Report as of FY2008 for 2008AL71B: "Grountwater-Surface Water Contributions of Nitrate Contamination and Discharge to Coastal Surface Waters, Baldwin County, Alabama"

Publications

- Dissertations:
  - Dissertation in process.

Report Follows

Synopsis

Title: Groundwater-Surface Water Contributions to Nitrate Contamination and Discharge to Coastal Surface Waters, Baldwin County, Alabama

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EXECUTIVE SUMMARY

The contamination of groundwater from nitrate and nutrients is major problem throughout the world. These related problems are often the result of anthropogenic activities, lack of management, and overdevelopment of water resources. Recently, a high level of interest has been generated in understanding interaction of nitrates/nutrients between groundwater and surface water systems. Currently there is a lack of information and understanding of nitrate/nitrogen input, contribution of nitrate/nitrogen input, and resulting effects on the quality of water resources and ecosystem health within these highly sensitive coastal areas of Alabama. Some of the major concerns of nitrate and nitrogen contamination/loading to both these groundwater and surface water systems include health risk to humans through drinking water and degradation of coastal surface water ecosystems such as estuaries, wetlands, lagoons, and the greater Gulf of Mexico. Groundwater and surface water resources in southern Baldwin County, Alabama are vital to support the rapidly growing population of the area, support a growing economy within the region, and to ensure that environmentally-sensitive ecosystems such as coastal estuaries and wetlands are preserved in the region. A local to regional-scale study was conducted to assess the extent of nitrate contamination, identify source zones of nitrate to groundwater and surface water systems, determine the primary processes controlling the fate of nitrate/nutrients in groundwater, and determine primary contributions of nitrate/nitrogen input to coastal surface waters of southern Baldwin County, Alabama. Detailed geochemical and nitrate analyses revealed that extensive areas within aquifer zone A2 were impacted with nitrate concentrations exceeding regulatory limits. These analyses coupled with land-use/land-cover classification schemes indicated that most of nitrate sources were most likely due to agricultural fertilizer inputs. However, other areas showed that nitrate levels were likely a result of various inputs ranging from residential septic systems to agricultural. Isotopic analyses of nitrate (e.g., nitrogen-$\delta^{15}N$ and oxygen-$\delta^{18}O$) indicate that the main sources of nitrate in the regional aquifer system are due to fertilizer application and that nitrate is primarily derived from nitrification of ammonium in the soil. The narrow range of $\delta^{18}O$ values further confirms the primary nitrate sources. The $\delta^{15}N$ and $\delta^{18}O$ data, which help to determine the fate of nitrate, indicate that denitrification was not an important process in this aquifer system. In the absence of denitrification and the presence of a permanent source, it is expected that the elevated groundwater nitrate concentrations will not be readily attenuated posing a potential contamination and degradation problem of coastal discharge zones (i.e.

wetlands, estuaries, lagoons, and coastal lakes) into the future. The $\delta_{15}N$ and $\delta_{18}O$ of surface water nitrate

Data revealed two potential sources of nitrate in Weeks Bay derived from fertilizer and manure/septic waste. A significant contribution of nutrient-rich groundwater to the surface water is supported by the presence of elevated levels of nitrate in groundwater and nitrogen and oxygen isotopic signatures (of nitrate) consistent with subsurface nitrification measured in specific regions of Weeks Bay (i.e. northern sample locations). The nitrogen and oxygen isotopic data of surface water nitrate further suggests that runoff also plays an important role in the degradation of surface water quality in this area. Further analysis of nitrogen, oxygen, carbon, and hydrogen isotopes should be conducted to better assess the types of sources and contributions of nitrate to the groundwater and surface water systems of southern Baldwin County, Alabama. Additional monitoring of the nitrate levels is necessary to evaluate the temporal evolution and distribution of nitrate concentrations within the aquifers underlying the region. ArcGIS proved to be a valuable tool used to determine the spatial extent and magnitude of nitrate contamination of groundwater. The use of these tools provides an opportunity to assemble, standardize, analyze, and visualize scientific data that comes from a variety of sources, making it available to others who may be able to continue with further research studies. The combination of detailed geochemical and isotope analyses of groundwater and surface water systems were used to constrain nitrate/nutrient sources, identify the fate of these chemicals through these systems, and determine likely contribution of nitrate/nutrients to the coastal surface water bodies and the Gulf of Mexico. These analyses can lead to improved groundwater management strategies and risk assessments for the region.

STATEMENT OF THE PROBLEM

In recent years, Baldwin County has experienced some of the most rapid growth in public and private sectors, ranking third among all counties within the state of Alabama. As a result, decreasing quality of groundwater and surface water due to extensive agricultural practices, and urban and residential expansion, has become a concern in the region. Groundwater and surface water resources in southern Baldwin County, Alabama are vital to support the rapidly growing population of the area and the evolving economy within the region, and to ensure that environmentally-sensitive ecosystems such as coastal estuaries and wetlands are preserved in the region. Growing population, tourism, and industry is dependent upon the quality and quantity of the water resources and health of the ecosystem within the region.

Continued and extensive residential and agricultural development of near-shore areas in southern Baldwin County is leading to increased inputs of nitrogen (N) from fertilizers, wastewater and septic tanks to groundwater, and as part of the hydrogeologic cycle, to the coastal waters and to the Gulf of Mexico (Valiela et al. 1990). The NO_3^- problem is most evident in the mobile form of NO_3^- and it is known to cause health problems in humans (Rajagopal and Tobin 1989) and contribute to the eutrophication of surface waters (Cooper 1993). Currently there is a lack of information and understanding of NO_3^--N input and the resulting effects on the quality of water resources and ecosystem health within these highly sensitive coastal areas of Alabama. Some of the major

concerns of NO_3-N contamination/loading to both these groundwater and surface water systems include heath risk to humans through drinking water such as methemoglobinemia and potential carcinogenic effects, and detriment to the local ecosystems by adversely affecting a variety of marine and freshwater organisms such as fish and shrimp (i.e. seafood industry) and the health of wetlands which can be severely impacted by excessive plant and algal growth and constriction. A large majority of NO_3^- sources have anthropogenic origin and they are mostly confined to the same watershed and groundwater basin.

In southern Baldwin County, agricultural and residential application of fertilizers, sewage breakthrough, precipitation, and land application of animal waste are some of the major sources of NO_3^-, the common form of N that infiltrates downward to the groundwater. Nitrate contamination may be a potential problem in some of the aquifers of Baldwin County. Nitrate levels in wells have been observed to exceed regulatory drinking water standards (45 mg/L as nitrate; or equivalently 10 mg/L nitrate as nitrogen). Not only is this a concern for human health, but groundwater discharge and surface-runoff of elevated nitrate levels to coastal surface waters and/or streams can have harmful effects on the ecological health of coastal wetlands, estuaries, and riparian zones. Excess nitrate (i.e. nutrient) loading can cause processes such as eutrophication which can adversely impact the ecology of these systems. Saltwater intrusion in coastal areas such as Baldwin County may further enhance the N flux associated with ion exchange and other reactions (Krest et al. 2000; Moore 1999). Hence, anthropogenic contamination of the aquifer system in the form of high NO_3^- concentrations and saltwater intrusion from the Gulf of Mexico may be a real concern in this area. Therefore, it is imperative to identify sources and fate of nitrate contamination of groundwater and surface water for this area allowing for better source control strategies and management. The results of this research will be critical for developing cost-effective aquifer management plans to ensure sustainable freshwater supplies and preserve the health of the regional ecosystems (i.e. wetland/estuaries, riparian zones, and lakes) in the study area.

PURPOSE AND OBJECTIVES OF RESEARCH

The purpose of this study was to determine the extent and severity of nitrate contamination in the aquifer system and in coastal surface waters receiving recharge from groundwater in southern Baldwin County. In addition, this study aims to identify the potential source zones and the origin of these nitrate sources contributing to groundwater pollution.

The objectives of this study are part of a large scale effort to 1) assess the extent of nitrate contamination in the aquifers of southern Baldwin County; 2) identify the source zones of nitrate to the groundwater and surface water systems 3) determine nitrate/nitrogen loading to coastal surface waters (i.e. estuaries and wetlands) from groundwater and surface water; 4) identify the fate of nitrate/nitrogen to coastal surface waters due to processes such as nitrification/denitrification; and 5) determine the primary contributions (i.e. groundwater versus surface water) of nitrate/nitrogen input to the coastal surface waters. Additionally, as part of the objectives of this research, a detailed user-friendly GIS database will be developed for the study area to integrate all of the collected data for easy update, visual display, and analysis. Tools such as these will be

critical to developing cost-effective aquifer management plans and protect ecologically sensitive surface water bodies such coastal estuaries and wetlands in the region.

The primary objectives of this study were to assess the extent of nitrate contamination in the aquifers of southern Baldwin County and to identify the source and fate of nitrate/nitrogen to groundwater and coastal surface waters. Additionally, the study aimed to identify the source zones of nitrate to the groundwater and surface water systems and to determine the primary contributions (i.e. groundwater versus surface water) of nitrate/nitrogen input to the coastal surface waters.

This proposed research is critical to understand the important role that coastal wetlands play as "buffering" systems which can act as natural attenuators of contaminant loading. Therefore, it is important to understand how elevated levels of nitrate may adversely impact these ecosystems. Excess nutrient (i.e. nitrate/nitrogen) loading can cause processes such as eutrophication which can cause negative impacts to the ecology of these systems. Characterizing the extent of nitrate contamination in the local and regional aquifers and surface waters of southern Baldwin County will also be important for conducting more accurate risk assessments and developing more effective management strategies.

CONCLUSIONS

The groundwater system of southern Baldwin County is comprised of three hydraulically distinct aquifers that will likely provide ample water supply if properly managed. However, nitrate contamination of groundwater may be a concern for the study area. The results of this study indicate that spatially extensive nitrate concentrations exceeding regulatory limits (MCL = 45 mg/L as nitrate) were present within aquifer zone A2 in southern Baldwin County, Alabama. The contamination is mainly confined to areas extensively developed for agricultural and residential practices. In addition, slight degradation of groundwater quality due to the presence of nitrate was observed for the surficial coastal aquifer zone A1 and to a smaller extent for the deeper aquifer zone A3. Iso-concentration maps for aquifer A2 demonstrate that three spatially distinct regions within the study area may serve as sources of nitrate. The most extensively impacted area of nitrate in groundwater was located in the surrounding area of Silverhill, Robertsdale, Summerdale, and Seminole (NZ-2B) and it is mainly the result of fertilizer NO_3^- input to the groundwater system based on a current land-use analysis. Two areas of smaller nitrate extent include the vicinity east of Weeks Bay near (NZ-2A), and between Foley and Gulf Shores (NZ-2C) which exhibit exceedingly high nitrate concentrations throughout this study, indicating that these may be potential nitrate sources. Based on a current land-use study the nitrate inputs from these sources would likely originate from residential areas possibly due to septic system wastes and small agricultural practices. The overall nitrate-chloride correlation was not significant for the surveyed wells. This suggests that the major source of nitrate for the surveyed area is likely associated with the application of fertilizers. However, elevated levels of nitrate and chloride occurring together may suggest the presence of some alternative sources for a few of the other nitrate zones within the study area.

Nitrogen and oxygen isotopes of NO_3^- (e.g., $\delta^{15}N$ and $\delta^{18}O$ of NO_3^-) were used in conjunction with other hydrogeochemical data to place constraints on potential sources of NO_3^-. The $\delta^{15}N$ and $\delta^{18}O$ of groundwater NO_3^- values ranged between +1.99 and +9.6‰

and +3.12 and +8.7‰, respectively. This range of values suggests that nitrate is primarily derived from nitrification of ammonium in the soil and indicates sources of NO_3^- as mixtures of fertilizer and manure. However, the overwhelming number of samples show isotopic signatures which indicate that the main source of NO_3^- in these aquifers is due to fertilizer application. The narrow range of $\delta^{18}O$ values further confirms the primary nitrate sources. The $\delta^{15}N$ and $\delta^{18}O$ data indicate that denitrification was not an important process in these aquifers. In the absence of denitrification and the presence of a permanent source, it is expected that the elevated groundwater NO_3^- concentrations will not be readily attenuated posing a potential contamination and degradation problem of coastal discharge zones (i.e. wetlands, estuaries, lagoons, and coastal lakes) into the future. The $\delta^{15}N$ and $\delta^{18}O$ of surface water NO_3^- data revealed two potential sources of nitrate in Weeks Bay derived from fertilizer and manure/septic waste. The contribution of nutrient-rich groundwater to the surface water is supported by the presence of elevated levels of nitrate in groundwater and nitrogen and oxygen isotopic signatures of nitrate consistent with subsurface nitrification measured in specific regions of Weeks Bay (i.e. northern sample locations). The nitrogen and oxygen isotopic data of surface water nitrate further suggests that runoff also plays an important role in the degradation of surface water quality in this area. Primary contribution of nitrate flux from groundwater to surface water in the region was supported by trophic level response (i.e. chlorophyll data) in surface water, measured nitrate concentrations in both groundwater and surface water, and reduced water levels in surface water bodies and minimal run-off from data collected during the summer months of 2007-2008.

Further analysis of nitrogen, oxygen, carbon and hydrogen isotopes should be conducted to better assess the types of sources and contributions of nitrate to the groundwater and surface water systems of southern Baldwin County. Although a large number of wells were sampled and analyzed to define the extent and magnitude of nitrate contamination in the aquifers of southern Baldwin County, a denser network of wells from all aquifer zones need to be identified and monitored to gain higher spatial and temporal resolution. In addition, more wells need to be constructed in areas that lack data, however, the addition of wells to these sparsely populated areas may be too costly and/or not feasible to implement. Further monitoring of the nitrate levels is necessary to evaluate the temporal evolution and distribution of nitrate concentrations within the aquifers underlying the region. Proper well placement and routine water quality monitoring is important to prevent aquifer zones A1, A2, and A3 from further nitrate contamination and to more accurately assess temporal changes in nitrate distribution.

ArcGIS proved to be a valuable tool used to determine the spatial extent and magnitude of nitrate contamination of groundwater. ArcGIS was effectively used to produce the groundwater elevation (potentiometric surface) map and assess groundwater flow conditions for the aquifer zone A2 within the study area. In addition, the use of GIS makes it possible to view the data in a viable format for those who make regulatory decisions whereas such data in the past has been much less accessible. Furthermore, the use of these tools 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.

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