Q-350 Application of Multivariate Statistical Analyses to Microbial Water Quality Parameters in Four Geographically Similar Creeks in Northeast Tennessee to Identify Patterns Associating Land Use to Fecal Pollution Sources

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ABSTRACT

The addition of surface water bodies to impaired waters (303D) lists for pathogen impairment and the need to address these through the Total Maximum Daily Load (TMDL) process has resulted in increased research to find methods that effectively and universally identify fecal pollution sources. A fundamental requirement to identify such methods is understanding the land use, and microbial and chemical processes that influence fate and transport of fecal indicators from various sources to receiving streams. To better understand current water quality and predict water quality changes as development occurs, we initiated a water quality monitoring program. Four creeks within the Watauga River watershed in Northeast Tennessee are routinely monitored using a targeted sampling approach to determine the extent and sources of fecal pollution. These creeks are monitored based on the existence of pathogen TMDLs or the expectation that they will require pathogen TMDLs. Boones, Cash Hollow and Sinking Creek are listed on the State of Tennessee's 303D list due to pathogen loading, but only Cash Hollow and Sinking Creeks have TMDLs. Buffalo and Sinking Creek have similar patterns of fecal coliform loading, suggesting that TMDL development may require multi-year data using a targeted sampling approach instead of a 30-day geometric mean. Boones and Cash Hollow Creek have elevated fecal coliform concentrations (1115 and 733 CFU/100ml, respectively) but different land use patterns. Agricultural land use impacts Boones Creek, while surface runoff and land development impact Cash Hollow Creek. Previous multivariate statistical analyses have demonstrated that the microbial and chemical parameters influencing water quality differ between creeks, further suggesting that land use patterns influence microbial contamination. The objective of this research is to update results of previous reports and apply multivariate statistical techniques to identify common patterns associating land use to monitored water quality parameters and various pollution sources. We will discuss the conclusion and usefulness of these data to accomplish this objective.

Keywords: water quality, TMDL, multivariate statistical analysis

INTRODUCTION

The rapid growth and urbanization that is occurring in many locations is increasing the already significant deterioration of surface water quality. Increased listing of surface water bodies on impaired waters (303D) lists for pathogen impairment and the need to address these through the Total Maximum Daily Load (TMDL) process has resulted in increased research to find methods that effectively and universally identify sources of fecal pollution. A fundamental requirement to identify such methods is understanding the land use, and microbial and chemical processes that influence fate and transport of fecal indicators and pathogens from the various sources to the receiving streams.The Tri-Cities (Bristol, Johnson City, Kingsport) area within Northeast Tennessee is experiencing rapid growth in the form of new residential developments. Due to terrain and land use patterns in this region, much of this development is occurring in close proximity to headwater streams in the Watauga River watershed. To better understand current water quality and predict water quality changes as development occurs, we initiated a water quality-monitoring program. Four creeks within the Watauga River watershed are routinely monitored using a targeted sampling approach to identify pollution sources and monitor remediation efforts. Boones Creek contains 19.3 miles of impaired water and is undergoing rapid transition from agricultural to mixed land use due to the construction of many housing developments. Sinking Creek and Cash Hollow Creek contain 10 and 3.4 miles of impaired water, respectively. The Tennessee Department of Environment and Conservation (TDEC) has not determined the status of water quality in Buffalo Creek. Boones, Cash Hollow and Sinking Creeks are listed on the state's 303D list due to pathogen loading. However, only Sinking Creek and Cash Hollow Creek have TMDLs. Buffalo and Sinking Creek have similar patterns of fecal coliform loading, suggesting that TMDL development may require multi-year data using a targeted sampling approach instead of a 30-day geometric mean. The sources and types of pollution in the Watauga River watershed may differ due to land use patterns within and between these creeks. Pollution in Boones Creek and Buffalo Creek is mainly due to agricultural input, while Cash Hollow Creek and Sinking Creek are impacted by a combination of sources including agriculture, and urban runoff due to storm sewers and land development. In addition to differences in land use patterns, interactions between chemical and microbial processes in the water add to the complexity of understanding pathogen loading and transport within the watershed. Examining these relationships can improve our understanding of the influence of chemical and microbial processes on water quality and can help identify sources of fecal pollution. Previous canonical correlation analysis have demonstrated that the microbial and chemical parameters influencing water dynamics differ between creeks, further suggesting the influence of land use patterns on microbial contamination. The specific objective of this study is to update results of previous reports and apply multivariate statistical techniques to identify common patterns associating land use to monitored water quality parameters and various pollution sources. The main objective of these studies are to learn more about the response of these creeks to anthropogenic stressors, to identify methods that help identify sources of impairment and to identify Best Management Practices (BMPs) that will prevent and remediate the effects of rapid urbanization.

OBJECTIVES

1. Update results of previous reports and compare chemical and microbial parameters using multivariate statistical analyses to identify common patterns associating land use to monitored water quality parameters and various pollution sources

2. Understand how seasonal and spatial patterns affect water quality in the Watauga River watershed

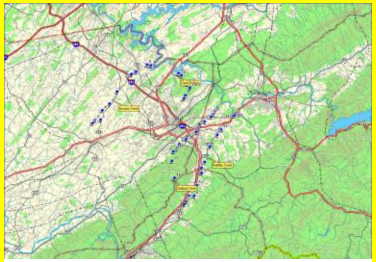

Figure 1. Map of Boones, Buffalo, Cash Hollow and Sinking Creeks showing sampling locations and surrounding region.

MATERIALS AND METHODS

Sample Collection: Water and sediment samples were collected in triplicate for total/fecal coliform and AODC analyses in 100ml sterile Whirl-Pak bags (Nasco, Fort Atkinson, WI). Water samples for nitrate, phosphate, alkalinity, hardness and BOD_5 analyses were collected in triplicate in 2L plastic Nalgene™ bottles. Sinking Creek was sampled quarterly since 2002 and Cash Hollow Creek was sampled monthly during 2002 and quarterly from 2003. Buffalo Creek was sampled quarterly since 2004 and Boones Creek was sampled monthly from March 2005 and quarterly from March 2006.

Total/Fecal Coliform Analyses: Total/fecal coliform analysis of water and sediment samples was conducted according to Standard Methods for Examination of Water and Wastewater (APHA, 1992). Samples were processed in triplicate and the sample volume was selected to produce 30 - 300 colonies. For total/fecal coliform sediment analysis, 0.5g was added to 25ml 1% Tween 20, mixed and allowed to settle. One milliliter of the supernatant was filtered according to Standard Methods for the Examination of Water and Wastewater (APHA, 1992). Samples were filtered through a 47mm Millipore MF (Millipore, Bedford, MA) type mixed cellulose filter with a 0.45μm pore size.

AODC Analysis: Three hundred milligrams of sediment were added to 30ml PBS+Tween 80, vortexed for one minute, and allowed to settle for 3h. Five hundred microliters of the supernatant was then added to 5ml sterile water containing 500μl AO stain, and vortexed for 30s. Samples were filtered using 25mm polycarbonate nucleopore filters with a 0.2μm pore size. Filters were mounted on slides and fixed, and bacteria were enumerated at 1000X using epifluorescent microscopy.

Nitrate/Phosphate/Alkalinity/Hardness Analyses: Nitrate, phosphate, alkalinity and hardness analyses were performed in triplicate using colorimetric HACH™ methods as described by the manufacturer (HACH Company, Loveland, CO).

Five-Day BOD Analysis: BOD_5 analysis was conducted according to Standard Methods for Examination of Water and Wastewater (APHA, 1992). Samples were analyzed in triplicate and dissolved oxygen was measured using the YSI Model 5000 (YSI Inc., Yellow Springs, OH) meter.

Statistical Analysis: Statistical analyses were performed using SAS/STAT software (SAS Institute, Cary, NC). Fecal coliform data were analyzed by ANOVA to compare concentrations by creek, site, season and year. Canonical correlations were performed using the CANCORR procedure and discriminant analysis was performed using the CANDISC procedure. Canonical correlation and discriminant analyses were performed at the creek, season and site levels.

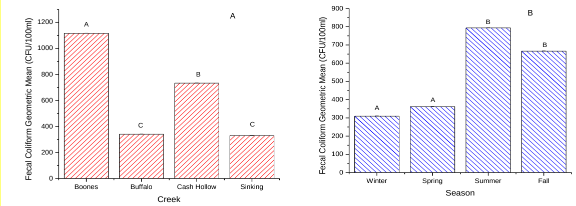

Figure 2. Fecal coliform concentrations by creek (A) and season (B)

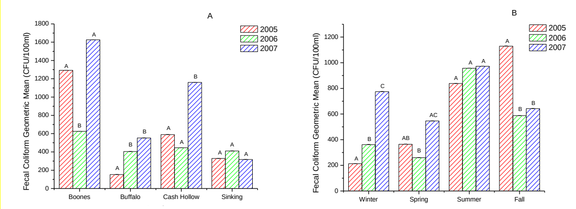

Figure 3. Yearly fecal coliform concentrations by creek (A) and season (B)

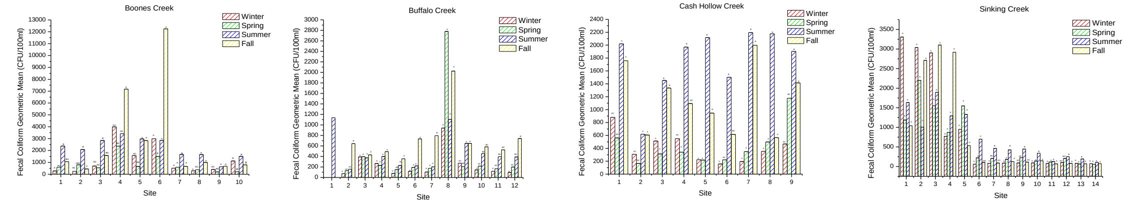

Figure 4. Fecal coliform concentrations by creek and site

RESULTS

- Boones, Buffalo and Cash Hollow Creeks demonstrate an increase in fecal coliform concentrations in 2007 compared to previous years
- As observed 2005 and 2006, there are no significant differences in fecal coliform concentrations between Buffalo and Sinking Creeks
- No significant differences in fecal coliform concentrations between Summer/Fall and Winter/Spring for all creeks
- Fecal coliform concentrations vary within and between creeks. The highest fecal coliform concentrations are observed at agricultural land use sites and demonstrate seasonal variation.
- Sources of impairment differed within and between creeks when analyzed by site, suggesting the influence of land use patterns on fecal contamination. Canonical correlation analyses conducted at the creek level demonstrate that organic matter pollution is most often associated with fecal pollution and heterotrophic activity in the watershed. In addition, surface runoff also impacts Buffalo and Cash Hollow Creeks.
- Canonical discriminant analysis demonstrates a grouping effect of class means based on land use patterns. Clusters are classified as agricultural, urban or forest land use.

CONCLUSIONS

- Fecal coliform concentrations exhibit seasonal and yearly variation. This variation suggests climatic variation within and between years, and the effects of development and urbanization within the watershed. Combined effects of increasing impervious surfaces and decreasing buffer zones may account for the increased fecal coliform concentrations observed in 2007.
- Buffalo and Sinking Creek have similar patterns of fecal coliform loading, suggesting that TMDL development may require multi-year data using a targeted sampling approach instead of a 30-day geometric mean.
- Fecal coliform concentrations vary between and within creeks. This difference is attributed to variation in land use patterns along the creeks. Agricultural land use sites demonstrate the highest fecal coliform concentrations, particularly in the summer and fall months.
- Canonical correlation analyses demonstrate that sources of impairment are related to land use patterns in the watershed. Surface runoff and organic matter pollution are the result of agricultural activity or urban activities including land disturbances and municipal sewage contamination.
- Canonical discriminant analysis further supports the influence of land use patterns on fecal coliform concentrations in the watershed. Three groups are observed, representing different land use patterns in the watershed. The inclusion of some agricultural land use sites in the urban cluster suggests mixed sources of fecal pollution.
- The application of multivariate statistical methods to water quality data has helped to identify common patterns associating land use to monitored water quality parameters and various pollution sources. Combined with a targeted water quality monitoring program, this data analysis approach is a useful method to identify sources of impairment and to identify BMPs that will prevent and remediate the effects of rapid urbanization in the Watauga River watershed.

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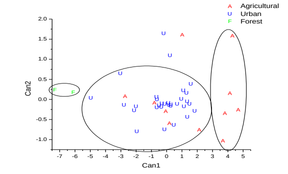

Figure 5. Class means of canonical variables

Table 1. Fecal pollution sources determined by canonical correlation analysis

Creek/Site	Land Use	Pollution Source
Boones 4	Agricultural	Organic matter
Boone 5	Urban	No Correlation
Boones 6	Agricultural	Organic matter
Buffalo 8	Agricultural	Organic matter
Cash Hollow 1	Urban	Surface runoff
Cash Hollow 4	Urban	Organic matter
Cash Hollow 7	Urban	Organic matter
Cash Hollow 8	Urban	Surface runoff
Cash Hollow 9	Agricultural	Surface runoff
Sinking 1	Agricultural	Surface runoff
Sinking 2	Agricultural	Organic matter
Sinking 3	Agricultural	Surface runoff
Sinking 4	Agricultural	Surface runoff
Sinking 5	Agricultural	Surface runoff