# Groundwater Recharge Estimation under Climate Change Impact for the Southern Hills Aquifer System of Southeastern Louisiana and Southwestern Mississippi

## Basic Information

| | |
|---|---|
| **Title:** | Groundwater Recharge Estimation under Climate Change Impact for the Southern Hills Aquifer System of Southeastern Louisiana and Southwestern Mississippi |
| **Project Number:** | 2014LA94B |
| **Start Date:** | 3/1/2014 |
| **End Date:** | 2/28/2015 |
| **Funding Source:** | 104B |
| **Congressional District:** | 6th |
| **Research Category:** | Climate and Hydrologic Processes |
| **Focus Category:** | Hydrology, Models, Methods |
| **Descriptors:** | None |
| **Principal Investigators:** | Frank Tsai |

## Publications

1. Beigi E., and F. T.-C. Tsai, 2014. "GIS-Based Water Budget Framework for High-Resolution Groundwater Recharge Estimation of Large-Scale Humid Regions". Journal of Hydrologic Engineering, ASCE, 19(8), 05014004, doi:10.1061/(ASCE)HE.1943-5584.0000993.
2. Beigi E. and F. T.-C. Tsai. 2015. "Comparative study of climate-change scenarios on groundwater recharge, southwestern Mississippi and southeastern Louisiana, USA". Hydrogeology Journal 23(4), 789-806. doi :10.1007/s10040-014-1228-8
3. Beigi E. and F. T.-C. Tsai, 2014 "Hierarchical BMA Analysis of Hydrologic Projections under Climate Modeling and Scenario Uncertainties", Abstract, 2014 American Geophysical Union Fall Meeting, San Francisco, California, December 2014.
4. Beigi E. and F. T.-C. Tsai, 2014 "Comparative Study of Climate Change on Groundwater Recharge", Abstract, American Society of Civil Engineers (ASCE), 2014 World Environmental and Water Resources Congress, Portland, Oregon, May 2014.
5. Beigi E. and F. T.-C. Tsai, 2014 "A Water Balance Approach to Estimate Surface Runoff and Potential Groundwater Recharge of Southern Louisiana", Abstract, US-China International Workshop on Key Processes and Regulation of Wetland Ecosystems." Louisiana State University, Baton Rouge, LA, November 12, 2014.
6. Beigi E. and F. T.-C. Tsai, 2014 "Impact of Climate Change on Groundwater Recharge of Southern Hills Aquifer System", 7th Annual Groundwater and Surface Water Resources Symposium, Louisiana Geological Survey (LGS), Baton Rouge, LA, April 18, 2014.

**Problem and Research Objectives**

Significantly increased emissions of greenhouse gases from anthropogenic activities has caused climate to change. As reported by the Intergovernmental Panel on Climate Change (IPCC), the global mean surface temperature and the global mean sea level have risen by 0.6±0.2 °C and by 20±5 cm, respectively since the late 19th century. Additionally, the IPCC predicted 2 to 4 °C global temperature increase and 18 to 59 cm sea level rise in the 21st century. The global warming is projected to intensify the global hydrologic cycle, alter precipitation amount, pattern and intensity, increase atmospheric water vapor, evaporation and evapotranspiration, and change groundwater recharge and runoff. Climate variation can impact on availability of groundwater through evapotranspiration and recharge processes. Because precipitation and surface water are the main sources to recharge aquifers, evaluating the impact of climate change on groundwater systems needs reliable estimation of recharge, which is important for assessing drought, water quality, groundwater availability and sustainability. Improving the understanding and modelling of climate changes on groundwater recharge have been highlighted in the last five IPCC reports. Recently, the increasing number of climate change studies with regard to groundwater resources has shown the importance of this subject. Knowledge of groundwater recharge is particularly important to regions where large demands of drinking water supplies rely heavily on groundwater, such as the Southern Hills aquifer system, southwestern Mississippi and southeastern Louisiana, USA. Reliable recharge estimation is important for efficient and sustainable groundwater resource management and for aquifer protection from rapidly expanding urbanization, drought or climate change.

This study assesses the climate change impact on groundwater recharge in humid areas using the water budget method. The HELP3 model (Schroeder et al. 1994), a water budget model, is employed to estimate potential recharge since HELP3 has been widely used to estimate recharge. To investigate the impact of climate change on groundwater recharge for a large-scale humid region, this study develops a water budget framework using HELP3 in conjunction with a geographic information system (GIS). The framework estimates potential recharge under three different emission scenarios (B1, A2 and A1FI) of two global climate models (GCMs), which are the National Center for Atmospheric Research's Parallel Climate Model 1 (PCM) and the National Oceanic and Atmospheric Administration Geophysical Fluid Dynamics Lab's (GFDL) model (Maurer et al. 2002 and Maurer 2013). The framework is applied to the area of the Southern Hills aquifer system, southwestern Mississippi and southeastern Louisiana, USA (Figure1). The historical condition in 1950-2009 is used as a baseline and is compared to the results of six climate change scenarios for three future periods: 2010-2039, 2040-2069 and 2070-2099.

**Principal Findings and Significance**

**1. Baseline Historical Potential Recharge**

The mean annual potential recharge shown in Figure 2 for the area of the Southern Hills aquifer system is considered as the baseline historical recharge for climate change comparisons. The mean annual potential recharge ranges from 0 to 857 mm. The average of the mean annual potential recharges (1950-2009) for the entire area is 227.5 mm. 45.6 % of the subdivisions have mean annual potential recharge above the average. 48.8 % of the subdivisions have mean annual potential recharge lower than 205 mm while 40.7 % have mean annual potential recharge between 205 mm and 410 mm, and 10.45 % have mean annual potential recharge higher than 410 mm. The west of the study area (including the parishes of Adams County, Claiborne County, Jefferson County, Wilkinson County, and West Feliciana) is the recharge zone of the Baton Rouge aquifer system and shows high potential recharge historically. High potential recharge is also demonstrated in the east and central Florida parishes. Low potential recharge is demonstrated in the north and northeast of the study area.

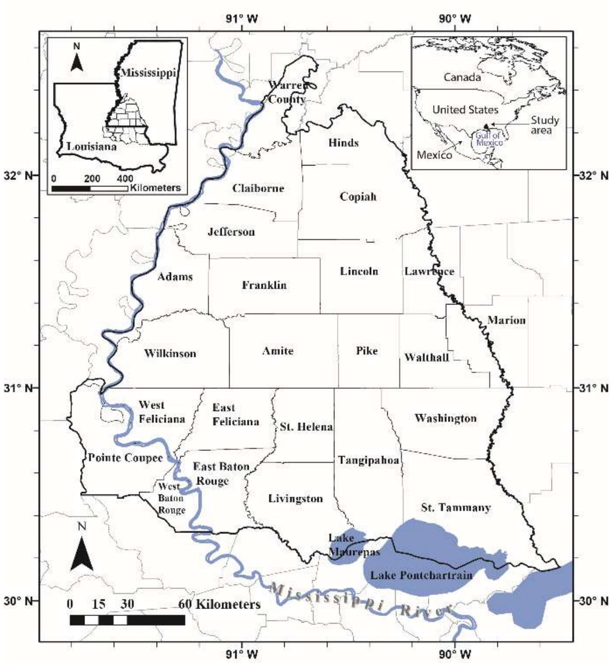


Figure 1: Location of the Southern Hills aquifer system (bounded by a thick black line). The parish boundaries are in thin black lines.

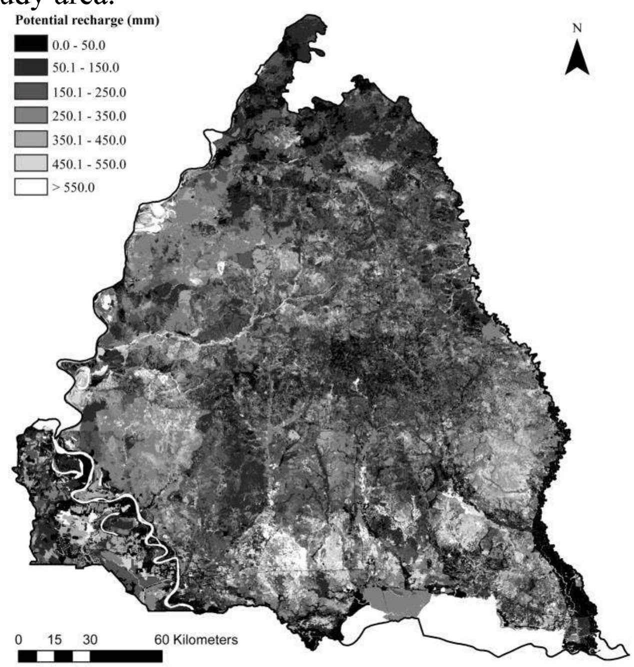


Figure 2: Mean annual potential recharge (mm) for 1950-2009 for the Southern Hills aquifer system.

## 2. Temporal Results

The changes in temperature and the cumulative changes in precipitation and solar radiation for individual scenarios with respect to the historical baseline (1950-2009) are shown in Figure 3. To calculate the changes for the Southern Hills aquifer system, the area-averaged values of the climate variables of all subdivisions were calculated and subtracted from the mean annual for 1950-2009. Sums of the changes over years show the cumulative changes. If changes in climate variables are negative over time, their cumulative changes will amplify this phenomenon by showing large negative values. For example, a fall of almost 10 m cumulative change in 2099 for GFDLA1F1 shows that the yearly precipitation continuously decreases from 2040 to 2099 with respect to the baseline precipitation. The differences of the cumulative changes between the scenarios become more evident over time. The cumulative changes of solar radiation projected by the PCM and GFDL models are opposite and distinguishable from the beginning of projection. After the mid-century, the cumulative changes of precipitation and the changes of temperature between emission scenarios are distinguishable, which is consistent with the global projections (Cubasch et al. 2001). Scenarios PCMB1, PCMA2, and GFDLB1 project overall precipitation increase while the other three scenarios project overall precipitation decrease for the 21st century. Moreover, scenarios PCMB1, PCMA2, and GFDLB1 project relatively less temperature change than the other three scenarios for the 21st century.

In general, the projections of the PCM and the GFDL models begin to diverge greatly after the mid-century for the study area. This divergence is in harmony with greenhouse forcing associated with the various scenarios and starts at the point at which substantial differences between the projections by these two models begin. These differences stem from the two models' parameterizations, sensitivities and responses to greenhouse gases and other forcings (Cayan et al. 2007).

Figure 4 presents the cumulative changes in potential recharge, runoff and evapotranspiration with respect to the historical baseline scenario for each climate change scenario. It is observed that potential recharge cumulative changes follow the same trend as precipitation cumulative changes, which highlights the fact that the potential recharge in the study area is more sensitive to precipitation than temperature and solar radiation. Scenarios GFDLA2 and GFDLA1FI project significant potential recharge decrease towards the end of the 21st century. On the other hand, scenarios PCMB1 and PCMA2 project the most potential recharge increase for the 21st century. Almost all of the climate change scenarios project runoff decreases for the 21st century except for the GFDLB1. PCMA1FI projects the highest runoff reduction, followed by PCMB1. Although projecting precipitation increase for the 21st century, scenarios PCMB1 and PCMA2 show runoff decrease due to projected high evapotranspiration shown in Figure 4(c). The PCM model projects continuous evapotranspiration increase for the 21st century. However, the GFDL model does not show significant change of evapotranspiration before 2069, but has a wide-ranging evapotranspiration projection in 2070-2099.

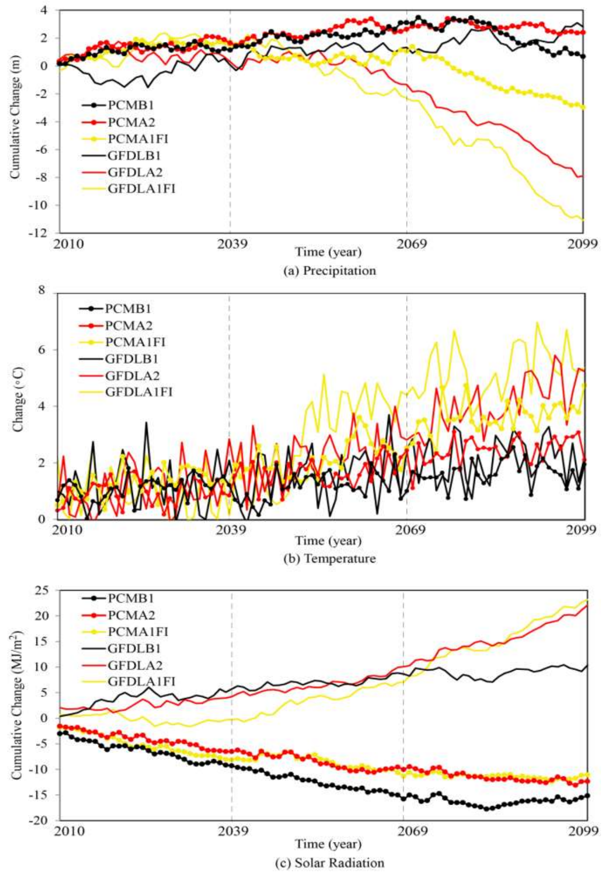


Figure 3: Cumulative changes of (a) precipitation, (b) changes of temperature, and (c) cumulative changes of solar radiation with respect to the historical baseline

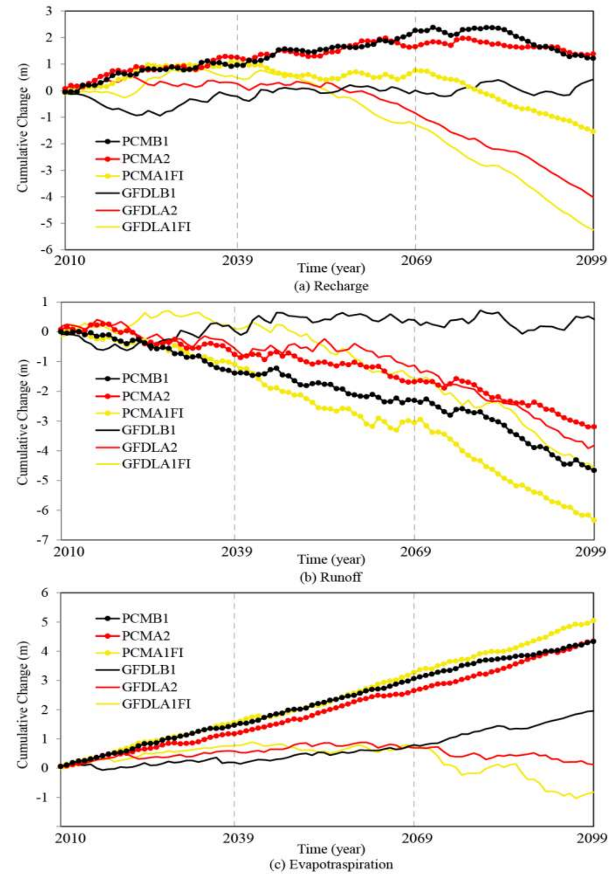


Figure 4: Cumulative changes of (a) potential groundwater recharge, (b) surface runoff, and (c) evapotranspiration with respect to the historical baseline

## 3. Spatial Results

Future mean annual potential recharge, runoff, and evapotranspiration with respect to the mean annual from 1950 to 2009 are listed in Table 1. The mean annual potential recharge, runoff, and evapotranspiration in 1950-2009 are 227.5 mm, 362.7 mm and 943.2 mm, respectively. The PCM model projects recharge change from −33.7 % to +19.1 % and the GFDL model projects recharge change from −58.1 % to +7.1 % for the 21st century. In general, the PCM projects more recharge than the GFDL. The potential recharge is likely to increase in 2010-2039 and is likely to decrease in 2070-2099. The mean annual potential recharge in 2070-2099 is projected to decrease from 227.5 to 95.4 mm/year under the most pessimistic scenario (GFDLA1FI), and decrease to 192.5 mm/year under the most optimistic scenario (PCMB1). As a result, the potential recharge to the Southern Hills aquifer system is projected to be reduced in 2070-2099 as the climate change studies have projected for other places (e.g., Serrat-Capdevila et al. 2007).

Table 1: Projected changes in mean annual potential recharge, runoff and evapotranspiration with respect to the mean annual for 1950-2009.

| Climate model | Scenario | Potential recharge (%) Mean annual = 227.5 mm | | | Runoff (%) Mean annual = 362.7 mm | | | Evapotranspiration (%) Mean annual = 943.2 mm | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2010-2039 | 2040-2069 | 2070-2099 | 2010-2039 | 2040-2069 | 2070-2099 | 2010-2039 | 2040-2069 | 2070-2099 |
| PCM | B1 | +14.1 | +19.1 | −15.4 | −12.8 | −8.4 | −21.6 | +5.2 | +5.6 | +4.5 |
| | A2 | +18.4 | +5.9 | −4.0 | −7.0 | −8.4 | −13.9 | +4.1 | +5.2 | +6.0 |
| | A1FI | +15.4 | −4.2 | −33.7 | −10.1 | −18.0 | −30.2 | +5.5 | +6.1 | +6.3 |
| GFDL | B1 | −3.1 | +3.3 | +6.0 | +0.2 | +3.4 | +0.2 | +0.7 | +2.1 | +4.1 |
| | A2 | +3.9 | −16.3 | −46.5 | −5.1 | −5.2 | −24.8 | +2.1 | +0.4 | −2.0 |
| | A1FI | +7.1 | −25.8 | −58.1 | +0.9 | −15.5 | −27.4 | +2.7 | −0.2 | −5.4 |

Runoff is likely to decrease for the 21st century as projected by the GCMs (Table 1). PCM projects runoff decrease from −7.0 % to −30.2 % while GFDL projects runoff change from +3.4 % to −27.4 %. In general, PCM projects less runoff than GFDL for the 21st century. Evapotranspiration is likely to increase for the 21st century. The PCM projects evapotranspiration increase from 4.1 % to 6.3 % and the GFDL projects evapotranspiration change from −5.4 % to +4.1 %.

In order to understand the range of possible future changes in potential recharge, results from the most optimistic scenario (PCMB1) and the most pessimistic scenario (GFDLA1FI) are investigated. Figure 5 shows the changes in 30-year mean annual potential recharge with respect to the mean annual potential recharge (1950-2009). The PCMB1 projects relatively higher potential recharge increase in southeastern Louisiana than southwestern Mississippi in 2010-2039 and 2040-2069. Recharge is projected to decrease in 2070-2099. The GFDLA1FI also projects more potential recharge in southeastern Louisiana in 2010-2039. Potential recharge is projected to decrease in 2040-2069 by the GFDLA1FI and more severely in 2070-2099. In general, the PCM model projects more potential recharge than that of the GFDL model.

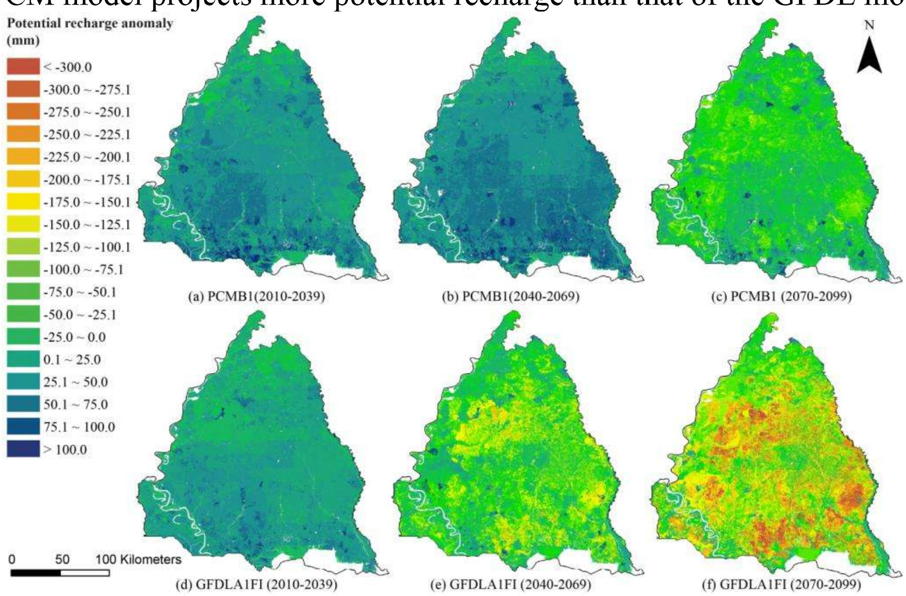


Figure 5: Potential recharge anomaly map for three future periods (2010-2039, 2040-2069, and 2070-2099) for the most optimistic scenario (PCMB1) and the most pessimistic scenario (GFDLA1FI), Each map shows the changes in 30-year mean annual potential recharge with respect to the mean annual potential recharge (1950-2009) in Figure 2.

## 4. Sensitivity Analyses of Recharge to Climate Change

The sensitivity of potential recharge to climate change was evaluated by using the linear regression method to analyze the relationship between the change in potential recharge and the change in individual climate variables such as precipitation, temperature and solar radiation under different climate change scenarios (Crosbie et al. 2013). The slope (dR/dP) of a linear regression represents the sensitivity of the potential recharge to a climate variable given a climate change scenario; and the intercept represents the sensitivity of the potential recharge to all other variables. A sensitivity analysis was conducted for each subdivision to assess sensitivity variation in space. This study selected GFDLA1FI scenario for the period 2070-2099 since it shows the highest potential recharge change for the study area. As shown in Figure 6, subdivisions with high potential recharge have the lowest slope and intercept while subdivisions with low potential recharge have the highest slope and intercept. As a result, subdivisions with high potential recharge show lower potential recharge sensitivity to precipitation, temperature and solar radiation and vice versa.

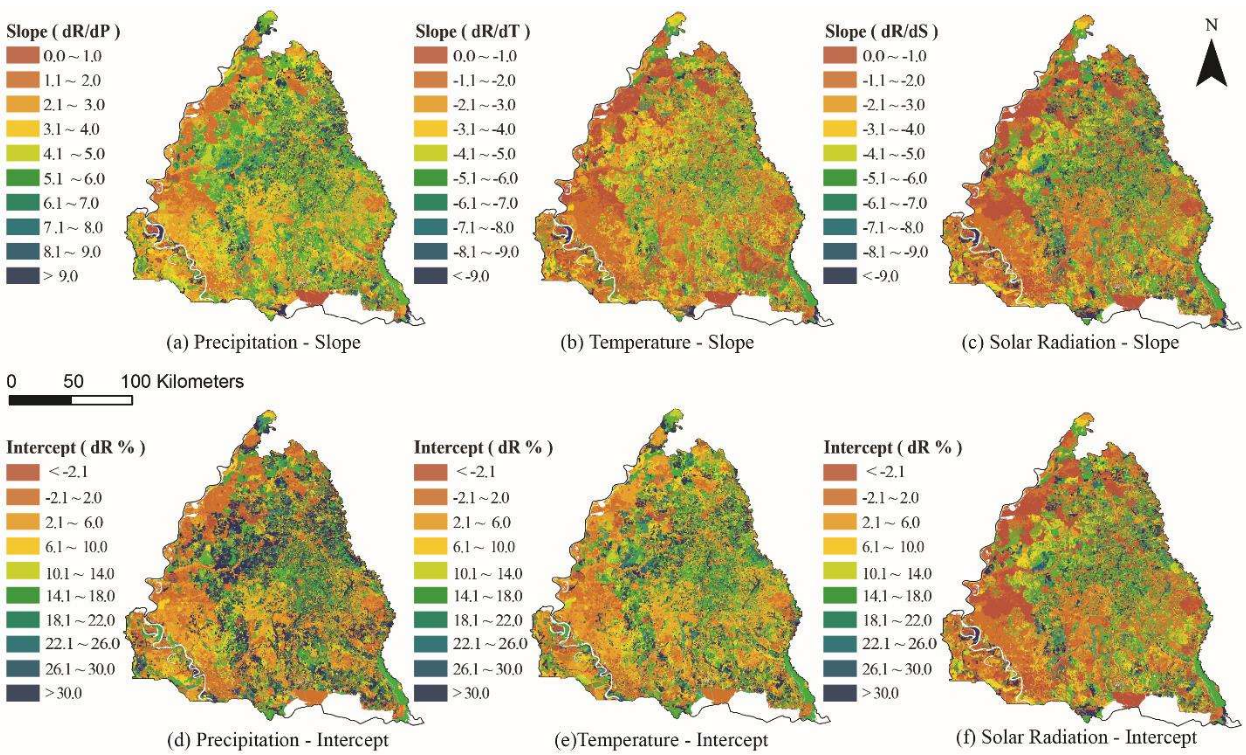


Figure 6: Slopes and intercepts of the relationship between changes in mean annual potential recharge and changes in mean annual precipitation, temperature and solar radiation for GFDLA1FI for 2070-2099.

## 5. Conclusions

Assessing the impact of climate change on potential groundwater recharge for humid areas can be achieved by the proposed HELP3 model in a GIS-based water budget framework. Intersecting various datasets through the GIS can easily create a great number of subdivisions, which makes the potential recharge estimation virtually infeasible on a single-core computer. The framework includes parallel programming to divide required HELP3 model runs to multiple cores of a supercomputer to significantly reduce computing time. The parallel programming allows the methodology to be applied to century-long potential groundwater recharge, surface runoff and evapotranspiration estimation for the area of the Southern Hills aquifer system, southwestern Mississippi and southeastern Louisiana, under a large number of emission scenarios and GCMs.

Under a wide range of climate change scenarios, it was found that the GFDL climate model projects more intense changes in future precipitation, temperature and solar radiation in the study area than the PCM model for the 21st century. Given these projected climate forcings, potential recharge is likely to increase in 2010-2039 and likely to decrease in 2070-2099 with respect to the estimated historical potential recharge (1950-2009). The study area is projected to have a wide range of future potential recharge. The potential recharge is projected to decrease in 2070-2099 by much as 58.1 % (GFDLA1FI) and to increase by as much as 19.1 % (PCMB1 scenario). Runoff is likely to decrease for the 21st century as projected by the GCMs (Table 1). PCM projects runoff decrease from -7.0 % to -30.2 % while GFDL projects runoff change from +3.4 % to -27.4 %. The PCM projects evapotranspiration increase from 4.1 % to 6.3 % and the GFDL projects evapotranspiration change from −5.4 % to +4.1 %.

It was found that the future potential recharge variation has strong correlation with the precipitation projections. Potential recharge was found to be most sensitive to the changes in future precipitation, followed by solar radiation, and then temperature. Moreover, both GCMs show a consistent result that the A1FI scenario projects the highest recharge sensitivity to the precipitation, temperature and solar radiation, followed by the A2 scenario, and then the B1 scenario. This order follows the increment of the degree of global warming in the emission scenarios. Subdivisions with high potential recharge show lower recharge sensitivity to precipitation, temperature and solar radiation.

The impact of climate change on groundwater recharge in the study area is unclear as it highly depends on selected climate models and scenarios. Using high-responsive and low-responsive climate models in conjunction with low, medium, and high emission scenarios exhibits a broad extent of uncertain future potential recharge projections. The precipitation and temperature uncertainty analyses show that precipitation influences potential recharge more than temperature.

**References**

Crosbie RS, Scanlon BR, Mpelasoka FS, Reedy RC, Gates JB Zhang L (2013). Potential climate change effects on groundwater recharge in the high plains aquifer, USA. Water Resour Res 49:3936–3951, doi 10.1002/wrcr.20292

Cubasch U, Meehl GA, Boer GJ, Stouffer RJ, Dix M, Noda A, Senior CA, Raper S, Yap KS (2001) Projections of future climate change., In: Houghton, J.T., et al. (eds.),Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, pp.526-582 Cambridge University Press Cambridge

Maurer EP, Wood AW, Adam JC, Lettenmaier, DP, Nijssen B (2002). A long-term hydrologically based dataset of land surface fluxes and states for the conterminous United States. J Climate 15(22):3237-3251, doi 10.1175/1520-0442(2002)015<3237:ALTHBD>2.0.CO;2

Maurer EP (2013) Gridded Meteorological Data: 1949-2010, Santa Clara University,

http://www.engr.scu.edu/~emaurer/gridded_obs/index_gridded_obs.html. Cited 21 August 2014.
Schroeder PR, Dozier TS, Zappi PA, McEnroe BM, Sjostrom JW, Peyton RL (1994) The hydrologic evaluation of landfill performance (HELP) model: Engineering documentation for version 3. EPA/600/R-94/168b, US Environmental Protection Agency Office of Research and Development, Washington, DC.
Serrat-Capdevila A, Valdés JB, Pérez JG, Baird K, Mata LJ Maddock Iii T (2007) Modeling climate change impacts - and uncertainty - on the hydrology of a riparian system: The San Pedro Basin (Arizona/Sonora). J Hydrol 347(1-2):48-66, doi 10.1016/j.jhydrol.2007.08.028

**Information Transfer**

The research results were disseminated to the public of Louisiana through the 7th Annual Groundwater and Surface Water Resources and PI's research website https://sites.google.com/site/franktctsai/home/recharge-estimation-for-southern-hills-aquifer-system

**Student Support**

Ehsan Beigi, Doctoral Student, Department of Civil and Environmental Engineering, Louisiana State University, Baton Rouge.