Assessing Well Field Impacts on Water Quality in the Upper Floridan Aquifer in Southwest Florida

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ABSTRACT
The Upper Floridan Aquifer is the principal freshwater source in Florida for public water supply, and consists of multiple geologic formations within a broad, thick carbonate platform that forms the Floridan Peninsula. Each formation may have variable lithology, intrinsic permeability and porosity due to changing depositional environments and diagenetic history. Additionally, structural and tectonic movement may have induced fractures and dissolution zones that affect distribution of ground water flow within these formations. Horizontal and vertical hydraulic conductivity of these units, and the aquifer as a whole, are variable by orders of magnitude, and are scale and location dependent.

In South Florida, water within the Upper Floridan Aquifer is brackish, as fresh ground water flow from central Florida mixes with relic seawater, connate water and seawater. A broad transition zone generally extends south beneath Lake Okeechobee, east to just offshore in the Atlantic Ocean, and west to far offshore in the Gulf of Mexico. The vertical transition of brackish to seawater salinity at depth occurs more abruptly.

Within the past decade water supply plans for southwest Florida have targeted the Upper Floridan Aquifer as a source to meet future water supply demands. Since the late 1990s, five Upper Floridan well fields have been constructed to produce potable drinking water using reverse osmosis treatment. However, unanticipated water quality deterioration in the raw water has been experienced at three of the five locations.

This paper examines available data and uses a density-dependent solute transport model to evaluate potential responses to varying pumping stress. Two-dimensional, axisymmetric SUTRA models and a Monte Carlo statistical approach are used to evaluate upconing potential.

INTRODUCTION
The need for sustainable drinking water sources has driven southwest Florida utilities to develop brackish water supply from the Upper Florida Aquifer (UFA). Regional water supply plans (South Florida Water Management District [SFWMD] 2000; 2006) list regulatory constraints, environmental and water resources protection, and a projected increase of 88 percent in public water demand from 2005 to 2025 as reasons to look for alternative water sources. Traditional freshwater supply from surface water and shallow ground water sources may have reached sustainable limits, at least for larger users. Since the late 1990s, five public-water well fields have been constructed that use the UFA, and expansion of these and other existing facilities are planned, under design or are being constructed. Three of the five public-water well fields have encountered unanticipated water quality deterioration with these changes occurring much sooner than predicted. Possible explanations for these changes include anomalies in geologic structure and lithology, fractures and influences from improperly constructed or abandoned wells.

The UFA is a multilayered sequence of carbonate units that has two to several thin flow zones of high permeability interlayered with thick zones of lower permeability (Reese 2000). The aquifer is bounded by overlying clay layers within the Hawthorn Group and by underlying gypsiferous dolomite in the Avon Park Formation or other low permeable materials within the Ocala Formation. The SFWMD defines a Middle Confining Unit (MCU) within the Ocala Formation and upper portion of the Avon Park Formation (SFWMD 2004). However, within this confining unit flow zones and secondary permeability may be locally present. Reported hydraulic properties of UFA demonstrate a heterogeneous distribution that reflect variations in lithology, post-depositional alternations, lateral continuity of units and structural features. The salinity of water in the UFA generally increases with depth and toward the coast, though anomalies may exist and greater change may be found within the MCU.

The premise of this paper is that the problems encountered at recently constructed well fields are associated with upconing of poor quality water from below and that future facilities should evaluate this potential and adjust the design and operation of the well field accordingly. This paper uses available hydrogeologic information, probability analysis and a density-dependent solute transport simulator to assess upconing potential.

METHODS

The SUTRA (Voss 1984) code is used to examine an upconing response to a pumping stress in a brackish water aquifer. Considering the challenges of calculating adjective and dispersive solute transport and the uncertainty of associated aquifer properties, some assumptions are made to assist in the analysis of this problem. A two-dimensional, axisymmetric finite-element grid is used to represent a vertical section of the UFA, and to approximate an assumed radial flow of a conservative solute to a well. Horizontal isotropic aquifer properties and saturated flow through porous media are assumed. Temperature is assumed to be constant and fluid density is dependent on only the one solute concentration. A numerical grid employs 9,315 elements of varying dimensions to cover 5,280 radial and 1,520 vertical feet of aquifer, and has 9,520 nodal points for calculating pressure and concentration. Perimeter boundary conditions are: specified constant pressure and concentration along the upper and lower limits of the modeled area, assumed constant hydrostatic pressure along the vertical seaward boundary, and a combination of a specified flux and no-flow conditions to represent the well and flow divide on the landward boundary.

The hydraulic properties, total hydraulic head and chloride concentrations used in the model are a composite of published values in reports and water use permit applications (Table 1 and Figure 1). The model conceptualization is representative of the southwest Florida area and not tied to a specific location, as the model is use for demonstration purposes.

Once a quasi-steady state simulation of estimated initial conditions and hydraulic properties is established, a Monte Carlo approach (Niederreiter and Spanier, 1998) is used to examine the probability of response to pumping stress. Due to the large range of uncertainty in hydraulic properties and computational times of sample runs, Latin hypercube sampling (McKay 1979) is used, and focus is given to four variables: vertical hydraulic conductivity, transverse dispersivity, porosity and pumping stress. Random values within ranges posted in Table 1 are used to represent probability distributions of these properties that are likely to affect vertical upconing. Pumping stress is varied in categories of four rates, increments of 500 gallons per minute, and with one to four pumping wells spaced 500 to 2,000 feet apart in 500-foot increments. Wells are assumed to tap the Upper Floridan with 500 and 700 feet of casing and total depths, respectively. The wells are pumped for one year.

Table 1. Initial and Range in Hydraulic Properties

Unit	K_x ft/d	K_y ft/d	S_s	n_e	m ft	d_l ft	d_t ft
Lower Hawthorn	50	50	1e-6	0.15	220	3.0	0.3
Suwannee	20	20	1e-6	0.15	250	3.0	0.3
Ocala	10	10	1e-6	0.15	350	3.0	0.3
Avon Park	250	250	1e-6	0.15	600	3.0	0.3

Unit	K_x	K_y	S_s	n_e	d_l	d_t
Lower Hawthorn	1.0-1000	0.1-100	1e-5-1e-7	0.01-0.2	0.3-30.0	0.1-30.0
Suwannee	0.1-100	0.001-100	1e-5-1e-7	0.01-0.2	0.3-30.0	0.1-30.0
Ocala	0.1-100	0.001-100	1e-5-1e-7	0.01-0.2	0.3-30.0	0.1-30.0
Avon Park	1.0-1000	0.1-100	1e-5-1e-7	0.01-0.2	0.3-30.0	0.1-30.0

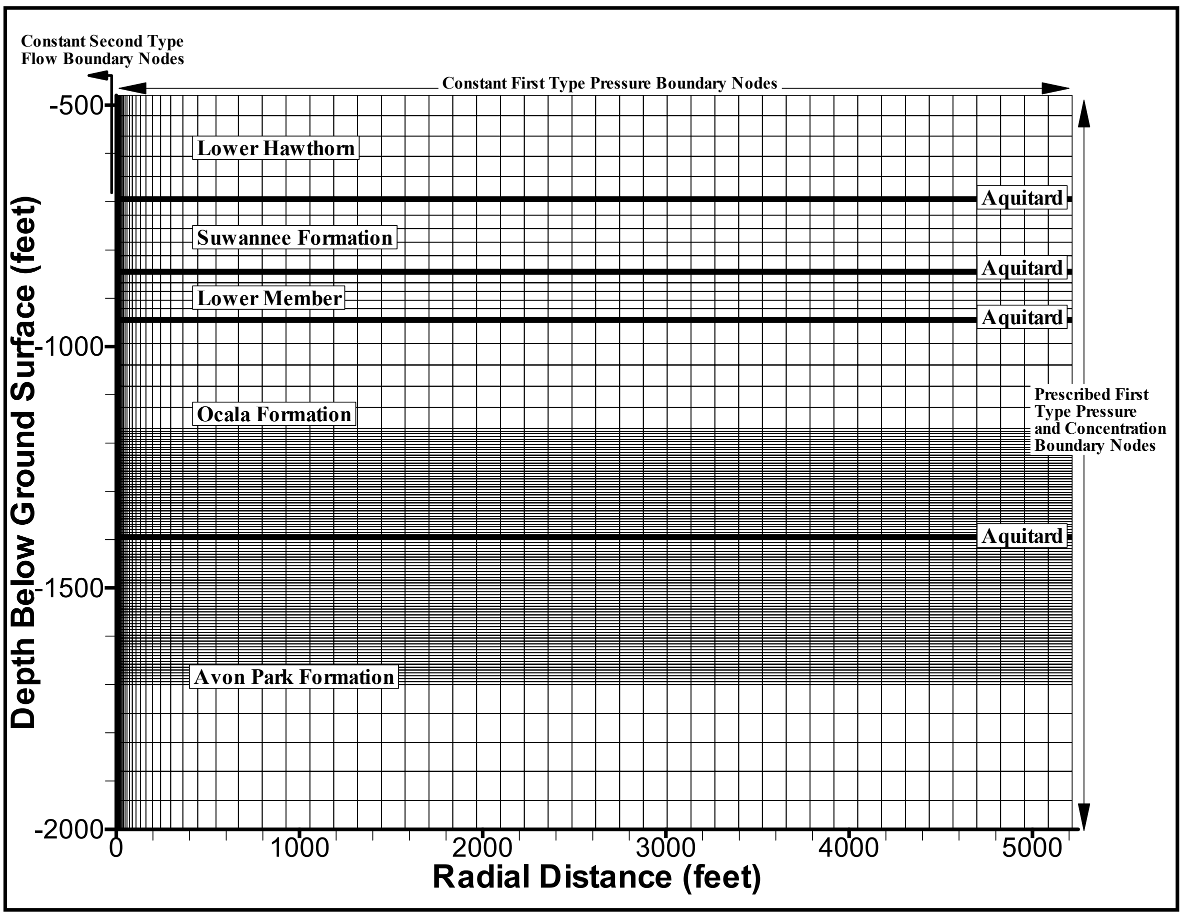

Figure 1. Model Grid (axisymmetric) and Boundary Conditions

RESULTS

This approach provides a framework to assess risk of meeting expectations of a planned well field. More rigorous statistical treatment may be used to define reliability or explore nonrandom distributions of the hydraulic properties. Greater complexities may be added to the numerical model if field data can support them. This modeling approach is useful in guiding a field investigation program to reduce uncertainty in the hydraulic properties.

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