University of North Carolina Asheville
Journal of Undergraduate Research
Asheville, North Carolina
December 2017

Investigating the Causes of Sedimentation and Algal Blooms in Enka Lake, Candler, North Carolina

Cody McMechen
Environmental Studies- Earth Science
University of North Carolina Asheville
One University Heights
Asheville, North Carolina 28804 USA

Faculty Advisor: Dr. Jeff Wilcox

Abstract

The Biltmore Lake community has more than 650 homes on over 1,000 acres surrounding Enka Lake in Candler, NC. In the fall of 2016, the residents of the community asked the UNC Asheville Environmental Studies Department to help assess water quality in their lake. Specifically, sedimentation had recently required dredging the bottom of the lake and algal blooms had posed an aesthetic nuisance. The goal of this research was to identify more specifically where the sediment and nutrient problems were coming from. Water samples and flow measurements were collected from tributary streams leading into Enka Lake and from the dam as surface water exited the lake. Groundwater discharge beneath the lake was evaluated via scuba diving and seepage meters. Surface water was tested for temperature, pH, conductivity, and turbidity. Surface water and groundwater samples were collected and tested for major ions with a specific focus on nitrate and ammonium. A majority of the surface water flow into the lake came from one tributary (Bill Moore Creek) and brought with it the highest turbidity values and nitrate flux. Groundwater into the lake was negligible to the overall water budget, but concentrated flow was found in select areas.

1. Introduction

Sedimentation is a significant water-quality issue in western North Carolina, as large storms and runoff wash sediments off steep slopes into rivers and lakes. Increased sedimentation leads to increased turbidity, limiting underwater visibility. Increased levels of turbidity are detrimental to stream and lake ecology and have been linked to decreasing primary productivity[1]. The removal of the sediment deposits in lakes is known as dredging. Dredging is costly, noisy, may release nutrients from sediments, and requires lake drawdowns. Lake sediment removal is usually done to decrease nutrient reserves, increase the number of fish, improve lake aesthetics, or to deepen lakes[2]. Lake restoration is a broad field that includes dredging as well as other solutions to sedimentation[3-5]. Finding the source of sediment loading is key for controlling and preventing sedimentation issues and for successful lake restoration.

Another significant water-quality issue is algal blooms in freshwater ecosystems caused by eutrophication- the addition of excess nutrients to a system. Fertilizer runoff is one of the most common ways that excess nutrients leach into a system. Adding nutrients to a system increases the amount of plant material; in return, the plant material requires more oxygen for decomposition, lowering the amount of oxygen in the water and possibly causing a fish kill. Adding nutrients, especially ammonium and nitrates (key ingredients in fertilizers), increases the chance of having an algal bloom[6-9].

Sedimentation and Eutrophication are mainly surface water quality issues, but groundwater can also play an important role in determining water quality in a lake. For example, a "gaining" lake is one where water infiltrating into the ground from some distance away flows as groundwater and is discharged directly into the lake[10]. On the other hand, water may instead be leaving the lake through the bottom of what is considered a "losing" lake. Finally, the lake could have a combination of gaining and losing aspects, considered an "interflow" lake. Interflow lakes have a more complex hyporheic zone—the area where surface water and shallow groundwater interact. The biogeochemical processes within this zone have a considerable effect on the chemistry of water interchange[11]. In particular, ammonium can fuel the process of nitrification in the hyporheic zone[12]. Determining where groundwater is flowing and how it is interacting with surface water can be a crucial step for identifying where a contaminant is coming from.

In this study, an overall water quality assessment of Enka Lake was preformed. Nitrate and turbidity measurements were of particular importance in order of locate the sources of excess sediment and nutrients to the lake.

2. Methodology

2.1. Water Flow Measurements

Surface water velocity was measured in two ways. The most common method used was a float method, placing an object on the surface of the water and measuring the time and distance it traveled. The second method involved a velocity meter. In both cases the velocity was multiplied by the stream depth and width to determine discharge.

Groundwater discharge was measured by scuba diving to the bottom of the lake and inserting a seepage meter. The seepage meter was constructed using a 55-gallon plastic barrel. The barrel was cut in half and two valves were inserted on the top of one half (Figure 1). One valve allowed water to flow out of the seepage meter as it was being seated into the ground. The other valve was attached to a 2000-mL medical urine bag. For effective measurements, the seepage meter was inserted approximately 8-12 inches into the sediment on the bottom of the lake. Once properly seated, the second valve was opened to measure the volume of water that would either enter or exit the urine bag (and the bottom of the lake).

2.2. Water Chemistry

2.2.1. sample collection

Surface water samples were collected from tributary streams leading into Enka Lake from February 2017 to July 2017 under baseflow and stormflow conditions. A grab sample was taken from each stream (shown in Figure 2a-b) and placed into a 500-mL plastic sample bottle. Each sample was refrigerated to limit growth of organisms that could occur between the time of sampling and analysis. At each tributary stream the turbidity, pH, temperature, and conductivity were measured, ensuring the stream was flowing where the measurements were taken.

Lake bottom water samples were taken in July 2017 (Figure 2c). A portable pump was used in a canoe at the surface while the tubing was inserted, via scuba diving, approximately 12 inches below the sediment. A filter was placed on the end of the tubing to reduce the amount of sediment in the sample being taken. The samples were placed on ice until they were refrigerated.

2.2.2 sample analysis

Samples were prepared by filtering through a nylon membrane filter (0.45μm) and divided into three aliquots for analysis of cations, anions, and alkalinity. One drop of concentrated HNO_3 was added to one aliquot to be tested for cations. Major cations and anions were analyzed using an ion chromatograph. The concentration of HCO_3^- was measured by titrating 0.012 N H_2SO_4 with a 50 mL sample until the pH reached a value of 4.5.

Figure 1. Seepage meter constructed to measure flow from lake bottom.

Figure 2a. Surface water sampling locations surrounding Enka Lake.

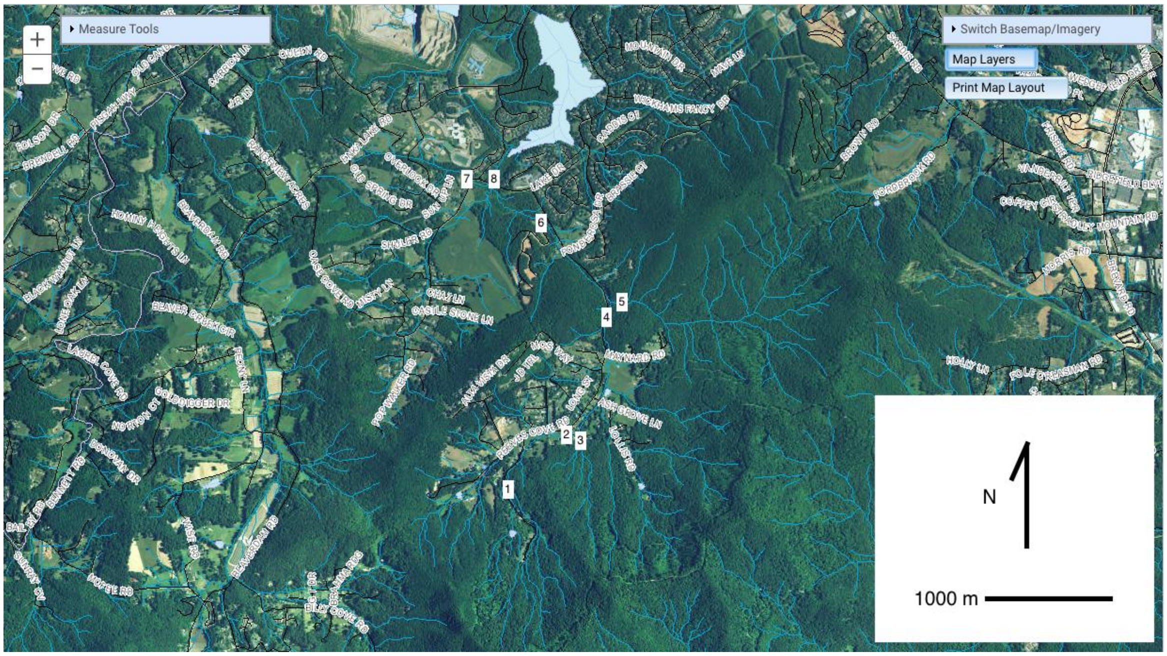

Figure 2b. Additional sampling sites for turbidity during stormflow conditions (collected by a local resident).

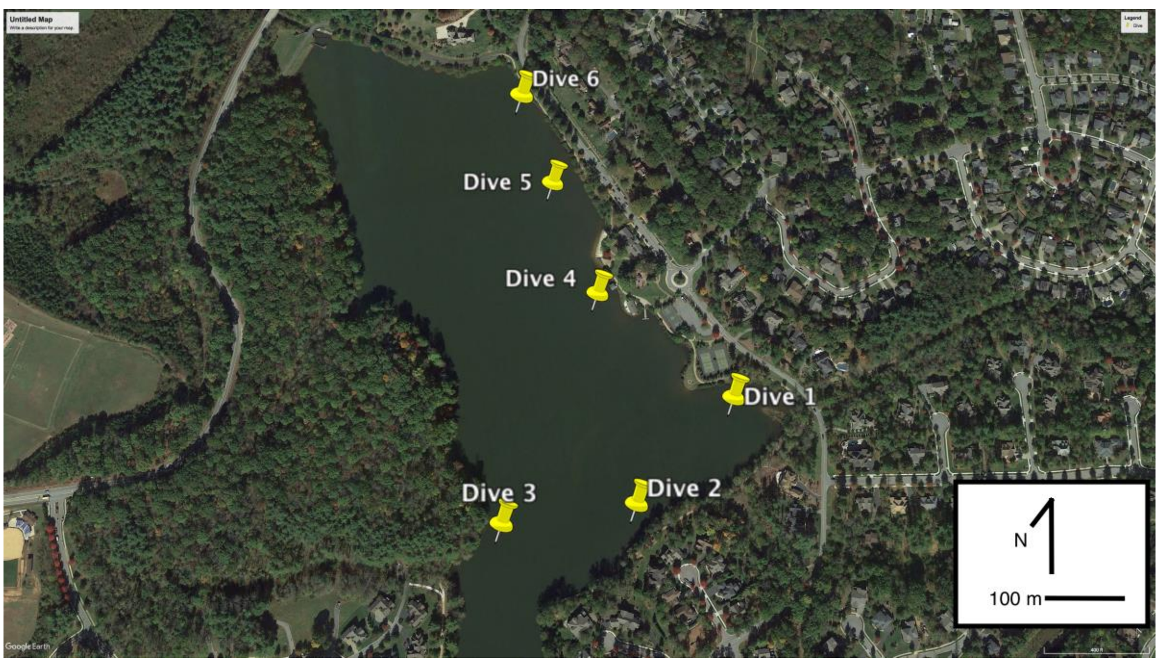

Figure 2c. Lake-bottom groundwater sampling locations.

3. Results

3.1. Water Flow Measurements

The total surface inflow into the Enka Lake was 472,600 cf/d (Table 1a). Tributary stream EL 3-A had the highest flow leading into Enka Lake with an inflow of 295,500 cf/d, around 63 percent of the total inflows.

Table 1a. Total surface water inflows into Enka Lake on March 2nd, 2017.

Sample	Inflows (cf/s)	(cf/d)
EL 3-F	0.170	14,700
EL 3-G	1.11	95,900
EL 3-A	3.42	295,500
EL 3-C	0.130	11,200
EL 2	0.270	23,300
EL 1	0.370	32,000
Sum	5.47	472,600

Total outflows fom Enka Lake were approximately 458,800 cf/d (Table 1b). This includes EL DAM- the only surface water outflow from the lake that had an approximate outflow of 428,500 cf/d. The other surface water outflow was evaporation. Using the North Carolina State Climate Office's database a value of 30,200 cf/d evaporates from the lake. This database uses a Penman-Monteith model to calculate their evaporation values.

Table 1b. Total surface water outflows out of Enka Lake and total evaporation value on March 2nd, 2017.

Sample	Outflows (cf/s)	(cf/d)
EL DAM	4.96	428,500
Evaporation	0.350	30,200
Sum	5.43	458,800

Groundwater linear flow measurements ranged from 0.001 cm/min to 0.008 cm/min, with an average value of 0.0045 cm/min (Table 2).

Table 2. Groundwater flow measurements from bottom of Enka Lake on July 19th and 20th, 2017.

Sample	Volumetric Flow (mL/min)	Linear Flow (cm/min)
Dive 1	9.5	0.005cm/min
Dive 2	2.4	0.001cm/min
Dive 3	14.5	0.008cm/min
Dive 4	7	0.004cm/min
Dive 5	8	0.004cm/min
Dive 6	9	0.005cm/min

3.2. Water Chemistry

3.2.1. surface water

Turbidity ranged from 0.680 to 581 NTU with an average turbidity during baseflow condition of 4.70 NTU and average turbidity during stormflow conditions of 165 NTU (Table 3 and Table 4). A majority of the higher turbidity measurements were located in the EL 3 area. pH ranged from 6.2 to 8.1 with an average pH value of 7.1. Surface water temperature increased steadily as the season changed from spring to late summer (Figure 3). Conductivity ranged from 31.3 to 122.0 μS/cm with an average conductivity of 60.3 μS/cm. with consistent high values coming from the EL 3 area with EL 3-F having the highest values. Alkalinity ranged from 5.5 to 14.5 ppm with an average alkalinity of 10.5 ppm (Table 3).

Bicarbonate, chloride, and sodium were the three dominant major ions in surface water overall. EL 3-F showed the most varied ion concentrations having consistently above average values of nitrate, chloride, and sodium. Nitrate concentrations ranged from 0.3 to 8.9 ppm in surface water samples, with an average of 3.0 ppm. The highest nitrate concentrations (up to 8.9 ppm) came from the EL 3 area (Figure 4). The average concentrations of chloride had an average concentration of 4.9 ppm across all surface water samples with EL 3-F having concentrations above 16.0 ppm. Ammonium was only detected in one surface water sample (0.7 ppm in EL 3-A (4-5-17)).

3.2.2. groundwater

The three dominant major ions in groundwater were bicarbonate, calcium, and sodium. Nitrate was not detected in any of the groundwater samples, but was detected (below LOQ) in Dive 2, which was a lake water sample taken just above the bottom of the lake. The average alkalinity value of the groundwater samples was 46.5 ppm. Ammonium was detected in all of the groundwater samples with an average of 3.4 ppm (Table 3).

4. Discussion

4.1. Turbidity

Turbidity measurements during baseflow conditions were very low but increased during stormflow conditions (Figure 5). The majority of the sediment was coming upstream from the EL 3-A. There were a few developments under construction that had bare soil that would easily be eroded. The overall color of the streams changed to rust orange, the color of the bare soil upstream (Figure 6).

Table 3. Raw surface and groundwater chemistry data.

Sample	Date	Flow/Water Type	Turbidity (NTU)	pH	Conductivity (μS/cm)	Temperature (°C)	Alkalinity (ppm)	HCO_3^-(ppm)	Cl^- (ppm)	NO_3^- (ppm)	SO_4^{2-} (ppm)	Na^+ (ppm)	NH_4^+ (ppm)	K^+ (ppm)	Mg^{2+} (ppm)	Ca^{2+} (ppm)
EL Dam	2/10/17	Baseflow	4.45	7.2	54.9	9.5	9.4	11.5	3.2	1.0	1.7	2.7	<0.1	1.5	0.4	3.1
EL 1-A	2/10/17	Baseflow	0.86	7.4	41.0	7.4	9.1	11.1	1.7	0.4	1.6	1.9	<0.1	0.8	0.3	2.0
EL 1-B	2/10/17	Baseflow	0.68	6.2	62.8	12.7	11.6	14.2	3.7	1.5	1.8	3.3	<0.1	1.3	0.7	3.1
EL 2	2/10/17	Baseflow		7.0	53.0	7.9	9.9	12.1	2.6	0.7	2.2	3.5	<0.1	1.0	0.3	2.6
EL 2-A	2/10/17	Baseflow	1.75	7.2	44.4	7.4	8.9	10.8	2.4	0.6	2.5	2.4	<0.1	0.9	0.3	2.4
EL 2-B	2/10/17	Baseflow	4.43	6.8	53.3	8.3	12.2	14.9	2.5	0.8	1.9	4.1	<0.1	1.0	0.3	2.5
EL 3-A	2/10/17	Baseflow	2.37	7.3	45.5	7.0	14.5	17.7	2.6	1.4	1.6	2.4	<0.1	1.0	0.3	2.4
EL 3-B	2/10/17	Baseflow	5.11	7.0	77.4	8.4	11.5	14.0	6.2	5.3	2.0	4.1	<0.1	2.0	0.3	3.8
EL 3-C	2/10/17	Baseflow	2.50	6.9	70.5	7.6	13.2	16.1	4.6	3.4	0.9	4.1	<0.1	2.2	0.2	4.1
EL 3-D	2/10/17	Baseflow	1.30	7.4	36.0	6.2	5.5	6.7	1.7	0.3	1.4	3.0	<0.1	1.2	0.2	2.0
EL 3-E	2/10/17	Baseflow	2.46	7.2	44.8	8.6	8.9	10.9	2.5	1.7	1.6	2.8	<0.1	1.3	0.3	2.4
EL 5	2/10/17	Baseflow		6.9	52.6	7.9	13.5	16.4	1.8	0.4	0.6	2.9	<0.1	2.1	0.3	3.0
EL 3-B	3/2/17	Baseflow	9.80	7.8	75.8	12.7	12.2	14.9	5.8	4.6	2.17	4.2	< 0.5	2.0	1.8	4.2
EL 3-A	3/2/17	Baseflow	10.80	7.8	46.6	10.5	9.8	12.0	2.6	1.4	1.88	2.4	< 0.5	1.2	1.1	2.7
EL 3-F	3/2/17	Baseflow	5.97	7.6	109.8	12.7	9.8	12.0	15.1	8.7	1.0	7.1	< 0.5	1.8	2.3	4.4
EL 3-G	3/2/17	Baseflow	5.50	7.3	65.3	11.2	12.7	15.5	4.1	4.6	2.27	3.7	< 0.5	1.9	1.7	3.9
EL 2	3/2/17	Baseflow	9.47	6.9	50.7	10.1	10.3	12.6	2.3	1.2	2.72	3.0	< 0.5	1.3	1.1	2.8
EL 1-A	3/2/17	Baseflow	2.34	6.6	40.1	10.9	9.8	12.0	1.8	0.8	1.89	2.3	< 0.5	1.1	1.3	2.5
EL DAM	3/2/17	Baseflow		7.9	54.6	10.1	12.2	14.9	3.3	1.0	1.8	2.8	< 0.5	1.7	1.3	3.3
EL 2-A	4/5/17	Stormflow	7.69	6.4	42.7	12.6	-	-	-	-	-	-	-	-	-	-
EL 2-B	4/5/17	Stormflow	16.00	6.6	54.8	12.5	-	-	-	-	-	-	-	-	-	-
EL 3-A	4/5/17	Stormflow	16.00	6.9	46.3	12.1	7.7	9.4	2.8	2.5	2.4	2.2	0.7	1.4	1.1	2.7
EL 3-F	4/5/17	Stormflow	49.30	6.9	81.4	12.8	8.4	10.2	9.0	4.8	1.8	5.3	-	1.8	1.6	3.5
EL 3-D	4/5/17	Stormflow	8.04	7.1	31.3	11.9	-	-	-	-	-	-	-	-	-	-
EL 3-E	4/5/17	Stormflow	17.40	6.9	46.2	12.6	-	-	-	-	-	-	-	-	-	-
EL 3-F	7/10/17	Baseflow	8.06	6.9	111.0	19.5	-	-	16.0	8.9	-	-	-	-	-	-
EL 3-G	7/10/17	Baseflow	5.26	7.0	61.3	20.5	-	-	3.4	3.7	1.4	-	-	-	-	-
EL 3-F	7/15/17	Stormflow	33.80	7.0	86.2	19.2	-	-	11.4	5.3	1.8	-	-	-	-	-
EL 3-G	7/15/17	Stormflow	256.00	6.8	63.8	20.2	-	-	4.0	2.9	4.4	-	-	-	-	-
EL Dam	7/15/17	Stormflow	8.27	8.1	51.5	20.5	-	-	3.5	2.2	2.2	-	-	-	-	-
EL 3-F	7/31/17	Baseflow	7.66	7.2	122.0	19.6	-	-	>16.0	8.1	-	-	-	-	-	-
EL 3-G	7/31/17	Baseflow	6.72	7.2	61.0	20.4	-	-	3.4	6.4	1.3	-	-	-	-	-
EL DAM	7/31/17	Baseflow	1.94	7.7	52.5	29.2	-	-	3.1	1.4	1.6	-	-	-	-	-
Dive 1	7/19/17	Groundwater	-	-	-	-	49.4	60.3	2.9	<0.5	<0.5	3.4	2.2	3.2	2.6	6.7
Dive 2	7/19/17	Bottome of Lake	-	-	-	-	-	-	3.7	<0.5	2.3	2.9	<0.5	1.4	0.9	2.3
Dive 3	7/19/17	Groundwater	-	-	-	-	45.8	55.8	3.0	<0.5	<0.5	3.0	5.2	3.0	2.3	6.0
Dive 4	7/20/17	Groundwater	-	-	-	-	42.2	51.5	3.5	<0.5	<0.5	5.0	2.6	3.6	2.7	7.5
Dive 5	7/20/17	Groundwater	-	-	-	-	48.5	59.1	3.1	<0.5	<0.5	3.4	3.4	3.4	2.8	9.2

Table 4. Local residents turbidity measurements with reference points located on Figure 1c.

Stormflow Turbidity Measurements (NTU)			
Site	April 4th 2017	May 1st 2017	May 23rd 2017
1	160	65.0	46.0
2	521	539	128
3		516	107
4	581	376	159
5	322	33.3	66.1
6	211	229	151
7		42.9	95.8
8	190	115	54.8

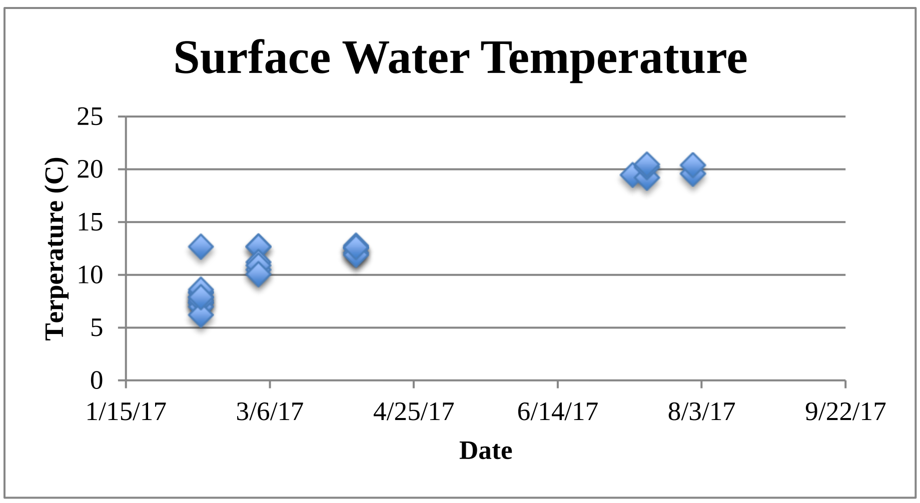

Figure 3. Surface water temperatures of tributary streams leading into Enka Lake.

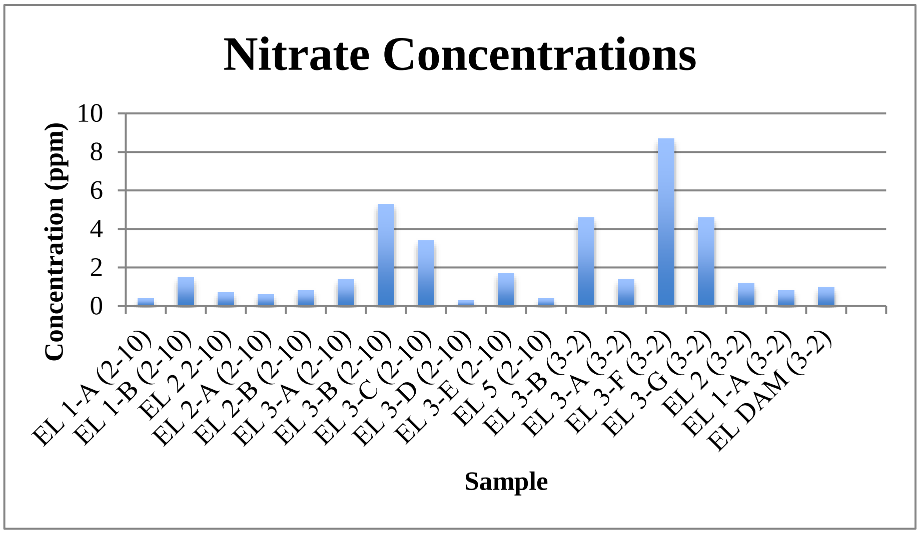

Figure 4. Nitrate concentrations across all surface water samples.

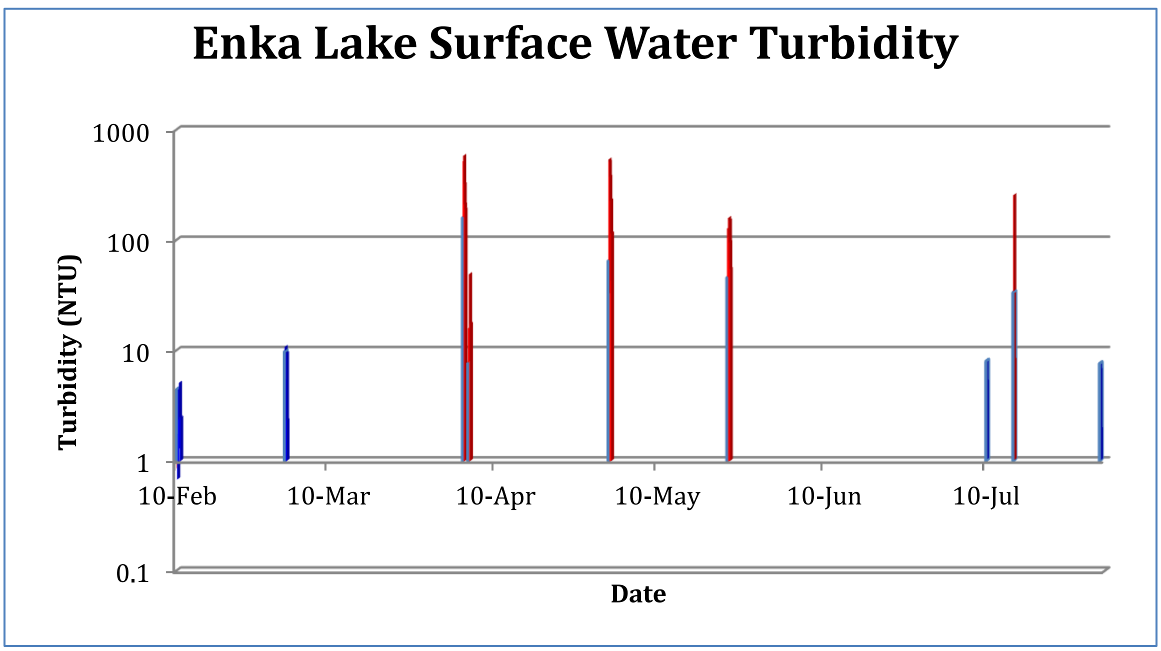

Figure 5. Turbidity measurements during baseflow (blue) and stromflow (red) conditions on a logarithmic scale.

Figure 6. This time-lapse sequence shows the change in the color of the water before, during and after a storm event.

4.2. Water Budget

A water budget for the lake was constructed using flow measurements calculated on 3-2-2017. Assuming steady-state conditions on that day,

$$\Delta S = 0 = Q_i - Q_o - E + G_{NET} \quad (1)$$

where ΔS is the change in storage, Q_i is the sum of surface water inflows, Q_o is the sum of surface water outflows, E is the evaporation, and G_{NET} is the net groundwater flow (Equation 1). It is assumed that ΔS is 0 because the lake level is controlled by a dam and there are no other inflows or outflows into the lake unaccounted for. Given measured and estimated values for Q_i, Q_o, and E on March 2nd, 2017 and solving for G_{NET} requires a net groundwater flow out of the lake of 13,800 cubic feet per day, or about 3 percent of total lake outflows. Therefore, it appears that groundwater flow plays a very minimal role in the overall water budget.

Taking the linear groundwater flow measurements from the bottom of the lake and multiply it by the surface area of the lake would net in a groundwater inflow of around $1.7 * 10^{13}$ cubic feet per day. This is obviously not the case since net groundwater flow is minimal. Instead, it suggests some areas of the lake bottom (measured in this study) have concentrated groundwater discharge into the lake, but this is balanced by groundwater outflow beneath other areas of the lake bottom.

4.3 Nitrate Flux

Nitrate concentrations in western North Carolina surface waters are typically less than 1.0 ppm[13]. EL 3-F had the highest concentrations of nitrate of the tributary streams leading into the lake, but EL 3-A and EL 3-G actually contributes more nitrate to the lake due to higher flow volumes. EL 3-A and EL 3-G deliver about 63 percent and 20 percent of the total flow volume to the lake, respectively (Figure 7). Multiplying the flow rate (L/d) of each tributary by the nitrate concentration (mg/L) results in a nitrate flux (mg/d). This reveals that EL 3-G was delivering the most nitrate by weight to the lake per day (41 percent), and EL 3-A the second most (38%). While EL 3-F had the highest concentrations of nitrate, it was delivering the third most nitrate by mass at about 12 percent (Figure 8). The total amount of nitrate entering the lake on 3-2-2017 was 30,400,000 mg/day.

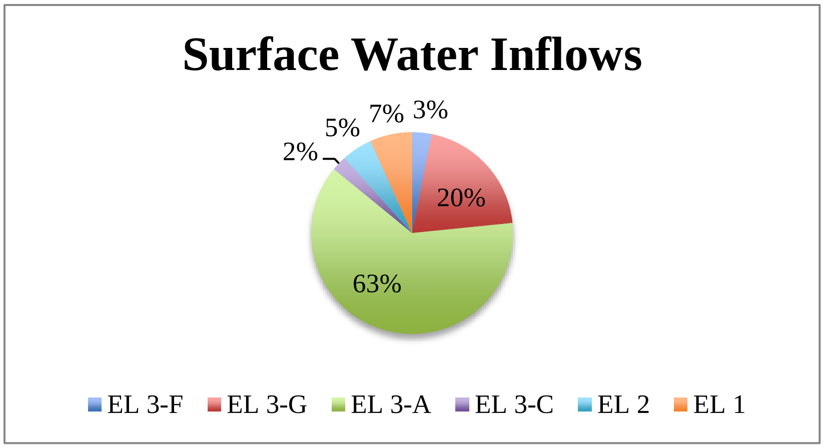

Figure 7. Pie chart illustrating the volume of surface water entering Enka Lake.

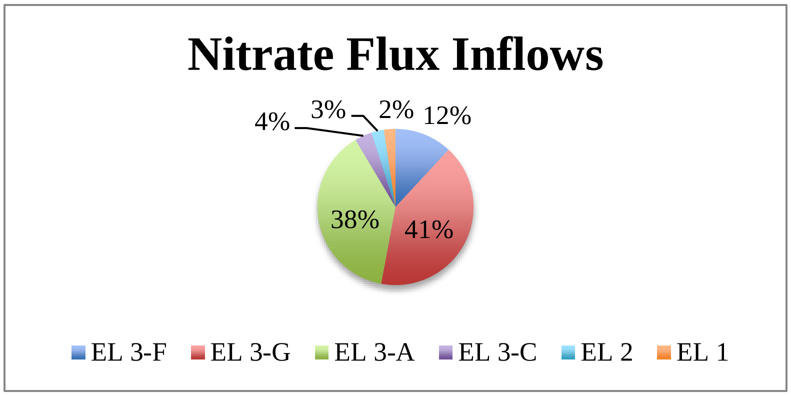

Figure 8. Pie chart illustrating the nitrate flux that each tributary stream delivers to the lake.

The only outflows from the lake were the EL DAM, evaporation, and possibly groundwater flow exiting the bottom of the lake (Figure 9). Multiplying the total volume of water leaving the lake via EL DAM by the concentration of nitrate, the total amount of nitrate leaving the lake via surface water on 3-2-2017 was 12,100,000 mg/day, which is only about 40 percent of the total nitrate entering the lake (Figure 10). This suggests a significant amount of nitrate that enters the lake (60%) is either being used for biological growth, being converted to a different form of nitrogen, or flowing out of the bottom of the lake through groundwater.

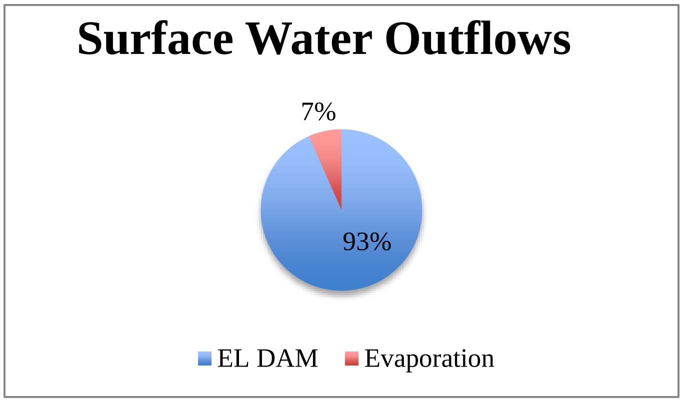

Figure 9. Pie chart illustrating the volume of surface water exiting Enka Lake via EL DAM and evaporation.

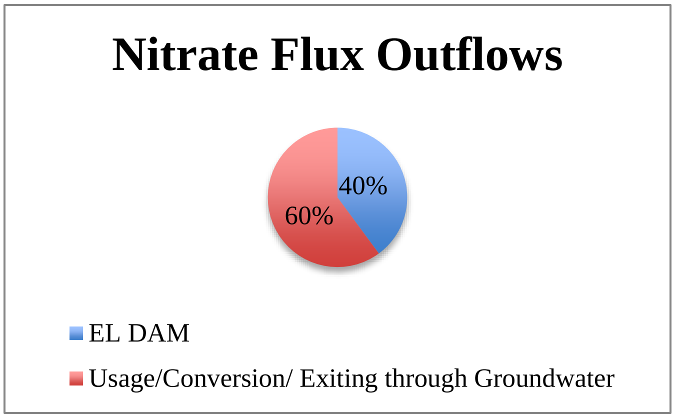

Figure 10. Pie chart illustrating the amount of nitrate exiting the lake via EL DAM and the amount of nitrate unaccounted for.

4.4 Groundwater Chemistry

Groundwater chemistry beneath the lake was noticeably different from the surface water chemistry of the lake and its tributaries. A Piper diagram illustrates that groundwater samples have a higher proportion of calcium, magnesium, and bicarbonate than the surface-water samples (Figure 11). Higher concentrations of calcium, potassium, and magnesium were expected because these are some of the most common elements found within rocks in WNC. Ammonium was also detected in all groundwater samples, despite being detected in only one surface-water sample. This is likely because as organic matter decomposes, the organic nitrogen goes through mineralization converting it to ammonium. These positively charged ions, or cations, have higher concentrations within groundwater because they more readily adhere to soil due to cation exchange capacity. This occurs when cations adhere to negatively charged surfaces, such as 2:1 clays and humus. Nitrate was not detected in any of the groundwater samples. This is likely because nitrate is not stable in anaerobic conditions and would be converted to nitrous oxide gas.

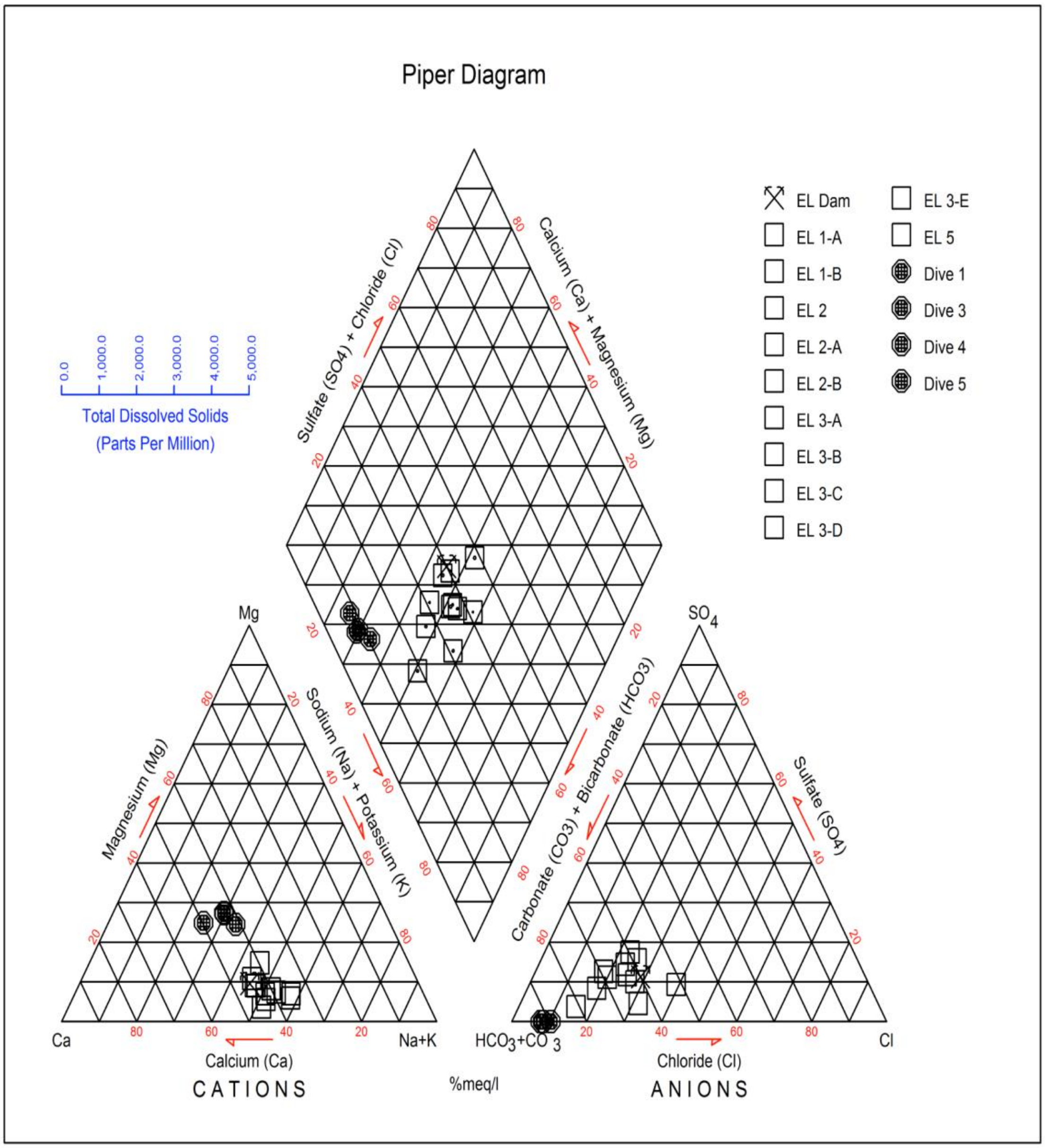

Figure 11. Piper diagram showing concentrations of ions in surface water samples (squares) and groundwater samples (circles).

5. Conclusion

Nitrate concentrations in a typical mountain streams should be less than the concentrations found in this study. Concentrations of up to 8.9 ppm suggest that there are most likely anthropogenic influences on stream chemistry in Enka Lake tributaries. Cow pastures and baseball fields surrounding the streams with the highest concentrations are the most likely sources of excess nitrogen. EL 3-F had the highest nitrate concentration, but because EL 3-G had a higher flow it was responsible for delivering the most nitrate to the lake. The highest turbidity values are likely caused by soil disturbance in areas currently under development in the EL 3 area. Net groundwater flow in or out of the lake is negligible, representing around three percent of the total water budget. Implementing silt fences, increasing vegetation, and building sediment basins can reduce sediment load to the lake. Reducing initial inputs and increasing the amount of vegetation that can use excess nutrients can reduce the risk of algal blooms. Future work should investigate upstream land uses, especially in the EL 3 area, to better locate the source of sediment and nutrients.

6. Acknowledgements

I would like to express my appreciation to the faculty of the Environmental Studies department Dr. Jackie Langille, Dr. Brittani McNamee, Dr. Kevin Moorhead and especially to my research advisor Dr. Jeff Wilcox. I would like to thank the Residents of the Biltmore Lake community, in particular Bill Miller, Ed Prestemon, and Bob Ware for their contributions to the study. I would like to thank UNCA for providing all the resources that I used throughout this study. A special gratitude goes out to the UNCA Undergraduate Research Program who provided all the funding to the research project. With a special mention to Megan Metcalf, who generously helped out in the field on multiple occasions.

7. References

1. Henley, W.F., M.A. Patterson, R.J Neves, A. Dennis Lemly. 2000. Effects of Sedimentation and Turbidity on Lotic Food Webs: A Concise Review for Natural Resource Managers. Reviews in Fisheries Science. 8:2:125-139.
2. Peterson, S. A. 1982. Lake Restoration by Sediment Removal. Journal of American Water Resources Association 18:3:423-436.
3. Annadotter, H., G. Cronberg, R. Aagren, B. Lundstedt, P. Nilsson, S. Strobeck. 1996. Multiple techniques for lake restoration. Develupments in Hydrobiology 136:77-85.
4. Does, J., P. Verstraelen, P. Boers, J. Roestel, R. Roijackers, G. Moser. 1992. Lake restoration with and without dredging of phosphorous- enriched upper sediment layers. Hydrobiologia 233:1:197-210.
5. Ryding, S. 1981. Lake Trehorningen restoration project. Changes in water quality after sediment dredging. Developments in Hydrobiology 9:549-558.
6. Ferber, L.R., S.N. Levine, A. Lini, G.P. Livingston. 2004. Do cyanobacteria dominate in eutrophic lake because they fix atmospheric nitrogen? Freshwater Biology. 49:6:690-708.
7. Oliver, R., G. G. Ganf. 2002. The Ecology of Cyanobacteria: Their Diversity in Time and Space. Chapter 6: Freshwater Blooms 149-194.
8. Paerl, H. W., R. S. Fulton, P. H. Moisander, J. Dyble. 2001. Harmful Freshwater Algae Blooms, With an Emphasis on Cyanobacteria 1:76-113.
9. Smith, V.H., G.D. Tilman, J.C. Nikola. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental Pollution 100:1-3:179-196.
10. John, P. H., M. A. Lock. 1977. The special distribution of groundwater discharge into littoral zone of a New Zealand lake. Journal of Hydrology 33:3-4:391-395.
11. Sophocleous, M. 2002. Interactions between groundwater and surface water: the state of science. Hydrogeology Journal. 10:1:52-67.
12. Jones, J. B. Jr., Stuart G. Fisher, Nancy B. Grimm. 1995. Nitrification in the Hyporheic Zone of a Desert Stream Ecosystem. Society for Freshwater Science. 14:2:249-258.
13. National Atmospheric Deposition Program (NRSP-3)/National Trends Network. (2004). NADP Program Office, Illinois State Water Survey, 2204 Griffith Dr., Champaign, IL 61820.