APPLICATION OF REMOTE SENSING FOR DETECTION OF POSSIBLE LEAKAGE OF THE UPPER FLORIDAN AQUIFER ALONG THE COAST OF GEORGIA

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Abstract. A number of hydrogeologic and groundwater modeling studies have addressed problems of saltwater intrusion into the Upper Floridan aquifer along the coast of Georgia, and more are being proposed for the near future by state and federal agencies. Some of the crucial questions that still await answers are the exact position of the seawater-fresh water interface off the coast, and the nature of natural discharge from the Floridan aquifer. There are suggestions that the historical (and current) discharge zone of the Floridan is along its outcrop at the Continental Slope. A possibility of upward leakage through the overlying sediments at the Continental Shelf has been suggested as well. One of the inexpensive methods that may prove useful in finding answers is offshore remote sensing which could detect physical disturbances at the ocean surface caused by groundwater discharge along the shallow ocean floor.

INTRODUCTION

The Upper Floridan aquifer is the major source of water in the eastern half of the coastal plain of Georgia. Some of the problems associated with groundwater withdrawal from the aquifer include decline in piezometric surface, upward leakage of highly mineralized water into the aquifer from underlying units (mainly Lower Floridan aquifer), and intrusion of seawater toward the mainland.

Hydrogeologic conditions along the Georgia coast indicate that there is a possibility for groundwater discharge from the Upper Floridan aquifer into the ocean salt water through the overlying, low permeable Miocene sediments. Locating such areas would aid in understanding regional flow patterns in the hydrogeologic system along the Georgia coast and help in developing more accurate models for the groundwater management. Since the water depth off shore is in most part less than 30 feet, there is a good chance that physical disturbances caused by groundwater discharge could be detected by a combination of remote sensing techniques.

HYDROGEOLOGIC FRAMEWORK

In most places along the Georgia coast, a thin surficial aquifer overlies Miocene sediments which confine the Floridan aquifer system. This surficial aquifer consists of post-Miocene unconsolidated sands, gravels and clays. An upper confining unit separates the surficial aquifer from the Floridan aquifer system. It consists primarily of the Hawthorne Formation and is late to middle Miocene in age (Krause and Randolph, 1989). The strata of the upper confining unit consist mainly of low permeable clay. However, beds of sand and silt are also present and may provide pathways for upward leakage and discharge of the Upper Floridan aquifer.

The Floridan aquifer system includes the Upper and Lower Floridan aquifers (Figure 1). The Upper Floridan aquifer consists mainly of the Ocala Limestone and equivalents of the late Eocene age (Krause and Randolph, 1989). In the Savannah area, the Suwannee Limestone of Oligocene age overlies the Ocala Limestone and is included as a member of the Upper Floridan aquifer. The Upper Floridan aquifer consists mainly of two permeable zones (zones 1 and 2), in the Savannah area.

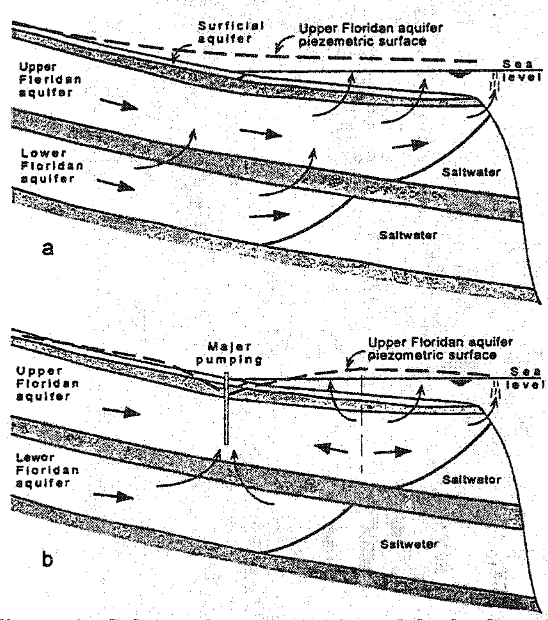

Figure 1. Schematic presentation of the hydrogeologic frame-work along the Georgia coast before (a) and after (b) development of the Upper Floridan Aquifer.

Zone 1 spans the Suwannee and Ocala Formations and is about 50 ft thick (Krause and Randolph, 1989). Zone 2 is located near the middle of the Ocala Formation and ranges from 25 to 75 ft in thickness.

The Lower Floridan aquifer is separated from the Upper Floridan aquifer by a middle semiconfining unit. This unit consists of low permeable clay, siltstone, and argillaceous limestone of the upper Eocene. The middle semiconfining unit grades into the Upper and Lower Floridan aquifers and is in places conductive enough so that it provides for little separation between the two aquifers (Krause and Randolph, 1989). The Lower Floridan aquifer consists primarily of dolomitic limestone of middle Eocene age. It is generally not tapped as a water supply in the Savannah area.

Figure 1 is an idealized cross-section of the hydro-stratigraphic units in the Savannah area showing the relationship between saltwater and freshwater, as well as probable patterns of fresh groundwater flow before and after aquifer development. The cross-section is along a path starting inland and then going out to sea. The thickness of the upper confining unit is not well known, and it may thin as it extends out to sea, allowing for increased potential for leakage from the Upper Floridan aquifer through the sea floor. The potential discharge through the upper confining unit is where the potentiometric surface of the Upper Floridan aquifer is above the sea floor as is the case with most of the Georgia coast.

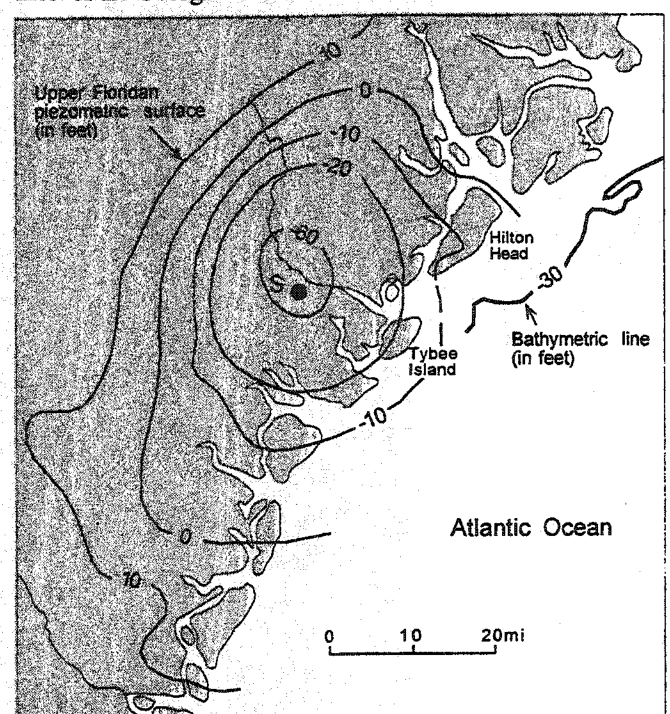

Figure 2. Recorded piezometric surface of the Upper Floridan aquifer as the result of heavy pumping in the Savannah/Hilton Head area (after Krause and Randolph, 1989). For the most part along the coast, the hydraulic gradient between the sea floor and the head in the aquifer is positive allowing for a possible aquifer discharge.

The Miocene layer that confines the Upper Floridan aquifer has the least thickness in the Hilton Head Island area. At the same time, the hydraulic head is mainly above the sea floor (see Figure 2) which makes this area a primary candidate for the remote sensing study of groundwater discharge. In general, the depth of water along the Georgia coast is 30 feet or less for 10 to 15 miles off the coast line

As the hydraulic head in the Upper Floridan aquifer and the corresponding vertical gradient increase south of Tybee Island, the potential for upward leakage remains considerable even though the thickness of the confining sediments increases as well.

REMOTE SENSING METHODS

Techniques of remote sensing has been successfully used to detect both concentrated and diffuse discharge of groundwater at lake and sea floors (Kohout et al., 1973, 1981; Lathorp and Lillesand, 1987; Milanovic, 1979; Roxburg, 1985, Whiting, 1984).

Remote sensing of the seafloor from satellites or aircrafts is restricted by the fact that water absorbs or reflects most wavelenghts of electromagnetic energy (Sabins, 1987). Only visible wavelengths penetrate water, and the depth of penetration is influenced by turbidity of water. In general, shallow water of up to 30 feet will allow for some degree of penetration even in optically dense (turbid) coastal/bay waters.

Another target of offshore remote sensing is sea surface which often, with various detail, reflects coastal processes below it. Textures at the sea surface are best analyzed with radar sensors, while its temperature is easily registered with thermal infrared scanners on board remote sensing satellites (such as Landsat) and commercial aircrafts.

Landsat Thematic Mapper (TM)

Offshore signatures of Landsat images are controlled by water depth, water clarity, reflectance of the bottom sediment, sunlight from sea surface, and atmospheric conditions (Sabins, 1987). Discharge of fresh water at the shallow seafloor along Georgia coast, if present, might cause various optical disturbances that could be registered with TM bands 2 (wavelength 0.52 to 0.60 μm) and 3 (0.63 to 0.69 μm). These bands have the highest water penetration and their ground resolution of 30 meters allows for a detail coastal and offshore analysis. Thirty feet of clear ocean water transmit almost 50 percent of incident blue and green wavelengths (0.4 to 0.6 μm) but transmit less than 10 percent of red light (0.6 to 0.7 μm). Closer to the coastal line, i.e. in more turbid water, the maximum transmittance shifts toward longer wavelengths of 0.5 to 0.6 μm (Sabins, 1987).

TM thermal infrared band (band 6, 10.40 to 12.50 μm) is used to analyze the sea surface temperatures and could locate zones of aquifer discharge if there is a detectable temperature difference between fresh and sea water (Roxburg, 1985; Kohout et al., 1973, 1981). This requirement, however, is not hard to fulfill since the calibrated TM's sensitivity can be set at less than 1°C (Lathorp and Lillesand, 1987). In addition, the salinity of sea water forces the fresher groundwater to the surface by convection and spreads it by diffusion over large areas (Whiting, 1984). TM band 6 has ground resolution of 120 m and is suitable for large-area coverage. Finer resolution is available from commercial airborne scanners but the acquisition cost is higher.

Radar

Currently there are two commercially available lines of radar imagery products that can be used for groundwater discharge study along Georgia coast. They are acquired by the Earth Remote Sensing Satellites (ERS1 and ERS2) operated by the European Space Agency (ESA), and by RADARSAT, Canada's Earth Observation Satellite. Both ERS and RADARSAT have Synthetic Aperture Radar (SAR) systems which acquire images of varying ground resolution, with the finest being 11-9x9m for RADARSAT and 12.5x12.5m for ERS.

SAR is very sensitive to surface roughness and has been successfully used to map spatial changes at sea surface due to regional and local circulation, tides, currents and current fronts. Multitemporal SAR data sets processed in false color are particularly useful in analyzing these changes. Another proven application of SAR is shallow water bathymetry which can provide very useful information when relating expected hydraulic heads in the aquifer and sea floor elevations.

The stability of the satellite orbit allows application of Radar Interferometry (RI) which derives extra information from the SAR data as indicated by ESA (1993). RI is based on the combination of two or more single-look complex data sets taken from only slightly different positions in orbit (in the order of hundreds of meters only). These phase differences can be used to compute the altitude of each pixel. In the case of more than two coherent data sets, spatial variations of an object or surface at the centimetric scale can be determined (ESA, 1993). This means that, if there is discharge of groundwater at the shallow sea floor, the resulting disturbances at the sea surface would form pattern that could be detected by Radar Interferometry.

CONCLUSIONS AND RECOMMENDATIONS

As relatively inexpensive and time-efficient, the remote sensing analysis should be included in the ongoing scientific effort to better understand characteristics of the hydrogeologic system along the Georgia coast. Successfully used in the past in similar settings, and coupled with field check, the techniques of remote sensing could accurately locate areas of groundwater discharge along the shallow ocean floor. An inventory of all available satellite and airborne imagery, for products in both public and commercial domain, should be made and analyzed for their applicability. The selection of specific types of imagery to be used in this analysis should be made after examining existing data on physical conditions at the ocean floor and the ocean surface offshore coast of Georgia.

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