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MIAMI
CONSERVANCY
DISTRICT

RELATIONSHIP OF *ESCHERICHIA COLI* LEVELS IN THE GREAT MIAMI RIVER TO ANTECEDENT RAINFALL AND RUNOFF IN AN URBAN AREA

Abstract

This report summarizes the results of an investigation to examine the relationship between occurrence and magnitude of *Escherichia Coli* (*E. coli*) with antecedent rainfall and runoff conditions in the Great Miami River in Dayton, Ohio. The results of the investigation illustrate statistical increases in *E. coli* concentrations from wet weather to dry weather conditions at seven sample stations on the Great Miami River and tributaries. The results also show an increase in *E. coli* concentrations from sampling stations upstream of the Dayton urban core to stations within the urban core. In this study, dry weather *E. coli* concentrations mostly met Ohio Class A primary contact recreation standards but wet weather concentrations often did not meet those standards. The concentrations of *E. coli* measured at three stormwater outfalls were highly variable. Statistical correlations for various rainfall and runoff event-based variables using simple and multiple linear and non-linear regressions illustrated that the variables of antecedent rainfall conditions and changes in river flow had the highest explanatory power for inter-event variations in *E. coli* concentration in the Dayton urban core. Statistically-significant relationships between river flow and water turbidity were also present at some sampling stations. Future studies are needed to better define intra-event variations in *E. coli* in urban runoff and to explore relationships that may exist with other explanatory variables.

Introduction

Background

The purpose of this investigation is to determine whether measurable antecedent rainfall and runoff conditions influence the occurrence and magnitude of microbial pollutant concentrations in the Great Miami River in Dayton, Ohio.

Stormwater that originates in urban areas is a major source of pollution in the Great Miami River Watershed (OEPA 2013). Surface water is contaminated by a variety of pollutants from urban stormwater including: sediment, nutrients, heavy metals, and microorganisms. The microbial pollutants in urban stormwater often have a fecal origin which possibly originate from sanitary sewer overflows, combined sewer overflows, cross connections between storm and sanitary sewers, and pet and wildlife waste.

Microbial pollutants that cause disease are referred to as pathogens. Pathogens in surface water pose potential health risk for people who engage in outdoor recreational activities in rivers, lakes, streams, and ponds. Studies show that increased health risks are associated with exposure to pathogens in water through bathing and other activities that result in full or partial immersion in water (Fleisher et. al., 2010). A recent study of the Great Miami River from Sidney to Dayton, Ohio by the Ohio Environmental Protection Agency (OEPA) concluded that microbial indicators or fecal contamination frequently exceed statewide contact recreation standards (OEPA, 2013).

Elevated levels of microbial contaminants in surface water may also pose a public health threat to shallow water supply wells located in close proximity to the Great Miami River and its tributaries. Production wells installed in sand and gravel aquifers adjacent to the Great Miami River cause movement of water from the river through the riverbed and into the underlying aquifer through a process known as induced infiltration. High flow events in the Great Miami River result in riverbed scour which removes fine sediment from the riverbed increasing movement of water across the surface water/groundwater interface (Levy et. al., 2013). As a result, movement of microbial contaminants from surface water to groundwater may be enhanced, and under certain conditions, may reach production wells more quickly.

If significant relationships exist between antecedent rainfall and runoff conditions and the occurrence and magnitude of microbial pollutants, it may be possible to predict when microbial pollutant concentrations in surface water are likely to exceed contact recreation standards. Knowledge of microbial pollutant behavior in response to measurable rainfall and runoff can be useful information for evaluating health risks from exposure to pathogens. This knowledge could also be useful for assessing the risk that pathogens pose to shallow production wells that receive recharge from the Great Miami River.

Applicable Water Quality Standards

In Ohio, statewide numerical standards for *E. coli* are determined by OEPA and are based upon state-designated recreation uses. OEPA sets recreational use standards for *E. coli* for streams designated for bathing and contact recreation (see Table 1). The Ohio Administrative Code defines Class A primary contact recreation waters as waters that are suitable for frequent full-body contact recreation activities such as, but not limited to, wading, swimming, boating, water skiing, canoeing, kayaking, and scuba diving. OEPA designated the Great Miami River in Dayton as Class A primary recreation use. For the purpose of this investigation, the Class A *E. coli* standards are used to evaluate *E. coli* data.

Table 1. Statewide numerical limits for the protection of recreation uses

Recreation use*	**E. coli (colony counts per 100 mL)**	
	Seasonal geometric mean	**Single sample maximum**
Bathing water	126	235
Class A primary contact recreation	126	298
Class B primary contact recreation	161	523
Class C primary contact recreation	206	940
Secondary contact recreation	1030	1030

*The criteria above apply inside and outside the mixing zone for wastewater treatment plant discharges during the recreation season which runs from May 1 to October 31

Methods of Data Collection and Analysis

Data Collection

It is difficult to measure pathogens in natural waters directly because the variety, and often low concentration, of pathogenic bacteria and viruses make them difficult to detect and quantify individually. An alternative approach is to use indicator organisms as a surrogate for pathogenic microbes. Microbial indicators of fecal contamination are assumed to be present in water whenever pathogens from fecal contamination are present. Thus, microbial indicators of fecal contamination may be used to evaluate the risk for the occurrence of fecal pathogens. One of the most commonly used microbial indicator bacteria is *Escherichia coli* (*E. coli*). *E. coli* is a rod-shaped, gram negative bacterium, commonly found in the gastrointestinal tract and feces of warm-blooded animals. It is one species within the fecal-coliform group of bacteria and can be distinguished from other fecal coliforms by biochemical tests. Most strains of *E. coli* are harmless, but some strains can cause illness. The presence of *E. coli* bacteria in water is indicative of the presence of fecal contamination which may contain pathogens.

From April 30 to November 13, 2012, Miami Conservancy District (MCD) staff conducted grab samples of surface water at seven locations on the Great Miami River and its tributaries; Mad River, Stillwater River, and Wolf Creek and at three stormwater outfalls that discharge into the Great Miami River (see Figure 1). Grab samples are individual samples which are each collected during a period of time not exceeding 15 minutes. Grab samples represent only the condition of the water at the time the sample was collected.

With the exception of stations GMR01 and SR01, all of the river sampling stations and stormwater outfalls are surrounded by medium to high density developed land according to the National Land Cover dataset 2006. Sampling stations GMR01 and SR01 are surrounded mostly by low density developed land and developed open space according to the National Land Cover dataset 2006.

Precipitation and streamflow data was obtained from a network of U.S. Geological Survey (USGS) and MCD cooperative stream gages and MCD's precipitation observer stations in the Dayton area. Precipitation measurements at MCD's precipitation observer stations were conducted with National Oceanic and Atmospheric Administration (NOAA) standard 8-inch rain gages. During the study, measurements were made at 8:00 am each day and reflect precipitation over the previous 24-hour interval. Stage and discharge were measured at 15-minute intervals at all cooperative stream gages. Water column turbidity data was obtained from two YSI EcoNet monitoring stations located on the Great Miami River and one YSI EcoNet monitoring station located on the Mad River. Turbidity measurements at the YSI EcoNet sites were made at hourly intervals using YSI water quality sondes equipped with turbidity sensors. See Table 2 for a list of water monitoring stations used to support this investigation.

The sampling frequency was chosen to be representative of water quality in the river during both wet weather and dry weather conditions. MCD staff collected the water samples by wading out to the middle of the river channel. They filled sterilized polypropylene sample containers preserved with sodium thiosulfate. The sample containers were packed in Ziploc plastic bags, placed immediately in a cooler filled with ice, and transported to the laboratory within four hours of sample collection. The laboratory enumerated E. coli colonies using an IDEXX Quanti-Tray 2000^{TM}. All E. coli results are reported as a most probable number of colony forming units per 100 milliliters (mL) of water.

Figure 1. Locations of *E.* coli sampling stations

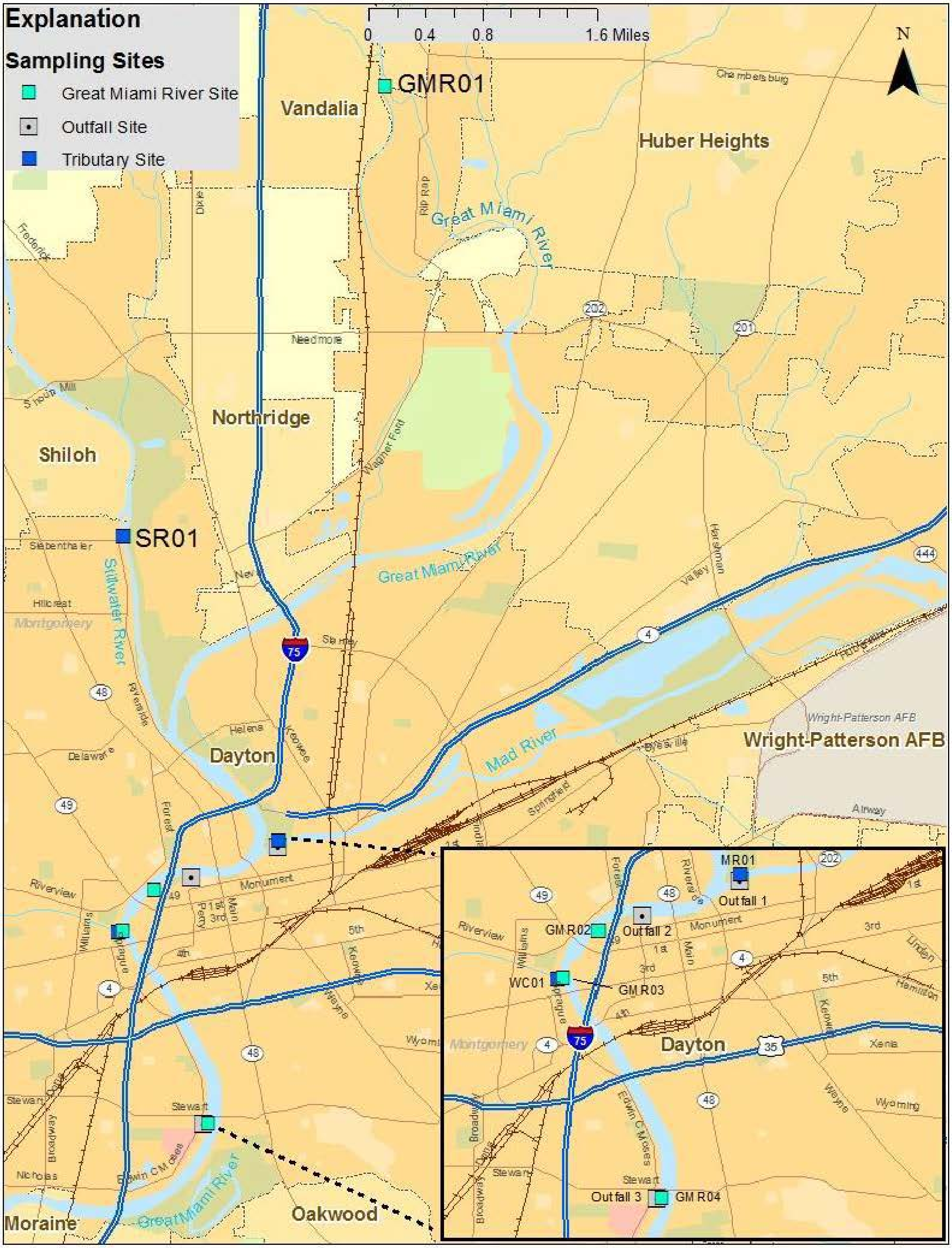


Table 2. Precipitation, streamflow, and turbidity monitoring stations

Monitoring Station	**Monitoring Network**	**Type of Data**	**Maintained by**	**Sampling Stations in Correlation Analysis**
Great Miami River at Taylorsville	USGS NWIS	Streamflow	USGS and MCD	GMR01
Taylorsville Observer	MCD Observer	Precipitation	MCD	GMR01
Rip Rap Road in Huber Heights	YSI EcoNet	Turbidity	YSI and MCD	GMR01
Englewood Observer	MCD Observer	Precipitation	MCD	SR01
Mad River near Dayton	USGS NWIS	Streamflow	USGS and MCD	MR01
Mad River at Huffman Dam	YSI EcoNet	Turbidity	YSI and MCD	MR01
Huffman Dam Observer	MCD Observer	Precipitation	MCD	MR01
Great Miami River at Dayton	USGS NWIS	Streamflow	USGS and MCD	GMR02, GMR03, GMR04
Dayton Observer	MCD Observer	Precipitation	MCD	All stations
Dayton Canoe Club	YSI EcoNet	Turbidity	YSI and MCD	GMR02, GMR03, GMR04
Wolf Creek at Dayton	USGS NWIS	Streamflow	USGS and MCD	WC01
Brookville Observer	MCD Observer	Precipitation	MCD	WC01

Statistics Used

Standard statistical methods using simple and multiple regressions were used to determine significant correlations between response and explanatory variables. The coefficient of determination R^2 and adjusted coefficient of determination ($\overline{R}^2$) were used to indicate if a linear relationship existed for the simple and multiple regressions. The adjusted coefficient of determination was used to account for the tendency of R^2 to increase when additional explanatory variables are added to the regression model. Non-linear relationships were identified by using simple and multiple regressions on log transformed data and looking at the coefficient of determination (R_l^2) and the adjusted coefficient of determination ($\overline{R}_l^2$). All linear and non linear regressions were performed at the 95% confidence level.

Explanatory and Response Variables

The seven explanatory variables used in the regression analyses were selected based on a review of data collected in the Great Miami River Watershed, a literature review, and available data (MCD, 2011), (OEPA, 2012), & (Reutter et. al., 2006). See Table 3 for a brief description of each explanatory variable.

Table 3. Explanatory variables used in the simple and multiple regressions

Explanatory Variable	**Definition**
Q	discharge (cfs) of nearest streamgage at time of sample collection
ABS ΔQ	absolute value of change in discharge at nearest streamgage over the hour prior to sample collection
P_{48hr}	total rainfall (in) measured at nearest upstream rain gage during the 48 hours prior to sample collection
P_{72hr}	total rainfall (in) measured at nearest upstream rain gage during the 72 hours prior to sample collection
P_{48hr} (Dayton)	total rainfall (in) measured at Dayton rain gage during the 48 hours prior to sample collection
P_{72hr} (Dayton	total rainfall (in) measured at Dayton rain gage during the 72 hours prior to sample collection
Turbidity	water column turbidity (fnu) measured at nearest EcoNet station

The variables Q and ABSΔQ are flow variables that reflect stormwater runoff and potential transport of *E. coli*. The variables P_{48hr}, P_{72hr}, P_{48hr} (Dayton), and P_{72hr} (Dayton) are antecedent climatic variables that represent *E. coli* die-off and build-up. The variable Turbidity is a water quality variable that reflects the quality of water in the stream or river.

The response variable used in all regression analyses was the grab sample *E. coli* concentration. Grab sample *E. coli* concentrations at monitoring stations were hypothesized to be significantly correlated with one or more explanatory variables.

Results and Discussion

Summary Statistics

A statistical summary of all sampling results is shown in Table 4. Concentrations of *E. coli* ranged from 4 to 24,200 colonies per 100 mL of water at all sample stations.

Of the river and stream sampling stations the sampling station, GMR01 located on the Great Miami River, had the lowest mean and median *E. coli* concentrations. The sampling station, WC01 located on Wolf Creek, had the highest mean and median concentrations.

Table 4. Summary statistics for *E. coli* concentrations at all sampling stations

Station	**Number of samples**	***E. coli* concentration as most probable number of colony forming units per 100 mL of water**				
		Minimum	**Maximum**	**Mean**	**Median**	**Standard Deviation**
GMR01	36	4	5,200	362	103	873
SR01	36	25	24,200	1,206	98	4,168
MR01	36	12	21,081	586	118	1,635
GMR02	34	25	9,680	701	116	1,728
GMR03	37	25	9,680	807	117	1,871
WC01	38	8	24,200	1,925	282	4,468
GMR04	32	30	9,680	1,176	277	2,140
Outfall #1	8	12	2,510	654	242	854
Outfall #2	8	4	98	36	32	30
Outfall #3	8	44	13,000	3,193	332	5,137

For the stormwater outfall sampling stations, Outfall #2 had the lowest statistical distribution of *E. coli* concentrations; significantly lower than any of the other sampling stations. This is likely due to the fact that Outfall #2 serves as a discharge point for a number of geothermal cooling wells in downtown Dayton. Groundwater pumped by the cooling wells dilutes stormwater runoff that enters the catch basin for Outfall #2. Outfall #3 had the highest statistical distribution of *E. coli* concentrations. Standard deviations were highest for the sample populations collected at

WC01 and Outfall #3. Standard deviations were lowest for the sample populations collected at GMR01 and Outfalls #1 and #2.

Regulatory Compliance and Wet vs. Dry Weather Comparisons

Seasonal geometric mean concentrations of *E. coli* exceeded Class A primary contact recreation standards at all sites with the exceptions of GMR01 and Outfall #2 (see Table 5). The single sample maximum standard was exceeded numerous times at all river and stream sampling stations and two of the three outfalls. *E. coli* concentrations measured in samples collected from Outfall #2 did not exceed the single sample standard during this investigation.

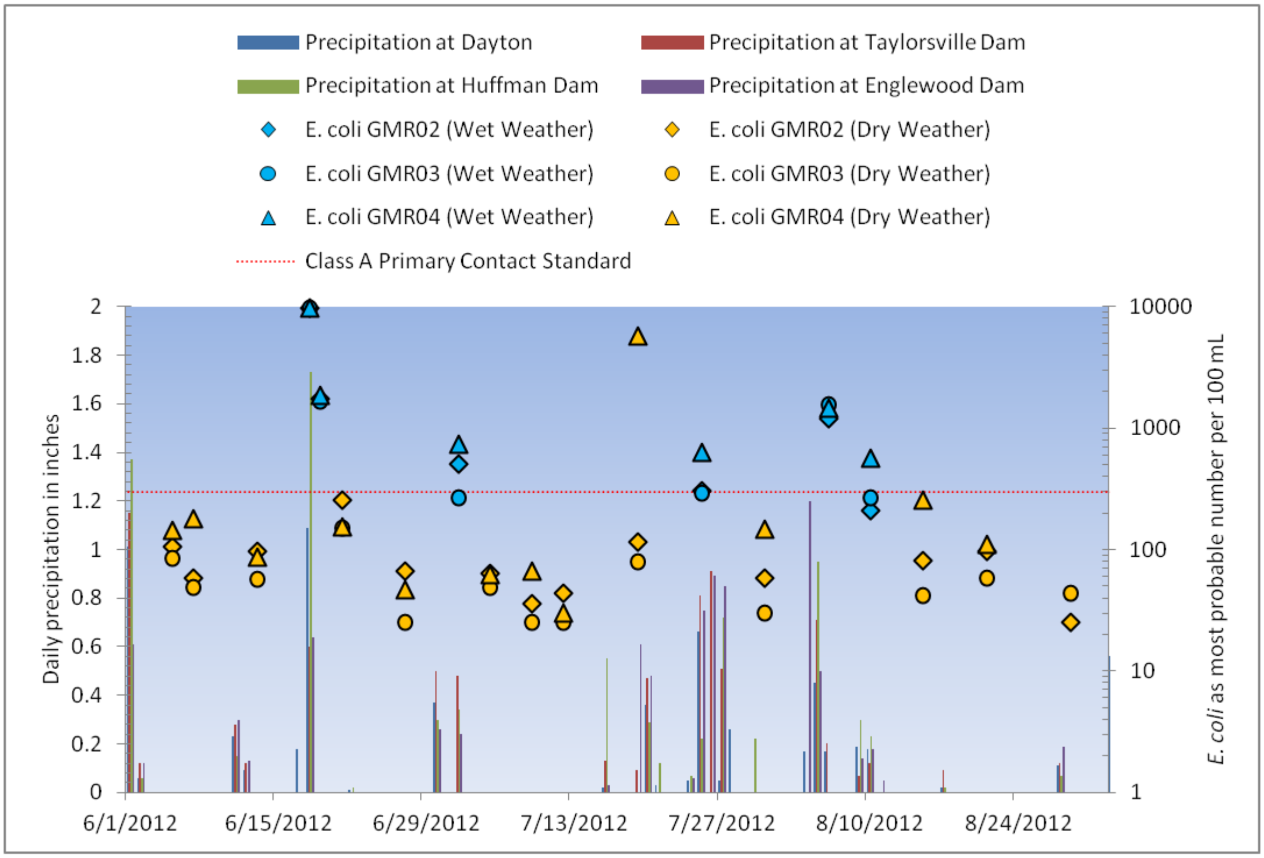
Table 5. Summary of *E. coli* data in relation to regulatory standards

Station	**Number of samples**	**Seasonal geometric mean (May 1 – Oct 31)**	**Number of samples with *E. coli* concentration > 298 colonies per 100 mL**
GMR01	36	103	10
SR01	36	183*	9
MR01	36	153*	11
GMR02	34	211*	13
GMR03	37	189*	11
WC01	38	360*	18
GMR04	32	391*	15
Outfall #1	8	256*	3
Outfall #2	8	25	0
Outfall #3	8	637*	5

*Geometric mean concentrations exceeded regulatory standards

When sample *E. coli* concentrations are plotted with daily precipitation, it's apparent that high *E. coli* concentrations (*E. coli* concentrations > 298 colonies per 100 mL) are often associated with rain events (see Figure 2). In order to examine the strength of this relationship, MCD staff divided all the *E. coli* sample results into two categories; wet weather and dry weather. A wet weather sample was defined as a sample collected when 0.3 inches or more of precipitation was recorded at Dayton or one of the upstream rain gages during the previous 72 hours. A dry weather sample was defined as a sample collected when less than 0.3 inches of precipitation was recorded at Dayton or one of the upstream rain gages during the previous 72 hours. Box and whisker plots of dry weather and wet weather sample concentrations show higher *E. coli* concentration distributions for wet weather samples when compared with dry weather samples (see Figure 3). Median concentrations for wet weather samples exceeded 298 colonies per 100mL at all stream and river sample stations. Sampling stations GMR02, GMR03, WC01, and GMR04 had higher sample distributions of *E. coli* concentrations than upstream sampling stations GMR01, SR01, and MR01. The wet weather results show a statistical increase in *E. coli* concentrations from upstream sampling stations to downstream stations with stations WC01 and GMR04 having the highest concentration distributions of all the stations. Both Median and 75th percentile *E. coli* concentrations for dry weather samples fell below 298 colonies per 100 mL at all sample locations.

Figure 2. Sample *E. coli* concentrations in Great Miami River samples collected in Dayton and daily precipitation at nearby observer stations. Wet weather samples were collected within72 hours of a rainfall event of 0.3 inches or greater. Dry weather samples had less than 0.3 inches of precipitation in the preceding 72 hours before sample collection.



Similar to wet weather sample concentration distributions, the dry weather sample results show a statistical increase in median *E. coli* concentrations from upstream stations to downstream stations. Sampling stations WC01 and GMR04 had the highest dry weather concentration distributions of all the stations.

A probability of exceedance analysis was conducted on all *E. coli* data collected during this investigation. Exceedance probabilities were determined for both wet and dry weather conditions. A comparison of sample exceedance probabilities for wet weather and dry weather *E. coli* concentration illustrates higher wet weather concentrations across all probability levels (see

Figure 4). The wet weather exceedance probability for an E. coli concentration of 298 colonies per 100 mL is 0.67 whereas the dry weather exceedance probability is 0.12. These results show a clear link between precipitation events and elevated *E. coli* concentrations in the Great Miami River and its tributaries in the Dayton area.

Figure 3. Box and whisker plots of wet and dry weather sample *E. coli* concentrations.

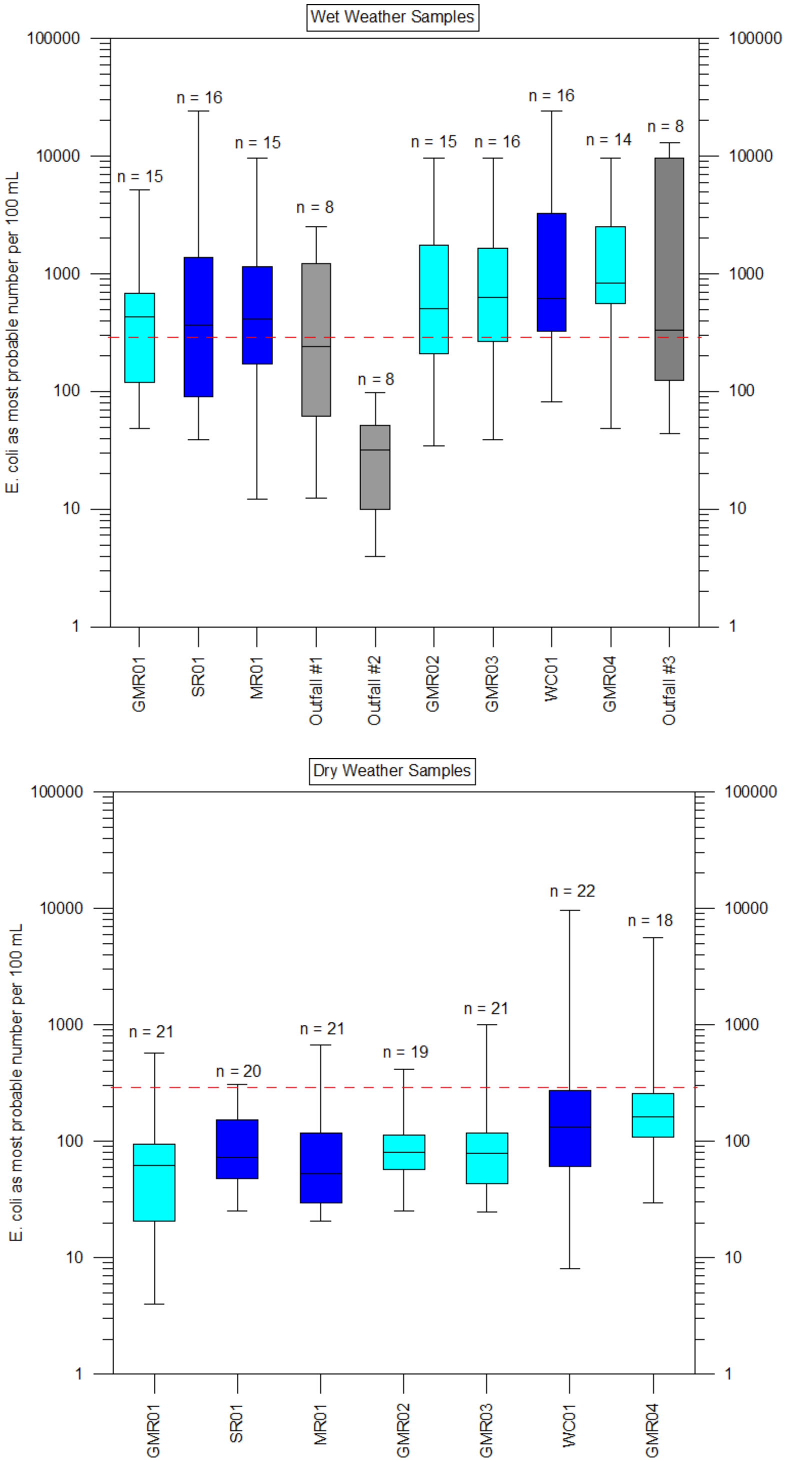
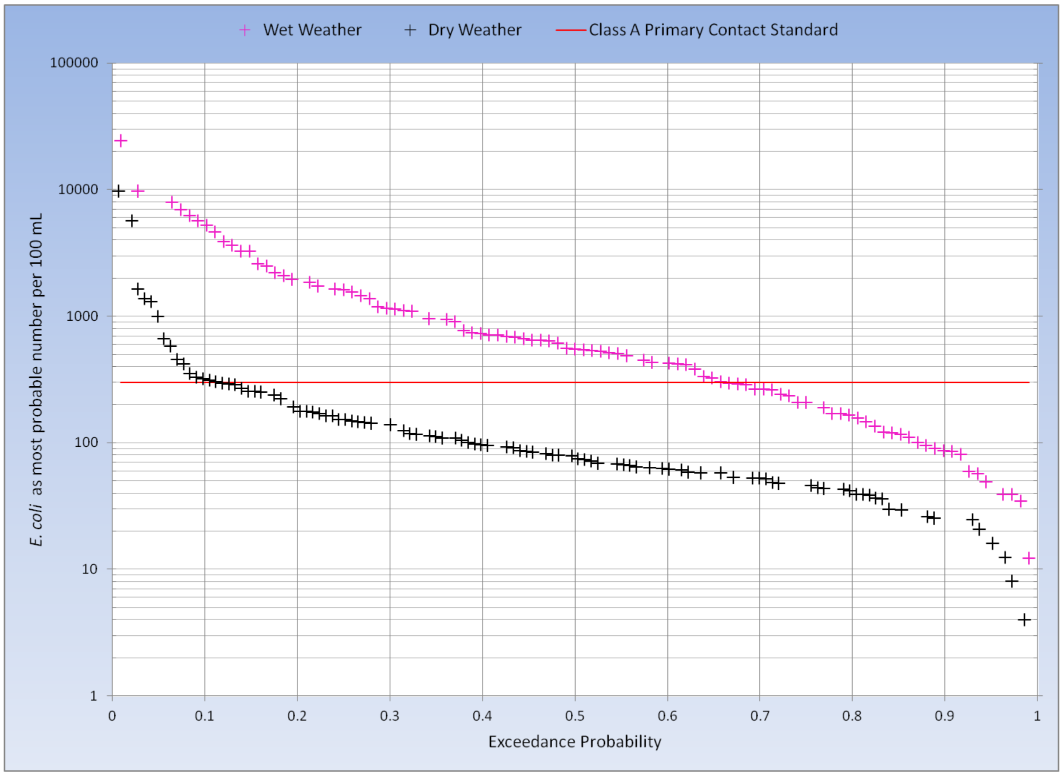


Figure 4. Exceedance probability curves for wet weather and dry weather sample concentrations



Simple Regressions

Table 6 shows coefficient of determination values for simple linear and non-linear regressions between grab sample E. coli concentration and the various explanatory variables. Values greater than or equal to 0.50 are highlighted in bold font to show which explanatory variables could account for more than half of the variance in the response variable *E. coli* concentration. Flow variables proved to have high linear correlations with *E. coli* concentrations at sampling stations GMR01, MR01, and WC01. Antecedent rainfall variables had high non-linear correlations with *E. coli* at sampling stations MR01, GMR02, and GMR03. The water quality variable Turbidity had a strong linear correlation with *E. coli* at sampling station MR01. Overall, antecedent rainfall variables correlated better with *E. coli* concentration than flow or water quality variables for sampling stations in high density developed areas. The flow variable ABSΔQ was the next best variable for explaining *E. coli* concentration variations.

Although significant simple regressions were obtained, very few of the regressions had high levels of explanatory power. Exceptions were the variables ABSΔQ at station MR01 and Turbidity at MR01. One possible explanation is that *E. coli* levels are dependent upon multiple explanatory variables. To explore this dependence multiple regressions are needed.

Table 6. Coefficient of determination values for simple linear and non-linear regressions

Explanatory Variable	SR01		GMR01		MR01		GMR02		GMR03		WC01		GMR04	
	R^2	R_l^2	R^2	R_l^2	R^2	R_l^2	R^2	R_l^2	R^2	R_l^2	R^2	R_l^2	R^2	R_l^2
Q	NA	NA	**0.74** *	0.28	0.26	0.33	NS	0.25	0.33	0.28	NS	NS	0.21	0.21
ABSΔQ	NA	NA	0.30	0.26	**0.92** *	0.39	0.37	0.43	0.31	0.29	**0.54** *	0.25	0.38	0.32
P_{48hr}	NS	0.30	0.40	0.45	0.49	**0.50** *	▨	▨	▨	▨	NS	0.13	▨	▨
P_{72hr}	NS	0.24	0.16	0.36	0.35	**0.53** *	▨	▨	▨	▨	NS	NS	▨	▨
P_{48hr} (Dayton)	NS	0.33	0.25	0.40	0.44	0.47	0.41	**0.58** *	0.46	**0.64** *	NS	0.22	0.43	0.49
P_{72hr} (Dayton)	NS	0.34	0.17	0.44	0.26	**0.51** *	0.31	**0.57** *	0.35	**0.64** *	NS	0.19	0.28	0.45
Turbidity	NA	NA	0.49	0.40	**0.83** *	0.41	NS	NS	0.19	0.19	NA	NA	NS	NS

* These values show the strongest correlations between the explanatory and response variables

NA – not analyzed due to absence of flow or turbidity data

NS – $p > 0.05$

Multiple Regressions

A multiple regression analysis was conducted on the results from the five sampling stations in the Dayton urban core. The results of the simple regression analysis were used to select six explanatory variables for the analysis. Four of the variables reflected antecedent rainfall conditions and two of the variables reflected runoff. Highest correlations were obtained when antecedent rainfall conditions were paired with changes in flow (see Table 7).

The multiple regressions failed to significantly improve linear correlations for sample station MR01, but non-linear correlations improved. Non-linear correlations for sampling stations GMR02 and GMR03 also improved significantly over the simple one variable regression results. Statistically significant multiple regression relationships for sampling stations WC01 and GMR04 did not exist for any combination of explanatory variables used in this investigation.

The highest adjusted coefficients of determination among the sampling stations did not consistently have the same pair of explanatory variables, but there were some similarities among sampling stations. The variables P_{48hr}(Dayton) and P_{72hr}(Dayton) were consistently present in the multiple regressions with the highest adjusted coefficient of determination values. The following regression relationships best describe inter-event variations in *E. coli* levels at three of the sampling stations:

Table 7. Adjusted coefficients of determination ≥ 0.50 and p < 0.05 for multiple linear and non-linear regressions

Variable 1	Variable 2	MR01		GMR02		GMR03		WC01		GMR04	
		$\overline{R}^2$	$\overline{R}_1^2$	$\overline{R}^2$	$\overline{R}_1^2$	$\overline{R}^2$	$\overline{R}_1^2$	$\overline{R}^2$	$\overline{R}_1^2$	$\overline{R}^2$	$\overline{R}_1^2$
P_{48hr}	ABSΔQ	-	-					-	-		
P_{72hr}	ABSΔQ	-	0.57					-	-		
P_{48hr} (Dayton)	ABSΔQ	-	-	-	0.62	0.54	0.70	-	-	-	-
P_{72hr} (Dayton)	ABSΔQ	-	0.58	-	0.62	-	0.71	-	-	-	-
P_{48hr} (Dayton)	Q	-	-	-	-	0.56	0.67	-	-	-	-
P_{72hr} (Dayton)	Q	-	-	-	-	-	0.65	-	-	-	-

"-" – $p > 0.05$, $\overline{R}^2 < 0.50$, or $\overline{R}_1^2 < 0.50$

MR01: (*E. coli*) = 1.78 + 0.01(ABSΔQ) + 0.84((P_{72hr}(Dayton)) ($\overline{R}_1^2 = 0.58$, $p < 0.05$)

GMR02: Log10(*E. coli*) = 1.92 + 0.01(ABSΔQ) + 0.80((P_{72hr}(Dayton)) ($\overline{R}_1^2 = 0.62$, $p < 0.05$)

GMR03: Log10(*E. coli*) = 1.79 + 0.007(ABSΔQ) + 1.12((P_{72hr}(Dayton)) ($\overline{R}_1^2 = 0.71$, $p < 0.05$)

These equations have an average adjusted coefficient of determination ($\overline{R}_1^2$) of 0.64 indicating the variables P_{72hr}(Dayton) and ABSΔQ can explain on average 64% of the variation in inter-event *E. coli* levels.

Overall, the multiple regressions improved explanatory power over the simple regressions at three of the sampling stations. However, the explanatory power for most of the multiple regressions is not extremely high. It is possible that other explanatory variables are needed to adequately capture *E. coli* buildup, wash off, and die off processes. This would allow for better modeling of variations in *E. coli* levels between different events.

Future studies

Other explanatory variables mentioned in the literature showing high levels of correlation with *E. coli* include total evaporation, net radiation, sunshine hours, rainfall intensity, and concentrations of various nitrogen and phosphorus species (McCarthy et. al., 2007). Many of these parameters are difficult to monitor in real-time limiting their usefulness for forecasting purposes. There also may be other anthropogenic factors at play such as variations in upstream municipal wastewater and agricultural runoff *E. coli* loads. The findings of this investigation and future studies could be used to create better predictive models of microorganism concentrations in urban runoff.

Conclusions

The results of this investigation identify influential factors that could explain levels of E. coli in the Great Miami River and its tributaries in the Dayton urban area. Data on variables related to antecedent rainfall, river flow, and river water quality are available from existing water monitoring networks, such as USGS stream gages, YSI EcoNet, NOAA Weather Stations, and could be used for forecasting E. coli levels. In this study, antecedent rainfall and changes in river flow were found to be the most important variables that explain variations in Great Miami River *E. coli* levels in the Dayton urban core. Future studies are needed to better define intra-event variations in E. coli in urban runoff and to explore relationships that may exist with other explanatory variables.

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