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Watershed Development and Sediment Accumulation in a Small Urban Lake

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Abstract

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The ever-increasing development of watersheds has raised the importance of assessing and mitigating the environmental impacts on water bodies located within disturbed areas. The removal of natural landcover can increase soil erosion and runoff along creeks and rivers, leading to heavier sediment build-up in ponds and lakes and to reductions in water quality and impoundment capabilities. For this paper, we described the possible impact from urbanization on sedimentation within a small lake. Landcover maps from two different time periods were compared against lake depths to assess relationships between development and sediment buildup. By understanding the mechanisms potentially leading to the ultimate loss of this lake, it is hoped that remediation strategies to reduce future degradation may be developed.

Key Words: watersheds, sedimentation, GIS, urbanization, reservoirs, storage capacity

Managing freshwater ecosystems requires an understanding of many complex processes, one of the most important being sedimentation (Thornton 1990). A rapidly flowing stream burdened with sediment may enter a still body of water such as a reservoir, dissipating its energy as flow slows, and depositing its sediment load (Salas and Shin 1999). When outflow of sediment from reservoirs is less than inflow (as is often the case), the reservoirs may act as sediment traps (Baxter 1977, Fan and Morris 1992). Although such traps may improve downstream aquatic environments by removing suspended solids along with pollutants, within the bodies of water themselves ecological relationships are disrupted, aesthetic qualities are diminished, and general water quality is degraded (Brugam 1978, Cohen *et al.* 1993, Waters 1995). In addition, as reservoirs become filled with sediment, their capacity for water storage decreases. Mahmod (1987) estimated a decrease in worldwide reservoir storage by 1% per year due to sedimentation, as approximately 20 billion tons of sediments are deposited in river channels and in reservoirs yearly (Mousavi and Samadi-Boroujeni 1998). This loss of storage capacity from sedimentation diminishes reservoir benefits including flood control, water supply, and recreational opportunities (Hotchkiss and Huang 1995).

Exposure of bare soils and increased impervious cover in urban areas augment problems of watershed erosion and downstream sedimentation (Douglas 1976). With the removal of ground cover that normally dissipates the energy of a heavy rain, runoff and erosion often increase as precipitation may now exceed the decreased ground infiltration rate (Krenisky *et al.* 1998). Such urbanization may increase annual sediment loads by as much as 50% (Nelson and Booth 2002), with developed areas contributing up to 14 times the loads of suspended sediment as forested watersheds (von Guerard 1989). Construction sites, in particular, can increase soil erosion and raise the amount of sediment found in a stream far above natural levels (Wolman and Schick 1967, USEPA 1997, Faucette *et al.* 2004).

In this paper, we build upon previous in-lake research (Perault *et al.* 2005) and correlate loss of storage capacity in College Lake to increases in development throughout its watershed. We first generated land-use maps of the region for two time periods, 1971 and 2002, to assess its degree of urbanization over the past few decades. We then measured and mapped water depths and sediment accumulations in the lake itself for those same times. By qualitatively developing a relationship between changing land-use and water quality, this information may be useful to managers attempting to address sediment buildup resulting from upstream development.

Materials and Methods

Study Area

College Lake is a small reservoir built in 1934 impounding Blackwater Creek, the primary drainage through the City of Lynchburg, Virginia, and a tributary of the James River and ultimately the Chesapeake Bay. The entire Blackwater Creek watershed has a drainage area of just over 3900 ha and encompasses adjacent counties consisting primarily of forest and agricultural land uses. Within the Blackwater Creek watershed, the College Lake drainage consists of approximately 517 ha and is considered urbanized (>50% development) with its few remaining forested areas under development pressure. When built, the lake surface area was approximately 18 ha with a maximum depth of almost 9 m (Carico *et al.* 1973). The original (1934) watershed to reservoir ratio was 29:1.

Over the years, College Lake has served as an interceptor of sewage during extreme precipitation and resulting 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). With sewage overflow occurrences decreasing in recent years, excess sedimentation has become the most prominent and problematic issue. This has become exacerbated as construction sites in this region often adhere to a minimum or even poor standard of compliance (Swackhammer and Shahady 2002).

Watershed Assessment

The College Lake watershed was delineated on a digital 7.5' USGS quadrangle maps via heads-up digitizing in ArcView GIS (Environmental Systems Research Institute 2005). Landcover data for 1971 were then obtained from USGS (2005) datasets created from interpretation of aerial photos from the 1970s and 1980s. These datasets broadly categorize land use during this time into 21 categories, based on a 4 ha minimum mapping unit. The original 21 landcover classes were then aggregated into more general categories of Forest, Agriculture, Residential, and Commercial.

The 2002 landcover map was generated from combining data from the Virginia Gap Analysis Project (1999) and the City of Lynchburg's zoning map, originally compiled for Lynchburg's regional stormwater management plan (AMEC 2004). The GAP data had a spatial resolution of 30 m while the resolution of the City's zoning data varied by parcel (land ownership) size. These datasets' landcover classes were generalized into the same four categories as used for the 1971 data. Finally, the landcover maps from both time periods were clipped to the extent of the College Lake watershed, and changes in landcover between the two dates were assessed. To better address changes in landcover potentially having the greatest impact on erosion and sedimentation, we repeated the change assessment for riparian areas – lands within 100' of streams – as suggested by Virginia's Department of Conservation and Recreation (2003).

Lake Mapping

Profiles of College Lake itself were created for the same two time periods, 1971 and 2002. For 1971, a map showing water depths measured by soundings taken at nearly 400 locations 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 these 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 across the lake.

For the 2002 lake profile, both water and sediment depth data were collected using a marked PVC pipe and a Garmin E-Trex Legend GPS unit. At each of 508 locations, the pipe was lowered to the lake bottom to measure water depth, then pushed through the sediment to the firm substrate below, providing sediment depth. Bathymetric contours were again generated, describing both water and sediment depths across the entire lake for this time period. Finally, 2002 mean water depths were compared to 1971 depths. Due to a lack of sediment data in 1971, only comparisons in water depths could be made between the two time periods.

Results

Watershed Assessment

All four land use categories were found in abundance in both 1971 (Fig. 1a) and 2002 (Fig. 1b). The primary difference between the two time periods is the shift from a predominantly Residential watershed in 1971 to a more Commercial watershed in 2002 (Table 1). This reflects the increased development throughout this region. The increase in Commercial coverage came at a cost primarily to the Residential category, with the amount of both Forest and Agriculture lands remaining relatively unchanged.

Limiting this assessment to only riparian areas revealed a similar pattern (Table 2). Commercial again increased dramatically (more than tripling), again at a cost to primarily Residential. In this analysis, both Forest and Agriculture declined as well, all of which reinforces the urbanization trend in this region, as well as indicating a lack of riparian protection.

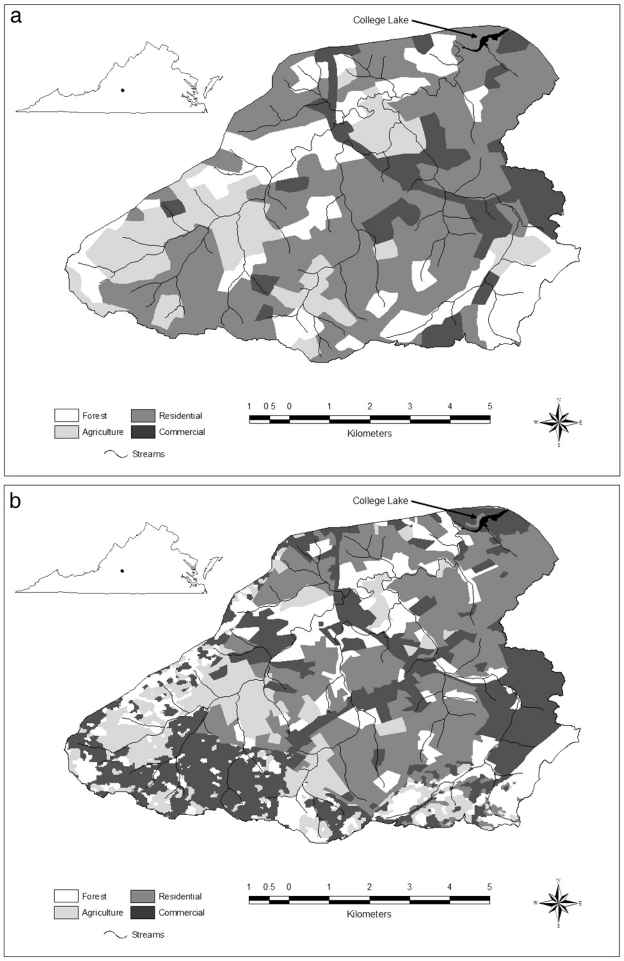

Figure 1.-Landcover across the College Lake Watershed, Virginia, in 1971 (a) and 2002 (b).

Table 1.-Percentage of landcover types for the College Lake, Virginia, watershed in 1971 and 2002.

	1971 (%)	2002 (%)
Forest	21.2	20.8
Agriculture	17.2	15.6
Residential	48.6	31.6
Commercial	13.0	32.0

Table 2.-Percentage of riparian (100' buffer) landcover types for the College Lake, Virginia, watershed in 1971 and 2002.

	1971 (%)	2002 (%)
Forest	26.4	20.0
Agriculture	18.8	14.4
Residential	45.4	36.6
Commercial	9.4	29.0

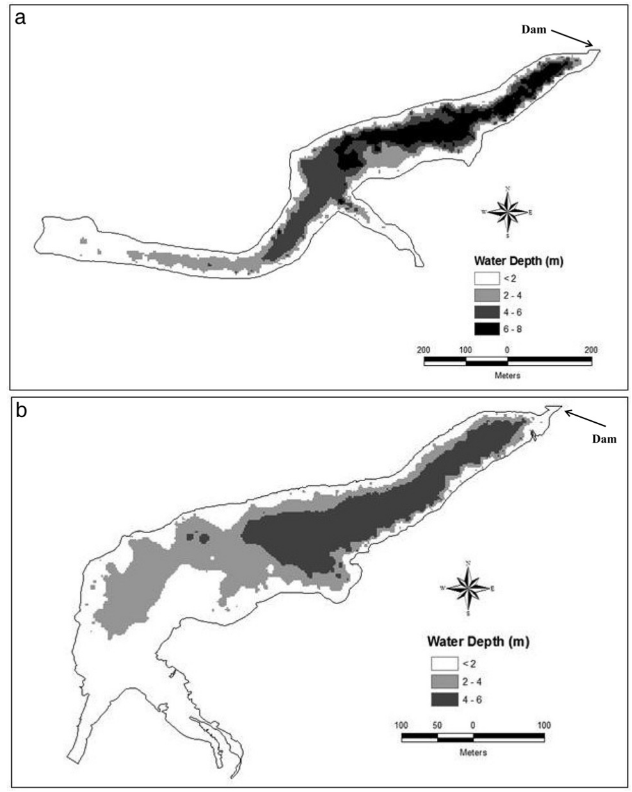

Figure 2.-Water depths across College Lake, Virginia, in 1971 (a) and 2002 (b) (adapted from Perault *et al.* 2005).

Lake Mapping

When College Lake was originally created in 1934, it was estimated to be approximately 18 ha in size, with a watershed to reservoir ratio of 29:1. In 1971, the lake area was 12.13 ha, with a 42:1 watershed to reservoir ratio, and having approximately 265,000 m^3 of water in storage capacity. By 2002, the area of the lake had decreased to <8 ha, smaller than half its original size. This decease in area more than doubled the watershed to reservoir ratio from its original 29:1 to approximately 68:1. In addition, the 2002 storage capacity of the lake was estimated to be about 96,000 m^3, having lost approximately 169,000 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 (Fig. 2a). By 2002, the lake had lost its channel near the headwaters and had generally lost depth throughout the entire lake (Fig. 2b). On average, the lake lost almost 1 m of water depth between 1971 and 2002, going from 2.18 m to 1.27 m, respectively. Maximum depths also decreased, from approximately 8 m in 1971 to <6 m in 2002, both of which were less than the original 1934 maximum depths of nearly 9 m.

Sediment depths in 2002 were greatest in the headwaters and middle sections of the lake, with depths reaching as much as 3 m in several locations (Fig. 3). In general, depths were higher in the channel of the lake and decreased toward the banks. 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.

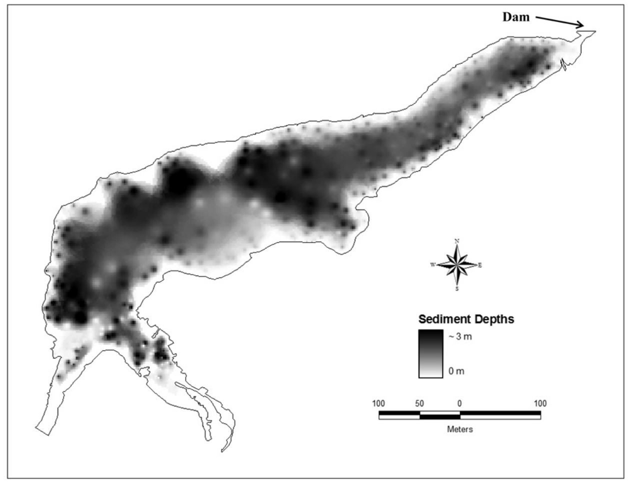

Figure 3.-Sediment depths for College Lake, Virginia, in 2002 (adapted from Perault *et al.* 2005).

Discussion

Our study reveals that development across the College Lake watershed is growing and that this urbanization may be negatively impacting the lake itself. While water levels of this lake do fluctuate naturally from precipitation events, our in-lake data suggest that over the past few decades large amounts of sediment have been filling in the lake. The distribution of these sediments appears to be driven primarily by the deposition of coarser particles as Blackwater Creek enters the lake and dissipates its energy (Hilton *et al.* 1986). The ultimate impact of this process has been a decrease in both water depth and overall storage capacity. Without confirming and 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 and, ultimately, becomes a marsh (Fan and Morris 1992).

Shallow urban lakes offer a special challenge for resource managers (Birch and McCaskie 1999). Here, reducing the impacts from upstream land disturbances appears to be the most critical step in stabilizing conditions. This could be accomplished by establishing riparian buffers around stream banks, constructing stormwater retention ponds, and implementing in-stream sediment exclusion structures (Krenitsky *et al.* 1998, Palmieri *et al.* 2001, Nelson and Booth 2002.). In addition, due to the dramatic increase in commercial development, stricter laws and increased enforcement of runoff controls at construction sites are especially important. Otherwise, continued development in this watershed will only exacerbate the problem. Even if sediment loads are successfully reduced, dredging of the lake may still be necessary to restore both its original storage capacity and ecological function as a sediment trap. Dredging, in fact, may be a recurring need; even under natural conditions, dredging may continue to be periodically necessary.

While sedimentation of water bodies is a natural event and can even improve downstream water quality, the apparent accelerated rates in College Lake is a problem symptomatic of many small urban reservoirs. In addition to reduced storage capacity, the ability of such reservoirs to continue trapping sediments becomes diminished as they fill, severely diminishing their positive service to downstream ecosystems. Counteracting this process requires improving our understanding of the entire role water bodies play in the environment (Karr 1991) and better managing stormwater and runoff issues, in this case addressing and mitigating the sources of sediment, regardless of land use or ownership. Such a solution moves beyond political boundaries and constraints, working instead from a perspective defined by nature. Ultimately, the restoration of College Lake, as with other urban reservoirs, will come only with an understanding of processes and impacts, both natural and anthropogenic, occurring across its entire watershed.

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References

AMEC 2004. Water quality assessment for the City of Lynchburg, Virginia. Earth & Environmental, Inc., Chantilly, Virginia.

Baxter, R.M. 1977. Environmental effects of dams and impoundments. Ann. Rev. Ecol. Syst. 8:255-283.

Birch, S. and J. McCaskie. 1999. Shallow urban lakes: a challenge for lake management. Hydrobiologia 395/396:365-377.

Brugam, R.B. 1978. Human disturbance and the historical development of Linsley Pond. Ecology 59:19-36.

Carico, J.E. S.J. Gamble, C. Gibbon, P.J. Osborne, G.W. Ramsey, W.G. Rivers, W.A. Sherwood, O.O. Stenroos and S. Whitt. 1973. An Outdoor Instructional Laboratory: Lynchburg College Lake. Lynchburg College. Lynchburg, Virginia.

City of Lynchburg Department of Public Works. 2000. Combined Sewer Overflow Program Annual Report FY 99-00. Lynchburg, Virginia.

Cohen, A.S., R. Bills, C.Z. Cocquyt and A.G. Caljon. 1993. The impact of sediment pollution on biodiversity in Lake Tanganyika. Conserv. Biol. 7:667-677.

Douglas, I. 1976. Urban Hydrology. Geogr. J. 142:65-72.

Environmental Systems Research Institute. 2005. ArcView 9.1. Redlands, California.

Fan, J. and G.L. Morris. 1992. Reservoir sedimentation II. Reservoir desiltation and long-term storage capacity. J. Hydrol. Eng. 118:370-384.

Faucette, L.B., L.M. Risse, M.A. Nearing, J.W. Gaskin and L.T. West. 2004. Runoff, erosion, and nutrient losses from compost and mulch blankets under simulated rainfall. J. Soil Water Conserv. 59:154-161.

Hilton, J., J.P. Lishman and P.V. Allen. 1986. Limnol. Oceanogr. 31:125-133.

Hotchkiss, R.H. and X. Huang. 1995. Hydrosuction Sediment-Removal System (HSRS): Principles and Field Test. J. Hydrol. Eng. 121:479-488.

Karr, J.R. 1991. Biological integrity: a long-neglected aspect of water resource management. Ecol. Appl. 66-84.

Krenitsky, F.C., M.J. Carroll, R.L. Hill and J.M. Krouse. 1998. Runoff and sediment losses from natural and man-made erosion control materials. Crop Sci. 38:1042-1046.

Mahmood, K. 1987. Reservoir Sedimentation: Impact, Extent, and Mitigation. World Bank Technical Paper Number 71. The World Bank, Washington, D.C.

Mousavi, S.F. and H. Samadi-Boroujeni. 1998. Evaluation of sedimentation in small dam reservoirs in Chaharmahal-Bakhtiary region. Iranian J. Sci. Technol. 22:421-429.

Nelson, E.J. and D.B. Booth. 2002. Sediment sources in an urbanizing, mixed land-use watershed. J. Hydrol. 264:51-68.

Palmieri, A., F. Shah and A. Dinar. 2001. Economics of reservoir sedimentation and sustainable management of dams. J. Environ. Manage. 61:149-164.

Perault, D.R., D.J. Newman and T.D. Shahady. 2005. Muddy Waters: Landcover and sedimentation in an urban lake. Proc. of the 25th ESRI International User Conference. San Diego, California.

Salas, J.D. and H. Shin. 1999. Uncertainty analysis of reservoir sedimentation. J. Hydrol. Eng. 125:339-350.

Swackhammer, C. and T.D. Shahady. 2002. Impact of construction site run-off on water quality and macroinvertebrate composition in Virginia piedmont streams. Water Resour. Res. Inst. Proc. Blacksburg, Virginia.

Thornton, K.W. 1990. Sedimentary Processes. P. 43-70. *In* K.W. Thornton, B.L. Kimmel and F.E. Payne (eds.). Reservoir Limnology. John Wiley & Sons, Inc., New York.

USEPA. 1997. Innovative uses of compost – erosion control, turf remediation, and landscaping. EPA530-F-97-043. United States Environmental Protection Agency, Washington, D.C.

USGS. 2005. Land Use and Land Cover. U.S. Geological Survey http://edc.usgs.gov/ products/landcover/lulc.html.

Virginia Department of Conservation and Recreation. 2003. Riparian Buffer Modification & Mitigation Guidance Manual. Richmond, Virginia. 114 p.

Virginia Gap Analysis Project. 1999. Conservation Management Institute. Blacksburg, Virginia.

von Guerard, P. 1989. Suspended sediment and sediment-source areas in the Fountain Creek Drainage Basin upstream from Widefield, Southeastern Colorado. USGS Water-Resources Investigations Report 88-4136.

Waters, T.F. 1995. Sediment in Streams: Sources, Biological Effects and Control. Am. Fish. Soc. Monogr. 7, Bethesda, Maryland.

Wolman, M.G. and A.P. Schick. 1967. Effects of construction on fluvial sediment, urban and suburban areas of Maryland. Water Resour. Res. 3:451-464.