Assessment of water quality of four Mahoning River Sub-Watersheds, Northeast Ohio

By

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Abstract

The water quality of the historically industrial Mahoning River continues to be impacted by non-point pollution sources from the watershed. We evaluated the current surface water quality of four important Mahoning River sub-watersheds: Meander Creek, Crab Creek, Lower Mosquito Creek, and Yellow Creek using the National Sanitation Foundation water quality index (NSF-WQI). Water quality parameters measured include, temperature, dissolved oxygen, pH, ammonia, soluble reactive phosphates, total phosphorus**,** nitrate-nitrogen, total suspended solids, volatile solids, total dissolved solids, total coliform, *Escherichia coli* and biochemical oxygen demand. All of the samples were taken during the summer at low flow conditions. NSF-WQI of four sub-watersheds are compared along with their land cover types identified as residential, commercial, industrial, forested, and agricultural areas. The NSF-WQI for Lower Mosquito Creek was found to be the highest at 70 and Crab Creek having the lowest at 64.5, respectively being in good and medium according to NSF-WQI range (0-100). Also, the Post-hoc Tukey HSD test indicates Crab Creek is statistically significantly lower than Lower Mosquito Creek. Land cover type of residential in Lower Mosquito Creek had the highest NSF-WQI at 72 and agriculture land cover in Crab Creek had the lowest at 53, respectively being in good and medium NSF-WQI range. When comparing NSF-WQI of overall land cover types, residential had the highest at 70 and agriculture had the lowest at 64, while forest and industrial were same at 67, respectively being in good and rest in medium NSF-WQI range. Tukey HSD test indicates the NSF-WQI for residential land cover is statistically significantly higher than agriculture land cover. The principal component analysis depicts a weak correlation with water variables and NSF-WQI of the sub-watersheds.

Keywords: National Sanitation Foundation, Water quality index, principal component analysis, Land cover, Water parameters, Mahoning River watershed

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I. Chapter: Introduction

Water is essential to sustain human life. Throughout history, human settlements and civilizations have developed around plentiful supplies of water. In modern times, tremendous demands have been placed on our water resources for drinking, cleaning, agriculture, industrial production, etc. Even though these uses are necessary to sustain present communities, it's no way the only use of the water resources. The lakes, streams, estuaries, and oceans of the planet also serve as receiving waters for wastewater discharges, routes of the transportation, sources of food, sites for recreation and an amazing diversity for plants and animals. Excessive and unregulated human activity close to the waterways can quickly deteriorate the water quality and meddle with the wanted use of water and the natural aquatic habitat. Surface water chemistry is controlled by many natural and anthropogenic factors. These factors can be either spatially diffused or concentrated (Bahar et al., 2008). In United states, numerous environmental regulations have been introduced since the 1970's to help save the water resources. This has resulted in meaningful improvements in the water quality of numerous waterways. However, countless others stay in unpleasant conditions, or carryon to deteriorate as human activity in the surrounding area increases. Activities happening on the surrounding land is directly responsible for the quality of the waterbodies. For example, forestland converted to agricultural or urban areas may have enhanced erosion, runoff, and flooding. Anthropogenic activities interacts with the land use and land cover which in turn affects the water quality of watersheds (Chu et al., 2013).

A watershed is an area of land that drains all precipitation into a stream or river. They are also known as drainage basin or catchment. Bigger watersheds can have many smaller watersheds within them. Watersheds are necessary because the streamflow and the water quality of a river are impacted by the activity, anthropogenic or not, occurring on the land area elevated to the river-outflow point. Industrial, residential, and forested land can all impact the water quality through changes in land surface characteristics which affect runoff volume, water temperature, amount of pollution, and nutrient loading to the streams. Nutrients can increase algal production causing algal blooms resulting in the decrease dissolved oxygen concentrations in water bodies (Ding et al., 2015). Surface waters can be polluted due to many human activities such as producing electricity, growing food etc. During the rain, water flows over the roadways, parking lots and other impervious surfaces which then carries oil leaks, animal waste, chemicals, and other open trash. These contaminants can then seep into the groundwater and then find its way into the lakes and rivers which is eventually brought down into the ocean. Many large dead zones are formed in the ocean due to the nutrients present in the non-point pollution (NOAA, 2017).

The current surface water quality of four sub-watersheds: Yellow Creek, Meander Creek, Crab Creek, and Lower Mosquito Creek in the Mahoning River Watershed were assessed using the National Sanitation Foundation Water Quality Index (NSF-WQI). The NSF-WQI is one of the most effective tools to communicate information on the quality of water to concerned citizens, stakeholders, and policy makers. Thus, it becomes an important parameter for the assessment and management of surface water (Bouslah et al., 2017).

Research Hypotheses

The water quality as evaluated by the NSF-WQI will be only modestly linked to patterns of land use immediately adjacent to sampling sites, and in the watershed upstream. However, expect that influence of land cover and use will be manifest in planned future studies of these Mahoning River tributaries under high-flow post-precipitation events that should generate large amounts of runoff from the surroundings.

Objectives

- To determine the water quality parameters to establish baseline conditions (temperature, DO, pH, Ammonia, soluble reactive phosphorous, soluble, and total phosphorous**,** nitrate-nitrogen, TSS, VSS, TDS, Total Coliform, *E. coli* and BOD).
- To determine NSF-WQI of the sub-watersheds and each of their land cover types and comparing them with one another.

II. Chapter: Literature Review

The Mahoning River watershed in northeastern Ohio has historically been degraded by human activities primarily in the Lower Mahoning River watershed. Prior to and through the early 1980s, the steel industry thrived in the Mahoning River Valley. Wastewater from steel production contained a variety of pollutants including heavy metals, phenols, polycyclic aromatic hydrocarbons, oil, and heat (Stoeckel and Covert 2002). These legacy pollutants collected in the river disrupting aquatic ecosystems. In addition, reports from the Ohio Environmental Protection Agency (OEPA) from the 1980s indicate that wastewater treatment plants in the Mahoning River watershed used only primary treatment. Primary treatment mainly removes material that can physically be separated through sedimentation or floatation, dissolved material is discharged into surface water. Chemical water-quality concerns were reported before 1994 due to incomplete treatment of the sewage that caused low dissolved oxygen concentrations (often less than 4 mg/L) and high ammonium concentrations (up to about 3 mg/L)(Stoeckel & Covert, 2002). Improvements were noticed by Ohio EPA in water-quality standards for dissolved oxygen and ammonium concentrations because most of the wastewater treatment plants started using secondary treatment in the late 1980's. Even after the significant improvements noted in the wastewater treatment, the Mahoning River's biological water quality still remained above primary-contact recreation standards from 1973–93 (Stoeckel & Covert, 2002).

According to the United States Environmental Protection Agency (EPA) any contaminant that enters the environment from an easily identified and confined place is known as point source pollution. Examples include smokestacks, discharge pipes, and drainage ditches and are mostly regulated through permitting. The pollutants which are released from a wider area are known as non-point source pollution and they are also harder to identify. The Lower Mahoning River watershed has been impacted by both point and non-point sources of pollution. Human development has two major impacts on natural areas: the clearing of natural vegetation and the draining of wetlands. Whether the proposed land cover is a residential subdivision, industrial park, retail area, or cornfield, the first step of development is almost always the same. Most or all of the land area is cleared of forests, meadows, and other vegetation. The loss of natural lands, including wetlands and riparian buffers or riparian zones, is the leading cause of excess nutrients reaching waterways (Richman, 2012). Land immediately adjacent to a waterbody is called the riparian buffer or the riparian zone. A riparian zone, a type of wildlife generally refers only to freshwater or mildly brackish habitats surrounded by vegetation and is usually found along the banks of a river, stream, or other water sources. They are also present around springs, waterfalls, and other running water bodies. Rivers which move through bare rock, are not considered riparian zones (Mayntz, 2019). When riparian zones are disturbed, decreased, or removed, storm water runoff increases as well as nutrient loads, and there is a loss in the land's ability to filter the water before entering the surface water. Additionally, when riparian buffers are lost, it also results in erosion and increase sedimentation. Algae blooms is another problem that causes the blockage of sunlight, deplete dissolved oxygen, hinder the growth of other aquatic plants. They occur when there is an excess amount of nutrients coming from farm fertilizers, septic systems, and animal wastes which can adversely affect recreational activities (Richman, 2012). Buildings and agriculture that extends to the edge of waterbodies destroy natural buffers and filtering mechanisms, allowing runoff to carry pollutants and sediments straight into rivers, lakes, and streams.

The increase of impervious surfaces is also a major problem associated with human development. Any kind of surface that stops rainwater from seeping into the ground is known as an impervious surface such as roads, parking lots, sidewalks, and rooftops etc. General trends indicate that as populations increase so do impervious surfaces because of additional roads, houses, and parking lots. Impervious surfaces and urban drainage systems acts as a catalyst in accelerating the transportation of pollutants from the watershed to rivers, lakes, and estuaries. The fecal coliform bacteria and nutrients are known to be the most concerning pollutants for the estuaries and their freshwater tributaries (NHEP, 2007). The amounts of fecal coliform bacteria are elevated during the rainstorms and are washed into the estuaries which leads to a temporary halt of the harvesting of shellfish. Waterbodies also receive other toxic contaminants such as metals and oil leaks from automobiles, businesses etc. as they are washed off impervious surfaces during the rainstorms. (NHEP, 2007).

The National Sanitation Foundation WQI (NSF-WQI)

Brown et al. (1970), developed the NSF-WQI for the US National Sanitation Foundation. The NSF-WQI is based on nine parameters; dissolved oxygen (DO), fecal coliform (FC), pH, 5-day Biochemical oxygen demand (BOD), temperature deviation, nitrate-nitrogen (NO_3-N), total phosphorus (TP), turbidity, and total suspended solids (TSS). These parameters were selected using the Delphi technique (Uddin et al., 2021). This method provided a group of experts with numerous rounds of questionnaires, and their answers were recorded and shared with the other members of the group while keeping their responses as anonymous. Depending on how they view the group response, they are allowed to change their answers in each round. After numerous rounds of questions asked to the group, the panel reveals what the group thinks as a whole. Consensus is reached which is hence known as a Delphi method (Twin, 2021). The NSF index parameters are divided into four groups: (1) the physical (temperature, turbidity, and total solids), (2) the chemical (pH and dissolved oxygen), (3) microbiological (fecal coliforms and biochemical oxygen demand), and (4) nutrients (total phosphorous and nitrate).

$$WQI = \sum_i^n Q_i w_i$$

Equation 1

Where Q_i is the sub-index value for parameter *i*, w_i is the corresponding parameter weight value and *n* is the total number of parameters.

Sub index value also known as the Q- value is a component of the water quality index (WQI) (Eq. 1). In general, to obtain the sub-index values, the index developers establish rating curves. The panelists were asked to produce a rating curve for each of the nine analytes with levels of water quality from 0 to 100 indicated on the y-axis of each graph whilst increasing levels of the particular analyte were indicated on the x-axis (Figure II-1). Brown et al. (1970), then averaged all the curves to produce a single line for each analyte (Wills & Irvine, 1996) (Appendix I).

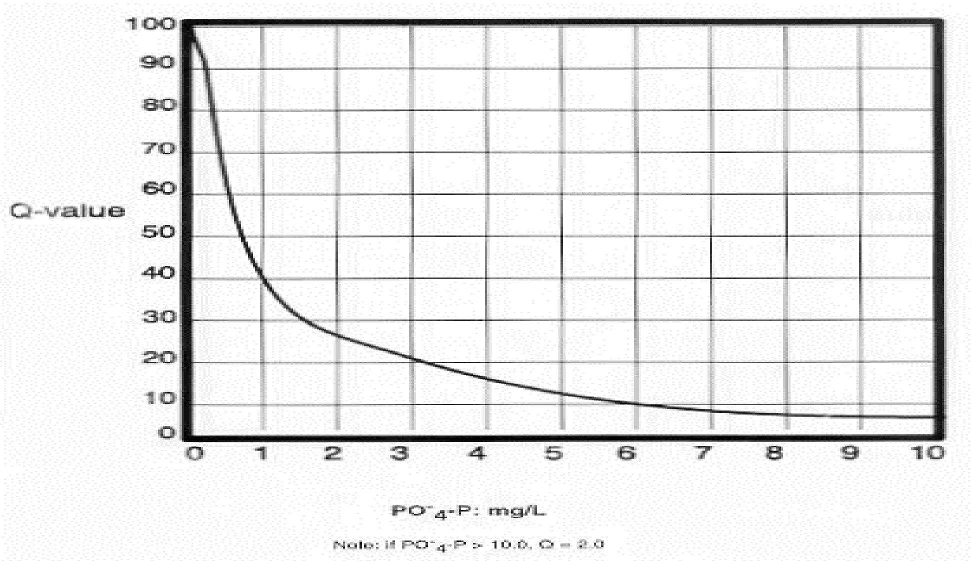


Figure II-1. Final phosphate rating curve for determining sub index value or Q to determine the National Sanitation Foundation – water quality index (Nasirian, 2007).

The parameter weight, w_i is another important component for equation 1. The Delphi method has been commonly used for summing up individual expert opinions to establish parameter weights for various WQIs. The water quality parameters required for the index were compared using a scale of 1 (highest) to 5 (lowest) by gathering the expert's responses. After calculating the arithmetic mean, the parameter that received the highest score was given a temporary weight of 1.0. The rest of the temporary weights were then attained by dividing the highest rating by the individual mean rating. The final weight is then achieved after each temporary weight was divided by the sum of all the temporary weights.

The NSF-WQI model uses unequal parameter weight values which sum to 1 (Table II-1). Several WQI models (e.g., Horton model, Scottish Research development Department model, NSF index – earlier version, House index, Malaysian and Dalmatian index models) employed a simple additive aggregation function. The original NSF weight values were obtained by employing an expert panel, but subsequent applications of the model have used modified weight values for evaluating surface water quality (Uddin et al., 2021) (Table II-1).

Table II-1. The original NSF-WQI model prescribed weight values.

Water Quality Weight Factor

Factors	Weight
Dissolved Oxygen	0.17
Fecal Coliform	0.16
pH	0.11
BOD	0.11
Temperature	0.10
Total phosphorous	0.10
Nitrates	0.10
Turbidity	0.08
Total Solids	0.07

WQI evaluation

The model outputs a WQI that ranges from 0 to 100. The results are separated into five water quality classes with 0 indicating the worst water quality and 100 indicating excellent water quality (Table II-2).

Table II-2. NSF water quality classes for Water Quality Index.

Range	Quality
90 – 100	Excellent
70 – 89	Good
50 – 69	Medium
25 – 49	Bad
0 – 24	Very Bad

Important water quality parameters

Biochemical oxygen demand

The biochemical oxygen demand (BOD) is a measure of the amount of food or organic material for bacteria that is found in water. Oxygen is reduced from the water when organic matter is consumed by bacteria for their respiration. The oxygen in water consumed by bacteria come from two sources: as a by-product of photosynthesis and diffusion from the atmosphere. As the amount of organic material pollution in water increases, the BOD increases. This increase in oxygen consumption and the organic material is degraded, resulting in lower dissolve oxygen in the water for other aquatic life. Uncontaminated surface water has BOD less than 5 mg/L (Standard methods; Baird et al., 2017).

Total Coliform and *E. Coli*

Coliform is a group of bacteria that can be found throughout our environment. Fecal Coliform and *Escherichia coli* are subgroups of the Total Coliform. They are usually found in the feces of warm-blooded animals and humans. The presence of *E. coli* doesn't necessarily mean they are dangerous, but they might indicate that the water have been exposed to other illness causing pathogens. The Ohio numerical criteria for the protection of recreation uses for *E.coli* bacteria is 1030 cfu/100mL for the maximum allowable concentration for recreation secondary contact and primary contact is 126 cfu/100 mL for a 90-day geometric mean and 410 cfu/100 mL for a statistical threshold (USEPA, 2012). CFU refers to "colony forming units", whereas MPN refers to "most probable number" (Lakna, 2018). The key difference between CFU and MPN is that CFU is calculated from the bacterial colonies growing on a solid agar plate while MPN is calculated from viable bacteria growing in a liquid medium (Samanthi, 2017).

Dissolved Oxygen

The dissolved oxygen is an important aspect for the aquatic habitat's survival in a waterbody. Adequate amounts of DO is required for the survival and breeding of the fish and other aquatic species. Low levels of dissolved oxygen in water is a serious concern and could also indicate presence of unwanted pollution causing contaminants in the waterbodies. About 12 parts of oxygen can dissolve in a million parts of water (12 mg/liter) at 7°C (Mesner & Geiger, 2010) as oxygen is usually not very soluble in water. In most cases waterbodies acquire oxygen in two ways: either it dissolves into water from contact with the atmosphere or is produced by plants during photosynthesis. Dissolved oxygen levels below 5 mg/liter stress many aquatic organisms.

Soluble Phosphate and Total Phosphate

Phosphates are chemical compounds derived from phosphoric acid. Phosphorus can be present in water in many forms including soluble phosphates and organic phosphates and are important for plant and animal growth. It is most commonly known as orthophosphate. Total phosphorus gives an estimate of the total amount of phosphorus potentially available in a given water supply (Gholizadeh et al., 2016). Phosphorous comes from agricultural fertilizers, manures, sewage, and industrial organic wastes (Gholizadeh et al., 2016). No mandates have been placed for presence of phosphorus compounds in water. Nevertheless, eutrophication is a major concern and to control that a guideline was put by EPA which states that total phosphate-phosphorous should not exceed 0.05 mg/L in a stream at a point where it enters a lake or reservoir and should not exceed 0.1 mg/L in streams that do not discharge directly into lakes or reservoirs (Litke, 1999). Cultural eutrophication occurs when there is an excess of nutrients in a lake or other body of water, due to anthropogenic activity which causes a dense growth of plant life or algae and resulting death of animal life from lack of oxygen.

Nitrates

Nitrates (NO_3^-) are a measure of the oxygen and nitrogen molecules. The ability of red blood cells to carry oxygen is jeopardized and is a serious health concern for humans as intestines can break nitrates down into nitrites (NO_2^-) and can also deteriorate fish health. According to Gholizadeh et al. (2016), the two main sources of nitrates in the watershed are wastes from livestock and nitrogen-based fertilizers. Because of these effects on humans and fish, water containing an excessive amount of nitrates is considered polluted water (Gholizadeh et al., 2016).

pH

The pH is the negative log of the molar hydrogen ion concentration. In simple terms pH level is a measure of the acid content $[H^+]$ of the water. Most forms of aquatic life tend to be very sensitive to pH. Water with a pH of 7 is considered neutral. If the pH is below 7, it is classified as acidic, while water with a pH greater than 7 is said to be alkaline or basic. The change in pH is influenced by different sources including carbonate forms (e.g., surrounding rocks), precipitation (e.g., acidic rain), mining discharges, and wastewater (Gholizadeh et al., 2016). The behavior of other chemicals in the water are also changed due to the pH which can in turn affect aquatic plants and animals. For example, ammonia in water can become more toxic as the pH becomes more basic as pH below 4 and above 11 can cause fish kills and only few aquatic species can survive in pH of water below 3 or above 11 (Mesner & Geiger, 2010).

Turbidity (tb)

It is a measure of how the light is scattered in the water due to presence of suspended matter. The appearance of water is cloudier with high turbidity. Plants and other aquatic organisms find it harder to survive if the turbidity is too high.

Temperature (T)

The water temperature plays a very vital role in maintaining and sustaining the overall health of a waterbody and the species residing in it. Aquatic organisms demand more oxygen as they require greater energy to survive if the water temperature rises. Algal blooms are also caused due to an exponential growth rate of plants if the temperature is beyond normal levels (Wai, 2003). The temperature changes seasonally but abundant amounts of warm or high temperature water being dumped into a pond, bay, or a river can cause thermal shock and can kill all aquatic organisms.

Total Dissolved Solids (TDS)

It is the measure of concentration of the dissolved solid particles such as salts, organic materials, or other toxic substances in a waterbody. Levels that are too high or too low may be of serious concern for the sustenance and health of the aquatic species. Waterbodies find TDS coming in them through many different places such as broken minute rock bits, run-off rainwater, leaves, silt, or plankton etc. Higher levels of total dissolved solids often disrupt osmotic regulation and harm aquatic species. Fertilization and egg development can be disrupted by high TDS. In addition, high dissolved salts can dehydrate the skin of aquatic animals, which can be fatal.

Electrical Conductivity (EC)

Electrical conductivity is the measure of concentration of dissolved solids in water. The conductivity of water increases with the increase in the concentration of ions. It is actually a measure of ionic process of a solution that enables it to transmit current. For e.g., pure water is not a good conductor of electricity but rather a good insulator as it contains minimal or no dissolved solids in it.

III. Chapter: Methodology

Mahoning River Watershed

The Mahoning River watershed, located in northeastern Ohio, drains a total of 2,801.13 square kilometers (Figure III-1). The Mahoning River watershed is divided into 2 sections: the upper more western section is a mixture of forest, hay, pasture lands, cultivated crops with some urban development, while the major municipalities, Youngstown, Warren, Alliance and Lordstown, are mostly in the lower, more eastern, section of the Mahoning River.

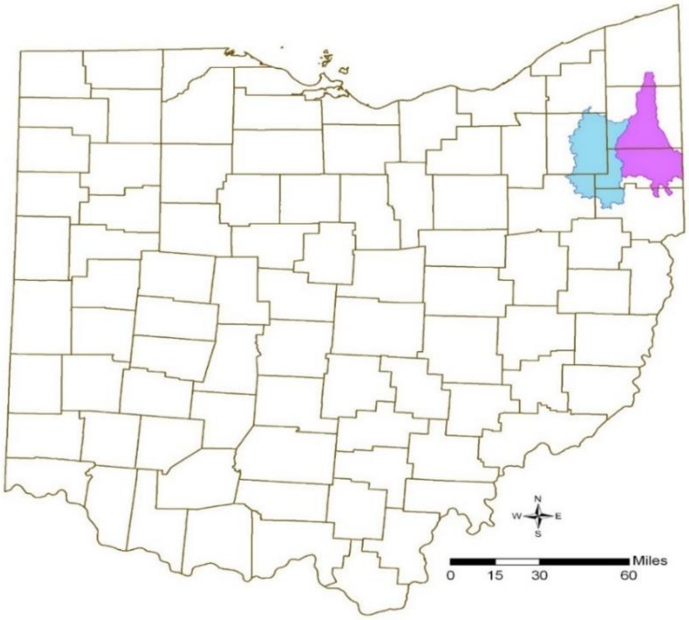
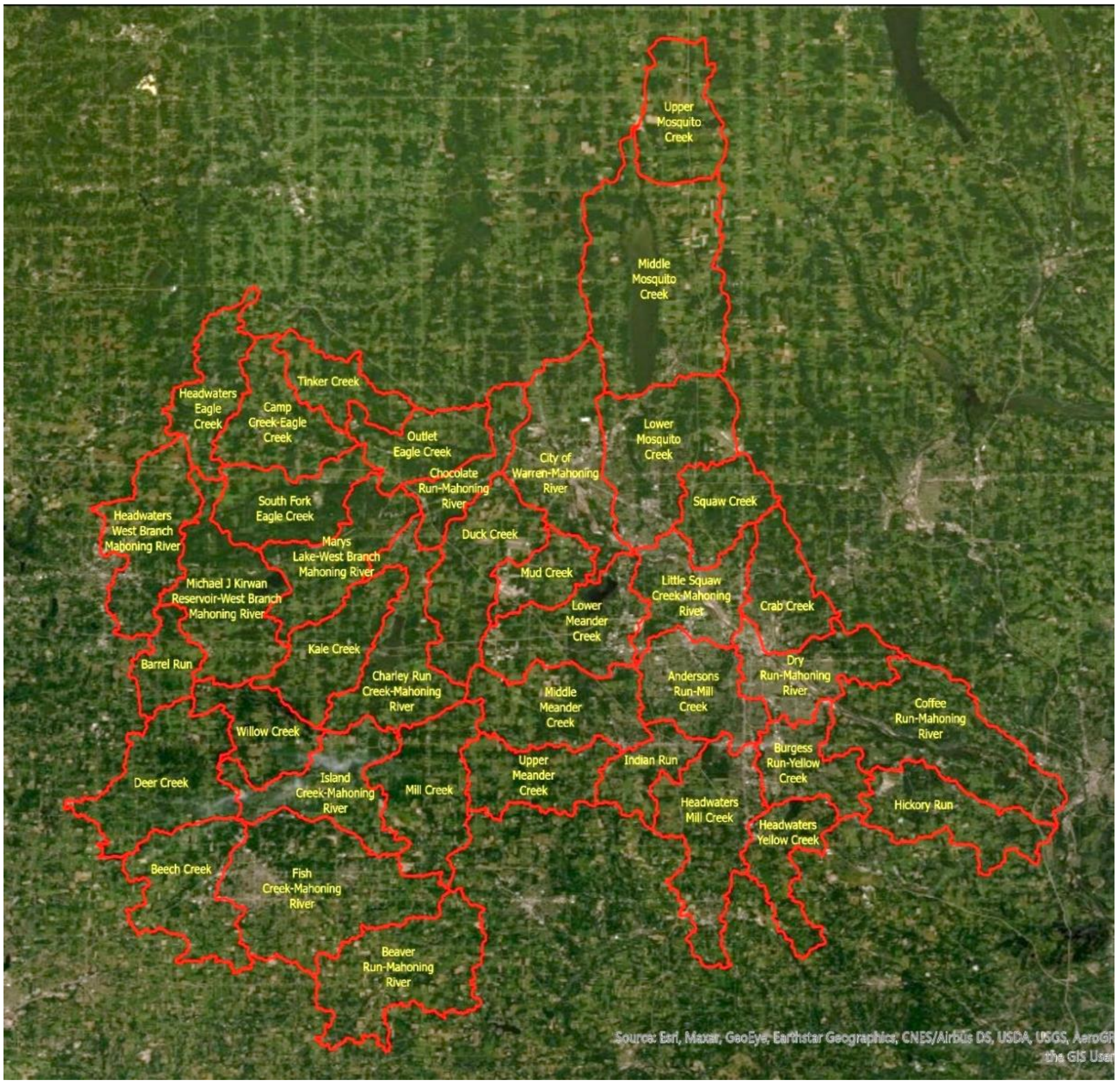


Figure III-1. Location of the Mahoning River watershed with the upper poriton of the watershed highlighted in blue and the lower Mahoning River Watershed highlighted in pink (OEPA, 2004).

Description of the Sampling Sites

Four sub-watersheds were studied based on their location (lower Mahoning River Watershed) and accessibility: Meander Creek, Crab Creek, Lower Mosquito and Yellow Creek, (Figure III-2 and III-3).

Using Google maps and other coordinate applications the locations were identified in the field. Sampling sites on each of the creeks were chosen wherever possible to correspond to the immediate land cover categories: industrial, residential, commercial, forested, and agriculture. The sampling site was described with respect to aquatic vegetation (submerged, emergent), substrate (silty, gravel, boulder), presence of fallen trees/snags, and undercut banks (photographs of sites are in Appendix II).



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGR
the GIS User

Figure III-2. Sub-watersheds of Mahoning River Watershed (Kimosop, 2021).

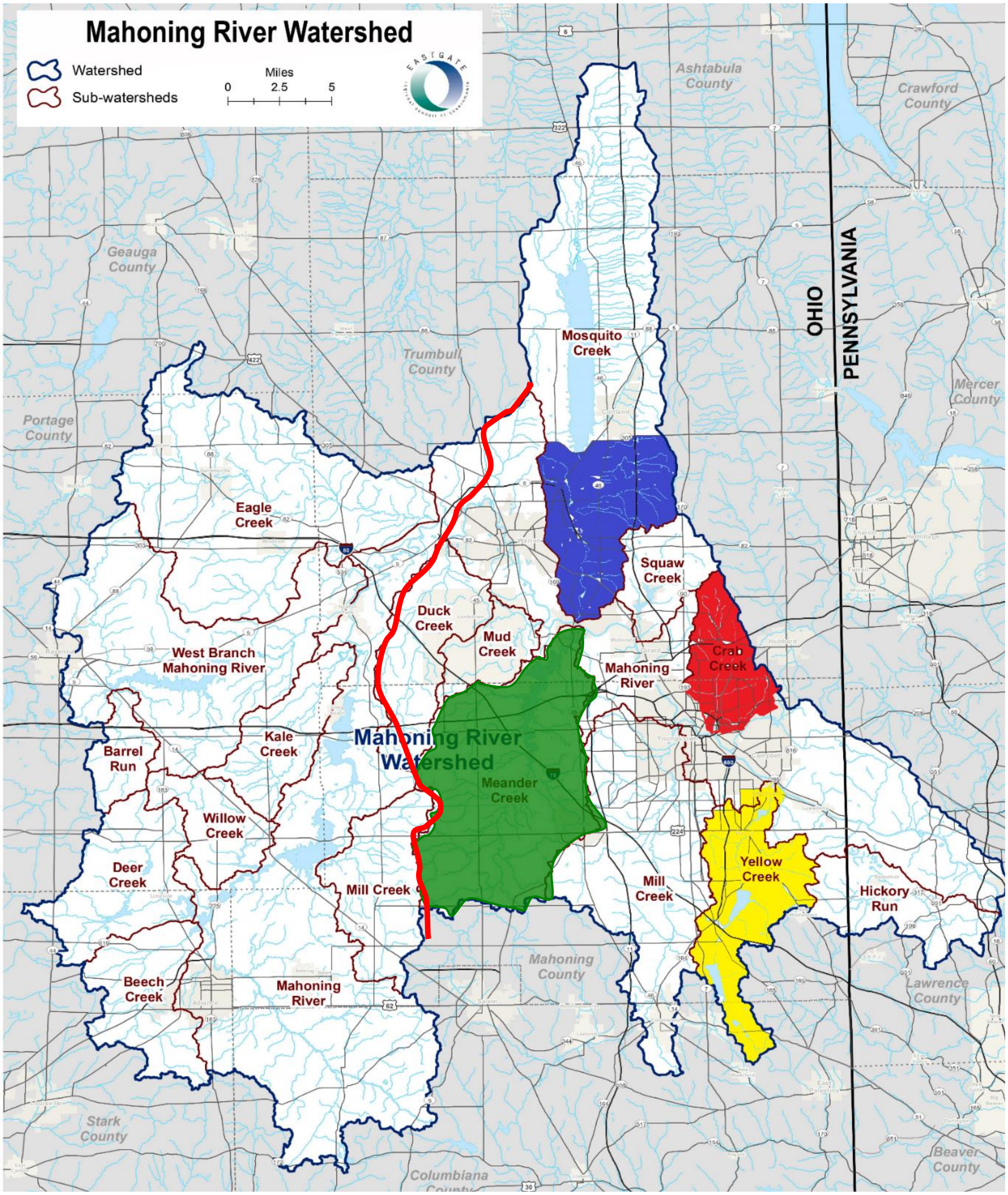


Figure III-3. Study area of sub-watersheds highlighted in the Mahoning River watershed. The bold red line indicates the division between upper and lower watersheds (Eastgate Regional Council of Governments, 2013).

Meander Creek overview

Meander Creek is the largest of the four watersheds investigated with 222.8 sq. km . The creek is impounded by the Meander Creek Reservoir on the north end of the watershed. The creek was so named on account of its meandering course. Meander Creek watershed has large swaths of deciduous forest, pastures/hay and cultivated crops area, while the developed area from the cities of Austintown and Mineral Ridge is present on the east and northeastern part of the watershed (Figure III-4). The deciduous land cover is predominant in this watershed followed by pastures/hay with less developed area compared to the other watersheds studied which could potentially lead to better water quality (Table III-1). The creek flows northwards and merges into the Mahoning River in the city of Niles. There were four sampling sites (residential, agricultural, industrial and forest) selected in this watershed (Figure III-4), the coordinates for each site can be found in the Appendix II.

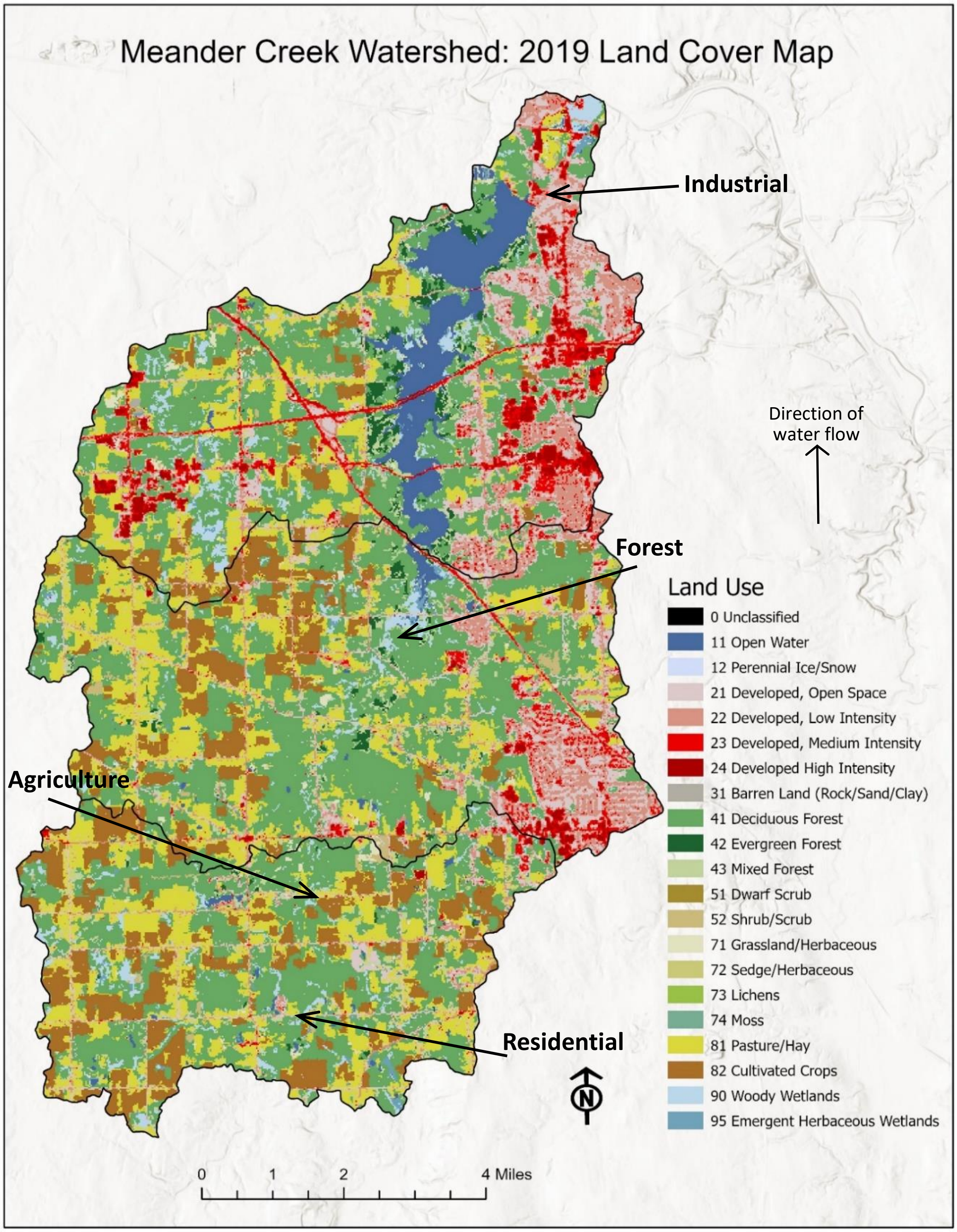


Figure III-4. Land cover and sample sites for the Meander Creek watershed (Kimosop, 2021)

Table III-1. Distribution of land cover for Meander Creek watershed.

Land cover	Area (km sq)	% Area
Open Water	8.62	3.87
Developed, Open Space	17.93	8.05
Developed, Low Intensity	19.68	8.83
Developed, Medium Intensity	8.38	3.76
Developed, High Intensity	3.28	1.47
Barren Land (rock/Sand/Clay)	0.28	0.13
Deciduous Forest	78.53	35.24
Evergreen Forest	2.63	1.18
Mixed Forest	6.33	2.84
Shrub/Scrub	1.39	0.62
Grassland/Herbaceous	2.15	0.96
Pasture/Hay	40.04	17.97
Cultivated Crops	26.06	11.70
Woody Wetlands	6.32	2.84
Emergent Herbaceous Wetlands	1.22	0.55
Total	222.81	100.00

Crab Creek Overview

Crab Creek also known as Grab Creek is a stream located just 1.3 km from Youngstown in Mahoning County. It is 54.5 sq. km watershed with large amount of development (~60%) mostly concentrated in the lower or southwestern side (Table III-2). The forest are found mostly in the northern portion of the watershed with scattering of cultivated land and pastures mixed throughout the watershed (Figure III-5). The creek flows south and merges with the Mahoning River in the city of Youngstown, in fact the majority of this watershed is in the city of Youngstown. Although this was the smallest of the watershed examined, there were five sampling locations (residential, industrial, commercial, forest, and agriculture), the coordinates for each site can be found in the Appendix II.

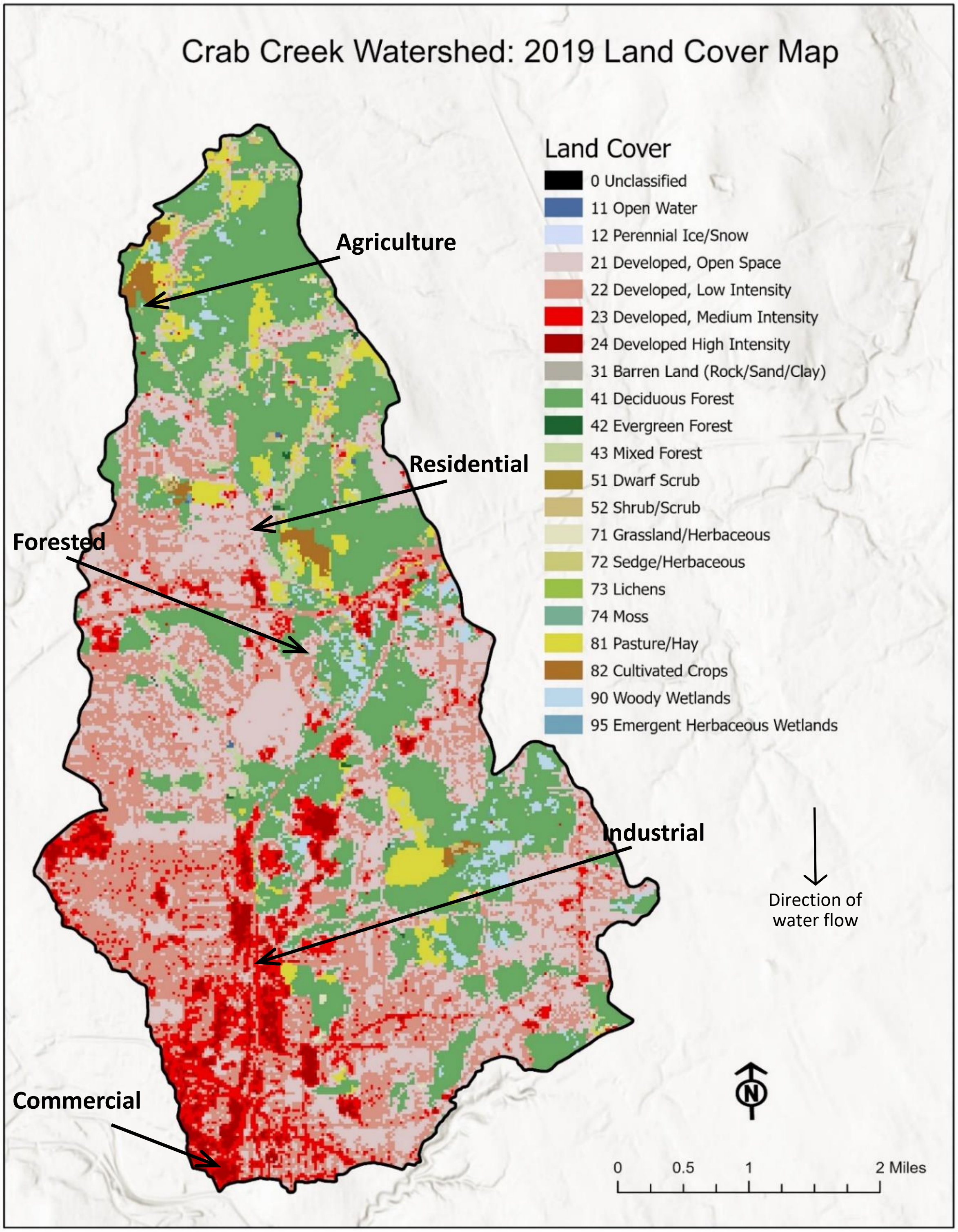


Figure III-5. Land cover and sample sites for the Crab Creek watershed (Kimosop, 2021).

Table III-2. Distribution of land cover for Crab Creek watershed.

Land cover	Area (km sq)	% Area
Open Water	0.03	0.05
Developed, Open Space	14.27	26.16
Developed, Low Intensity	13.42	24.61
Developed, Medium Intensity	4.35	7.98
Developed, High Intensity	1.39	2.56
Barren Land (rock/Sand/Clay)	0.02	0.04
Deciduous Forest	15.72	28.82
Evergreen Forest	0.04	0.07
Mixed Forest	1.09	2.00
Shrub/Scrub	0.16	0.30
Grassland/Herbaceous	0.16	0.29
Pasture/Hay	2.20	4.04
Cultivated Crops	0.48	0.87
Woody Wetlands	1.17	2.15
Emergent Herbaceous Wetlands	0.03	0.05
Total	54.53	100.00

Lower Mosquito Creek overview

The entire 106 sq. km watershed lies within Trumbull County, Ohio and has three major tributaries: Confusion Run, Big Run and Spring Run, which have their headwaters in Vienna Township and Fowler Township. The creeks flow westward through Bazetta and Howland Townships and into Lower Mosquito Creek. The north-eastern part of the watershed is mostly deciduous forest, pastures/hay, and cultivated crop cover while the south is mostly dominated by developed area (>50%) with small amount of forest and pastures/hay (Figure III-6). Mosquito Lake a reservoir is at the northern border of the watershed and the amount of stream flow is primarily controlled by the dam. The creek flows downwards through Niles with Warren on the east then merges with the Mahoning River. There were four sampling sites including commercial, forest and two mainly residential sites (Figure III-6), the coordinates for each site can be found in the Appendix II.

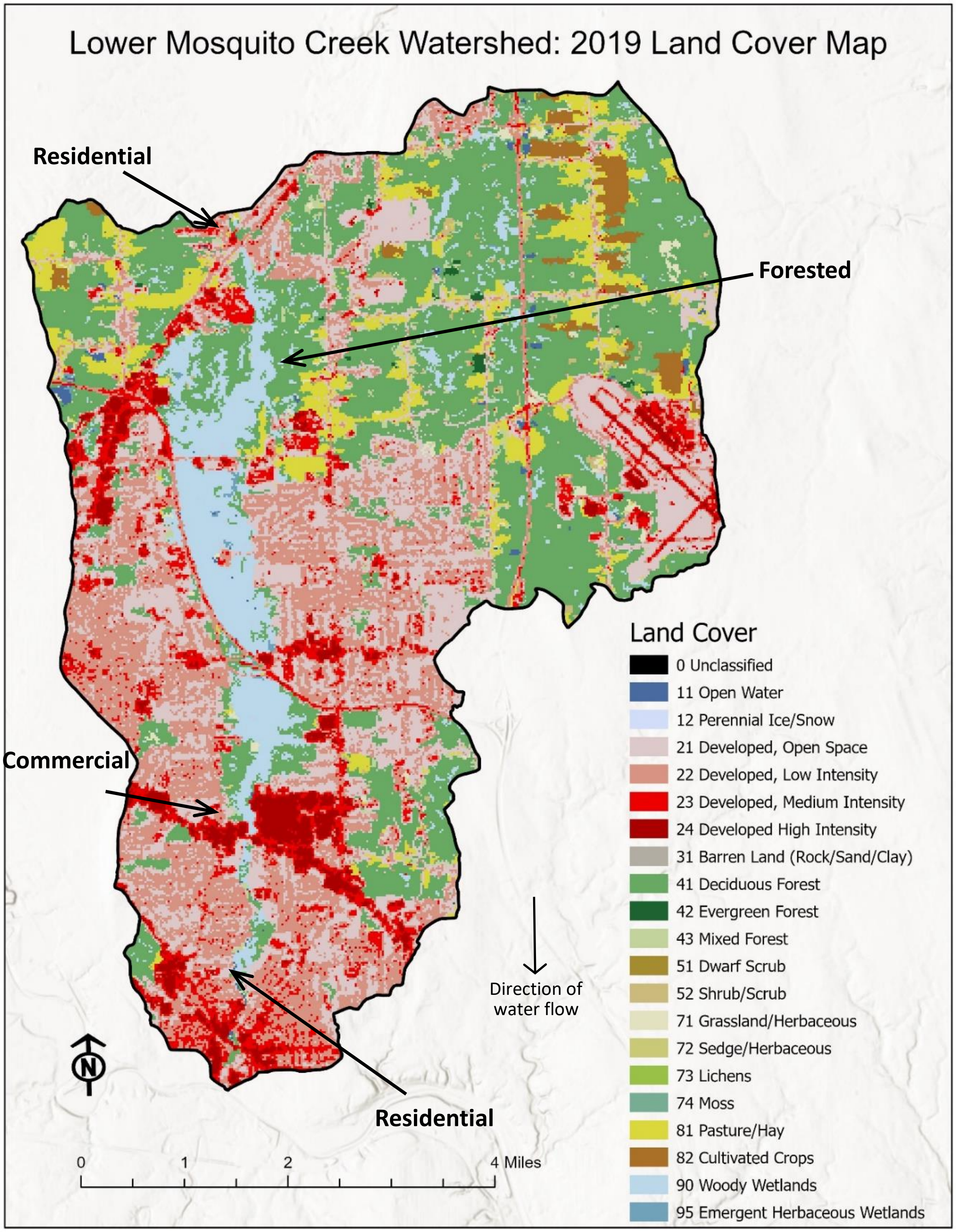


Figure III-6. Land cover and sample sites for the Lower Mosquito Creek watershed (Kimosop, 2021).

Table III-3. Distribution of land cover for Lower Mosquito Creek watershed.

Land cover	Area (km sq)	% Area
Open Water	0.35	0.33
Developed, Open Space	21.41	20.22
Developed, Low Intensity	23.13	21.85
Developed, Medium Intensity	7.85	7.41
Developed, High Intensity	3.66	3.45
Barren Land (rock/Sand/Clay)	0.05	0.05
Deciduous Forest	30.63	28.93
Evergreen Forest	0.16	0.15
Mixed Forest	1.35	1.27
Shrub/Scrub	0.42	0.40
Grassland/Herbaceous	0.69	0.66
Pasture/Hay	6.69	6.32
Cultivated Crops	1.74	1.65
Woody Wetlands	7.60	7.17
Emergent Herbaceous Wetlands	0.14	0.14
Total	105.87	100.00

Yellow Creek Watershed overview

Yellow Creek begins in Northeast Columbiana County and flows north into eastern Mahoning County. The watershed for this creek covers 102.38 sq. km. and is mainly rural, but transitions to a suburban and urban setting as it travels to its confluence with the Mahoning River in the City of Struthers. There are four reservoirs in the watershed: Beaver Lake (Columbiana County), Pine Lake, Evans Lake, and Lake Hamilton (Mahoning County). The northern part of the watershed is dominated by developed land accounting for about 40% of the watershed (Table III-4). The southern part is much less developed with about equal parts forest and cultivated crop/pastures/hay cover (Figure III-7). The creek flows north passing through or near North Lima, Poland, and Struthers before merging with the Mahoning River. Five sampling sites were identified in this watershed (commercial, industrial, residential, forest, agricultural), the coordinates for each site can be found in the Appendix II.

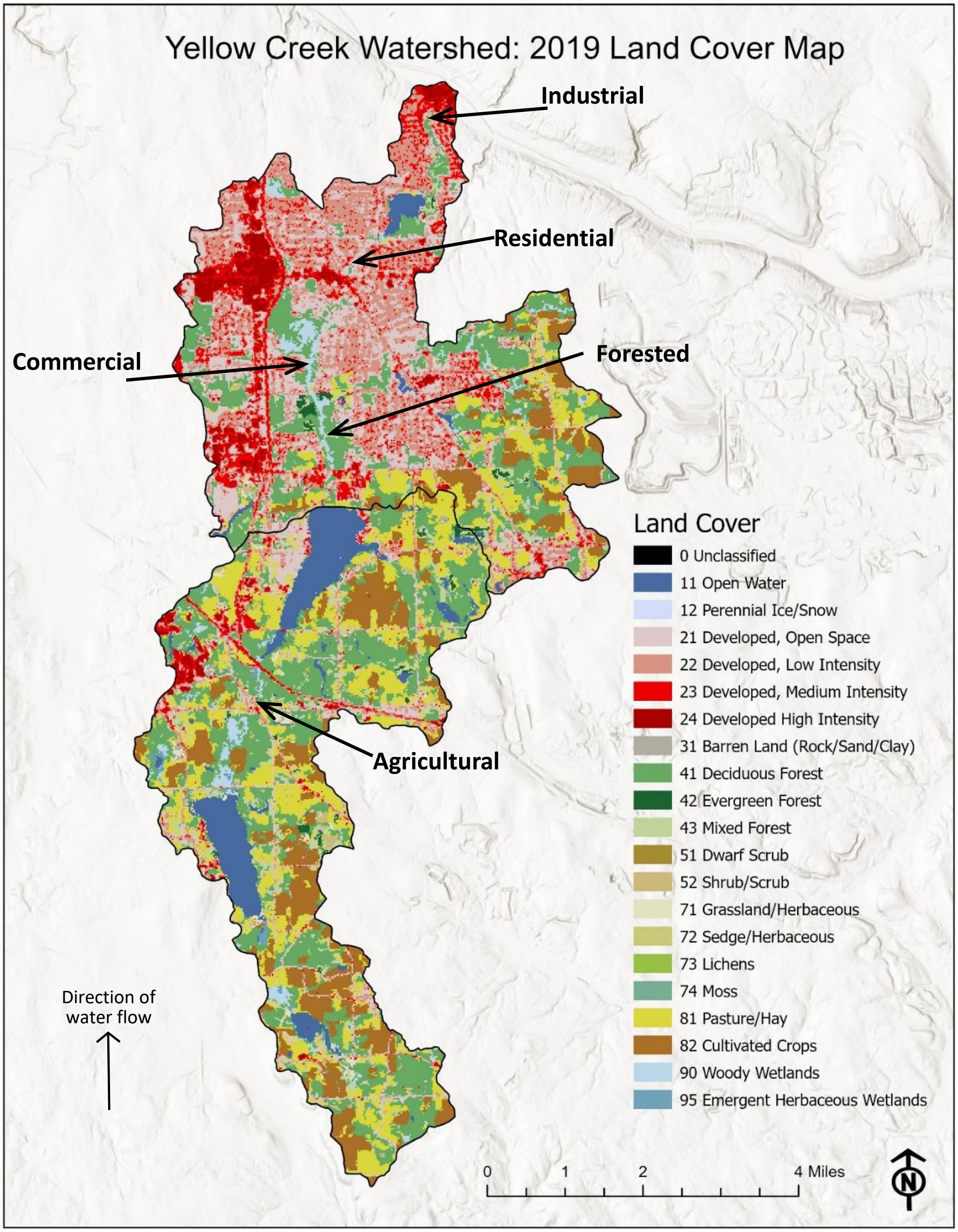


Figure III-7. Land cover and sample sites for the Yellow Creek watershed (Kimosop, 2021).

Table III-4. Distribution of land cover for Yellow Creek watershed.

Land cover	Area (km sq)	% Area
Open Water	5.57	5.44
Developed, Open Space	13.84	13.52
Developed, Low Intensity	16.66	16.27
Developed, Medium Intensity	7.06	6.90
Developed, High Intensity	2.77	2.71
Barren Land (rock/Sand/Clay)	0.14	0.14
Deciduous Forest	22.98	22.44
Evergreen Forest	0.52	0.51
Mixed Forest	3.62	3.54
Shrub/Scrub	0.31	0.30
Grassland/Herbaceous	0.76	0.75
Pasture/Hay	15.13	14.78
Cultivated Crops	10.70	10.45
Woody Wetlands	1.94	1.89
Emergent Herbaceous Wetlands	0.38	0.37
Total	102.38	100.00

Water quality parameters and their testing methods

The parameters used in this study include physical (temperature, conductivity/salinity, and solids), chemical (pH, phosphate, ammonia, nitrate, dissolved oxygen, biochemical oxygen demand, alkalinity, hardness) and bacterial (total coliform and *E.coli*).

The grab sampling method was used in this study. For homogeneous materials such as water, a grab sample offers quick and accurate insight into the quality of the environment. Samples are collected in a single vessel which is then transported back to a lab for analysis. This technique is one of the most commonly used sampling methods and is great for establishing base measurements such as chemical composition and salinity. That said, grab samples are also limited in that they only offer a snapshot of a certain area at a certain time. As a dynamic substance, water quality can rapidly fluctuate due to changes in flow, evaporation, and other external factors.

Samples were taken between 1 m of shoreline and middle of the Creek where applicable, 3cm below the surface. Samples were collected each month during the summer, from May 22nd – September 12th . Water samples were preserved according to (USEPA,1983) protocol. pH, temperature and DO are measured on the field whereas solids, E coli and soluble PO_4^{+3} were measured within first 48 hours. NH_4 and total PO_4^{+3} can be held for a maximum of 28 days.

Temperature, pH, conductivity, and dissolved oxygen were measured on site using YSI plus multi-probe. Replicate dip or grab water samples were collected and placed in a cooler while being transported to the laboratory and then stored in the refrigerator until analysis.

In order to analyze the impact of different local land cover types on the surface water quality of four Mahoning River sub-watersheds the water quality index (NSF-WQI) was calculated using Equation 1, $WQI = \sum_{i}^{n} Q_i w_i$

Spectrophotometric method

This method utilized the chemical analysis kits from HACH for the measuring of total phosphate, nitrate, and ammonia. The water samples were mixed with reagents from the kits for each particular water chemical procedure. The procedure is done until the water samples analyzed for a particular chemical changes to a required color. They are then measured at the wavelength needed for each water chemical and the concentrations are expressed in mg/L. Standards with specific laboratory solution and concentration are prepared to check the accuracy of the water samples and instruments along with blank samples. Finally, graphs are plotted for the measured results against the standard concentrations and obtain a curve of best fit for calibration.

Total phosphate used HACH -TNT 843 LR, Method 10209/10210. Soluble reactive (orthophosphate) phosphate was determined using the ascorbic acid method (Baird et al., 2017).

Two nitrogen forms were analyzed, ammonia-nitrogen using Hach reagents (Salicylate Method 8155) and cadmium reduction method for nitrate (Hach method 8192). All the samples and corresponding standards were read on the DRB 3900 spectrophotometer.

The Colilert Quanti-tray 2000 method from IDEX was used to determine total coliform and *E. coli*. All equipment and deionized water were sterilized in a UV box prior to use, both positive and negative control were used to insure consistent results.

Biochemical oxygen demand (BOD) was determined using method 5210 B without the nitrification inhibitor (Baird et al., 2017). All bottles were autoclaved prior to use and replicates of 3 levels of water were used for each sample. The first sampling in two of the sub-watersheds used the local wastewater treatment plant as seed but this seed was very strong and resulted in excess oxygen removal. Therefore, commercial seed (InterLab Polyseed) was used for all later samples.

For hardness, EDTA titrimetric method was used (method 2340 C, Baird et al., 2017). Buffer solution is added to a sample and titrated with EDTA using Eriochrome Black T powder as the indicator (Hach Chemical) until sample changed from wine red to blue. Titration method was also used to test total alkalinity, (Method 2320 B). Bromocresol green is added to the sample as the indicator and titrated with 0.02N H_2SO_4 until blue solution turns green.

Solids were measured using standard methods in duplicate (method 2540 B – total solids and 2540 D - total suspended solids). Total dissolved solids was determined based on total solids = total suspended solids + total dissolved solids.

Statistical Analysis

Two independent one-factor analysis of variance (ANOVA) were done for National Sanitation Foundation -water quality indexes (NSF-WQI) calculated, for comparing among each separate watershed and between watersheds and the other comparing among the different land cover types using SPSS (version 27). The one-way ANOVA is used to determine whether there are any statistically significant differences between the means of three or more independent (unrelated) groups. Since ANOVA tests whether there is an overall difference between the groups, it does not say which specific groups differed.

These analyses could not be combined into a single two-factor ANOVA (watersheds and land cover at the same time) because not all land cover types were represented in every tributary watershed.

The homogeneity of variances, and Levene's test also indicated satisfaction of this model assumption. So, Tukey Honestly significant Difference (HSD), a post-hoc multiple comparison test was done to determine if there are any significant differences between NSF-WQI means. Post hoc tests are termed *a posteriori* tests; that is, performed after the event (the event in this case being a study).

To further interpret the large data set in a more convenient way, the Principal Component Analysis (PCA) ordination was employed which reduces the dimension of the data. The PCA procedure is a bit involved and requires sophisticated optimization tools. Fortunately, statistical packages such as SPSS have made these calculations convenient. The PCA reorganizes pre-existing variables into a new set of "component" axes that maximize the amount of data variation within a smaller number of statistical output variables. In other words, it presents the pattern among multiple variables which in this case are the water quality variables, onto a pair of interpretable axes. Markers near one another on the ordination plot are similar in terms of the included water quality variables. Markers distant from each other are dissimilar.

The PCA tables shows how much variance is explained by each axis, individually and cumulatively. Explaining 60-70%+ of variance on a pair of axes is very good. Around 50% is still good but not as strong. The Component Matrix tables are also termed loadings, of the original variables. Each value is actually a Pearson correlation coefficient between -1.0 and +1.0 of the indicated variable with each PCA axis (i.e., the axes of the ordination graph). These values indicate how strongly the original variable is associated with the new axes, and in what direction.

IV. Chapter: Results

Seven water parameters out of thirteen in industrial land cover had higher means than others. No trends were seen for ammonia and soluble phosphate with respect to land cover within watershed. Agricultural areas tend to produce greater ammonia and phosphates are predominantly found in agricultural fertilizers and manures, but it did not seem to be the case in this watershed. DO and *E.coli* have higher means in agricultural and residential landcover (Table IV-1). The NSF-WQI of agriculture and residential are the same (Figure IV-1).

Ammonia values were higher in industrial land cover as opposed to agriculture cover. Soluble phosphates were highest in agriculture land cover which could be because of fertilizer and manure use. DO value was also low in this land cover (Table IV-2). Also, conductivity increases with more amount of TDS present in the water which seems to be the case in all sub-watershed samples. The measure of water quality parameters at low or baseline flow had fairly low variability during the sampling period. An exception to this was the highly variable conductivity readings in Crab Creek (Table IV-2). There are several industrial stormwater National Pollution Discharge Elimination System (NPDES) permits that send water to Crab Creek. This could be the source of the conductivity changes in this watershed. In addition, Crab Creek had the highest *E. coli* levels, since there is little or no overland flow carrying the bacteria into the streams, the source of bacteria could be through direct input from warm-blooded wildlife or effluent from point sources. The forest, industrial and residential land covers had similar NSF-WQI (Figure IV-2).

Table IV-1. Average (± standard deviation) of water quality parameters from Meander Creek, by land cover type.

Land cover	Total Alkalinity (mg/L)	Hardness (mg/L)	Conductivity (µS/cm)	NH4-N (mg/L)	Soluble P (mg/L)	Total phosphate (mg/L)	Nitrate (mg/L)	BOD (mg/L)	TDS (mg/L)	pH	Temperature (°C)	DO (mg/L)	DO (sat %)	Geometric mean *E. coli*, (MPN/100)
Agriculture	126 ±25	170 ±69	449 ±227	0.06 ±0.02	0.04 ±0.03	0.02 ±0.02	0.5 ±0.5	1.7 ±0.6	392 ±66	8 ±0.3	22 ±3	9 ±1.6	103 ±24	166
Forest	145 ±32	184 ±59	373 ±70	0.09 ±0.05	0.03 ±0.02	0.03 ±0.03	0.7 ±0.8	3 ±0.3	392 ±58	8 ±0.3	20 ±1	5 ±0.7	55 ±8	80
Industrial	206 ±71	137 ±34	591 ±167	0.12 ±0.1	0.08 ±0.1	0.07 ±0.1	3 ±2	2 ±0.5	587 ±131	8.1 ±0.4	21 ±3	7 ±1	80 ±13	83
Residential	86 ±17	423 ±142	631 ±157	0.04 ±0.04	0.02 ±0.02	0.007 ±0.01	0.5 ±0.4	1 ±0.4	751 ±196	7.3 ±0.3	20 ±2	9 ±1	96 ±12	369

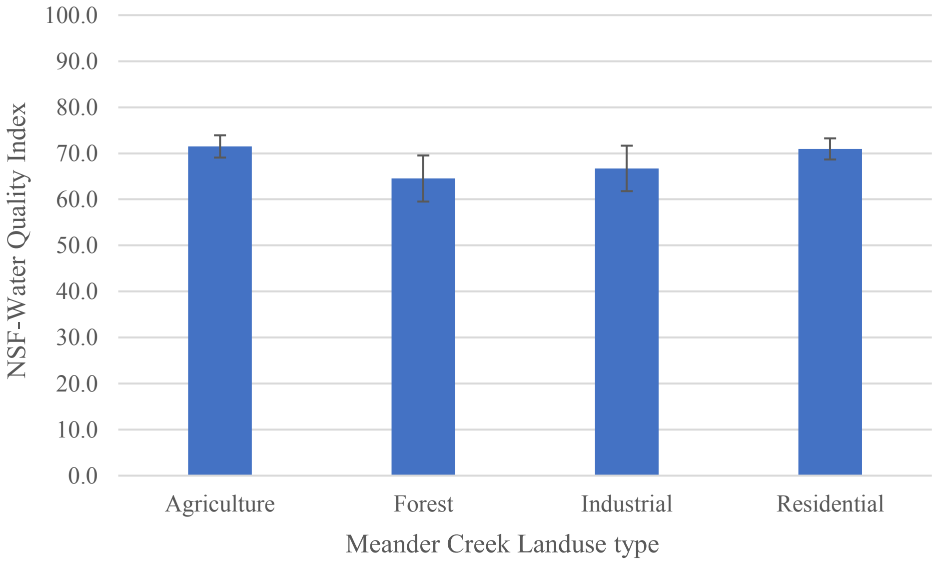


Figure IV-1. NSF-WQI for each land cover type for Meander Creek. Bars represent standard deviation.

Table IV-2. Average (± standard deviation) of water quality parameters from Crab Creek, by land cover type.

Land cover	Total Alkalinity (mg/L)	Hardness (mg/L)	Conductivity (µS/cm)	NH4-N (mg/L)	Soluble P (mg/L)	Total phosphate (mg/L)	Nitrate (mg/L)	BOD (mg/L)	TDS (mg/L)	pH	Temperature (°C)	DO (mg/L)	DO (sat %)	Geometric mean *E. coli*, (MPN/100)
Agriculture	168 ±66	137 ±50	846 ±195	0.03 ±0.04	0.5 ±0.4	0.5 ±0.4	1.25 ±1	6.3 ±5.5	491 ±248	7.2 ±0.1	19 ±2.4	5 ±0.7	53 ±10	249
Commercial	175 ±24	178 ±32	1050 ±1135	0.08 ±0.1	0.04 ±0.04	0.05 ±0.04	0.3 ±0.1	2 ±1	490 ±93	8.4 ±0.4	20 ±1.4	10 ±1.8	110 ±21	332
Forest	174 ±12	158 ±13	848 ±863	0.02 ±0.03	0.07 ±0.05	0.06 ±0.03	0.6 ±0.2	1.2 ±0.6	382 ±111	8.3 ±0.3	19 ±1.3	9.3 ±3.5	100 ±40	332
Industrial	173 ±27	175 ±32	889 ±916	0.05 ±0.04	0.04 ±0.03	0.1 ±0.1	0.4 ±0.2	2 ±1	412 ±57	8.3 ±0.4	19 ±1.2	10 ±1.4	105 ±16	601
Residential	145 ±20	119 ±23	627 ±505	0.02 ±0.03	0.1 ±0.1	0.1 ±0.1	0.5 ±0.3	2 ±0.3	312 ±88	8 ±0.2	22 ±1.1	6.3 ±1	71 ±11	245

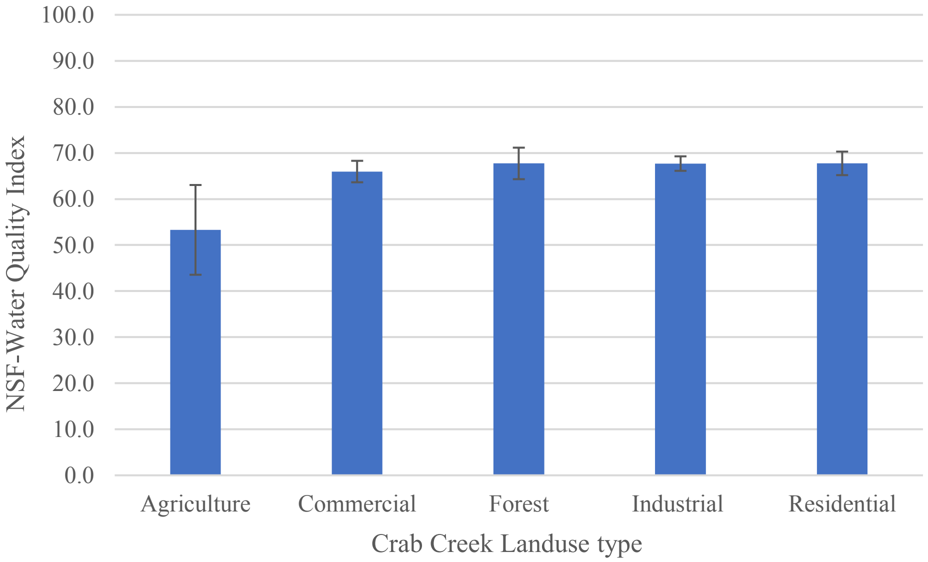


Figure IV-2. NSF-WQI for each land cover type for Crab Creek. Bars represent standard deviation.

There are only three land covers which could potentially increase the NSF-WQI of this sub-watershed. Also, the absence of industrial cover could further increase the NSF-WQI (Table IV-3). The NSF-WQI was almost same for both forest and residential land cover (Figure IV-3).

TDS were the highest in this sub-watershed as compared to other watersheds especially in the agriculture and forest land covers. This would potentially be due to the past industrial activity in the region. The DO values were consistent in this sub-watershed (Table IV-4). Yellow Creek also had higher *E.Coli* levels similar to Crab Creek as both watersheds have high amounts of development as compared to other watersheds examined. Another interesting thing is the similarity in the NSF-WQI of the land cover types in this sub-watershed (Figure IV-4).

Table IV-3. Average (± standard deviation) of water quality parameters from Lower Mosquito Creek, by land cover type.

Land cover	Total Alkalinity (mg/L)	Hardness (mg/L)	Conductivity (µS/cm)	NH4-N (mg/L)	Soluble P (mg/L)	Total phosphate (mg/L)	Nitrate (mg/L)	BOD (mg/L)	TDS (mg/L)	pH	Temperature (°C)	DO (mg/L)	DO (sat %)	Geometric mean *E. coli*, (MPN/100)
Commercial	85 ±12	56 ±18	229 ±86	0.1 ±0.1	0.1 ±0.1	0.1 ±0.1	0.8 ±0.9	2.2 ±1.3	172 ±46	7.4 ±0.5	21 ±1.3	5 ±1	57 ±10	152
Forest	82 ±15	52 ±24	175 ±38	0.1 ±0.1	.02 ±0.0	0.06 ±0.0	0.4 ±0.7	1.9 ±0.7	156 ±60	8 ±1	22 ±2.2	6.4 ±0.6	72 ±8	97
Residential	75.3 ±8.5	43 ±10	198 ±74	0.1 ±0.1	0.1 ±0.06	0.1 ±0.05	0.3 ±0.3	2.3 ±1	165 ±48	7.5 ±0.7	22 ±2.2	7 ±1.7	78 ±18	60

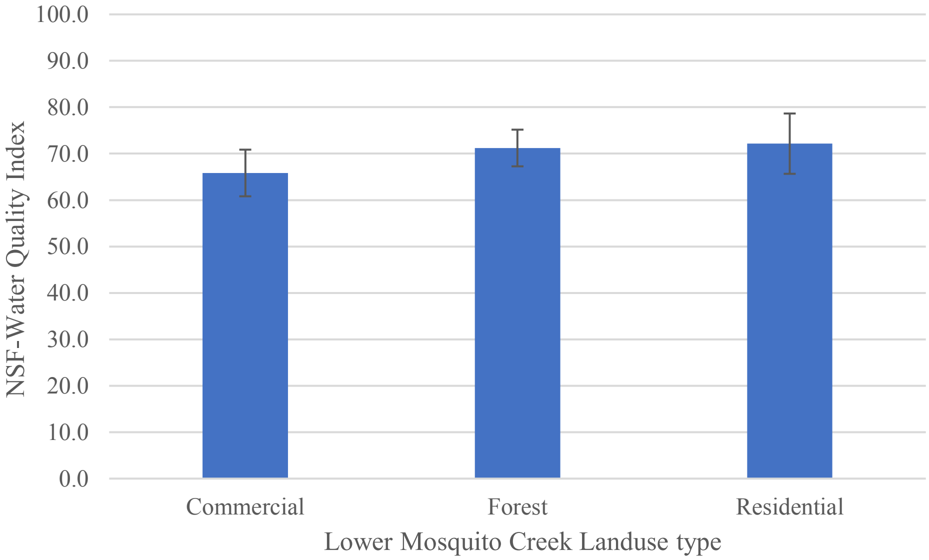


Figure IV-3. NSF-WQI for each land cover type for Lower Mosquito Creek. Bars represent standard deviation.

Table IV-4. Average (± standard deviation) of water quality parameters from Yellow Creek, by land cover type.

Land cover	Total Alkalinity (mg/L)	Hardness (mg/L)	Conductivity (µS/cm)	NH4-N (mg/L)	Soluble P (mg/L)	Total phosphate (mg/L)	Nitrate (mg/L)	BOD (mg/L)	TDS (mg/L)	pH	Temperature (°C)	DO (mg/L)	DO (sat %)	Geometric mean *E. coli*, (MPN/100)
Agriculture	208 ±52	536 ±44	807 ±118	0.06 ±0.1	0.02 ±0.01	0.04 ±0.01	0.3 ±0.4	1.3 ±1.2	1124 ±243	7.8 ±0.3	21 ±2	7.3 ±1.6	81 ±16	251
Commercial	151 ±33	286 ±113	696 ±44	0.05 ±0.01	0.03 ±0.01	0.04 ±0.01	0.4 ±0.4	2.2 ±2.1	657 ±219	8.5 ±0.5	23 ±1.7	7.9 ±1.2	91 ±12	296
Forest	186 ±46	490 ±94	801 ±63	0.07 ±0.01	0.03 ±0.01	0.05 ±0.04	0.4 ±0.3	2.1 1.1	1069 ±69	8.2 ±0.4	22 ±0.8	7.2 ±1.1	81 ±12	350
Industrial	116 ±8	179 ±61	531 ±160	0.06 ±0.04	0.04 ±0.04	0.06 ±0.1	0.6 ±0.3	1.7 ±0.4	490 ±122	8.5 ±0.2	21 ±0.8	7.6 ±1.7	85 ±18	174
Residential	135 ±26	243 ±97	523 ±168	0.05 ±0.01	0.03 ±0.04	0.05 ±0.03	0.4 ±0.3	1.2 ±0.3	682 ±100	8.6 ±0.3	22 ±1.7	8.5 ±1	98 ±8	144

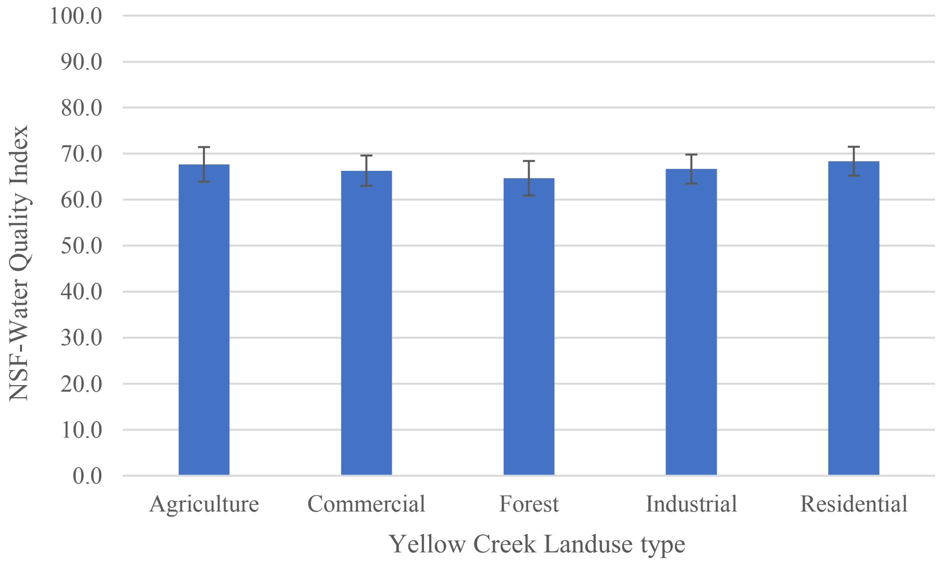


Figure IV-4. NSF-WQI for each land cover type for Yellow Creek. Bars represent standard deviation.

The NSF-WQI varied from 53 in Crab Creek agriculture to 72 in Lower Mosquito Creek residential land cover area (Table IV-5). The WQI of sub-watersheds ranged from 64–70 (Table IV-5). Lower Mosquito Creek is in the good while the rest are in medium NSF-WQI range (Table II-2). Meander and Lower Mosquito Creeks have a higher WQI as compared to the other two creeks. (Table IV-6).

A bar graph representation of the WQI for four sub-watersheds can be found in Figure IV-5.

The one-factor ANOVA summarized in Table IV-7 show that there is a significant difference in NSF-WQI scores among the sub-watersheds.

The Post-hoc Tukey HSD test for NSF-WQI indicates Crab Creek is statistically significantly lower than Lower Mosquito Creek. All other creeks have no significant difference (Table IV-8).

Table IV-5. Summary of NSF-WQI data, averaged for each watershed, and for each land cover type within watersheds.

Sub-watershed	Land cover	WQI	Overall Average WQI
Meander Creek	Agriculture	71.5±2.4	68.4 ±4.6
	Forest	65.5±5	
	Industrial	66.7±4.9	
	Residential	71.0±2.3	
Crab Creek	Agriculture	53.3±8	64.5 ±7.2
	Commercial	66±2.3	
	Forest	67.7±3.4	
	Industrial	67.7±1.6	
	Residential	67.7±2.6	
Lower Mosquito Creek	Commercial	65.8±5	70.3 ±6
	Forest	71.2±4	
	Residential	72.2±6.5	
Yellow Creek	Agriculture	67.7±3.8	66.7 ±3.3
	Commercial	66.3±3.3	
	Forest	64.7±3.8	
	Industrial	66.7±3.1	
	Residential	68.4±3.1	

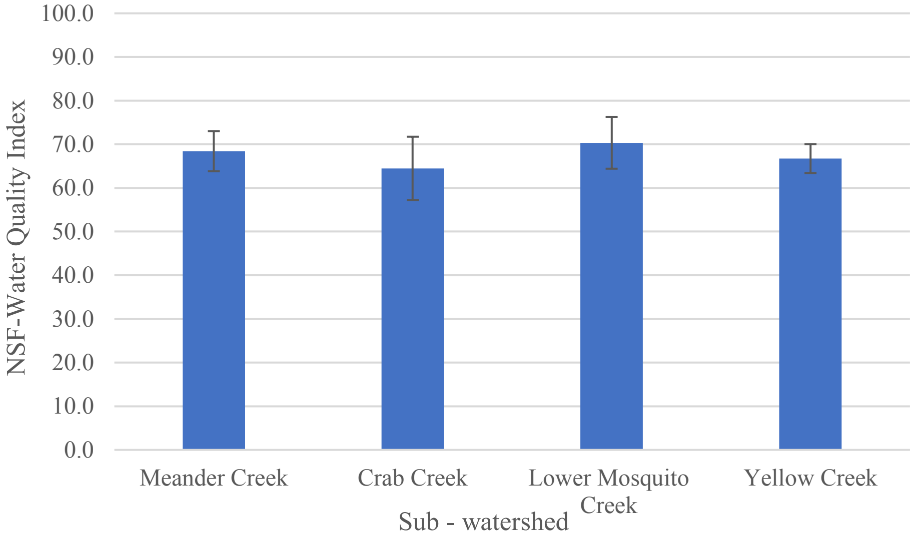


Figure IV-5. Average NSF-WQI of four sub-watersheds in the Mahoning River watershed. Bars represent standard deviation.

Table IV-6. Descriptive statistics for NSF-WQI by watershed.

	n	Mean	Std. Deviation	Minimum	Maximum
Meander Creek	16	68.4	4.78	59	75
Crab Creek	20	64.4	7.37	43	71
Lower Mosquito Creek	16	70.3	5.97	59	82
Yellow Creek	20	67.0	3.99	56	72
Total	72	67.1	6.00	43	82

Table IV-7. One way ANOVA for NSF-WQI, with the factor being the four sub-watershed.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	343.4	3	114.4	3.511	0.020
Within Groups	2217.1	68	32.6		
Total	2560.6	71			

Table IV-8. Post-hoc Multiple Comparison for NSF-WQI between the four sub-watersheds using Tukey HSD.

(I) Watershed	(J) Watershed	Mean Difference (I-J)	Sig.
Meander Creek	Crab Creek	3.90	0.185
	Yellow Creek	2.45	0.579
	Lower Mosquito Creek	-1.81	0.806
Crab Creek	Meander Creek	-3.90	0.185
	Yellow Creek	-1.45	0.853
	Lower Mosquito Creek	-5.71*	0.020
Lower Mosquito Creek	Meander Creek	1.81	0.806
	Crab Creek	5.71*	0.020
	Yellow Creek	4.26	0.127
Yellow Creek	Meander Creek	-2.45	0.579
	Crab Creek	1.45	0.853
	Lower Mosquito Creek	-4.26	0.127

*. The mean difference is significant at the 0.05 level.

The NSF-WQI for overall land cover types of four sub-watersheds have a range of 64-70 with residential being the highest and agriculture the lowest (Figure IV-6). According to NSF-WQI range, residential is in good while rest are in medium. Also, industrial and forest land cover types have the same index value (Table IV-9).

A bar graph representation of the NSF-WQI for overall land cover can be found in Figure IV-6.

The one-factor ANOVA shows that there is a significant difference in the NSF-WQI of the land cover types (Table IV- 10).

The Post-hoc Tukey HSD test for NSF-WQI indicates residential land cover is statistically significantly higher than agriculture land cover (Table IV-11).

Table IV-9. Descriptive statistics for NSF-WQI by land cover type for all sub-watersheds.

	n	Mean	Std. Deviation	Minimum	Maximum
Agriculture	12	64.0	10.1	43	75
Commercial	12	66.1	3.43	59	71
Forest	16	67.0	4.63	60	74
Industrial	12	67.0	3.31	59	71
Residential	20	70.3	4.80	60	82
Total	72	67.1	6.00	43	82

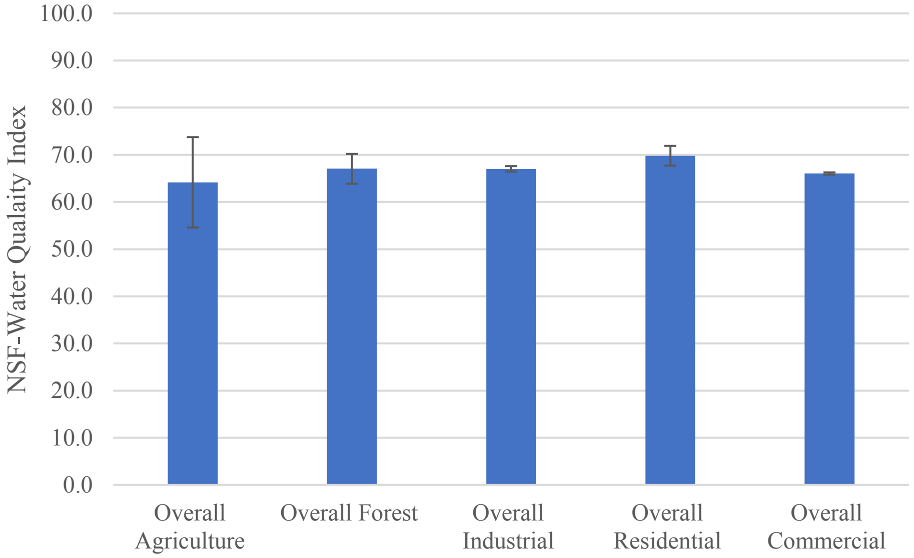


Figure IV-6. Average NSF-WQI of overall land cover types of all four sub-watersheds. Bars represent standard deviation.

Table IV-10. One way ANOVA for overall land cover types of four sub-watersheds.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	423.4	4	105.8	3.319	0.015
Within Groups	2137.1	67	31.8		
Total	2560.6	71			

Table IV-11. Post hoc Multiple Comparisons for NSF-WQI between land cover types using Tukey HSD.

(I) Land cover	(J) Land cover	Mean Difference (I-J)	Sig.
Agriculture	Commercial	-3.16	0.647
	Forest	-4.00	0.352
	Industrial	-4.08	0.399
	Residential	-7.350	0.006
Commercial	Agriculture	3.16	0.647
	Forest	-0.83	0.995
	Industrial	-0.91	0.995
	Residential	-4.18	0.264
Forest	Agriculture	4.00	0.352
	Commercial	0.83	0.995
	Industrial	-0.08	1.000
	Residential	-3.35	0.400
Industrial	Agriculture	4.08	0.399
	Commercial	0.91	0.995
	Forest	0.08	1.000
	Residential	-3.26	0.513
Residential	Agriculture	7.35	0.006
	Commercial	4.18	0.264
	Forest	3.35	0.400
	Industrial	3.26	0.513

PCA constructs 13 different principal components because there are 13 different variables and the eigenvalues for each of these principal components are shown below in table IV-12. The first principal component explains 27.9% of the variation in the data. Similarly, the second explain 24.8% of the variance. Additionally, the first 2 principal components together contain 52.7% of the total variance in the data which is good but not as strong. The relationship of each of these two principal components with the original variables is shown in the component matrix Table IV-13. The first principal component is strongly positively correlated with 5 of the original variables (Nitrate, BOD, Total P, Sol P, *E.Coli*). It shows that the first component is actually a measure of these five variables. Similarly, the second component is strongly negatively correlated with ammonia, and strongly positively correlated with alkalinity, hardness, conductivity, TDS, pH, DO.

Table IV-12. Eigen values of the principal components and the variance they contain.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.6	27.9	27.9	3.6	27.9	27.9
2	3.2	24.8	52.7	3.2	24.8	52.7
3	1.4	10.7	63.5			
4	1.0	8.0	71.5			
5	0.9	6.9	78.4			
6	0.71	5.5	84.0			
7	0.59	4.5	88.5			
8	0.48	3.7	92.3			
9	0.41	3.1	95.5			
10	0.27	2.1	97.6			
11	0.22	1.7	99.3			
12	0.05	0.4	99.7			
13	0.02	0.2	100.0			

Table IV-13. Component matrix.

	Component	
Variable	1	2
Alkalinity	0.42	0.72
Hardness	-0.06	0.77
Conductivity	0.17	0.66
NH4-N	-0.06	-0.51
Soluble P	0.92	-0.07
Tot P	0.89	-0.08
Nitrate	0.66	-0.04
BOD	0.70	-0.14
TDS	0.10	0.83
pH	-0.29	0.55
Temp	-0.55	-0.14
DO	-0.35	0.55
E.coli	0.53	0.12

Principal component analysis conducted on the parameters and NSF-WQI displays each sampling site in the sub-watershed as it relates to water quality parameters (Figure IV-7), with principal components 1 and 2 which respectively explains 27.9% and 24.8% of the data variation.

Not much or weak pattern is depicted in the figure below. This could possibly be due to the samples collected during the low flow. Also, notice how the markers are present on the y-axis of the plot. Since, the PCA 2 is strongly negatively correlated with ammonia, and strongly positively correlated with alkalinity, hardness, conductivity, TDS, pH, DO. It implies ammonia is negatively correlated with the NSF-WQI and the positively correlated variables implies they are positively correlated with NSF-WQI.

The vectors of the variables nitrate, total P and soluble P are close to one another, and they are forming a small angle implying that they are positively correlated. The variables that are at 90° are not likely to be correlated such as TDS and BOD, hardness and temperature etc. When they diverge and form a large angle (close to 180°), they are negative correlated such as temperature and alkalinity and DO and BOD etc.

The loading plot graph (Figure IV-8) shows how each vector or water quality variables influence the principal components. Comparing PCA and loading plots, the variables DO, Alkalinity, TDS, hardness, conductivity, and pH have a positive correlation with the sites of Crab creek, Yellow Creek, and some of the Meander Creek. Also, temperature and ammonia have a negative correlation with most of the Lower Mosquito Creek sites.

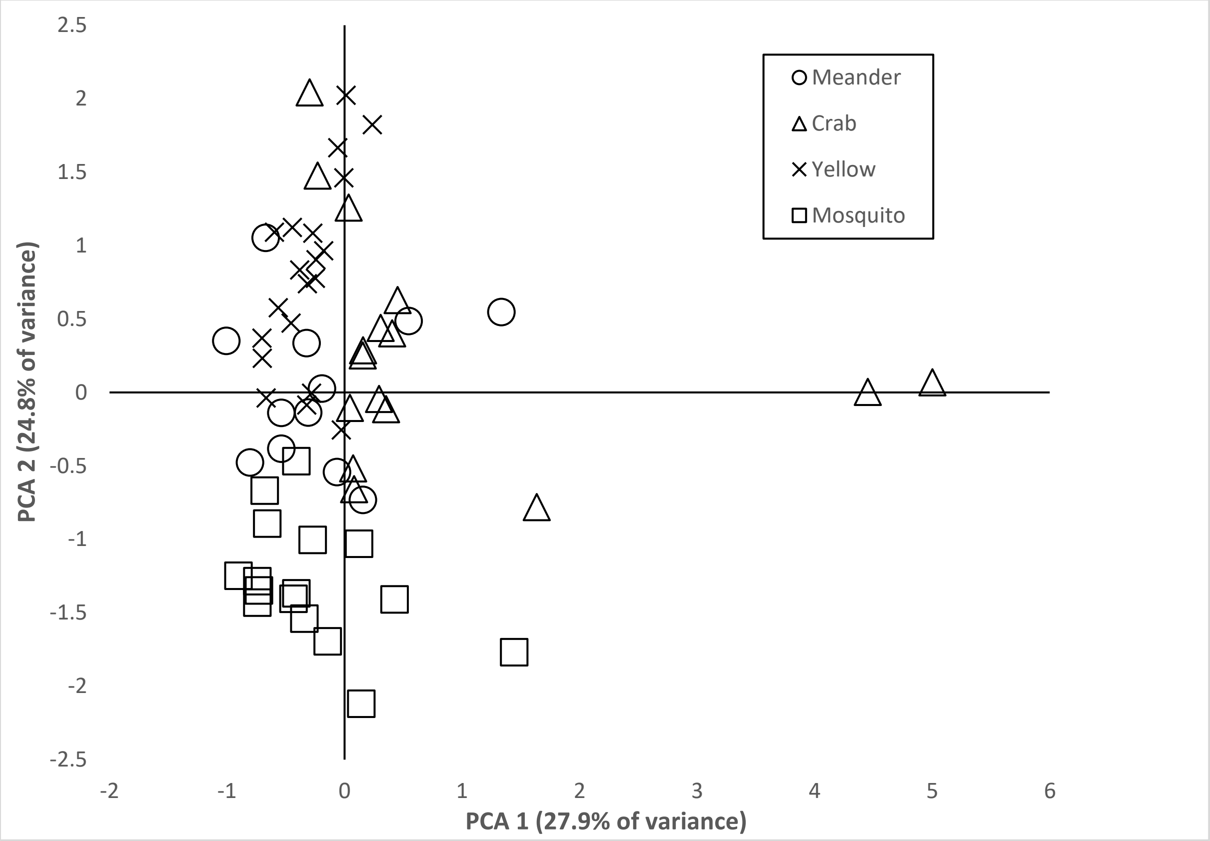


Figure IV-7. Principal Component Analysis for NSF-WQI for four sub-watershed in the Mahoning River Watershed.

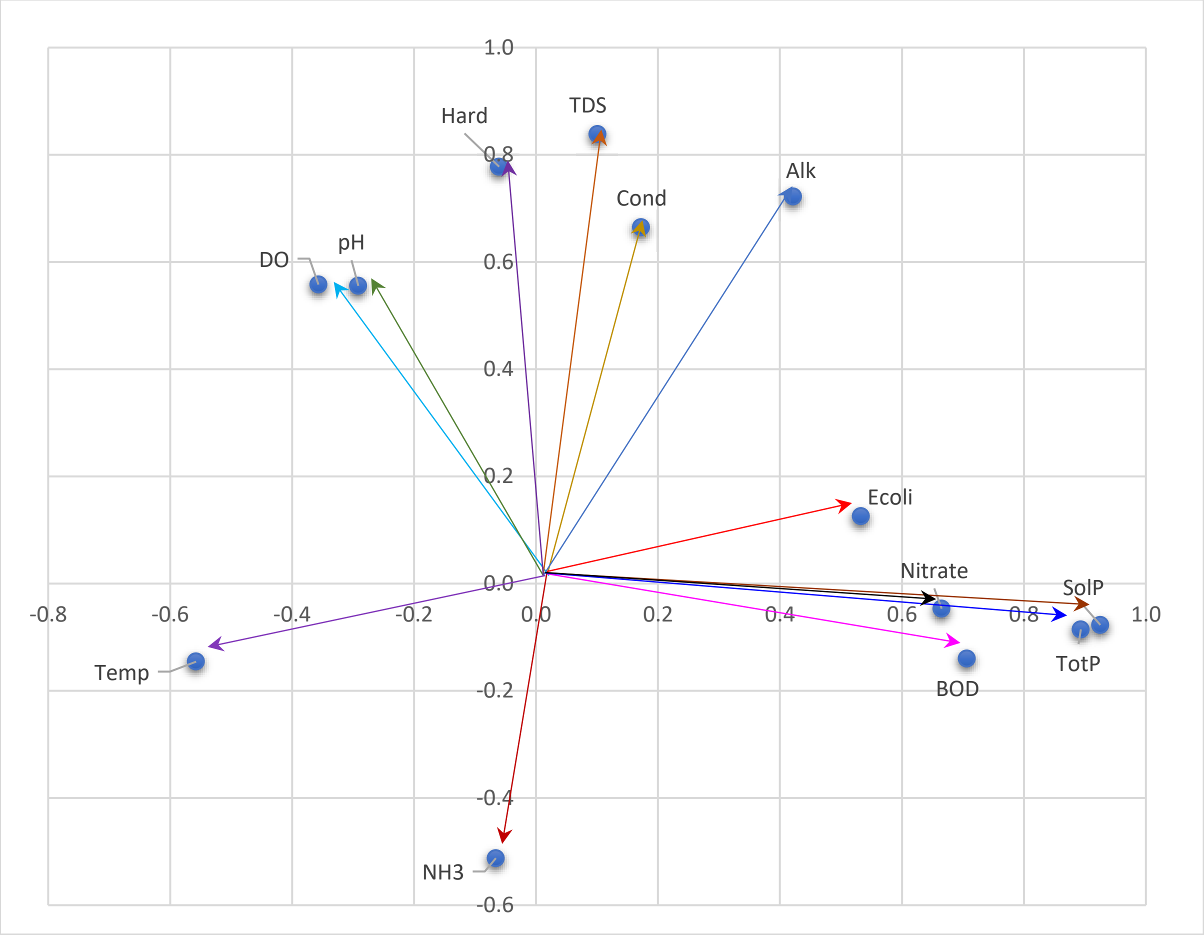


Figure IV-8. Principal component analysis loading plot of the water quality variables.

V. Chapter: Discussions

Since the sampling took place during low flow conditions, not much difference was seen in the NSF-WQI calculations. This trend was further seen during PCA plots as there was a weak depiction of water quality variables to NSF-WQI of the sub-watersheds.

In Meander Creek, agriculture and residential land cover types had some of the highest WQI (Table IV-5). Meander Creek's overall higher WQI can be attributed to these two high WQI. A possible reason for the creek's higher water quality could be the large land cover of deciduous forest and minimal developed area including both high and low intensity (Figure III-4). Dissolved oxygen values ranged from 7.71 mg/L to 11.25 mg/L and 7.4 mg/L to 10.58 mg/L for agriculture and residential respectively (Appendix I). Low values of DO, such as less than 4 mg/L cannot support desirable aquatic life. Dissolved oxygen levels at 5 mg/L or above is a desired level that will support many types of aquatic life (FELC, 2019). DO values for agriculture and residential are well above 5 mg/L. Another factor in the WQI determination that had a large influence was the *E. coli* counts. Although this water is not used for recreational activity, *E. coli* values were consistently lower in this watershed (Appendix I). DO and *E. coli* are the highest weighted parameter for the NSF-WQI, so their values have a significant impact on the overall WQI of a particular creek.

Crab Creek has a high degree of development in the watershed especially in the southern and western parts (Figure III-5). Overall Crab Creek has a lower WQI compared to the other Creeks which could be attributed to the agricultural site which has the lowest WQI in this study. (Table IV-1). Agricultural areas are usually affected by parameters like nitrogen and phosphates and can cause quality problems when they enter water systems. Nitrogen, in the form of nitrate, is easily soluble and is transported in runoff, in tile drainage, and with leachate. Nitrogen and phosphates can accelerate algal production in receiving surface water, resulting in a variety of problems including clogged pipelines, fish kills, and reduced recreational opportunities (USGS, 2019). Phosphates (and other contaminants) from manure are an increasing concern given the recent trend towards larger, more specialized beef, dairy, swine, and poultry operations (USDA, 1995). The total phosphates WQI values for agricultural site are ranged 0.139 mg/L to 1.037 mg/L which is high as compared with other land types. DO values are also low with a WQI range of 4.1 mg/L to 5.85 mg/L (Appendix I). Both these parameters along with *E.coli* which values at more than 2400 MPN/100ml, had the biggest influence on the agriculture land site low WQI.

In Lower Mosquito Creek land cover site of residential has the highest WQI of 72 which is also the highest in this study and lowest in this sub-watershed is commercial with WQI of 66. This sub-watershed had the highest WQI as compared to other creeks (Table IV-1) while Meander also had almost the same value. One of the possible reasons for this watershed's higher index value could be the absence of industrial land site. Dissolved oxygen values ranged from 3.82mg/L to 8.64 mg/L. The lowest DO values belonged to one commercial site with 3.82mg/L and another for residential with 3.99 mg/L. *E. coli* ranged from 8.1 MPN/100mL to 236.3 MPN/100ml (Appendix I). The DO levels had a significant impact in somewhat lowering the WQI in both commercial and residential and hence slightly pulling down the overall WQI of the watershed since DO has a high weightage in NSF-WQI.

Yellow Creek had a moderate or medium NSF-WQI (between 50-69). All the land cover types in this creek have almost the same water quality index (Table IV-1). One of the reasons for the creek's water quality could be with the history of industrial activity in the northern portion of the watershed and agricultural activity in the southern portion which could have deteriorated the water quality over time (Figure III-7). The *E. coli* values have a large range in values from 20.5MPN/100mL to 1485 MPN/100mL the highest level exceeds the maximum allowable limit of 1030 MPN/100mL for secondary contact recreation, but the lower levels are in range for both secondary and primary contact for activities such as swimming or boating. DO values also ranged from 5.73mg/L to 10.02mg/L which is an ideal range since below 4mg/L cannot sustain desired aquatic life. Also, the creek has a higher level of TDS than the other creeks ranging from 340mg/L to 1445 mg/L (Appendix I) which could be directly a result of the industrial activity in the past.

The data accept and support the hypothesis that states, water quality as evaluated by the NSF-WQI will be only modestly linked to patterns of land use immediately adjacent to sampling sites, and in the watershed upstream.

The water quality index (WQI) has emerged as a central way to convey water quality information to policy makers and the general public. NSF-Water Quality Index provides a single number to reflect multiple physio-chemical parameters. This single number makes it understandable for the public and others to compare water quality. One drawback is that the WQI is only as good as the number of samples that are used to determine the value. Although this study used four sampling times and four to five locations in each watershed during low flow or baseline conditions, therefore it does not include the entire watershed. Further sampling is needed in more locations and after rainfall to determine runoff effects to better understand the surface water conditions and the NSF-WQI values obtained for this study. Post rainfall sampling when runoff waters are high, may get better indication of land cover effects. At any point in future, the NSF-WQI results or individual water quality parameters from this study can be compared. Some of the general ways to improve water quality include combined surface overflow, shoreline (undercutting, etc.), modifications and improvements to riparian area.

VI. Chapter: Conclusion

Four sub-watersheds have an overall NSF-WQI range of 64 to 70 which according to NSF-WQI (50-69) puts them in medium and (70-89) in good range. Lower Mosquito Creek water quality index is good (70) while Meander Creek is borderline good (68) whereas Yellow Creek and Crab Creek are both medium with (67) and (64), respectively. The higher WQI of Meander Creek and Lower Mosquito could be due to the lower amount of developed land cover (both medium and high) and larger land cover of deciduous forest. Low WQI of Crab Creek and Yellow Creek is potentially due to the thriving industrial activity both currently and from past activity and the associated higher amount of developed land cover (both medium and high) which negatively affected the water quality. The highest WQI for a land site was for residential in Lower Mosquito Creek with a water quality index value of 72 and the lowest was for agriculture in Crab Creek with 53. DO and *E. coli* values played a important role in shaping the overall WQI of the watersheds as they have a highest weightage than other parameters in NSF-WQI.

It is fair to say that there is an immense pressure on water resources and the systems pertaining to it due to fast changes happening such as urbanization, population growth, socioeconomic change, energy needs, and climate change. The index presented in this study does not provide us with solutions to the problems relating directly to the human health or any kind of aquatic life regulations but gives us a simple indication of water quality of a particular waterbody as the water index is based on some important water parameters. It also helps non-technical people understand the situation of a particular waterbody. It is recommended to expand the sampling to more sites on the four sub-watersheds and sampling post precipitation might give better indication of the influence of different land cover.

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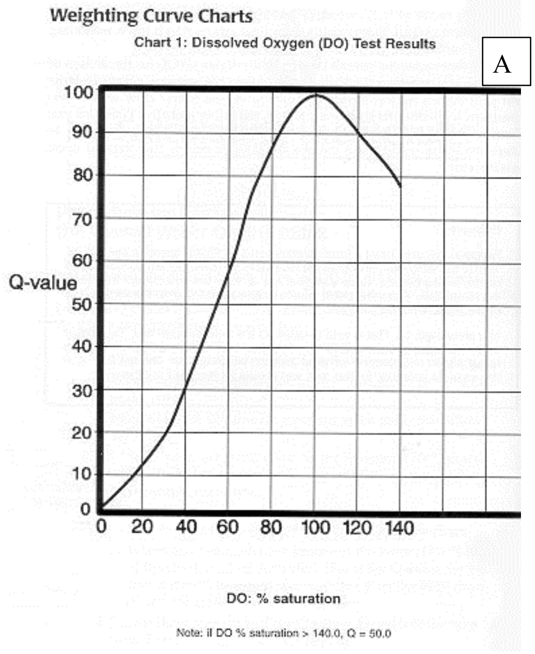
Appendix I

Qi value charts of the water parameters for calculation of the NSF-WQI.

A



Weighting Curve Charts

Chart 1: Dissolved Oxygen (DO) Test Results

Note: if DO % saturation > 140.0, Q = 50.0

B

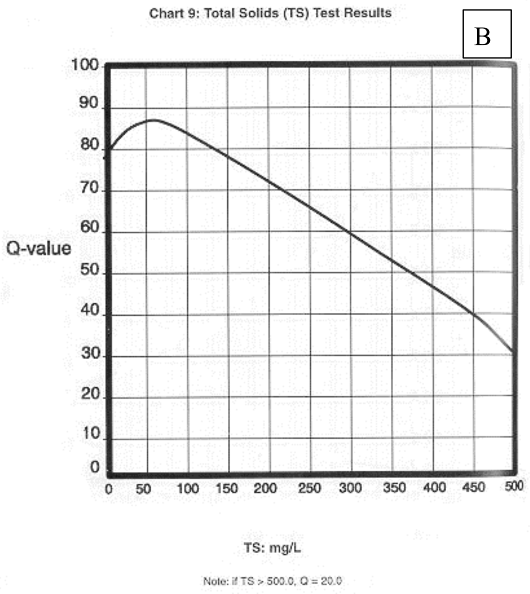


Chart 9: Total Solids (TS) Test Results

Note: if TS > 500.0, Q = 20.0

C

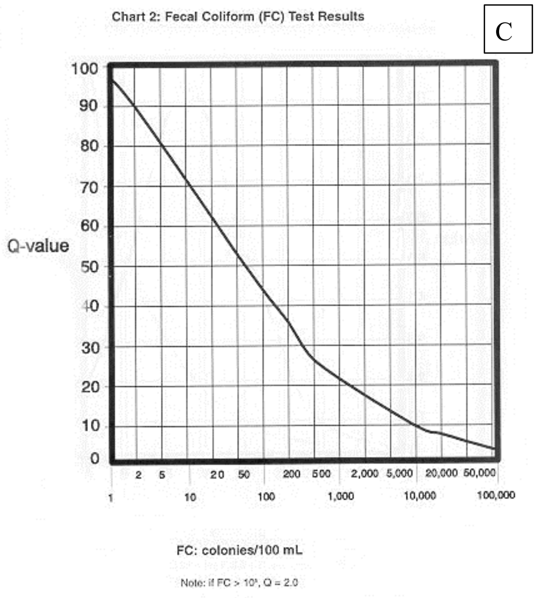


Chart 2: Fecal Coliform (FC) Test Results

Note: if FC > 10^5, Q = 2.0

D

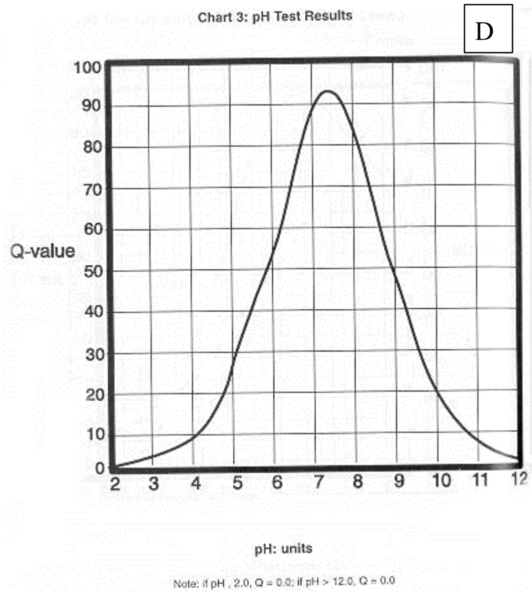
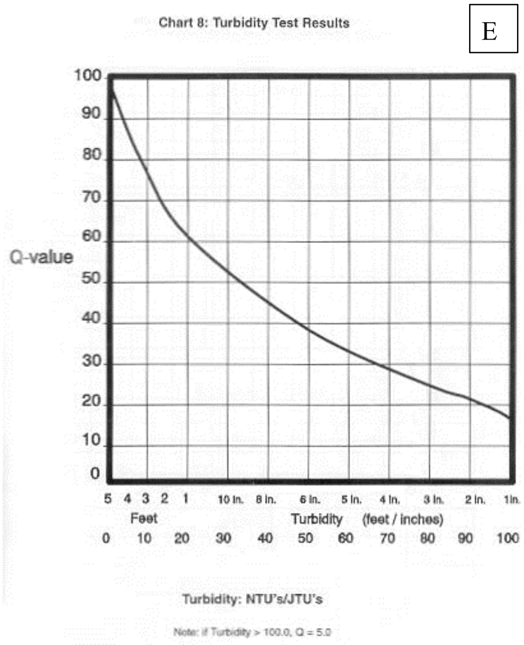
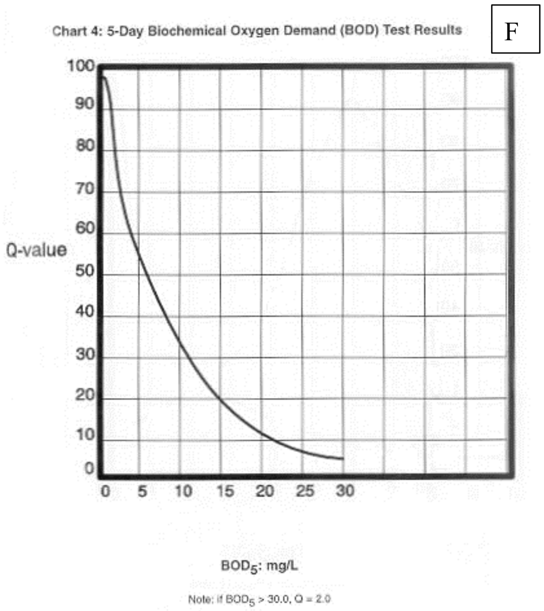


Chart 3: pH Test Results

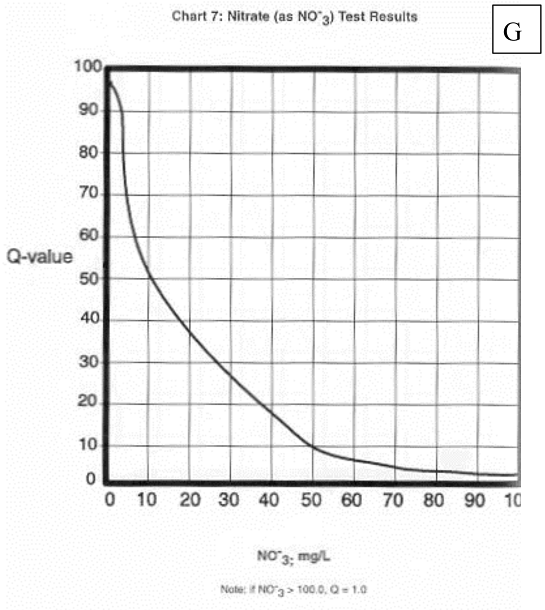
Note: if pH , 2.0, Q = 0.0; if pH > 12.0, Q = 0.0



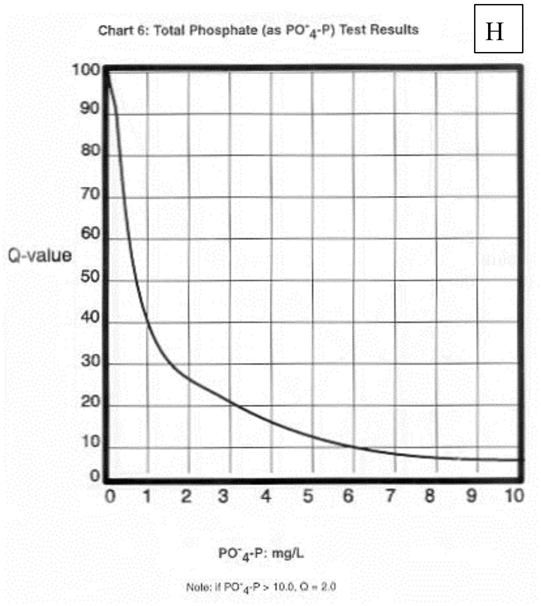
E



F



G



H

Figures A-H, graphical water quality parameters for each value used in determining the Q-value for NSF-WQI (Available from….) https://www.engineering.iastate.edu/~dslutz/dmrwqn/water_quality_index_calc.htm

Raw data from May-August 2021

Meander Creek raw data

Watershed	Date of Collection	Landuse type	Average Alkalinity, mg/L	Average Hardness, mg/L	Weather conditions	Cond., uS/cm	Average Ammonia, mg/L	Flow rate	Averages Sol P, mg/L	Average TP, mg/L	Average Nitrate, mg/L	Average BOD, mg/L	Average TDS, mg/L	pH	Water Temp., °C	DO, mg/L	DO sat(%)	E.coli Average , MPN/10
Meander Creek	22-May-21	Agriculture	110	184	81/ outcast	766.9	0.084	13.05 sec/1m	0.014	0.000	1.222	NA	369	7.47	19.2	8.69	94.02	316.5
Meander Creek	29-Jun-21	Agriculture	152	256	90/ sunny	448.5	0.069	>0.01 sec/1m	0.014	0.016	0.168	2.34	490	7.95	26	11.25	138.69	37.8
Meander Creek	15-Jul-21	Agriculture	100	92	90/sunny	250	0.032	5.39	0.070	0.038	0.407	1.54	361	8.19	22.4	7.71	88.85	178.7
Meander Creek	10-Aug-21	Agriculture	142	148	rainy	332.4	0.050		0.043	0.038	0.015	1.26	346	7.95	21.7	8.08	91.86	356.4
Meander Creek	22-May-21	Forest	130	174	81/ outcast	416.9	0.093	little to no flow	0.017	0.000	1.377	NA	311	7.37	19.3	5.74	62.23	43
Meander Creek	29-Jun-21	Forest	171	236	90/ sunny	397.3	0.055	little to no flow	0.012	0.005	0.008	2.57	448	7.72	21.6	5.4	61.27	120
Meander Creek	15-Jul-21	Forest	107	104	90/sunny	268.9	0.066	little to no flow	0.060	0.071	1.254	2.42	399	8.05	20.4	4.62	51.09	54.05
Meander Creek	10-Aug-21	Forest	171	220	rainy	410	0.159	little to no flow	0.031	0.023	0.010	2.98	409	7.8	20.1	4.26	46.93	147.3
Meander Creek	22-May-21	Industrial	221	168	81/ outcast	564	0.212	11.96 sec/1m	0.062	0.037	4.431	NA	673	7.68	16	7.38	74.73	80.15
Meander Creek	29-Jun-21	Industrial	257	148	90/ sunny	736	0.113	little to no flow	0.173	0.198	3.695	2.76	641	8.27	21.5	8.5	96.26	20.3
Meander Creek	15-Jul-21	Industrial	101	88	90/sunny	366.8	0.093	little to no flow	0.022	0.016	0.462	1.75	392	8.52	24.2	7.15	85.26	51.1
Meander Creek	10-Aug-21	Industrial	244	142	rainy	698	0.072	little to no flow	0.078	0.034	1.395	2.33	641	8.23	20.2	5.91	65.24	580.3
Meander Creek	22-May-21	Residential	67	432	81/ outcast	774	0.092	15.09 sec/1m	0.009	0.000	0.580	NA	791	7.03	17.4	10.58	110.33	78.15
Meander Creek	29-Jun-21	Residential	81	586	90/ sunny	732	0.012	5.19 sec/1m	0.010	0.001	0.205	1.36	971	7.79	22.1	8.47	97.04	481.9
Meander Creek	15-Jul-21	Residential	108	240	90/sunny	426.4	0.014	12.48	0.020	0.005	0.988	0.59	496	7.19	20.3	8.75	96.78	889.3
Meander Creek	10-Aug-21	Residential	86	434	rainy	591	0.042	4.84	0.045	0.023	0.148	1.02	744	7.34	19.7	7.4	80.87	555

Crab Creek raw data

Watershed	Date of Collection	Landuse type	Average Alkalinity, mg/L	Average Hardness, mg/L	Weather conditions	Cond., uS/cm	Average Ammonia, mg/L	Flow rate	Averages Sol P, mg/L	Average TP, mg/L	Average Nitrate, mg/L	Average BOD, mg/L	Average TDS, mg/L	pH	Water Temp., °C	DO, mg/L	DO sat(%)	E.coli Average, MPN/100 ml
Crab Creek	23-May-21	Agriculture	240	194	81/ outcast	873	0.021	NDF	0.905	1.037	2.495	4.62	629	7.08	16.5	4.94	50.56	>1715.4
Crab Creek	13-Jun-21	Agriculture	204	136	90/ sunny	1102	0.004	NDF	0.66	0.579	1.346	14.4	771	7.36	18.7	4.1	43.91	>2419.6
Crab Creek	11-Jul-21	Agriculture	96	72	90/sunny	641	0.000	NDF	0.205	0.311	1.059	3.12	280	7.04	18.4	4.69	49.93	>2419.6
Crab Creek	22-Aug-21	Agriculture	130	144	rainy	767	0.079	NDF	0.090	0.139	0.086	2.99	284	7.21	22.2	5.85	67.15	248.5
Crab Creek	23-May-21	Commercial	206	224	81/ outcast	659	0.183	14.78	0.014	0.022	0.352	NA	496	8.39	20.6	10.05	111.82	876.3
Crab Creek	13-Jun-21	Commercial	150	148	90/ sunny	397.9	0.044	11.6	0.04	0.069	0.275	1.76	445	7.99	19.9	9.36	102.7	>2419.6
Crab Creek	11-Jul-21	Commercial	181	172	90/sunny	399.7	0.073	13.47	0.027	0.024	0.229	2.94	403	8.42	17.5	8.3	86.74	>2419.6
Crab Creek	22-Aug-21	Commercial	164	168	rainy	2742	0.015	13.73	0.080	0.094	0.265	1.20	618	8.93	20.1	12.51	137.82	106.35
Crab Creek	23-May-21	Forest	162	164	81/ outcast	460.4	0.058	High: 1.0 Low: 8.8	0.015	0.029	0.807	NA	223	8.46	19.2	13.76	148.88	91.7
Crab Creek	13-Jun-21	Forest	190	172	90/ sunny	430.1	0.000	High: 0.6 Low: 0.1	0.088	0.087	0.612	1.81	466	8.01	19.3	9.4	101.91	2076.3
Crab Creek	11-Jul-21	Forest	168	142	90/sunny	359.4	0.006	High: 0.4 Low: 0.1	0.043	0.044	0.757	0.85	390	7.94	16.6	5.09	52.2	456.45
Crab Creek	22-Aug-21	Forest	174	154	rainy	2140	0.014	High: 0.5 Low: 0.1	0.115	0.090	0.359	0.84	448	8.59	18.9	8.93	96.04	139.65
Crab Creek	23-May-21	Industrial	196	206	81/ outcast	558	0.030	6.98	0.014	0.227	0.549	NA	413	8.25	19.7	11.71	127.98	887
Crab Creek	13-Jun-21	Industrial	142	130	90/ sunny	353.7	0.100	0.3	0.039	0.067	0.440	2.94	371	7.9	19.5	8.78	95.57	>2419.6
Crab Creek	11-Jul-21	Industrial	195	178	90/sunny	387.3	0.069	<0.01m/s	0.028	0.027	0.447	2.05	372	8.22	17	8.91	92.15	1769.7
Crab Creek	22-Aug-21	Industrial	158	184	rainy	2256	0.007	0.1 m/s	0.074	0.059	0.101	0.84	491	8.76	18.7	9.61	102.93	138.15
Crab Creek	23-May-21	Residential	138	114	81/ outcast	418.7	0.039	7.86	0.047	0.079	0.921	NA	208	7.66	22.1	5.36	61.41	649.9
Crab Creek	13-Jun-21	Residential	165	144	90/ sunny	416	0.002	0.1 m/s	0.077	0.061	0.277	2.14	387	7.68	22.4	6.3	72.6	1119.2
Crab Creek	11-Jul-21	Residential	121	90	90/sunny	294.4	0.000	<0.01 m/s	0.083	0.121	0.425	2.38	270	7.88	19.9	5.92	64.96	46.55
Crab Creek	22-Aug-21	Residential	156	128	rainy	1380	0.055	0.1 m/s	0.188	0.185	0.171	1.71	383	8.08	21.8	7.48	85.2	107.05

Yellow Creek raw data

Watershed	Date of Collection	Landuse type	Average Alkalinity, mg/L	Average Hardness, mg/L	Weather conditions	Cond., uS/cm	Average Ammonia, mg/L	Flow rate	Averages Sol P, mg/L	Average TP, mg/L	Average Nitrate, mg/L	Average BOD, mg/L	Average TDS, mg/L	pH	Water Temp., °C	DO, mg/L	DO sat(%)	E.coli Average, MPN/100 ml
Yellow Creek	6-Jun-21	Agriculture	211	586	Clear/Warm	723	0.000	6.78	0.031	0.000	0.921	1.13	1179	7.24	17.7	9.38	101.9	583
Yellow Creek	7/7/2021	Agriculture	272	544	Clear/Warm	982	0.033	25.5	0.010	0.046	0.072	0.81	1445	7.82	20.3	5.73	63.38	175.2
Yellow Creek	July-28-2021	Agriculture	204	532	loudy/War	770	0.127	0	0.034	0.047	0.074	0.25	939	7.92	21.4	7.5	84.77	141.4
Yellow Creek	ugust -23-202	Agriculture	144	480	Clear/Hot	754.5	0.086	7.1	0.009	0.047	0.112	2.91	932	8	22.4	6.43	74.1	274.95
Yellow Creek	6-Jun-21	Commercial	151	380	Clear/Warm	672	0.056	3.5	0.035	0.000	0.942	0.84	867	7.89	20.3	8.91	98.55	388
Yellow Creek	7/7/2021	Commercial	172	344	Clear/Warm	683	0.060	7.21	0.027	0.054	0.166	0.91	732	8.45	22.2	7.43	85.29	893.6
Yellow Creek	July-28-2021	Commercial	176	296	loudy/War	667	0.048	17.9	0.039	0.047	0.150	5.33	679	8.67	23.1	8.71	101.72	27.5
Yellow Creek	ugust -23-202	Commercial	104	124	Clear/Hot	760.9	0.046	9.12	0.006	0.047	0.293	1.69	351	8.99	24.4	6.44	77.08	805.8
Yellow Creek	6-Jun-21	Forest	134	498	Clear/Warm	738	0.047	10.08	0.031	0.000	0.807	1.93	999	7.65	20.5	7.87	87.39	156.9
Yellow Creek	July- 7-2021	Forest	178	356	Clear/Warm	846	0.049	29.65	0.024	0.069	0.251	0.81	1021	8.34	21.8	6.49	73.93	531.6
Yellow Creek	July-28-2021	Forest	187	570	loudy/War	863	0.043	0	0.059	0.086	0.062	3.56	1124	8.4	22.3	8.25	94.89	617.1
Yellow Creek	ugust -23-202	Forest	246	536	Clear/Hot	755.6	0.127	0	0.010	0.037	0.621	2.16	1132	8.54	21.3	6.01	67.8	292.5
Yellow Creek	6-Jun-21	Industrial	126	238	Clear/Warm	502	0.030	15.3	0.029	0.000	0.590	1.27	634	8.25	20.5	10.02	111.27	90
Yellow Creek	July- 7-2021	Industrial	112	224	Clear/Warm	469.7	0.109	0	0.093	0.125	1.053	2.19	466	8.27	21.9	6.98	79.66	101.2
Yellow Creek	July-28-2021	Industrial	119	124	loudy/War	390.2	0.070	0	0.042	0.067	0.469	1.87	520	8.6	20.4	7	77.58	68.25
Yellow Creek	ugust -23-202	Industrial	107	128	Clear/Hot	760.1	0.037	0	0.004	0.056	0.268	1.51	340	8.71	21.7	6.23	70.83	1485
Yellow Creek	6-Jun-21	Residential	125	240	Clear/Warm	492.8	0.061	5.8	0.031	0.000	0.787	1.24	652	8.16	20	9.88	108.63	126.1
Yellow Creek	July- 7-2021	Residential	124	248	Clear/Warm	485.1	0.052	21.86	0.024	0.041	0.233	0.79	579	8.56	23.4	8.17	95.96	767.3
Yellow Creek	July-28-2021	Residential	118	124	loudy/War	355.5	0.054	17	0.044	0.072	0.338	1.14	678	8.83	22.7	8.35	96.78	20.45
Yellow Creek	ugust -23-202	Residential	174	360	Clear/Hot	756.6	0.032	23	0.017	0.073	0.126	1.63	819	8.82	23.7	7.66	90.48	214.45

Lower Mosquito Creek raw data

Watershed	Date of Collection	Landuse type	Average Alkalinity, mg/L	Average Hardness, mg/L	Weather conditions	Cond., uS/cm	Average Ammonia, mg/L	Flow rate	Averages Sol P, mg/L	Average TP, mg/L	Average Nitrate, mg/L	Average BOD, mg/L	Average TDS, mg/L	pH	Water Temp., °C	DO, mg/L	DO sat(%)	E.coli Average MPN/100 ml
Lower Mosquito Creek	7-Jun-21	Commercial	101	80	unny, 80-85	337.1	0.223	17.87 m/s	0.314	0.246	2.070	4.08	220.9	7.22	20.1	3.99	44.0	196.2
Lower Mosquito Creek	7/25/2021	Commercial	72	40	Sunny, 84°F	177.9	0.061	5.81 m/s	0.039	0.065	0.200	0.92	195.3	7	22	5.06	57.9	132.5
Lower Mosquito Creek	8/23/2021	Commercial	86	44	cloudy, 75	143.4	0.165	7.48 m/s	0.063	0.126	0.527	1.95	159.4	7.13	22.7	5.01	58.1	236.3
Lower Mosquito Creek	9/12/2021	Commercial	80	60	Sunny, 81°F	257.1	0.080	7.98 m/s	0.052	0.101	0.446	1.75	114.2	8.06	20.3	6.22	68.8	87.0
Lower Mosquito Creek	7-Jun-21	Forest	105	86	unny, 80-85	189.8	0.188	22.72 m/s	0.029	0.126	1.470	2.68	191.9	7.25	18.7	5.73	61.4	224.9
Lower Mosquito Creek	7/25/2021	Forest	72	32	Sunny, 84°F	172.1	0.120	2.72 m/s	0.016	0.025	0.042	1.01	214.7	7.12	22.7	6.2	71.9	45.7
Lower Mosquito Creek	8/23/2021	Forest	74	48	cloudy, 75	124	0.082	3.57 m/s	0.001	0.045	0.099	1.86	137.6	7.34	23.7	6.28	74.2	91.5
Lower Mosquito Creek	9/12/2021	Forest	78	40	Sunny, 81°F	213.3	0.072	7.03 m/s	0.023	0.050	0.035	1.90	81.4	8.32	21	7.2	80.7	92.7
Lower Mosquito Creek	7-Jun-21	Residential	71	52	unny, 80-85	149.8	0.044	15.62 m/s	0.008	0.002	0.880	4.00	165.4	6.9	16.7	8.62	88.6	19.8
Lower Mosquito Creek	7/25/2021	Residential	72	36	Sunny, 84°F	170.5	0.101	3.65 m/s	0.016	0.008	0.052	1.10	187.3	7.14	23.3	7.85	92.0	8.1
Lower Mosquito Creek	8/23/2021	Residential	90	36	cloudy, 75	123.9	0.080	4.37 m/s	0.027	0.027	0.015	1.92	121.8	7.24	23.9	6.9	81.8	29.2
Lower Mosquito Creek	9/12/2021	Residential	78	38	Sunny, 81°F	215.5	0.059	18.91 m/s	0.027	0.073	0.025	2.64	93.6	8.82	21.4	7.9	89.3	42.8
Lower Mosquito Creek	7-Jun-21	Residential	70	38	unny, 80-85	349.7	0.330	8.83 m/s	0.187	0.020	0.497	3.24	253.3	7.3	21	3.82	42.8	229.6
Lower Mosquito Creek	7/25/2021	Residential	74	36	Sunny, 84°F	178.5	0.053	1.66 m/s	0.043	0.068	0.176	1.30	182.2	6.98	22.1	5.5	63.0	132.5
Lower Mosquito Creek	8/23/2021	Residential	63	44	cloudy, 75	145.2	0.115	5.21 m/s	0.054	0.126	0.198	2.12	167.9	7.18	22.7	5.96	69.1	165.9
Lower Mosquito Creek	9/12/2021	Residential	84	64	Sunny, 81°F	252	0.006	6.69 m/s	0.045	0.119	0.321	1.83	147.4	8.25	20.6	8.64	96.1	171.3

Qi values of all parameters for all land cover types of all four sub-watersheds

Meander Creek - Agriculture site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	98	17	79	13	94	16	96	16	16±1
Fecal Coliform	0.16	33	5	56	9	38	6	32	5	6±2
pH	0.11	93	10	86	9	77	8	86	9	9±1
BOD	0.11	100	11	73	8	89	10	92	10	10±1
Temperature	0.1	23	2	14	1	18	2	19	2	2±0
Total Phosphate	0.1	99	10	99	10	97	10	98	10	10±0
Nitrate	0.1	96	10	97	10	97	10	97	10	10±0
Total Solids	0.07	51	4	33	2	52	4	54	4	3±1
Turbidity	0.08*									
Total WQI	0.92		75		69		71		72	71±2
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Meander Creek - Industrial site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	81	14	99	17	91	15	66	11	14±2
Fecal Coliform	0.16	47	8	63	10	52	8	27	4	8±2
pH	0.11	91	10	74	8	66	7	76	8	8±1
BOD	0.11	100	11	68	7	85	9	73	8	9±2
Temperature	0.1	29	3	19	2	16	2	21	2	2±1
Total Phosphate	0.1	98	10	92	9	99	10	97	10	10±0
Nitrate	0.1	68	7	76	8	97	10	96	10	8±1
Total Solids	0.07	20	1	20	1	48	3	20	1	2±1
Turbidity	0.08*									
Total WQI	0.92		69		68		71		59	67±5
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Meander Creek - Residential site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	95	16	99	17	99	17	88	15	16±1
Fecal Coliform	0.16	47	8	29	5	23	4	28	4	5±2
pH	0.11	89	10	90	10	92	10	93	10	10±0
BOD	0.11	100	11	91	10	97	11	95	10	11±0
Temperature	0.1	27	3	19	2	21	2	22	2	2±0
Total Phosphate	0.1	100	10	100	10	99	10	98	10	10±0
Nitrate	0.1	96	10	97	10	98	10	97	10	10±0
Total Solids	0.07	20	1	20	1	32	2	20	1	2±0
Turbidity	0.08*									
Total WQI	0.92		74		70		71		69	71±2
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Meander Creek - Forest site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	60	10	59	10	45	8	40	7	9±2
Fecal Coliform	0.16	54	9	42	7	51	8	40	6	7±1
pH	0.11	93	10	91	10	82	9	90	10	10±1
BOD	0.11	100	11	70	8	72	8	67	7	8±2
Temperature	0.1	23	2	19	2	21	2	21	2	2±0
Total Phosphate	0.1	99	10	99	10	97	10	99	10	10±0
Nitrate	0.1	96	10	97	10	96	10	97	10	10±0
Total Solids	0.07	58	4	40	3	47	3	45	3	3±1
Turbidity	0.08*									
Total WQI	0.92		72		64		62		60	65±5
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Crab Creek - Agriculture site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	44	7	35	6	44	7	70	12	8±3
Fecal Coliform	0.16	19	3	17	3	17	3	35	6	4±1
pH	0.11	90	10	93	10	89	10	92	10	10±0
BOD	0.11	58	6	22	2	66	7	67	7	6±2
Temperature	0.1	28	3	24	2	25	3	19	2	2±0
Total Phosphate	0.1	39	4	52	5	80	8	94	9	7±3
Nitrate	0.1	93	9	96	10	96	10	97	10	10±0
Total Solids	0.07	20	1	20	1	62	4	62	4	3±2
Turbidity	0.08*									
Total WQI	0.92		48		43		56		66	53±10
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Crab Creek - Commercial site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	95	16	99	17	92	16	79	13	16±1
Fecal Coliform	0.16	23	4	17	3	17	3	43	7	4±2
pH	0.11	70	8	84	9	68	7	51	6	8±1
BOD	0.11	100	11	85	9	67	7	93	10	9±2
Temperature	0.1	21	2	22	2	26	3	22	2	2±0
Total Phosphate	0.1	99	10	97	10	99	10	96	10	10±0
Nitrate	0.1	97	10	97	10	97	10	97	10	10±0
Total Solids	0.07	32	2	41	3	46	3	20	1	2±1
Turbidity	0.08*									
Total WQI	0.92		68		68		64		64	66±2
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Crab Creek - Forest site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	50	9	99	17	47	8	99	17	13±5
Fecal Coliform	0.16	62	10	18	3	29	5	41	7	6±3
pH	0.11	68	7	84	9	84	9	63	7	8±1
BOD	0.11	100	11	84	9	96	11	96	11	10±1
Temperature	0.1	23	2	23	2	28	3	25	3	2±0
Total Phosphate	0.1	99	10	96	10	98	10	95	10	10±0
Nitrate	0.1	96	10	96	10	96	10	97	10	10±0
Total Solids	0.07	70	5	37	3	48	3	40	3	3±1
Turbidity	0.08*									
Total WQI	0.92		69		68		63		71	68±3
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Crab Creek - Industrial site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	85	14	98	17	97	16	99	17	16±1
Fecal Coliform	0.16	23	4	17	3	19	3	41	7	4±2
pH	0.11	75	8	84	9	75	8	57	6	8±1
BOD	0.11	100	11	67	7	79	9	96	11	9±2
Temperature	0.1	22	2	24	2	27	3	24	2	2±0
Total Phosphate	0.1	89	9	97	10	99	10	97	10	10±0
Nitrate	0.1	96	10	97	10	97	10	97	10	10±0
Total Solids	0.07	45	3	50	4	50	4	33	2	3±1
Turbidity	0.08*									
Total WQI	0.92		67		67		68		70	68±2
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Crab Creek - Residential site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	WQI± SD
Dissolved Oxygen	0.17	59	10	78	13	66	11	91	15	12±2
Fecal Coliform	0.16	26	4	21	3	53	8	43	7	6±2
pH	0.11	91	10	91	10	88	10	81	9	10±1
BOD	0.11	100	11	77	8	72	8	85	9	9±1
Temperature	0.1	19	2	18	2	22	2	19	2	2±0
Total Phosphate	0.1	97	10	97	10	95	10	95	10	10±0
Nitrate	0.1	96	10	97	10	97	10	97	10	10±0
Total Solids	0.07	71	5	48	3	63	4	49	3	4±1
Turbidity	0.08*									
Total WQI	0.92		67		65		69		71	68±3
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Lower Mosquito Creek - Commercial site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	WQI± SD
Dissolved Oxygen	0.17	36	6	54	9	55	9	73	12	9±3
Fecal Coliform	0.16	38	6	41	7	36	6	46	7	6±1
pH	0.11	92	10	88	10	91	10	82	9	10±0
BOD	0.11	61	7	95	10	81	9	85	9	9±2
Temperature	0.1	22	2	19	2	18	2	21	2	2±0
Total Phosphate	0.1	87	9	97	10	95	10	96	10	9±0
Nitrate	0.1	95	10	97	10	96	10	97	10	10±0
Total Solids	0.07	70	5	73	5	78	5	82	6	5±0
Turbidity	0.08*									
Total WQI	0.92		59		68		66		71	66±5
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Lower Mosquito Creek - Forest site calculation of NSF-WQI index for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	59	10	77	13	80	14	88	15	13±2
Fecal Coliform	0.16	36	6	53	8	45	7	45	7	7±1
pH	0.11	92	10	90	10	93	10	73	8	10±1
BOD	0.11	69	8	95	10	83	9	82	9	9±1
Temperature	0.1	24	2	18	2	17	2	20	2	2±0
Total Phosphate	0.1	95	10	99	10	98	10	98	10	10±0
Nitrate	0.1	96	10	97	10	97	10	97	10	10±0
Total Solids	0.07	74	5	71	5	80	6	85	6	5±0
Turbidity	0.08*									
Total WQI	0.92		65		74		73		72	71±4
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Lower Mosquito Creek - Residential site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	94	16	97	16	88	15	94	16	16±1
Fecal Coliform	0.16	63	10	74	12	59	9	54	9	10±1
pH	0.11	86	9	91	10	92	10	55	6	9±2
BOD	0.11	61	7	94	10	82	9	69	8	8±2
Temperature	0.1	28	3	17	2	17	2	20	2	2±1
Total Phosphate	0.1	100	10	100	10	99	10	97	10	10±0
Nitrate	0.1	96	10	97	10	97	10	97	10	10±0
Total Solids	0.07	77	5	81	6	81	6	84	6	6±0
Turbidity	0.08*									
Total WQI	0.92		76		82		77		71	77±5
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Lower Mosquito Creek - Residential site calculation of NSF-WQI index for all sampling periods (continuation)

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	34	6	62	11	73	12	99	17	11±5
Fecal Coliform	0.16	36	6	41	7	39	6	39	6	6±0
pH	0.11	93	10	88	10	92	10	75	8	10±1
BOD	0.11	66	7	92	10	78	9	83	9	9±1
Temperature	0.1	20	2	19	2	18	2	21	2	2±0
Total Phosphate	0.1	99	10	97	10	95	10	95	10	10±0
Nitrate	0.1	97	10	97	10	97	10	97	10	10±0
Total Solids	0.07	66	5	75	5	77	5	79	6	5±0
Turbidity	0.08*									
Total WQI	0.92		60		69		69		73	68±6
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Yellow Creek - Agriculture site calculation of NSF-WQI index for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	99	17	63	11	91	15	80	14	14±3
Fecal Coliform	0.16	27	4	39	6	41	7	34	5	6±1
pH	0.11	92	10	89	10	86	9	84	9	10±0
BOD	0.11	94	10	96	11	100	11	68	7	10±2
Temperature	0.1	26	3	21	2	20	2	18	2	2±0
Total Phosphate	0.1	99	10	97	10	98	10	98	10	10±0
Nitrate	0.1	96	10	97	10	97	10	97	10	10±0
Total Solids	0.07	20	1	20	1	20	1	20	1	1±0
Turbidity	0.08*									
Total WQI	0.92		71		65		71		64	68±4
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Yellow Creek - Commercial site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	99	17	91	15	99	17	84	14	16±1
Fecal Coliform	0.16	31	5	23	4	59	9	24	4	5±3
pH	0.11	87	10	68	7	60	7	49	5	7±2
BOD	0.11	96	11	96	11	54	6	86	9	9±2
Temperature	0.1	21	2	19	2	18	2	16	2	2±0
Total Phosphate	0.1	99	10	96	10	98	10	98	10	10±0
Nitrate	0.1	96	10	97	10	97	10	97	10	10±0
Total Solids	0.07	20	1	20	1	20	1	53	4	2±1
Turbidity	0.08*									
Total WQI	0.92		71		65		67		63	66±3
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Yellow Creek - Forest site calculation of NSF-WQI for all sampling periods

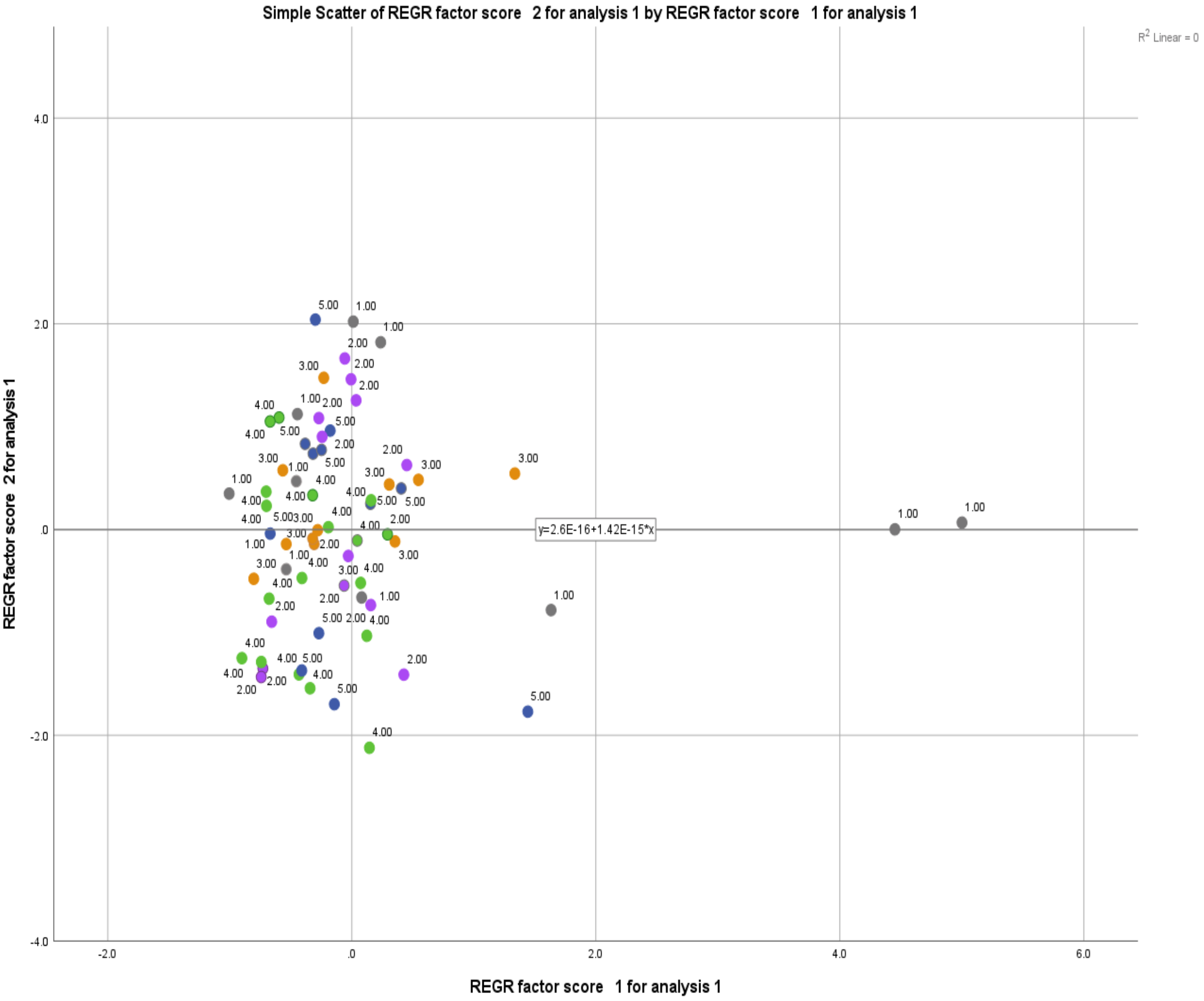
		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	93	16	80	14	98	17	71	12	15±2
Fecal Coliform	0.16	40	6	28	4	27	4	34	5	5±1
pH	0.11	92	10	72	8	70	8	65	7	8±1
BOD	0.11	81	9	96	11	64	7	77	8	9±1
Temperature	0.1	21	2	19	2	19	2	20	2	2±0
Total Phosphate	0.1	99	10	97	10	97	10	99	10	10±0
Nitrate	0.1	96	10	97	10	97	10	96	10	10±0
Total Solids	0.07	20	1	20	1	20	1	20	1	1±0
Turbidity	0.08*									
Total WQI	0.92		70		64		64		61	65±4
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Yellow Creek - Industrial site calculation of NSF-WQI index for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	95	16	87	15	84	14	76	13	15±1
Fecal Coliform	0.16	45	7	44	7	49	8	20	3	6±2
pH	0.11	75	8	74	8	63	7	59	6	7±1
BOD	0.11	97	11	76	8	83	9	90	10	10±1
Temperature	0.1	21	2	19	2	21	2	19	2	2±0
Total Phosphate	0.1	99	10	94	9	97	10	98	10	10±0
Nitrate	0.1	96	10	96	10	97	10	97	10	10±0
Total Solids	0.07	20	1	37	3	20	1	54	4	2±1
Turbidity	0.08*									
Total WQI	0.92		71		67		66		63	67±3
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								

Yellow Creek - Residential site calculation of NSF-WQI for all sampling periods

		22-May-21		29-Jun-21		15-Jul-21		10-Aug-21		Mean WQI± SD
Factors	Weight (wi)	Qi	WQI	Qi	WQI	Qi	WQI	Qi	WQI	
Dissolved Oxygen	0.17	96	16	98	17	99	17	95	16	16±0
Fecal Coliform	0.16	42	7	25	4	63	10	37	6	7±3
pH	0.11	78	9	64	7	54	6	55	6	7±1
BOD	0.11	93	10	96	11	94	10	87	10	10±0
Temperature	0.1	22	2	17	2	18	2	17	2	2±0
Total Phosphate	0.1	99	10	96	10	97	10	97	10	10±0
Nitrate	0.1	96	10	97	10	97	10	97	10	10±0
Total Solids	0.07	20	1	20	1	20	1	20	1	1±0
Turbidity	0.08*									
Total WQI	0.92		71		66		72		65	68±3
		*Turbidity was not recorded therefore totals were corrected to 100 by dividing by 0.92.								



Principal Component Analysis for NSF-WQI for overall land cover of the four sub-watersheds in the Mahoning River Watershed.

Appendix II

Co-ordinates/Location of sampling sites for each creek, categorized by watershed land cover.

	Yellow Creek	Lower Mosquito Creek	Crab Creek	Meander Creek
Residential	17 Lowelville Rd Struthers, OH 44471 41.0543501,-80.5889815 41°03’15.7”N,80°35’20.3”W	Dragon Dr Niles, OH 44446 41.192293,-80.760848	Liberty Township Hubbard,44425 4725-4753 Loganway 41.173538,-80.636713	S. Salem-Warren Rd. Mahoning County 40.985546, -80.855671 40°59’08.0”N, 80°51’20.4”W
Industrial	CASTLO Industrial Park 41.056701, -80.585881 41°03’24.1”N,80°35’09.2”		Landsowne Youngstown , OH 41.123454,-80.634879	S. Main St. Weathersfield Township 41.170501, -80.767112 41°10’13.8”N, 80°46’01.6”W
Commercial	Cortland St. or Green Meadow Pl. 41.021725, -80.610221 41°01’18.3”N,80°36’36.8”W	1801-2321 Park Dr Niles, OH 44446 41.208667,-80.756870	2099-2001 Burning Tree Ln Youngstown , OH 44505 41.155984,-80.624516	
Agriculture	Next to 11818 Woodworth Rd. 40.946626, -80.637963 40°56’38.3”N 80°38’28.9”		2501-2565 Tibbetts Wick Rd Hubbard ,OH 44425 41.188686,-80.634879	10325-9743 Berlin Station Rd, Canfield 41.012332, -80.838980 41°00’44.4”N, 80°50’20.3”W
Forested	Near 1650 Walker Mill Rd 41.002404, -80.620827 40°00’08.7”N,80°37’15.0”	4045-4001 Co Hwy 142 Warren, OH 44484 41.265543,-80.763721	Liberty Township 41.150202,-80.617995	Kirk Rd. (Co Rd 146) North Jackson 41.069238, -80.810060 41°04’09.6”N, 80°48’36.2”W
Residential 2		Warren Meadville Rd. (Alternate: Elm Rd.) (Near 2482-2662 State Rt. 5) 41.297263, -80.757837 41°17’50.2”N, 80°45’28.2”W		

Photos of the Sampling Sites

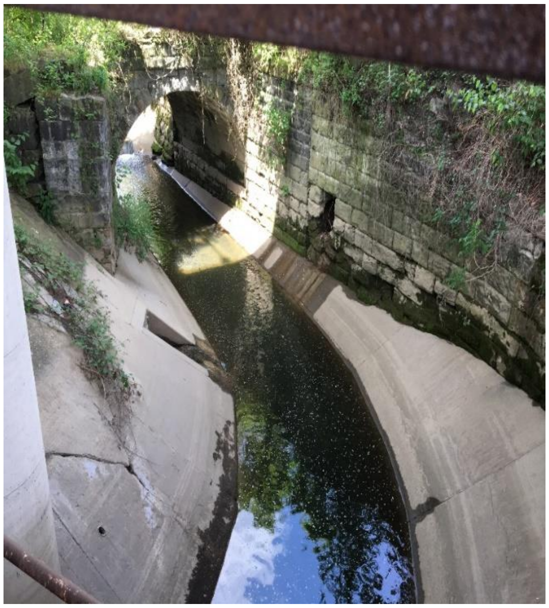
Meander Creek ; Agriculture

Meander Creek ; Forested

Meander Creek ; Industrial

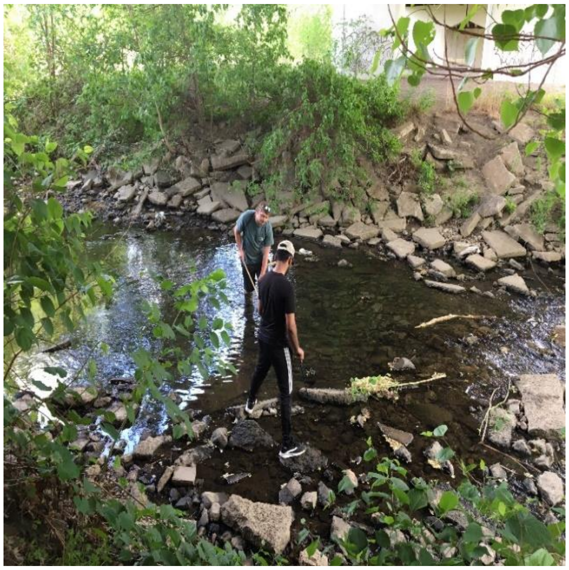
Meander Creek ; Residential

Crab Creek ; Agriculture

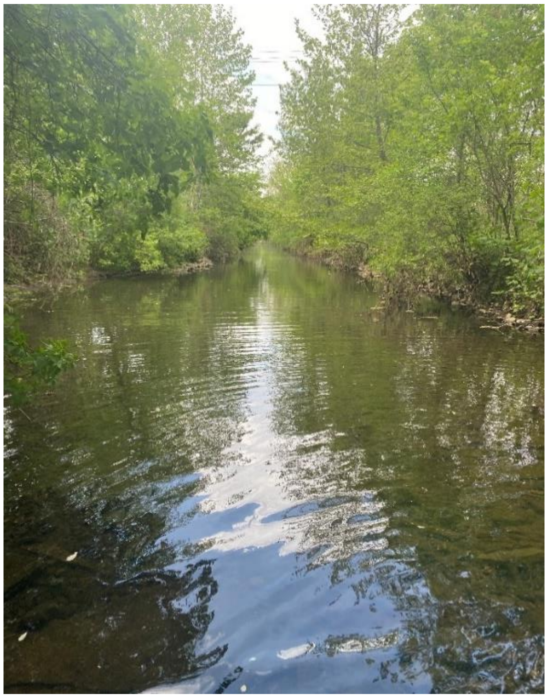


Crab Creek ; Commercial

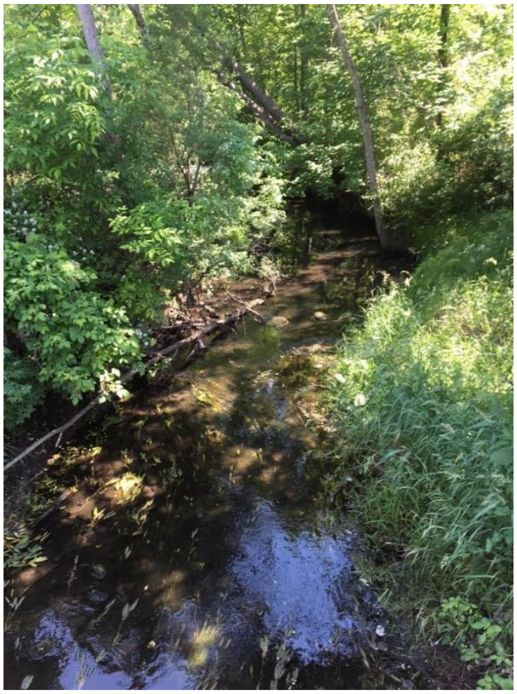
Crab Creek ; Industrial



Crab Creek ; Forested



Crab Creek ; Residential

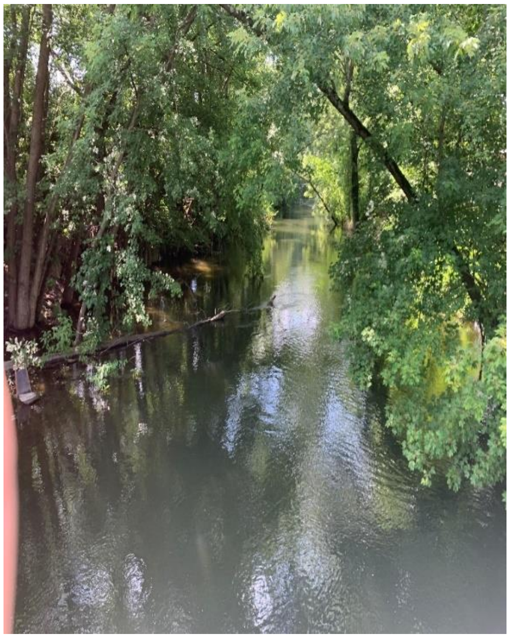


Yellow Creek ; Agriculture

Yellow Creek ; Commercial

Yellow Creek ; Commercial

Lower Mosquito Creek; Commercial



Lower Mosquito Creek ; Residential

Lower Mosquito Creek ; Forest

Lower Mosquito Creek ; Residential