Partnership to Examine the Condition of Regional Lakes and their Influence on Tributaries of the St. Lawrence River

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Introduction

The lakes of northern New York (NNY) support abundant and diverse wildlife communities as well as a variety of valuable human uses. Given the relatively remote and undisturbed condition of our region, these water bodies are attractive and appear to be healthy and thriving. However, certain of these regional ecosystems are showing signs of human impact and degradation and need to be carefully managed. For example, the US Environmental Protection Agency found that over 60% of nearly 350 lakes across 8 New England states (including NY) showed one to several types of ecosystem stress (Whittier et al. 2002). Two of the most familiar forms of disturbance are lake acidification and cultural eutrophication. Many lakes in our Adirondack region are acidified while eutrophication is common in lowland lakes situated in drainage basins with high levels of agriculture (Whittier et al. 2002, Carpenter et al. 2007). Shoreline development can also cause eutrophication (Whittier et al. 2002, Moore et al. 2003) and, along with clearance of natural riparian vegetation, lake fish communities have become degraded (Whittier et al. 2002, Carpenter et al. 2007).

More recent work also stresses the impacts of atmospheric mercury deposition and exotic species invasions. Mercury is biomagnifying in many lake food webs and causing certain sport fish to become so toxic that humans need to limit their consumption of these fish (Whittier et al. 2002, Evers et al. 2007). Also, as humans move between lakes we spread non-native species (e.g. zebra mussels, round gobies, Eurasian milfoil) that displace familiar lake biota and alter the function and even appearance of these water bodies (Whittier et al. 2002, Baldwin et al. 2012). Finally, some lakes are showing signs of warming, reduced mixing, and a resultant decrease in ecological production due to global climate change (Williamson et al. 2009).

Many of these ecosystem disturbances can also impact rivers but thankfully, since the Clean Water Act of 1972, most (~85%) New York rivers have returned to a nearly pristine state (Bode et al. 2004). Most rivers of NNY are tributaries of the St. Lawrence River, draining the Adirondacks highlands and St. Lawrence River lowlands, neither of which is heavily populated or industrialized (Thorp et al. 2005). Even so, periodic stream surveys by the NYS DEC have assessed each of our area's Oswegatchie, Grasse, Raquette, and St. Regis rivers as being slightly impacted (Bode et al. 2004).

Those of us who have studied the water quality of the SLR along NNY recognize the significant influence of regional tributary rivers, such as the Oswegatchie, Grasse, Raquette, and St. Regis. In turn, what shapes their water quality? These tributaries drain a large, glacially carved landscape with hundreds of wildlife-filled lakes, each with the character of its particular watershed and the human activity within. Unlike streams, lakes gather surface and ground waters and hold the water for years, if not decades, modifying their traits before water is released to SLR tributary rivers. More dramatically, some tributaries have been dammed, creating lake-like reservoirs (hereafter, called lakes) that likely cause even more pronounced effects on the rivers. Furthermore, because lakes, in effect, concentrate human use (recreation, housing, etc.) and impact within a particular landscape, modifications of water quality may be striking. Collectively, then, our multitude of lakes may have a large, if undocumented, influence on the water quality of SLR tributaries and perhaps even the SLR itself.

For years, the NYS Department of Environmental Conservation (DEC) has partnered with the NYS Federation of Lake Associations to monitor basic water quality parameters of some lakes in our region (http://www.dec.ny.gov/chemical/81576.html, Citizens Statewide Lake Assessment Program, CSLAP). Paul Smiths College examines select Adirondack lakes in a similar way (http://www.paulsmiths.edu/awi/stewardship.php). While these programs are valuable, they do not cover all lakes in our region (Table 1); are not meant to provide a holistic assessment of lake ecosystems; do not measure environmental toxins like Hg; and do not assess potential lake influence on the SLR watershed.

Project Goals

I sought to develop more comprehensive assessments of lake ecology and water quality for major lakes in the NNY watershed of the St. Lawrence River (SLR) over the 2011 and 2012 open ice seasons. I also examined whether outflows from these lakes might influence the receiving tributary rivers (e.g., Grasse, Raquette, Oswegatchie) feeding the SLR. I did this, in part, as a citizen-science collaboration with area lake association members and SLU students. While I had hoped to initiate an annual "Healthy Landscapes" conference, at which collaborators would work cooperatively to learn about and safeguard our portion of the SLR watershed, I could not generate enough interest in attendance.

Methods

This study focused on: (1) the physical and chemical conditions of several lake habitats (open water basins, outflow and inflow streams), and (2) the biological conditions of lower trophic levels (phytoplankton, zooplankton). These characteristics were measured during spring, summer, and fall in GPS marked locations in 11 lakes during 2011 and 2012 (Figure 1). We (research students and I) measured vertical profiles of several environmental conditions in deep pelagic locations using a Hydrolab DataSonde 4a lowered from a boat. This instrument records conditions such as temperature, dissolved oxygen (DO), pH, etc. from known depths and thus we can tell whether the lakes had a warm, low density epilimnion above a cooler, high density hypolimnion. If such layering was noticed, the lakes were judged to be stratified, with little mixing of chemicals between the layers. If the lake was not stratified, then it was likely that, on windy days at least, chemicals and plankton were mixed throughout the depths of the lake. Because sunlight heats lake waters and fuels photosynthetic production of food, we measured light penetration and water clarity using a Secchi disc.

Because of the problems associated with cultural eutrophication, we judged whether lakes had low primary production (they were in an oligotrophic state), medium primary production (mesotrophic), or high/excessive primary production (eutrophic). The main concern was to identify eutrophic ecosystems that need to be managed to prevent negative consequences to fish; for example, low DO and pH resulting from high decomposition rates. We measured 2 lake conditions to determine trophic status. First, we measured average epilimnion levels of photosynthetic pigment (Chlorophyll a, Chl a) using the Hydrolab and we used this as our estimate of phytoplankton abundance. Second, we estimated water clarity of the epilimnion using the Secchi disc. Estimations of trophic status were then derived using the criteria listed in Table 2. Although we also attempted to measure total phosphorus concentrations in each lake during each sampling event this analysis proved too problematic and expensive.

In lakes, the main consumer of microscopic phytoplankton is the community of microscopic zooplankton (which themselves are important first foods for larval fish). To estimate the abundance of zooplankton in the epilimnion, we captured these organisms in zooplankton nets (153µm mesh, 30 cm diamter opening) towed vertically from the bottom to the top of this layer. Where stratification was not detected (e.g. Black Lake) we assumed zooplankton could be mixed throughout the water column and thus vertical zooplankton tows were made from the bottom of the lake to the surface. Concentrated zooplankton was transferred from the net to a sample bottle and anaesthetized (for better preservation) using club soda. Back at the lab, these samples were preserved in 70% ethanol and 2 ml subsamples were placed on a zooplankton counting wheel and enumerated under a stereomicroscope. This was normally done for about 10 subsamples. Calculations were then made to estimate field densities (individuals m^{-3}) of zooplankton for each lake.

We also assessed ecological health of lakes by examining other environmental data that indicate whether conditions are suitable for aquatic life (Table 3). Crucially important are levels of DO and pH, but other parameters such as acid neutralizing capacity (ANC) and hardness can significantly influence the abundance and diversity of biota. Some of these measurements were made directly using the Hydrolab. Others were made on field samples returned to the lab in clean plastic bottles. For example, hardness was measured using a LaMotte chemical kit and ANC (http://water.usgs.gov/owq/FieldManual/Chapter6/section6.6/) was calculated based on the volume of acid (0.05 M HCL) needed to reduce the field sample pH to 4.5.

To help characterize the inorganic chemical composition of lakes and their inlet and outlet waters we also sent waters samples (summer 2011) to ACME Analytical Laboratories

(Vancouver, British Columbia) for analyses of 70 elements. This was not in my original proposal but it seemed like a valuable way to chemically "fingerprint" each lake and outlet and compare their values to those of tributary rivers. Water samples were collected by hand in 150 mL Clean-pak plastic sample bottles held open 10-15 cm below the surface. Field samples were stored on ice in a cooler, transported to the lab, and stored at 4 ˚C in a refrigerator until shipment to ACME.

Results & Discussion

Seven of the 11 lakes became stratified during warmer summer months while the other four maintained uniform vertical profiles of temperature and dissolved oxygen (DO) and were thus assumed to be polymictic, mixing many times per year (Table 4). Polymictic lakes were relatively shallow and the mixing within two reservoirs (Higley and Norwood) was also promoted by the constant flux of the Raquette river. This may also be true for Black Lake, which receives significant input from the Indian river. As a result of summer stratification, epilimnion levels of DO (expressed as % saturation) remain high whereas those in the bottom hypolimnion decline due to decomposition. Yearly patterns of temperature and DO stratification are illustrated for representative lakes within each tributary watershed (Figs. 2-4). Loss of DO in the hypolimnion, particularly when levels decline to hypoxic levels (<30%), stresses fish and other aquatic life and may cause habitat compression for these animals, in effect, crowding them into the epilimnion where they may compete with or be preyed upon by other aquatic life, and where they may also be stressed by warmer waters. This "biotic crisis" (Table 3) level of DO (<30% is similar to <3 mg/L) was measured during summer for all stratified lakes but typically only in water 1-2m above bottom sediments.

Another concern in our study was whether these and other chemical changes brought on by stratification might influence their outlets and perhaps their receiving tributary rivers. Besides declines in DO, hypolimnetic waters also experience declines in pH. Generally our pH levels remained near or above neutral (Table 4) but occasionally we measured pH levels as low as 5.8 in Cranberry, Tupper, and Carry Falls (all above the biotic crisis levels in Table 3). However, outlet pH levels, as well as DO levels, remained normal (Table 4) and by this measure, stressed lake waters were not exiting lakes and moving toward tributary rivers. This conclusion is further supported by our specific conductivity levels, which did not vary from lake to outlet waters (Table 4).

While not an originally planned analysis of this grant project, we incorporated the additional assessment of inorganic chemical elements to judge whether lake waters were negatively impacting outlet streams and perhaps tributary rivers. Based on an analysis of 17 key inorganic elements (of 70 total) measured in lake and river waters in summer 2011 it appears that many lakes within the Oswegatchie river watershed have higher values than the mainstem of the

Oswegatchie itself (river data shared by Drs. Chiarenzelli and Skeels of SLU, who were also awarded a SLRREF grant for 2011 and 2012) and thus may be local sources of these elements (Table 5). Sylvia Lake in particular appears to have higher concentrations of a number of elements and this may be due to its unique, deep basin, the geological composition of its watershed, and/or the mining activity around the lake (see below). However, none of the measured elements are above EPA health thresholds (http://water.epa.gov/drink/contaminants/index.cfm#Inorganic). Most of these lakes are outside of the Adirondack highlands and in general their geological setting includes softer rocks that can more easily dissolve and contribute elements to surface and ground waters. Cranberry Lake, within the Adirondack Park and surrounded by more resistant rock (see below), generally has lower elemental concentrations than the Oswegatchie river itself although both lake aluminum and iron is high. In these two cases it is interesting that these chemical levels dissipate as the inlet waters travel through the lake and exit at outlet streams (Table 5). It is unclear whether these two incoming elements decline due to chemical, physical, or biological reasons. Within the Grasse river watershed, Trout and Silver lakes seem high in only two elements and none of the lakes within the Raquette river watershed have higher elemental concentrations that the tributary itself. This is not surprising given that these lakes all lie within or in close contact (Tupper Lake) with the Raquette river. Based on this analysis, it appears that our study lakes are largely not sources of polluting chemicals to the tributary rivers that receive their outflowing waters and ultimately contribute them to the St. Lawrence River.

We also sought to delineate and characterize the watersheds of each lake, to provide crucial landscape-scale context to the ecological status of our lakes. We have successfully accomplished this for many, but not all of our lakes and are continuing to work on remaining watersheds this spring (in short, our GIS specialist at SLU is consulting with software designers to overcome limitations in delineating watersheds for remaining lakes). For several lakes we see how the geological composition of watersheds impacts lake chemistry. For example, Cranberry Lake, near the Adirondack Highlands (Fig. 1) receives water draining from a watershed dominated by resistant, igneous rock (Fig. 5) and this helps explain the neutral pH and low specific conductivity (SC) of its waters (Table 4), as well as many of its low elemental concentrations (Table 5). Closer to the St. Lawrence river valley, Sylvia Lake receives water from a watershed dominated by softer calcitic rock (Fig. 6), which helps explain why it has elevated levels of pH, SC and several elements. Within the St. Lawrence river valley itself, Black Lake also has a significant amount of softer calcitic and sedimentary rocks (Fig. 7), which helps explain why it has elevated levels of pH, SC and several elements. Trout lake (Fig. 8), of the Grasse river watershed and also near the St. Lawrence river valley, has lower levels due to the dominance of igneous rock in its watershed. Lower elemental concentrations and SC also correlate with lower levels of water hardness and acid neutralizing capacity (also known as alkalinity) in these lakes (Table 6). Based on water quality standards in Table 3, all lakes have sufficient buffering capacity (to offset acidic inputs) but Adirondack lakes such as Cranberry, Tupper, and Carry Falls do have marginally low pH levels (Table 4).

Only 2 lakes (Black and Norwood) showed eutrophic traits while the majority had mesotrophic traits (Table 7). Sylvia lake was consistently oligotrophic, which may explain how this small, unusually deep (~42 m or 140 ft.), and stratified lake never developed low and stressful DO levels, even in its hypolimnion. Given how developed its shoreline is with camps and homes (and their septic systems), I assumed the lake would be more productive. However the watershed beyond the immediate shoreline is mainly undisturbed and dominated by forests (Fig. 9) so few nutrients must reach the lake via its inlet streams. Hopefully the shoreline and watershed can be managed well in the future to maintain this rare status. Surprisingly, Cranberry lake is mesotrophic, despite having a watershed (mainly that of the upper Oswegatchie River) so dominated by forest lands (Fig. 10) and despite having only about 20% of its shoreline developed with camps and the village of Cranberry Lake. A possible explanation is that the shallower depth of the lake (10m or so) allows greater mixing of hypolimnion nutrients (from benthic decomposition) into the epilimnion for plankton production. Still, managers should ensure that shoreline nutrient inputs remain low, to prevent overproduction and loss of aesthetic values (clarity, etc.) for this beautiful Adirondack lake.

A classic eutrophic lake, in the fertile St. Lawrence valley and at the receiving end of the large Indian River, is Black Lake. Total phosphorus (TP) measurements I have from another project average 0.072 mg/L, well above the 0.02 mg/L threshold (Table 3) and thus this lake is definitely eutrophic and likely hypertrophic, meaning that it has excessive productivity of plankton and aquatic weeds. In part this is due to high nutrient inputs from extensive shoreline development and a large watershed with significant agricultural runoff (Fig. 11). But its shallow, frequently mixing waters also ensure that nutrients are kept suspended in the photic zone to support plant production. As a result, the aesthetic values of the lake are low (turbid, weedy waters) but the recreational fishing value remains high. If managers could reduce nutrient input, they might retain fishing value while increasing aesthetic value of the lake. Finally, because the lake outlet waters enter the Oswegatchie River very close to its confluence with the St. Lawrence River, it is possible that this productive lake fuels fish and other biota in those receiving rivers. Trout Lake, draining into the Grasse River, is another mesotrophic lake despite having a small watershed that is dominated by forests (Fig. 12). Being deeper than Cranberry Lake, and thus less likely to receive nutrients from the hypolimnion, managers might focus more on nutrients supplied by extensive shoreline development, in order to maintain or reduce its mesotrophic status. Similar insights into the potential relationships between watershed landuse and trophic status should be possible for other lakes once we manage to delineate and characterize their watersheds.

Lake trophic status ultimately supports lake fisheries through the zooplankton; microscopic, shrimp-like animals which consume phytoplankton and are eaten by larval and some adult fish. Zooplankton community (all individuals of all species) densities for the lakes are generally in line with their trophic status, with oligotrophic Sylvia Lake having the lowest density and eutrophic Black the highest (Table 6). The biodiversity of zooplankton was typically split between copepods and cladocerans and, to my relief, no exotic species (fish hook flea, etc.) were detected in our samples.

Conclusions

This two year study showed that NNY lakes are generally in good ecological health and are not negatively influencing their outlet streams and receiving tributary rivers, which eventually influence the St. Lawrence River. Ecological traits of these lakes vary in interesting ways and are undoubtedly influenced by the size, geology, and landuse of their watersheds. All or a representative subset of these lakes should be more carefully examined to better describe their ecology and to guide managers tasked with safeguarding the lakes and fisheries within. Residents of most lakes were very generous in assisting this research and themselves represent a talented, caring pool of citizen scientists that can help with such studies in the future.

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Table 1. Characteristics of study lakes.

Lake	Tributary watershed	Surface Area (acres)	Elevation (ft)	Lake Association?	CSLAP participant?	ALAP participant?
Cranberry	Oswegatchie	6976	1486	Yes		Yes
Bonaparte	Oswegatchie	1286	768	Yes	yes	
Sylvia	Oswegatchie	314	653	Yes		Yes
Black	Oswegatchie	8352	272	Yes	yes	
Massawepie	Grasse	437	1512			
Trout	Grasse	371	745	Yes		
Silver	Grasse	112	1473		yes	
Tupper	Raquette	4800	1542			Yes
Carry Falls	Raquette	5753	1528	RR Blueway Corridor		
Higley Flow	Raquette	698	882	yes		
Norwood	Raquette	352	328	yes		

Table 2. Trophic status determination (modified from Cooke et al. 1993).

	Eutrophic	Mesotrophic	Oligotrophic
Total Phosphorus (mg/L)	>0.02	0.01-0.02	<0.01
Chl. A (µg/L)	>8	2 to 8	<2
Secchi depth (m)	<2	2 to 5	>5

Table 3. US EPA water quality guidelines for aquatic biota (modified from Bain 1999).

Criterion	Ideal Levels	Biotic Crisis Levels
Dissolved Oxygen (mg/L)	>5	≤3
pH	6.5-9.0	<4
ANC (mg/L)	>75	<20
Hardness (mg/L)	75-300	0

Table 4. Stratification conditions of sampled lakes, measured over the spring, summer, and fall of 2011 and 2012. Entire depth of pelagic zone sampling is compared with the portion that forms the epilimnion in the summer. Dissolved oxygen (DO) levels (range of % saturation values) in the epilimnion and hypolimnion are compared to illustrate the degree of oxygen depletion in the hypolimnion. Lakes with these two established layers are dimictic and turnover in the spring and fall. Lakes without these layers are polymictic (poly/shaded) and mix frequently thoughout the year. Ranges of lake pH and specific conductivity (SC) are also presented. For comparison to lakes, DO, pH, and SC values for outlet waters are included. Lakes are presented in order of highest to lowest elevation within the tributary watershed (see Table 1).

Trib.	Lake	Sampling Depth (m)	Epilimnion Depth (m)	Epilimnion DO (%)	Hypolimnion DO (%)	pH	Spec. Cond. (uS/cm)	Outlet DO (%)	Outlet pH	Outlet Spec. Cond. (uS/cm)
Osw.	Cranberry	11	8-9	64-96	0.6-74	6.2-7.2	15-17	80-92	6.2-6.5	16-17
	Bonaparte	17	5-7	76-95	58-65	7.4-8.4	180-190	84-94	7.6-8.4	176-184
	Sylvia	43	10-15	82-92	34-82	7.4-8.3	230-235	87-100	8.1-8.9	221-228
	Black	5	poly	85-134	poly	7.3-9.6	160-190	91-116	7.6-9.5	174-178
Gra.	Massawepie	17	4-6	78-105	1-79	7.3-7.7	47-54	83-89	7.4-7.8	51-55
	Silver	3	poly	89-94	poly	7.5-7.8	150-158	78-95	7.2-7.5	154-157
	Trout	17	6-8	68-97	35-64	7.1-8.2	72-75	81-97	7.1-7.8	69-78
Raq.	Tupper	17	6-8	74-99	41-72	6.8-7.4	23-28	80-91	6.7-7.2	23-27
	Carry Falls	15	10-11	71-87	28-55	6.4-6.9	28-30	83-95	6.6-6.9	22-29
	Higley	7	poly	88-96	poly	6.6-6.9	30-35	79-96	6.8-6.9	27-32
	Norwood	5	poly	85-92	poly	6.8-7.2	36-40	83-92	7.0-7.1	31-40

Table 5. Inorganic chemical composition of lakes, inlets, outlets, and tributary rivers measured in July 2011. Lakes are presented in order of highest to lowest elevation within the tributary watershed. Vertical lines beside data indicate lake readings that appear higher than recipient tributary rivers (shaded data, provided by Drs. Chiarenzelli and Skeels of SLU). Abbreviations are given for Cranberry (Cranb.) Lake waters, Bonaparte (Bonap.) Lake waters, and Massawepie (Mass.) Lake waters. Chemical elements are Aluminum (Al), Boron (B), Barium (Ba), Bromide (Br), Calcium (Ca), chloride (Cl), Chromium (Cr), Iron (Fe), Mercury (Hg), Magnesium (Mg), Manganese (Mn), Sodium (Na), Phosphorus (P), Selenium (Se), Silicon (Si), Strontium (Sr), and Zinc (Zn).

		Select Chemical Elements																
		Al	B	Ba	Br	Ca	Cl	Cr	Fe	Hg	Mg	Mn	Na	P	Se	Si	Sr	Zn
	units	ppb	ppb	ppb	ppm	ppb	ppb	ppb	ppb	ppb	ppm	ppb	ppm	ppb	ppb	ppb	ppb	ppb
	detection limits	1	5	0.05	5	0.05	1	0.5	10	0.1	0.05	0.05	0.05	20	0.5	40	0.01	0.5
Tributary	Site																	
Oswegatchie	Cranb. Lake	104	<5	10.82	<5	2.12	<1	<0.5	102	<0.1	0.46	1.86	0.78	<20	<0.5	2275	9.68	6.2
	Cranb. Inlet	231	6	8.96	<5	2.71	<1	<0.5	816	<0.1	0.59	1.75	0.97	<20	<0.5	2781	13.12	4.5
	Cranb. Outlet	94	5	10.59	<5	2.08	<1	<0.5	95	<0.1	0.45	1.01	1.04	<20	<0.5	2261	9.46	6.3
	Bonap. Lake	1	60	18.83	6	28.41	9	4.8	<10	<0.1	5.88	0.31	7.23	<20	<0.5	1846	113.1	<0.5
	Bonap. Inlet	2	57	18.51	8	28.38	9	4.5	<10	<0.1	5.82	0.53	7.31	<20	<0.5	1877	113.7	<0.5
	Bonap. Outlet	1	59	19.24	7	27.61	9	4.6	<10	<0.1	5.82	0.29	7.19	<20	<0.5	2029	111.1	1.9
	Sylvia lake	5	57	39.27	14	30.98	12	4	<10	<0.1	7.43	0.52	9.76	75	<0.5	2535	112.4	53.7
	Sylvia Inlet	6	53	38.66	14	30.76	12	3.9	<10	<0.1	7.51	1.49	9.89	76	<0.5	2546	111.1	56.7
	Sylvia Outlet	5	53	38.21	14	30.97	12	4.1	<10	<0.1	7.41	0.89	9.58	72	<0.5	2506	112.1	56.3
	Black Lake	3	50	24.66	16	22.77	14	3.9	<10	<0.1	5.68	0.36	11.27	24	<0.5	654	113.9	3.4
	Black Inlet	4	46	21.99	16	21.78	15	3.6	97	<0.1	5.01	0.45	11.54	39	<0.5	2301	110.3	<0.5
	Black Outlet	4	49	21.99	13	21.45	12	3.8	<10	<0.1	5.6	0.75	9.91	22	<0.5	1029	104	<0.5
	Oswegatchie River 5	57	10	15.84	10	10.48	3	1.9	399	<0.1	2.89	2.07	3.70	<20	<0.5	2689	44.88	4.1
	Oswegatchie River 7	36	11	20.46	12	12.85	5	2.4	312	<0.1	3.84	2.16	5.26	<20	<0.5	2872	58.57	2.3
Grasse	Mass. Lake	27	8	7.09	<5	4.57	4	0.6	114	<0.1	1.36	2.82	3.98	21	<0.5	3168	20.95	2.7
	Mass. Inlet	32	6	6.98	<5	4.21	6	<0.5	124	<0.1	1.29	2.64	3.64	<20	<0.5	3149	21.48	3.2
	Mass. Outlet	24	7	7.21	<5	4.65	4	0.7	109	<0.1	1.38	2.91	4.06	22	<0.5	3171	20.37	2.9
	Silver Lake	3	13	20.46	7	6.39	31	0.7	<10	<0.1	1.39	0.37	24.55	<20	<0.5	2043	30.59	1.4
	Trout Lake	10	22	18.05	7	10.69	3	1.7	<10	<0.1	3.4	0.14	2.3	20	<0.5	1125	33.65	0.9
	Trout Inlet	12	21	18.01	7	10.62	3	1.6	<10	<0.1	3.3	0.17	2.46	21	<0.5	1117	33.27	0.8
	Trout Outlet	11	22	17.94	8	10.59	3	1.7	<10	<0.1	3.4	0.21	2.27	23	<0.5	1105	32.79	0.8
	Grasse River 5a	89	9	13.75	9	9.19	3	1.9	534	<0.1	3.22	2.89	3.17	20	<0.5	2876	30.88	2.2
	Grasse River 8	55	10	13.88	9	10.25	3	2.1	396	<0.1	3.57	3.41	3.53	<20	<0.5	3155	31.68	8.3
Raquette	Tupper Lake	74	<5	7.86	<5	2.61	1	<0.5	62	<0.1	0.55	1.32	1.82	<20	<0.5	2449	12.63	4.2
	Tupper Inlet	80	6	7.13	<5	2.54	<1	<0.5	204	<0.1	0.55	2.01	1.11	<20	<0.5	2191	12.37	3.4
	Tupper Outlet	68	6	7.76	5	3.1	2	<0.5	151	<0.1	0.62	2.37	2.64	<20	<0.5	2359	15.57	3.4
	Carry Falls Lake	74	7	8.03	<5	3.27	2	<0.5	194	<0.1	0.72	3.01	2.75	<20	<0.5	2209	16.45	2.6
	Carry Falls Inlet	41	7	7.65	6	3.42	3	<0.5	138	<0.1	0.77	1.86	3.09	<20	<0.5	1516	17.42	1
	Higley Lake	67	8	8.87	<5	3.72	2	<0.5	96	<0.1	0.9	1.6	2.53	<20	<0.5	2379	16.29	3.1
	Higley Inlet	73	6	8.51	<5	3.17	1	<0.5	104	<0.1	0.68	2.02	2.23	<20	<0.5	2327	15.76	4.5
	Norwood Lake	57	11	10.51	5	4.59	3	0.7	124	<0.1	1.24	1.95	3.02	<20	<0.5	2455	18.26	1.5
	Norwood Inlet	65	10	10.51	<5	4.51	3	0.6	114	<0.1	1.23	1.69	2.94	<20	<0.5	2412	18.38	1.8
	Raquette River 5b	102	9	14.04	8	9.30	3	1.7	513	<0.1	3.21	2.81	3.21	21	<0.5	2853	31.45	2.0
	Raquette River 6a	52	6	10.29	5	4.32	2	0.8	172	<0.1	1.17	3.09	2.82	<20	<0.5	2212	16.83	1.7
	Raquette River 8	39	6	11.11	6	5.21	3	0.9	158	<0.1	1.51	2.50	3.52	<20	<0.5	2175	19.56	1.6

Table 6. Hardness and acid neutralizing capacity (ANC) for study lakes in summer 2011.

Trib.	Lake	Hardness (mg CaCO3/L)	ANC (mg CaCO3/L)
Osw.	Cranberry	17.9	67.7
	Bonaparte	116.0	269.4
	Sylvia	125.6	278.0
	Black	95.0	247.8
Gra.	Massawepie	27.1	112.2
	Silver	33.9	136.4
	Trout	49.9	178.3
Raq.	Tupper	19.8	78.2
	Carry Falls	22.2	90.9
	Higley	23.9	98.8
	Norwood	27.1	112.5

Table 7. Trophic status estimation for study lakes. Mean values of phytoplankton biomass and secchi disc depth and resultant status, based on criteria in Table 2. One lake was oligotrophic, 3 lakes had oligotrophic and mesotrophic traits, 5 lakes were mesotrophic, and 2 had mesotrophic and eutrophic traits. Mean zooplankton densities (individuals/m^3) are given for all lakes but Silver, which was not determined.

Trib.	Lake	Epilimnion Chl a (ug/L)	Secchi Depth (m)	Trophic Status	Zooplankton indiv./m3
Osw.	Cranberry	2.4	2.7	meso	751.4
	Bonaparte	1.4	4.2	oligo-meso	637.8
	Sylvia	1.3	6.7	oligo	532.5
	Black	4.2	2.1	meso-eutro	1143.7
Gra.	Massawepie	2.6	2.3	meso	654.7
	Silver	2.6	3.2	meso	nd
	Trout	2.5	4.1	meso	714.4
Raq.	Tupper	1.8	2.7	oligo-meso	645.7
	Carry Falls	1.5	3.4	oligo-meso	625.2
	Higley	2.9	2.3	meso	676.4
	Norwood	3.2	0.8	meso-eutro	847.9

Figure 1. Location of open lake, inlet, and outlet sampling sites in northern New York lakes.

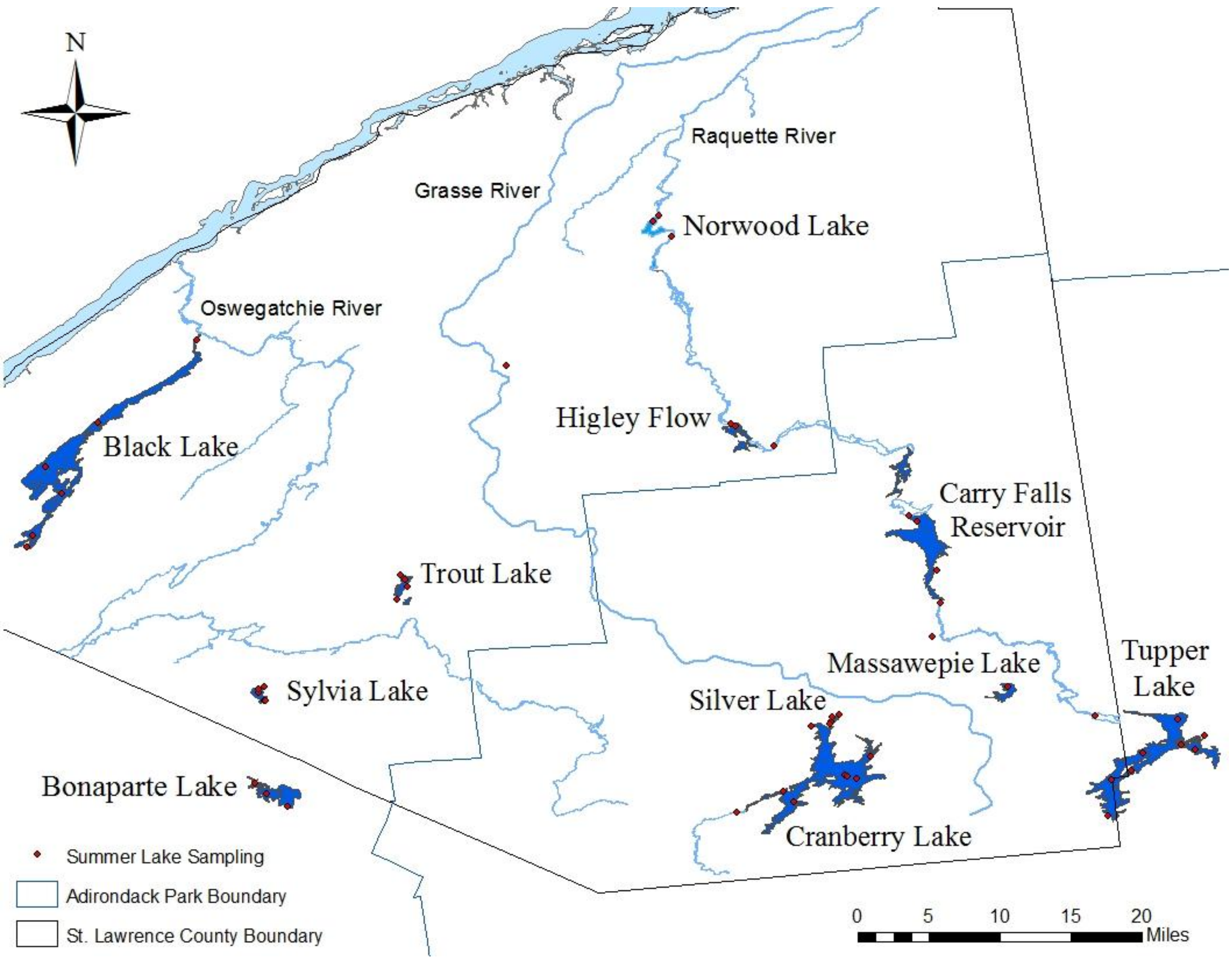
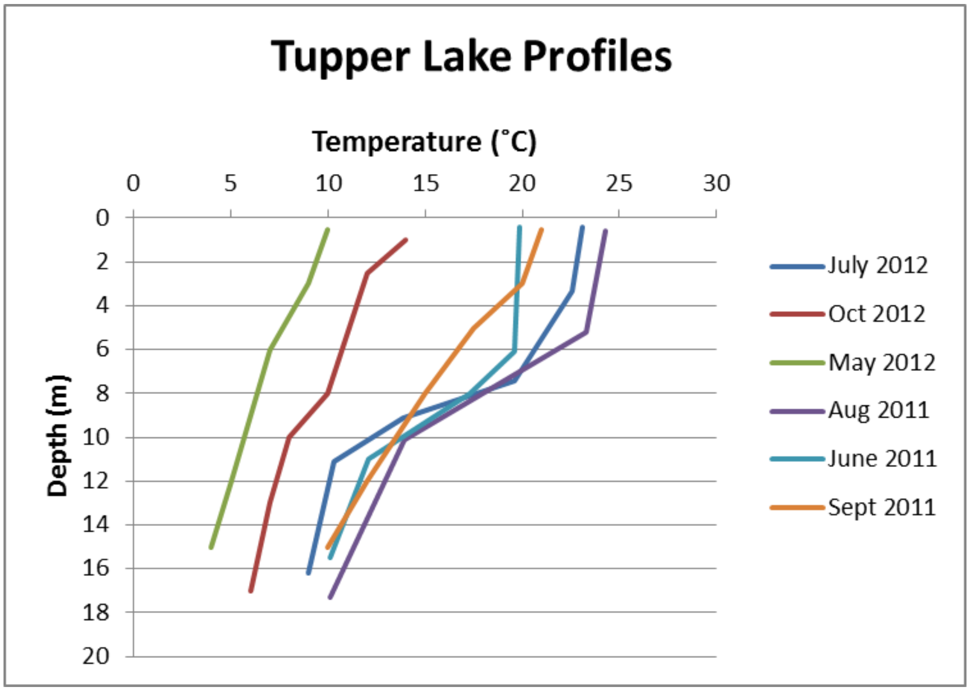


Figure 2. Vertical profiles of temperature and dissolved oxygen (% saturation) of Tupper Lake in spring, summer, and fall of 2011 and 2012.



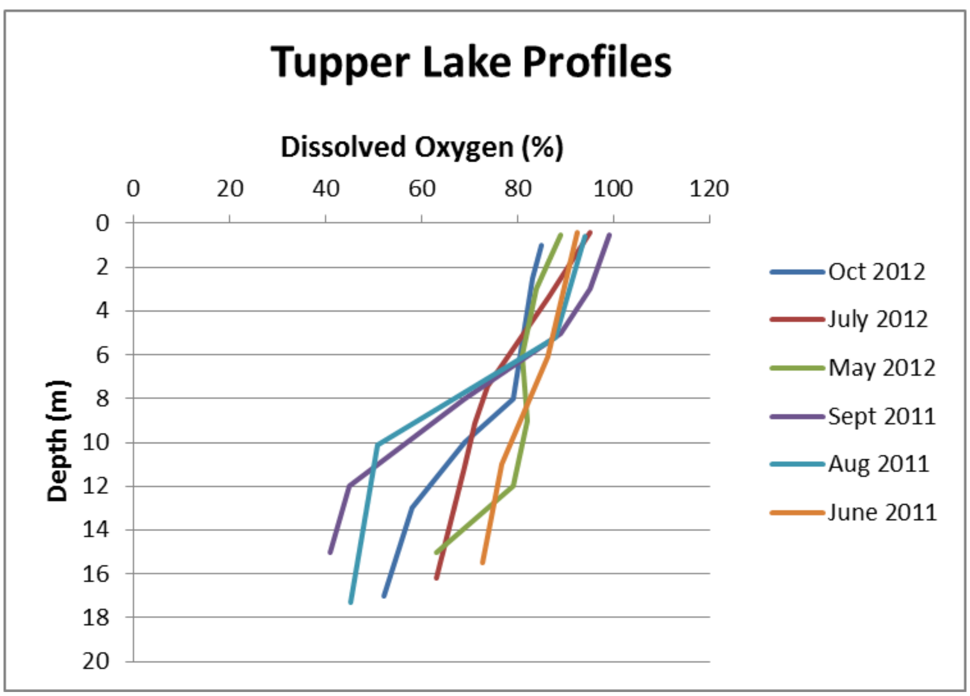
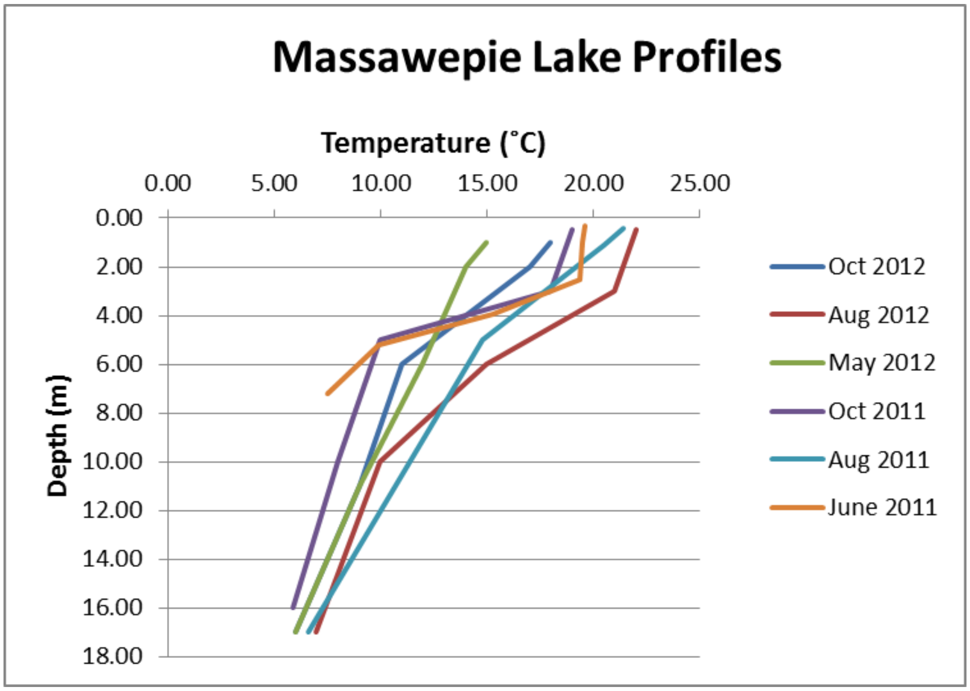


Figure 3. Vertical profiles of temperature and dissolved oxygen (% saturation) of Massawepie Lake in spring, summer, and fall of 2011 and 2012.



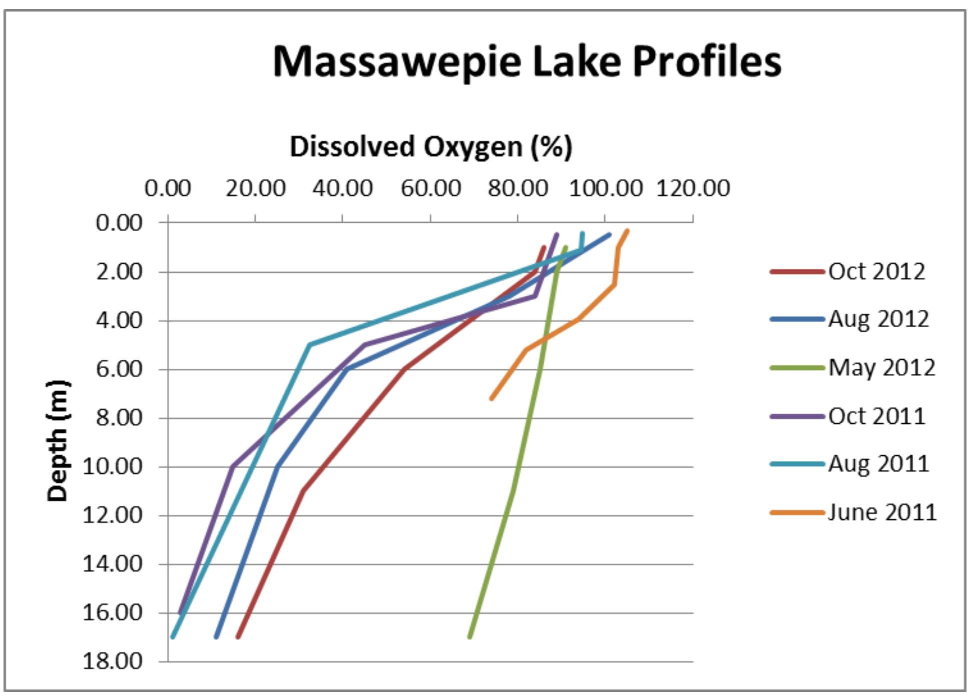
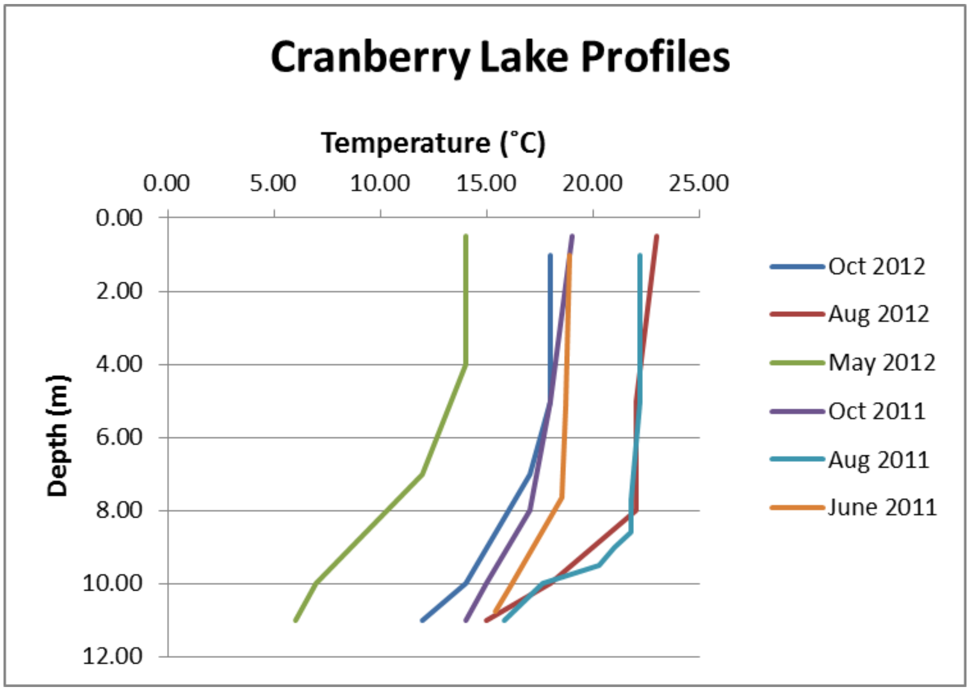


Figure 4. Vertical profiles of temperature and dissolved oxygen (% saturation) of Cranberry Lake in spring, summer, and fall of 2011 and 2012.



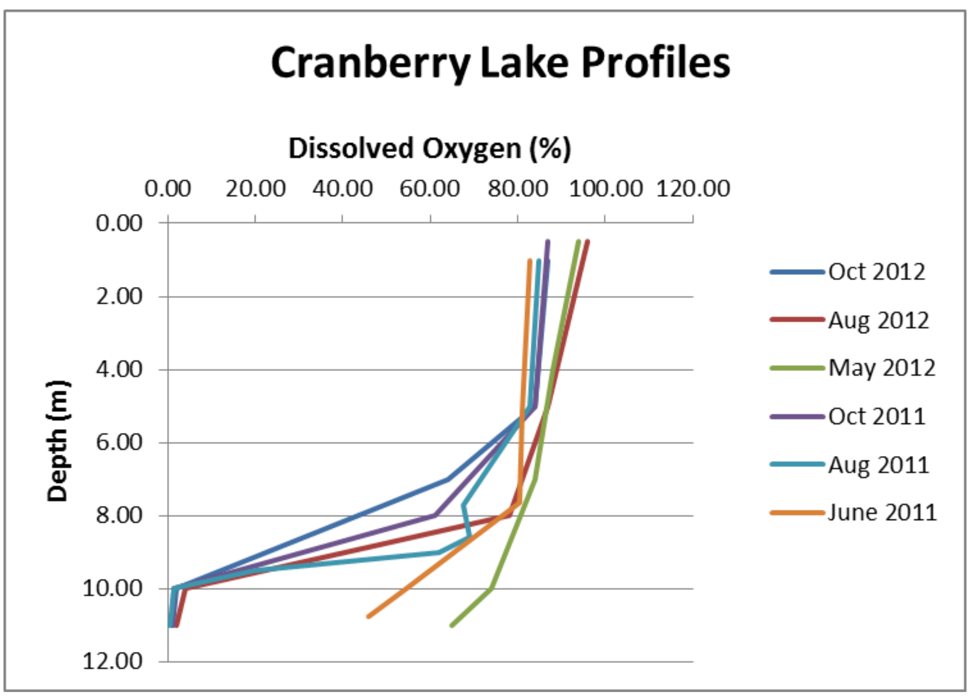
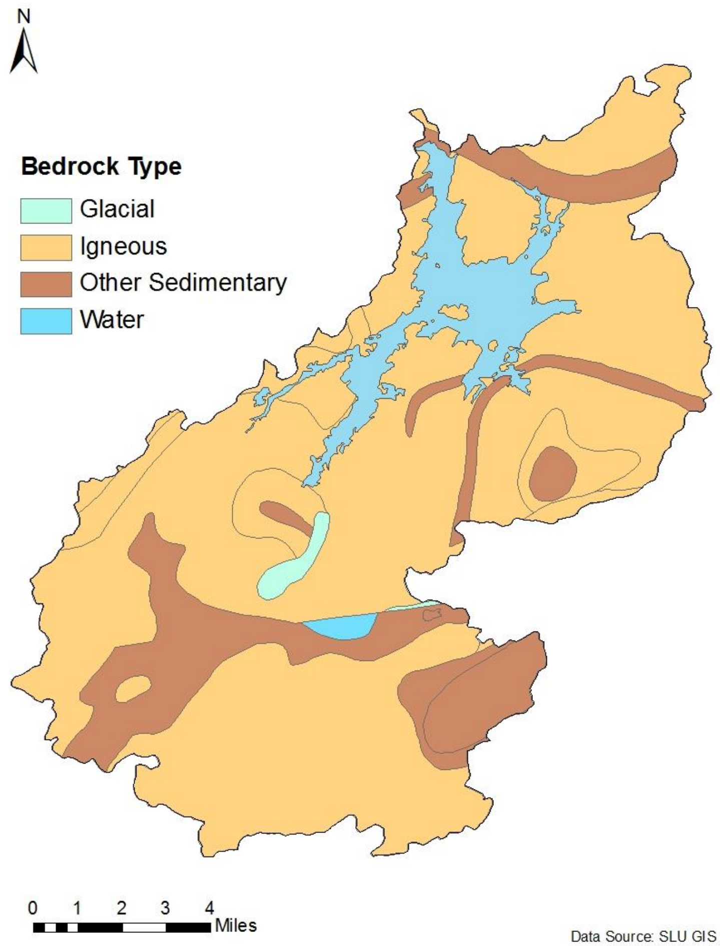


Figure 5. Watershed shape and bedrock geology of Cranberry Lake. Spatial patterns of generally rock types are illustrated in the top figure, while the spatial contribution of each type is quantified in the bottom pie chart.



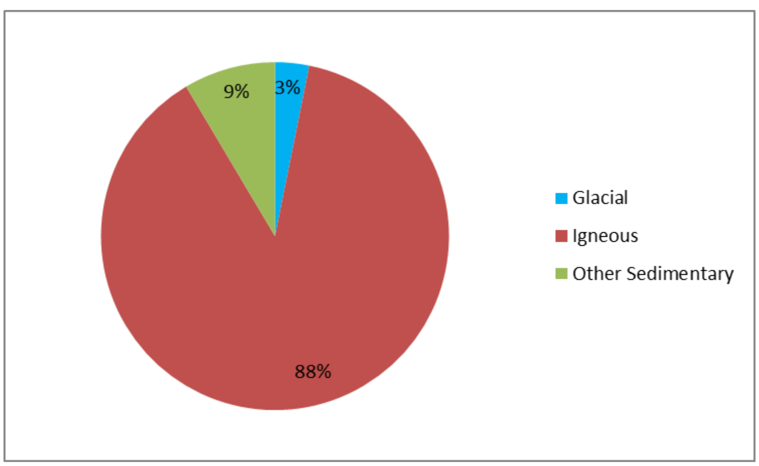
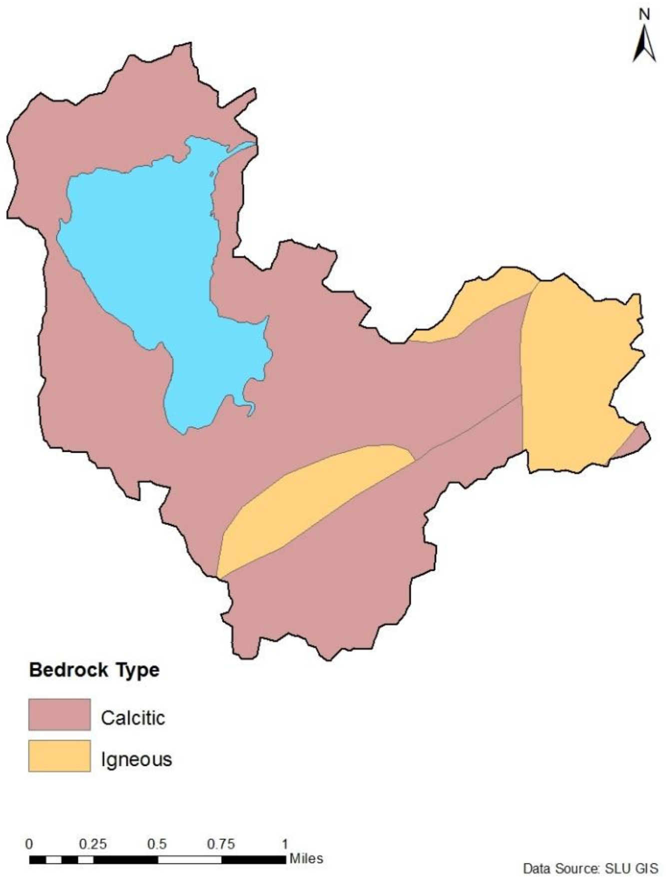


Figure 6. Watershed shape and bedrock geology of Sylvia Lake. Spatial patterns of generally rock types are illustrated in the top figure, while the spatial contribution of each type is quantified in the bottom pie chart.



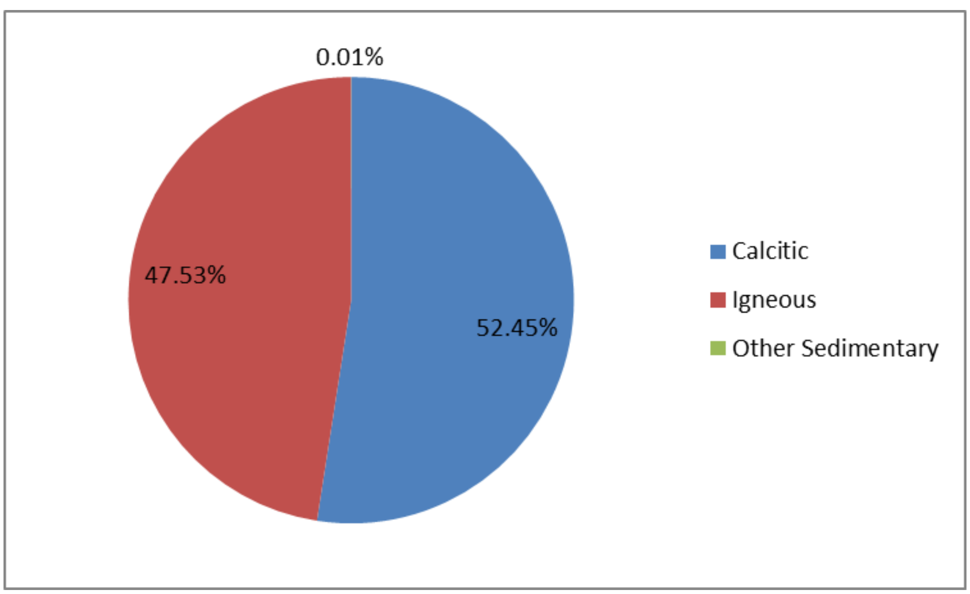
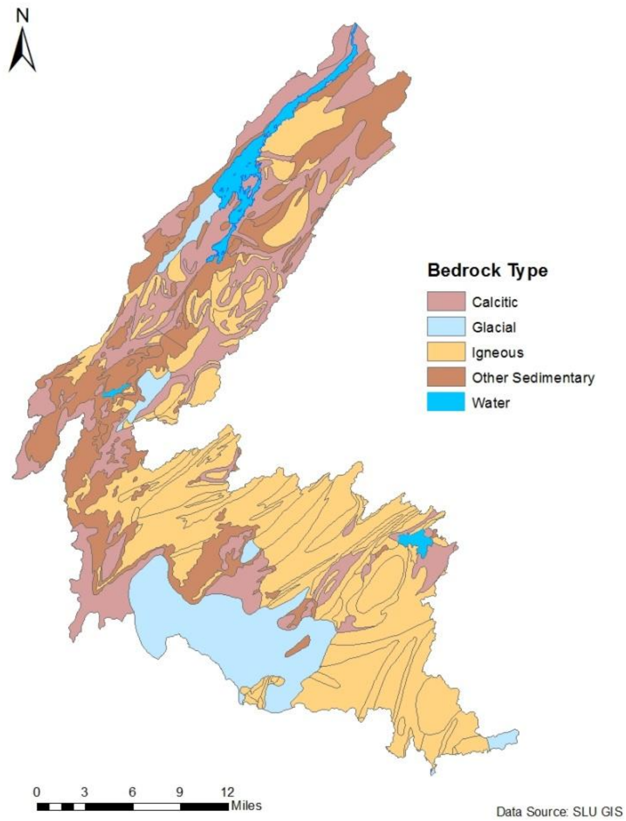


Figure 7. Watershed shape and bedrock geology of Black Lake. Spatial patterns of generally rock types are illustrated in the top figure, while the spatial contribution of each type is quantified in the bottom pie chart.



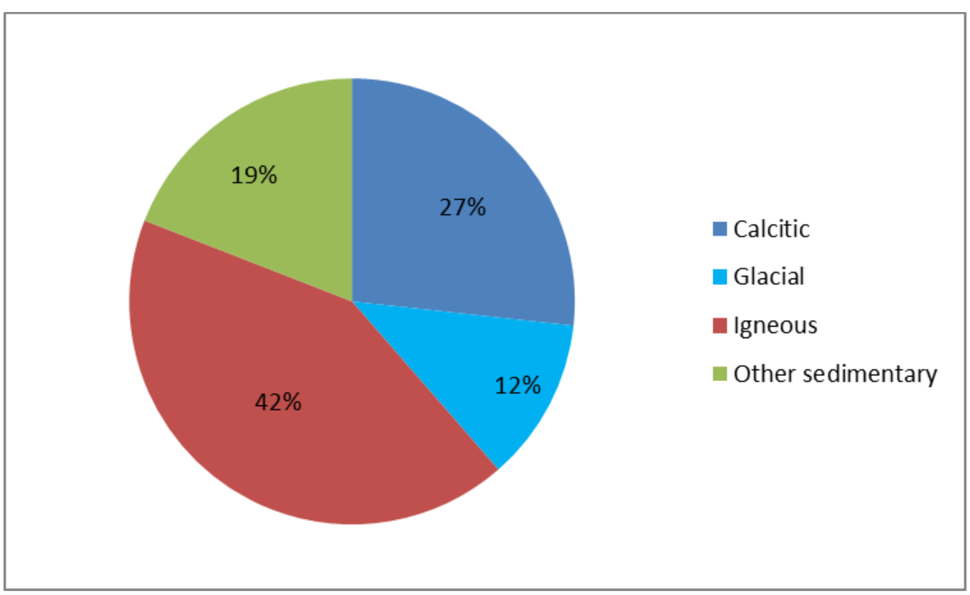
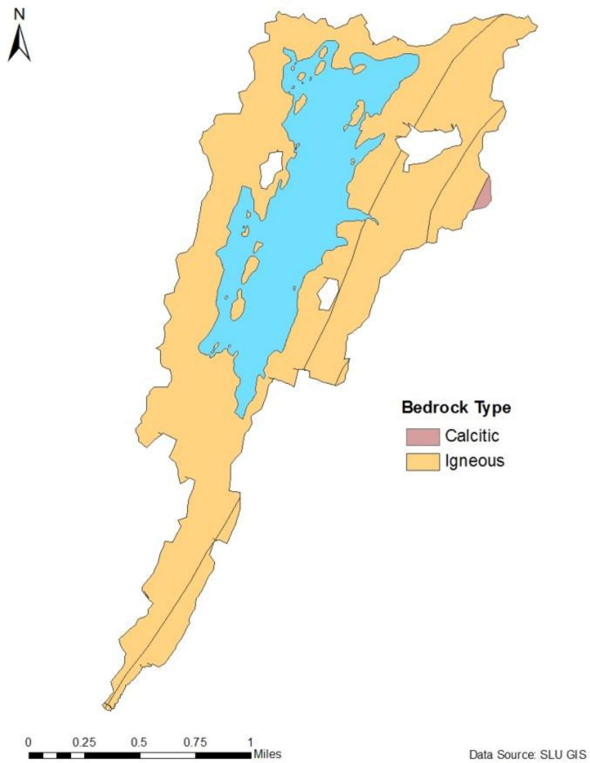


Figure 8. Watershed shape and bedrock geology of Trout Lake. Spatial patterns of generally rock types are illustrated in the top figure, while the spatial contribution of each type is quantified in the bottom pie chart.



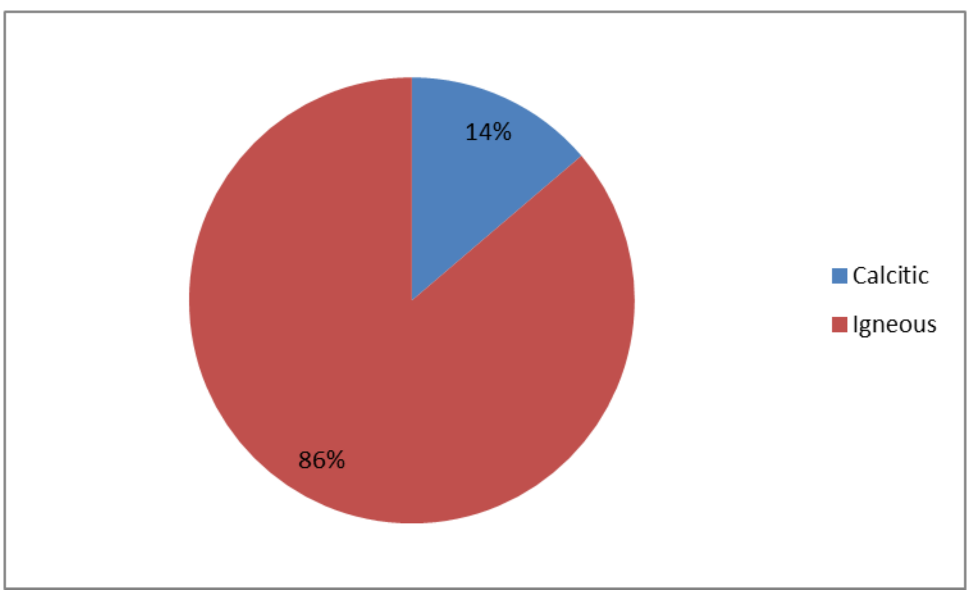
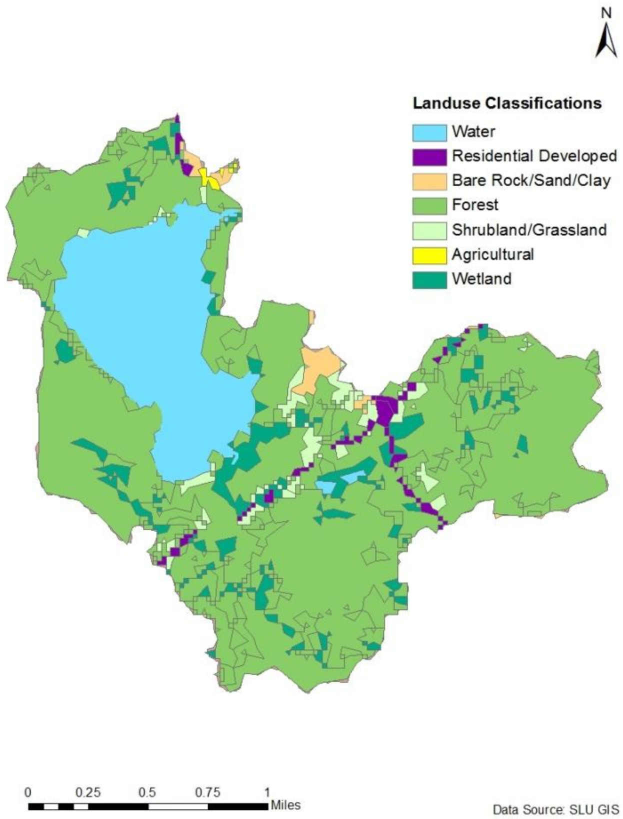


Figure 9. Watershed shape and human landuse around Sylvia Lake. Spatial patterns of generally landuse types are illustrated in the top figure, while the spatial contribution of each type is quantified in the bottom pie chart.



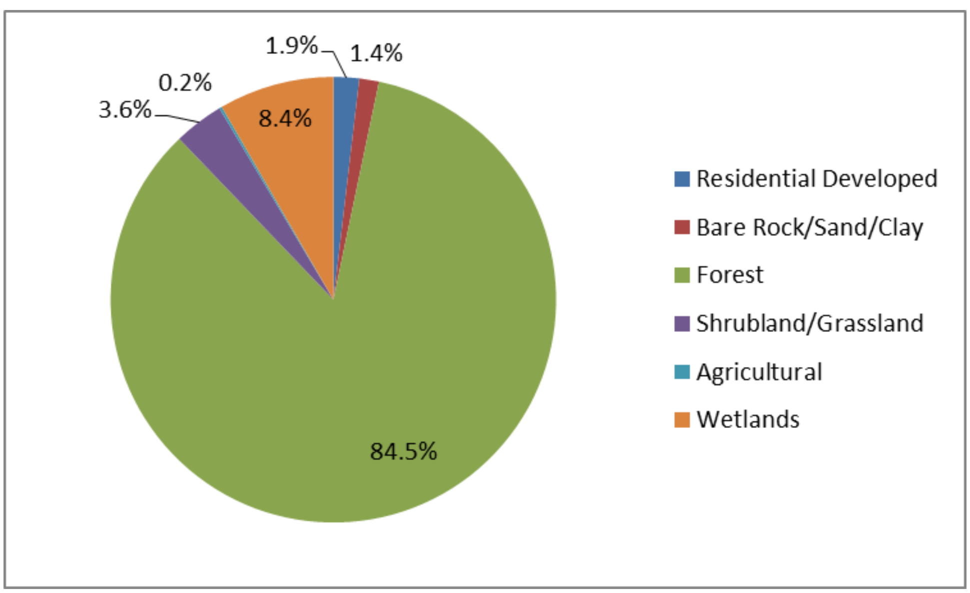


Figure 10. Watershed shape and human landuse around Cranberry Lake. Spatial patterns of generally landuse types are illustrated in the top figure, while the spatial contribution of each type is quantified in the bottom pie chart.

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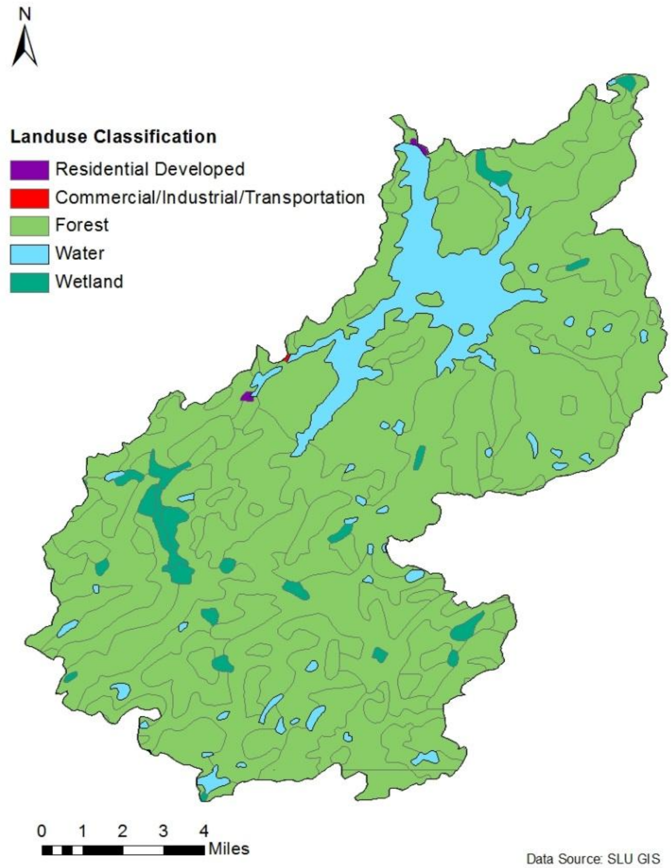


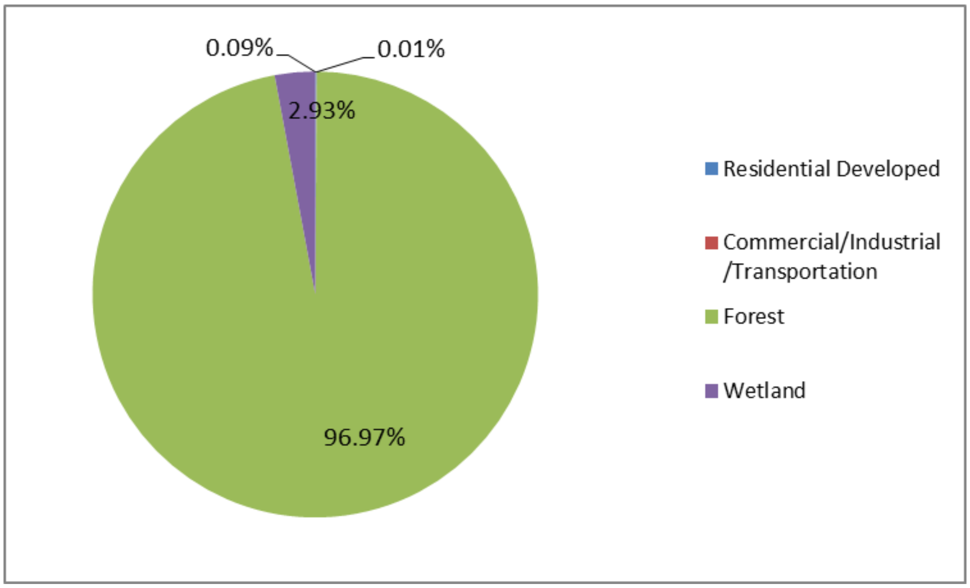
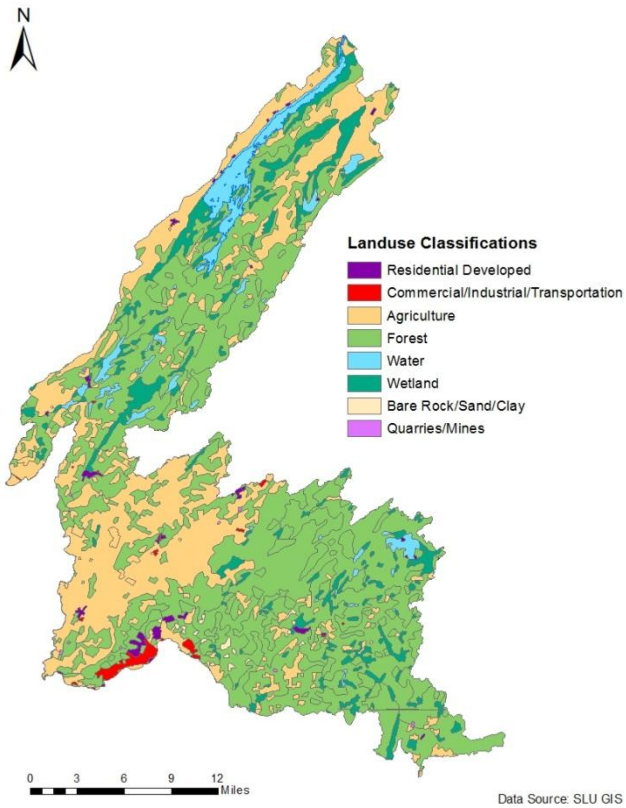


Figure 11. Watershed shape and human landuse around Black Lake. Spatial patterns of generally landuse types are illustrated in the top figure, while the spatial contribution of each type is quantified in the bottom pie chart.



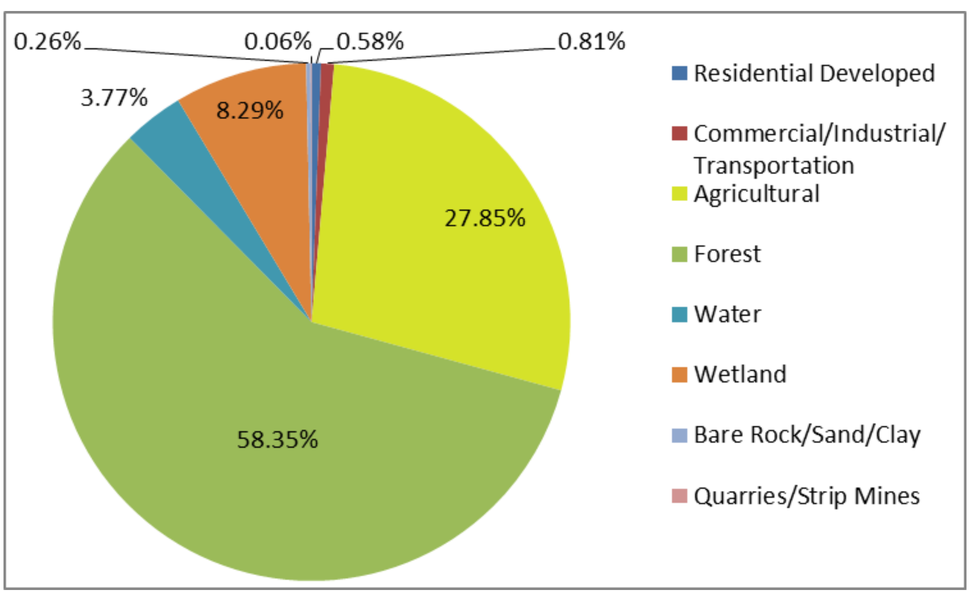
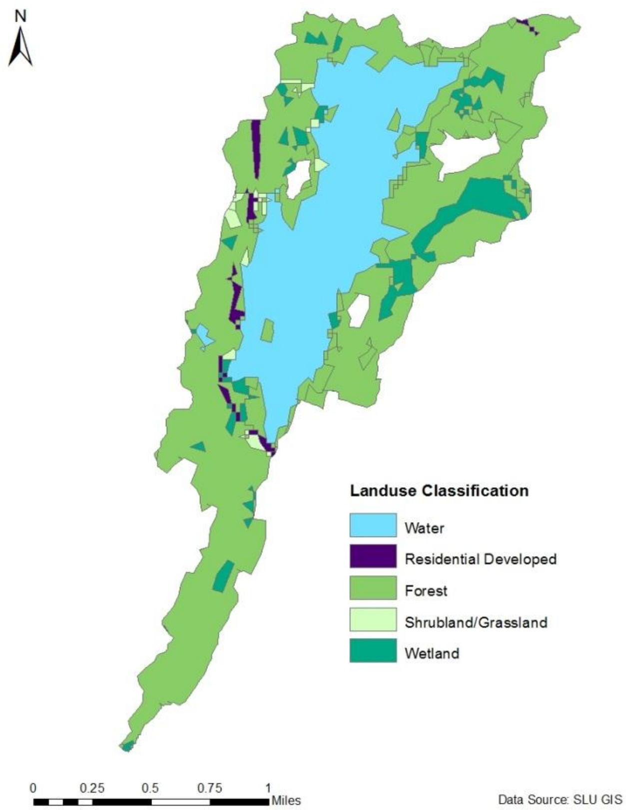
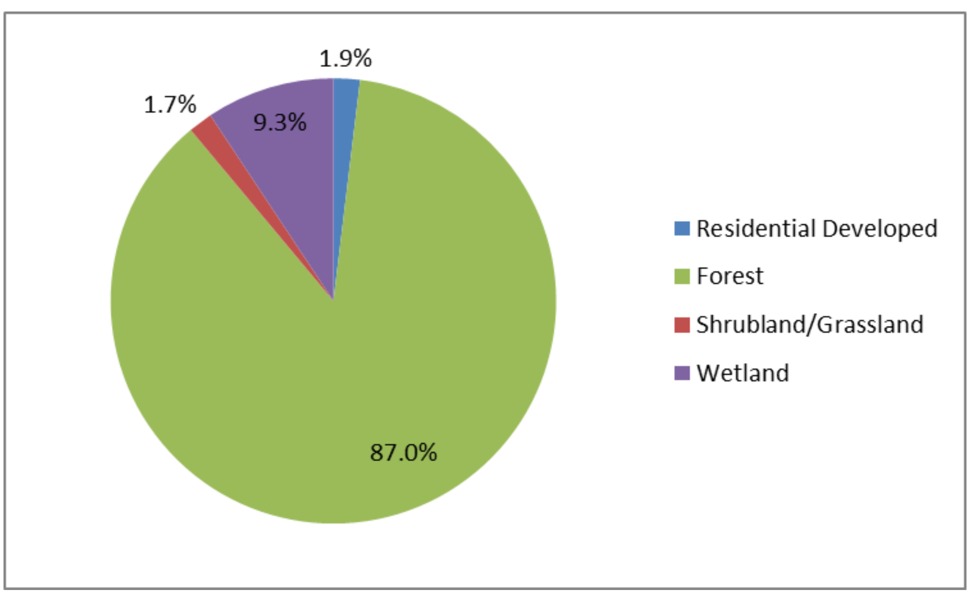


Figure 12. Watershed shape and human landuse around Trout Lake. Spatial patterns of generally landuse types are illustrated in the top figure, while the spatial contribution of each type is quantified in the bottom pie chart.





We thank SLRREF for generously providing funds for this project. Our final financial report is summarized below.

PROJECT FINANCIAL REPORT

Budget Component	**Expenses**
Faculty Salary/Benefits	$ 16,092
Project Supplies	$ 936
Equipment Parts/Repairs	$ 470
Travel to Research Sites	$ 1,152
Total	**$ 18,650**
SLRREF Grant Payments	
May 2011	$ 6,549
October 2012	$ 6,549
Subtotal	**$ 13,098**
Balance Due from SLRREF	**$ 5,552**