Nitrogen (N): Budgets, Estimated Loads, and Measured Exports

Lisa Helper, University of Texas at Austin, Jackson School of Geosciences

1. Introduction

Understanding the full pathways of nitrogen is critical to reduce hypoxia in the Gulf of Mexico. The lack of oxygen in coastal waters can be largely attributed to harmful algae blooms in coastal estuaries. These large algae blooms eventually are decomposed by microbial populations which take up much of the ecosystem's dissolved oxygen. A feedback loop is produced which results in low dissolved oxygen levels, that are referred to as hypoxic conditions. These conditions can limit fish and plankton populations which can have an effect on the entire ecosystem.

In order to control these conditions, nutrients for these blooms must be limited. Limiting nutrients requires understanding the spatial distribution of sources and transport mechanisms of the sources to the Gulf of Mexico.

Texas is a perfect test case to understand agriculture and urban influences on these hypoxic events. The state contains one of the largest agriculture industries in the United States (NASS US Census 2007) and within the San Antonio and Guadalupe River Basins two major urban areas reside. For this study nutrient influence from the San Antonio and Guadalupe River basins will be examined; both basins have a rich crop nitrogen impact and urban lands. On average, the Guadalupe basin is considered the less urban of the two, more agricultural practices occur within the basin.

Quantification spatially of inputs and sources of nitrogen across Texas (including the basins of interest) has been completed as part of the NASA Interdisciplinary Science Project. Assessment of inputs from agriculture include N fixation from crops and pasture lands, fertilizer input from farming practices, and livestock N input from all types of manure. These sources and inputs have been mapped spatially at county level and the next step is to understand how these sources and inputs get to the Gulf. Modeling the transport can be accomplished through use of RAPID, a river routing and stream flow model (David et al. 2009).

RAPID uses the input data for network connectivity from the NHDplus dataset, lateral land surface inflow from a land surface model, and gauge measurements from USGS NWIS. The model takes the inputs and uses parallel computation to move water down the rivers, ultimately modeling water flow spatially and temporally. An important component of modeling flow is the discharge from the land.

These critical inputs are modeled by a sophisticated land surface model developed at the University of Texas called Noah-MP(Yang 2011); it is a modified version of the former Noah LSM with multi-physics options. Noah-MP uses NARR and NEXRAD for the atmospheric forcing data and a simple discharge model for a runoff scheme. What limits RAPID from nutrient transport modeling currently is nutrient flow/flux capabilities. Through collaboration with Ahmad Tavakoly, a PhD candidate at the University of Texas at Austin, a simple nutrient flow equation has been developed based on principals from (Chapra 2008) which requires quantification of nutrient inputs at catchment level over time. In order to complete this, a GIS was utilized to compile agriculture data from inventory datasets at county level and scaled to catchment level.

2. Methods

In order to understand the full impacts of agriculture and urbanization on downstream coastal environments within the San Antonio and Guadalupe basins, inventory of N inputs from livestock and fertilizer was necessary. The Texas State Chemist Office (SOURCE) provides look-up tables online which estimate fertilizer distribution amounts per year at county level. This information was collected for each of the counties in Texas and symbolized using 'StratMapCountypolys' projected in United States Albers Equal Area Conic USGS version (TNRIS 2011). Livestock inventory data was collected from the Texas National Agriculture Statistics Survey office in Austin, TX (NASS US Census 2007). The total number of animals were accounted for in each county and N kg per animal per year estimates were multiplied by their respective animal total and added to obtain a total input of N for each county as the result of livestock(see table 1).

Animal (number based on Census of Agriculture 2007)	N excretion rates in waste production [kg N animal^{-1}yr^{-1}]
Beef Cattle	58.51
Dairy Cattle	121.00
Pigs & Hogs	5.84
Sheep	5.00
Goats	5.00
Horses	40.00

Chickens (broilers-layers)	0.07-0.55
Turkeys	0.39

Table 1: Boyer et al. 2002 and others have used the above estimates assuming each animal excretes a fixed amount of nitrogen per year.

In addition, the USDA Cropland Data Layer for 2008 (CLD2008)(NASS R&D 2008) was considered to incorporate the lands which contained legumes. Legumes are plants which fix their own N through fungal symbiotic relationship within their root. This additional N source is can be found by considering what types of crops or land classifications are present. Within the basins of interest there existed a lot of range and pasture lands. Estimates from Boyer et al. 2002 suggest pasture lands fix 9,600 kg N per km per year. The lands denoted as pasture lands (scaled from 56m to 1km grid), were isolated by creating a binary raster based on pasture lands alone. These lands across Texas were masked to the two basins and a raster was created with the expected fixation value per km per year(Figure 1).

Eventually up scaling beyond the two basins is a goal, thus a method developed by Ahmad Tavakoly was used to decrease the number of catchments from what typically is seen from NHDPlus data (Figure 2). This quick Fortran code utilized hydrography AV tables to find all rivers with thinnercode equal to one. If thinnercode equaled one, the river segment was selected and a catchment was developed for that specific COMID. This method decreased the number of catchments and COMIDs for RAPID to compute. Although the two basins are small enough computational time is minimal using full NHDplus catchments, this method would prove useful for future projects. Once completed, each catchment contained one single COMID.

In order to total the full impact of nutrients contributed from agriculture sources, the county level N contributions from fertilizer and livestock were converted to concentration of inputs (kg per square kilometer per year) rather than total inputs in kilograms per county. This conversion was done through use of the field calculator in the attribute table. Converting to density of inputs (kilogram per kilometer per year) allowed for overlay functions to be utilized in transferring county level information to catchment level(Figure 3).

Overlay tools within the Analysis Toolbox were used to scale the density of N inputs from county to catchment level. The Intersect function created new feature classes which contained the attributes from the counties as well as the catchments (figure 4). Each catchment contained one COMID which could be used in to compute flow in RAPID.

Because the overlap of counties and catchments occurred, summary statistics was used to obtain the total density of N input from agriculture. Field calculations were then performed on attributes to get total input values for each catchment (figure 5).

3. Results and Analysis

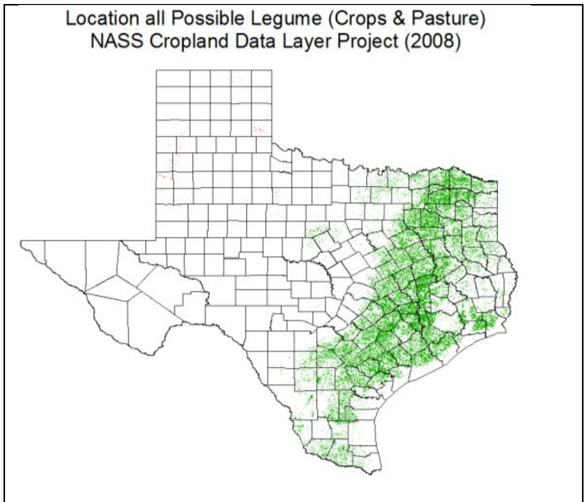

Figure 1: All legume land across Texas symbolized from the USDA National Crop Land Data Layer project from 2008

Legume land across Texas was considered and noted that most of the land containing legumes (peanuts, soybeans, or pasture) through the San Antonio and Guadalupe region was pasture lands (Figure 1). The impact of fixation from these lands is based on an estimate developed for the full United States that depends on pasture lands being home to legumes such as clovers. Texas however, is frequently overgrazed through pasture lands and it is likely there are fewer legumes across the lands fixing less nitrogen. In addition, drought can limit the growth of clovers in pasture lands, thus counting fixation in pasture lands as a fixed rate applicable to the whole U.S. would produce a large fixation input error during drier years.

Decreasing the number of catchments was also done (figure 2). This was done with the intention of eventually expanding this work beyond these two basins. The resolution of the N data from livestock and fertilizer limits the accuracy and spatial representation of the N inputs. As a result, changing the shape of the catchments likely doesn't reduce accuracy considering the location of N inputs within each county is unknown.

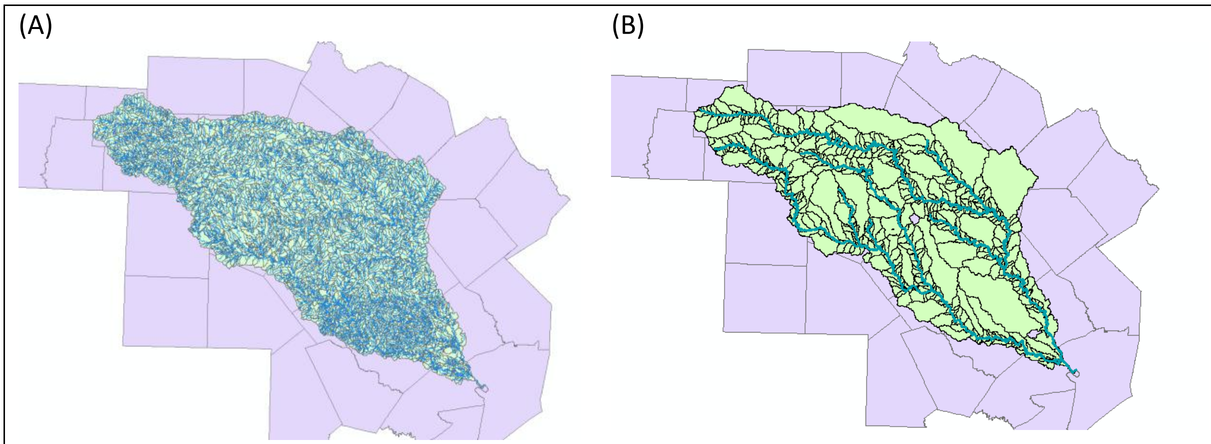

Figure 2: NHDplus Data has many river segments and catchments. The number of rivers and catchments were decreased using a simple Fortran script and NHDplus thinner code (thinner code=1) with Hydrography AV tables. Panel (a) displays NHDplus catchments and stream segments without decreasing with thinnercode=1 and (b) shows the decreased number of rivers and catchments after using thinnercode=1.

Since spatial input information is unknown, concentration (kilograms per kilometer squared per year) was calculated (Figure 3). This created the concentration attribute which was spatially joined to the catchment attributes by use of the intersect tool so each polygon now had a N value (Figure 4).

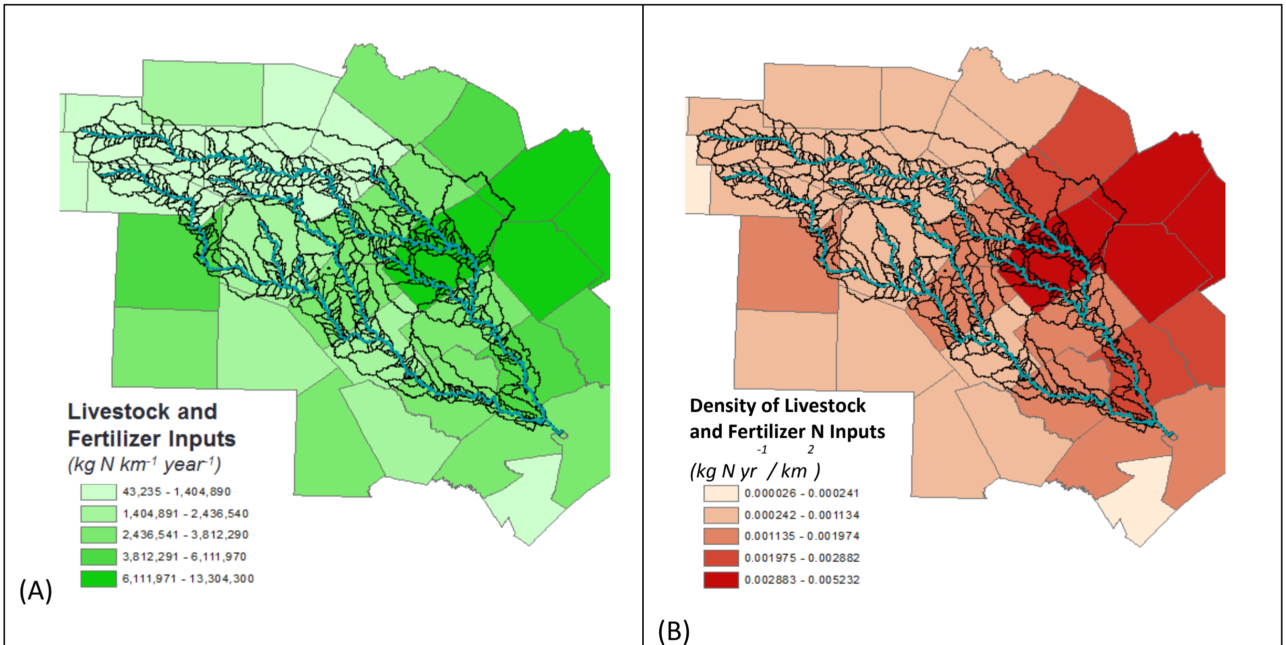

Figure 3: Each county was symbolized for inputs of nitrogen from livestock and fertilizer (totals were added to form one feature class). Using a simple density calculation (input/county area), input was converted into from kilograms input per year (A) to kilograms input per year per kilometer (B).

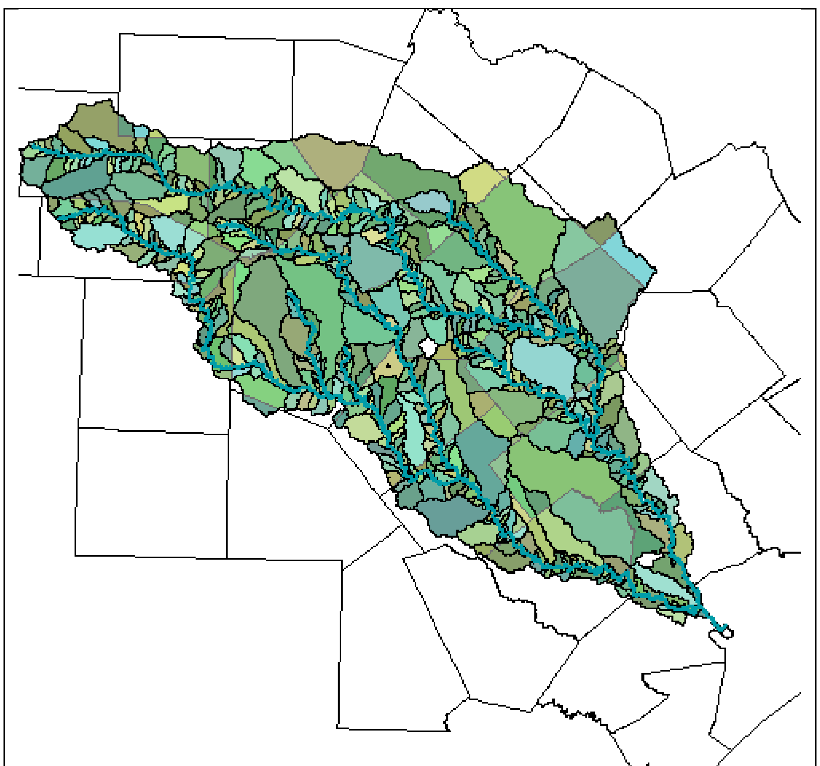

Figure 4: Catchment and county attributes joined using the overlay intersect tool. Each new polygon shares both county and catchment attributes, which in this case includes COMIDs and nitrogen inputs.

Each catchment had a COMID corresponding to a river segment, thus summary statistics was computed on all polygons that contained the same COMID. This resulted in a N concentration of input for each catchment/COMID. This was then multiplied by the area to get total inputs of N from agriculture per catchment per year (Figure 5).

Full estimated loads were calculated for each of the basins (figure 5) and compared with output from Jim McClelland's research group at the Texas Marine Institute. The input of fertilizer from the San Antonio, which can be considered the "more urban" case, had a larger contribution from fertilizer and a lesser contribution of N from livestock. The total inputs were larger in the Guadalupe basin, which is considered the more agricultural region. This is what originally was expected. When looking at the NH4 exported to the Gulf (what was measured from McCleland), the Guadalupe also saw much high concentration of NH4. The total over 2009 was ~2.3 mg/l for the Guadalupe and ~1.95 mg/l for the San Antonio, these measurements are taken only at high flow events, thus creating a bit of a high concentration bias. However, if fertilizer and livestock inputs are considered, the total input from fertilizer and livestock from the San Antonio Basin is 1.105E+9kg and the total output concentration is 33.6E+9kg. This indicates there a missing N amount.

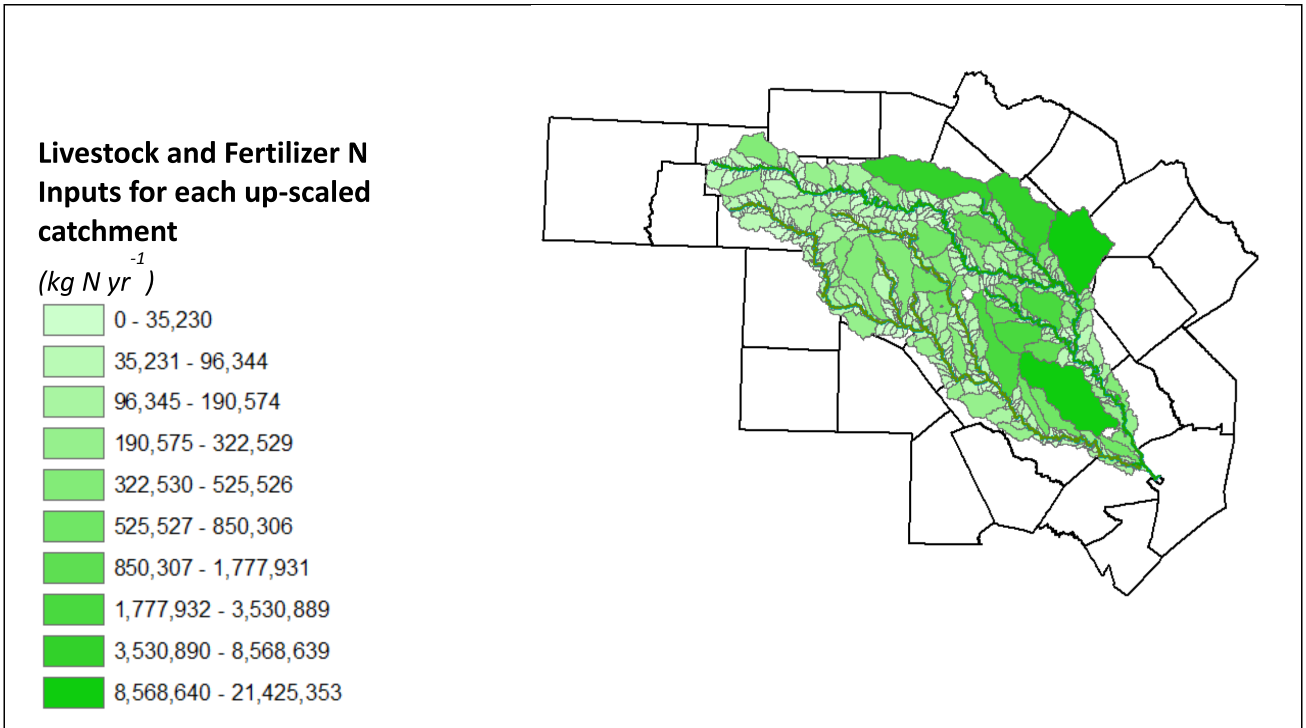

Figure 5: Kilograms input of nitrogen per year for each catchment within the San Antonio and Guadalupe Basin.

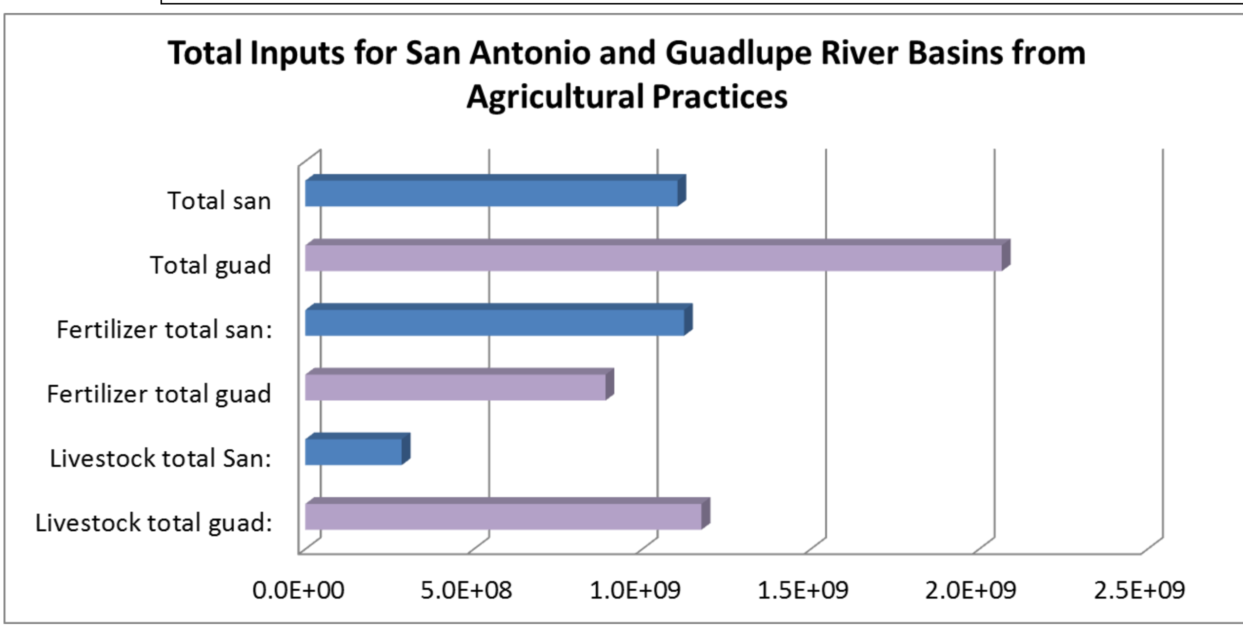

Figure 6: Full inputs across total basin area (San Antonio and Guadalupe) of fertilizer and livestock.

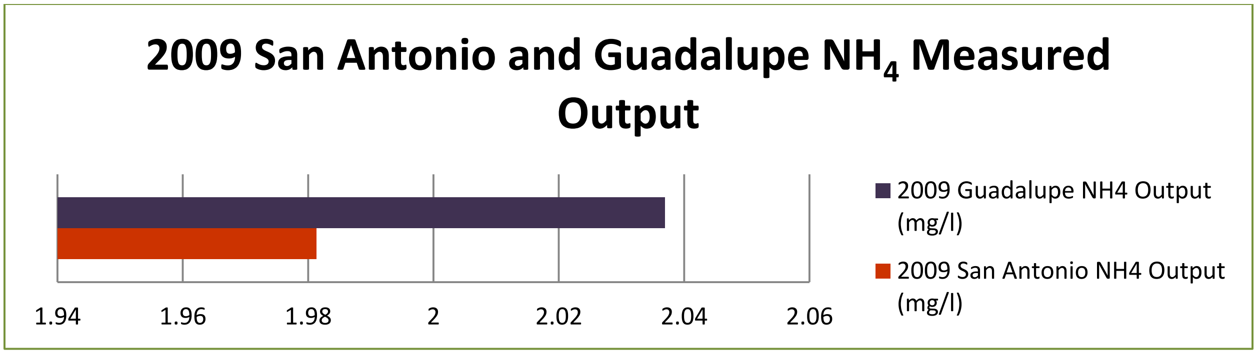

Figure 7: San Antonio and Guadalupe measured NH4 output.

Multiple problems with this study lead to possible resolutions as to why the outputs at the San Antonio are larger than the inputs of N. Firstly, the measurements were taken at high flow events creating a high concentration bias. In addition, inputs considered were only of land based inputs such as fertilizer application and manure. From manure and feedlots where there are high concentrations of animals/manure, there is a lot of NH4 released in to the atmosphere. This gas eventually is deposited through wet scavenging or dry deposition. It can be considered an additional input and one that shouldn't be under estimated. The atmospheric component could be the missing input; however previous literature (Howarth et al. 2002a; Boyer et al. 2002) suggest the atmospheric component will not cover this large of a deficit. Further work needs to be pursued to fully understand the full pathways and inputs of N to the Gulf.

4. Conclusions and Future Work

Understanding the N cycle is critical in preventative efforts for limiting hypoxia in the Gulf of Mexico. Quantification of sources spatially is the first step in improving nutrient pollution. From this study, ArcGIS has been proven to be successful in taking inventory N data available from county to catchment level; this process is critical for future applications of nutrient export modeling. The process of obtaining catchment level N information however, enabled comparisons to be made to measurements at of NH4 outputs at two stream gauges at the base of the San Antonio and Guadalupe basin. This assessment indicated that the total inputs from the Guadalupe basin was 2.067E+9 kg, however the output was considerably more. This was also the case for the San Antonio; the input was 1.03E+9 kg and the output for the total year was 33E+9 kg. The deficit shown in the input might have been a factor of the high concentration bias introduced by the measurements being taken only at high flow events when N concentration would be highest. The lack of consideration from atmospheric deposition could also play a large role.

Future work will be spent refining the current budget with hopes of creating high resolution inputs. Atmospheric deposition also needs to be added to the budget. Ultimately the goal is to produce a high resolution budget at catchment level which can be utilized for nutrient export modeling with RAPID.

5. References

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for more information about this data, visit the above website or ask for more info:
lhelper@mail.utexas.edu

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