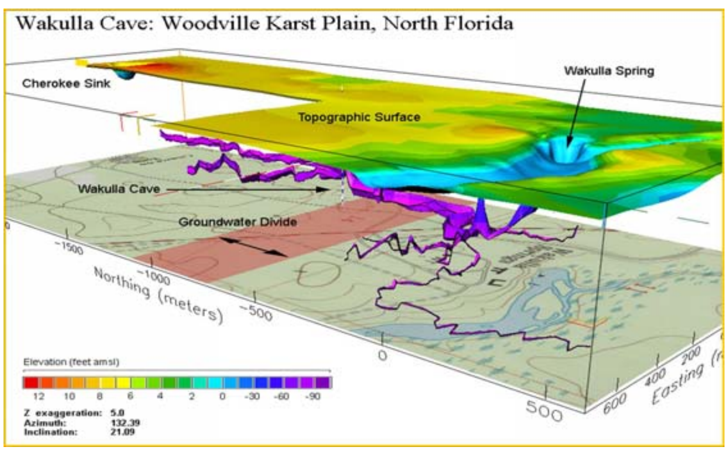

Figure 2. Identified large conduits and caves in WKP (adopted from Hazlett-Kincaid inc, 2007).

In this study, we propose to develop a novel triple-domain model to simulate the flow in the Karst aquifer. The matrix and small conduits are treated as the two continuum domains, like the dual-porosity model for a fractured medium (Hu et al., 2002; Gerke and van Genuchten, 1993). The distributions of hydraulic parameters in the limestone matrix will be determined according to the various hydraulic tests conducted in this area. The conductivity distribution in the small conduit domain will be simulated through Monte Carlo simulation according to their geostatistical properties obtained from various field measurements. The third domain will be the large conduits exist in the medium. Since the locations and configurations of the large conduits have been well studied through scuba divers, they will be treated as deterministic and special domain. Pipe flow model will be adopted to describe flow and solute transport in the conduits. Water and chemicals will be transferred between any two of the three domains according to the hydraulic and chemical gradients.

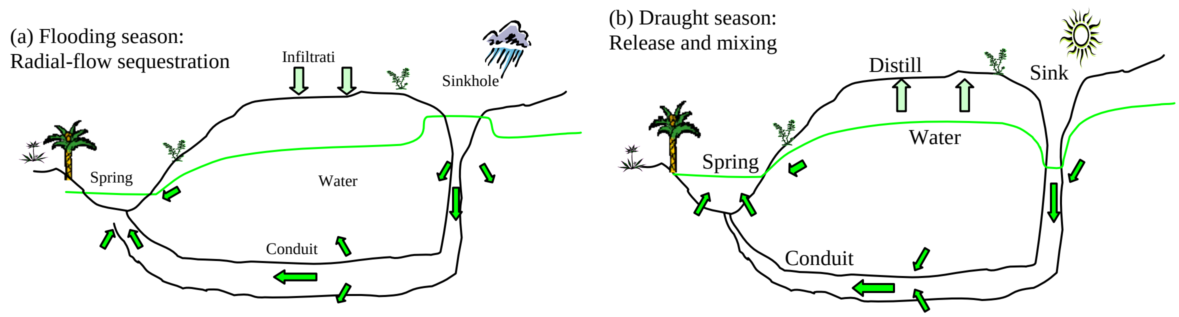

Figure 3. The schematic water and contaminant interaction between conduit and limestone matrix with different hydrogeologic seasons. (a) in a flooding season, the higher conduit water pressure drives a radial-flow which carries contaminants into limestone matrix; (b) in a draught season, the higher water pressure in the matrix pushes water into the conduit and releases the contaminant back. From *Li* [2004].

4.3. Mathematical/numerical modeling and model calibration

According to the concept model described above, a triplet-domain mathematical model will be developed. In each domain, one flow equation and one solute transport will be used to describe the flow and transport processes. The equations will be coupled together through the coupled terms for water and solute exchanges between the domains. A similar model has been developed by Wu and Pruess (2000) to describe the groundwater flow and solute transport in fractured media with large faults. However, in their model, the large voids, like the large faults, are treated as reservoirs, the flow and transport processes are not well described. Here, pipe flow and transport models will be used to describe flow and transport in the large conduits. In comparison with current modeling approach, this model can describe the fast flow and transport processes in conduits, and also can describe the solute detention process in the matrix.

The flow boundaries in the east, west and north sides will be determined from the regional groundwater modeling results, while the south boundary will be treated as a specified boundary conditions. The east and west sides are chosen alone flow lines and are treated as no-flow boundaries. Fresh water and seawater modeling results by SEAWAT code (Guo et al., 2002) will be used to simulate the boundary. The treatment of this boundary condition will allow us to study the tidal effect on groundwater flow and solute transport.

The developed mathematical model will be numerically solved with appropriate external and internal boundary conditions. The developed model will then be verified and calibrated against various on-site observations using the software PEST (Parameter ESTimation) (Doherty, 2006). The PEST uses the same least-square inversion algorithm used in MODFLOW, but implements it in different manners. Advantage of using the PEST is that the inversion is independent to the numerical model, and thus can be integrated with the proposed numerical model. The calibrated model is then used to evaluate nitrite distributions in the study area with various nitrogen sources collected by FDEP. The predicted nitrite breakthrough curves will be compared with the measurements. The model will also used to identify the nitrite contamination sources. The study results will help to solve the legal issue related to the sprayfield contamination to Wakulla Springs.

4.4. Research team and collaboration

The research team consists of the Lead Principal Investigator, Dr. Paul Lee, at the Florida Department of Environmental Protection (FDEP), and two partners, Dr. Bill Hu and Dr. Ming Ye, at the Florida State University (FSU), Tallahassee, Florida. A FSU graduate student will be supported by this project. The three PIs have substantial working experience at the WKP and the Wakulla Springs. Dr. Lee will lead the project, guide development of the multimedium strategy of Environmental Management System (EMS), and implement the EMS plan-do-check-act process to the Tallahassee sprayfield. Dr. Lee will coordinate with other state agencies (e.g., Florida Department of Health) and the Wakulla Spring basin working group (http://www.wakullasprings.org/), a local public organization of environmental protection, to enhance public involvement through workshops and public meetings and presentations. Dr. Hu is currently supported by the National Science Foundation (NSF) to study Karst flow and transport at the southeast region. In this project, Dr. Hu will be in charge of developing the triplet-porosity method and the mathematical/numerical model. Dr. Ye, working with Dr. Paul, will be in charge of compiling available data at the WKP and using them to calibrate the numerical model. Dr. Ye will also assess uncertainty of model predictions (e.g., nitrate transport) and facilitate decision-making and permitting under uncertainty. Drs. Hu and Ye will jointly supervise the graduate students. The project will last for three years, and project milestones are given below.

5. Outcomes and Measures

The three-year project is expected to produce a final report at the end of the project, and two letter reports at the end of each of the first two years. The reports will summarize project progress and major scientific findings. Research results will be presented in research articles related to environmental management and permitting. The research team will also present their research results at national and state conferences. At the end of project, a workshop will be held at the FDEP to transfer the developed techniques to related employee of the FDEP and other state agencies. The project is expected to broaden knowledge of the nitrate transport at the WKP as well as other similar places in Florida, facilitate permitting of the facilities of sprayfields, and protect the Wakulla Springs. As the developed model is general and not limited to nitrate, it also can be used for long-term planning of water resource management. In particular, since the model considers groundwater, surface water, and the tidal conditions, it will provide a more quantitative framework of the on-going TDML calculation. Below is milestone of the project:

Year 1: Collect and compile parameter measurements and observations of hydraulic head, flow rate, and nitrate concentrations. Develop the triplet-porosity method.

Year 2: Develop the mathematical/numerical model and conduct model calibration.

Year 3: Predict nitrate transport from lawn fertilizer, septic tanks, wastewater sprayfields, and sewage treatment plants to the Wakulla Springs. Conduct technique transfer to employ of the Florida Department of Environmental Protection. Coordinate workshops to deliver project results to the general public.

Budget Summary

Financial Information removed by EPA as confidential business information.

Programmatic Capability and

Environmental Results Past Performance

Dr. Lee has been involved in a number of well completed original Ground Water modeling project formulations and executions, and many EPA supported projects, such as TMDL reports. Dr. Hu, a well-known hydrogeologist, especially in groundwater modeling, has been conducted and successfully completed a score of NSF, DOD and DOE funded projects, two of the projects are to study the groundwater flow and seawater/groundwater interface in the propose study area. Dr. Ye is conducting two DOE projects to study groundwater flow and solute transport in complicated geological media. Their various publications and awards prove their capacity to conduct the proposed research tasks.

The following is a list of federally funded agreements similar in size, scope and relevance to the proposed project that the Florida Dept. of Environmental Protection performed within the last three years (no more than 5, and preferably EPA agreements)

370000	5.96E+08	809396690	UIC06	U. S. Environmental Protection Agency	66.433	State Underground Water Source Protection
370000	5.96E+08	809396690	60406	U. S. Environmental Protection Agency	66.454	Water Quality Management Planning
370000	5.96E+08	809396690	31900	U. S. Environmental Protection Agency	66.460	Nonpoint Source Implementation Grants
370000	5.96E+08	809396690	ERP03	U. S. Environmental Protection Agency	66.461	Regional Wetland Program Development Grants
370000	5.96E+08	809396690	UIC05	U. S. Environmental Protection Agency	66.433	State Underground Water Source Protection

The Federal EPA fundings are keys to the success of Environmental programs in Florida with significant Environmental results and impacts. The most well-known programs are TMDL, Hazardous Waste Management, Everglades Restoration, etc. Most of these grants, contracts and projects are funded or delegated to the Florida Department of Environmental Protection from EPA. The formats and schedules of the interim and final reports of these programs, contracts and projects submitted from Florida DEP to EPA are different from one another. For single granted project, quarterly interim reports and a final report will be the essential and conventional deliverables. For some projects or programs with distinctive operational stages, the stage interim reports with operational landmarks will become more appropriate than reports based only on time intervals.

In all, the leadership and fundings provided by Federal EPA to the Florida DEP through years, have made real world environmental results more visible and made Florida one of the best managed environment in the world

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