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Spatial and temporal analysis of lake sedimentation under reforestation

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Abstract

Spatial and temporal land cover changes can reduce or accelerate lake sedimentation. This study was conducted to examine morphometry and bathymetry, and the long-term changes (over 75 years) in sedimentation in the Lake Issaqueena reservoir, South Carolina. The watershed and catchment areas were delineated using Light Detection and Ranging (LiDAR) based data. Trends in lake surface area and riparian buffer condition (vegetated or unvegetated) were determined from historical aerial photography. From 1938 to 2009, the lake experienced a decrease in surface area of approximately 11.33 ha while catchment area increased by 6.99 ha, and lake volume decreased by 320,800.00 m^3. Lake surface area decreased in years corresponding to equal coverage or largely unvegetated riparian buffers. Surface area and average annual precipitation were not correlated; therefore other factors such as soil type, riparian buffer condition and changes in land use likely contributed to sedimentation. Shift from agricultural land to forestland in this watershed resulted in a decrease in sedimentation rates by 88.28%.

Keywords: Bathymetry; Erosion; Geographic Information Systems (GIS); Land cover; Riparian buffer; Soils

1. Introduction

Sedimentation is the most important water quality problem in the United States and impact reservoir storage capacity worldwide (Neary et al., 1989). Erosion is a natural process that is intimately related to sedimentation. Erosion rates are influenced by geology, topography, slope, climate, soil type and vegetation (Brooks et al., 2012). Rainfall amount and intensity, soil moisture and texture, infiltration rate, upland erosion rate, drainage network density, slope, size and alignment of channels, runoff, sediment characteristics and channel hydraulic characteristics are all factors contributing to the amount and location of sediment deposits (United States, 2013). Anthropogenic factors are the leading cause

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of erosion and sediment transfer (Lexartza-Artza and Wainwright, 2011). These factors include urbanization and development, forestry practices such as clear-cutting, and many others. Cumulative environmental effects of activities in a watershed can adversely impact beneficial uses of the land (Brooks et al., 2012). In order to understand the dynamics of sedimentation processes all factors must be assessed and relationships established.

Reservoirs are important for water storage, sediment control, groundwater recharge, stream flow moderation, water filtration and purification, plant and fish products, and biodiversity and wildlife habitats (McHugh et al., 2007). Surface erosion (e.g. sheet or gully erosion) contributes soil particles, rock fragments, pollutants and contaminants, nutrients and other items into a waterway. Sediment accumulation degrades water quality, limits available water supply, decreases biodiversity of flora and fauna, impairs drainage ways and channels creating flood opportunities and can also dampen local economic and community efforts. Sediments have been widely studied as indicators of environmental change because they can document variations over time of sediment inputs and characteristics (Lexartza-Artza and Wainwright, 2011; Jackson et al., 2005). The period of sedimentation is usually known for reservoirs making them extremely valuable for studying sediment fluctuations in response to environmental and land use changes within a watershed (Wren and Davidson, 2011; Wren et al., 2007).

Watershed responds to climatic, geographic and anthropogenic changes because of the spatial and temporal variation in climate and environmental conditions. Lack of long term data, differences in field and data collection complicate spatial and temporal analysis of sedimentation. However, identification of impacts of land cover changes on watersheds is essential to maintaining healthy, functional freshwater systems that will continue to provide for plants, wildlife and human needs. There are many studies worldwide pertaining to sediments and freshwater environments (e.g. lakes, rivers, reservoirs and other water bodies. For example, a study in Ethiopia analyzed water availability for community use as well as economic impacts and found that impoundments greatly altered the landscape (Tefera and Sterk, 2008). Other studies examined the positive and negative impacts of sedimentation including: the ability of sediments to trap pollutants and contaminants in Mexico (Ruiz-Fernandez et al., 2012); deposition of agricultural soil loss and subsequent degradation in aquatic ecosystems in the Midwest, United States (Heathcote et al., 2013). Land use changes are often attributed to changes in sedimentation rates. Mattheus et al. (2010) analyzed the impact of land-use change and hard structures on the evolution of fringing marsh shorelines in North Carolina. A study in the United Kingdom (Lexartza-Artza and Wainwright, 2011) identified areas within a catchment that are most susceptible to erosion from land use changes. Odhiambo and Ricker (2012) found that land use changes primarily in areas cleared for agricultural fields contributed the most sediment to the Lake Anna watershed in Virginia, US.

Many studies demonstrate the importance of riparian buffers on water quality and sedimentation rates. Riparian buffers slow surface runoff, reducing velocity, which increases sediment removal by increasing infiltration rate. Riparian buffers frequently have over 90% efficiency in trapping sediments (Lee et al., 2000). Stream buffers can include many species of vegetation from herbaceous forbs to large woody species. Lee et al. (2000) found that during simulated rainfall events riparian buffers trapped 93% sand and silt particles and 52% of clay particles. Buffering capacity also increases as buffer width increases. Changes to land cover result in billions of tons more sediment being deposited in streams and water bodies (Weathers et al., 2013). Removing vegetation increases the amount of water that enters a stream, thereby increasing the amount of sediments as well (Weathers et al., 2013).

In 1950, a report was prepared by the USDA (1950) to determine the effects of soil conservation on sedimentation in Lake Issaqueena. This report included data on the bathymetry and morphometry of the lake, and a detailed sedimentation survey that was completed in 1941 by the Soil Conservation Service. The watershed was resurveyed in October of 1949 and detailed comparisons of data as well as land use changes were included in the report. USDA (1950) found that annual storage loss for the period from 1938 to 1941 was 1.67%, while the average annual rate of loss for the 8.5-year period from 1941 to 1949 was reduced to 1.01%. This reduction was attributed to the adoption of improved agricultural practices as well as the best management practices (BMPs) that were used on the CEF (USDA, 1950). Rainfall and excess inflow over discharge were actually higher during the second period studied and yet sedimentation rates were lower (USDA, 1950). USDA (1950) also determined that the sediment was being deposited in the upper fourth of the reservoir, which is even more evident today. Sheet erosion on cultivated fields was identified as the primary source of sediment, followed by gullies, road banks and stream banks (USDA, 1950).

Long-term data and a consistent method for measuring sedimentation and identifying erosion factors are essential for sustainable watershed management in the future. Methods used to determine sediment yield within this watershed could be used for other similar reservoirs within South Carolina and other parts of the world. The Soil Conservation Service collected limited reservoir data years ago, but assemblage of new data will provide a means to compare sedimentation