THE EFFECTS OF SEDIMENT REMOVAL ON INTERNAL NUTRIENT CYCLING AND EUTROPHICATION IN LAKE ALLATOONA

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Abstract Release of nutrients from benthic sediments can be a major cause of algal blooms in Southeastern reservoirs. Interrupting the supply of nutrients from this source by sediment removal may achieve water quality goals. This study evaluates the processes and magnitudes of sediment nutrient release in Lake Allatoona, a major water-supply reservoir in the Atlanta Metropolitan Area.

INTRODUCTION

Primary sources of lake-nutrient enrichment are either external (allochthonous) or internal (autochthonous). External inputs include point sources (wastewater treatment facilities) and nonpoint sources including agricultural, urban, and other land uses. Internal inputs include release of phosphorus from sediment as well as from decaying organic matter. Internal loading occurs when nutrients previously sorbed to lake sediments, desorb, and become available for algal growth.

Of concern is the relative magnitude and importance of external vs. internal nutrient sources. While current nutrient control strategies focus on limiting external inputs, the control of internal inputs has not been addressed. Internal loading and its resulting effects are region-specific as they vary based on physical, chemical and biological conditions in lakes. While external nutrient loading is widely assumed to be the primary cause of cultural eutrophication, many lakes continue to experience algal blooms and lake anoxia after external loading has been reduced. Internal loading is the main mechanism providing P to algal biomass in lake systems with low concentrations of orthophosphate in water and high concentrations in sediment.

This paper summarizes research performed by Ceballos (2007), which examined the relative importance of internal loading at Lake Allatoona, and provides recommendations regarding appropriate methods for abating internal loading. Of special interest is the magnitude of allochthonous sediment and phosphorus inputs, how these inputs compare to the likely inventory of sediments and nutrients within the lake, and how much of this material is being removed by dredging operations.

PROBLEM STATEMENT

Lake Allatoona is a U.S. Army Corps of Engineers reservoir located in northwest Georgia. The reservoir was created in January 1950 upon completion of Allatoona dam. When full, the surface area of the reservoir covers approximately 12,010 acres, the maximum depth at the Dam is 145 feet, and the storage volume is approximately 367,500 acre-feet. The watershed area upstream of the dam is 1110 mi^2 and contains one large tributary (the Etowah River), and several smaller tributaries (the Little River, Noonday Creek, and Allatoona Creek). The designated uses for the reservoir include flood control, hydropower generation, water supply, recreation, fish and wildlife management, water quality, and navigation.

Suspended and bed sediments from influent tributaries accumulate in the upper reaches of the reservoir - primarily in the eastern part of the lake near the Etowah and Little River inlets and in the southern part near Allatoona Creek (Lake Acworth) - forming depositional features including deltas and levees. These areas receive substantial inputs of sediments and nutrients from point and nonpoint sources. In addition, legacy sediments from historic sources have accumulated, providing long-term sources of sediment-related nutrients. Nutrients within these sediments may contribute to lake eutrophication via sediment release, thus contributing to internal loading.

Lake Allatoona, like many of Georgia's reservoirs, experiences seasonal algal blooms. These blooms are typically during the warm season (June through September) and are attributed to increased eutrophication from nutrient enrichment, primarily phosphorus. Phosphorus (P) is assumed to be the limiting nutrient in Southeastern Piedmont impoundments. Causes of eutrophication for Lake Allatoona included phosphorus loads from watershed sources, including point and nonpoint sources. Point loads generally consist of soluble nutrients, while nonpoint loads consist of both soluble and particulate sources. Soluble loads are likely to become sorbed to suspended and bed sediments, as well as sequestration via biological uptake, while in transit to the lake.

In response to concerns about lake eutrophication, nutrient limits have been established for Lake Allatoona tributaries. Total maximum daily loads (TMDLs) are required by a federally mandated program to improve water quality. TMDLs for Chlorophyll *a* (and waste load allocations of total phosphorus for point-sources) have been established within the Little River Embayment (TMDL ID 9825).

Dredging of nutrient-rich lake sediments has been proposed as a management tool for reducing within-lake nutrients. Small-scale dredging in Lake Allatoona has been conducted primarily for increasing navigability of the lake. Blankenship Sand operates dredges to remove sediment (primarily sand) from North Georgia lakes and rivers, including Lake Allatoona and its tributaries. Sediment dredging involves a mobile, floating, diesel-powered suction dredge with a cutting head. Dredged materials are transported either to the shore by pipeline, or to a waiting clamshell barge that carries the sediments to an in-lake holding area that is re-dredged by pipeline to the shore.

An important question is whether this dredging affects lake water quality. The dredging of sediments may reduce internal loading by removing internal sources of lake nutrients. While dredging may remove sand-sized particles from sediments, it may also result in the resuspension of clay and silt-sized particles during initial dredging, with subsequent transfer to the holding area and return of tail-waters to the lake. If desorption of P from the finer materials occurs, then this action may degrade water quality. Yet, it is also possible that these finer materials may remove P from the water column by sorption and subsequent sedimentation. Removing within-lake sediments may benefit lake water quality by reducing the potential release of nutrients and toxic metals from these sediments.

METHODS

This study examines the possible benefits of removing benthic lake sediments on lake water quality by reducing the biologically available nutrients contained in these sediments. The key concerns are the total amount and release rates of phosphorus from lake sediments. An initial goal for this study is to assess Lake Allatoona sediment composition and water quality. This was achieved by field data collection and sediment and water analyses.

Both field and laboratory data were used for collecting data about lake water quality. Field measurements were collected using a Hydrolab Quanta (Austin, TX). The instrument provides field temperature, pH, specific conductance, turbidity, and dissolved oxygen concentrations. The instrument was calibrated prior to each field trip. Additional data were obtained from USGS published sources.

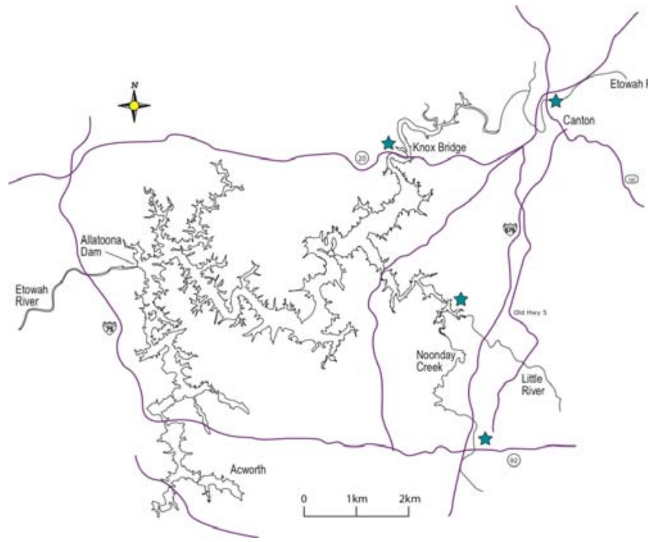

Figure 1. Lake Allatoona map showing tributaries and dredging sites (stars).

Sand, silt and water samples were collected on multiple dates in Lake Allatoona from Blankenship Sand's Little River and Knox Bridge locations, as well as from the Etowah and Little Rivers (Figure 1). Measurements of *in situ* lake water quality were made using a Hydrolab Quanta from a pontoon boat. Water samples were also collected near and down-lake from the dredging operation and the Little River and Noonday Creek embayments.

Field water and sediment samples were collected in acid-washed bottles, given a unique identifier label, and placed on ice during transport back to the University of Georgia. At least two samples were collected from each location. Water samples from river sites were collected using a USGS DH-48 sampler lowered by a rope from a bridge. Samples were collected at approximately one- and two-thirds of the distance across the channel. Samples were collected in acid-washed bottles, stored on ice, and returned for analysis within ten hours.

Water and sediment samples were analyzed at three laboratories at the University of Georgia. The UGA Soil, Plant, and Water Laboratory was used for both sediment and water testing. The UGA Laboratory for Environmental Analysis was used for sediment testing. The UGA Stable Isotope and Soil Biology Laboratory was used to determine soluble reactive phosphorus concentrations.

RESULTS AND DISCUSSION

The sediment load to Lake Allatoona is substantial. Sediment inputs from three tributaries studied here were estimated using U.S. Geological Survey suspended sediment concentration and discharge data to vary from approximately 1,000 Mg/yr (1 Mg = 1000 kg = 1 metric ton) from the Noonday Creek watershed, to 9,000 Mg from the Little River watershed, to over 23,000 Mg from the Etowah River basin. These enormous sediment loads settle to the bottom of the reservoir, primarily near the discharge points of these tributaries into the reservoir. These are conservative estimates of the sediment load because they do not account for bedload transport. Bedload transport of sand-sized and larger sediments is expected to be a significant - yet unmeasured - input to the reservoir.

A crude estimate of the time required to fill the reservoir can be calculated by assuming:

- The total sediment loading to the reservoir is limited to the inputs from the Etowah River, Little River, and Noonday Creek, totaling 33,000 Mg/yr;
- The sediment density in the lake is 1.2 Mg/m^3, yielding a sediment input of approximately 27,500 m^3/yr; and
- The total storage volume is 367,500 acre feet, equivalent to approximately 454 million cubic meters.

The resulting time to fill the lake with sediment is approximately 16,500 years. Yet this estimate grossly underestimates the total sediment inputs by neglecting bedload transport as well as other lake tributaries. In addition, the sediments will accumulate in the shallower zones nearer to tributary inputs, thus adversely affecting shallower zones than near the dam.

Large quantities of nutrients are contained within these tributary sediments. Using U.S. Geological Survey water quality data, the total phosphorus concentration within tributary suspended sediments was estimated to be 1.1, 1.2, and 0.8 g/kg for the Etowah River, Little River and Noonday Creek. These values are equivalent to 2.2, 2.4, and 1.6 pounds per ton, respectively. Corresponding estimates for stormwater samples collected for this project on the Etowah River (2.6 g/kg) and the Little River (1.8 g/kg) were slightly higher.

The total phosphorus load to Lake Allatoona was estimated using U.S. Geologic Survey water quality and discharge data to be approximately 5.84 Mg/yr from Noonday Creek, 21.9 Mg/yr from the Little River, and 62.8 Mg/yr from the Etowah River basin. These estimates are larger than - but generally consistent with - estimates obtained independently by the Lake Allatoona Phase I Diagnostic Feasibility Study conducted by Kennesaw State University between 1992 and 1997 as part of an EPA Clean Lakes Study. The total phosphorus load estimated in the Clean Lakes Study yielded an estimate of 4.6 Mg/yr from Noonday Creek, 10 Mg/yr from the Little River, and 38.4 Mg/yr from the Etowah River Basin. Discrepancies between these estimates can be attributed to differences in the data and methods of analysis used. Additional studies using in-lake sediment accumulation surveys are needed to independently corroborate these estimates.

Lake Allatoona sediments are removed by commercial dredging operations by Blankenship Sand. These dredging operations focus on the separation and removal of the sand-size fraction. Dredging operations at the Knox Bridge facility yields a product with approximately 97.7% sand, 0.3% silt, and 2% clay. Dredging operations at the Little River facility yields a product with approximately 94% sand, 4% silt, and 2% clay. There is a small amount of residual organic matter within this material, ranging from 0.4 to 0.7% at Knox Bridge, and 0.3 to 0.8% at Little River.

The texture of undisturbed benthic sediments samples obtained from the Noonday Creek embayment was highly variable, but was generally dominated by the sand- and silt-sized fraction. The average texture was a sandy loam, with approximately 53% sand, 36% silt, and 11% clay. In addition to the mineral fraction, the samples contained approximately 8.2% organic matter.

Tailings are also produced as a waste byproduct at these facilities, and are currently handled separately than the sand product. The composition of these tailings was highly variable, ranging between 12 and 44% sand at Knox Bridge, and between 11 and 80% sand at Little River. Silt composition varied between 48 and 70% at Knox Bridge, and between 18 and 77% at Little River. The clay composition varied from 6 to 18% at Knox Bridge, and 2 to 20% at Little River. Organic matter varied from 3 to 7% at Knox Bridge, and 2.5 to 7.5% at Little River. The tailings ranged in soil texture from a silt loam to a loamy sand.

Another waste byproduct is dredging tailwater effluent. Samples collected from tailwater at the Knox Bridge dredging operation showed low levels of suspended solids (approximately 50 mg/L), while samples collected at the Little River dredging operation showed higher levels (approximately 1100 mg/L). The predominant texture of dredging tailwaters is likely to be clay due to extended holding times provided by the tailings collection basins. Estimates of total return loads from tailwater effluent are unavailable, as estimates of discharge volumes would be required for this estimate. Due to the nature of the operations, however, routine measurements of discharge and concentration would be required for adequate precision to be achieved. Yet the total magnitude of return loads appears to be small in comparison to the sand- and silt-size fractions removed.

Dredging operations by Blankenship Sand yielded a sand product at the Knox Bridge dredging operations that contained approximately 0.13-g/kg total phosphorus (0.26 pounds per ton) and a tailings byproduct that contained approximately 0.60-g/kg total phosphorus (1.2 pounds per ton). The sand product at the Little River dredging operations contained approximately 0.077-g/kg total phosphorus (0.15 pounds per ton) and a tailings byproduct that contained approximately 0.21-g/kg total phosphorus (0.42

pounds per ton). Lake benthic sediment collected from the Noonday Creek embayment contains approximately 0.35-g/kg total phosphorus (0.7 pounds per ton).

The phosphorus contents of the dredged and benthic sediment materials were slightly less that those estimated using U.S. Geological Survey tributary water quality data. One explanation that may reconcile these conflicting estimates is the possibility that the phosphorus was more likely associated with the clay-size fraction. Because dredging operations focus on the removal of the larger sediments with correspondingly lower clay content, these materials are less likely to contain phosphorus.

Dividing the sediment phosphorus concentration by the percent clay content yielded substantially higher sediment phosphorus concentrations; 6.4 g/kg for Knox Bridge sands, 3.2 g/kg for Knox Bridge tailings, 3.8 g/kg for Little River sands, 2.3 g/kg for Little River tailings, and 3.3 for Noonday Creek sediments. These values are substantially larger in the bulk sediments, and are even larger than tributary observations, indicating that this is a possible reason for the lower bulk total phosphorus concentrations.

Algal available phosphorus (i.e., the form of phosphorus that phytoplankton can use for growth) concentrations are usually low in lake water, as P tends to sorb to the surface of soil minerals (e.g., iron oxyhydroxides and calcium cations). Because clay particles are smaller, they have much greater surface area per unit volume than do the larger sand particles, and so the majority of phosphates bond to the finer materials.

While results varied depending on the method of analysis, the smaller clay fraction of the sediment consistently contained considerably more phosphorus than the larger sand fraction. Three fractions of sediment from both the Little River and the Knox Bridge sites were tested, including the dredged product and waste tailings from near or within the settling pond. Using the alkaline desorption (NaOH) method, clay contained 75.7-mg/kg phosphorus, while sand contained 20.7 mg/kg. The water in the settling ponds, and from two tributaries of the lake, was also tested. The amount of phosphorus in the water samples was small relative to that in the sediment. All values of total phosphorus in water samples were less than 0.5 mg/L, and many were below detection limits.

Analysis of the iron composition in the sediments indicated that the amorphous form dominated the tailings while the crystalline form dominated the sand product at both dredging locations. The sorption of phosphorus to iron is favored on the amorphous form, suggesting that the sorption of phosphorus to iron within the tailings material is likely.

Soil organic matter is the fraction of the soil composed of anything that once lived. As with phosphorus, a much higher percent organic matter was found within the tailings (5.7%) than within the sand samples (0.034%). In general, soils in Georgia contain only small amounts of organic matter (1 to 2%) compared to the very fertile soils found in the Midwest (4 to 5%). The decay of organic materials provides another source of nutrients (including phosphorus, nitrogen, and carbon) for biological systems.

The removal of benthic sediments from Lake Allatoona by dredging or other methods will remove nutrients (especially phosphorus) that are bound to these sediments. The amount of nutrients removed by dredging depends on the size of the sediment particles removed. The presence of these nutrients means that the dredged tailings are an excellent medium for plant growth, having ideal soil textures, including loams, silt loams, sandy loams, and loamy sands. Coupled with plentiful organic matter, these materials could be marketed for landscaping purposes.

While health risks associated with toxic metals contamination are a concern, test results failed to show metal contamination, and all results were well below state regulatory limits. A current limitation for the use of these materials for landscaping purposes is the poor soil structure. Improvements in soil structure by composting or other means would allow more widespread use of these materials as soil amendments.

Reductions of internal nutrient loadings within Lake Allatoona requires both reductions in lake loading, as well as reductions in the internal sediment pool. Removal of benthic sediments containing nutrients is a key component of improving lake water quality. While sand removal is currently the only economically viable option for sediment removal, incentives to remove what are currently dredged byproducts should be considered.

REFERENCES

Ceballos EL, 2007, Effects of internal loading on algal biomass in Lake Allatoona, a Southeastern Piedmont impoundment, M.S. Thesis, The University of Georgia, Athens.