GIS ANALYSIS OF WATERSHED ECOLOGICAL FACTORS AND LAKE ECOLOGY IN NORTHERN NEW YORK

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Table of Contents

ABSTRACT

Ecological systems are regulated by the confluence of natural and human pressures. Although the influences of watershed-scale patterns on lake ecology have been studied extensively, few studies have focused on the lakes of northern New York, which drain into the ecologically and economically important St. Lawrence River. A GIS-based analysis was conducted on 10 lake watersheds in northern New York to investigate the influence of geology, soil composition, land use, and landscape composition on lake ecology and health. The metamorphic and igneous bedrock watersheds were characterized by low pH, specific conductivity, and dissolved oxygen, and high concentrations of chlorophyll a. The sedimentary bedrock watersheds were characterized by the exact opposite. Watersheds containing more impermeable surficial geology appeared to have slight influence on pH, DO, and specific conductivity. The influence of a soil composition appeared slight, with watersheds containing mostly high and medium rates of infiltration having low pH and DO, whereas slow infiltration rates linked to low Secchi depth and specific conductivity, but high chlorophyll a. There was a significant relationship between land use and water quality: watersheds with high forest cover exhibited lakes with better water quality whereas watersheds with human development exhibited worse water quality. In contrast, landscape composition disclosed no correlation to lake water quality, suggesting other factors are more influential. This study suggests that no single factor determines lake ecology and health; instead, water quality is determined through the complex interaction of multiple natural and human factors.

Key Words: lake ecology, watershed, landscape composition, water quality, GIS-based analysis, land use, bedrock geology, soil composition, anthropogenic activity, PC-ORD

1. INTRODUCTION

1.1 Overview

Human populations have expanded into many terrestrial ecosystems and aquatic ecosystems (Carpenter *et al*. 1998), altering the landscape (Gaston & Spicer 2004; Foley *et al*. 2005). Freshwater ecosystems, in particular, have felt a greater impact of these alterations because humans gene rally gather around or near lakes and rivers (Weijters *et al*. 2009). Widespread anthropogenic activities have caused strong negative effects on these aquatic ecosystems, such as biodiversity loss (Gaston & Spicer 2004), and decreasing water quality. Water quality is the encompassment of the biological, chemical and physical characteristics of water and measures the condition relative to health of ecosystems. Studies have concentrated on anthropogenic activities, such as land use and landscape composition, in order to evaluate the effects they have on water quality (Johnson *et al*. 1997; Wang & Yin 1997; Ahearn *et al*. 2005), but few have examined other natural factors of a watershed, such as bedrock geology, surficial geology, and soils (Sliva & Williams 2001; Gémesi *et al*. 2011). With the availability of high quality spatial data, Geographic Information Systems (GIS), and water ecology data, a more comprehensive approach is now possible to study the watershed-water quality relationship (Griffith 2002). The purpose of the present study was to analyze natural and anthropogenic factors of lake watersheds and compare corresponding water quality in order to better understand the relationships influencing lake health.

1.2 Importance of Watersheds

A watershed is a collective area draining to a single point. All terrestrial ecosystems are in a watershed, but no two are the same because numerous characteristics differentiate them. For instance, the size of the watershed helps determine the amount of water flowing in, whereas the shape will determine the intensity or degree in which the water flows. Water flow impacts erosion rates and watershed water quality. Further, soil type and land use determine how much water is absorbed, affecting the amount of water reaching the watershed lowlands. Water quality in larger watersheds is harder to predict due to the combined variability of size, shape, and other watershed characteristics.

Many characteristics of streams and rivers reflect the physical and biological processes of the watershed, allowing for the storing of past and present environmental conditions in lakes. The rate and quantity of water flowing over a landscape will determine the amount of nutrients, sediment, and pollutants collected and carried down the watershed. Species, including humans, would not survive without the ecological functions watersheds provide. Watersheds clean water and habitat for aquatic and terrestrial species, while indulging human recreational and extraction of resources. Despite gains in improving lake health over the past 30 years, most watersheds are vulnerable in one form or another.

1.3 Vulnerability of Watersheds

Humans congregate around bodies of water since water is essential for their survival. Congregation and urbanization around water bodies is increasing on a global scale (MA 2005), and the resulting anthropogenic activities on major aquatic ecosystems have drastically altered ecosystems' abilities to retain and discharge nutrients (He *et al*. 2011). As a result, eutrophication is becoming one of the world's foremost problems and is projected to only worsen (Huang *et al*. 2008; Deng 2011).

Alterations to river catchments are generally due to either deforestation, improvements on drainage in wet areas, soil amelioration measures, planting of crops, or introduction of domestic grazers (Weijters *et al*. 2009). These changes can lead to erosion, nutrient increases, and increased pollutant runoff (Bouwman *et al*. 2005). Such inputs have a damaging relationship with surface water quality (Smith 2009) and can lead to overall changes in the river system itself (Smith *et al*. 1999; Potter *et al*. 2004). Even previously uncontaminated lakes can undergo rapid and dramatic changes in lake ecology from direct or indirect human activities (Wang & Wang 2009; Smith 2009). With enough alteration, species composition shifts in the watershed, because of declining sensitive, native species and/or an increase in more tolerant, sometimes non-native species (Nijboer & Verdonschot 2004; Nijboer *et al*. 2004).

1.3.1 Water Quality

The overall biological, chemical, and physical properties, inclusively known as water quality, in lakes are shaped by natural and anthropogenic factors, with relative importance of each changing over temporal and spatial scales (Baker 2003). Watershed characteristics determine the watershed's ability to manage and control water quality. A watershed's location influences water quality through climatic factors, such as precipitation intensity and amount, since both determine the amount of water flow through the watershed. Places receiving higher intensity or greater amounts of precipitation are likely to experience lower water quality since more earth, sediment, and other unwanted materials are found in the water. In conjunction with precipitation, size and shape of the watershed direct the discharge rate, thereby affecting how long certain containments stay in the watershed. High discharge rates force unwanted sediment from staying in the lake, but cause higher levels of erosion and, therefore, higher sediment loads, which lead to lower water quality. Furthermore, the topography of the landscape can shape the degree of sediment influx within the watershed (Richards *et al*. 1996).

Many watershed characteristics, aside from the natural landscape, interact and help establish water quality. Natural factors affecting water quality include geology, soil, and vegetation covers. In landscapes with complex geology and topography, hydrology, geology, and land use are all factors influencing water chemistry (Close & Davies-Colley 1990), suggesting landscape form and composition are important in water chemistry regulation. Studies have linked poor land use practices with water quality, suggesting a strong relationship between increasing development and declining water quality (Carpenter *et al*. 1998). Humans influence most factors in one form or another. Investigation of these factors is useful when trying to understand how human activities have altered water quality.

Early studies concentrated on physical (Kuehne 1962, 1966; Harrel & Dorris 1968) and chemical characteristics (Hynes 1960) and elemental dynamics and pollutants (Bormann *et al*. 1969; Likens *et al*. 1970; Omernik 1976; Correll *et al*. 1977), but more recent studies integrated a suite of natural and human factors (Biggs *et al*. 1990; Johnson *et al*. 1997; King *et al*. 2005; Chang 2008). Water quality is not only important to humans for health standards, but has a larger overall importance on an ecological scale to vegetation (Bayley & Prather 2003; Mäkelä *et al*. 2004), fishes (Xenopoulos *et al*. 2005; Bilotta & Brazier 2008), zooplankton (Hoffmann & Dodson 2005), macrophytes (Sass *et al*. 2010), and food webs (Carpenter *et al*. 2005).

1.4 Ecological Factors

Character of lake watersheds reflects an integration of many physical, biological, and ecological processes occurring in the catchment. In addition to watershed location, size, shape, and topography, investigations of natural factors in watersheds have examined precipitation, river discharge, soil properties, vegetative cover, and surface geology (Müller *et al*. 1998; Morales-Baquero *et al*. 1999; Kopáček *et al*. 2000; Lee *et al*. 2009; Liu *et al*. 2010). Yet, despite their importance, these natural landscape variables are rarely included in watershed studies because of their difficulty in studying. The majority of studies examine human impacts, partially because of the relative ease of studying the impacts and partially because these studies suggest approaches to alleviating the problems, for example reducing the rate of deforestation or landscape transformation.

1.4.1 Bedrock Geology

Underlying entire watersheds is bedrock geology. After waters infiltrate past the surface, bedrock geology begins to interact and influence the groundwater, as water pick up ions stored in the bedrock geology for millions of years, some are harmful pollutants (Ortiz 2004). Rock porosity determines how much water is stored in the bedrock. Geological formations with higher porosity will have water stay longer in place, providing an opportunity for more pollutants or nutrients to gather. Although not found in the literature, porosity is a variable used in models for predicting water's ability uphold pollutants from the surrounding environment (Ambrose *et al*. 1993).

Bedrock geology and water quality are, at times, correlated. There exist, however, few studies examining what pathways link bedrock geology and water quality. Often they are removed from analysis (Ahearn *et al*. 2005) or considered only for drinking water analysis (Ortiz 2004). Almost all factors were understudied in how they influence water quality. This may be due to the breadth of known bedrock types.

Bedrock types are known to have poor abilities to buffer inputs of acidity (McNeil *et al*. 2008), which is problematic for the Adirondacks, because they have low pH levels (Driscoll *et al*. 2003). Geological spatial heterogeneity influences a watershed's ability to release or buffer against high pH (Chang 2008). In South Korea, bedrock geology in the North Han River, with high amounts of silicates, had low pH, whereas the South Han River geology comprised mostly of carbonates and experienced contrasting characteristics (Chang 2008; Ryu *et al*. 2007). Geologic composition can also control mineral and nutrient availability in aquatic systems (Sterner & Elser 2002). As a result, geologic composition and soil factors are major determinants of pH spatial variation.

1.4.2 Surficial Geology

Surficial geology has been understudied and no clear definition of surficial geology is evident, but is generally understood as deposits of geology near the surface or the earth and the parent material to soils (Richards & Host 1994). When water flows through the unconsolidated material, only reactions that can occur quickly can occur, such as cation exchange (Newton *et al*. 1987). In freshwater ecosystems, surficial geology controls the availability of certain nutrients (McNeil *et al*. 2008), with shallow geology types promoting systems to become more sensitive to acidic deposition (Driscoll *et al*. 2003). Within the riparian zones around the freshwater lakes and rivers, Tomer *et al*. (2009) linked surficial geology with land cover, especially forests landscapes.

1.4.3 Hydrologic Soil Groups

Soil type complexity led to the consolidation of four groups based on rainfall, runoff, and infiltrometer data measurements (Musgrave 1955). Group assignments are made on mainly comparisons and judgments, but are based on four factors: intake and transmission of water under conditions of maximum yearly wetness, soil not frozen, bare soil surface, and maximum swelling of expansive clays (USDA 2007). Simply put, hydrologic groups assign how permeable are the soils.

Group A soils are well-drained with high permeability and mostly excessively drained sands and gravelly sands. Moderately permeable and moderate to well-drained soils are grouped into B. Soils characterized by Group C are poor or moderately well-drained, but have slow permeability. They usually possess a layer that impedes the downward movement of water and are moderately fine texture or fine texture. Poorly drained soils, mostly clays or clay-like soils, with a high watertable are in Group D. Permeability of hydrologic soil groups influences how much water reaches the lower sections of the watershed (Newton *et al*. 1987). Types absorbing more water, because less water with reach lower sections, will lead to waters with higher concentrations of nutrients and watersheds with mostly impermeable soils will have diluted water given more water will progress down the watershed.

1.4.4 Landscape Composition

Most watershed analysis studies predicting water quality simply measure percentages of different features, ignoring other forms of measure (Gémesi *et al.* 2011), thereby limiting the ability to fully analyze the influences watershed factors have on water quality (Jordan *et al*. 1997; Gergel 2005). A more appropriate analysis would use an approach incorporating landscape composition, the actual make-up of the landscape (Uuemaa *et al*. 2005, 2007; Gémesi *et al*. 2011) and configuration, the spatial arrangement, of watershed elements in shaping water quality in aquatic ecosystems. Due to the difficulty in quantifying watershed configuration (Gustafson 1998), very few studies have attempted to do so (Bennett *et al*. 2004; Gémesi *et al*. 2011).

Key landscape composition factors include shape, topography, and size. Wide watersheds are usually characterized by slower moving water (Chang 2008), reducing the amount of erosion or sediment uptake by water. In comparison, a thinner watershed will have faster water flow, correlating to higher erosion and higher sediment loads.

A combination of steepness and length determine how quickly water will reach the output point. Water reaches the bottom the fastest if the landscape is steep and short. Steep landscapes continuing for long distances allow for greater rates of erosion and for a longer period of time, increasing the probability of water quality degradation. Studies have associated steeper topography with increases in nutrient concentrations (Richards *et al*. 1996; Sliva & Williams 2001), but Chang (2008) noticed steeper, forested slopes might absorb more nutrients. Steeper elevations should propel increased nutrient concentrations, because faster water erodes landscapes, picking up pollutants on impermeable surfaces, and does not allow for infiltration or percolation through the soils; however, these steeper slopes are often left undeveloped and have more vegetative cover (Brett *et al*. 2005). Therefore, steeper landscapes could better absorb nutrients than gentler slopes.

Larger sized watersheds will often have greater variety in the topography and landscape characteristics providing a different set of impacts within the watershed than a smaller one. In supplement to landscape composition, land use, or how the land is applied to a human construct (e.g., agriculture, residential, forest, etc.) influences water quality in watersheds (Johnson *et al*. 1997).

1.4.5 Land use and Land Cover

Concern over the impacts of environmental stressors on freshwater ecosystems is increasing, since acid precipitation, eutrophication, climatic warming, changing biodiversity, and pollutants are known to negatively affect these ecosystems (Lacoul *et al*. 2011). Humans influence most of these factors by land use or land cover change in the catchment area (Baker 2003). Removing vegetative cover of surrounding areas and damming of lakes increases the rate of inflow and decreases the rate of outflow, contributing to eutrophication by allowing for increased amounts of nutrients to enter the system and remain there. Many studies have shown the connection between agriculture and land use change to eutrophication and decreasing water quality (Arhonditsis & Brett 2005; Davis & Koop 2006; Chang 2008).

In locations with high inputs of nitrogen and phosphorus, surface water quality is degraded (Johnson *et al*. 1997); although, these non-point sources of pollution are often located spatially near the water bodies, as agriculture and urban centers are usually found near water sources and in the lowland areas, causes and outcomes can happen anywhere along the watershed. Changes or perturbations in upstream landscapes can negatively impact locations downstream (Soranno *et al*. 1996; Jordan *et al*. 1997; Goolsby & Battaglin 2001). Turner and Rabalais (1994) noticed high nutrient inputs and perturbations upstream caused hypoxia at coastal areas.

Land cover is the strongest predictor of water quality examined by past studies (Johnson *et al*. 1997; Sliva & Williams 2001; Carpenter *et al*. 2007). Major determents of degrading water quality are agriculture and urban development, altering stream channels, disrupting water flow rates, increasing sediment loads (Schultz *et al*. 1995), and constructing more impervious surfaces (Chang 2008). Supply rates of nutrients are linked to the land cover amount (Dillon & Kirchner 1975; Hill 1978; Mason *et al*. 1990; Correll *et al*. 1992; Jordan *et al*. 1997), implying decreases in human disturbed land would decrease inputs of nutrients (Jones *et al*. 2001).

Anthropogenic activities dump excess nutrients into freshwater ecosystems, causing wetlands, critical in maintaining healthy lakes by acting as sinks for these excess nutrients, to become overloaded (Verhoeven *et al*. 2006). Forests strongly contribute in minimizing the effects of local climate conditions while also promoting biodiversity protection (Carnaval *et al*. 2009), reducing soil erosion, transpiring large amounts of water vapor, contributing to cloud cover, mitigating different forms of pollution, and maintaining many assemblages of flora and fauna (Southwick 1996). Forested landscapes are primary in maintaining lower nutrient levels and ameliorating water quality (Hunsaker & Levine 1995). Certain levels of nutrients are needed and replenishing of those nutrients is essential. Grasslands are a nitrate source (Holloway and Dahlgren 2001) and help with nutrient cycling by mineralizing and storing nitrogen in soils during summer and fall months (Hart *et al*. 1993). Humans shape the landscapes they inhabit and land use/land cover data reflect these impacts (Johnson *et al*. 1997).

1.5 Importance of GIS-Based Analysis

In the past, most water quality studies examined factors at a small-scale, typically around the general vicinity of the water bodies (Garbecht 1991), because it was difficult to establish a relationship among variables due to lack of data (Wang & Yin 1997). Accurately describing a landscape composition and configuration for geology, structure, and biology for a large area takes more people and time than most agencies or authorities have the ability for. Smaller-scale projects were more accurate and less costly to undertake. Development of remote sensing and Geographic Information Systems technologies, however, help assess water quality in larger areas, such as on a watershed-scale, than were previously possible (Johnson & Gage 1997), and development of supercomputers is only increasing this capability (Griffith 2002). Remote sensing and GIS have become more readily available for investigators (Chang 2008), offering an exciting, inexpensive alternative to the costly ground-based monitoring, especially for large geographic scales (O'Neill *et al*. 1997), and studies have implemented many of these applications of GIS (inspect Johnson & Gage 1997; Johnson *et al*. 1997; Sliva & Williams 2001; Griffith 2002; Chang 2008).

Remote sensing and GIS in watershed analysis were practically non-existent, but are now instrumented in almost every study. They allow for a better analysis because they can look at multi-spatial scales, such as entire catchment or buffer/riparian zones, and are ideally suited to identify and analyze processes encompassing the full range of spatial scales. GIS assists hydrologists, in multifactorial cases, determine relationships among land use, geology, soils, and any other variables they need. For landscape ecology, composition and configuration are easily spatial shown and calculated using GIS methods, giving geographers and hydrologists unprecedented capacity to quantify land cover patterns and understand heterogeneity and landscape structure. GIS is able to handle the large and complex datasets, which are quickly becoming popular in watershed management (see Sliva & Williams 2001), with ease.

Effectiveness of a GIS analysis, however, is dependent on the quality and quantity of data collected in the field. Watershed analysis implementing only GIS techniques to analyze watershed relationships can cause misleading results. Ground-truthing is supplemented with GIS to reinforce the accuracy of data, when data are gathered through aerial photography, as most land use/land cover and other GIS data are (Griffith 2002). Ground-truthing provides more detailed and specific information about study sites, which is important when studying riparian zones. In these zones, knowing species of vegetation is more important than type, which is tough with remote sensing if it is not high end, as most of the time only the plant type (deciduous, evergreen, etc.) are known. Resolution of data matters for discerning patters (Griffiths 2002), especially if looking at buffers. If the resolution of data is 100m, then all buffers calculated shorter than that distance will appear the same. Griffith (2002) suggests small watersheds should have a resolution of at least 30m.

1.6 Present Study

Substantial work in other areas has connected lake ecology to watershed traits, but similar perspectives and tools to key lakes of northern New York, which drain into and possibly influence the important St. Lawrence River, have yet been utilized. The few studies on land use and water quality in New York have examined only rivers (Haith 1976; Tran *et al*. 2010) and for human quality levels (Tran *et al*. 2010). The purpose of the present study was to determine the relationships among natural and anthropocentric characteristics in entire watersheds and lake water quality values to garner a better understanding how these characteristics work as a collective in northern New York. By implementing a GIS-based analysis on lake watersheds for 10 lakes in northern New York (Black Lake, Lake Bonaparte, Carry Falls, Cranberry Lake, Higley Flow, Massawepie Lake, Norwood Lake, Sylvia Lake, Trout Lake, and Tupper Lake) and their corresponding ecological and anthropogenic factors (bedrock geology, surficial geology, soil, landscape composition, land use/land cover), this study attempts to validate how these factors influence the lake ecology and health (Figure 1). Despite the vast literature on lake ecology and watershed traits, land use and landscape composition have dominated the studies, but this study provides one of the first studies looking at a combination of natural and anthropogenic factors.

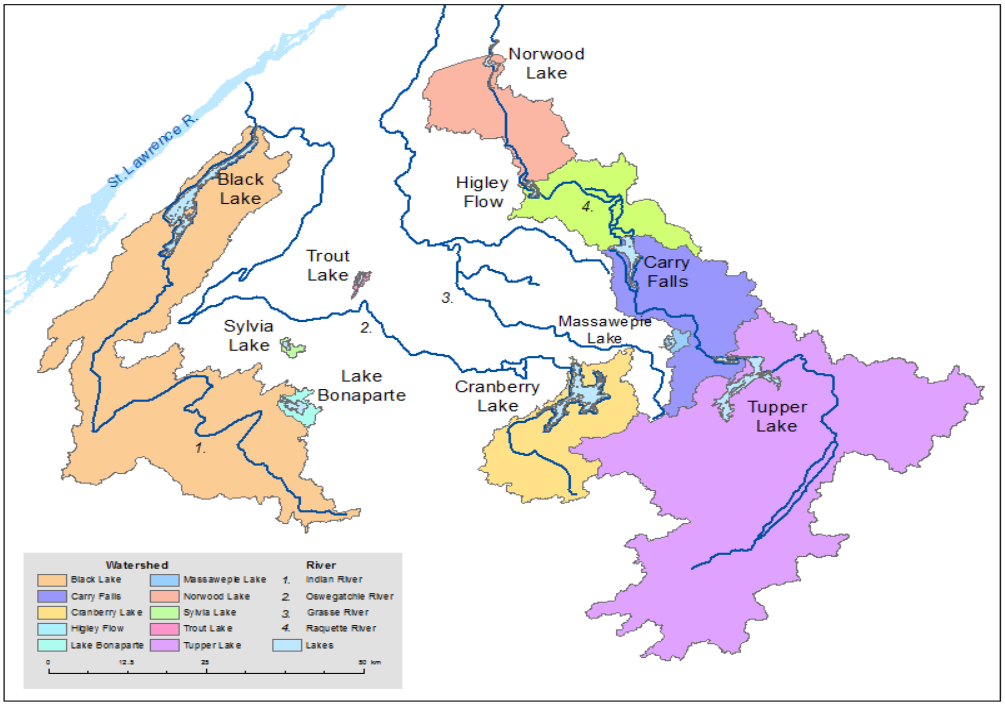

Figure 1: Lakes and their corresponding watersheds with river systems at study sites in northern New York.

2. METHODS

2.1 Study Area

The St. Lawrence River, situated between Canada and New York State, is a corridor from the Great Lakes to the North Atlantic and drains nearly 776,996 square kilometers (NYSDEC 2009). A 14,500 square kilometer region of the northern and western Adirondacks, as well as the St. Lawrence Valley, relies on the water draining to the St. Lawrence River to maintain ecological processes (NYSDEC 2009). Overall land use of this portion of the St. Lawrence River watershed is split mostly between the agricultural northern and western area covering the lowlands and the forested woodlands of the Adirondack Park. Agriculture, logging, mining, and recreation/tourism are the predominant economic activities in the region (NYSDEC 2009).

The Adirondack Park is 24,280 km^2, encompassing both public and private lands located across 11 counties in northeastern New York (43°00'–44°55'N, 73°15'–75°20'W). The area was designated for conservation in 1892 to protect it from the uncontrolled forest clearing that was common during the 1800s and protect water quality from degrading further. Currently, there are about 130,000 permanent residents living in the park, owning just above 50% of the land. The mean elevation is 460 meters (Figure 2). Land cover is mostly forest, with 47% deciduous forest, 20% coniferous forest, 10% mixed, and the rest either open water or wetlands (Yu *et al*. 2013). Land set aside for resource management covers the most space (25.90%), followed by wild forest (22.08%), wilderness (19.43%), and rural use (17.23%). Industrial use, moderate-, and high intensity develop all together only cover approximately 7% land cover. Most of the private land is devoted to forestry, agriculture or open space. Bedrock geology varies slightly across the park, but most in the form of sedimentary rocks. Over 3,000 lakes and 48,280 kilometers of streams/rivers are found in the park. The Adirondack Region, because of its bedrock geology and shallow soils, is prone to low available nutrients and lakes with high acidic deposition risks (Driscoll *et al*. 2003).

Despite being one of the largest watersheds in the state, the St. Lawrence Valley Basin ranks eleventh in population with 194,869 people in 2000 (NYSDEC 2009). Only a small portion of the population lives in the urban or residential setting, with almost 60% living in a rural setting (NYSDEC 2009). Massena is the largest urban center (11,931 citizens) and has the main industrial complex of the region. Other large urban centers are Gouverneur, Canton, Ogdensburg, Malone, and Potsdam. Sedimentary rocks and more agriculture and developed land use characterize the St. Lawrence River lowlands (Figure 3).

2.1.1 Study Rivers

Major tributary watersheds linking to the St. Lawrence River within northern New York, accounting for 13,573 river/stream kilometers, are the Oswegatchie River (5,777 km), Raquette River (3,244 km), St. Regis River (2790 km), Grasse River (2586 km), and Indian River (1,966 km—included within the Oswegatchie drainage) (NYSDEC 2009). The Oswegatchie and Indian Rivers unite at the outflow point of Black Lake. Although most rivers draining from the Adirondacks and St. Lawrence River lowlands are not heavily populated or industrialized (Thorp *et al*. 2005), the distribution is unequal, with more people living on or around the Indian River or the Raquette River. Population centers affecting lake watersheds on the Indian River are Natural Bridge, Antwerp, Philadelphia, and Theresa. Cranberry Lake is the only major populated town on the Oswegatchie River, while the Grasse River has none impacting study lakes. Six significant towns along the Raquette River are Long Lake, Tupper Lake, South Colton, Colton, Hannawa Falls, and Potsdam. Unlike the other river systems, the Raquette River is dammed at several points. Due to the human presence many of these rivers have become impacted, but since the Clean Water Act of 1972, Bode *et al*. (2004) have estimated almost 85% of rivers have returned to their natural states. Despite the improvements, recent assessments of the Oswegatchie, Grasse River, and Raquette Rivers suggest they are continually impacted (Bode *et al*. 2004).

2.1.2 Study Lakes

Lakes of northern New York vary drastically in size and landscape, but support a diverse set of flora and fauna while also providing for human uses. Many of the lakes are remote and left undisturbed, suggesting they are healthy. Their remoteness also makes them harder to study, which is evident, as 68% of lakes, ponds, and reservoirs in northern New York have not been assessed for water quality (NYSDEC 2009). This is more worrisome, as the United States Environmental Protection Agency found over 60% of sampled lakes in New England showed one or more types of environmental stress

(Whittier *et al*. 2002). Though the Adirondacks are more prone to lake acidification, eutrophication is more problematic for St. Lawrence River lowland lakes with high levels of agriculture and high development near the shoreline (Whittier *et al*. 2002). Lakes differ from streams and rivers since surface water is held for years, sometimes decades, allowing for modification before exiting and proceeding downstream, carrying any nutrients or pollutants it may have gathered. Lakes often concentrate human use, only adding to the lake water quality degradation.

Study lakes were found along four main tributaries (Figure 1). Black Lake (44°30’N, 75°36’W) is a reservoir at the end of the Indian River, whereas Lake Bonaparte (44°09’N, 75°23’W) courses into the river. Black Lake is 83 meters above sea level and is 58 square kilometers in size, whereas Lake Bonaparte sits at an elevation of 234m and is only 5.6 km^2. Land use for Black Lake is about half forest, but it has the most agriculture, development, and shrub/grassland of all the lakes. Lake Bonaparte’s land cover is mostly forest, water, and wetlands.

Cranberry Lake (44°10’N, 74°49’W) is the only lake influenced by the Oswegatchie River, as Sylvia Lake (44°15’N, 75°24’W) discharges down into the river. At 452 meters, the 27.5 km^2 meter Cranberry Lake is covered predominately by forest but has slight urban development at the north end. Sylvia Lake is significantly smaller at only 1.3 km^2. Massawepie Lake (44°15’N, 74°38’W) and Trout Lake (44°21’N, 75°16’W) discharge into the Grasse River. Massawepie Lake, at 460 meters, is only surrounded by forest and wetlands due to its remoteness and small size (1.7 km^2), similarly to Trout Lake (1.4 km^2).

The last four lakes are on the Raquette River. Tupper Lake (44°11’N, 74°30’W) is the closest to the head source and is 470m above sea level. Tupper Lake, comprised of Tupper Lake, Simon Pond, and Raquette Pond, is the third largest lake in the study area at 26.4 km^2. Near the outlet of the lake resides the town of Tupper Lake. Farther down the river, Carry Falls Reservoir (44°24’N, 74°44’W) is at a slightly lower elevation (422m) and lesser size (12 km^2), but has practically the same land use coverage as Tupper Lake. Higley Flow (44°31’N, 74°55’W) and Norwood Lake (44°43’N, 75°00’W) are approximately the same size, 2.4 and 3.1 km^2 respectively, but Norwood is at a lower elevation (100m compared to 270m) and has a more urban presence due to Potsdam and

Norwood. All were created as part of damming projects. Tupper Lake, Carry Falls, Cranberry Lake, and Massawepie Lake are located in the Adirondack Park. All others are positioned in the St. Lawrence River valley.

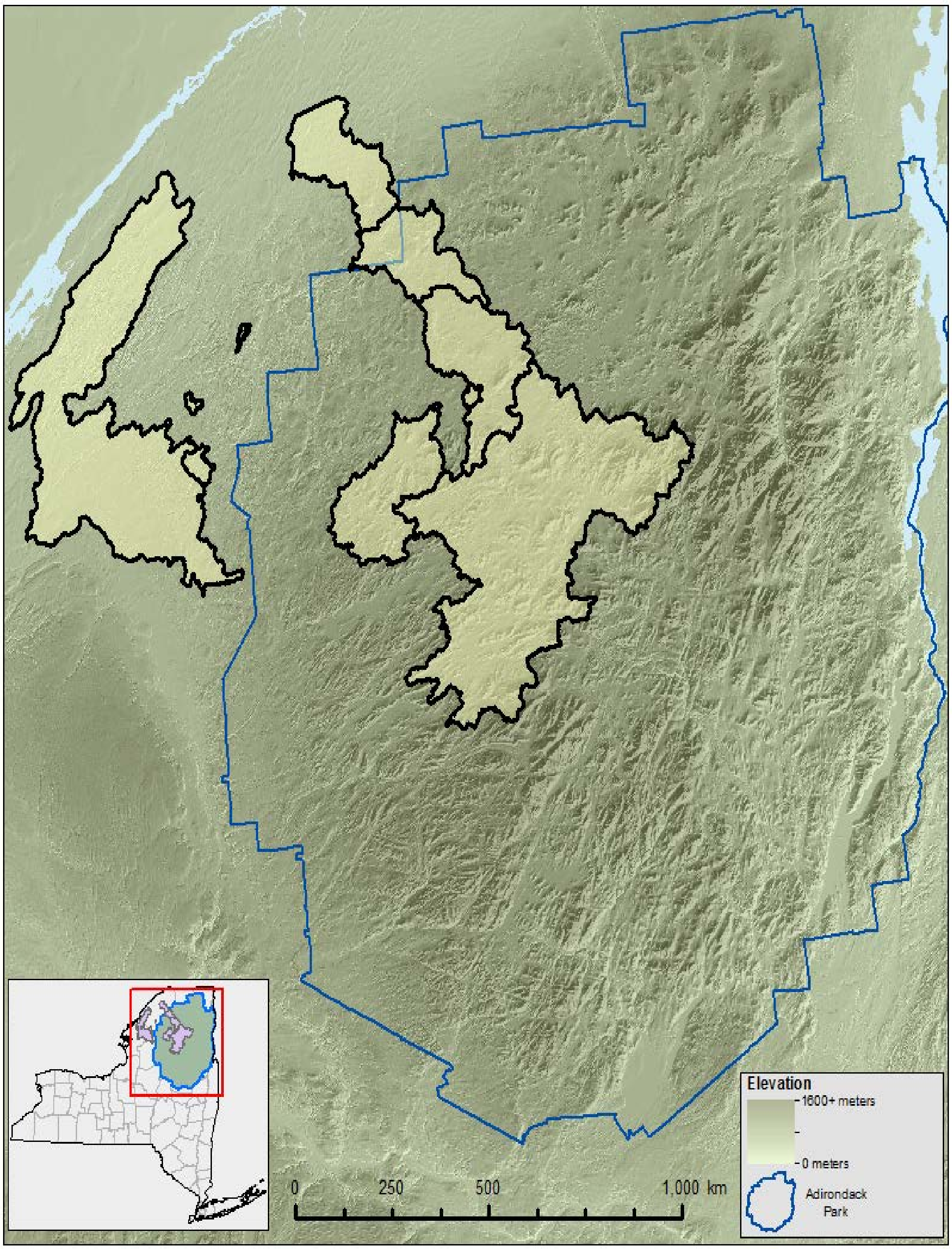

Figure 2: Elevation of study area and relative spatial positioning to New York state.

2.1.3 Watershed Characteristics and Water Quality

For each watershed, the characteristics of each variable were located and extracted. A principal components analysis was the main form of multivariate regression statistical analysis run to determine relationships among variables, lake watersheds, and lake water quality and is explained in more detail below. However, variables were examined simple prelimanary correlations analysis for their dependency and were deemed dependent when correlations had $r > 0.850$. In the case of bedrock geology, nine characteristics were extracted: anorthosite, orthogneiss, syenite, y sedimentary rocks, younger y granitic rocks, Cambrian, Lower Ordovician (Canadian), Middle Ordovician (Mohawkian), and paragneiss and schist. After results from the correlations analysis, anorthosite was grouped with paragneiss and schist, while Cambrian, Lower Ordovician, and Middle Ordovician parameters were grouped together. After correlations and renaming, six groups were left for the multivariate regression analysis: anorthosite and paragneiss/schist, orthogneiss, syenite, sedimentary, granitic, and Cambrian and Lower Ordovician/Middle Ordovician. Bedrock values were reported and analyzed as percentages of total area.

Eighteen different types of surficial geology were found among the ten watersheds: alluvial inwash, bedrock, inwash, kame deposits, kame moraine, lacustrine beach, lacustrine delta, lacustrine sand, lacustrine silt and clay, marine beach, outwash sand and gravel, recent alluvium, subaqueous fan, swamp deposits, till, till moraine, undifferentiated marine and lacustrine silt and clay, and water. Parameters with similar characteristics were combined, resulting the following groupings: alluvial inwash with inwash and recent alluvium; kame deposits with kame moraine and outwash sand and gravel; lacustrine beach with lacustrine delta, lacustrine sand, and marine beach; lacustrine silt and clay with undifferentiated marine and lacustrine silt and clay; subaqueous fan with swamp deposits; and till was merged with till moraine. After a simple correlation analyses, the alluvial group was incorporated with the till group and bedrock. This left six parameters for the multivariate regression analysis: alluvial-bedrock-till, kame, lacustrine sand and gravel, silt-clay, subaqueous material, and water. Surficial geology values were reported and analyzed as percentages of total catchment area.

Due to the vast number of soil types, the hydrologic groups were analyzed for each catchment. Therefore, all the soil types were grouped into one of eight classes: Other, A, A/D, B, B/D, C, C/D, or D. Statistical correlations allowed for the collapses of A and A/D, B and B/D, and C and C/D groups. Thus, five groups remained for analysis: A, B, C, D, and Other. Soil data were notated and analyzed as percentage of total catchment.

Lake size, watershed size, elevation, deepest collection depth, human density in catchment, and human density within 100m of lake were used to quantify several aspects of landscape composition. Lake temperature was added as a landscape composition parameter for the final analysis. The former four parameters and temperature were used to investigate how natural landscape composition impact water quality, while the latter two investigated how human landscape composition impacts water quality.

Land use and land cover reflect natural and developed landscapes in the study area. For these study lakes, 15 major land use/land cover types were extracted: water, developed open space, developed low intensity, developed medium intensity, developed high intensity, barren land (rock/sand/clay), deciduous forest, evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, pasture/hay, cultivated crops, woody wetlands, emergent wetlands. Due to similarity, three aggregate groups were formed. All developed areas formed developed, aggregate; pasture/hay and cultivated crops were aggregated into agriculture; and woody wetlands and emergent wetlands were renamed wetlands. Following preliminary analysis, the shrub/scrub and grasslands/herbaceous were combined as one group. This left 9 land use/land cover classes for analysis: water; developed, aggregate; barren land; deciduous forest; evergreen forest; mixed forest; shrub/scrub/grasslands/herbaceous; agriculture, aggregate; and wetlands. Land use/land cover types were reported and analyzed as percentages of total catchment.

These watershed variables were compared to water quality characteristics from each lake: lake temperature (Celsius), dissolved oxygen percentage, chlorophyll a (μg/L), Secchi depth (meters), pH, and specific conductivity (μS/cm). Depth differences among recordings were ignored, as were seasonal differences, except when stated otherwise. For lake temperature and dissolved oxygen, seasonal slope and intercepts were determined after linear regressions were calculated. Linear regressions compared lake water quality changes over season and determine if there were any differences (Sliva & Williams 2001). Slopes, after preliminary analyses, were deemed correlated together and were averaged together for final analysis, but intercept values remained separate. Except for chlorophyll a, the remaining variables were not found to show any difference between seasons and were averaged for the final analysis. Chlorophyll a levels were averaged only for spring and summer (Sliva & Williams 2001). With lake temperature added to the landscape composition, 8 parameters were run in the PCA: dissolved oxygen slope average, spring dissolved oxygen, summer dissolved oxygen, spring chlorophyll a, summer chlorophyll a, Secchi depth average, pH average, and specific conductivity average.

2.2 Data Sources

All lake water quality data were collected and provided by Brad Baldwin. The characteristics were measured for the 10 lakes during the spring, summer, and fall during 2011 and 2012. A Hydrolab DataSonde 4a was used to measure lake temperature, dissolved oxygen, pH, and specific conductance at different depths to generate a vertical profile of the lake. Measurements of light penetration and water clarity of the lakes were conducted using a Secchi disc.

Multiple sources were accessed to ascertain all required GIS data to determine the descriptive and functional metrics' influence on lake ecology. Land cover data were obtained from the United States Geological Survey's National Land Cover Database. National Land Cover Database 2001 (NLCD2001) is a 16-class land cover scheme universal for the United States at a spatial resolution of 30 meters (available for download: http://www.mrlc.gov/nlcd2001.php). NLCD2001 Version 2.0 implements an improved classification algorithm to NLCD1992, allowing for a more precise rendering of spatial boundaries and land cover classes, and comprised of three elements: land cover, percent developed impervious surface, and percent tree canopy density (Homer *et al* 2007). The impervious surface and percent tree canopy density were not used in the analysis, and only 15 of the 16 land cover classes were present in northern New York. The classification system for NLCD2001 data is an updated version of the classification system designed by Anderson *et al*. (1976).

National Land Cover Database 2006 (NLCD2006) was not used because it would not project correctly to allow for proper analysis. NLCD2006 does improve many of the problems in NLCD2001 land cover and percent-developed imperviousness products (Fry *et al* 2006), but these changes were also reissued in NLCD2001 Version 2.0. Moreover, most of the issues dealt with coastal areas because it was before the completion of the National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP) 2001 land cover products. Although, northern New York has no coastal areas, NLCD2001 Version 2.0 does provide integrated land cover for all coastal zones (Fry *et al*. 2006).

Most lake watersheds existed in a spatial layer provided by St. Lawrence University, downloaded the layer from NYS GIS Clearinghouse (http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1099). The United States Geologic Survey previously delineated watersheds as part of the National Hydrography Dataset. Naturally occurring and constructed bodies of water, paths water flows, and watersheds are displayed as a 1:24000 high-resolution map. In order to determine individual lake watersheds, lakes were overlaid on the subwatershed layer, allowing for the determination of which features within the layer would correspond to each particular lake. Selected features were then exported as their own shapefile. These steps were completed for each lake.

Three lakes needed their watersheds delineated, as they were only small sections of the obtained watershed layer. In this event, a 10m spatial resolution digital elevation models (DEMs) for northern New York was obtained from Lawrence's GIS drive, originally downloaded from the USGS National Map Viewer (http://viewer.nationalmap.gov/viewer/). Numerous methods exist for collecting data for DEMs, but the most common are aerial photography, airborne digital imagery, and LIDAR (Light Detection and Ranging) and RADAR (Radio Detection and Ranging) (Griffith 2000). The National Elevation Dataset, to produce this seamless raster product, was derived from LIDAR, interferometric synthetic aperture radar (IFSAR), and high-resolution imagery sources (http://ned.usgs.gov/). NED data are available at 1, 1/3, and 1/9 arc-seconds (or 30, 10, and 3 meters, respectively). Unlike vector data, elevation can be represented spatially through a DEM by storing data in cells along a continuous surface. How accurate the DEM is at displaying true elevation of an area is dependent upon the method of sampling; resolution, the distance between two sample points; and the data type, integer or float.

Digital elevation models are used in a wide range of applications, such as mapping and spatial analyzing landslide prediction and characterization (Dikau *et al*. 1996), route optimization (Ehlschlaeger & Shortridge 1996), landform analysis (Weibel & Heller 1990), land use planning (Mellerowicz *et al*. 1992), and soil landscape modeling (McKenzie & Austin 1993). For more exhaustive summaries of DEMs and practical applications inspect Moore *et al*. (1990), Weibel and Heller (1990), and Milne and Sear (1997). By archiving elevation as values, DEMs are widely used to delineate watersheds (Johnson *et al*. 1997; Wang & Yin 1997; Sliva & Williams 2001; Ahearn *et al*. 2005; King *et al*. 2005; Chang 2008; Dodds & Oakes 2008; Li *et al*. 2009; Gémesi *et al*. 2011), helping better analyze relationships between watershed catachments and lake water quality.

Geology data for bedrock (http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=923) and surficial geology (http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=412) were provided by the New York State Museum and had a 1:25000 scale. The 2010 real property data for the state (http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1248) were used to calculate the human density of the watersheds.

Soil data for the study area were retrieved from Soil Data Mart (http://soildatamart.nrcs.usda.gov/). Soil surveys were digitized from the Natural Resources Conservation Service, part of the United States Department of Agriculture, and its Soil Survey Geographic (SSURGO) database. This data depicts information about the kind and distribution of soils on the landscape. Surveys were conducted and separated by county. Therefore, St. Lawrence, Jefferson, Lewis, Herkimer, Hamilton, Essex, and Franklin county soil tabular and spatial layers were downloaded separately and later merged together to generate soil layers for each watershed. Unfortunately, some county surveys are still on going and are incomplete, resulting in some gaps in the watershed data. Tabular data were joined with spatial data in order to examine hydrologic groups instead of individual soil types. The join was based on the "mukey" field for the "muaggatt" table.

2.3 Analysis Software

All spatial data were compiled and analyzed using ArcGIS Version 10, a high-level GIS software suite for use on personal computers. ArcGIS origins date back to 1981 with the development and release of ArcInfo by Environmental Systems Research Institute in Redlands, California. At that time, ArcInfo offered limited functionality, when compared to today's standards, but developments throughout the early 1990s saw the rise of ArcTools, making the software easier to use and writing own ArcInfo-based applications (Longley *et al*. 2011). The release of ArcInfo 8, the new integrated suite of menu-driven, end-user applications: ArcMap, for editing and viewing of spatial data; ArcCatalog, for browsing and managing data; and ArcToolbox, for performing geoprocessing tasks (Longley *et al*. 2011), offered more free-rein with the software. No longer ArcInfo, ArcGIS is a full-featured professional software package whose strengths include its comprehensive selection of capabilities, high-quality cartography creation, analysis functions, customization ability, and vast array of third party tools and extensions (Longley *et al*. 2011). ArcGIS was selected because of these strengths, its availability and accessibility, and general ease to complete GIS functions and final map creation.

To evaluate the influence of watershed composition on water quality in the receiving lake bodies, PC-ORD 6.12, a statistical software package (McCune & Grace 2002), compared the amount of variance in water quality explained by the composition of the watersheds. The program integrates data management, exploration, graphing, and analysis tools and tailors them specifically for ecologists (Peck 2011). A major benefit of this software is its comprehensive statistical techniques not offered in many other statistical packages, such as Bray-Curtis ordination, canonical correspondence analysis, non-metric multidimensional scaling (NMS), principal components analysis (PCA), and weighted averaging.

2.4 Analysis Overview

In order to assess how natural and human factors influence lake ecology, numerous GIS steps, in ArcMap, were developed. Before analyses, lake watersheds were either separated from the already existing watersheds layer or created from the subwatershed layer. Knowing what types of the variables were present and in what degree are needed, because the magnitude of the type is important for determining water quality.

2.4.1 Watershed Delineation

While most of the lakes already had their corresponding watersheds created, from the watershed layer, three lakes did not have their watersheds available (Lake Bonaparte, Sylvia Lake, and Trout Lake). Their watersheds were delineated using available DEM models and ArcGIS. With the 10-meter resolution DEM set as the input raster and area of interest as the feature mask data, using the "Extract by Mask" tool allowed the creation of a new raster with the corresponding elevation data just for the area of interest. This new raster would later enter into the "Flow direction" tool and generate a new raster.

Two hydrology-processing tools, within the Spatial Analyst tool, were instrumental in creating lake watersheds. First, watersheds were delineated with help from the "Flow direction" tool. "Flow direction" works by calculating the direction of steepest descent of the input elevation surface raster, and outputs a raster showing the direction of water flow. This is calculated using:

$$\textit{Maximum drop} = \textit{change in z-value} / \textit{distance} * 100$$

Output values correspond to the 8 cardinal and intercardinal directions (1 is east, 2 is southeast, 4 is south, 8 is southwest, 16 is west, 32 is northwest, 64 is north, and 128 is northeast). If flow directions of cells converge towards each other, they are a sink and have an undefined flow direction (Jenson & Dominque 1988). No sinks were found for any of the study lakes. "Flow direction" is important for delineating a watershed since it will determine where water will flow from any point on the surface. In addition to the "Flow direction," the user must add a pour point, the outlet water flows out of an area. A pour point is located at the lowest elevation point along the boundary of a watershed. By setting the "Flow direction" as one input and the pour point as another, the "Watershed" tool is able to determine the contributing area of water flow. This tool works by extrapolating backwards from the pour point and determines the area water will flow to. When Trout Lake watershed was delineated, three holes were created, which caused small discrepancies between calculated area of variables and actual presences.

2.4.2 Watershed Characteristic Calculation

After watersheds were delineated, the amount of each variable type in the watershed was calculated. The area for each variable type was quantified by overlaying catchment layers with each of the factors (bedrock geology, surficial geology, soils, human density, and land use/land cover). Soils data were slightly more complicated, as soil data were collected for individual counties. As a result, before they were clipped watersheds they were merged with the soil layers using the “Merge” tool. Using the Analysis tool “Clip” within ArcMap, a new shapefile was exported containing only the extracted features for that watershed. To calculate the percentage of each element in the watershed, a field was added for area and another for percentage in the new shapefile. “Calculate geometry” function in the attribute table calculated the area in terms of square kilometers. Calculating percentage occurred in “Field Calculator,” by multiplying 100 by the element’s summed area dividing that quotient by the sum of all areas.

As preliminary analysis showed correlations among certain variable features, these features were combined in ArcMap. Land use/land cover saw the combination of open, low-, medium-, and high-intensity developed classes; pasture/hay and cultivated crops land-cover classes were summed together and renamed agriculture; and the two wetland types were grouped together as wetlands. The same process was also done for the bedrock geology, surficial geology, and soils variable features for those that demonstrated high correlation.

Human density was calculated at two different landscape sizes: full catchment and within 100 meters of the lake. The Analysis tool “Buffer” was used to create a new shapefile that generated a 100-meter buffer around the lakes. Parcel data were clipped by the 100m buffer and entire catchment layers, giving total number of properties in each size. For human density, the Spatial Analysis tool “Point Density” calculates a magnitude per unit area from point features that are in spatial proximity. A cell size of 30m was chosen to match resolution of other layers. For the expanding neighborhood around the point, circle was chosen as it maximizes area radiating in all directions, and its radius was 100 meters.

If projections were not already in UTM NAD 1983 Zone 18N they were reprojected as such a projection.

2.5 Statistical Analysis of Water Quality

In this study, a principal components analysis (PCA) was used for analysis. Before the PCA was run, preliminary analysis tested the correlation between features to determine what variables had similar impacts. In Minitab 16, correlations were run separately for each factor set to look for characterizes that displayed dependence. The threshold for a "strong" collinearity bivariate between features was set at $r > 0.850$. When this threshold was reached, an aggregate of those features was calculated and the individual features were removed from analysis. For example in bedrock geology, anorthosite and paragneiss and schist displayed high collinearity. As a result, the percentages of the two groups were summed and the two individual groups were removed from analysis leaving only the aggregated variable. In the end, a total of 35 parameters were used in the PCA analysis.

Principal components analysis is a basic eigenvector form of ordination (McCune & Grace 2002). This form analysis operates by representing the multiple variables in the dataset with a smaller number of component variables, or axes; the variables with the strongest covariation become the first few axes. In effect, PCA reduces a data set with *n* cases and *p* variables into a smaller set of variables that represent most of the information in the original dataset. Lakes were not separated dependent on river or elevation, because doing so would have reduced the power of the resulting analysis.

A cluster analyses were run in both Minitab 16 and PC-ORD 6.12. Cluster analysis works by grouping observations (lakes) together by similarity of the variables. To understand the impact of variable on clustering, a cluster analysis was run once with each variable separate and then run with all variables together. Lastly, ANOVA tests were run to calculate the relationships between the location (Adirondacks or St. Lawrence River Valley) and river system (Raquette, Oswegatchie, Grasse, Indian Rivers) to water quality.

3. BEDROCK GEOLOGY

The PCA multi-linear analysis and visual observation of the generated maps confirmed the presence of two main geology types (Figure 3; Table 1). The study area's western section was predominately sedimentary bedrock (minimum of 72%). The subcategory sedimentary bedrock composed large parts of Lake Bonaparte watershed (86%) and the entire Sylvia Lake watershed (100%). Black Lake watershed showed high amounts of subcategory sedimentary (37%), but also Cambrian, Lower Ordovician, and Middle Ordovician (35%), with metamorphic and igneous rock spatially interment (Figure 4). Lake Bonaparte and its corresponding watershed headwaters had mostly sedimentary bedrock geology influencing water quality (Figure 5), while the bedrock of Sylvia Lake's watershed was entirely sedimentary (Figure 6).

Lake watersheds on the middle and eastern portions of the study area displayed greater amounts of metamorphic and igneous bedrock types. Trout Lake watershed had 76% of its bedrock as granitic (Figure 7). The lake was entirely resting on top of metamorphic bedrock, with only a small portion of the watershed influenced by sedimentary rock near the outflow point. Tupper Lake watershed was completely metamorphic bedrock (Figure 8), having mostly anorthosite or paragneiss and schist. Carry Falls (Figure 9) and Higley Flow (Figure 10) watersheds both have generally the same amount of the anorthosite group and orthgneiss resting below. Only Norwood Lake watershed had any Cambrian or Middle and Lower Ordovician in its watershed (Figure 11), and located only the very northern tip, just around the contact line. Massawepie Lake (Figure 12) and Cranberry Lake (Figure 13) watersheds are mostly underlain by orthogneiss.

When tested for correlation, the syenite and anorthosite groups were deemed highly correlated and slightly correlated with orthogneiss (Table 2). Sediment and Cambrian-Ordovician groups were barely correlated to each other. Interestingly, granitic rock is negatively correlated with metamorphic rocks and slightly positively correlated with sedimentary rocks, suggesting they might be closely related. Lake Bonaparte and Trout Lake may explain this correlation, as both have the same bedrock geology: sedimentary rock and granitic rock, which was the only form of metamorphic and igneous type present.

The PCA split lakes into four main groupings (Figure 14). The Raquette River lakes were grouped together near the syenite and the anorthosite-paragneiss group line, suggesting those bedrocks are major influencers. Massawepie Lake and Cranberry Lake were similarly grouped and linked with orthogneiss bedrock. The PCA graph suggested lake watersheds resting on metamorphic and igneous rocks are more prone to have lakes with lower pH, specific conductivity, and chlorophyll a values in the spring and summer. Water quality data collected from the lakes reinforced the lower pH values and specific conductivity. Despite having similar bedrock geology, Cranberry Lake experienced different trends in chlorophyll a concentrations between seasons. Chlorophyll a in Cranberry Lake increased from spring to summer, whereas Massawepie Lake concentrations decreased. In both seasons, metamorphic and igneous rock watershed chlorophyll a levels were higher than sedimentary rock watersheds.

Sedimentary rock types strongly influenced Lake Bonaparte, Black Lake, and Sylvia Lake, matching the fact they are mostly residing on sedimentary rocks. Trout Lake, according to the PCA, was more influenced by sedimentary rock than the other mainly metamorphic watersheds. This is explained by visual observation, because Trout Lake contains the most sedimentary rock of the metamorphic watersheds. These lakes were characterized in the PCA to have higher pH, specific conductivity, dissolved oxygen values and deeper Seechi depths. Actual water quality data reinforced those predictions, most specifically with pH, specific conductivity and dissolved oxygen, but Secchi depth was harder to attribute to bedrock geology, given Trout and Sylvia Lakes were notably higher than the other lakes. Moreover, Secchi depths varied widely in the sedimentary lakes, having values as low as 1.20 meters in Black Lake to as high as 7.18m in Sylvia Lake.

Cluster analysis dendrograms reinforced the main groupings seen in the PCA, but also showed a further breakdown. Minitab (Figure 15) and PC-ORD (Figure 16) dendrograms grouped Lake Bonaparte and Sylvia Lake, Massawepie Lake and Cranberry Lake, and the four Raquette River lakes together. Where the two diverged was in the placement of Trout Lake and Black Lake, though they did group both lakes closer to Lake Bonaparte and Sylvia Lake than the Raquette River lakes. In the PC-ORD dendrogram, Black Lake was more closely tied to the other pair than Trout Lake was; the opposite occurs with Minitab. Black Lake has more bedrock geology similarities to the pair, but Trout Lake is more similar in terms of water quality measurements.

A clear trend in bedrock geology is the relationship between it and specific conductivity. Specific conductivity has been linked to depict the extent of salt water intrusion (Gondwe 1991; Kumaraswamy & Sivagnanam 1991; Beke *et al*. 1993), total dissolved solids (Reichman & Trooien 1993), cations (Hounslow 1995), total concentration of ionic species (Tyson 1988), and pollutants (Gurnell *et al*. 1994). Additionally, specific conductivity has been linked to dissolved oxygen (Rajapogal *et al*. 1993) and nutrient levels (Hakamata *et al*. 1992), both of which could impact the lakes biological community (Jensen 1990; Conlon *et al*. 1992). Freshwater inputs in these lakes and distance from coastal waters make salt water intrusion unlikely (Galvin 1993), suggesting high levels of specific conductivity are the result of some other source. For lakes with predominately sedimentary bedrock, specific conductivity was substantially higher than those in more metamorphic rock. Mathuthu *et al*. (1995) linked specific conductivity with sewage discharge, which may explain Black Lake and Lake Bonaparte, but not Sylvia Lake, given its isolation. Yet, Sylvia Lake is surrounded by lakeshore homes with septic systems. Therefore, a factor outside aside from those previously proposed was influencing specific conductivity or specific conductivity is reflecting another water chemistry variable.

Although the pH value in Sylvia Lake was high in comparison to other sedimentary lakes, it was not as high as Trout Lake, whom it also had a much lower specific conductivity then. Primary productivity can influence pH, indicating why Sylvia Lake's pH is low in comparison to more productive Trout Lake. Interestingly, Trout Lake and Sylvia Lake have the same two geologic features, just at different poles of each other. As metamorphic and igneous rock dissolve fewer ions into water and poor abilities to buffer inputs of acidity (McNeil *et al*. 2008), and Adirondack lakes experience low pH levels (Driscoll *et al*. 2003), sedimentary bedrock is the main indicator to higher specific conductivity. With almost all water chemistry values and watershed characteristics comparable, the bedrock geology attributes to differences in specific conductivity between the two lakes.

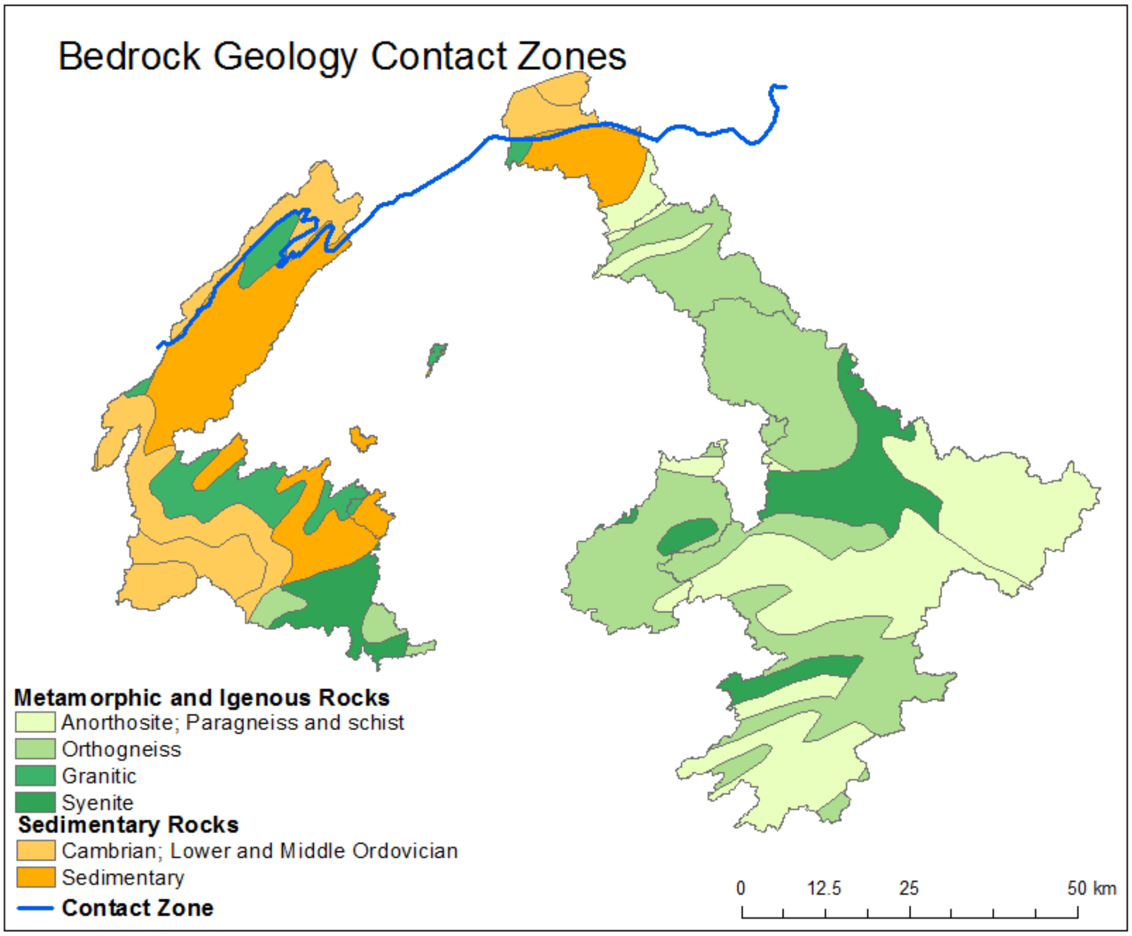

Figure 3: Bedrock geology contact zone in northern New York, depicting the shift from sedimentary type rocks to metamorphic and igneous.

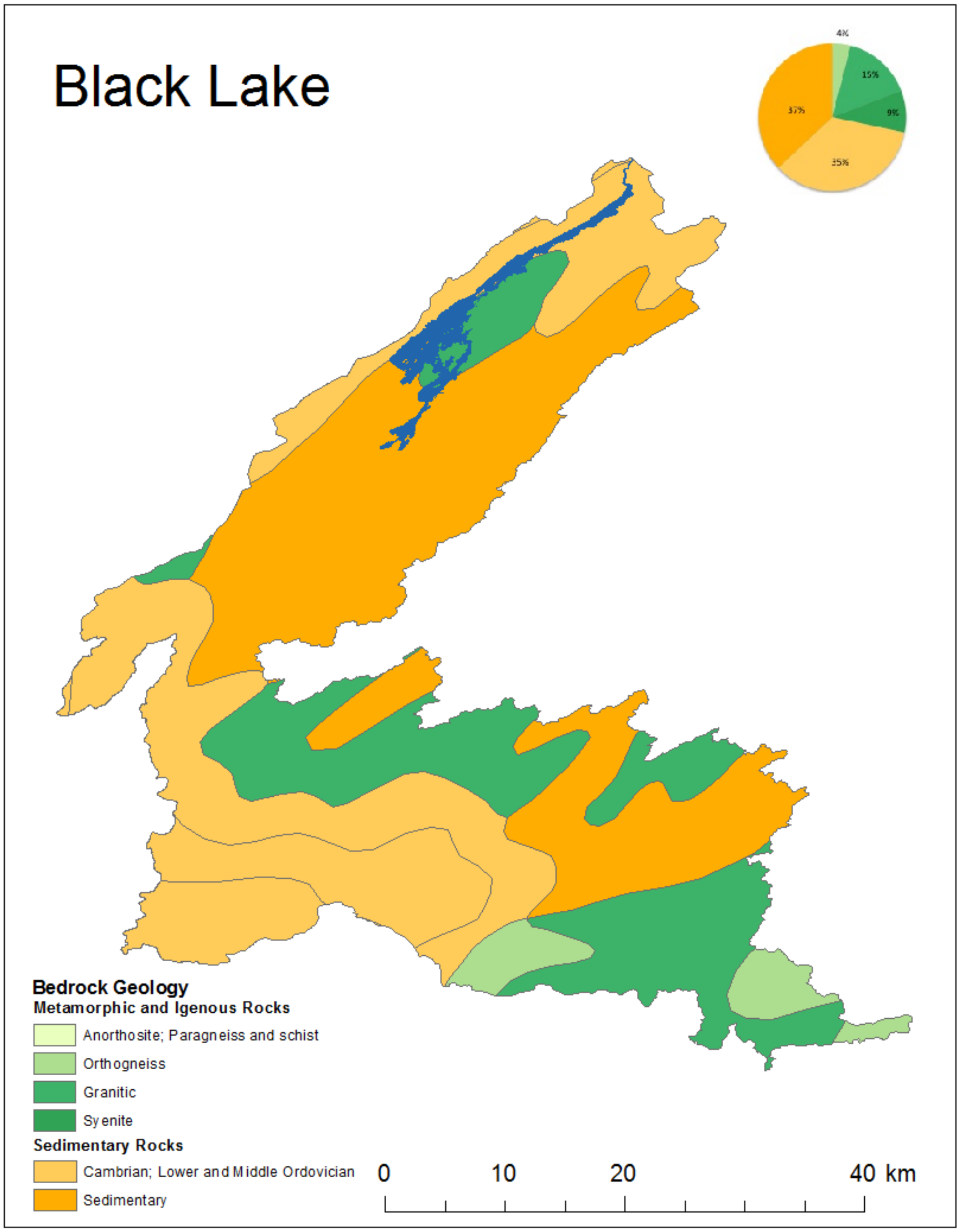

Figure 4: Bedrock geology distribution across Black Lake’s watershed.

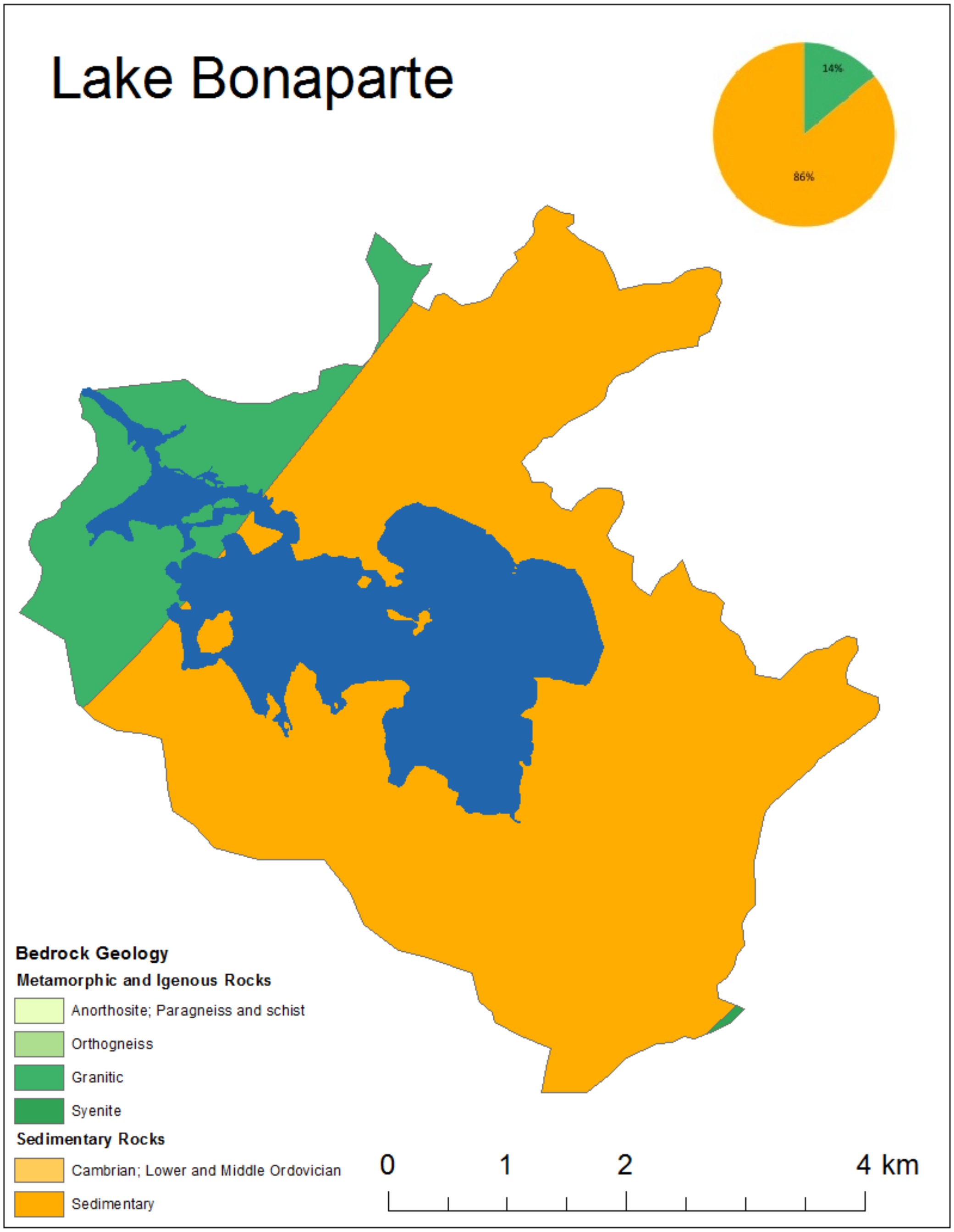

Figure 5: Bedrock geology distribution across Lake Bonaparte's watershed.

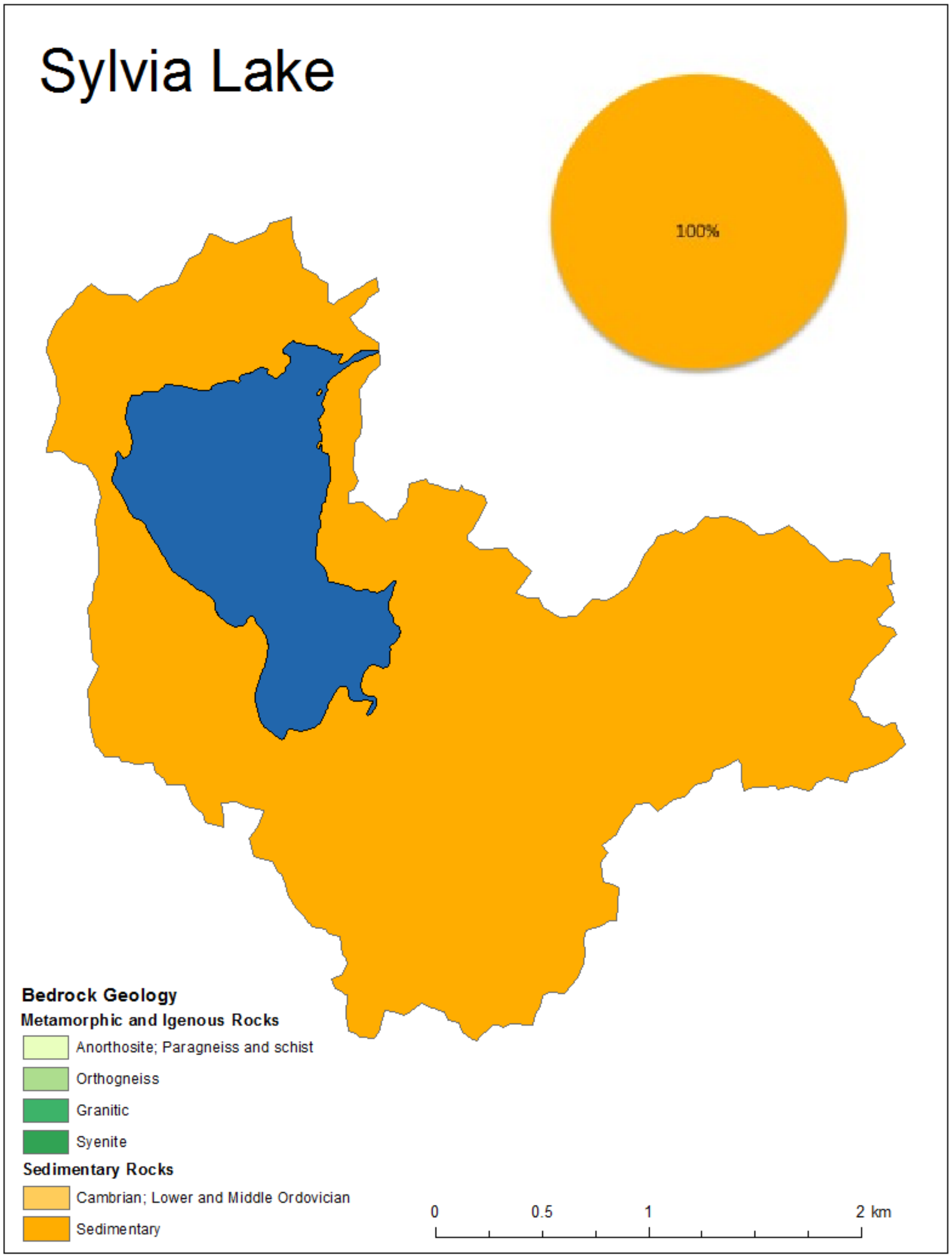

Figure 6: Bedrock geology distribution across Sylvia Lake’s watershed.

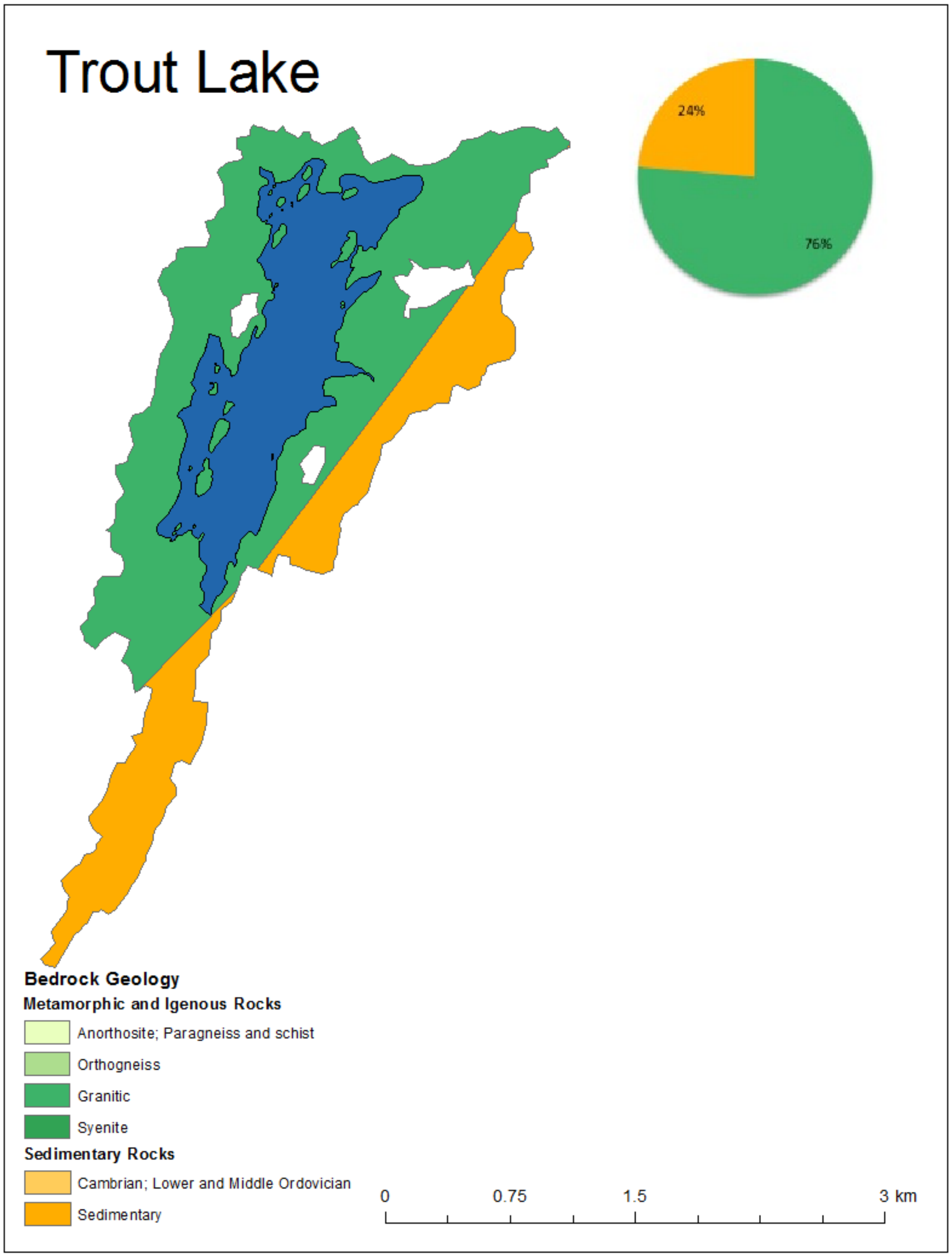

Figure 7: Bedrock geology distribution across Trout Lake's watershed.

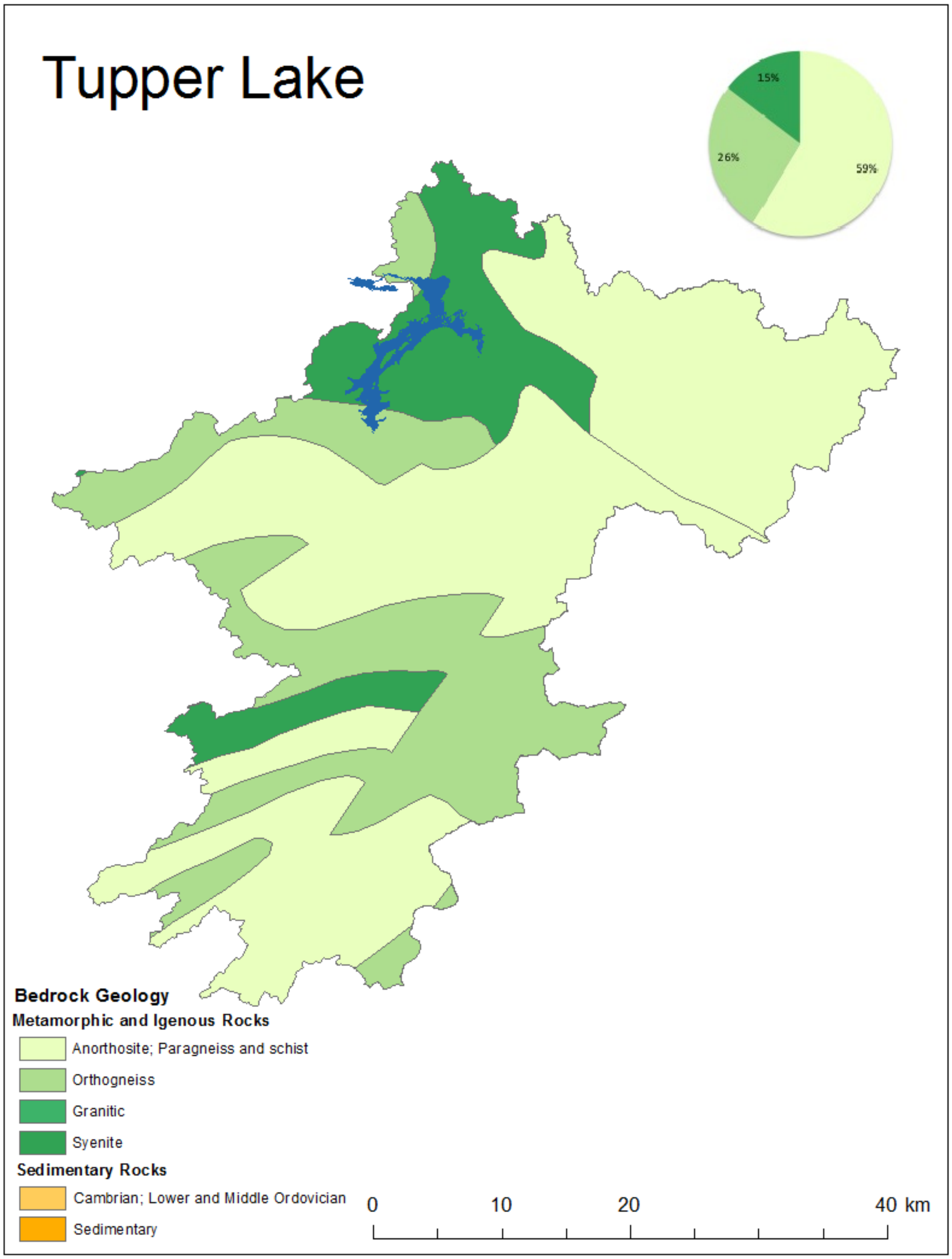

Figure 8: Bedrock geology distribution across Tupper Lake's watershed.

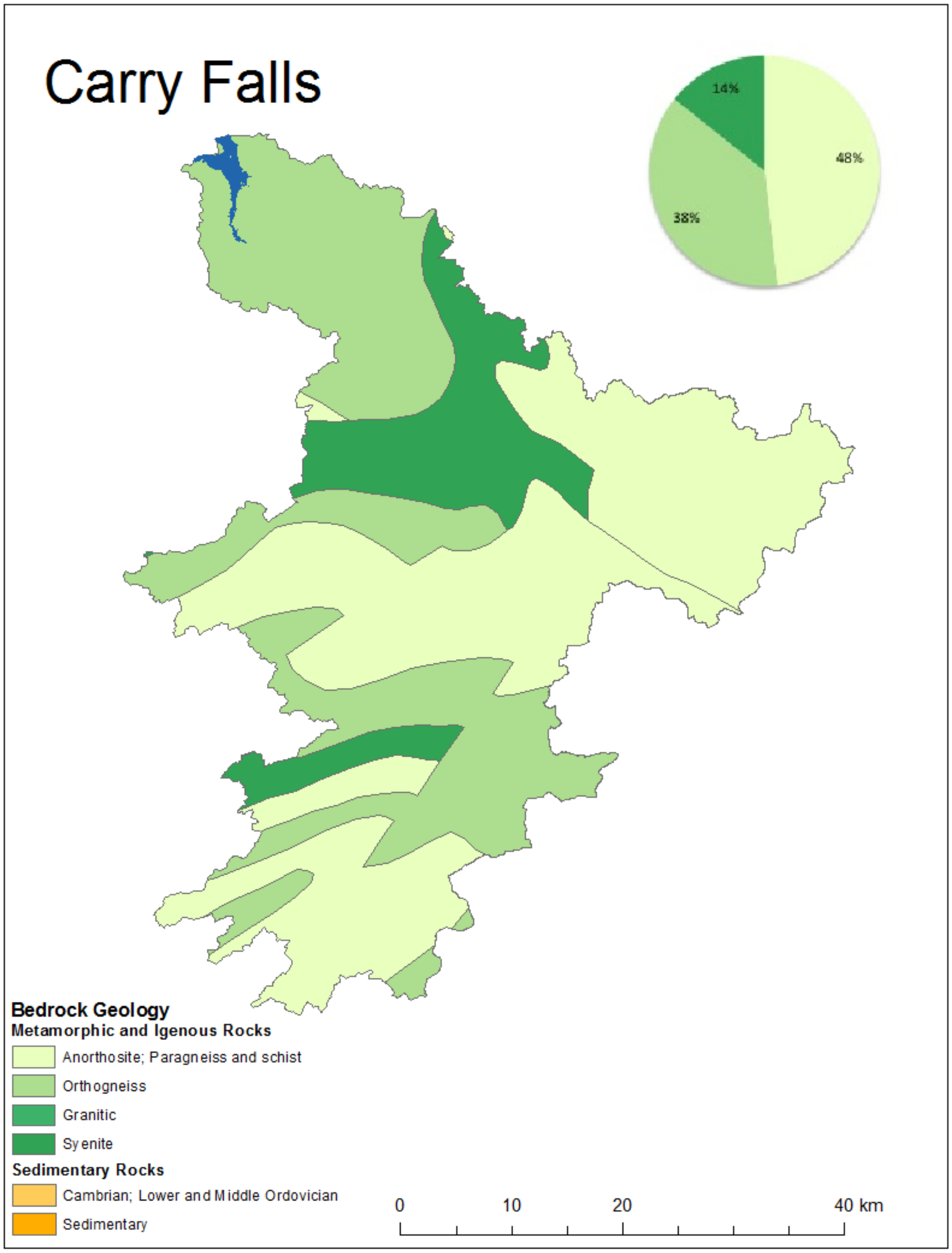

Figure 9: Bedrock geology distribution across Carry Falls' watershed.

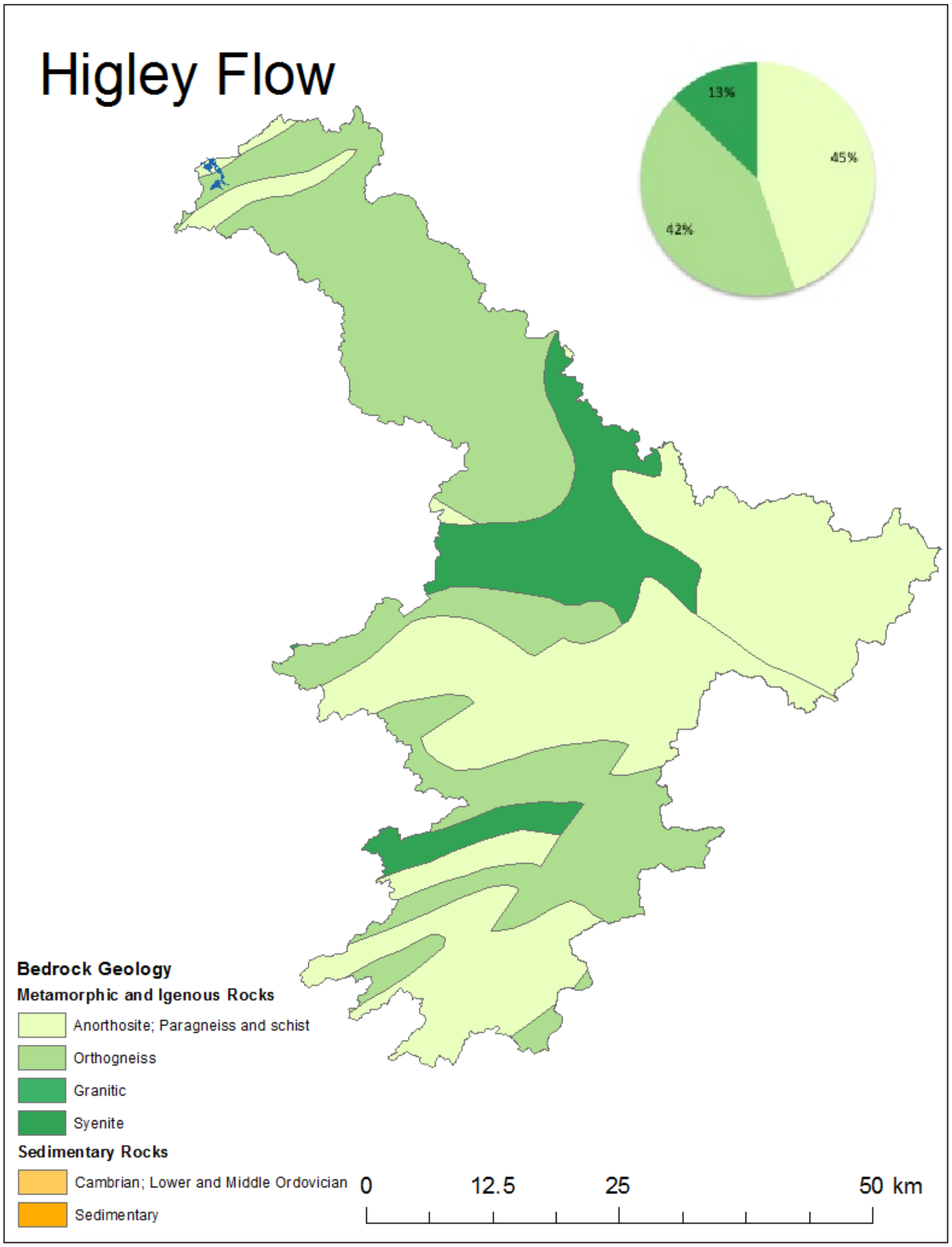

Figure 10: Bedrock geology distribution across Higley Flow's watershed.

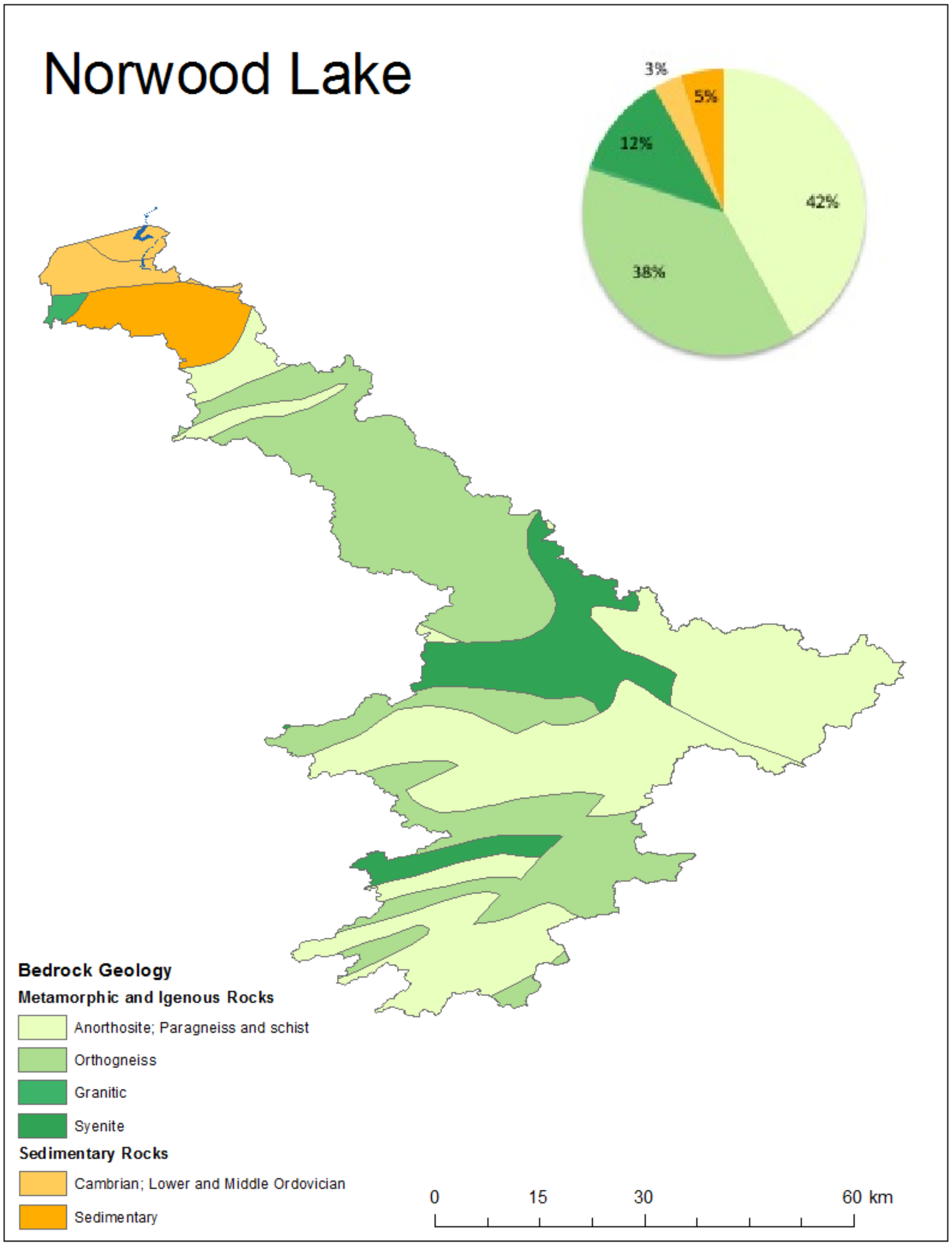

Figure 11: Bedrock geology distribution across Norwood Lake's watershed.

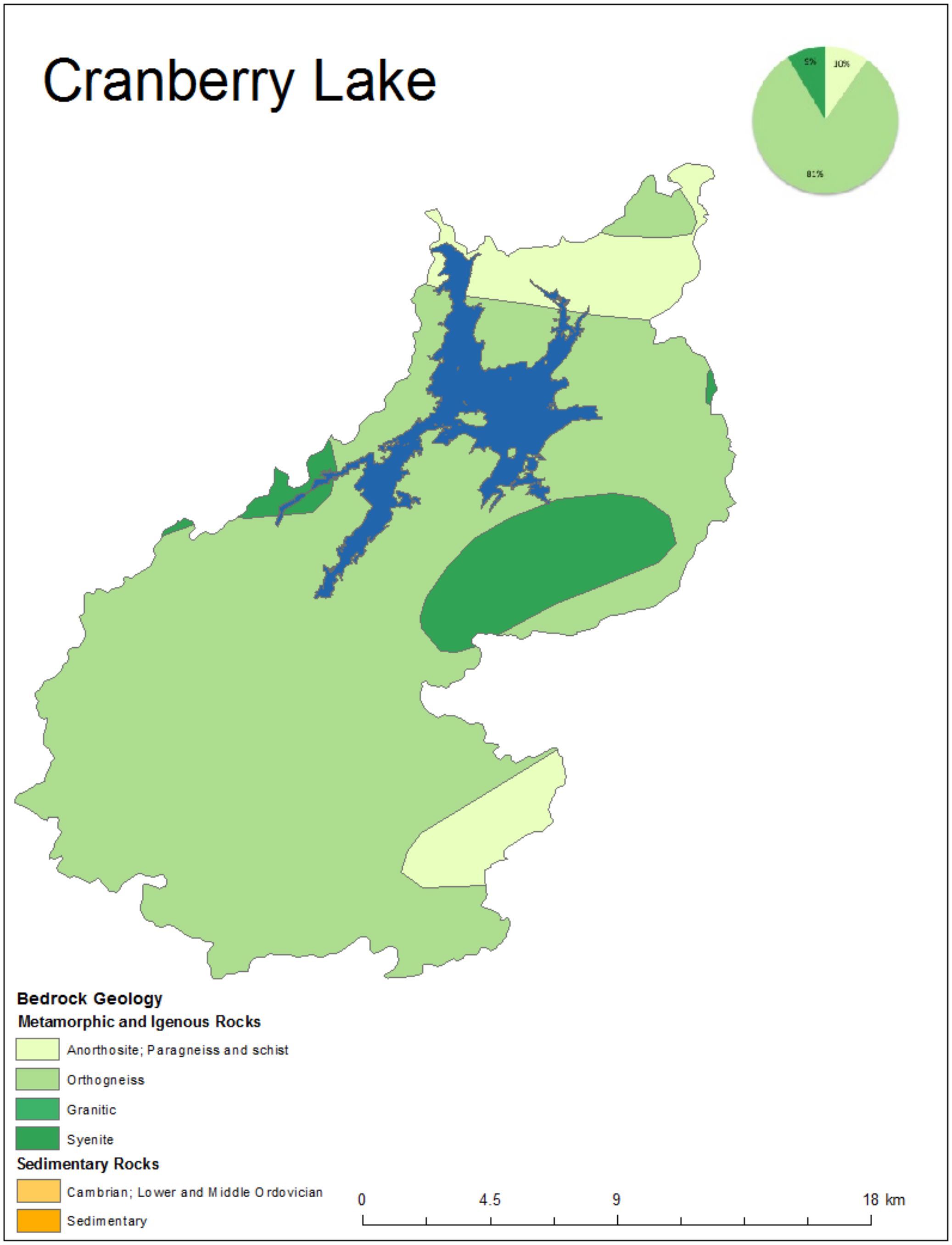

Figure 12: Bedrock geology distribution across Cranberry Lake's watershed.

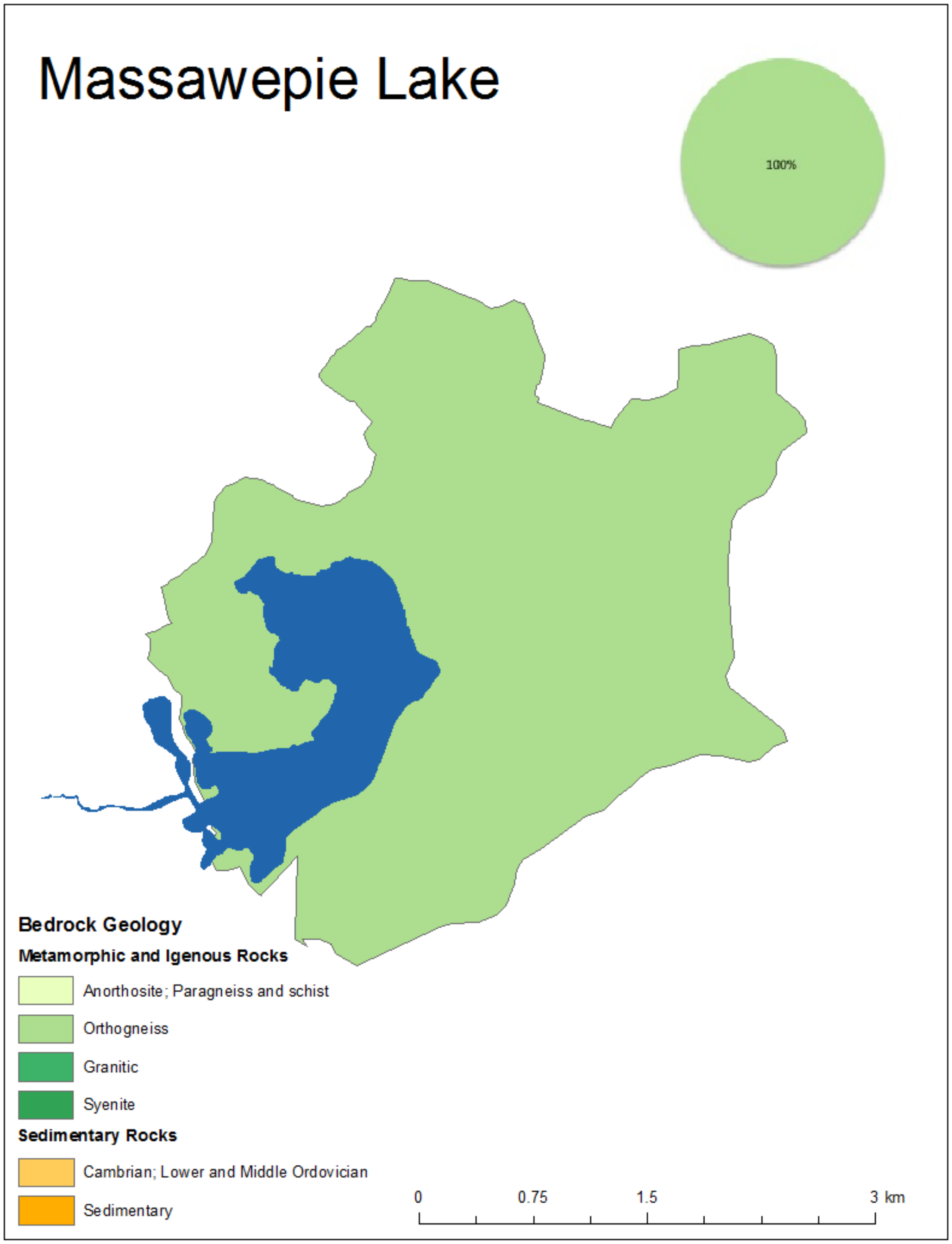

Figure 13: Bedrock geology distribution across Massawepie Lake's watershed.

Table 1: Calculated lake watershed bedrock geology percentages.

	Anorthosite; Paragneiss and schist	Orthogneiss	Syenite	Sedimentary	Granitic	Cambrian; Middle and Lower Ordovician
Lake Bonaparte	0.00	0.00	0.07	86.00	13.94	0.00
Black Lake	0.00	4.04	9.17	36.97	15.15	34.68
Tupper Lake	58.72	26.61	14.67	0.00	0.00	0.00
Carry Falls	48.29	37.42	14.30	0.00	0.00	0.00
Higley Flow	44.86	42.36	12.78	0.00	0.00	0.00
Norwood Lake	41.84	38.03	11.47	4.90	0.41	3.35
Massawepie Lake	0.00	100.00	0.00	0.00	0.00	0.00
Cranberry Lake	9.82	81.46	8.71	0.00	0.00	0.00
Trout Lake	0.00	0.00	0.00	23.64	76.36	0.00
Sylvia Lake	0.00	0.00	0.00	100.00	0.00	0.00

Table 2: Correlations table for bedrock geology types (top value is Pearson correlation and bottom value is p-value)

	ANPA	ORTH	SYEN	YSED	YGRN
ORTH	0.121 0.739				
SYEN	**0.873** **0.001**	0.149 0.681			
YSED	-0.581 0.078	-0.662 0.037	-0.635 0.049		
YGRN	-0.402 0.249	-0.452 0.190	-0.443 0.200	0.111 0.761	
CLMO	-0.261 0.466	-0.286 0.422	0.137 0.707	0.092 0.801	0.053 0.884

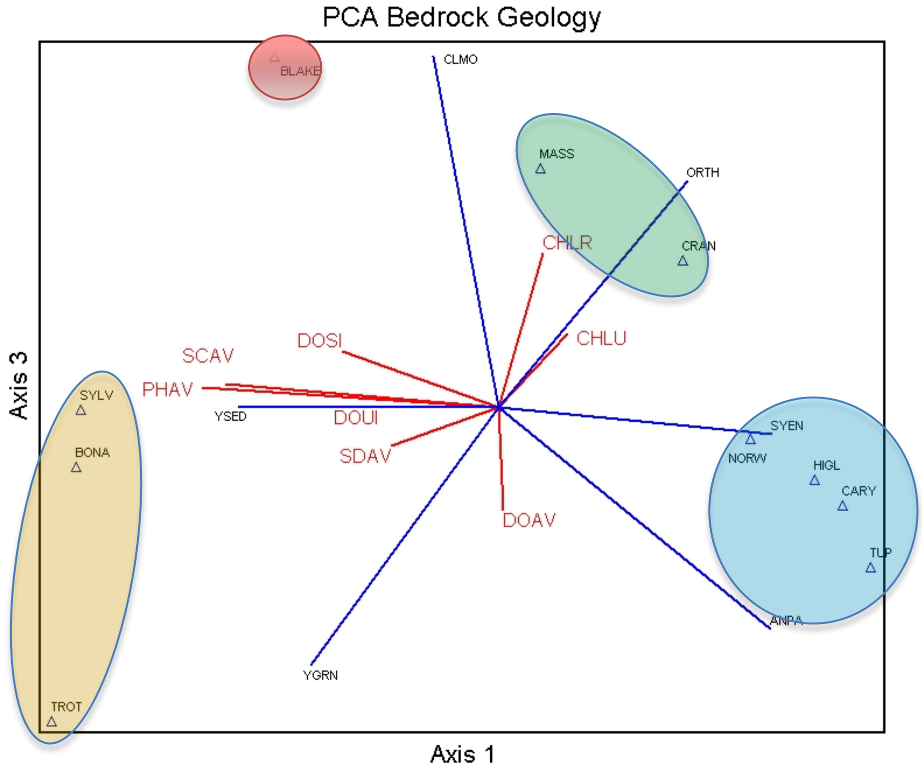

Figure 14: PCA graph on lake watershed bedrock geology. Blue lines depict associations between bedrock geology types and lakes. Red lines depict associations between water quality characteristics and lakes. Longer lines have stronger relationships than shorter lines. Colored circles demonstrate groupings of lakes.

Table 3: PCA eigenvalues for lake watershed surficial geology

Variable	1	2	3	4	5	6
ANPA	0.5045	0.2516	-0.4108	-0.1602	-0.5797	-0.3896
ORTH	0.3494	-0.5936	0.4189	0.1958	0.0679	-0.5542
SYEN	0.5050	0.4411	-0.0500	0.0031	**0.7333**	-0.1009
YSED	-0.4824	0.1012	0.0021	-0.6006	0.1915	-0.5997
YGRN	-0.3476	0.0540	-0.4786	**0.7008**	0.1195	-0.3766
CLMO	-0.1217	**0.6137**	**0.6513**	0.2902	-0.2658	-0.1718

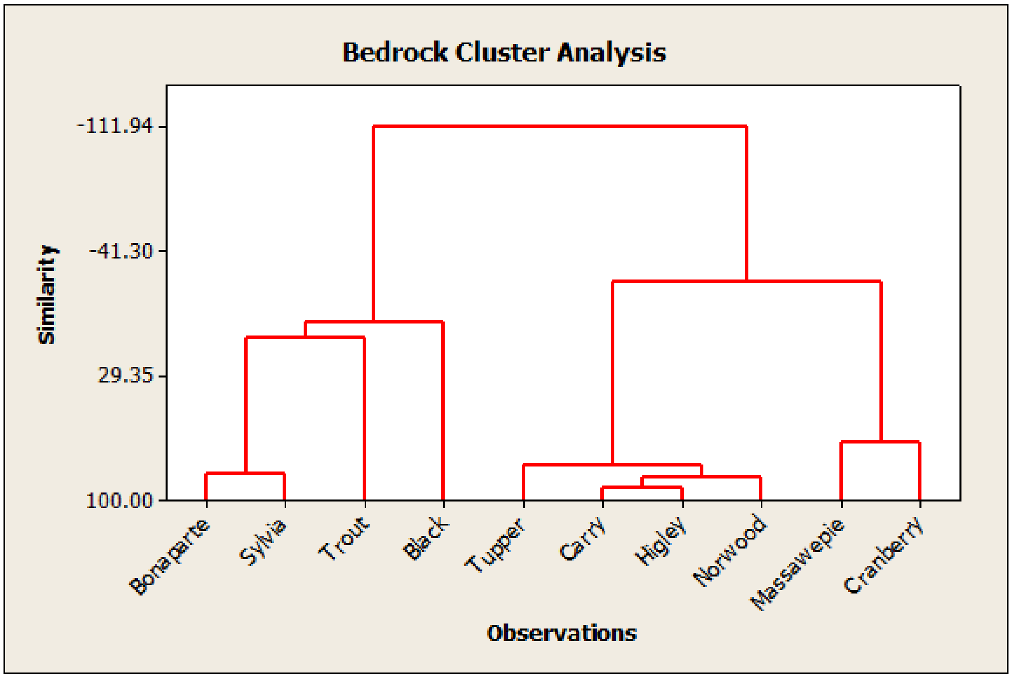

Figure 15: Dendrogram on lake watershed bedrock geology (generated in Minitab 16).

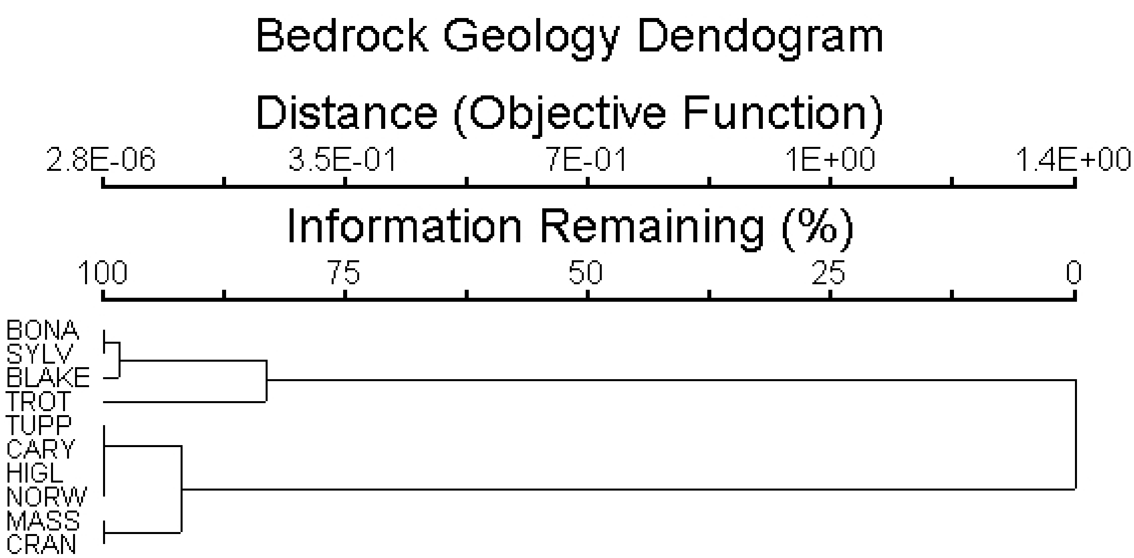

Figure 16: Dendrogram on lake watershed bedrock geology (generated in PC-ORD Version 6.12).

4. SURFICIAL GEOLOGY

Visual observation and regression analysis confirmed the presence of four main splits in surficial geology (Table 4). Surficial geology did not display such a strong split as bedrock geology. More silt-clay was found in the western portion than the eastern portion. Silt-clay covered over half of Black Lake's watershed (Figure 17), responsible for the high pH values of the lake. Lake Bonparte watershed was mainly influenced by alluvial-bedrock-till and lacustrine sand and gravel, but substantial amount of kame existed (Figure 18). Similarly to Black Lake and its watershed, high amounts of silt-clay geology may have led to Sylvia Lake (Figure 19) and Trout Lake's (Figure 20) high pH values.

Comparatively, Raquette River lake watersheds were dominantly alluvial-bedrock-till based, losing slightly less total percentage the further down the river. Tupper Lake watershed (Figure 21) had over 80% of its watershed as such, with Carry Falls watershed still over 75% (Figure 22). The loss of alluvial-bedrock-till saw an increase in kame or sand and gravel. Higley Flow watershed had the greatest amount of kame along the river (Figure 23). Norwood Lake almost doubled the amount of sand and gravel in its watershed than the other lakes (Figure 24).

Cranberry Lake and its watershed was the most similar to the Raquette River group, but saw even higher amounts of kame (Figure 25). The watershed of Massawepie Lake diverged from all the other lakes, processing lower amounts of alluvial-bedrock-till and higher amounts of kame, sand and gravel (Figure 26). Kame and water are highly correlated (Table 5), which is sensible given kame are remnants of past glacial events. Silt and alluvial-bedrock-till, on the other hand, are strongly negatively correlated and appear to have opposite effects on lake ecology health.

Principal components analysis linked silt-clay to higher pH, dissolved oxygen, and specific conductivity values (Figure 27). Silt-clay was the most influential on water quality (Sliva & Williams 2001), because the potential of clay minerals for adsorption of nutrients, such as phosphorus and ammonia, could lead to increased levels of those characteristics in lakes (Johnson *et al*. 1997). Also, surficial geology types are more impermeable to water runoff and could have higher nutrient concentrations, because water would carry them more easily. Longer residence times of water in the material, which may have more nutrients, could allow more nutrients to leach into the water, promoting higher net primary productivity chlorophyll a, and dissolved oxygen, but lower Secchi depth when the water eventually reaches the lake. Sliva and Williams (2001) noticed this to hold true, for their watersheds with clay soils contained higher nutrient contents. Contrary to the PCA, in this study, the western lakes have the greatest amount of silt-clay geology and had the highest nutrient concentrations.

Clay minerals and humics have a high potential for absorbing nutrients and may cause nutrient fluxes (Hingston *et al*. 1967; Boatman & Murray 1982). Johnson *et* al. 1997 noticed geology can sufficiently obscure land use effects in autumn. Similar patterns did not appear to happen in the study area lakes with high amounts of clay minerals, as many of the water quality characteristics improved in the fall, lending support that the silt-clay are acting as sinks and holding the nutrients (Tam & Wong 1995; Van Straalen & Reolofs 2008).

For the most part, both generated dendrograms align. In both, Sylvia and Trout Lakes are grouped together, with Black Lake soon entering due to its general exclusivity to silt. Raquette River lakes are seen as one group for their selectiveness to alluvial-bedrock-till, with Cranberry Lake as an additional entry. Massawepie Lake is an outlier, due to its high presence of numerous geology types in its watershed. Lake Bonaparte, however, moves its location depending on the dendrogram examined. In Minitab, Lake Bonaparte is located just after Black Lake and grouped with Sylvia and Trout Lakes (Figure 28). For PC-ORD, Lake Bonaparte's alluvial-bedrock-till amount groups it with the Raquette River lakes (Figure 29). Like Massawepie Lake, the high percentage of subaqueous material in the watershed creates difficulty in clustering Lake Bonaparte with any of the other lakes.

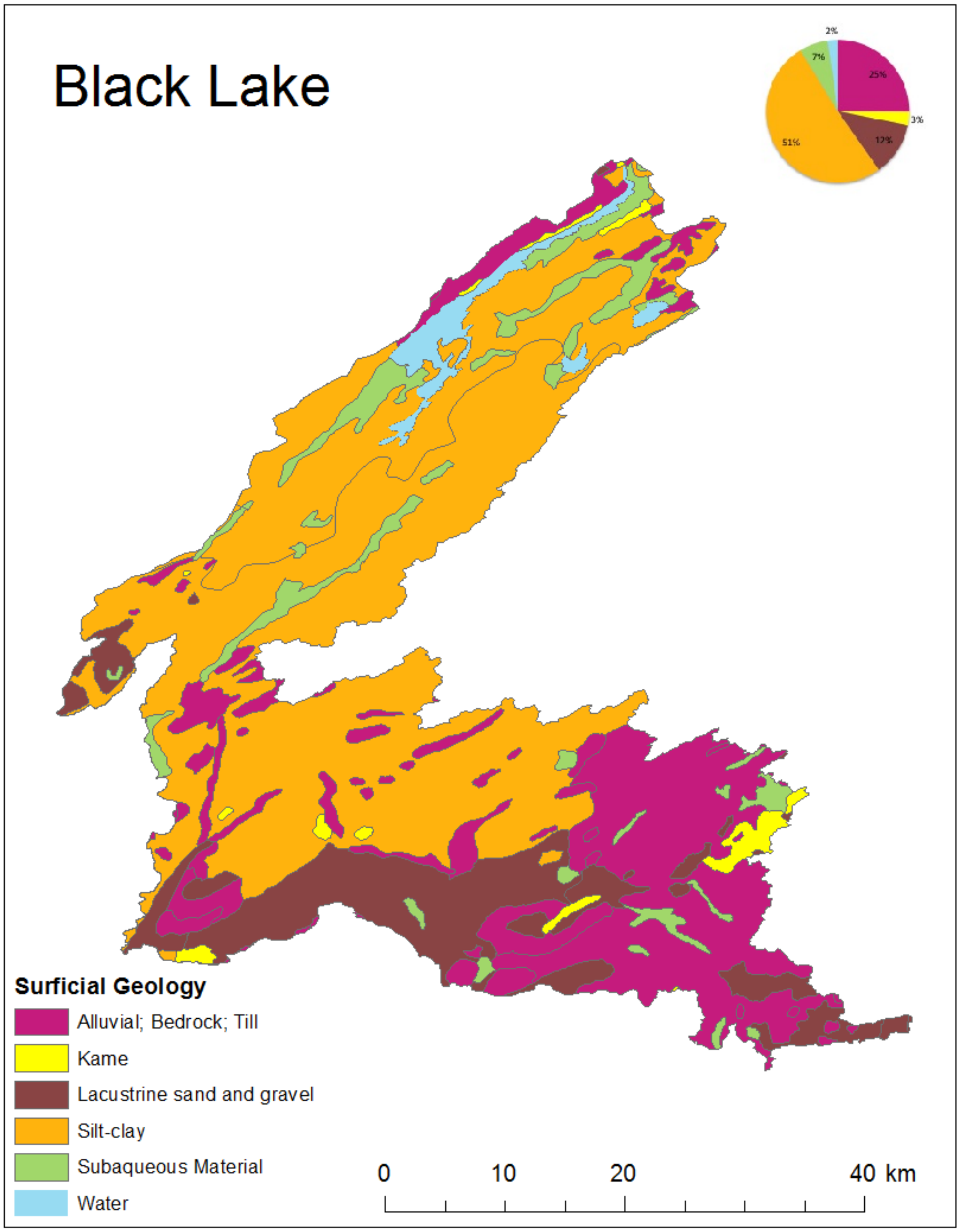

Figure 17: Surficial geology distribution across Black Lake's watershed.

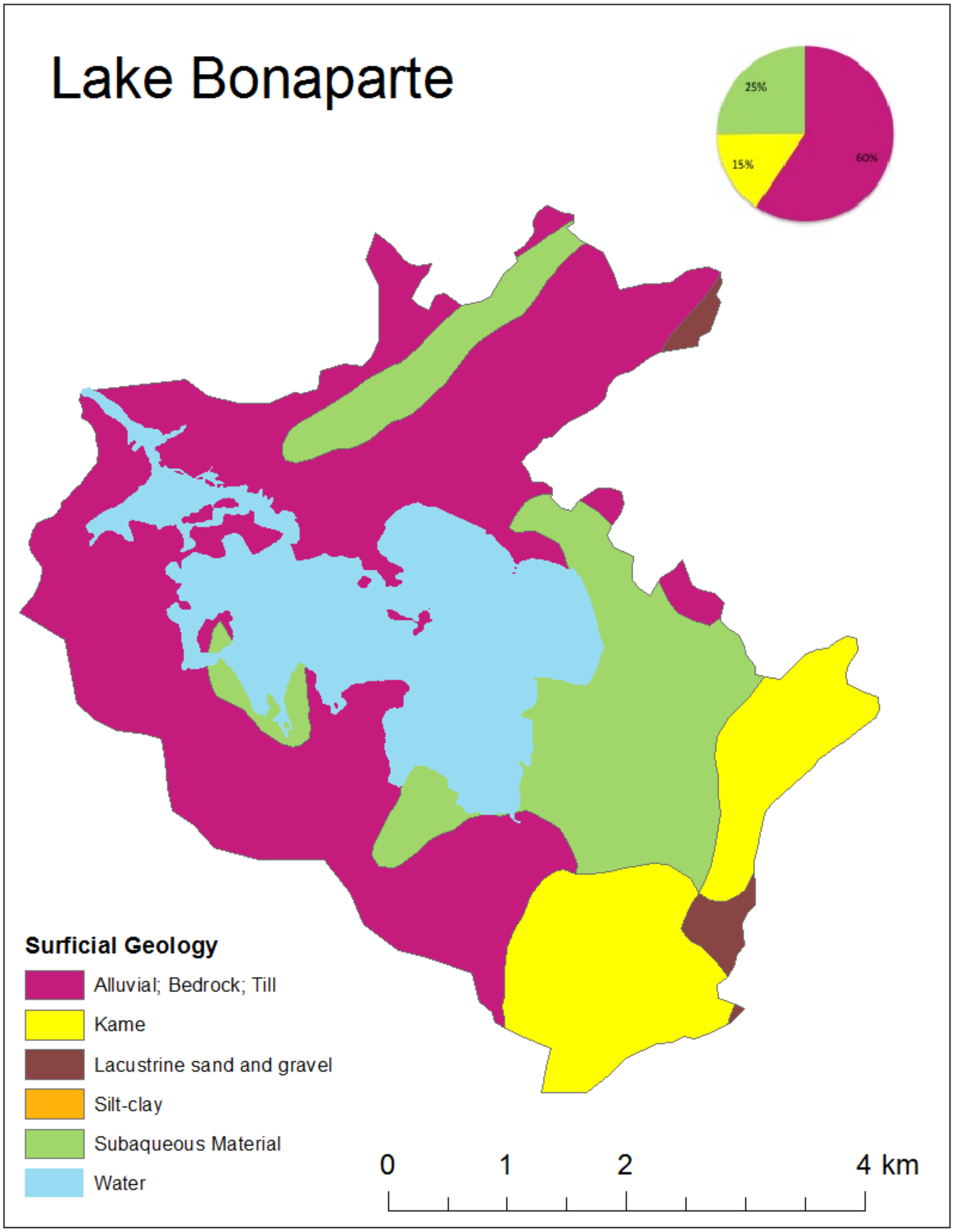

Figure 18: Surficial geology distribution across Lake Bonaparte's watershed.

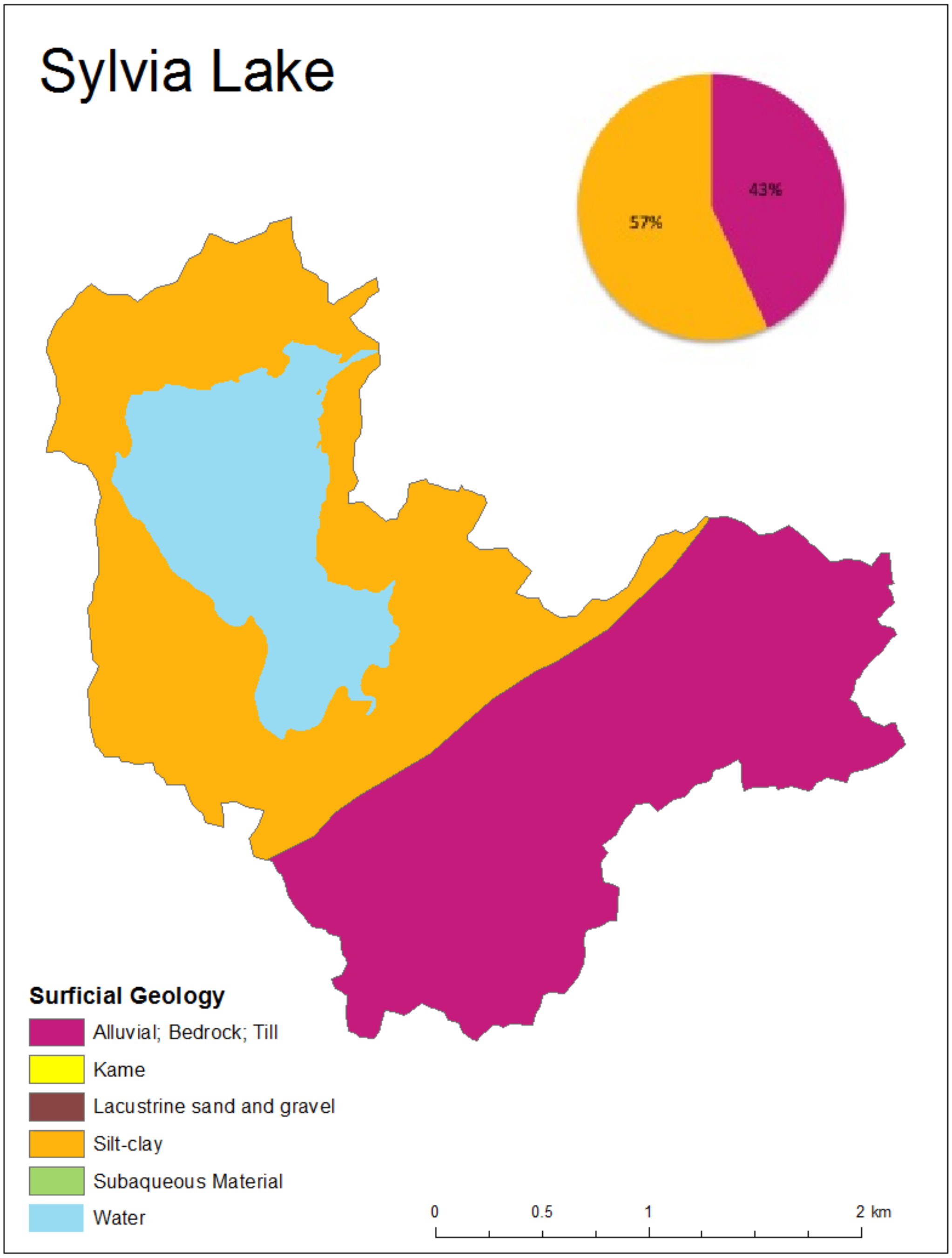

Figure 19: Surficial geology distribution across Sylvia Lake's watershed.

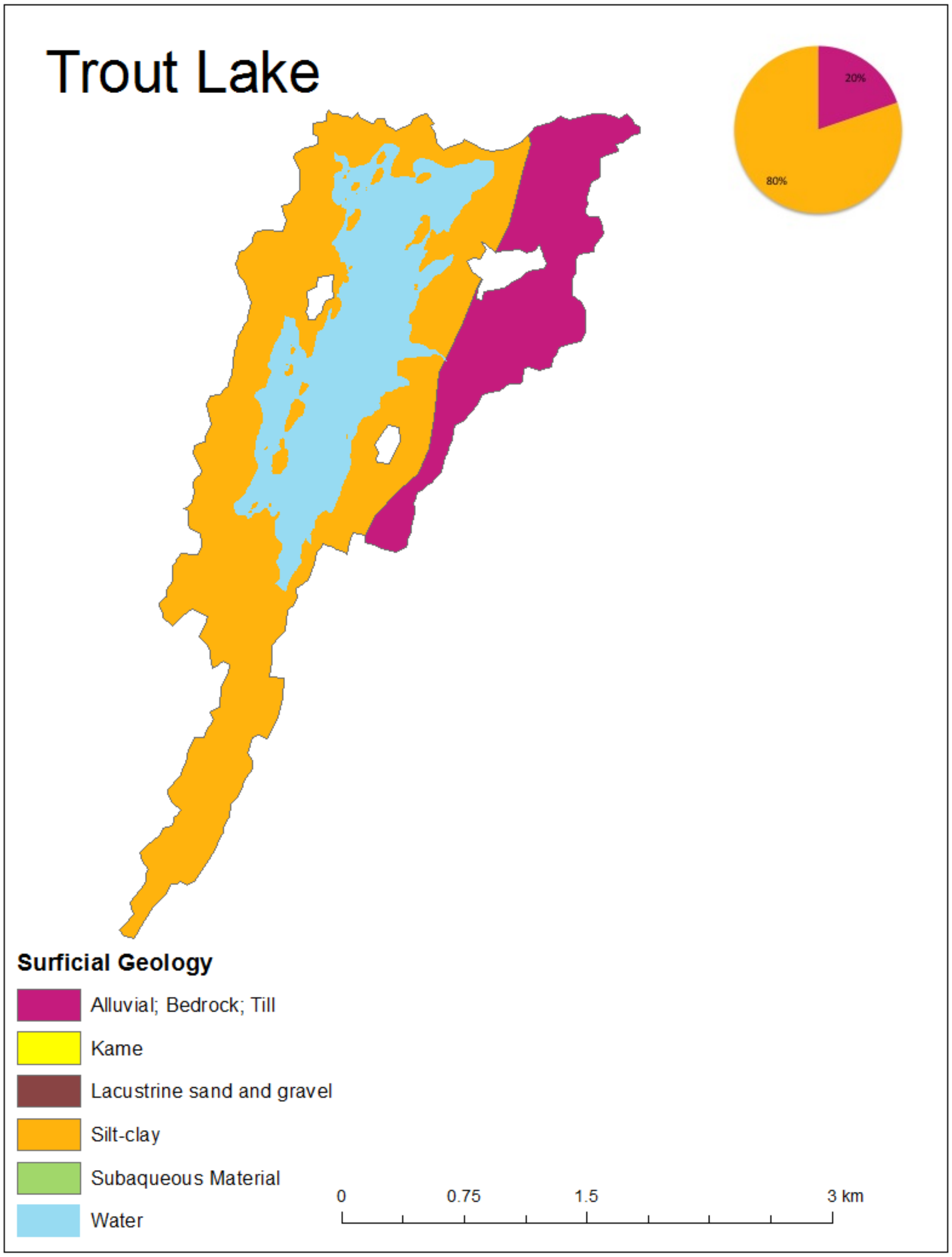

Figure 20: Surficial geology distribution across Trout Lake’s watershed.

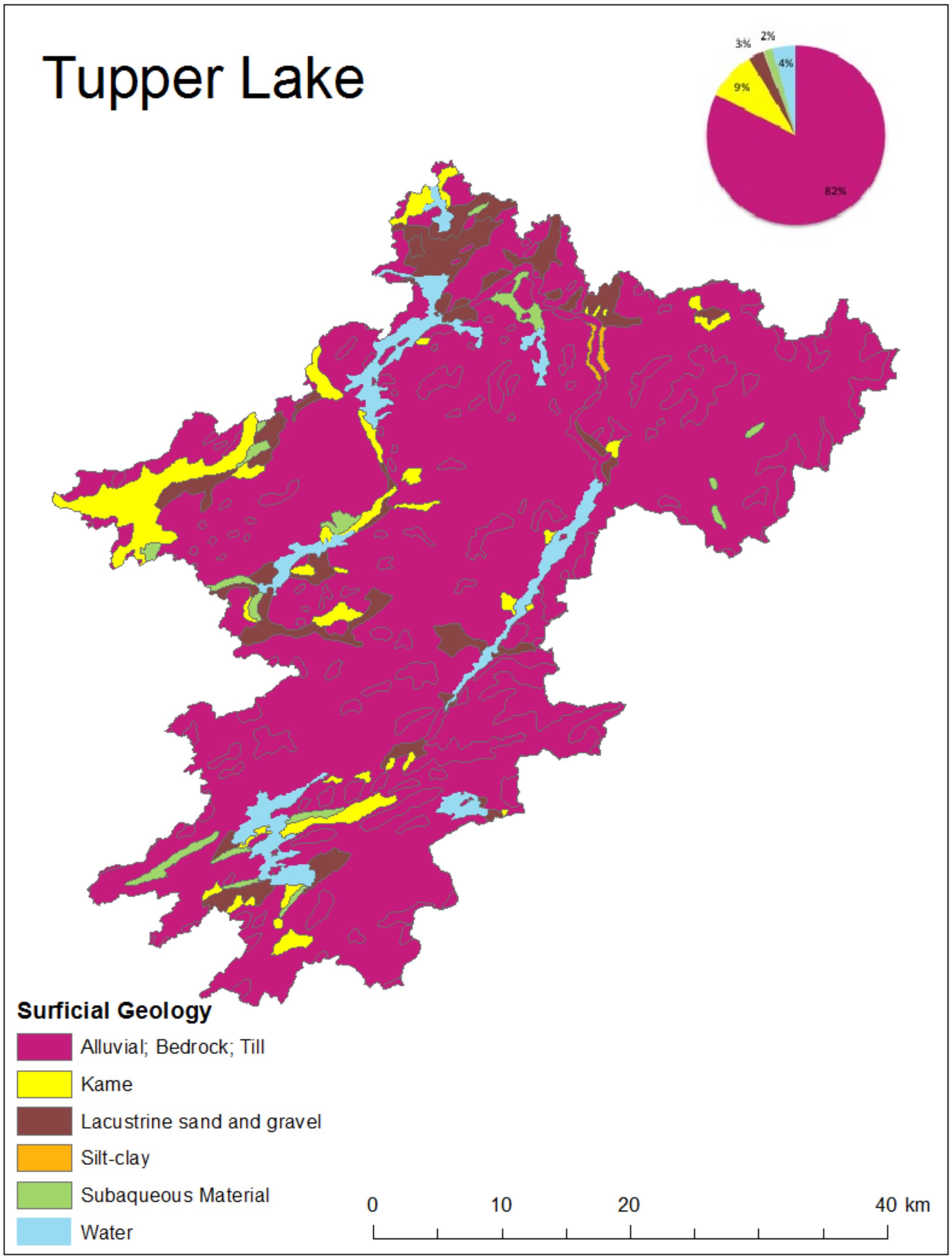

Figure 21: Surficial geology distribution across Tupper Lake's watershed.

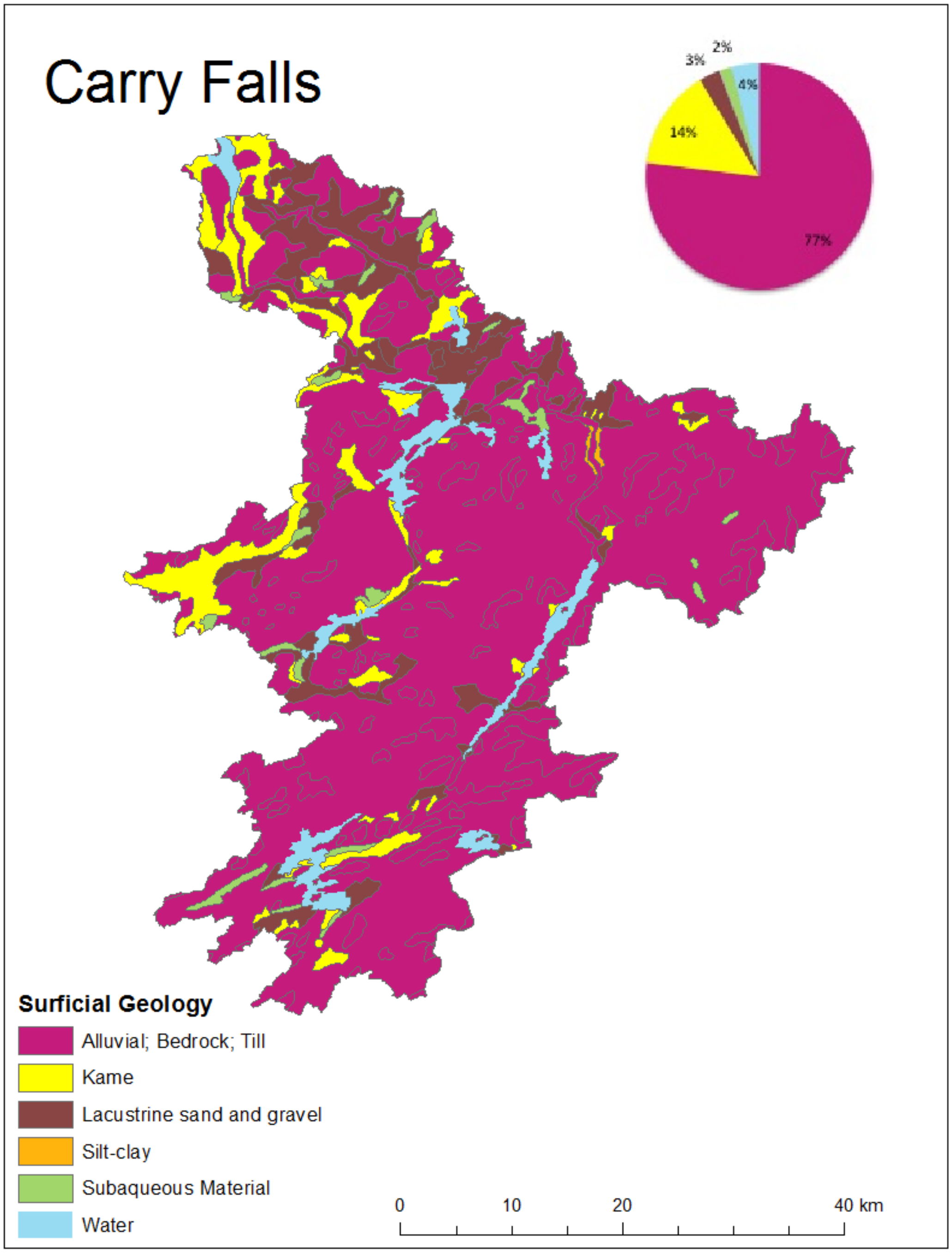

Figure 22: Surficial geology distribution across Carry Falls' watershed.

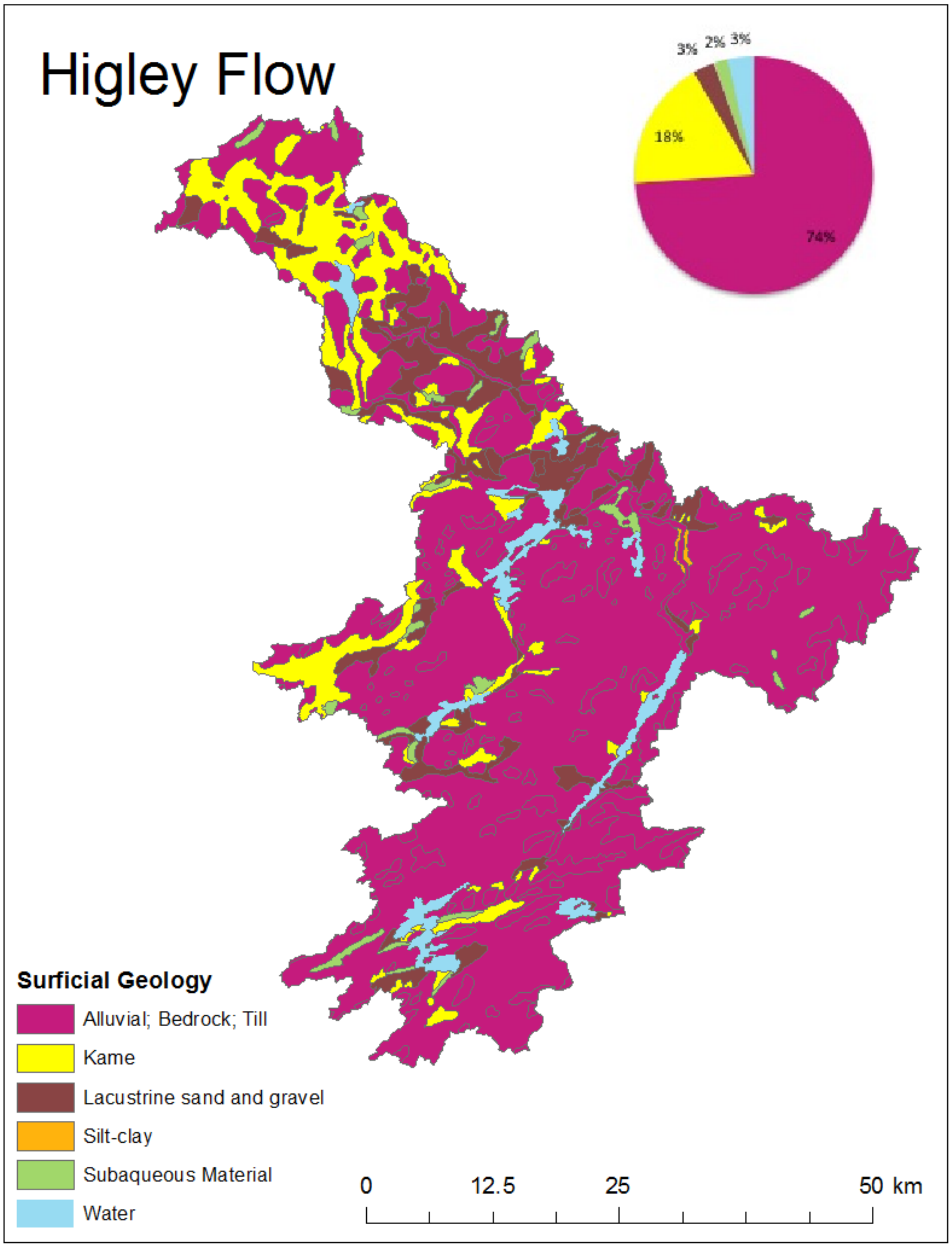

Figure 23: Surficial geology distribution across Higley Flow’s watershed.

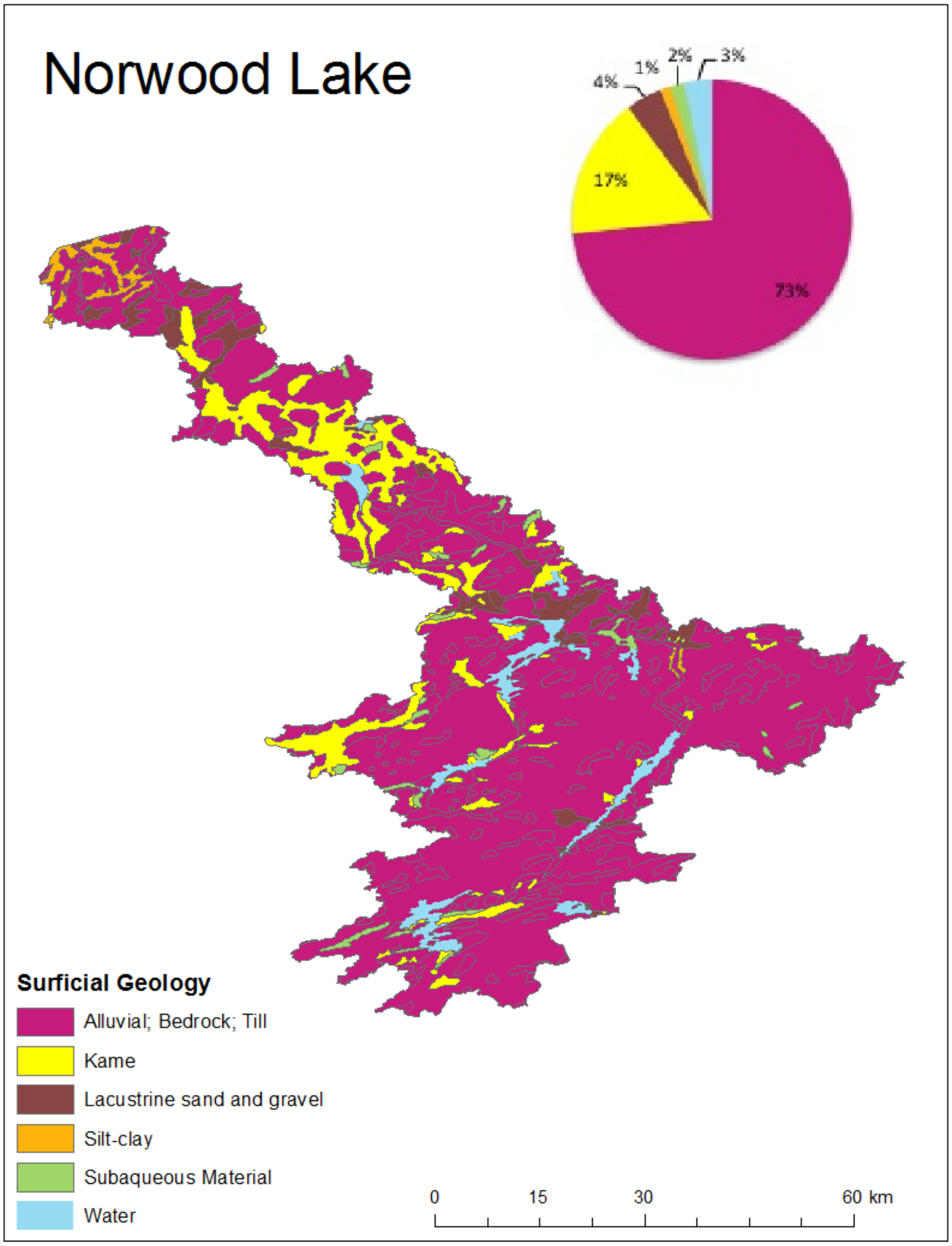

Figure 24: Surficial geology distribution across Norwood Lake's watershed.

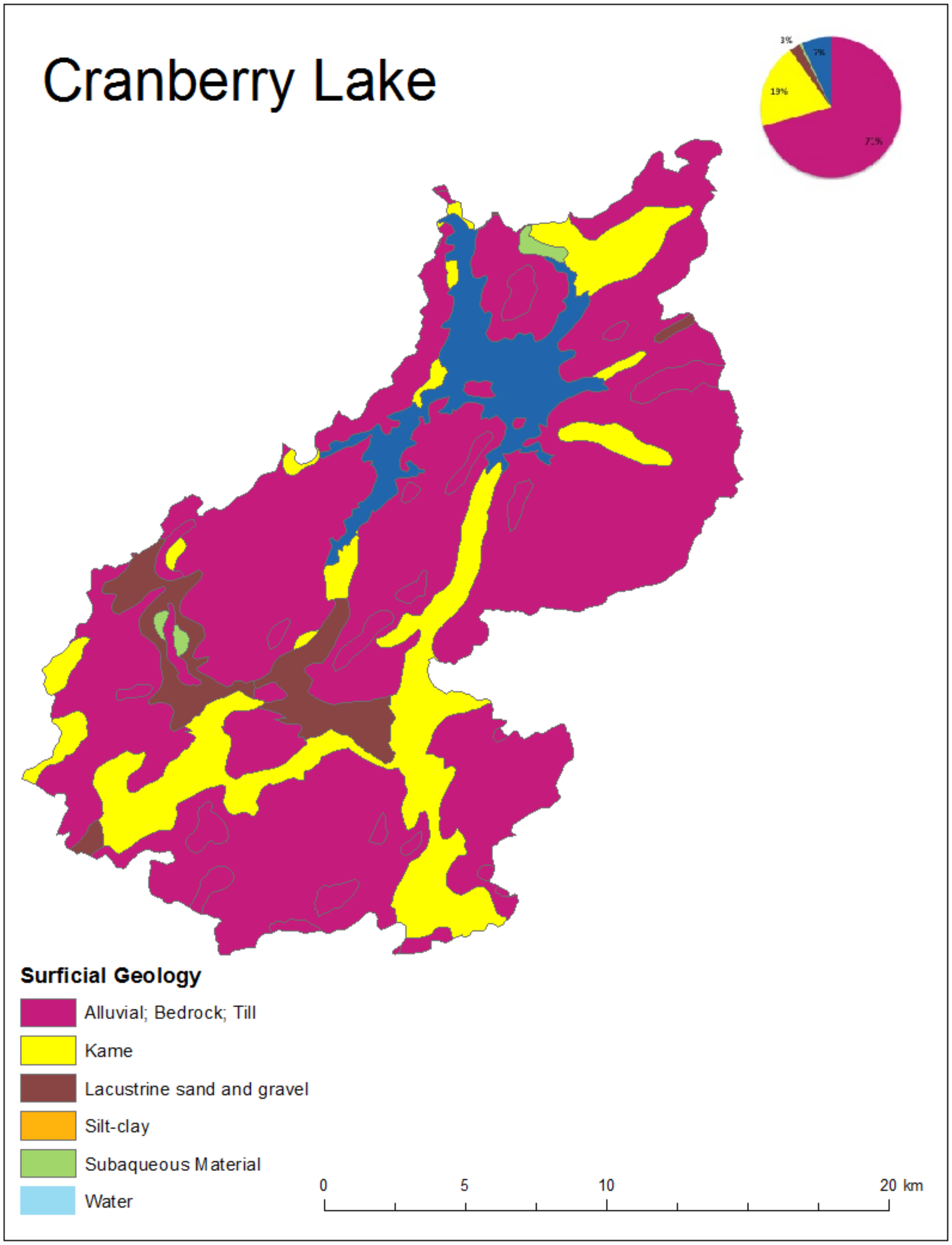

Figure 25: Surficial geology distribution across Cranberry Lake’s watershed.

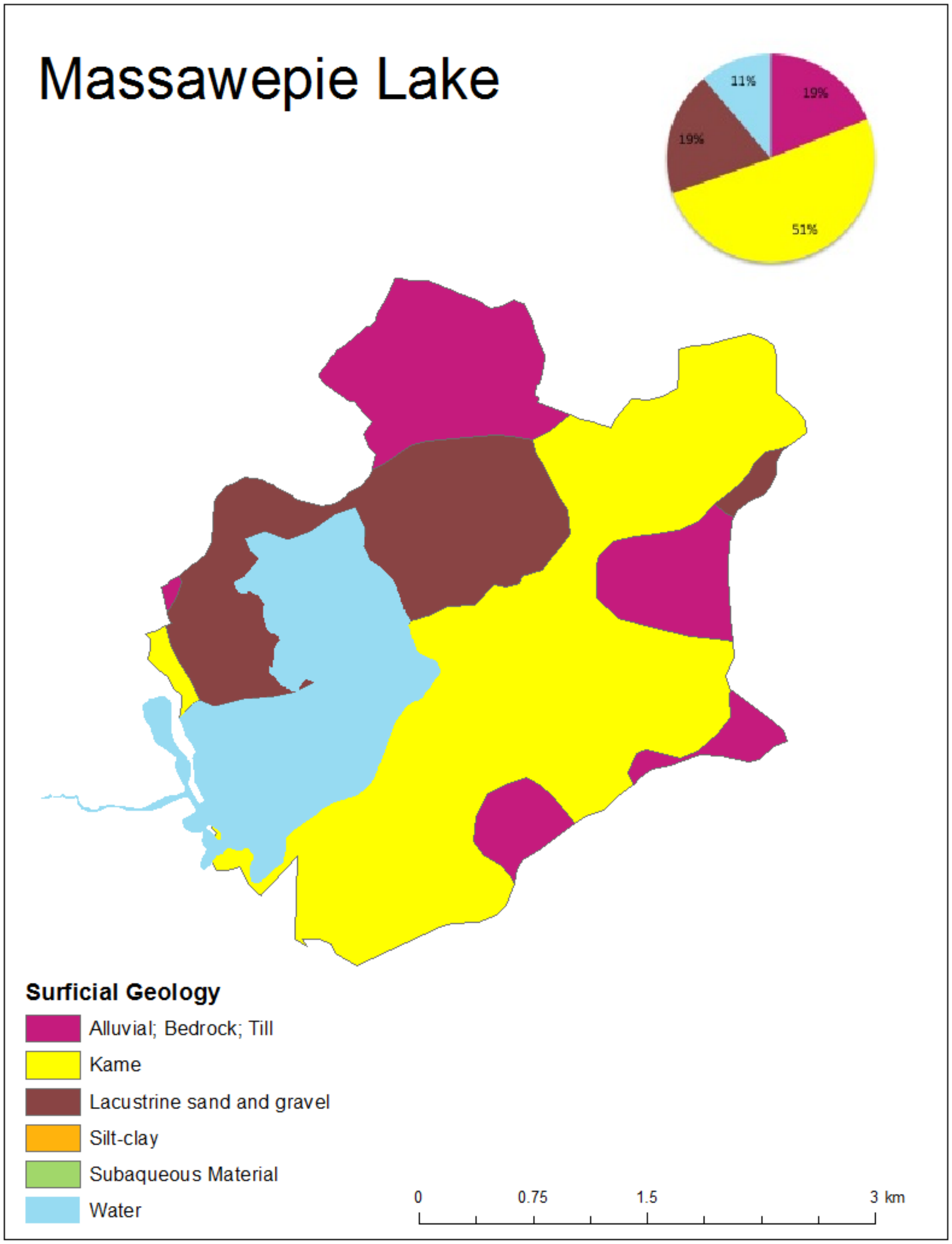

Figure 26: Surficial geology distribution across Massawepie Lake's watershed.

Table 4: Calculated lake watershed surficial geology percentages.

	Alluviall; Bedrock; Till	Kame	Lacustrine Sand and Gravel	Silt	Subaqueous Material	Water
Lake Bonaparte	59.44	15.42	0.43	0.00	24.71	0.00
Black Lake	25.13	3.01	12.14	50.97	6.51	2.25
Tupper Lake	82.49	8.75	2.74	0.16	1.58	4.26
Carry Falls	76.98	14.29	2.95	0.13	1.69	3.96
Higley Flow	73.96	17.59	2.97	0.12	1.78	3.58
Norwood Lake	73.21	16.37	4.16	1.20	1.59	3.21
Massawepie Lake	18.94	50.60	19.30	0.00	0.00	11.15
Cranberry Lake	70.72	19.39	2.51	0.00	0.48	6.89
Trout Lake	19.77	0.00	0.00	80.23	0.00	0.00
Sylvia Lake	43.08	0.00	0.00	56.92	0.00	0.00

Table 5: Correlations table for surficial geology types (top value is Pearson correlation and bottom value is p-value)

```
          ABTT    KAME    LACU    SILT    SUBA
KAME    -0.079
         0.828

LACU    -0.506   0.696
         0.135   0.025

SILT    -0.689  -0.631  -0.156
         0.027   0.050   0.666

SUBA     0.052  -0.052  -0.163  -0.186
         0.886   0.886   0.653   0.608

WATR_1  -0.010   0.873   0.723  -0.565  -0.389
         0.978   0.001   0.018   0.089   0.266
```

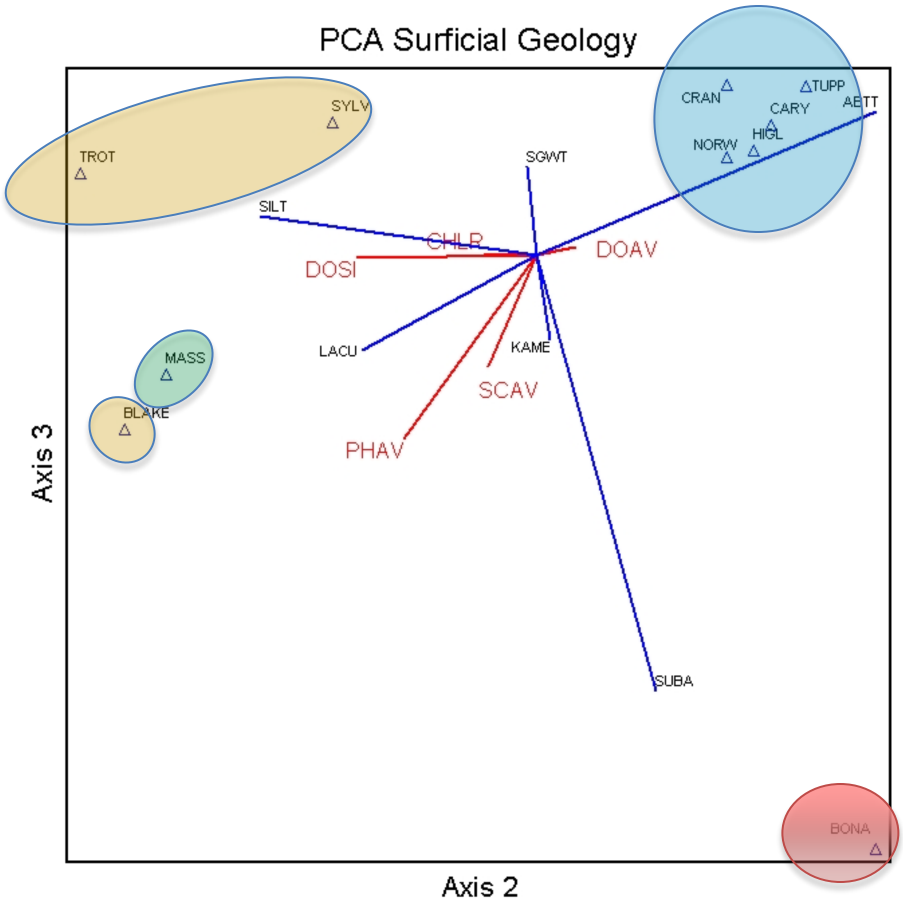

Figure 27: PCA graph on lake watershed surficial geology. Blue lines depict associations between surficial geology types and lakes. Red lines depict associations between water quality characteristics and lakes. Longer lines have stronger relationships than shorter lines. Colored circles demonstrate groupings of lakes.

Table 6: PCA eigenvalues for lake watershed surficial geology

Variable	1	2	3	4	5	6
ABTT	-0.0197	**0.6973**	0.2942	0.2998	-0.0592	**0.5774**
KAME	**0.5553**	0.0277	-0.1750	-0.5897	-0.4476	0.3349
LACU	0.4643	-0.3583	-0.1966	**0.7367**	-0.2333	0.1424
SILT	-0.3690	-0.5685	0.0801	-0.1113	0.1509	**0.7064**
SUBA	-0.1351	0.2468	-0.8972	0.0254	0.2931	0.1712
SGWT	**0.5668**	-0.0207	0.1811	-0.0817	**0.7957**	0.0761

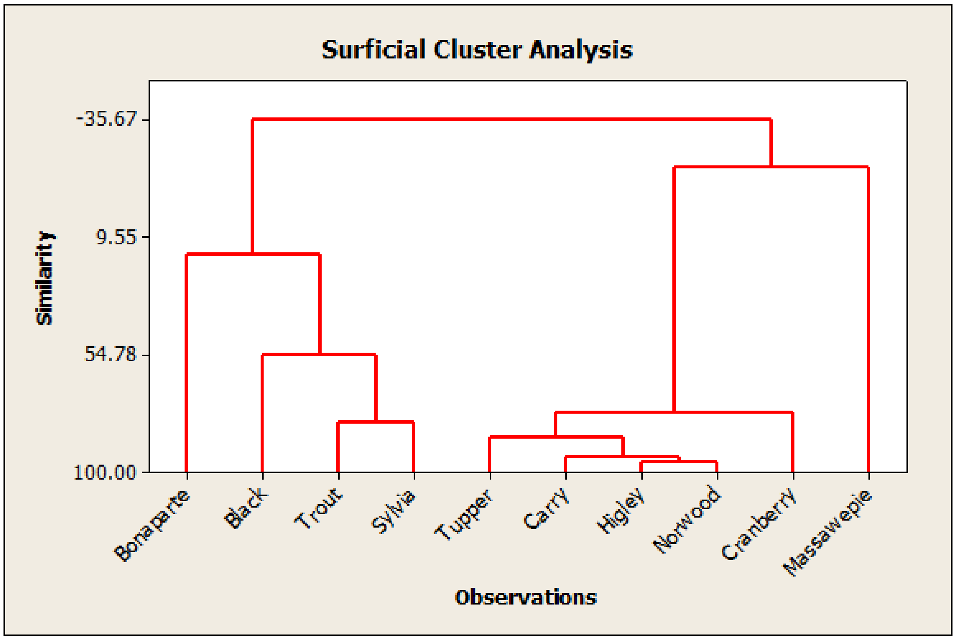

Figure 28: Cluster analysis dendrogram on lake watershed surficial geology (generated in Minitab 16).

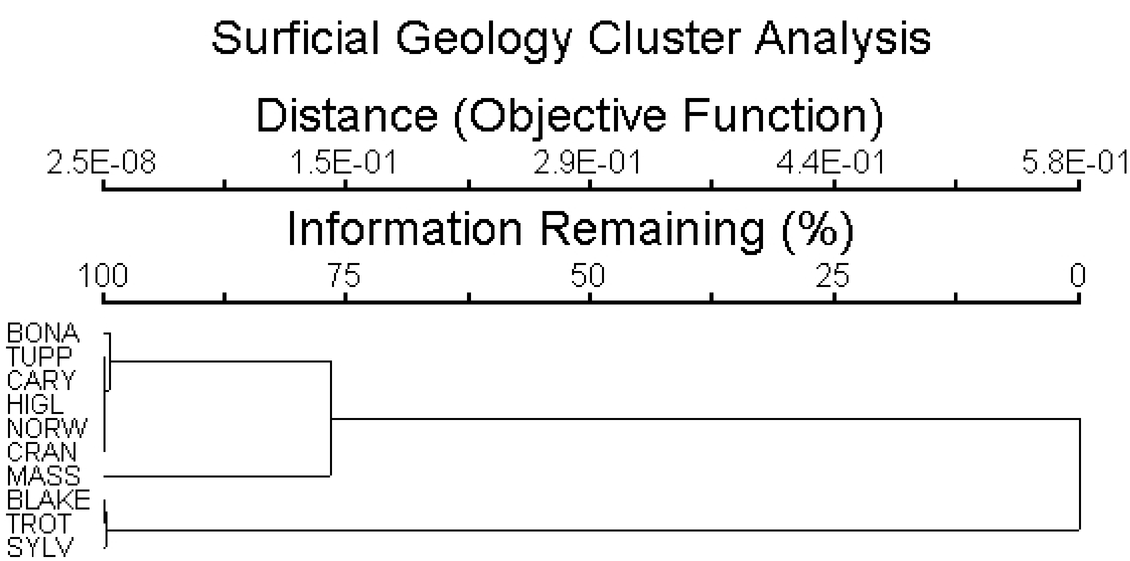

Figure 29: Cluster analysis dendrogram on lake watershed bedrock geology (generated in PC-ORD 6.12).

5. HYDROLOGIC SOIL GROUPS COMPOSITION

Soil data were not available for all watershed areas, complicating the analyses. Comparing watersheds with full watersheds of data to ones missing large sections, which may produce conclusive results, cannot be met with full authority (Table 7). Black Lake watershed has even distributed soil hydrologic groups (Figure 30), whereas Lake Bonaparte, missing data in close to half its watershed, was largely A or B groups (Figure 31). Sylvia Lake (Figure 32) and Trout Lake (Figure 33) had over 75% of their watersheds cover with Other. Sylvia Lake watershed was further covered with less impermeable soils and Trout Lake watershed contained more permeable groups. Over half of Tupper Lake was less permeable soils in its watershed (Figure 34), but the opposite was the case for Carry Falls (Figure 35). The split between more and less permeable groups were visually the same in Higley Flow (Figure 36) and Norwood Lake watersheds (Figure 37). Lake Massawepie’s watershed contained slightly higher amounts of more permeable soils, but Other was also slightly increased in amount (Figure 38). Cranberry Lake watershed was similar, but contains greater amounts of more permeable soils (Figure 39).

As expected, hydrologic soil groups A and B were well correlated and C and D were highly correlated (Table 8). In effect, three groups would probably have sufficed for analysis: more permeable, less permeable, and other. This was clearly seen in the PCA showing the three groupings of hydrologic soil types (Figure 40). In the PCA graph, more permeable soils aligned well with increased amounts of dissolved oxygen, shallower Secchi depths, and higher levels of pH. Gémesi *et al*. (2011) noticed hydrologic soil potential impacted Secchi depth in more permeable soil by allowing for more sediment transport, decreasing visibility. Because many nutrients have strange particulate dynamics and temporal scales of transport, they are difficult to relate to land use; therefore, soil types’ adsorption ability is important to consider. The importance of soil types was described by Johnson *et al*. (1997).

Soil importance increases the closer one approaches the lake. Chang (2008) demonstrated the importance of soil factors in riparian zones especially for pH total nitrogen, and total phosphorus, and oxygen demand. Well drained soils allow movement of oxygen demand variables and nutrients. Soils around the lakes determine how quickly water moves through lake, whereas catchment soils would regulate how quickly water reaches the lake.

Surficial geology is the parent material for soils, implying soil characteristics would reflect surficial geology characteristics. This, however, was not seen in the study area. Often lake watersheds with C and D soils were ones with more permeable surface geology, while the opposite was true for the A and B soils. Types absorbing more water, as less water will reach lower sections, led to waters with higher concentrations of nutrients. Watersheds with mostly impermeable soils will have diluted water given more water progresses down the watershed. This was reflected in the lake health, for the Raquette River lakes generally had better water quality than the other lakes.

Cluster analysis for hydrologic groups varied minutely between the two software programs. Minitab put the grouping of Black Lake and Massawepie Lake after the Raquette River grouping plus Cranberry and before Lake Bonaparte (Figure 41). PC-ORD put Black Lake and Massawepie Lake meeting with Trout and Sylvia Lakes before proceeding to the others.

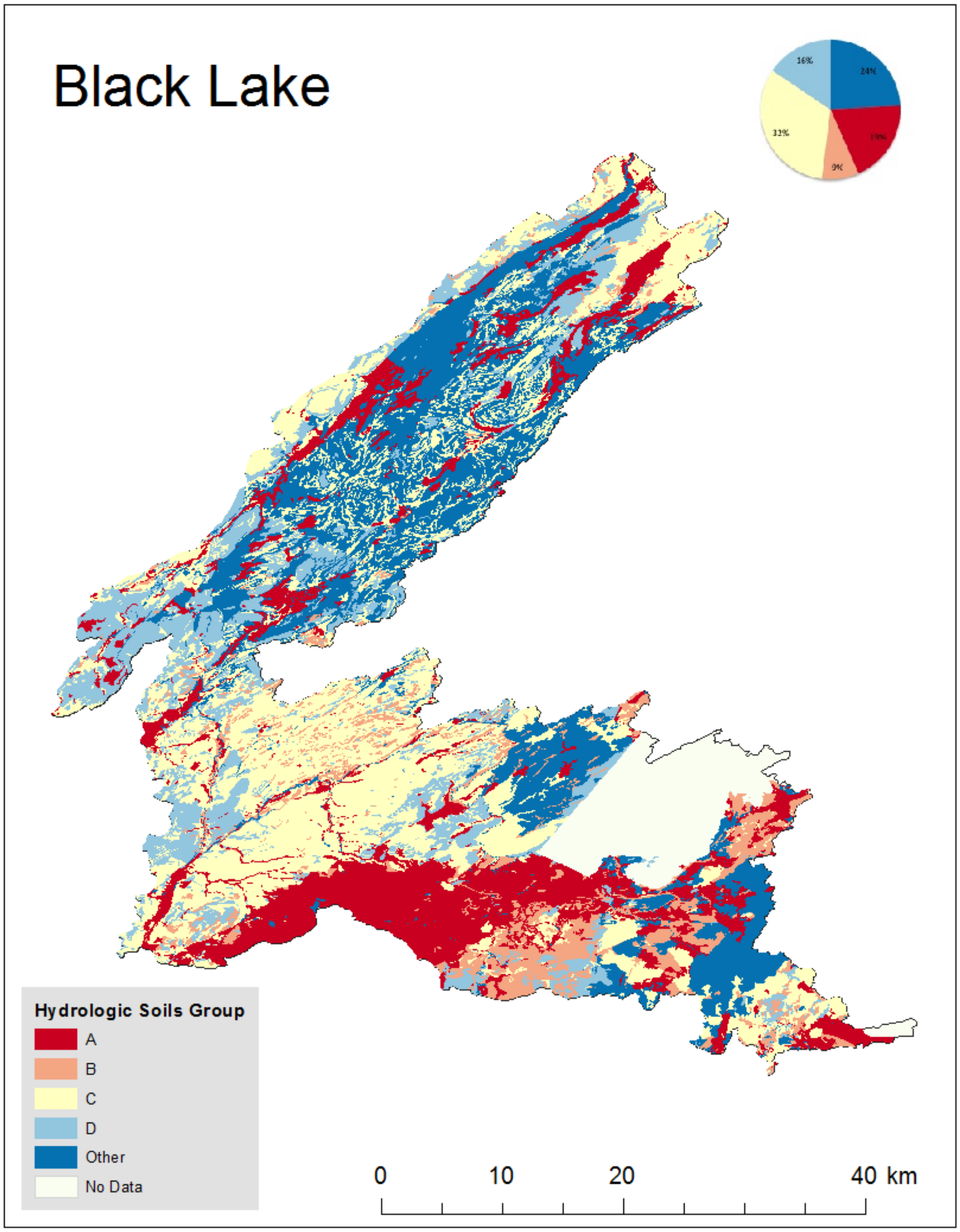

Figure 30: Soil hydrologic group distribution across Black Lake's watershed.

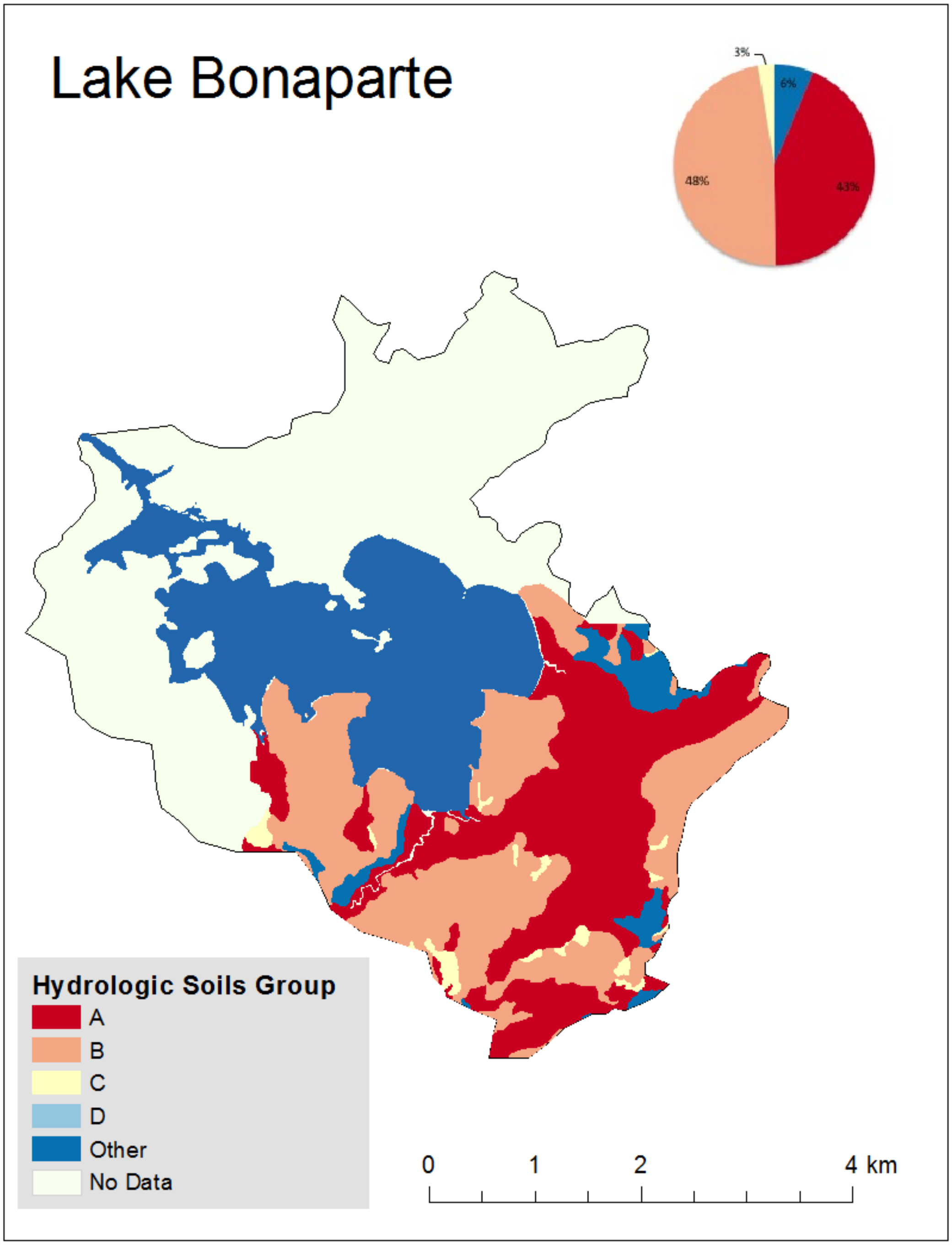

Figure 31: Soil hydrologic group distribution across Lake Bonaparte's watershed.

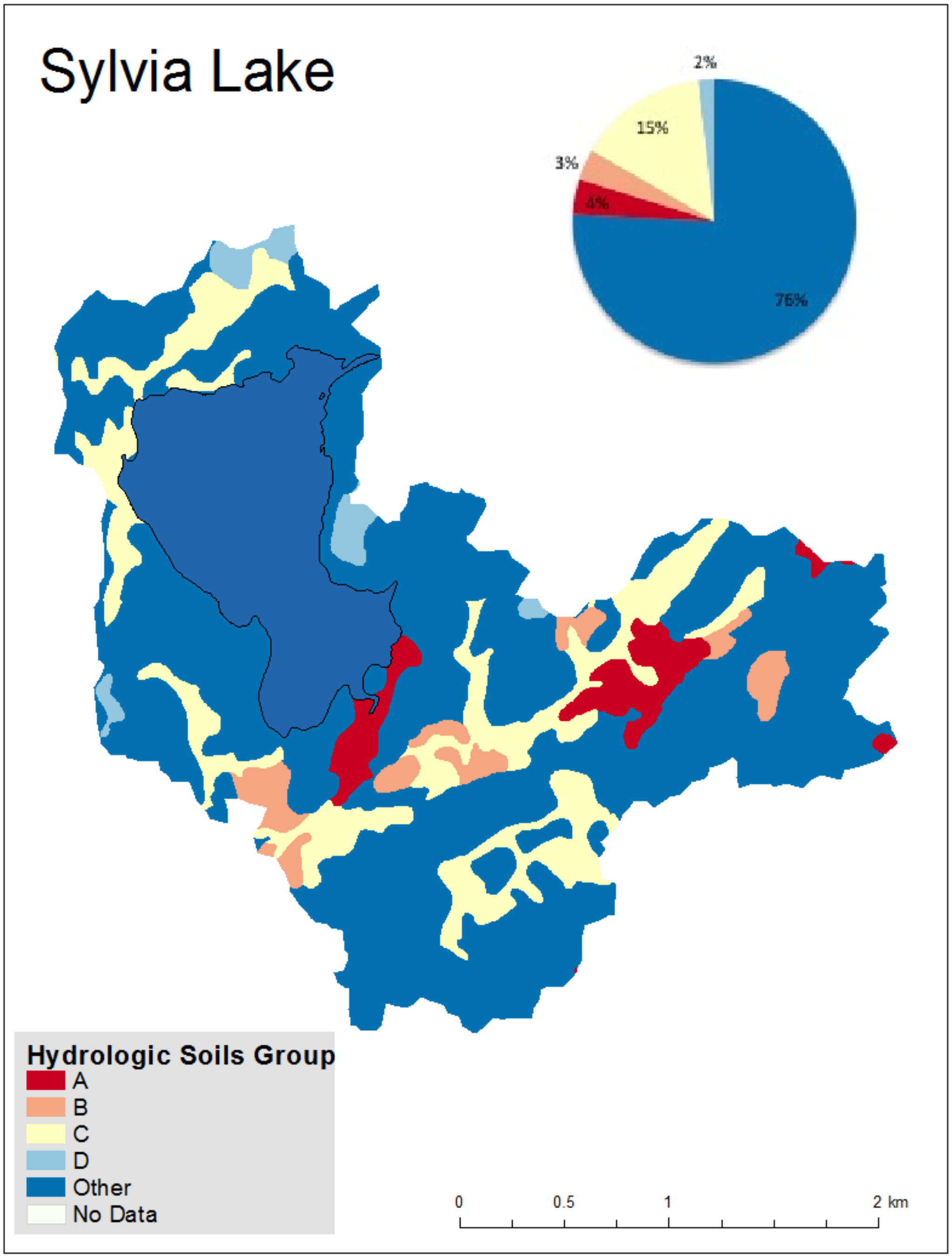

Figure 32: Soil hydrologic group distribution across Sylvia Lake's watershed.

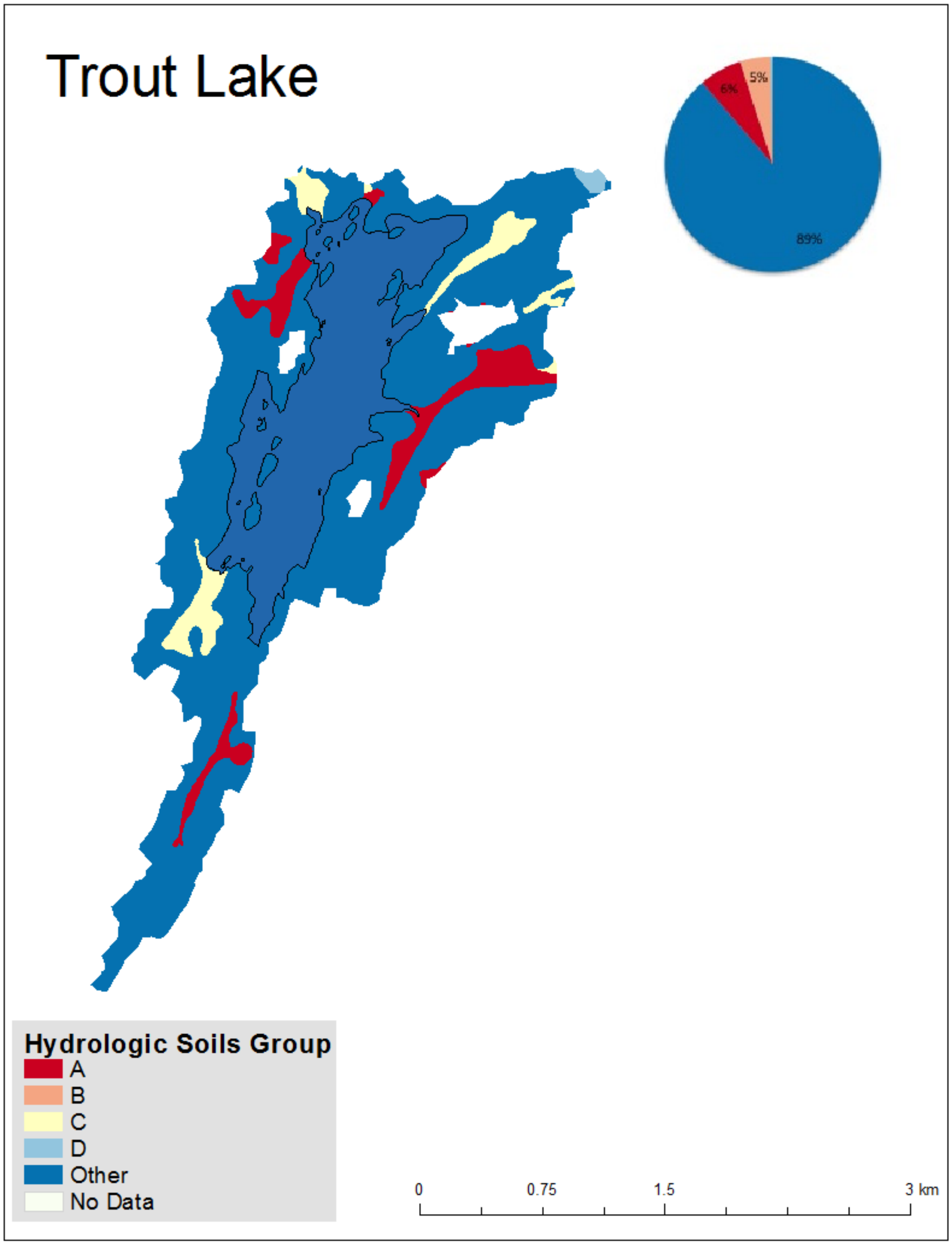

Figure 33: Soil hydrologic group distribution across Trout Lake's watershed.

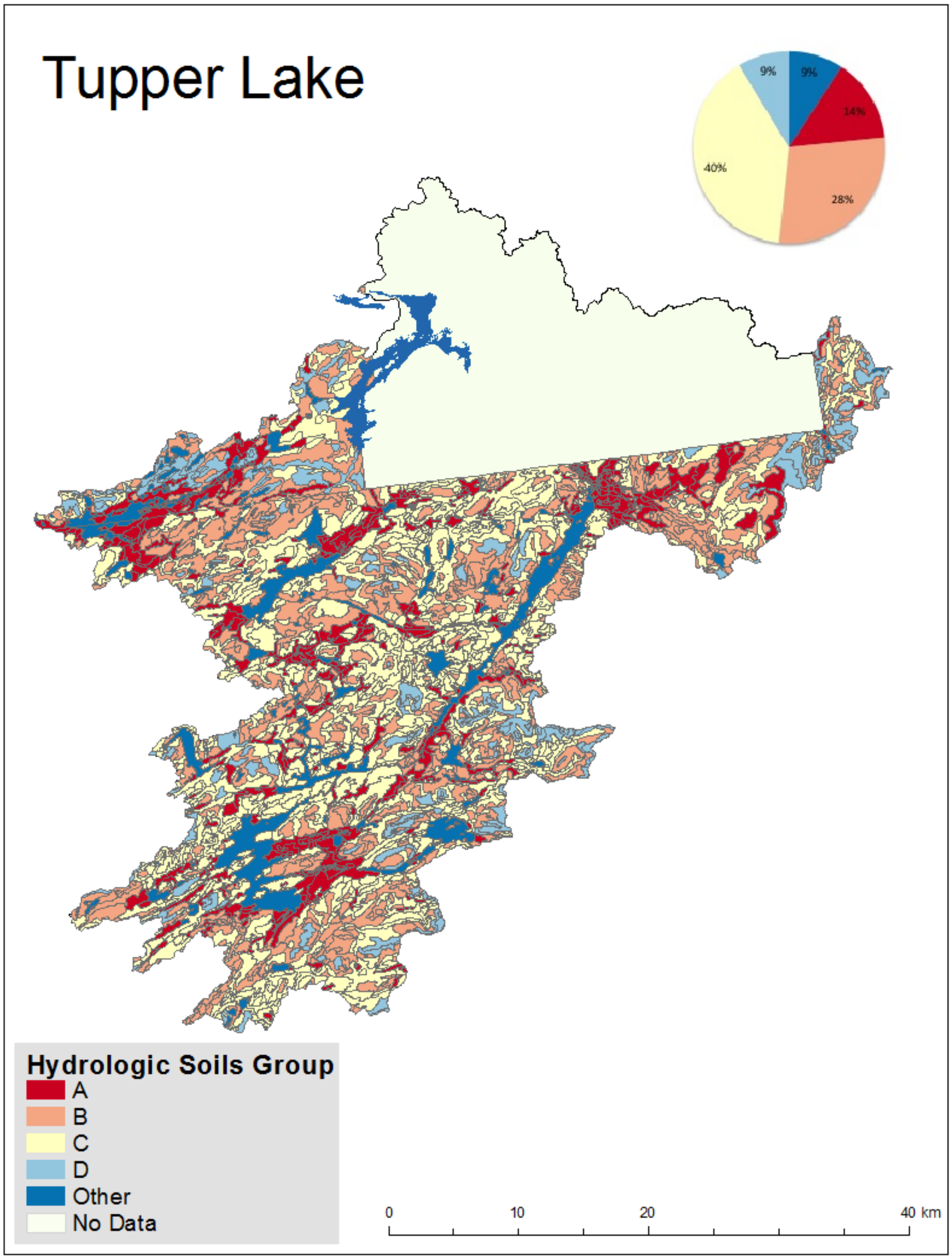

Figure 34: Soil hydrologic group distribution across Tupper Lake's watershed.

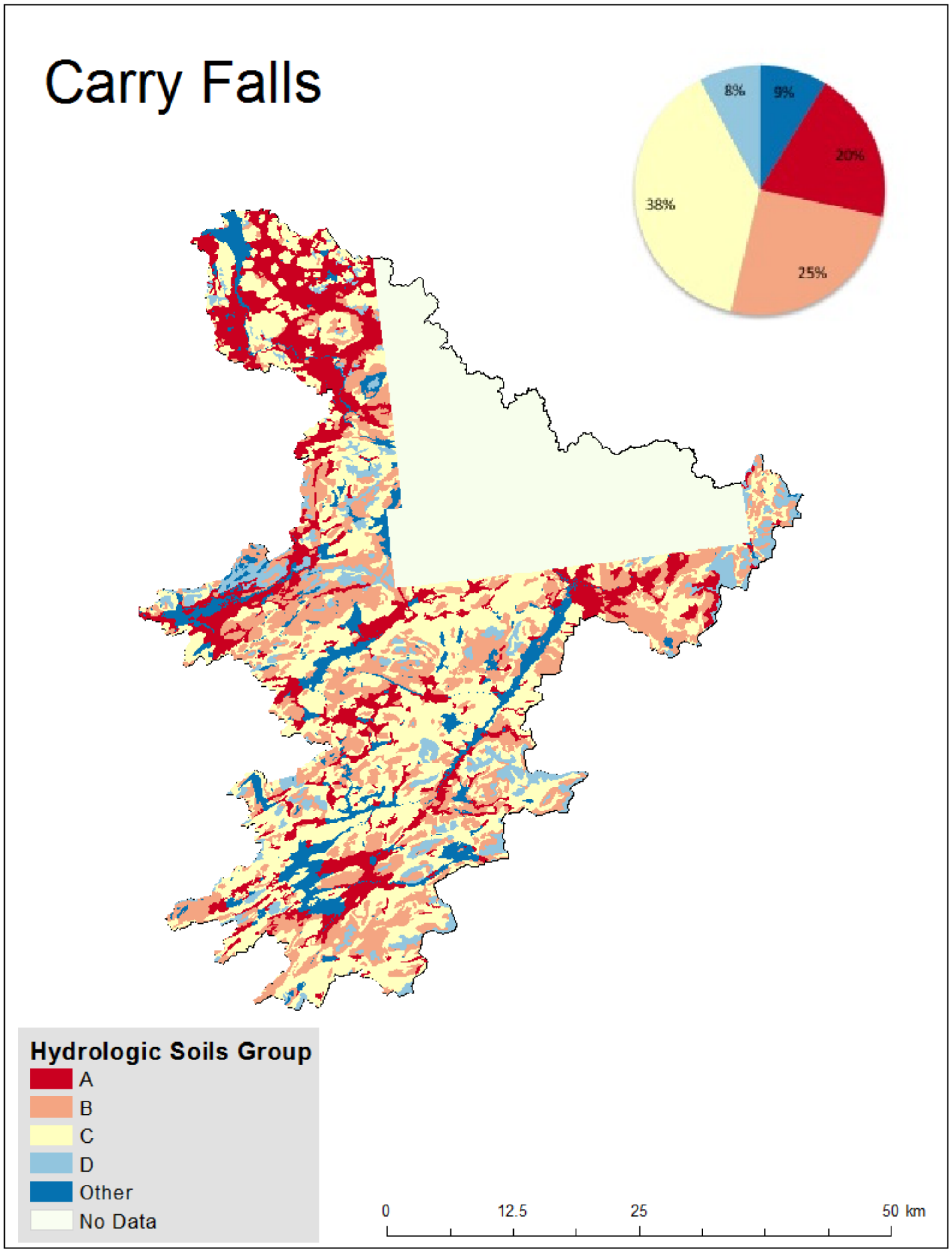

Figure 35: Soil hydrologic group distribution across Carry Falls' watershed.

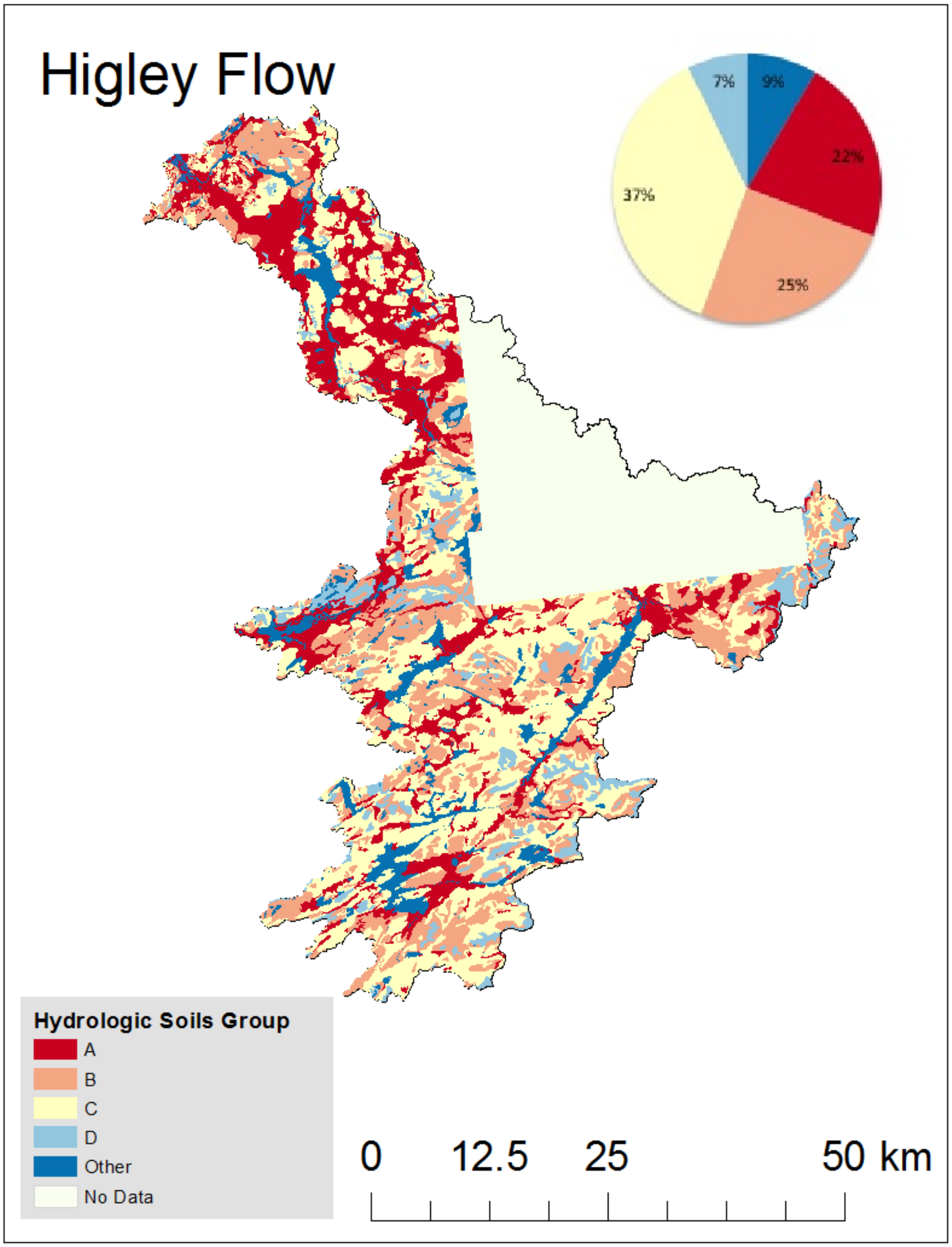

Figure 36: Soil hydrologic group distribution across Higley Flow's watershed.

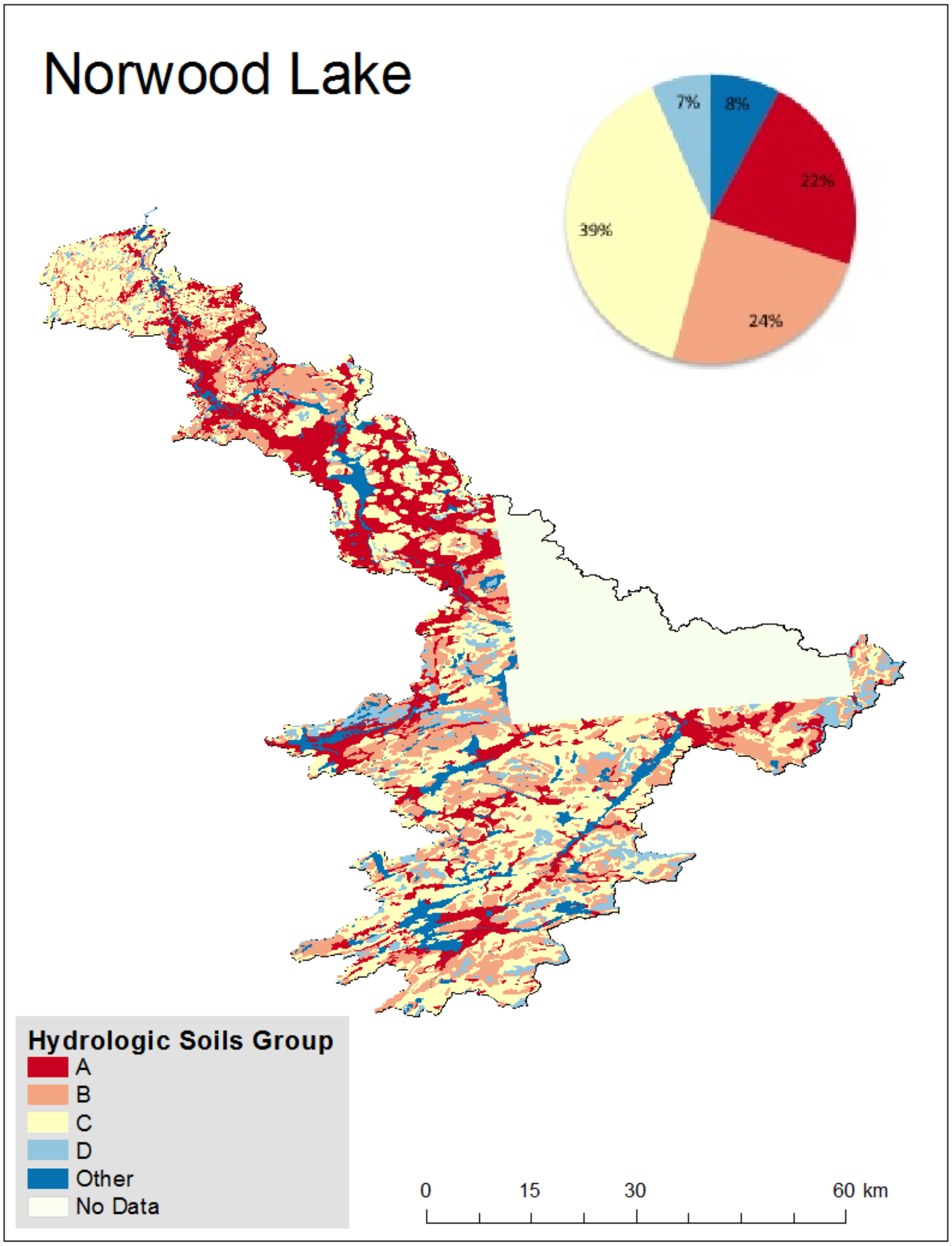

Figure 37: Soil hydrologic group distribution across Norwood Lake's watershed.

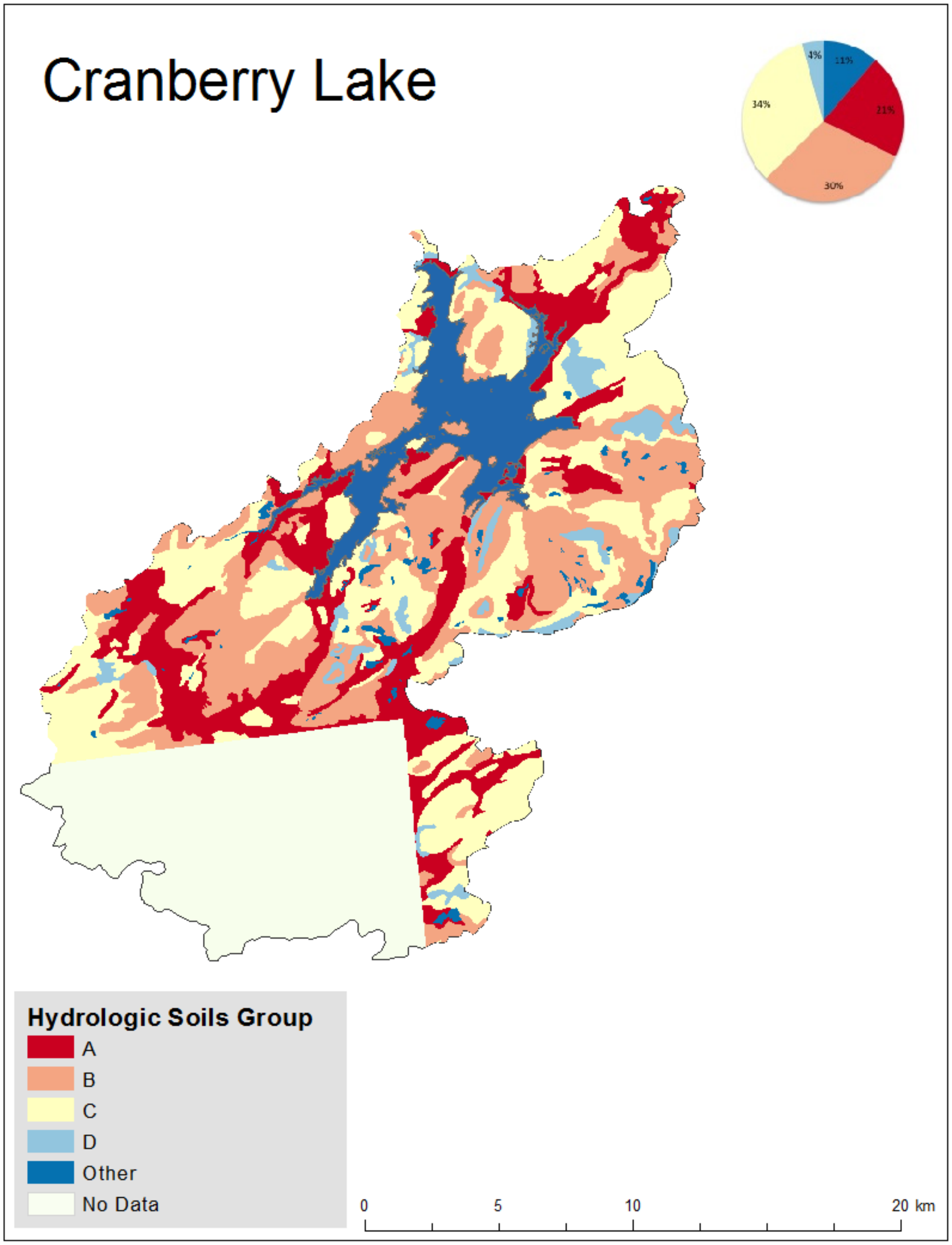

Figure 38: Soil hydrologic group distribution across Cranberry Lake's watershed.

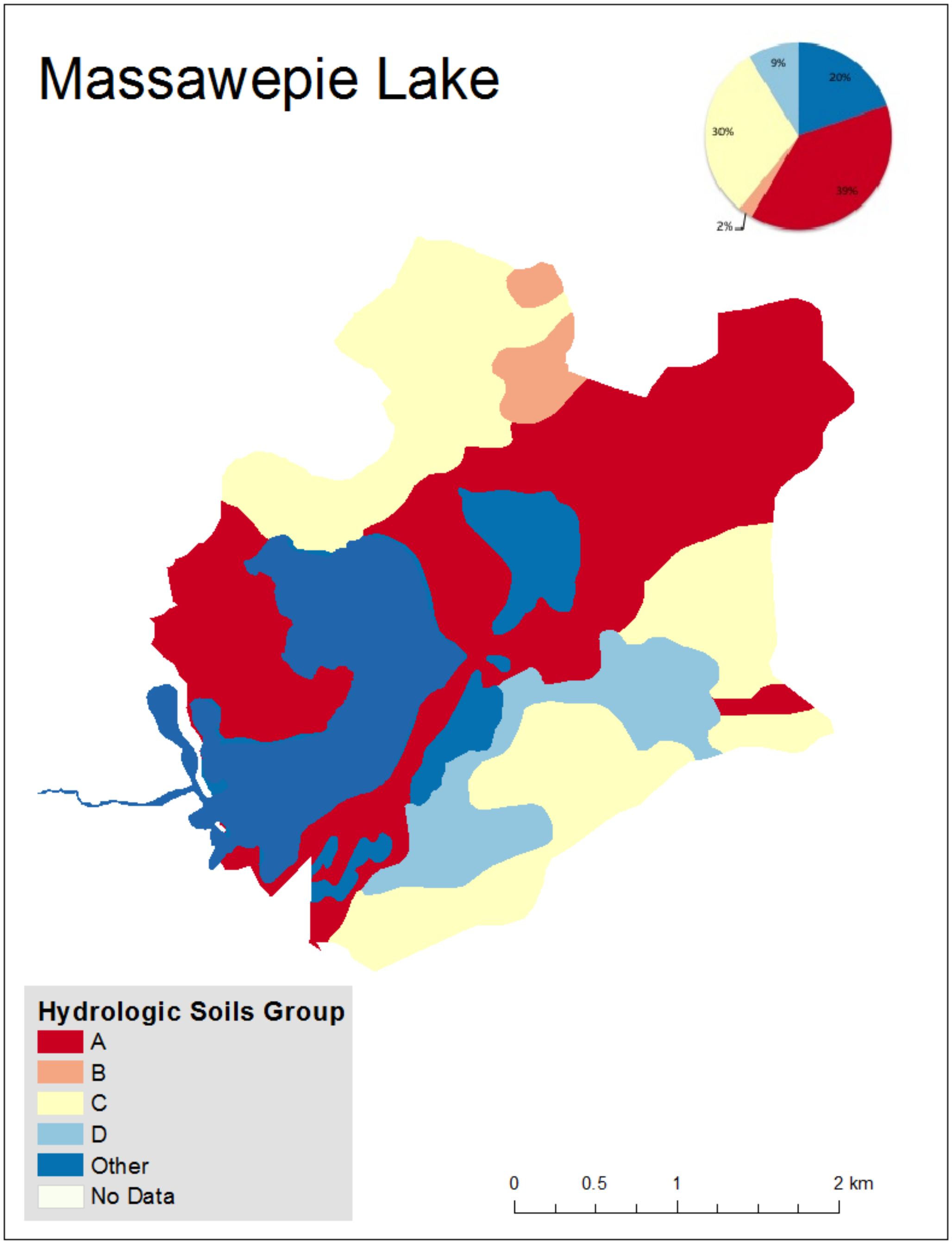

Figure 39: Soil hydrologic group distribution across Massawepie Lake's watershed.

Table 7: Calculated lake watershed soil hydrologic group percentages.

	Other	A	B	C	D
Lake Bonaparte	6.35	43.37	47.71	2.56	0.00
Black Lake	24.07	19.34	8.61	32.36	15.62
Tupper Lake	9.23	14.15	28.26	39.69	8.67
Carry Falls	8.77	19.67	25.27	38.43	7.86
Higley Flow	8.48	22.30	24.82	37.21	7.20
Norwood Lake	7.82	22.28	24.14	39.10	6.65
Massawepie Lake	19.68	38.69	2.50	30.33	8.81
Cranberry Lake	11.25	20.97	30.22	33.36	4.19
Trout Lake	88.65	6.43	0.00	4.55	0.37
Sylvia Lake	75.78	3.99	3.52	14.92	1.79

Table 8: Correlations table for soil hydrologic groups (top value is Pearson correlation and bottom value is p-value)

```
        OTHR     ASOL     BSOL     CSOL
ASOL  -0.659
       0.038

BSOL  -0.724    0.499
       0.018    0.142

CSOL  -0.626   -0.024    0.092
       0.053    0.948    0.801

DSOL  -0.437    0.066   -0.185    0.731
       0.207    0.857    0.609    0.016
```

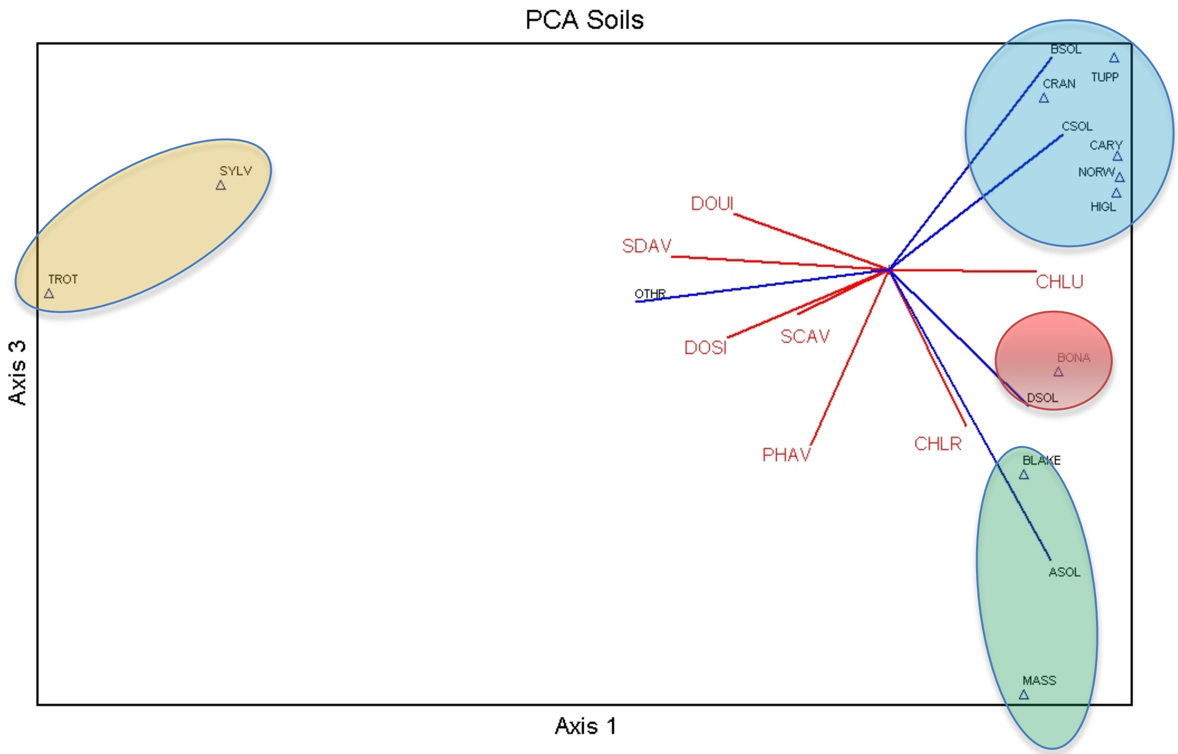

Figure 40: PCA graph on lake watershed soil hydrologic groups. Blue lines depict associations between hydrologic soil groups and lakes. Red lines depict associations between water quality characteristics and lakes. Longer lines have stronger relationships than shorter lines. Colored circles demonstrate groupings of lakes.

Table 9: PCA eigenvalues for lake watershed soil hydrologic groups

Variable	1	2	3	4	5
OTHR	-0.6196	0.0866	-0.0784	0.0656	**0.7734**
ASOL	0.3971	-0.4094	-0.7098	-0.2680	0.3147
BSOL	0.3988	-0.4895	0.5193	0.4226	0.3912
CSOL	0.4265	0.4984	0.3297	-0.5708	0.3677
DSOL	0.3427	**0.5804**	-0.3341	**0.6477**	0.1207

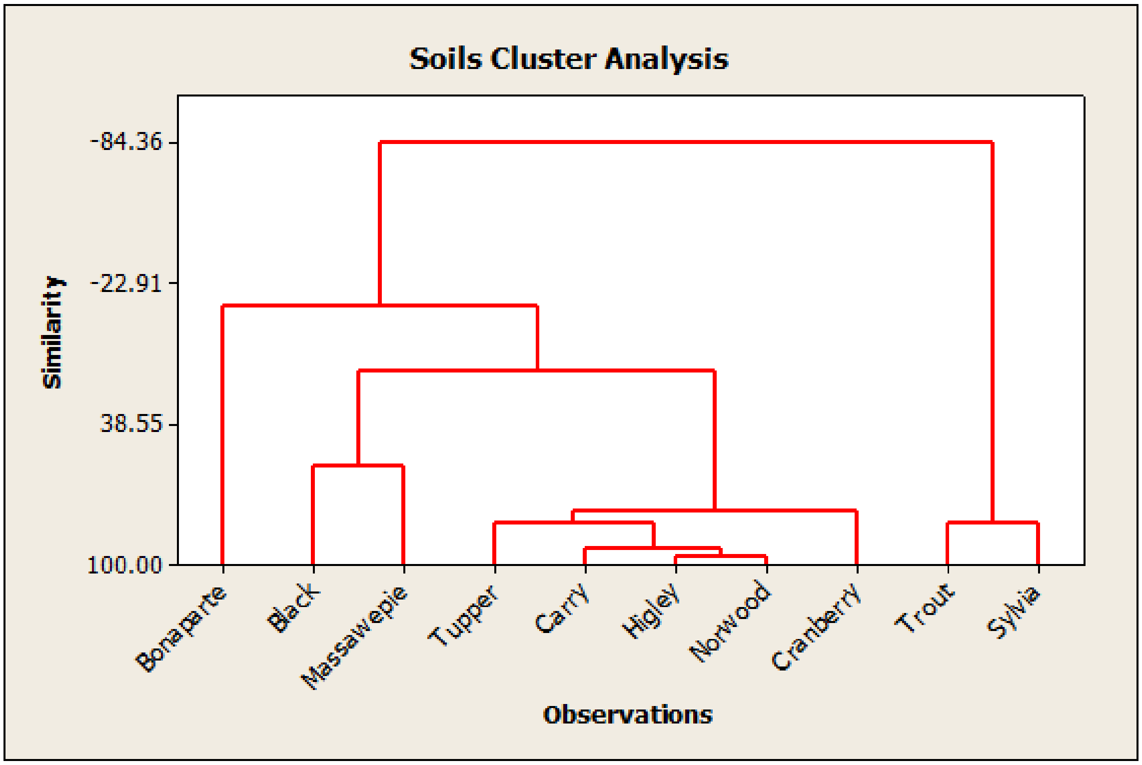

Figure 41: Cluster dendrogram on lake watershed surficial geology (generated in Minitab 16).

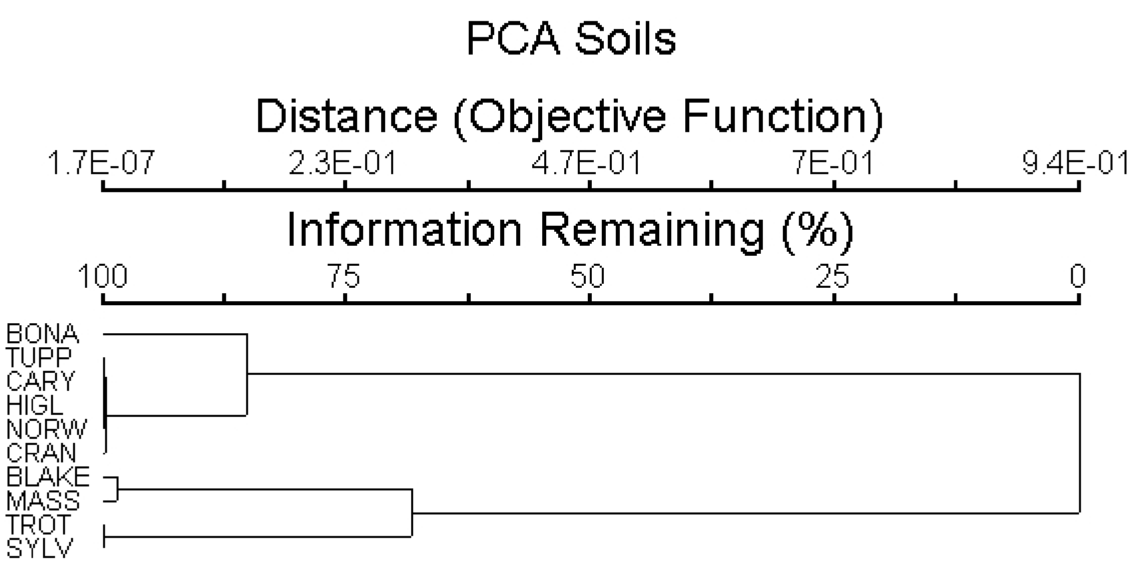

Figure 42: Cluster dendrogram on lake watershed surficial geology (generated in PC-ORD 6.12).

6. LANDSCAPE COMPOSITION

Landscape composition incorporates many natural factors, such as slope, elevation, lake size, and watershed size. Although we can visually display landscape composition easily, it is much harder to analyze through a regression means due to the interconnectedness of all the variables. For instance, a large lake body typically has a larger watershed, as seen in this study area except Norwood Lake, so separating the influence of the lake size from the watershed size, which is influencing the lake size, is a challenge. Numerous landscape composition factors were investigated (Table 10). Although many landscape patterns are difficult to analyze, some are not. Human density in a catchment and around the lake were easily measured and linked to water quality. When the entire catchment was taken into consideration, human density ranged dramatically (Figure 43), with Massawepie Lake having the least number of individuals and Norwood Lake the greatest. Watershed size and human density in the catchment were highly correlated. Human densities around lakes were well correlated with the size of the lake (Figure 44). Larger lakes, typically, had more people around them.

Urban centers were significant factors in the landscape composition, as they concentrated human populations, with Indian River and Raquette Rivers possessing almost all major urban centers of influence in the study area. Along the Indian River, Antwerp, Philadelphia, Theresa, Redwood, and Hammond concentrated humans, allowing for increased anthropogenic activities to affect the lake bodies. The one urban center on the Oswegatchie River is Cranberry Lake, but it is at the north end of the lake, reducing its impact on the lake water quality. Except for villages of Long Lake and Tupper Lake, the Raquette River does not experience major urban influence until the north end. Four urban centers align to impact Norwood Lake, experiencing greater impacts from human density (Figure 45). Greater lake isolation, distance from a town or city, suspects a less dense human population and reduced impact from the population, allowing for more improved lake water quality.

Data from the correlation analysis supported the PCA results (Table 11). Lake temperature and lake size were highly correlated and had the same direction of influence in the PCA. Lakes with smaller area, if all else is equal, should have higher lake temperatures, but this was not the case for the study lakes. On the other hand, lakes at higher altitudes may have lower temperatures due to the colder climate and colder water entering the system sooner. When separated by high and low elevation, lakes in the study area showed no trend between lake size and lake temperature. Lake temperature and human density were also highly correlated. Numerous anthropogenic activities are known to have impacts on lakes, increasing lake temperature; for instance, nutrient dumping by humans increases chlorophyll a levels, making the lake darker and absorbing more energy. Correlations displayed catchment density and watershed size were linked as were lake size and 100-meter density, suggesting larger catchments can hold more people because larger lakes will support more people. The Minitab (Figure 46) and PC-ORD (Figure 47) dendograms were highly variable and did not appear to show any general trend.

Geography, more importantly spatial proximity, is believed to play an important role in determining lake ecology. Kratz *et al*. (2006) suggests a lake's location relative to other lakes can influence the physical, chemical, and biotic differences among lakes and explain how each lake responds differently to regional climate. Within the Han River basin, South Korea, geographically adjacent systems possessed similar lake temperature, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, total phosphorus, and total nitrogen levels (Chang 2008). Suspended sediment and pH, however, were not spatial similar, indicating surface geology spatial heterogeneity can influence lake water quality. Geography appeared to have an influence on water quality in the study area, as two major spatial groupings were noticed (Figure 45): (1) Sylvia Lake, Trout Lake, and Lake Bonaparte; (2) Massawepie Lake and Cranberry Lake. However, the Raquette River seemed to have overall control on its lakes and Black Lake was different from all the rest.

Gémesi *et al*. (2011) found watershed configuration accounted for more variation in lake water quality than simple composition. Spatial proximity also played a significant role. He proposed changing the configuration of the land cover could reduce nutrient runoff and improve water quality, whereas composition would have no effect. Decreasing agriculture land cover percentage, although helps reduce sediment and nutrient input, has significant economic ramifications, especially for the North Country and any other farming community. Changing composition is ideal for these types of communities because it improves water quality but does not alter production. Ideal composition, according to Gémesi *et al*. (2011) would have high forest concentration, with forest clusters or grasslands to buffer the cropland (create small islands). When lakes have urban centers within 30m, riparian vegetation should be increased, with trees and perennials preferred. Additionally, limiting future development needs or having practices maintain natural vegetation will ensure water quality is not degraded. Land managers should work together with the agriculture community to change the configuration of the land, to maintain productivity while decreasing impacts on water quality.

Composition has many dimensions influencing water quality. Locations of certain landscapes, for instance, have immense impacts on the effectiveness of the habitat to maintain water quality. When forests were close to water bodies, water bodies typically had lower total phosphorus (Gémesi *et al*. 2011). Land cover type distance from a lake is important to water quality. When forests are further away from lakes, lakes are more prone to poorer water quality. Cohesion of landscape and high connectivity ability allow for the possibility of higher levels nutrients, since they provide an easier ability to move through the system. Because slope increases runoff potential, steeper watersheds will more likely have higher sediment loads (Richards *et al*. 1996; Sliva and Williams 2001). Slope is more of a secondary factor, behind geology and land use/land cover, but watershed slope characteristics cannot be altered easily. Many lakes in the study area comparatively more isolated than others generally had better water quality. In comparison to land cover percentage, Wear *et al*. (1998) found evidence that remote portions of a watershed and outer edge of urban development may hold disproportionate amount of influences over future water quality.

Undertaking a landscape composition analysis is very challenging. Landscape composition is better understood in natural or simpler watersheds or where a strong urban-rural gradient existed (Griffith 2000). Due to variation among lakes, if a landscape pattern metric form of analysis is rendered, stratification of watersheds between size classes would reduce the effect of size (O'Neill *et al*. 1996; Griffith 2002). More characteristics and variables need weighting in these forms of analyses. Population, for instance, is heavily weighted towards lowlands and is highly correlated to nitrogen

(Ahearn *et al*. 2005) and total suspended sediment is predicated to increase. Lastly, depth is strong indicator of Secchi depth, suggesting deeper lakes would have a better capacity for clearer waters than shallower lakes.

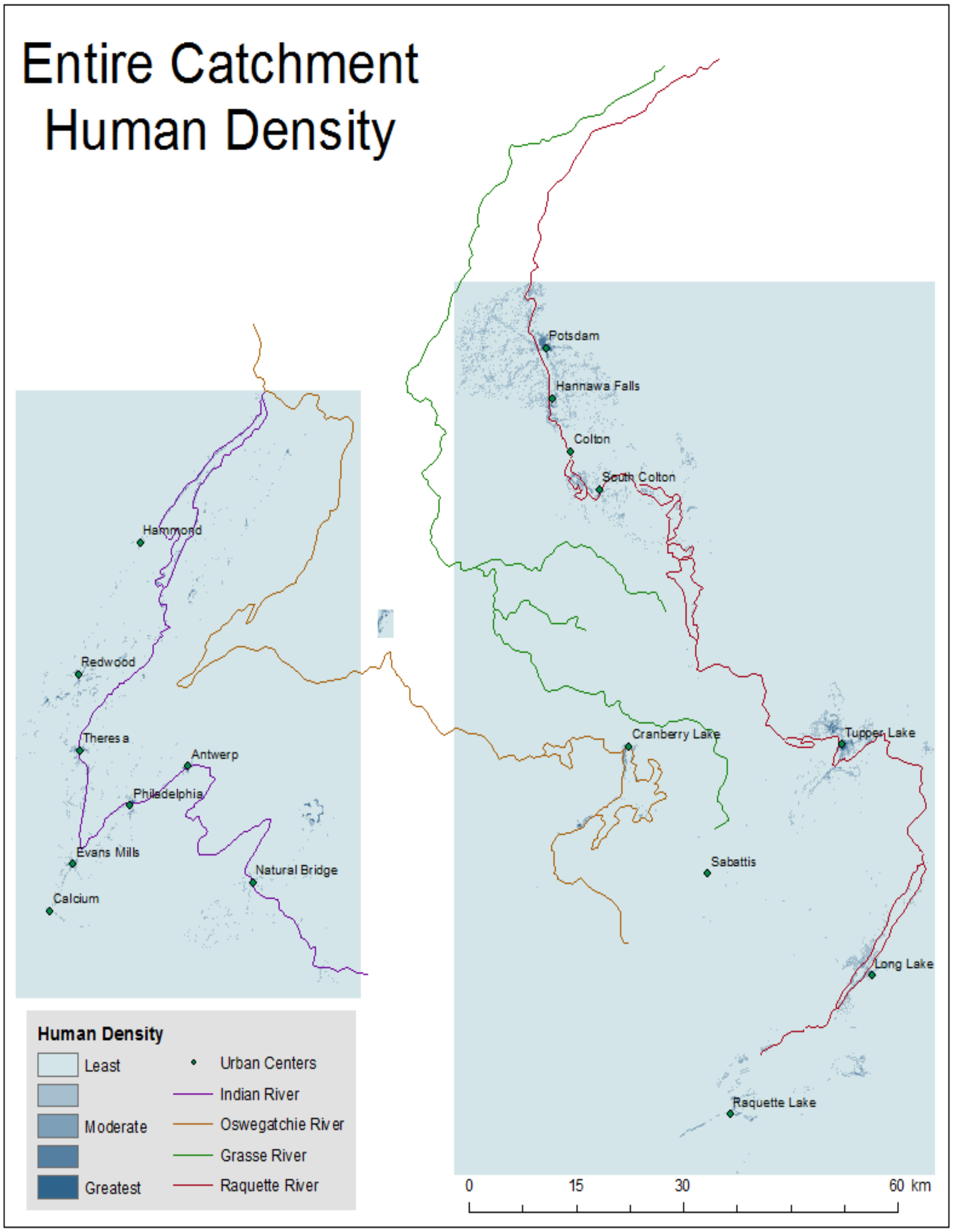

Figure 43: Human density in lake watersheds for the entire study area.

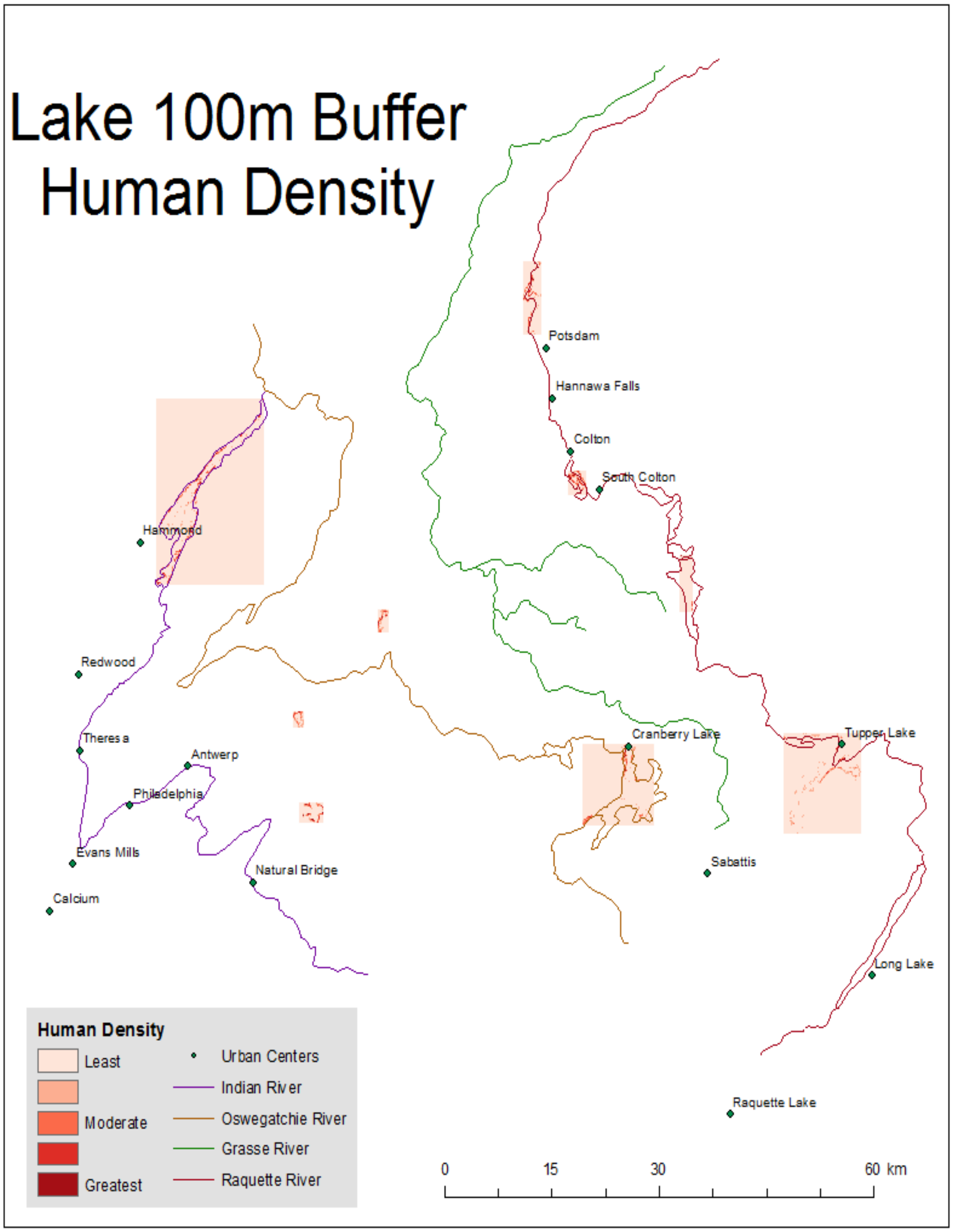

Figure 44: Human density in 100m-lake buffer for the entire study area.

Table 10: Calculated lake watershed landscape composition values.

	Lake Size(m^2)	Watershed Size (m^2)	Elevation (m)	Depth (m)	Temperature (°C), slope	Temperature (°C), spring	Temperature, (°C) summer	Human Density Catchment	Human Density 100m
Lake Bonaparte	5665487	27370000	234	17	-1.02	22.57	23.60	648	445
Black Lake	58550231	1460571928	83	5	0.17	23.22	19.26	10034	875
Tupper Lake	26380000	1840442370	470	17	-0.66	14.87	21.25	5427	403
Carry Falls	12008932	2251248126	422	15	-0.56	21.28	20.41	5953	15
Higley Flow	2408876	2518568417	269	6	-0.30	20.33	21.04	7252	357
Norwood Lake	3147811	2805742784	100	5	-0.23	19.60	21.02	12425	218
Massawepie Lake	1778708	11720287	461	17	-0.85	17.63	19.73	13	0
Cranberry Lake	27500547	371773271	452	11	-0.52	17.75	22.00	647	402
Trout Lake	1446199	5447758	227	18	-0.83	20.50	21.97	237	218
Sylvia Lake	1271211	7569691	199	42	-0.36	15.84	16.12	273	192

Table 11: Correlations table for landscape composition (top value is Pearson correlation and bottom value is p-value)

	LSZE	WSZE	ELEV	DPTH	TEMP	TSPI	TSUI	HDCT
WSZE	0.144 0.692							
ELEV	-0.098 0.788	-0.141 0.697						
DPTH	-0.379 0.280	-0.587 0.074	0.101 0.782					
TEMP	**0.568** **0.087**	0.529 0.116	-0.551 0.099	-0.302 0.397				
TSPI	0.219 0.543	0.147 0.685	-0.512 0.130	-0.523 0.121	0.177 0.625			
TSUI	-0.049 0.892	0.058 0.874	0.190 0.599	-0.574 0.083	-0.497 0.144	0.365 0.300		
HDCT	0.364 0.301	**0.894** **0.000**	-0.467 0.174	-0.640 0.046	**0.729** **0.017**	0.316 0.374	-0.029 0.936	
HDNR	**0.805** **0.005**	0.075 0.837	-0.449 0.193	-0.375 0.286	0.526 0.119	0.374 0.287	0.120 0.741	0.346 0.327

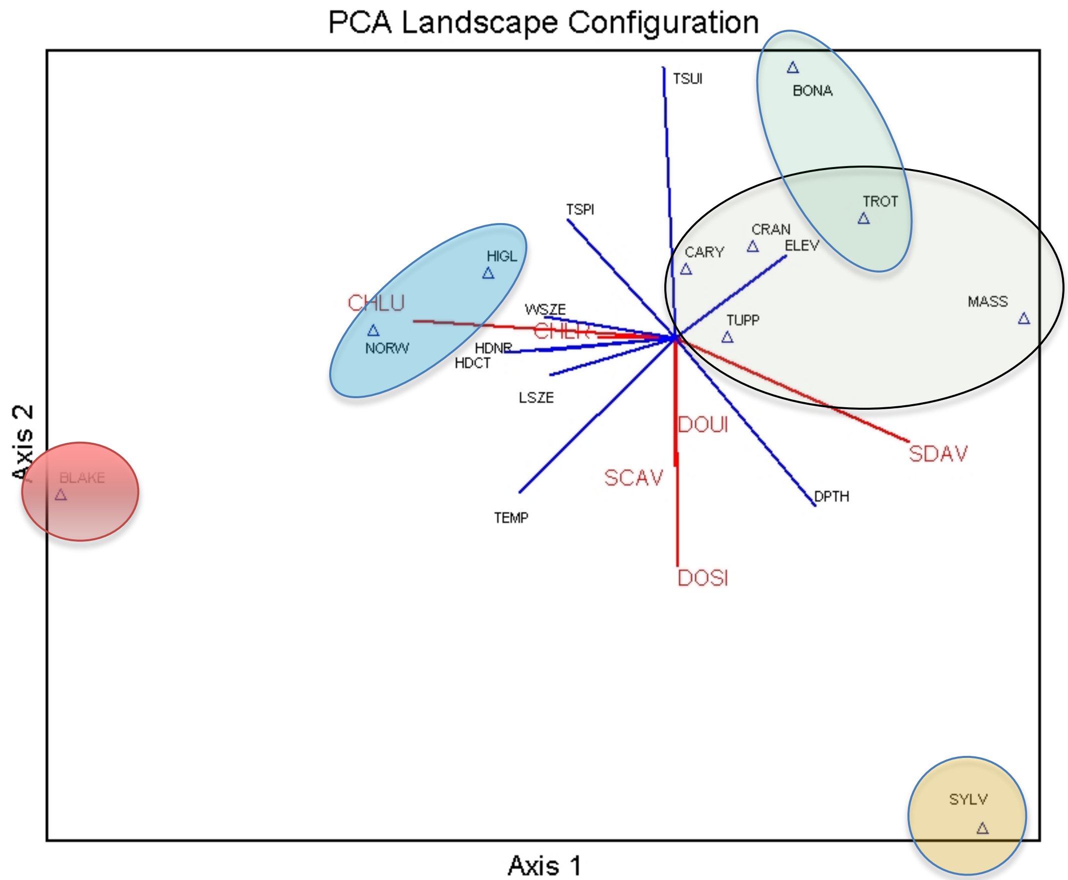

Figure 45: PCA graph on lake watershed landscape composition. Blue lines depict associations between landscape composition and lakes. Red lines depict associations between water quality characteristics and lakes. Longer lines have stronger relationships than shorter lines. Colored circles demonstrate groupings of lakes.

Table 12: PCA eigenvalues for lake watershed landscape composition

Variable	1	2	3	4	5	6
LSZE	-0.3264	-0.0960	0.3840	-0.5206	-0.2351	-0.2004
WSZE	-0.3379	0.0546	-0.5807	-0.0889	0.0648	-0.4543
ELEV	0.2887	0.2132	-0.1727	-0.6560	-0.3934	-0.1125
DPTH	0.3623	-0.4375	0.1241	0.1354	0.1160	-0.6888
TEMP	-0.4046	-0.4013	-0.0647	-0.0505	-0.1248	0.3617
TSPI	-0.2795	0.3083	0.2518	0.4837	-0.6442	-0.2780
TSUI	-0.0300	**0.7015**	0.0843	-0.0294	0.3930	-0.0750
HDCT	-0.4443	-0.0385	-0.3641	0.0255	0.1258	-0.1654
HDNR	-0.3530	-0.0333	0.5127	-0.1855	0.4142	-0.1586

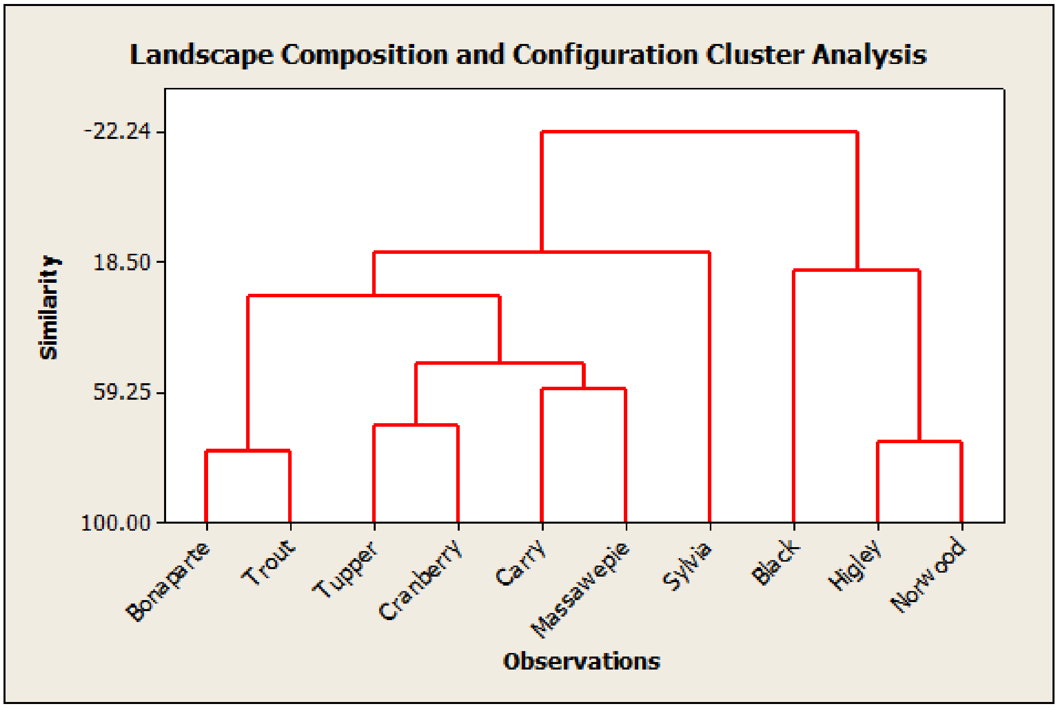

Figure 46: Cluster analysis dendrogram on lake watershed landscape composition (generated in Minitab 16).

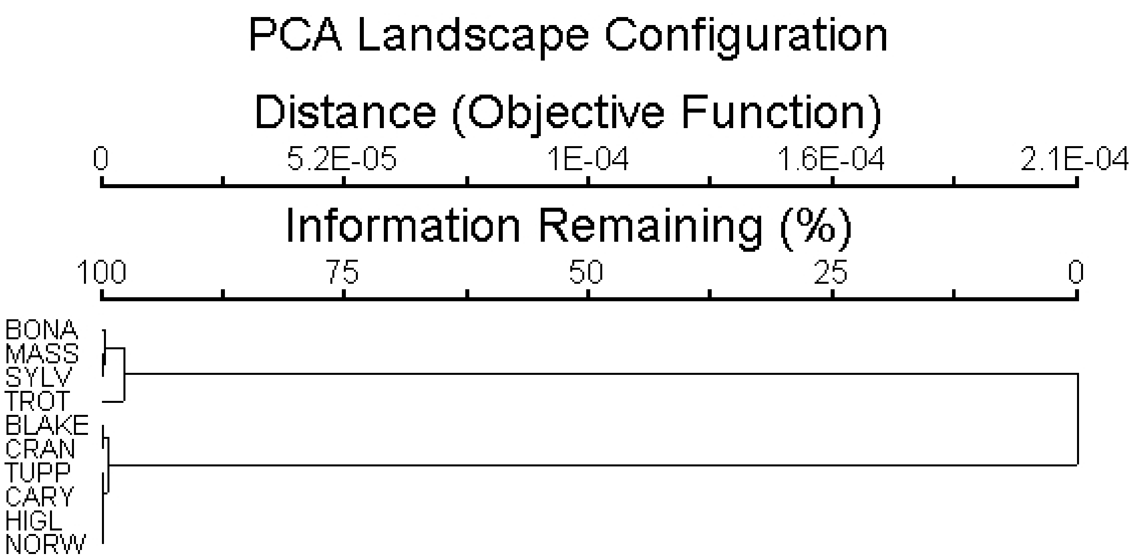

Figure 47: Cluster analysis dendrogram on lake watershed landscape composition (generated in PC-ORD Version 6.12).

7. LAND USE AND LAND COVER

Land use/land cover is the most widely investigated factor influencing water quality in watersheds and often viewed as the most persuasive. Deciduous forest was the prominent land cover value; therefore, lakes were observed on the relative ratio of human use land to matura forestland in the watersheds (Table 13). Black Lake diverged from the rest because of its vast amounts of agricultural lands in the southern end of the watershed (Figure 48). Black Lake had almost 17% of the watershed deemed agriculture. Higley Flow was the next closest at 1.4%. Due to the small size and isolation, Lake Bonaparte remained almost pristine in land cover, with developed, barren, and agriculture lands summing to about 2% of the entire watershed (Figure 49). Approximately 80% of land cover for the Sylvia Lake watershed was in deciduous forest or water, with evergreen forests and wetlands making up another 14% (Figure 50). Trout Lake watershed was mostly forestland cover with the three forest types aggregating to about 70% (Figure 51).

Moving down the Raquette River emerged many spatial patterns in regards to land use/land cover. Tupper Lake, near the headsource, generally had the least amount of developed, barren, and agriculture landscapes (Figure 52), while maintaining large pacts of water and wetlands in its watershed. Carry Falls watershed had comparable land cover percentages to Tupper Lake, and actually possessed less of an urban presence (Figure 53). Higley Flow was an anomaly of the four lakes, as it had the lowest human disturbance to forestland ratio in the watershed (Figure 54), despite being situated between two cities. Norwood Lake watershed, on the other hand, had the greatest human disturbance on the Raquette River (Figure 55). Urban centers populate the northern section of the watershed leading to increased amounts of developed land and agriculture to pollute the lakes.

In many ways, Cranberry Lake was the opposite of Massawepie Lake. Forestland cover encompasses 70% of the watershed with another 28% in water and wetlands (Figure 56). Massawepie Lake and its watershed had the most evergreen forest of all the study lakes (Figure 57), but had the least forest cover of all the study watersheds contained in the Adirondack Park. Its small size also meant water was a large percentage of the land cover.

Developed, grasslands, and agriculture land covers were highly correlated (Table 14), showing similar influences on Black Lake (Figure 58). They led to high pH values and chlorophyll a concentrations and negatively influenced dissolved oxygen and Secchi depth. Research has linked total phosphorus and chlorophyll a (Brown *et al*. 2000) and urban landscapes with phosphorus export (Osborne & Wiley 1988), suggesting lakes with high chlorophyll a will also have high levels of total phosphorus. Urban and croplands increased chlorophyll a levels, which feed phytoplankton, reducing Secchi depth and possibly leading to a hypoxic state (Osborne & Wiley 1988). Increases of chlorophyll a are often attributed to excess nutrients, mainly nitrogen and phosphorus. These nutrients are the limiting factors for crop production and often used in excess; however, they become major human point and non-point sourced pollutants when used in excess (Schepers *et al*. 1995; Oenema *et al*. 1998; Baker 2003).

Point and non-point pollution from urban land use have major impacts on water quality (Sliva & Williams 2001). Excess nitrogen disturbs the biogeochemical nitrogen cycle leading to stratospheric ozone depletion, soil acidification, eutrophication, and nitrate pollution of ground and surface waters (Davis & Koop 2006; Ding *et al*. 2006; Smith *et al*. 2006), making it one of the most important environmental issues (Galloway *et al*. 1995; Galloway 1998, 2000; Galloway & Cowling 2002). Even though nitrogen and phosphorus are the primary regulators in most lakes, it has been shown factors such as light limitation, hydrology, and grazing are also influence the responses of primary producers in the system (Smith *et al*. 2006).

Controlling inputs of nitrogen and phosphorus to reduce eutrophication is imperative (Havens *et al*. 2003; Arhonditsis & Brett 2005). This is difficult since its sources vary, as both natural and anthropogenic activities can contribute to the pollution (He *et al*. 2009a, 2009b). Runoff contaminants vary by location and type, with agricultural runoff generally contributing sediments, pesticides, and plant nutrients while industrial runoff contains higher levels of heavy metals, hydrocarbons, sulfates, and chlorides (Tong & Chen 2002; Abbaspour *et al*. 2007; Chang 2008; Li *et al*. 2009). Moreover, urban landscapes within lake watersheds can alter the processes in which water flows through the system (DeFries & Eshleman 2004). Increasing impervious surfaces within the watersheds causes less water to percolate into the soil, resulting in increased surface water and decreased water quality (Rose & Peters 2001), due to higher amounts of nutrients remaining in system.

Disturbed agricultural lands transport nutrients more rapidly than other lands. Randomly placed patches of isolated agriculture may not cause nutrient losses and water quality impairments, but as the network of disturbed landscape increases nutrient transport becomes easier. Increasing fractured landscapes connectedness allows for higher rates of percolation and efficiency, washing away key nutrients and decreasing water quality (Sahimi 1994). Models have indicated configuration or spatial arrangement of the landscape may be important (Sahimi 1994; Gergel 2005). Sliva and Williams (2001) noticed urban land use had a greater influence when concentrated adjacent to lakes than when spread out. A similar pattern occurred in the present study, lakes with closer urban centers experienced lower water quality measurements. Moreover, analysis completed by Carpenter (2005) show it might be 1,000 years before some aquatic ecosystems are able to recover from eutrophication, making water quality improvements challenging on a human lifetime scale.

In northern New York, expansion and urbanization have remained relatively stable, possibly due to its current economic situation. For instance, St. Lawrence and Herkimer counties have been declining in population since around the mid-1980s. Hamilton County, the heart of the Adirondack Park, increased between the 1960s through the 2000s at an average rate of 4%, but saw a 10% from 2000 to 2010. Other counties in the Adirondacks have seen increasing populations. Franklin County saw dramatic rises in residents in the 2000s and Essex County has seen a stable increase of 3% since the 1980s. Jefferson County has been stable, except the 25% increase in population from the 1980s to the 1990s. The Fort Drum expansion between 1986 and 1992 led to this increase. Fort Drum lies outside of all watersheds, thereby eliminating any impact the population increase would have on these study lakes, but has major implications on any water bodies downstream of its location. Lewis County experienced relative stable increases for the past four decades (4%). Slow levels of development could allow lakes to recover.

Attention with land cover has addressed the impacts of human perturbations to the land cover, but composition of natural land cover can help improve or maintain healthy lakes. From the PCA, water and wetland areas contributed to increases of dissolved oxygen, Secchi depth, and specific conductivity for Massawepie Lake. Forest landscapes showed a reversal from the impacts of urban and agriculture land uses. In comparison to many other studies (Lenat & Crawford 1994; Johnson *et al*. 1997), Sliva and Williams (2001) found no impact of agriculture, but did find a clear relationship for forest landscapes. Watersheds predominately covered by forest landscapes had lower values to practically all water chemistry characteristics in this study. Dissolved oxygen had a slightly positive influence from forest landscapes. Forested lake watersheds generally had healthier lakes. Often lowlands have less forest cover due to past human conversion, resulting in lakes to have poorer health in those areas. Lowland lakes in this study showed a similar trend. Interestingly, more isolated lowland lakes had similar land use percentages as higher elevation lakes. Forested landscapes, containing low degrees of land use fragmentation, were correlated to lower nutrient levels (Hunsaker & Levine 1995). Forested lands around lakes are fundamental to reduce bank erosion, but lakes surrounded by barren land are more prone to high contributions of sediments, indicating high runoff potential, especially during times of low precipitation. Grasslands are major sources of nitrate for systems (Holloway and Dahlgren 2001) allowing for chlorophyll a levels and other phytoplankton to sustain the ecosystem. If no major storms come to wash away nitrate stored in soil, instead of acting as a source, they become nitrate sinks (Holloway and Dahlgren 2001). Amount of water flow and season help nutrients flow and be released back into the environment.

Clustering in dendrograms reinforced the grouping of locations depending where they fall on the human disruption spectrum, both had five major groupings, but the location of Massawepie Lake and Trout Lake differed. Minitab clustered Trout Lake more with the four forested lakes (Figure 59), whereas PC-ORD clustered Trout Lake with Sylvia Lake then meeting with Massawepie Lake (Figure 60).

As spatial and temporal variations in water quality are evidently linked with land development, anthropogenic influences are just as important as natural ones. Studies looking at watersheds over time have shown land use increases in influence over time (Chang 2008). Importance and influence of land use is expected to increase with changing landscapes, as natural variables cannot be altered. In northern New York, cities might have faulty waste management systems due to poor economic situation and agriculture and farming may not have adequate waste treatment facilities and discharge waste into the surrounding areas. Aside from agriculture, developed land is probably correlated well with impervious surfaces. As impervious surfaces were not included in the study, this could have implications in future studies for landscape management and ecological response forecasting (Nilsson *et al*. 2003; Van Sickle *et al*. 2004).

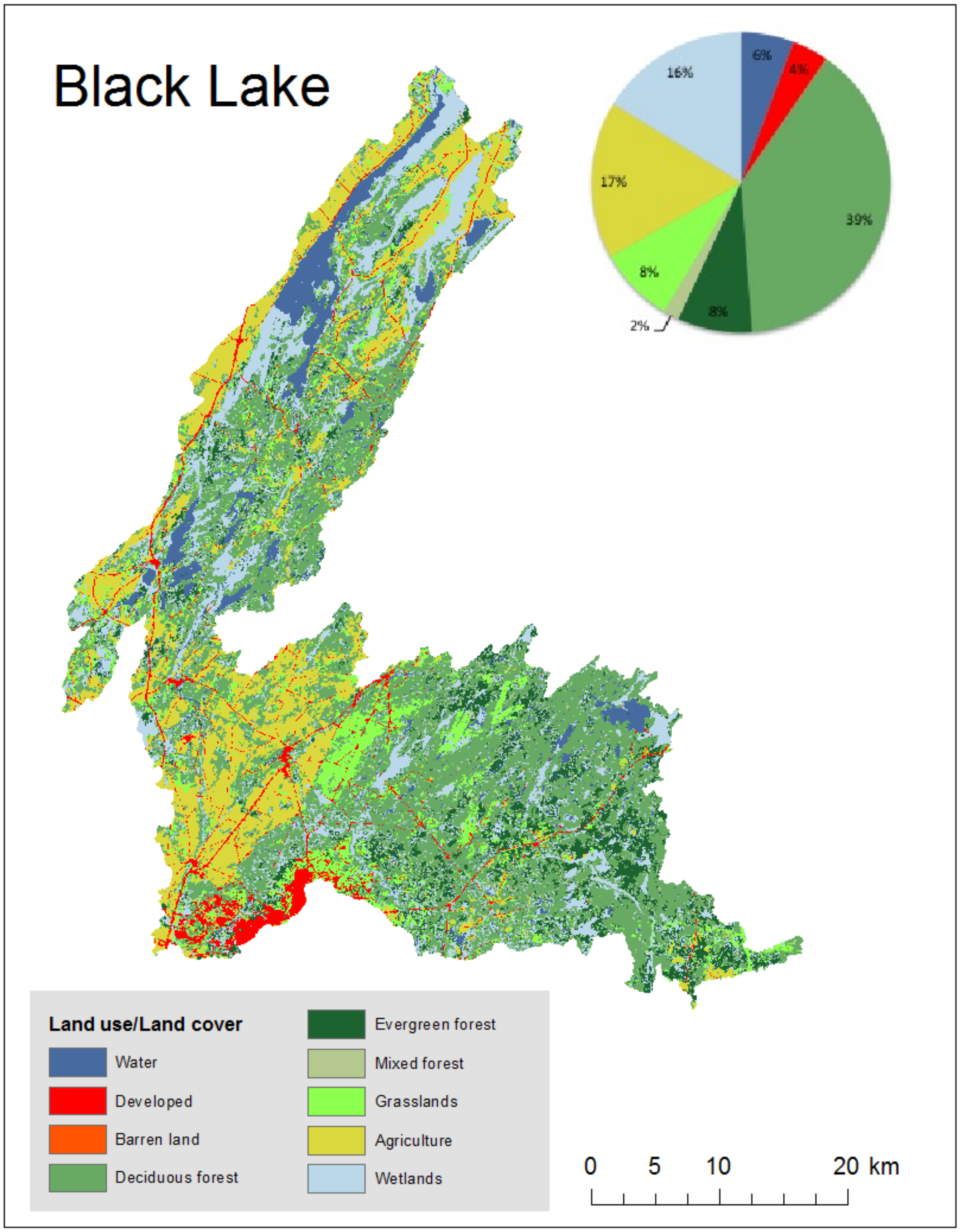

Figure 48: Land use/land cover distribution across Black Lake's watershed.

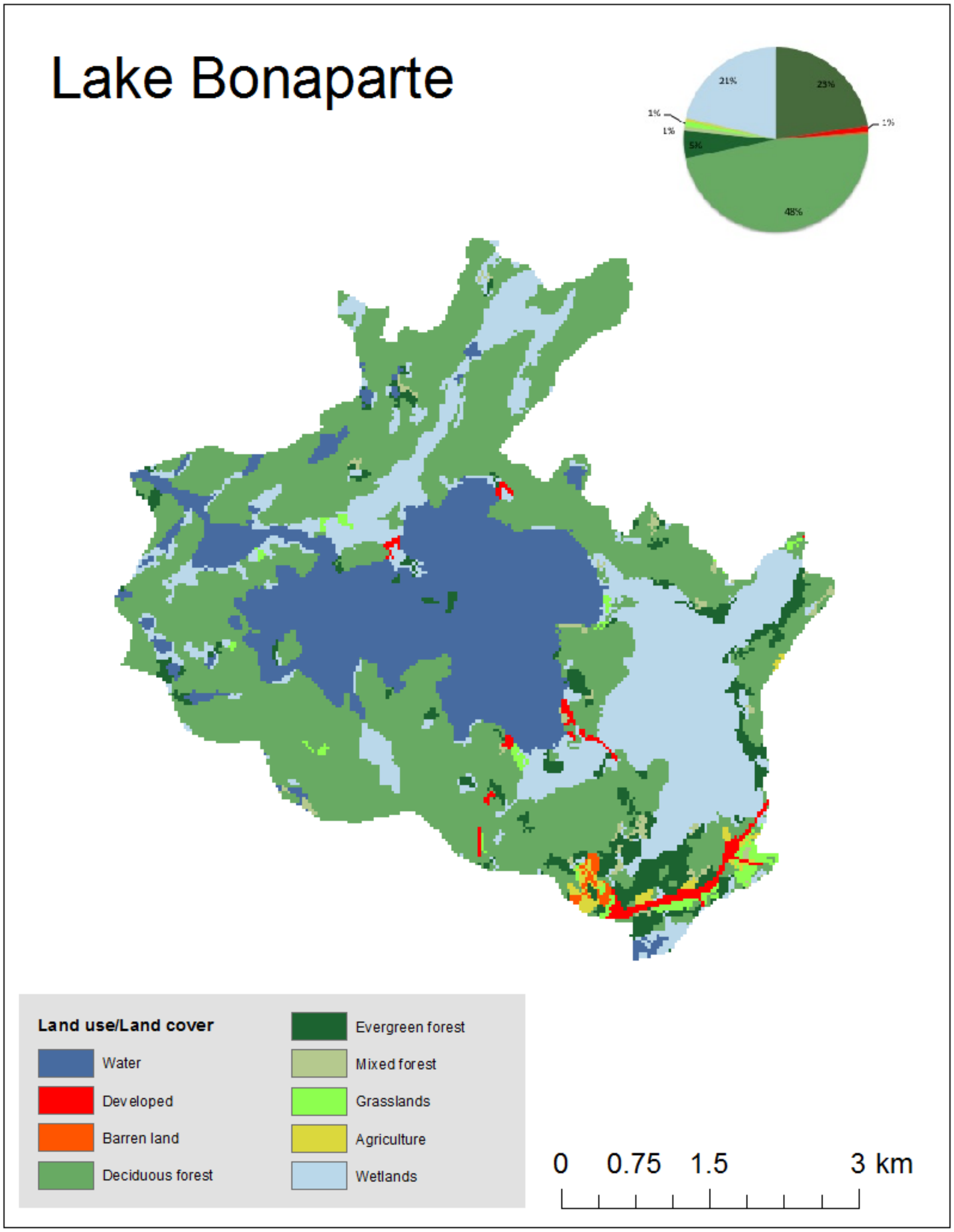

Figure 49: Land use/land cover distribution across Lake Bonaparte's watershed.

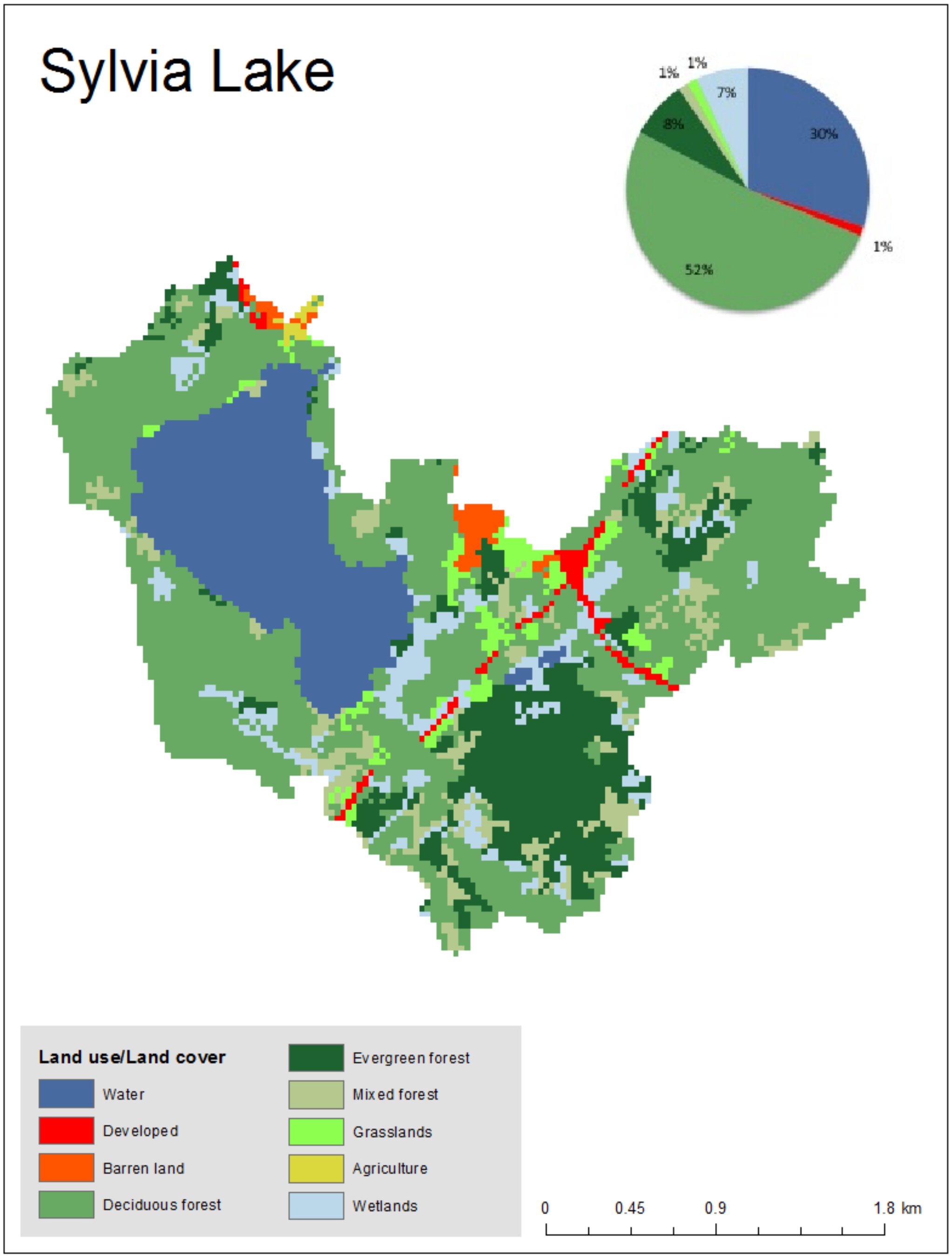

Figure 50: Land use/land cover distribution across Sylvia Lake's watershed.

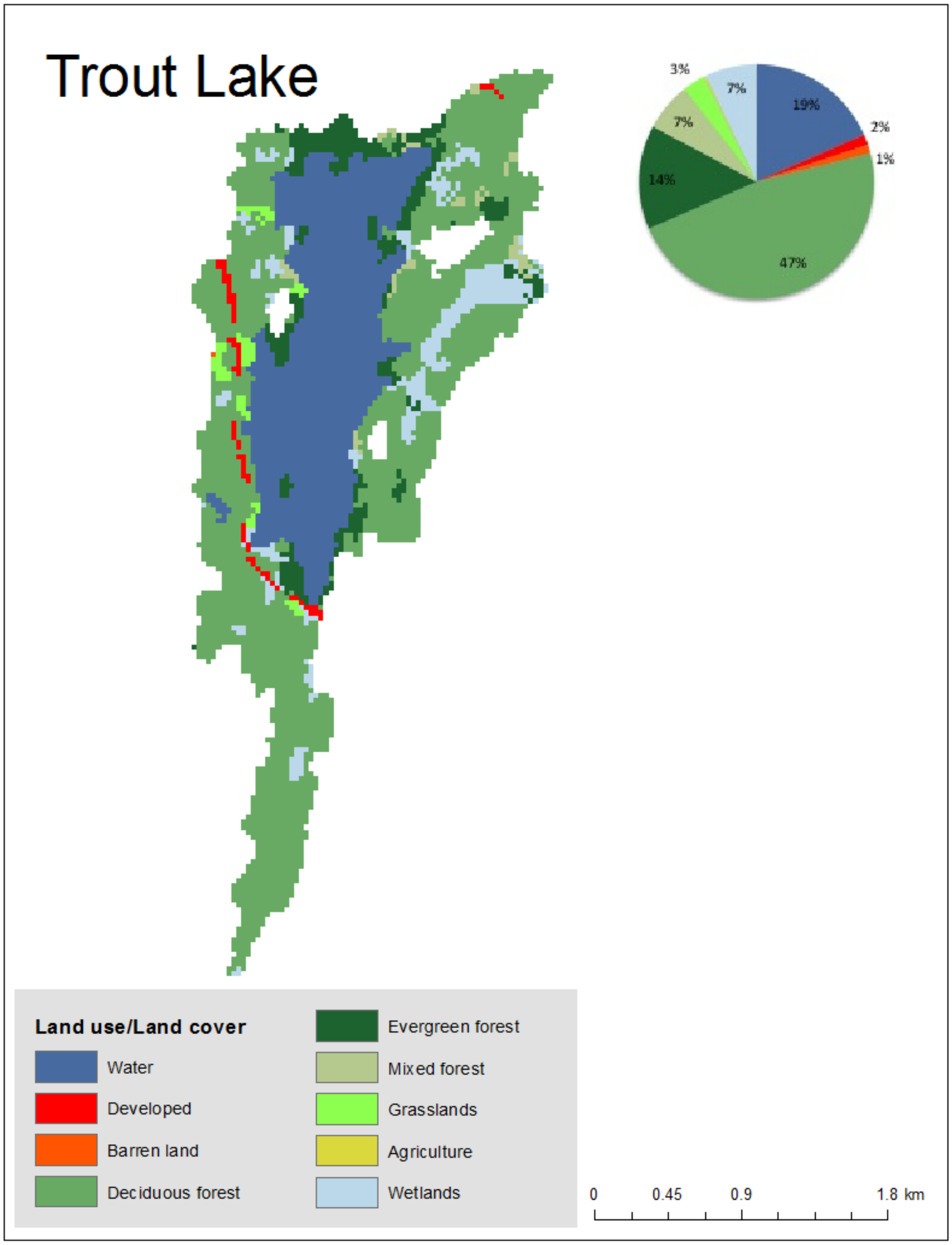

Figure 51: Land use/land cover distribution across Trout Lake's watershed.

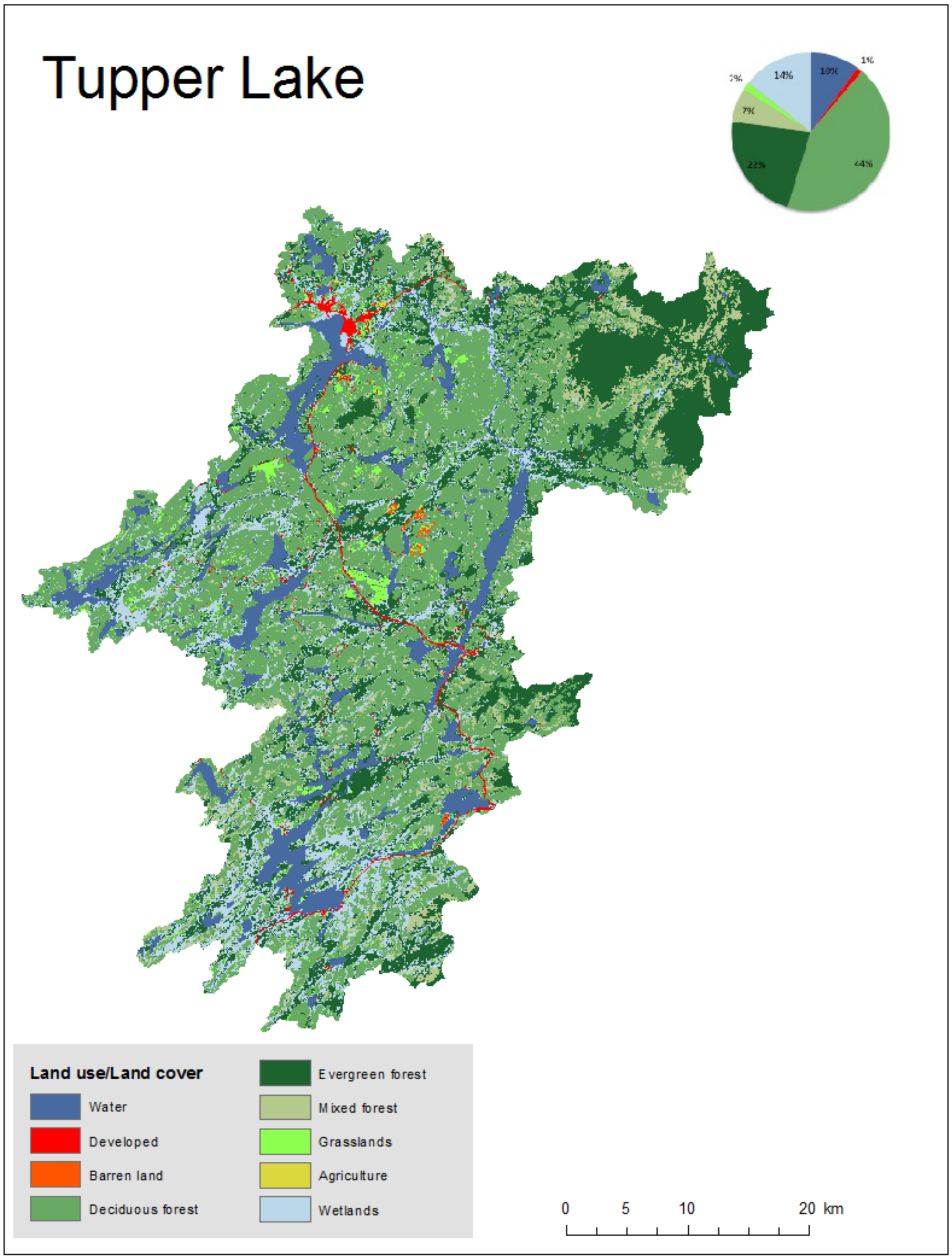

Figure 52: Land use/land cover distribution across Tupper Lake's watershed.

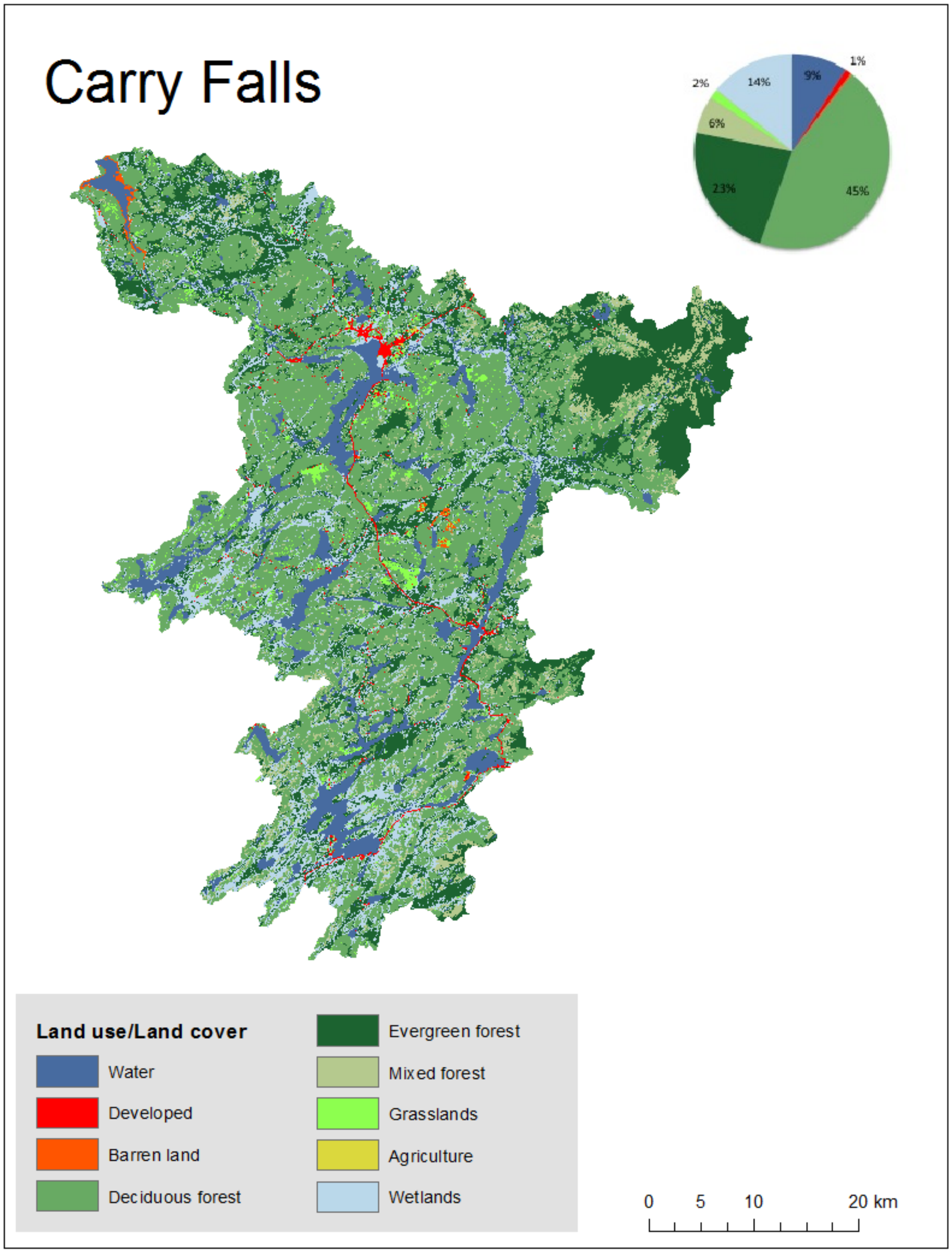

Figure 53: Land use/land cover distribution across Carry Falls' watershed.

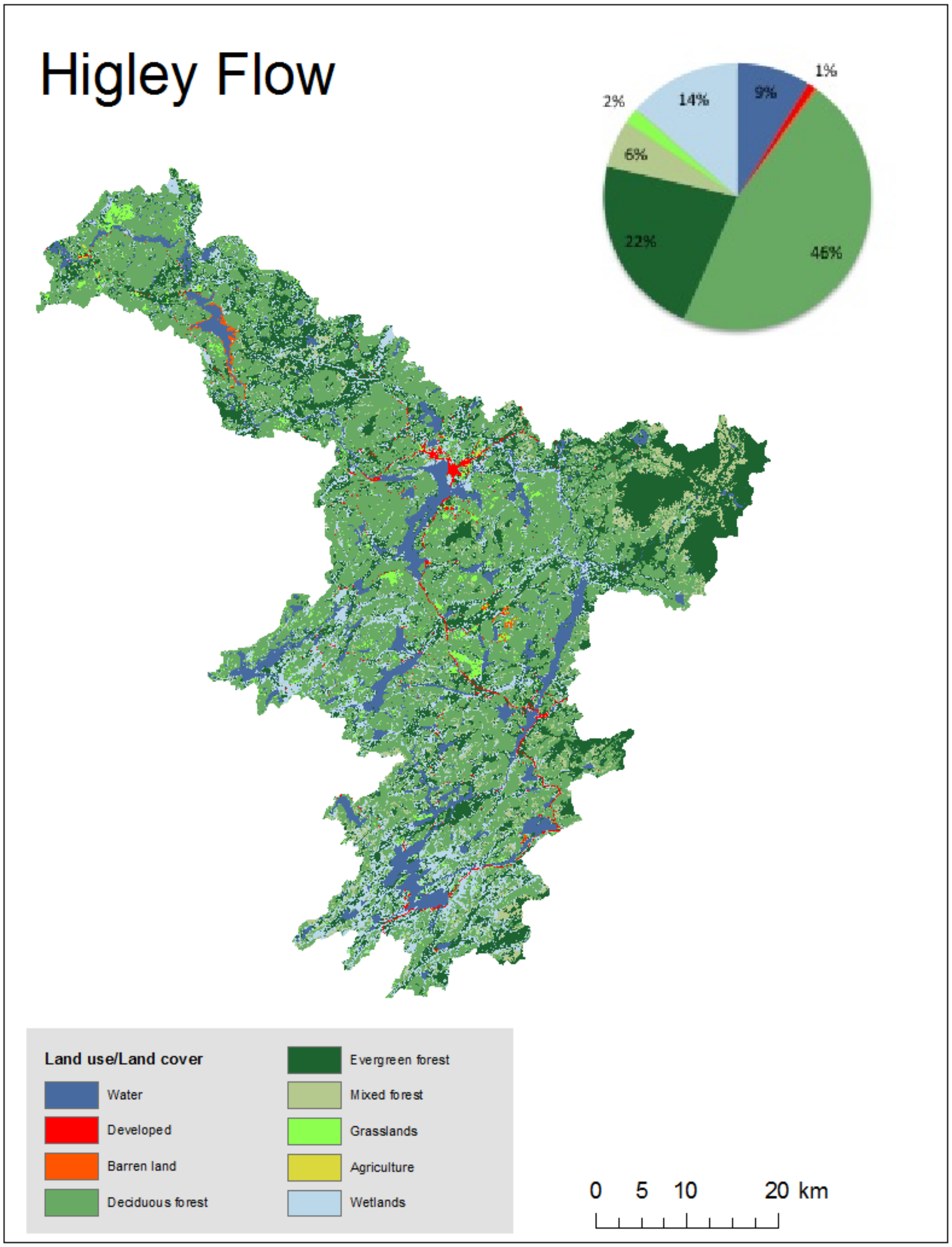

Figure 54: Land use/land cover distribution across Higley Flow's watershed.

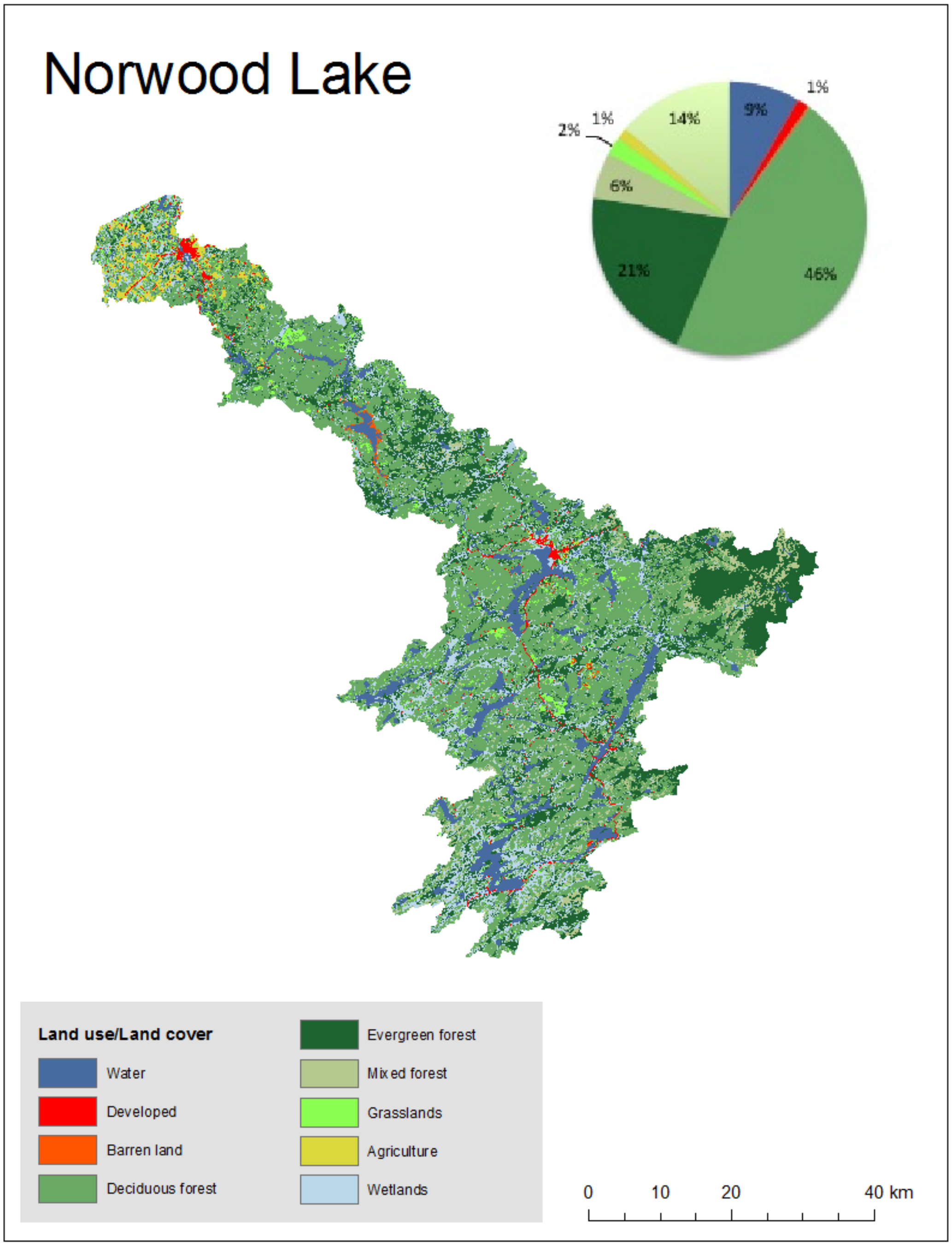

Figure 55: Land use/land cover distribution across Norwood Lake’s watershed.

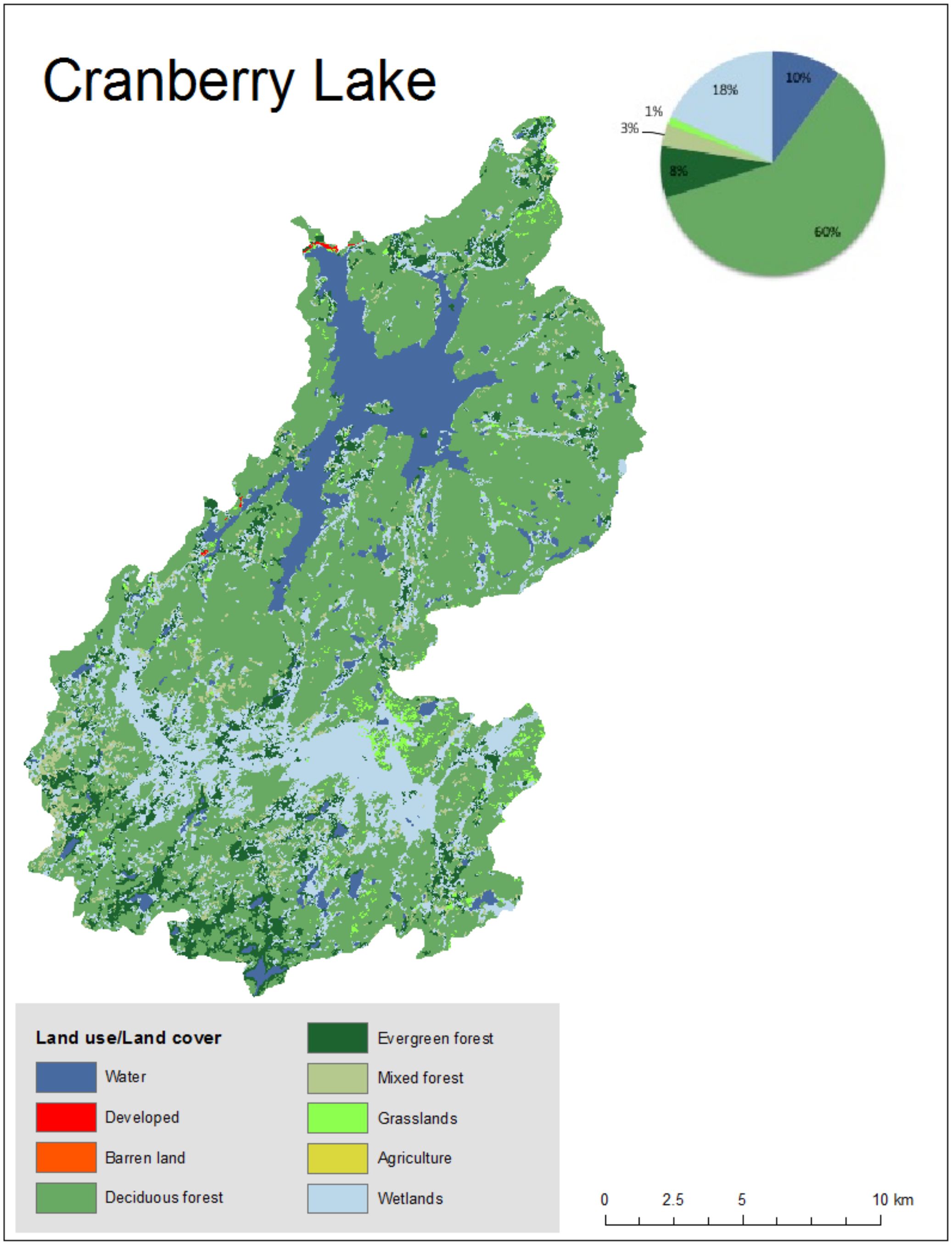

Figure 56: Land use/land cover distribution across Cranberry Lake's watershed.

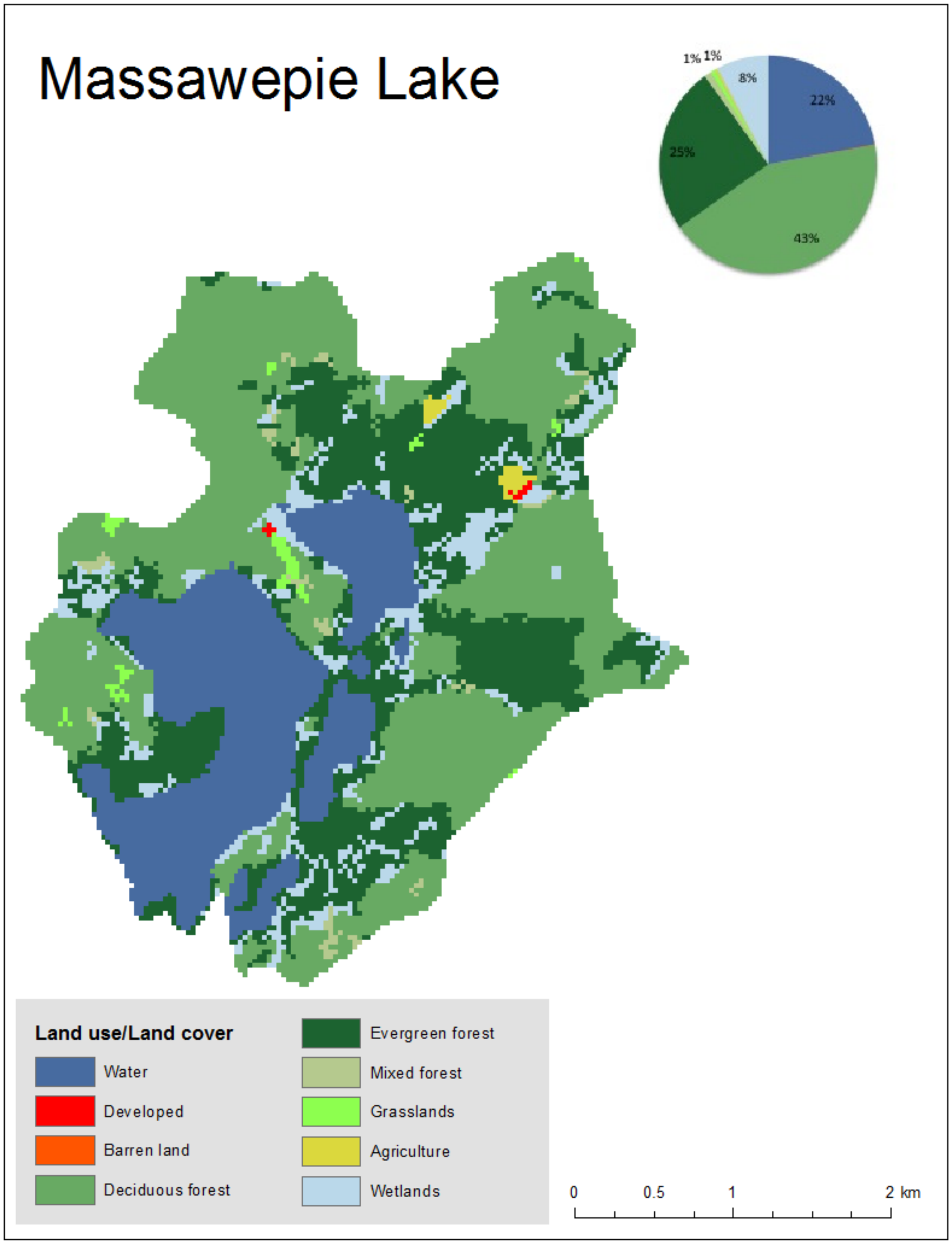

Figure 57: Land use/land cover distribution across Massawepie Lake's watershed.

Table 13: Calculated lake land use/land cover percentages.

	Water	Developed	Barren land	Deciduous forest	Evergreen forest	Mixed Forest	Grasslands	Agriculture	Wetlands
Lake Bonaparte	22.69	1.03	0.25	47.71	4.79	0.78	0.94	0.49	21.32
Black Lake	5.72	3.88	0.08	39.14	8.08	1.68	8.23	16.95	16.24
Tupper Lake	10.07	1.10	0.10	43.48	22.26	6.89	1.67	0.04	14.38
Carry Falls	9.20	1.01	0.26	44.91	22.72	6.19	1.60	0.04	14.09
Higley Flow	8.96	0.94	0.24	46.46	22.07	5.73	1.87	0.05	13.69
Norwood Lake	8.42	1.33	0.23	46.28	21.11	5.39	2.15	1.38	13.70
Massawepie Lake	21.99	0.10	0.00	43.11	24.87	1.00	0.72	0.40	7.81
Cranberry Lake	10.10	0.06	0.00	59.83	7.53	3.11	1.17	0.00	18.21
Trout Lake	18.44	1.49	1.18	47.34	14.38	6.68	3.12	0.26	7.12
Sylvia Lake	30.06	1.22	0.02	51.46	7.66	1.32	1.36	0.00	6.90

Table 14: Correlations table for land use/land cover (top value is Pearson correlation and bottom value is p-value)

	WATR	DEVL	BARR	DFOR	EFOR	MFOR	SRGR	AGRU
DEVL	-0.320							
	0.368							
BARR	0.060	0.112						
	0.869	0.759						
DFOR	0.231	-0.580	-0.062					
	0.521	0.079	0.865					
EFOR	-0.318	-0.307	0.027	-0.431				
	0.371	0.389	0.940	0.214				
MFOR	-0.530	-0.067	0.507	-0.091	0.575			
	0.115	0.854	0.135	0.803	0.082			
SRGR	-0.446	**0.946**	0.105	-0.507	-0.269	-0.064		
	0.196	**0.000**	0.772	0.135	0.453	0.860		
AGRU	-0.391	**0.897**	-0.154	-0.510	-0.321	-0.305	**0.952**	
	0.263	**0.000**	0.670	0.133	0.366	0.392	**0.000**	
WTLD	-0.456	0.104	-0.316	0.125	-0.362	-0.126	0.096	0.217
	0.185	0.776	0.374	0.730	0.303	0.729	0.792	0.546

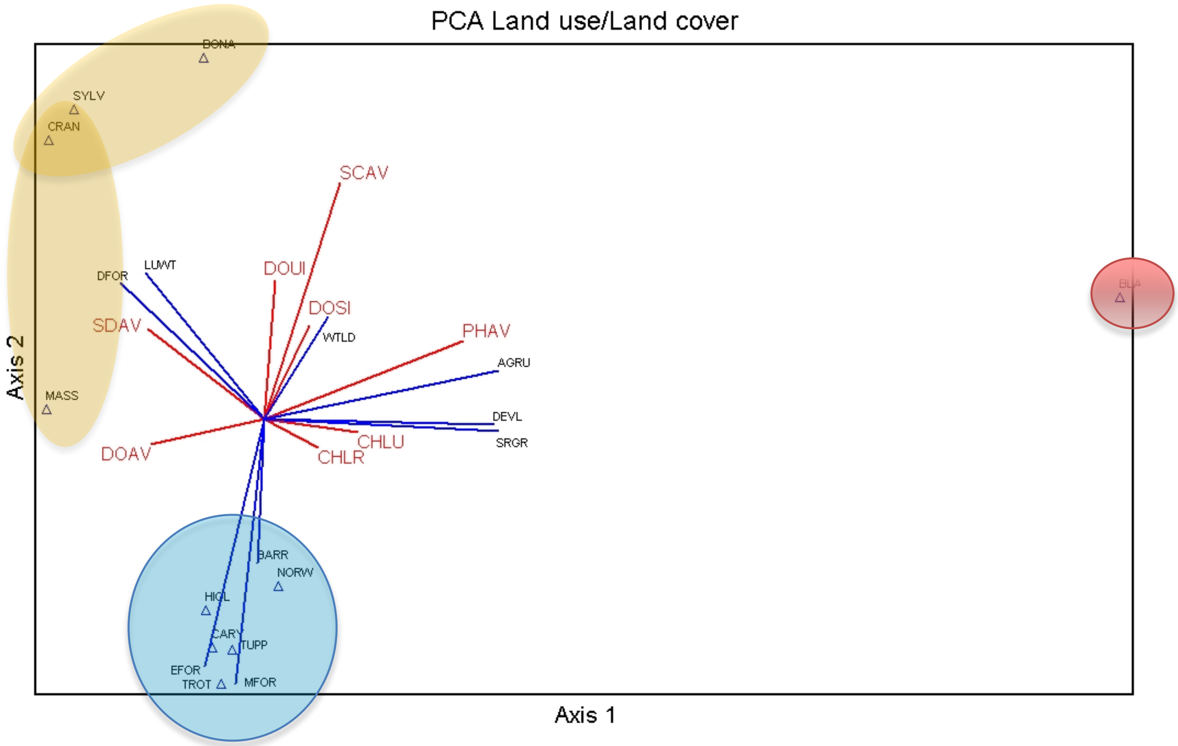

Figure 58: PCA graph on lake watershed land use/land cover. Blue lines depict associations between land use and lakes. Red lines depict associations between water quality characteristics and lakes. Longer lines have stronger relationships than shorter lines. Colored circles demonstrate groupings of lakes.

Table 15: PCA eigenvalues for lake watershed land use/land cover.

Variable	1	2	3	4	5	6
LUWT	-0.2616	0.3229	**0.5621**	-0.0915	0.2650	-0.2981
DEVL	0.5066	-0.0118	0.1702	0.0938	0.0084	-0.4964
BARR	-0.0156	-0.3181	0.3914	**0.6355**	0.3431	0.4459
DFOR	-0.3169	0.3013	-0.1913	0.4524	-0.5929	0.0864
EFOR	-0.1300	-0.5457	-0.0895	-0.4646	-0.0196	0.2585
MFOR	-0.0626	-0.5852	-0.1687	0.3226	-0.1153	-0.5522
SRGR	0.5159	-0.0269	0.1108	0.1081	-0.2423	0.1422
AGRU	0.5172	0.1075	0.0339	-0.0792	-0.1674	0.2579
WTLD	0.1405	0.2260	-0.6445	0.1911	0.6001	0.0007

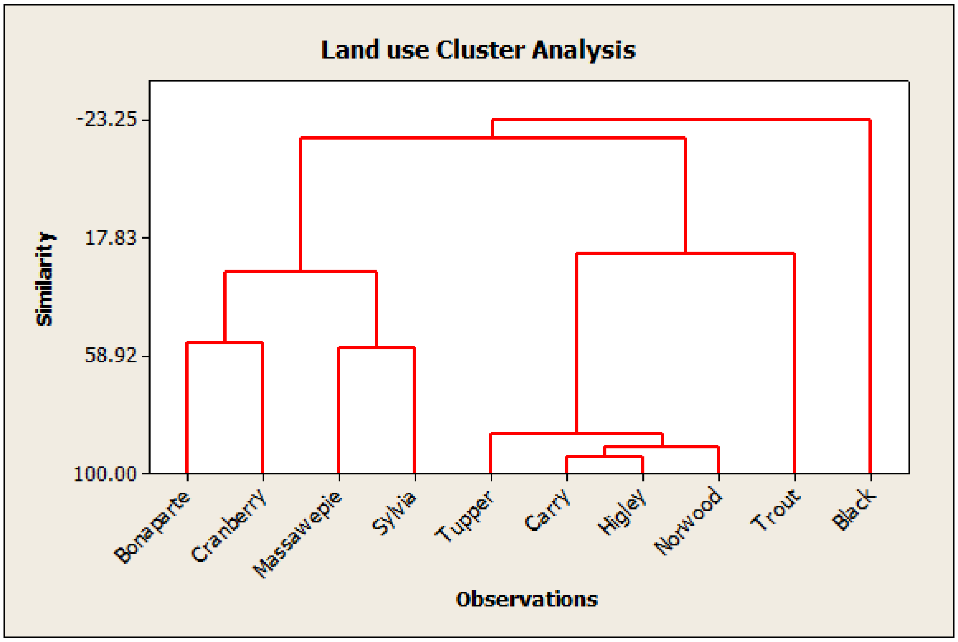

Figure 59: Cluster analysis dendrogram on lake watershed landscape composition (generated in Minitab 16).

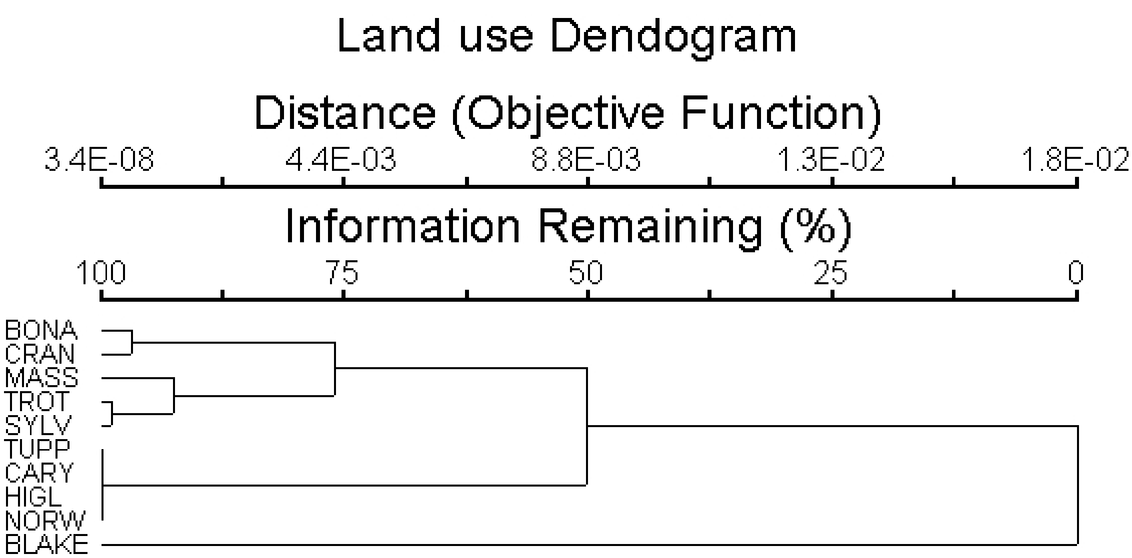

Figure 60: Cluster analysis dendrogram on lake watershed landscape composition (generated in PC-ORD 6.12).

8. ENDING COMMENTARY

8.1 Overview

The present study highlighted the interconnectedness of lake water quality and watershed characteristics. Visual observation and multi-linear regression analysis for each factor produced similar lake groupings: (1) Lake Bonaparte, Trout Lake, and Sylvia Lake; (2) Tupper Lake, Higley Flow, Carry Falls, and Norwood Lake; (3) Massawepie Lake and Cranberry Lake; and (4) Black Lake. Bedrock geology and land use experienced the greatest amount of definitive lake splitting. Slight variation among the major groups existed in the other factors. Consequently, bedrock geology and land use exhibited better predictability of lake water quality. Despite the differences, water quality appears to have interactions with all of the factors, suggesting a comprehensive approach needs undertaking to improve and maintain water quality. This finding has major implications for understanding water quality, role of landscape management, and the relationship between watersheds characteristics. However, the results are limited by numerous statistical and technological constraints, namely the inability to analyze in a non-linear form and using older datasets, and should be understood within this context. The study provides a comprehensive analysis on the watershed-lake relationship and should be incorporated into future research of the role watersheds shape lake health.

8.2 Similarities and Differences

Lake health is reflective not of one characteristic, but all the characteristics. If one water quality characteristic were at a dangerously high or low level, a single watershed characteristic is most likely the root cause. When multiple water qualities are deemed poor, the cause is more imbedded within the system. Understanding that web of complexity and influence would help combat degrading water quality.

Black Lake was deemed to have positive chlorophyll a relationships in four of the five factors. Only surficial geology type did not correlate with chlorophyll a content. Specific conductivity and pH were both found having positive relationship in three factors. Specific conductivity lacked in soils and landscape composition, while pH was not found in bedrock geology or landscape composition. Dissolved oxygen was only positively related twice and Secchi depth was negatively related once, in the landscape composition. Black Lake real water data reflected most of the statistical implications.

Black Lake had high levels of dissolved oxygen, chlorophyll a, pH, and specific conductivity were high, but a low Secchi depth.

Surficial geology led to the same relationships in Lake Bonaparte, Trout Lake, and Sylvia Lake. Soils and landscape composition provided conflicting relationships in the Lake Bonaparte water quality from the other factors. Dissolved oxygen was negatively correlated in landscape composition and chlorophyll a concentrations were positive in soils. Actual water quality data supported the poor predictability of soils for Lake Bonaparte chlorophyll a levels, because the lake had comparatively very low levels. Specific conductivity and pH were the best-predicted variables with three factors each. Trout Lake, although similar to Sylvia Lake in most factors, varied drastically in the landscape composition and land use analyses, and the specific conductivity characteristic. In terms of the land use classification, Trout Lake was more in line with the Raquette River lakes. Specific conductivity and dissolved oxygen were well predicted by the watershed factors for Sylvia Lake. All five factors predicted specific conductivity and all but land use predicted dissolved oxygen.

The Raquette River lake set shared similar characteristics in all but landscape composition. They all had strong negative relationships with pH, specific conductivity, dissolved oxygen, and Secchi depth. Variation in landscape composition was probably due to the influence of elevation, watershed size, and lake size.

Massawepie Lake had conflicting relationships for its water quality and the factors. For instance two positive and two negative relationships with chlorophyll a occurred; a similar result was noticed with pH as well. Cranberry Lake had conflicting relationships with pH and slightly with chlorophyll a. Three factors determined the lake had negative relationships with chlorophyll a, but bedrock had a positive relationship. This was unsuspected because the entire bedrock geology is metamorphic rock and the metamorphic rock did result in validating the negative relationship with specific conductivity.

Noticeable patterns in factor analysis, can inform a lot about the relationship, but can lack in describing relationships not found in the analysis. For instance, Chang (2008) noticed uplands had better dissolved oxygen than lowlands. Lower amounts of development and rates of erosion than lowlands attribute to better water quality in uplands. They are also often more forested, allowing for more uptakes of bad or excess nutrients. Furthermore, it was noticed more acidic lakes occur in uplands, where it is colder, than the lowlands, which were warmer and more basic, hinting at the role temperature plays in pH. Ahearn *et al*. (2005) saw population density and agriculture have similar effects on total suspended solids loading, suggesting both are equally detrimental. Nevertheless, similar water quality values in different watersheds suggest natural factors are determining water quality. It is also possible to associate the same type of correlation when different factors show the same lake having similar water quality relationships.

Impoundments (dams) can sever the movement of chemicals from uplands down to lowlands. Reservoirs reduce the flux of solutes from reaching the lowland area, decreasing the influence of upland regions (Higgins 1978; Soltero *et al*. 1973; Kelly 2001). When lowlands are cut off from uplands, land use gains influence on water quality (Ahearn *et al*. 2005). The nestedness nature of the Raquette River watersheds should cause a decrease in water quality further down the river. This does not appear to be the case in the study area, as the groupings of lakes appear river linked, a slight decline in water quality on Raquette River, but not that drastic, suggesting one of the watersheds has the ability to clean water from the time water leaves one watershed and arrives at the lake.

8.3 Assumptions and Limitations

Despite the breadth of this present study, certain assumptions and limitations were made. This study used land use data for 2001. Therefore, it was assumed that land use change did not occur since then, or if it did, not enough to limit the effectiveness of the study. No ground-truthing was completed for this study either, so it was assumed data were correct at time of collection. In regards to the soil data, the study assumed the areas missing data would follow similar patterns for known data in the watershed. This allowed for the extrapolation of the known data and watershed comparisons with complete surveys and those with incomplete surveys, for percentages were analyzed. Some watersheds were nested within other ones, but this was ignored given statistical analyses were beyond the feasibility of the study. Further, the study was limited to a linear relationship between variables and observations, albeit the infrequency of that occurring in nature. More often than not, significant relationships with one feature in a variable are accompanied by significant relationships with one or more features of the same variable or other variables. For instance, land use/land cover most often has the gain of one type lead to the loss of another type (King *et al*. 2005). Lastly, spatial arrangement was not taken into consideration for analysis due to complications in determining the weights of the arrangements.

8.4 Buffer vs. Catchment Debate

A debate is currently underway on whether a riparian zone is more important in influencing water quality than the entire catchment (Osborne & Wiley 1988; Delong & Brusven 1991; Johnson *et al*. 1997; Sliva & Williams 2001). Catchment characteristics vary drastically, so determining linkages between sizes of influence with water quality is difficult (Sliva and Williams 2001) and studying at the watershed scale was challenging before GIS technologies advanced (Wang & Yin 1997).

It is unclear if riparian vegetation helps maintain water quality or if the entire catchment has a larger role. Osborne and Wiley (1988) found only minimal differences between riparian zones less than 100m and greater than 1000m, and it was due to the presence or absence of discharge from municipal point source. Sliva and Williams (2001) concurred by finding entire catchments better correlated to water quality than buffer landscapes. Other studies have found mixed results. Hunsaker and Levine (1995) saw differences between scales only if certain buffer distances were considered. Li *et al*. (2009) noticed in their study that a 100m buffer explained more than the whole catchment for land use, supporting similar findings by Johnson *et al*. (1997). Differences in season denoted differences in size correlation: spring and summer were more correlated with buffers while fall was more correlated to catchments (Sliva & Williams 2001). Because different hydrologic and biogeochemical processes occur at different spatial scales, it is important to consider a multi-scale approach to understand watershed-water quality dynamics.

These studies demonstrate how difficult it is at determining the riparian width, for physical, ecological, and land use conditions all affect its ability to mediate nutrient loading. Resolution of data is important in determining an effective buffer. For instance, 30m, 50m, and 100m buffers will appear the same if 100m resolution data were used.

Data needs up-to-date vegetation types within a buffer strip, since the vegetation is important in determining the buffer's effectiveness. Although forested buffers are more effective at reducing nitrate concentrations than grassland buffers, grasslands were able to retain more total and dissolved phosphate (Osborne & Kavacic 1993). More research needs undertaking because there is still a general lack of consensus.

8.5 Seasonal Variation

The role of seasonality is a contentious debate. Many argue that only the storm season should be analyzed, because that is when the landscape is the most connected to water pathways (Bolstad & Swank 1997; Basnyat *et al*. 1999; Arheimer and Linden 2000). Others circumvented this problem by analyzing variables separately for each season (Osborne & Wiley 1988; Johnson *et al*. 1997; Sliva & Williams 2001; Chang 2008; Li *et al*. 2009). Climatic and biotic factors drive the seasonal variations seen in river water chemistry, suggesting the terrestrial portion of the watershed, such as natural or human land cover, is important for governance (Moldan & Cerny 1994).

Human activities also change depending on the season. Fertilizing is completed during the spring to prepare for the growing during the summer, possibly overloading the system and causing eutrophication. Land use was important for spring and summer, but less so in autumn. In contrast, geology had little impact in spring and summer, but the most in autumn (Johnson *et al*. 1997). Land use masked geology during those seasons. Low flow conditions, often occurring during the summer, can enable geological influences to dominate. Additionally, agriculture is reducing fertilizer applications, so less runoff would occur in the autumn.

In dry years, forested uplands were the source of many solutes and drained diluted, clearer water to the lowlands, while the lower elevation watersheds produced more turbid waters (Ahearn *et al*. 2005). Chang (2008) noticed during wet years the uplands serve as way to dilute the sediments, as they are not the major source of solutes. This was not the case for these study lakes, as Secchi depth did not show any correlation to elevation or season. In comparison, the dry season has been shown to be better for nutrients, as a consequence of less rainfall having the ability to move nutrients or pollutants through the soil (Li *et al*. 2009).

In the present study, only dissolved oxygen, temperature, and chlorophyll a were averaged in separate seasons. Secchi depth, pH, and specific conductivity had no clear trend between seasons. For dissolved oxygen and temperature regressions, the slopes were of comparable value, but the y-intercepts were dissimilar enough to be included separately. In other words, although lakes began the seasons at different values, the rates of decrease for both parameters were similar.

8.6 Future Research

As mentioned earlier, there is a great debate currently underway examining the roles of riparian zones and entire catchments to discover if one or both serve important ecological functions. To determine the impact of riparian zones, future studies should conduct a more detailed analysis of characteristics in catchment and buffer zones. Spatial scales could include 30m, 60m, 100m, 200m, and 500m. This could help resolve any issues with the effectiveness of riparian zones and help management efforts aimed at curtailing worsening lake health. For the small buffer zones, resolution of data must match or better the buffer distance; otherwise, multiple buffer results will appear the same.

The lack of knowledge in how bedrock geology and surficial geology influence water chemistry is worrisome. Most studies investigate the outcome of bedrock geology, as a factor, influences water quality, not how separate groups, through their characteristics, impact water quality in specific manners. Future studies should direct efforts in investigating on qualities of different geologic features influence a lake’s ability to buffer against pH and move nutrients through the system effectively and prudently. Porosity, for instance, impacts the ease of water flow.

The present study was limited to examining lake health for two years, providing a limited understanding of the dynamics of changing water quality and landscape factors. It is imperative, therefore, to garner base measurements for future comparisons. Future studies could incorporate climate change and land use change models to predict how future changes will influence water quality. This will help landscape managers, for many factors cannot be altered. Future practices will have to delve with land use/land cover management.

When human density was calculated in this study, it was assumed all types of human use would have a similar impact, but that is rarely the case. A farm will have a much greater impact than a cabin without electricity or plumbing. Future studies should use up-to-date data to weigh human impact types and investigate where major point sources are located. An extension would investigate the age of buildings and their major developments to determine how efficiently current waste management systems function.

A more complex form of statistical analysis is needed. Ecological data are rarely linear relationship; therefore, principal components analysis is not an ideal technique for data. It is difficult to interpret results if correlation between variables and water quality are poorly understood (MacNally 2000). Removing the effects of one feature on others shows the independent correlations between features and the observations (King *et al*. 2005). Non-metric multidimensional scaling provides a better method to define the relationship between watershed composition and configuration influence lake health, by analyzing data at non-metric scale. Future studies should incorporate more lakes, compare seasonal variation, and analyze nestedness of watersheds.

Lastly, composition and configuration of land use has been shown to be important factors in lake health. Knowing the location of land use types allows for weighting the importance of the land use relative to spatial proximity to water systems. Additionally, calculating how fragmented or connected land use features are will help landscape managers better direct efforts help designing an area, because it could be designed to maximize water quality without risking economic function.

8.7 Conclusions

This study departed from the usual studies examining the watershed-water quality literature given it investigated numerous natural and anthropocentric factors and the relationships they have on lake health. Further, there exists a disconnect in what we know happens and how we know it happens, so in attempt to close that gap, this study investigated at a more detailed level within each factor. This modification added depth to how certain factors influence water quality; however, a more founded and complex form of analysis is needed. The study, although limited in its statistical analysis and outdated data, should help land management become more efficient and designing landscapes or protecting certain areas. For, if they know underlying bedrock geology, surficial geology, and soils, they could accurately presume how prone the lake would be to degrading water quality. Managers could designate areas that are more prone for protection from land use/land cover change, because it is one of the only factors they could control, and less prone for development. Landscape composition and configuration are rapidly changing to meet the demands of a growing population and climate change, forcing interplay of numerous vectors in order to accomplish objectives to maintain ecosystem services and processes.

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APPENDIX

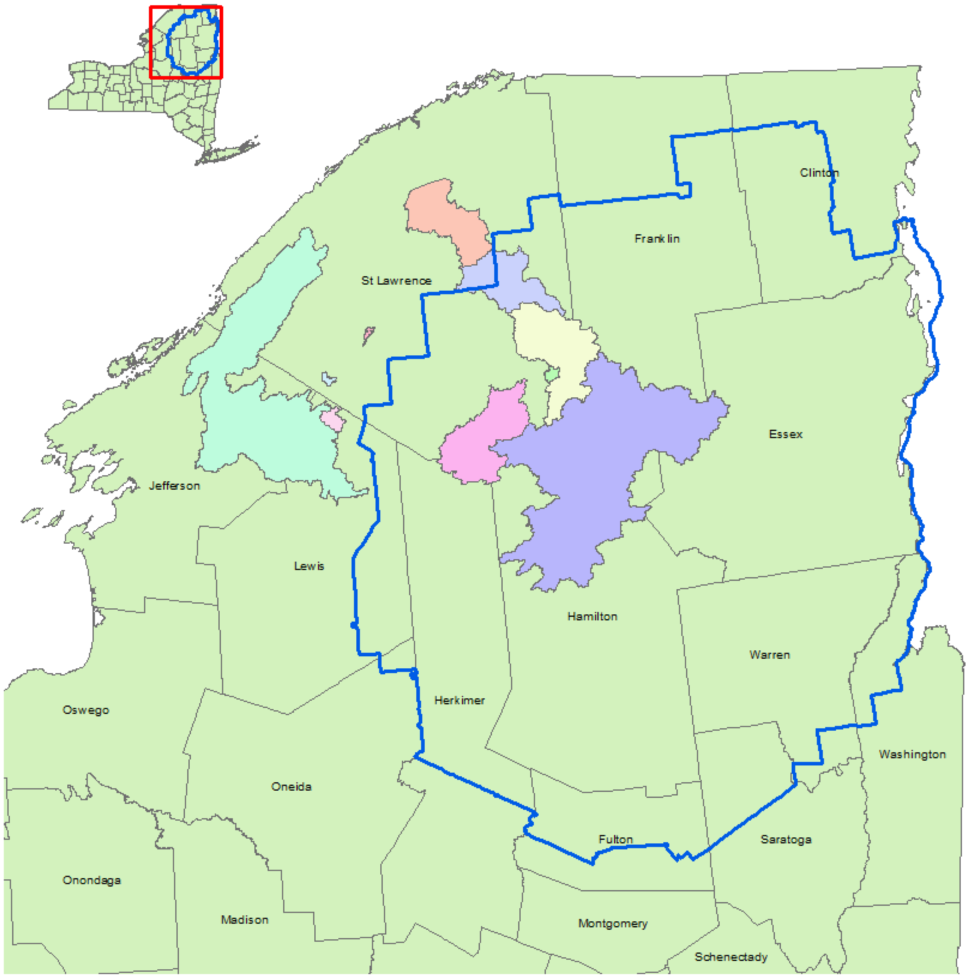


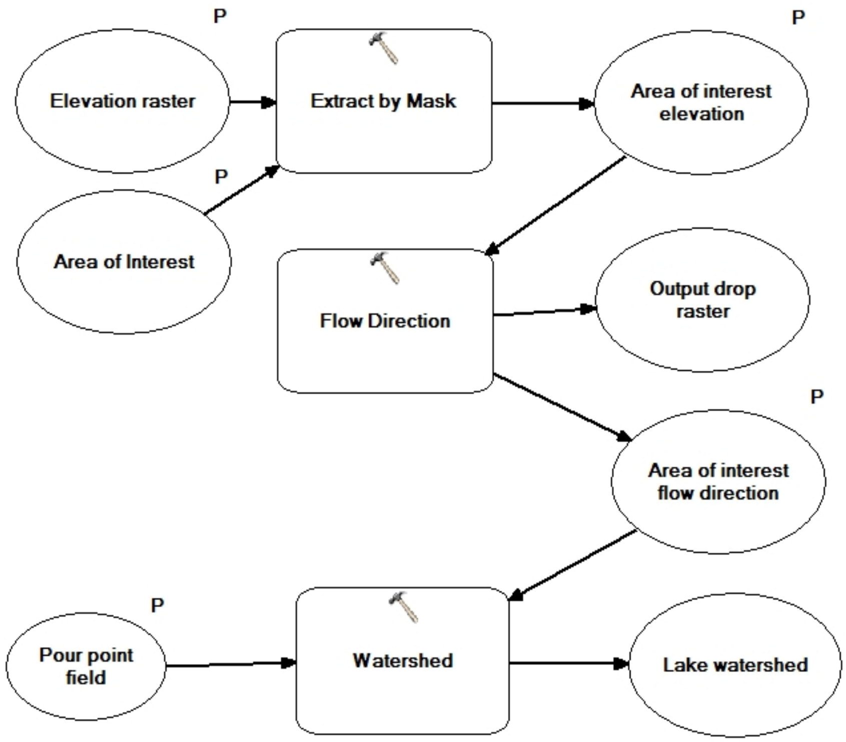
Figure 61: Spatial positioning of study lake watersheds and New York state counties.

PCA eigenvalues for lake watershed landscape composition

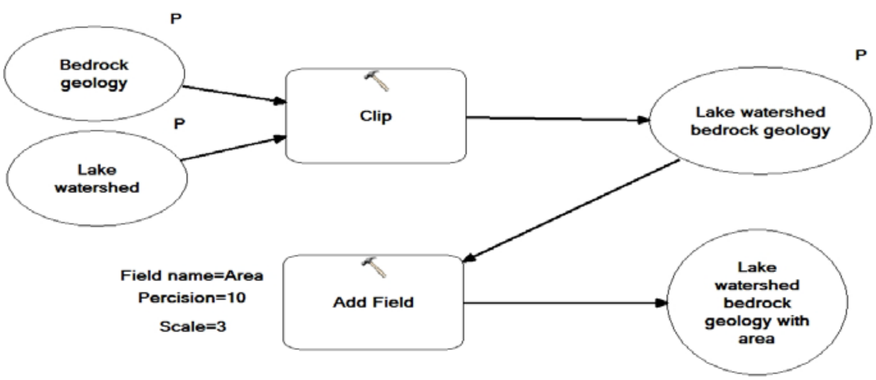
Variable	1	2	3	4	5	6
ANPA	-0.1665	0.1868	-0.1232	-0.2195	-0.1267	0.1235
ORTH	-0.0403	0.2350	-0.0368	0.2737	0.1308	-0.1647
SYEN	-0.2558	0.1098	-0.0953	-0.1453	-0.1344	-0.0647
YSED	0.1630	-0.1901	0.1610	0.0100	-0.2583	0.1991
YGRN	0.1237	-0.1527	-0.0509	-0.2134	0.3645	-0.1689
CLMO	-0.1825	-0.2478	0.0036	0.1331	0.0471	-0.0353
LUWT	0.2826	-0.0349	0.0452	0.1147	-0.0874	0.1894
DEVL	-0.1427	-0.2843	-0.0372	-0.0391	0.0159	0.0839
BARR	0.1098	-0.0787	-0.0827	-0.3168	0.3557	-0.0628
DFOR	0.1340	0.0937	0.0839	-0.0386	-0.2311	-0.4323
EFOR	-0.0844	0.2054	-0.2361	-0.0099	0.1936	0.2605
MFOR	-0.0776	0.1081	-0.2152	-0.3546	0.0949	-0.0929
SRGR	-0.1644	-0.2662	-0.0594	0.0265	0.1053	-0.0795
AGRU	-0.1774	-0.2496	0.0127	0.1382	0.0598	-0.0328
WTLD	-0.1598	0.0211	0.3527	-0.0782	-0.0938	-0.1372
ABTT	-0.1569	0.2063	0.0995	-0.2258	-0.1683	-0.0459
KAME	-0.0041	0.2067	0.0621	0.3053	0.2295	0.1305
LACU	0.2313	-0.1522	-0.2071	-0.0366	-0.0051	-0.0269

SILT	-0.1764	-0.2495	0.0069	0.1397	0.0480	-0.0546
SUBA	0.0085	-0.0724	0.4026	-0.0624	0.0123	0.1977
SGWT	-0.0643	0.2040	-0.0579	0.3261	0.1620	-0.1248
OTHR	0.2160	-0.1723	-0.2007	-0.0609	0.0329	-0.0863
ASOL	-0.0417	0.1067	0.3196	0.1788	0.2051	0.2310
BSOL	-0.0890	0.1313	0.3314	-0.1702	-0.1531	-0.0007
CSOL	-0.2396	0.1467	-0.1650	0.0889	-0.0991	-0.0290
DSOL	-0.2569	-0.0463	-0.1189	0.2042	0.0528	0.0409
LSZE	-0.2047	-0.1528	0.0384	0.1121	-0.0556	-0.3394
WSZE	-0.2446	0.0804	-0.1176	-0.1759	-0.0739	0.2197
ELEV	0.0353	0.2467	-0.0149	0.1094	0.0296	-0.2768
DPTH	0.2441	-0.0400	-0.0805	0.0609	-0.2896	0.0780
TEMP	-0.2007	-0.1512	-0.1537	0.0558	-0.2014	0.0050
TSPI	-0.1003	-0.1463	0.1918	-0.1012	0.2743	0.1566
TSUI	-0.0414	0.1048	0.2634	-0.2243	0.2901	-0.1764
HDCT	-0.2639	-0.0384	-0.0872	-0.1079	-0.0402	0.2356
HDNR	-0.1586	-0.2093	0.1525	-0.0031	-0.0738	-0.2222

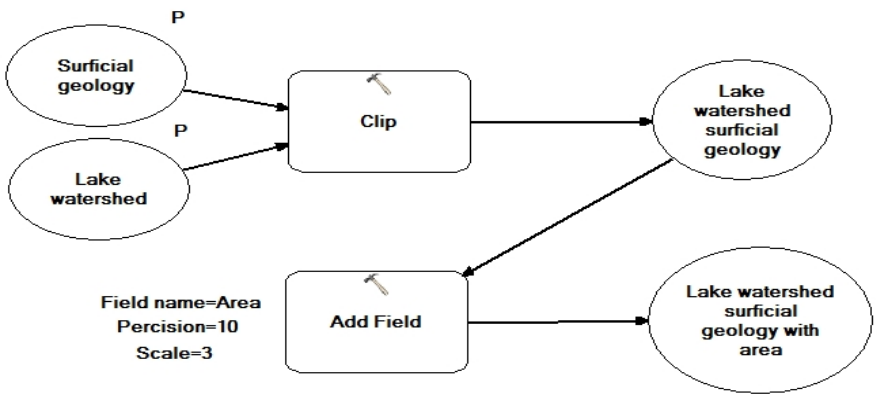
Module 1: Watershed creation module in ArcGIS



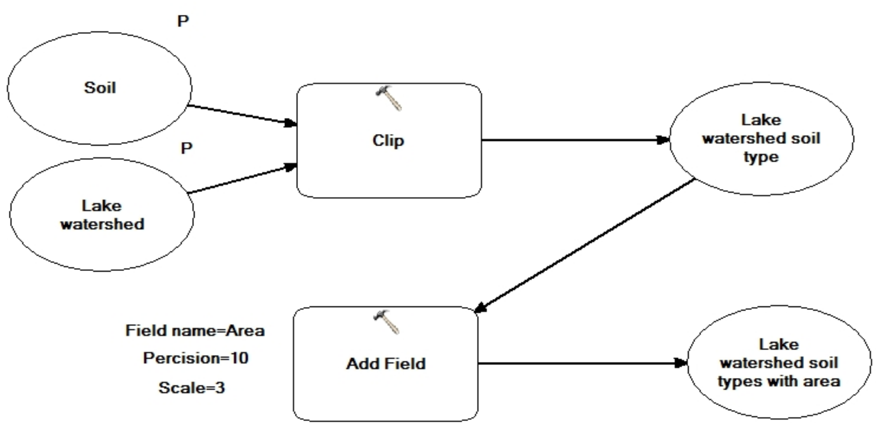
Module 2: Bedrock geology percentage calculation module in ArcGIS



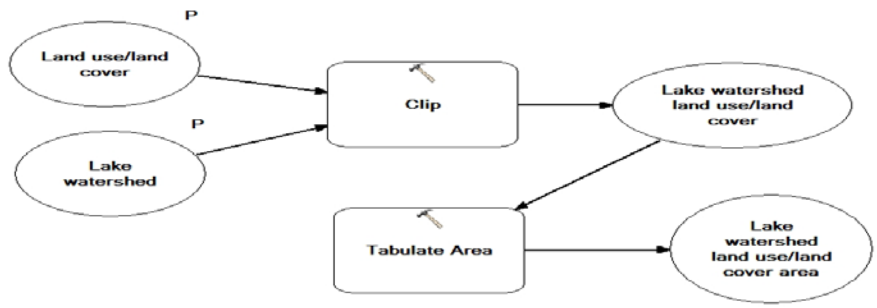
Module 3: Surficial geology percentage calculation module in ArcGIS



Module 4: Soil type percentage calculation module in ArcGIS



Module 5: Land use/Land cover percentage calculation module in ArcGIS



Module 6: Human density calculation module in ArcGIS