WATER QUALITY IN THE KETTLE CREEK WATERSHED: A SUMMARY OF 1991-1995 CONDITIONS AND TRENDS

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EXECUTIVE SUMMARY

The purpose of this report is to characterize surface water quality and identify key water quality issues within the Kettle Creek watershed. This was accomplished through:

a) Analysis of data from the Provincial Water Quality Monitoring Network (PWQMN), and
b) A review of existing literature.

Although Kettle Creek Conservation Authority has participated in the PWQMN for more than thirty years, a water quality report has never been produced for the watershed. To provide a benchmark indicative of the current water quality conditions found within the Kettle Creek watershed and to identify potential water quality issues, our analysis investigated the most recent five year contiguous set of data, 1991-1995, for which seven monitoring sites could be evaluated. The entire dataset (historical to current) for each of the seven sites was also assessed for preliminary long-term temporal trends where possible.

The watershed was divided into three major study areas: Dodd Creek; Upper Kettle Creek; and, Lower Kettle Creek (Figure 2). While each basin was evaluated and discussed on an individual basis, it is recognized that the areas are not autonomous.

In general, surface water quality within the watershed appears to be negatively affected by increasing summer temperatures (Figure 28), decreasing baseflows (Tim Lanthier, KCCA, pers.communication), potentially low levels of dissolved oxygen, and extensive nutrient and sediment loading.

Lower Kettle Creek and Dodd Creek sub-watersheds are the most impaired regions within the watershed. Water quality appears to progressively deteriorate from upstream to downstream. Located on the Norfolk Sand Plain, Beaver Creek was found to be the least impaired region within the watershed. This is likely due to the natural characteristics of that sub-basin, primarily the sandy soils and groundwater-sourced stream baseflow.

Nutrient levels, primarily phosphorus and nitrate, are high throughout the watershed. Nitrate concentrations are significantly higher within Lower Kettle Creek than the rest of the watershed. Phosphorus concentrations, although highest in Lower Kettle Creek and Dodd Creek, are consistently high throughout the watershed, and typically exceed the Provincial Guideline of 0.03mg/L. Due to the importance of these nutrients for plant growth, there is a clear indication that these levels could lead to an increase in eutrophication of water resources across the watershed.

Both the nutrient and sediment loading issues within the Kettle Creek watershed are primarily the result of runoff and erosion. These conditions are amplified by land-use practices such as agriculture and urbanization, and the dramatic elevation change within the watershed. Nutrient and sediment loading issues are typically linked as nutrients bond to clayey and silty sediments (Hairston and Leigh, 1995).

A review of other studies within the Kettle Creek watershed was included to fill in some of the data gaps subsequent to the analysis of the PWQMN data. Depuydt (1994) suggested that the primary sources of fecal coliform loading to the Creek were faulty septic systems, urban runoff and livestock access to streams. Griffiths (2003) indicated that there was a correlation between the level of riparian cover along stream banks and the type of benthic assemblage found. Griffiths found that 67% of the watercourses within the watershed are impaired, 25% are unimpaired, and the remaining 8% are deemed indeterminate. Griffiths (1988); Acres and Associates (2001); and Riggs Engineering (2004) investigated a known area of PAH contamination near the mouth of Kettle Creek. These studies showed significant exceedances of provincial and federal sediment quality guidelines.

The primary recommendations from this report include: an increase in the number of samples taken at each of the PWQMN monitoring sites in order to improve statistical analysis; continue sampling at the current Source Water Protection (SWP) monitoring stations to ensure adequate spatial cover of the

watershed; incorporation of diurnal and high flow monitoring in order to better assess the total range of conditions; conduct future investigations into the water quality conditions of Lake Whittaker to acquire current information on the state of the lake; conduct future investigations into the water quality of the Dalewood Reservoir to build on existing baseline information; conduct future investigations into the connection between local soil conditions and ambient water quality to determine realistic water quality goals; and, conduct further investigations into the state and movement of PAH contamination in the Port Stanley harbour and Lake Erie.

The analysis of physiochemical water quality data in this report is intended to be used as a benchmark against which future information can be compared. This will allow for the determination of whether water quality within the watershed is improving, degrading, or remaining the same. Similar reports are expected to be compiled at five year intervals as consecutive years of data are obtained.

INTRODUCTION

The general public expects and is entitled to a healthy watershed with waterways that will support a variety of uses. Within the Kettle Creek watershed there are a variety of water uses such as habitat for aquatic organisms, recreational use in Lake Whittaker, livestock watering, agricultural irrigation and waste assimilation. Although this watershed is relatively small in area, the population of the watershed is 44,406 people (2001), with a forecasted growth of 30 percent by 2031. The pressures on the watershed, through growing urban centres and the intensification of agricultural production, could in turn lead to deleterious effects on the environment and decrease the water quality if precautionary and management measures are not implemented. These concerns along with the current water quality issues the watershed is experiencing highlight the need for baseline and continuous water quality assessment.

It is important not only to monitor water quality but to also document and report on it so as to identify issues and recommend actions to improve the state of the waterways. Within Ontario the Provincial Water Quality Monitoring Network (PWQMN) provides an invaluable source of data and is the primary dataset employed by this report to determine the ambient water quality within the watershed. Therefore, much of this report will focus on characterizing nutrients, non-filterable residue, metals, major ions, and bacteria at the selected long-term monitoring sites in the watershed.

The purpose of this report is to characterize the chemical and physical aspects of surface water quality and identify the water quality issues which affect Kettle Creek through the analysis of historical data and a review of existing literature.

Watershed Characteristics

The Kettle Creek watershed drains approximately 520 km² of land from the southern end of London, Ontario through to Port Stanley with a drop in elevation of approximately 1.5m/km. The Y-shaped drainage network within the watershed has been separated into three major sub-basin units: Dodd Creek, Upper Kettle Creek, and Lower Kettle Creek (Figure 1 and 2). The upper portion of the watershed is drained via two major tributaries, Dodd Creek in the northwest quadrant and Upper Kettle Creek in the northeast quadrant of the watershed. Both drain over the Mount Elgin Ridges. The Upper Kettle Creek is defined on the north and south by the Westminster and St. Thomas moraines, respectively (Figure 3). These two tributaries converge at St. Thomas and continue to drain towards Lake Erie via Lower Kettle Creek, draining over the Ekfrid Clay Plain and a portion of the Norfolk Sand Plain. Beaver Creek, located in the southeastern portion of the Lower Kettle Creek sub-basin, primarily drains a small segment of the Norfolk Sand Plain. This difference in substrate makes Beaver Creek a very different system than either Kettle Creek or Dodd Creek.

Land use in the watershed is primarily agriculture (80%), with a small percentage classified as forested or marginal (KCCA, 2005) (Figure 4). The City of St. Thomas and the villages of Belmont and Port Stanley are the primary urban centers and comprise approximately 5% of the land cover. The watershed contains some of the best agricultural land in Ontario (KCCA, 1967), and as such feels the effects associated with intensive agriculture. It has been suggested that several of the water quality problems facing Kettle Creek are directly related to land use through an increase in erosion (Griffiths, 2003).

At the head waters of Upper Kettle Creek is Lake Whittaker which is groundwater fed and helps to supply some of the baseflow present in that basin during drier months. There are also two reservoirs within the watershed: the Dalewood Reservoir, located along Upper Kettle Creek and Union Pond, located along Beaver Creek. Union Reservoir is actually a series of online ponds which are controlled by a dam near the confluence of Beaver Creek and Lower Kettle Creek. Dalewood Reservoir, formerly called the St. Thomas Reservoir, was initially developed as a water supply reservoir for the City of St. Thomas. In

1976 when St. Thomas connected to the Elgin Area Primary Water Supply System, the KCCA purchased the reservoir for use in flood management. Over time the reservoir has become heavily silted, which has allowed for the surrounding wetland to expand. The reservoir is presently at equilibrium, according to Peter Crook, P.Eng., who does not anticipate any further (net) siltation of the reservoir. Where wide open waters once lay 25 years ago, there is now a cattail marsh and wooded swamp where the endangered Least Bittern was recently found nesting. Due to this nesting site the area was recently confirmed as a provincially significant wetland by the Ministry of Natural Resources and is now considered to be part of the Kettle Creek Woods wetland feature.

Currently, about 98% of the 44,406 residents within the Kettle Creek watershed receive their drinking water from Lake Erie through the Elgin Area Primary Water Supply System. The intake pipe for this system is located immediately east of Port Stanley. The exceptions to this are a few privately owned wells, and the Village of Belmont which receives its water from a municipal well system.

The three major urban centres within the watershed all have municipal sewage treatment facilities. Both Belmont and Port Stanley utilize a lagoon treatment system, while St. Thomas has a tertiary wastewater treatment plant that treats both sewage waste and stormwater.

A combination of the land cover/use, intrinsic geology and anthropogenic sources (e.g. wastewater treatment plants) all contribute to the water quality issues present in the Kettle Creek watershed.

Major Water Uses

Water quality is generally evaluated according to the primary use of the water body. Some of the common designated uses within a watershed include drinking water supplies, habitat for aquatic life, industrial/commercial uses, agricultural uses and contact and non-contact recreational uses.

The tributaries within the Kettle Creek watershed are used for recreation (e.g. swimming and fishing along the Lake Erie shore at Port Stanley and within Lake Whittaker), industry (e.g. Port Stanley deep water harbour/ shipping facility) and agriculture (crop irrigation or livestock watering). However the tributaries of the Kettle Creek watershed are primarily used for waste assimilation from industrial and/or sewage treatment plant discharge and as habitat for aquatic life. Thus evaluation of water quality parameters in this report will be compared against the criteria for the protection of aquatic life

It is important to point out that while there are no direct drinking water intakes within the watershed, Kettle Creek is a potential point source of contamination to the Elgin Area drinking water supply. Raw water for the Elgin Area Primary Water Supply System is taken from Lake Erie into which Kettle Creek drains. Littoral drift within the Lake carries sediment from the mouth of Kettle Creek to the intake pipe (Riggs, 2004). Therefore, it is also important to evaluate the influence the water from Kettle Creek may have on this Lake Erie drinking water intake.

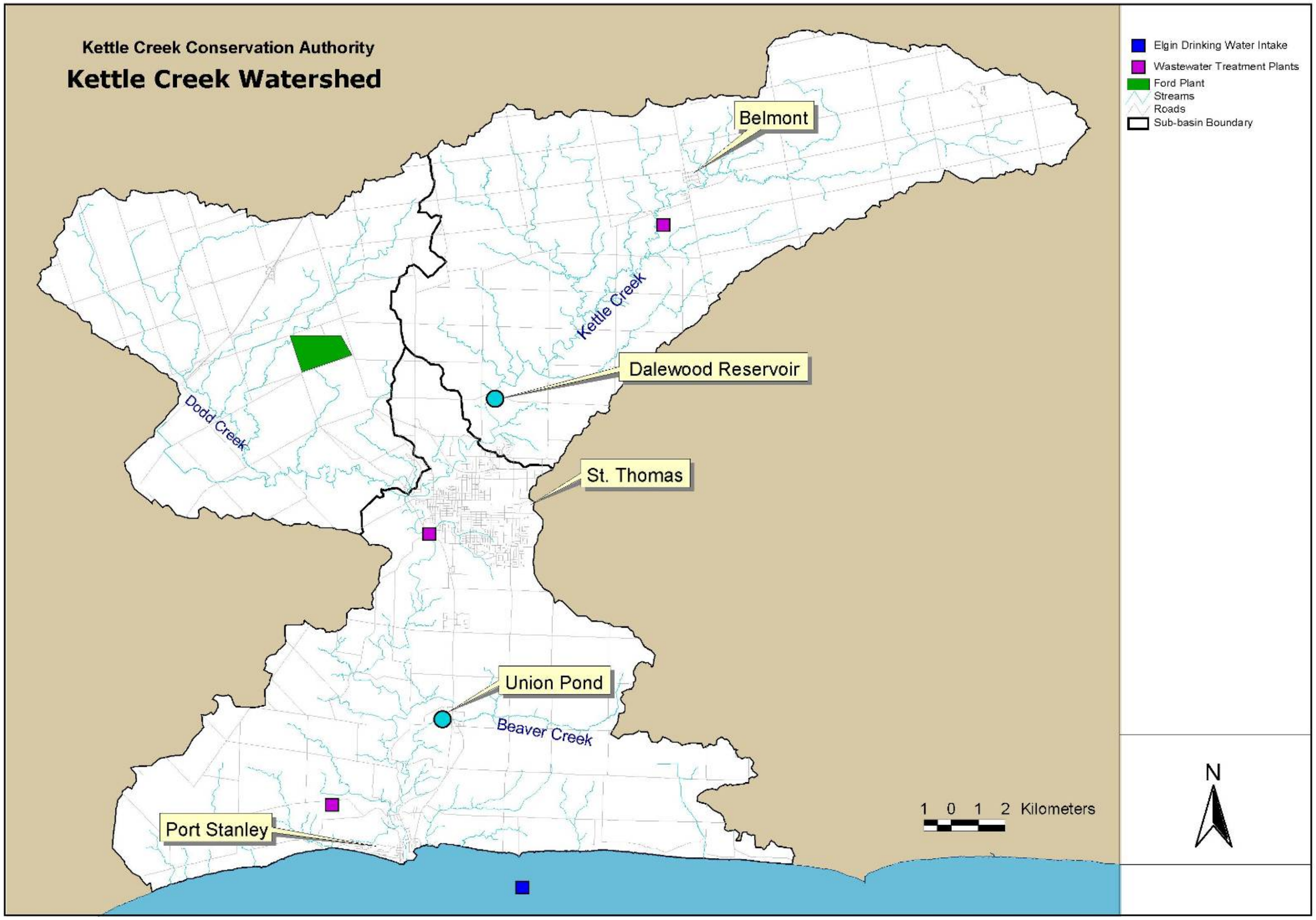

Figure 1. Kettle Creek watershed characteristics illustrating location of: urban centres, industrial areas, wastewater treatment plants, drinking water intakes, streams, & reservoirs.

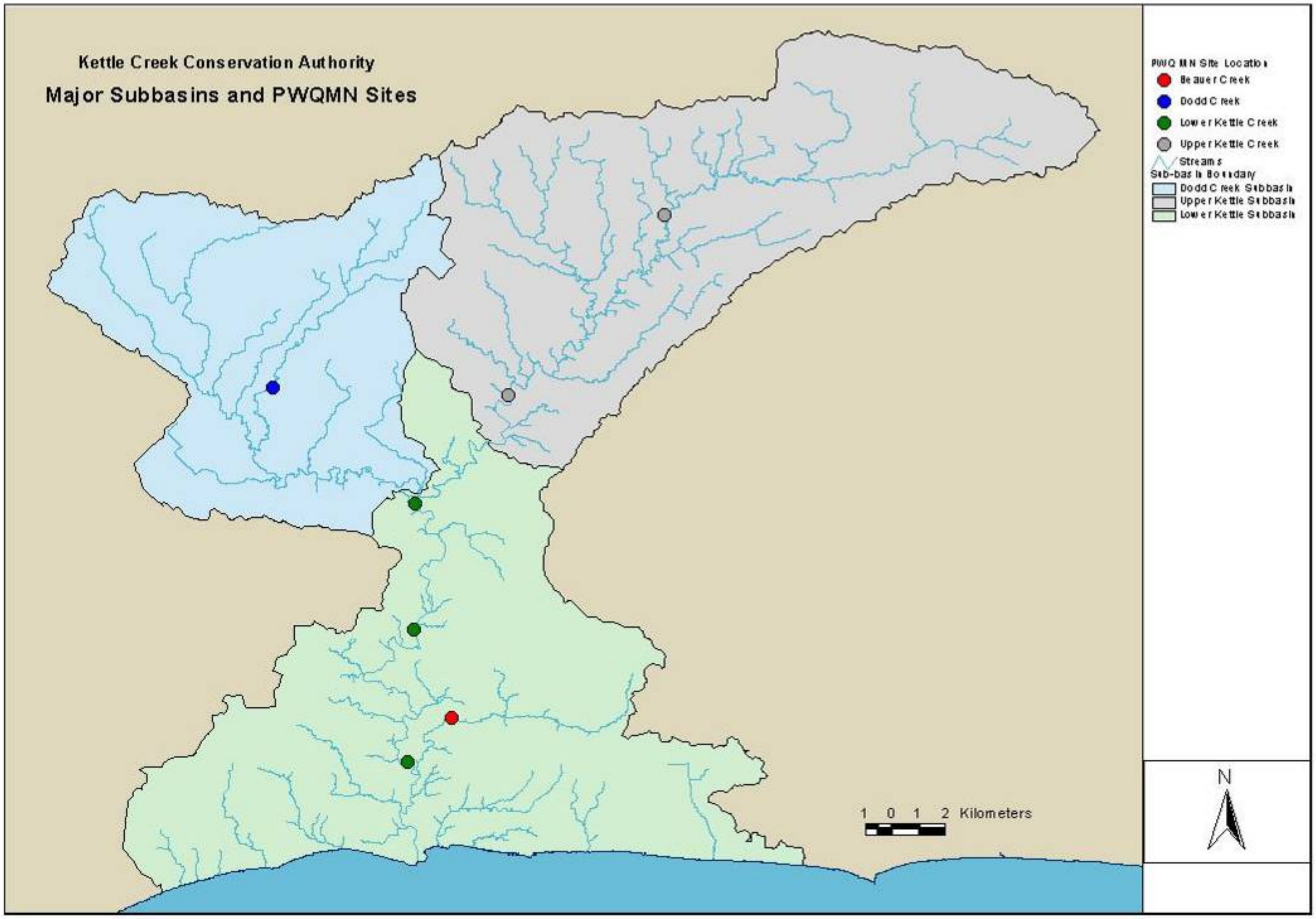

Figure 2. Location of the 7 long-term monitoring stations from the Provincial Water Quality Monitoring Network (PWQMN) within the 3 major sub-basins within the Kettle Creek watershed: Upper Kettle Creek (grey), Dodd Creek (blue) and Lower Kettle Creek (green).

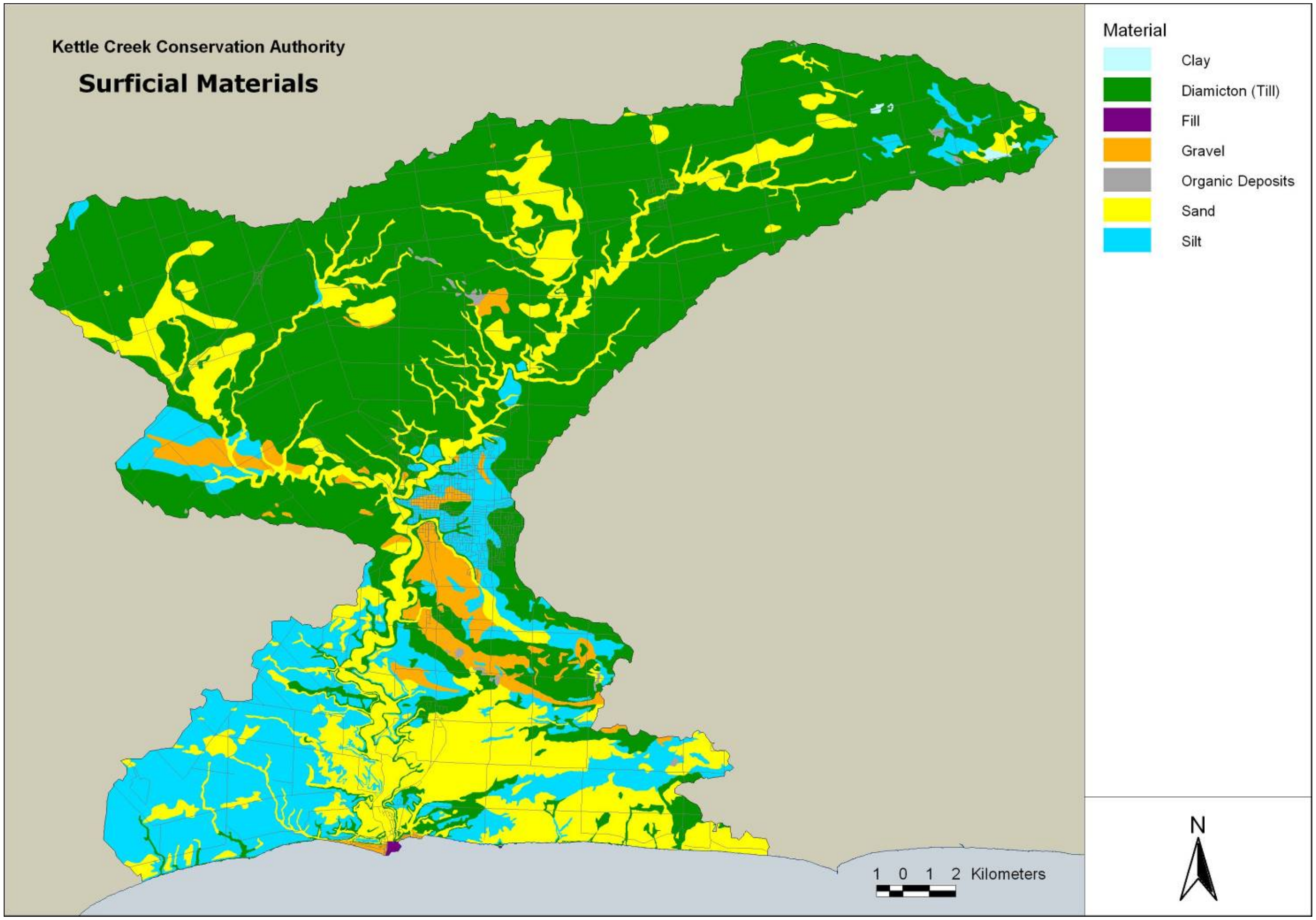

Figure 3. Surficial Materials of the Kettle Creek watershed.

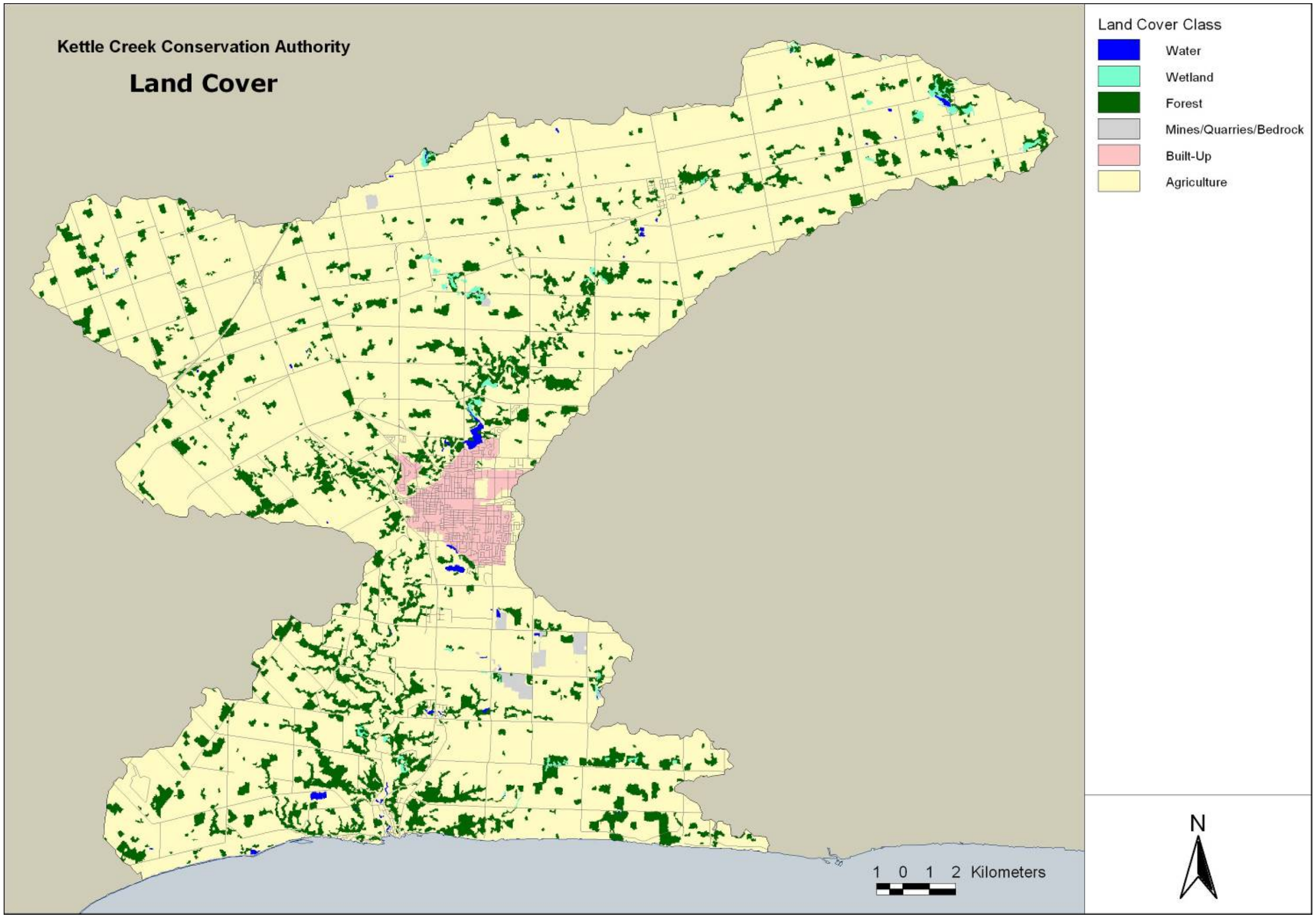

Figure 4. Land cover in the Kettle Creek watershed.

METHODS

Dataset Selection

Surface water quality monitoring has historically focused on characterizing the chemical and physical attributes of the creeks and rivers within a watershed. The Provincial Water Quality Monitoring Network (PWQMN) is an important long-term monitoring program for Ontario which facilitates the characterization of the chemical and physical aspects of water quality. However, financial cutbacks by the province over the last decade, along with limited capacity at conservation authorities, have resulted in a decrease in the number of sites monitored and the frequency at which they are sampled.

As part of the partnership in the PWQMN program the Ontario Ministry of the Environment (MOE) is responsible for the laboratory analysis while the Conservation Authorities are responsible for collecting the samples. There are 16 historic monitoring sites in the Kettle Creek watershed that were at some point part of the PWQMN. Appendix 1 describes the location of the active and inactive PWQMN sampling sites and the period for which samples were taken at each site. In the Kettle Creek watershed, the number of monitoring sites fell from a high of 12 in 1975 to a low of zero from 1996 to 2003. In 1996 when the MOE cut funding to the PWQMN program, Kettle Creek Conservation Authority (KCCA) did not have the internal capacity to continue monitoring on its own leaving an eight year data gap for watershed wide sampling from 1996 to 2003. However, in 2004 two years after the MOE started re-building the PWQMN, KCCA resumed sampling. This data gap resulted in the 1991-1995 sampling period being the most recent 5 year contiguous set of data. This report will focus on the seven sites which were sampled during the five year period from 1991 to 1995, illustrated in Figure 5.

The number of annual samples taken per site has also declined over the years. Currently the MOE allows for eight samples per year to be taken at each of the PWQMN sites; however, historically a total of 12 samples per year were taken at each of the sites. During the 1991-1995 sampling period, the number of samples taken generally ranged between eight and eleven per year.

To provide a benchmark indicative of the current water quality conditions found within the Kettle Creek watershed, our analysis investigated the most recent five year contiguous set of data, 1991-1995, for which seven monitoring sites could be evaluated. The entire dataset (historical to current) for each of the seven sites was also assessed for preliminary long-term temporal trends where possible.

Summarizing the most recent contiguous five years of data helps to increase the likelihood of characterizing the full range of flow and climatic conditions. This approach also reduces the strong year-to-year variability from extremes in climate (e.g. wet and dry periods).

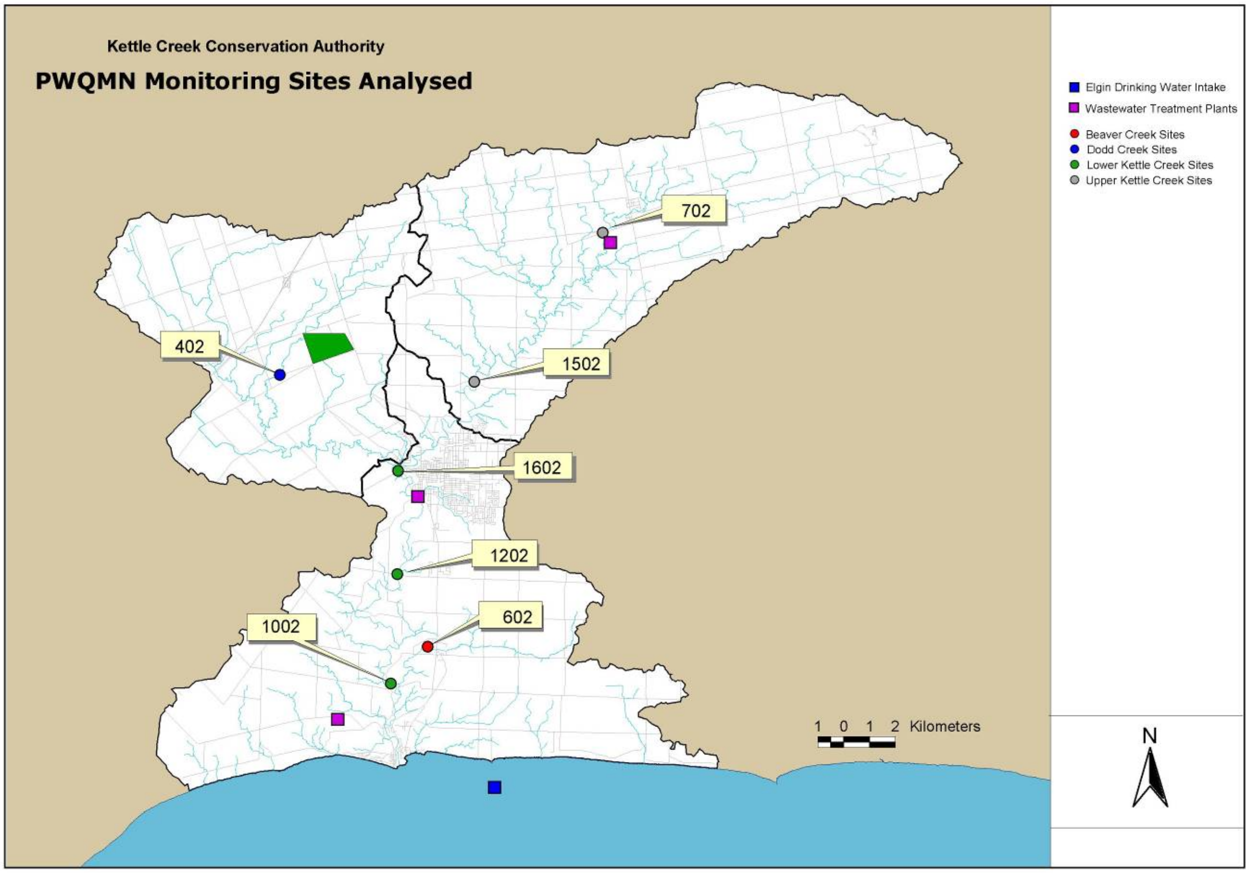

Figure 5. Location of the 7 long-term monitoring sites from the Provincial Water Quality Monitoring Network (PWQMN) analysed in this study.

Parameters Analysed

Routine Chemistry, Nutrients, Metals and Pesticides

Water quality samples were analyzed for routine chemistry, nutrients and metals (Table 1). For more information on laboratory methods and detection limits refer to MOE (1994). Water samples were collected using standard sampling procedures depending on access type. Sites with easy access were sampled directly from the stream with the sample bottle upstream of where the technician was standing. Sites with bank access were sampled from the shore with a stainless steel bucket attached to an extension rod. Finally, sites with only bridge access were sampled by lowering a stainless steel pail from the bridge into the stream. Sample bottles were rinsed three times on site with the sample water prior to filling. Samples were preserved if necessary, stored on ice and couriered to the MOE laboratory.

Pesticides were only monitored for at PWQMN site 16008701002 (near Sparta Line on Lower Kettle Creek), sporadically from 1981 to 1992 and during the 1994 and 1995 sampling seasons. Water samples were also collected using the procedure previously described.

Dissolved oxygen, conductivity, pH and temperature were monitored in the field at the time of sample collection, historically using titration kits and more recently using handheld data sondes.

Table 1. List of water quality variables analyzed in PWQMN stream samples.

Water Quality Variable Category	Water Quality Variables
Nutrients	Dissolved nutrients: ammonia, nitrate, nitrite, phosphate Total nutrients: total phosphorus, total kjeldahl nitrogen
Solids	Non-filterable residue, total dissolved solids
Major Ions/Anions	Calcium, magnesium, sodium, potassium; hardness, chloride
Routine Chemistry	pH, alkalinity, conductivity
Metals	Aluminum, barium, peryllium, cadmium, chromium, copper; iron, manganese, molybdenum, nickel, lead, strontium, titanium, vanadium, zinc
Routine Physical	Turbidity, temperature

Bacteria and Pathogens

Samples for bacteria or pathogens were not routinely collected as part of the long-term PWQMN monitoring program. The seven sites reviewed in this report sampled for *E. coli* throughout the 1994 and 1995 sampling seasons and fecal coliforms from 1991-1994. Other projects apart from the PWQMN have also sought to look into the presence of bacteria and/or pathogens within the Kettle Creek watershed (e.g. Hawkins 1993; Depuydt 1994; McMaster 1995) which can provide insight into the potential bacterial issues within the region.

Reservoirs

Historically, routine monitoring of the major reservoirs within the Kettle Creek watershed was not carried out. However, in 1993 water and sediment samples from the Dalewood Reservoir were collected and analysed to evaluate the water quality (Hawkins, 1993). Relevant findings from this analysis will be highlighted within the discussion.

Data Analysis

Streamflow

Streamflow was analyzed to help characterize the study period since water quality in streams is strongly influenced by the amount and timing of rainfall and snowmelt. Three gauge stations are located within the Kettle Creek watershed (Figure 6). Station 02GC029 is located on Upper Kettle Creek downstream of Belmont, station 02GC002 is located on Kettle Creek at St. Thomas and station 02GC031 is located on Dodd Creek at Paynes Mill. Data from these stations were provided by the Water Survey of Canada (Environment Canada, 2005).

The historical long-term average annual flow was calculated and compared with the annual average flows for each year from 1991-1995. This comparison indicated whether stream levels were rising or falling, denoting a wetter or dryer period than normal.

The strength of the relationship between water quality parameters and streamflow was investigated using the non parametric Kendall Correlation Coefficient (Kendall tau statistic).

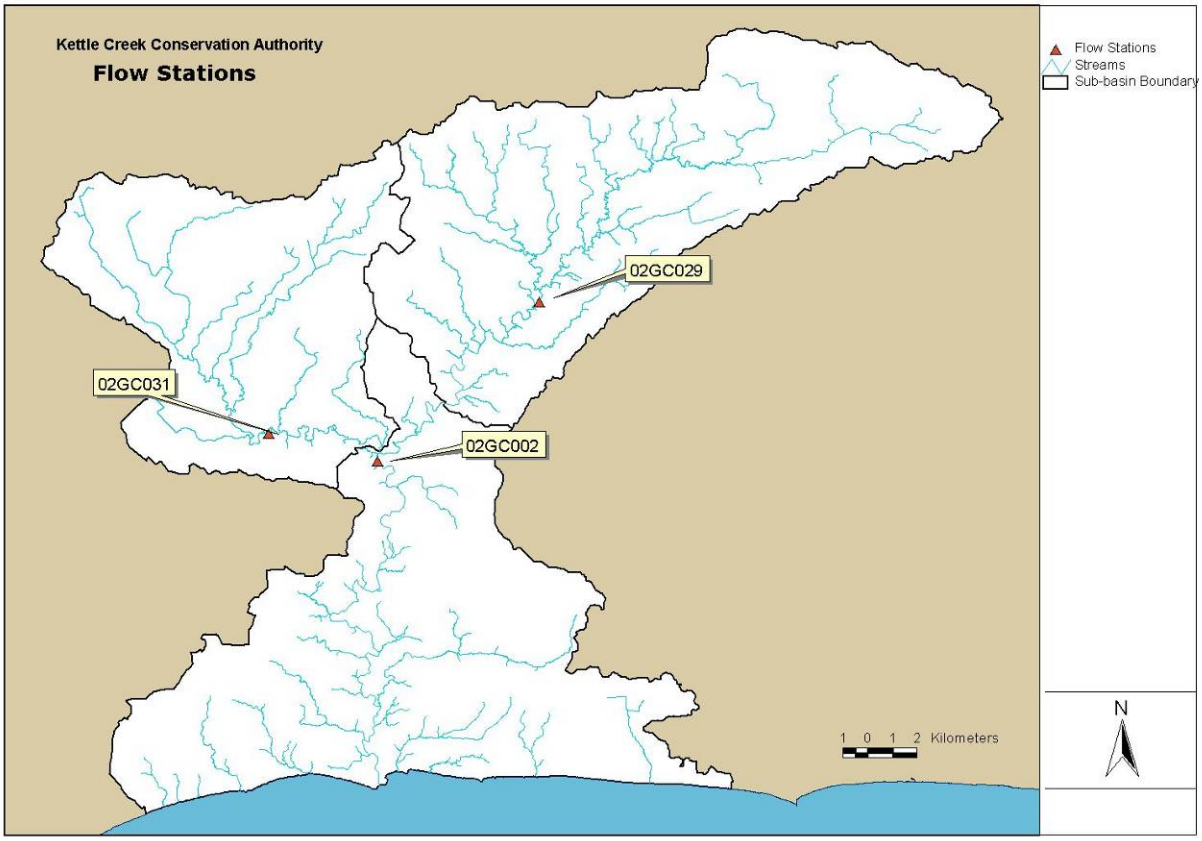

Figure 6. Location of flow stations monitored by the Water Survey of Canada within the Kettle Creek watershed.

Summary Statistics

Box and whisker plots were used to present the data graphically. Box and whisker plots can illustrate the distribution and statistics of a dataset. The box in the box-whisker plot shows the 25th and 75th percentiles of the dataset, called the lower and upper quartiles, and the median (50th percentile) (Figure 7). The whiskers represent the range of the data set to the 90th and 10th percentiles (Sigma Plot 8.0, 2002). The circles illustrate outliers beyond the 10th and 90th percentiles (values more than 2 standard deviations from the mean).

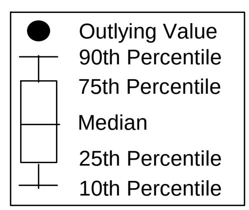

Figure 7. Box and whisker plot illustrating the 5th, 25th, 50th (median), 75th and 95th percentiles and outliers of the 1991-1995 dataset.

A summary of the descriptive statistics (including the minimum, maximum, mean, and median values) for each water quality parameter analyzed from the 1991-1995 dataset are included in Appendix 3.

Comparative Statistics

Statistical methods for detecting spatial and temporal changes in water quality have greatly improved throughout the years (Hirsch, R.M et al., 1991). Nonparametric statistical methods can accommodate data that are not normally distributed, are robust against outliers, and have missing data (Hrynkiw et al., 2003). These characteristics are typical of water quality data (Trkulja, 1997).

Nonparametric regression analyses were carried out, using Mann-Whitney or Kruskal-Wallis tests (Analyse-it Software, 2003), to identify differences between PWQMN sites for each water quality parameter (nutrients, non-filterable residue and chloride). Sites were considered to be significantly different if the p values resulting from these tests were < 0.05. However, it is cautioned that finding a statistically significant result does not necessarily imply that one has found an environmentally significant result (Griffiths et al., 2001; Trkulja, 1997).

Compliance with Guidelines

Provincial Water Quality Objectives (PWQO), Federal Guidelines and other relevant criteria were used to evaluate whether stream water quality within the region was meeting the specified levels for protection of aquatic life (Table 2). The level of compliance was determined at each site for each water quality parameter by calculating the percentage or frequency of samples above the objective, guideline or criteria for the data collected between 1991 and 1995. For presentation purposes and relative comparison of compliance levels between sites, results of this analysis were subsequently classed into five percentage groups (0%, 1-25%, 26-50%, 51-75%, 76-100%) and each group was assigned a representative colour. Actual values for the percentage of samples above the objective, guideline or criteria for each water quality parameter measured can be found in Appendix 6. Results for each sampling site were then graphically represented on maps of the watershed region as coloured dots corresponding to the percentage group previously mentioned. These maps along with similar maps representing the 75th percentile value at each site for each parameter were developed to be used as communication tools for illustrating where the areas for improvement likely are (actual 75th percentile values can be found in Appendix 7).

Trend analysis (LOWESS)

Although sampling frequency has fluctuated over the years, the long-term nature of the PWQMN warrants the evaluation of long-term monotonic trends to determine whether conditions are improving or deteriorating. Furthermore, this is one of the objectives of the network (A. Todd, Ministry of the Environment, pers. communication).

Time series plots were created for each parameter at each of the seven PWQMN sites for the entire period of record, to explore the data for temporal variability and preliminary trends. A LOWESS (LOcally WEighted Scatterplot Smoothing) smoothing algorithm was then applied, which is helpful in visually inspecting the data for potential trends. However, the results from the LOWESS analysis do not represent a statistical trend analysis and as such are only considered preliminary. With the aforementioned sampling frequency and timing there is the potential for these trend estimates to be incorrect. Trkulja (1997) suggested that trend estimates based on monthly sampling are less reliable than estimates based on daily and weekly sampling schemes. Consequently, more detailed analyses are required to accurately evaluate statistical trends.

Table 2. Water quality parameters and corresponding Federal Guideline or Provincial Objective.

Water Quality Parameters	Objective or Criteria Used	Jurisdiction
Nitrate	2.93 mg/L	Canadian Environmental Quality Guidelines
Nitrite	0.06 mg/L	Canadian Environmental Quality Guidelines
Total Ammonia	pH and temperature dependant	Ontario Ministry of the Environment
Total Phosphorus	0.030 mg/L	Ontario Ministry of the Environment
Non-Filterable Residue	25.0 mg/L	General criteria
Chloride	250 mg/L	Benchmark identified in Environment Canada report[1]; Drinking Water Quality Guideline
pH	6.5- 8.5	Ontario Ministry of the Environment
Dissolved Oxygen	Temperature dependant	Ontario Ministry of the Environment
Temperature	Natural thermal regime shall not be altered	Ontario Ministry of the Environment

1. Environment Canada. 2001. Priority Substances List Assessment Report: Road Salt. Environment Canada, Health Canada, Ottawa, Ontario, 165p.

RESULTS

Streamflow

Streamflow for the five year period between 1991 and 1995 was higher within Lower Kettle Creek at St. Thomas than within Upper Kettle above Dalewood Reservoir or along Dodd Creek at Paynes Mills (Figure 8). Flow recorded on Upper Kettle Creek was of similar magnitude as that found in Dodd Creek.

To give an indication of how wet or dry a particular year was relative to a long-term average (58 years from 1945-2004), the average annual flow was calculated for each year during the period from 1968 to 2004 for station 02GC002 on Lower Kettle Creek at St. Thomas and then plotted with the 58 year long-term average (Figure 9). Average annual flows within Kettle Creek at St. Thomas were above the 58 year long-term average in 1992 but below in 1991, 1993, 1994 and 1995 (Figure 9).

Sampling Frequency

Historic sampling occurred on a routine basis whereby flow in the stream was not considered. This is evident when dates of sampling events are graphed against stream flow (Figure 10). This was likely a result of limited manpower and logistical challenges associated with sampling high flow events. However, recently there has been an attempt to characterize high flow events.

Water quality in Kettle Creek and its tributaries is significantly influenced by climate and the amount of rainfall or snow pack that runs off the land. High stream flows can contribute to high contaminant levels by mobilizing land-based contaminants into Kettle Creek, such as phosphorus or non-filterable residue. Alternatively, high flows can help reduce some negative impacts by cooling in-stream temperatures and for example, subsequently increasing dissolved oxygen levels. Therefore, it is important to sample both high and low stream flows when characterizing stream water quality.

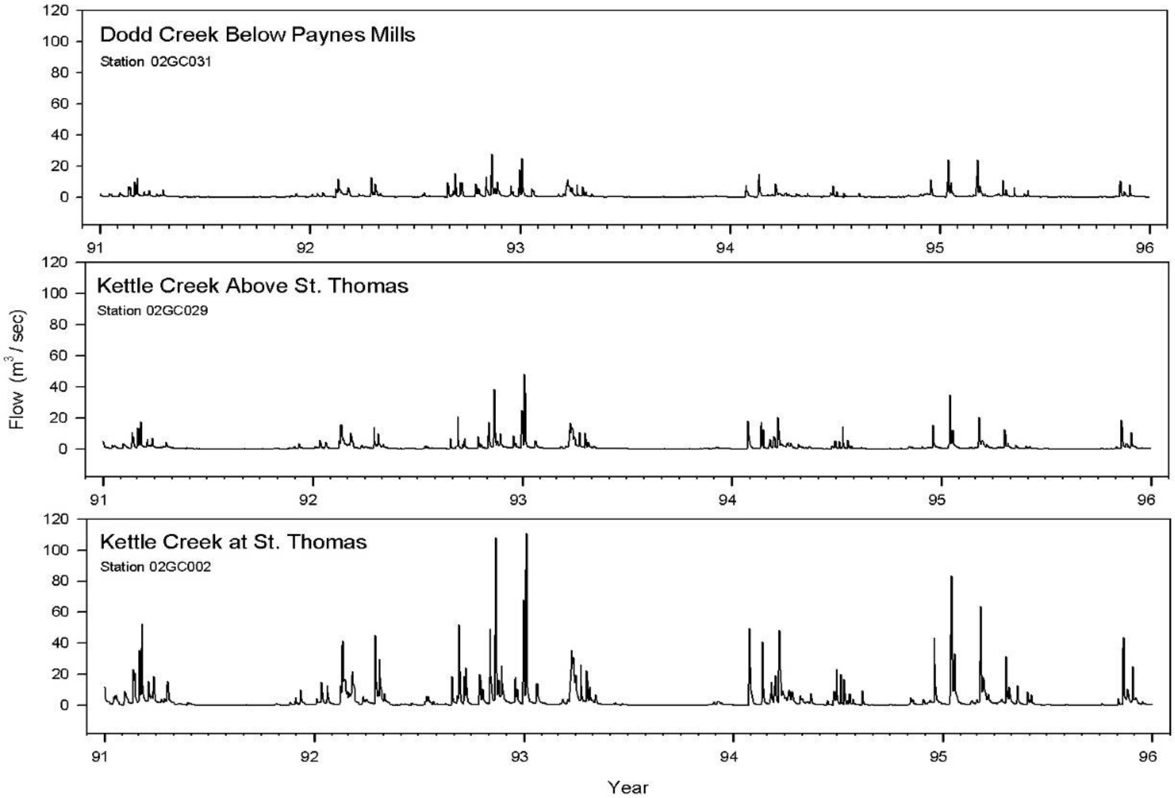

Figure 8. Flow rates at the three Water Survey of Canada gauge stations for the period from 1991-1995 within Kettle Creek watershed.

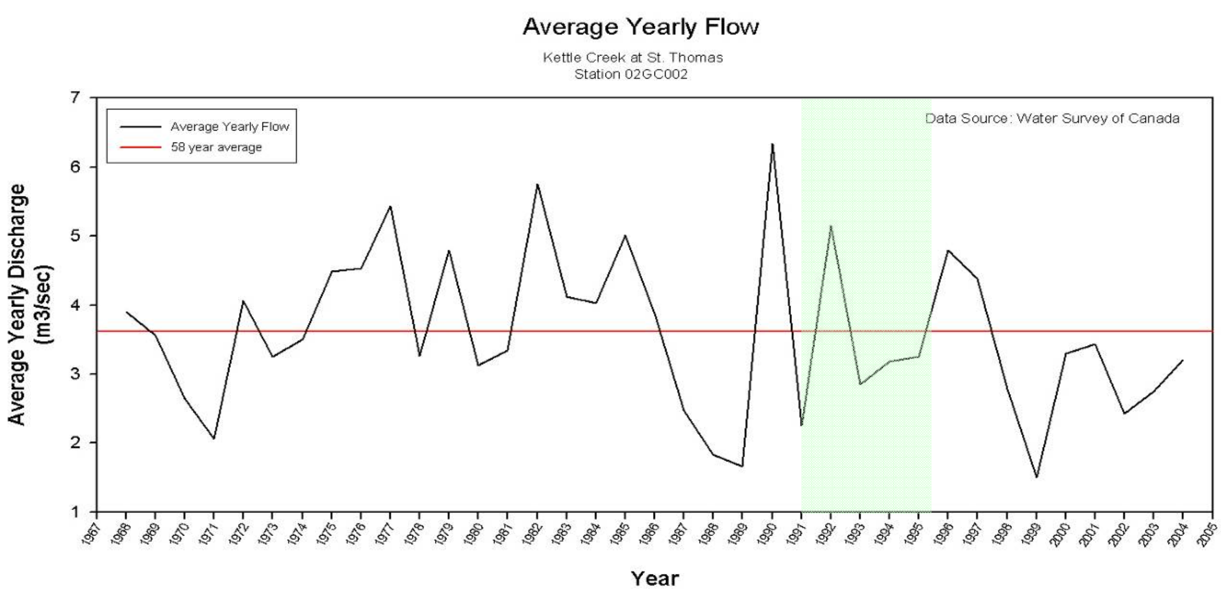

Figure 9. Average annual stream flow from 1967-2004 for station 02GC002 at St. Thomas.

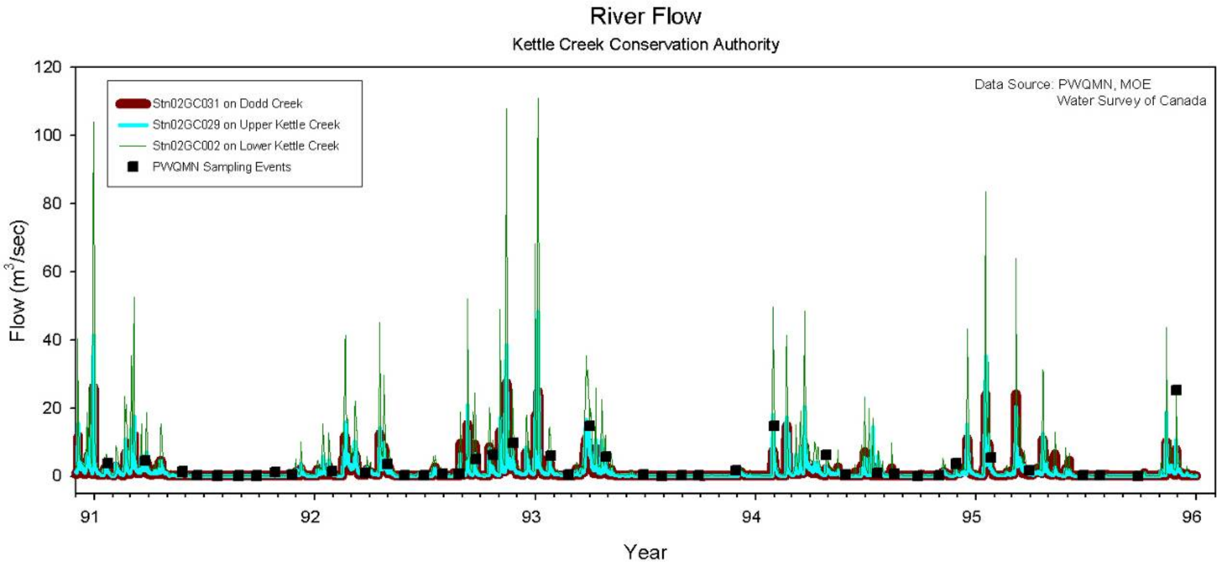

Figure 10. Daily stream flow rates at three locations within the Kettle Creek watershed plotted with the time of sampling events.

Water Quality Conditions 1991-1995

Upon first inspection of the nutrient, non-filterable residue, and major ion data there appeared to be several outliers (data more than 2 standard deviations from the mean as evident from a visual inspection of the box and whisker plots shown below). To account for this characteristic of the data when describing the data range this study will be reporting on the 95th percentiles from each PWQMN site (Appendix 4). Actual min and max values can be found in the descriptive statistics table in Appendix 3. Results, including p values, from the Kruskal-Wallis and Mann-Whitney tests are listed in Appendix 5. For the purpose of discussing the PWQMN sites across the Kettle Creek Watershed, the sites will be referred to by their short name (Figure 5, Appendix 1).

Nitrate

Range within watershed:

Nitrate levels within the region ranged from 0.10 mg/L on Upper and Mid Kettle Creek at sites 702 and 1602, to 19.8 mg/L on Upper Kettle just above Dalewood Reservoir (site 1502) and 12.675 mg/L below St. Thomas (site 1202).

Relationship between sites:

In general, median nitrate concentrations appear to be higher further downstream on Kettle Creek compared to the rest of the watershed (Figure 11). When the seven PWQMN sites within Kettle Creek watershed were statistically analyzed using a Kruskal-Wallis test it was determined that median values significantly differed between sites (p value of <0.0001). To spatially determine where within the watershed these differences occurred, a series of Kruskal-Wallis and Mann-Whitney tests were carried out. No significant difference was found amongst sites within the Upper Kettle sub-basin (702, & 1502) or between the two sites within Lower Kettle sub-basin downstream of St. Thomas (1202 & 1002). However, a significant difference was found between site 1602 midway along Kettle and the other two Lower Kettle sites ($p < 0.0001$). Site 1202 displayed significantly higher nitrate concentrations than site 1602 ($p < 0.0001$) indicating a potential input somewhere between these two sites. Both Beaver and

Dodd Creek displayed median values more similar to those in Upper and Mid (site 1602) Kettle Creek but had significantly lower nitrate values than site 1202 on Lower Kettle (p value < 0.0001 for both).

Percentage of samples exceeding objective:
The number of times a sample did not meet the Canadian Guideline for nitrate of 2.93 mg NO_3/L was highest along the lower reaches of Kettle Creek. Samples exceeded the guideline 94% of the time at station 1202, just below St. Thomas and 93% of the time at site 1002 between St. Thomas and Port Stanley (Appendix 6). Nitrate levels within Upper Kettle exceeded the guideline less frequently than the lower reaches of Kettle Creek, but exhibited a higher percentage of samples with exceedances than either Dodd or Beaver Creek. Overall Beaver Creek exceeded the guideline the fewest number of times with only 34% of the samples taken at this site being greater than 2.93 mg NO_3/L.

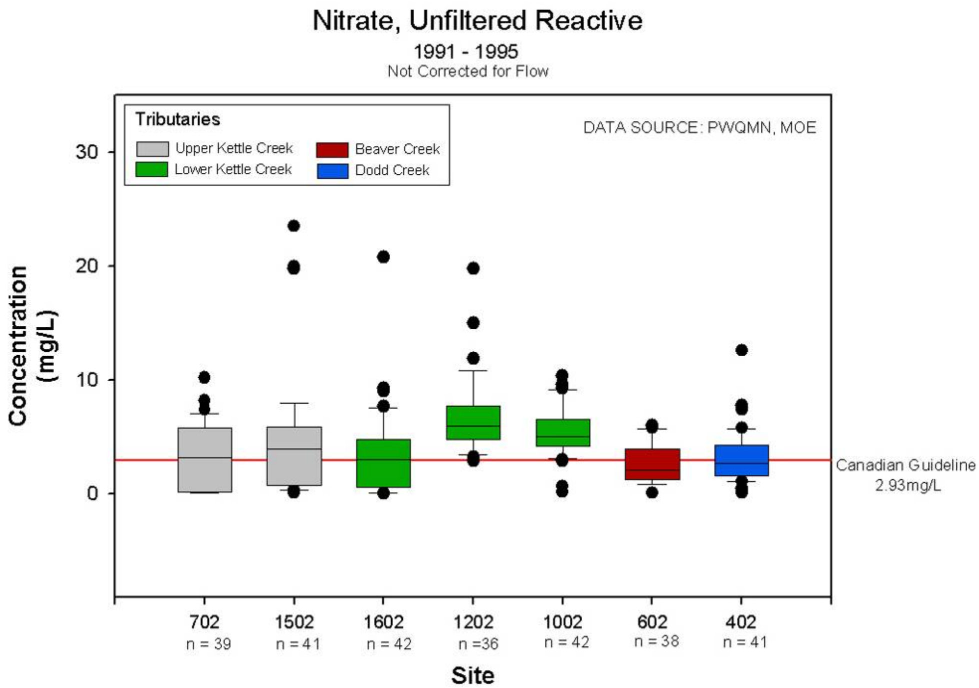

Figure 11. Total Nitrate concentrations at 7 PWQMN monitoring sites in the Kettle Creek watershed from 1991-1995.

Nitrite

Range within watershed:
Nitrite levels within the Kettle Creek watershed range from 0.01 mg/L observed at all PWQMN sites to 0.380 mg/L along Dodd Creek (site 402) and 0.303 mg/L below St. Thomas (site 1202). It should be noted that there is higher variation within sites for nitrite concentrations than there is for other parameters tested (Figure 12). This is likely due to the detection methods.

Relationship between sites:
In general, nitrite concentrations increased from upstream to downstream along Kettle Creek (Figure 11). There was no significant difference between median values for the two sites situated on Upper Kettle Creek (702 and 1502) or between both Upper Kettle sites and the first downstream site just above St. Thomas (1602). Similar to the trends found with nitrate, site 1202 below St. Thomas had significantly higher nitrite concentrations than site 1602 , 702 or 1502 but, was not significantly different from site 1002, furthest downstream on Kettle Creek (for p values see Appendix 5). Nitrite concentrations recorded for site 402 along Dodd Creek were not significantly different from values at any other site

within the watershed. Nitrite concentrations within Beaver Creek were not found to be significantly different from all other sites within the watershed except for site 702, the upper most site on Kettle Creek, which had significantly lower nitrite concentrations from Beaver Creek (p = 0.02).

Percentage of samples exceeding objective:
Across the watershed samples were above the Canadian Guideline (0.06 mg/L) 23% to 36% of the time (Appendix 6). Site 1202, directly downstream of St. Thomas, exhibited the greatest number of samples above the guideline where as site 702, the upper most point on Kettle Creek, had the fewest (Appendix 6).

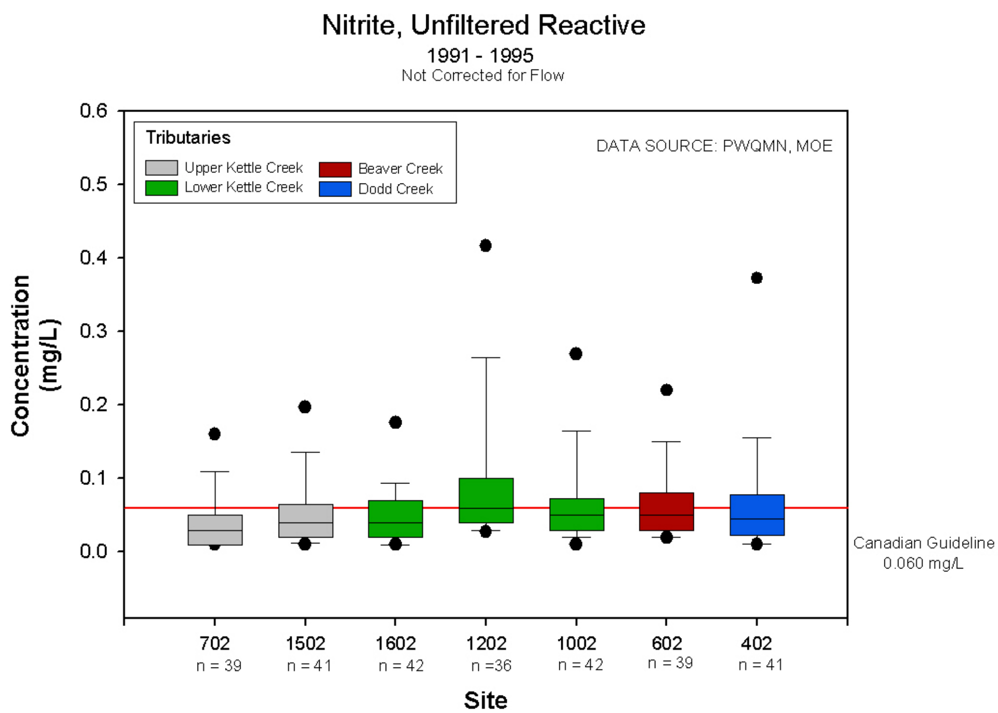

Figure 12. Total Nitrite concentrations at 7 PWQMN monitoring sites in the Kettle Creek watershed from 1991-1995.

Ammonia

Range within watershed:
Within the watershed total unionized ammonia ranged from below the detection limit at all sites to 0.019 mg/L at site 1202, just below St. Thomas and 0.013 mg/L at site 602 on Beaver Creek.

Relationship between sites:
In general, median unionized ammonia concentrations did not vary widely from site to site (Figure 13). In fact, when concentrations for all of the PWQMN sites were compared using a Kruskal-Wallis test no significant differences were found (p = 0.14).

Percentage of samples exceeding objective:
Generally, sites within the Kettle Creek watershed do not exceed the Provincial Water Quality Objective (PWQO) of 0.0165 mg/L (Figure 12). However, three sites did have a small number of samples with values higher than the objective (Appendix 6). Site 1202 just below St. Thomas on Lower Kettle Creek had 11% of samples above the objective, further downstream site 1002 had 2% of the samples above the objective and site 402 on Dodd Creek had 3% of samples with concentrations above the objective.

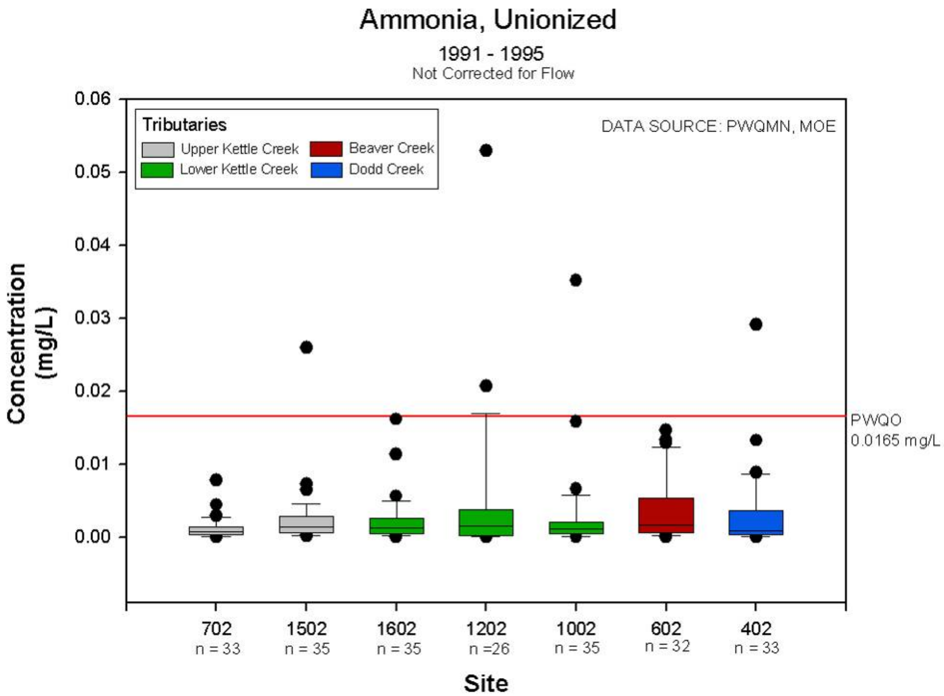

Figure 13. Unionized Ammonia concentrations at 7 PWQMN monitoring sites in the Kettle Creek watershed from 1991-1995.

Total Kjeldahl Nitrogen

Range within watershed:
Total kjeldahl nitrogen (TKN) varied widely across the watershed ranging in values from 1.0 mg/L furthest upstream on Kettle creek to 4.25 mg/L within Dodd Creek and 2.383 mg/L below St. Thomas at site 1202 (Appendix 4).

Relationship between sites:
In general, higher total kjeldahl nitrogen values were found within Dodd Creek and downstream of St. Thomas along Kettle Creek relative to the rest of the sites within the Kettle Creek watershed (Figure 14). When comparing the median values between all seven PWQMN sites a significant difference was found ($p < 0.0001$). No significant difference was found between the two upstream sites ($p = 0.56$) or between the three sites along Lower Kettle Creek ($p = 0.85$) however, significant differences were found between upstream and downstream sites (p values can be found in Appendix 5). Total kjeldahl nitrogen concentrations within Dodd Creek were significantly higher than all other sites within the Kettle Creek watershed except for site 1602 and 1202 immediately downstream of the Dodd, Lower Kettle confluence (p values = 0.07 and 0.15 respectively). Concentrations within Beaver Creek were found to be more similar to those within the Upper Kettle Creek sub-basin but significantly lower than all other sites within the watershed.

Total nitrogen is made up of three constituents: nitrate, nitrite and total kjeldahl nitrogen ($TN = NO_3 + NO_2 + TKN$) ($TKN = NH_4 + \text{Organic N}$). On average nitrates tend to make up greater than 50% of the total nitrogen pool at all PWQMN sites within the Kettle Creek watershed. Organic nitrogen levels range from 41% just below St. Thomas to 25% on Upper Kettle. Unionized ammonia levels make up less than

1% of the total nitrogen pool for the entire region ranging from 0.1% just above Dalewood Reservoir on Upper Kettle Creek to 0.097% on Beaver Creek.

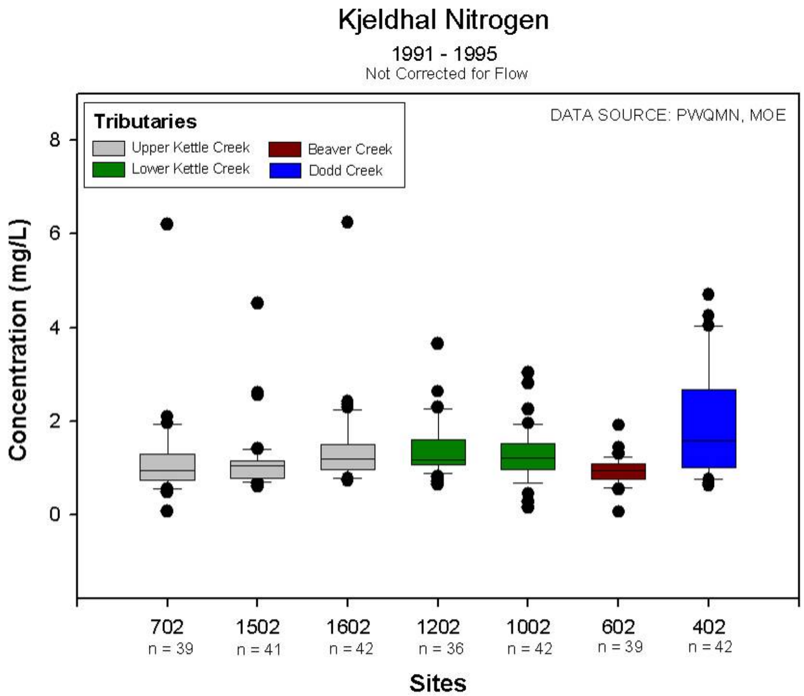

Figure 14. Total kjeldahl nitrogen concentrations at 7 PWQMN monitoring sites in the Kettle Creek watershed from 1991-1995.

Phosphorus

<u>Range within watershed:</u>
Phosphorus levels within the region are quite high and range from 0.042 mg/L within Beaver Creek to 0.77 mg/L observed at site 1502 (upstream of Dalewood Reservoir) and 0.590 mg/L at site 402 on Dodd Creek (Appendix 4).

<u>Relationship between sites:</u>
When sites were compared using a Kruskal-Wallis test a significant difference was found between the median phosphorus concentrations for all PWQMN sites within the Kettle Creek watershed ($p < 0.0001$). Along Kettle Creek there appeared to be an increasing trend from upstream to downstream (Figure 15). When investigating the spatial trends within the region, there were no significant differences in median values found between those sites situated along Upper Kettle Creek ($p = 0.59$). Similarly the lower downstream sites (1202 and 1002) were also not significantly different from each other ($p = 0.95$) but had significantly higher concentrations than the first site along Lower Kettle (1602) just above St. Thomas. Site 1602 had concentrations more similar to those found within the Upper Kettle sites (p value = 0.1). Median phosphorus levels within Dodd Creek were the highest across the watershed and were more similar to those sites on Lower Kettle below St. Thomas ($p = 0.48$). Beaver Creek had phosphorus levels significantly lower than any other site within the Kettle Creek watershed (Appendix 5).

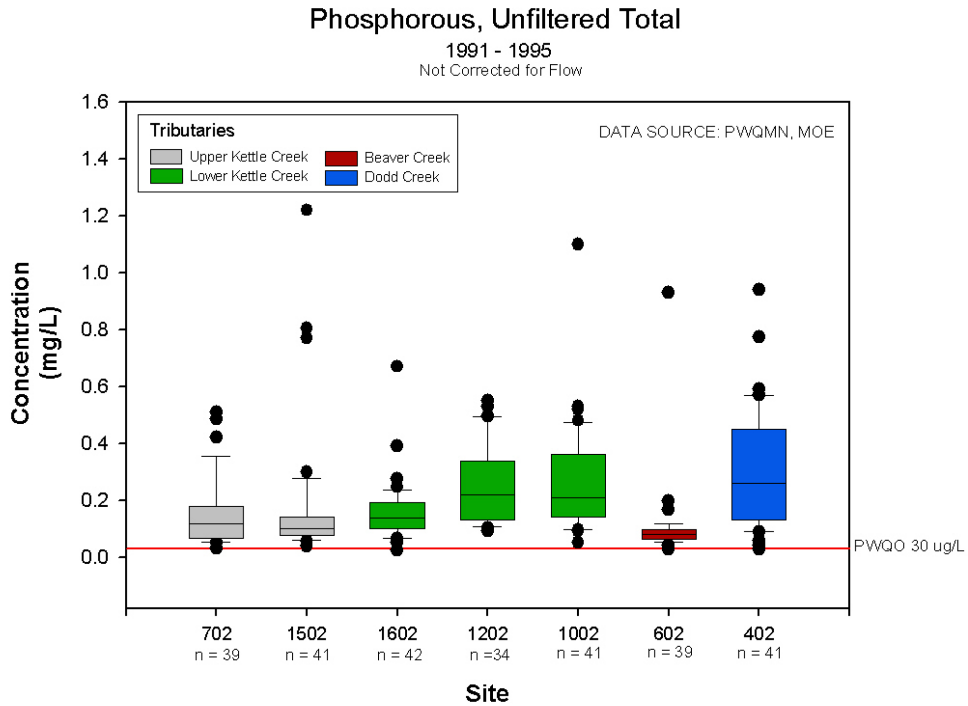

Figure 15. Total Phosphorus concentrations at 7 PWQMN monitoring sites in the Kettle Creek watershed from 1991-1995.

Percentage of samples exceeding objective:

Phosphorus samples throughout the Kettle Creek watershed are routinely above the provincial objective, 0.03 mg/L. Samples from all of the downstream sites along Kettle Creek (sites 1602, 1202 and 1002) had recorded concentrations above the objective 100% of the time while all other sites range between 97% and 98% of samples higher than the objective (Appendix 6).

Non-Filterable Residue (NFR)

Range within watershed:

Across the watershed the lowest NFR concentration of 5.0 mg/L was found at both Beaver and Dodd Creek, while the highest NFR concentrations were found directly below St. Thomas at sites 1202 and 1002 with concentrations of 264.8 mg/L and 216 mg/L respectively (Appendix 4).

Relationship between sites:

In general, NFR concentrations increased from upstream to downstream along Kettle Creek (Figure 16). Again, no significant differences were found amongst either site on Upper Kettle (sites 702 and 1502) or the first site on Lower Kettle (site 1602) ($p = 0.39$). However, the Upper Kettle Creek sites were both significantly lower in NFR than either of the Lower Kettle Creek sites situated below St. Thomas (sites 1202 and 1002). Unlike several of the previous nutrients analysed no significant difference in total non-filterable residue concentrations was found between sites 1602 and 1202 on Lower Kettle ($p = 0.15$). However, site 1002 (furthest downstream) had significantly higher NFR concentrations than site 1602 on

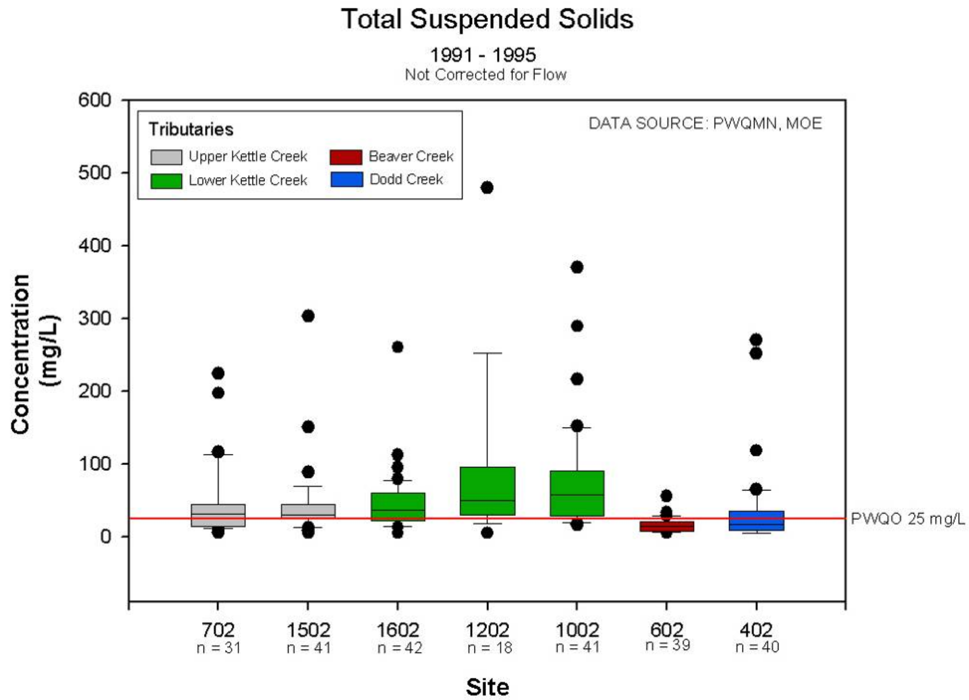

Figure 16. Total Suspended Solids concentrations at 7 PWQMN monitoring sites in the Kettle Creek watershed from 1991-1995.

Lower Kettle (p = 0.01). Dodd and Beaver Creek did not display significant differences from each other (p = 0.25) but were significantly lower in NFR than any site within Kettle Creek (see Appendix 5 for p values).

<u>Percentage of samples exceeding objective:</u>
Although there is no PWQO for NFR, a benchmark of 25 mg/L is usually used. Occurrences of samples with concentrations above this benchmark appear to be more of an issue within Kettle Creek than either Dodd or Beaver Creek. Both Dodd and Beaver Creek have samples with recorded concentrations above this benchmark less than 40% of the time (Appendix 6). However, within Kettle Creek the percent of samples with concentrations above the benchmark ranged from 58 % at site 702, furthest upstream, to 83% at site 1202 directly downstream of St. Thomas.

Chloride

<u>Range within watershed:</u>
Across the entire Kettle Creek watershed, chloride levels were low ranging from 14.8 mg/L on Upper Kettle upstream of Dalewood Reservoir (site 1502) to 112.0 mg/L on Dodd Creek (Appendix 4).

<u>Relationship between sites:</u>
In general, chloride levels within Kettle Creek appeared to increase from upstream to downstream (Figure 17). No significant differences were found amongst the Upper Kettle Creek sites or amongst the Lower Kettle Creek sites (p = 0.84 and p = 0.77 respectively). However, significantly lower chloride concentrations were found within Upper Kettle Creek when compared to lower (all p values >0.0001, see Appendix 5). Beaver Creek had similar median chloride concentrations as sites 1502 & 702 on Upper Kettle (p = 0.82) while Dodd Creek had median values significantly higher than all other sites within the watershed (see Appendix 5 for p values).

Percentage of samples exceeding objective:
Total chloride levels within the Kettle Creek watershed do not appear to be a problem. Although there is no federal or provincial criteria set for chloride levels, Environment Canada has identified 250mg/L as a benchmark level (Environment Canada, 2001). All of the PWQMN sites examined did not have any samples with concentrations above the Environment Canada benchmark (Appendix 6).

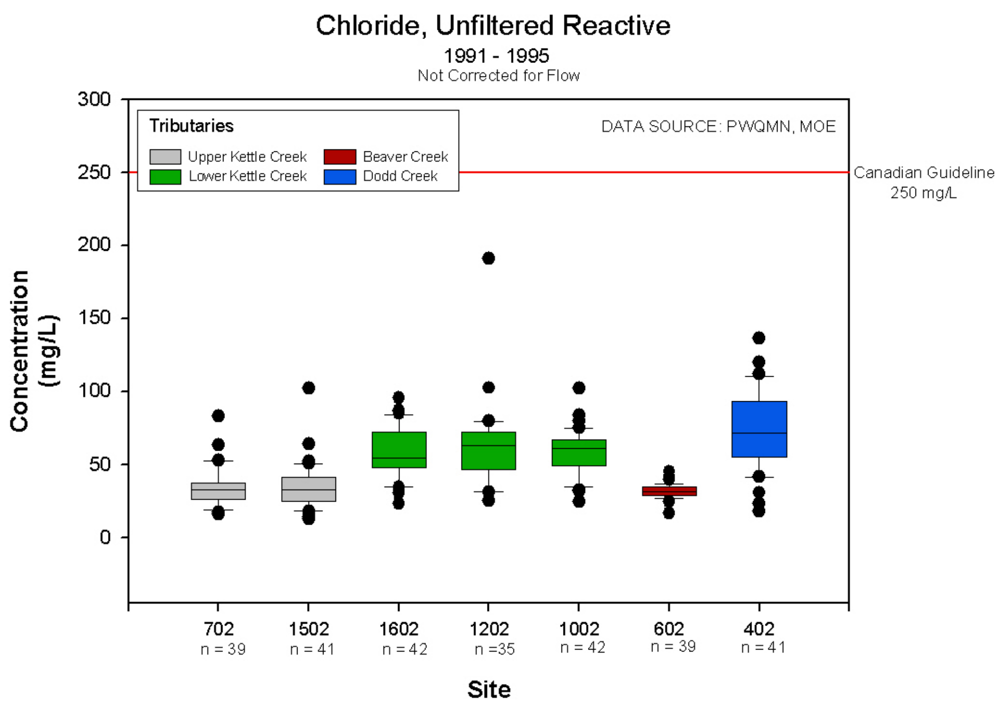

Figure 17. Total Chloride concentrations at 7 PWQMN monitoring sites in the Kettle Creek watershed from 1991-1995

Correlation between Flow and Nutrients

Positive correlations were found between flow and the following suite of nutrients: nitrate, nitrite, and total nitrogen. A negative correlation was found between flow and chloride. It was expected that a correlation would exist between flow and phosphorus and/or total suspended solids (Wall et al., 1996) however; no correlation was found (Appendix 8). In fact, phosphorus concentrations appear to be just as high in low flow as high flow periods, which is likely a result of the bias in sampling towards low to moderate flow regimes (Figure 18).

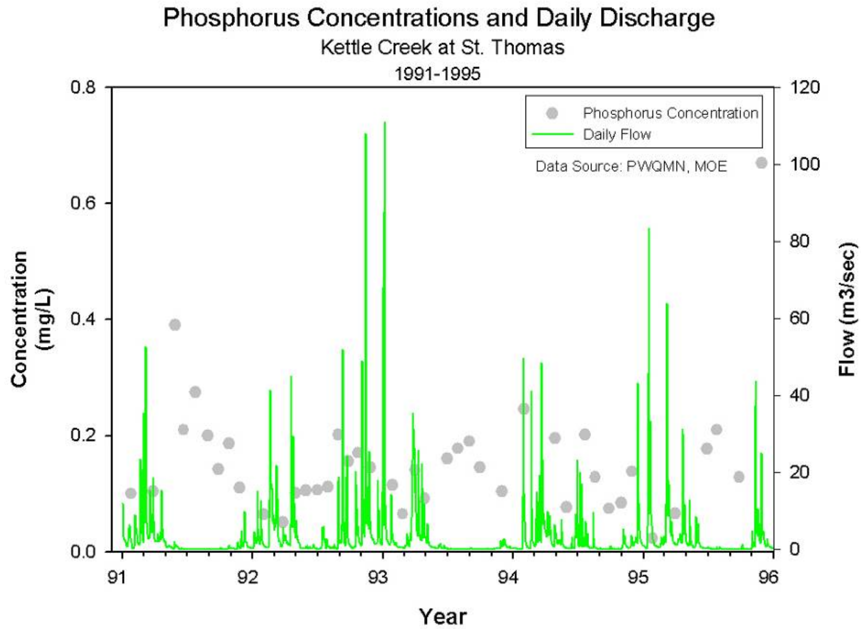

Figure 18. Phosphorus concentrations at site 1602 near St. Thomas plotted with daily stream flow at St. Thomas.

pH

The pH values varied only slightly between the seven PWQMN sampling sites (Figure 19). The Provincial Water Quality Objective (PWQO) for aquatic health indicates that pH should be maintained between 6.5 and 8.5. The pH values throughout the Kettle Creek watershed appeared to be closer towards the upper end of the range.

Dissolved Oxygen

Dissolved oxygen (DO) levels during the period from 1991-1995 were not observed below the critical 4 mg/L threshold for cold water biota. All samples report values above 5 mg/L with most around 9 mg/L. Sampling generally occurred between 11a.m. and 3p.m. and as a result, the data presented here does not represent diurnal fluctuations in DO levels (Figure 20).

Temperature

Temperature fluctuates depending on the time of day the sample was taken. Historically temperature was taken at the same time all other sampling was performed, generally between 11a.m. and 3p.m. This bias should be accounted for when interpreting the data in this report. Ambient water temperatures within the Kettle Creek watershed tend to follow a seasonal pattern ranging from 0 degrees in the winter to 26 degrees in the summer. Very little variation in temperature was found in a comparison of PWQMN sites during the 1991-1995 sampling period (Figure 21).

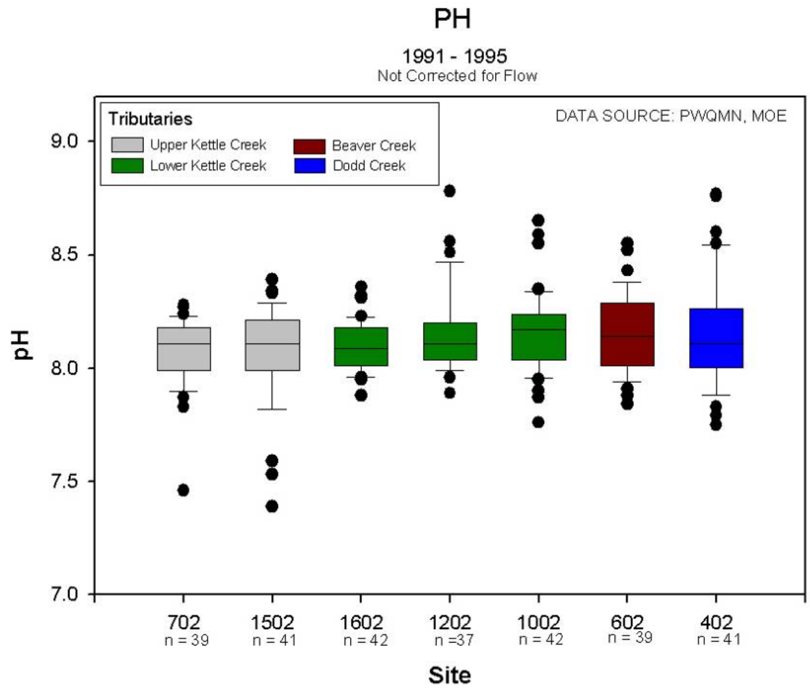

Figure 19. pH at 7 PWQMN monitoring sites in the Kettle Creek watershed from 1991-1995.

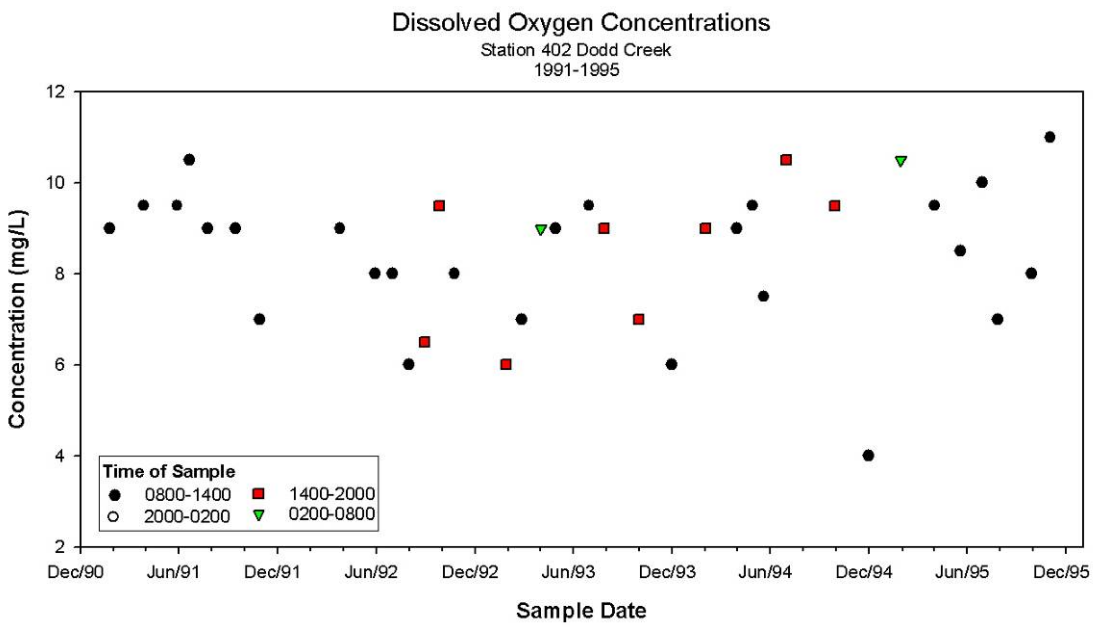

Figure 20. Dissolved oxygen at PWQMN site 402 within Dodd Creek illustrating the time of day samples were taken.

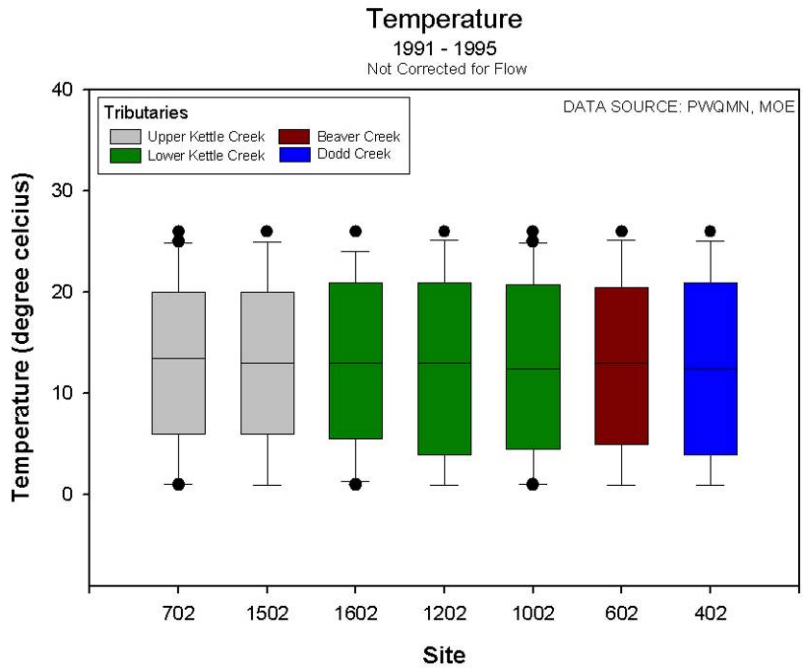

Figure 21. Temperature at 7 PWQMN monitoring sites in the Kettle Creek watershed from 1991-1995.

Metals

Metals data were not fully analyzed in this report due to concerns with historical laboratory detection methods. In 1997, MOE replaced the historical method for detecting metals in surface water, MET33386 with MET3080. This change replaced the digestion step with an ultrasonic nebulizer to reduce contamination problems previously found (Rusty Moody, Ministry of the Environment pers. communication). MOE did not continue to run samples with the old method once the new method was adopted thereby leaving no data from which an adjustment factor could be calculated.

Pesticides

Water samples collected at PWQMN site 16008701002 (Sparta Line) were monitored for pesticides during the 1994 and 1995 sampling seasons and sporadically from 1981 to 1992. The concentrations within the samples were below the detection limit and thus no measurable response could be collected. Detection limits for the pesticides sampled don't allow for trace amounts to be identified and thus comparison of levels to the PWQO for aquatic health could not accurately be assessed.

Bacteria and Pathogens

The presence of bacteria or pathogens has not been routinely monitored throughout the Kettle Creek watershed. However, periodic sampling at several of the PWQMN sites was carried out during the 1991 to 1995 sampling season.

Fecal coliform data was collected at all PWQMN sites from 1991-1994, while E. coli data was only collected from 1994-1995. Given the inherent variability in sampling and analyzing bacteria in surface waters, as well as the small sample size for E. coli (8-11 samples per site), no statistical analyses could be carried out for this report. Instead, this report has only commented on general characteristics in the data.

Fecal coliform levels were highly variable and ranged from four counts / 100ml to 58,000 counts / 100ml (Figure 22). E. coli levels ranged from 10 counts / 100ml to 4400 counts / 100ml. To account for some of the outliers, as evident in the box plots (Figure 23), the upper and lower 95th percentiles were used to spatially compare amongst sites within the watershed (Appendix 4).

Beaver Creek appeared to have the narrowest range in fecal coliform counts (8.7 to 841.5 counts per 100ml) whereas Dodd Creek had the widest range (30.8 to 4620 counts per 100ml). A similar trend in range values was also observed for E. coli counts with Dodd Creek having the widest and Beaver Creek having the narrowest range. High levels of both E. coli and fecal coliform were found directly downstream of both the urban centers of Belmont (site 702) and St. Thomas (site 1202).

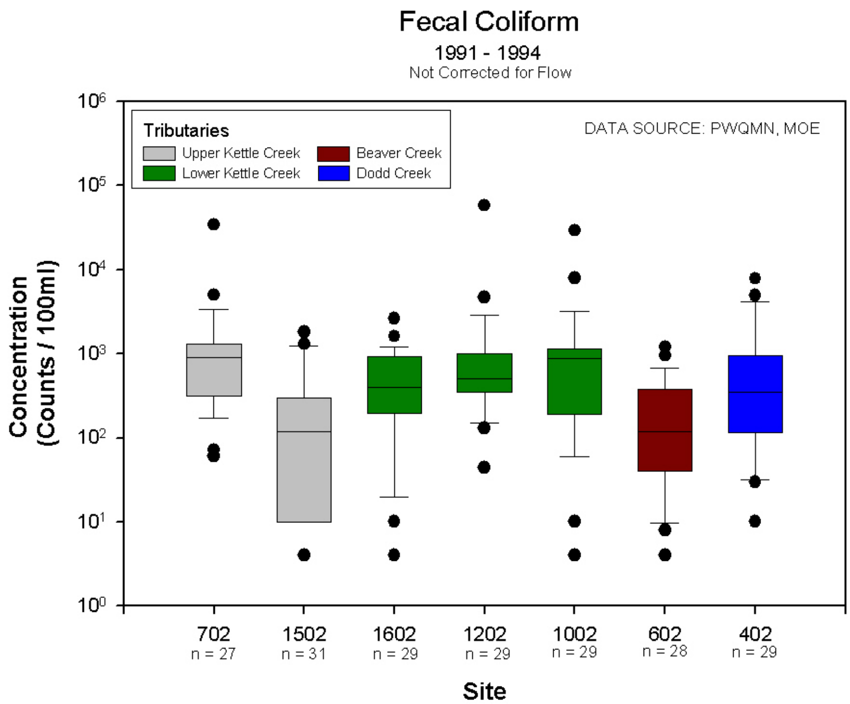

Figure 22. Total fecal coliform counts at 7 PWQMN monitoring sites in the Kettle Creek watershed from 1991-1994.

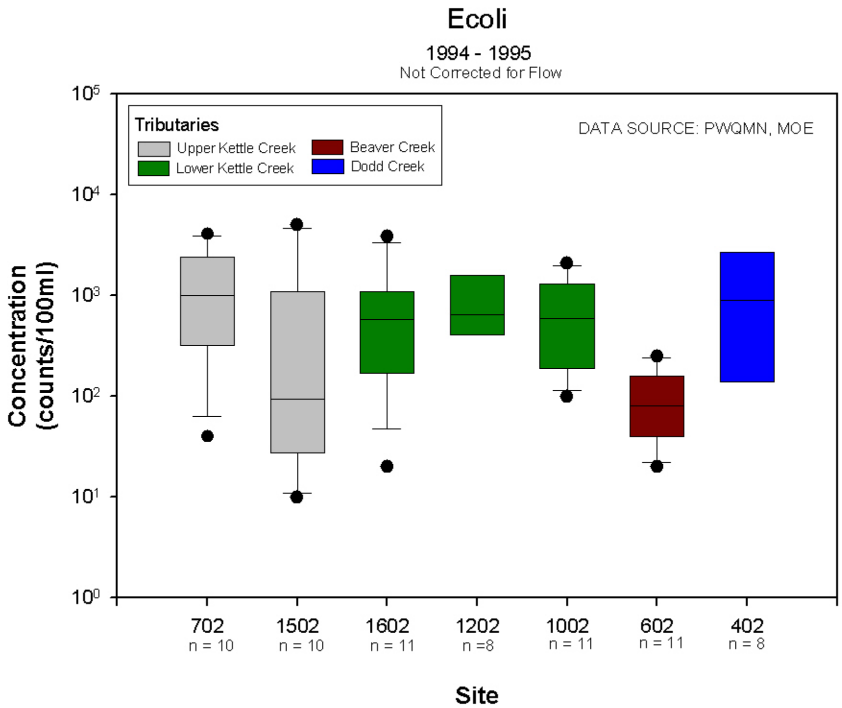

Figure 23. Total *E. coli* counts at 7 PWQMN monitoring sites in the Kettle Creek watershed from 1994-1995.

Preliminary Trend Analysis (LOWESS Plots)

Due to the low sampling frequency for the 1991-1995 sampling period and the fact that there are only a handful of samples that have currently been collected (2004-2005), statistical trend analysis was not undertaken. It was decided that there was not enough confidence in the historic data or statistical power in the current data to adequately report on statistical trends over time. Therefore, only a preliminary analysis to explore the data for temporal variability is provided.

Time series plots were created for each water quality parameter at each of the seven PWQMN sites for the period of record (Appendix 11). A LOWESS (LOcally WEighted Scatterplot Smoothing) smoothing algorithm was then applied to visually assess preliminary trends (Appendix 11). Most of the parameters did not exhibit any discernable trends over time. Since the late 1980's, nitrate concentrations appeared to be slightly decreasing within Upper and Lower Kettle Creek (Figure 24). Preliminary trends in total phosphorus concentrations were only evident in Dodd Creek, where levels appeared to have been decreasing since the mid 1980's (Figure 25). Non-filterable residue concentrations appeared to be slightly increasing over time within Dodd and Lower Kettle Creeks (Figure 26). Chloride concentrations appeared to increase in the 1980's and then level off in the early 1990's for both Dodd Creek and Lower Kettle Creek (Figure 27).

Although summer temperatures did not appear to increase within the study time period (1991-1995), the current data for 2004-2005 indicates there has been an increase in summer temperatures, namely August (Figure 28).

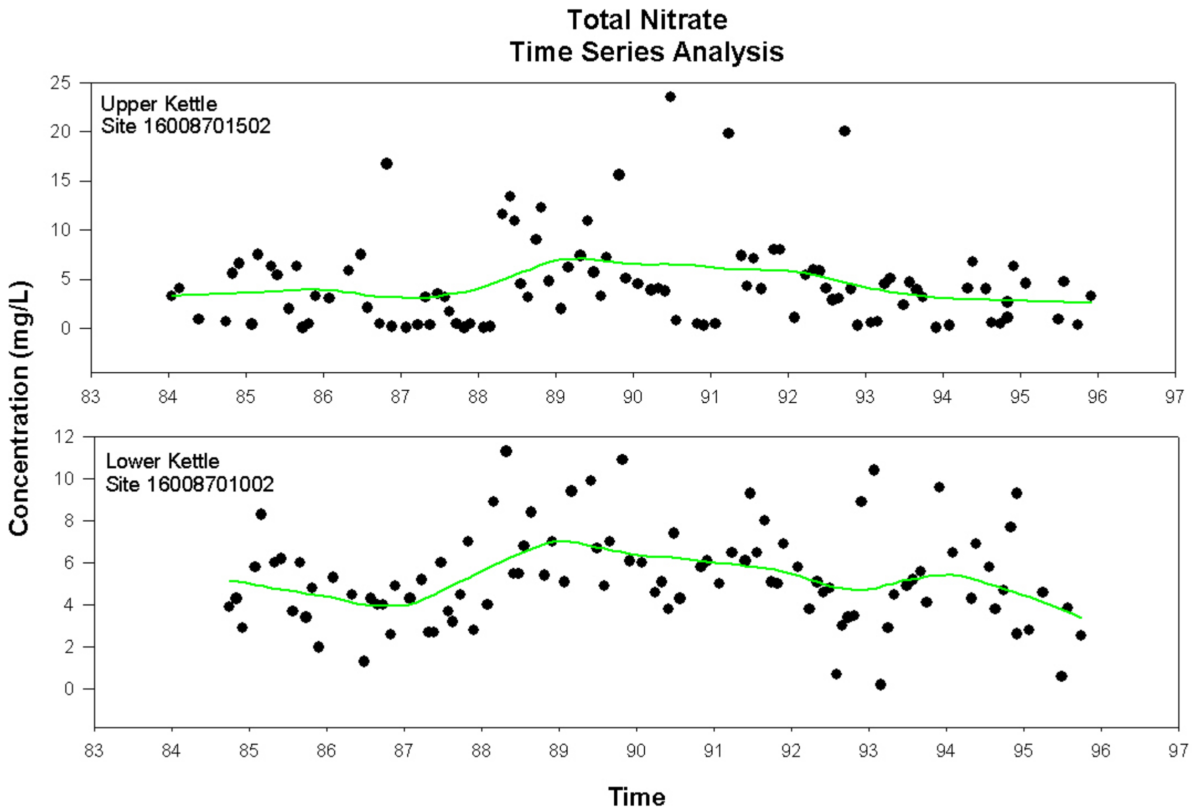

Figure 24. Time series plots for total nitrate concentrations from 1984-1996 at two PWQMN locations within Upper and Lower Kettle Creek. Lowess plots (green line) were applied to visually smooth the data and facilitate interpretations.

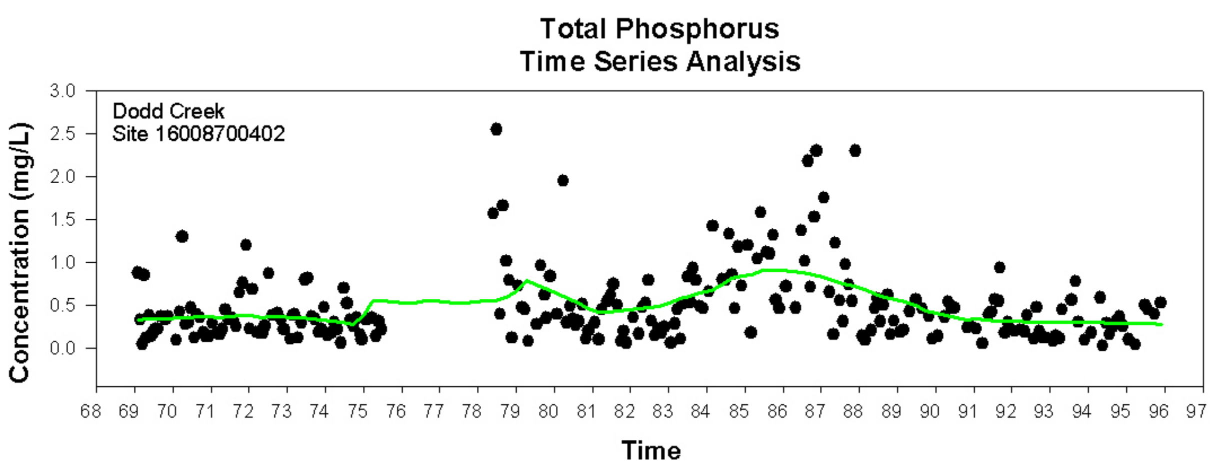

Figure 25. Time series plot for total phosphorus concentrations from 1968-1996 at PWQMN site 402 within Dodd Creek. Lowess plots (green line) were applied to visually smooth the data and facilitate interpretations.

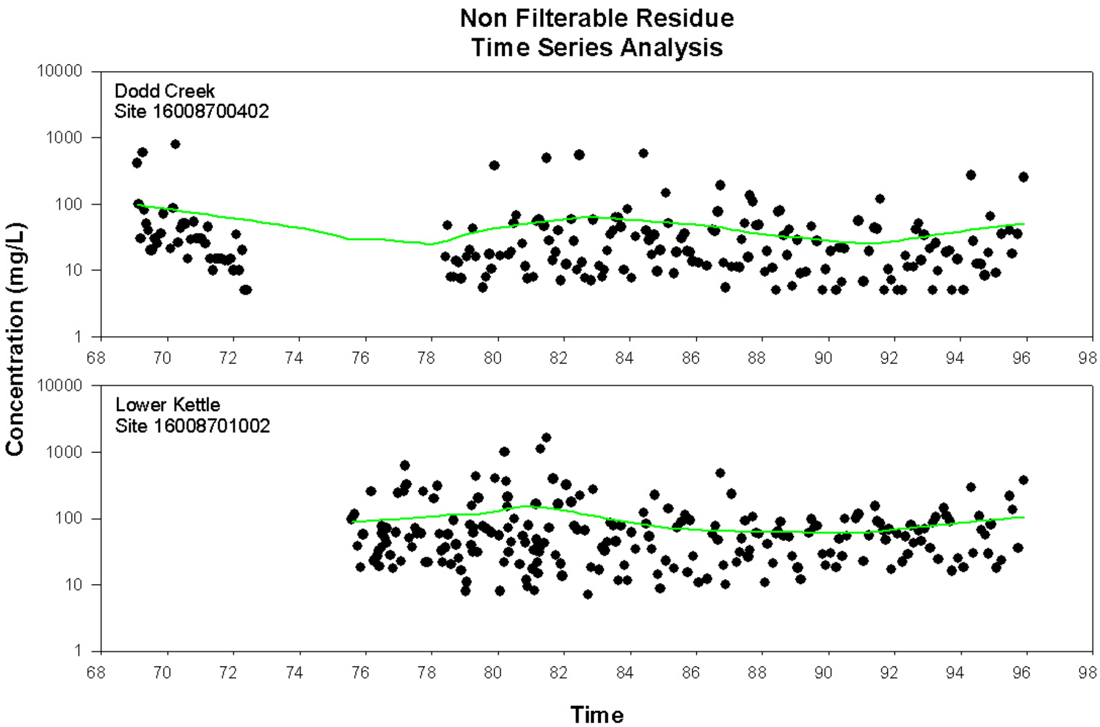

Figure 26. Time series plots for non-filterable residue concentrations from 1968-1996 at two PWQMN locations within Lower Kettle Creek and Dodd Creek. Lowess plots (green line) were applied to visually smooth the data and facilitate interpretations

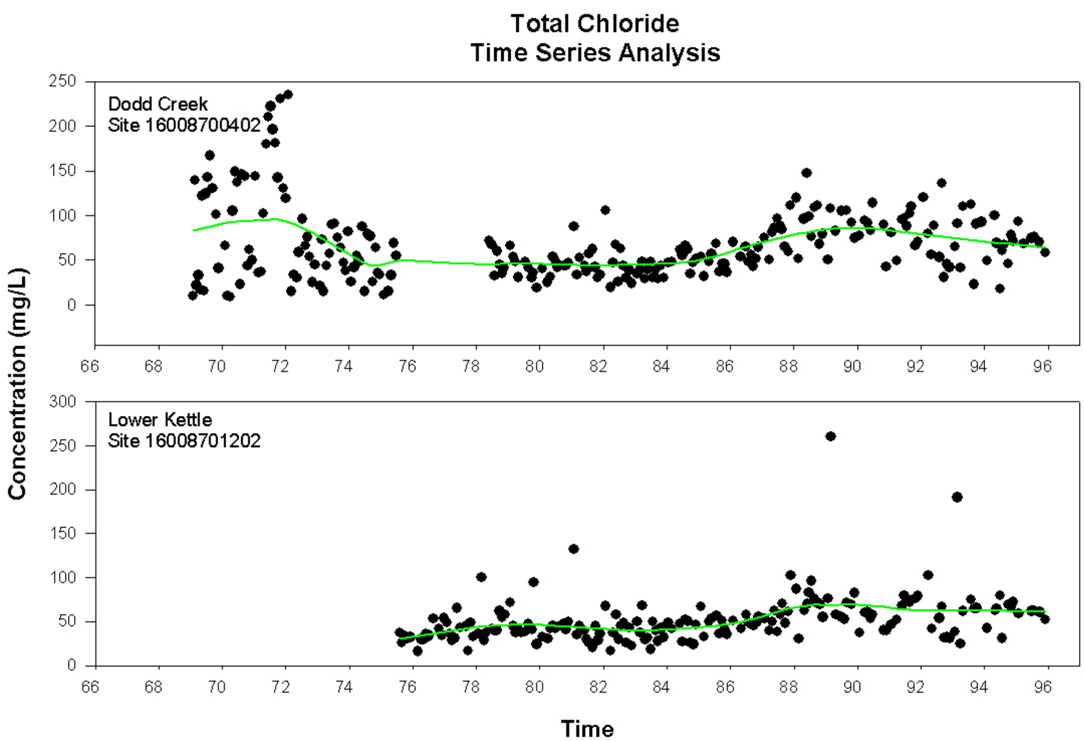

Figure 27. Time series plots for total chloride concentrations from 1968-1996 at two PWQMN locations within Lower Kettle Creek and Dodd Creek. Lowess plots (green line) were applied to visually smooth the data and facilitate interpretations

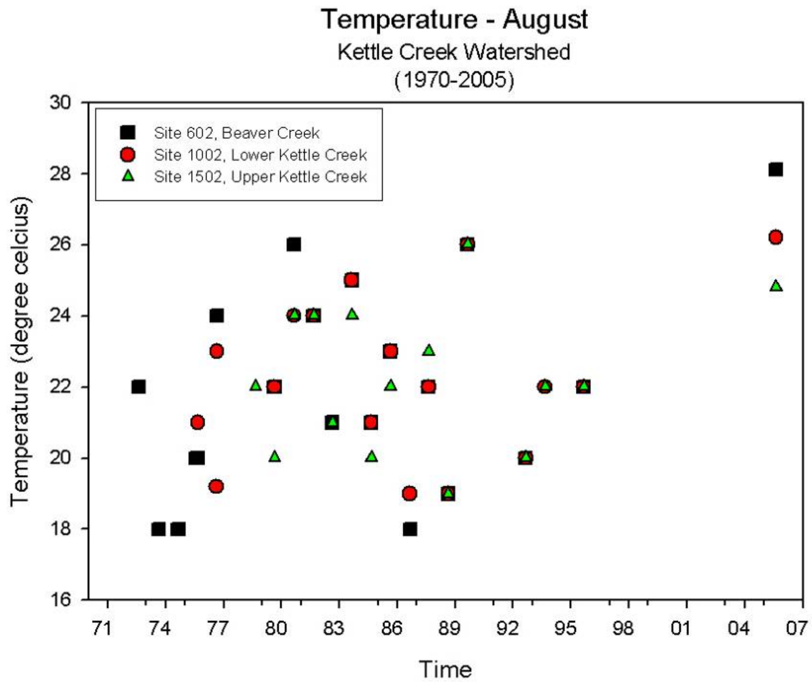

Figure 28. August temperatures for three long-term monitoring stations with the Kettle Creek Watershed.

REVIEW OF EXISTING LITERATURE

Benthic Macroinvertebrate Monitoring

Historically there was no routine monitoring of the benthic macroinvertebrate assemblages within the Kettle Creek watershed. Benthic macroinvertebrates are excellent ‘integrators’ of the many different environmental stressors, reflecting the combined effects of issues such as low dissolved oxygen, contaminant spills or chronic low pollutant levels that can impact or impair aquatic health. Several kinds of biotic indices have been developed and can be used as water quality assessment tools for a specific geographic location. The system KCCA employs is a biological index, known as BioMAP, developed for use in southern Ontario streams (Griffiths, 1998; Griffiths, 1999). Although KCCA has not completed any long-term routine monitoring, benthic macroinvertebrate studies within the region have occurred (Griffiths 1988, Griffiths, 2003).

Griffiths (2003) examined the use of riparian stream cover as a surrogate for water quality by determining if there was a positive correlation between results from the BioMap benthic water quality index and the level of riparian stream cover present. A positive correlation between riparian stream cover and stream health, as determined by benthic communities, was found. Results indicated that 25% of the watercourses within the Kettle Creek watershed showed unimpaired conditions, while 67% were deemed to be impaired (Appendices 12 and 13). Those areas identified as unimpaired (e.g. Beaver Creek) were consistent with the results from the analysis in this report. Griffiths (2003) suggested that the high percentage of impaired watercourses was likely due to the vast amount of agricultural land present within the watershed without riparian vegetation. The remaining 8% of watercourse was considered to be indeterminate. Indeterminate ratings are given to stream channels with BioMAP scores between 10 and 12. These areas typically exist immediately downstream of unimpaired areas. These indeterminate zones are prime target areas for stewardship projects because the rehabilitation process will be encouraged by the unimpaired upstream water quality.

General Bacterial Conditions within all Sub-basins

Depuydt (1994) endeavored to determine the source and extent of rural sources of bacterial contamination within the Kettle Creek watershed. Through extensive landowner surveys and water quality testing this study was able to identify the major sources of contamination and the extent to which they were affecting the creek.

Depuydt (1994) determined that the primary sources of fecal coliform loading within the Kettle Creek watershed were livestock access, septic system failure, and urban runoff. Milk house wash water and manure storage were also noted as issues, but not to the extent of the others (Appendix 12).

Time of travel studies were conducted to determine the average amount of time required for impaired water to reach the mouth of Kettle Creek (Depuydt, 1994). At the time this study was conducted, the primary concern was beach postings in Port Stanley. During flow events it was found that non-point farm related inputs would reach the mouth of Kettle Creek on average approximately three times faster than during base-flow periods (Depuydt, 1994).

To determine travel times for septic systems and urban runoff inputs, a separate investigation for each of the urban areas not serviced by a municipal sewage treatment facility (Union, Talbotville and Glanworth) was conducted. Results of these investigations also indicated that during flow events loads would reach the mouth of Kettle Creek on average three times faster than during base-flow.

Ultimately the report showed that fecal coliform counts at the creek mouth during baseflow were approximately 94 counts per 100ml and were as high as 2793 counts per 100ml during event flows. *E. coli* samples taken during baseflow displayed concentrations of 290 counts per 100ml. This count is well above the MOE bathing guideline of 100 organisms per 100ml.

Depuydt (1994) recommended that the most cost effective means of reducing and controlling bacterial loads in Kettle Creek would be through cattle access restrictions as well as septic system repairs and/or replacements.

Monitoring of PAH Contamination in Port Stanley

A major contamination issue affecting the water quality in Lower Kettle Creek at Port Stanley is the presence of Polynuclear Aromatic Hydrocarbons (PAHs) within the bed sediments. Two main areas within Lower Kettle Creek downstream of the George St. Drain in Port Stanley and adjacent to former petroleum tank farms have been identified as containing contaminated sediments. Several studies (Griffiths, 1988; Riggs Engineering, 2004; Acres and Associates, 2001) have investigated the extent and severity of the contamination. These studies have shown that the area furthest downstream is significantly contaminated (Appendices 13 and 14) and will continue to be a chronic source of pollution for the waterway if clean-up measures are not taken. PAHs are extremely toxic and can lead to odour problems and habitat degradation for aquatic life.

Griffiths (1988) examined the relationship between the presence of benthic community assemblages and their proximity to a known area with PAH contaminated sediments. Results indicated that the contaminated sediments had a negative impact on the worm community present which can likely be attributed to their close interaction with the sediments as detritivors and burrowers. These results suggest that the PAH contamination is affecting the water quality within Lower Kettle Creek and could be limiting the distribution of benthic macroinvertebrates communities.

Cumming Cockburn and Associates Limited (1987) determined that Kettle Creek deposits approximately 40,000 m^3 of silty sediment into the Port Stanley harbour every year. This plume of sediment from Kettle Creek into Lake Erie was identified by the Elgin Area Primary Water Board as a significant potential point source of contaminant laden sediments (Riggs, 2004).

In 2004, Letterhos & Vincent investigated contaminant levels contained within bed sediments at the mouth of the major tributaries draining into Lake Erie. Results indicated that sediments at the mouth of Kettle Creek had detectable levels of PAHs which were relatively high ranging from 1,610 - 22,800 ug/kg. Riggs Engineering Ltd (2004) found more evidence that the PAH contamination within Kettle Creek could be directly impacting the quality of the raw water taken up by the Elgin Area Primary Water Supply System. Riggs Engineering Ltd. (2004) also found a connection between the sediment plume at Kettle Creek's outfall and the sediment build-up within the Water Supply System's intake pipe. Analyses indicated that the sediments accumulating within the pipe were predominantly silt and clayey materials and likely originated from the Kettle Creek plume at Port Stanley and erosion of the Lake Erie bluffs. It was also noted that the transport of these sediments into the intake pipe was facilitated by the prevailing west to east littoral drift. Chemical analysis of the sediments within the intake pipe revealed high levels of phosphorus and nitrogen as well as trace levels of PAH contamination. These findings are of potential concern for two reasons: elevated sediment accumulation within the intake pipe could impede the effectiveness of the treatment facility and there is the potential for these contaminated suspended sediments to be taken up by the intake pipe.

DISCUSSION

Data Limitations

Environmental monitoring is imperative to good environmental decision-making (ECO, 1997). However, the interpretation of results from monitoring programs can be strongly influenced by the quality of data gathered. Therefore it is important to be transparent about the limitations of the data used in decision-making. This is not to say that investigating an issue should be postponed until better data presents itself. On the contrary, using the best available data at the time of investigation allows gaps in our existing datasets to be identified and thus better direct future data gathering expeditions.

Two of the most common data limitations found in environmental studies are the quantity (number of samples taken spatially and temporally) and quality (time and location of sampling event) of the data available.

Data Quantity Limitations

Historically, the KCCA carried out water quality sampling on a variety of scales. These included site specific studies (such as within the Dalewood Reservoir and the Port Stanley harbour) and watershed wide studies (such as the Provincial Water Quality Monitoring Network). Due to financial cutbacks by the province and limited internal capacity of the conservation authority, there has been a drastic reduction in water quality monitoring since 1996 until 2005. Across Ontario the PWQMN currently monitors at 350 stream sites (A.Todd, Ministry of the Envrionment, pers. communication), which is down from a high of 730 sampling sites in 1995 but up from the 240 sites monitored in 2000 (ECO, 2000). The decrease in spatial coverage of the PWQMN within the Kettle Creek Watershed (from a high of 12 sites to the current 4sites) and the reduction of yearly samples taken at each site (from 12 to 8) has limited the ability to conduct comprehensive spatial and temporal analyses at the watershed scale.

Water quality is highly variable and sensitive to season, time of day, temperature, flow-stage, spills, soil types, basin topography and many other factors. Due to this, water quality samples must be collected over a range of stream-flows that are representative of the stream at the sample-collection site (ECO, 2002; Painter et al., 2000). Consequently, many samples are required to adequately characterize water quality over a range of environmental conditions. Painter et al. (2000) recommends that at least 10 samples be taken per year to adequately characterize ambient surface water quality in streams, while Maybeck et al., (1996) suggest 12 samples per year for a multipurpose monitoring program, such as the PWQMN. The current eight samples per year per site limits the network's ability to characterize water quality over a full range of environmental conditions such as low and high flows or the effects of seasonality (e.g. under ice conditions).

Data Quality Limitations

Generally, water quality samples collected at sites in the Kettle Creek watershed were collected during low to moderate flows (Figure 10). This was likely a result of limited manpower and the logistical challenges of sampling high flow events.

The determination of contaminant loads or 'fluxes' is critical to understand the contribution of non-point sources of contaminants to a waterbody since most of these contaminants are mobilized during runoff events. It is not uncommon for 80-90% of the annual load to be delivered during 10% of the time when the highest discharges are occurring (Richards, 2002). As a result, it is important that water quality sampling be targeted to characterize both high and low flows. Painter et al. (2000) suggests that as few as 30 to as many as 75 or more samples may be used to estimate river loads using various estimator techniques, such as, statistical or regression approaches. However, censored data must be kept to a minimum of 50 percent.

Since only eight samples per year are collected at the PWQMN sites and generally at low to moderate flows, accurate annual loads cannot be made with any certainty. More frequent and targeted sampling of both high and low flows over the long-term is required to adequately characterize both ambient water quality and contaminant fluxes within sub-basins.

The approached used in this report whereby the most recent contiguous five years of data is summarized helps to increase the likelihood of characterizing the full range of flow and climatic conditions. This approach also reduces the strong year-to-year variability from extremes in climate (e.g. wet and dry periods).

The use of non-parametric statistics to anlayse the data also allowed our analysis to accommodate for the inherent characteristics of water quality data (i.e. non-normal distribution, outliers, missing data) (Hrynkiw et al., 2003; Trkulja, 1997). However a numerical statistical difference does not always translate into an ecological significant difference.

Water Quality Conditions in the Kettle Creek watershed

Generally, water quality conditions are described according to chemical and physical characteristics of the stream water. However, biological indicators such as benthic macroinvertebrates and fish species should also be used, in conjunction with chemical and physical characteristics, to further describe the overall health of a watershed. Currently, KCCA is in the process of developing a more integrative approach to water quality monitoring for the watershed, which will begin in 2007. This program will include a combination of benthic macroinvertebrate sampling, surface water sampling, sediment sampling, and groundwater monitoring.

General Physiochemical Conditions within all Sub-basins

Dissolved oxygen, temperature and pH levels were consistent at sites throughout the Kettle Creek watershed (Figure 19 and 21). All three parameters are important indicators of stress on aquatic organisms. Not only is it important to watch for the upper or lower tolerable thresholds, but also the range of values an organism experiences to determine if the conditions within an area are limiting.

Within the Kettle Creek watershed dissolved oxygen levels were rarely observed to dip below 8 mg/L which is well above the 4 mg/L lower threshold for cold water biota. While this value is considered to be adequate for aquatic life, samples were generally only taken during the day which would not have accounted for the diurnal fluctuation or the range of values an organism truly experiences (Figure 20). Thus, determining if dissolved oxygen within the Kettle Creek watershed was limiting to aquatic organisms can not be accurately assessed with the current sampling regime.

Twenty four degrees Celsius is generally the temperature threshold between cool water and warm water fish species (Stoneman and Jones, 1996). Prolonged periods of time for which temperatures are above 24°C creates stress for cold and cool water species thus limiting their ability to inhabit these areas of the creek. For the period between 1991 and 1995 summer temperatures were consistently above 20°C and reached as high as 26°C. Currently temperatures have been reported as high as 28°C, which is approaching the upper threshold for many warm water species (Figure 28). Increased water temperatures can also impact oxygen saturation of freshwaters thereby impacting metabolic rates, growth and reproduction of freshwater fish (Gordon et al., 1994).

The pH levels within the Kettle Creek watershed have tended to be within the upper end of the range given by the Provincial Water Quality Objective (PWQO). This could be of potential concern as pH levels greater than 8.5 indicate high levels of photosynthesis (Wurts and Durborow, 1992).

The following sections describe the chemical and physical conditions for the period between 1991 and 1995 found within the major sub-basins of the Kettle Creek watershed.

Conditions Specific to the Upper Kettle Creek Sub-basin

The Upper Kettle Creek sub-basin extends from Lake Whittaker in the northeast corner of the watershed to just below the Dalewood Reservoir north of St. Thomas and drains over a fluted till plain. Land-use across this region is mainly agriculture except for the Village of Belmont (Figure 1).

Generally water quality in Upper Kettle tends to be better than or as good as the rest of the watershed, with the exception of Beaver Creek, and tends to slightly deteriorate as it flows downstream from Lake Whittaker to the Dalewood Reservoir.

Lake Whittaker, a spring-fed lake, is a headwater source to Kettle Creek. Thus water levels and quality found within Lake Whittaker directly influence levels found within Upper Kettle Creek. A 1971 water survey by the Department of Lands and Forests (Loblaw and Pell, 1975) indicated that Lake Whittaker was in an advanced state of eutrophication and in the stages of succession leading to a marsh lake. To date a marsh has developed in two locations: at the north end of the lake; and, adjacent to the outlet of Kettle Creek, in the south end. Low water levels and flow rates along with the eutrophication of Lake Whittaker resulted in the development of stagnant pockets of water with decomposing aquatic vegetation leading to minimal dissolved oxygen (KCCA, 1989). Low dissolved oxygen can limit the number of fish species capable of inhabiting the lake, reduce water quality, and thus affect recreational activities. To combat these issues an experimental aerator was installed in early July 1989. The purpose of the aerator was to pump water from the deepest part of the lake bottom up to the surface, oxygenate it under compression and then return it to the lake bottom. A 1995 study conducted by the MOE indicated that the aerator was responsible for several improvements in water quality within Lake Whittaker (Gemza, 1997). Dissolved oxygen levels were shown to increase throughout the season, while levels of nutrients, metals, and hydrogen sulphide decreased considerably (Gemza, 1997).

Phosphorus loading is a serious concern across the entire watershed. Samples exceed the provincial guideline 97-100% of the time at all PWQMN sites monitored. Phosphorus levels within Upper Kettle Creek are significantly lower than those found within Dodd Creek or Lower Kettle Creek below St. Thomas. However, the levels are significantly higher than those found within Beaver Creek.

Phosphorus levels between the two Upper Kettle sites and site 1602 did not significantly differ. This indicates that phosphorus loading was not occurring within the upper sub-basin and that the characteristics of the watershed could be naturally elevating the phosphorus levels reported. Although not statistically significant, phosphorus levels were slightly higher directly downstream of Lake Whittaker. As phosphorus is considered to be the primary contributing factor to the eutrophication of freshwaters, this may indicate that the water coming from Lake Whittaker is slightly eutrophic.

Median nitrate concentrations within the Upper Kettle sub-basin are at or approaching the Canadian Guideline of 2.93 mg/L. However, they are significantly lower than levels within Lower Kettle Creek downstream of St. Thomas. Concentrations found within Upper Kettle do not significantly differ from each other or from levels found within Beaver Creek and Dodd Creek. Therefore, the elevated levels found within Upper Kettle are probably not as a result of the natural characteristics of the watershed, as Beaver Creek drains over a vastly different physiographic region. The higher nitrate levels may be as a result of the land-use within this region, which is mainly agricultural and the high percentage of tile drains present which can facilitate nitrogen leaching from fertilizers on farm land into waterways.

Non-filterable residue (NFR) levels appear to be a greater concern along Kettle Creek compared to the other tributaries within the watershed. Median concentrations at each of the sampling sites along Kettle Creek were above the 25mg/L benchmark while levels within the Dodd and Beaver Creeks were significantly lower. NFR levels within the upper portion of Kettle Creek tend to progressively increase from upstream to downstream. No significant increase was found between the sites along Upper Kettle Creek or site 1602 on Lower Kettle Creek. However, sites within Upper Kettle have significantly lower NFR concentrations than those sites downstream of St. Thomas.

Although there is a lack of long-term monitoring data for bacteria and pathogens, elevated levels of *E. coli*, relative to other sampling sites, was found downstream of Belmont. However, given the error associated with the methods for assessing bacterial counts in natural systems, further analysis is required to determine if bacteria within this area is of real concern.

Within the downstream portion of the Upper Kettle Creek sub-basin is the Dalewood Reservoir. KCCA purchased the Dalewood Reservoir and surrounding lands, approximately 243 Ha, from The City of St. Thomas in 1976. Formerly the St. Thomas Waterworks Reservoir, this reservoir was historically used as a drinking water supply to the city. In 1967 St. Thomas' water supply was connected to the Elgin Area Primary Water Supply system, and by 1970 St. Thomas was supplied exclusively by this system.

Over time the Dalewood Reservoir has become heavily silted, which has allowed for the surrounding provincially significant wetland to expand. Although this expansion of the wetland can be considered an advantage, it is important to note that the Dalewoood Reservoir is seen as both a sink and source of sediment within the watershed. Unfortunately, none of the PWQMN sites analysed in this report were situated directly downstream of the reservoir to accurately assess its influence on Kettle Creek. Earlier studies have indicated that sedimentation through the process of erosion has become a serious issue within the reservoir decreasing the number of deep pools for fish habitat and the ability of the reservoir to act as a flood control device (Philips Engineering Ltd., 1981; KCCA, 1989). The source of these sediments is likely from a combination of intensive agricultural practices and the steep nature of the watershed. In 1981 Philips Planning and Engineering Limited (1981) reported the general state of the reservoir as poor based on decreased water quantity, impaired water quality, and a decrease in the diversity of aquatic life present. More specifically the water quality within the reservoir is impaired based on the presence of excessive amounts of nutrient and bacteria laden sediments.

These findings were also supported by Hawkins (1993) who indirectly evaluated the success of the initiatives taken in response to the recommendations in Philips Engineering Ltd. (1981). Hawkins (1993) found that the measures taken by KCCA to reduce sediment transport into the Dalewood Reservoir between 1981 and 1993 had not significantly improved the water quality or sediment loading and suggested rehabilitative activities should continue. However, a more recent study (Peter Crook, Riggs Engineering Ltd., pers. communication) suggests that the sediment loading within the reservoir has reached equilibrium.

Given these reported concerns with the water quality within the Dalewood Reservoir and the potential sediment loading to Kettle Creek, KCCA is currently monitoring directly downstream of the reservoir to determine if it is contributing to some of the elevated nutrient and non-filterable residue levels reported within Lower Kettle Creek.

Conditions Specific to the Dodd Creek Sub-basin

The Dodd Creek sub-basin is in the northwest quadrant of the watershed and drains over the Mount Elgin Ridges, a clayey till plain. Land-use across this region is mainly agriculture with the exception of a few industrial sites north of Talbotville.

Only one long-term monitoring site exists in the Dodd Creek sub-basin, on Clinton Line just west of Highway 4. Water quality at this site tends to be impacted by the intensive agricultural production and shows high phosphorus levels.

Median nitrate, nitrite and ammonia levels are below their respective Canadian guideline or Provincial objective within Dodd Creek. However, median levels for total Kjeldahl nitrogen (TKN) within Dodd Creek were significantly higher than median values found at all other sampling sites except for those within the first two sites along Lower Kettle Creek (sites 1602 and 1202). The Lower Kettle sites are downstream of the confluence between Dodd and Kettle Creek and likely are heavily impacted by the high levels of Kjeldahl nitrogen emptying into the Lower Kettle from Dodd Creek. Considering ammonia ($NH4^+$) levels within Dodd Creek are fairly low, it is likely that the elevated TKN levels found are as a result of high levels of organic nitrogen. Organic nitrogen can easily be converted by microbes into useable forms of nitrogen for uptake by plants such as nitrate. Therefore the high levels of TKN found could also indirectly be contributing to the increased productivity found within Dodd Creek.

Generally, high phosphorus concentrations are seen in areas that drain highly intensive agricultural lands situated on till or clay plains, which is the case for Dodd Creek. While concentrations exceed the provincial objective 97 to 100 % of the time across the entire watershed, median levels are highest within Dodd Creek. Phosphorus levels within Dodd Creek are statistically similar to those found within Lower Kettle Creek downstream of St. Thomas, but are significantly higher than levels found within the rest of the watershed.

Lower than expected non-filterable residue (NFR) levels were found within Dodd Creek. Given the extremely high phosphorus levels found, it would be expected that NFR levels would also be high as these two parameters are usually positively correlated (Wall et al., 1996). The lower NFR levels are likely an indication that most of the total phosphorus within Dodd Creek is dissolved. However, these results could also be an artifact of the extremely low flow within the creek which may not allow for the re-suspension of sediments and thus are not adequately captured in the sampling protocol used.

Chloride is an important ion in metabolic processes of aquatic organisms as it influences osmotic balance and ion exchange. The highest chloride concentrations were found in Dodd Creek, although none of the samples analysed were above the 250mg/L benchmark. Usually excess chloride within streams is attributed to road salting in urban areas. Within the Dodd Creek sub-basin runoff from Highway 401, Highway 4 and/or the industrial parking lots adjacent to Hwy 4 could be contributing to these higher concentrations. It is also possible that the lower natural stream flow found within Dodd Creek could be artificially elevating the levels of chloride found as concentrations may be less dilute than what would be found in other parts of the watershed.

Dodd Creek had the highest *E. coli* counts observed compared to the rest of the Kettle Creek watershed (Appendix 4). However, for the entire study period the bacterial counts within Dodd Creek were extremely variable and did not result in the highest median value during the 1991 to 1995 sampling period compared to other sites within the watershed.

Conditions Specific to the Lower Kettle Creek Sub-basin

The Lower Kettle Creek sub-basin drains two distinct physiographic regions. The lower portion of Kettle Creek drains over the Ekfrid Clay Plain while Beaver Creek, a tributary to the east of the Lower Kettle, drains primarily over the Norfolk Sand Plain. These two physiographic regions differ dramatically in soil composition which can influence the inherent water quality found.

Land-use across this region is mainly agriculture, but is bordered north and south by the urban developments of St. Thomas and Port Stanley, respectively. Land-use such as this can intensify the influence local geology has on the water quality within an area.

Generally water quality tends to be impaired within Lower Kettle Creek and progressively deteriorates from upstream to downstream, reflecting the cumulative impact of the upstream watershed and the watershed’s natural characteristics. In contrast, water quality within Beaver Creek is comparatively good as it had the lowest median values for most of the water quality parameters analyzed.

Beaver Creek flows into Lower Kettle Creek downstream of where Sparta Line and Roberts Line intersect. This creek drains mostly non-intensive agricultural land within the Norfolk Sand Plain. Along Beaver Creek there is a series of online ponds backed up by the Union Dam. To date no study has directly investigated the water quality present within the online ponds. However, PWQMN site 602 is located immediately downstream of the dam which can give a relatively accurate picture of the effect these online ponds have on the stream water quality, but not on the water quality within the ponds themselves. Results from the analysis of this site indicate that although there were exceedances for some of the nutrient parameters, Beaver Creek was one of the least impaired sections within the greater watershed.

These findings are likely due to the natural geology unique to this region of the watershed. The sandy overburden is more likely to allow water to filter through to the water table, reducing run-off. Also, the coarser particles are less likely to transport nutrients and metals than the silt and clay particles which are abundant throughout the rest of the watershed. This combined with shallow aquifer feeds into the creek likely account for the lower level of contaminants. A water quality map presented by Griffiths (2003) also echoed these thoughts.

The confluence of Beaver and Kettle Creeks is downstream of the PWQMN monitoring site 1002, the furthest downstream site on Lower Kettle Creek. Therefore, the potential moderating influence that the less impaired water from Beaver Creek may be having on Kettle Creek can not be assessed. In future it would be of interest to establish a monitoring site downstream of this confluence to determine if the less impacted water from Beaver Creek is influencing water quality within Lower Kettle Creek. Consequently, if it is shown to be having a positive affect on water quality then efforts should be directed toward protecting Beaver Creek so that this creek can continue to improve water quality within the Lower Kettle.

Generally the lower portion of Kettle Creek, downstream of St. Thomas is highly productive and exhibited some of the highest nutrient and non-filterable residue loads within the watershed.

Within the Lower Kettle Creek sub-basin, nitrate levels are significantly higher downstream of St. Thomas relative to all other sites within the watershed. Although not significant, a decrease in median nitrate levels was found between site 1502, on the Upper Kettle, and 1602, at the confluence of Dodd with Lower Kettle. This indicates that the low levels found in Dodd Creek may be positively impacting Lower Kettle Creek. The significant increase in nitrate levels found between site 1602 and site 1202 indicates that there is an input somewhere between these sites. A potential source of this loading could be attributed to discharge from the St. Thomas sewage treatment plant located between these two sites or a known livestock access point directly upstream of site 1202. Another potential input could be as a result of the numerous tile drains within the area. However, due to the wide coverage of agricultural land and tile drainage across other regions of the watershed, this may not be the major contributing factor here.

Phosphorus is the most serious nutrient loading issue within this sub-basin as all three sites consistently had samples with concentrations above the PWQO. Phosphorus is considered to be the primary contributing factor to eutrophication in freshwaters as it is the most limiting factor for plant growth. Generally high phosphorus concentrations are seen in areas that drain highly intensive agricultural lands situated within till or clay plains, which is the case for Kettle Creek. Given the excessively high levels found at other sites within the watershed also situated within clay or till plains, the underlying geology may be driving this water quality issue. This phenomenon is likely being exacerbated by the land-use within this region such as fertilizer application. However, the significant increase in concentrations found between site 1602 and 1202 indicates that urban sources, such as waste water treatment effluent, are potentially the primary contributor to the elevated levels found below St. Thomas.

The highest non-filterable residue (NFR) concentrations were found along Lower Kettle Creek. The watershed's natural characteristics and higher natural flows increase the potential for erosion and re-suspension of bed sediments to occur within Lower Kettle Creek which could be the primary cause for the elevated levels. The discharge from the St. Thomas sewage treatment plant (STP), the bank erosion caused by livestock access to streams, the sediment deposition occurring in Dalewood Reservoir and the general steepness of the watershed could also be contributing to the high NFR levels found along Lower Kettle Creek.

High levels of non-filterable residue can increase turbidity and restrict light penetration thus disrupting plant growth. High NFR can also damage fish gills and interfere with drinking water treatment processes. The high rate of bank erosion occurring throughout the watershed along streams and the bluff face at Lake Erie are of obvious concern to the KCCA.

Chloride levels within the Lower Kettle Creek sub-basin are relatively low compared to the Environment Canada benchmark of 250 mg/L (Environment Canada, 2001). Usually excess chloride concentrations within streams can be attributed to road salting in urban areas. The increased levels found at all sites within Lower Kettle Creek relative to the Upper Kettle or Beaver Creek indicates that there is a potential input of chloride coming from either Dodd Creek (where the highest median levels were found) and/or St. Thomas' city centre.

Bacterial and pathogen data from the PWQMN suggests that there are elevated levels within Lower Kettle Creek below St. Thomas. The highest fecal coliform counts were found at site 1202, situated directly downstream of both the St. Thomas wastewater treatment plant and a known livestock crossing. The ability for livestock to enter the waterways can have a great impact on both fecal coliform and *Escherichia Coli* counts. Depuydt (1994) also found that the occurrence of bacteria and pathogens was common within the Lower Kettle Creek sub-watershed. This is likely due to the fact that up until 2000 the St. Thomas Sewage Treatment Plant (STP) did not have a separate retention facility to accommodate combined sewer flows during high rainfall events and therefore, was forced to frequently bypass (Depuydt, 1994). In a study evaluating the efficacy of the upgrade to the St. Thomas STP, it was found that bypasses were reduced by 94% (EDC, 2004). Further investigation of current bacterial loads and frequency of bypasses from the St. Thomas STP should be conducted to determine benchmark levels of bacteria for the Kettle Creek watershed. However, the methods used for enumerating and quantifying bacteria and pathogen levels in natural waters have a large degree of error associated with them and requires additional research. Therefore, academia should continue to pursue methodological research for quantifying pathogen levels in the Kettle Creek watershed in an effort to reduce these inherent sampling errors.

Trends in Water Quality

To determine whether water quality conditions are improving or deteriorating proves to be particularly difficult as there are confounding variables that must be considered before statistically analyzing the data (Helsel and Hirsch, 2002). For example, water quality time series data tend to be non-normally distributed, have large variability, are influenced by season, and have covariate effects, such as flow (Trkulja, 1997). Water quality data collected for the PWQMN program routinely are affected by these confounding variables. The preliminary trend analysis performed in this study indicated that nitrate may be decreasing along Kettle Creek, total phosphorus levels were decreasing within Dodd Creek, NFR was increasing across the watershed with the exception of Beaver Creek, chloride levels were increasing in Dodd and Lower Kettle Creek, and summer temperatures were increasing.

However, the temporal variability was likely biased by the high occurrence of sampling at low flow periods. This could have had an influence on whether a trend was discernable or if the one displayed was in fact true. Therefore, a more detailed analysis is required following a change in the sampling regime which will encompass higher flows to accurately comment on temporal trends.

Spills

Spills can be defined as releases of pollutants into the natural environment originating from a structure, vehicle, or other container and are abnormal in light of all circumstances. All spills must be reported to the Ministry of the Environment so the necessary remedial actions and protection measures can be taken. Relatively few spills have been recorded within the Kettle Creek watershed.

Although spills are not considered to be a chronic water quality problem they can still have a tremendous impact on aquatic health and are of potential risk to drinking water if the spill is substantial enough to cause contamination of the Lake Erie intake waters. Current time-of-travel studies within the watershed indicate that a spill in Dodd Creek would reach Port Stanley within nine hours during a peak event (Bryan

Hall, Kettle Creek, pers. communication). Given inherent risk to the region's drinking water supply and the limited response time in a spill emergency, it is imperative that spill response protocols are in place.

SUMMARY & CONCLUSIONS

Water quality sampling within the Kettle Creek watershed occurred on a routine basis whereby flow was not always considered. This is evident when dates of sampling events are graphed against stream flow (see section 2.7.1 Figure 1). Generally, sampling was performed across a range of flow events; however, peak events were missed for some years. This potential bias towards sampling at low to moderate flows indicates that the results from the monitoring data presented here has mainly characterized base-flow and likely has not captured the changes in water quality which occur during high flow events.

The lower Kettle Creek and Dodd Creek sub-basins are the most impaired regions within the watershed where water quality appears to progressively deteriorate from upstream to downstream. Located on the Norfolk Sand Plain, Beaver Creek was found to be the least impaired region within the watershed. This is likely due to the natural characteristics of that sub-basin, primarily the sandy soils and groundwater-sourced stream baseflow.

Nutrient levels, primarily phosphorus (Figure 1) and nitrate (Figure 2), are high throughout the watershed. Nitrate concentrations are significantly higher within Lower Kettle Creek relative to the rest of the watershed. Phosphorus concentrations, although highest in Lower Kettle Creek and Dodd Creek, are consistently high throughout the watershed, and typically exceed the provincial water quality objective of 0.03mg/L. Due to the importance of these nutrients for plant growth, there is a clear indication that these levels could lead to an increase in eutrophication of water resources across the watershed. Generally high phosphorus concentrations are seen in areas that drain highly intensive agricultural lands situated on till or clay plains, which is the case for both Dodd and Kettle Creek. However, there are also urban sources entering the Creek, such as wastewater treatment plant effluent, that could also be elevating phosphorus levels found below St. Thomas.

Non-filterable residue (NFR) levels appear to be of more concern along Kettle Creek compared to the other tributaries within the watershed (Figure 3). NFR levels are routinely above the 25mg/L general criteria within Kettle Creek and progressively increased from upstream to downstream. High levels of non-filterable residues can increase turbidity and restrict light penetration thus disrupting plant growth. High NFR can also damage fish gills and interfere with drinking water treatment processes. The discharge from the St. Thomas wastewater treatment plant (WWTP), the bank erosion caused by livestock access to streams, the sediment deposition occurring in Dalewood Reservoir and the general steepness of the watershed could all be contributing to the high NFR levels found along Lower Kettle Creek.

Both the nutrient and sediment issues within the Kettle Creek watershed are primarily the result of runoff and erosion. These conditions are amplified by land-use practices, such as agriculture and urbanization, and the dramatic elevation change within the watershed. Nutrient and sediment concentrations are typically linked as nutrients readily bind to clayey and silty sediments (Hairston and Stribling, 1995).

Chloride is an important ion to metabolic processes of aquatic organisms as it influences osmotic balance and ion exchange. Usually excess chloride within streams is attributed to road salting in urban areas. Within Kettle Creek's watershed chloride is not a water quality concern as levels do not appear to be approaching the 250mg/L Canadian guideline (Figure 4).

Most of the tributaries within the Kettle Creek watershed are thermally stressed and with the increasing trend in summer temperatures it has become a primary water quality concern. High water temperatures can limit the diversity of aquatic species present as well as impact dissolved oxygen saturations. For the period between 1991 and 1995 summer water temperatures were consistently above 20°C and reached as high as 26°C. Currently water temperatures have been reported as high as 28°C, which is approaching the upper threshold for many warm water species. These higher summer water temperatures are amplified in the upper Kettle and Dodd Creek sub-basins by the relatively low natural base-flows which tends to be intermittent during the dry season. Future investigations into possible ways to manage these very high summer temperatures should be examined.

Within the Kettle Creek watershed dissolved oxygen levels were rarely observed to dip below 8 mg/L which is well above the 4 mg/L lower threshold for cold water biota. While this value is considered to be adequate for aquatic life, samples were generally only taken during the day which would not have accounted for the diurnal fluctuation or the range of values an organism truly experiences. Thus, determining if dissolved oxygen within the Kettle Creek watershed was limiting to aquatic organisms can not be accurately assessed with the 1991-1995 sampling regime and diurnal monitoring should be employed as part of future monitoring programs.

The Kettle Creek watershed has relatively low natural base-flows and areas within the upper portion of the watershed have intermittent flow during dry seasons. This could potentially have an affect on the relationships observed between flow and nutrient concentrations. For example, phosphorus concentrations appear to be just as high in low flow as high flow periods (Figure 17). Elevated levels during low flow could be due to sampling stagnant waters under anoxic conditions which facilitates the release of phosphorus from sediments or as a result of less dilute concentrations being sampled. Sampling at higher flow periods should be done to fully understand if this is a potential mechanism for the relationship observed in this study.

Also associated with the low natural base flow is the limited assimilative capacity of Kettle Creek. Several studies assessing the assimilative capacity of the tributaries within the Kettle Creek watershed (McTavish, 1976; Mohring, 1995; KCCA, 1967) have indicated that there is inadequate streamflow throughout to sufficiently dilute municipal and industrial waste discharged during the summer low flow period. KCCA (1967) indicated that the Ford plant and the St. Thomas WWTP make up most of the baseflow within Dodd and Lower Kettle Creek during the summer low flow season.

Bacteria and pathogens in the Kettle Creek watershed tend to be highly variable likely as a result of the land-use within the watershed. Dorner (2004) identified both agricultural and urban watersheds as areas that have a high occurrence of pathogens. Depuydt (1994) suggested that the primary rural sources of fecal coliform concentrations to the Kettle Creek were faulty septic systems, urban runoff and livestock access to streams.

A major contamination issue affecting water quality within Lower Kettle Creek at Port Stanley is the presence of Polynuclear Aromatic Hydrocarbons (PAHs) within the bed sediments. Two main areas within Lower Kettle Creek downstream of the George Street Drain in Port Stanley and adjacent to former petroleum tank farms have been identified as containing contaminated sediments. Several studies (Griffiths, 1988; Riggs Engineering, 2004; Acres and Associates, 2001) have investigated the extent and severity of the contamination. These studies have shown that the area furthest downstream is significantly contaminated and will continue to be a chronic source of pollution for the waterway if clean-up measures are not taken. PAHs are extremely toxic and can lead to odour problems and habitat degradation for aquatic life. Cumming Cockburn and Associates Limited (1987) determined that Kettle Creek deposits approximately 40,000 m^3 of silty sediment into the Port Stanley harbour every year. This plume of sediment from Kettle Creek into Lake Erie was later identified by the Elgin Area Primary Water Board as a significant potential point source of contaminant laden sediments to the intake pipe (Riggs, 2004).

Spills and wastewater treatment plant bypasses are a significant threat to downstream water users in the Kettle Creek watershed. They represent an acute and immediate impairment to water quality that can compromise drinking water treatment at the Elgin Area Primary Water Supply System as well as interfere with recreation occurring at Port Stanley beaches. Therefore, it is imperative to have an effective spills response protocol and accurate stream information for timely response.

Preliminary trend assessment yields variable results with respect to whether nutrients levels are decreasing or increasing over time. Re-assessing these trends in the future with current data would be beneficial in evaluating if new trends are emerging.

Although the characterization of the water quality within this analysis focused mainly on chemical and physical data from the PWQMN other sources and types of data should ideally be incorporated to create a more integrative approach to monitoring and assessing water quality within a watershed. In 2006 KCCA proposed such an approach to water quality management. This program will include a combination of benthic macroinvertebrate sampling, surface water monitoring, sediment sampling, and groundwater monitoring.

RECOMMENDATIONS

To improve the understanding of the water quality conditions of the Kettle Creek watershed, the following recommendations are made:

Sampling Regime

1. At a minimum, 12 samples per year should be taken at each long-term monitoring site to characterize ambient water quality conditions. This will require additional financial resources from the province to complete the laboratory analysis as well as manpower resources from the KCCA.
2. The sampling regime should be designed so that the complete range of flow conditions are sampled. For example, additional high flow samples should be targeted during spring runoff and summer rainfall events. This will characterize the range of environmental conditions that exist in the watershed.

Monitoring

1. Continue monitoring chemical and physical parameters within the watershed including metals at the current four PWQMN sites and the five sites added as part of KCCA's capacity building under the Source Water Protection Program.
2. Conduct continuous monitoring of dissolved oxygen, pH, temperature, and conductivity to adequately capture the range of values organisms are truly experiencing within a day.
3. Use continuous conductivity monitoring up and down stream of suspected point source contamination contributors to identify issues.
4. Continue with the development of an integrative monitoring program that combines chemical, physical and biological (e.g. benthic macroinvertebrate, fish community) data.
5. Make the Source Water Protection (SWP) sampling sites permanent sites to gain better spatial coverage of the watershed.
6. Monitor for pesticide contamination pre and post application and target sampling during high flow events within smaller agricultural and urban tributaries.
7. Monitor watershed out-flow quality and quantity.

Reporting

1. Identify specific long-term indicators that can be used for progress measurement. Review monitoring activities to ensure that these indicators will be collected annually. Ensure that these indicators are incorporated into the monitoring design.
2. Prepare an annual "big picture" report of current conditions to report on progress.

3. Every five years, prepare an in-depth technical report for each monitoring program (e.g. Benthics).
4. Complete a future statistical trend analyses upon completion of a current five year set of physiochemical surface water sampling data. This is to properly assess if areas within the watershed are improving or deteriorating over time.

Future Investigations

1) Investigate the linkage between sub-watershed characteristics and nutrient concentrations (bound to sediment or within the water column) in order to establish basin specific benchmarks.
2) Investigate the linkage between land-use and water quality to determine best management practices for agriculture and watershed rehabilitation in each sub-watershed.
3) Undertake time-of-travel studies to assist with predicting and responding to spills.
4) Investigate potential point and non-point sources of sediment and nutrient loading within the Kettle Creek watershed, specifically from the St. Thomas sewage treatment plant and the Dalewood Reservoir.
5) Perform assimilative capacity studies to determine if the decrease in summer base-flow is having an impact on the water quality downstream of effluent outfalls.
6) Conduct site specific water quality studies to determine the influence, if any, caused by different municipal and industrial effluent discharges within Kettle Creek.
7) Perform an analysis of current water quality conditions and dam operations within the Dalewood and Union Reservoirs to determine their ability to assist in flow augmentation / supplementation during low flow seasons.
8) Conduct an analysis of current water quality conditions within Lake Whittaker.
9) Perform sediment sampling throughout Lower Kettle Creek to assess the potential risks the sediment plume may pose on the Elgin Area Primary Water Supply System.
10) Continue the monitoring of PAH contamination in Kettle Creek and Port Stanley Harbour sampling locations to determine if the PAH data trend is an artifact or continuing trend (Riggs Engineering Ltd., 2004).
11) Investigate the benefits of increasing the riparian cover as a method for mitigating water temperature and sedimentation.
12) Conduct a follow-up investigation, similar to the CURB report (Depuydt, 1994), into the variability of *Escherichia coli* in Kettle Creek to determine the present state of bacterial loading in the watershed.
13) Conduct an investigation into nutrient loading in the Kettle Creek watershed to determine where the areas of highest loading are located.

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APPENDICES

Appendix 1. Table of Provincial Water Quality Monitoring Network (PWQMN) Sites within the Kettle Creek watershed.

Station ID	Short ID	Location Description	Tributary	Start Year	End Year	Total Years
16008700102	102	Bridge St, Port Stanley	Kettle Creek	1964	1975	12
16008700202	202	Railway Trestle, dwnstrm St. Thomas	Kettle Creek	1964	1971	8
16008700302	302	Elgin Rd 52, Ron McNeil Ln, W of Dalewood Rd	Kettle Creek	1969	1989	12
16008700402	402	Clinton Line, W of Hwy 4, NW of St. Thomas	Dodd Creek	1969	1995	25
16008700502	502	Lyle Rd, W of St. Thomas	Dodd Creek	1971	1989	7
16008700602	602	Pond outlet, Mill Rd, dwnstrm of Union	Beaver Creek	1971	1995	25
16008700702	702	Glanworth Dr, SW of Belmont	Kettle Creek	1971	1995	25
16008700802	802	Fulton Bridge Ln, S of St. Thomas	Kettle Creek	1972	1975	4
16008700902	902	Elgin Rd 26, St. Georges St, St. Thomas	Kettle Creek	1973	1981	9
16008701002	1002	Elgin Rd 27, Sparta Ln, N of Port Stanley	Kettle Creek	1975	1995	21
16008701102	1102	Centennial Rd, E of Union	Beaver Creek	1975	1978	4
16008701202	1202	Elgin Rd 45, John Wise Ln, S of St. Thomas	Kettle Creek	1975	1995	21
16008701302	1302	Elgin Rd 4, Sunset Rd, St. Thomas	Dodd Creek	1975	1982	8
16008701402	1402	Glanworth Dr, E of Glanworth	Dodd Creek	1977	1979	3
16008701502	1502	Elgin Rd 52, Ron McNeil Ln, E of Dalewood Rd	Kettle Creek	1978	1995	18
16008701602	1602	Elgin Rd 16, Fingal Ln, St. Thomas	Kettle Creek	1982	1995	14

= Sites with data from 1991-1995

Appendix 2. Current method detection limit at MOE laboratory for various water quality variables.

Variable	Detection Limit	Units
Alkalinity - TFE	0.2	mg/L as CaCO3
Ammonia nitrogen	0.002	mg/L as N
Calcium	0.05	mg/L
Conductivity, 25C	1	mS/cm
Copper	0.0002	mg/L
Dissolved Solids	2	mg/L
Hardness	0.2	mg/L
Lead	0.0005	mg/L
Magnesium	0.02	mg/L
Nickel	0.0005	mg/L
Nitrate + Nitrite Nitrogen	0.005	mg/L as N
Nitrite nitrogen	0.001	mg/L as N
Potassium	0.01	mg/L
Reactive Phosphorus	0.0005	mg/L as P
Sodium	0.02	mg/L
Suspended Solids	1	mg/L
Total Kjeldahl Nitrogen	0.02	mg/L as N
Total Phosphorus	0.002	mg/L as P
Total Solids	2	mg/L
Zinc	0.0005	mg/L

SOURCE: MOE, 1994.

Appendix 3. Summary statistics for the 1991-1995 dataset for all the water quality parameters at the 7 long-term PWQMN monitoring sites in the Kettle Creek watershed.

Summary Statistics for Kettle Creek CA 1991-1995

Nitrate							
	702	1502	1602	1202	1002	602	402
Mean	3.346	4.724	3.564	6.806	5.498	2.637	3.244
Median	3.200	4.000	3.050	5.950	5.100	2.150	2.700
Std dev	2.844	5.247	3.764	3.365	2.177	1.723	2.314
Std err	0.455	0.819	0.581	0.561	0.336	0.280	0.361
95% Conf	0.922	1.656	1.173	1.139	0.678	0.566	0.730
99% Conf	1.235	2.216	1.569	1.528	0.907	0.759	0.977
n	39	41	42	36	42	38	41
Min	0.100	0.100	0.050	2.900	0.200	0.100	0.100
Max	10.200	23.500	20.800	19.800	10.400	6.000	12.600
% Exceedance	53.8	63.4	50	94.4	92.9	34.2	46.3
10th	0.100	0.500	0.200	3.550	3.410	0.970	1.300
25th	0.300	0.800	0.625	4.875	4.300	1.300	1.600
75th	5.600	5.800	4.800	7.725	6.500	3.700	4.000
90th	7.100	8.000	7.140	9.850	8.810	5.630	5.400

Nitrite							
	702	1502	1602	1202	1002	602	402
Mean	0.054	0.056	0.063	0.108	0.074	0.069	0.074
Median	0.030	0.040	0.040	0.060	0.050	0.050	0.050
Std dev	0.087	0.051	0.119	0.173	0.091	0.074	0.107
Std err	0.014	0.008	0.018	0.029	0.014	0.012	0.017
95% Conf	0.028	0.016	0.037	0.058	0.028	0.024	0.034
99% Conf	0.038	0.021	0.050	0.078	0.038	0.032	0.046
n	39	41	42	36	42	39	41
Min	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Max	0.530	0.220	0.780	1.020	0.540	0.430	0.590
% Exceedance	23.1	24.4	26.2	36.1	31.0	35.9	31.7
10th	0.010	0.020	0.011	0.030	0.021	0.020	0.020
25th	0.010	0.020	0.020	0.040	0.030	0.030	0.030
75th	0.050	0.060	0.068	0.080	0.070	0.075	0.080
90th	0.094	0.120	0.080	0.215	0.129	0.150	0.160

Ammonia							
	702	1502	1602	1202	1002	602	402
Mean	0.0012	0.0025	0.0022	0.0053	0.0028	0.0036	0.0031
Median	0.0007	0.0015	0.0012	0.0016	0.0011	0.0017	0.0009
Std dev	0.0015	0.0044	0.0032	0.0109	0.0063	0.0043	0.0057
Std err	0.0003	0.0007	0.0005	0.0021	0.0011	0.0008	0.0010
95% Conf	0.0005	0.0015	0.0011	0.0044	0.0022	0.0016	0.0020
99% Conf	0.0007	0.0020	0.0015	0.0060	0.0029	0.0021	0.0027
n	33	35	35	26	35	32	33
Min	0.0001	0.0002	0.0001	0.0000	0.0000	0.0001	0.0000
Max	0.0078	0.0260	0.0161	0.0529	0.0352	0.0146	0.0291
% Exceedance	0	0	0	11.1	2.4	0	2.5

10th	0.0002	0.0004	0.0003	0.0001	0.0002	0.0004	0.0002
25th	0.0005	0.0006	0.0006	0.0003	0.0005	0.0007	0.0003
75th	0.0012	0.0028	0.0024	0.0026	0.0020	0.0047	0.0030
90th	0.0023	0.0033	0.0041	0.0120	0.0044	0.0109	0.0083

Kjeldahl Nitrogen							
	702	**1502**	**1602**	**1202**	**1002**	**602**	**402**
Mean	1.154	1.137	1.393	1.369	1.276	0.933	1.902
Median	0.940	1.040	1.190	1.170	1.220	0.940	1.580
Std dev	0.944	0.678	0.885	0.586	0.572	0.296	1.187
Std err	0.151	0.106	0.137	0.098	0.088	0.047	0.185
95% Conf	0.306	0.214	0.276	0.198	0.178	0.096	0.375
99% Conf	0.410	0.286	0.369	0.266	0.239	0.128	0.501
n	39	41	42	36	42	39	41
Min	0.063	0.600	0.730	0.650	0.149	0.059	0.630
Max	6.200	4.520	6.250	3.650	3.040	1.910	4.700
10th	0.566	0.720	0.804	0.910	0.677	0.644	0.780
25th	0.745	0.780	0.973	1.060	0.965	0.755	1.020
75th	1.270	1.150	1.488	1.600	1.495	1.065	2.650
90th	1.908	1.400	2.090	2.035	1.900	1.240	3.930

Total Nitrogen							
	702	**1502**	**1602**	**1202**	**1002**	**602**	**402**
Mean	4.743	5.917	5.020	8.343	6.848	3.638	5.287
Median	4.670	5.060	4.480	7.480	6.520	3.165	5.040
Std dev	3.176	5.637	3.962	3.738	2.416	1.672	2.513
Std err	0.522	0.880	0.611	0.632	0.373	0.271	0.393
95% Conf	1.059	1.819	1.219	1.284	0.753	0.550	0.793
99% Conf	1.420	2.435	1.630	1.724	1.007	0.737	1.062
n	37	41	42	35	42	38	41
Min	0.660	0.890	0.890	4.110	1.160	1.009	0.920
Max	13.630	28.240	24.000	21.650	12.400	6.900	17.120
10th	0.946	1.310	1.424	4.718	4.481	2.020	3.484
25th	2.190	1.960	2.318	6.105	5.395	2.270	3.890
75th	6.020	6.640	6.338	9.175	8.023	4.650	5.815
90th	8.680	9.080	8.593	12.248	10.715	6.296	6.875

Phosphorous							
	702	**1502**	**1602**	**1202**	**1002**	**602**	**402**
Mean	0.153	0.167	0.156	0.249	0.262	0.104	0.308
Median	0.118	0.100	0.139	0.220	0.210	0.079	0.260
Std dev	0.121	0.230	0.106	0.136	0.187	0.139	0.208
Std err	0.019	0.036	0.016	0.023	0.029	0.022	0.032
95% Conf	0.039	0.072	0.033	0.048	0.059	0.045	0.066
99% Conf	0.053	0.097	0.044	0.064	0.079	0.060	0.088
n	39	41	42	34	41	39	41
Min	0.030	0.037	0.023	0.091	0.050	0.025	0.026

Max	0.510	1.220	0.670	0.550	1.100	0.930	0.940
% Exceedance	97.4	97.6	100	100	100	97.4	97.6
10th	0.054	0.064	0.067	0.110	0.099	0.052	0.091
25th	0.071	0.078	0.102	0.132	0.145	0.066	0.143
75th	0.173	0.138	0.189	0.325	0.360	0.095	0.450
90th	0.343	0.192	0.210	0.475	0.450	0.115	0.560

Residue, Particulate							
	702	**1502**	**1602**	**1202**	**1002**	**602**	**402**
Mean	45.474	42.644	46.655	85.450	77.156	15.972	34.558
Median	30.700	30.300	36.600	49.700	58.000	14.000	17.250
Std dev	50.763	48.925	41.903	111.181	72.550	9.987	56.755
Std err	9.117	7.641	6.466	26.206	11.330	1.599	8.974
95% Conf	18.620	15.443	13.058	55.290	22.900	3.238	18.151
99% Conf	25.074	20.666	17.466	75.956	30.645	4.337	24.302
n	31	41	42	18	41	39	40
Min	5.000	5.000	5.000	5.000	16.100	5.000	5.000
Max	224.000	303.000	260.000	479.000	370.000	55.300	270.000
% Exceedance	58.1	70.7	71.4	83.3	78.0	15.4	35
10th	12.400	13.000	15.070	20.780	22.000	5.960	5.000
25th	14.800	24.000	23.350	30.050	29.550	8.000	9.625
75th	43.550	42.200	57.650	84.025	89.600	20.450	35.175
90th	98.000	70.000	74.280	161.200	141.000	26.700	51.960

Chloride							
	702	**1502**	**1602**	**1202**	**1002**	**602**	**402**
Mean	33.785	34.541	58.655	63.203	58.221	31.510	74.054
Median	32.800	32.900	54.350	62.600	60.650	31.100	71.200
Std dev	12.892	15.775	18.045	28.174	15.343	5.496	26.565
Std err	2.064	2.464	2.784	4.762	2.368	0.880	4.149
95% Conf	4.179	4.979	5.623	9.678	4.781	1.782	8.385
99% Conf	5.598	6.663	7.522	12.994	6.396	2.387	11.221
n	39	41	42	35	42	39	41
Min	15.700	12.500	23.200	25.000	24.400	16.700	17.800
Max	83.000	102.000	95.500	191.000	102.000	45.100	136.000
% Exceedance	0	0	0	0	0	0	0
10th	19.820	18.600	35.640	31.840	39.100	27.280	41.900
25th	26.250	25.700	48.000	49.050	49.875	28.900	56.100
75th	37.050	40.500	72.000	71.800	66.350	34.750	92.700
90th	47.720	49.200	82.580	79.320	73.710	36.740	110.000

Appendix 4. Table of 95th confidence limits for each nutrient for each site.

95% Confidence Limits

	Upper Kettle		Lower Kettle			Beaver	Dodd
	16008700702	16008701502	16008701602	16008701202	16008701002	16008700602	16008700402
Nitrate							
Upper	7.480	19.800	8.935	12.675	9.300	5.830	7.400
Lower	0.100	0.300	0.100	3.200	2.905	0.900	0.500
Mean	3.346	4.724	3.564	6.806	5.498	2.637	3.244
Std dev	2.844	5.247	3.764	3.365	2.177	1.723	2.314
Nitrite							
Upper	0.142	0.170	0.148	0.303	0.209	0.175	0.380
Lower	0.010	0.010	0.010	0.030	0.011	0.020	0.010
Mean	0.054	0.056	0.063	0.108	0.074	0.069	0.074
Std dev	0.087	0.051	0.119	0.173	0.091	0.074	0.107
Ammonia							
Upper	0.004	0.007	0.007	0.019	0.009	0.013	0.011
Lower	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mean	0.001	0.003	0.002	0.005	0.003	0.004	0.003
Std dev	0.002	0.004	0.003	0.011	0.006	0.004	0.006
Kjeldahl Nitrogen							
Upper	1.000	2.550	2.347	2.383	2.235	1.323	4.250
Lower	0.534	0.660	0.780	0.785	0.461	0.549	0.660
Mean	1.154	1.137	1.393	1.369	1.276	0.933	1.902
Std dev	0.944	0.678	0.885	0.586	0.572	0.296	1.187
Total Nitrogen							
Upper	9.904	21.060	10.140	15.094	10.859	6.799	8.314
Lower	0.730	1.080	1.112	4.385	4.127	1.852	2.460
Mean	4.743	5.840	5.113	8.343	6.848	3.638	5.286
Std dev	3.176	5.686	3.962	3.738	2.416	1.672	2.513
Phosphorus							
Upper	0.427	0.770	0.274	0.507	0.520	0.169	0.590
Lower	0.050	0.053	0.064	0.102	0.093	0.042	0.057
Mean	0.153	0.167	0.156	0.249	0.262	0.104	0.308
Std dev	0.121	0.230	0.106	0.136	0.187	0.139	0.208
NFR							
Upper	156.500	88.200	94.305	264.800	216.000	29.790	124.700
Lower	8.700	11.500	5.395	16.985	17.900	5.000	5.000
Mean	45.474	42.644	46.655	85.450	77.156	15.972	34.558
Std dev	50.763	48.925	41.903	111.181	72.550	9.987	56.755
Chloride							
Upper	53.550	52.000	86.310	86.510	79.265	39.730	112.000
Lower	17.180	14.800	31.455	31.070	31.445	23.720	30.700
Mean	33.785	34.541	58.655	63.203	58.221	31.510	74.054
Std dev	12.892	15.775	18.045	28.174	15.343	5.496	26.565

Appendix 5. Nonparametric regression statistics for comparison of each water quality parameter between the 7 PWQMN sites within Kettle Creek watershed.

Parameter		Total Nitrate	Total Nitrite	Unionized Ammonia	Total Kjeldahl Nitrogen	Total Phosphorus	Total Non-filterable residue	Chloride
All Sites								
	p	**<0.0001**	**0.0077**	0.1383	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Upper Kettle Creek Sites								
702 vs 1502	*p*	0.2518	0.1723	n/a	0.5602	0.5898	0.7849	0.8436
702 vs 1502 vs 1602	*p*	0.4672	0.3830	n/a	**0.0084**	0.0991	0.3874	**<0.0001**
1502 vs 1602	*p*	n/a	n/a	n/a	**0.0095**	n/a	n/a	**<0.0001**
702 vs 1602	*p*	n/a	n/a	n/a	**0.0073**	n/a	n/a	**<0.0001**
702 vs 1202	*p*	**<0.0001**	**0.0007**	n/a	**0.0050**	**0.0003**	**0.0344**	**<0.0001**
702 vs 1002	*p*	**0.0008**	**0.0134**	n/a	**0.0297**	**0.0001**	**0.0033**	**<0.0001**
1502 vs 1202	*p*	**0.0002**	**0.0107**	n/a	**0.0028**	**<0.0001**	**0.0252**	**<0.0001**
1502 vs 1002	*p*	**0.0065**	0.1650	n/a	**0.0158**	**<0.0001**	**0.0015**	**<0.0001**
Lower Kettle Creek Sites								
1602 vs 1202 vs 1002	*p*	**<0.0001**	**0.0143**	n/a	0.8520	**0.0004**	**0.0423**	0.7678
1602 vs 1202	*p*	**<0.0001**	**0.0048**	n/a	n/a	**0.0007**	0.1533	n/a
1602 vs 1002		**0.0001**	0.0718	n/a	n/a	**0.0008**	**0.0134**	n/a
1202 vs 1002	*p*	0.1065	0.2089	n/a	n/a	0.9533	0.7172	n/a
1602 vs 602	*p*	0.6892	0.0932	n/a	**0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
1202 vs 602	*p*	**<0.0001**	0.1988	n/a	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
1002 vs 602	*p*	**<0.0001**	0.9091	n/a	**0.0004**	**<0.0001**	**<0.0001**	**<0.0001**
602 vs 702	*p*	0.4849	**0.0198**	n/a	0.5893	**0.0068**	**<0.0001**	0.6279
602 vs 1502	*p*	0.1477	0.2178	n/a	0.1761	**0.0053**	**<0.0001**	0.5701
Dodd Creek Site								
402 vs 1602	*p*	0.8733	0.2568	n/a	0.0678	**0.0002**	**0.0007**	**0.0047**
402 vs 1202	*p*	**<0.0001**	0.0808	n/a	0.1499	0.3301	**0.0003**	**0.0225**
402 vs 1002	*p*	**<0.0001**	0.5393	n/a	**0.0470**	0.2697	**<0.0001**	**0.0019**
402 vs 602	*p*	0.1708	0.6630	n/a	**<0.0001**	**<0.0001**	0.2550	**<0.0001**
402 vs 702	*p*	0.9962	0.0629	n/a	**0.0005**	**0.0001**	**0.0204**	**<0.0001**
402 vs 1502	*p*	0.2798	0.4806	n/a	**0.0007**	**<0.0001**	**0.0041**	**<0.0001**

Appendix 6. Percentage of samples per site with values greater than the provincial objective or Canadian Guideline.

Percent of Samples That Do Not Meet Guideline/Objective

Site	Tributary	Nitrates	Nitrite	Unionized Ammonia	Total Phosphorus	Total Suspended Solids	Chloride
	Objective:	2.93 mg/L	0.060 mg/L	0.0165 mg/L	0.030 mg/L	25.0 mg/L	250.0 mg/L
16008700402	Dodd Creek	0.463	0.317	0.025	0.975	0.350	0.000
16008700602	Beaver Creek	0.342	0.359	0.000	0.974	0.154	0.000
16008700702	Upper Kettle Creek	0.538	0.231	0.000	0.974	0.581	0.000
16008701002	Lower Kettle Creek	0.929	0.310	0.024	1.000	0.780	0.000
16008701202	Lower Kettle Creek	0.944	0.361	0.111	1.000	0.833	0.000
16008701502	Upper Kettle Creek	0.634	0.244	0.000	0.976	0.707	0.000
16008701602	Lower Kettle Creek	0.500	0.262	0.000	1.000	0.714	0.000

Appendix 7. 75th percentile values at each of the 7 PWQMN sites for each water quality parameter analysed.

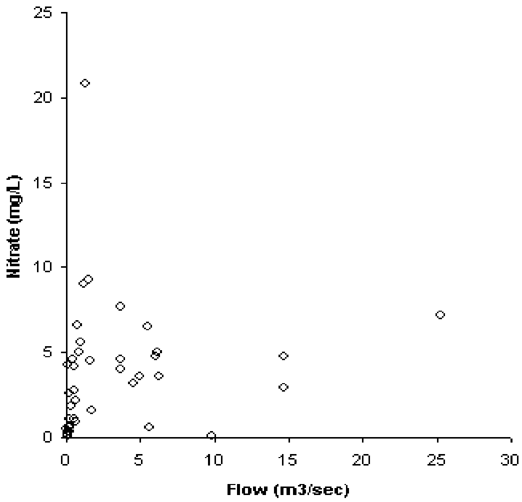
75th Percentile Value for Samples Taken (1991-1995)

Site	Tributary	Nitrates	Nitrite	Unionized Ammonia	Total Kjeldahl	Total Phosphorus	Total Suspended Solids	Chloride
16008700402	Dodd Creek	4.000	0.080	0.0030	1.270	0.450	35.175	92.700
16008700602	Beaver Creek	3.700	0.075	0.0047	1.150	0.095	20.450	34.750
16008700702	Upper Kettle Creek	5.600	0.050	0.0012	1.487	0.173	43.550	37.050
16008701002	Lower Kettle Creek	6.500	0.070	0.0020	1.600	0.360	89.600	66.350
16008701202	Lower Kettle Creek	7.725	0.080	0.0026	1.495	0.325	84.025	71.800
16008701502	Upper Kettle Creek	5.800	0.060	0.0028	1.065	0.138	42.200	40.500
16008701602	Lower Kettle Creek	4.800	0.068	0.0024	2.650	0.189	57.650	72.000

Appendix 8. Kendall correlation p values and graphs between stream flow and each of the nutrients analysed for the flow station 02GC002 and PWQMN site 16008701602 at St. Thomas.

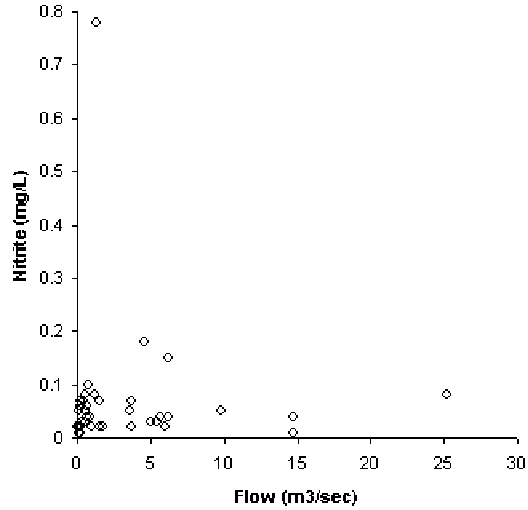
Nitrate vs Flow

tau statistic	0.41
2-tailed p	0.0002



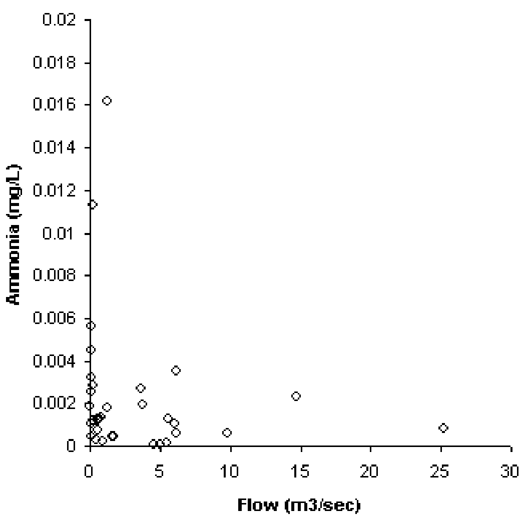
Nitrite vs Flow

tau statistic	0.27
2-tailed p	0.0182



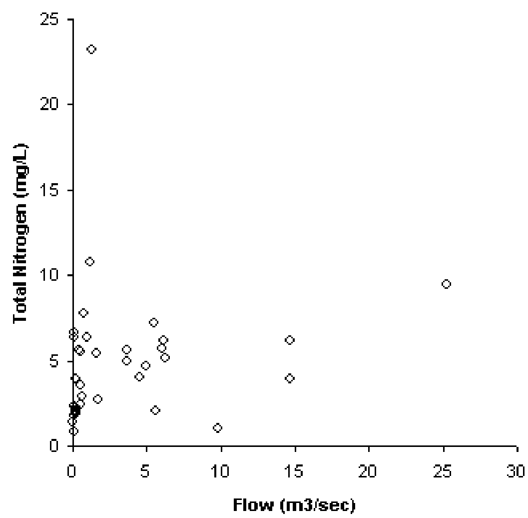
Ammonia vs Flow

tau statistic	-0.16
2-tailed p	0.1727



Total Nitrogen vs Flow

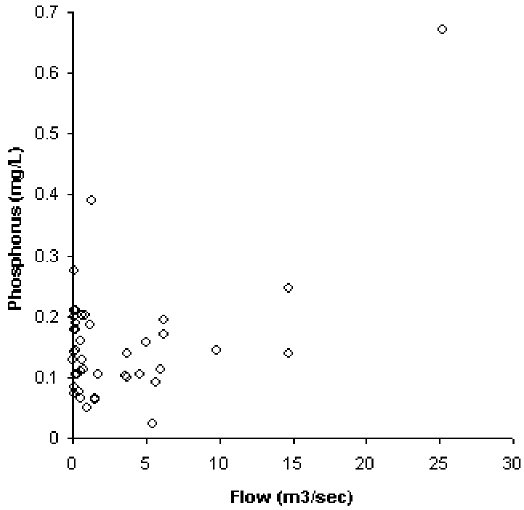
tau statistic	0.3
2-tailed p	0.0124



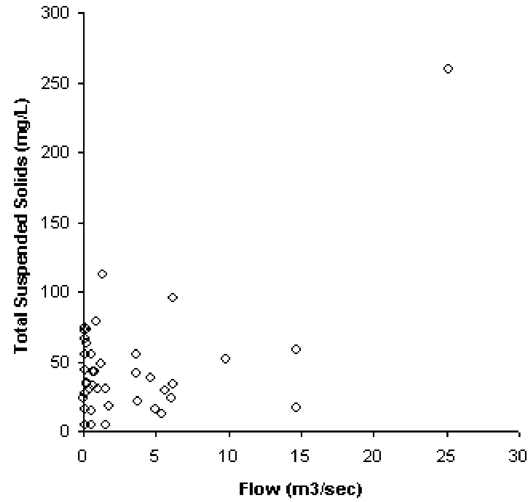
Phosphorus vs Flow

NFR vs Flow

tau statistic	-0.02
2-tailed p	0.8199

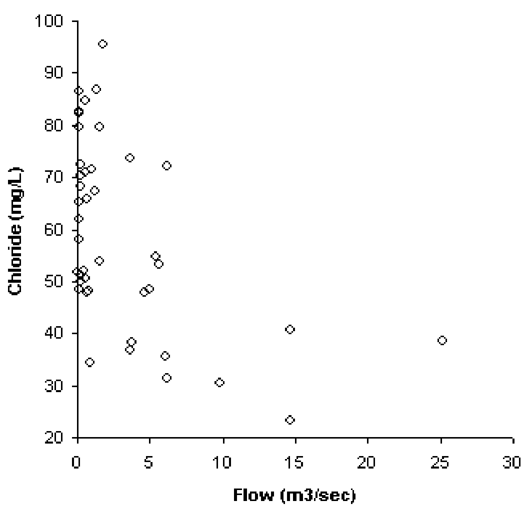


tau statistic	-0.05
2-tailed p	0.6567

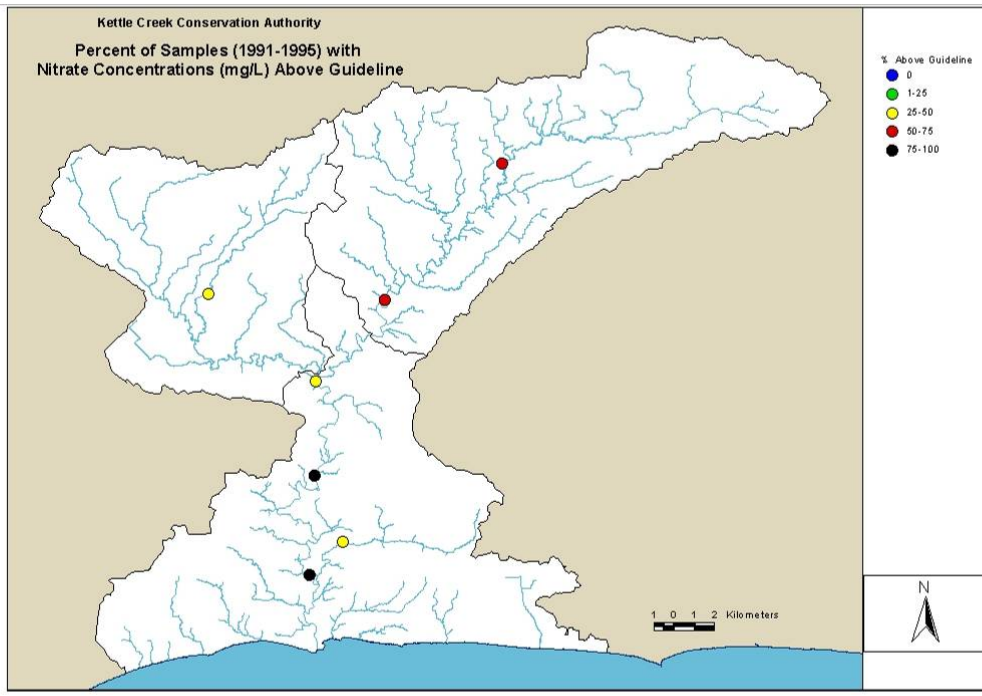


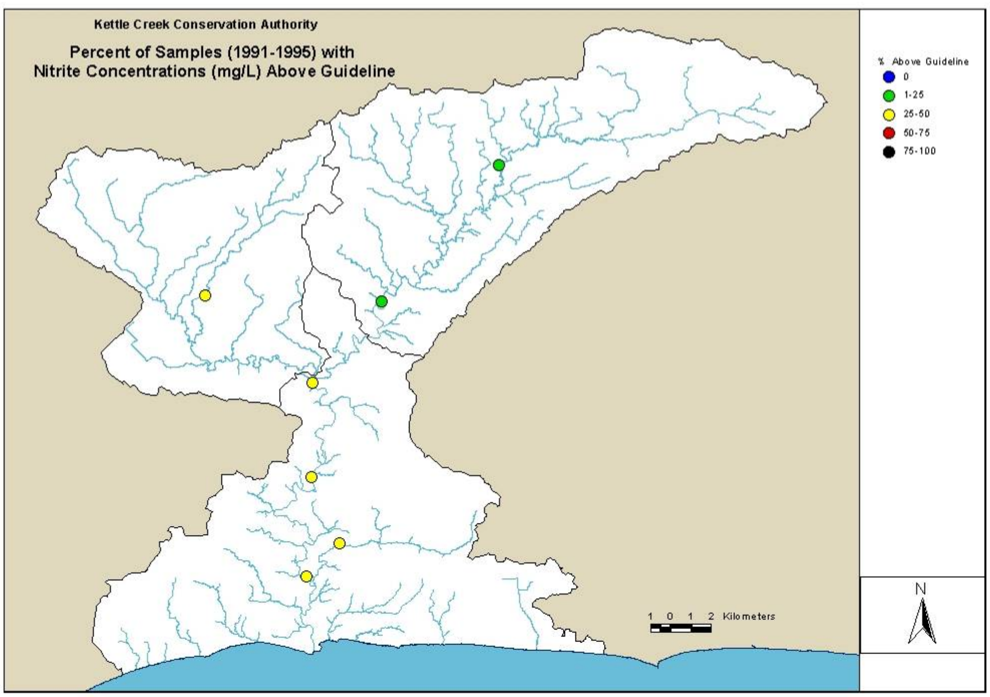
Chloride vs Flow

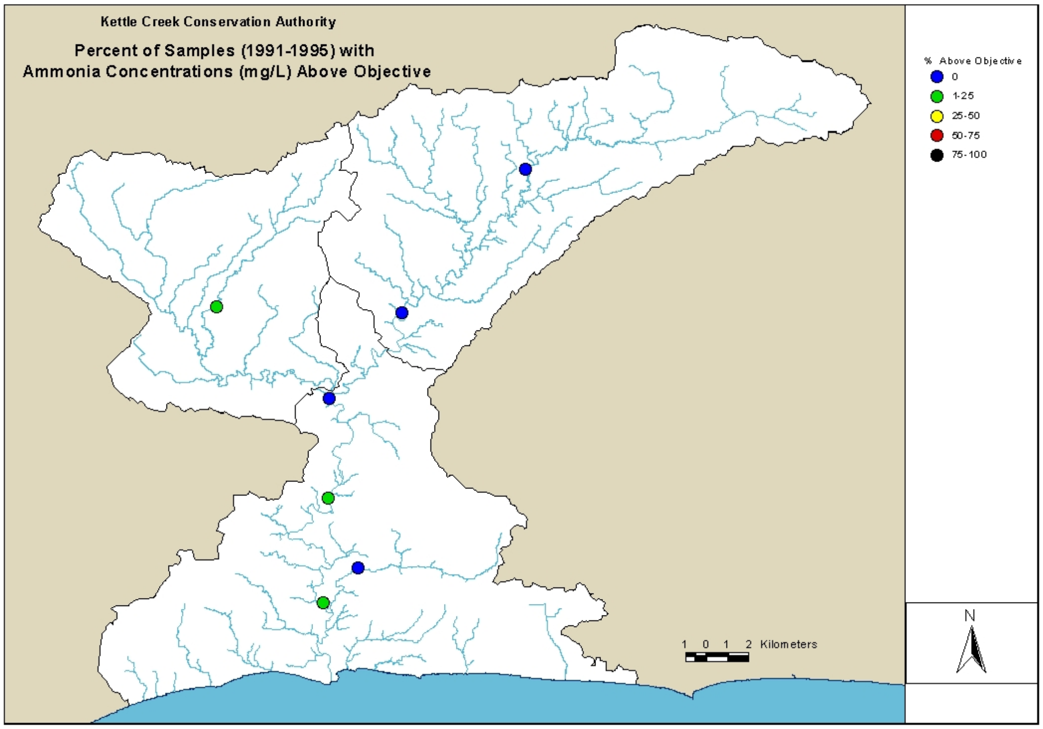
tau statistic	-0.31
2-tailed p	0.0041

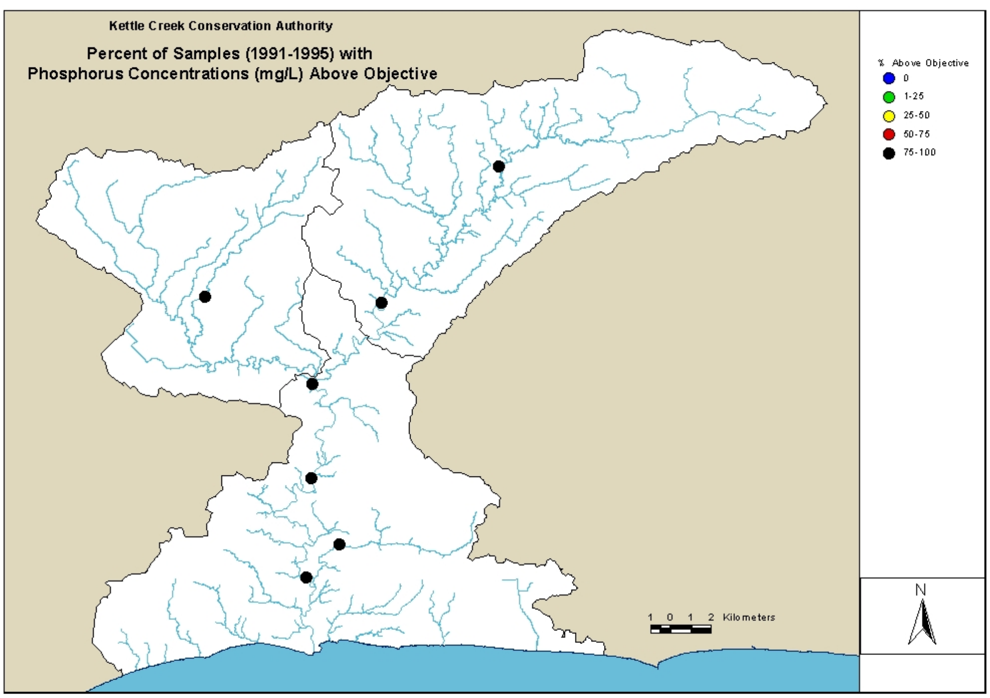


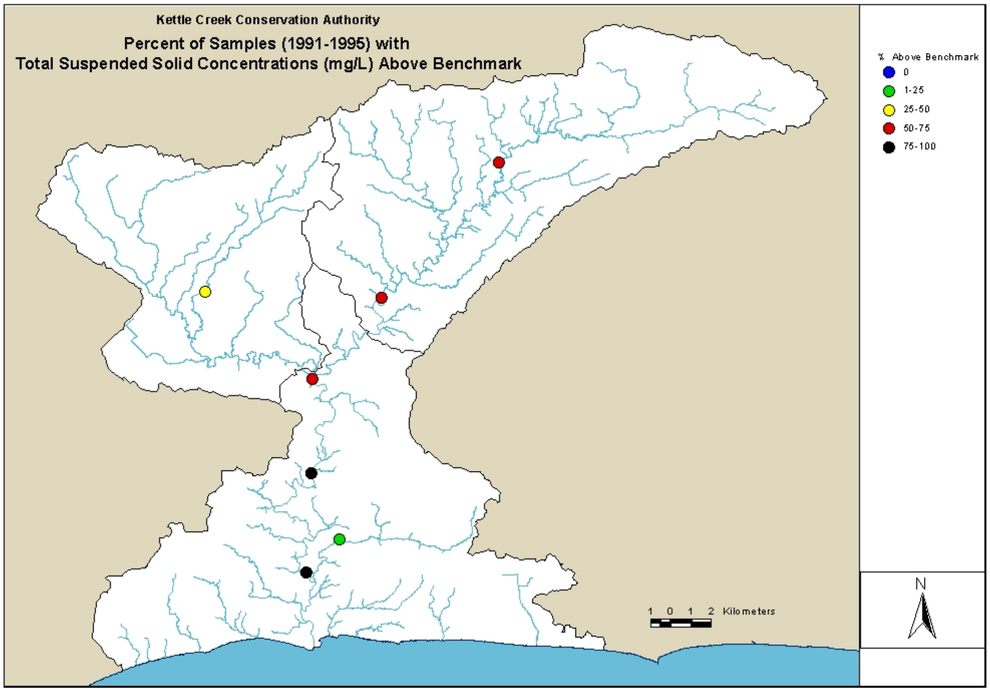
Appendix 9. Maps of the Kettle Creek watershed illustrating the percent of times samples taken at one of the 7 PWQMN sites does not meet the Provincial Water Quality Objective or the Canadian Guideline for the 1991-1995 dataset.

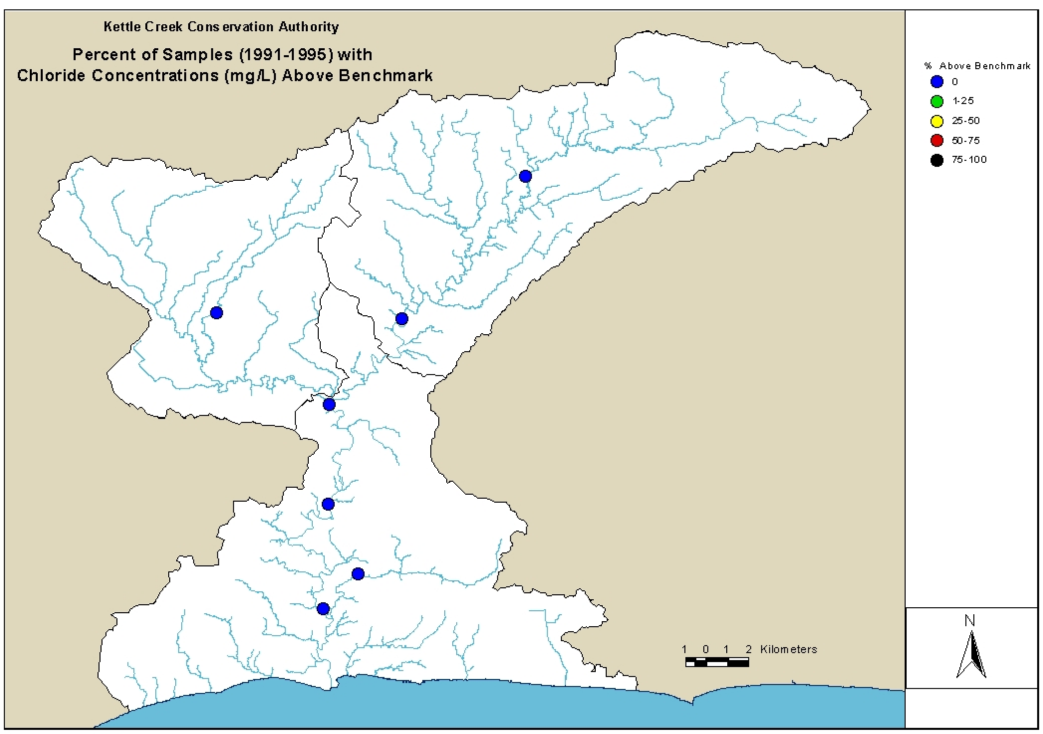




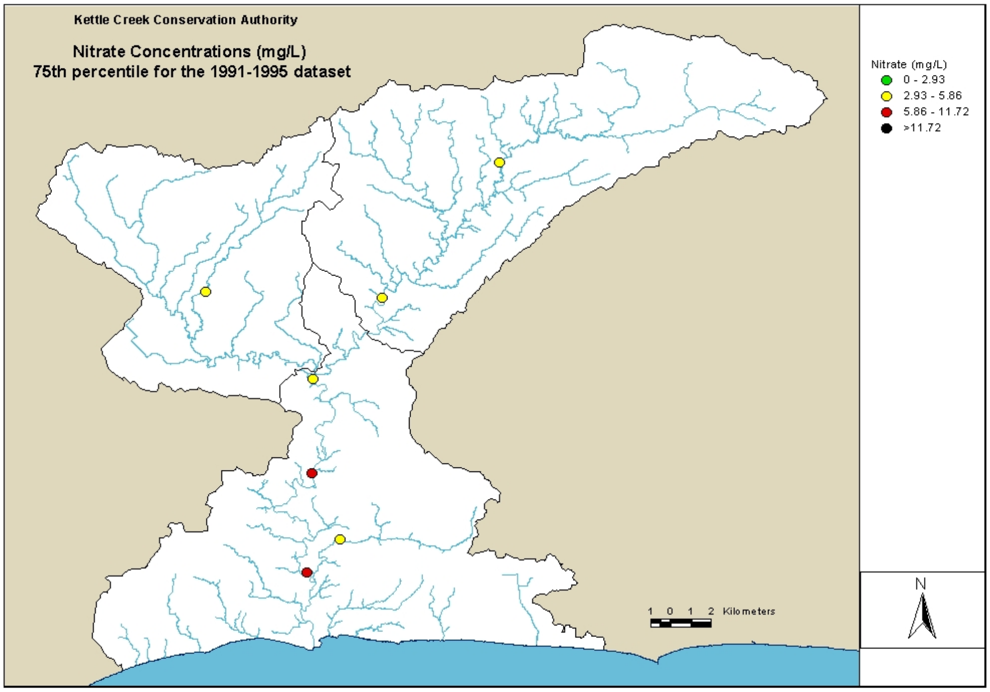

Kettle Creek Conservation Authority
Percent of Samples (1991-1995) with
Ammonia Concentrations (mg/L) Above Objective
% Above Objective
0
1-25
25-50
50-75
75-100
1 0 1 2 Kilometers
N

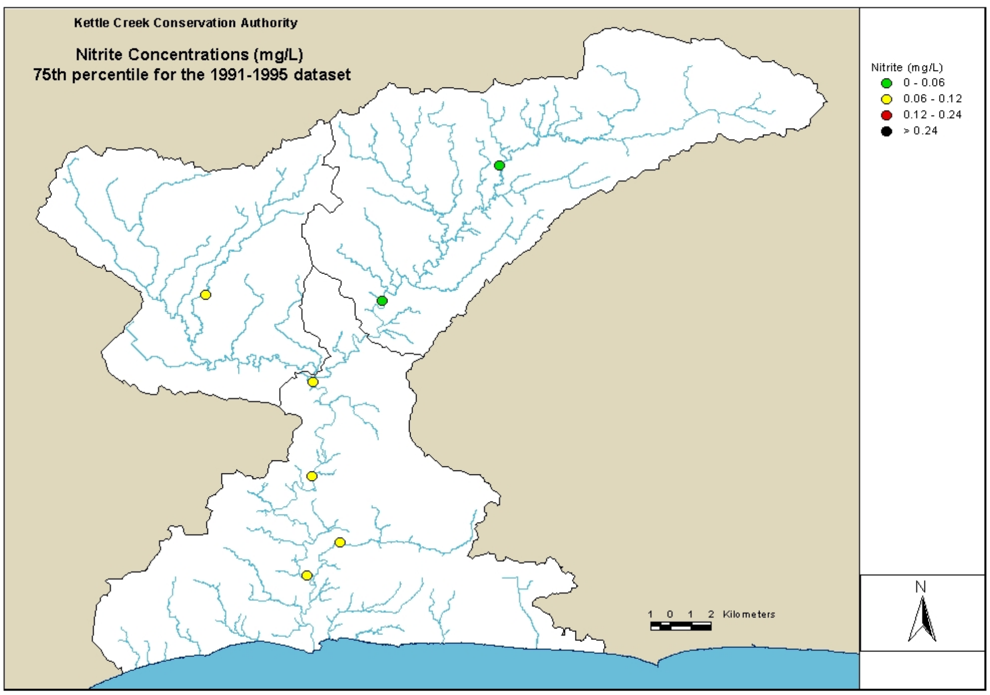

Kettle Creek Conservation Authority
Percent of Samples (1991-1995) with
Phosphorus Concentrations (mg/L) Above Objective
% Above Objective
0
1-25
25-50
50-75
75-100
1 0 1 2 Kilometers
N

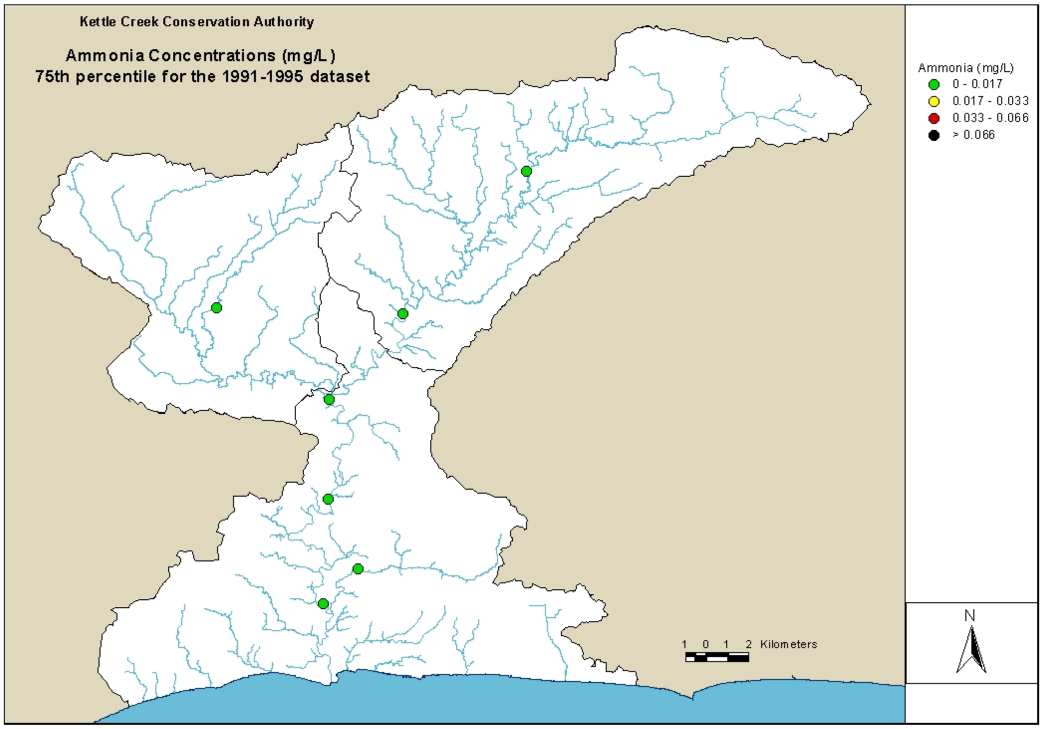

Kettle Creek Conservation Authority
Percent of Samples (1991-1995) with
Total Suspended Solid Concentrations (mg/L) Above Benchmark
% Above Benchmark
0
1-25
25-50
50-75
75-100
1 0 1 2 Kilometers
N

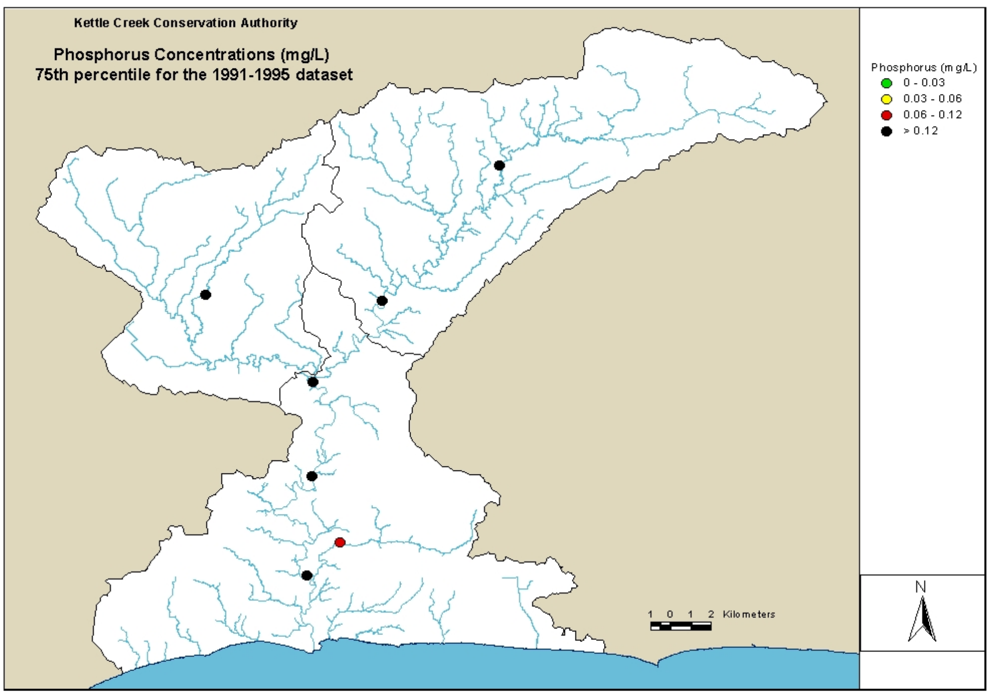

Kettle Creek Conservation Authority
Percent of Samples (1991-1995) with
Chloride Concentrations (mg/L) Above Benchmark
% Above Benchmark
0
1-25
25-50
50-75
75-100
1 0 1 2 Kilometers
N

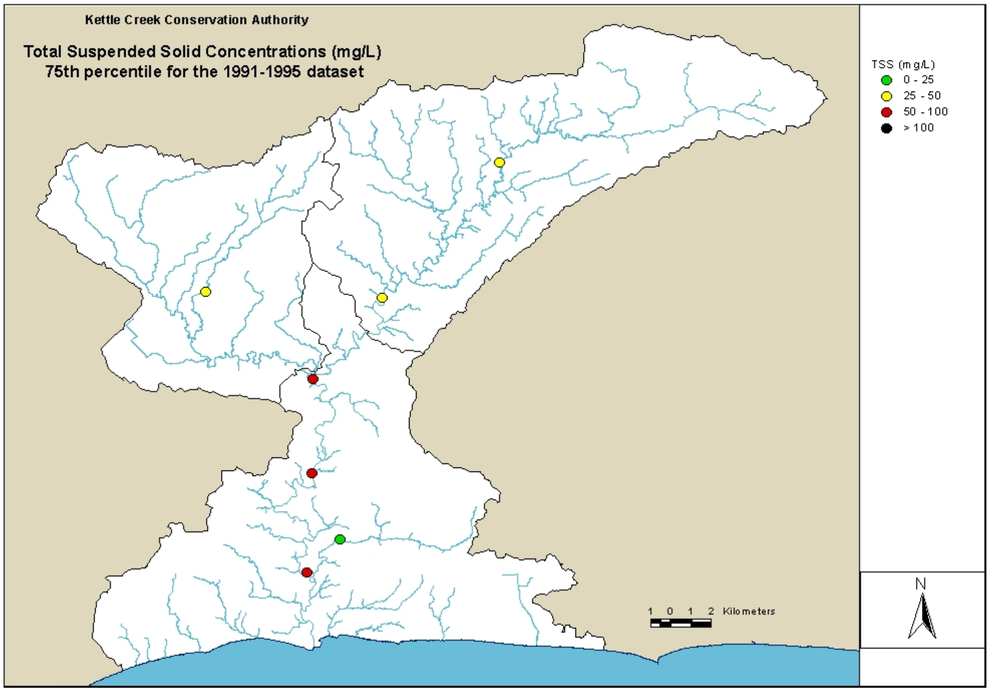
Appendix 10. Maps of the Kettle Creek watershed illustrating how the 75th percentile value for each site ranks against the provincial water quality objective or Canadian Guideline.



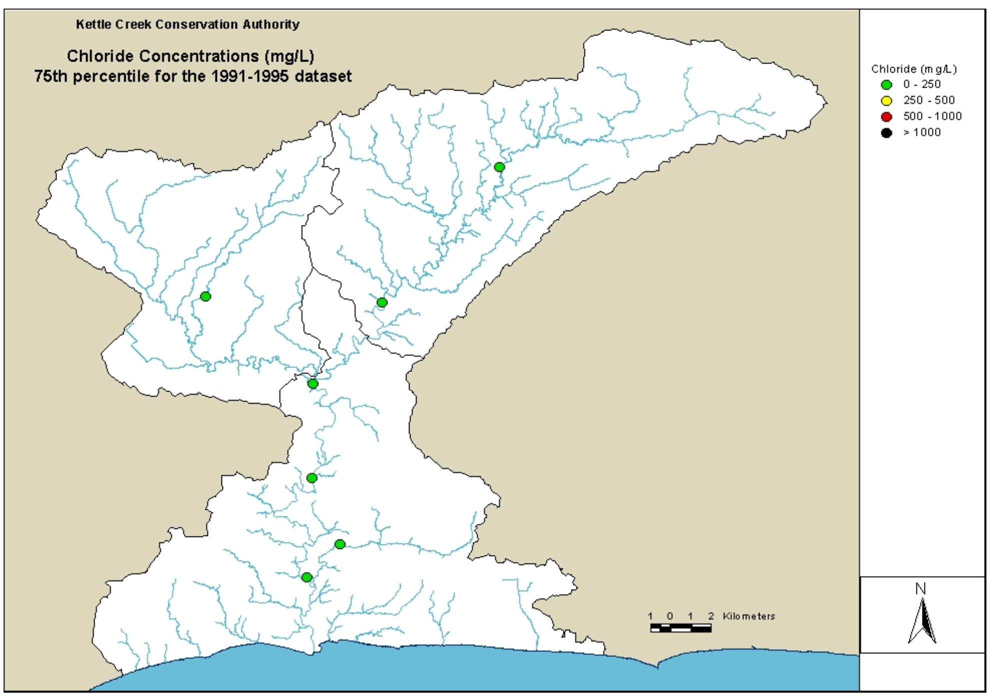



Kettle Creek Conservation Authority
Ammonia Concentrations (mg/L)
75th percentile for the 1991-1995 dataset
Ammonia (mg/L)
0 - 0.017
0.017 - 0.033
0.033 - 0.066
> 0.066
1 0 1 2 Kilometers
N


Kettle Creek Conservation Authority
Phosphorus Concentrations (mg/L)
75th percentile for the 1991-1995 dataset
Phosphorus (mg/L)
0 - 0.03
0.03 - 0.06
0.06 - 0.12
> 0.12
1 0 1 2 Kilometers
N

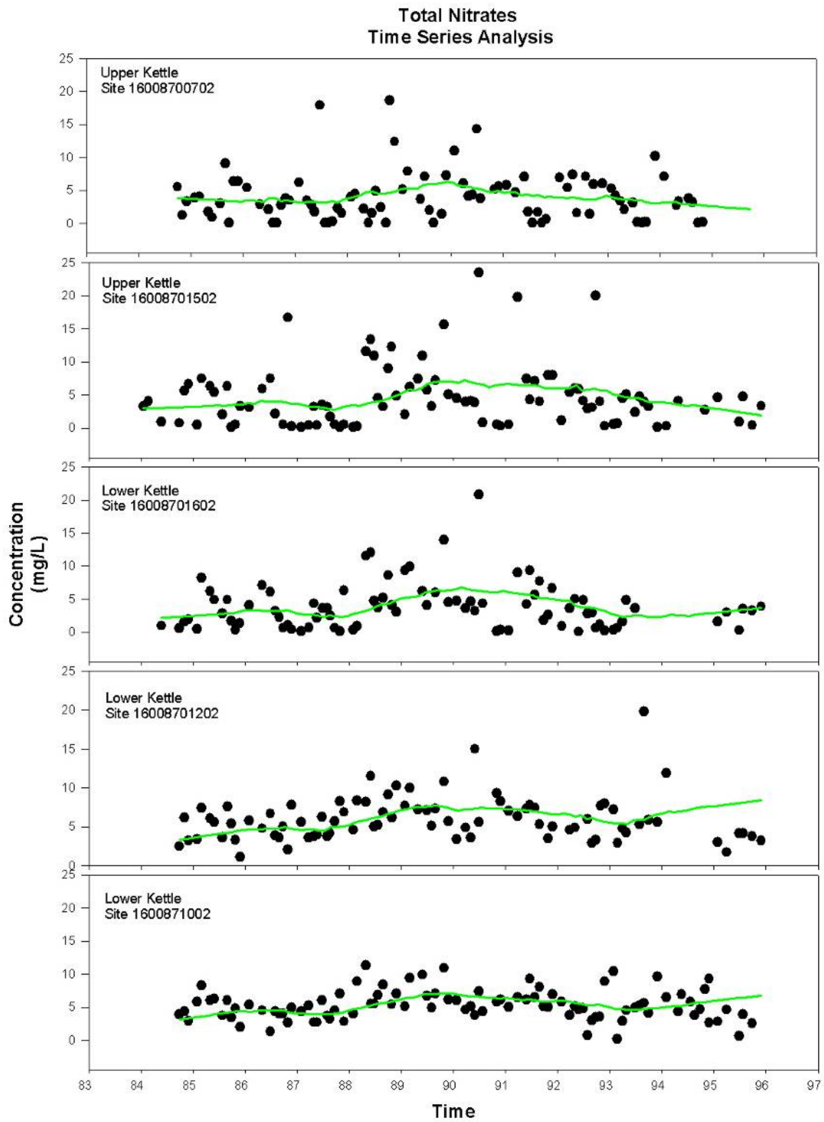


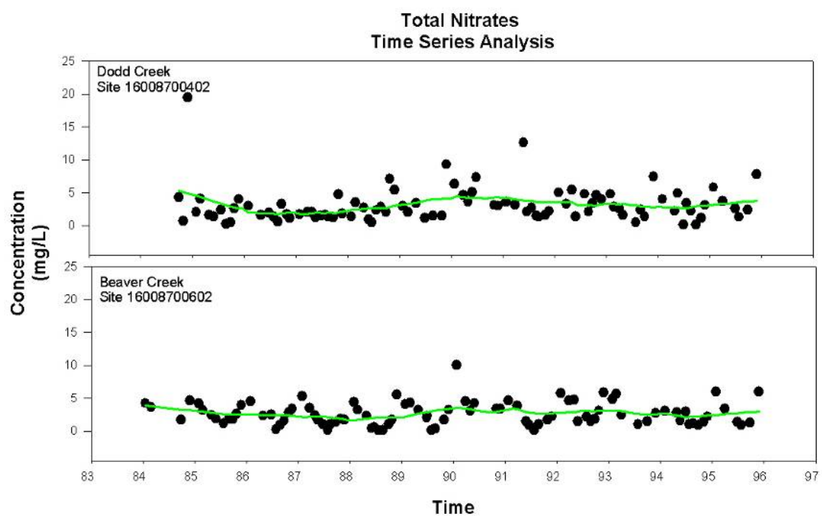
Kettle Creek Conservation Authority
Total Suspended Solid Concentrations (mg/L)
75th percentile for the 1991-1995 dataset
TSS (mg/L)
0 - 25
25 - 50
50 - 100
> 100
1 0 1 2 Kilometers
N

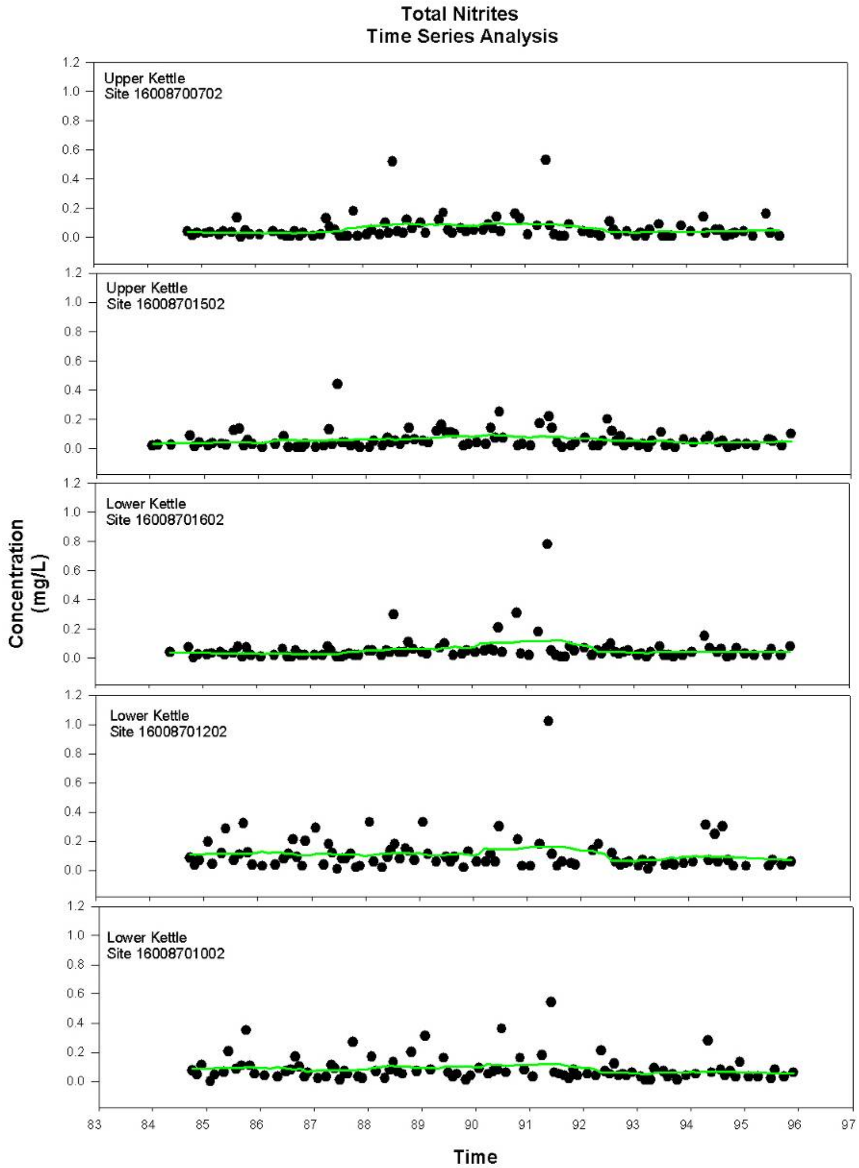


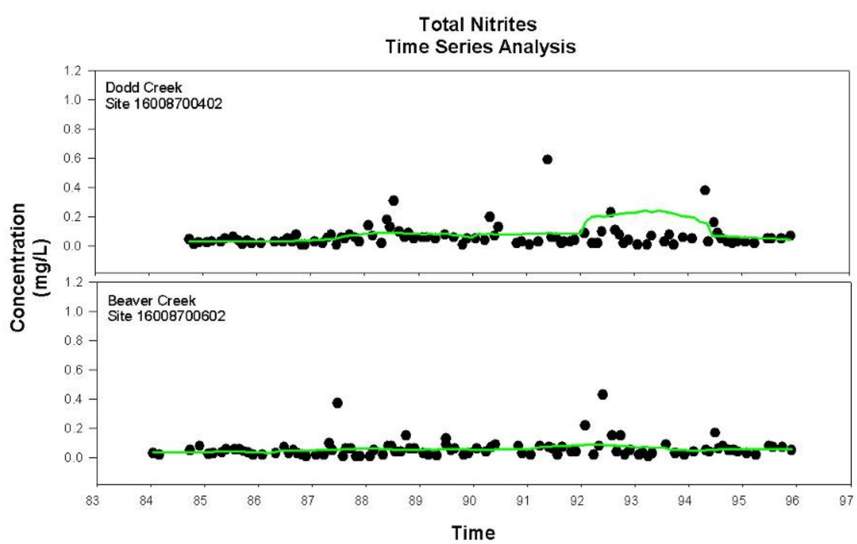
Kettle Creek Conservation Authority
Chloride Concentrations (mg/L)
75th percentile for the 1991-1995 dataset
Chloride (mg/L)
0 - 250
250 - 500
500 - 1000
> 1000
1 0 1 2 Kilometers
N

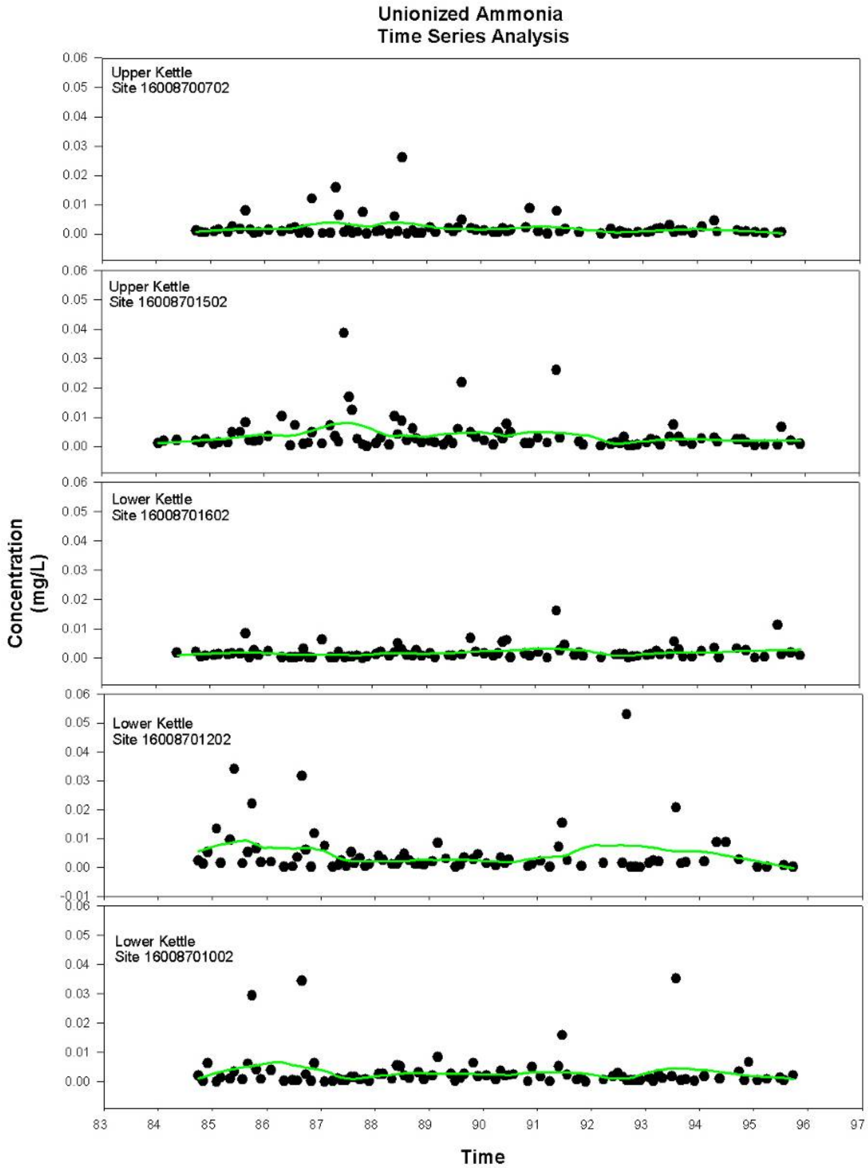
Appendix 11. Time Series Analysis at each of the 7 PWQMN sites for each of the water quality parameters tested.

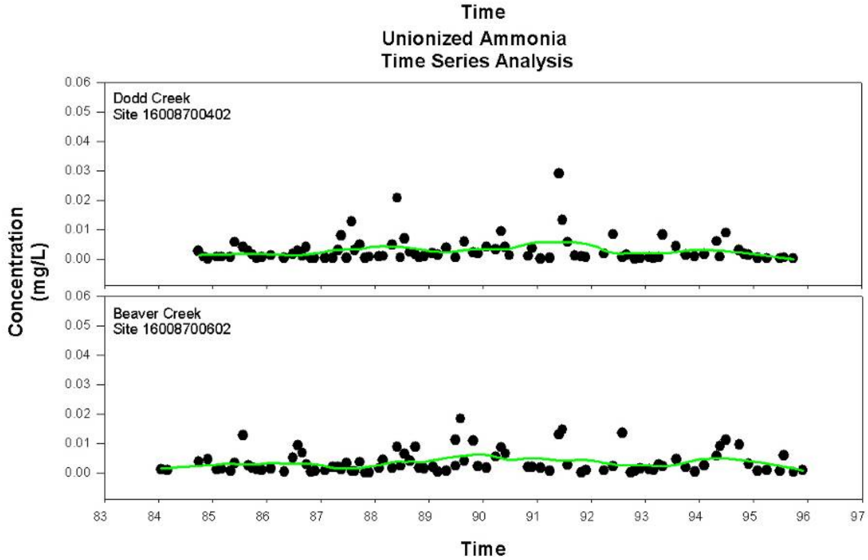


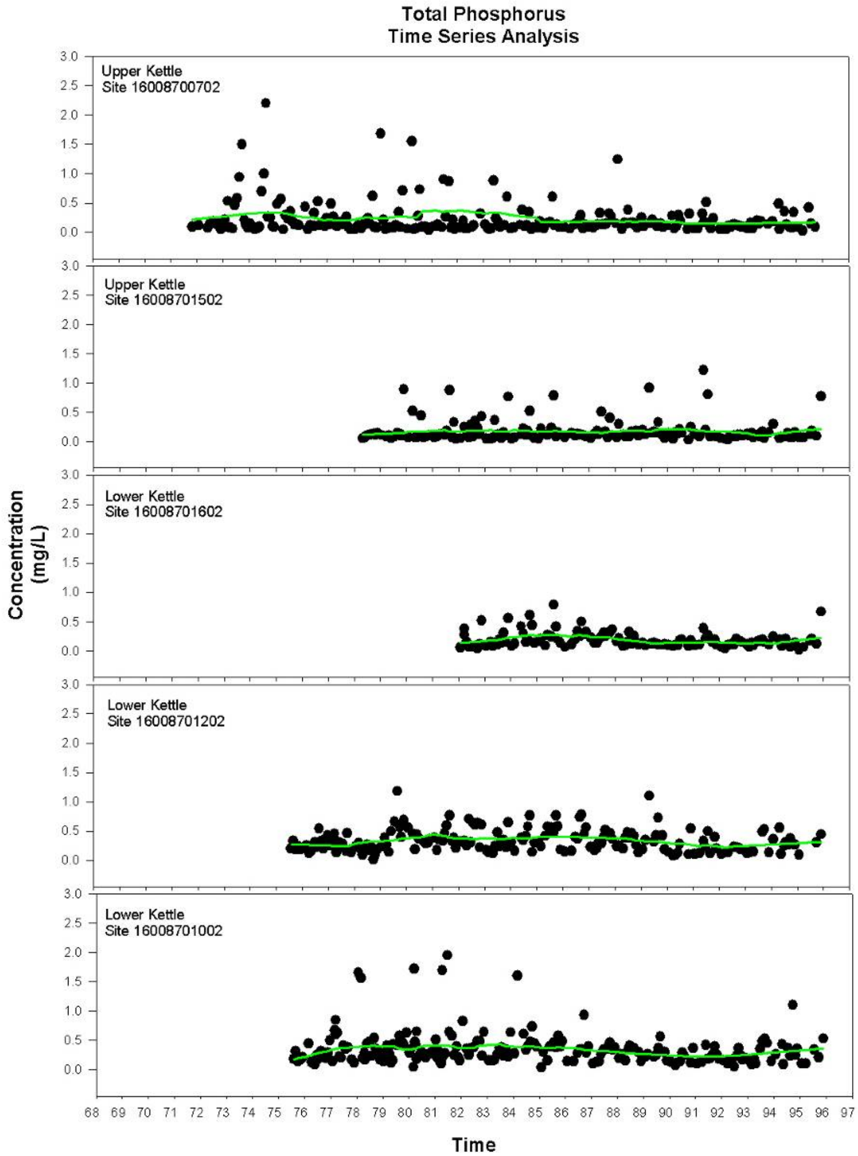


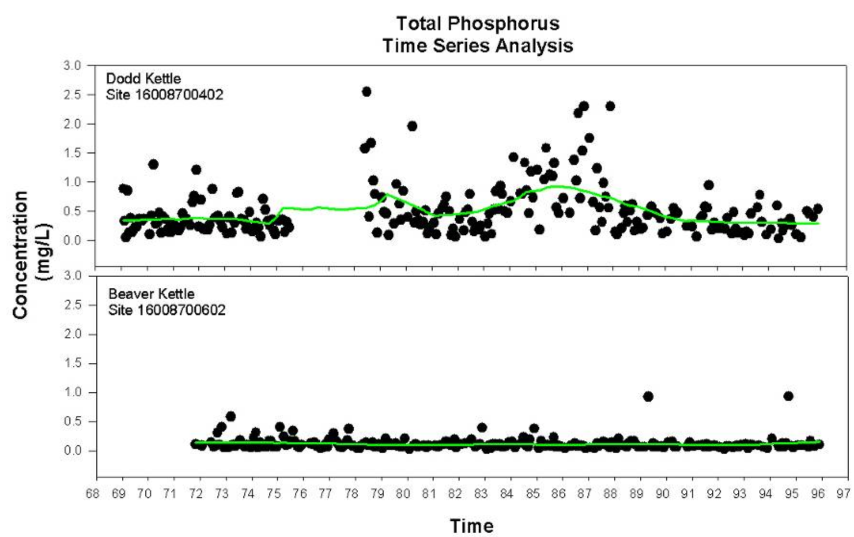

Total Nitrites
Time Series Analysis
Upper Kettle
Site 16008700702
Upper Kettle
Site 16008701502
Lower Kettle
Site 16008701602
Lower Kettle
Site 16008701202
Lower Kettle
Site 16008701002
Concentration (mg/L)
Time

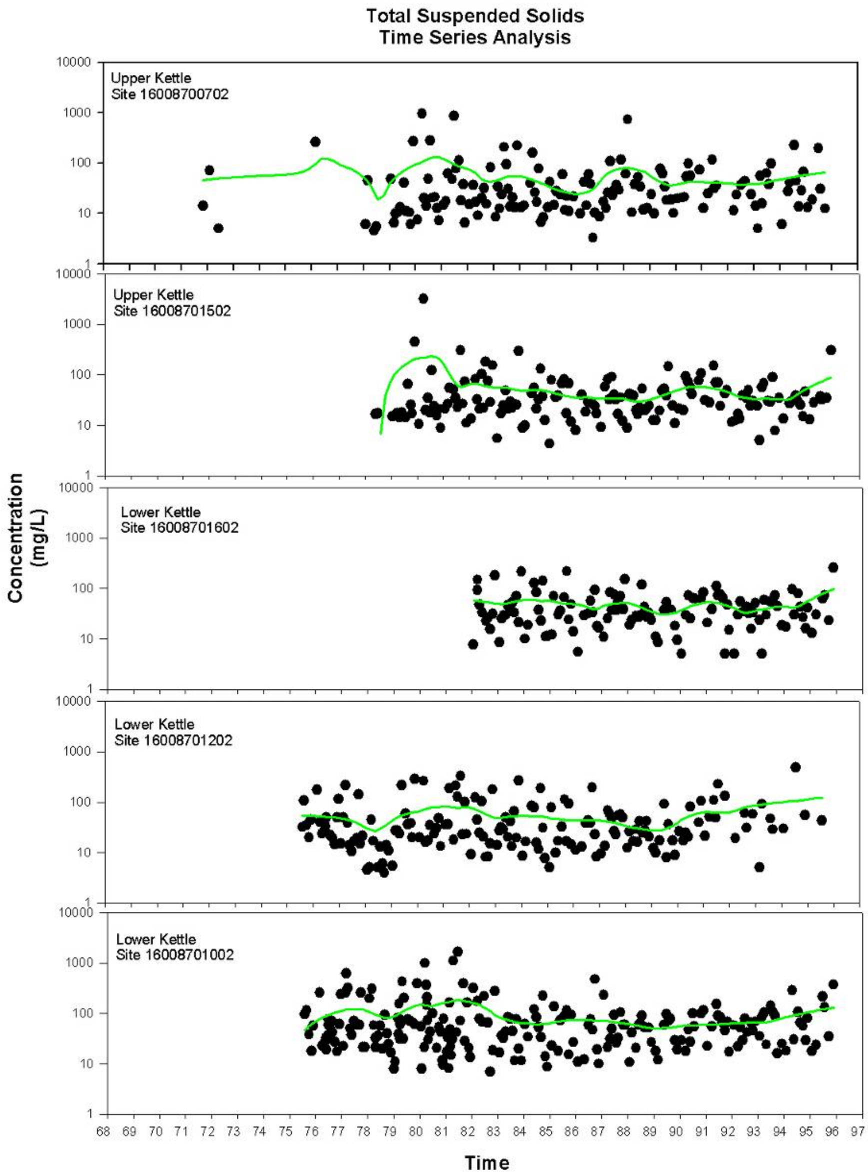

Total Nitrites
Time Series Analysis
Dodd Creek
Site 16008700402
Beaver Creek
Site 16008700602
Concentration (mg/L)
Time

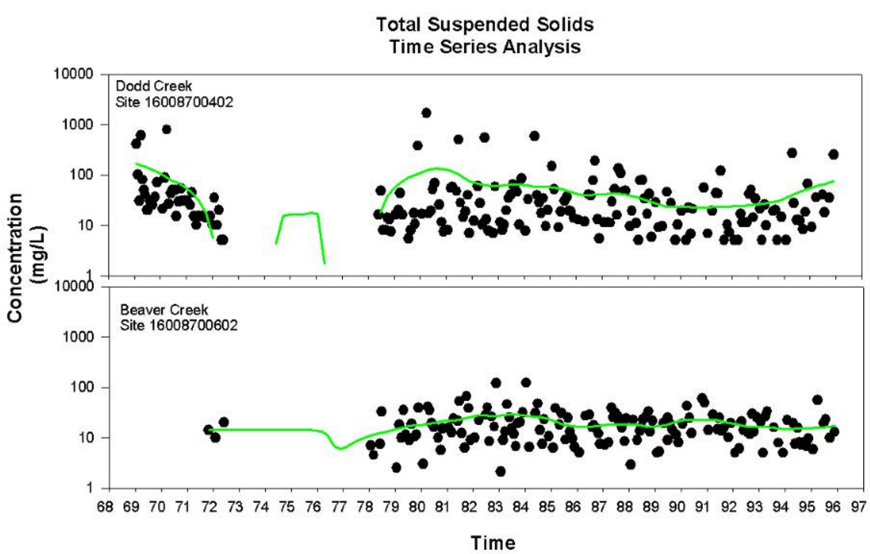

Unionized Ammonia
Time Series Analysis
Upper Kettle
Site 16008700702
Upper Kettle
Site 16008701502
Lower Kettle
Site 16008701602
Lower Kettle
Site 16008701202
Lower Kettle
Site 16008701002
Concentration
(mg/L)
Time

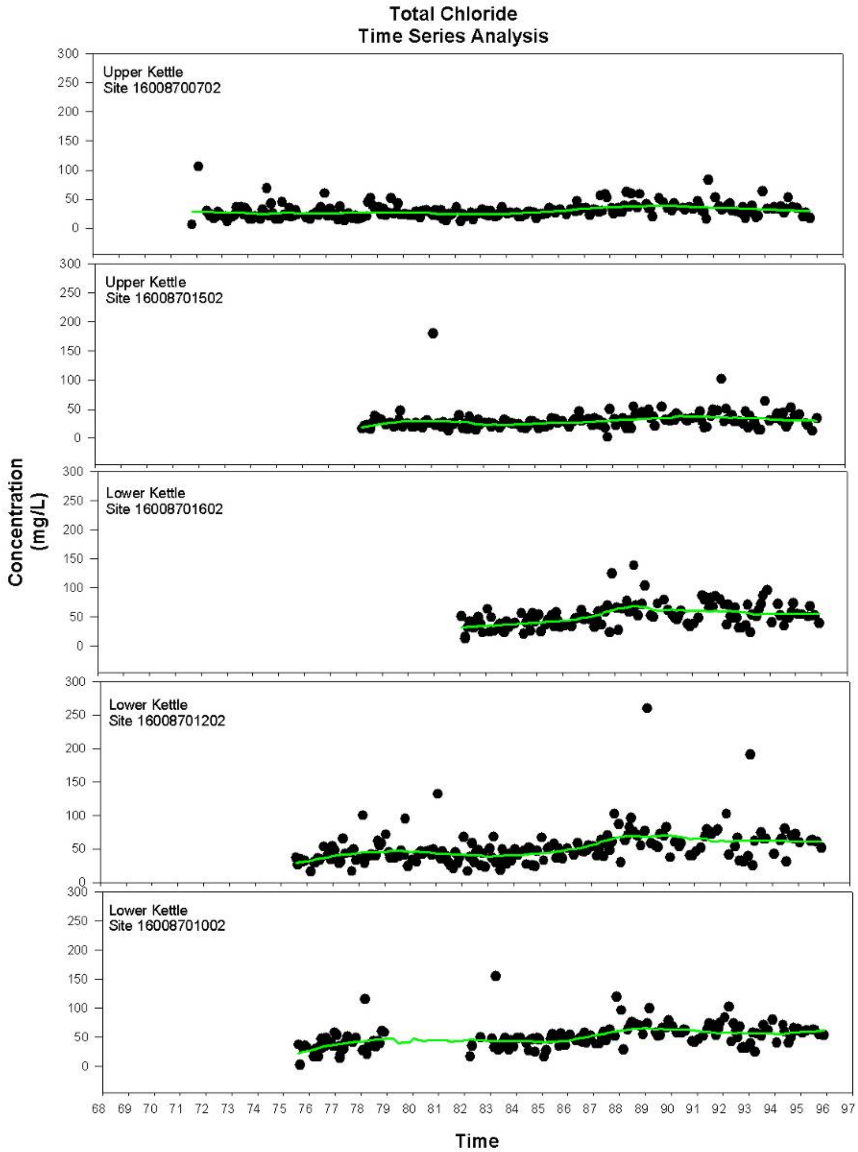

Unionized Ammonia
Time Series Analysis
Dodd Creek
Site 16008700402
Beaver Creek
Site 16008700602
Concentration
(mg/L)
Time

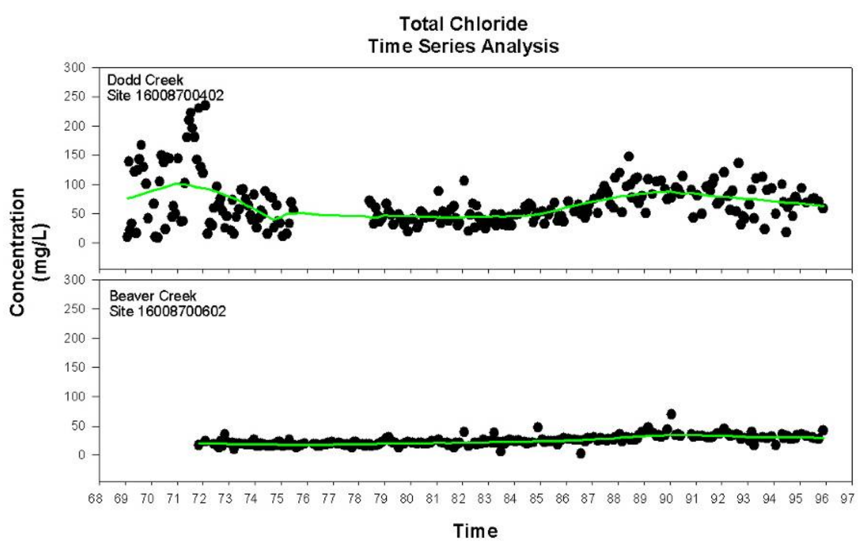

Total Phosphorus
Time Series Analysis
Upper Kettle
Site 16008700702
Upper Kettle
Site 16008701502
Lower Kettle
Site 16008701602
Lower Kettle
Site 16008701202
Lower Kettle
Site 16008701002
Concentration (mg/L)
Time
68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97


Total Phosphorus
Time Series Analysis
Dodd Kettle
Site 16008700402
Beaver Kettle
Site 16008700602
Concentration (mg/L)
Time
68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97

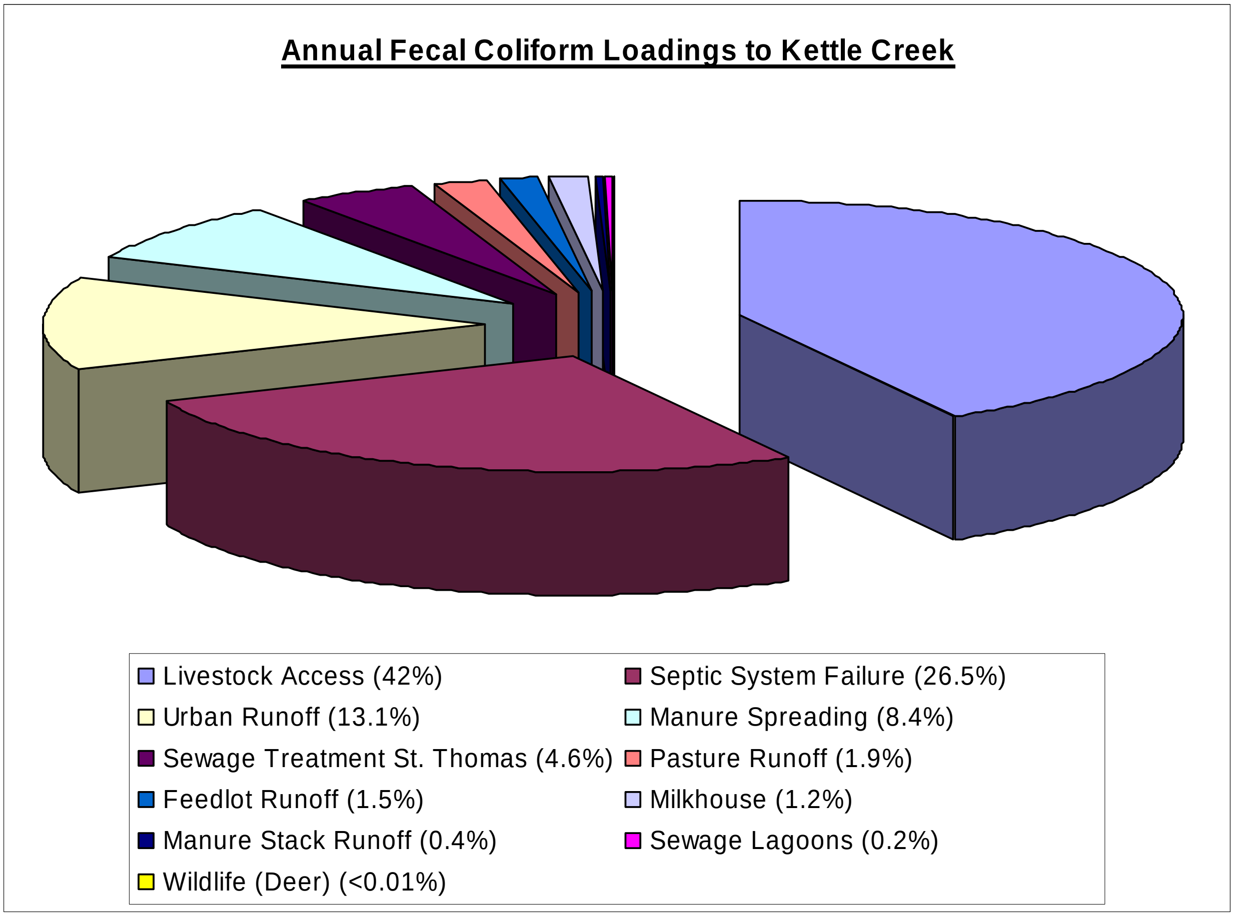

Total Suspended Solids
Time Series Analysis
Upper Kettle
Site 16008700702
Upper Kettle
Site 16008701502
Lower Kettle
Site 16008701602
Lower Kettle
Site 16008701202
Lower Kettle
Site 16008701002
Concentration (mg/L)
Time


Total Suspended Solids
Time Series Analysis
Dodd Creek
Site 16008700402
Beaver Creek
Site 16008700602
Concentration (mg/L)
Time





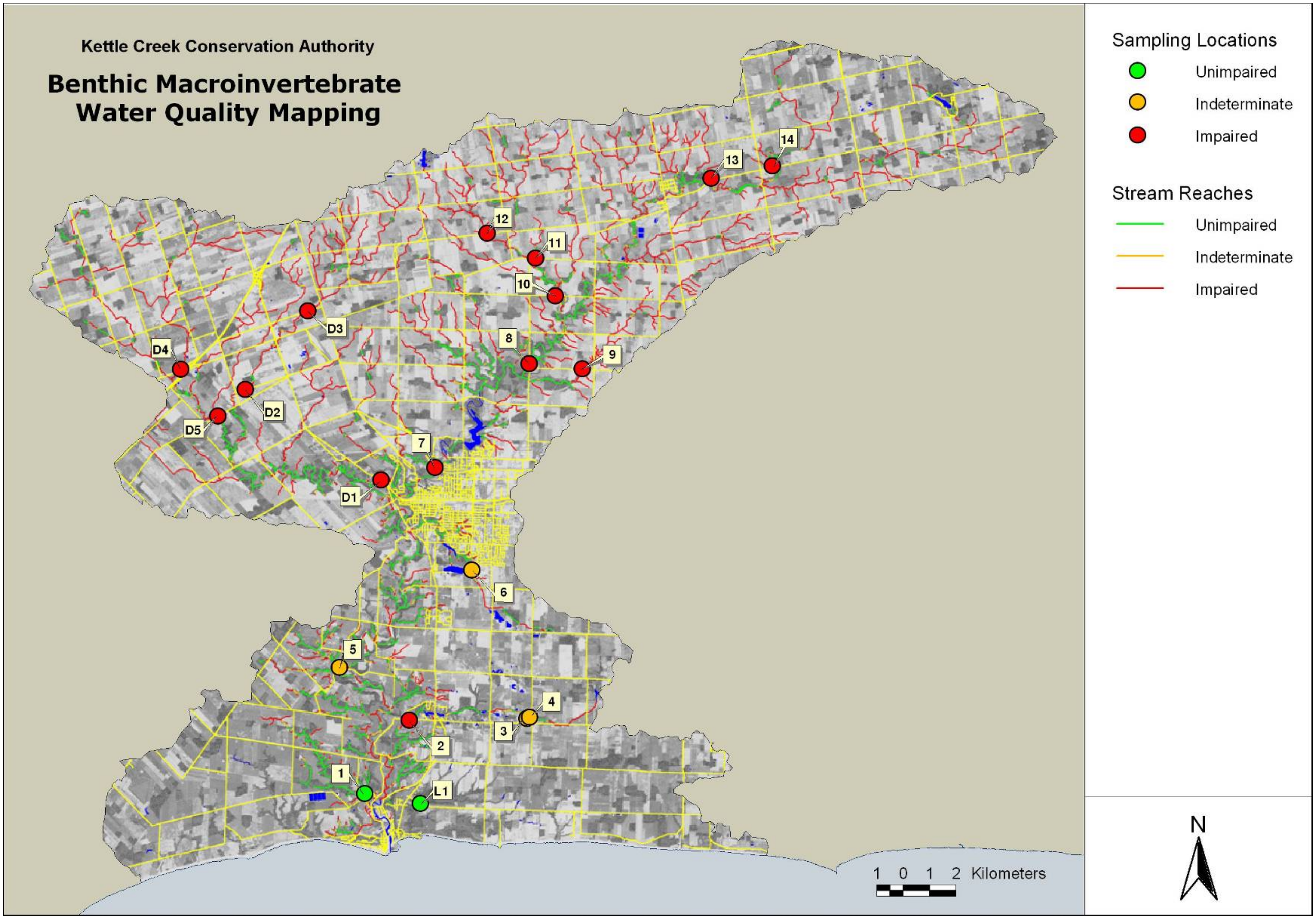
Appendix 12. Annual Faecal Coliform Loadings determined in CURB Report (Depuydt, 1994).


Annual Fecal Coliform Loadings to Kettle Creek
Livestock Access (42%)
Septic System Failure (26.5%)
Urban Runoff (13.1%)
Manure Spreading (8.4%)
Sewage Treatment St. Thomas (4.6%)
Pasture Runoff (1.9%)
Feedlot Runoff (1.5%)
Milkhouse (1.2%)
Manure Stack Runoff (0.4%)
Sewage Lagoons (0.2%)
Wildlife (Deer) (<0.01%)

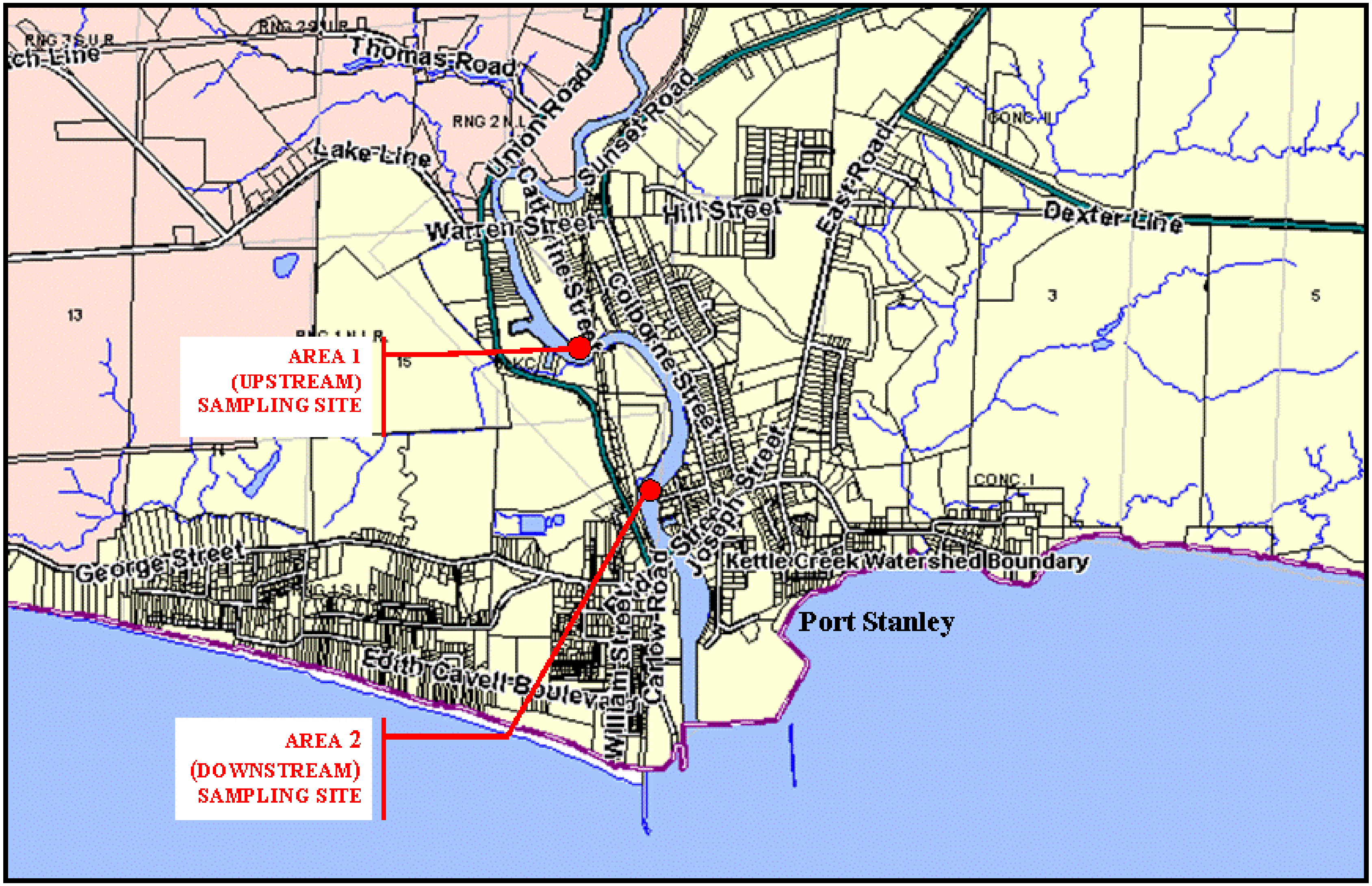
Appendix 13. BioMap scores at Kettle Creek monitoring sites (Griffiths, 2003)

Stations	Mean BioMAP scores	Impaired / Unimpaired
1	12.8	Unimpaired
2	8.0	Impaired
3	11.4	Indeterminate
4	10.7	Indeterminate
5	10.2	Indeterminate
6	10.9	Indeterminate
7	9.8	Impaired
8	6.6	Impaired
9	8.7	Impaired
10	8.1	Impaired
11	5.7	Impaired
12	5.4	Impaired
13	4.5	Impaired
14	7.7	Impaired
D1	5.8	Impaired
D2	6.5	Impaired
D3	6.4	Impaired
D4	6.8	Impaired
D5	4.4	Impaired
L1	15.1	Unimpaired

Appendix 14. Map of the Kettle Creek watershed illustrating water quality based on BioMAP scores and riparian cover (Griffiths, 2003)



Appendix 15. Map of Port Stanley illustrating Sediment Study Locations (Acres and Associates, 2001).



Appendix 16. Summary of results found in the 1995 study by Riggs Engineering on PAH sediment contamination

Area 1 Sediment Analysis Results (Upstream Site)
Comparison with Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario

Parameter	Units	MOE/GOC Guideline		Location														Range
		LEL/ISQG	SEL/PEL	1-5/AQ1	3-5/AQ1	7-5/AQ1	7-5/AQ2	9-5/AQ1	10-15/AQ1	10-5/AQ1	10-5/AQ2	10-5R/AQ1	11-5/AQ1	11-10/AQ1	12-5R/AQ1(A)	12-5R/AQ1(B)	12-5R/AQ2	
Oil & Grease - Mineral/Synthetic	µg/g			578	<20	<20	<20	<20	<20	<20	<20	<20	65	<20	70	20	<20	<20-578
Petroleum Hydrocarbon (heavy oils)	µg/g	NG	NG	578	<20	<20	<20	<20	<20	<20	<20	<20	65	<20	70	20	<20	<20-578
Non-Halogenated Volatiles																		
-Benzene	µg/g			ND	ND	ND	0.026	ND	ND	ND	0.027	ND	ND	ND	ND	ND	ND	ND - 0.027
-Toluene	µg/g			ND	ND	ND	0.14	ND	ND	ND	0.054	ND	ND	ND	ND	ND	0.011	ND - 0.14
-Ethylbenzene	µg/g			ND	ND	ND	0.43	ND	ND	ND	0.91	ND	ND	ND	ND	ND	0.36	ND - 0.91
-o-Xylene	µg/g			0.01	ND	ND	0.35	ND	ND	ND	0.1	ND	ND	ND	ND	ND	0.024	ND - 0.35
-p+m-Xylene	µg/g			0.04	ND	ND	1.6	ND	ND	ND	4.4	ND	0.016	ND	ND	ND	1.1	ND - 4.4
Purgeable Petroleum Hydrocarbons	µg/g			5.8	0.5	ND	4.1	0.6	ND	ND	13	0.3	0.8	ND	0.3	0.8	3.3	ND - 13
Extractable Petroleum Hydrocarbons	µg/g			132	ND	ND	ND	ND	ND	38	ND	21	43	ND	18	ND	24	ND - 132
Petroleum Hydrocarbons (gas/diesel)	µg/g	NG	NG	138	1	0	7	1	0	38	18	21	44	0	18	1	29	ND - 138
Total Organic Carbon	%	1	10										1.07				0.97	
Acenaphthene	µg/g	0.0067*	0.0889*										ND				ND	
Acenaphthylene	µg/g	0.00587*	0.128*										0.049				ND	
Anthracene	µg/g	0.22	370										ND				ND	
Benzo(a)anthracene	µg/g	0.32	1480										ND				ND	
Benzo(b)fluoranthene	µg/g	NG	NG										ND				ND	
Benzo(k)fluoranthene	µg/g	0.24	1340										ND				ND	
Benzo(ghi)perylene	µg/g	NG	NG										ND				ND	
Benzo(a)pyrene	µg/g	0.37	1440										0.058				ND	
Chrysene	µg/g	0.34	460										ND				ND	
Dibenzo(a,h)anthracene	µg/g	0.06	130										ND				ND	
Fluoranthene	µg/g	0.75	1020										0.089				ND	
Fluorene	µg/g	0.19	160										0.027				ND	
Indeno(1,2,3-cd)pyrene	µg/g	0.2	320										ND				ND	
Naphthalene	µg/g	0.0346*	0.391*										0.304				0.361	
Phenanthrene	µg/g	0.56	950										0.072				0.042	
Pyrene	µg/g	0.49	850										0.076				ND	
Total Polycyclic Aromatic Hydrocarbons	µg/g	4	10000										0.675				0.403	

ND = Not Detected, NG = No Guideline for this parameter
MOE/GOC Guidelines = Ontario Ministry of Environment/Government of Canada Sediment Quality Guidelines
Ontario Sediment Quality Guidelines - LEL = Lowest Effect Level, SEL = Severe Effect Level
*Canadian Sediment Quality Guideline - ISQG = Interim Sediment Quality Guideline, PEL = Probable Effect Level

Significance Rating - [yellow] = Above LEL [red] = Above SEL
[light blue] = Above ISQG [blue] = Above PEL

Area 2 Sediment Analysis Results (Downstream Site)
Comparison with Guidelines for the Protection and Managemetn of Aquatic Sediment Quality in Ontario

Parameter	Units	MOE/GOC Guideline		Location																				Range
		LEL/ISQG	SEL/PEL	3-10/AQ2		5-5AQ2(A)		5-5AQ2(B)		5-10R/AQ1		5-10R2/AQ1		7-10/AQ3		8-10/AQ2		8-10/AQ3		8-20/AQ1		12-10/AQ2		
Oil & Grease - Mineral/Synthetic	µg/g			21		54		352		<20		<20		8810		145		161		50		66		<20 - 8810
Petroleum Hydrocarbon (heavy oils)	µg/g	NG	NG	21		54		352		<20		<20		8810		145		161		50		66		<20 - 8810
Non-Halogenated Volatiles																								
-Benzene	µg/g			ND		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND
-Toluene	µg/g			ND		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND
-Ethylbenzene	µg/g			ND		ND		0.041		ND		ND		51		5.5		ND		ND		0.009		ND - 51
-o-Xylene	µg/g			ND		ND		0.17		ND		ND		140		1.4		ND		ND		0.015		ND - 140
-p+m-Xylene	µg/g			ND		ND		0.12		ND		ND		24		0.27		ND		ND		ND		ND - 24
Purgeable Petroleum Hydrocarbons	µg/g			ND		0.7		4.4		0.5		ND		520		74		0.8		0.4		0.7		ND - 520
Extractable Petroleum Hydrocarbons	µg/g			84		207		789		70		32		27500		1930		248		361		717		32 - 27500
Petroleum Hydrocarbons (gas/diesel)	µg/g	NG	NG	84		208		794		71		32		28235		2011		249		361		718		32 - 28235
Total Organic Carbon	%	1	10	0.24		0.37		0.3		0.71		1.46		5.95		2.01		1.02		1.73		1.37		0.24 - 5.95
					SEL corrected for TOC**		SEL corrected for TOC**		SEL corrected for TOC**		SEL corrected for TOC**		SEL corrected for TOC**		SEL corrected for TOC**		SEL corrected for TOC**		SEL corrected for TOC**		SEL corrected for TOC**		SEL corrected for TOC**	
Acenaphthene	µg/g	0.0067*	0.0889*	3.000		10.700		29.200		6.360		0.320		118.000		19.500		16.000		0.315		7.790		0.315 - 118
Acenaphthylene	µg/g	0.00587*	0.128*	0.615		2.990		9.680		1.050		0.202		569.000		1.650		1.140		0.136		0.926		0.136 - 569
Anthracene	µg/g	0.22	370	2.830	3.700	7.040	3.700	21.700	3.700	4.740	3.700	0.464	5.402	362.000	22.015	9.400	7.770	9.850	3.774	0.422	6.401	5.090	5.069	0.422 - 362
Benzo(a)anthracene	µg/g	0.32	1480	2.270	14.800	3.450	14.800	10.100	14.800	3.010	14.800	0.531	21.608	174.000	88.060	5.330	31.080	5.640	15.096	0.429	25.604	2.820	20.276	0.429 - 174
Benzo(b)fluoranthene	µg/g	NG	NG	0.886		1.180		3.170		1.110		0.236		47.900		1.900		1.830		0.233		1.050		0.233 - 47.9
Benzo(k)fluoranthene	µg/g	0.24	1340	0.410	13.400	0.581	13.400	1.970	13.400	0.582	13.400	0.125	19.564	32.200	79.730	0.999	28.140	1.210	13.668	0.134	23.182	0.562	18.358	0.125 - 32.2
Benzo(ghi)perylene	µg/g	NG	NG	1.220		1.650		4.630		1.660		0.341		64.600		2.670		2.510		0.250		1.340		0.341 - 64.6
Benzo(a)pyrene	µg/g	0.37	1440	2.470	14.400	3.550	14.400	9.740	14.400	3.260	14.400	0.613	21.024	136.000	85.680	5.420	30.240	5.450	14.688	0.424	24.912	2.790	19.728	0.613 - 136
Chrysene	µg/g	0.34	460	1.830	4.600	2.800	4.600	8.030	4.600	2.490	4.600	0.475	6.716	142.000	27.370	4.390	9.660	4.540	4.692	0.401	7.958	2.310	6.302	0.401 - 142
Dibenzo(a,h)anthracene	µg/g	0.06	130	0.312	1.300	0.412	1.300	1.230	1.300	0.394	1.300	ND	1.898	16.400	7.735	0.718	2.730	0.708	1.326	ND	2.249	0.359	1.781	ND - 16.4
Fluoranthene	µg/g	0.75	1020	3.550	10.200	6.030	10.200	18.500	10.200	4.900	10.200	0.752	14.892	303.000	60.690	9.400	21.420	10.400	10.404	0.878	17.646	5.030	13.974	0.752 - 303
Fluorene	µg/g	0.19	160	1.390	1.600	6.380	1.600	19.400	1.600	3.270	1.600	0.307	2.336	366.000	9.520	9.290	3.360	7.920	1.632	0.411	2.768	4.190	2.192	0.307 - 366
Indeno(1,2,3-cd)pyrene	µg/g	0.2	320	0.845	3.200	1.090	3.200	3.290	3.200	1.080	3.200	0.239	4.672	40.100	19.040	1.890	6.720	1.850	3.264	0.196	5.536	0.967	4.384	0.196 - 40.1
Naphthalene	µg/g	0.0346*	0.391*	1.180		13.600		49.200		2.580		0.186		1880.000		79.700		29.300		0.269		4.410		0.186 - 1880
Phenanthrene	µg/g	0.56	950	6.990	9.500	22.700	9.500	79.300	9.500	14.800	9.500	1.350	13.870	1220.000	56.525	33.100	19.950	33.000	9.690	1.430	16.435	18.000	13.015	1.35 - 1220
Pyrene	µg/g	0.49	850	7.880	8.500	13.200	8.500	43.100	8.500	10.600	8.500	1.650	12.410	668.000	50.575	21.200	17.850	23.600	8.670	1.230	14.705	11.100	11.645	1.23 - 668
Total Polycyclic Aromatic Hydrocarbons	µg/g	4	10000	37.678		97.353		312.240		61.886		7.791		6139.200		206.557		154.948		7.158		68.734		

ND = Not Detected, NG = No Guideline for this parameter
MOE/GOC Guidelines = Ontario Ministry of Environment/Government of Canada Sediment Quality Guidelines
Ontario Sediment Quality Guidelines - LEL = Lowest Effect Level, SEL = Severe Effect Level
*Canadian Sediment Quality Guideline - ISQG = Interim Sediment Quality Guideline, PEL = Probable Effect Level
**Minimum sediment TOC of 1% applied

Significance Rating - = Above LEL = Above SEL
= Above ISQG = Above PEL