Final Report

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Peak Flow Sampling and Analysis of Sediment Nutrient Release

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INTRODUCTION

Lake Greenwood sits at the confluence of the Reedy and Saluda Rivers in the Upstate of South Carolina. During the past decade qualitative and semi-quantitative observations have noticed a continued deterioration in water quality in this critical water body. Lake Greenwood is used for habitat, recreation and the water supply for the city of Greenwood, SC. While many have attempted to blame the water quality problems in Lake Greenwood on point source dischargers in the Reedy River watershed, there exists little quantitative data to support this claim. In addition, little quantitative data exists to describe the magnitude of nonpoint source contaminants entering the lake. Several efforts spearheaded by Upstate Forever, South Carolina Department of Natural Resources, and others have recently tried to quantify sources of contaminants moving into Lake Greenwood, the dynamics of contaminant fate within the lake, and the export of these contaminants from the lake. This research was designed to characterize loadings of contaminants into Lake Greenwood from the Reedy and Saluda Rivers from 2004 to 2007 and to quantify export of these contaminants over the dam during 2006 and 2007. Further, the dynamics of sediment-bound phosphorus in the lake was quantified in an attempt to determine the contribution of the sediments to soluble phosphorus concentrations in the water column. This report summarizes the 3 years of loading data collected on the Reedy and Saluda Rivers, the 2 years of contaminant export data collected at the dam on Lake Greenwood, and the 3 years of sediment-phosphorus release data collected at different sites in Lake Greenwood.

CONTAMINANT LOADING INTO LAKE GREENWOOD

Between January 2004 and June 2007, base flow and storm event samples were taken from the Reedy and Saluda Rivers upstream of Lake Greenwood. These samples were analyzed for a suite of water quality characteristics and combined with stream flow data to produce estimates of contaminant loadings for each of the river systems. Based on our previous research that demonstrates that water quality during base flow does not change significantly, more water samples were taken and analyzed during storm events and fewer samples taken between storm events. Data were extrapolated to provide daily estimates of contaminant loading into Lake Greenwood. From these daily estimates, monthly averages and annual totals were computed.

Methods:

One-liter storm run off samples were collected using automated battery operated water quality samplers (Teledyne ISCO Model 6712). Base flow water samples were collected by hand using a 500 ml polypropylene dipper. Samples were returned to Clemson University Institute of Environmental Toxicology (ENTOX) for processing. Water samples were analyzed for alkalinity, hardness, chloride, nitrate, bromide, nitrite, phosphate, sulfate, select metals including P, K, Ca, Mg, Zn, Cu, Mn, Fe, S, Na, B, Al, total dissolved nitrogen, dissolved organic carbon, turbidity, and total suspended sediments. Specific methodology was as follows:

1. Alkalinity was measured using Standards methods 2320 B. Titration method. Hardness will be determined by calculation, Standard Methods 2340 B. Hardness by Calculation.
2. Select anions (chloride, nitrate, bromide, nitrite, phosphate, sulfate) were measured using HPLC-IC techniques. Method 4110 B. Ion Chromatography with Chemical Suppression of Eluent Conductivity. Samples were stored at 4'C until analysis with a Dionex AS50 IC with AS50 auto sampler (Dionex Corp., Sunnyvale, Calif.)
3. Select metals (P, K, Ca, Mg, Zn, Cu, Mn, Fe, S, Na, B, Al) were measured using Standard Method 3125 B. Inductively Coupled Plasma/Mass Spectrometry Method. An aliquot for total metals analysis was processed following Standard methods 3030 C. Treatment for Acid-Extractable Metals, 3030 D. Digestion for Metals, 3030 E. Nitric Acid Digestion.
4. Samples were analyzed at Clemson University for Total Dissolved Nitrogen (TDN) and nonpurgable organic carbon (DOC) Standard Methods 5310B High Temperature Combustion Mehtod. using a Shimadzu total organic carbon analyzer TOC-V CPH with a TNM-1 total nitrogen measuring unit (Shimadzu Scientific Instruments, Kyoto, Japan)
5. Turbidity measurements were taken at Clemson University following Standard Methods 2130 B. Nephelometric Method, using a HACH 2100N Turbidimeter (HACH Company, Colorado, USA)
6. Total Suspended Sediment was determined by Standards Method 2540D. Total Suspended Solids Dried at 103-105'C

Results and Discussion:

Detailed results, daily loadings, and monthly averages are available on the attached EXCEL file. Annual flow and dissolved nitrogen loading for the Reedy and Saluda

Rivers are illustrated in Figure 1. From these data it is obvious that flows in the Saluda River are greater than those in the Reedy River. This results in higher dissolved nitrogen loading into Lake Greenwood from the Saluda River than from the Reedy River. This is also apparent for annual nitrate loadings (Figure 2) and dissolved phosphorus (Figure 3) .

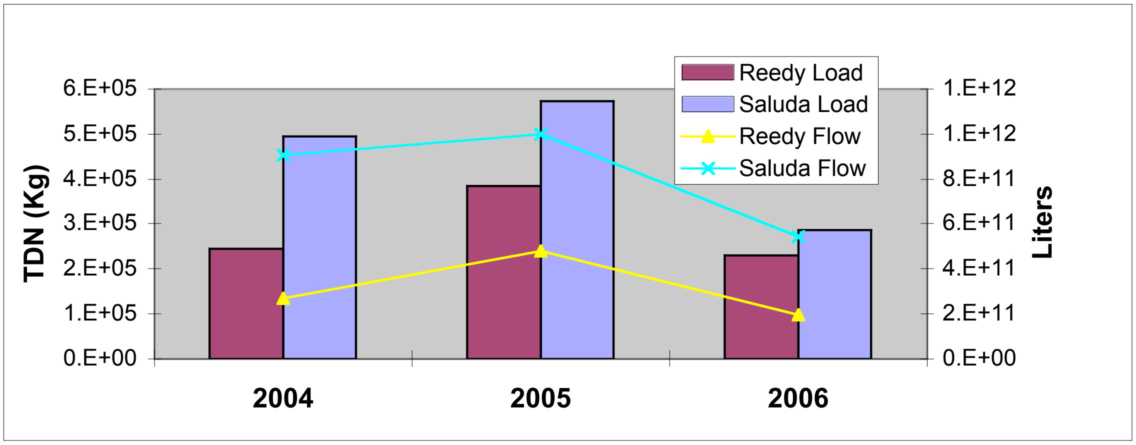

Figure 1. Annual loading of total dissolved nitrogen (TDN) (bars) and total annual flow (lines) for the Reedy and Saluda Rivers entering Lake Greenwood between 2004 and 2006.

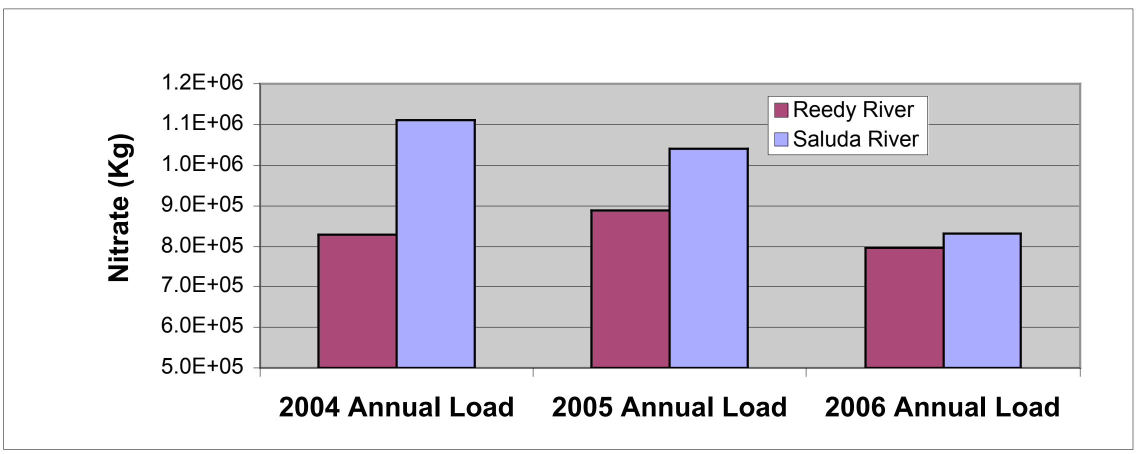

Figure 2. Annual loading of nitrate for the Reedy and Saluda Rivers entering Lake Greenwood between 2004 and 2006.

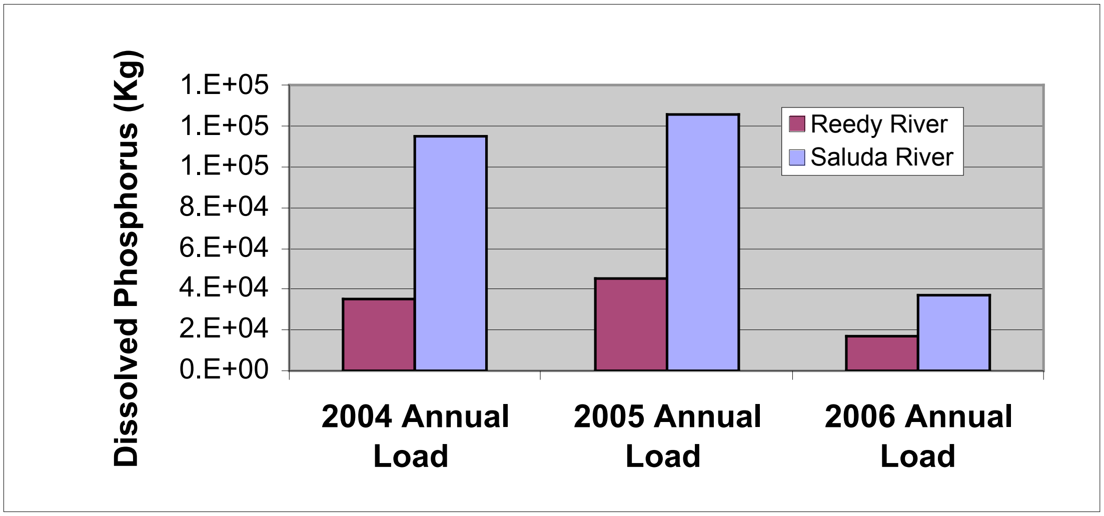

Figure 3. Annual loading of dissolved phosphorus for the Reedy and Saluda Rivers entering Lake Greenwood between 2004 and 2006.

The same phenomenon is apparent with suspended sediment loading into Lake Greenwood (Figure 4). Hence, while the extensive urbanization in the Reedy River watershed has changed the river from a stormwater runoff dominated system to a point source discharge dominated one, actual impact on contaminants in Lake Greenwood may

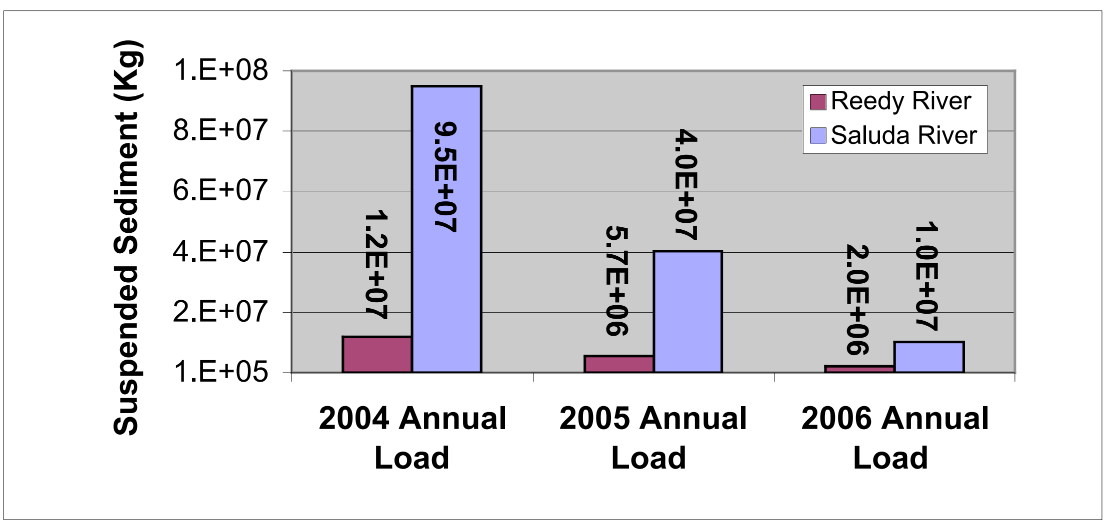

Figure 4. Annual loading of suspended sediments for the Reedy and Saluda Rivers entering Lake Greenwood between 2004 and 2006.

be greater from the Saluda River watershed which is still stormwater runoff dominated. Because of the larger size, rapid urbanization in the Saluda River watershed may have a much greater impact on Lake Greenwood than past urbanization in the Reedy River watershed. This is particularly true if development strategies do not change in the Saluda River watershed.

COMPARISON OF LOADING INTO AND EXPORT FROM LAKE GREENWOOD

Between March 2006 and June 2007, samples were taken from water flowing over the Lake Greenwood dam using an ISCO automated sampler. These samples were transported to ENTOX and analyzed in the same manner as described above for the Reedy and Saluda River water samples. Monthly averages of flow and contaminant export were generated from these data and compared with loading data from the Reedy and Saluda Rivers.

A comparison between flow entering Lake Greenwood through two primary sources (Reedy and Saluda Rivers) and flow leaving Lake Greenwood over the dam reveals that, on average, 89% of all water leaving the lake via the dam during this time came from the Reedy and Saluda Rivers (Figure 5).

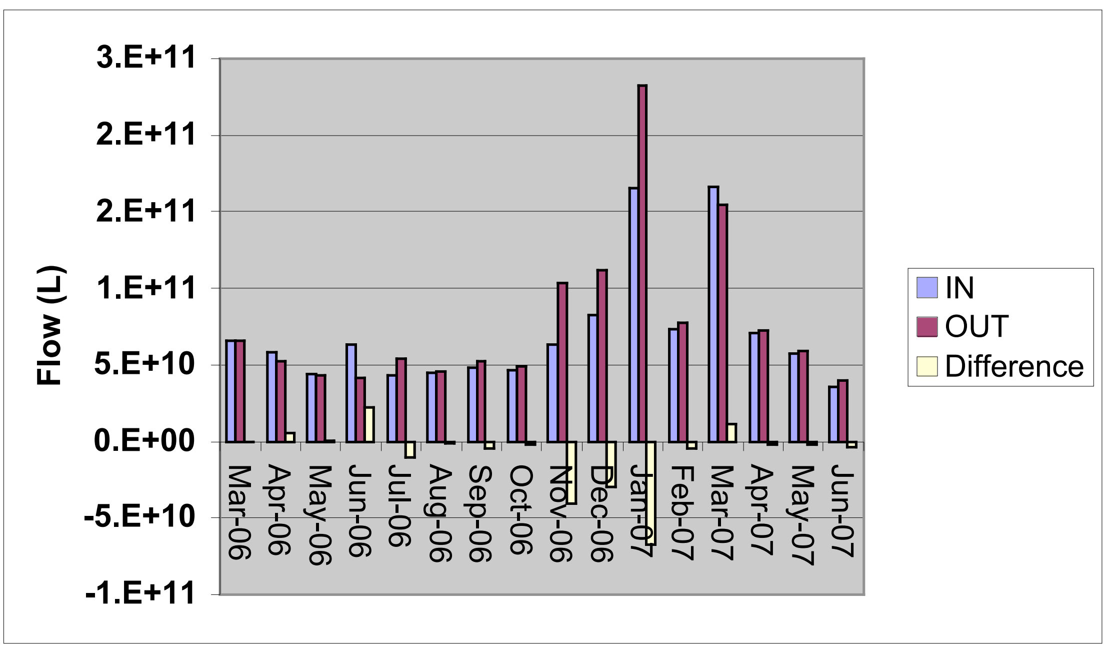

Figure 5. Flow balance in Lake Greenwood. "IN" bar represents combined flow from the Reedy and Saluda Rivers; "OUT" represents flow over the dam; "Difference" is the numerical difference between the two values.

Similar comparisons can be made for total phosphorus, total nitrogen, nitrate, and total suspended solids. The analysis for total phosphorus revealed that approximately 24% of the total phosphorus entering the lake via the two rivers stayed in the lake (Figure 6).

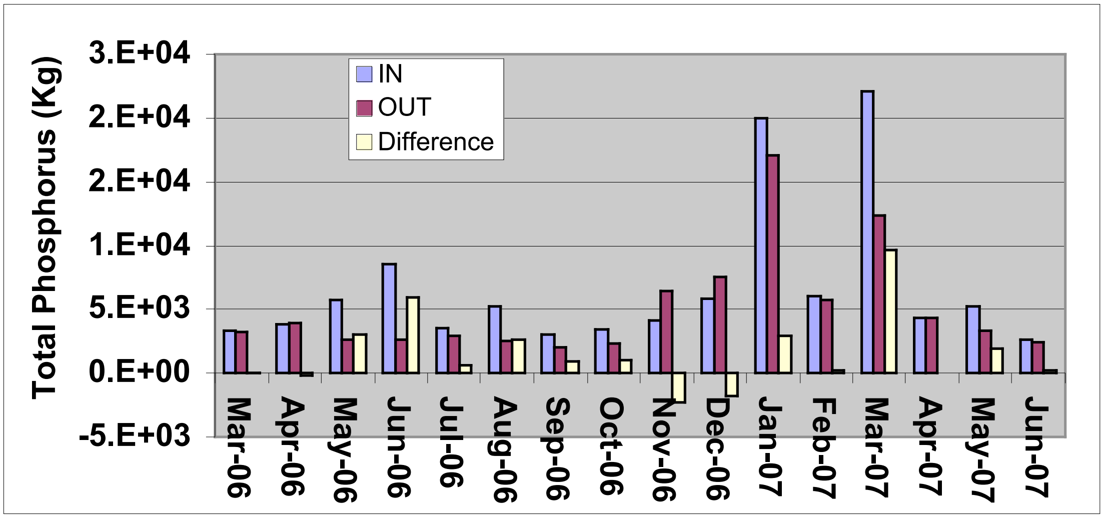

Figure 6. Total Phosphorus balance in Lake Greenwood. "IN" bar represents combined phosphorus loading from the Reedy and Saluda Rivers; "OUT" represents phosphorus load exported over the dam; "Difference" is the numerical difference between the two values.

Phosphorus retention takes two forms: incorporation into plants and algae via photosynthesis; adsorption to suspended solids, sedimentation, and deposition into the bed sediments. The phosphorus incorporated into plant material may also reach the lake sediment if the plants die and sink to the bottom before they decompose.

The analysis for total nitrogen revealed that approximately 72% of the total nitrogen entering the lake via the two rivers was exported over the dam (Figure 7). Total dissolved nitrogen represents the sum of nitrate, nitrite, and dissolved organic nitrogen. Particulate organic nitrogen (usually decaying plant material) is not accounted for in this measurement as the sample was filtered prior to analysis. While some of the 28% nitrogen that is not exported over the dam can be assumed to have been incorporated into plant material via photosynthesis (similar to phosphorus), denitrification and export back into the atmosphere probably accounts for the rest.

The analysis for nitrate nitrogen revealed that approximately 68% of all nitrate coming into the lake via the two rivers was staying in the lake (Figure 8). This was most likely

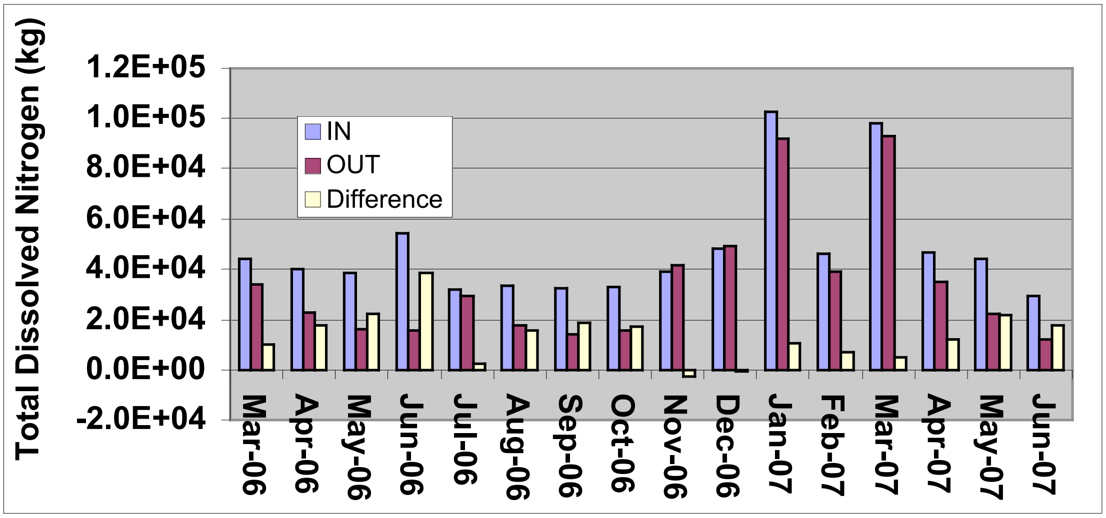

Figure 7. Total dissolved nitrogen balance in Lake Greenwood. "IN" bar represents combined nitrogen loading from the Reedy and Saluda Rivers; "OUT" represents nitrogen load exported over the dam; "Difference" is the numerical difference between the two values.

incorporated into photosynthetic material as it is the most readily available form of nitrogen. The results for nitrate are consistent with the results for total dissolved nitrogen and suggests that the 28% of total dissolved nitrogen that is staying in the lake is largely composed of nitrate.

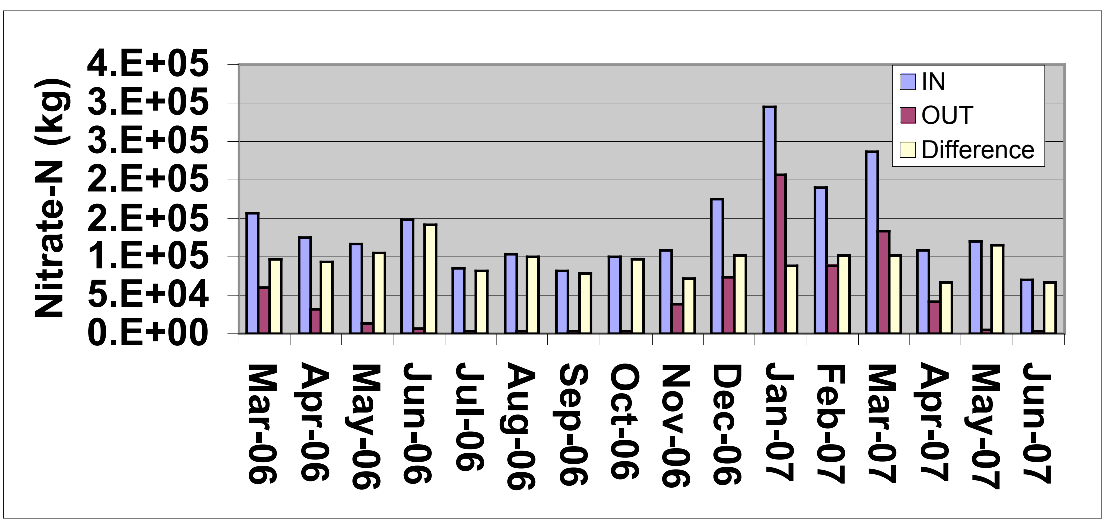

Figure 8. Nitrate nitrogen balance in Lake Greenwood. "IN" bar represents combined nitrate nitrogen loading from the Reedy and Saluda Rivers; "OUT" represents nitrate nitrogen load exported over the dam; "Difference" is the numerical difference between the two values.

The balance for total suspended sediments provides and indication of sediment retention by Lake Greenwood and can be used as a conservative estimate of how rapid the reservoir is filling in with sediment. Analysis of the data indicates that 80% of the total suspended sediment that enter the lake via the Reedy and Saluda Rivers stays within the reservoir (Figure 9). This analysis suggests that, conservatively, 3.77×10^7 kg (82,940,000 lb) of sediment were deposited in Lake Greenwood during the 16 months of this study. Reasons these data are conservative is that they do not consider additional sources of sediment loading such as direct runoff from adjacent land, and the methods of water sample collection provides no indication of bed sediment loading (movement of sediments downstream at the sediment-water interface) from the rivers.

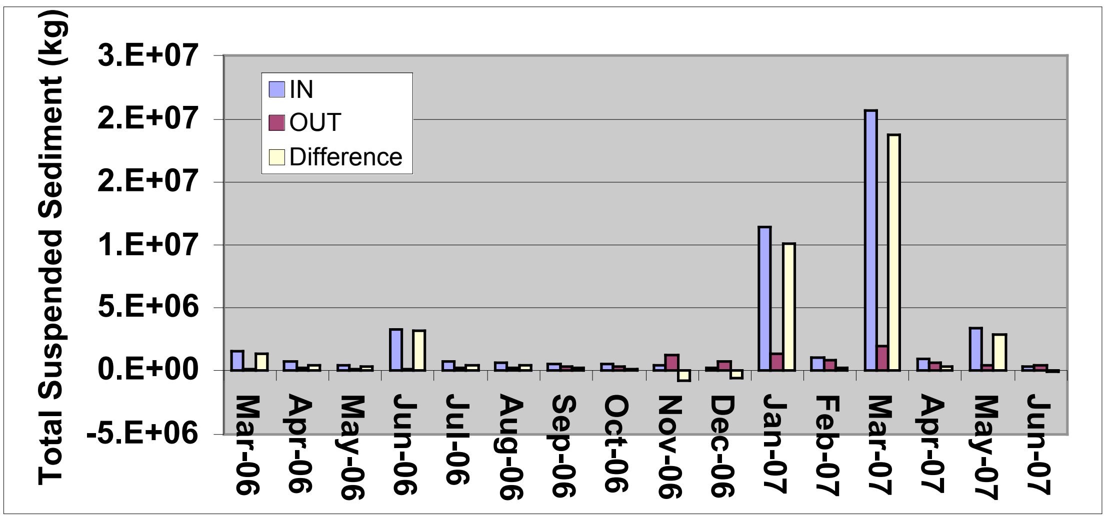

Figure 9. Total suspended sediment balance in Lake Greenwood. "IN" bar represents combined suspended sediments loading from the Reedy and Saluda Rivers; "OUT" represents suspended sediments load exported over the dam; "Difference" is the numerical difference between the two values.

In summary, these data suggest that Lake Greenwood retains significant amounts of contaminants and sediments from the Reedy and Saluda Rivers (Figure 10). These data are consistent with other observations that reservoirs in general and those in the Upstate of South Carolina in particular, serve as retention basins for many contaminants and sediments that otherwise would migrate downstream and be deposited ultimately into the coastal estuary. This has both positive and negative impacts on the estuary. First, it reduces contamination of the estuary by the myriad of athropogenic contaminants migrating from various land uses within the watershed. Second, it reduces the amount of sediments migrating downstream and filling in reservoirs. However, the reduction in nutrient loading may reduce the productivity of the estuary.

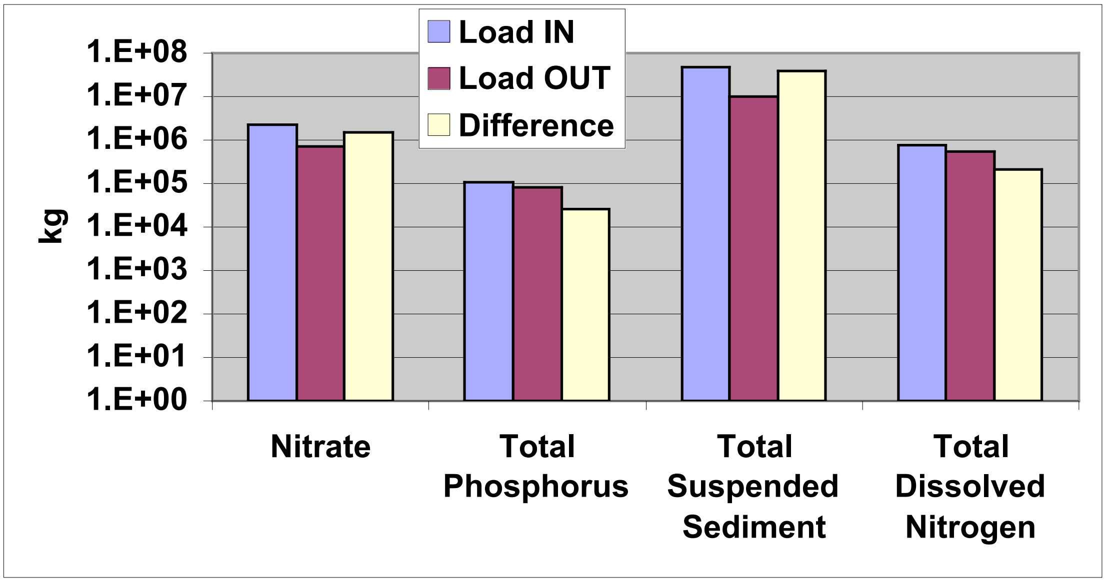

Figure 10. Nutrient and sediment balances in Lake Greenwood. "IN" bar represents combined loading from the Reedy and Saluda Rivers; "OUT" represents load exported over the dam; "Difference" is the numerical difference between the two values.

PHOSPHORUS RELEASE FROM LAKE GREENWOOD SEDIMENTS

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Investigators at Lander University quantified phosphorus release from Lake Greenwood, SC. Sediment and water samples were collected at three sites on Lake Greenwood for phosphorus flux measurements. Fluxes were measured over a 14-day period under aerobic and anaerobic conditions. Results indicate that sediment release of phosphorus is a significant contribution to water column phosphorus concentrations. These results suggest that reduction of phosphorus inputs into Lake Greenwood may not be as effective at reducing eutrophication as reduction of nitrogen sources.

Season	Middle part at Puckett's Anaerobic conditions	of the lake Ferry boat dock Aerobic conditions	Saluda River at highway Anaerobic conditions	arm of the lake 39 bridge Aerobic conditions	Reedy River at highway Anaerobic conditions	arm of the lake 29 bridge Aerobic conditions
Summer 2006	5	13	89	10	4	3
Fall 2006	91	24	146	38	14	168
Winter 2007	31	25	84	5	42	23
Spring 2007	17	119	226	61	38	41
Average	36	45	136	29	25	59
Total Average			55			

Table 1. Phosphorus Flux across the Sediment-Water Interface in Lake Greenwood (mg/m^2/day)