Estimates of Nitrate Concentration in the San Antonio River Basin

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Class Project Report
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1. Introduction

Estuarine ecosystems are critical for exchanging nutrients between upland watersheds and coastal oceans [*Mayorga et al.*, 2010; *Mooney and McClelland*, 2012; *Tavakoly et al.*, 2016]. Nutrient transport and processes are significantly modified by human activities in estuaries where metropolitan areas are located. Land use and land cover have impacts on nutrient inputs and pathways in the terrestrial ecosystems and on nutrient loading in rivers and other water bodies [*Townsend and Howarth*, 2010]. The nutrient export to downstream plays a critical role in coastal water quality and is the primary condition for eutrophication. The effect of landscape change on coastal oceans is predicted to intensify in the future due to climate change and growing populations. Climate change is expected not only to change climate patterns, but also to alter terrestrial and estuarine ecosystems in the future. These changes cause difficulties in nutrient export prediction which is needed for environmental reservation and management. The challenge is to connect, combine, and integrate the different elements of nutrient dynamics on landscape and coastal ecosystems.

Nutrient processes have been included in land surface, water quality, and hydrological models for climate, environmental, and agricultural predictions [*Bonan and Levis*, 2010; *Elhassan et al.*, 2015; *Mayorga et al.*, 2010; *McCrackin et al.*, 2013; *Neitsch et al.*, 2011; *Niu et al.*, 2011; *Tavakoly et al.*, 2015; *Yang et al.*, 2011]. The focus of each model is different. For example, water quality and hydrological models include nutrient transport and transformation processes, but they require a multitude of data in order to calibrate the processes. Land surface models incorporate nitrogen (N) processes to regulate carbon uptake. The community Noah land surface model with multi-parameterization options (Noah-MP-CN) was originally developed for weather and climate prediction [*Cai et al.*, 2016; *Niu et al.*, 2011; *Yang et al.*, 2011]. Recent modifications to the Noah-MP-CN model introduce large capabilities for N dynamics and hydrological simulations in river networks [*Lin et al.*, 2015], and those are advantages for further development of N export prediction.

In this project, I obtained anthropogenic N input data on landscape for two reasons: I investigated the effects of human activates on regional N cycle, and I implemented the N inputs into the Noah-MP-CN model as statistics-based input parameters. Using statistics-based N inputs and N dynamics, I modeled grid-based nitrate concentration as an initial step of nitrogen transport estimation.

2. Methods

In this project, ArcGIS, NCAR Command Language (NCL), Excel and Fortran90 are used for data processing, calculation, analysis and display. Figure 1 is a schematic diagram of this project. Detailed information for data, models and procedures are described in following sections.

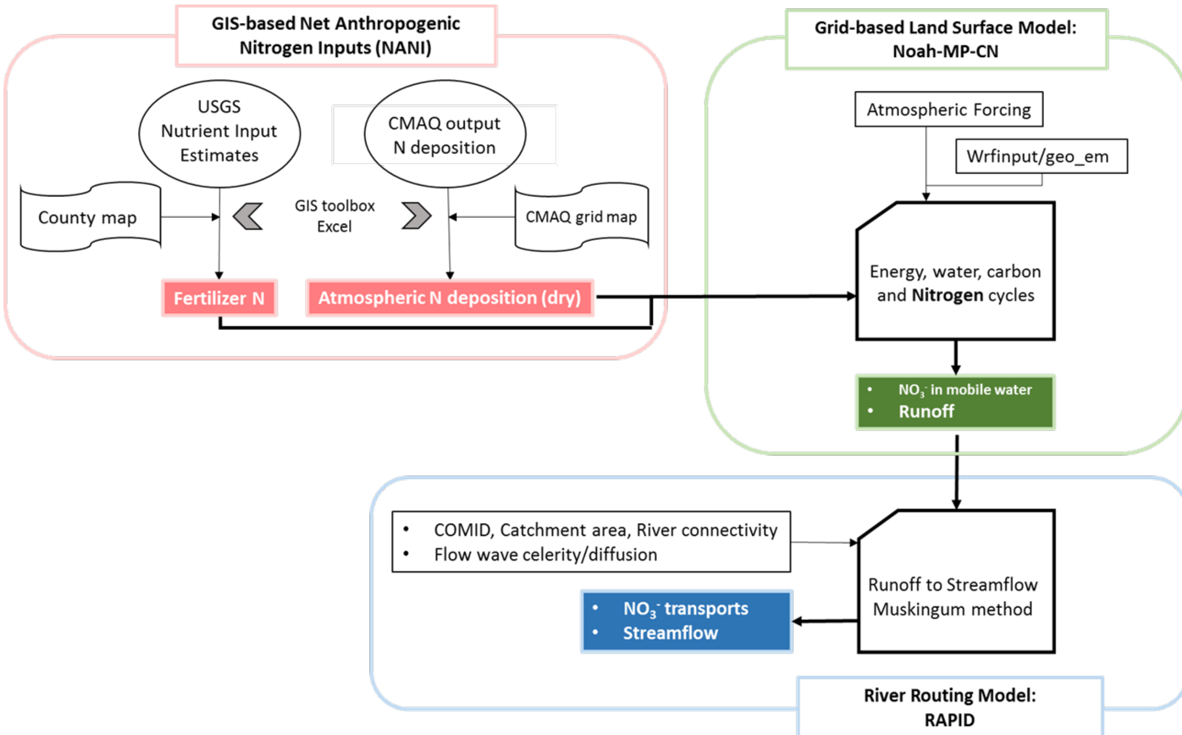

Figure 1 Workflow of this project

2.1. Net Anthropogenic Nitrogen Inputs (NANI)

The NANI represents an estimate of the net anthropogenic N fluxes [*Hong et al.*, 2011; *Howarth et al.*, 2006; *Howarth et al.*, 1996]. NANI was first introduced to investigate the rivers running to the North Atlantic Ocean and has since been improved in terms of its methodology. NANI includes the N fluxes of atmospheric deposition, fertilizer application, agricultural fixation, and net food and feed imports for regions. Dr. Robert Howarth's group has provided an open-sourced database on a national scale along with a set of GIS and Excel-based tools (i.e., the "NANI Calculator Toolbox") to generate the NANIs (http://www.eeb.cornell.edu/biogeo/nanc/nani/nani.htm). In this study, two of the NANI components, the fertilizer application and the dry deposition, are generated and used for the model inputs.

2.2. **Models**

The Noah-MP-CN was recently modified to simulate N transports and processes by integrating the N parameterizations of the Fixation and Uptake of N (FUN) plant model and the Soil and Water Assessment Tool (SWAT) soil N dynamics [*Cai et al.*, 2016]. The N processes introduced from FUN are uptake and symbiotic biological N fixation, leaf N retranslocation, and symbiotic biological N fixation [*Fisher et al.*, 2010], while the parameterizations for mineralization, decomposition, immobilization, nitrification, volatilization, atmospheric deposition, denitrification, fertilizer application, and leaching are based on SWAT [*Neitsch et al.*, 2011]. The Noah-MP-CN also adopts the model structure for N processes from SWAT, including five soil layers and five N pools (ammonium (NH_4^+), NO_3^-, active, stable and fresh pools). The full description for N processes is available in *Cai et al.* [2016], *Fisher et al.* [2010] and *Neitsch et al.* [2011].

The fertilizer model needs various information for its simulation. In this project, the start date of fertilizer application is assigned as Julian day 90 of a year in the model, and the amount of fertilizer is evenly distributed over 30 days from the start date. This information can be defined by model users and available data. The amount of N added to the soil through the application of fertilizer, separated into N pools, is calculated as follows:

$$NO_{3,fert} = fert_{minN} \cdot (1 - fert_{NH4}) \cdot fert$$

where $NO_{3,fert}$ is the amount of nitrate added to the soil (gNm^{-2}), $fert_{minN}$ is the fraction of mineral N in the fertilizer, $fert_{NH4}$ is the fraction of ammonium in the fertilizer, and $fert$ is the amount of fertilizer applied to the soil (gNm^{-2}). N enters soil and water bodies through atmospheric deposition in the form of nitrate and ammonium. Dry deposition directly adds nitrate and ammonium into the top soil, and the annual rate of dry deposition is evenly distributed through a year. The amounts of nitrate and ammonium are calculated as follows:

$$NO_{3,sfc} = NO_{3,sfc} + NO_{3,drydep}$$

where $NO_{3,sfc}$ is the amount of nitrate in the top soil layer, and $NO_{3,drydep}$ is the nitrate dry deposition rate for a model time step.

The atmospheric forcing applied on the Noah-MP-CN model is hourly data from the North American Land Data Assimilation System (NLDAS-2) [*Mitchell et al.*, 2004]. The NLDAS-2 data consists of temperature, precipitation, solar radiation, wind, pressure, and specific humidity

The Routing Application for Parallel computation of Discharge (RAPID) model is used to calculate streamflow transporting N. It is a vector-based river-routing model that uses a matrix-based version of the Muskingum method to simulate river flow through river networks [*David et al.*, 2011]. The RAPID model has been connected to the Noah-MP model [*Lin et al.*, 2015]. The Noah-MP provides the gridded runoff as RAPID model inputs.

2.3. Study Region

The study region is the San Antonio River Basin. It is located in south-central Texas, and drains toward the Gulf of Mexico (Figure 2). The basin drains a land area of about 10,000km^2. The land cover of the San Antonio River Basin is shown in Figure 3 and 4. More than a third of drainage area is covered by shrubs and grass, and agricultural land and forest follow the next. Developed area contributes 16% of land cover, and comprises mainly the city of San Antonio. The human activities can have large effects on the basin, especially the downstream, because the developed and cultivated area are largely distributed from center to southern part of the basin.

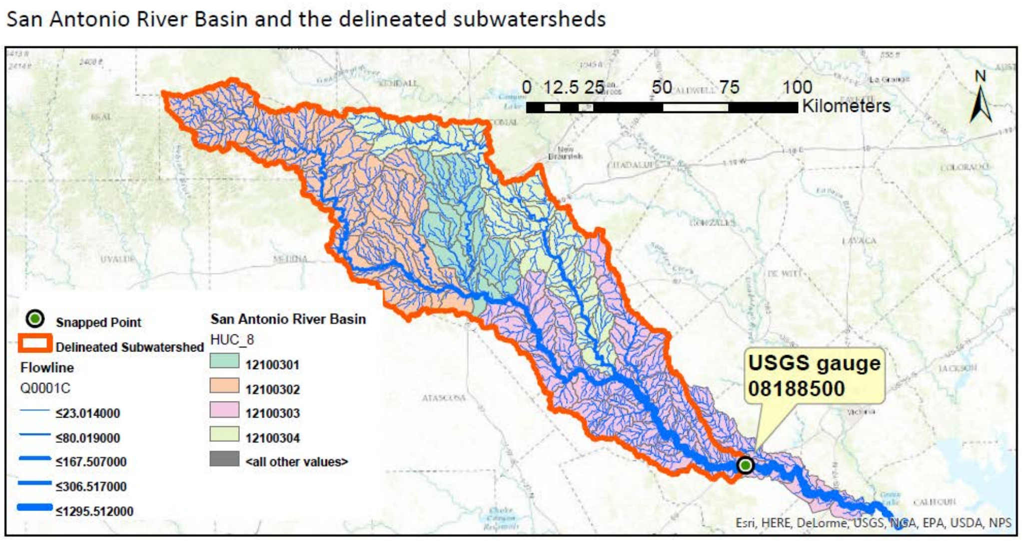

Figure 2 San Antonio River Basin

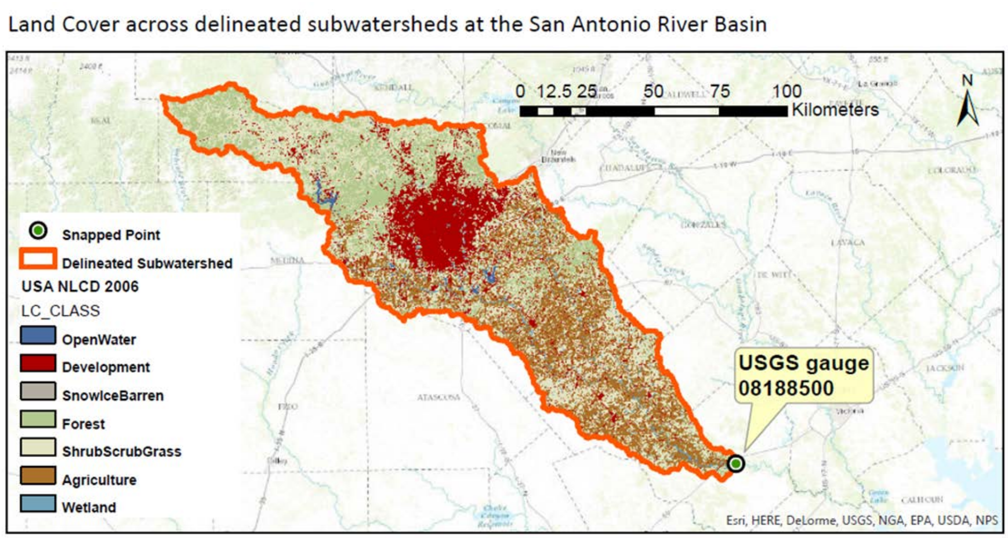

Figure 3 Land cover at the San Antonio River Basin in 2006 based on National Land Cover Database (NLCD)

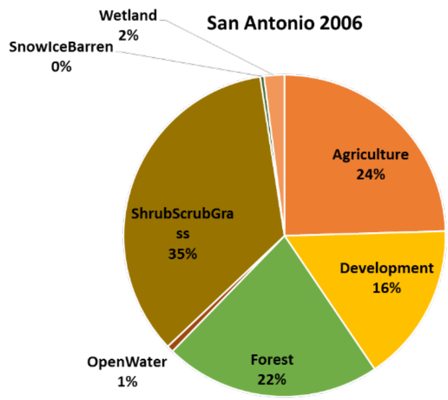

Figure 4 Percentages of land cover in the San Antonio River Basin in 2006 based on Figure 3

3. Results

3.1. Anthropogenic Nitrogen Inputs

The N inputs, especially fertilization and atmospheric dry deposition, were obtained from NANI data and extracted for study region. N loading from human activities in Texas is relatively lower than in other parts of CONUS [*Hong et al.*, 2011], but the gradient of N loading is apparent from west to east, and shows high values of input for coastal regions near the Gulf of Mexico (Figure 5). Among the NANI components, the amount of N fertilizer is ranked as the highest contributor of N loading. The database uses 1987–2006 county-level, nutrient-input estimates by the United States Geological Survey (USGS) for fertilizer application as well as a grid-scale Community Multiscale Air Quality (CMAQ) output for deposition, which was pulled annually from 2002 to 2006 [*Ruddy et al.*, 2006; *Schwede et al.*, 2009]. NANI was first generated for county-level Texas, and then extracted for study region. NANI only provides data for a limited number of years because of database availability. USGS provides the nutrient-input estimates every five years from 1987 to 2006, and the CMAQ output includes annual deposition rates for only five consecutive years. Therefore, the fertilizer data from NANI are interpolated to provide consecutive annual rates. The dry deposition rate from NANI are averaged through the five years, and the annual averaged dry deposition rates are used through the model simulation period. To apply NANI in the Noah-MP-CN model as inputs, the data was converted from GIS-based polygon to grid-based NetCDF (Figure 6). The Noah-MP-CN model uses NANI as parameters for the annual rate of N fertilizer application and dry deposition.

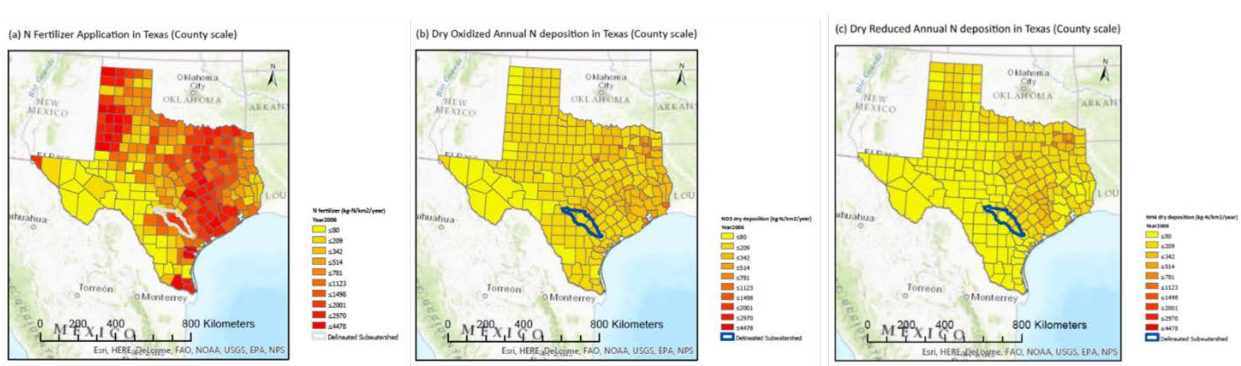

Figure 5 County scale NANI for Texas, 2006

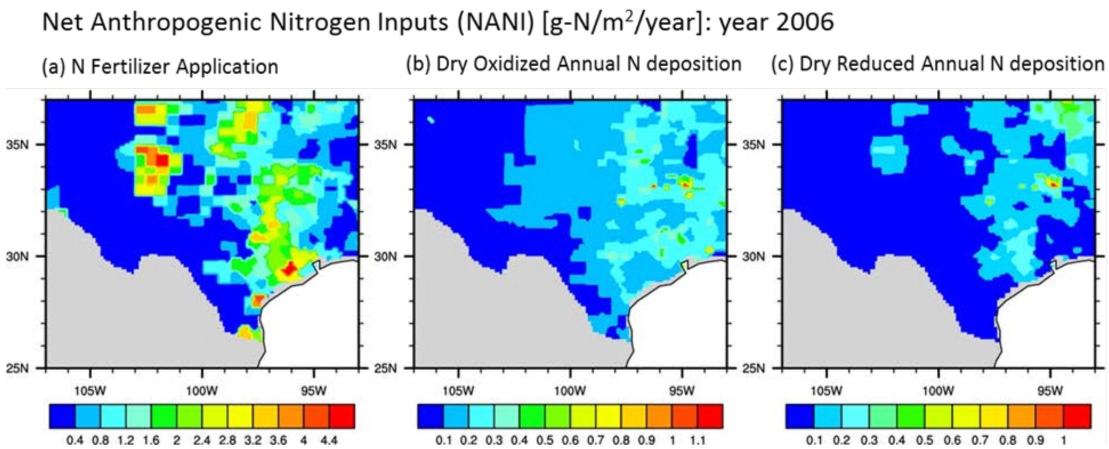

Figure 6 Grid-based NANI for Texas, 2006

In Figure 7, the largest anthropogenic N source is fertilization in the San Antonio River Basin. The spatial distribution of fertilization implies the impact of land cover; N fertilizer is applied dominantly in developed area and agricultural land. Dry deposition contributes for nitrogen loading less than fertilizer application does. I compared NANI with Texas Anthropogenic N Budget (TX-ANB), which used Texas specific database to estimate N budget [*Meyer*, 2012]. NANI Fertilizer shows higher rate than TX-ANB. This difference is caused by how they distribute N fertilizer for counties. Both of them use fertilizer sales data from USGS and Texas State Chemist (OTSC). USGS provides fertilizer sales data for entire state, and distributes the inputs for each county based on crop growth, while OTC provides fertilizer sales data for each county in Texas. Atmospheric dry deposition from NANI was not compared with one from TX-ANB, because both of them used CMAQ output to estimate dry deposition.

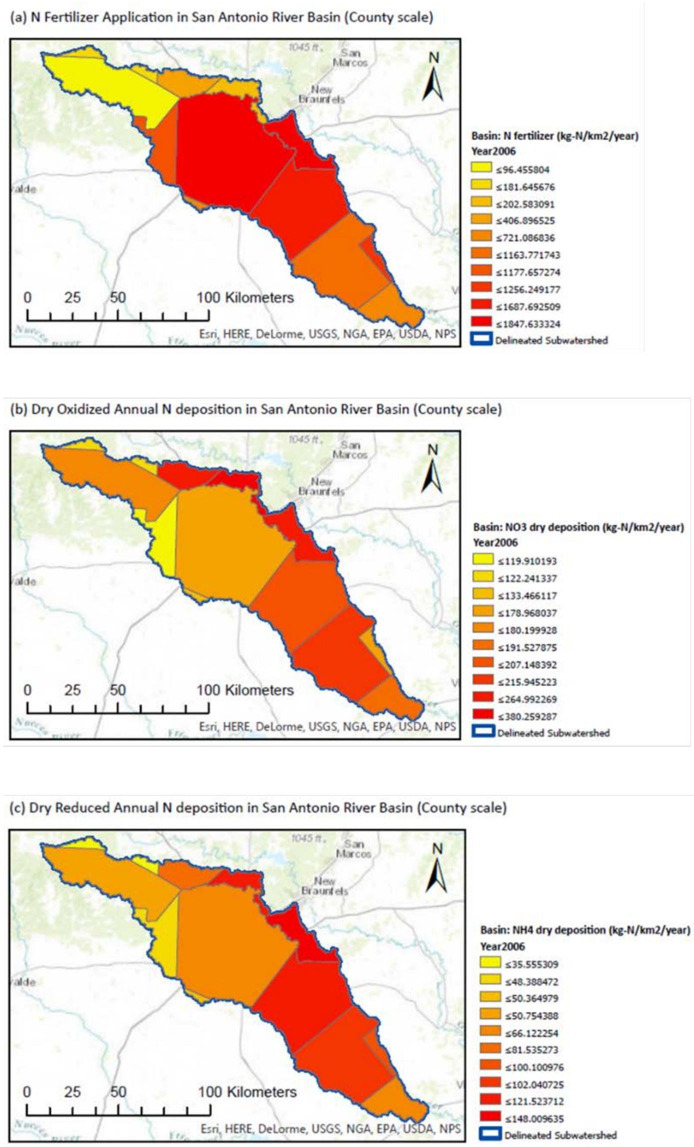

Figure 7 Extracted NANI in the San Antonio River Basin (a) N fertilizer application, (B) Dry Oxidized annual N deposition, and (c) Dry Reduced annual N deposition

3.2. Modeled Nitrogen Loading

Nitrogen leaching from soil is modeled using Noah-MP-CN model. Nitrate transports with surface and subsurface runoff in the model. To calculate the amount of nitrogen along runoff, the concentration of nitrate is firstly calculated. The concentration of nitrogen is determined by the amount of nitrated remained in soil layer after other processes, the fraction of porosity, and saturated water content. Then, this concentration is multiplied by the volume of runoff and converted into daily nitrate loads based on terrestrial N inputs and dynamics. Figure 8 shows the daily nitrate concentration across Texas, and the result shows high concentration in western Texas. This implies the nitrogen loading depends not only on N inputs, but also on soil N dynamics such as mineralization, nitrification, and plant uptake.

RAPID model uses runoff from Noah-MP-CN outputs, and provides streamflow (Figure 9). Using RAPID process which assigns a grid to corresponding river reach, the gridded nitrate concentration can be directly poured into the streamflow or largely stored in soil.

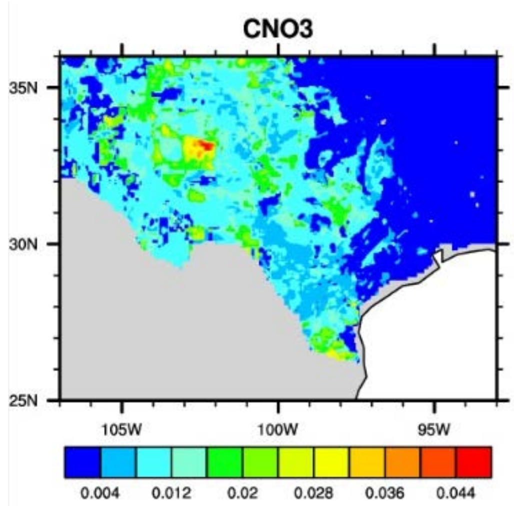

Figure 8 Daily nitrate concentration (2008-05-12, g-Nm2)

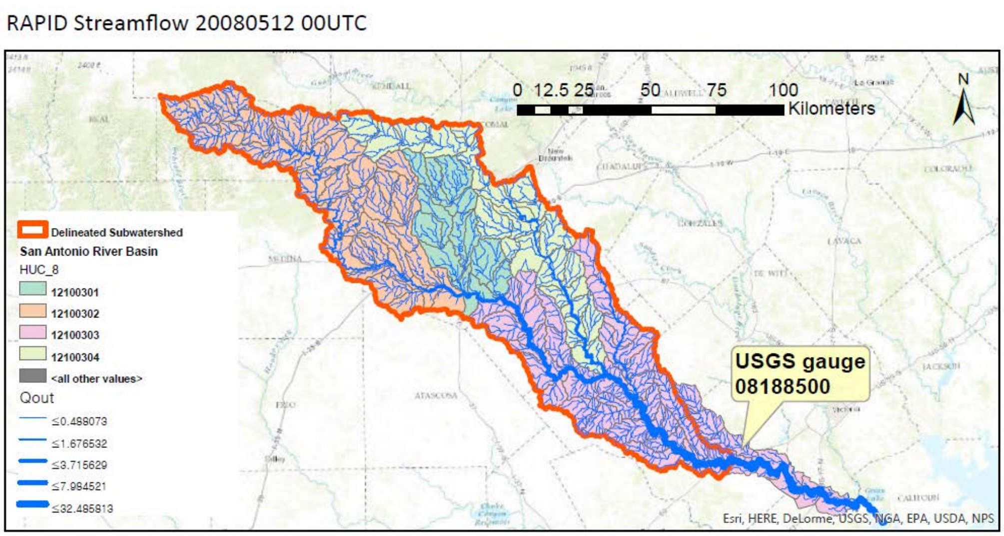

Figure 9 RAPID streamflow (2008-05-12 00UTC, m3/s)

4. Conclusion

The landscape has an effect on coastal oceans under the impact of climate and land use. Nutrient transport and processes are critical to link between terrestrial and coastal ecosystems including human influences. This project is conducted as an initial step of connecting different elements of nutrient dynamics on upland watersheds and downstream to provide nitrogen loading. In terrestrial ecosystems, I generated anthropogenic N input data, implemented this input into a land surface model including N cycle, and provided nitrogen leaching from soil. In hydrological cycle, I provided streamflow which transports leached N from soil.

Future work will primarily include calculation of riverine nitrogen fluxes fed by landscape nitrogen. Terrestrial N inputs are estimated by various methods, and the users should consider whether the assumptions, which are used to estiamte N inputs are proper to their purposes.

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