Assessing the Extent of Saltwater Intrusion in the Aquifer System of Southern Baldwin County, Alabama

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ABSTRACT
Contamination of groundwater due to saltwater intrusion has become a major concern for coastal communities which rely on groundwater as their principal source of drinking water. The protection of groundwater resources from saltwater intrusion and groundwater overdraft is a critical concern in these areas as both groundwater resources and environmentally sensitive areas such as coastal wetlands and ecological coastal habitats may be at risk. A regional-scale study was conducted to assess the extent of saltwater intrusion for Baldwin County, Alabama. Groundwater wells were sampled and analyzed for salinity, chloride (Cl^-), total dissolved solids (TDS), and other geochemical parameters to determine the extent of saltwater intrusion, and the location of the freshwater/saltwater interface in the region. To meet the objectives of this study, spatial iso-concentration maps (i.e. salinity, Cl^-, and TDS) for the aquifer system were constructed using ArcGIS. Concentration data show relatively low salinity levels in the central and northern extent of the study area. Elevated levels of salinity, Cl^-, and TDS were observed in the local aquifers A1 and A2 along the coastal areas adjacent to the Gulf of Mexico with the highest concentration at Romar Beach and continuing towards the Intracoastal Waterway. The study provides an initial current data set of areas impacted or most vulnerable to saltwater intrusion and provides a scientific basis for effective management of the coastal aquifers in the study region.

INTRODUCTION
The coastal regions of Baldwin County are characterized by a continuously increasing economy and rate of development. Protection of groundwater resources from seawater encroachment is a real concern for coastal communities in this area due to impacts associated with increasing population, development, local industries, and tourism. In addition, predictions of increasing sea level and increased frequency and intensity of tropical storms and hurricanes in the region may exacerbate the problem over the long term.

The purpose of this study was to determine the extent and severity of saltwater intrusion in the aquifers underlying southern Baldwin County, Alabama using the most recently collected geochemical, geological, and hydrogeological information. To meet these objectives, well surveys and groundwater analyses were conducted over a two year period (2006 and 2007) and integrated with existing data attained primarily from the Alabama Department of Environmental Management (ADEM), the Geological Survey of Alabama (GSA) well records, and GSA Bulletin 126 (Chandler *et al.* 1985).

Background
The study area comprises approximately 1,625 square kilometers (628 square miles) of southern Baldwin County and is bounded by Interstate 10 to the north, by the Gulf of Mexico to the south, and by Mobile Bay, Perdido River, and Perdido Bay on the west, southeast and east, respectively. This region includes areas vulnerable to saltwater encroachment such as Fort Morgan Peninsula, Gulf Shores, Orange Beach, and Perdido Beach. The population of Baldwin County increased significantly from the year 2000 with the highest growth rates in Fort Morgan Peninsula, Gulf Shores, Orange Beach, and Ono Island. As a result of increasing population,

tourism, and development, groundwater pumping in the region increased from 2.7 x 10^7 L/day to 1.6 x 10^8 L/day between 1966 and 1995 (Reed and McCain 1971; Robinson et al., 1996a). Land use in Baldwin County varies considerably. The major types of land use include agriculture, recreation and tourism, seafood industries, and urbanization. Agriculture makes up approximately 40% of the land use/land cover of southern Baldwin County (Murgulet 2006, unpublished).

The stratigraphy of southern Baldwin County, as well as that of coastal and offshore Alabama, consists of a relatively thick Jurassic to Holocene sedimentary rocks (Chandler *et al*., 1985). At relatively shallow depths, interbedded sands, silts, gravels and clays comprise the middle Miocene to Holocene sedimentary rocks which hosts the freshwater aquifer zones of Baldwin County area. The sediments are part of three widely recognized geologic units defined by Reed (1971) as 1) the Miocene Series undifferentiated; 2) the Citronelle Formation; and 3) alluvium, low terrace, and coastal deposits. The aquifer system beneath southern Baldwin County that serves as the source of freshwater is divided into three distinct units: a) Aquifer zone A1, the upper unit, known as the Beach Sand aquifer, an unconfined aquifer that is roughly 6 to 20 meters thick in the study area (Chandler *et al*., 1985); b) Aquifer zone A2**,** the Miocene-shallow Pliocene aquifer varies from confined to semi-confined (southern part of the study area) to unconfined throughout the extent of the study area (north of the Intracoastal Waterway); c) Aquifer zone A3, the lower unit known as the Deep Miocene aquifer, extends from the upper confining unit that underlies aquifer zone A2 to the top of the Pensacola Clay (200 meters to more than 300 meters below sea level). Moreover, the aquifer system consists of two distinct units through the central and northern portion of the study area.

METHODS

To meet the objectives of this paper, a multitude of tools were used to link the hydrogeologic system and groundwater geochemical data of southern Baldwin County to spatial statistics and map modeling. Such integration allows, for example, meaningful identification of the seawater contaminated regions. For this purpose, geologic and hydrogeologic information, and groundwater quality parameters including salinity, Cl^- and TDS concentration data were collected and compiled to generate spatial distribution and contamination maps. For the purposes of this study and consistency with current definitions, “freshwater” is considered to be water comprising concentrations no more than 500 mg/L, 250 mg/L, and 500 mg/L for salinity, Cl^-, and TDS, respectively (MCLs “maximum contaminant levels” reported by USEPA, 1986). Once these limits are exceeded, the water is no longer potable for drinking water purposes and additional water treatment is needed or well abandonment or discontinued operation is required. The relationships between the three parameters were examined as a means of assuring consistency between samples and verification of the saltwater source (i.e. seawater).

Digital maps have been produced and used to construct a spatial database for the study area. Results obtained from this methodology have been incorporated with data collected for this project and used to create the final contamination digital maps. Concentration and hydraulic head contour maps were prepared to determine areas most vulnerable to saltwater intrusion and the extent of saltwater intrusion for each of the developed aquifer zones.

RESULTS

Integration of hydrogeologic and geochemical data (i.e. salinity, Cl^-, TDS, etc.) from approximately 200 wells throughout Baldwin County, to spatial relations and map modeling allowed for comprehensive identification of the seawater contaminated regions. Elevated concentrations of salinity, Cl^-, TDS and high conductivities were observed for both aquifer zones A1 and A2. Groundwater samples from aquifer zone A1 exhibited salinity, Cl^-, and TDS concentrations above MCLs in close coastal proximity to Gulf Shores (including part of Fort Morgan Peninsula), Orange Beach, and Ono Island. Groundwater in aquifer A2, near the coastal margin, was determined to possess lower water quality with relatively high salinity (e.g. Figure 1), Cl^- and TDS concentrations. As part of this current study, groundwater samples obtained from wells completed in aquifer zone A3 exhibited low concentrations of salinity, Cl^-, and TDS. The results shown here include only the chloride concentration map for aquifer A1. Groundwater head contour maps constructed using the head values corrected for the density effects, provided the current state of regional and local groundwater flow for the study. Groundwater flow trended generally south, south-southeast and south-southwest with relatively steeper hydraulic gradients observed in those areas less impacted by saltwater intrusion.

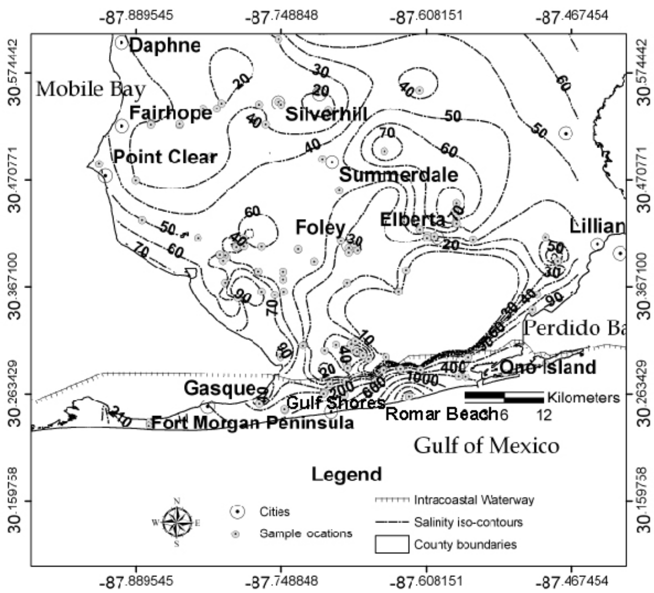

Figure 1. Aquifer zone A2- salinity concentration map.
Concentrations are in mg/L; contour lines are labeled correspondingly.

DISCUSSIONS AND CONCLUSIONS

The hydrogeochemical data (e.g. salinity, Cl^-, and TDS concentrations and resistivity and specific conductance) and the location of the impacted areas revealed the Gulf of Mexico and the Intracoastal Waterway as the main sources of saltwater intrusion. The results of this study indicate that saltwater intrusion may have occurred in aquifer A1, especially in regions relatively close to the Gulf of Mexico. Thus, the presence of saltwater in aquifer A1 is likely the result of a combination of both saltwater intrusion from the Gulf of Mexico (e.g. Fort Morgan Peninsula) and surface contamination (i.e. from storm events due to seawater surface infiltration). Another source of contamination of aquifer A1 is due to the direct infiltration from the Intracoastal Waterway which crosses the southern part of the study area from east to west and from saltwater ponds located north of Intracoastal Waterway. The results of this study indicate that saltwater intrusion has occurred in aquifer A2, specifically in the close proximity to the Gulf of Mexico (e.g. Romar Beach). The results are confirmed by geochemical data collected over a two year period. Back in 1985, Chandler et.al. (1985) revealed the fact that aquifer A2 was contaminated with seawater at Romar Beach from the Gulf of Mexico and that the saltwater ponds are an additional source of saltwater contamination to the aquifer A2. Therefore, based on these previous results and the new geochemical data it is speculated that the saltwater contamination of aquifer zone A2 may be the result of aquifer overdevelopment and saltwater infiltration from upper aquifer A1. In addition to these sources we identify the Intracoastal Waterway as an important source of saltwater contamination to both aquifer A1 and A2. Groundwater samples and iso-concentration maps revealed that aquifer zone A3 did not exhibit significant degradation of water quality due to saltwater intrusion. The groundwater concentration data suggest that aquifer zone A3 is less vulnerable to saltwater contamination. However, this does not mean that saltwater intrusion has not occurred or exists within this aquifer zone (A3) but may rather be due to the absence of groundwater wells (i.e. water quality data) developed in this aquifer in close proximity to the coastline or that the surveyed wells are either established in a relatively shallow portion of the aquifer zone A3 or that aquifer A3 in that region has not been infiltrated with saline water.

The combination of tools used for the purpose of this study provides an opportunity to assemble, standardize, and analyze scientific data that comes from a variety of sources, making it available to others who may be able to continue with further research studies and/or use the information for improved groundwater management strategies in the area.

REFERENCES

Chandler, R.V.; Moore, J.D.; and Gillett, B. **1985**, Ground-Water Chemistry and Salt-Water Encroachment, Baldwin County, Alabama: *Geological Survey of Alabama Bulletin 126*. pp. 16, 17, 53, 54, 78-80, 84-86.

Reed, P.C. and McCain, J.F. **1971**, Water Availability of Baldwin County, Alabama: *Geological Survey of Alabama, Division of Water Resources, Map 96*.

Reed, P.C. **1971**, Geologic Map of Baldwin County, Alabama: *Alabama Geological Survey Special Map 94*, p.55.

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