Total Nitrogen Input, Output, and Land Cover in the Mission and Aransas Watersheds

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Introduction

Estuaries serve as the link between watersheds and the coastal ocean via transporting and processing materials. They also have great economic and ecological values. In the Gulf of Mexico, estuarine ecosystems are the home and nursery grounds for numerous shellfish and finfish species that support the regional and national economies. Estuarine-dependent shrimp, menhaden, blue crab, and oyster fisheries are of particular importance in the Gulf of Mexico. (NOAA, 1990)

Excessive nutrient (nitrogen and phosphorus) input to estuaries can negatively impact estuary ecosystems in several ways, including stimulate algal blooms that lead to reduced water transparency and increased bottom-water hypoxia, which in turn exert a range of ecological consequences, including mortality of marine animals, modulation of food web structures, and alteration the oxidation-reduction balance in marine sediments and related biogeochemical processes (Bricker et al., 2014; Kemp et al., 2009). Humans produce and apply huge amount of N to watersheds via agricultural, industrial, and urban activities. However, only a small portion of the N application is transported to streams, thanks to watershed processes such as denitrification in soil, decay in streams, and plant-uptake (Ator et al., 2011). On the other hand, human activities can also alter the land cover of watersheds; hereby decrease watersheds' ability to process N loadings. For example, the vast impermeable surface of urban land causes greater volume of overflow during storm events in comparison to natural permeable surfaces, and transport N directly to rivers not allowing soils and plants to process it (Ator et al., 2011).

The climatic and geographic conditions in South Texas feature highly variable inter- and intra-annual precipitation, high storm flow and low base-flow discharge, intense agriculture activities, and low forest percentage land cover. These conditions are presumably less favorable for N processing by watersheds, and thus impose challenges to watershed managers. Therefore, a better understanding of the relation between the allocation of N loadings in watersheds, the land cover of watersheds, and the riverine N flux would help us evaluate the watershed's ability to handle N loadings, thereby help make better watershed managements. The Mission and Aransas River watersheds (MR and AR) in South Texas reflect the features described above well, and thus were selected as the study sites of this project.

Toward that end, in this term project, I specially
(a) obtained nutrient flux estimates in the down-stream locations of MR and AR;
(b) compiled land cover data for the MR and AR watersheds and investigate the changes in land cover over the past two decades;
(c) obtained the TN input for MR and AR using the TX-ANB dataset(Meyer, 2012); and
(d) compared the TN input, output, and land cover in these two watersheds.

Study Site

This study focuses on the Mission and Aransas watersheds and the Copano Bay where they drain. The Aransas River flows into the west end of Copano Bay, whereas the Mission River flows into Copano Bay more centrally, via Mission Bay (Figure 1). Copano Bay and the lower reaches of the Mission River are a part of the Mission–Aransas NERR. The Aransas watershed drains 2,146 km2 while the Mission watershed drains 2,675 km2. Both watersheds also include multiple permitted wastewater treatment plants (WWTP)(Mooney and McClelland, 2012). The Aransas watershed discharges 14.4 million liters per day (mld) from 10 WWTPs, with 8.3 mld from one treatment plant upstream of our sampling site near Skidmore whereas the Mission watershed discharges only 1.9 mld from its three WWTPs (USEPA, 2008). In general Mission watershed is dominated by shrub land and Aransas is dominated by croplands. Their land cover distributions and temporal trends over past 15 years will be discussed in greater detail in the result and discussion section.

Copano Bay is a shallow estuary with an average depth of 2 m, average tidal range of 0.15 m, surface area of 463 km2, and volume of 0.93 km3. On average, evaporation exceeds precipitation in this area: Average precipitation is 88.6 cm/year and average evaporation 151.3 cm/year (Armstrong, 1982).

Mission and Aransas Watersheds

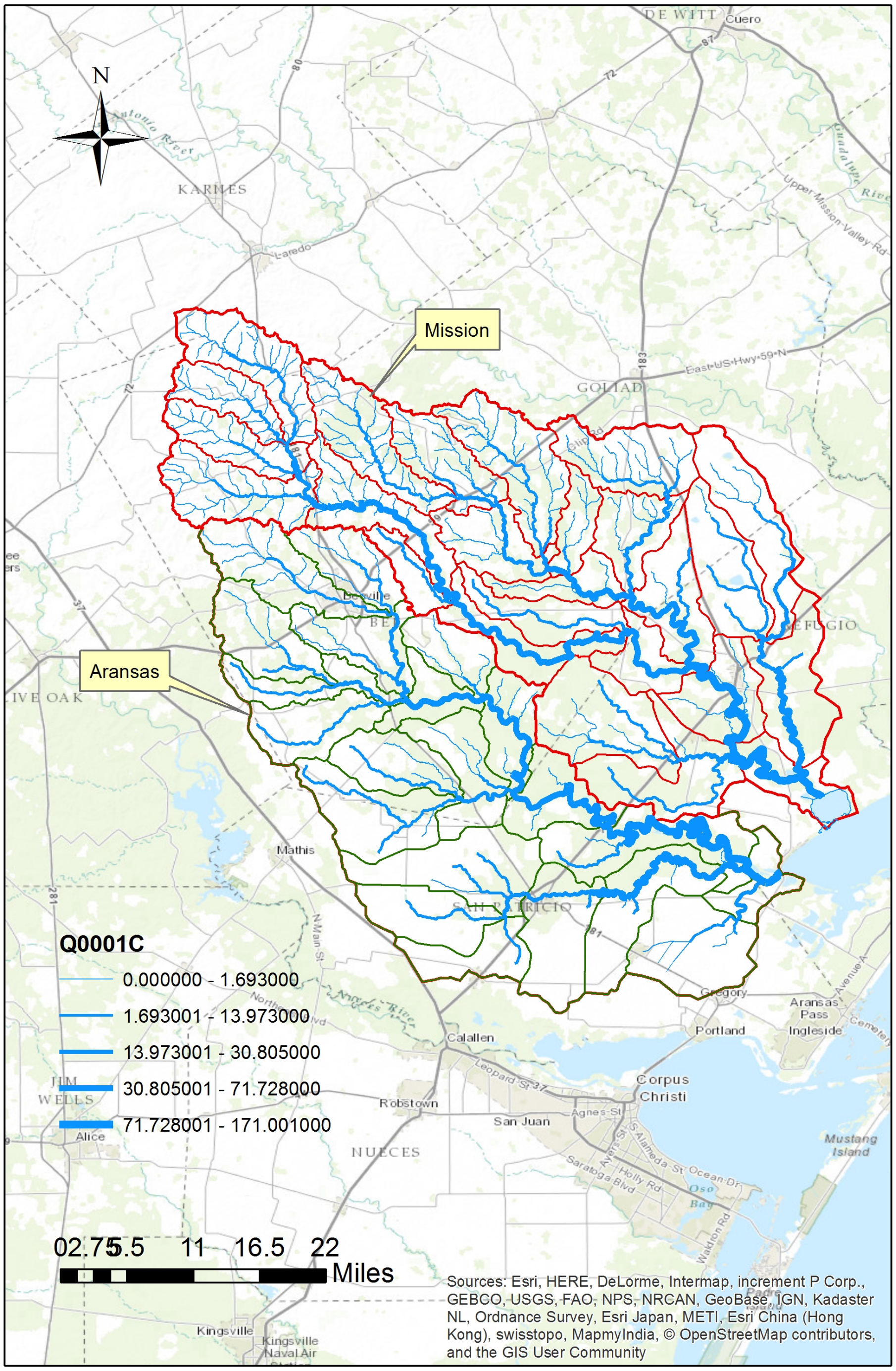


Figure 1. The Mission and Aransas Watersheds.

Data and Methods

The nutrient fluxes of MR and AR from 2007 to 2008 were reported by McClelland et al. estimated by LOADEST model. The model was specified as

$$\ln(x) = a0 + a1\ln Q + a2\ln Q^2 ,$$

where x represents flux or concentration, and Q equals discharge. The model was calibrated with discharge data and total N flux or concentration measured at the sites. Daily discharge data were available at the USGS real-time water data for Texas website (http://waterdata.usgs.gov/tx/nwis/rt). The total N was measured near Refugio on MR and Skidmore on AR, where USGS measures discharges.

The land cover data were downloaded from the National Land Cover Database (NLCD, http://www.mrlc.gov/index.php). Although the database covers land cover data from 1992 to 2011, in this study only 1992, 2001, and 2006 data were used due to the time period of the total N flux data. The land cover raw data were for the entire US and has 20 different land cover types under 8 classes, which are water, developed, barren, forest, shrubland, herbaceous, planted/cultivated, and wetlands. The raw data were processed using ArcGIS's "extract by mask" function to get the land cover for the study sites. And to simplify the land cover classification, only land cover classes were used in land cover distribution mapping and quantitative comparison.

Total N input data were obtained from the TX-ANB dataset via personal communication with the author. The original TX-ANB was built at county-level for 2008 and 2009, but was re-constructed by (Tavakoly et al., 2015) for NHDPlus catchments. Their TX-ANB data were then compiled in this study to obtained the N budget for our AR and MR watersheds.

The total N fluxes (in kg/year), land cover (km2 or percent), and N budget (kg) were all exported as CSV and compared and plotted in Microsoft Excel.

Results and Discussion

Total N fluxes of the Mission and Aransas rivers

The total N fluxes of MR and AR were heavily driven by discharges caused by summer storm events. Total annual N flux in 2007 was 9 times higher than in 2008 for MR and 6 times for AR, probably because 2007 was a wet year whereas 2008 was relatively dry. Similar to the fact that discharge is driven by storms, in the wet year (2007), N flux was also dominated by storm events, with 96% annual flux generated during storms in MR and 86% in AR (Table 1). Comparing between MR and AR, in the wet year MR transported more N flux than AR but in the dry year MR did much less (Figure 2). Such pattern becomes much stronger when fluxes are normalized to the area of the two watersheds, as MR basin is larger than AR, its flux per area in the dry year was much less than AR. In general, both rivers generated higher N fluxes during the wet year, but MR had much less flux in dry conditions than AR. MR's less N flux during base-flow condition may be related to its less WWTP discharge, which could be the major source of N in base flows. The difference in the land cover distributions of the two basins may also contribute to the flux pattern, and will be discussed later.

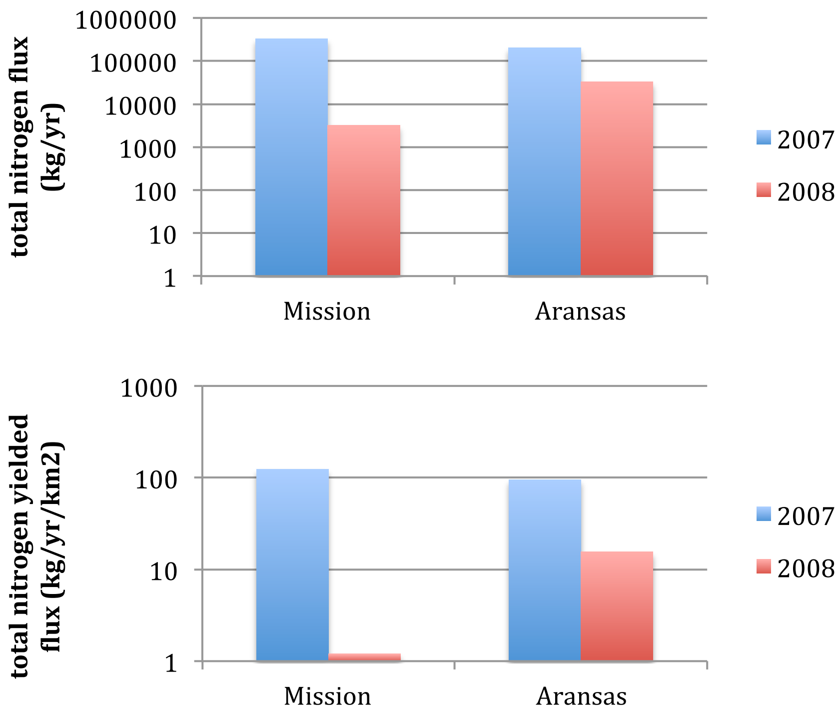


Figure 2. Total nitrogen flux and yielded flux of the Mission and Aransas rivers in 2007 and 2008.

	Mission				Aransas			
	Annual Flux (kg/yr)		% during storm		Annual Flux (kg/yr)		% during storm	
	2007	2008	2007	2008	2007	2008	2007	2008
Nitrate	32547	262	96	5	67324	22376	66	23
Ammonium	12242	142	94	4	5492	773	90	73
DON	195815	1742	97	8	54600	5388	95	76
PON	91286	1057	95	3	77496	4786	97	83
TN	331890	3203	96	6	204912	33323	86	41

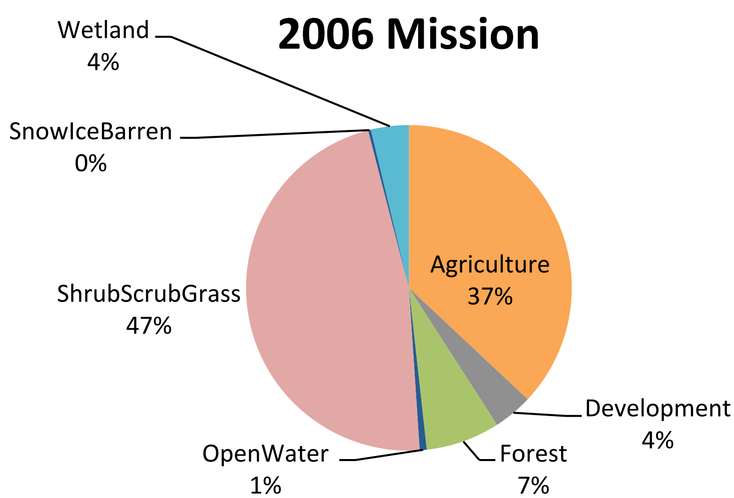
Table 1. The annual flux and the percent flux during storm events of nitrate, ammonium, DON, PON, total N of Mission and Aransas River in 2007 and 2008.

Land covers of the Mission and Aransas watersheds and their changes over past two decades

Mission and Aransas basins are two adjacent watersheds, but have very different land covers (map 1, appendix). In the Aransas watershed, more than 60% land cover is agricultural land, and the percentage of developed land is relatively high. In contrast, the Mission basin is dominated by shrub land, and has lower developed percentage, and higher forest and wetland, in comparison to the Aransas, based on the NLCD 2006 data. In general, Aransas basin is more human-impacted than Mission.

Temporally, agricultural and developed lands have been increasing for both basins over the past 15 years. In Aransas, the area has increased 32% in agricultural land and 427% in developed land, while in Mission the growth rates are 189% and 838%. Forest, shrub, and wetlands, on the other hand, have shown decrease-then-increase trends in both basins. These three types of land cover all have experienced dramatic decrease from 1992 to 2001, and a slight recovery from 2001 to 2006. Shrub land's recovery rate exceeds forest, probably because forest has degraded to shrub after human activities.

To sum up, Mission basin seems to be less impacted by human activities, with higher portions of shrub, forest, and wetland and lower agricultural and developed land than Aransas, as of in 2006. However, Mission has also seen dramatic increase in the three natural land covers and decrease in the latter two human-activity land covers. The result seems to suggest, both two basins is going to be more human impacted, and Mission may change faster.



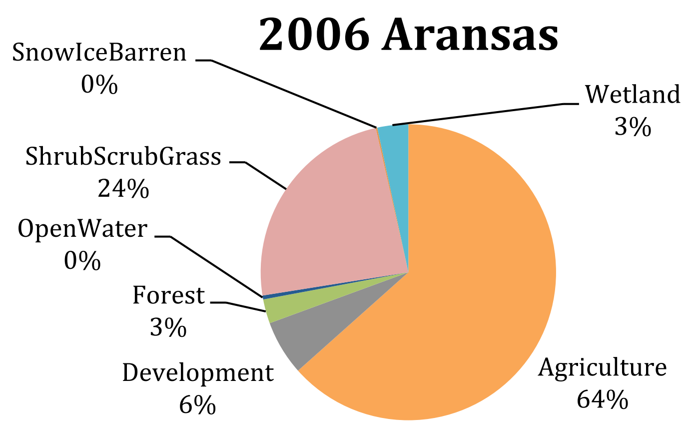
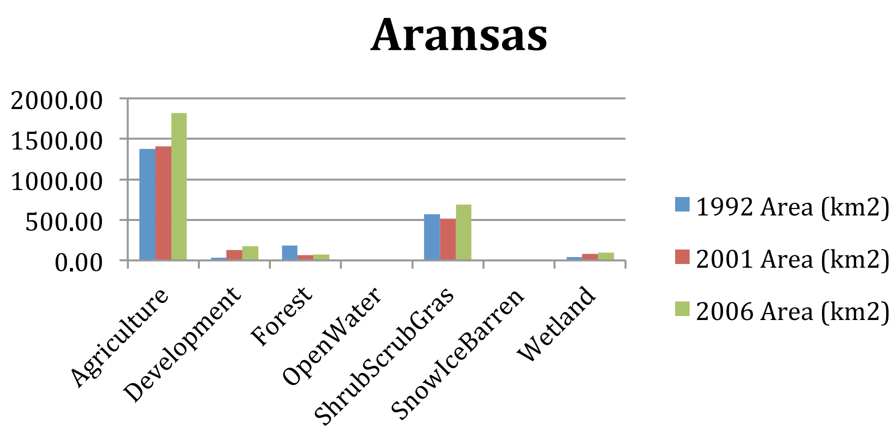


Figure 3. The percentage of land covers of Mission and Aransas basins in 2006.



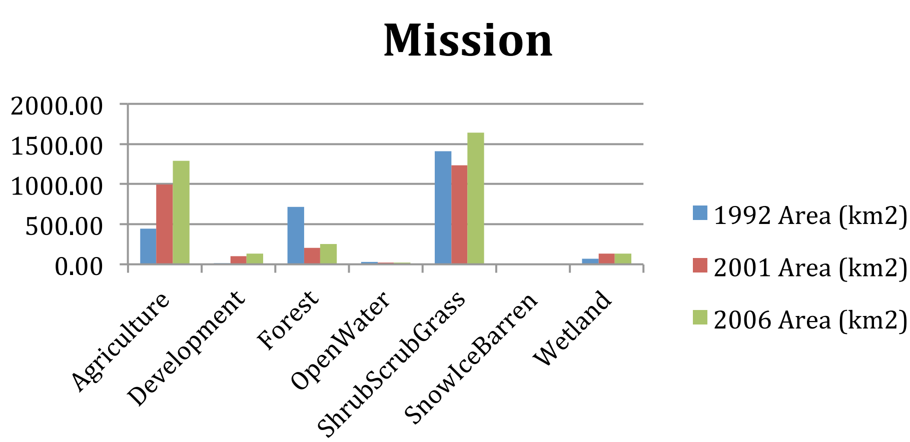


Figure 4. Temporal changes of land covers in Mission and Aransas basins from 1992 to 2006.

Nitrogen loadings in Mission and Aransas basins

Nitrogen loadings were only available for 2008 and 2009. The N loading map can be found in appendix (map 2). Similar to total N flux, Mission had lower N input than Aransas, and the difference is even more evident for N loading yields, as shown in Figure 5. Between years, AR has witnessed a mild reduction in N input, whereas MR had a slight increase. Such change may reflect N controls in AR and agricultural expansion in MR, which agrees with the land cover trends.

The N loadings were mapped for 2008 only to demonstrate the spatial distribution of N input, as the pattern didn't change obviously for 2009. The allocation of N input in general coincides with the land cover map; agricultural lands on the south Aransas basin have the highest N loading probably due to fertilizer applications, whereas forest and shrub land in Mission have less N loadings.

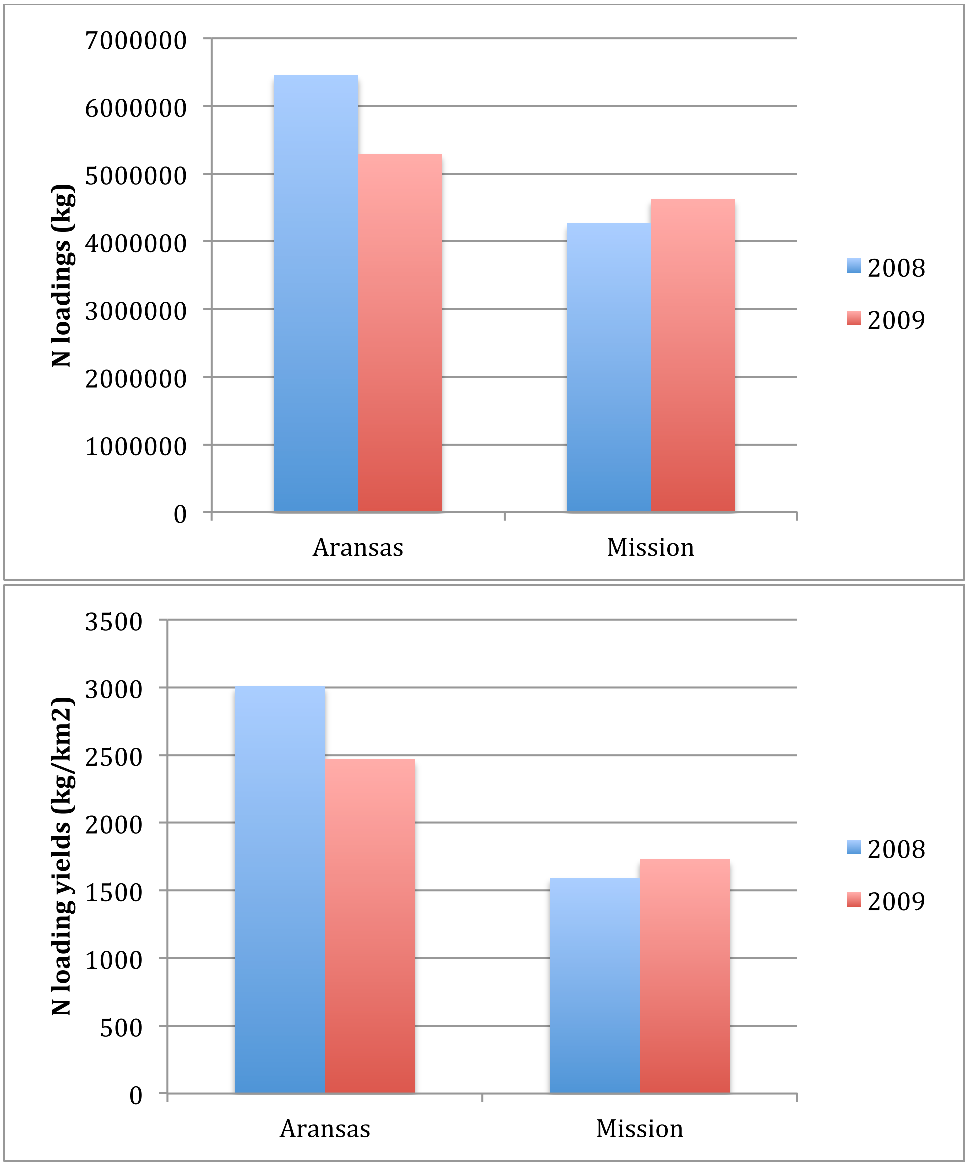


Figure 5. Annual N loadings and loading yields in Mission and Aransas basins in 2008 and 2009.

The relationship between N loadings and N riverine fluxes

The comparison between N loadings and riverine fluxes is limited by the availability of data, especially the lack of flux data of the sub-watersheds of the two basins and the inconsistency of the years of the two datasets (N loadings are for 2008 and 2009; N fluxes are for 2007 and 2008). N loadings tend to be more stable in compare to fluxes (figure 5) with 18% decrease in Aransas and 8% increase in Mission; thus they are extrapolated for 2007 assuming the same changing rate. The portion of N loading that doesn't appear in river flux is considered removed or stored in watersheds via processes such as denitrification, plant up-take, or mineralization. This portion is referred to as watershed retention and is calculated as

$$Retention = 1 - \frac{N\ flux}{N\ loading}.$$

Both Mission and Aransas had high N retention rates from 96% to almost 99.96% (Figure 6). Mission generally had higher retention rate than Aransas, possibly due to its more forest, shrub, and wetlands where N removal and storage processes are more effective. In contrast, Aransas has more developed and agricultural lands, where impermeable surface, tillage, and ditches could negatively impact N processing. Another factor may contribute to Mission's higher retention rate is its lower WWTP discharge. WWTP discharge contains high N content and is discharged directly to rivers, which when close to sampling locations, can greatly raises fluxes. Aransas has more WWTP than Mission, and the sampling location near Skidmore is downstream to a WWTP. Both basins had lower retention rates in wet year than in dry year, which may be related to the storms when high surface flow washes lots of N deposited on surface into rivers and short water retention time doesn't allow N to be processed in streams.

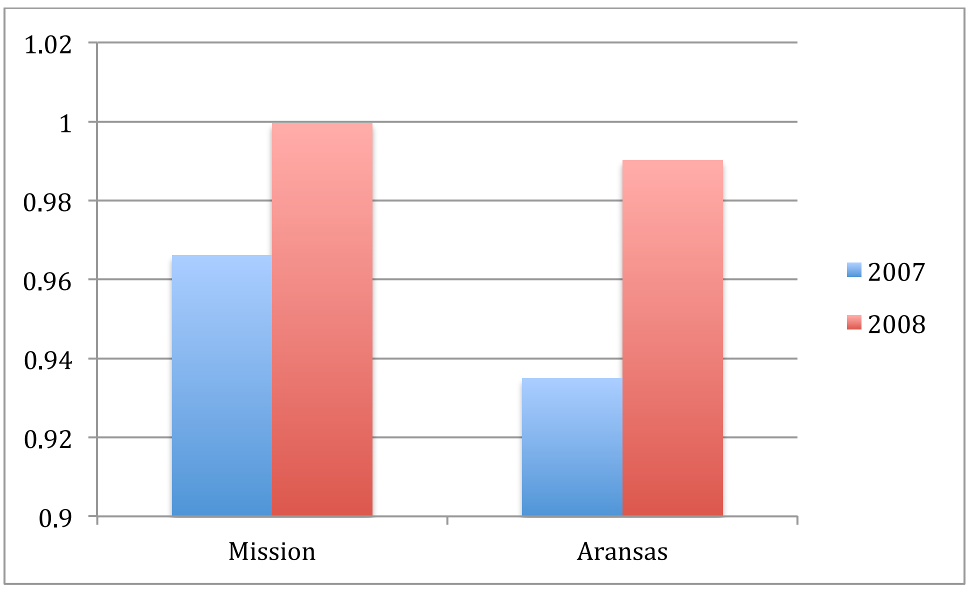


Figure 6. Watershed N retention rate of Mission and Aransas in 2007 and 2008.

Conclusion

Mission and Aransas watersheds in general are effective in processing N loadings, especially during base-flow conditions when N retention rate can reach up to 99.96%. Mission basin was more effective than Aransas, possibly due to its more natural land cover with higher portions of shrub, forest, and wetland that are favorable to N removal and storage processes. However, the temporal trend shows that Mission is losing its forest and wetlands turning into agricultural and developed lands over the past 15 years. Such change in land cover combined with the factor of climate change, which may lead to more storm events, could lower Mission's ability to process N loadings, and we may see more N input from these two basins to the Copano Bay in the future.

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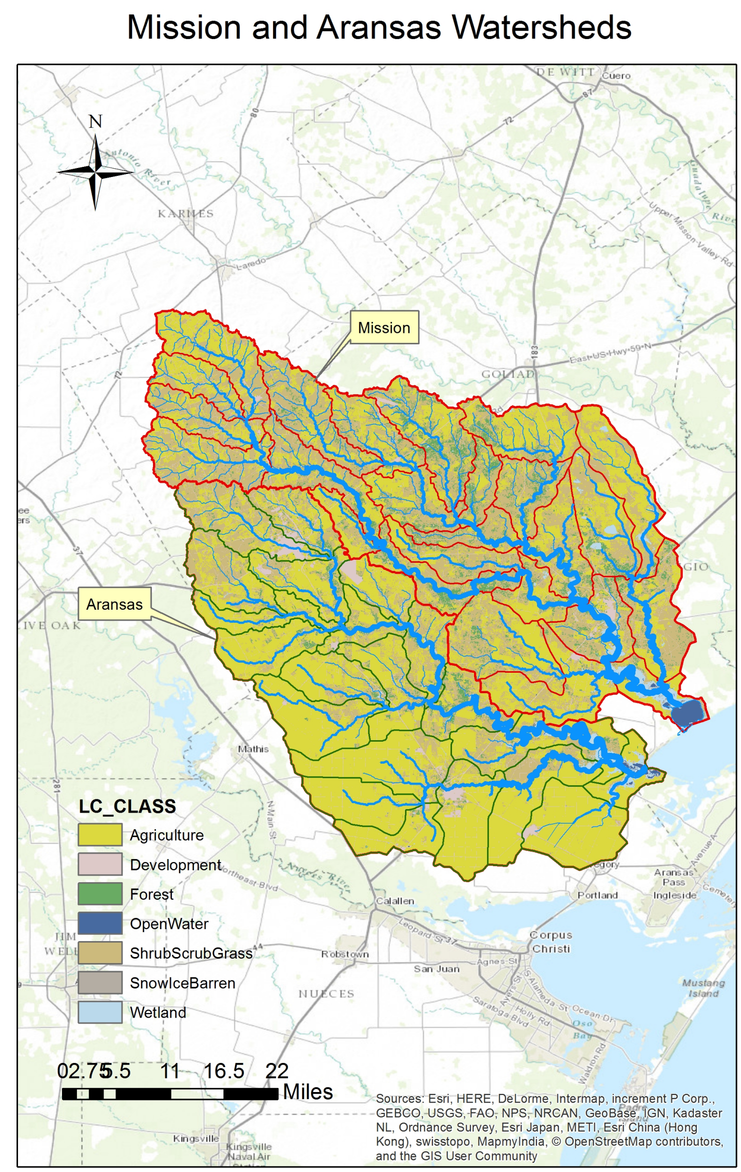
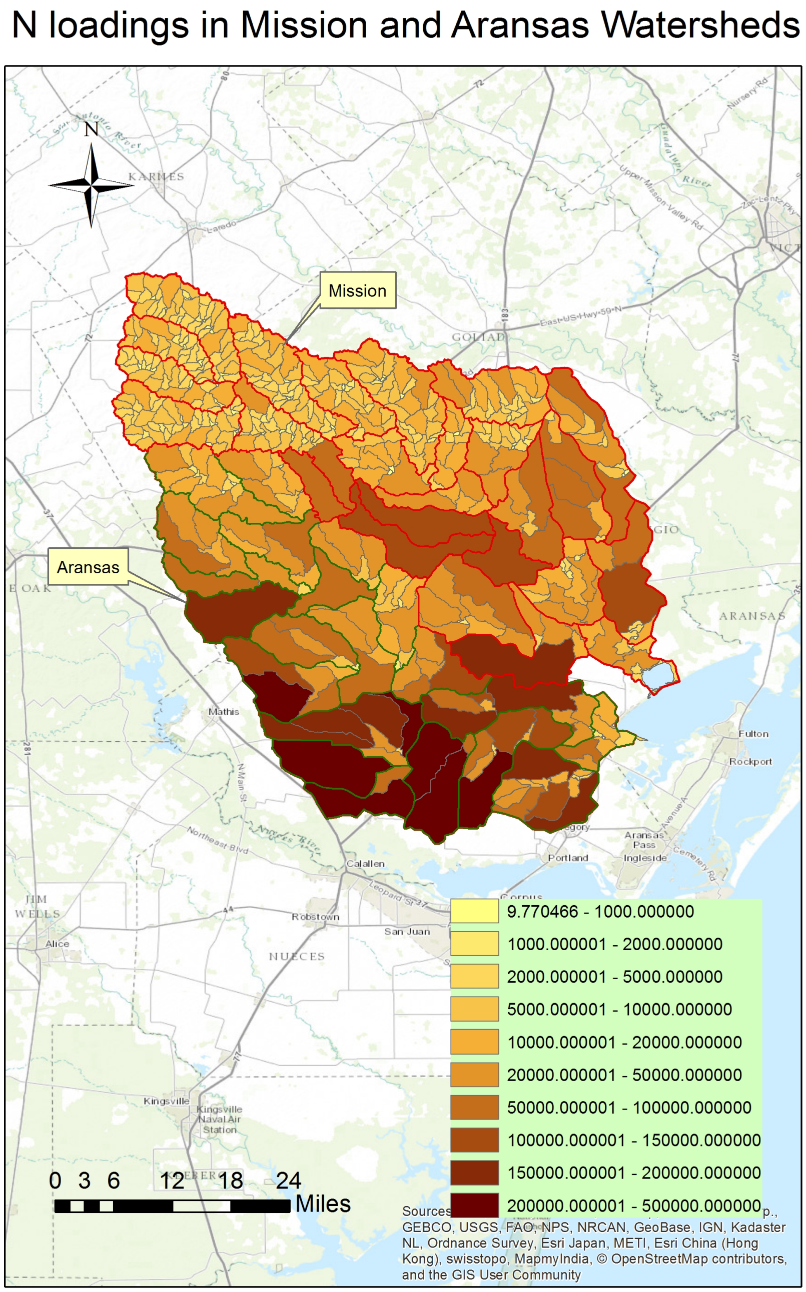
Appendix



Map 1. The land cover map of Mission and Aransas Watersheds. Land cover data come from the NLCD 2006 dataset.



Map 2. The N loadings of Mission and Aransas Watershed. N data come from the TX-ANB dataset and were compiled for these two watersheds. The loadings in the legend are in kg/year.