WATER QUALITY AND POLLUTION SOURCES TO THE KEUKA OUTLET, 2003 – 2005

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Introduction

Water quality issues along the Keuka Outlet, New York, including municipal wastewater treatment plants, coal-burning power plants, chemical processing and manufacturing plants, and abandoned mill/industrial sites came to the forefront of public concern during the August 2003 town meeting of the Town of Torrey. Foremost was the realization that the Keuka Outlet is restricted to a Class C waterbody, Seneca Lake is restricted to Class B waterbody for a one-mile radius surrounding the Outlet's entry point, and both are on New York State Priority Waterbody List (PWL). This surprised many participants as Seneca Lake is typically Class AA (the best quality) drinking water. The best use for Class C water is fishing. It may also be used for primary and secondary contact recreation although other factors may limit its use for these purposes (see appendix for the DEC's "best use" descriptors for Class AA through Class D water). The town appointed the Torrey Ad-Hoc Environmental Committee comprised of a cross-section of local elected officials, representatives from the region's state senator office, residents, Hobart and William Smith Colleges, and Seneca Lake Pure Waters Association to investigate these concerns. A grant from the Great Lakes Aquatic Habitat Network awarded to Seneca Lake Pure Waters Association enabled John D. Halfman and his students at Hobart and William Smith Colleges (HWS) to augment water quality monitoring efforts within the Seneca Lake watershed to include a segment analysis of Keuka Outlet. The Keuka Outlet water quality study by Halfman and his students is the focus of this report.

Keuka Outlet drains Keuka Lake at the lake's northeastern corner and flows eastward through Penn Yan approximately 12 km (8 miles) to Seneca Lake at Dresden, NY (see maps). The communities of Penn Yan and Dresden are at opposite ends of the Outlet with a rural/agricultural landscape in between. The majority of the land use in the 80 km^2 (30 $mile^2$) watershed is agricultural (~85%), both animal-husbandry and crops, with forested land typically restricted to the gorge next to the Outlet. Discharge (stream flow) is primarily controlled by a dam in Penn Yan, which in turn is used to control the level of Keuka Lake. Other sources of water are runoff from the watershed, and contributions from groundwater. Discharge is monitored by the USGS at Dresden. The creek drops approximately 83 m (274 ft) from its headwaters to Seneca Lake, through Paleozoic shales and limestones, with the limestones providing relief to the waterfalls in the Outlet. Hydropower potential attracted Jemima Wilkinson to establish the first mill in 1789, one of up to 40 mills creating paper, flour, carbon disulfide, lumber and other products by the 1840's and later abandoned by the mid to late 1900s. In the 1990's, the Friends of the Outlet established a public access nature trail along the reach of the Outlet using the old canal and railroad bed along the streambed. The majority of the Outlet Park is coincident with the Crooked Lake Canal Historic District, which is listed on the New York and federal registers of historic places. The Yates County Legislature also designated the gorge area as the Keuka Lake Outlet Preservation Area, in recognition of its natural and historic importance and need for special protection. In recent years, the creek has been stocked with brown trout in both the spring and the fall; in many places, fishermen may access the creek by way of the trail.

Water Quality

Water quality is the sum of everything within and entering the watershed, and is a concern because water is a critical resource that is easily abused and polluted. Pollutants are materials found in sufficient quantities to create a nuisance or health threat. They are subdivided into point and nonpoint sources. Point source pollutants are discharged from an identifiable spot, like a sewer outlet, a factory drain pipe, or power plant cooling-water outflow. Nonpoint source pollutants are more diffuse; examples include runoff from road salt or fertilizer after their application. Typically point source pollutants are easier to regulate, monitor, and control. For example, the Penn Yan municipal wastewater treatment plant and the AES Greenidge power plant have permits for their discharge of wastes into neighboring bodies of water. The permit process is designed to minimize the health risks by maintaining water quality standards, and balance economic considerations that allow corporations to function. Nonpoint source pollutants are more difficult to regulate, monitor, and control, but are becoming the focus of recent legislation. The Keuka Watershed experiences contributions from both point source (e.g., wastewater plant in Penn Yan, AES Greenidge Station, and the abandoned mill sites) and nonpoint source pollutants (e.g., agricultural activities & road salt).

Pollutants are also subdivided by source, and are typically split into organic (e.g., from living and dead organisms and their byproducts), agricultural (e.g., runoff of fertilizers, organics, sediment, herbicides and pesticides), and industrial sources (e.g., metals, organic compounds and their byproducts, thermal wastes). Each source has its own degree of legislation and control, with some controls more effective than others. For example, current law requires treatment of human organic wastes before it enters nearby waterways. Treatment is accomplished through municipal wastewater treatment facilities or individual onsite wastewater systems (e.g., a household septic system). Runoff from areas cleared for agricultural use is notorious for sediment laden and fertilizer/pesticide rich water, and current legislation attempts control through various best management practices. Prevention is problematic because agricultural land must be cleared to plant crops, and crop yields typically increase with the application of fertilizers and pesticides. Cleared land is a problem, because soil erosion is faster on bare ground than forested landscapes as the vegetation reduces soil erosion and decreases surface runoff of water. Contour plowing, settling ponds, buffer vegetation strips, minimal tillage farming and other “best management” strategies can reduce agricultural impact on nearby waterways but always at a cost to the farmer.

Water Quality Indicators

The rural and agricultural land use activities within the Keuka Outlet and the Seneca and Keuka Lake watersheds suggest that organic and agricultural pollutants should be the focus of this study. Water quality indicators of these sources include total coliform and *E. coli* bacteria, nutrients, total suspended solids, and too a lesser degree dissolved ion concentrations.

Total coliform and *E. coli* bacteria are used as potential indicators for excess human fecal contamination in waterways. The bacteria are created by humans, are relatively easy to measure, and if present above the Environmental Protection Agency’s (EPA’s) maximum contamination level (MCL), flag the potential for other water quality vectors that cause dysentery and other gastrointestinal water-borne diseases. An MCL is the highest concentration of a pollutant permissible in a public water supply. Each pollutant has its own MCL, and they are set to minimize health threats to the general public. *E. coli* are specific strains of total coliform bacteria. Although they are not normally pathogenic themselves, they are the best predictor of gastrointestinal illness. One strain, E. coli O157:H7, is particularly harmful if humans swim in or drink from contaminated water. The presence of these bacteria however do not dictate human fecal contamination because humans are not the only source. Any warm blooded animal is a source of these bacteria, including wild geese, ducks, deer and domesticated pigs and cows. Therefore, the presence of high concentrations of bacteria on any sample date might only reflect the temporary occupation of the site by wild geese, and excessive numbers of water fowl are the source of bacteria at a number of sites in the Finger Lakes region.

Water quality standards for total coliform and *E. coli* bacteria are complicated as they are determined from monthly median or geometric mean values of multiple analyses. The averages are necessary to remove sporadic results that may occur due to the technique that may not be indicative of impaired water. Total coliform MCLs for Class AA drinking water set by the New York State Department of Environmental Conservation (NYS DEC) is a monthly median concentration of 50 colony-forming units per 100 mL (CFU/100mL), and no more than 20% of the samples, from a minimum of 5 analyses, should exceed 240 CFU/100mL. Limits for Class A, B, C, and D waterways (recreational water) are set to a monthly median of 2,400 CFUs/100mL, with no more than 20% of the analyses exceeding 5,000 CFUs/100mL. *E. coli* water quality standard for Class A, B, C, and D waterways (recreational water) is a geometric mean of 126 CFUs/100mL based on several samples collected during dry weather conditions, or 235 CFUs/100mL for any single water sample.

Because Keuka Outlet is primarily a recreational waterway and we analyzed individual or duplicate samples at each site on each sample date, this study will use the 2,400 CFUs/100mL and 235 CFUs/100mL MCLs for total coliform and *E. coli* bacteria, respectively. This study reports individual results, not median or geometric means, because the available resources constrained the number of analyses at each site on each day to enable sufficient geographic distribution for the segment analysis survey. Therefore, the occasional result above these MCLs should not immediately be interpreted as a problem. Instead, consistent counts above these MCLs at one site on a number of dates or from a number of sites on one date is problematic.

Nutrients (nitrate, phosphate and silica) enter nearby waterways from municipal waste water plants, onsite waste water systems, agricultural runoff and related sources, and are water quality concerns as they “fertilize” the waterway with excess nutrients and make the aquatic system more productive and potentially eutrophic. The extra nutrients stimulate algal (microscopic aquatic plants), macrophyte (rooted plants) and other plant growth. If the aquatic system becomes eutrophic, then a slimy scum of blue-green algae accumulates on the surface of the water. The algae eventually die and are decomposed naturally. The decomposition process consumes dissolved oxygen from the water and recycles the nutrients back into the environment. The removal of oxygen may be severe enough to kill organisms in the aquatic realm that need dissolved oxygen to respire, like brown trout, crawfish and worms. The recycled nutrients provide the “fertilizer” to continue the excess growth of plants and more importantly allow the de-oxygenation and recycling of the excess nutrients to repeat itself when the plants die.

Excess nitrates also induce health risks, specifically methemoglobinemia or blue-baby syndrome. Accordingly the EPA sets a maximum contaminant level (MCL) for nitrate concentrations at 10 mg/L for safe drinking water. Phosphates and silica at natural concentrations do not impose health risks but contribute to the fertilization and eutrophication of waterways. We include dissolved silica in the list of nutrients because silica is required by diatoms, a form of algae found in most lakes, to form their frustules (shells).

Excessive suspended sediment in waterways not only cause the water to be murky and unpleasant to look at, swim in, or drink, it also reduces the light available to underwater plants, algae (microscopic plants) within the water, and blankets food supplies and the habitat of fish, shellfish and other benthic (bottom dwelling) organisms. The sediment fills in reservoirs and lakes, and may clog filters and damage water-cooling equipment for power plants. Some suspended sediment transport is natural, a consequence of stream erosion, and more sediments is naturally transported by faster stream discharge (current velocities). However, agricultural and new construction activities typically increase erosion rates by 10 times compared to forested landscapes unless these activities are chosen wisely.

Dissolved salts enter streams and lakes from the natural weathering of bedrock and soils, runoff of road salt application, municipal wastewater treatment systems, and road-salt mining activities. Conductivity data measure the total ionic charge of the solution and is proportional to the total dissolved ion concentration in the water. If salt concentrations are above 500 mg/L (or 1,000 mg/L by some regulations), then the water is too salty to drink. If above 2,000 mg/L, then it is too salty for livestock. For comparison, sea water is 35,000 mg/L, and is too salty to drink. Some specific ions have specific concerns. For example, water with over 100 mg/L of calcium and magnesium is considered hard. Hard water will prevent the lathering of soap, and precipitate dingy coatings or rings on bathtubs, pots and appliances. Hard water can be softened with water softeners which typically exchange the calcium and magnesium ions for sodium and/or potassium ions. Excess quantities of sodium ions (>250 mg/L) are unsafe for human consumption, especially for those on low salt diets due to a heart condition or infants before their first birthday.

Experimental Design

Water quality monitoring assesses both the amount and source of common pollutants and how their concentrations change over time. The ongoing program at Hobart and William Smith Colleges under the direction of Professor Halfman focuses on the hydrogeochemistry of the streams that flow into Seneca Lake and hydrogeochemistry of Seneca Lake. For streams, water temperature, conductivity (salinity), dissolved oxygen, pH, major ions (chloride, sulfate, sodium, potassium, calcium and magnesium), alkalinity, nutrients (nitrates, soluble reactive phosphates and soluble reactive silica), total suspended solids, and discharge are routinely measured from a selected suite of streams including Wilson Cr, Kashong Cr, Keuka Outlet, Plum Pt, Big Stream, Reeder Cr, and Kendig Cr. These streams were selected as they represent the diversity of land use and bedrock geology available in the Seneca Lake watershed, and are readily accessible by car. Sample sites are near the terminus of each stream, typically where a road crosses the stream just upstream from Seneca Lake, to asses the impact on water quality by the entire watershed. Sampling is periodic, typically on a weekly basis during the spring and early summer (typically May through mid July). Seneca Lake is sampled at 4 sites at the northern end of the lake. The lake monitoring has recently expanded to include 6 neighboring Finger Lakes.

Weekly monitoring is not perfect. Precipitation and runoff events typically provide more suspended sediments, nutrients and bacteria than base-flow or sunny conditions, especially in agriculturally rich areas. Hourly samples from Wilson Creek facilitated by an automated ISCO 6712 Portable Water Sampler just after 27.43 mm (~1.1 inches) of rain fell from May 31 to June 2, 2003, revealed an increase in total dissolved solids, phosphates, nitrates and silica concentrations during the flood event, especially during the beginning of the event, while major ion concentrations decreased during the event (Kostick & Halfman, 2003). The increased concentrations were attributed to runoff from the agricultural-rich watershed, whereas the decreased major ion concentrations were interpreted less concentrated runoff diluting the relatively smaller contribution of more concentrated groundwater. Weekly monitoring may also completely miss a pollutant. For example, if a pollutant is intermittently discharged into the Outlet at Penn Yan, then the stream flow would probably carry it to Dresden within a day or so, assuming a typical 0.2 to 0.5 m/s flow rate. Thus, if pollutants are not discharged into the Outlet within a few days of the sample date, the pollutant could flow down the stream before the next sample date.

Segment analysis is used to identify the source of the pollutant. Segment analysis measures the same water quality parameters at a number of locations along the reach of a stream. Thus, it divides the stream into discrete segments between each sample location. If a pollutant is discharged to the stream between two sample sites then, in theory, the concentration of the pollutant increases at the sites downstream from the source. This assumes that the pollutant does not degrade, decompose or in some other way disappear on its downstream journey. Segment analysis was utilized in this study to locate potential sources of the measured pollutants.

This study did not measure fertilizers, pesticides, heavy metals like mercury or lead, toxic organic compounds like DDT or PCBs, or other threats to water quality due to economic considerations. An earlier study investigated atrazine concentrations during 1999 & 2000 in various streams and the lake (http://people.hws.edu/Halfman/Atrazine/Atrazine.html). Atrazine is a common herbicide used to control broadleaf plants in corn crops. In summary, atrazine concentrations in the Keuka Outlet at Dresden averaged below 1 ppb, below the EPA's MCL of 3 ppb. The mean concentration detected at the Keuka Outlet was smaller than that at watersheds with more agricultural land like Kendig and Wilson Creeks, and larger than that at watersheds with less agricultural land like Big Stream and Plum Pt Creek. The correlation suggests but does not dictate an agricultural source to the "pollutant". It also revealed the highest concentrations, some concentrations up to 3 times higher than the EPA's MCL, during and just after an intense rainfall event.

Methods

Water quality samples were collected on a weekly basis from a number of sites along the Keuka Outlet during the summer and fall of 2003, and the summers of 2004 and 2005 (see maps). Samples were collected from four sites during 2003 and seven sites during 2005 for the segment analysis. These sites were identified by the adjacent road or nearby feature and include (from upstream to downstream): the boat basin in Penn Yan, Fox Mills Rd (Kenka Mills), Milo Mills, Seneca Mils, Mays Mills, Hopeton Rd. and Dresden, with the Milo, Seneca and Hopeton sites added in 2005. In 2004, samples were restricted to the most upstream site at the boat launch in Penn Yan and/or the most downstream site just downstream of Milo Street bridge in Dresden. For comparison, water quality samples were also collected from 7 streams in or adjacent to the Seneca Lake watershed (Wilson, Kashong, Keuka Outlet, Plum Pt, Big Stream, Reeder, and Kendig), Seneca Lake during 1998 – 2005, and from the western arm and the "Y" intersection in Keuka Lake during 2005.

Bacteria samples were collected in sterile, 100 mL, whirl-pak bags and stored at 4° C until analysis in the lab. Typically duplicate analyses were performed at each individual site on each sample date, and the average result reported for that sample site and date. The lab procedure followed the EPA approved method (HACH #10029) that incubated filtered samples in m-ColiBlue24 broth at 35° C for 24 hours. The coliform and *E. coli* colonies where then counted under low power microscope and reported as colony forming units / 100 mL of sample water (CFU/100mL). Sterile technique is critical, as the samples are easily contaminated. Sterile technique occasionally yields false positives as well. This study reports results of individual analyses, not the median or geometric means required to compare the results to the published MCLs. Therefore, the occasional result above the MCL should not immediately be interpreted as a problem. Consistent counts above these MCLs at one site on a number of dates or from a number of sites on one date are problematic.

Total suspended solids and nutrient assays followed standard limnological techniques (Wetzel and Likens, 2000). Water was collected, brought to the lab, and exactly one liter was filtered through a 0.45 um pre-weighed glass-fiber filter. The residue and filter was dried at 80° C overnight and the weight gain used to calculate the total suspended sediment concentrations (mg/L). The filtrate was analyzed for nutrient and major ions. Soluble reactive phosphates (ug/L), nitrates (mg/L) and silica (ug/L) were measured using standard spectrophotometric techniques. Major ions (chloride, sulfate, sodium, potassium, calcium and magnesium) concentrations (mg/L) were measured by Dionex DX-120 ion chromatograph. Stream discharge (volume flow / time) was measured at each site using a Marsh-McBirney velocity meter, where the discharge equals the measured velocity multiplied by the cross-sectional area at 5 or 10 equally spaced sections across the stream. Water temperature (°C) and conductivity (salinity in uS/cm) by Oakton EC Tesr, pH by Oakton pHTestr 2, dissolved oxygen (mg/L) by DO 300 series probe, and alkalinity (mg/L) by titration using LaMotte's WAT-MP-DR kit were also measured on site for each sample site and date. Laboratory precision was determined using replicate tests on the same water sample on a number of occasions: temperature ± 0.1° C, conductivity 5 uS/cm, dissolved oxygen 0.2 mg/L, alkalinity 5 ppm, total suspended solids 0.2 mg/L, phosphate 0.1 ug/L, nitrate 0.1 mg/L, silica 5 ug/L, major ions 1 mg/L, and discharge 0.1 m^3/s.

Results & Discussion

The water quality and major ion data from the Keuka Outlet do not reveal life threatening water quality concerns or major sources of critical pollutants along the Outlet. Some spatial and temporal trends were detected and elaborated on below. None of the results are considered life threatening.

Bacteria: Bacteria were present at all of the sample locations on all of the dates sampled. The individual bacteria counts were typically below 2,400 CFU/100mL for total coliform and 235 CFU/100mL for *E. coli* bacteria, the EPA MCLs for recreational water. The occasional counts that are above the MCLs do not raise the annual average data above the MCLs. Thus, none of the results are persistent, life-threatening problems. Spatially, the counts are consistently low along the length of the Outlet, and preclude a major point source along the Outlet from Keuka Lake to Dresden. One sample date, 6/16/05, revealed the largest counts when compared to the other data, with individual concentrations near or above the MCLs for *E. coli* and to a lesser degree for total coliform at all of the Outlet sites. This date was just after a major precipitation event (>3 cm rain in 3 days) and suggests that runoff from, for example, agricultural feed-lot operations and individual onsite treatment systems (septic systems) within Keuka Lake and Keuka Outlet watershed, may be the source of this contamination. Total coliform and *E. coli* counts were also large on 6/7/05, especially at the Milo Mill site, and are more difficult to explain as rain did not fall during the preceding week. Perhaps geese and other wild animals, provided a short pulse of contaminated water, the occasional false positives from the laboratory technique, or analytical error contributed to these large values. The lack of consistent counts at or above the NYS DEC MCLs indicate that bacterial contamination is not a major water quality concern for the outlet, except perhaps during major runoff events.

Annual average bacterial counts from Keuka Outlet are similar to other streams within the Seneca Lake watershed. Wilson Creek revealed larger counts that may reflect the higher percentage of agricultural activities within its watershed. The steady increase in bacterial counts from one year to the next at Reeder Creek is also a concern as it may reflect the increased contamination by pig wastes from concentrated animal feedlot operations (CAFO). These wastes are spread on agricultural fields in its watershed and could runoff into the creek. All of the streams revealed larger counts than Seneca and Keuka Lakes. The low Seneca Lake data suggests that the bacteria entering the lake from the watershed must dissipate in the lake due to the lack of food and/or predation by organisms in the water. The low Keuka Lake counts suggests that the bacteria entering Keuka Outlet got there somewhere between the Keuka Lake sample sites and the Penn Yan site. Potential sources include aging onsite wastewater treatment, local runoff, geese and other wild animal populations.

Nutrients: Nutrient data from the Keuka Outlet are also within NYS DEC MCLs. Two non life-threatening trends are observed in the nitrate data. Nitrate concentrations were higher downstream of Fox Mills, suggesting a source of nitrates between Fox Mills and Milo Mills of unknown origin. The pervasiveness of the downstream change, even during low flow conditions, suggests a groundwater source for the nitrates. Nitrates were slightly higher in 2003 than 2005 suggesting more nitrates entered the outlet in 2003 for unknown reasons. Dissolved phosphate concentrations were consistently larger on 6/16/05 than any other sample date, and was the reason for larger average concentrations in 2005 than 2003. The trend is consistent with extra phosphorus in the runoff from the precipitation event just before this date. Dissolved silica doesn't change along the Outlet. Concentrations below the MCL for nitrate, and lower concentrations of phosphate and silica suggest that nutrients are not a major water quality threat to Keuka Outlet, except perhaps during major runoff events.

Annual average nutrient data from Keuka Outlet were similar to or lower than the other streams within the Seneca Lake watershed. Wilson and Kashong Creeks reveal larger nutrient concentrations than other streams in the survey. The loading may reflect the larger percentage of agricultural activities in these watersheds. Big Stream and Reeder Creek reveal the highest dissolved phosphate concentrations than the other watersheds. The high concentrations may reflect the discharge of municipal waste water that is treated for organic wastes but not dissolved nutrient concentrations, and/or runoff from urban areas in the town of Dundee to Big Stream; and the runoff of concentrated pig wastes from the CAFO operations to Reeder Creek. All of the streams revealed higher nutrient concentrations than Seneca and Keuka Lakes. The low Seneca Lake data suggest that the nutrients entering the lake from the watershed are readily utilized by algae and other plants in the lake. It also suggests that additional nutrient loading will make Seneca Lake more productive. Finally, nutrients enter the Outlet somewhere upstream of the Penn Yan sample site from sources like aging onsite wastewater treatment, local runoff of fertilizer, and geese and other wild animal populations.

Total Suspended Sediments: Total suspended sediment concentrations were typically low enough to easily observe the streambed and are not considered a threat to water quality. One sample date, 6/16/05, revealed the largest TSS concentrations. The trend is consistent with the precipitation event just before this date mentioned earlier where suspended sediment concentrations increase due to faster stream discharge and runoff from the surrounding agriculturally-rich watershed. Most of the 2005 data at the Penn Yan site are larger in 2005 than in 2003 but these larger values are not observed farther downstream. It suggests that the Penn Yan values may reflect the input of particles from geese and other wild animals that are later removed perhaps by deposition before reaching the next downstream site.

Annual average TSS data from the Keuka Outlet were similar to the other streams within the Seneca Lake watershed. All of the streams revealed higher TSS concentrations than Seneca and Keuka Lakes. The low Seneca Lake data suggest that the TSS entering the lake from the watershed are readily deposited on the lake floor. It also suggests that the TSS entering Keuka Outlet got there upstream of the Penn Yan sample site from sources like aging onsite wastewater treatment, local runoff in the urban environment, geese and other wild animal populations.

Conductivity and Major Ions: Conductivity and major ion concentrations were not concentrated enough to be life-threatening. Conductivity values of 400 to 500 uS/cm correspond to total dissolved solid concentrations of 250 mg/L (includes alkalinity data), significantly below the drinking water limit of 500 mg/L. Spatially, conductivity and major ion concentrations increase slightly from Keuka Lake to the Outlet and again along the Keuka Outlet, and are explained by the accumulation of ions from weathering bedrock and groundwater seepage. The small temporal variability from one sample date to the next may reflect the variable amount of relatively dilute Keuka Lake water that enters the Outlet.

Annual average conductivity data from the Keuka Outlet were similar to the other streams within the Seneca Lake watershed. The variability between streams is attributable to the solubility and composition of the bedrock. For example, the higher calcium and magnesium concentration in the northern streams (Wilson, Kashong, Reeder and Kendig) compared to the southern streams are consistent with limestone underlying the northern portions of the Seneca Lake watershed. Limestone is rich in calcium and magnesium, and is more soluble than the other Paleozoic rocks underlying the watershed. The higher chloride and sodium concentration in Plum Pt Creek probably reflect the mine wastes from an abandoned rock-salt mine within its watershed. Seneca Lake revealed much more chloride and sodium than the streams because the lake has a significant saline groundwater source from the underlying Silurian rock-salt under the lake. In contrast, dissolved calcium and magnesium are removed from the lake through the precipitation of calcite and growth of zebra & quagga mussel shells.

No noticeable concerns were observed in the temperature, pH, dissolved oxygen and alakinity data.

Conclusions & Recommendations

1) The bacteria, nutrient, suspended sediment, and major ion data do not reveal life threatening water quality concerns for the Keuka Outlet. The concentrations, especially the annual average concentrations, were below maximum contaminant levels (MCLs) established by the New York State Department of Environmental Conservation (NYS DEC).

2) Segment analysis did not reveal life-threatening sources of bacteria, nutrients, suspended sediment, and major ions along the Keuka Outlet, especially from the Penn Yan wastewater treatment facility. One consistent exception is that nitrate concentrations increased somewhere between Fox Mills and Milo Mills sites. The source for these nitrates was not obvious.

3) Temporal variability in the bacteria, nutrient and suspended sediment concentrations were observed. Bacteria, phosphate and suspended sediment concentrations peaked on 6/16/05 and probably reflect runoff from a precipitation event just before the sample date. Major ion concentration fluctuations probably relate to the variable flow of dilute water from Keuka Lake through the dam at Penn Yan. Other isolated high bacterial counts may reflect contributions from localized sources including geese, deer and other wild animals, aging onsite wastewater treatment sites, and/or runoff from agricultural and urban areas.

4) The major source of the bacteria, nutrients and suspended sediments to the Keuka Outlet is upstream from the Penn Yan sample site. Potential sources of these pollutants include aging onsite wastewater treatment, local runoff or urban areas, geese, ducks and other wild animal populations.

5) The Keuka Outlet is contributing an equal or smaller flux of bacteria and nutrients to Seneca Lake than the other streams in the survey. Watersheds with larger fluxes of bacteria or nutrients also contained more agricultural land use and/or old municipal wastewater treatment facilities.

6) Additional research is required to quantify the impact of precipitation events on the water quality of the Outlet to follow up on the event that preceded the 6/16/05 elevated bacterial and phosphate concentrations.

7) Additional research should investigate other pollutants to the Outlet like fertilizers, pesticides, heavy metals, personal care products, hormones and antibodies.

8) Even though the measured water quality parameters are below the MCLs, efforts can be made to reduce the input of pollutants to the Outlet. Examples include:
   a. reduce the input of bacteria and nutrients entering Keuka Outlet from upstream of the Penn Yan site;
   b. inspect, clean, and improve onsite wastewater systems within the watershed or replace them with a sewer system and adequate municipal wastewater treatment;
   c. reduce the runoff of pollutants from agricultural and urban landscapes.

References and Publications

The students collecting and analyzing the water quality data from the Keuka Outlet or elsewhere in the Seneca Watershed presented their results at a number of regional and national meetings or was used in various reports and theses. The references to their presentations and reports are below.

Selected Publications (*undergraduate student co-authors)

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Selected Undergraduate Honors Projects

Bush, Kathleen, in progress. Water quality of the Finger Lakes. Undergraduate Honors Thesis, Hobart and William Smith Colleges. xx pg.

Hintz, Tana, 2004. Water quality survey and policy for the Keuka Outlet. Undergraduate Honors Thesis, Hobart and William Smith Colleges. 52 pg. Co-Advisor: Jim Ryan.

Baldwin, Sandra M., 2002. The effect of meteorological events on chlorophyll-a concentrations. Undergraduate Honors Thesis, Hobart and William Smith Colleges. 39 pg.

Bowser, Lindsey Paige, 2002. Nitrate loading in the Seneca Lake Watershed: Is Hog farming having an effect? Undergraduate Honors Thesis, Hobart and William Smith Colleges. 45 pg.

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McSweeney, Jennifer C.(Cory), 1999. The concentration and source of atrazine in Seneca Lake, New York. Undergraduate Honors Thesis, Hobart and William Smith Colleges. 37 pg.

Spitzer, Tara, 1999. The environmental impact of hog farming on the Seneca Lake Watershed and surrounding areas. Undergraduate Honors Thesis, Hobart and William Smith Colleges. 52 pg.

Dedrick, Robert Russell, 1998. Development of an inexpensive data logging system with an application to periodicall measure stream stage. Undergraduate Honors Thesis, Hobart and William Smith Colleges. 105 pg. Co-Advisor: D. Brooks McKinney, Geoscience.

Selected Presentations

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Bush*, K.F., and **J.D. Halfman**, 2005. Water Quality Analysis of the Finger Lakes, New York. Geological Society of America Annual Meeting Abstracts with Programs, v. 37, p. 352.

Sukeforth*, R.L., and **J.D. Halfman**. 2005. Spatial and temporal trends in major ion concentrations from the Finger Lakes, NY. Geological Society of America Northeast Regional Annual Meeting Abstracts with Programs, v. 37, p. 62.

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Appendix:

NYS Department of Environmental Conservation (DEC) Water Quality Standards "Best Use" Designations.
from: http://www.dec.state.ny.us/website/regs/part701.html#701.8

§701.5 Class AA fresh surface waters

(a) The best usages of Class AA waters are: a source of water supply for drinking, culinary or food processing purposes; primary and secondary contact recreation; and fishing. The waters shall be suitable for fish propagation and survival.

(b) This classification may be given to those waters that, if subjected to approved disinfection treatment, with additional treatment if necessary to remove naturally present impurities, meet or will meet New York State Department of Health drinking water standards and are or will be considered safe and satisfactory for drinking water purposes.

§701.6 Class A fresh surface waters

(a) The best usages of Class A waters are: a source of water supply for drinking, culinary or food processing purposes; primary and secondary contact recreation; and fishing. The waters shall be suitable for fish propagation and survival.

(a) (b)This classification may be given to those waters that, if subjected to approved treatment equal to coagulation, sedimentation, filtration and disinfection, with additional treatment if necessary to reduce naturally present impurities, meet or will meet New York State Department of Health drinking water standards and are or will be considered safe and satisfactory for drinking water purposes.

§701.7 Class B fresh surface waters

The best usages of Class B waters are primary and secondary contact recreation and fishing. These waters shall be suitable for fish propagation and survival.

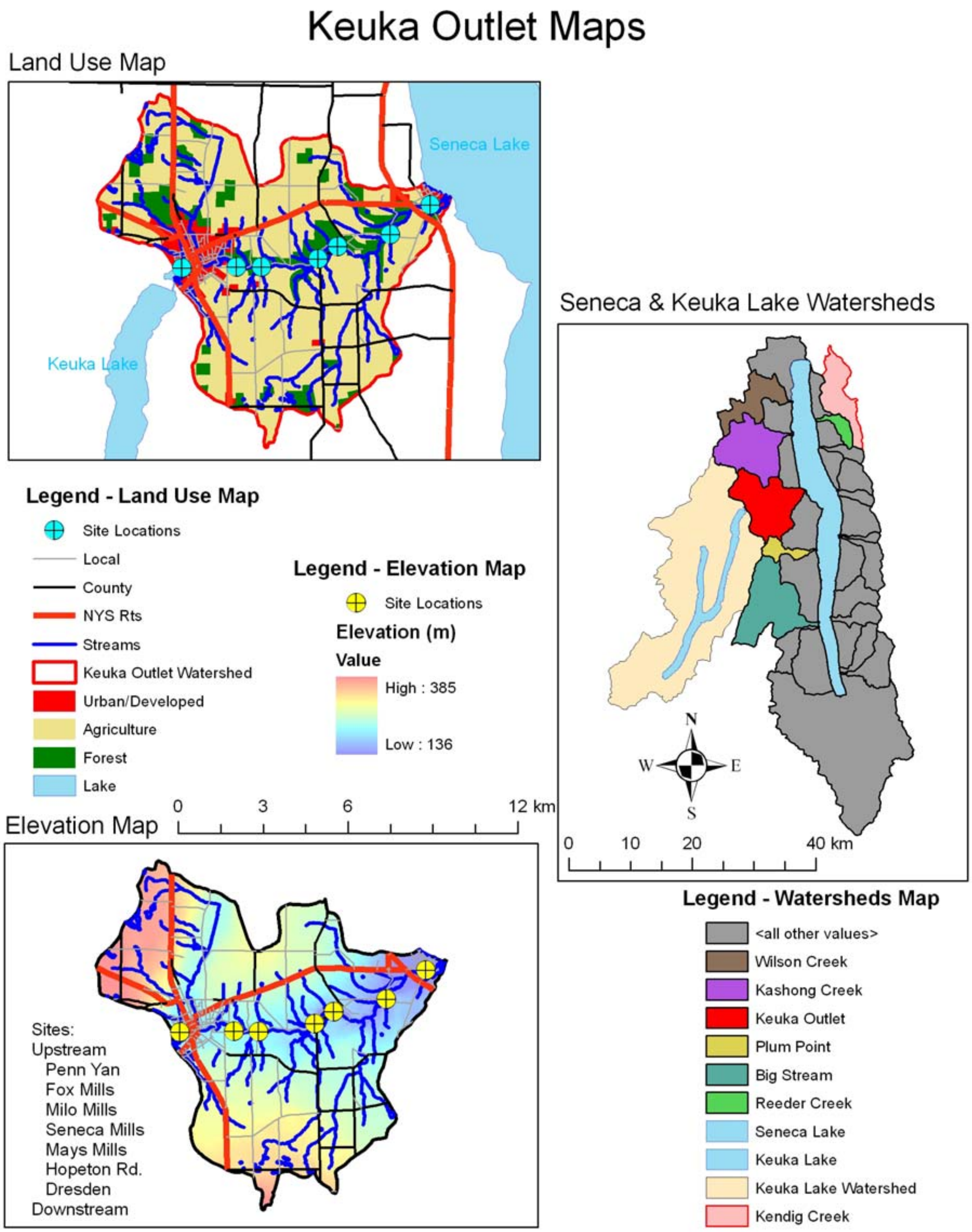
§701.8 Class C fresh surface waters

The best usage of Class C waters is fishing. These waters shall be suitable for fish propagation and survival. The water quality shall be suitable for primary and secondary contact recreation, although other factors may limit the use for these purposes.

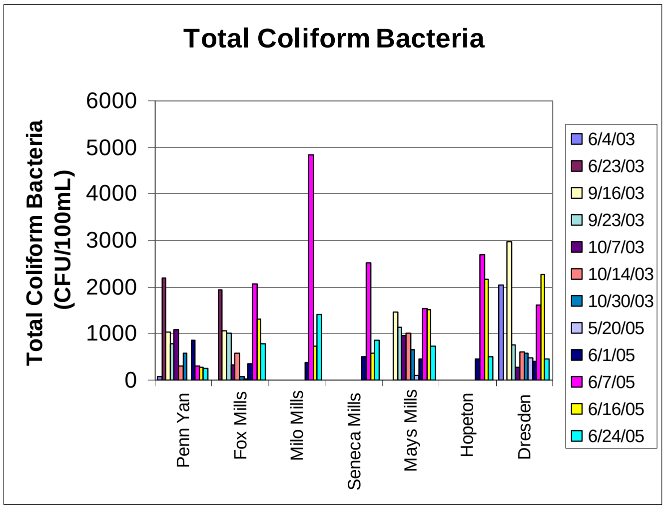
§701.9 Class D fresh surface waters

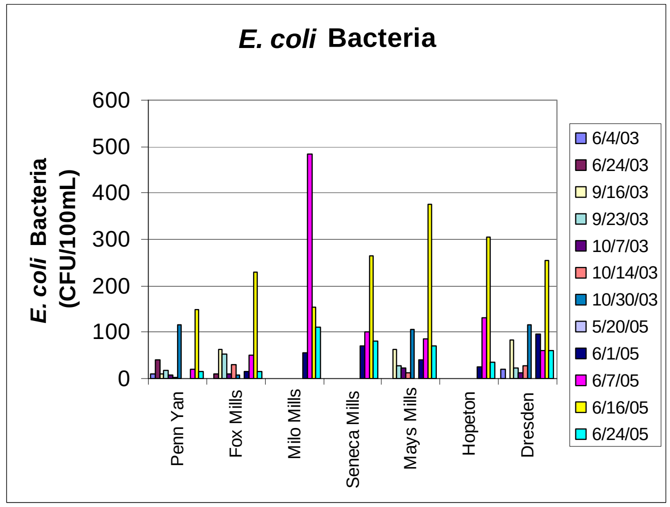
The best usage of Class D waters is fishing. Due to such natural conditions as intermittency of flow, water conditions not conducive to propagation of game fishery, or stream bed conditions, the waters will not support fish propagation. These waters shall be suitable for fish survival. The water quality shall be suitable for primary and secondary contact recreation, although other factors may limit the use for these purposes.

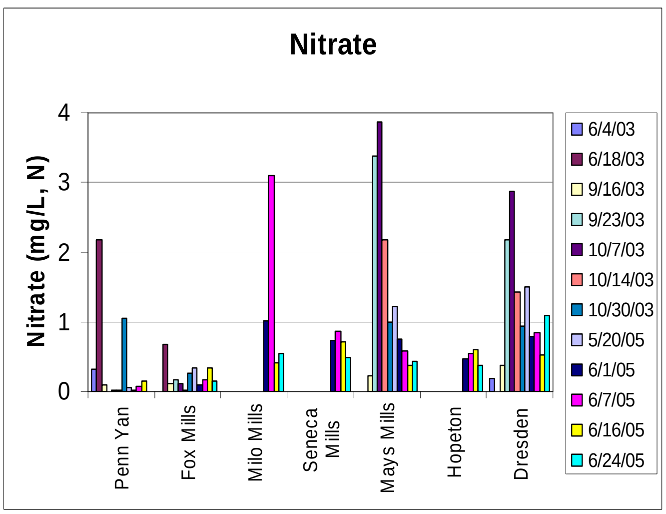
Elevation and land use maps of the Keuka Outlet watershed. Site locations are also shown. The third map is of Keuka Lake, its watershed, Seneca Lake and it's major subwatersheds.

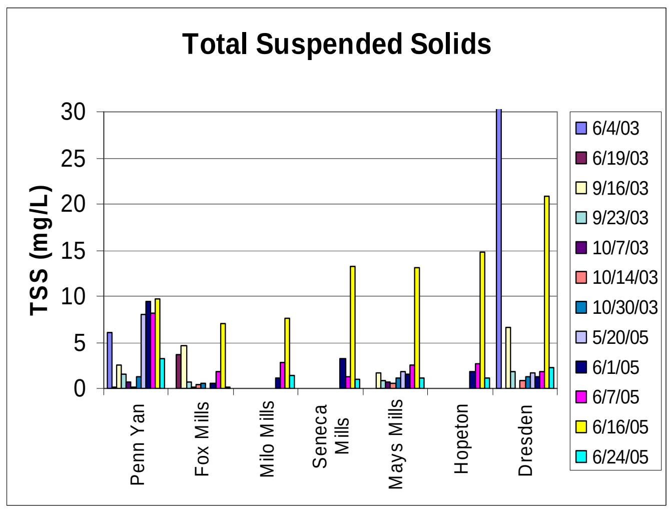


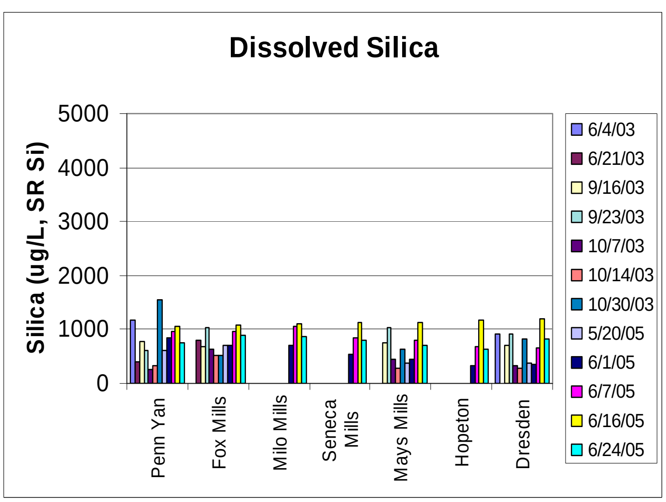
Keuka Outlet water quality results.

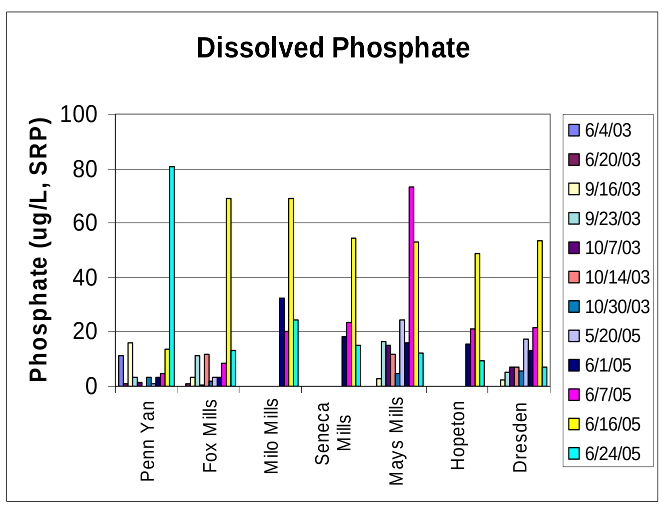




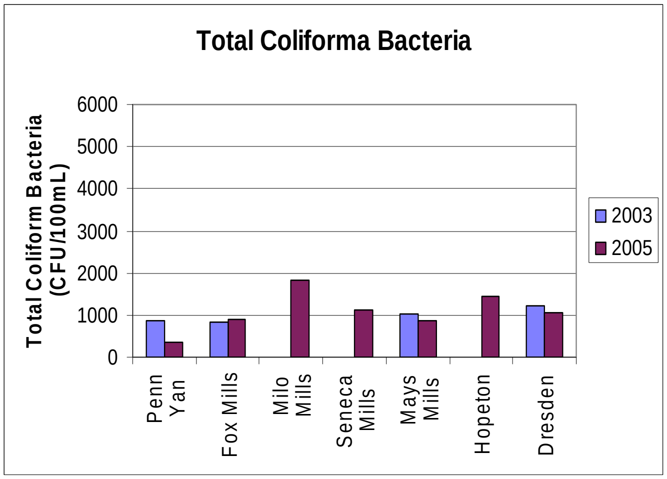


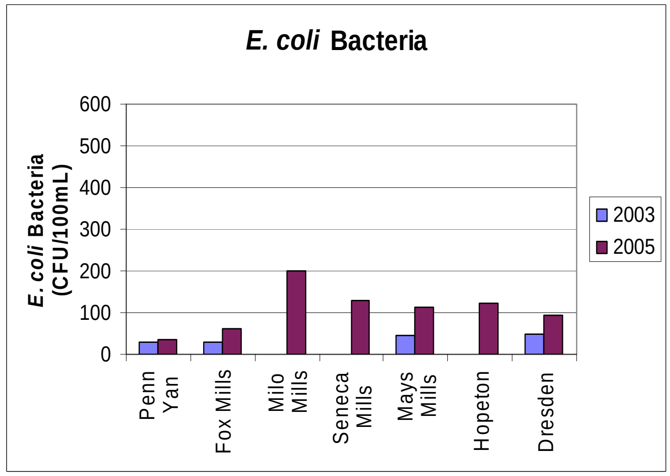


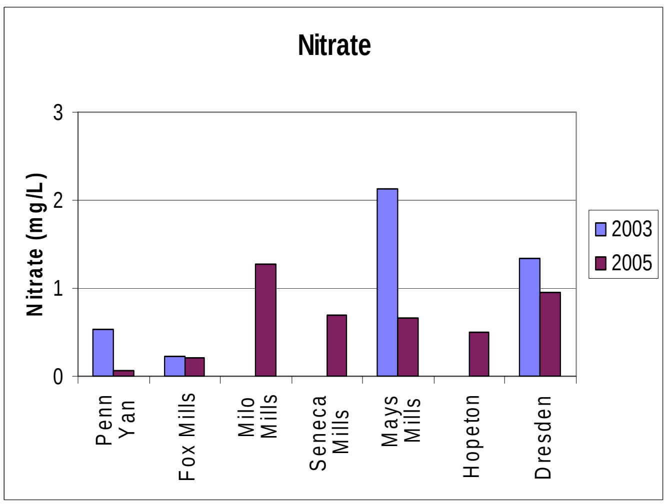


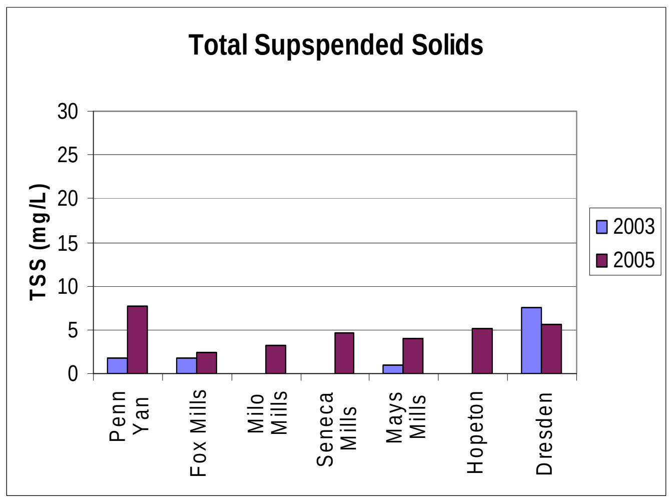


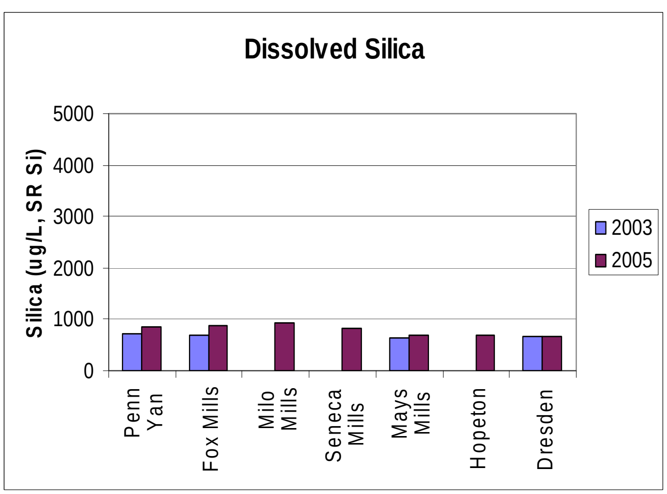
Keuka Outlet annual average water quality data.

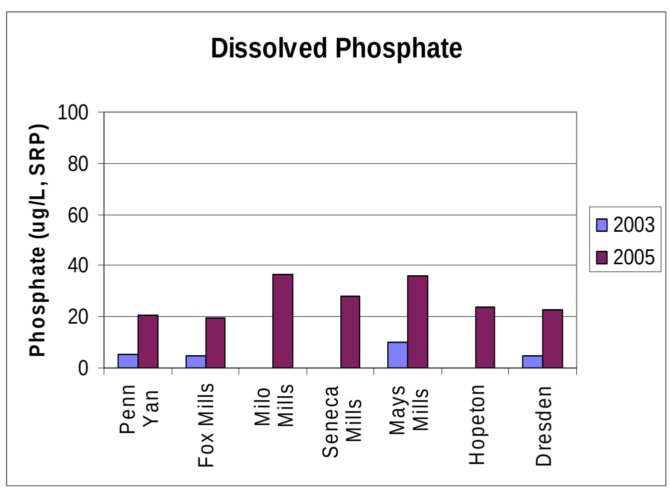




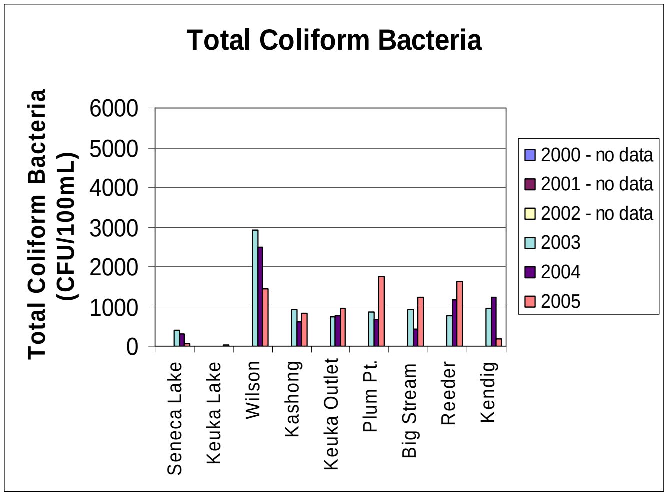


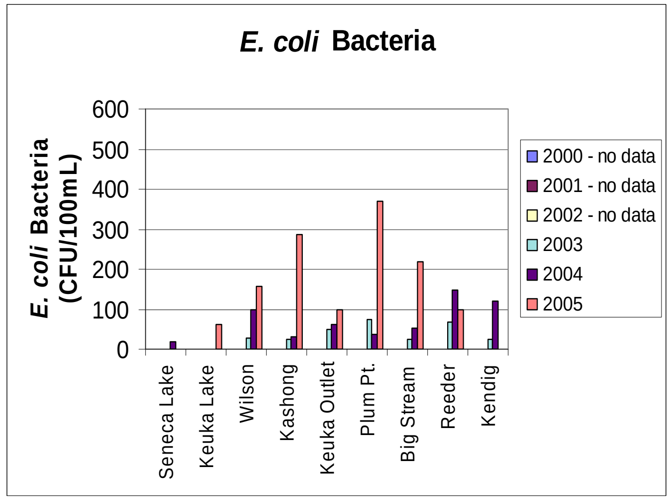


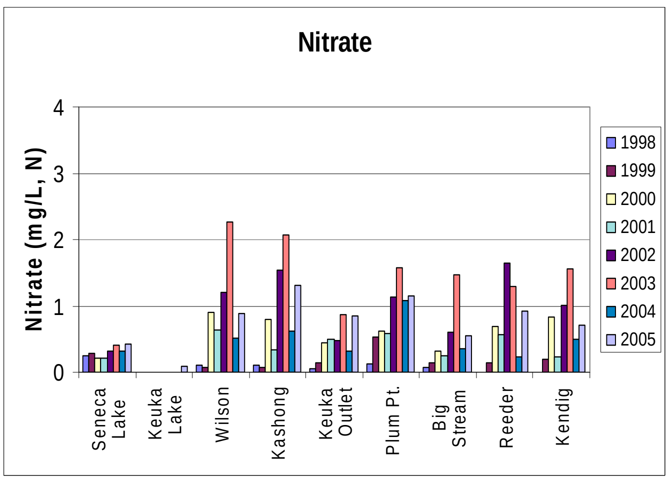


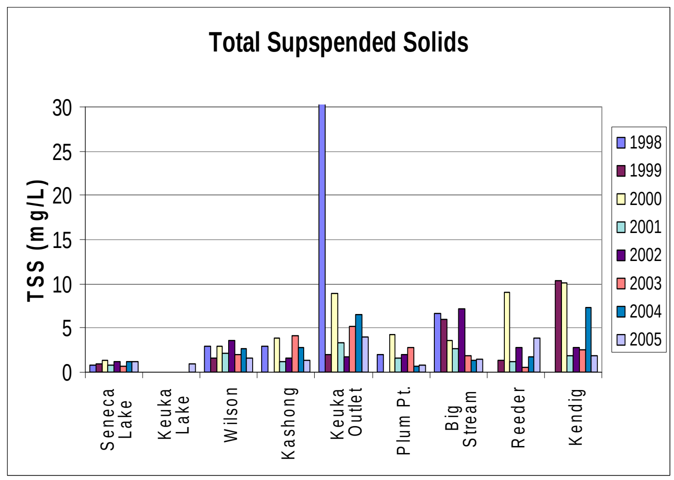


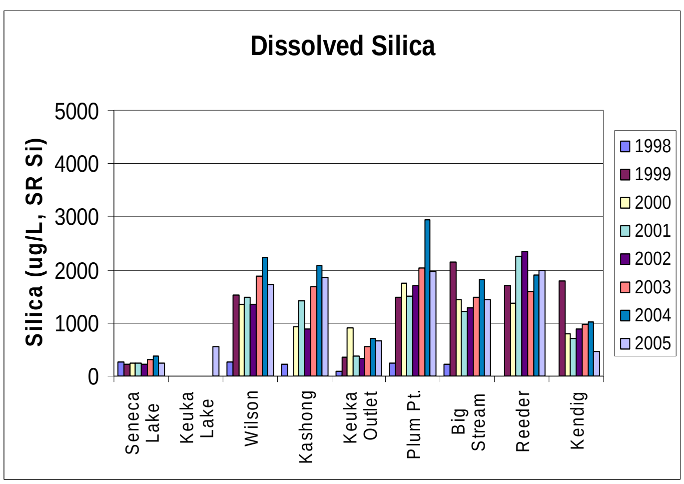
Annual average water quality data from Seneca and Keuka Lakes, and selected Seneca Lake subwatersheds.

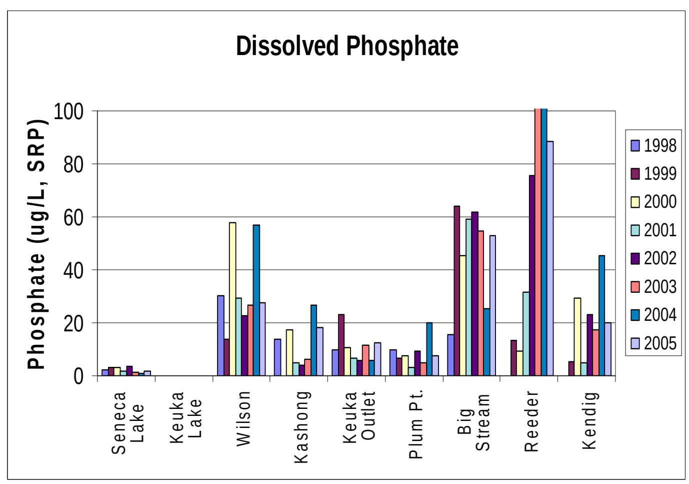




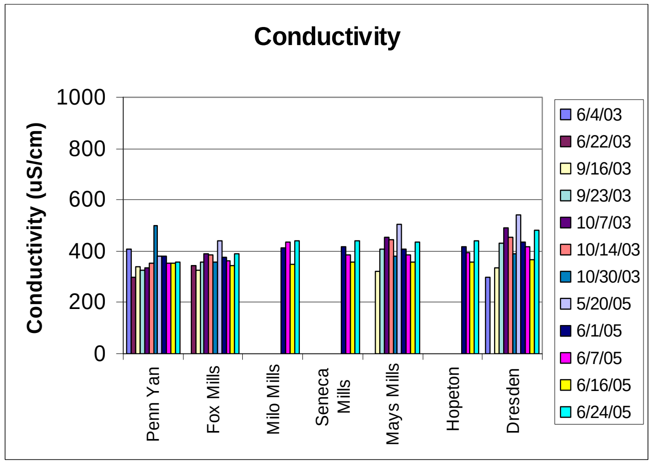


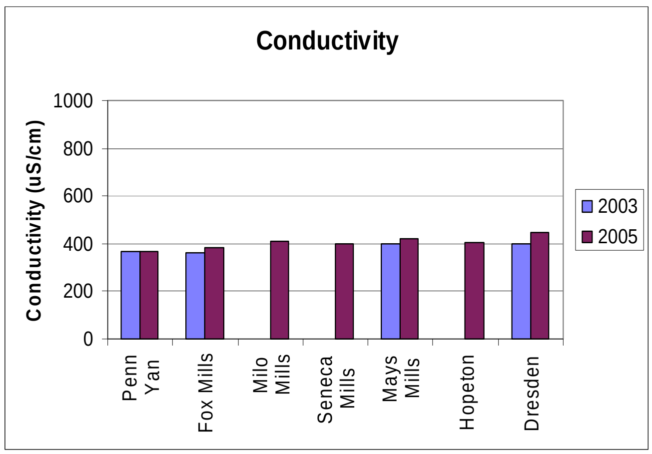


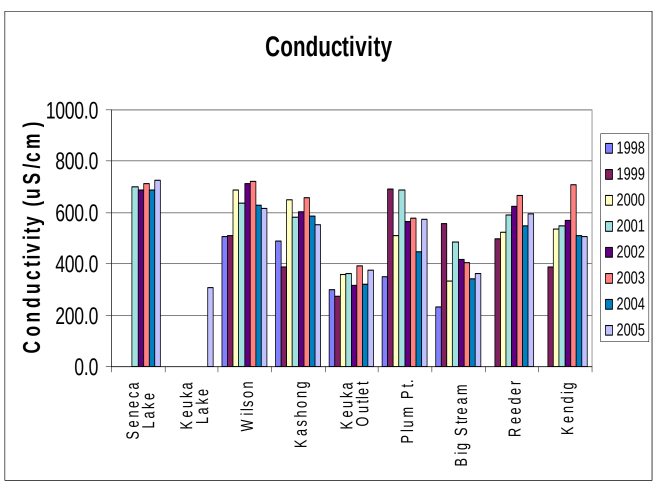




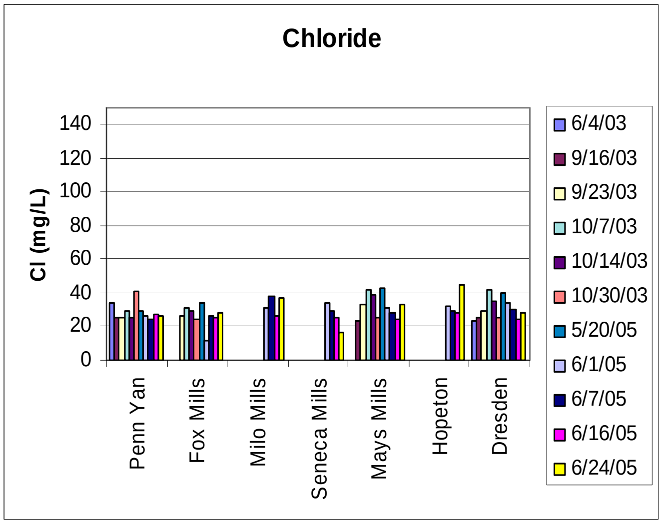
Conductivity Data

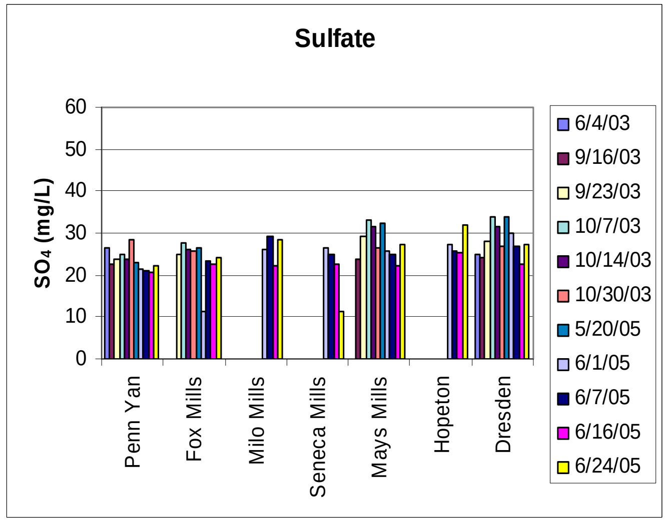


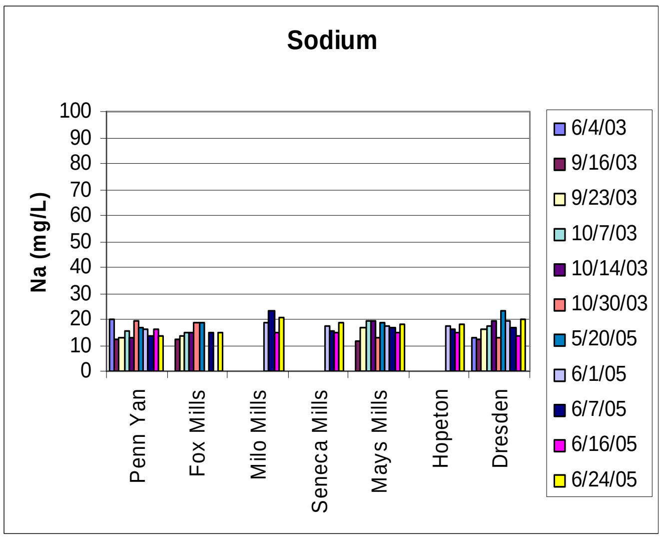


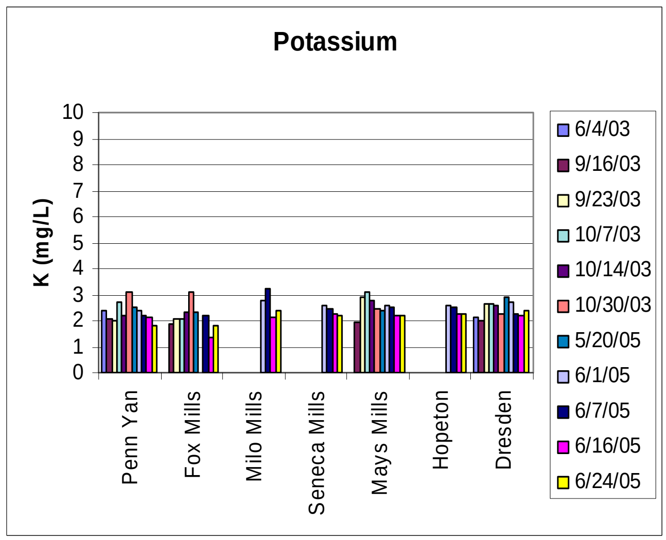


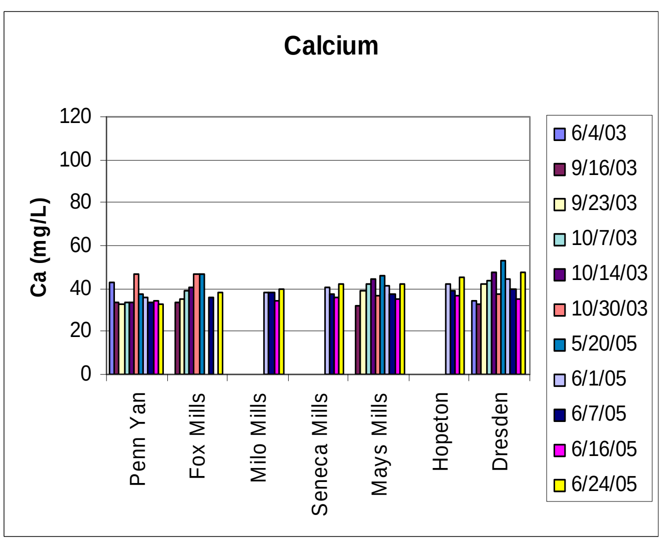
Keuka Outlet major ion results.

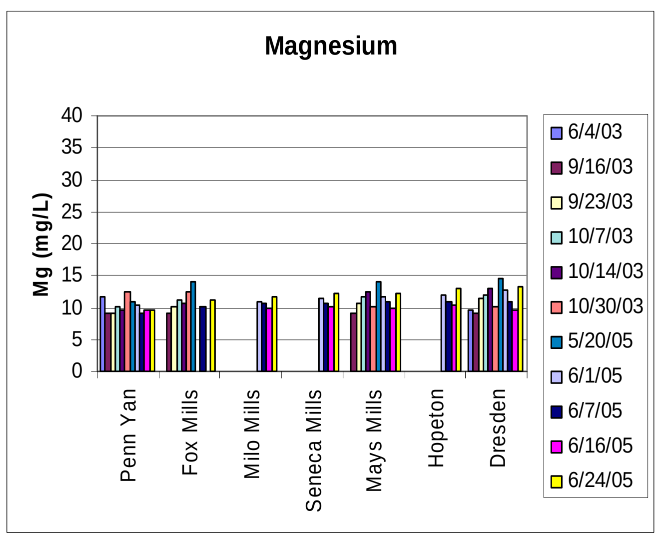




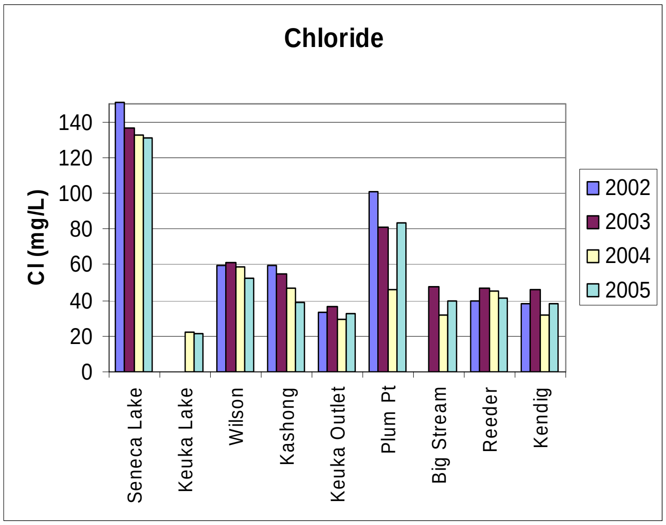


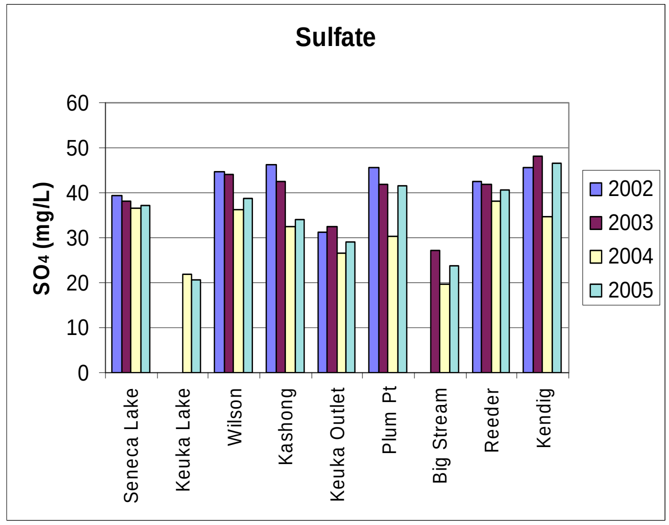


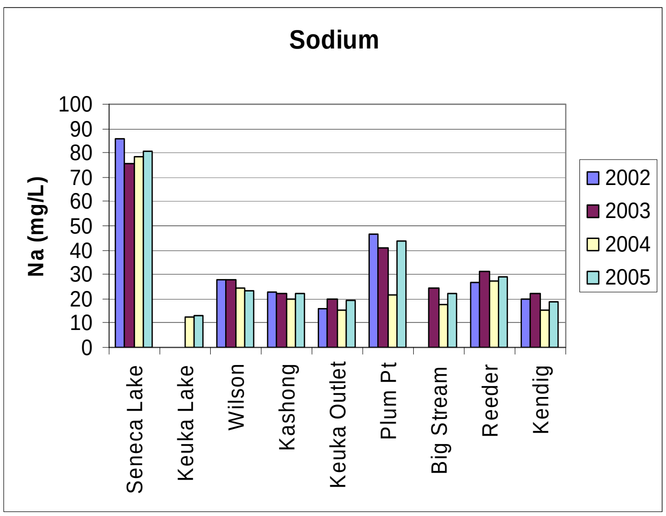


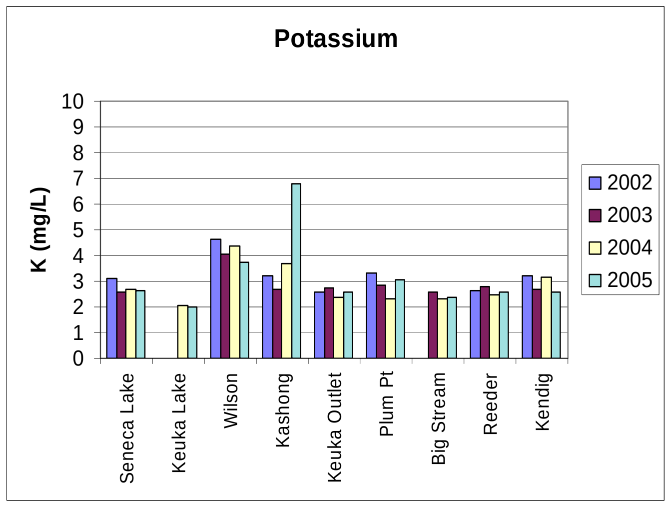


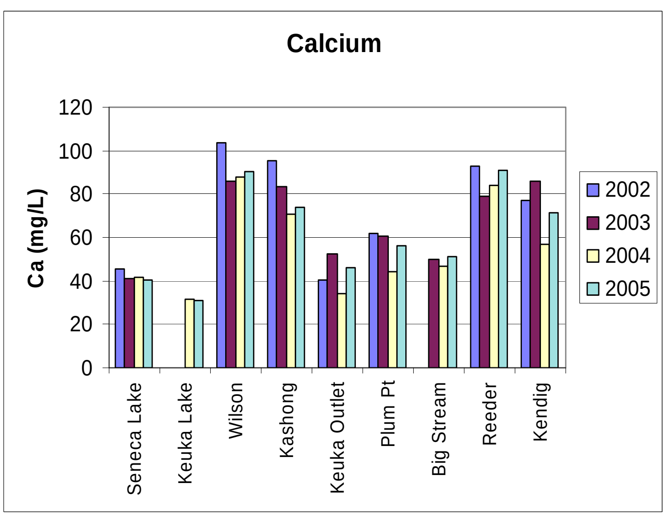
Annual average major ion data from Seneca and Keuka Lakes, and selected Seneca Lake subwatersheds.

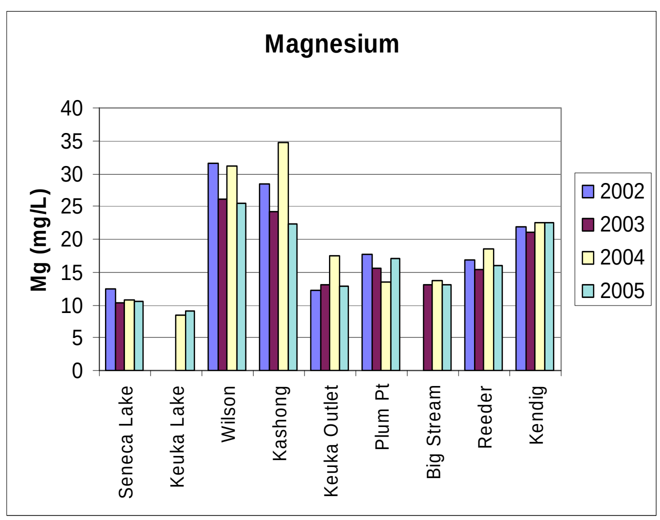












Data Below

Keuka Outlet - Annual Average Data

Water Quality Parameter	Year	Penn Yan	Fox Mills*	Milo Mills*	Seneca Mills*	Mays Mills	Hopeton	Dresden
Total Coliform Bacteria, CFU/100mL	2003	861.0	831.0			1036.2		1203.7
	2005	337.0	912.0	1837.5	1113.8	865.0	1453.8	1047.0
E. coli Bacteria, CFU/100mL	2003	29.1	28.8			46.6		47.2
	2005	37.0	62.0	201.3	128.8	114.0	123.8	94.0
Nitrate, N mg/L	2003	0.5	0.2			2.1		1.3
	2005	0.1	0.2	1.3	0.7	0.7	0.5	1.0
Phosphate, SRP ug/L	2003	5.1	4.9			10.2		4.6
	2005	20.6	19.4	36.5	27.9	35.7	23.7	22.6
Silica, SR Si, ug/L	2003	729.4	691.9			630.9		656.8
	2005	847.5	870.5	934.1	831.3	689.9	699.0	677.9
Total Suspended Solids, mg/L	2003	1.8	1.7			1.0		7.5
	2005	7.7	2.4	3.2	4.7	4.0	5.1	5.5
Conductivity, uS/cm	2003	365.7	360.7			401.4		398.8
	2005	364.6	382.6	409.5	401.0	418.6	403.5	448.2

Major Ions	Year	Penn Yan	Fox Mills*	Milo Mills*	Seneca Mills*	Mays Mills	Hopeton	Dresden
Calcium, Ca mg/L	2003	37.1	38.7			38.7		39.6
	2005	34.7	40.0	37.7	39.0	40.4	40.7	44.0
Magnesium, Mg mg/L	2003	10.4	10.7			10.8		10.9
	2005	9.9	11.8	10.8	11.1	11.7	11.5	12.2
Potassium, K mg/L	2003	2.4	2.3			2.6		2.4
	2005	2.2	1.9	2.6	2.4	2.4	2.4	2.5
Sodium, Na mg/L	2003	15.3	14.7			16.1		15.2
	2005	15.2	16.1	19.3	16.6	17.1	16.4	18.6
Chloride, Cl mg/L	2003	30.0	27.7			32.3		30.1
	2005	26.5	25.2	33.3	26.0	32.0	33.5	31.4
Sulfate, SO_4 mg/L	2003	25.0	26.1			28.8		28.2
	2005	21.6	21.6	26.5	21.4	26.5	27.6	28.2

*Samples were not collected from Fox Mills, Milo Mills and Seneca Mills in 2003.

Keuka Outlet - Raw Data

Water Quality Parameter	Date	Penn Yan	Fox Mills*	Milo Mills*	Seneca Mills*	Mays Mills	Hopeton	Dresden
Total Coliform Bacteria, CFU/100mL	6/4/03	80.0						2040.0
	6/23/03	2200.0	1940.0					
	9/16/03	1027.0	1063.0			1450.0		2970.0
	9/23/03	773.0	1003.0			1130.0		753.0
	10/7/03	1077.0	323.0			947.0		273.0
	10/14/03	297.0	570.0			997.0		613.0
	10/30/03	573.0	87.0			657.0		573.0
	5/20/05	10.0	30.0			100.0		480.0
	6/1/05	845.0	345.0	380.0	510.0	445.0	460.0	410.0
	6/7/05	305.0	2075.0	4835.0	2520.0	1550.0	2690.0	1615.0
	6/16/05	285.0	1320.0	720.0	570.0	1505.0	2165.0	2265.0
	6/24/05	240.0	790.0	1415.0	855.0	725.0	500.0	465.0
E. coli Bacteria, CFU/100mL	6/4/03	10.0						20.0
	6/24/03	40.0	10.0					
	9/16/03	10.0	63.0			63.0		83.0
	9/23/03	17.0	53.0			27.0		23.0
	10/7/03	7.0	10.0			23.0		13.0
	10/14/03	3.0	30.0			13.0		27.0
	10/30/03	117.0	7.0			107.0		117.0
	5/20/05	0.0	0.0			0.0		0.0
	6/1/05	0.0	15.0	55.0	70.0	40.0	25.0	95.0
	6/7/05	20.0	50.0	485.0	100.0	85.0	130.0	60.0
	6/16/05	150.0	230.0	155.0	265.0	375.0	305.0	255.0
	6/24/05	15.0	15.0	110.0	80.0	70.0	35.0	60.0
Nitrate, N mg/L	6/4/03	0.3						0.2
	6/18/03	2.2	0.7					
	9/16/03	0.1	0.1			0.2		0.4
	9/23/03	0.0	0.2			3.4		2.2
	10/7/03	0.0	0.1			3.9		2.9
	10/14/03	0.0	0.0			2.2		1.4
	10/30/03	1.0	0.3			1.0		0.9
	5/20/05	0.1	0.3			1.2		1.5
	6/1/05	0.0	0.1	1.0	0.7	0.7	0.5	0.8
	6/7/05	0.1	0.2	3.1	0.9	0.6	0.5	0.9
	6/16/05	0.1	0.3	0.4	0.7	0.4	0.6	0.5
	6/24/05	0.0	0.1	0.6	0.5	0.4	0.4	1.1
Phosphate, SRP ug/L	6/4/03	11.1						0.0
	6/20/03	0.7	1.0					
	9/16/03	15.8	3.2			2.9		2.1
	9/23/03	3.5	11.0			16.5		5.1
	10/7/03	1.4	0.3			15.2		7.2
	10/14/03	0.0	11.8			11.9		7.2
	10/30/03	3.3	1.8			4.7		5.8
	5/20/05	1.0	3.1			24.5		17.2
	6/1/05	3.1	3.1	32.3	18.4	16.2	15.4	13.0
	6/7/05	4.6	8.4	20.0	23.6	73.0	21.1	21.7

	6/16/05	13.6	69.1	69.1	54.4	53.0	49.0	53.7
	6/24/05	80.9	13.1	24.5	15.1	12.1	9.4	7.2
Silica, SR Si, ug/L	6/4/03	1181.1						907.6
	6/21/03	392.8	796.2					
	9/16/03	783.4	675.2			751.7		693.7
	9/23/03	598.7	1023.4			1041.8		917.9
	10/7/03	269.0	625.1			445.7		319.1
	10/14/03	321.8	506.4			279.6		279.6
	10/30/03	1558.8	524.9			635.7		822.9
	5/20/05	614.4	711.4			375.3		377.1
	6/1/05	854.4	696.8	711.4	541.6	437.3	333.0	342.7
	6/7/05	971.6	973.9	1054.9	847.7	798.2	669.8	654.0
	6/16/05	1050.4	1082.0	1095.5	1138.3	1127.0	1163.1	1199.1
	6/24/05	746.5	888.6	874.6	797.7	711.5	629.9	816.4
Total Suspended Solids, mg/L	6/4/03	6.0						34.5
	6/19/03	0.1	3.7					
	9/16/03	2.5	4.7			1.7		6.6
	9/23/03	1.6	0.7			0.8		1.8
	10/7/03	0.7	0.2			0.7		0.0
	10/14/03	0.2	0.4			0.6		0.9
	10/30/03	1.3	0.6			1.1		1.2
	5/20/05	8.0				1.9		1.7
	6/1/05	9.5	0.6	1.1	3.3	1.5	1.8	1.2
	6/7/05	8.1	1.8	2.8	1.2	2.6	2.7	1.8
	6/16/05	9.7	7.1	7.6	13.2	13.1	14.8	20.8
	6/24/05	3.3	0.2	1.4	1.0	1.1	1.1	2.2
Conductivity, uS/cm	6/4/03	406.0						299.0
	6/22/03	298.0	345.0					
	9/16/03	338.0	324.0			323.0		333.0
	9/23/03	324.0	357.0			409.0		432.0
	10/7/03	337.0	392.0			453.0		489.0
	10/14/03	355.0	386.0			443.0		452.0
	10/30/03	502.0	360.0			379.0		388.0
	5/20/05	380.0	442.0			503.0		539.0
	6/1/05	379.0	376.0	414.0	417.0	408.0	418.0	437.0
	6/7/05	351.0	362.0	435.0	386.0	384.0	395.0	416.0
	6/16/05	353.0	343.0	350.0	359.0	360.0	360.0	368.0
	6/24/05	360.0	390.0	439.0	442.0	438.0	441.0	481.0
Major Ions	**Date**	**Penn Yan**	**Fox Mills***	**Milo Mills***	**Seneca Mills***	**Mays Mills**	**Hopeton**	**Dresden**
Calcium, Ca mg/L	6/4/03	43.0						34.1
	9/16/03	33.4	33.1			31.7		32.5
	9/23/03	32.4	34.8			38.9		42.2
	10/7/03	33.8	38.8			41.9		43.4
	10/14/03	33.3	40.3			44.5		47.9
	10/30/03	46.5	46.4			36.5		37.8
	5/20/05	37.4	46.4			46.1		52.9
	6/1/05	35.5		38.5	40.8	41.3	42.2	44.3
	6/7/05	33.7	35.7	37.8	37.4	37.4	38.8	39.9

	6/16/05	33.9		34.5	35.7	34.7	36.9	35.0
	6/24/05	33.0	37.9	40.0	42.0	42.4	45.1	47.8
Magnesium, Mg mg/L	6/4/03	11.7						9.7
	9/16/03	9.2	9.0			9.0		9.2
	9/23/03	9.2	10.1			10.6		11.4
	10/7/03	10.1	11.2			11.6		11.8
	10/14/03	9.6	10.7			12.5		12.9
	10/30/03	12.4	12.4			10.0		10.2
	5/20/05	11.0	14.0			13.9		14.7
	6/1/05	10.3		10.9	11.4	11.7	11.8	12.7
	6/7/05	9.2	10.2	10.7	10.6	10.8	11.0	10.8
	6/16/05	9.5		9.9	10.1	9.8	10.3	9.6
	6/24/05	9.6	11.2	11.7	12.1	12.3	12.9	13.1
Potassium, K mg/L	6/4/03	2.4						2.1
	9/16/03	2.1	1.9			1.9		2.0
	9/23/03	2.0	2.1			2.9		2.7
	10/7/03	2.7	2.0			3.1		2.7
	10/14/03	2.2	2.3			2.8		2.6
	10/30/03	3.1	3.1			2.4		2.3
	5/20/05	2.5	2.3			2.4		2.9
	6/1/05	2.4		2.8	2.6	2.6	2.6	2.7
	6/7/05	2.2	2.2	3.3	2.4	2.5	2.5	2.3
	6/16/05	2.1	1.3	2.2	2.3	2.2	2.2	2.2
	6/24/05	1.8	1.8	2.4	2.2	2.2	2.2	2.4
Sodium, Na mg/L	6/4/03	19.7						13.1
	9/16/03	12.3	12.0			11.9		12.4
	9/23/03	12.8	13.4			17.1		16.1
	10/7/03	15.2	14.9			19.1		17.1
	10/14/03	13.0	14.6			19.5		19.5
	10/30/03	19.1	18.8			13.1		12.9
	5/20/05	16.8	18.9			18.9		22.9
	6/1/05	16.2		18.5	17.3	17.3	17.2	19.5
	6/7/05	13.8	14.5	23.3	15.7	16.5	15.9	16.7
	6/16/05	15.8		14.9	14.7	14.8	14.6	13.7
	6/24/05	13.7	14.9	20.4	18.9	18.0	18.0	20.2
Chloride, Cl mg/L	6/4/03	34.3						23.3
	9/16/03	25.0				23.0		25.1
	9/23/03	25.3	26.3			32.8		29.2
	10/7/03	28.8	31.3			41.8		42.2
	10/14/03	25.5	28.8			39.0		35.1
	10/30/03	41.2	24.5			25.2		25.7
	5/20/05	28.9	34.3			42.9		40.4
	6/1/05	26.2	11.8	31.6	34.2	31.1	32.0	34.1
	6/7/05	24.2	25.9	38.4	28.8	28.4	28.8	30.0
	6/16/05	27.0	25.6	26.1	24.9	24.8	28.3	23.9
	6/24/05	26.4	28.4	37.1	16.2	32.9	45.1	28.6
Sulfate, SO_4 mg/L	6/4/03	26.6						24.7
	9/16/03	22.5	n.a.			23.8		24.2

9/23/03	23.6	25.1			29.4		28.0
10/7/03	24.8	27.5			33.1		33.8
10/14/03	23.9	26.1			31.6		31.5
10/30/03	28.6	25.5			26.3		26.9
5/20/05	22.8	26.7			32.2		33.8
6/1/05	21.5	11.3	26.0	26.4	25.9	27.4	30.1
6/7/05	21.1	23.3	29.3	25.0	24.9	25.9	27.1
6/16/05	20.5	22.8	22.3	22.8	22.1	25.2	22.6
6/24/05	22.1	24.1	28.4	11.4	27.4	31.8	27.3

Seneca Watershed & Keuka Lake - Annual Average Data

Water Quality Parameter	Year	Seneca Lake	Keuka Lake*	Wilson Cr.	Kashong Cr.	Keuka Outlet	Plum Pt.	Big Stream	Reeder Cr	Kendig Cr.
Total Coliform Bacteria, CFU/100mL	2003	387.6		2915.0	928.1	745.3	856.1	932.9	779.6	946.0
	2004	294.1		2496.6	622.9	764.7	678.3	438.6	1181.7	1220.0
	2005	71.5	36.8	1438.8	835.0	960.0	1741.7	1240.0	1618.3	197.5
E. coli Bacteria, CFU/100mL	2003	0.3		28.9	23.6	50.7	73.9	24.3	68.9	23.9
	2004	18.9		97.9	30.5	60.2	36.4	52.1	148.3	119.2
	2005	1.1	62.7	156.3	285.0	98.8	368.3	220.0	98.3	0.0
Nitrate, N mg/L	2000	0.2		0.9	0.8	0.4	0.6	0.3	0.7	0.8
	2001	0.2		0.6	0.3	0.5	0.6	0.2	0.6	0.2
	2002	0.3		1.2	1.5	0.5	1.1	0.6	1.6	1.0
	2003	0.4		2.3	2.1	0.9	1.6	1.5	1.3	1.5
	2004	0.3		0.5	0.6	0.3	1.1	0.3	0.2	0.5
	2005	0.4	0.1	0.9	1.3	0.9	1.1	0.6	0.9	0.7
Phosphate, SRP ug/L	2000	3.0		57.8	17.6	10.9	7.6	45.3	9.5	29.4
	2001	1.7		29.4	4.8	6.5	3.2	59.2	31.6	5.1
	2002	3.5		22.8	4.1	5.7	9.6	61.6	75.4	22.9
	2003	1.4		26.5	6.3	11.5	4.7	54.8	117.5	17.5
	2004	0.9		57.0	26.5	5.7	20.1	25.4	196.8	45.1
	2005	1.8	0.1	27.7	18.2	12.4	7.5	52.7	88.3	20.1
Silica, SR Si, ug/L	2000	251.7		1356.2	920.8	904.3	1740.3	1444.9	1381.8	801.7
	2001	239.0		1490.6	1423.3	367.5	1502.2	1227.7	2254.8	705.3
	2002	214.5		1358.6	878.0	336.4	1705.2	1284.5	2351.8	875.2
	2003	301.3		1876.2	1679.3	544.9	2033.1	1488.3	1584.1	979.8
	2004	386.9		2231.6	2083.3	710.3	2952.0	1821.2	1896.3	1026.3
	2005	253.9	560.8	1716.5	1847.7	669.8	1958.9	1439.1	1993.8	464.6
Total Suspended Solids, mg/L	2000	1.3		2.9	3.8	8.9	4.2	3.6	9.0	10.1
	2001	0.9		2.1	1.2	3.3	1.6	2.7	1.2	1.8
	2002	1.2		3.6	1.5	1.7	2.0	7.2	2.7	2.9
	2003	0.7		2.0	4.2	5.2	2.8	1.9	0.5	2.6
	2004	1.2		2.6	2.7	6.5	0.7	1.3	1.7	7.3
	2005	1.3	1.0	1.7	1.3	4.0	0.9	1.5	3.9	1.8
Conductivity, uS/cm	2000			686.9	650.7	359.3	509.8	334.8	524.4	537.6
	2001	699.0		635.6	583.6	362.1	688.6	485.4	590.9	550.5
	2002	688.1		714.7	601.6	316.4	563.4	417.4	626.1	570.1
	2003	715.1		720.9	657.3	393.2	579.5	404.1	668.4	708.6
	2004	687.8		630.4	585.6	321.3	446.7	340.6	549.9	509.7
	2005	727.7	309.0	614.8	554.4	377.6	574.8	364.5	594.8	506.0

*Keuka Lake samples were only collected in 2004 & 2005, and water quality data only measured in 2005.

Seneca Watershed & Keuka Lake - Annual Average Data

Major Ions	Year	Seneca Lake	Keuka Lake*	Wilson Cr.	Kashong Cr.	Keuka Outlet	Plum Pt.	Big Stream	Reeder Cr	Kendig Cr.
Calcium, Ca mg/L	2002	45.2		103.6	95.4	40.5	62.1		93.0	76.8
	2003	41.0		85.6	83.7	52.4	60.5	49.7	79.1	86.2
	2004	41.8	31.6	88.1	70.5	34.3	44.4	46.6	84.1	57.0
	2005	40.6	31.3	90.5	74.0	46.2	56.0	51.4	91.1	71.1
Magnesium, Mg mg/L	2002	12.4		31.6	28.3	12.3	17.6		16.9	22.0
	2003	10.3		26.1	24.2	13.1	15.5	13.0	15.3	21.0
	2004	10.7	8.4	31.2	34.8	17.4	13.5	13.8	18.5	22.6
	2005	10.6	9.0	25.5	22.3	12.7	17.0	13.0	16.0	22.5
Potassium, K mg/L	2002	3.1		4.6	3.2	2.6	3.3		2.6	3.2
	2003	2.6		4.0	2.7	2.7	2.9	2.6	2.8	2.7
	2004	2.7	2.0	4.4	3.7	2.3	2.3	2.3	2.5	3.2
	2005	2.6	2.0	3.7	6.8	2.6	3.1	2.4	2.6	2.6
Sodium, Na mg/L	2002	86.0		27.8	23.0	15.9	46.7		26.9	20.0
	2003	75.7		28.0	22.2	19.9	40.8	24.5	31.1	22.4
	2004	78.3	12.4	24.4	20.2	15.3	21.4	17.6	27.4	15.4
	2005	80.6	13.1	23.2	22.2	19.3	43.9	22.1	28.8	18.6
Chloride, Cl mg/L	2002	150.8		59.4	59.5	33.0	100.6		39.8	38.5
	2003	136.9		61.0	54.5	36.6	81.3	47.6	47.1	45.8
	2004	132.9	22.6	58.5	46.7	29.4	46.2	31.5	45.0	32.0
	2005	131.3	21.5	52.4	39.0	32.8	83.1	39.4	41.0	38.0
Sulfate, SO_4 mg/L	2002	39.3		44.7	46.3	31.4	45.6		42.3	45.7
	2003	38.1		44.1	42.5	32.6	42.0	27.2	41.8	48.1
	2004	36.6	21.9	36.2	32.3	26.6	30.4	19.5	38.0	34.6
	2005	37.0	20.7	38.8	34.1	29.0	41.5	23.8	40.6	46.5

*Keuka Lake samples were only collected in 2004 & 2005, and water quality data only measured in 2005.