Muddy Waters: Landcover and Sedimentation in an Urban Lake

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ABSTRACT

As watersheds become increasingly urbanized, managers are faced with the daunting task of understanding environmental impacts on waterways. In particular, loss of natural landcover can lead to higher soil erosion and runoff along creeks and rivers, heavier sediment build-up in ponds and lakes, and decreases in water quality and impoundment capabilities. Here, a multi-agency team of personnel from academic, government, and private sectors in central Virginia is addressing the relationship between changing land use in an urbanized watershed and resulting sedimentation into a typical, small lake within that watershed. Historical lake depth data from the 1970s were mapped and combined with current lake depths to visualize sedimentation patterns, with these maps then being assessed against development maps of the region. Together, this information is being used by local officials to help mitigate impacts from future development and ultimately to create more sustainable watershed management plans.

Introduction

An ongoing problem in the management of freshwater ecosystems is sedimentation. Sedimentation occurs when rapidly flowing streams burdened with sediment enter a still body of water such as a reservoir, causing the sediment to settle due to the lower flow rate (Salas and Shin 1999). Such reservoirs, capturing the runoff from their upstream watersheds, and often without a method to balance the inflow of sediment with outflow, function as sediment traps (Fan and Morris 1992). The end result is often degraded water, disrupted ecological relationships, and diminished aesthetic qualities (Waters 1995). In addition, as reservoirs become filled, their capacity for storage decreases. Mahmod (1987) estimated a decrease in worldwide reservoir storage by one percent per year through sedimentation. Others estimate approximately 20 billion tons of sediments settle out in river channels and in reservoirs each year (Mousavi and Samadi-Boroujeni 1998). The continued loss of storage capacity due to sedimentation is diminishing the benefits reservoirs were built to provide including flood control, water supply, and recreational opportunities (Hotchkiss and Huang 1995).

The potential for watershed erosion and reservoir sedimentation increases as areas urbanize, both exposing bare soil and increasing the amount of impervious surfaces. During an intense rain, the lack of ground cover, which normally dissipates the energy of rain, allows more runoff and erosion as precipitation intensity exceeds the decreased infiltration rate (Krenisky et al. 1998). Urban development has been found to cause up to a fifty percent increase in the annual sediment load in a given watershed (Nelson and Booth 2002), and may contribute up to fourteen times the load of suspended sediment as forested watersheds (von Guerard (1989). Construction sites, in particular, can increase the sediment found in a stream by as much as five times the normal amounts (Wolman and Schick 1967). Such sites are increasingly found to be the primary sources of sediment, with soil erosion rates up to twenty times higher than at comparable agricultural sites (USEPA 1997, Faucette et al. 2004).

The purpose of this project was to study sediment accumulation in a small reservoir located within an urbanized watershed. Our approach was two-tiered. We first measured and mapped changing water depths and sediment accumulations in this lake over the past few decades. We then generated land-use maps of the watershed to assess its degree of urbanization. Working with a multi-agency team of personnel from academic, government, and private sectors, we are using this information to develop management guidelines for reducing erosion and sediment buildup throughout this and other urban watersheds.

Materials and Methods

Study Area

College Lake is a small reservoir built in 1934 along Blackwater Creek, the primary drainage around Lynchburg, Virginia. The Blackwater Creek Watershed has a drainage area of just over 17,000 ha with approximately 5,600 ha located upstream of College Lake (Figure 1). When built, the lake surface area was approximately 18 ha with a maximum depth of almost 9 m (Carico et al. 1973). The original watershed to reservoir ratio was 311:1.

Over the years, College Lake has served as an interceptor of sewage during extreme stormwater events. Such occurrences have dramatically decreased since the 1980s as the City of Lynchburg began implementing a Combined Sewer Overflow Program (City of Lynchburg Department of Public Works 2000). While bacteria from such events, as well as agricultural runoff and septic system failure from the rural, upper portions of the watershed are still problematic, excess sedimentation has now become the most prominent issue. The Blackwater Creek Watershed is considered urbanized (> 50% development), with its few remaining forested areas under development pressure. Sedimentation is a long-standing problem in the Blackwater Creek Watershed with construction sites adhering to a very poor standard of compliance (Swackhammer and Shahady 2002).

Lake Mapping

Geographic Information System (GIS) profiles of the lake were created for two time periods: 1971 and 2002. For 1971, a map showing water depths (collected from soundings) across College Lake was obtained from an unpublished research project (Ramsey and Carico personal communication). This map was scanned, brought into ArcView GIS and georectified. Data from the nearly 400 water depth points were then used to run a spatial interpolation and generate bathymetric contours for the entire lake. Mean water depths were also calculated, both for the lake as a whole and for smaller subsections of the lake. For the 2002 lake profile, the most current aerial photos of College Lake available (1997), were obtained from the City of Lynchburg Map Office for use as a basemap. Both water and sediment depth data were collected for this time period using a PVC pipe and a Garmin E-Trex Legend GPS unit. Bathymetric contours were again generated, describing both water and sediment depths across the entire lake in 2002. Finally, mean water depths were then compared to 1971 depths. Due to a lack of sediment data in 1971, only comparisons in water depths could be made.

Watershed Landcover Assessment

Both the Blackwater Creek and College Lake Watersheds were delineated on 7.5' USGS quadrangle maps via heads-up digitizing in ArcView. Landcover data were then obtained from the USGS (2005) that broadly categorize land use into 21 categories. This dataset was created from interpretation of aerial photos from the 1970s and 1980s, and consisted of a 4 ha minimum mapping unit. The original landcover classes were aggregated into more general classes of Forest, Agriculture, Residential, and Industrial. The final landcover maps were clipped to each watershed and assessed for water quality impacts.

Results

Lake Mapping

When College Lake was originally created in 1934 it was estimated to be 17.8 ha in size. In 1971 the lake's area was 12.13 ha with a mean depth of 2.18 m and having approximately 265,000 m^3 of water in storage capacity. By 2002 the lake area had decreased to 7.56 ha, less than half its original size. This decease in area more than doubles the watershed to reservoir ratio from its original 311:1 to approximately 741:1. In 2002 the lake's storage capacity was estimated to be about 96,000 m^3, losing approximately 170,000 m^3 in storage capacity since 1971.

In 1971, College Lake had a defined channel from the inlet of Blackwater creek to the dam, with the deepest water depths in the lake's center near the dam (Figure 2a). By 2002, the lake had lost its channel near the headwaters and had generally lost depth throughout the entire lake (Figure 2b). On average, the lake lost almost 1 meter of water depth between 1971 and 2002, going from 2.18 m to 1.27 m, respectively.

Sediment depths in 2002 were greatest in the headwaters and transition sections of the lake with sediment depths reaching as much as 3 m in several locations. Depths also tended to be greater in the center of the lake, and decreasing towards the banks (Figure 3). The mean sediment depth for the entire lake in 2002 was calculated to be 0.85 m with approximately 64,000 m^3 of sediment found throughout the lake. Again, no sediment data were available from 1971.

Watershed Landcover Assessment

Figure 4 displays the distribution of landcover types across both the Blackwater Creek and College Lake Watersheds. Across the entire Blackwater Creek Watershed, the greatest landcover type was Forest, followed by Residential, Agriculture, and Industrial. Limiting the analysis to just the College Lake Watershed changed the order to Residential, Agriculture, Forest, and Industrial (Table 1). In general, this reflects a shift from a more rural watershed (Blackwater Creek), less impacted by human activities, to a more urbanized one (College Lake) with higher potential for sedimentation impacts.

Discussion

Overall, our study suggests erosion throughout the watershed is accelerating the succession of College Lake. The GIS profiles illustrate that the lake is filling in with large amounts of sediment over time. This accumulation of sediments is greatly decreasing both water depth and overall storage capacity. Without addressing the sources of these sediments, or developing methods to balance sediment inflow and outflow, the lake will continue to lose storage capacity until it is completely filled in (Fan and Morris 1992). At current rates, this will take less then twenty years; as the watershed surface area to reservoir ratio continues to increase, however, this time may be considerably shortened.

Reducing the impacts from upstream land disturbance activities seems to be the most important step in improving the situation at College Lake. This could be accomplished with riparian buffers around stream banks, storm water retention ponds, stricter laws and increased enforcement concerning runoff at construction sites, and the use of in-stream sediment exclusion structures (Krenitsky et al. 1998, Palmieri et al. 2001, Nelson and Booth 2002.). Otherwise, continued development in this watershed will only exacerbate the issue. Even if sediment loads are reduced, dredging of the lake may still be necessary to restore both its original ecological function and storage capacity. Dredging, in fact, may be a recurring need; under current conditions, it is likely that dredging may continue to be necessary at 30 year intervals.

Management Implications

While sedimentation of water bodies is a natural process, and by acting as a trap can even improve downstream water quality, the apparent accelerated rates in College Lake is a problem symptomatic of many urban reservoirs. Ultimately, a political solution addressing regional stormwater management issues may be needed to truly minimize erosion in this watershed. To address this, a multi-agency team of personnel from academic, government, and private sectors in this region has been assembled to develop a comprehensive watershed management plan. Members represent such varying organizations as Lynchburg College, City of Lynchburg (Virginia), Bedford County (Virginia), Campbell County (Virginia), Peaks of Otter Soil and Water Conservation District, Robert E. Lee Soil and Water Conservation District, Virginia Department of Environmental Quality, U.S. Army Corps of Engineers, and representatives from Virginia's state government. Together, this team hopes to move past political boundaries and constraints, and work from a perspective defined by nature. Ultimately, restoration of College

Lake, as with other urban reservoirs, will come only with an understanding of processes – both natural and anthropogenic – occurring across its entire watershed.

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Table 1. Percentage of landcover types for the Blackwater Creek and College Lake, Virginia, Watersheds.

	Blackwater Creek	College Lake
Forest	36	14
Agriculture	26	33
Residential	30	45
Industrial	8	8

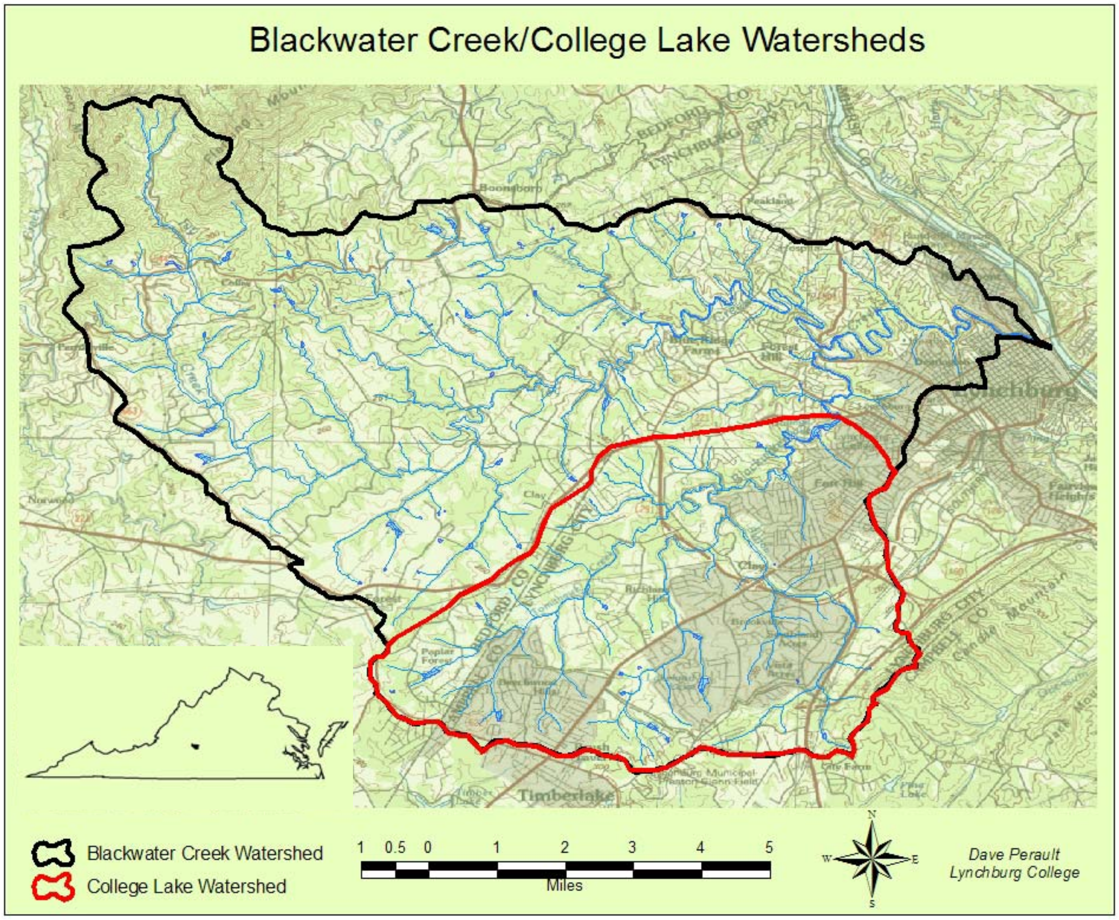

Figure 1. – Blackwater and College Lake Watersheds, located in central Virginia.

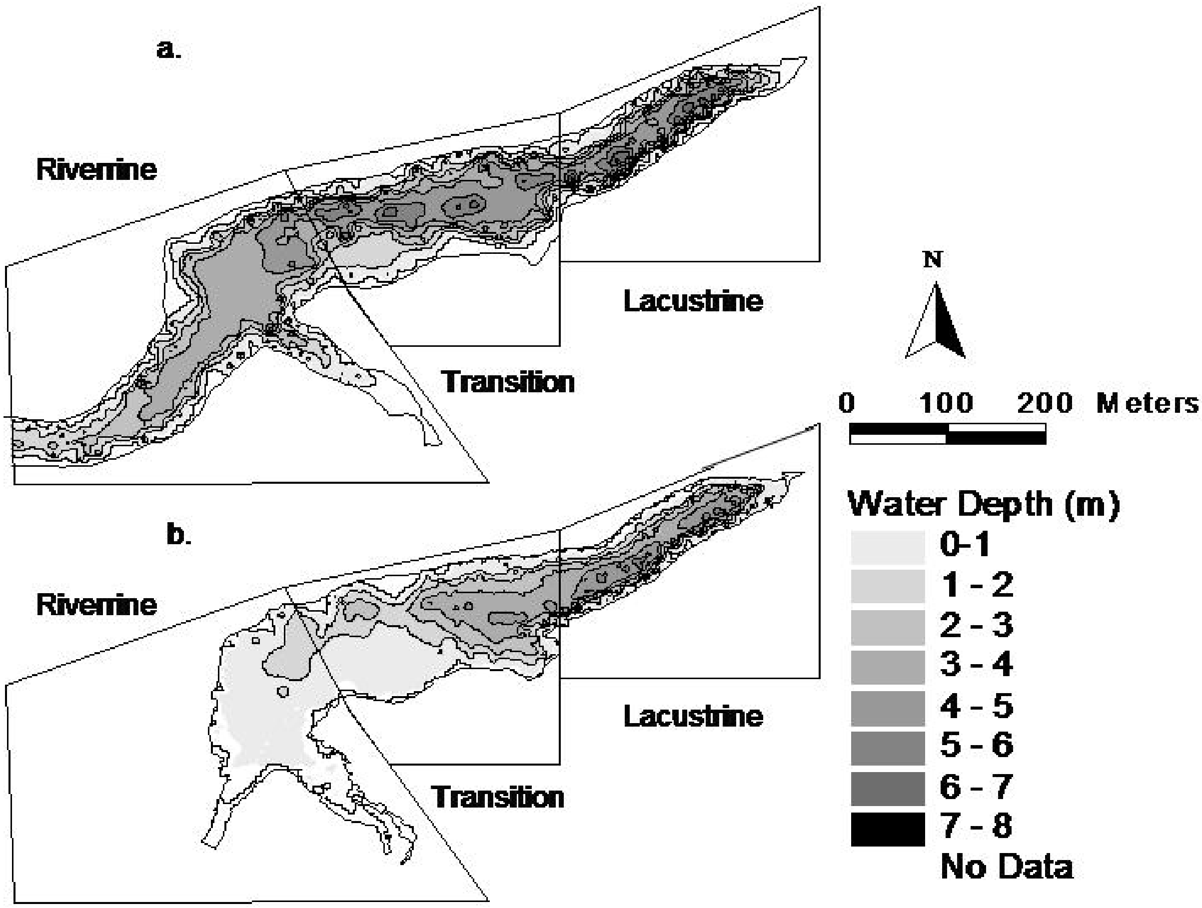

Figure 2. – Water depths and the three lake sections of College Lake, Virginia, in 1971 (a) and 2002 (b).

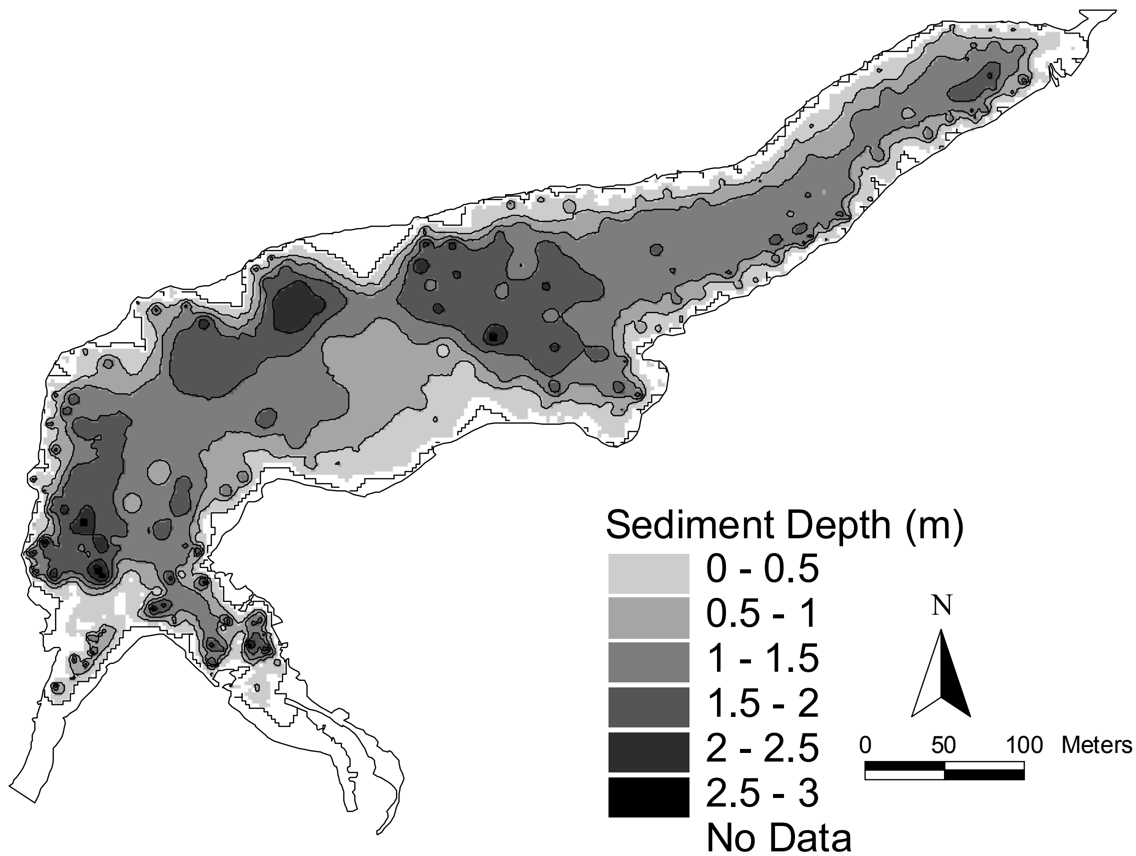

Figure 3. – Sediment depths for College Lake, Virginia, in 2002.

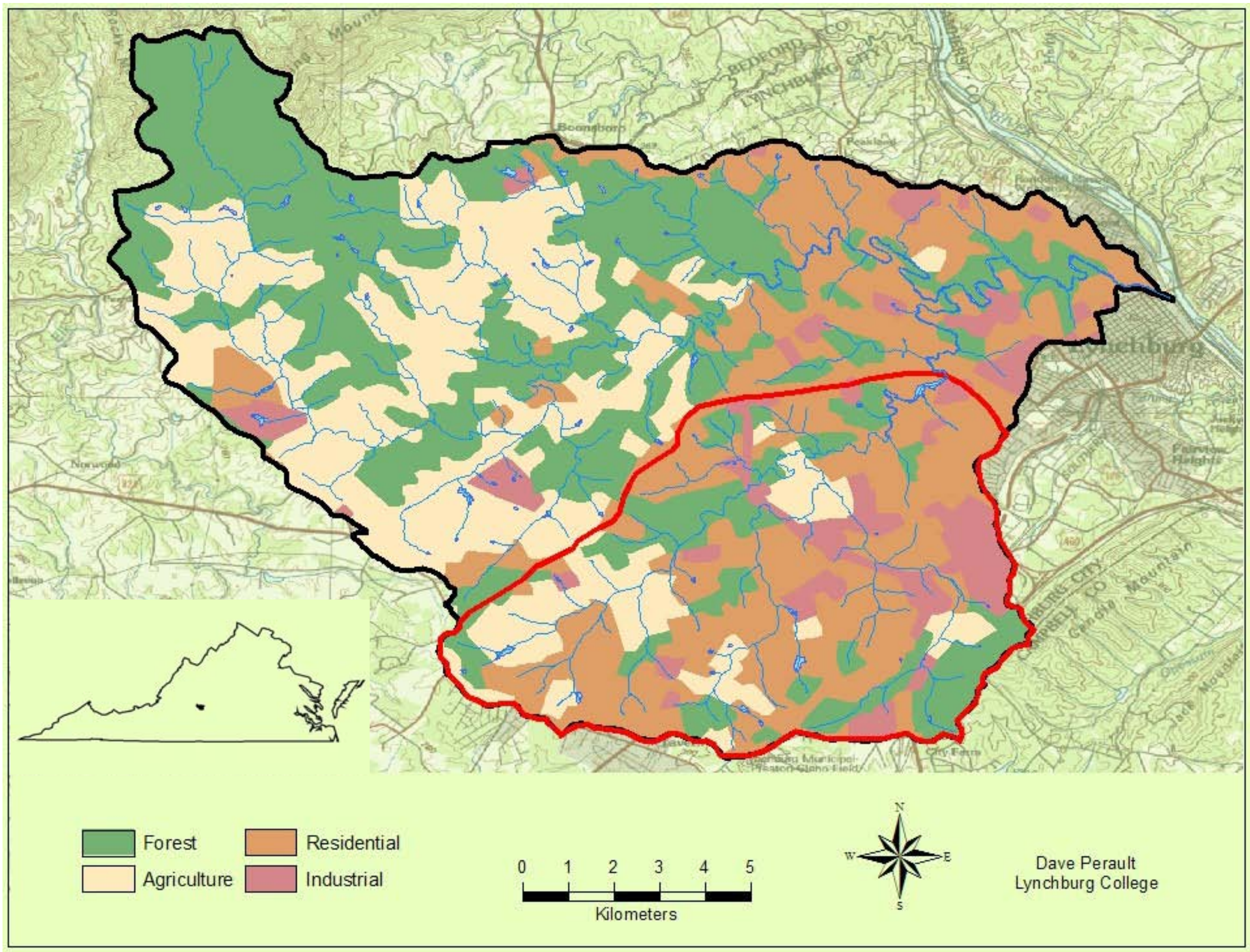

Figure 4. – Landcover across the Blackwater and College Lake Watersheds, Virginia.

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