**NASA DEVELOP National Program**



University of Georgia

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Georgia Water Resources

Groundwater Resources Quantity and Quality Evaluation

combining satellite-based datasets in Southwestern Georgia

 **Technical Report**

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# I. Abstract

[Placeholder - do not put anything here until the final draft submission. The abstract in the project summary is where the working draft of the abstract should “live”]

**Keywords**

Groundwater, Georgia, Water Quality, Water Quantity, Sinkholes, Remote Sensing, Hydrology

# II. Introduction

**Background**

An aquifer is a geologic formation that can store and transmit significant quantities of water. The Floridan Aquifer, made of a highly fossiliferous limestone, is one of the most productive aquifers in the world. Because of the Floridan Aquifer’s limestone composition, groundwater seeps through the bedrock and has widened natural fractures, and bedding planes to create an extremely permeable layer (Hicks, D. W., et al., 1987). The Floridan Aquifer is geographically divided into the Upper Floridan and Lower Floridan. Near Albany, the Upper Floridan Aquifer (UFA) lies entirely within the Dougherty Plain and is widely exposed in southwest Georgia. According to the Dougherty County Health Department, the uppermost portion of the UFA supports the majority of domestic, industrial, and agricultural water supplies. Therefore, monitoring and maintaining groundwater storage in the UFA to meet supply requirement is a primary concern for local water resource managers. Groundwater levels are generally higher where aquifers are recharged and lower in areas where the groundwater discharges naturally to rivers or pumping stations. In the UFA, however, it is hard to predict groundwater response times to changes in precipitation or drought conditions because of its location in a karst landscape. The extensive karst region of southwest Georgia is highly fractured and experiences active sinkhole formation and local well development, resulting in an increased permeability. Both sinkhole formation and well development promote the transmission of groundwater in the aquifer (Torak, G. S., et al., 1993). Dramatic groundwater-level changes have occurred in this area of Georgia due to heaving pumping from wells, which have added to the concerns of local and state water resource officials. Southwest Georgia plays an important role in groundwater storage change in the UFA and an efficient monitoring approach is always in demand to capture real-time changes in Dougherty County and the surrounding area.

Water in the UFA generally is hard and less mineralized than water in deeper aquifers (Hicks, et al., 1981). Hicks et al. (1987) indicated that the water quality in UFA is suitable for most purposes. Nevertheless, researchers have shown that some of their sample regions are subject to contamination related to land-use practices. Organic components were detected in groundwater when sample sites were close to agriculture lands with pesticide application. The UFA is directly connected to much of the local surface drainage networks such that any contamination going into surface water will eventually flow into the UAF, further expanding contaminated zones.

Before NASA’s Gravity Recovery and Climate Experiment (GRACE) mission began, it was extremely difficult to measure changes in water quantity over large regions (Rezaie-Boroon and Fisher, 2012). Groundwater study was one of the last research areas to benefit from remote sensing applications (Becker, 2006). Multiple studies have demonstrated the value of GRACE data to water resources science and management (Rodell et al. 2004; Chen et al. 2005; Syed et al. 2005; Velicogna et al. 2005; Swenson and Wahr 2006; Rodell et al. 2007). In particular, Rodell (2007) first demonstrated the use of GRACE total water storage data with soil moisture and snow water equivalent data to quantify groundwater changes for a given region. Remote sensing applications are a valuable resource to monitor water quantity changes and NASA Earth Observations will influence decisions made by the end users of this project.

**Study Area**

Dougherty County is located within the Dougherty Plain of southwest Georgia and is at the northern edge of Georgia’s portion of the UFA (Figure 1). The county has a growing population that relies on groundwater resources from the UFA, the Flint River, and Lake Chehaw. Albany is Dougherty County’s largest metropolitan area with a population of approximately 76,000 residents. The local topography is generally flat and underlain by the Ocala Limestone, making this area an importance source of groundwater quantity change and sensitive to contamination. To address the increased demand for sustainable groundwater supply in Dougherty County, an effective groundwater monitoring and evaluation tool is critical for local water resources management.



*Figure 1: Study Area*

**Objectives**

Evaluation of groundwater resources quantity and quality is necessary to facilitate sustainable consumption and management decisions. This project aims to develop an applied methodology that incorporates remote sensing data and ecological model for groundwater resources evaluation. To generate a comprehensive water resources evaluation tool, two complementary perspectives will be examined in this methodology:

1. Build groundwater storage change records using GRACE. These quantitative evaluations will estimate groundwater depth changes from 2002 to 2009 in the UFA portion of southwestern Georgia (Figure 1).
2. The DRASTIC model will be applied to create corresponding groundwater contamination vulnerability maps using Dougherty County as the focal area. Building upon the traditional DRASTIC model, sinkhole susceptibility, which was generated by the Summer 2015 NASA DEVELOP Georgia Disasters team, will be incorporated to assess groundwater contamination vulnerability (Figure 1).

**National Application Area**

The national application addressed in this project is water resources. NASA’s Applied Sciences Water Resources Program addresses concerns and decision processes related to water availability, water forecast, and water quality. The goal of this application area is to apply NASA satellite data to improve decision support tools to project partners that manage water resources in Georgia.

**Project Partners**

The partners of this project include Randy Weathersby from the City of Albany and Dougherty County Planning and Development Services. He is also associated with Southwest Georgia Water Resources Task Force. This project fall in the application field of water resources, and will provide end-user and partner who work directly in karst aquifer systems a tool designed to enhance decision-making processes associated with managing groundwater consumption and contamination risks. The GRACE-based groundwater storage monitoring will enable the end-users to monitor up-to-date groundwater storage change in a relatively large region. While water storage is a geographically larger-scale phenomenon, water quality is more regionally specific and local groundwater quality evaluation is more practical for water resource managers to develop adaptive policies. With the quantity change information at a broad scale, the augmented DRASTIC model will provide end-users take a closer look at the focal area with local details.

# III. Methodology

The goal of groundwater vulnerability assessment is to identify areas which are more susceptible to pollution than others (Piscopo 2001). Generally, process-based methods, statistical analyses, and overlay and indexing techniques are used in the assessment process. Overlay and indexing methods are most-suitable for overcoming the limitations of both statistical and process-based methodologies (Shirazi 2012). Usage of overlay and indexing techniques does not require extensive datasets to capture physical, chemical, and biological reactions that are required by process-based methods (Shirazi 2012). The DRASTIC model, which employs overlay and indexing methodologies, is widely-recognized and used to assess groundwater vulnerability. DRASTIC was first developed by the United States Environmental Protection Agency (EPA) and later modified by researchers to account for a range of different environmental settings (Shirazi 2012). This study followed the traditional DRASTIC model considering seven hydrogeological parameters: depth to groundwater (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I) and hydraulic conductivity (C). An additional term, corresponding to sinkhole susceptibility, was then incorporated into the model.

**Objective 1: Groundwater quantity assessment using GRACE**

**GRACE data acquisition:** To calculate the total groundwater storage in our study area region, we downloaded datasets from the GRACE mission and the NLDAS data platforms. The team acquired monthly averages from the years 2002 and 2009. GRACE imagery with a monthly, 400 km resolution was also collected for the years 2002 and 2009. The soil moisture and snow water equivalent parameters were acquired from the NLDAS-2 model. The spatial resolution of the NLDAS imagery is about 140 km with a monthly temporal resolution.

**GRACE data processing:** The team re-projected the data files of both GRACE and NLDAS parameters from the original WGS84 datum to the North America Albers Equal-Area Conic. This was necessary to resample the cell size to 1 kilometer for all the datasets. After resampling, all data files were clipped to the study area with a 10 km buffer area to ensure full coverage. The soil moisture and snow water equivalent NLDAS-2 parameters have a different unit measurement (kg/m²) than the GRACE data (cm). To convert the soil moisture and snow water equivalent parameters into cm as well as extract pixel values from each data layer, the team converted the raster data to points. A random sample of 100 points were created in the GME Spatial Ecology software, whose specific locations were used to convert the NLDAS-2 raster files into 100 individual data points. To convert the NLDAS-2 parameters from (kg/m²) to (cm), the data was multiplied by a 0.1 factor. Finally, the 100 pixel values from all three datasets were integrated by the following equation (Rodell et. al, 2007):

$$∆GW=∆TWS-\left(∆SM+∆SWE\right)$$

 Equation 1

**GRACE Data Analysis:** Computation of variations in groundwater storage allowed comparisons of the results from 2002 and 2009. Assessment of the correlation between sinkhole formation and groundwater storage variation was done using a simple linear regression model. All statistical analyses of the groundwater change data were performed in the R statistical program.

**Objective 2: Groundwater contamination vulnerability using DRASTIC**

**DRASTIC data acquisition**: Implementation of the DRASTIC model required obtaining multiple datasets (Figure 2; Table 1) from different sources. The depth to water dataset was collected and compiled from the United States Geologic Survey (USGS) National Water Information System (NWIS) showing monthly and yearly average values from wells in 2002 and 2009. A total of 29 well sites located either within or around Dougherty County boundary were selected in this manner. Next, 4 km resolution precipitation data from PRISM Climate Group and 1 km evapotranspiration (ET) data from Numerical Terradynamic Simulation Group (NTSG) were incorporated for calculation of net recharge in both 2002 and 2009. An aquifer extent shapefile for the UFA from the USGS was used as reference to obtain information about aquifer media in Dougherty County. The Gridded Soil Survey Geographic (gSSURGO) database provided 10m resolution soil maps and was used to obtain the soil media parameters within Dougherty County. Topographic data was derived from the National Elevation Dataset (NED) 1 km Digital Elevation Model (DEM) product. The vadose zone and hydraulic conductivity information were derived from geologic maps of Georgia available through USGS Mineral Resources.



*Figure 2: Conceptual Data Used in the DRASTIC model*

|  |  |  |  |
| --- | --- | --- | --- |
| **Source** | **Description Parameter** | **Date** | **Role in DRASTIC** |
| USGS National Water Information System (NWIS) | Average Depth to water | 2002 and 2009 | D |
| PRISM Climate Group | Annualized accumulated Precipitation | 2002 and 2009 | R |
| MODISMOD16 | Annualized accumulated Evapotranspiration | 2002 and 2009 | R |
| United States Geological Survey (USGS) | Aquifer Media, Vadose Zone, Hydrolic Conductivity | 2005 | A, I, C |
| USDA Natural Resources Conservation Service (NRCS) | Soil Media | 2014 | S |
| GRACE  | Total Water Storage | 2002 and 2009 | N/A |
| North American Land Data Assimilation System (NLDAS-2) | Soil Moisture and Snow Water Equivalent | 2002 and 2009 | N/A |

*Table 1: Description of datasets required in DRASTIC model*

**DRASTIC data processing**: Well log data was geocoded using Inverse-Distance Weighted (IDW) interpolation and Kriging techniques to create a continuous surface showing predicted values of depth to water. Aquifer media, soil media and geologic map shapefiles were clipped to study area. For all raster data, a 10 km buffer around Dougherty County was created to mask raster images for full coverage of study area. To calculate net recharge, resampling was performed to transform 4 km resolution precipitation files to 1 km datasets to match the ET data resolution. SEDAS was applied to reproject and transform ET data, making it compatible in resolution with precipitation data. SEADAS is a comprehensive image analysis package originally developed by NASA to support the SeaWiFS mission and is now applied to many satellite-based earth science data analyses. Calculation of net recharge was done by subtracting total ET from total precipitation using the Raster Calculator tool in ArcGIS. To extract required information from soil data, gSSURGO spatial data was joined to the attribute table using the MUKEY field, allowing identification of soil series by pixel. Because the DRASTIC model requires soil media as input, all soil series in Dougherty County have were reclassified into soil media types according to USDA-NRCS official soil series descriptions.

$$Contamination Vulnerability=D\_{r}D\_{w}+R\_{r}R\_{w}+A\_{r}A\_{w}+S\_{r}S\_{w}+T\_{r}T\_{w}+I\_{r}I\_{w}+C\_{r}C\_{w}$$

Equation 2

The influences of seven DRASTIC parameters on groundwater pollution vulnerability were combined following Equation 2. A DRASTIC model value, including the rate (r) and weight (w), recommended by Aller and others (1987) was assigned to each parameter for each pixel (1 km). Once the DRASTIC ratings were assigned, the pollution vulnerability for each pixel was estimated by calculating the DRASTIC Index value, from which the groundwater susceptibility map was generated for the years 2002 and 2009. Building upon the traditional DRASTIC model, sinkhole susceptibility was incorporated as a multiplier term to calculate a final, modified DRASTIC index (DRASTICS).

**DRASTIC data Analysis**: Using sinkhole susceptibility maps from the Georgia Disasters team, groundwater contamination vulnerability can be associated with sinkhole formation, offering comprehensive details for groundwater quality.

# IV. Results & Discussion

Insert images, graphs, maps, charts, etc. here. Choose the most important results to highlight here. No word cap, but two to six pages is a good range.

Things to discuss:

* Analysis of Results: What can you tell from your graphs, images, etc? What does this mean for your project?
* Errors & Uncertainty: What factors could you not account for, what things didn’t work out like you expected they would, etc.
* Future Work: If this project was to be selected for another term, what would be the focus? What other areas would be of interest?

# V. Conclusions

Final conclusions. Word count: 200-600 (~a page).

# VI. Acknowledgments

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.

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# IV. Appendices

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