North Carolina's Section 319 NPS Program
Final Report for EW07015

TITLE PAGE

Project Title: Evaluation and Remediation of Nitrate Flux from Biosolid Application Fields to Surface Waters in the Neuse River Basin

Sponsor: Section 319 Non-Point Source Pollution Control Grant

Project Number: NPS 319 Contract EW07015- FY06

Contract Period: 9/25/06-12/25/2007

FY2007 Funds: $101,838

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Tim Woody, Reuse Division, City of Raleigh, Public Utilities Division
Dr. Robert Evans, Biological & Agricultural Engineering, NCSU
Dr. John Fountain, Marine, Earth & Atmospheric Sciences, NCSU

Reporting Period: Fifth Quarter 2007 FINAL REPORT

Report Date: February 15, 2007

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

This project is located in the Upper Neuse River Basin at the Neuse River Wastewater Treatment Plant (NRWWTP). The NRWWTP is located on the Neuse River just north of the Wake County/Johnston County boundary. (SubBasin 03-04-02, HUNC 0302021100030, Figure 1). Biosolids have been land applied at the NRWWTP since 1980 on ~1030 acres of farmland owned or leased by The City of Raleigh Public Utilities Division (CORPUD). Previous studies have indicated that the river is receiving non-point source nitrogen from biosolid applications fields. The amount of nitrate entering the river from deep groundwater pathways or from streams draining the fields was not known. This study measured the flux of nitrate in four streams which flow directly into the Neuse River and that drain biosolid application fields. These streams were monitored because of elevated nitrate concentrations (20-80 mg/l NO_3). The surface drainage nitrate fluxes were then compared to the non-point source nitrate gains measured in the river and the elevation of groundwater in the fields to better understand the flow paths and processes that control the movement of nitrate from the biosolid application fields into the river.

Over a five year period the amount of Non-point source (NPS) nitrate gains in the 7 mile river reach adjacent to the wastewater treatment plant varied from 28,000 kg/year to over 87,000 kg/year. Nitrate gains in the river are related to the phase of El Nino/La Nina and to the groundwater elevation in the mid-slope fields. Lower slope groundwater elevations are controlled by river stage and are not diagnostic of NPS nitrate fluxes into the river. The warm El Nino phase is associated with higher groundwater elevation levels in mid-slope fields and increased NPS nitrate gains in the river. The colder La Nina phase is associated with lower groundwater elevations, decreased NPS nitrate gains in the river and persistent drought in the area. The total nitrate flux in the streams draining the biosolid application fields measured during the cold La Nina phase varies from 1500 to 5000 kg/month. During the low flow La Nino phase, the stream nitrate flux can account for 100% of the NPS nitrate gains in the river adjacent to the biosolid application fields. During the high flow El Nino phase, stream nitrate flux accounts for 50% of the river NPS nitrate gains. Over a 5 year period, on average 734 kg/NO_3/day_{ave} enters the reach, and 1004 kg/NO_3/day_{ave} leaves the reach below the plant. The plant, on average over the past 5 years, has discharged 256 kg/NO_3/day_{ave} into the river. Streams draining the biosolid application fields transport ~101 kg/NO_3/day_{ave} into the river (last six months of 2007, La Nina phase). Using this data, the daily average nitrate gains into the reach are equal to ~58% of the amount of nitrate discharged in effluent from the plant, and the stream nitrate flux is ~39% of the amount of nitrate discharged in effluent from the plant. This data suggests that constructing treatment wetlands in the drainages to prevent the stream nitrate flux from entering the river would have a significant impact on downstream water quality.

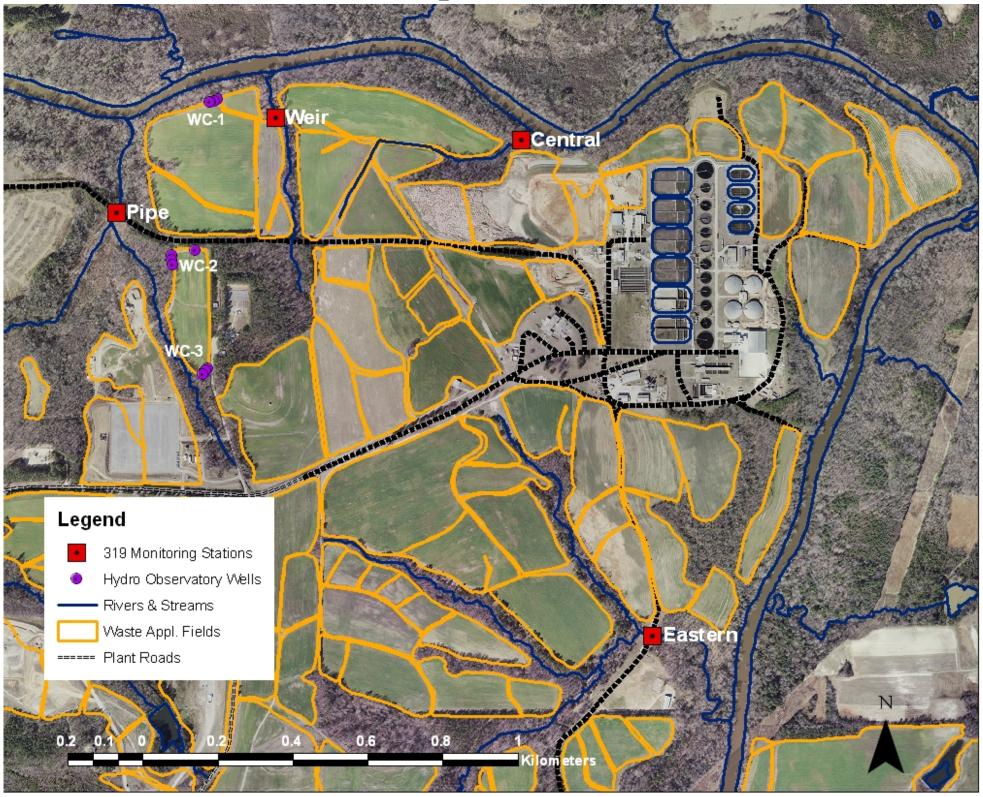

Figure 1. Neuse River Waste Water Treatment Plant in south eastern Wake County North Carolina and the four stream monitoring stations and three groundwater monitoring well clusters used in this study.

INTRODUCTION AND BACKGROUND: Municipal biosolid sludge is a product of wastewater treatment. Biosolids can be burned, placed in a land fill, or land applied to croplands. Land application of biosolids is a common practice in many countries, and is a cost effective reuse of material produced at sewage treatment facilities in areas of rapidly growing urban populations. Original errors in the estimation of the PAN at the NRWWTP which serves the City of Raleigh and surrounding municipalities, resulted in biosolid over-application on city owned or leased biosolid Waste Application Fields (WAFs). Biosolid over application occurred primarily during the early 1980's in the northern fields, and from the mid 1990's to 2001 at fields in other areas of the plant (ENSR, 2002). The City of Raleigh paid a fine of $73,937 to NC DENR for biosolid application permit violations, and ceased spreading biosolids in 2002. Public concern about groundwater contamination increased in Fall 2002, when a number of private drinking wells along Mial Plantation Road next to the WAFs were found to have nitrate levels about 10 mg/l. CORPUD connected the private residences to municipal water supply, joined the National Biosolids Partnership's (NBP) Biosolids Environmental Management System (EMS) program to remediate the groundwater in the southeastern part of the plant. CORPUD has applied for a NPDES permit variance to resume biosolid applications at the site. This application is pending with the Environmental Review Commission (ERC). CORPUD has co-operated with researchers from North Carolina State University, North Carolina Department of the Environment and Natural Resources, Division of Aquifer Protection, and the US Geological Survey, North Carolina Division to better understand nitrate transport offsite. This project is part of this ongoing effort.

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Project Purpose and Goals: To evaluate the nitrate flux in surface streams and groundwater draining into the Neuse River from the biosolid application fields at the NRWWTP (operated by the City of Raleigh Public Utilities Division- CORPUD; Figure 1). These results are then combined with river monitoring data (RiverNet, http://rivernet.ncsu.edu) and groundwater monitoring results (Piedmont Hydrogeological Observatory) to evaluate nitrogen transported from biosolid applications fields into the Neuse River.

Project Deliverables (from Proposal)

1. Install stream monitoring stations, USGS and NCSU
   - *Two stream gauges were installed by NCSU and USGS, and were operational in January 2007.*
   - *Two stream gauges required more extensive bank protection and were installed by the USGS with equipment and material supplied by CORPUD, these stations were operational in June 2007.*

2. Monitor stream nitrate concentrations and discharge, calibrate stream stage / discharge curves, USGS and NCSU.
   - *Stream grab samples were collected weekly at all four sites and analyzed for nutrients, major ions, and specific conductivity by NCSU*
   - *Temperature, specific conductivity, and depth were measured at two sites for 12 months, and two sites for 6 months.*
   - *Stage discharge curves were determined with Acoustic Doppler Current Profilers with wading rods after the stations were installed. Drought conditions in the latter part of 2007 prevented enough high flow measurements to be made.*
   - *High flow estimates were made with the HEC RAS model and topographic surveys of the drainages below the stations. HEC RAS models were verified by the USGS, and model comparisons to measured data were favorable.*
   - *Stream monitoring will continue until June 2008 to obtain high flow discharge measurements to compare to the HEC RAS mode.*

3. Monitor river nitrate fluxes, NCSU
   - *Nitrate fluxes were monitored in the river by the RiverNet program, NCSU.*

4. Monitor groundwater levels at lower slope and mid slope wells, USGS and NCDENR
   - *Groundwater levels in the Piedmont Hydrogeological Observatory was monitored by the USGS and NC DENR.*

5. Conduct tour of monitoring stations
   - *A tour of the monitoring stations was conducted for 319 managers in June 2007 after the stations were installed.*

6. Submit Final Report
   - *Enclosed*

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METHODOLOGY AND EXECUTION:
Contract agreements between the 319 NPS program and NCSU were completed in April, 2007, while subcontract agreements between NSCU and the USGS NC Division were completed in May, 2007.

Construction of Steam Monitoring Stations

Four small streams were monitored for discharge and nitrate flux, and each presented a unique challenge to obtain quality stage and water chemistry data. The stream basins vary in size from 70 to 1390 acres, with 43 to 219 acres of biosolid application fields in each drainage (Figure 2a). The eastern and pipe drainage basins have the most PAN applied. The pipe basin has the lowest surface water nitrate concentrations, and the largest amount of buffer (forested) area. The central

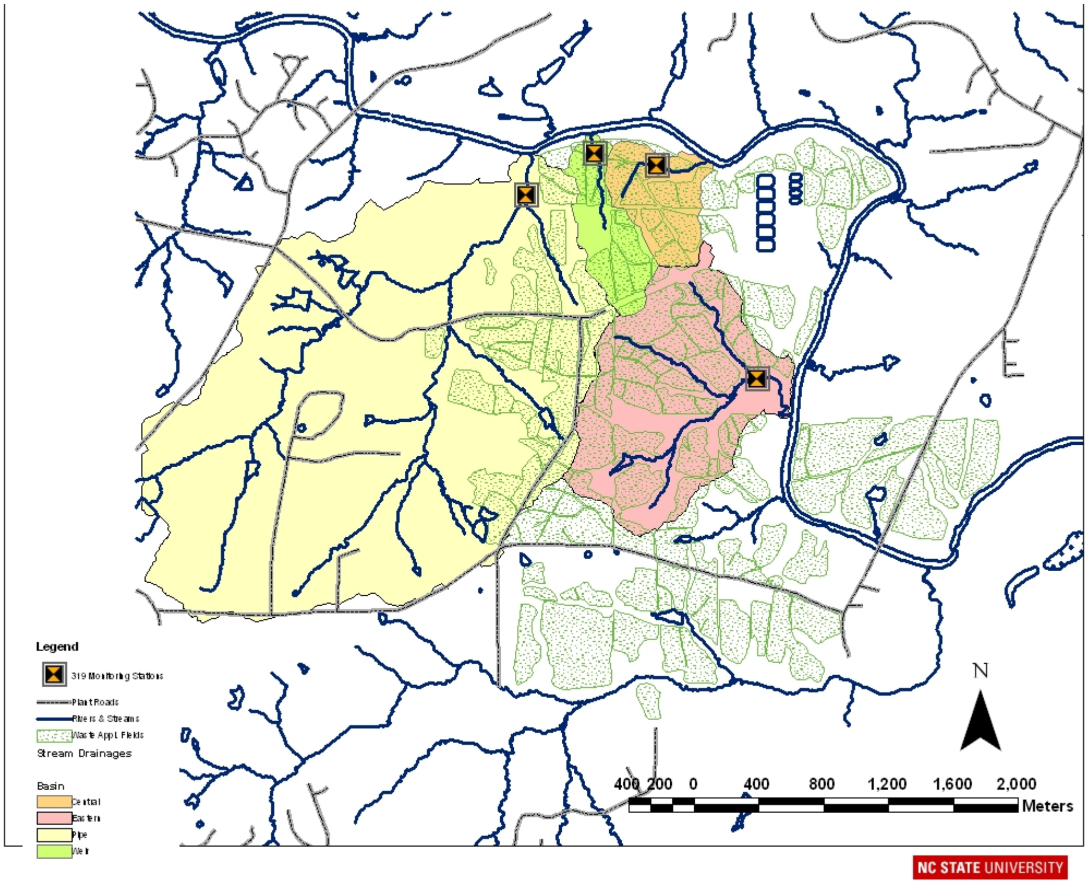

Figure 2a The four streams and drainage basins monitored by this project. The Pipe basin (yellow) is the largest, the eastern basin (rose) has the highest nitrate surface water concentrations, the weir (green) and central (orange) are the smallest and have nitrate concentrations that vary and discharge that is seasonal.

and weir basins have the lowest relief , the smallest size drainage basins, but both have elevated surface water nitrate concentrations. Discharge was intermittent in the central basin during the summer drought of 2007. The other streams had discharge throughout the year.

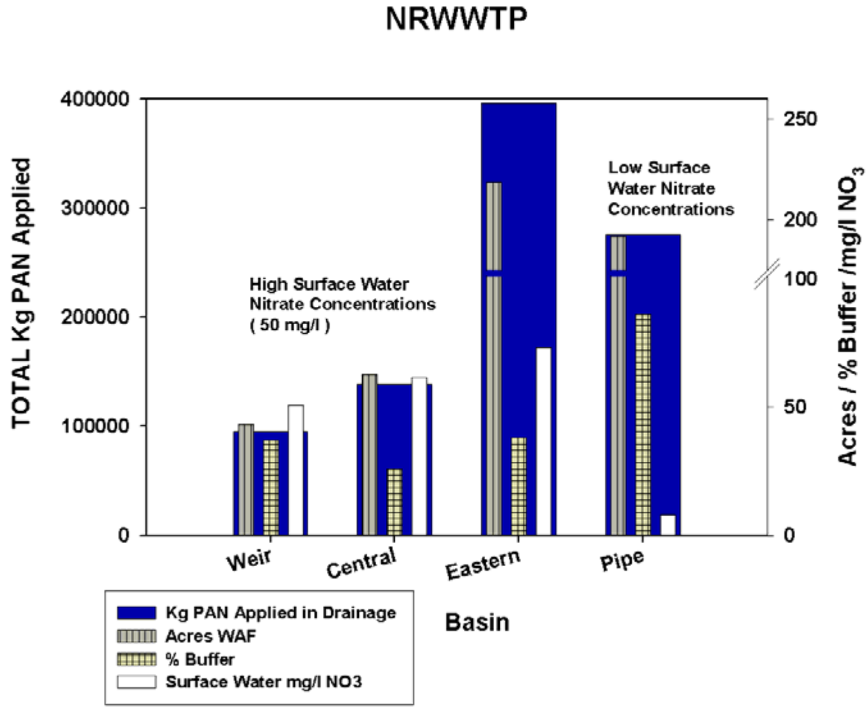

Figure 2b. Drainage basins with size, surface water NO_3 concentrations and amount of PAN applied in each basin.

The largest stream draining the plant flows through a large corrugated drainage pipe (Figure 3). This drainage pipe is located under the sewage lines that come into the plant from Raleigh, and the monitoring station was placed upstream from this pipe. Beavers periodically built dams in the pipe, but these are easily removed. The stage discharge relationship was modeled as

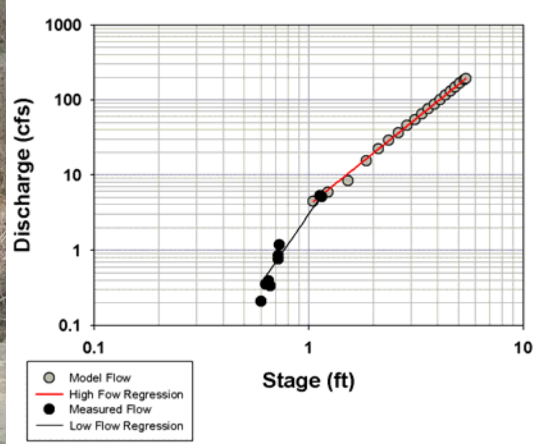

Figure 3. Drainage pipe under the sewage lines coming into the NRWWTP from Raleigh, NC

Manning flow through the pipe at higher stage. Sediment fill is not a problem at this site because flow maintains a pool at both ends of the pipe. This site has lower nitrate stream concentrations, but higher discharge resulting in a fairly high nitrate flux to the river.

The eastern site has high stream nitrate concentrations and drains under a road before entering the river. The monitoring station was placed on the upstream side of the drainage pipes (Figure 4). Beavers have been a problem at this site, and dams were destroyed frequently in the summer of 2007. The beavers began to stuff debris into the pipes to prevent dam destruction, and the City of Raleigh brought in a professional trapper to remove the beavers from this site.

Figure 4. Eastern stream monitoring site with drainage under a road at the plant.

The weir stream site is a smaller intermittent stream with nitrate concentrations that vary from 20 to 80 mg/l. A temporary plastic lined weir was destroyed by tropical storm Alberto in June 2006 when large logs were transported down the drainage (Figure 5). Profiting from this experience, a low cement weir was anchored to an existing rock outcrop with rebar cemented into holes that were drilled into the rock outcrop. (Figure 5). Sediment needs to be cleaned from the pool during low flow, but is not a problem during high flows because the pool is scoured clean. Logs and large debris is not caught by the low lying weir during high flow events. The stage

Figure 5a. Temporary (2005) and cement weirs (2007) used to measure flow in this intermittent flashy stream. The temporary weir was destroyed by flooding in June 2006. Rebar was cemented into holes drilled into the rock outcrop. The measured stage discharge curve fit well with the HEC-RAS model results

discharge relationship has a break when the water level goes over the top of the cement weir during storm events (Figure 5b).

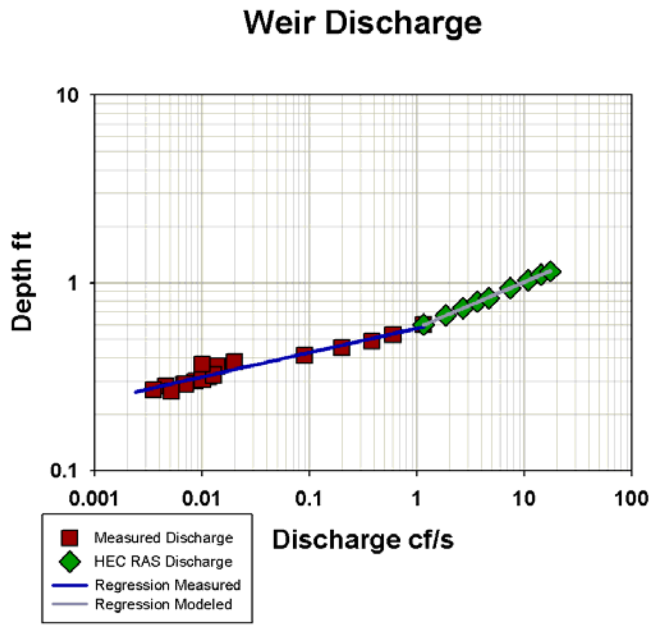

Figure 5b. Measured and HEC-RAS model stage discharge estimates show good agreement. The break in the exponential relationship is the stage where the water is over the weir top.

The central monitoring station was the most difficult to construct. The central stream is the smallest drainage basin and is an un-buffered drainage between two fields that goes into a wooded area. Beavers are a problem in the lower areas of this drainage, but the weir was constructed upstream from the river to avoid the flooding problems (Figure 6).

Figure 6. At the central stream site, a plywood board and steel pipe weir was constructed and pushed into the ground with a backhoe. The backhoe can also remove the structure by pulling up on cables attached to the pipes.

OUTPUTS AND RESULTS:

Stream Monitoring

Temperature, specific conductivity, and depth were monitored at the Pipe and Weir sites for 12 months and at the Eastern and Central sites for 6 months after installation of the monitoring stations (see appendix). Weekly grab samples for over the past two years indicate that large seasonal nitrate concentration changes observed in 2006 were not observed in 2007 in the smaller streams (Weir and Central). The changes in the nitrate concentration in the streams are similar to the water table changes in the mid-slope hydro-observatory wells and not the lower hydro-observatory wells (Figure 8). It is likely that the water table elevation in the lower slope wells is controlled by river stage, because there is a good correlation of groundwater elevation to river stage in these wells. To calculate the flux of nitrate from the streams, the discharge computed from the stage/discharge curves was multiplied, on a 15 minute interval, by the nitrate concentrations computed from the specific conductivity calibrated by the discrete grab samples. After the monitoring stations were installed the SE United State entered a drought phase and rainfall events became very rare. To estimate the discharge a higher stages, topographic surveys were complete downstream from all the monitoring sites and the US Army Corp of Engineers HEC-RAS model was used to estimate stream flow according to USGS protocol. Monitoring will continue until June 2008 to measure higher flows in the streams to validate the HEC-RAS estimates of flow.

The daily nitrate flux varies with stream size (Figure 9). The larger Pipe and Eastern streams have average daily nitrate fluxes of 37 and 39 kg/d with maximum fluxes of 833 and 206 kg/d. The Central and Weir streams are smaller and have average nitrate fluxes of 4 and 7 kg/d with maximum fluxes of 30 and 199 kg/d (Table 1). Over the six month period that all four streams were monitored, the Eastern stream contributed 51% of the total nitrate flux, the Pipe stream contributed 38% of the total nitrate flux, and the Weir and Central streams each contributed

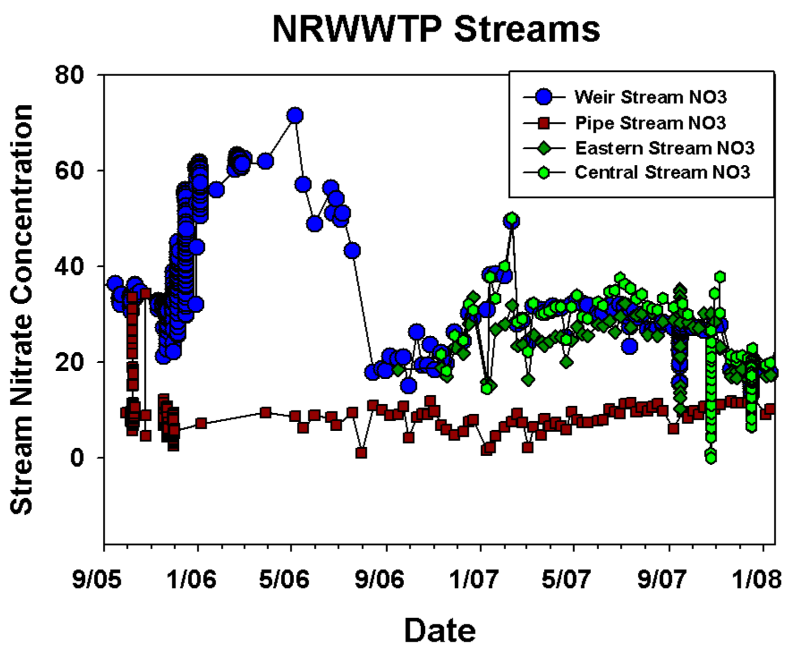

Figure 7. Nitrate concentrations from weekly grab samples in the streams draining the biosolid application fields. Note the differences between Spring 2006 and Spring 2007.

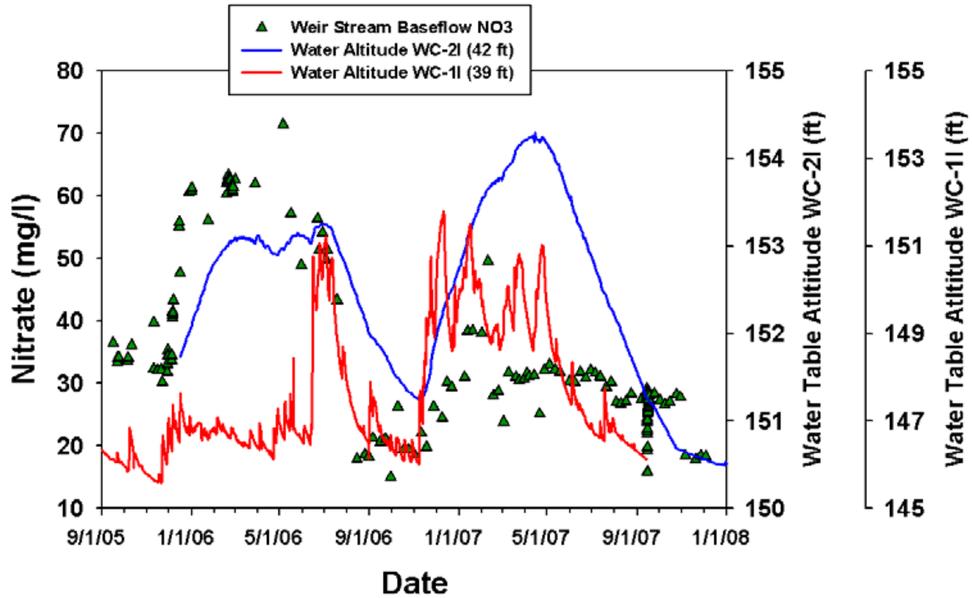

Figure 8. Weir stream nitrate concentrations from weekly grab samples compared to the water table elevation in the mid-slope wells (blue) and the lower slope wells near the river (red). See figure 1 for well locations.

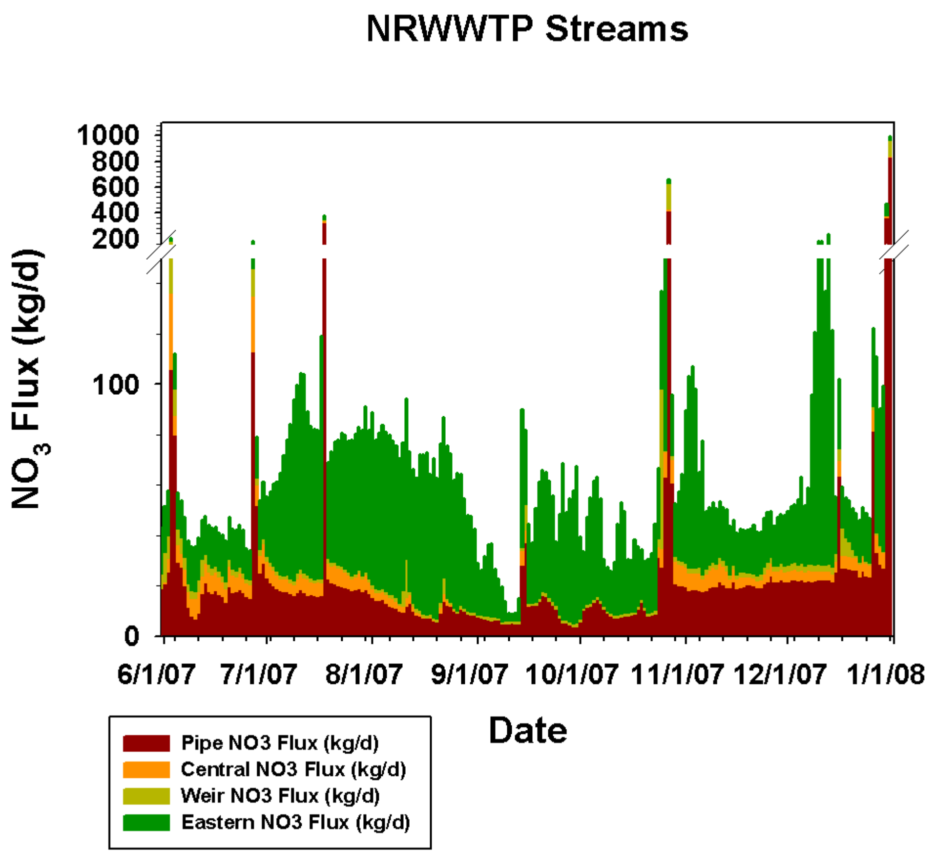

Figure 9. Daily stream nitrate flux into the Neuse River from biosolid application fields measured on a 15 minute interval. Daily nitrate fluxes average 37-39 kg/d for the large streams (Pipe and Eastern) and 4-7 kg/d for the small streams (Central and Weir).

TABLE 1 Nitrate Flux and Discharge from Biosolid Application Fields – 6 months

Stream	Nitrate kg/6 mon	Q cf/6 mon	% NO3 Flux	N Flux Ave kgd	Q Average cfd
Weir	717	1325523	5.50	7	8816
Central	645	908463	4.95	4	5447
Eastern	6686	8041442	51.34	39	51494
Pipe	4975	16487331	38.20	37	137022
Total	**13023**	**26762760**			

about 5%. The flux in the Pipe stream is fairly constant, while the other streams are flashy and have rapid increases and decreases in discharge and nitrate flux (Figure 9).

RiverNet Monitoring Results

The amount of NPS nitrate entering the Neuse River was quantified using CORPUD discharge data from the NRWWTP, and RiverNet station data in the Neuse River above and below the plant biosolid application fields (Showers et al., 2005). The amount of NPS nitrate gains in the reach varies from year to year (Table 2). The NPS nitrate gains do not follow the Modflow model that predicted offsite nitrate transport until 2050 that has been used by CORPUD (Figure 10, ENSR 2003). The amount of nitrogen entering the Neuse River from the biosolid application fields was approximately 58% of the effluent nitrogen released from the plant over a five year period (Table 2). While the amount of nitrogen released from the plant in treated waste water has dropped over the study period, the amount of nitrate entering the river from streams draining the biosolid waste application fields and the amount of NPS nitrate entering the river reach has varied on a three to four year time scale. (Figures 10 & 11). This correlates to the oscillation of the El Nino/La Nina index over the past two cycles. 2003 and 2006 were weak El Nino (warm phase) years and nitrate fluxes were higher than non-El Nino years. In 2007 a La Nino (cold

TABLE 2 NPS Nitrate Gains in the Neuse River Adjacent to the NRWWTP

Calender Year	Daily Integrated NO3 Gains	% Total NO3 Output NRWWTP	% Total NO3 Output NRCP	Clayton & RDU Precipitation Average (in)	NRWWTP Flux NO3 kg/yr	NRWWTP Flux Total N kg/yr
2003	58950	59	13	43	140,082	202253
2004	34072	32	11	41	107,262	182390
2005	29065	30	8	38	96,390	163178
2006	27819	33	8	44	84,579	143066
2007	87806	134	30	32	65,610	106514
Average	**47543**	**58**	**14**	**40**	**98785**	**159480**

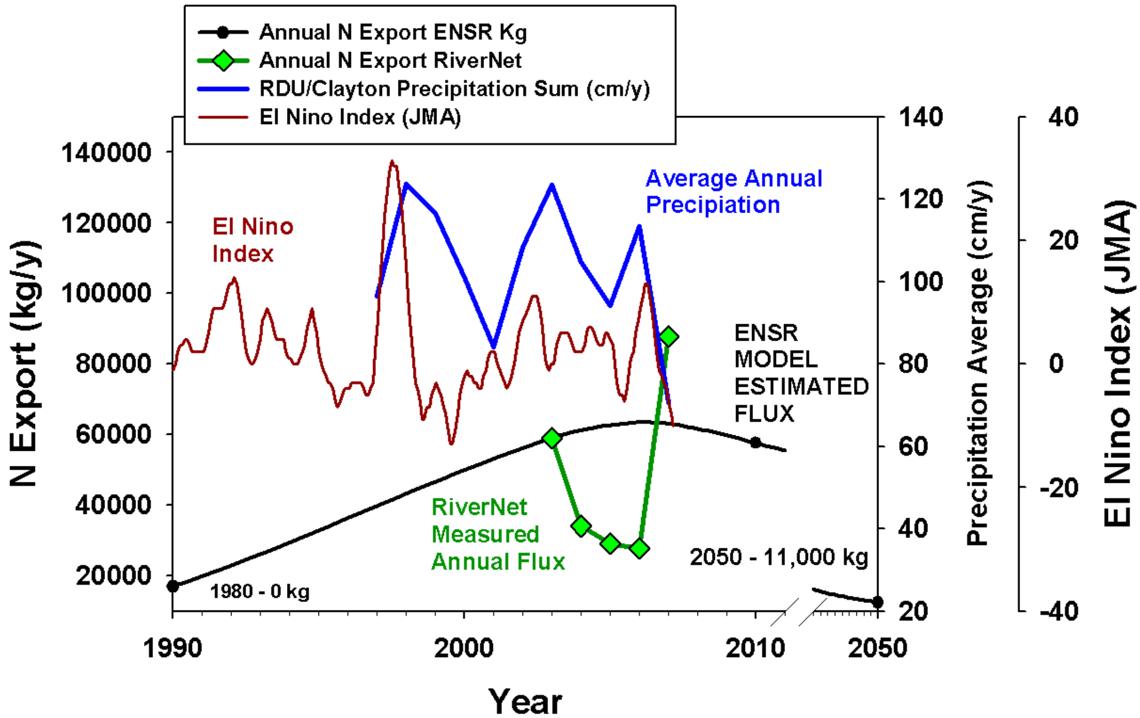

Figure 10. Model versus monitoring comparison of NPS nitrate gains in the Neuse River adjacent to the NRWWTP. Measured results indicate a 3-4 year oscillation like the El Nino variations, but longer records are needed. Model from ENSR 2002, 2003.

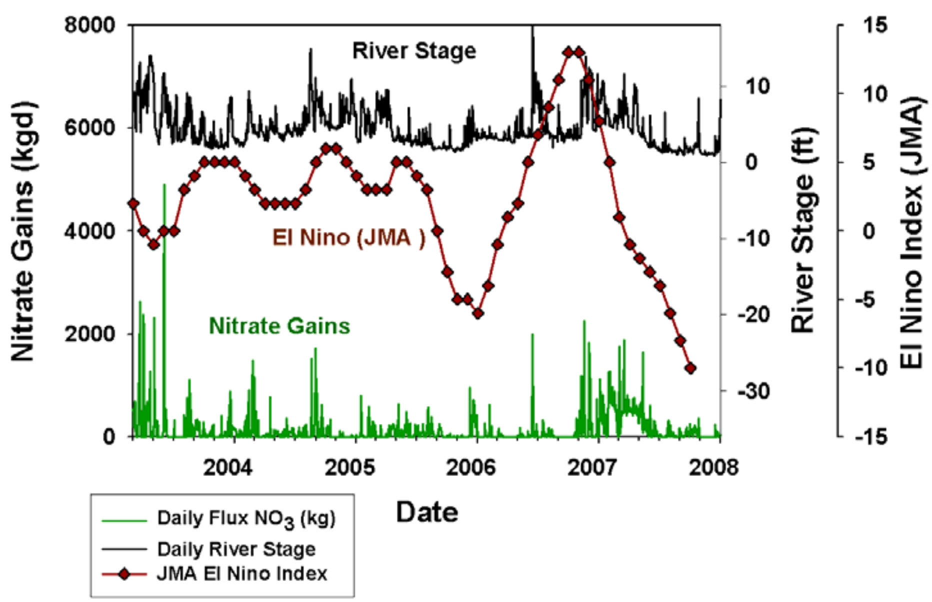

Figure 11. River stage and NPS nitrate gains at the NRWWTP vary on a 3-4 year time scale like the El Nino oscillation.

phase) developed and the southeastern United States has been in a significant drought. The stream nitrate flux can account for over 100% of the NPS nitrate gains in the river during low flow conditions, and for ~50% of the NPS nitrate gains in the river during high flow. This suggests that deep groundwater pathways become active at higher flows when water table elevations are higher.

Nutrient River Mapping and River Nitrate "Hotspots"

In addition nutrient concentration changes in the river, river "hotspots" or areas where deep groundwater contaminated with nitrate enters the river has been mapped with the same optical nitrate analyzers employed in the RiverNet stations (Figure 12). These nitrate "hotspots" are located where large basaltic dike systems cross the river. Contact metamorphic zones in the country rock next to the dike complex may be highly fractured zones of enhanced permeability that permits water to enter the river during times of high groundwater elevations, and where water is lost from the river during periods of low groundwater elevation. This deep groundwater - fractured dike pathway would be highly variable time. NPS river nitrate gains are related to the elevation of the water table (Figure 12). Monthly discharge and nitrate flux in the pipe stream is also controlled by groundwater elevation modulated by the amount of rainfall during the month (Figure 13). This data suggests that NPS nitrate gains in the river is an underestimate of how much nitrate is exported from the biosolid application fields into the river. During low flow conditions the amount of water and nitrate flowing into the reach from the river and streams can exceed the amount of water and nitrate leaving the reach. During high flow conditions ~ 30-50% of the nitrate leaving the reach is comes from sources other than the surface streams. The source of this other nitrate is most likely deep groundwater entering at the "hotspot" locations.

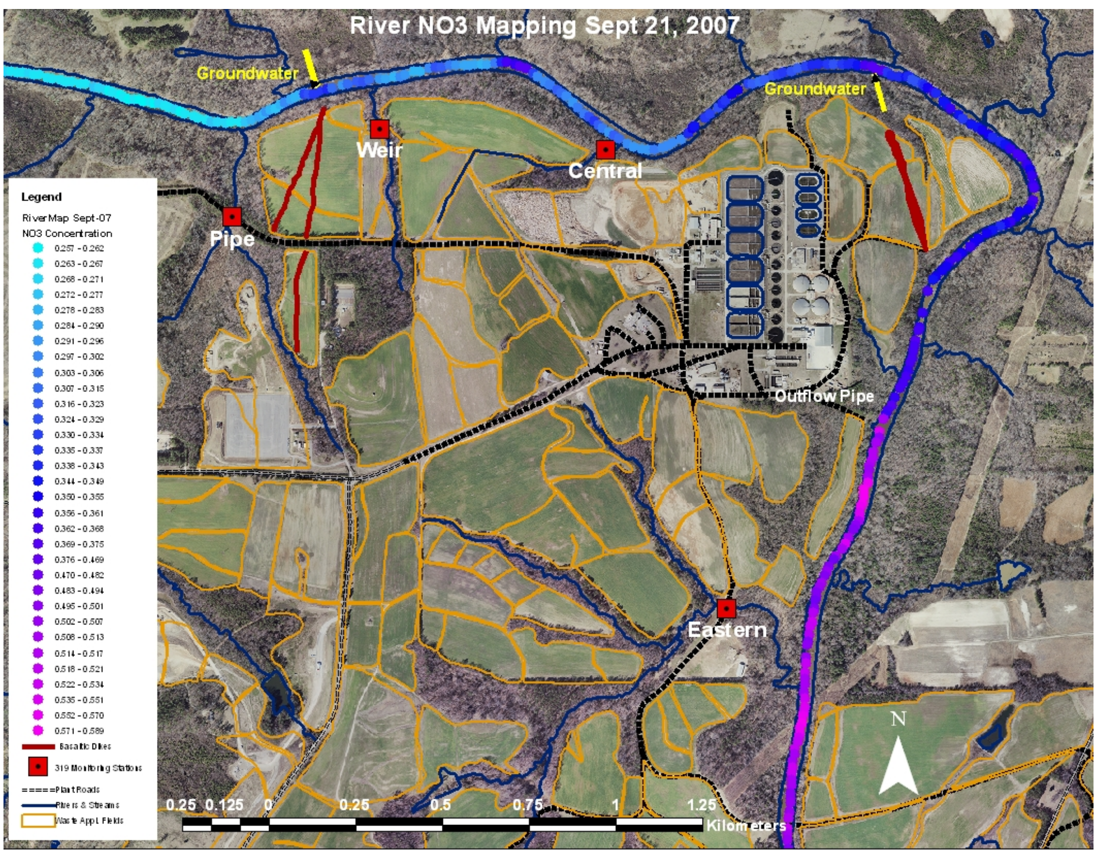

Figure 12. River nutrient mapping of stream nitrate concentrations indicate that deep groundwater contaminated with nitrate enters the Neuse River at "Hotspots" where large basaltic dikes cross the river.

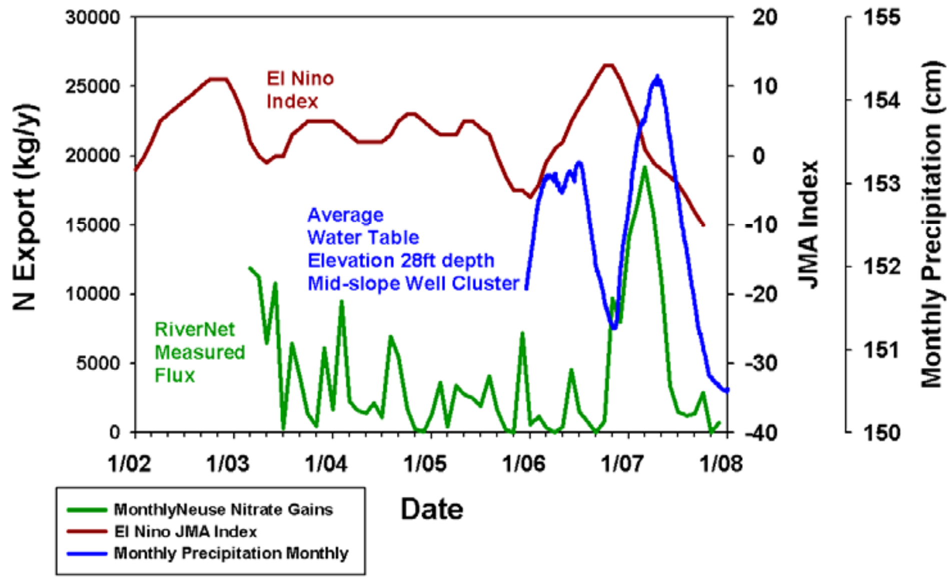

Figure 13. NPS nitrate gains in the Neuse River at the NRWWTP are related to mid-slope groundwater elevation changes. Groundwater elevation may be the link between climate oscillations and stream flux.

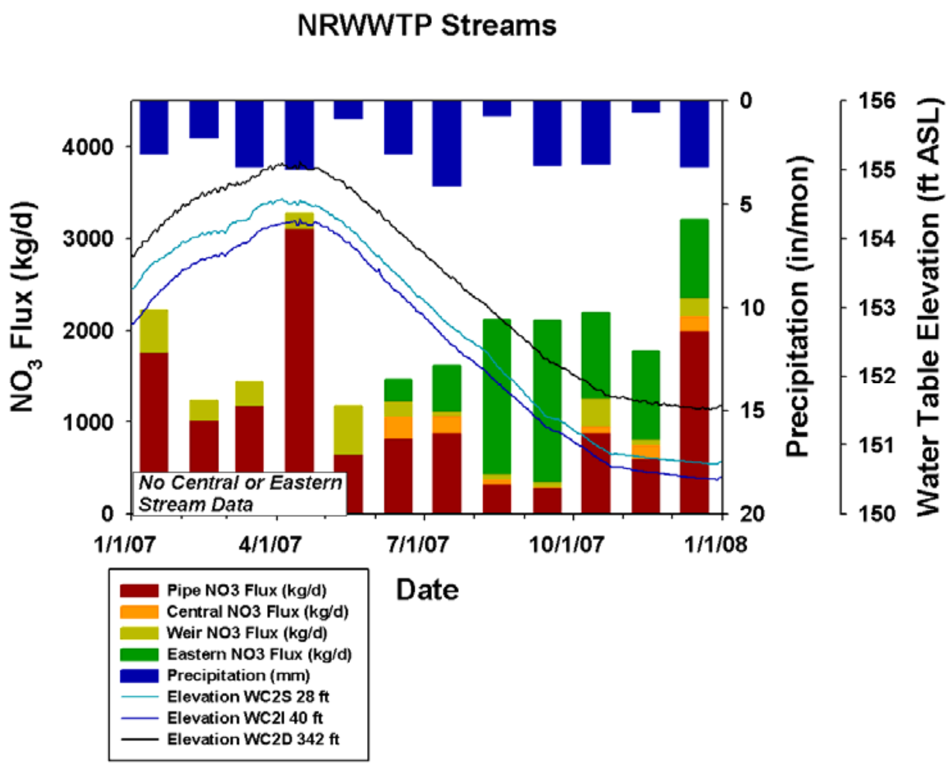

Figure 14. Monthly stream nitrate flux is related to groundwater elevation in the mid-slope wells. There is no data for the central or eastern stream in the first half of 2007 when groundwater elevations are high, but the highest flux from the pipe stream correlates to groundwater elevation and amount of precipitation.

Outcomes and Conclusions

Managing surface water quality will be crucial in the future as population growth in the Research Triangle area which will increase sewage discharge into surface waters. Surface waters will become more important sources of drinking water as groundwater resources are over-committed or contaminated. The groundwater/surface water nitrogen transport from biosolid waste application fields to the Neuse River described here is a new source of nitrogen to our watersheds that has not been previously quantified. These results suggest that the amount of nitrogen released to the environment by these waste water treatment plants has been seriously underestimated. Accurately measuring this new offsite N flux is the first step in designed remediation systems to protect river water quality.

At the NRWWTP, the mechanism for nitrate contaminated groundwater transport to the river is a combination of surface drainages and deeper groundwater flowpaths. The groundwater pathways and smaller stream nitrate fluxes are intermittent. The larger streams transport ~90% of the surface water nitrate, and would logically be the first areas to begin remediation efforts. However, these surface water nitrate fluxes in these streams are large on an event flow basis. The effectiveness of a treatment wetlands to remediate nitrate is determined by the size of the wetland and nitrate flux, type of plants, and the water retention time which is dependent upon the flow (Kadlec & Knight 1995). The Pipe and Eastern streams have 1-2 hectare areas that could be flooded and turned into treatment wetlands with minimal costs. If we assume that a 1 Ha wetland in this area can be designed to effectively treat a 10 kg/d stream N flux, these new wetlands could effectively treat stream nitrate flux in the Weir and Central streams, and reduce the N flux during low to medium stage flows in the Pipe and Eastern stream. CORPUD has constructed a large storm water overflow basin at the plant as part of several recent major improvements and upgrades. If wetlands of sufficient size cannot be constructed to remediate the nitrogen flux in the larger streams, then perhaps the excess storm water flow in the streams could be directed into the overflow basin and could be treated by the plant before it is released into the river.

Land application of biosolids produced from waste water treatment in areas of rapidly growing urban populations is a cost effective reuse of nitrogen and phosphorus, as well as an effective disposal method of the sediment and sludge produced during the treatment process. Land application of biosolids may increase significantly in the future as treatment plants expand and other disposal practices such as landfills, incineration, and ocean dumping become too expensive or are banned. The accumulation and export of nutrients from biosolid waste application fields must be considered for sustainable biosolid management. The results from this project are the first important steps in the design and implementation of sustainable biosolid management programs at the NRWWTP.

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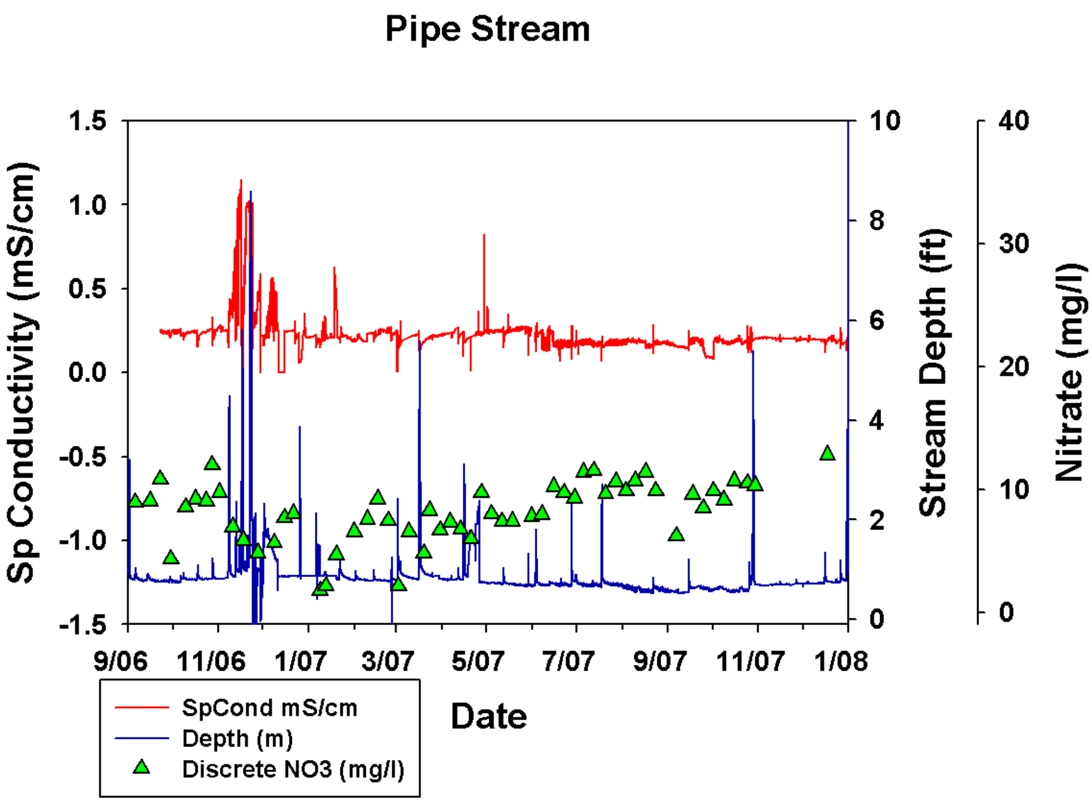
BUDGET:

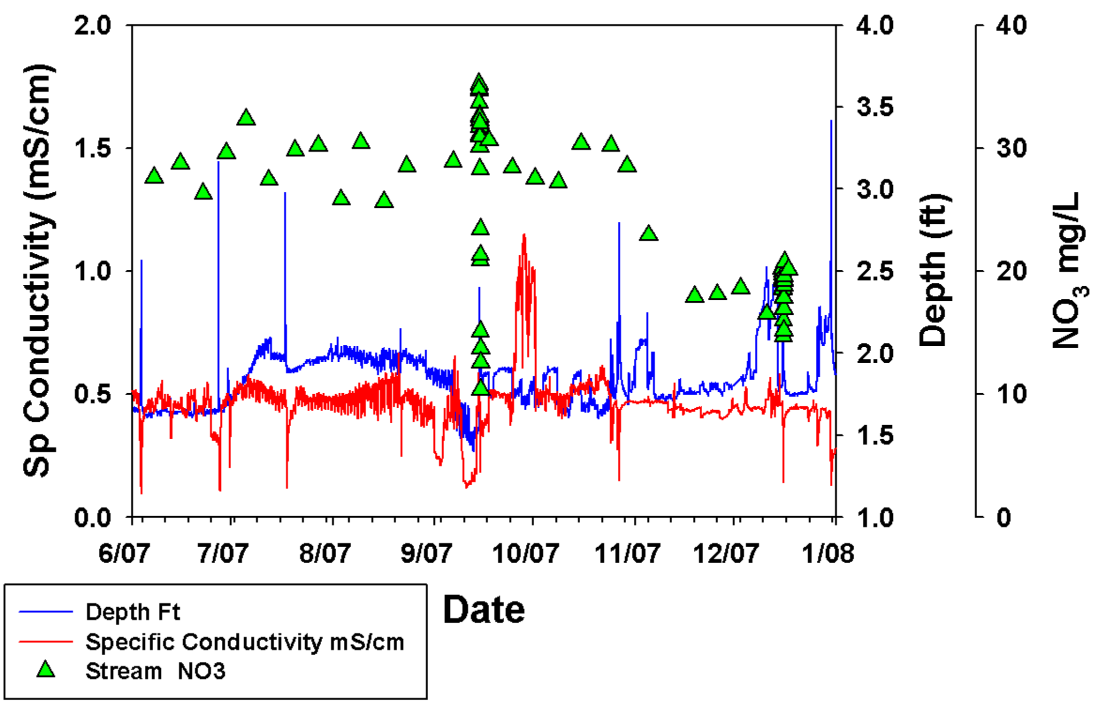
FUNDED REQUEST

15. Funding Requested				
Budget Categories (itemize all categories)	Section 319	Non-Federal Match *****	Total	Justification
Personnel/Salary	22500	24570	47070	Student Salary, Faculty/Tech Match
Fringe Benefits	2925	5651	8576	23% Faculty/Tech. 13% Student
Supplies	21737	0	21737	Water Chem Anal., Field and Lab Supplies
Equipment	0	0	0	
Travel	800	0	800	To Field Site
Contractual - USGS	34920	0	34920	3 Stream Gauges Install & Operate USGS
Other (Student Tuition 1 yr)	8314		8314	Student Tuition
Total Direct	91196	30221	121417	
Indirect	10133	37332	47465	10% of TDC, 46% MTDC – 10% TDC Match
Total	101329	67553	168882	
	60%	40%	100%	
*****Note: Non-Federal match must be a minimum of 40% of the total project budget				

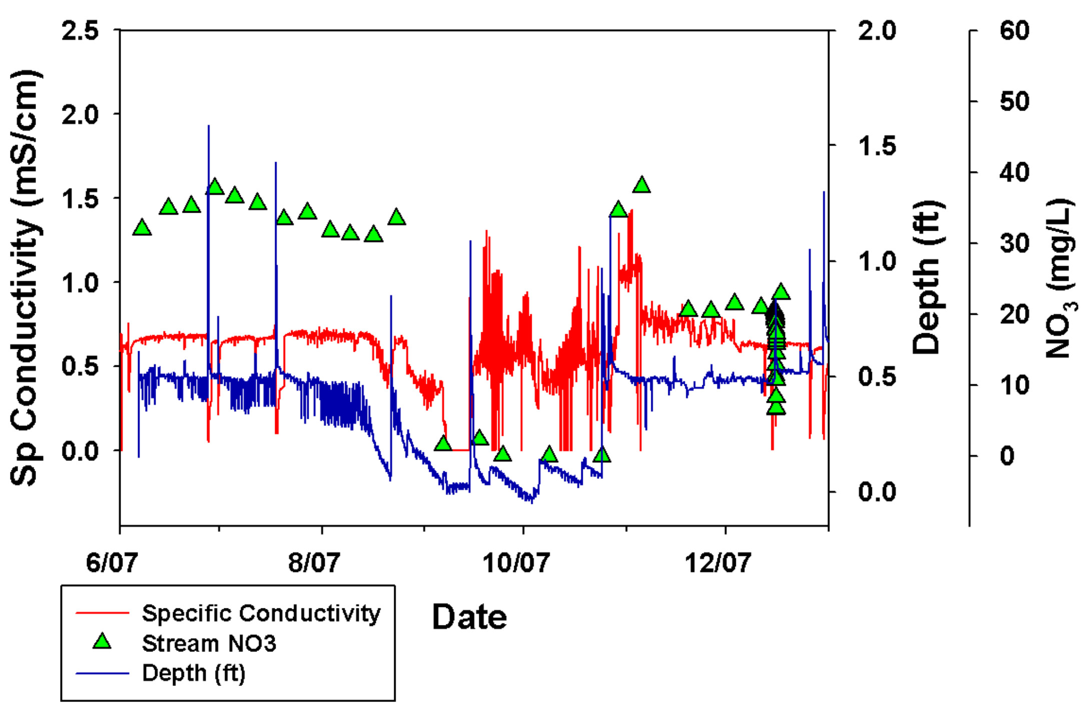
Appendix:
Monitoring Station Data

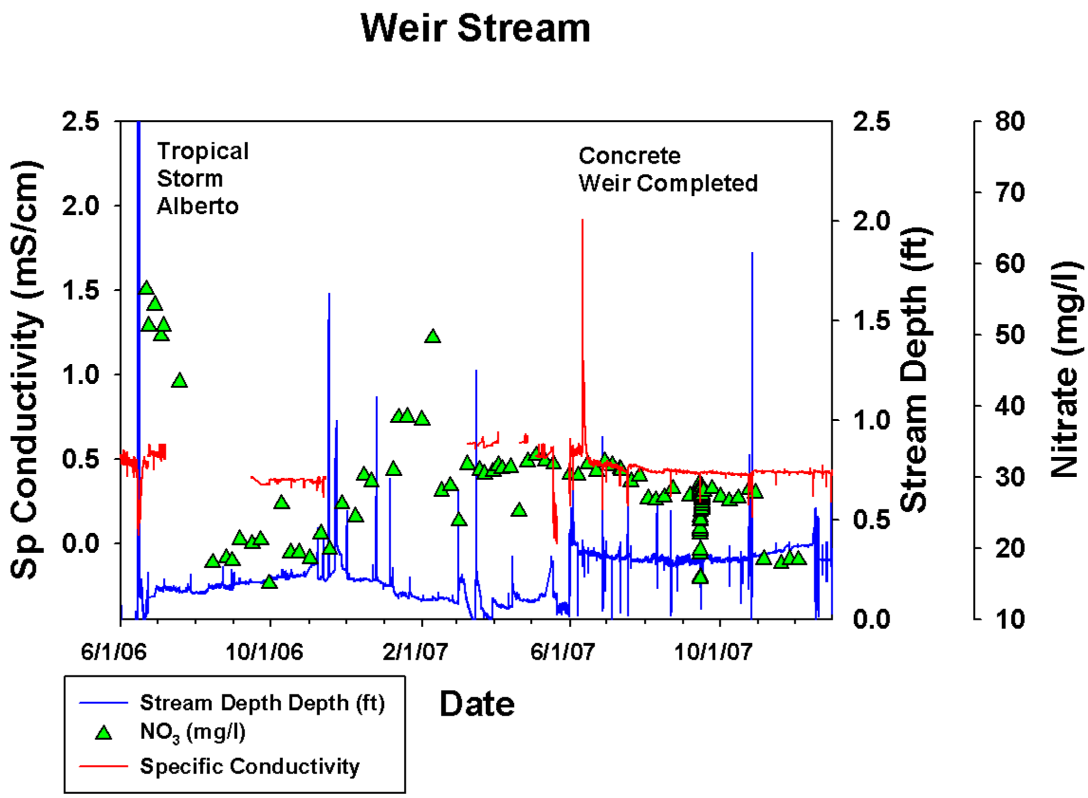


Eastern Stream



Central Stream




Weir Stream
Tropical Storm Alberto
Concrete Weir Completed
Sp Conductivity (mS/cm)
Stream Depth (ft)
Nitrate (mg/l)
2.5
2.0
1.5
1.0
0.5
0.0
80
70
60
50
40
30
20
10
6/1/06
10/1/06
2/1/07
6/1/07
10/1/07
Date
Stream Depth Depth (ft)
NO_3 (mg/l)
Specific Conductivity