

# HYDRAULIC EVIDENCE FOR VERTICAL FLOW FROM OKEFENOKEE SWAMP TO THE UNDERLYING FLORIDAN AQUIFER IN SOUTHEAST GEORGIA

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**Abstract.** A rapid response is observed between water level fluctuations in the Okefenokee Swamp and water levels in the underlying Floridan Aquifer. A lag of approximately one month is common, and a hydraulic diffusivity of  $3.83 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$  best matches the calculated aquifer response to the swamp water level perturbations. The magnitude of leakage between the swamp and the aquifer is uncertain because of a lack of knowledge about the specific storage coefficient in the aquitard separating the swamp and the aquifer which has not been explicitly measured. An intermediate value of specific storage within the likely range of values results in a downward vertical flow of 1.2 meters of water per year. This induced recharge can significantly alter the natural water balance within the swamp. Such a large loss of water from the swamp may be responsible for observed pH and water level changes, and increased heavy metal accumulations in aquatic organisms in the swamp.

## INTRODUCTION

The Okefenokee Swamp is situated near several large pumping nodes along the southeastern coast of Georgia. Groundwater extraction from the Brunswick and St. Marys regions have caused a substantial lowering of the piezometric surface in the Floridan aquifer which serves as the source of water for municipal and industrial water demands. Long-term water-level declines in the Okefenokee Swamp have generally been attributed to the exclusion of fire, which is assumed to have caused a substantial increase in forested areas and associated evapotranspiration losses. The fire-exclusion hypothesis has recently lost credibility because significant areas of the swamp burned during the late-1980s and early-1990s with no concomitant rise in water levels. In addition to decreased water levels in the swamp, a substantial lowering of swamp pH, increases in lead and mercury contamination in fish, and a reduction in fish numbers and species have recently been noted.

Vertical flow from the swamp to the aquifer has previously been discounted for two reasons: A lack of a geochemical signature that indicates discharge of calcium-rich aquifer water to the swamp; and the assumption that the

intervening aquitard has a low leakance (Yu, 1986). Both of these reasons can be easily rebutted. While the first reason indicates that aquifer water is not flowing upward into the swamp, it can not be used to prove the absence of downward flow from the swamp to the aquifer. In fact, isotopic evidence suggests that groundwater in the aquifer below the swamp is different from groundwater in the same aquifer away from the swamp. Also, water levels in the swamp are higher than in the aquifer, indicating that the direction of movement must be downward; the only issue to be resolved being the magnitude of the downward flux.

The second reason can be discounted because aquitard hydraulic properties have not been estimated in the swamp. Regional estimates based on values from other areas are extrapolated under the swamp and lack sufficient accuracy to exclude the possibility that higher flow rates through the aquitard may be present. Another line of evidence that suggests rapid interaction between the Floridan aquifer and Okefenokee Swamp lies in age-dates of basal peat deposits in the swamp. The ages of basal peats appear to be less than 10,000 years, indicating that a riverine system was present prior to that time. A plausible explanation for the existence of the riverine system is the global lowering of sea levels during the ice ages that induced a regional lowering of the potentiometric surface in the Floridan aquifer. A substantial lowering of the water levels in the Floridan aquifer can cause a lowering of the swamp potentiometric surface only if substantial flow through the intervening aquitard can occur.

Lowering of water levels within the swamp can alter the chemistry of the swamp by introducing oxygen into swamp sediments. Increasing pE results in the biological conversion of reduced forms of sulfur to sulfuric acid, causing a substantial reduction in pH, which is what has been observed. A change in pE and pH can also result in the formation of soluble forms of heavy metals, including lead and mercury, which has also been noted. Thus, many of the environmental problems associated with the Okefenokee Swamp can be attributed to aquifer dewatering if a hydraulic connection can be established between the swamp and the underlying aquifer.

## ESTIMATION OF FLOW MODEL

To evaluate the magnitude of vertical leakage between the Okefenokee Swamp and the underlying Floridan Aquifer, a linear, vertical hydraulic transfer model was hypothesized that relates water levels in the swamp to water levels in the underlying aquifer. Nine years (1985 to 1983) of mean monthly discharges in the Suwannee River at Fargo (USGS Station 02314500) were used as an index of swamp water levels. Coincident mean monthly water levels in the Floridan Aquifer were obtained from USGS Well 304942072213801-27E004 located in Stephen Foster Park near the center of the swamp.

A unit response function was estimated using regression deconvolution of the swamp and aquifer time series. Convolution is a concept widely used in hydrologic modeling to relate an input time series (in this case the water level in the swamp,  $x$ ) to an output time series (i.e., the water level in the aquifer,  $y$ ). The convolution summation was written in the form:

$$y(t) = y_0 + \sum_{\tau=0}^n u(\tau) x(t-\tau) \quad (1)$$

where  $u(\tau)$  is the impulse response function. The step response function,  $U(\tau)$  is the cumulative sum of the input response function, and is found using (Carslaw and Jaeger, 1959, Equation 3.3.8):

$$U(\tau) = \frac{4}{\pi} \sum_{j=1,3,5,\dots}^{\infty} \frac{(-1)^{(j-1)/2}}{j} \exp(-j^2 \pi^2 v) \quad (2)$$

and  $v = \tau D_z / 4L^2$  is a dimensionless diffusivity coefficient that incorporates the vertical hydraulic diffusivity,  $D_z$ , the lag,  $\tau$ , between the impulse and response and the thickness of the aquitard. For the nine years of record, an average response lag of one month was found between swamp and aquifer water levels, with swamp water levels leading aquifer water levels. Most of the water level perturbations within the swamp were due to variations in seasonal evapotranspiration losses and precipitation inputs. These perturbations were also observed in the underlying aquifer, only lagged by approximately one month. Figure 1 presents the estimated impulse response function for the period of record. The vertical hydraulic diffusivity coefficient that best matches the response function was found to be  $D_z = 3.83 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$ .

Determining vertical flow rates requires that the vertical hydraulic conductivity be estimated. The one-dimensional vertical hydraulic diffusivity coefficient for the aquitard is the ratio of the vertical hydraulic conductivity,  $K_z$ , to the vertical specific storage coefficient,  $S_s$ , within the aquitard:

$$D_z = K_z / S_s \quad (3)$$

Equation (3) can be used to estimate the hydraulic conductivity if the specific storage is known. A sensitivity analysis was used to estimate the hydraulic conductivity by varying the specific storage over two orders of magnitude. The estimates of specific storage range from  $10^{-3}$  to  $10^{-5}$  for plastic clay and medium-hard clay, respectively. Using this range results in hydraulic conductivity estimates of  $3.83 \times 10^{-6}$  to  $3.83 \times 10^{-8} \text{ m s}^{-1}$ . The vertical flow rate between the swamp and aquifer is calculated using Darcy's law assuming a total head difference of 14 meters and an aquitard thickness of 140 m. The flow rate was found to range from  $0.12$  to  $12 \text{ m yr}^{-1}$  for the low and high storage coefficients, respectively. An intermediate value of  $1.2 \text{ m yr}^{-1}$  is a likely estimate for the regional loss of water from the swamp to the underlying Floridan Aquifer.

## LITERATURE CITED

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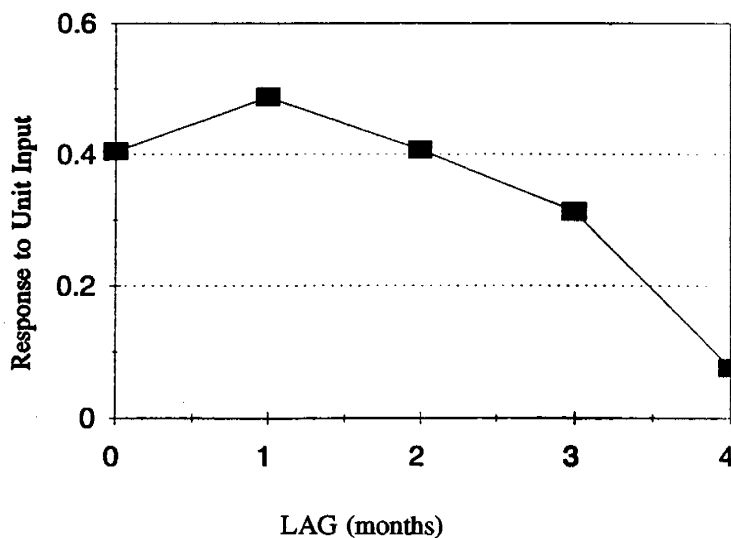


Figure 1. Estimated response in the Floridan Aquifer to a unit change in Okefenokee Swamp water levels.