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Spatial and temporal analysis of land cover change, sedimentation and water quality in the Lake Issaqueena watershed, South Carolina

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SPATIAL AND TEMPORAL ANALYSIS OF LAND COVER CHANGE, SEDIMENTATION AND WATER QUALITY IN THE LAKE ISSAQUEENA WATERSHED, SOUTH CAROLINA

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Forest Resources

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by
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Accepted by:
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ABSTRACT

Soil erosion and increased sediment yields within a watershed lead to impaired water quality, decreased availability of wildlife habitat and reduced recreational opportunities. While some sedimentation occurs naturally within a water system, most erosion processes are the result of anthropogenic activities across a landscape, namely changes in land use and land cover (LULC). This study was conducted to determine temporal and spatial sedimentation trends in the Lake Issaquena watershed using sonar logging equipment, geographic information systems (GIS) and limited hydrologic data from the Soil Conservation Service (1941 and 1949). Sediment deposition was analyzed in relation to several key factors that influence erosion and sediment yields; these being dominant land cover, topography and slopes, soils and geology, rainfall and climatological aspects. Significant sedimentation has occurred in the Sixmile Creek delta, located at the northern end of Lake Issaqueena. Sedimentation rates inferred from an analysis of afore mentioned factors show considerable changes in erosion potential that correspond with substantial changes in riparian vegetation, extreme variations in rainfall events, conversion of land from agricultural to forestland and application of management practices. Water quality data, including sampling depth, water temperature, dissolved oxygen content, *Fecal coliform* levels, inorganic nitrogen concentrations and turbidity, were obtained from the South Carolina Department of Environmental Health and Safety (SCDHEC) for two stations and analyzed for trends as they related to land cover change. Data was available for the Sixmile Creek site for dates ranging from 1962 to 2005 and from 1999 to 2005 for the Lake Issaqueena site. From 1951 to 2009, the watershed experienced an increase of tree cover and bare ground (+17.4% evergreen, +62.3% deciduous, +9.8% bare ground) and a decrease of pasture/ grassland and cultivated (-42.6% pasture/ grassland, -57.1% cultivated). From 2005 to 2009, there was an increase of 21.5% in residential/ other development. Sampling depth ranged from 0.1 meters to 0.3 meters. Water temperature fluctuated corresponding to changing air temperatures, and dissolved oxygen content fluctuated as a factor of water temperature. Inorganic nitrogen content was higher from December to April possibly due to application of fertilizers prior to the growing season. *Fecal coliform* levels stayed relatively the same, there was however, a slight decrease overall, likely due to the decrease in pasture/ grassland. Turbidity remained relatively the same from 1962 to 2005, but a slight decrease in pH can be observed at both stations. Sedimentation analysis has shown that overall the lake surface area has decreased by 11.333 hectares and lake volume has decreased by 320,800 m^3, while catchment area increased by 6.99 hectares. Average annual precipitation rates were shown to have no direct correlation with these bathymetric measurements, and it is hypothesized that changes in land cover, slope and extreme precipitation events are largely responsible for sedimentation in Lake Issaqueena.

DEDICATION

This thesis is dedicated to my family, Darren Pilgrim, Susan Kilstrom and Gladys Ellenburg, and my fiancée, Travis Lance, who have supported me throughout my college career.

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CHAPTER ONE

Preface

This research examines the intricate relationship between land cover change, sedimentation and water quality and how changes in one factor can be beneficial or detrimental to the others. The research is organized into two main topics due to the overall abundance of information. The first topic as described in Chapter 2 analyzes historical aerial photography and land cover change as they relate to water quality. The second topic as described in Chapter 3 identifies changes in the morphometry of Lake Issaqueena due to sedimentation and identifies possible causes for high sediment yield. Both topics utilize geographic information systems software (ArcGIS) for various analyses.

This study is unique because there is historical data (aerial photographs, climatological and limited hydrological data) available for analysis and comparison and because there are few studies which show the reverse effects of going from more intensive to less intensive land use.

CHAPTER TWO

Spatial and temporal analysis of land-cover changes and water quality in the Lake Issaqueena watershed, South Carolina

Abstract

Monitoring changes in land cover and the subsequent environmental responses are essential for water quality assessment, natural resource planning, management and policies. Over the last 75 years, the Lake Issaqueena watershed has experienced a drastic shift in land use. This study was conducted to examine the changes in land cover and the implied changes in land use that have occurred and their environmental, water quality impacts. Aerial photography of the watershed (1951, 1956, 1968, 1977, 1989, 1999, 2005, 2006 and 2009) was analyzed and classified using the geographic information systems (GIS) software. Seven land cover classes were defined: evergreen, deciduous, bare ground, pasture/ grassland, cultivated and residential/ other development. Water quality data, including sampling depth, water temperature, dissolved oxygen content, fecal coliform levels, inorganic nitrogen concentrations and turbidity, were obtained from the South Carolina (SC) Department of Health and Environmental Control (SCDHEC) for two stations and analyzed for trends as they relate to land cover change. From 1951 to 2009, the watershed experienced an increase of tree cover and bare ground (+17.4% evergreen, +62.3% deciduous, +9.8% bare ground) and a decrease of pasture/ grassland and cultivated (-42.6% pasture/grassland and -57.1% cultivated). From 2005 to 2009, there was an increase of 21.5% in residential/ other development. Sampling depth ranged from 0.1 meters to 0.3 meters. Water temperature fluctuated corresponding to changing air temperatures, and dissolved oxygen content fluctuated as a factor of water temperature. Inorganic nitrogen content was higher from December to April possibly due to application of fertilizers prior to the growing season. Turbidity and fecal coliform bacteria levels remained relatively the same from 1962 to 2005, but a slight decline in pH can be observed at both stations. Prior to 1938, the area consisted of single-crop cotton farms, after 1938 the farms were abandoned, leaving large bare areas with highly eroded soil. Starting in 1938, Clemson reforested almost 30% of the watershed. Currently, 3/4 of the watershed is forestland, with a limited coverage of small farms and residential developments. Monitoring

water quality is essential in maintaining adequate freshwater supply. Water quality monitoring focuses mainly on the collection of field data, but current water quality conditions depend on the cumulative impacts of land cover change over time.

Introduction

Remote sensing of high-resolution aerial photography can provide a historical record of land cover change, which in turn can help understand difference in land use, which drive environmental change. Land cover, which is determined by remote sensing observation of the earth, is different from land use which can be defined as the human activities which take place on that same area of the earth (Comber 2008; Cihlar and Jansen 2001). Mixing of land use and land cover (LULC) classifications is common in environmental assessment (Jansen and Di Gregorio 2002). Changes in LULC can be attributed to a variety of complex interacting factors (ecological, political, and economic), therefore it is important to develop an understanding of this interaction to preserve natural resources (Mundia and Aniya 2006). Globally, land use changes have been studied because of their role in environmental goods and services (Tefera and Sterk 2008). Historically, shifts in the local economy have played a major role in determining land uses. As market trends, supply/ demand and job availability are changing, landowners are forced to adapt. Today, many changes are based on personal choices and values. Land-use change models have been developed that can predict land-use change patterns both spatially and temporally (Lin et al. 2008; Corner et al. 2014). This land cover classification and implied land use change analysis can be applied to planning, economic development, habitat suitability and environmental monitoring (Dewan and Yamaguchi 2009 a,b; Kalyanapu et al. 2013; Kamusoko et al. 2009).

Land use/land cover changes provoke a variety of biogeochemical and hydrological responses. At the watershed level, these changes have the potential to modify hydrology, local climate, precipitation, water quality, soil erosion, biological community structure and function. A study by Allan (2004) found that a range of stream conditions (from pristine to impacted) demonstrated the system’s total reaction to many anthropogenic disturbances on habitat structure and the food web. Lin et al. (2007a,b) found that hydrologic components (particularly runoff and groundwater discharge) of the Wu-Tu watershed in Taiwan were significantly influenced by changes in land use. Lin and et al. (2007a,b) concluded that future land use scenarios influenced land-use patterns and hydrology both upstream and downstream of the watershed. Li et al. (2013) analyzed LULC change in the Daqinghe watershed in China and reported that conversion from agricultural/grassland to forest led to a decrease in flood peak and volume for flood events. Dewan and Yamaguchi (2008) examined the effects of land cover change on flooding in Greater Dhaka of Bangladesh. Changes in LULC also affect functional groups and biota within the watershed. Miranda et al. (2014) determined that there is an identifiable relationship between land use, nutrients, primary production and fishery communities in freshwater lakes. Lakes, as open systems, are linked to their catchments through surface runoff and nutrient input, which determines primary production and composition, therefore affecting hydrologic components, and the structure and function of aquatic species communities (Miranda el al. 2014).

Changes in LULC can also have a major impact on water quality and can become impaired by herbicides, pesticides, fertilizers and bacteria due to land use practices (Coulter et al. 2004). Shifts in LULC may cause changes in water temperature, dissolved oxygen content, and total nitrogen (Zhao et al. 2006). Remote sensing has been used throughout the world to monitor and assess LULC changes: Choi and Han (2013) used remote sensing to monitor land use change and water quality in Korea; Bakr et al. (2010) classified land cover changes in Egypt; and Tefera and Sterk (2008) in Ethiopia.

Remote sensing techniques to monitor land cover change most commonly use satellite images, however historical aerial photos, that can represent much older remote sensing products, are increasingly being digitized and becoming available. These aerial images require more effort to classify, but can provide a detailed record of land cover change over time and multiple dates throughout time. This is important because land cover (and the implied land use) change do not always go in one direction (for example, towards urbanization), but as in the case of this study can go from degraded agricultural to more sustainable forested land cover over time. The uniqueness of this study is that it demonstrates the benefit of assessing land cover change (and corresponding water quality data) at high resolution and at multiple points in time to monitor restoration efforts. For the purpose of this study only land cover was considered. Remote sensing analysis can only determine the land cover because aerial photos provide only a snapshot and not a dynamic picture of land use. Some land cover categories (e.g. field crop and residential) directly imply land use, but most of the study area considers only land cover (e.g. forest, grassland/fields).

The overall objective of this study is to classify changes in land cover over time to identify the driving factors in land cover changes at the watershed scale using the Lake Issaqueena watershed as a case study. The specific objectives of this study are to: 1. Analyze historical and current aerial photos (1951, 1956, 1968, 1977, 1989, 1999, 2005, 2006 and 2009) to create detailed land cover maps, 2. Conduct analysis of land use changes within the watershed, 3. Analyze trends in water quality data in relation to changes in land cover.

Study area and land use history

Lake Issaqueena is a man-made lake located within the Clemson Experimental Forest (CEF), about seven miles north of the Clemson University campus in Pickens County, South Carolina. However, the Lake Issaqueena watershed is not located entirely within the boundaries of the CEF (Fig. 1.1). In 1938, about 73% of the watershed was privately owned and the remainder was government owned (USDA1950). Farms within the watershed averaged about 17 hectares with 69% being owner-operated and only 31% operated by tenants (USDA 1950). Most of the 980 ha of government-owned land was acquired under the Bankhead-Jones Farm Tenant Act (there were 11088.4 ha procured in Pickens and Oconee Counties) (USDA 1950). Today about 69.27% of the total watershed is residentially owned and only 0.07% is commercially owned. Clemson University owns 29.67% or 1044.47 ha. Local government owns 0.4%, leaving the remaining 0.59% owned by area churches. The United States Environmental Protection Agency (EPA) classifies the lake as located in the Inner Southern Piedmont region. The dam at Lake Issaqueena is a cyclopean concrete, gravity structure that is 99.06 m long, with the top of the dam being about 15.70 m above bedrock (USDA 1950). The spillway is located approximately in the middle of the dam and is 30.48 m long with a freeboard of 2.13 m and a maximum capacity 1,428.90 m^3/sec (USDA 1950). Storage for the lake began in June of 1938 (USDA 1950).

The reservoir basin is long and narrow with relatively steep shorelines (USDA 1950). When first created, the lake covered approximately 47.35 ha (2.25 km long by 0.18 km wide on average) and had a storage capacity of 226.48 ha m (USDA 1950). Today, the reservoir covers approximately 36.14 ha. The total watershed area in 1938 was 36.31 km^2 with a length of 12.71 km and an average width of 2.74 km (Reservoir 2013). The total watershed was 36.39 km^2 with a length of 13.13 km in 2011. The Lake Issaqueena watershed has a diverse topography. The average slope is 9.33 % with mostly south to west orientation. The highest slope is 49.09 %. In 1950, the average elevation was approximately 305 m. The upper region of the watershed was classified as having rolling ridge tops on wide, highly cultivated areas and rough, broken wooded slopes in lower areas (USDA 1950).

Currently the Lake Issaqueena portion of the Clemson Forest is used by the public for educational and recreational opportunities such as, hunting, fishing, wildlife viewing, bird watching, hiking, biking, horseback riding, and picnicking. Average yearly precipitation for this area from 1920 to 2012 is 133.22 centimeters (National Climatic Data Center 2014). Mean summer season temperatures for years 1895-2012 is 21.9°C, while average winter season temperature is 4.06°C (National Climatic Data Center 2014). Adequate rainfall and moderate temperatures allow this region to support a variety of habitat and forest types, such as mature oak-hickory forest, pine plantations and mixed successional habitats.

Land use history

Cherokee Indians once hunted and farmed the lands that now make up Pickens County (Fig. 1.2). Vegetation was predominately mature deciduous forest that was relatively free of undergrowth. Native Americans cultivated small patches along stream bottoms and “managed” forests by burning and thinning trees and underbrush. In the late 1600s, European settlers began to colonize what is now the coastal region of South Carolina. They were mainly trappers and subsistence farmers (Sorrells 1984; Galang et al. 2007). In 1788, South Carolina became an official state under the Constitution, but there were still few settlers in the Upstate region. The earliest pioneers to this region settled on subsistence farms in fertile bottomlands. As the need for land grew, uplands were cleared and put into cultivation. By 1787, cotton was a major export and commercially important crop to farmers in SC (Sorrells 1984; Galang et al. 2007). Intensive farming of cotton and other commercial crops degraded soil conditions from 1860-1930 (Sorrells 1984; Galang et al. 2007).

Since 1947, best management practices (BMP) have been used to continue land reclamation and improvement for the Clemson Experimental Forest (CEF), as it came to be known. In 2008, CEF staff enacted a revised Natural Resource Plan. The plan identifies 13 divisions for the entire CEF, 4 of which lie within the Lake Issaqueena watershed. The majority of the watershed lies within a Special Natural Resource Area, which is a protected area where new activities are prohibited and the goal of maintaining existing roads, trails, and recreation areas is to minimize impacts related to sedimentation and on floral, faunal and water resources (Management Planning for the Clemson Experimental Forest 2013). Stream buffers are also identified and maintained to protect water quality and biodiversity. Part of the watershed is identified as Mixed Successional Habitat Areas, which are managed to provide areas in various successional stages to provide quality habitat for an assortment of wildlife species. There are also two small areas labeled as Intensive Habitat Management Areas which are open fields maintained for game and non-game species (Management Planning for the Clemson Experimental Forest. (2013).

Methodology

Aerial photography inventory and analysis

Aerial photography was obtained from EarthExplorer (http://earthexplorer.usgs.gov/), the United States Department of Agriculture (USDA) Geospatial Database and Pickens County GIS office (Table 1). All images were processed with ArcGIS 10.1 Desktop and projected in the NAD State Plant 1983 S coordinate system. Images acquired from USGS (1951, 1956, 1977, 1989, and 1999) were aerial photo single frames and did not have coordinate systems defined. These photos had various scales and none contained the entire watershed. The auto registration georeferencing tool was used to match photos based on identical features between photos within the watershed boundaries. The aerial photos were then orthorectified to predetermined reference points along the lake shoreline and stream channel using the Georeferencing toolset. The Clip tool was used to subset the aerial photographs within the watershed boundary. Images from the USDA (2005, 2006 and 2009) were projected into the correct coordinate system within the watershed extent.

Land cover class determination

Land cover classes were determined by examining the aerial photographs, studying local land use history and adapting classes determined from similar studies (Choi and Han 2013, Martinuzzi et al. 2014, Tefera and Sterk 2008). Six land cover classes were identified: evergreen, deciduous, bare ground, pasture/ grassland, cultivated and residential/ other development (Table 2). Residential/ other development (classes that strongly imply land use) could only be determined for the 2005, 2006 and 2009 images because of the low resolution of the images and because there was little development present in the earlier images. The remaining five classes were analyzed for every year of data. These classes were easily distinguished on each image.

Land cover class maps

In previous studies, the use of Maximum Likelihood Supervised Classification was used as a dependable method for classifying images (Mertens and Limbin 2000; Dean and Smith 1993; Dewan and Yamaguchi 2009a,b; Choi and Han 2013). Choi and Han (2013) determined that the maximum likelihood supervised classification technique is one of the most widely used and accurate methods for classifying land cover. Land cover class maps for each year of aerials photos were created using the classification toolset in the software. Because the photographs were taken at different scales and different resolution, training samples had to be individually determined for each year. Samples were identified for areas that were representative for each class. After the images were classified the majority filter and boundary clean tools were used to remove errors. The attribute tables for each land class map were exported as a Microsoft Excel document and analyzed. Figure 1.3 provides a flow chart for data analysis methodology.

The South Carolina Department of Health and Environmental Control (SCDHEC), Water Quality Monitoring and Modeling Section, has developed a program called the Ambient Surface Water Monitoring Program (SCDHEC 2014). Through this program a large number of stations are monitored statewide, including two located within the Lake Issaqueena watershed (Fig. 1.1). Data for the SV-205 station (Six Mile Creek) and the SV-360 (Lake Issaqueena) is available for download through STORET. Six Mile Creek is the main surface water input for this lake, so the SV-205 station was also included in this analysis.

Data for SV-205 dates back to October 1962 and continued until December 2005. Monitoring at the SV-360 site began in December 1999 and ended in December 2005. For this study, depth of sampling, water temperature (°C), dissolved oxygen (DO) (mg/L), pH, fecal coliform (#/100mL), inorganic nitrogen (nitrate and nitrite) (mg/L) and turbidity (NTU) were analyzed. Changes in these factors were correlated to land cover changes.

Results and discussion

Land cover class maps

Overall, this watershed experienced a shift from agricultural land (both pasture/ grassland and cultivated) to forestland (Fig. 1.4, 1.5). Li et al. (2013) found similar results due to the passage of conservation policies in Daqinghe watershed, China. Cultivated coverage in the Lake Issaqueena watershed drastically decreased due to poor soil conditions and shifts in the local economy. Lin et al. (2007) found an estimated decrease in forestland from 1999 to 2020, despite land use conservation policies that were set to protect hillsides, water supply sources and large forested areas. In contrast, studies by Tefera and Sterk (2008) and Choi and Han (2013) found a decrease in forestland and an increase in either agriculture or urban development. Agricultural land use can impact water quality by increasing inputs of nonpoint source pollution, altering flow regimes, increasing nutrient inflow and fluxes and degrading riparian habitat.

From 1951 to 2009, the Lake Issaqueena watershed experienced an increase of tree cover and bare ground (+17.4% evergreen, +62.3% deciduous, +9.8% bare ground) and a decrease of pasture/ grassland and cultivated land (-42.6% pasture/grassland and -57.1% cultivated) (Fig. 1.5a). Increased forestland (especially within the riparian zone) benefits aquatic communities by decreasing water temperature due to shading, increasing dissolved oxygen content and inputs of organic matter (leaf litter and woody debris). From 2005 to 2009, there was an increase of 21.5% in residential/other development. There were fluctuations for each class from year to year (Fig. 1.5a). Overall, deciduous tree coverage increased the most as a result of land reclamation within the watershed and the conversion of cropland to forests. Coniferous tree coverage also steadily increased until the late 1990s when the Southern pine beetle, *Dendroctonus frontalis,* devastated pine species across the Southeast (Fig. 1.5b) (Cabe 2014). From 1995 to 1996, over $125 million worth of timber was lost due to the Southern pine beetle (Cabe 2014).

Lake Issaqueena also experienced a decrease in surface area due to sediment loading.. The lake has lost approximately 10.5 hectares since its creation in 1938. Tefera and Sterk (2008) found an increase in water coverage in the Fincha'a watershed in Ethiopia from 1957 to 2001. Li et al. (2013) also found a decrease in watershed size in Korea.

Water Quality Analysis

For the SV-205 and the SV-360 station water temperature fluctuations correlated with changes in air temperature (Fig. 1.6 and 1.7). The SV-205 site experienced an average temperature of 16.2 °C, while the SV-360 site had an average temperature of 19.46 °C for the data collected (Fig. 1.6, 1.8). Decrease in forest cover from the early 1990s until 2000, likely caused an increase in water temperature due to loss of shading. Water has a high specific heat index; therefore the fluxes seen in air temperature are not as apparent in regards to water temperature. For the Six Mile Creek station water temperature tends to follow trends in air temperature due to a smaller volume of water. The Lake Issaqueena station temperatures are generally a little above air temperature in both the winter and the summer, due to a much larger volume of water (Fig. 1.7). Dissolved oxygen (DO) levels are regulated by water temperature, as temperature increases the amount of dissolved oxygen present decreases and vice versa. This is also supported by the strong correlation indicated by the Pearson correlation coefficient that found DO levels for each station inversely related to water temperature (Fig. 1.6c and 1.8c). The SV-205 site average 9.52 mg/L, while the SV-360 site averaged 8.85mg/L (Fig. 1.6c and 1.8c) because faster moving water in Six Mile Creek would allow for more opportunities of oxygen to enter the water than the lentic lake system. A study by Choi and Han (2013) on land cover and water quality dynamics on the west coast of Korea found that water temperature and dissolved oxygen were affected by seasons rather than a reclamation project.

Water pH for each site remained similar for each of the time periods observed with the SV-205 station experiencing an average pH of 6.89 and SV-360 7.19 (Fig. 1.6d and 1.8d). For the SV-360 station levels of inorganic nitrogen fluctuated corresponding with the period before the growing season (from late

December to early April) (Fig. 1.8g). This could be due to application of fertilizer to cultivated fields. Similar findings were reported by Choi and Han (2013) in Korea, who reported that total nitrogen and total phosphorus were influenced by the fertilizers and pesticides as a result of agricultural activity.

There was a decrease in the average amount of inorganic nitrogen at the SV-205 site at 0.56 mg/L from 1962-1976 to 0.38 mg/L from 1995-2005 (Fig. 1.6g). By 1977, the amount of cultivated land within the watershed had decreased dramatically. There was also a significant difference in the level of inorganic nitrogen between Six Mile Creek and Lake Issaqueena (Fig. 1.6f and 1.8f). An average of 0.36 mg/L was present in Six Mile versus 0.14 mg/L in the lake for the same time period. Levels of fecal coliform bacteria also varied greatly between the stream and the lake (Fig. 1.6f and 1.8f). Between 1999 and 2005, SV-205 experienced average levels of 475.63 /100mL, while SV-360 averaged only 26.14 /100mL. Most likely these differences between lake and stream are attributed to the much higher volume of water within the lake and potentially "urban stream syndrome" since Six mile Creek area is more developed (Halstead et al. 2014). Halstead et al. (2014) found strong associations between water quality and urban development in the Kayaderosseras Creek watershed in Sratoga County, NY, where "urban stream syndrome" was even detected on a small scale in lightly developed area. However, levels within the stream have also significantly decreased from an average of 13475 /100mL from 1962-1976 to 821.86 /100mL from 1995-2005. Fecal coliform bacteria are associated with animal wastes, so decreases in pasture/ grassland would also attribute to decreases in bacteria concentrations. Turbidity levels remained roughly the same for the SV-205 station (Fig. 1.6e) and the SV-360 site (Fig. 1.8e). The results of this study provide insight into the associations between the water quality and historical changes in the land cover of man-made lake. The results of the study show that forests play an important role in maintaining clean water. Study by Wang et al. (2012) also showed that it was necessary to preserve sufficient forest land area and to control agriculture to maintain good water quality in the upper reach of the Hun River, Northeast China.

Conclusion

Overall the Lake Issaqueena watershed experienced a shift from agriculture to forestland. This land cover change was brought about by shifts in the local economy. Land within the northern part of CEF remains largely forested and is the result of implementation of best management practices. The water quality data suggests that large inputs of inorganic nitrogen are still occurring during months prior to the growing season. Conservation tillage and reduced fertilizer application could help correct this problem. Management of land cover within the watershed is of great important due to the possibility of impairing water quality, changing the local climate, and hydrology. Long-term high-resolution remote sensing and water quality datasets for man-made lakes is scare worldwide. Utilization of high-resolution aerial photos allows for a longer-term view of how land cover has changed over time. There are few studies that show the reverse effects of going from more intensive to less intensive land use. In many ways, degraded lands around the world would benefit by this type of conversion, and data is needed to document the environmental benefits of these types of strategies.

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CHAPTER 3

Spatial and temporal analysis of sedimentation in Lake Issaqueena, South Carolina

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 using classification tools in ArcGIS and aerial photography of the watershed (1951, 1956, 1968, 1977, 1989, 1999, 2005, 2006 and 2009). 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. A bathymetric map and three-dimensional image of the lake were also created to provide a visual representation of the lake as it is today. Shift from agricultural land to forestland in this watershed resulted in a decrease in sedimentation rates by 88.28%.

Introduction

Environmental factors and changes in land cover impact reservoir storage capacity worldwide. 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 of erosion and sediment transfer (Lexarta-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 (Lexarta-Artza and Wainwright, 2011). 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.

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 (Lexarta-Artza and Wainwright, 2011) identified areas within a catchment that are most susceptible to erosion from land use changes. Odhaimbo 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 fluxes and changes within the watershed to that of known land cover changes. Knowledge of reservoir sedimentation, watershed erosion trends and sediment chemistry are important factors in predicting future water quality of surface water reservoirs.

The overall objective of this study is to conduct spatial and temporal analysis of sedimentation in Lake Issaqueena, South Carolina. The specific objectives area to: 1. Delineate the Lake Issaqueena watershed and create the stream network using LiDAR derived data; 2. Document changes in lake volume, surface area and catchment area between 1938 and present using historical and field data; 3. Classify stream buffers (30 meters) as vegetated or un-vegetated in relation to sediment yield; 4. Analyze factors which contribute to sedimentation in Lake Issaqueena.

Study Area and Land Use History

The Lake Issaqueena watershed is located in the uplands of the Savannah River Basin in Pickens County, South Carolina (Figure 2.1). The United States Environmental Protection Agency (EPA) classifies the lake as located in the Inner Southern Piedmont region. Currently, various types of forestlands, ranging from small pine plantations to mature oak-hickory forests, dominate the landscape. Clemson University owns and manages approximately 30% of the watershed, while the remaining land is owned privately owned.

The watershed is principally drained by one fourth-order stream (Sixmile Creek), two third-order streams (Indian Creek and Wildcat Creek), and many second and first-order ephemeral streams. The stream network is approximately 69.48 km, with an average length of 0.61 km, a minimum of 0.01 km and a maximum of 1.89 km. The Lake Issaqueena reservoir was completed in 1938 under the Works Progress Administration (WPA) as part of the “Clemson College Community Conservation Project” (Figure 2.2).

Since 1947, best management practices (BMP) have been used to continue land reclamation and improvement for the Clemson Experimental Forest (CEF), as it came to be known. In 2008, CEF staff enacted a revised Natural Resource Plan, which identifies 13 divisions for the entire CEF, 4 of which lie within the Lake Issaqueena watershed (Clemson University, 2008). The majority of the watershed lies within a Special Natural Resource Area, which is a protected area where new activities are prohibited and the goal of maintaining existing roads, trails, and recreation areas is to minimize impacts related to sedimentation and on floral, faunal and water resources (Clemson University, 2008). Stream Buffers are also identified and maintained to protect water quality and biodiversity. Part of the watershed is identified as Mixed Successional Habitat Areas, which are managed to provide areas in various successional stages to provide quality habitat for an assortment of wildlife species. There are also two small areas labeled as Intensive Habitat Management Areas which are open fields maintained for game and non-game species (Clemson University, 2008). Figure 2.2 provides a timeline of events that relate to sedimentation and management of Lake Issaqueena.

Methods

Aerial photographs used for riparian buffer classification and lake surface area estimates were provided by the Pickens County GIS Department, United States Geological Survey (USGS) EarthExplorer and the United States Department of Agriculture (USDA) Geospatial Database (Table I). Photographs were available for the following years: (1947, 1951, 1956, 1968, 1977, 1989, 1999, 2005, 2006 and 2009). Limited hydrologic data was available from the aforementioned report collected by the Soil Conservation Service in April 1941 and October 1949. Data available from this report includes elevation, surface area, drainage area, sediment deposits, rainfall information and storage loss. The Federal Interagency Sedimentation Committee provided instructions for completing the Summary Data report, but not specific methods for determining data. The Committee included members from the United States Department of Agriculture (USDA), Department of the Interior (USDI), Environmental Protection Agency (EPA), Department of Army, Department of Commerce, Department of Transportation, Department of Energy and the Tennessee Valley Authority. The instructions have not been revised since 1978.

Watershed characteristics

The watershed boundary was delineated using ArcGIS Desktop 10.1 and 2011 LiDAR files provided by the Pickens County GIS office. From the LiDAR files, a DEM was created using a terrain dataset. The DEM was then used along with the hydrology spatial analyst toolset. Figure 2.3a provides a flow chart for ArcGIS processes used in creating the watershed map and the stream network.

Historical imagery (1947, 1951, 1956, 1968, 1977, 1989, 1999, 2005, 2006 and 2009) was classified using maximum likelihood supervised classification. Training samples were made for each year of photographs due to inconsistencies in resolution. A 30 meter buffer was then created around the stream network for each of the classified maps. South Carolina does not have a stream buffer width requirement, but the SC Department of Health and Environmental Control (SCDHEC) recommends at least thirty-meter (approximately 100-foot) buffers. The stream buffers were then classified as either vegetated or unvegetated. The number of hectares was then compared for each buffer width.

Surface area, catchment area, and lake volume comparison

Change in lake surface area was calculated using the measure polygon tool in ArcGIS 10.1. For each year of historical photography a polygon was created to encompass the lake surface. These areas were then compared using Microsoft Excel.

Limited hydrologic data was available from a Reservoir Sedimentation Data Summary report (RESSED) collected by the Soil Conservation Service in April 1941 and October 1949. Catchment area could only be compared using the created watershed boundary from the 2011 LiDAR files. Area was then compared to the catchment areas listed on the RESSED report for 1941 and 1949.

Lake volume was determined using a Lowrance Elite 4 HDI sonar logging depth finder, SonarTRX (www.sonartrx.com) software and ArcMap 10.1. Transects were made evenly across the lake from shoreline to shoreline, while recording sonar logs. These logs included geographic coordinate points (XY) and their associated depths (Z) and also a sonar image of the lake bottom and sediment. These files (.sl2) were imported into SonarTRX, viewed and then exported as comma separated values (.csv) with an XY-coordinate system of UTM Zone 17N and a Z-coordinate system of WGS 1984. The resulting data

(8335 XYZ points) were added to ArcGIS 10.2, projected into the correct coordinate system and exported as ESRI shapefiles. These shapefiles were then merged together to simplify processing. From the resulting shapefile, a Triangular Irregular Network (TIN) was created using the Create TIN 3D Analyst tool. It was then converted into a raster based on depth. The raster was then clipped to the lake extent created from LiDAR data. The Surface Volume 3D Analyst tool was used to then determine the surface area and volume below a named plane height of 10.353 meters, which represented the maximum lake depth. This tool was also used to determine the volume of water in meter depth increments, from 1 meter to 10.353 meters. From this data a hypsograph was created in Microsoft Excel. Figure 2.3b provides a flow chart for SonarTRX and ArcGIS processes used to determine lake volume.

A contour map, a bathymetric map and a three-dimensional image of the lake bottom were also created using the Natural Neighbor Raster Interpolation 3D Analyst tool. The contour map was created from the resulting layer using the Contour 3D Analyst tool in ArcMap 10.1. Because Lake Issaqueena is relatively shallow, contour lines were set 1 m intervals. The bathymetric map was created using the Adjust 3D Z Data Management tool and reversing the values to reflect depth instead of elevation. The symbology was then changed to reflect 10 depth classes ranging from the most shallow to deepest depths. A 3D image of the lake bottom was also created from the TIN data layer using ArcScene 10.1. The TIN was added to the map and base height properties were changed from 1 m to 10.353 m to encompass all depths present within the lake.

Climatological data analysis

Climatological analysis was performed on data from the National Climatic Data Center (NCDC, 2014). Average annual precipitation data was exported and analyzed using Microsoft Excel. Data was collected for 1938 to 2009 and plotted on the primary y-axis. Surface area data was plotted on the same line graph (on the secondary y-axis) for the available years.

Soil inventory and analysis

Soil inventory data was provided by Pickens County GIS (Table I). This data was clipped to the watershed extent.

Discussion

Watershed characteristics

Based upon 2011 LiDAR data, the Lake Issaqueena catchment drains approximately 3638.15 ha. In 1938, the catchment area was slightly smaller at 3631.16 ha. This difference could be attributed to the various means for collecting data or because of expansion of the stream network. Figure 2.1 provides aerial imagery from 1951, 1977, 1989 and 2009. It is evident from these photos that the northern portion of Lake Issaqueena has experienced extensive sedimentation. Because reservoirs are man-made structures that disturb the natural flow of rivers and streams, as well as sediment transportation and deposition, sedimentation in reservoirs occurs much more rapidly than in naturally occurring lakes. Substantial allochthonous sedimentation occurs due to the large size of the catchment area. Catchment size is usually larger for reservoirs as opposed to natural lakes due the construction of man-made lakes in areas with limited water supply.

It is evident from Table III that significant erosion has occurred. Steep slopes that were once more than 25% have drastically decreased (-296.75 ha), while gentle slopes that are between 2 and 7% have significantly increased (+318.92). The soils that are being eroded away are likely deposited in areas of lower elevation, which include the stream channels and the lake.

Surface area, catchment area, and lake volume comparison

When the lake was created in 1938 the lake covered approximately 47.35 ha, but by 2011 the lake only covered only 36.02 ha, a 23.93% decrease. Lake surface area significantly decreased (by almost 10 ha) between 1941 and 1947. High rainfall possibly contributed to an increase in surface area in 1949, yet area decreased again by 1951. In 1954, Lake Issaqueena was drained due to fisheries re-stocking, which led to a man-made change in surface area. Surface area remained steady until 1989 when it again decreased by over 7 ha. Since 1989, the lake surface area has remained relatively similar from year to year. For the last 75 years, the lake had an average surface area of 35.86 ha. Figure 2.4 shows lake surface area for each year of aerial photography analyzed. Sedimentation of the lake causes a loss in surface area and volume. Factors that contribute to sedimentation include severe storm events, natural erosion processes and many anthropogenic causes such as agricultural and forestry practices. Changes in land cover are the likely cause for sedimentation of Lake Issaqueena. Peak loss years coincide with years that were not well managed (1942-1945) and years that saw a large decrease in vegetated buffers. Other studies have found similar results with varying causes. A study completed by Haack (1996) in East Africa states that the growth of the river delta is the result of both increased sedimentation and decreased lake levels and river flows. The Lake Issaqueena watershed has experienced an increase in rainfall from1938 to present, so decrease in flow is not a major contributor to surface area loss. Another study, completed at Seyfe Lake in Turkey concluded that the 33% loss in surface area from 1975 to 2006 was the result of a change in climatic conditions and anthropogenic factors (Reis and Yilmaz, 2008).

Catchment area increased from 3631.16 ha to 3638.15 ha. The catchment area could vary due to the method for determining area. By using LiDAR data various stream orders can be included in the drainage area; these streams may not have been included in the original contour survey. Another possible explanation is an extension of the stream network due to an increase in precipitation, but this cannot be confirmed due to lack of data. LiDAR data has been shown provide a highly accurate depiction of hydrologic features derived from DEMs.

Lake volume decreased from 2,264,700 m^3 in 1938 to 1,943,900 m^3 in 2014 (Figure 2.5). From the raw data collected, average mean depth was approximately 4.66 meters. Table IV provides a comparison of surface area, volume and mean depth for 1938, 1941, 1947 and 2014. Figure 2.5 depicts the hypsographic curve from data collected from the Lowrance depth finder. It is hypothesized that this 320,800 m^3 decrease is a result of changes in land cover, as well as a factor of soil type and vegetated buffer coverage. Data collected by the Soil Conservation Service in 1941 and 1949 showed that on average, storage capacity of the lake was decreasing by 1.34% or 28132.17 m^3. Had this trend continued it is predicted that Lake Issaqueena would be completely filled with sediment within the next four years. However, due to land reclamation sedimentation rates have significantly decreased and storage capacity loss for 2014 is roughly 4220.53 m^3. A similar study was conducted on Lake Hayq in Ethiopia, by Yesuf *et al.* (2013), also measured lake volume using an echo sounding device and ArcGIS. They found that a loss in storage capacity was also not attributed to a decrease in precipitation, but due to a decrease in discharge from upstream watersheds and from degradation within those watersheds (Yesuf *et al.,* 2013). This degradation included poor farming and land management practices, which increased soil erosion and increased surface runoff (Yesuf *et al.,* 2013). Lake Issaqueena watershed is unique in comparison to other studies in that there was a shift from agricultural land to forestland, which greatly reduced sedimentation rates by approximately 88.28%.

A contour map (Figure 2.6), bathymetric map (Figure 2.7) and 3D surface map (Figure 2.8) were created based upon the XYZ data collected. The contour map provides a 2D representation for the 3D data collected (Yesuf *et al.,* 2013). The contour lines are labeled for every meter depth starting from 1 m up to 10 m. At the southern end of the lake, closest to the dam, the contour lines are very close together; this represents the steepest slopes, or the deepest depths. Yesuf *et al.* (2013) utilized a similar process in ArcGIS to create a contour lake with 5 m intervals and contour lines ranging from 0 m to 80 m. The darkest areas of the map represent the deepest depths, which are located in thalweg. This information can be used to monitor long-term morphological changes and sedimentation (Yesuf *et al.,* 2013). A study in Turkey also created bathymetric maps for the Altinapa reservoir and found that sedimentation was serious threat to the continued operation of their reservoirs (Ceylan and Ekizoglu, 2014). Ceylan and Ekizoglu (2014) found that within a 25-year span nearly 12.7% of the lake had been lost due to sedimentation; causes were not discussed. Using the same data layer as the bathymetric map (TIN), a 3D image of the lake bottom was created using ArcScene (Figure 2.8). A 3D image can provide a clearer visual for how sediments are being deposited on the lake bottom.

Climatological data analysis

From 1938 to 2009, the watershed received an average of 1294.43 mm of precipitation annually. From observing Figure 2.9 alone, it would appear that lake surface area is correlated to annual rainfall. However, by applying the Pearson correlation coefficient, precipitation and lake surface area are not correlated. This suggests that sedimentation of Lake Issaqueena does not heavily rely on average rainfall across the watershed. However, it is possible that strong storm events do contribute significant amounts of sediment. Overall, there has been an increase in annual precipitation rates from 1938 to 2011 of 19.59%. Kebede *et al.* (2006) found that low sensitivity of lakes to rainfall is typical for lakes with significant outflow. From a preliminary analysis of Lake Tana in Ethiopia, Kebede *et al.* (2006) hypothesized that the sensitivity of lake level and outflow was controlled more by a variation in rainfall than by basin-scale anthropogenic factors. However, Lake Issaqueena is controlled more by human activity than by changes in precipitation.

Soil inventory and analysis

There are seventeen soil series represented in this study area with Cecil being the predominant series at 24.46%, followed by Pacolet series at 23.59% (Figure 2.10). These soils are highly erodible. Cecil soils are located on predominately on 2-10 % slopes, whereas Pacolet soils are located primarily on 10-40% slopes (Table II). Bank steepness has a significant impact on the surface runoff, which causes erosion. Three soil orders are represented in this study area with Ultisols being the most abundant, followed by Inceptisols and then Entisols. Stone *et al.* (1985) analyzed the effect of past erosion on North Carolina Piedmont soils that are very similar to those in the Lake Issaqueena watershed. They found that clay content increased by approximately 10% for each erosion class (slight, moderate and severe), organic matter content was higher on more eroded sites and that available water capacity decreased with erosion severity (Stone *et al.,* 1985). Sediment that has been deposited at the delta of Sixmile Creek has been classified as Chewacla soils. Chewacla soils are common in Piedmont river valleys (Soil Survey Staff, 2014). Chewacla soils are somewhat poorly drained and are frequently flooded for short to long periods (Soil Survey Staff, 2014). When sediments are transported from the lentic stream system to the lotic lake system larger particles (e.g. sand) are quickly deposited at the delta, while smaller particles (e.g. clay) stay suspended in the water column quite a distance before settling out. Over time this process leads to the creation of soils and decreases lake surface area.

Vegetated versus Unvegetated Buffer Analysis

Figure 2.11 provides a comparison of vegetated versus unvegetated buffers for the following years of aerial photography: 1947, 1951, 1956, 1968, 1977, 1989, 1999, 2005, 2006 and 2009. All years were analyzed to show a trend in land cover change within the riparian buffer. During 1947 and 1951, years directly following lease to Greenville Air Force Base, the amount of vegetated versus unvegetated buffers were nearly even. In 1956, unvegetated buffers exceeded the amount of vegetated buffers. Table V provides information about land use classes (Pilgrim et al., 2014) in hectares for 1951, 1977, 1989 and 2009. For each year of aerial photographs, forestland (evergreen and deciduous) dominated the watershed. In 1951, the amount of vegetated versus unvegetated buffers was roughly even, by 1977 vegetated buffers had increased significantly, and lake surface area had increased. While the relationship between vegetated buffer increase and surface area increase are not directly related (likely an increase in precipitation led to increased surface area), this suggests that the rate of sediment inflow is slowed. This trend is can also be noted from 1977 to 1989 when the amount of unvegetated buffers increased and surface area decreased, and also from 1989 to 2009 when again surface area and vegetated buffer coverage increased. Vegetated buffers increase infiltration rate, reducing erosion rate and therefore decreasing the sedimentation rate. Hook (2003) found that average sediment retention in plots of various widths and vegetation in Montana trapped between 63 and 99% of sediments. He also found that 6 m wide buffers retained between 94 and 99% of sediment regardless of vegetation type or slope (Hook, 2003). He noted that narrow buffer widths, steep slopes and sparse vegetation increase the risk of sediment delivery (Hook, 2003).

Conclusions

Lake Issaqueena has accumulated a significant amount of sediment in the past 75 years. The lake has lost over 14.74 hectares due to sedimentation. It is speculated that changes in land cover significantly contributed to the accumulation of sediments within the lake. There was not a significant relationship between average precipitation rates and loss of surface area, while there was a relationship between loss of vegetated buffers and surface area. Understanding the rate of sedimentation for reservoirs is very important in planning and creating man-made lakes. Few studies have examined long-term impacts of reforestation of eroded agricultural lands on reservoir sedimentation rates. Land cover changes associated with this reforestation included improved stream buffers which likely lowered the sediment loads through the stream networks to the reservoir. Long term studies are critical to understand erosion processes that occur over decades instead of seasons, such as watershed slope changes. Aerial photography is widely available over a long period of time, and this study demonstrated their utility to examine both land cover and reservoir surface area changes. Methodologies and work flows have been develop to integrate the latest technological tools, such as LiDAR and Sonar, into watershed and reservoir assessment. These tools provide an accurate baseline for future studies, while also demonstrating a rapid assessment tool for future updates.

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CHAPTER 4

Conclusion

This research analyzes the intimate relationship between land cover change, sedimentation and water quality. It uses advanced technology to provide a depiction of what has happened in Lake Issaqueena and the surrounding watershed over the past 76 years.

Chapter two provided an analysis of land cover change for nine years of aerial photographs. Water quality data was provided for over forty years for the Sixmile Creek station and approximately six years for the Lake Issaqueena station. This chapter focused on linking changes in water quality and significant changes in land cover throughout the watershed. The methodology applied to this study can be used not just on a local scale, but also at the regional scale.

Chapter three provided information on changes in lake morphometry due to sedimentation and identified possible causes of sediment accumulation. Equipment utilized in this study was relatively inexpensive and did not require specialized training for use. Due to reclamation of this landscape this lake and watershed are very unique.

Table 1.1 Data sources and descriptions

Data Layer	Source	Coordinate System	Date
LiDAR (LAS) files	Pickens County GIS	NAD State Plane 1983 SC	2011
Lake Polygon	Pickens County GIS	NAD State Plane 1983 SC	2013
Subdivisions	Pickens County GIS	NAD State Plane 1983 SC	2013
Parcels	Pickens County GIS	NAD State Plane 1983 SC	2013
Single-frame Aerial Photos			
5/14/51	USGS Earth Explorer	NAD State Plane 1983 SC	1951
3/17/56	USGS Earth Explorer	NAD State Plane 1983 SC	1956
3/14/77	USGS Earth Explorer	NAD State Plane 1983 SC	1977
1989	USGS Earth Explorer	NAD State Plane 1983 SC	1989
1999	USGS Earth Explorer	NAD State Plane 1983 SC	1999
Aerial Photos			
2005	USDA Geospatial Data Gateway	NAD State Plane 1983 SC	2005
2006	USDA Geospatial Data Gateway	NAD State Plane 1983 SC	2006
2009	USDA Geospatial Data Gateway	NAD State Plane 1983 SC	2008

Table 1.2 Land use/ land cover descriptions

Land Use Class	Description
1. Evergreen	Defined by the presence of evergreen species
2. Deciduous	Defined by the presence of hardwood/ deciduous species
3. Bare Ground	Areas of bare soil with little to no vegetation
4. Pasture/ Grassland	Defined by the presence of grass species
5. Cultivated	Defined by the presence of rows and/ or strips of bare ground alternated with green vegetation
6. Residential/ Other Development*	Identified by impervious surfaces, homes, commercial buildings, etc.

Table 2.1 Data sources and descriptions

Data Layer	Source	Coordinate System	Date
LiDAR (LAS) files	Pickens County GIS	NAD State Plane 1983 SC	2011
Lake Polygon	Pickens County GIS	NAD State Plane 1983 SC	2013
1968 Aerial Photo	Pickens County GIS	NAD State Plane 1983 SC	2013
SSURGO Soils Data	USDA-NRCS	Geographic	na
Single-frame Aerial Photos			
2/24/47	USGS Earth Explorer	NAD State Plane 1983 SC	1947
5/14/51	USGS Earth Explorer	NAD State Plane 1983 SC	1951
3/17/56	USGS Earth Explorer	NAD State Plane 1983 SC	1956
3/14/77	USGS Earth Explorer	NAD State Plane 1983 SC	1977
1989	USGS Earth Explorer	NAD State Plane 1983 SC	1989
1999	USGS Earth Explorer	NAD State Plane 1983 SC	1999
Aerial Photos			
2005	USDA Geospatial Data Gateway	NAD State Plane 1983 SC	2005
2006	USDA Geospatial Data Gateway	NAD State Plane 1983 SC	2006
2009	USDA Geospatial Data Gateway	NAD State Plane 1983 SC	2008

Table 2.2 Soils of the Lake Issaqueena watershed

Soil map unit name	Map unit symbol	Percent slopes	Surface soil type	Watershed area (%)	Family of higher taxonomic classification
Cecil	CeB3	2-6	Clay loam	0.41	Fine, kaolinitic, thermic Typic Kanhapludults
	CeC3	6-10	Clay loam	4.17	
	ClB2	2-6	Sandy loam	8.98	
	ClC2	6-10	Sandy loam	8.19	
	ClD2	10-15	Sandy loam	2.71	
				(24.46)	
Chewacla	Co	--	Soils, frequently flooded	0.30	Fine-loamy, mixed, active, thermic Fluvaquentic Dystrudepts
Clifton	CtF	15-35	Fine sandy loam	0.05	Fine, mixed, semiactive, mesic, Typic Hapludults
Grover	GrB2	2-6	Fine sandy loam	0.45	Fine-loamy, micaceous, thermic Typic Hapludults
	GrG	40-80	Fine sandy loam	0.18	
				(0.63)	
Gwinnett	GwF	24-40	Sandy loam	0.16	Fine, kaolinitic, thermic Rhodic Kanhapludults
Hiwassee	HwB2	2-6	Sandy loam	0.35	Very-fine, kaolinitic, thermic Rhodic Kanhapludults
	HwC2	6-10	Sandy loam	0.75	
	HwE2	10-25	Sandy loam	2.58	
	HyB2	2-6	Clay loam	0.36	
	HyC3	6-10	Clay loam	1.16	
	HyE3	10-25	Clay loam	1.53	
				(6.73)	
Louisburg	LoE	10-25	Sandy loam	0.04	Coarse-loamy, mixed,semiactive, thermic Typic Hapludults
	LoF	25-40	Sandy loam	0.10	
				0.14	
Madison	MaB2	2-6	Sandy loam		Fine, kaolinitic, thermic Typic Kanhapludults

	MaC2	6-10	Sandy loam	1.66	
	MaE2	10-25	Sandy loam	5.70	
	McE3	10-25	Clay loam	8.94	
				2.14	
				(18.44)	
Musella	MuG	40-80	Soils	0.04	Loamy, mixed, subactive, thermic shallow Typic Rhodudults
Pacolet	PaB2	2-6	Fine sandy loam	.02	Fine, kaolinitic, thermic Typic Kanhapludults
	PaE2	10-25	Fine sandy loam	5.66	
	PaF	25-40	Fine sandy loam	8.44	
	PaG	40-80	Fine sandy loam	1.55	
	PcE3	10-25	Clay loam	7.92	
				(23.59)	
Rabun	RbE	10-25	Loam	0.07	Fine, kaolinitic, mesic Typic Kanhapludults
	RaF	25-40	Cobbly loam	0.03	
	RaG	40-70	Cobbly loam	0.04	
				(0.14)	
Saluda	SaF	25-40	Sandy loam	1.78	Loamy, mixed, active, mesic, shallow Typic Hapludults
	SaG	40-70	Sandy loam	0.18	
				(1.96)	
Starr	SrB	0-6	Loam	0.65	Fine-loamy, mixed, semiactive, thermic Fluventic Dystrudepts
Stony	St	--	Land	0.11	--
Tallapoosa	TaD	6-15	Loam	0.02	Loamy, mixed, semiactive, thermic shallow Typic Hapludults
	TaF	25-40	Loam	0.17	
	TaG	40-80	Loam	0.05	
				(0.24)	
Toccoa	To	--	--	2.18	Coarse-loamy, mixed, active, nonacid, thermic Typic Udifluvents
Worsham	WoB	2-6	Sandy loam	0.31	Fine, mixed, active, thermic Typic Endoaquults
Water	W	-	Water	19.94	-

Table 2.3 Distribution of land slope classes for net-sediment contributing area for 1950 to 2011 (1950 measurements adapted from Noll *et al.* 1950)

Slope class	Hectares		Watershed Percent		Change	
	1950	2011	1950	2011	Hectares	Watershed Percent
0-2%	124.24	133.95	3.5	3.68	9.72	0.18
2-7%	460.13	779.04	12.8	21.43	318.92	8.63
7-10%	797.64	744.21	22.2	20.46	-53.42	-1.74
10-14%	552.80	782.29	17.6	21.51	229.49	3.91
14-25%	1028.71	949.95	28.7	26.12	-78.76	-2.58
> 25%	544.30	247.55	15.2	6.8	-296.75	-8.4
Total:	3588.75*	3636.91**	100	100	48.16	--

Table 2.4 Comparison of lake characteristics

Year	Surface Area (ha)	Volume (m^3)	Mean Depth (m)	Average Yearly Storage Capacity Loss (m^3)
1938	47.35	2,264,700	4.78	--
1941	46.13	2,156,100	4.91	36007.37
1947	42.90	2,005,600	5.28	20256.96
2014	36.02	1,943,900	6.29	4220.53
Total Change:	-11.33	-320,800	-1.51	--

Table 2.5 Land use/ land cover descriptions

Land Use Class	Description	1951 (ha)	1977 (ha)	1989 (ha)	2009 (ha)
7. Evergreen	Defined by the presence of evergreen species	651.40	1139.29	1052.45	764.51
8. Deciduous	Defined by the presence of hardwood/ deciduous species	911.13	1332.20	1393.51	1478.61
9. Bare Ground	Areas of bare soil with little to no vegetation	167.50	252.03	317.04	183.86
10. Pasture/ Grassland	Defined by the presence of grass species	821.30	398.94	581.42	471.46
11. Cultivated	Defined by the presence of rows and/ or strips of bare ground alternated with green vegetation	1081.50	514.59	292.66	528.08
12. Residential/ Other Development*	Identified by impervious surfaces, homes, commercial buildings, etc.	--	--	--	209.86
Total area (ha):	------------------------------	3632.83	3637.05	3637.08	3636.38

- Only applicable for 2009

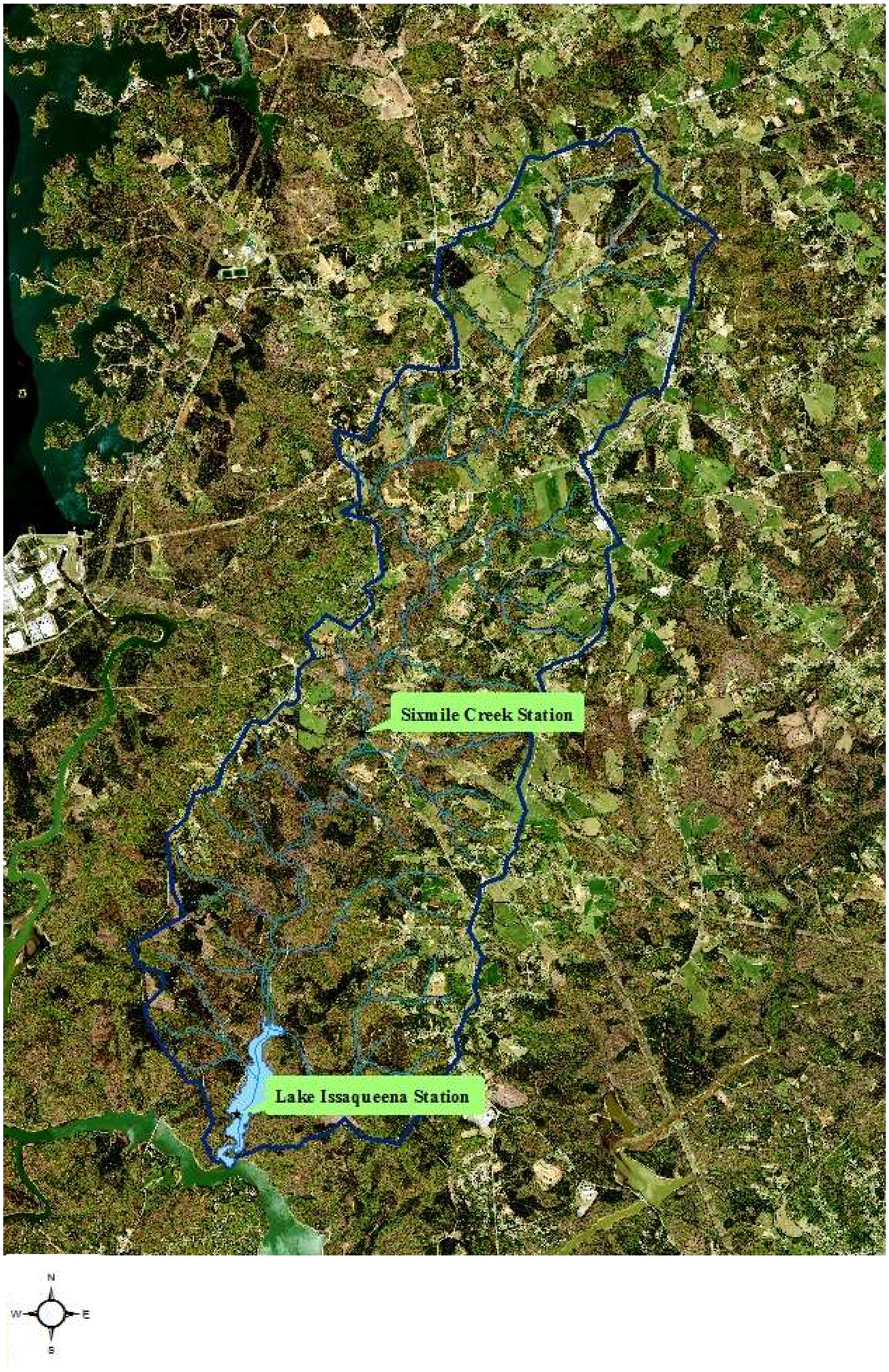


Figure 1.1 Map of the study area: Lake Issaqueena

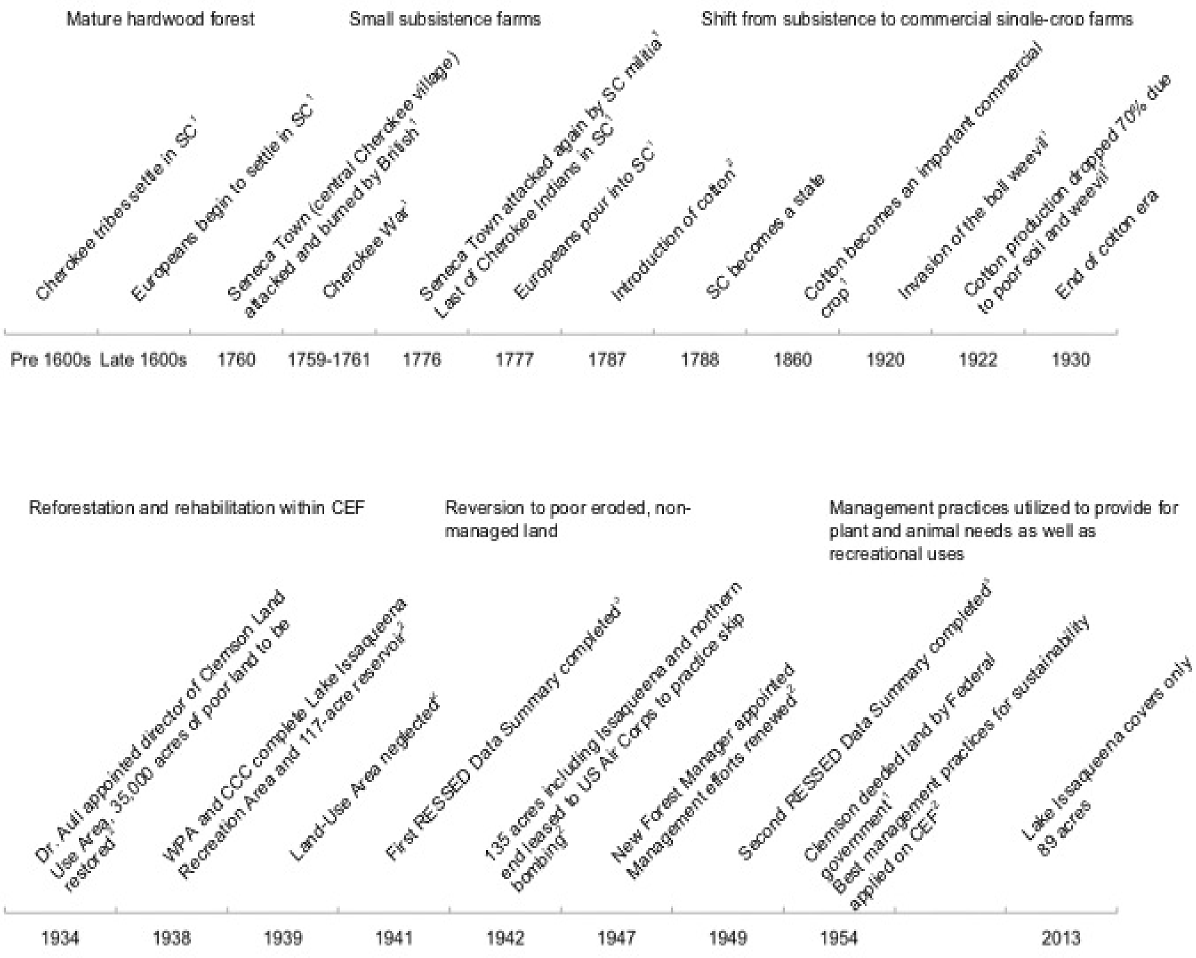


Figure 1.2 Timeline of events for the Clemson Experimental Forest (CEF) and Lake Issaqueena watershed

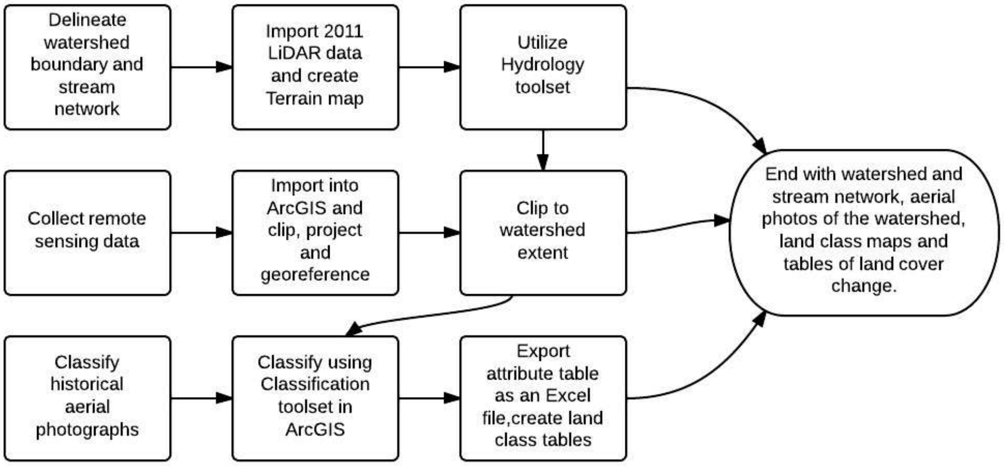


Figure 1.3 Flow chart for ArcGIS processes

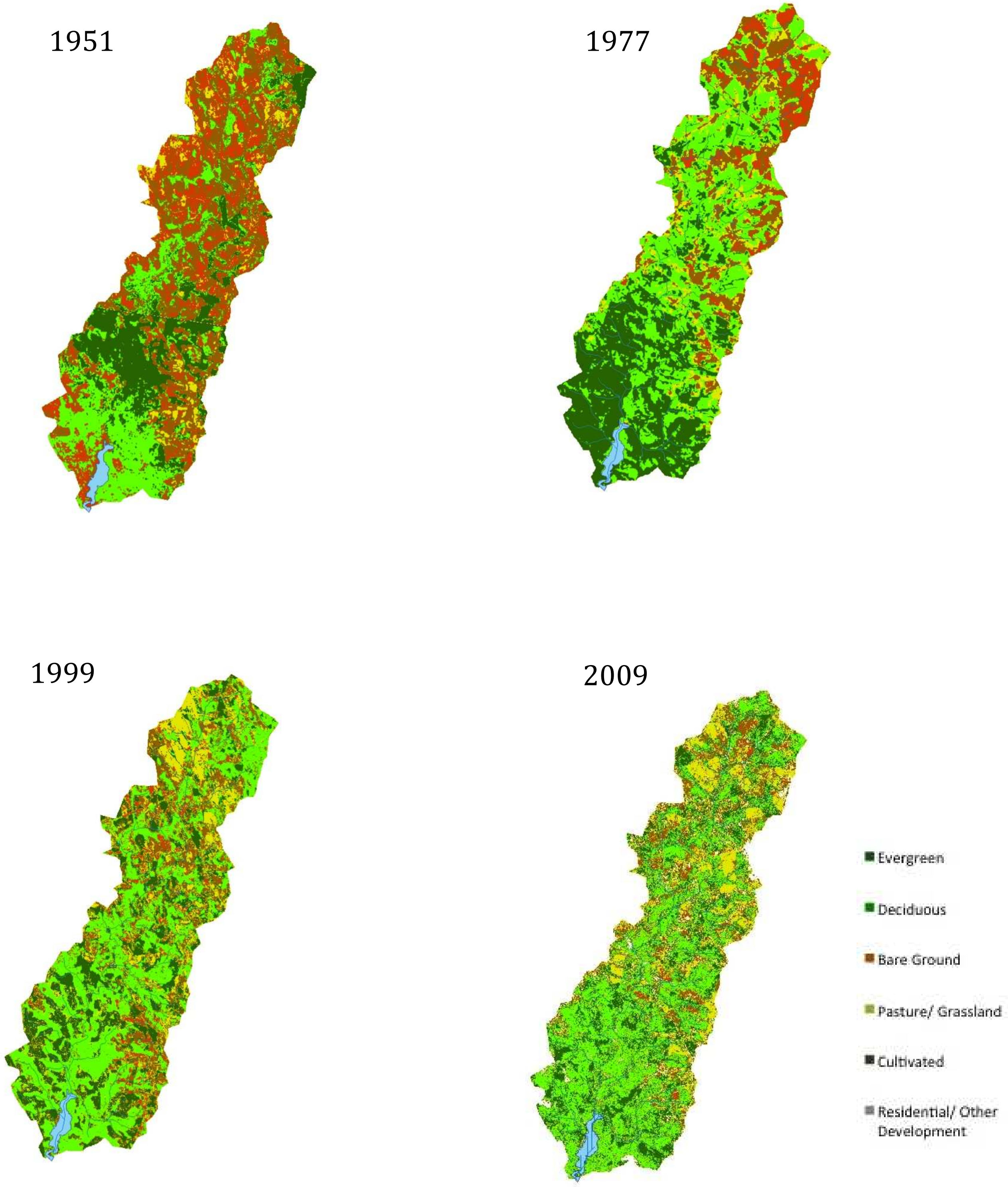
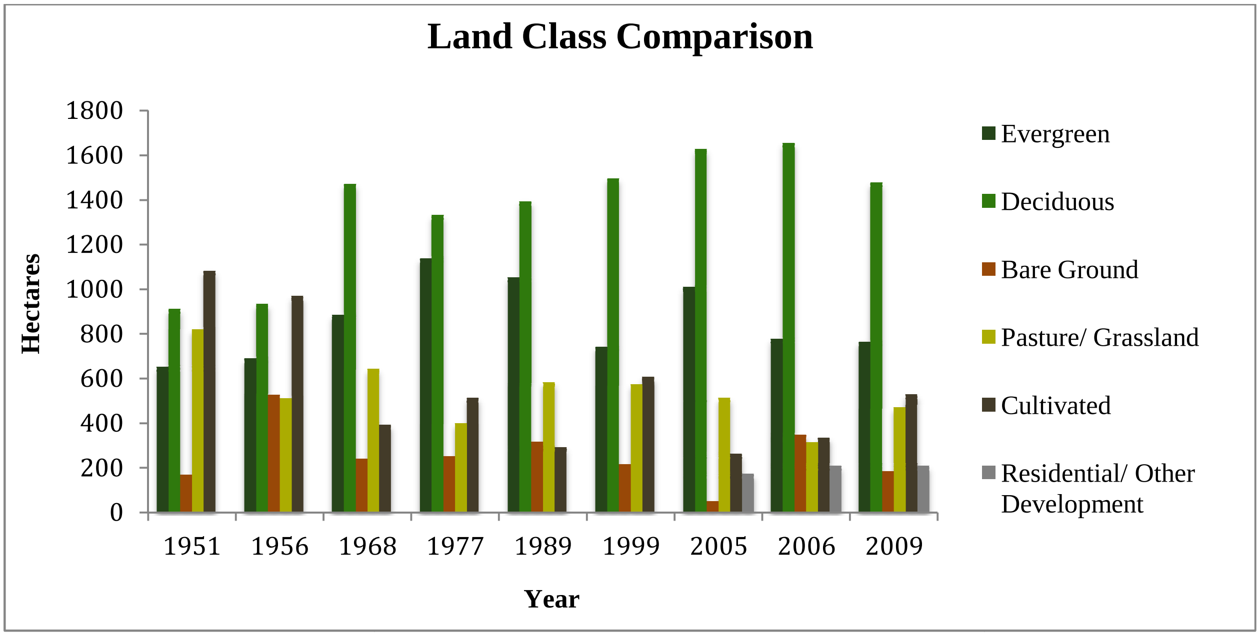


Figure 1.4 Land class map comparison for 1951, 1977, 1999 and 2009

a Comparison of land class coverage for each year in hectares



b Total tree cover in hectares by year

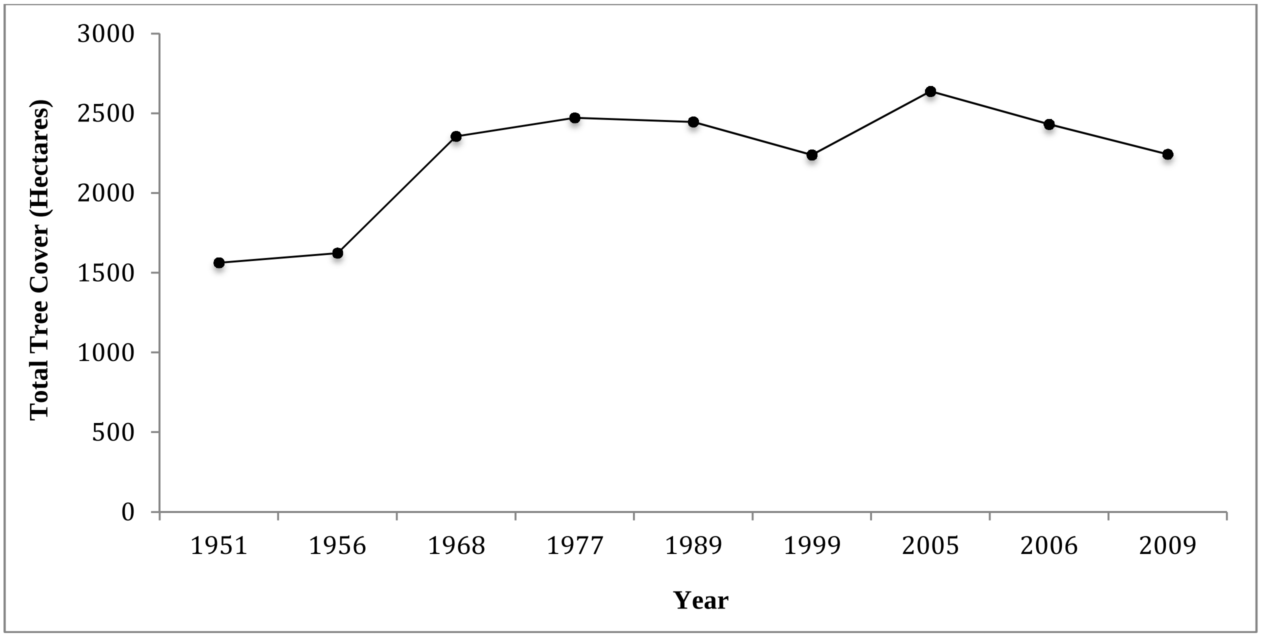
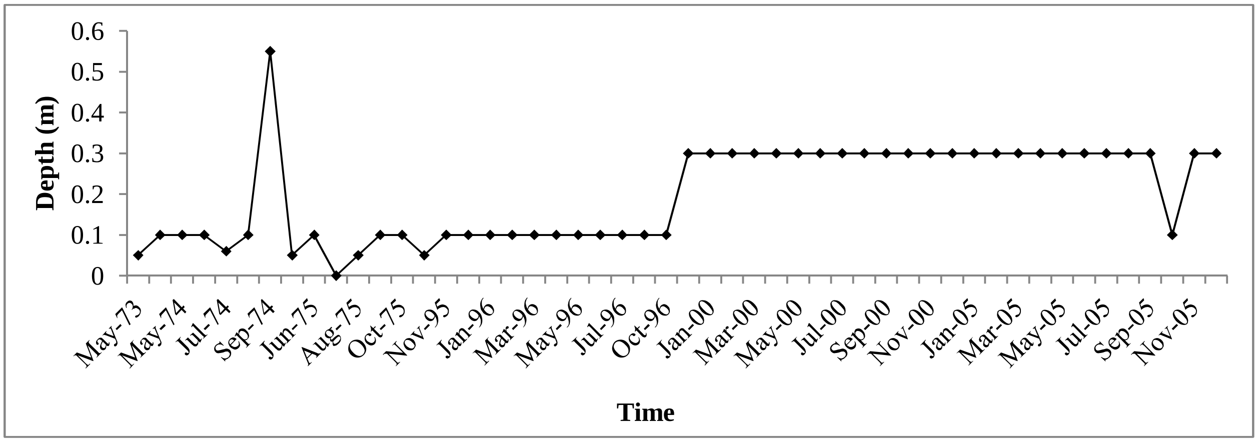
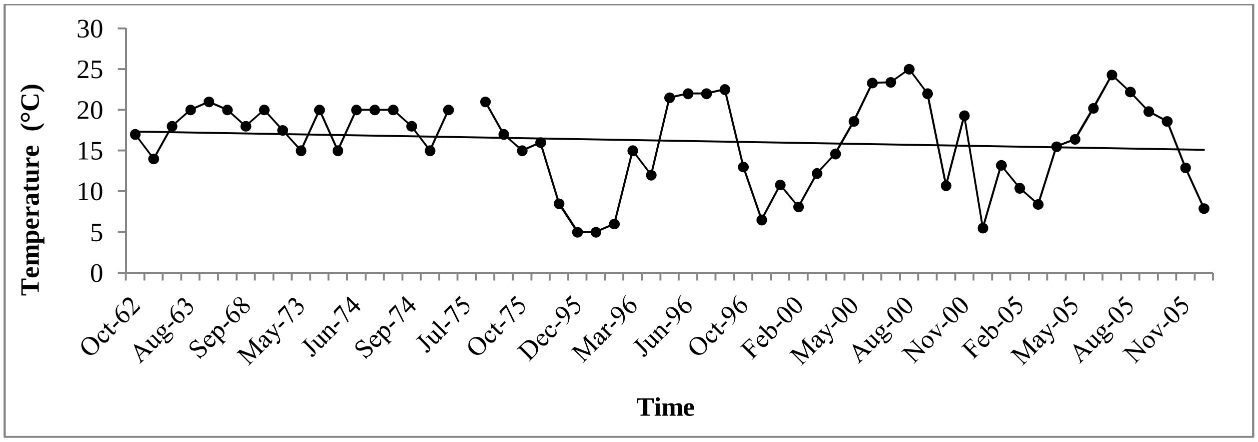


Figure 1.5 Land class data **a** Comparison of land class coverage for each year in hectares **b** Total tree cover in hectares by year

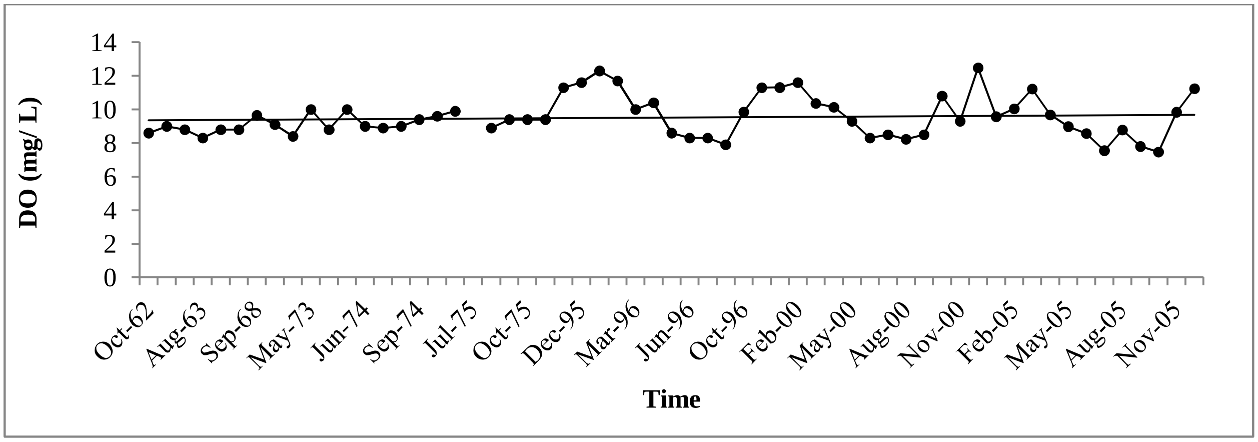
a Sampling depth for SV-205



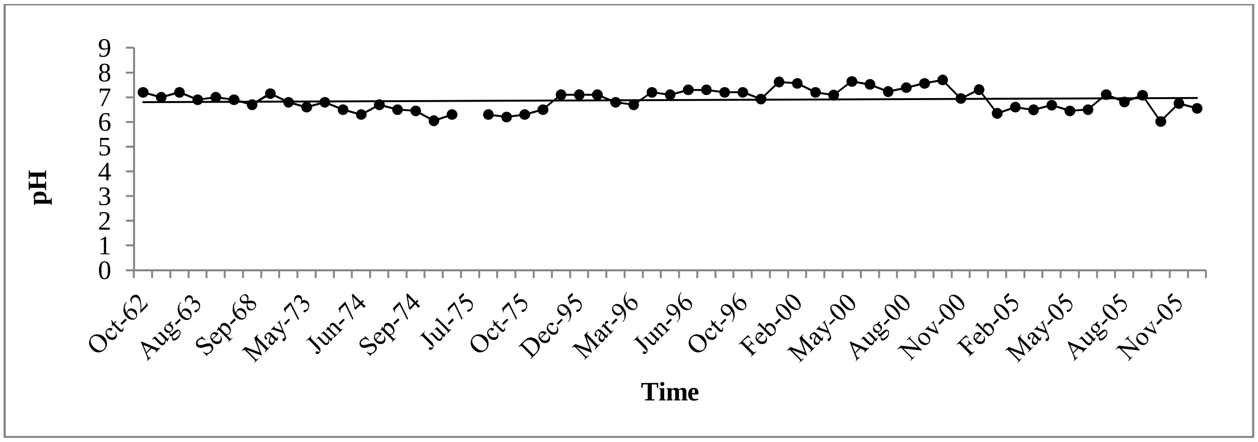
b Water temperature for SV-205



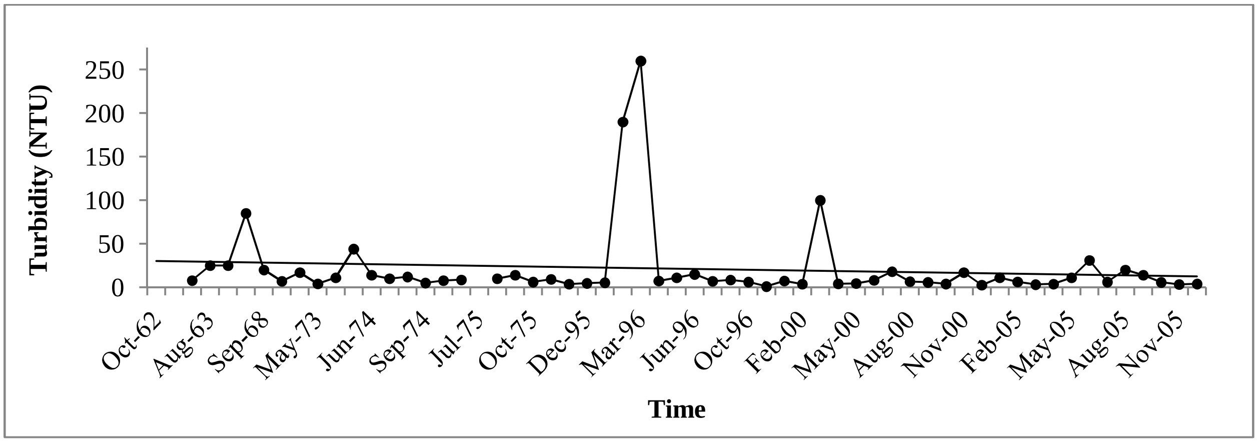
c Dissolved oxygen content for SV-205



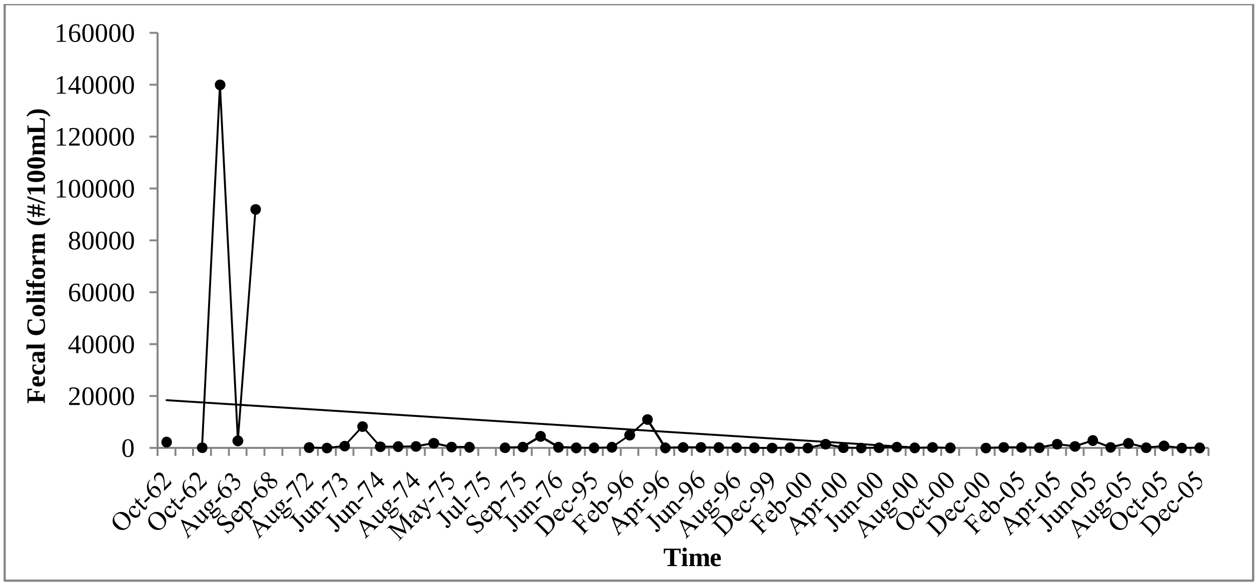
d pH for SV-205



e Turbidity for SV-205



f Fecal coliform concentrations for SV-205



g Inorganic nitrogen level for SV-205

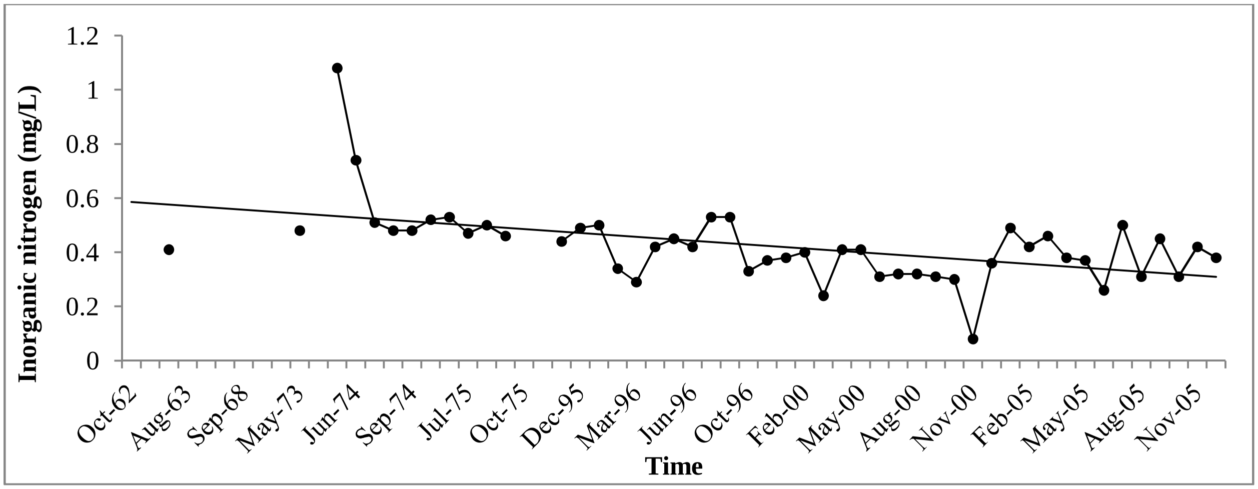
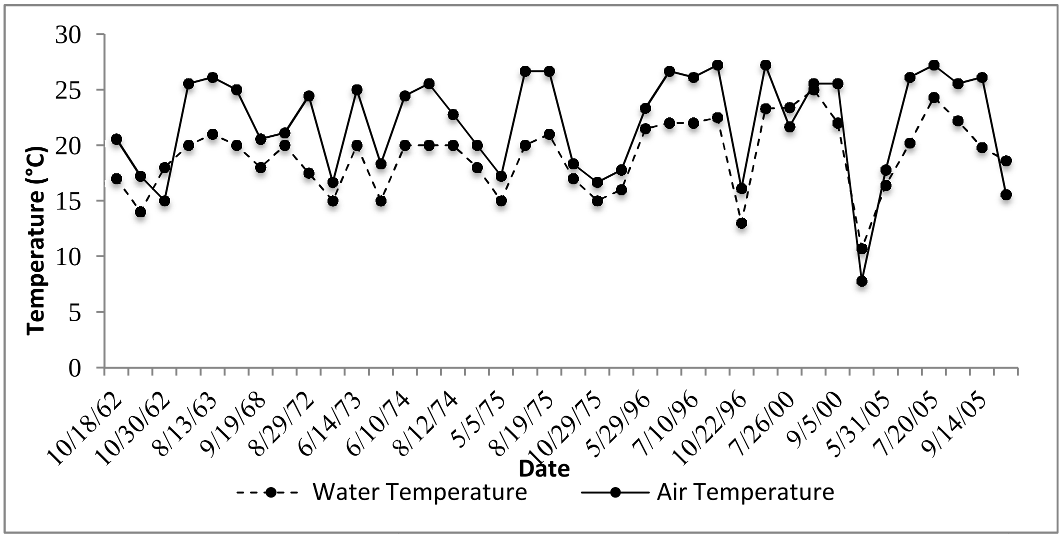


Figure 1.6 Water quality data for Sixmile Creek water quality monitoring station (SV-205) **a** Sampling depth (m) **b** Water temperature (℃) **c** Dissolved oxygen (mg/L) **d** pH **e** Turbidity (NTU) **f** Fecal coliform (#/100mL) **g** Inorganic nitrogen (mg/L)

a Water/ air temperature for the Sixmile Creek data station



b. Water/ air temperature for the Lake Issaqueena data station

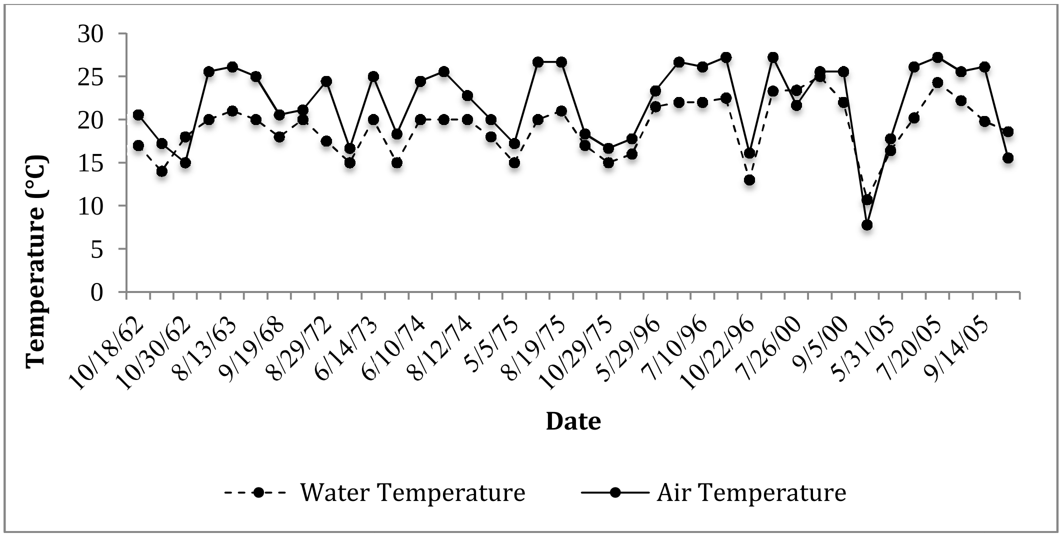
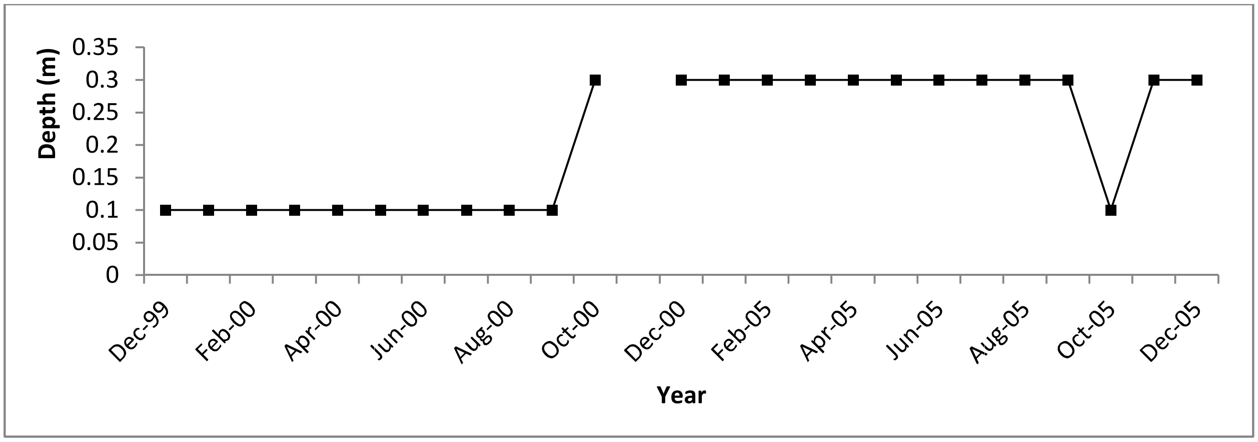
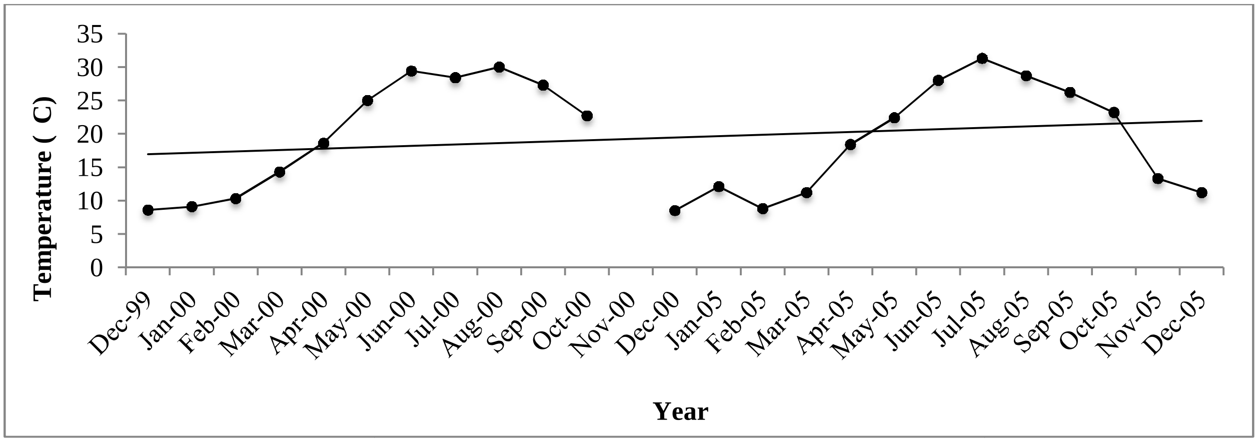


Figure 1.7 Water temperature and average daily air temperature comparison (Air temperature data from USHCN) **a** Water/ air temperature for the Sixmile Creek data station **b** Water/ air temperature for the Lake Issaqueena data station

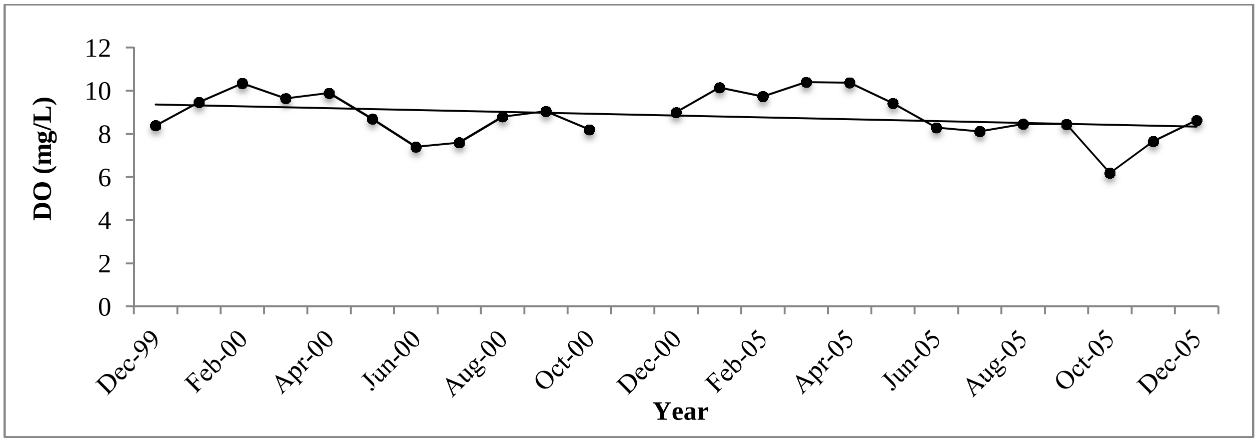
a Sampling depth for SV-360



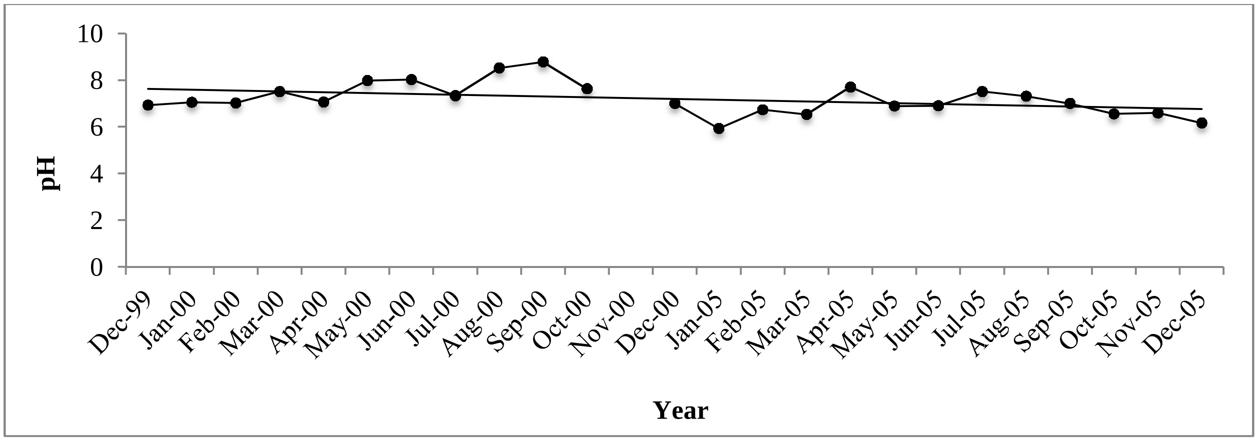
b Water temperature for SV-360



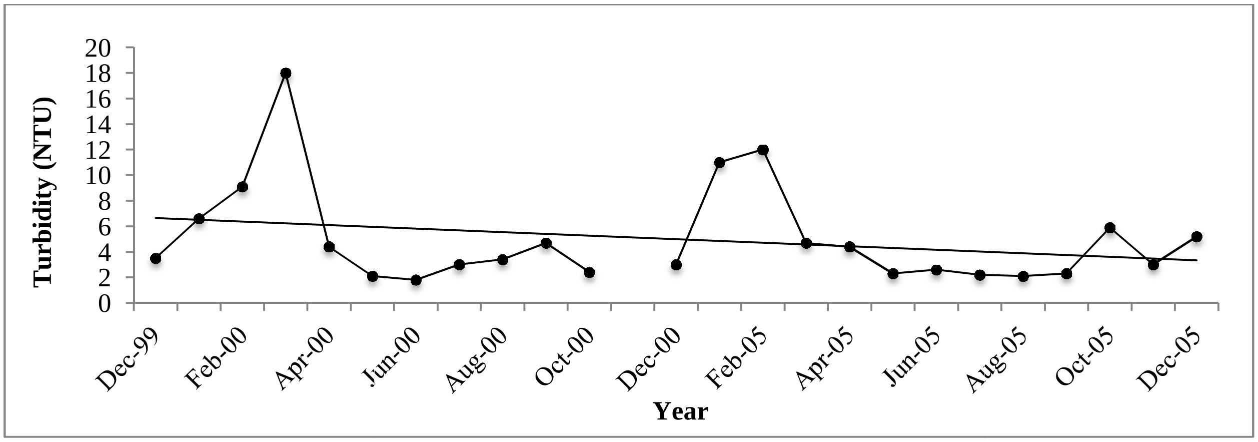
c Dissolved oxygen content for SV-360



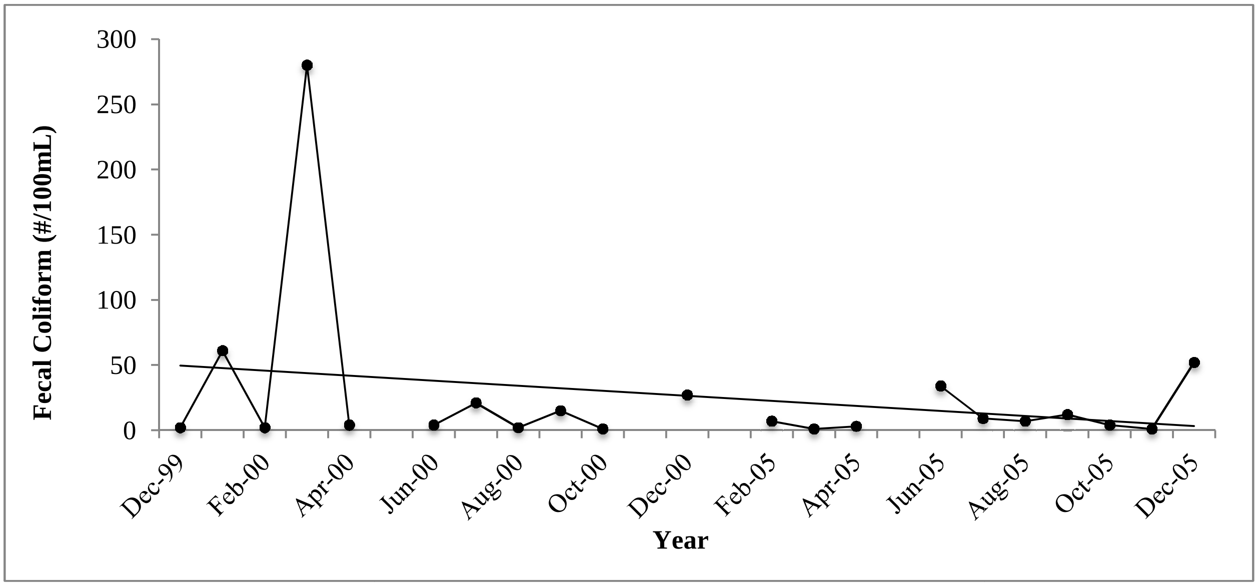
d pH for SV-360



e Turbidity for SV-360



f Fecal coliform concentrations for SV-360



g Inorganic nitrogen levels for SV-360

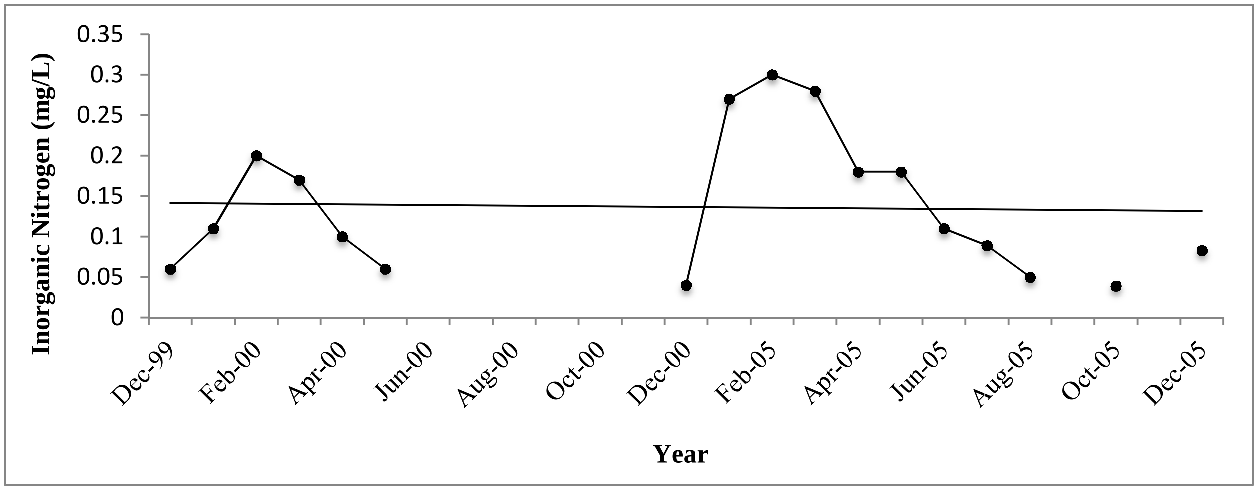


Figure 1.8 Water quality data for Lake Issaqueena water quality monitoring station (SV-360) **a** Sampling depth (m) **b** Water temperature (℃) **c** Dissolved oxygen (mg/L) **d** pH **e** Turbidity (NTU) **f** Fecal coliform (#/100mL) **g** Inorganic nitrogen (mg/L)

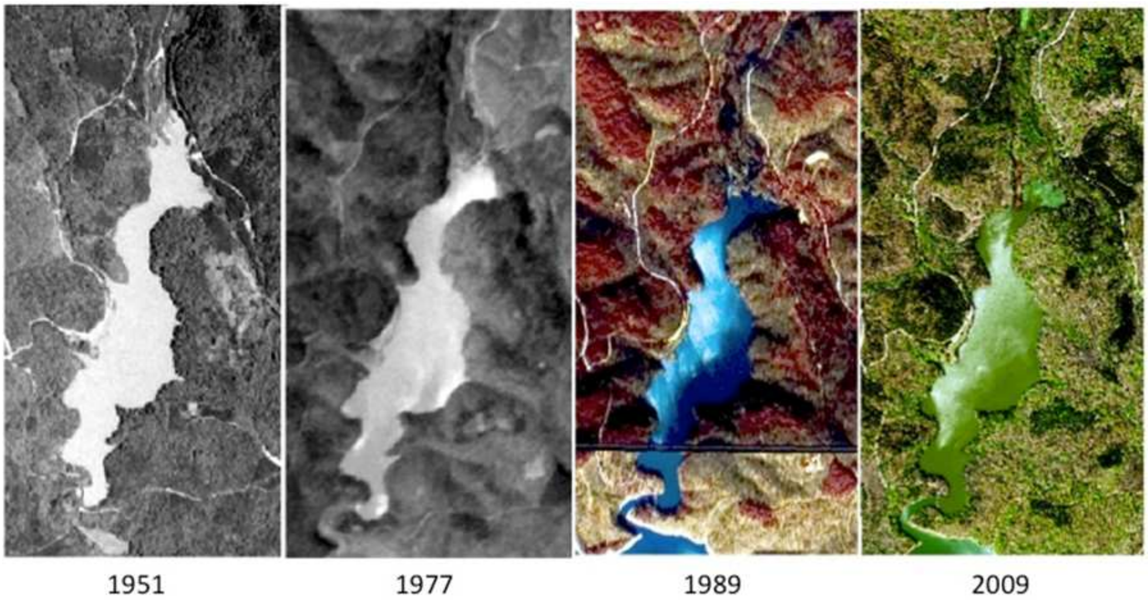
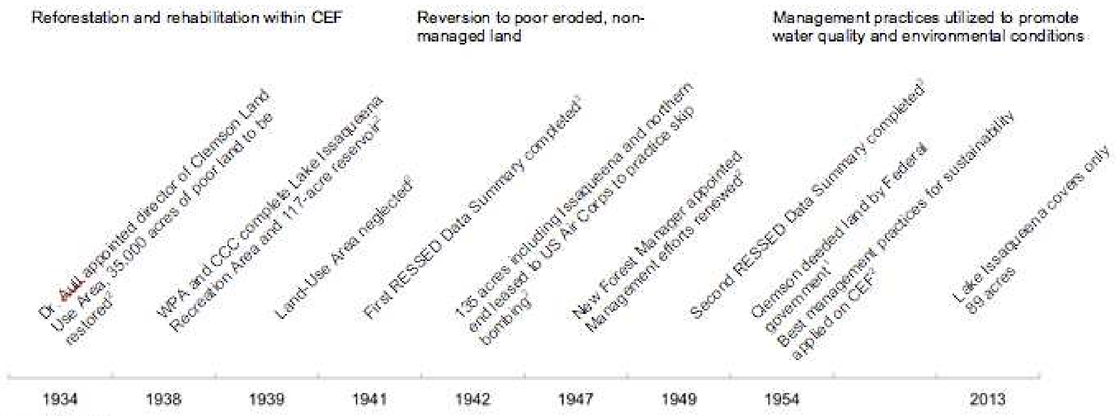


Figure 2.1. Aerial photographs (scale 1:3657.6 m) of the study site showing decrease in lake surface area (1951, surface area: 35.23 ha; 1977, surface area: 38.48 ha; 1989, surface area: 31.01 ha; and 2009, surface area: 32.61 ha)

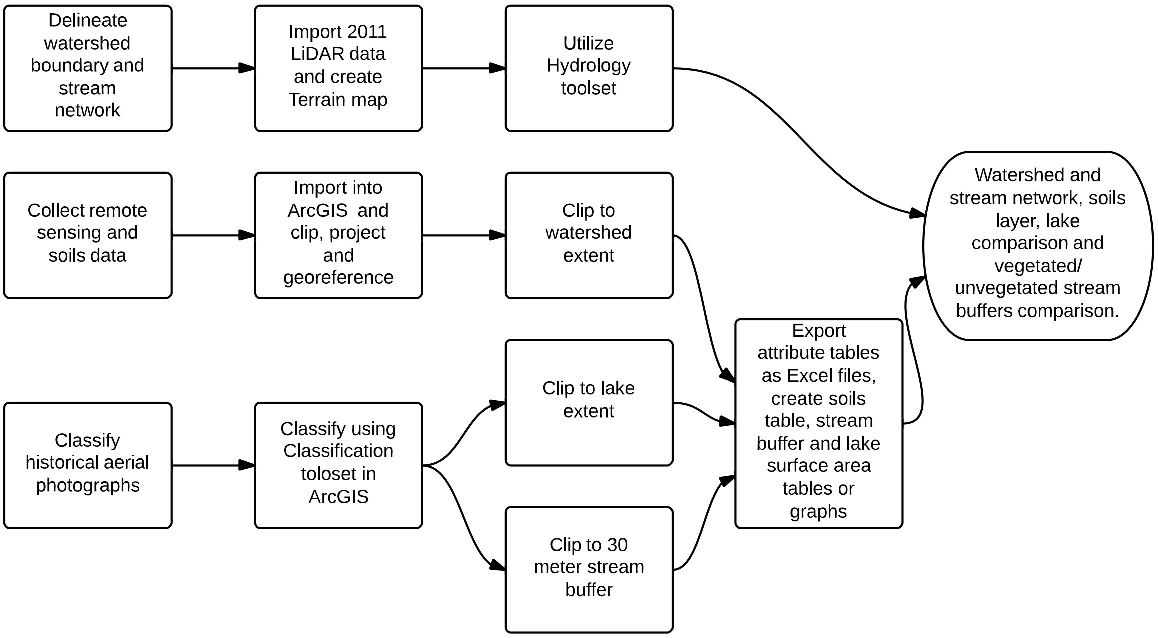


[1] Cox *et al.* 2013

[2] Dunn 1977

[3] "The Reservoir Sedimentation Database (RESSED)" 2013

Figure 2.2 Timeline of events and historical measurements of sedimentation in the Lake Issaqueena watershed.


Delineate watershed boundary and stream network
Import 2011 LiDAR data and create Terrain map
Utilize Hydrology toolset
Collect remote sensing and soils data
Import into ArcGIS and clip, project and georeference
Clip to watershed extent
Classify historical aerial photographs
Classify using Classification toloset in ArcGIS
Clip to lake extent
Clip to 30 meter stream buffer
Export attribute tables as Excel files, create soils table, stream buffer and lake surface area tables or graphs
Watershed and stream network, soils layer, lake comparison and vegetated/ unvegetated stream buffers comparison.

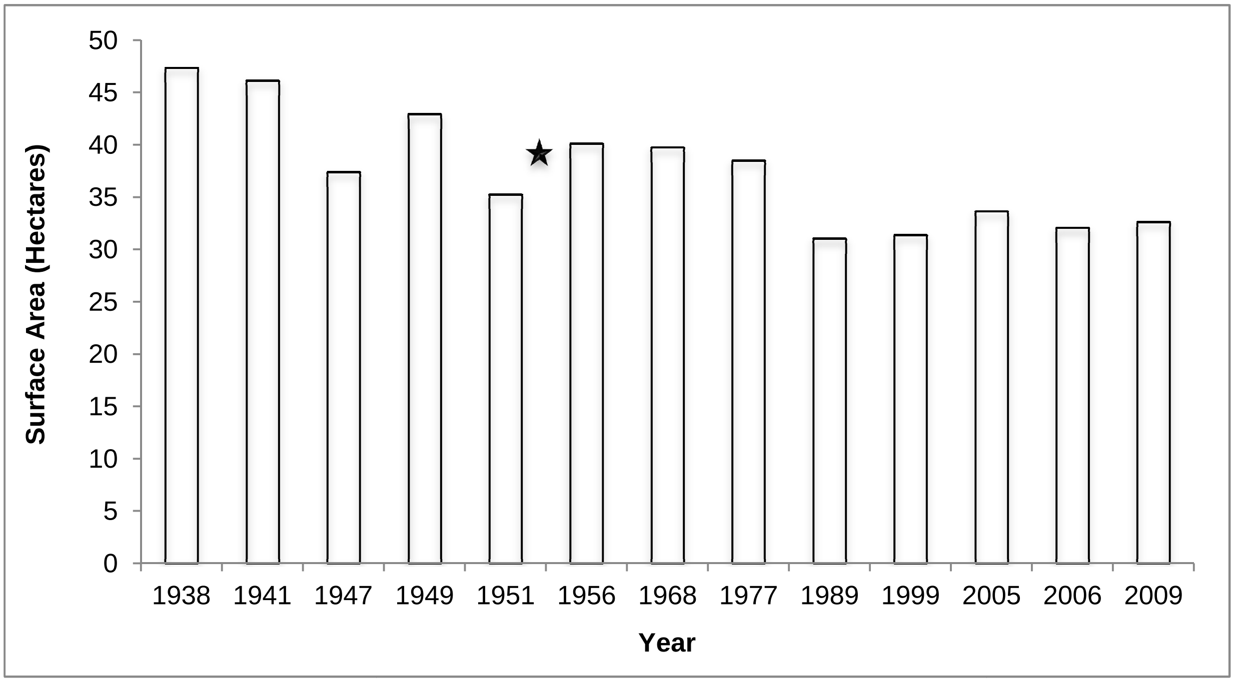


Figure 2.4 Lake surface area comparison in hectares, *Lake drained in 1954

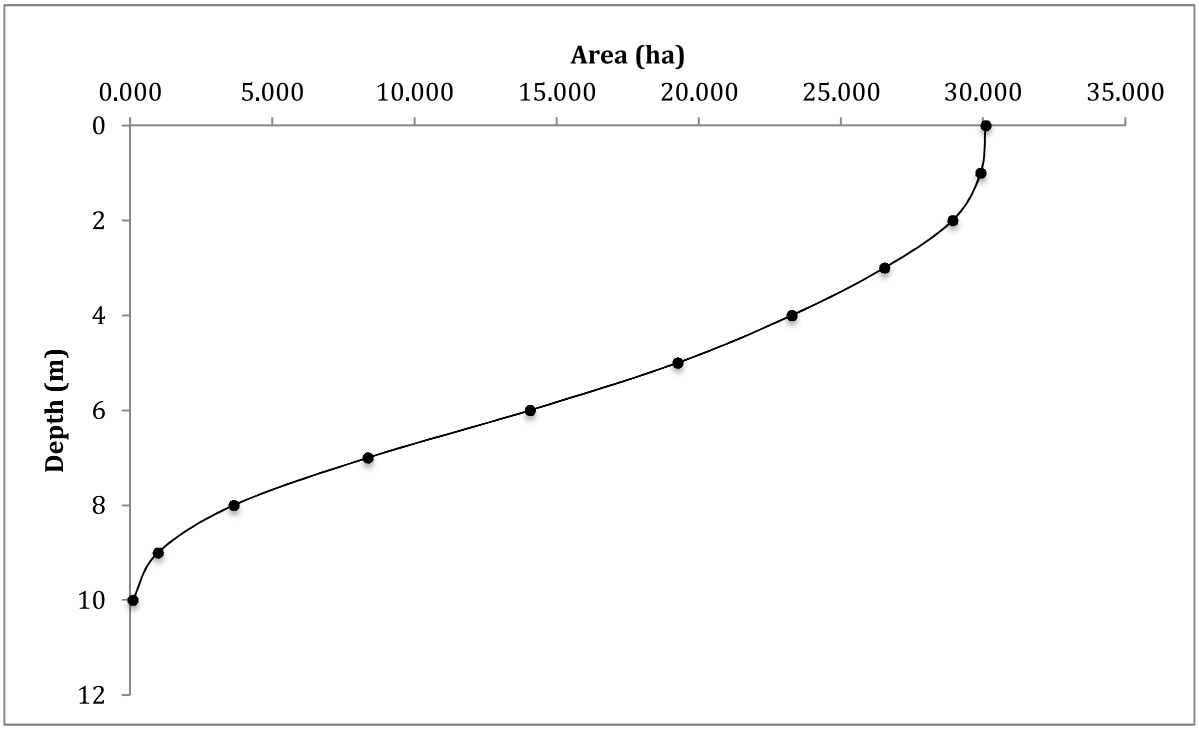


Figure 2.5 Hypsographic curve for Lake Issaqueena (2014)

Figure 2.6 Contour map for Lake Issaqueena in meter depth (2014)

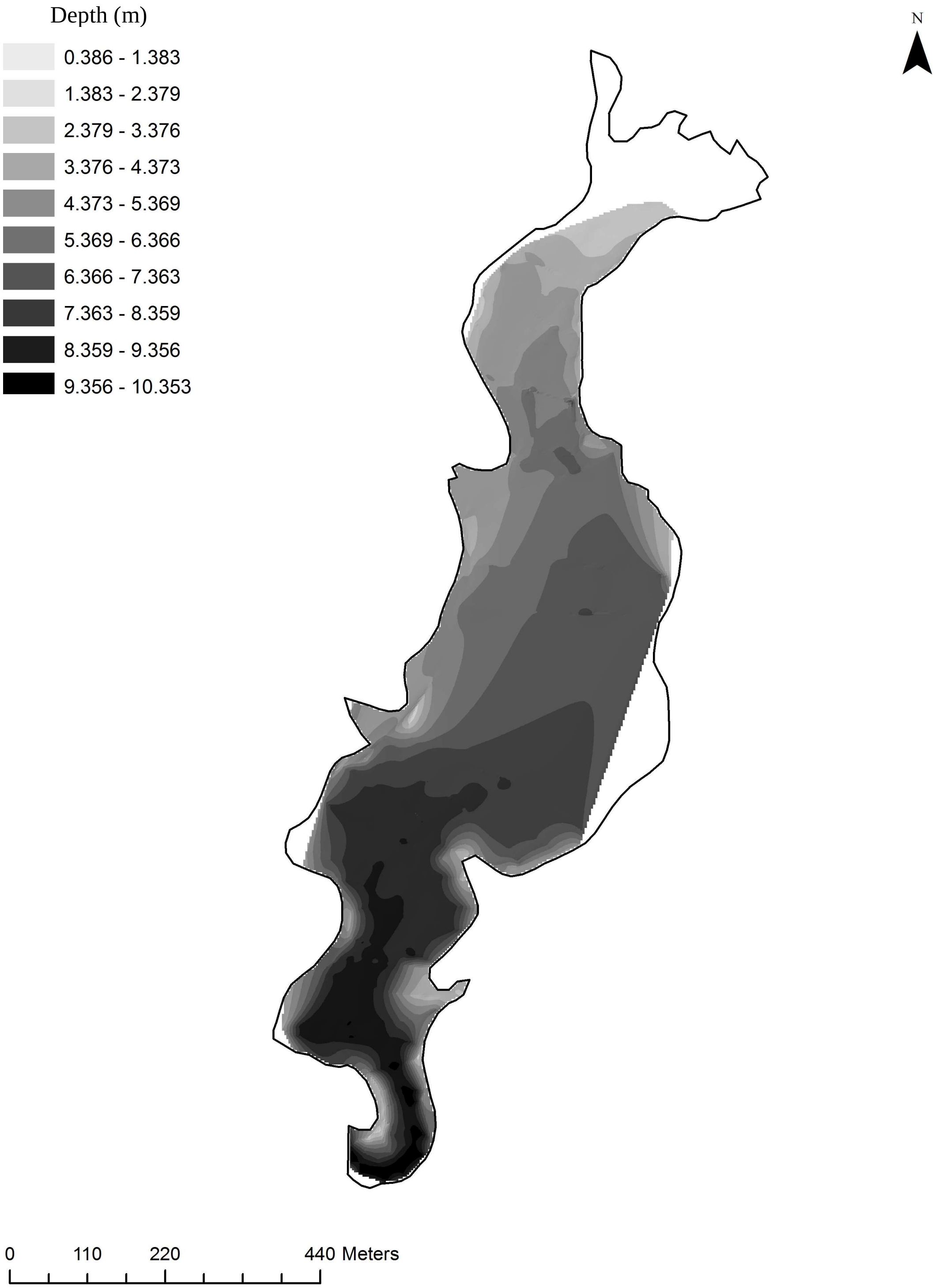


Figure 2.7 Bathymetric map for Lake Issaqueena (2014)

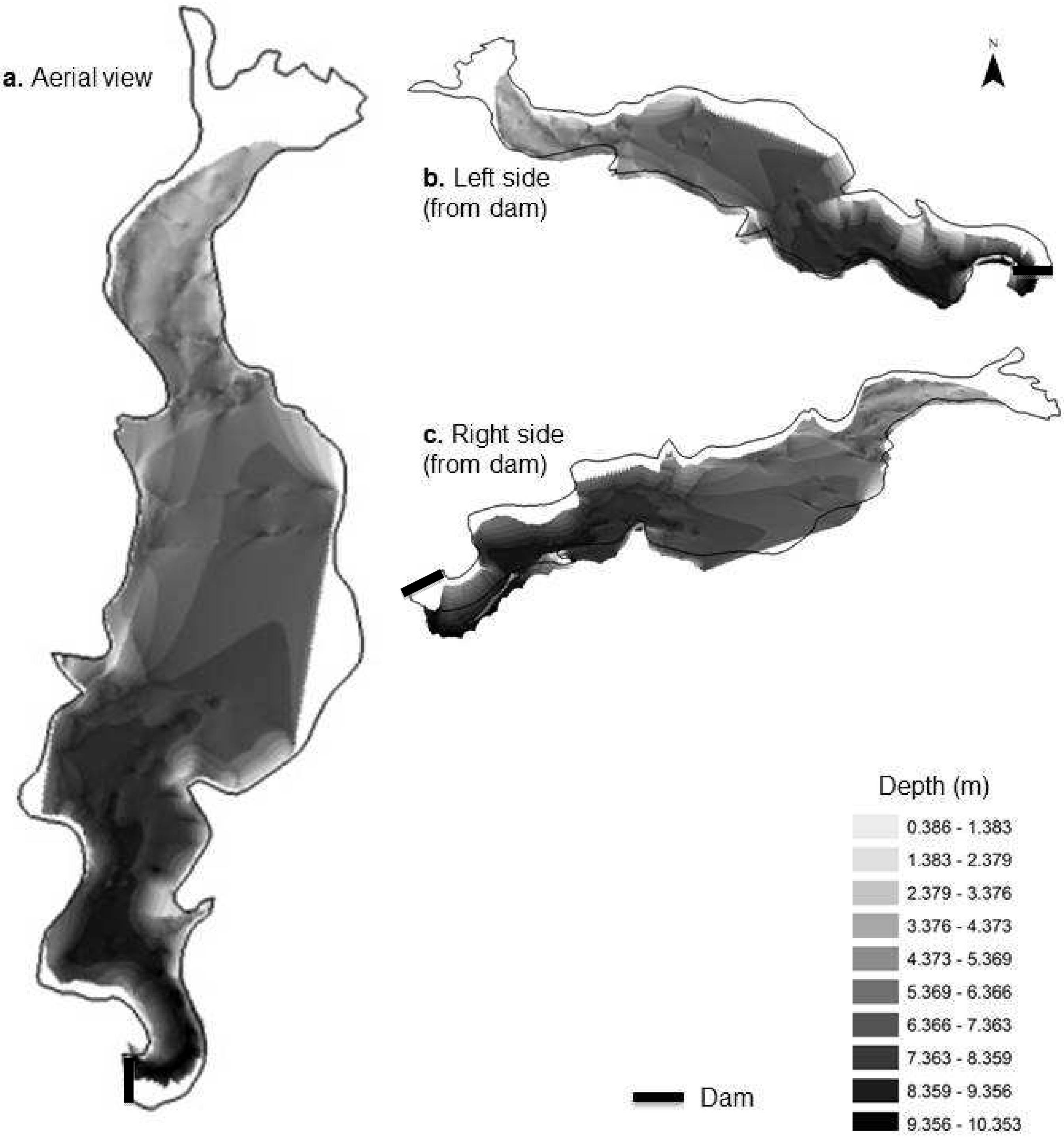


Figure 2.8 Three-dimensional view of lakebed for Lake Issaqueena **a.** Aerial view **b.** Left side view (from dam), **c.** Right side view (from dam)

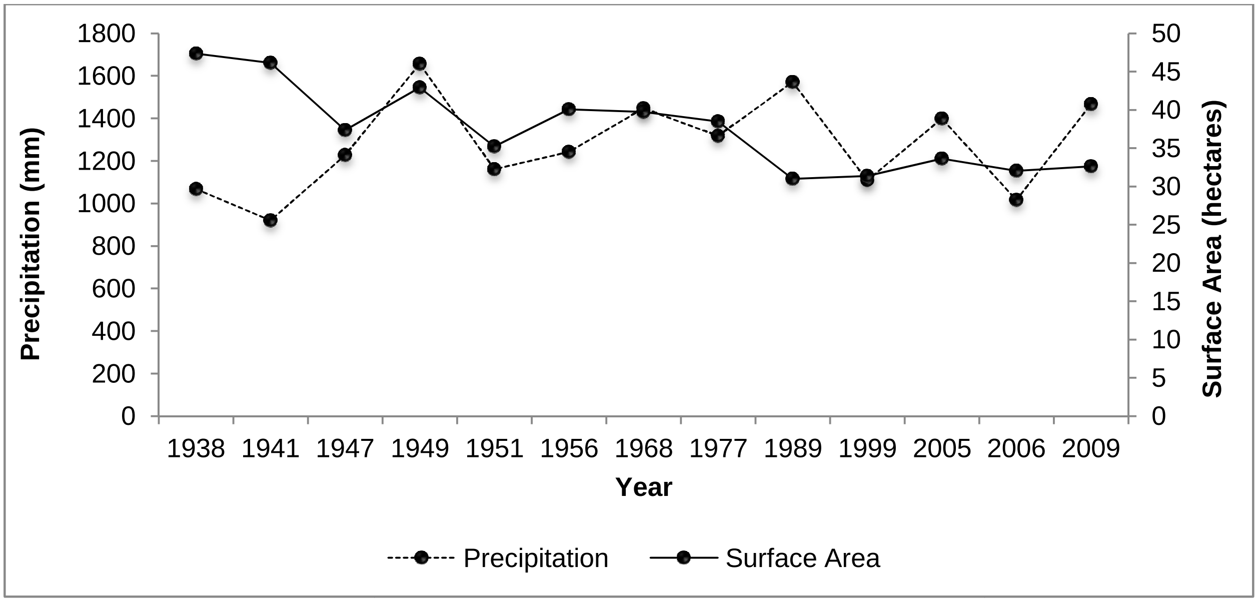


Figure 2.9 Lake surface area and precipitation comparison

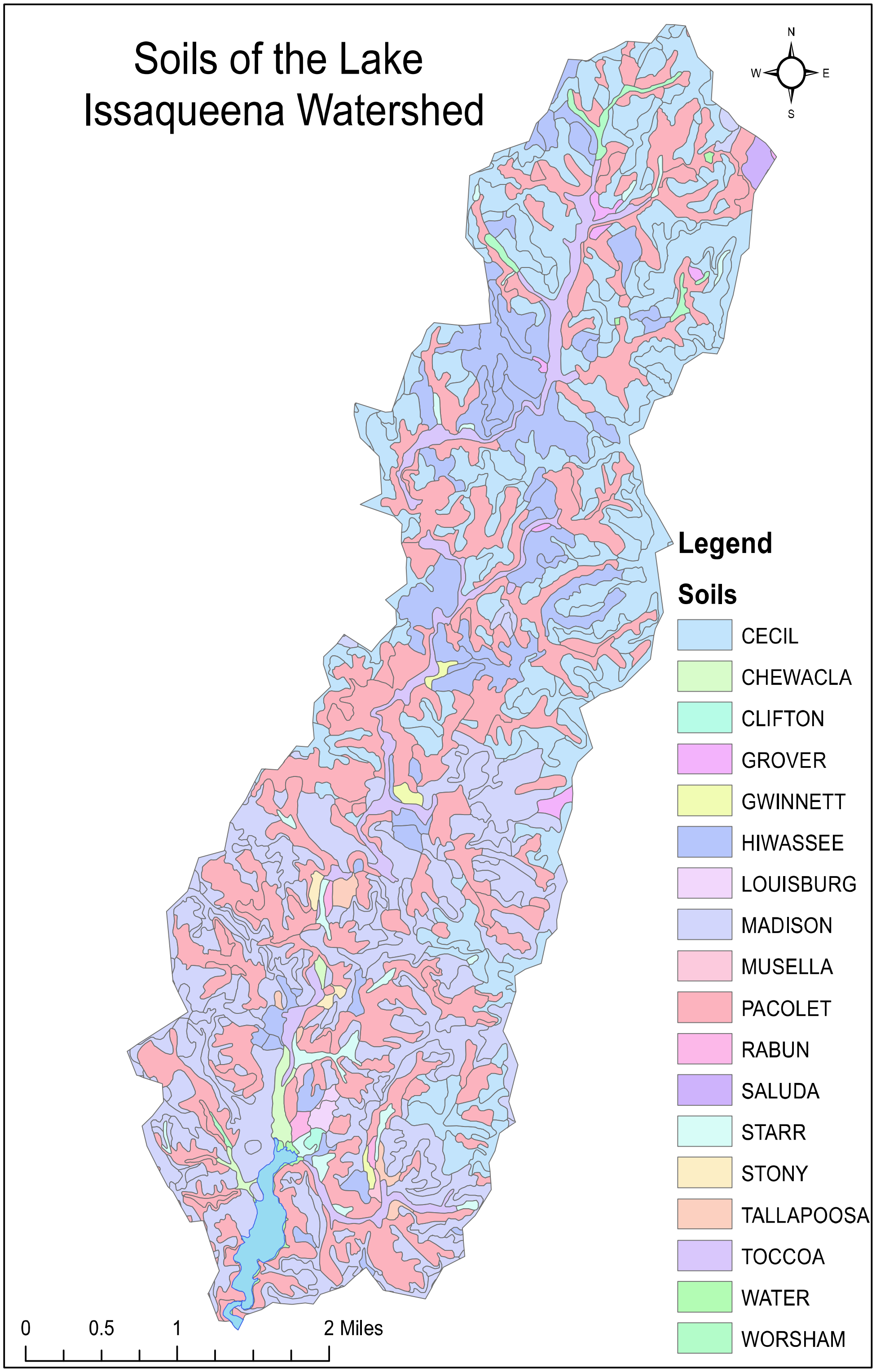


Figure 2.10 Soils of the Lake Issaqueena watershed.

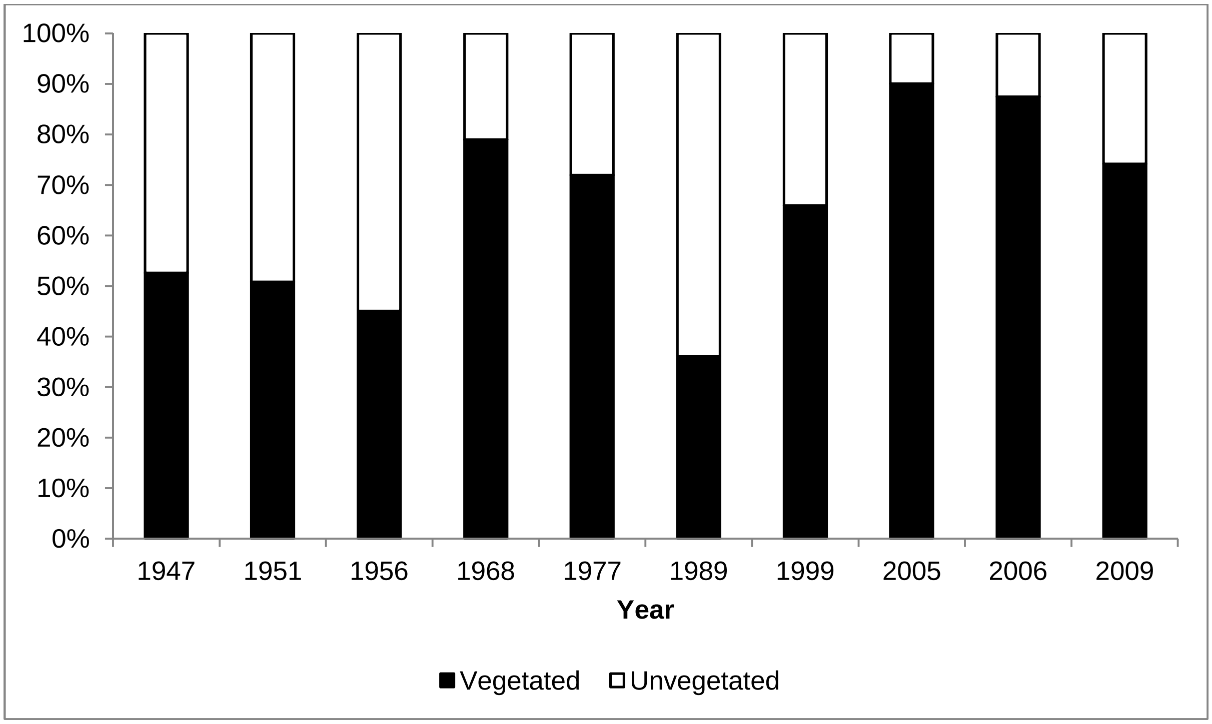


Figure 2.11**.** Vegetated versus unvegetated 30-meter riparian buffers

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