The State of Surface Water Quality in Knox County

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Introduction

Is that stream safe for swimming? Is my tap water safe to drink? Is my city killing fish? Water is an integral part of our daily life, but how much do you really know about the streams and rivers where you live? Water quality is hard to quantify because many indicators play a role and the data used to measure these factors are sparse and difficult to interpret. This project created a data analysis tool and framework that allows the user to see which indicators were in good or bad shape over time. This report provides background information about these indicators and illustrates the current state of water quality in Knox County, Tennessee using the framework.

What are surface waters?

This report focuses on surface waters, which include rivers, streams, and creeks. These waters flow in a bed or channel and are typically considered "open" as they have a free surface exposed to air. Some streams flow through human-made conduits, like culverts, which are still considered open channels because they are not pressurized. Surface waters differ from ground waters, which include wells, aquifers, and the water table. Surface waters are also different from drinking water because drinking water is treated by municipalities and piped to consumers. While different in category, these water bodies are all highly connected in the water cycle, and poor surface water quality can feed into the others.

What is surface water quality?

Surface water quality has many different aspects that feed into the overall health of the stream. The primary domains are chemical, ecological, and physical. In the chemical domain, surface waters must have adequate levels of oxygen and nutrients to support life. Also, chemical pollution and toxins are a significant threat to riverine organisms. In the physical domain, water temperature and pH must stay within an appropriate range for the species in the water. Sediment has been a major physical problem for urban streams in the Knoxville area. Sand and dirt material, from construction sites especially, are washed into streams during rainfall events. These large dumps of sediment can make water cloudy and uninhabitable. Lastly, in the ecological domain, many forms of life must remain balanced to support a natural river system. Bacteria is a primary concern as bacteria from sewage can infect fish and recreationists. Fish and the small organisms that live on the bottom of the streambed, called "benthic macroinvertebrates" are also important to stream health. There are numerous components to surface water quality, but this report focuses on the major "indicators" of stream health that have available data in the region. These indicator metrics are not direct measurements of ecosystem health but can be used to infer the overall water quality when compiled together.

Why is surface water quality important?

Surface waters, directly and indirectly, affect human health and economic success. Recreational activities, like swimming and boating, can boost local economies, but require clean water to ensure the safety of participants. Fishing is another major attraction in Tennessee that requires healthy streams for trout reproduction. Surface water contamination has significant implications for drinking water safety as well because some water bodies are used for drinking water supply. Polluted surface waters can also leak into the groundwater sources used for drinking water. In addition, whenever waterways are out of compliance with standards set by the state or local government agencies, like the Tennessee Department of Environment and Conservation (TDEC), the agencies must create restoration plans to improve the waterway. These improvement projects require significant investment, but the results are often hard to quantify because urban streams are always under pressure from anthropogenic pollution. Quantifying surface water quality will allow stakeholders to visualize the return on investment from improvement projects and assess the overall safety and health of local waterways.

How is it currently regulated?

The Tennessee Department of Environment and Conservation (TDEC) is currently responsible for permitting water emissions and monitoring compliance under various national and state regulations. The Clean Water Act requires states to report a list of impaired waters, called the 303(d) list, every two years. For each waterway that is identified as impaired, the state must also produce a Total Maximum Daily Load (TMDL) report that sets an emission limit on the specific pollutant that is causing the impairment.

The state of Tennessee also has a set of General Water Quality Criteria in order to comply with the Clean Water Act. This set of rules outlines the requirements for indicator levels in streams based on their use classification. Streams may be classified as Domestic Water Supply, Industrial Water Supply, Fish and Aquatic Life, Trout Streams, Naturally Reproducing Trout Streams, Recreation, Irrigation, Navigation, or Livestock Watering and Wildlife. These criteria set the baseline for the scoring methodology in this report.

Another critical note to highlight is the difference between point and nonpoint source emissions. Point source emissions are those that release water and pollutants from particular outlets, primarily outfalls from large industrial facilities. Nonpoint source emissions stem from large areas, such as fertilizer runoff from farms. Nonpoint sources are much more difficult to quantify and thus regulate. The primary focuses of TDEC are point source permitting and implementing best management practices for nonpoint sources. Point source permits are a part of the National Pollutant Discharge Elimination System (NPDES) program from the Environmental Protection Agency (EPA). In addition, stormwater systems are a major component of point source emissions and are regulated under the Municipal Separate Storm Sewer System (MS4) program in most large cities.

TDEC and other agencies have gaging stations across the U.S. that are used to take water samples and measure water quality indicators. Some indicators, such as temperature, are measured continuously at the site without user intervention, but most indicators, like bacteria concentration, require human sampling and lab work. Measurement standards vary over time, between agencies, and across metrics. As a result, water quality data is disparate in time and space, comes in different formats, and is hard to find. The National Water Quality Monitoring Council (NWQMC) created a database that collects water quality measurements from many government agencies; however, the data is still challenging to compile into comparable metrics. One primary outcome of this report is a Python script that can aggregate and clean select water quality metrics from the NWQMC database (refer to the Methodology section for details).

What is in this report?

This project aimed to accomplish a few tasks:

- Create a tool for collecting and cleaning water quality data from the NWQMC
- Create a framework for scoring water quality metrics based on a consistent and interpretable scale
- Report on the current state of surface water quality in the Knox County area

This report discusses the scoring framework developed in this project and presents a case study on the quality of surface waters in the Knox County area. The methodology and source code for the data collection tool can be found in the appendix.

What is the scoring framework?

The scoring framework is based on a fuzzy logic approach that not only classifies water quality metrics as in good or bad condition but also quantifies how close the measurements are to compliance. Currently, regulations can only track whether waterways are in compliance with state standards or out of compliance. This method is considered a binary approach where there are only two options, good or bad. In fuzzy logic, values may be good, bad, or somewhere in between. For this report, we use a score of 1 to represent good water quality and 0 to represent poor or out of compliance water quality. However, scores may also be decimal values between 0 and 1, which show how close they are to being good or bad.

These scores are generated for each measurement in the data by applying a fuzzy scoring function. These functions are metric specific and essentially tell which measurement values are good and which values are bad. The criteria for good and bad quality were determined from state standards and scientific literature where appropriate. The sources and language for the criteria of each metric can be found in in the Appendix. Usually, multiple criteria are available for each indicator, some that would maintain better water quality and some that would tolerate poorer water quality. The fuzzy logic indicator assigned a score of 1 if the measurement is better than required under the most stringent requirement. A score of 0 was assigned if the measurement would fail to meet even less stringent requirements also described in policy documents. The framework assumes a linear function to determine the decimal scores between full compliance and noncompliance. This framework has been used in other papers (Gharibi et al., 2012; Varadharajan, Reinier, & Mohan, 2009). This method has the added benefit of accounting for scale and directionality (whether more or less of a metric is desired) for each metric. The fuzzy scoring functions are shown on each page for the specific metrics.

FAQ

What is the difference between metric and indicator?

In this report, an indicator is a general category of water quality. Each indicator has one or more metrics that are used to quantify the indicator. For example, sediment is an indicator, and both turbidity and total suspended solids are metrics used to quantify sediment quality. Each metric has a different scoring function.

Can this framework be applied to other cities?

Yes, the framework can be used in other areas. This case study focuses on Knox County, but the code developed will work with any U.S. region available in the National Water Quality Monitoring Council dataset. Look in the Appendix to learn about the methodology or contact Colin Sasthav (csasthav@vols.utk.edu) for more information.

Where can I learn more?

To learn more about the metrics and measurements: https://www.fondriest.com/environmental-measurements/

To learn more about the water quality regulations: https://www.epa.gov/wqs-tech

To learn more about the dataset: https://acwi.gov/monitoring/

Conclusions

Data Management Needs

Through the process of developing this tool, we learned that three main barriers impede the understanding of water quality by the public in the United States:

1) Data are disorganized

The NWQMC database is a great starting point for combining abundant sources of water quality measurements; however; the database is still plagued by varying metric names, units, and sampling schemes.

2) Data are not interpretable

Many watershed-wide reports on water quality exist; however, most reports are too detailed or technical to be readily interpretable by the public.

3) Data are lacking

While some areas (i.e. specific monitoring locations) have frequent and consistent measurements, the amount of data we found was not sufficient to fully understand the state of water quality. More measurements across time and space are required to support sound policy decisions.

Environmental Mitigation Needs

Of the indicators analyzed, indicator bacteria are the most pressing concern for Knox County as many streams across the area reported higher than standard concentrations on a nine-year average. Systemic mitigation measures are suggested for bacteria across Knox county water systems.

Suggested actions for bacteria:

- Incentivize drinking water systems and fencing that keep livestock away from streams.
- Minimize sewage leaks through infrastructure investment and public education about proper waste management.

Dissolved oxygen, phosphorus, and nitrogen scored well overall, but scored poorly at a few stations, which may require site-specific mitigation measures. Possible localized measures include designing for ripples to increase oxygen uptake, tightening point source regulations on wastewater plants, and adding riparian buffers along agricultural lands to slow nutrient runoff.

Sediment and the physical indicators scored well and do not require significant investment in mitigation measures.

Indicator Bacteria

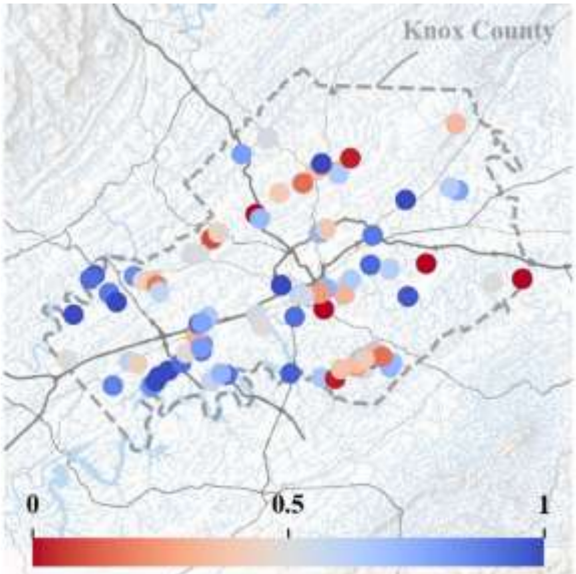

Figure 1: Map of the E. coli scores in Knox County. Dark red markers indicate stations reporting higher than standard E. coli concentrations (630 CFU/100mL) on average from 2010-2018.

Indicator Description

There are several types of bacteria commonly analyzed to determine surface water quality. These types are termed, "Indicator Bacteria," because while they are not generally harmful to people themselves, they indicate the presence of other harmful pathogens. The EPA recommends monitoring *Escherichia coli* (*E. coli*) to measure health risks in recreational fresh water (Agency, 2012). *E. coli* is a bacterium common to fecal matter in warm-blooded animals and humans. *E. coli* is categorized as a coliform bacterium and some agencies measure either Total Coliform or Fecal Coliform concentrations, which include *E. coli* and other types of coliform bacteria. Based on the availability of data and stakeholder input, our model focused on *E. coli*, which is a prevalent concern among stakeholders in Knox County.

Bacteria are introduced to the waterway usually through either wildlife or agricultural animal interaction with the waterway. Many streams used for agriculture will naturally contain these bacteria in lower levels, which may not present a high risk if used only for this purpose. In urban areas, leaks from wastewater pipes can be a source of harmful bacteria, which pose an immediate health risk in streams used for recreation. There have been cases in which the ingestion of water from impaired areas has caused children and adults to be hospitalized or die due to complications from *E. coli*.

The level of these bacteria within a waterway can be measured utilizing two different methods. The membrane filtration method first filters a 100 mL sample of water and then places the filter onto a selective-nutrient agar plate. The desired bacteria will grow and form a certain number of colonies on these plates based on the number of bacteria in the sample. The number of colonies is recorded to determine the bacteria concentration in colony forming units per 100 milliliters (CFU/100mL). The other method measures the change in gas composition from these colonies when cultured in a tube. This method estimates the most probable number (MPN/100mL) of bacteria within the tube. Both methods are acceptable in reporting, but in our report, we will focus on CFU data as it is a more complete set of data from the data source.

Desired Condition

The desired condition for any stream is to have low levels of *E. coli* bacteria. According to TDEC regulations, recreation stream concentrations must be lower than 126 CFU/100mL. Domestic water supply and aquatic life streams have the least stringent requirements of 630 CFU/100mL. As such, any streams with greater than this level of bacteria are out of compliance and may be a health hazard. The regulations state that these requirements are for measurements comprised of at least five mean samples taken over 30 days. Due to the nature of the data, we applied these requirements directly to single measurements, rather than 30-day averages.

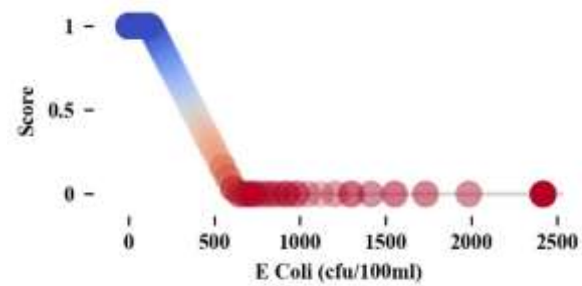

Figure 2: Scoring curve for E. coli measurements with 2010-2018 data points shown along the curve. Scores range from 1 (Good) to 0 (Bad).

Status and Trends

The level of *E. coli* in most streams of Knox county has stayed within the desired condition from 2010 to 2018. The risk of infection from most streams is typically low. However, some streams show a history of non-compliance and several spikes in bacterial concentrations that can be significant health hazards. In Figure 3, we can see that the French Broad River and the Tennessee River have moved outside of the upper bound for *E. coli* concentration in recent years. The smaller streams feed these two rivers, which are the most likely to receive surge from storms or waste discharge. This behavior is consistent with the data seen in Figure 4 on the right where the timing of spikes corresponds to certain collection times.

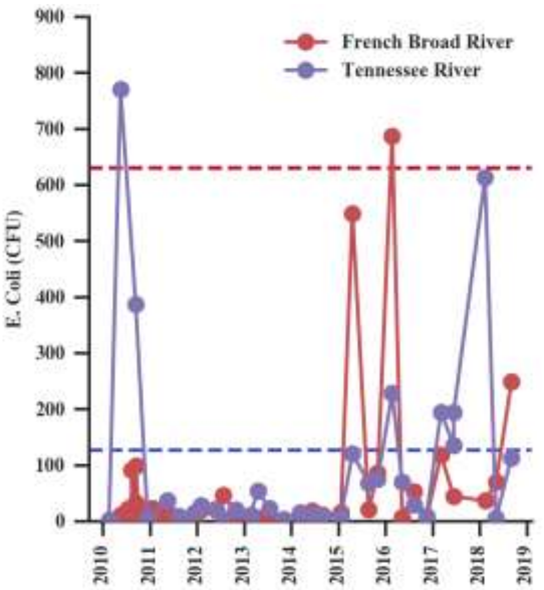

Figure 3: Time series of E. coli measurements in the French Broad and Tennessee Rivers.

Figure 4 also shows a similar time series for First, Second, and Third Creek. Due to the smaller size of these streams, they may be more susceptible to higher bacteria concentrations. Second creek shows consistent measurements above the safe recreational water criteria of 126 CFU/mL. Third and Second Creek have surpassed the maximum allowable concentrations within the last two years.

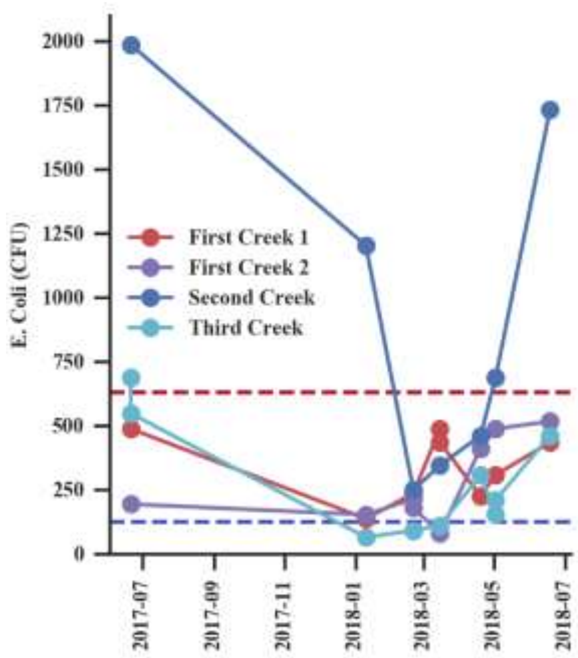

Figure 4: Time series of E. coli measurements for three streams near downtown Knoxville.

Actions and Needs

The issue most often highlighted when speaking to experts in Knox County is the aging infrastructure of the sewer system. When storm surges occur, the pipes can become overwhelmed with the amount of discharge and wastewater can leak into the surrounding area. The Knoxville Utilities Board and other municipalities have already begun remediation by updating the wastewater infrastructure. However, infrastructure is always aging, and this will likely be a continuous problem. To slow the aging process, these systems may benefit from public education about proper disposal strategies. Grease and large objects can severely damage a sewer system over time, so increased awareness may limit leaks.

Another noted source is agricultural emissions. Livestock, when allowed to drink from and interact with streams openly, often defecate in these open waters, which contribute many bacteria. Upstream farms can also contribute to bacteria concentrations around the city through rainwater runoff. The City of Knoxville is working with local farmers to incentivize drinking water systems and fencing that keep livestock away from streams. These management practices are not ubiquitous and do not have economic drivers without government support.

Conclusions

Of the indicators listed in this report, bacteria should be one of the top concerns for Knox County. Several stations report non-compliant levels of E. coli on a nine-year average and Second Creek has consistently exceeded recommended levels in the last year. Public education and investment into proper disposal strategies and livestock management can help mitigate this problem. In addition, more frequent measurements will help pinpoint problem areas and root causes.

Dissolved Oxygen

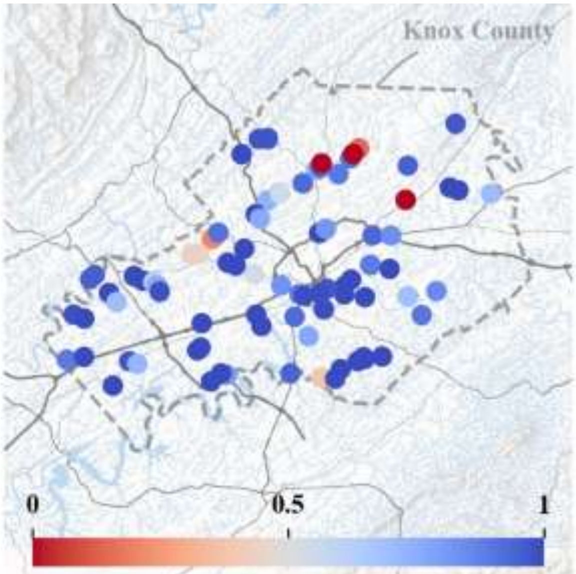

Figure 5: Map of Dissolved Oxygen scores in Knox County. Dark red markers indicate stations reporting lower than standard DO concentrations (5 mg/L) on average from 2010-2018.

Indicator Description

Dissolved oxygen (DO) is the amount of free O_2 dissolved directly into a waterbody. O_2 is commonly dissolved into a waterway directly from air through the water's surface; however, photosynthesis from underwater plants, algae, or phytoplankton can introduce DO as well. The amount of DO in the waterway is affected by the water temperature, flow, altitude, and sediment quantity. DO is often measured with digital DO sensors.

The amount of DO in a waterbody is vital for fish, invertebrate, and plant quality of life. When dissolved oxygen levels drop below 5.0 mg/L, it can cause stress to many forms of aquatic life, and if the DO drops below a critical level (1-2 mg/L) for a few hours, it can kill large aquatic organisms. Low DO can also have chronic (long term) impacts such as shifts in biological communities. For example, communities of fish will leave ecosystems due to the stress exerted from low concentrations.

Factors that can negatively affect DO in a stream are excess nutrients such as nitrogen and phosphorus which can cause excessive plant growth. Growth and decomposition can lead to overutilization of the oxygen in the waterway. Water that is not moving at its usual rate will also cause a decrease in DO content due to less uptake of oxygen into the waterway. DO is a common focus for hydropower plants because dams can cause reservoirs to stratify where lower levels of stationary water become colder and less oxygenated than higher levels. This report focuses on streams, rather than reservoirs, where stratification is not often an issue.

Desired Condition

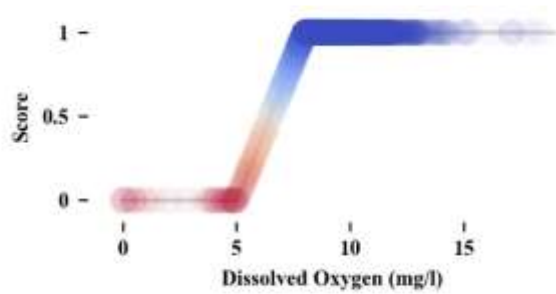

Figure 6: Scoring curve for Dissolved Oxygen measurements with 2010-2018 data points shown along the curve. Scores range from 1 (Good) to 0 (Bad).

Dissolved oxygen levels should meet standards that support native aquatic life. For example, Tennessee is very popular for trout fishing and has several trout hatcheries, tailwater stocking stations, and wild trout streams. The mountains of East Tennessee are where naturally reproducing trout live; however, the Tennessee Wildlife Resource Agency (TWRA) stock trout in cold tailwaters near dams for fishing purposes. Naturally reproducing trout streams require DO amount of 8 mg/L and tailwater stocking streams require 6 mg/L DO to be maintained. All other streams should be kept at 5 mg/L.

Status and Trends

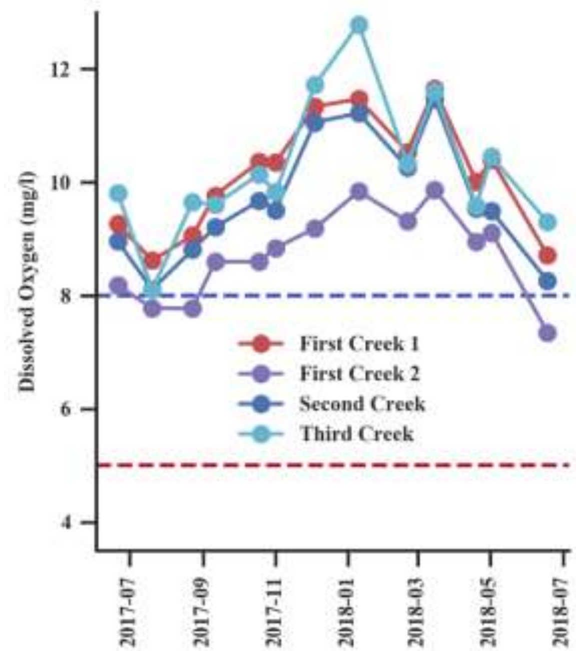

Figure 7: Time series of Dissolved Oxygen concentration for *three* streams *near downtown* Knoxville*.*

The time series in Figure 7 shows that DO concentrations generally meet or exceed the 5 mg/L criteria. The time series also demonstrates the change in DO when the temperature of the water changes. Cold water can hold more oxygen, so the DO content of the streams is generally higher in the winter and spring than in the summer and fall months that have warmer water. Of the two First Creek stations shown, the upstream location (First Creek 1) has consistently higher DO concentrations than the downstream location (First Creek 2). The downstream location is near its opening to the Tennessee River. The lower oxygen levels could result from the change in current that occurs near the mouth or estuary of a larger body of water.

Figure 8: Image of Baker Creek. Ripples, as shown here, can increase the dissolved oxygen concentration.

The DO content of the majority of the streams in the watershed is considered good, meaning that the DO concentrations are higher than the Tennessee standards of 5 mg/L. So, there is plenty of dissolved oxygen in the streams to support aquatic life. For the higher DO content to cause danger to the aquatic life (gas bubble trauma or gas bubble disease) concentrations would have to reach 110% of the stream capacity. These high concentrations of DO, such that can cause danger to aquatic life, occur near dam spills, when there are high populations of algae, or near waterfalls. No data points were close to the upper limit, so high DO is not a major concern.

A small number of water bodies in the watershed, however, have lower than the standard concentration levels. When the DO content is below the 5 mg/L standard, then there is a possibility of large fish suffocation especially on the low end of the scale (1-2 mg/L). Before 2010 most of the non-compliant water bodies are wells or small rural springs (Hunter Spring). Wells and small water bodies, not having to support large aquatic life, are required by Tennessee state standards to have sufficient DO concentrations so that there are no odors. Odors are often produced when there are little to no dissolved oxygen (0 to 1 mg/L for most odors) (Keys, 2012). Fouls smells may be produced when small aquatic organisms decompose in the absence of oxygen. Organic material that decomposes, like dead branches, can come out of solution when DO concentrations are low.

Figure 5 and Figure 6 show the score for data collected post-2010. In this range of data, Beaver Creek, highlighted in Figure 9, exhibits a couple of low DO concentrations that are near to or not in compliance for DO. Beaver Creek is a 44-mile long stretch of water in the northern portion of Knox County. This stretch of water is considered heavily impaired due to the rapid urbanization of the watershed.

Actions and Needs

The majority of streams in Knoxville do not need significant DO improvement based on the results of this framework. Beaver Creek stands out as having the lowest average DO levels and could benefit from intervention. A group of private, government, and non-profit organizations called the Beaver Creek Task Force has been in place since 1988 to address the impacts of Beaver Creek.

Mitigation measures focus on increasing air uptake, decreasing reservoir stratification, and reducing oxygen demand. Agencies can increase air uptake by modifying stream designs to add ripples/waterfalls and retrofitting aerators to hydropower turbines.

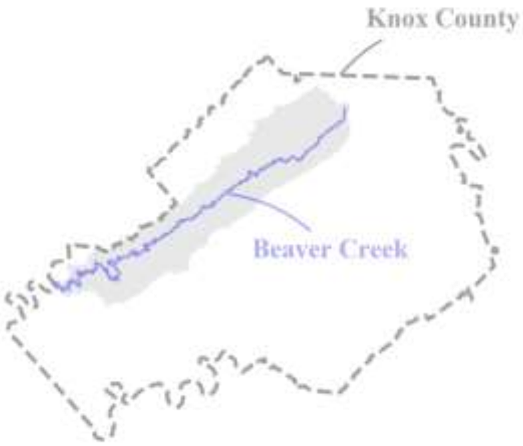

Figure 9: Map showing the Beaver Creek Watershed (bright green highlight) and Beaver Creek (blue highlighted line).

Conclusions

Measurements within the last nine years show that most streams comply with Tennessee standards. Mitigation measures are not suggested for Knox County. Potential mitigation practices, if desired, include changing of dam operation practices, restriction of industry releases, and installation of aerators to local ponds and reservoirs.

Sediment

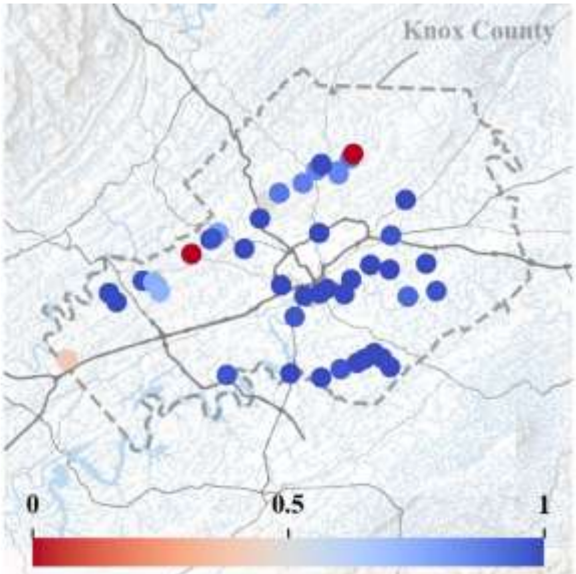

Figure 10: Map of Turbidity in Knox County. Dark red markers indicate high turbidity levels across the monitoring stations. Blue markers indicate stations reporting lower than standard turbidity (50 NTU) on average from 2010-2018.

Indicator Description

Sediment is eroded soil from land either through natural or industrial processes (construction, farming, loss of riparian barriers, etc.). The process of this eroded or lost soil being transported to a new location either through rainwater, water flow, or physical movement is called sedimentation. Sediment can find its way into waterways, becoming suspended solids. The more suspended solids, the higher the turbidity (transparency of the waterway). Total Suspended Solids (TSS) is a common metric that quantifies sediment prevalence. TSS is reported in mg/L and measured by filtering a water sample and weighing the filtered material. Similarly, Total Dissolved Solids (TDS) measures the amount of dissolved material (salts, minerals, and metals) in the water that can pass through a filter. The filtered water is evaporated and weighed to determine the TDS in mg/L. Turbidity, measured in Nephelometric Turbidity Units (NTUs), is not a direct measurement of the sediment in the water and is based on the amount of light scattered by the suspended solids or dissolved material in the water. For example, when the turbidity is low the water tends to be transparent. This feature can be seen in the top image of Figure 11, which demonstrates that when the turbidity is low the bottom of the stream is visible to the naked eye. The bottom image of Figure 11 shows a more opaque stream, which means the turbidity is higher.

Figure 11: (Top) Image of Baker Creek demonstrating the transparent nature of low turbidity creeks. (Bottom) Image of First Creek demonstrating higher turbidity levels than the top image.

Extreme cases when the stream is entirely opaque or muddy in color can occur during heavy storms or rainfall, close to construction sites, or even near livestock or grouped animals. Sediment or solids are also capable of carrying chemicals and toxins. If introduced to a waterbody then traces of these chemicals and toxins can be introduced into the waterbody. Furthermore, total suspended solids are not only sand and dirt as one might initially think. Stormwater runoff can introduce metals, other inorganic materials (plastics, rubber, asphalt, etc.), and organic materials to the water body.

The higher the turbidity of the stream the more danger to aquatic life. Large amounts of suspended solids can suffocate aquatic life, ruin aquatic habitats, and increase the water temperature. The increased turbidity stunts an aquatic plant's ability to photosynthesize and the increasing water temperatures directly impact the ability of the waterbody to dissolve oxygen further endangering aquatic life.

Desired Condition

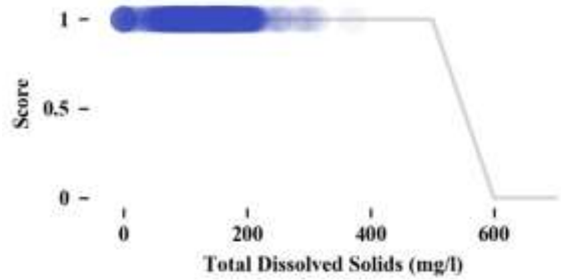

Figure 12: Scoring curve for Total Dissolved Solids measurements with 2010-2018 data points shown along the curve. Scores range from 1 (Good) to 0 (Bad).

For all metrics, regulations require low levels of sediment. Many state agencies do not set specific limits on sediment concentration but set qualitative limits on appearance and impact on stream function.

For recreational streams, the sediment quantity is measured by the water color. Recreational waterways must have colors such that the waterway does not appear objectionable in appearance. For waterways to serve as domestic water supply a water treatment facility must be able to reduce the suspended solids to an acceptable level through conventional water treatment means. Often recommendations governing sediment are qualitative making them challenging to integrate into our numerical scoring method. According to TDEC, TDS levels must remain below 500 mg/L. The Indiana Department of Environmental Management requires TSS levels to remain below 46 mg/L. When applying these limits in the fuzzy logic framework, almost all data points were satisfactory, indicating that sediment levels are low on average. This trend may result from high regulation limits and routine measurement practices that do not capture short term spikes from acute storm events. A description of regulations can be found in in the Appendix. More targeted adaptive sampling protocols may be needed to see whether results change during high run-off events.

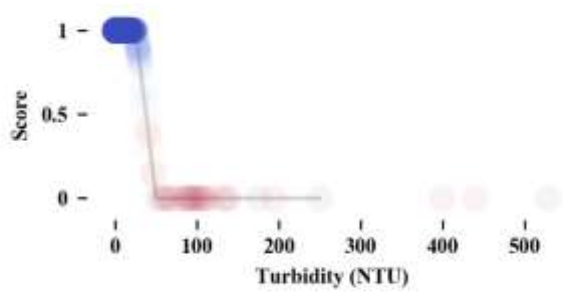

Figure 13: Scoring curve for Turbidity measurements with 2010-2018 data points shown along the curve. Scores range from 1 (Good) to 0 (Bad).

Turbidity levels, as shown in Figure 13, must be below 25 NTU for non-trout inhabiting streams and less than 50 NTU for non-trout inhabiting lakes.

Status and Trends

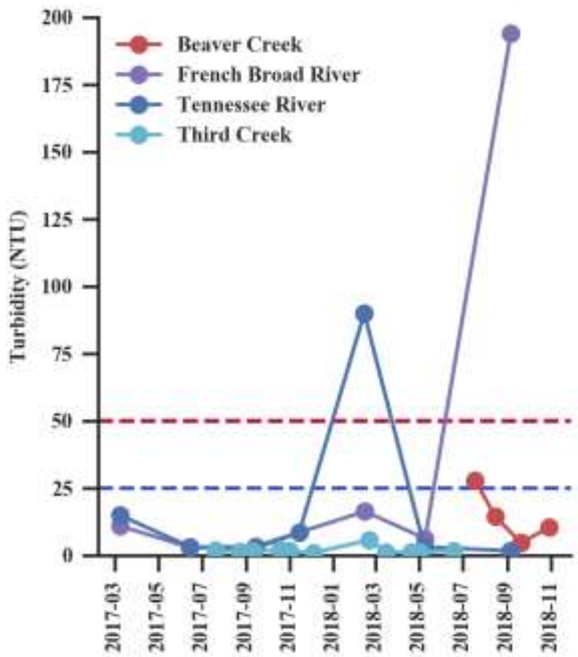

Figure 14: Time series of Turbidity for select waterways *in Knox County.*

Figure 14 is a time series of the turbidity levels measured in four separate water bodies. Generally, the turbidity levels are compliant; however, instances within the timeline cause the turbidity levels to spike. This time dependence makes finding a trend very difficult. These spikes can occur after storm events, when new construction work is taking place nearby in the watershed, or when other events cause the stirring of particulates in the water. Figure 14 shows that the spikes are rapid, meaning that the solids have settled. The settling of suspended solids may be a good thing in removing the material from affecting fish and light penetration, but the resettling of solids on the bed of a water body can cause issues as well. When the solids resettle habitats can be drastically changed, and small organisms and fish eggs can suffocate. Naturally occurring causes of solids being suspended in a waterbody (heavy storms) cannot be avoided but minimizing the external disturbances by adhering to stormwater regulations, protecting the banks, and minimizing impact from urbanization is very important to maintain a healthy water system.

Actions and Needs

The waterways in the Knox County region are generally in compliance with standardized turbidity levels according to the current framework. However, sediment loading occurs in bursts during storms and large flow periods. The regulations and framework do not adequately assess the impacts of short-term spikes. More frequent measurements and measurements during rain events would enable better assessment of sediment problems.

Conclusions

Data collected over the last nine years show that the waterways in Knox county comply with Tennessee standards. The occasional heavy rain or storm creates spikes in turbidity values that are unavoidable. Mitigation measures are not suggested for Knox county; however, the continuation of good practices such as stormwater drainage, proper construction regulations, and improvements to banks/riparian buffers will minimize the number of disturbances in Tennessee waterways, protecting aquatic life and keeping the water healthy.

Physical Properties

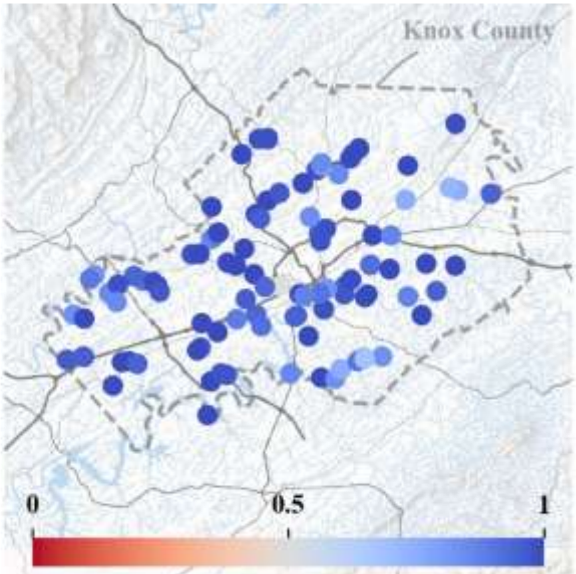

Figure 15: Map of the pH scores in Knox County. The absence of red markers indicates satisfactory pH levels across the monitoring stations. Blue markers indicate stations reporting standard pH values (6-9 pH) on average from 2010-2018.

Indicator Description

The physical indicator is a combination of physical properties including pH and temperature. These properties have an acute effect on the organisms that live in the streams. Small changes in these properties can have significant impacts.

Temperature impacts both the chemical and biological characteristics of a waterway. It can affect the dissolved oxygen level, metabolic rates of aquatic organisms, photosynthesis of aquatic plants, and the sensitivity of these organisms to parasites and disease. Changes in the temperature of waterways often result from urbanization around streams. The cutting of vegetation from the banks of waterways can raise the temperature by reducing shading. Stream temperature may be impacted further if impervious surfaces, like asphalt, replace vegetation, which also increases stormwater runoff. The warming of the waterway will greatly affect the ability of the water to hold dissolved oxygen. The warmer the water, the less ability it has to hold DO. The less DO in a waterway the less likely the biological organisms in the stream can survive. Our source recorded data in degrees Celsius from sampling stations throughout the region.

The pH in most streams is neutral to slightly basic with a pH of 6.5 to 8.5. If the stream has a pH less than 5.5, it may be too acidic for fish to survive in, while a pH higher than 8.5 may be too basic. A change in pH can also affect aquatic life indirectly by altering other aspects of water chemistry. An example being, low pH levels increasing the solubility of certain heavy metals. Increased solubility allows the metals to be more easily absorbed by organisms in the waterway. Sources of change in pH can be pollution or stormwater runoff. As rain runs over impervious surfaces, they can pick up chemicals and carry them into waterways. pH can be measured using digital pH meters or indicator paper at gaging stations.

Desired Condition

The temperature in a stream can vary widely with the season and the location of the waterway due to differences in the ambient temperature around the waterway. To mitigate the lack of a precise temperature range, regulators also limit the change in temperature from station to station. The maximum change prescribed for a water waterway is 3°C relative to an upstream control point. The absolute maximum temperature recommendation is 30.5°C for all streams and 20.0°C for trout streams.

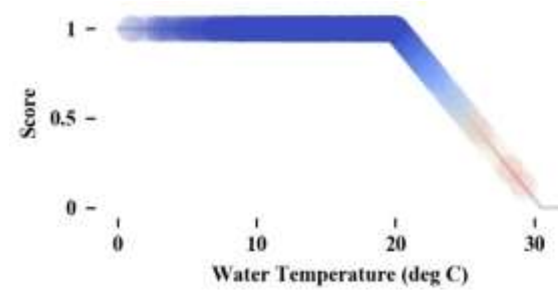

Figure 16: Scoring curve for Water Temperature *measurements with 2010-2018 data points shown along the curve. Scores range from 1 (Good) to 0 (Bad).*

pH is simpler to quantify as the value must be between 6 and 9 to limit harmful effects on biological organisms in the stream.

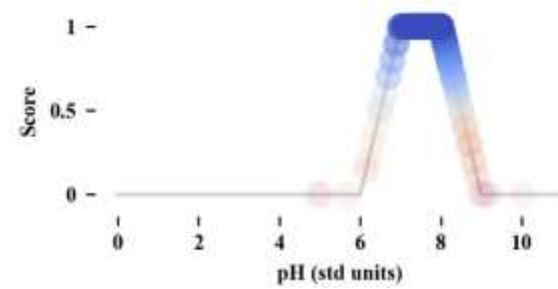

Figure 17: Scoring curve for pH *measurements with 2010-2018 data points shown along the curve. Scores range from 1 (Good) to 0 (Bad).*

Status and Trends

As we can see from Figure 17 the waterways in Knox county almost all measurements fall within the desired limits for pH between 7 and 8. The waterway temperatures in Knox county all fall below the

30.5°C maximum limit. This framework did not track the temperature differences between upstream and downstream stations, because this requires data from similar locations and times, which were not available.

The French Broad river exhibited an acidic spike in pH during 2011. According to Tutweiler and Clark (2011), TDEC attributed these low pH levels to acid rain in the area. Despite this one instance, pH and temperature levels look normal on average with this framework.

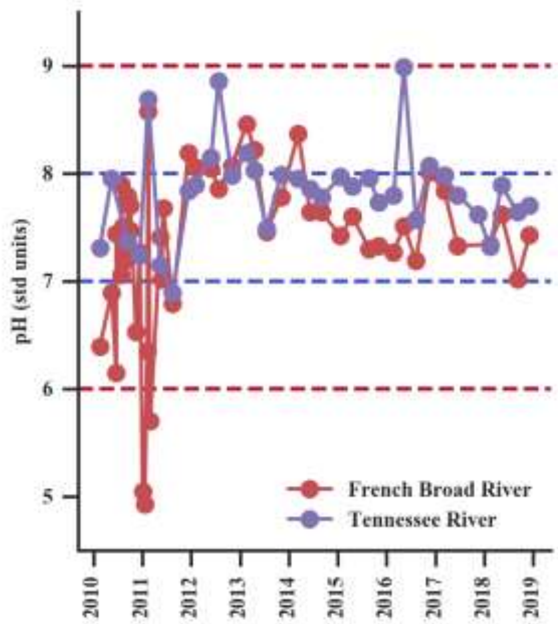

Figure 18: Time series of pH from the French Broad and Tennessee Rivers.

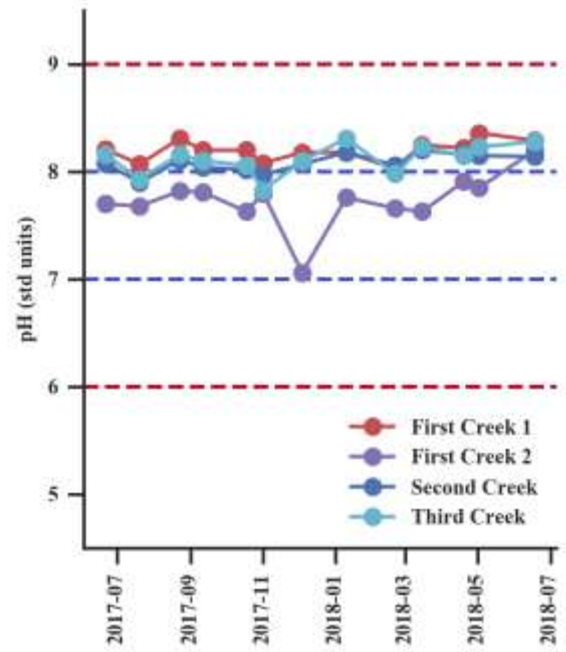

Figure 19: Time series of pH for *three* streams *near downtown* Knoxville.

Actions and Needs

Although the data trends show that the measured waterways within Knox county are all within the correct ranges for pH, and below the threshold for maximum temperature it does not mean that the waterways are without impairment. There is a significant challenge involved with the consistent monitoring of a waterway to ensure that the temperature change does not exceed 3°C. Urban areas drastically affect water temperature. The vast amounts of impervious surfaces and the lack of tree cover can cause significant fluctuations in temperature from direct sun exposure. Riparian buffers increase the amount of tree cover and can successfully regulate natural water temperatures.

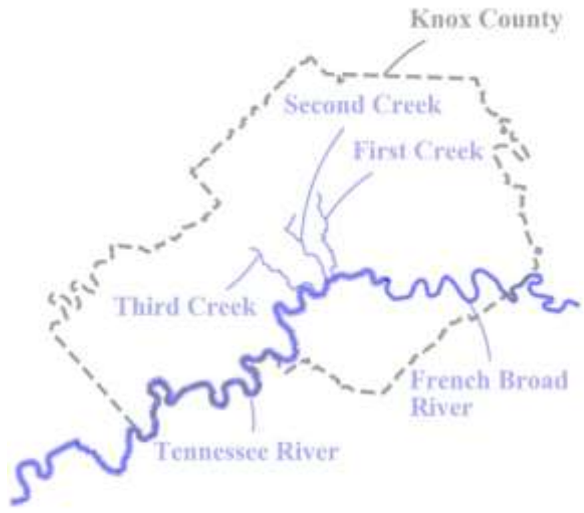

Figure 20: Map of select waterways in Knox County.

This strategy also positively affects the pH of waterways as it reduces the concentration of contaminants entering the waterway from flow across the impervious surface. This allows the soil and vegetation to mediate the impact of urban areas on the streams.

Conclusions

Knox County is compliant on average with regards to the pH and temperature. Urban streams are typically susceptible to pH and temperature fluctuations if not regulated properly. While these indicators are not directly out of compliance, they may have joint impacts on other indicators, like bacteria and heavy metal contamination. Mitigation investment on these indicators is not suggested, but improved measurement frequency and improvements to the framework could better highlight issues.

Nutrients

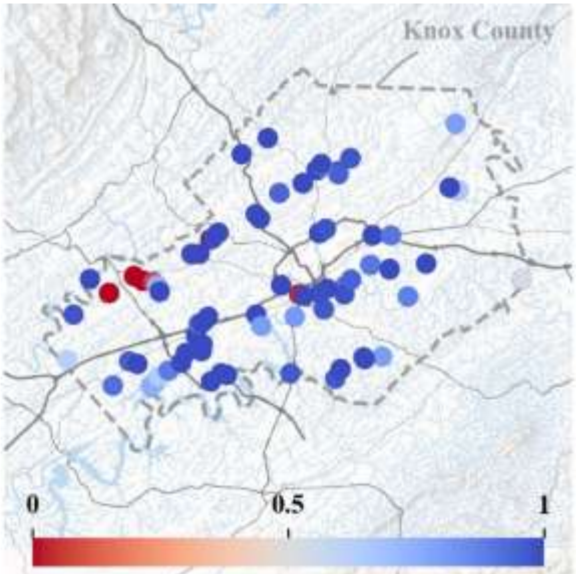

Figure 21: Map of the Phosphorus scores in Knox County. Dark red markers indicate stations reporting higher than standard concentrations (0.10 mg/L) on average from 2010-2018.

Indicator Description

Nutrients, such as nitrogen and phosphorus, are essential to plants and animals in a water body. Nitrogen is an essential nutrient that is required by all plants and animals. In its molecular form, nitrogen is not useful to most aquatic plants. Instead, these nitrogen forms can be harmful, so organisms must convert them to beneficial forms. Ammonia ($NH3$) is one of these molecular forms and may be taken up by plants or oxidized by bacteria into nitrate ($NO3^-$) or nitrite ($NO2$). Total Kjeldahl nitrogen (TKN), the most often reported measurement of nitrogen, is the sum of organic nitrogen, ammonia ($NH3$), and ammonium ($NH4^+$) in the chemical analysis of water.

The nitrogen cycle in waterways will turn the waste from fish into ammonia. Bacteria will then convert the ammonia into bioavailable nitrate that can be used by aquatic plant life for growth. If the TKN exceeds a certain level, this process can become unbalanced leading to rapid growth in aquatic plant life and algal blooms. These large masses of algae can remove many vital nutrients, limit light penetration into the water, and even clog dam intakes and other manmade structures.

Phosphorus also plays a crucial role in plant and animal growth and can enter a stream naturally through erosion of rocks or mineral deposits. At the same time, too much phosphorus can cause dissolved oxygen depletion and algal blooms. Significant contributors to phosphorus levels in waterways are agricultural runoff and bank erosion. Phosphorus is used heavily in fertilizers on farms, which can flow into water bodies through rain runoff or soil transport. Phosphorus tends to attach to the soil, meaning that phosphorus can also enter water bodies through sedimentation and the destruction of water banks.

Both nitrogen and phosphorous in large quantities can over stimulate plant growth and cause things like algal blooms. When this happens, the organisms use up the dissolved oxygen in the water. A water body impacted by excessive nutrients can sometimes be identified by the appearance of a bright green film along the top or around the edges where algae growth has increased. The decline in oxygen levels beneath this filmy layer, resulting from too many nutrients in the water, can endanger aquatic life. Therefore, it is essential to keep nutrient levels balanced in a water body for the ecosystem to thrive and stay healthy.

Desired Condition

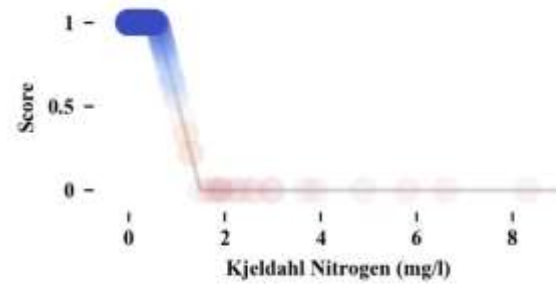

Figure 22: Scoring curve for Kjeldahl Nitrogen measurements with 2010-2018 data points shown along the curve. Scores range from 1 (Good) to 0 (Bad).

TKN above levels of 0.591 mg/L have been shown to cause adverse effects on the aquatic life in streams. Excess levels can cause a harmful nitrogen cycle that leads to algal blooms.

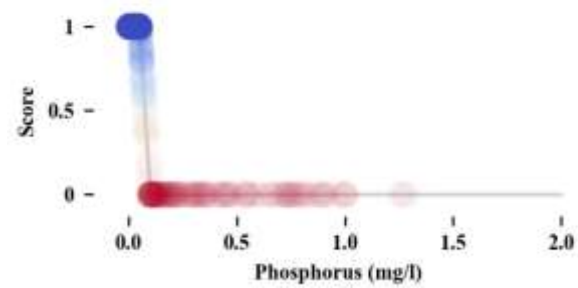

Figure 23: Scoring curve for Phosphorus measurements with 2010-2018 data points shown along the curve. Scores range from 1 (Good) to 0 (Bad).

Measurements of phosphorus can be much less than 1 mg/L (0.025 mg/L for reservoirs) making it difficult to measure. For this study, phosphorus will be considered non-compliant when less than or equal to 0.1 mg/L. Limiting phosphorus should prevent algal blooms, plant decay, and the decrease in dissolved oxygen.

Status and Trends

Figure 24: Google Earth image of waste treatment plant between two measurement points on Beaver Creek. The downstream point (red dot) is out of compliance whereas the upstream point (blue dot) complies with Phosphorus requirements. The waste treatment plant outfall (white circle) may release emissions from a potential algal growth in the treatment plant (red circle).

Figure 24 illustrates a clear comparison between two points on the same water body. The upstream measurement (blue dot) complies with phosphorus standards; however, the measurement location directly downstream is out of compliance with the phosphorus standards. This trend could be explained by the water treatment plant situated directly between the two points. According to the Google Earth image in Figure 24, the discharge from the water treatment plant, indicated by a white circle, is directly downstream of the in-compliance point and directly upstream of the out-of-compliance point. This trend implies that the water treatment plant has discharged phosphorus into the water body. Further evidence that this may be the case is the algal growth indicated by the red circle located within the boundaries of the water treatment plant.

The values of phosphorus measured at the red dot in Figure 24 are 5-8 times higher than the lowest possible compliant value of 0.1 mg/L, and 12-20 times higher than the compliant point upstream of the plant. Points downstream of the non-compliant point are out of compliance as well.

As seen from Figure 22, the dark blue points on the trend show the levels of Kjeldahl nitrogen that fall well within the standard water quality standards laid out in this document. The majority of the select streams in Knoxville fall below the threshold of 0.591 mg/L and thus are operating in the correct phase of the nitrogen cycle.

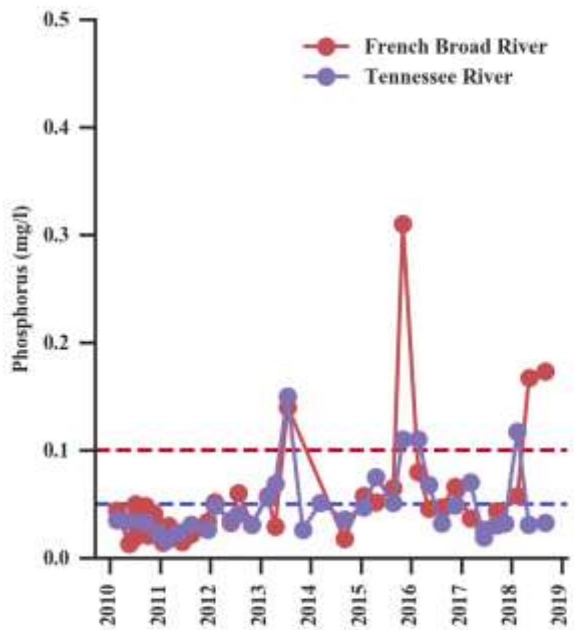

Figure 25: Time series of Phosphorus concentrations from the French Broad and Tennessee Rivers.

Majority of streams within Knox county fall are compliant in terms of phosphorus; however, some locations such as Beaver Creek need to be properly monitored, and efforts need to be made to bring phosphorus levels below the compliant threshold of 1.0 mg/L.

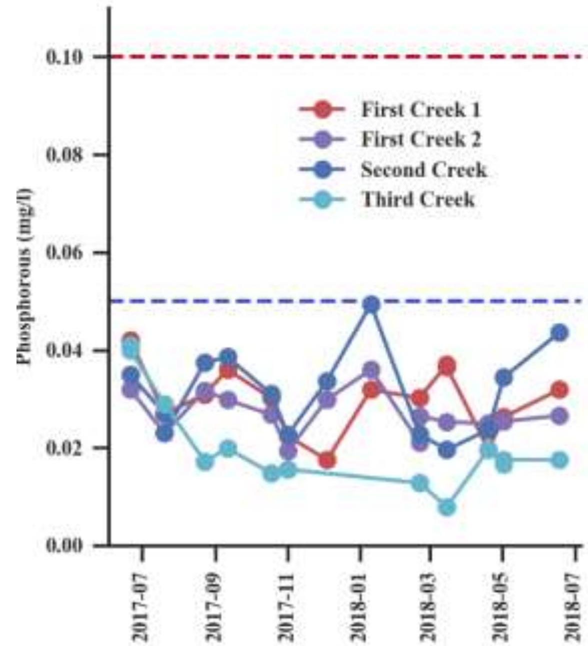

Figure 26: Time series of Phosphorus concentrations from three streams near downtown Knoxville.

Actions and Needs

Kjeldahl Nitrogen shows consistent compliance throughout Knox county and does not require any actions to be made. Phosphorus is in compliance for a majority of streams; however, actions should be made to reduce the high levels of phosphorous in the waterways that are well below compliance. A reduction plan should be made that would make an effort to reduce phosphorous at the point of entry. Figure 24 demonstrates a scenario where the increase in phosphorous is most likely coming from the exhaust of a water treatment plan. In order to reduce the amount of phosphorus reaching the waterway, turf filters can be placed around the exhaust area closest to the point of entrance into Beaver Creek. Also, increasing the native vegetation near the exhaust area would buffer excess phosphorous from reaching the stream. If cleaning of the waterway is necessary then biological (waste activated sludge) or chemical (metal salts) can be used to reduce the phosphorous in the stream, but this is not a long-term solution for streams, and the source of the phosphorus must be reduced first.

Conclusions

Kjeldahl nitrogen shows great compliance with the water quality standards laid out in this document. The data in Figure 20 shows that the Kjeldahl nitrogen data collected for Knox county waterways are well below the non-compliant standard of 1.5 mg/L and consistently below the 0.591 mg/L requirement.

Phosphorous shows compliance on average with the water quality standards, but some streams such as Beaver Creek suffer from an increase in phosphorus due to what seems like exhaust from plants nearby. Actions should be made to decrease the amount of phosphorous in the streams through long term solutions that limit the amount of phosphorous that reaches the waterway and/or short-term solutions such as chemical and biological means.

Additional Maps

Nitrogen

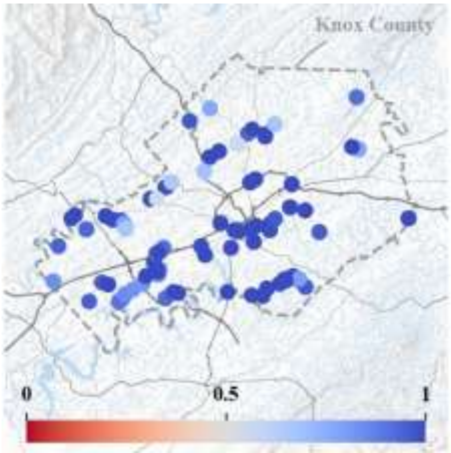

Figure 27: Map of the Nitrogen scores in Knox County. The absence of red markers indicate that stations report satisfactory nitrogen levels (<0.591 mg/L) on average from 2010-2018.

Water Temperature

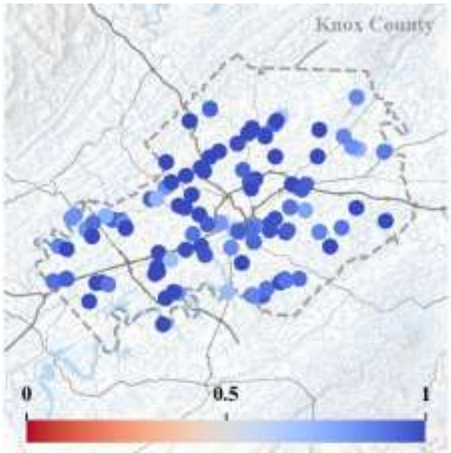

Figure 28: Map of the Water Temperature scores in Knox County. The absence of red markers indicates that stations report satisfactory temperature levels (<30.0°C) on average from 2010-2018.

Total Dissolved Solids

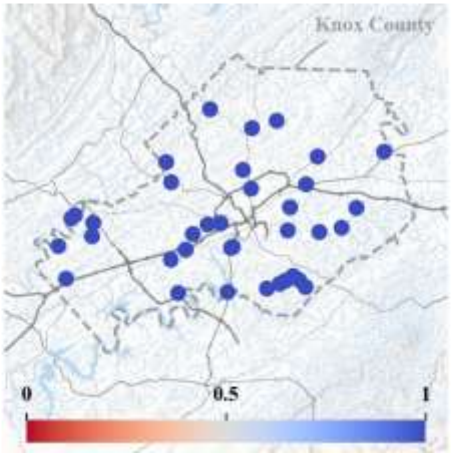

Figure 29: Map of Total Dissolved Solids scores in Knox County. The absence of red markers indicates that stations report satisfactory TDS levels (<500 mg/L) on average from 2010-2018.

Total Suspended Solids

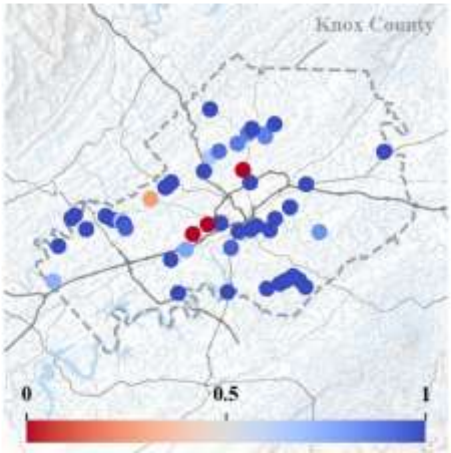

Figure 30: Map of Total Suspended Solids scores in Knox County. Dark red markers indicate stations reporting higher than standard TSS levels (>80 mg/L) on average from 2010-2018.

Methodology

We designed a data collection and processing workflow to help answer a simple question: "What is the water quality where I live?" We hope that by sharing the tool we developed, along with an interpretation of water quality where we applied the tool (Knox County, Tennessee), others can use the tool to learn about water quality where they live. We envision this tool as a starting point—to be further developed and refined by others who wish to contribute improvements. For this reason, we shared all the code for this project on GitHub[1].

Data Collection

Water quality measurements were gathered from the National Water Quality Monitoring Council website using a location filter for Knox County. The sample results (narrow) option provides a simplified report of measurements. Also, the site data only option reports the location of each measurement station.

Data Analysis

The cleaning process is summarized as follows:

- Clean the data by removing null values, stripping trailing whitespace, remove non-numeric values, and reformat the date
- Create a set of aliases and units for each metric and group by indicator
- Create and apply a threshold function to score each measurement
- Match the gauging station ID with its latitude and longitude

Data Visualization

We developed three figure types to visualize the scores across time and space, as well as within each indicator (i.e., a plot of score versus result values overlain on the ranking line). Maps of the indicators across space show the average score at each monitoring location over a specified measuring period. The maps can quickly identify spatial trends in the indicators, helping to identify potential local influences. Time series show indicator result values over time for selected monitoring locations, helping to identify local trends over time.

We published all the scores for each indicator online, along with a brief description and interpretation.

Online viewer[2]

Next Steps

- Create a web scraping function to automate the data collection process
- Connect the visualization and data analysis process to create automatic reports
- Repeat this framework on other scales and in other locations
- Add functionality for other indicators including toxins
- Create a separate database to track aliases, units, and metrics
- Account for time of measurement in rating

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Tutweiler, M., & Clark, P. (2011). *French Broad River Basinwide Water Quality Plan*. Raleigh, NC

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1 https://github.com/ColinSasthav/Water_Quality_Tool

2 https://myutk.maps.arcgis.com/apps/MapSeries/index.html?appid=78429bbd4be947489c6fb36f0baaa48b

Appendix

Table 1: Metric list descriptions and scoring rationale

Metric	Unit	Description	Source
Dissolved Oxygen	mg/L	Dissolved should not be less than: 5mg/L for Fish and Aquatic Life Streams 6mg/L for Trout Streams 8mg/L for Naturally Reproducing Trout Streams	(Link) Tennessee State Standards in Effect for Clean Water Act Purposes Tennessee Department of Environment and Conservation (TDEC) Chapter 1200-4-3 General Water Quality Criteria
E. Coli.	Colony Forming Units (CFU)/100mL	For a mean sample over 30 days, concentration of the E. Coli group should not exceed: 630 CFU/100mL in Domestic Water Supply or Fish and Aquatic Life Streams 126 CFU/100mL in Recreation Streams	(Link) Tennessee State Standards in Effect for Clean Water Act Purposes Tennessee Department of Environment and Conservation (TDEC) Chapter 1200-4-3 General Water Quality Criteria
pH	Standard Units	The pH value shall lie within the range of 6.0 to 9.0 and shall not fluctuate more than 1.0 unit in this range over a period of 24 hours.	(Link) Tennessee State Standards in Effect for Clean Water Act Purposes Tennessee Department of Environment and Conservation (TDEC) Chapter 1200-4-3 General Water Quality Criteria
Temperature	Degrees Celsius	The maximum water temperature change shall not exceed 3°C relative to an upstream control point. The maximum rate of change shall not exceed 2°C per hour. The temperature of the water shall not exceed 20°C for Trout Streams and Naturally Reproducing Trout Streams 30.5°C for all other classifications	(Link) Tennessee State Standards in Effect for Clean Water Act Purposes Tennessee Department of Environment and Conservation (TDEC) Chapter 1200-4-3 General Water Quality Criteria
Total Dissolved Solids	mg/L	The total dissolved solids shall at no time exceed 500 mg/L	(Link) Tennessee State Standards in Effect for Clean Water Act Purposes Tennessee Department of Environment and Conservation (TDEC) Chapter 1200-4-3 General Water Quality Criteria

Turbidity	NTU (Nephelometric Turbidity Units)	Turbidity in receiving water should not exceed: 10 NTU in Trout Streams 25 NTU in Non-Trout Streams 50 NTU in Non-Trout Lakes	(Link) North Carolina State Standards in Effect for Clean Water Act Purposes Sections .0100-.0231, Classifications and Water Quality Standards Applicable to Surface Waters and Wetlands of North Carolina
Phosphorus	mg/L	Phosphorus concentrations should not exceed: 0.1 mg/L for streams which do not empty into reservoirs 0.05 mg/L for streams discharging into reservoirs 0.025 mg/L for reservoirs	(Link) Water Research Center US EPA (1986)
Kjeldahl Nitrogen	mg/L	The maximum Total Kjeldahl Nitrogen should be 0.591 mg/L.	(Link) Indiana Department of Environmental Management (IDEM) IDEM Watershed Management Plan Water Quality Targets U.S. EPA Recommendation
Total Suspended Solids	mg/L	The maximum concentration of Total Dissolved Solids should be 46 mg/L. Concentrations between 25 mg/L and 80 mg/L can reduce fish concentrations (Waters, T.F., 1995).	(Link) Indiana Department of Environmental Management (IDEM) IDEM Watershed Management Plan Water Quality Targets Minnesota TMDL criteria for protection of fish/macroinvertebrate health
Conductivity	umho/cm (Microhmos per centimeter)	Specific Conductance not be increased more than 50% above background or to 1275 umho/cm (whichever is greater) for Class I Streams and shall not exceed 4000 umho/cm for Class V Streams.	(Link) Florida State Standards in Effect for Clean Water Act Purposes Chapter 62-302: Water Quality Standards