Microbial Risk Assessment for Recreational Use of the Malden River

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Submitted to the Department of Civil and Environmental Engineering
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Abstract:

The Malden River is located in the Greater Boston area of Massachusetts. The River has a long history of abuse and neglect stemming from urbanization and industrial activity along the River and in the surrounding areas. Community groups, however, are advocating restoration of the Malden River to a healthy and thriving ecosystem that also provides a viable outdoor recreational area for the local community. There is concern, however, that bacterial concentrations are at levels that can cause excess gastrointestinal illness to recreational users. As part of assessing this issue, I performed a recreational risk assessment based on microbial concentration data from water quality sampling performed by the Mystic River Watershed Association (MyRWA) and the Massachusetts Water Resources Authority (MWRA). A significant difference in the bacterial data from the two organizations, in which samples are taken approximately one mile from each other, was found. This indicated the possibility of significant bacterial variability in the River and, therefore, risk was calculated separately for each data set. The Wiedenmann (2007) dose response model was used to analyze risk; however, not all site-specific parameters were known. Overall risk, risk after significant rainfall, and seasonal risk were all analyzed. Using the Wiedenmann risk model, I determined that after 0.5 inches of rain in 72 hours, exposure associated with primary and secondary recreation causes the incremental risk to double. The overall and seasonal risk analysis showed that the risks associated with the MyRWA sampling location were consistently at least twice that of the MWRA location.

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To my brother Michael- thank you believing in me.

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1. Background

This section describes the geography of the Malden River, including important landmarks and characteristics, followed by an overview of the history of the Malden River. A summary of the watershed's stormwater and sewer systems is also included. The last part of the section provides the current status of the River, including community groups and ongoing studies.

1.1 Introduction

The Malden River, located in the Greater Boston area of Massachusetts, has an extensive history of industrial activity and urbanization along its banks. Centuries of abuse by these activities have reduced the river to a degraded condition, leading to concern about the River's ecological health and its suitability for recreational use. The Malden River is classified as a Class B warm water. and as such, should be suitable for primary and secondary recreation; however, it is currently listed on the Massachusetts '303(d)' list of Impaired Water Bodies (MADEP 2014b). Over the past few decades, the communities surrounding the Malden River have become interested in improving its condition. This thesis presents one portion of a joint effort at the Massachusetts Institute of Technology (MIT) to provide the community with further scientific information about the Malden River. Studies include a hydrological runoff model, an evaluation of stormwater Best Management Practice (BMP) alternatives and an investigation of sediment contamination. This report focuses specifically on providing a better understanding of the microbial risks associated with recreational use of the Malden River.

1.2 Geography of the Malden River

The Malden River is a tributary to the much larger Mystic River which is located within the 76-square-mile Mystic River Watershed. The Malden River Sub-Watershed covers 11 square miles in the towns of Everett, Malden, Medford, Wakefield, Stoneham and Melrose within the Mystic River Watershed (Figure 1-1).

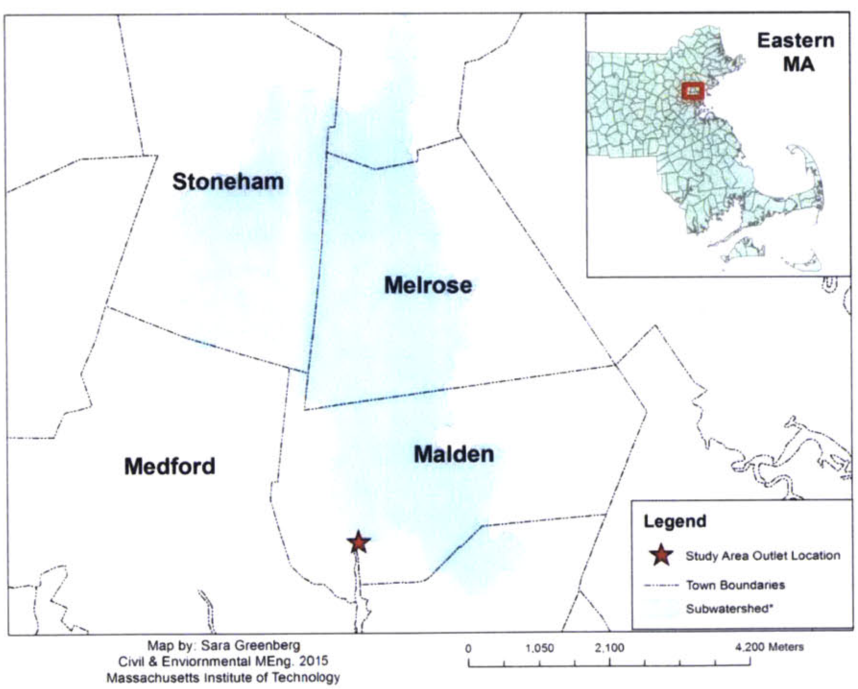


Figure 1-1: Malden river sub-watershed.
Source: (*ArcMap* 10.2.2 2010)

Much of the Malden River flows underground, where it is hidden from view by the urban landscape. The River begins at Spot Pond in the Fells Reservation and flows completely covered beneath the cities of Melrose and Malden. The River re-surfaces from two stormwater culverts, shown circled in red in Figure 1-3, near the center of Malden. From the two culverts, the River flows aboveground for two miles, before discharging into the Mystic River. The Amelia Earhart Dam is located a short distance downstream of where the Malden and Mystic Rivers converge.

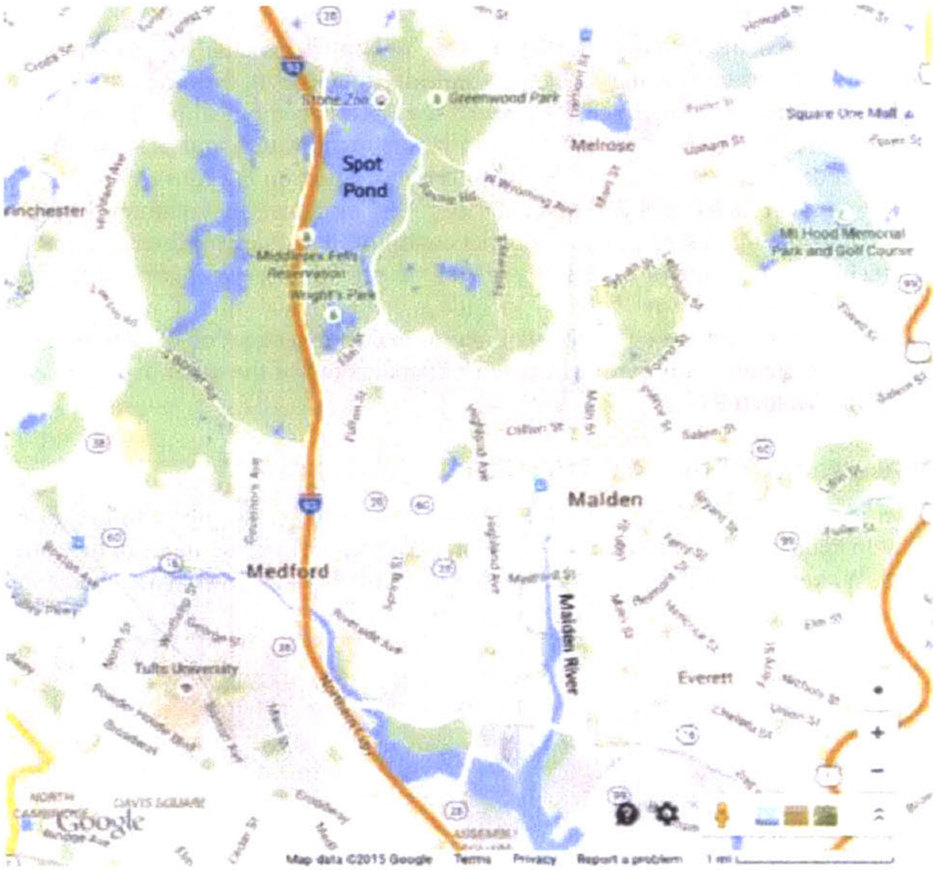


Figure 1-2: Geography surrounding the Malden River.
Source: Google Maps (2015)

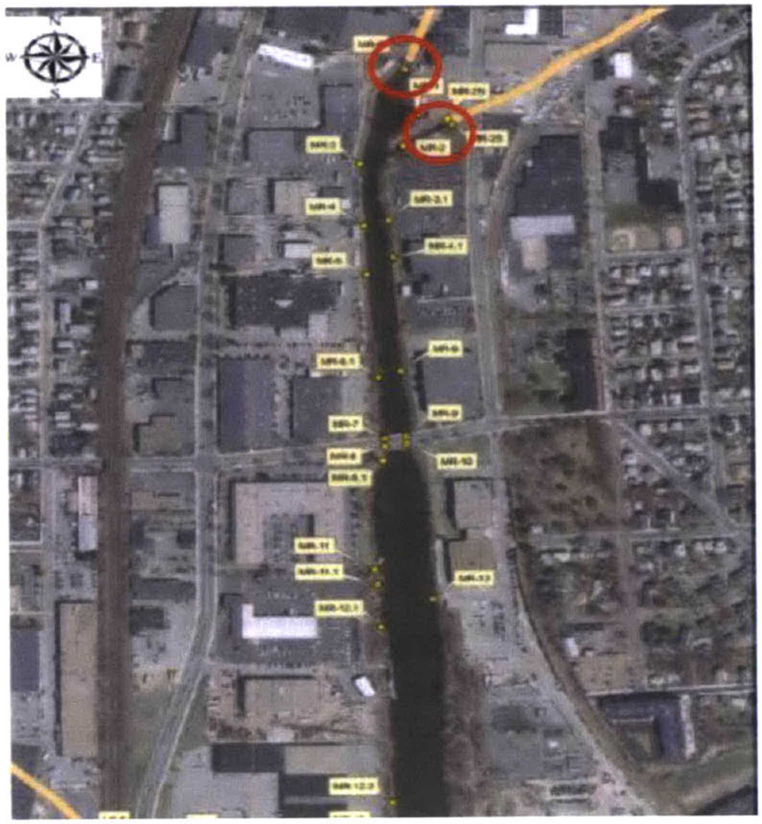


Figure 1-3: Malden River stormwater outfall locations.
Source: (Nangle Associates 2014)

1.3 History of the Malden River

This section describes the impact of human activity on the Malden River beginning with the industrial and urban legacy and how this has contributed to the River's degraded state. The section concludes with the man-made features of the River including both the stormwater and the sewer system.

1.3.1 Industrial and Urban Legacy

The Malden River has a legacy of abuse as a result of industrial activity (U.S. Army Corps of Engineers 2008). During the Industrial Revolution, the River provided an essential means of transportation and waste disposal for chemical, coal gasification, and, manufacturing plants. In order to support these industries, much of the wetlands were dredged and filled to straighten the river channels. Many of these historical activities resulted in the release of oil and hazardous materials (OHM) into the River. These contaminants include fuel by-products, volatile organic compounds, and various metals, which can leach into the groundwater or directly contaminate the River through natural hydrological pathways. Although many of the industrial plants were relocated after World War II, industrial waste and dredged materials remain.

The surrounding towns of Malden, Medford, and Everett have continued to develop since the Industrial Revolution, creating an increasingly urban environment. Urban environments are characterized by large areas of impervious surfaces, such as roadways, buildings, and parking lots, which prevent natural ground infiltration of rainfall. Instead of percolating through the ground, rainfall runs off into the storm drainage system and eventually into the River, which increases the frequency and intensity of flooding in extreme rain events. This increased volume of stormwater runoff can cause a variety of environmental problems, including increased erosion and reduced base flows into the river. These reduced base flows result in low water velocities and poor mixing conditions between storm run-off events, which ultimately contributes to high bacteria concentrations in the Malden River (Herron 2014).

Just downstream from the confluence of the Mystic and Malden Rivers, the Amelia Earhart Dam changes the height of the river and controls the flow and flushing of the Malden River upstream (U.S. Army Corps of Engineers 2008). The Dam, completed in 1966, was intended to provide flood control; however, the water column has become stratified, and stagnant with low dissolved oxygen which ultimately prohibits a healthy, thriving ecosystem. The dam is currently controlled by the Metropolitan District Commission (MDC).

The industrial activity, urbanization of towns surrounding the Malden River, and the construction of the Amelia Earhart Dam all have contributed to the current state of the River. Stormwater and sewage systems also have impacted the natural state of the River and will be discussed in Sections 1.3.2 and 1.3.3, respectively.

1.3.2 Stormwater System

Much of the flow into the Malden River enters from stormwater drainage systems of the towns located along the River. For example, the city of Malden has a series of conduits that connect to form a stormwater drainage system, shown in Figure 1-4.

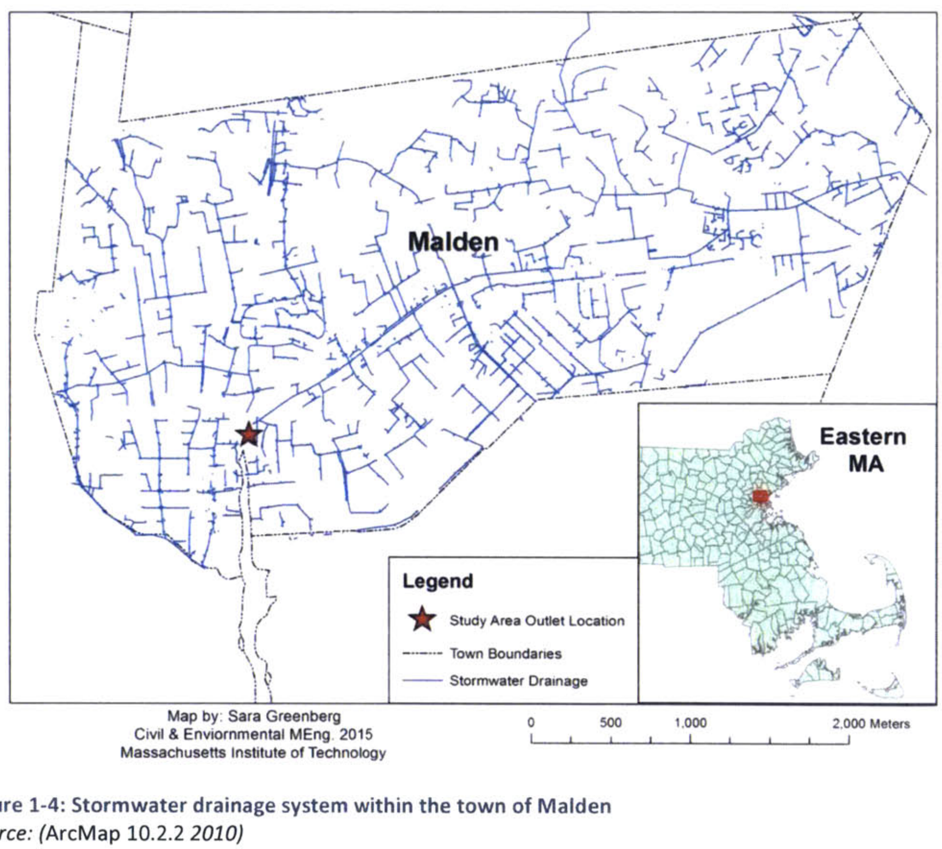


Figure 1-4: Stormwater drainage system within the town of Malden
Source: (ArcMap 10.2.2 *2010)*

1.3.3 Sewer System

Sewer systems in older cities such as Boston, and the surrounding communities, commonly include Combined Sewer Overflows (CSO's), which are a result of combined sewer and stormwater systems. CSO's discharge into rivers when extreme rain events occur because the volume of water exceeds system capacity. The communities surrounding the Malden River have separate storm water and sewage systems; therefore, CSO's are not an issue and are not a potential source of bacterial contamination. The surrounding communities do have, however, sanitary sewer overflow (SSO) occurrences. Under extreme wet weather conditions, groundwater or stormwater can enter the sewer system at vulnerable points (such as blockages and line breaks) and cause sewage to overflow downstream (US EPA 2014). Unlike CSO's, these discharges are unanticipated. SSO's are required to be reported to the Massachusetts Department of Environmental Protection (MA DEP) (Coughlin 2015).

Figure 1-5 and Figure 1-6 show known locations of SSO's in the Malden River watershed. Figure 1-5 is especially pertinent to this report because it shows an SSO at 4+25 along the Malden River right next to the Tufts University boathouse. The only reported occurrence of sewage overflowing and discharging directly into the Malden River, occurred at 1+26 on Figure 1-6 on March 29, 2010. This particular SSO was quantified at over 1 million gallons of raw sewage. The other SSO's denoted on this map discharged into basements or streets (MADEP 2015).

Figure 1-5: SSO map #15 of reported SSO's in the Malden River watershed.
Source: (MWRA 2015).

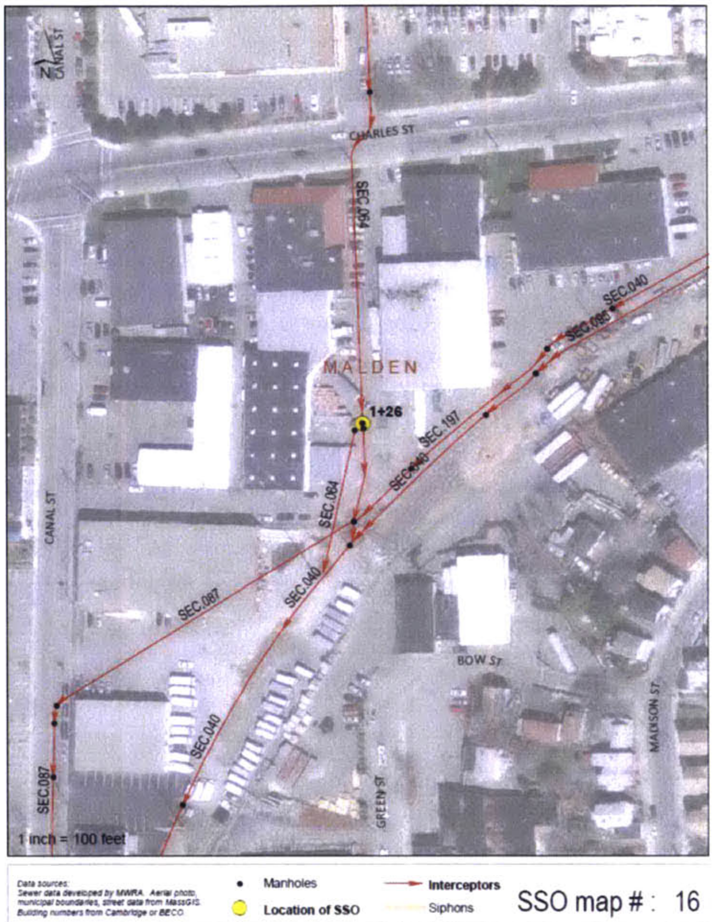


Figure 1-6: SSO map #16 of reported SSO's in the Malden River watershed.
Source: (MWRA 2015).

1.3.4 Malden River Regulatory Framework

The Massachusetts Surface Water Quality Standards (314 CMR 4.00) categorize the Malden River as a Class B warm water. Class B waters are designated as "a habitat for fish, other aquatic life, and wildlife" and for "primary and secondary contact recreation." Class B waters should be "suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses" and should have "consistently good aesthetic value" (MADEP 2014a). The standards that apply to the Malden River, under this framework, are summarized in Table 1-1 below.

Table 1-1: Summary of surface water quality standards for class B warm waters

Parameter	Class B Standard
Dissolved Oxygen	>5.0 mg/l Where natural background conditions are lower, DO shall not be less than natural background conditions. [1]
Temperature	<83°F The rise in temperature due to a discharge shall not exceed 5°F [12]
pH	6.5 – 8.3 No more than 0.5 units outside of the natural background range. [1]
Bacteria	Bathing (non-bathing): E.coli as indicator – geometric mean of five most recent samples taken during the same bathing season (within the most recent six months) shall not exceed 126 colonies per 100 m and no single sample shall exceed 235 colonies per 100 ml Bathing (non-bathing): Enterococci as indicator- geometric mean of five most recent samples taken during the same bathing season (within the most recent six months) shall not exceed 33 colonies per 100 m and no single sample shall exceed 61 colonies per 100 ml
Solids	Shall be free from floating, suspended and settleable solids in concentrations and combinations that would impair any use assigned to this Class, that would cause aesthetically objectionable conditions, or that would impair the benthic biota or degrade the chemical composition of the bottom.
Color and Turbidity	Shall be free from color and turbidity in concentrations or combinations that are aesthetically objectionable or would impair any use assigned to this Class.
Oil and Grease	These waters shall be free from oil, grease and petrochemicals that produce a visible film on the surface of the water, impart an oily taste to the water or an oily or other undesirable taste to the edible portions of aquatic life, coat the banks or bottom of the water course, or are deleterious or become toxic to aquatic life.
Taste and Odor	None in such concentrations or combinations that are aesthetically objectionable, that would impair any use assigned to this Class, or that would cause tainting or undesirable flavors in the edible portions of aquatic life.

[1] Natural seasonal and daily variations that are necessary to protect existing and designated uses shall be maintained.
Source: (MADEP 2014a)

Currently, the Malden River is not in compliance with these surface water quality (MADEP 2013). Section 303(d) of the Clean Water Act requires each state to publish a list of water bodies that do not meet state water quality standards. In compliance with this mandate, the Malden River is included on the Massachusetts' 303(d) list (MADEP 2013). The specific causes of impairment are listed in Table 1-2 below.

Table 1-2: Water quality impairment causes on the Malden River.

Malden River Impairment Causes	
(Debris/Floatables/Trash*)	PCB in Fish Tissue
Chlordane	Phosphorus (Total)
DDT	Secchi disk transparency
Dissolved oxygen saturation	Secchi disk transparency
Escherichia coli	Sediment Bioassays -- Chronic Toxicity
Fecal Coliform	Freshwater
Foam/Flocs/Scum/Oil Slicks	Taste and Odor
High pH	Total Suspended Solids (TSS)
Oxygen, Dissolved	

* TMDL not required (Non-pollutant)
This table is in agreement with the version in the proposed *2014 Integrated List of Waters* report.
Source: (MassDEP, 2013)

After identifying the impaired water bodies, each state is also required to establish priorities for development of Total Maximum Daily Loads (TMDL) that specify "the maximum amount of a pollutant that a water body can receive and still meet water quality standards". Massachusetts's current schedule for TMDL development makes no specific reference to the Malden River (MADEP 2013). However, the Malden River is included under a broader priority to develop watershed wide bacteria TMDLs for Boston Harbor. The proposed *Massachusetts Year 2014 Integrated List of Waters* anticipates that final EPA approval of Boston Harbor bacteria TMDLs will occur in Fiscal Year 2015 (MADEP 2014b).

1.3.5 River Rehabilitation Efforts

In response to the Malden River's degraded water quality, there has been a growing community effort to transform the River into a healthy ecosystem that can provide recreational space to the public. Some key organizations leading this effort include the Mystic River Watershed Association (MyRWA), Friends of the Malden River (FOMR), and the Army Corps of Engineers.

The Mystic River Watershed Association (MyRWA) works to protect the entire Mystic River watershed through advocacy, outreach and education, water quality monitoring, and restoration efforts. MyRWA manages an extensive water quality monitoring program across the Mystic River Watershed, including a sampling site on the Malden River at which samples have been collected since July 2000.

The Friends of the Malden River (FOMR) is a community group that advocates for a healthier ecosystem. FOMR's vision is to one day see the Malden River utilized for recreation and community events.

The Army Corps of Engineers (2008) evaluated several strategies for ecosystem restoration along the Malden River. This report expressed concern about the potential for toxic pollution in sediments in the banks of the Malden. This type of toxic contamination would seriously threaten the local ecosystems and could potentially inhibit recreational use of the river. The report also includes an environmental assessment of the Malden River, an analysis of several restoration activities, and a final recommended plan for ecosystem restoration. The final plan recommends the creation of a wetland habitat through deposition of sand and gravel and the removal of invasive plant species in various sub-areas along the Malden River. These activities aim to reduce the inflow of contaminated sediments, groundwater and urban stormwater runoff, which have all been identified as major sources of water contamination on the Malden (U.S. Army Corps of Engineers 2008).

1.4 MIT Studies

Several MIT studies were conducted to provide the communities surrounding the Malden River with a better understanding of its current state. This report presents a microbial risk assessment of the Malden River. Other studies include a hydrological runoff model, an analysis of potential (BMP's) along the River, and an investigation of sediment conditions. Brief summaries are presented below.

Hydrologic Runoff Model

The hydrology portion of the Malden River watershed was modeled using the Environmental Protection Agency's Stormwater Management Model (SWMM) (Greenberg 2015). The model quantifies volume and flow rates of rainfall runoff as it travels across the watershed, through the drainage system, and into the River.

BMP Analysis

The BMP analysis presents alternatives to manage stormwater runoff along the Malden River (Smith 2015). A feasibility and performance analysis of proposed BMP's is also included.

Investigation of Sediment Contamination

Investigations of the sediment contamination of the Malden River were conducted (Sylman 2015; Khweis 2015; Oehmke 2015). Sediment quality data was used to calculate the potential concentration distributions of various contaminants in the Malden River. The potential for sediment suspension in the water column was also calculated. Further, this information was used to conduct a preliminary risk assessment of the sediment exposure during recreational activities.

1.5 Microbial Risk Assessment for Recreational Use of the Malden River

This report presents a microbial risk assessment conducted to determine the potential health hazards to recreational users of the Malden River. Section 1.6 provides a basic description of the steps involved in a recreational risk assessment. Section 2 includes a literature review of key topics related to conducting a microbial risk assessment. Section 4 presents the risk assessment results, and Section 5 discusses the results of the analysis. Appendices provide supporting information.

1.6 Steps in a Recreational Risk Assessment

The purpose of this recreational risk assessment is to determine human health risk associated with activity on or in the Malden River due to microbial populations. In this case, the recreational risk assessment is a combination of an environmental risk assessment and a quantitative microbial risk assessment (QMRA). An environmental risk assessment is comprised of three steps: site characterization, risk quantification, and risk management and communication(Salhotra 2014). Within the risk quantification step is where the QMRA occurs. The steps of a QMRA are: hazard identification, exposure assessment, dose-response analysis and risk characterization (Haas, Rose, and Gerba 1999). These steps are summarized in Table 1-3.

Table 1-3: A comprehensive guideline of the steps involved in a recreational risk assessment.

Steps of a Recreational Risk Assessment	
Environmental Risk Assessment[1]	
1. Site Characterization	
2. Risk Quantification	
Quantitative Microbial Risk Assessment[2]	2a. Hazard Identification
	2b. Exposure Assessment
	2c. Dose-Response Analysis
	2d. Risk Characterization
3. Risk Management & Communication	

Source: [1]Haas, Rose, and Gerba 1999, [2]Salhotra 2014

1.6.1 Site Characterization

Site characterization involves the collection and analysis of field data which is used later in the assessment process to quantify the risk (US EPA 2015a). Site characterization commonly includes both characterization of environmental media through sampling and chemical analysis and evaluation of the physical and social setting for the site. The appropriate scope for a risk assessment, in terms of the actual or desired activity patterns, is also commonly part of the site characterization.

1.6.2 Risk Quantification

The QMRA step includes the four steps shown in Table 1-3, each of which is discussed below.

1.6.2.1 Hazard Identification

Microbial hazard identification involves identifying specific microorganisms that can cause of human illness (Haas, Rose, and Gerba 1999). QMRA's conducted on recreational waters use concentrations of fecal indicator organisms (FIO's) to identify potential microbial hazards. An indicator organism must be exclusively of fecal origin, occur in greater numbers than associated pathogens, be resistant to environmental stresses, must not proliferate to any great extent in the environment, and detection must be simple and inexpensive. Two bacteria that fit this criteria are *enterococci* and *Escherichia coli* (Sloat and Ziel 1992). High concentrations of FIO suggest the possibility of disease causing pathogens that cause gastro-intestinal illness (GI) in humans (Haas, Rose, and Gerba 1999).

1.6.2.2 Exposure Assessment

The exposure assessment identifies sources of contamination, exposure routes, and potential receptors (Haas, Rose, and Gerba 1999). In a microbial risk assessment, the sources of potential microbial contamination include water, sediment and surficial soil. The exposure routes for a microbial risk assessment focused on water are: dermal contact, inhalation, and ingestion. Potential receptors for this risk assessment include recreational users of the river. A complete exposure pathway is one in which a potential receptor is exposed to bacteria through an exposure route. A complete and detailed exposure model for the Malden River is described in Section 3.3.

An exposure assessment also estimates the number of organisms that correspond to a single exposure, otherwise known as the dose. The dose is found by determining three variables: the pathway of exposure, the concentration of bacteria in the medium, and the amount of medium the user is exposed to. The pathway of exposure is how one would come in contact with the hazard of concern. *Enterococci* and *Escherichia coli*, are the indicators used to indicate pathogens for recreational waters, are transmitted only through ingestion, as shown in Table 1-4; therefore, only ingestion will be considered as an exposure route in this study.

Table 1-4: Transmission pathways for waterborne pathogens.

Ingestion	Inhalation	Contact	Wound Infections
V. cholera	*Legionella* spp.	*P. aeruginosa*	*Aeromonas* spp.
Salmonella spp.	*Mycobacteria* spp.	*Aeromonas* spp.	*Pseudomonas* spp.
E. coli		*Mycobacteria* spp.	*Vibrio vulnificus*
Shigella spp.		*Acanthamoeba* spp.	*Vibrio parahaemolyticus*
Campylobacter spp.		*Naegleria* spp.	
Helicobacter spp.		Schistosoma.	
Enteroviruses			
Noroviruses			
Hepatoviruses			
Rotaviruses			

Source: (Pond 2014)

The concentrations of bacteria in a river vary, so a geometric mean of the concentrations is usually taken as a representative value (Haas, Rose, and Gerba 1999). The amount of exposure per event is found by multiplying the geometric mean bacteria concentrations by the volume of medium ingested. The exposure duration is the length of time a human is exposed to the medium containing the contaminant (Park 2014). Characterizing the ingestion rate of water during recreational activity is complex and will be discussed further in Section 2.2.

1.6.2.3 Dose-Response Analysis

A dose-response analysis is conducted using a dose-response model or equation. The model represents a relationship between the amount of microbial exposure and adverse health effects (Haas, Rose, and Gerba 1999). The first step involves choosing an appropriate dose-response model. The dose-response relationship depends on a variety of epidemiological factors but all models assume that risk increases with increased dose due to increased exposure (Wiedenmann 2007). Section 2.3 presents an analysis of four dose-response models, and selection of the model used in this risk assessment.

1.6.2.4 Risk Characterization

Risk characterization combines the results of the exposure assessment and dose-response analysis to give an estimate of risk (Haas, Rose, and Gerba 1999). In this risk assessment, the risk is stated in terms of the incremental probability of incurring gastrointestinal illness (GI) due to the exposure.

1.6.3 Risk Management and Communication

Risk management is the process of mitigating excess risks and risk communication is the process of communicating the results to the public. Regulatory agencies frequently take the lead for both risk management and communication (Salhotra 2014). A common approach is to set acceptable standards for concentrations of bacteria and restricting access to the water body when those criteria are exceeded (Dixon 2009). The United States currently uses the US EPA's Recreational Water Guidelines, which are discussed further in Section 2.3.1.1.

2. Literature Review

The literature review focuses on several key areas that are needed to evaluate microbial risk including the potential sources of bacterial contamination, the characterization of ingestion rates, and the selection of an appropriate dose-response model.

2.1 Potential Sources of Bacterial Contamination

Although bacteria and pollutants can originate from many possible sources, there are two general routes though which they can enter waterways: point source run-off or non-point source run-off.

2.1.1 Point Sources

According to the EPA (2015), a point source of pollution refers "any discernible, confined and discrete conveyance from which pollutants are or may be discharged." Wastewater treatment plants, combined sewer overflows (CSO's), sanitary sewer overflows (SSO's), and illicit connections (US EPA 2014) are all examples of sewage system components than can discharge raw sewage directly into a waterbody. SSO's on the Malden River were discussed in more detail in Section 1.3.3. Sewage systems can get overwhelmed by heavy rainfall and cause direct fecal input into the waterbody (Shehane *et al.* 2005). In dry weather, these locations are rarely the cause of bacterial contamination.

2.1.2 Non-Point Sources

The EPA (2015) defines non-point source pollution as "pollution generally resulting from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification." Urbanized communities contain impervious surfaces that do not allow infiltration of rainwater and also cause significant increases in rainfall run-off. The run-off can accumulate bacteria and potentially disease causing pathogen populations that can then contaminate waterbodies (US EPA 1983).

A study done on South Shore Beach located on Lake Michigan (McLellan and Salmore 2003) attempted to find the source of high bacteria concentrations because they were causing the beach to be closed. Water samples were collected at sites varying in distance from the shore during both dry and wet conditions. Environmental factors including precipitation, hours from last rainfall, and wind speed were recorded so that they could be tested for significance. All of the water samples were tested for *E. coli* concentrations. One of the major conclusions was that there was a significant increase in bacteria levels at the shoreline after precipitation events.

Another study was conducted on St. John's River in Florida (Shehane *et al.* 2005). Seven sites were tested regularly for water quality, while the team also collected rainfall data. Several analyses were done to determine when and where microbial contamination was the highest, including a seasonal assessment and a spatial assessment. Changes in faecal indicator densities during changing rainfall patterns strongly suggested that precipitation plays a major role in microbial pollution in urban areas.

It is apparent through the review of literature that both point-source and non-point source bacterial contamination occur because of, or are made significantly worse by, precipitation events. Fifty-one percent of disease outbreaks in the United States between 1948 and 1994 followed rain events (Shehane *et al.* 2005). When considering risk of illness by recreational activity on the Malden, therefore, precipitation is considered as a factor that can increase risk. An analysis of microbial concentrations following precipitation events can be found in Section 3.1.3.

2.2 Characterization of Ingestion Rates

The amount of water ingested during recreational activity is an extremely difficult variable to quantify. The EPA's Exposure Factors Handbook (US EPA 2011) provides estimates for primary contact recreation, but does not provide estimates for limited contact recreation. The volume of water ingested through recreational activity is primarily estimated by survey, but there have been attempts to quantify it.

In a microbial risk assessment on the risk of GI among surfers in Oregon (Stone *et al.* 2008), volume of water ingested was quantified using a web based survey. The survey was approved by the Oregon State University's Institutional Review Board for protection of human subjects. Surfers were asked to estimate the amount of water accidentally ingested through the nose or mouth and were given the following options: "a few drops or 1-3 teaspoons," "amount in a shot glass or 1-2 ounces," or "amount in a small juice glass." The majority of surfers reported swallowing 1-2 ounces of water.

Dutch divers were also asked to estimate volume of water ingested through a survey (Schijven and Husman 2006). The survey was designed to be user friendly so that participants could easily estimate the amount ingested. Diver were given the following options: "none," "a few drops (0.5-5mL)," "a shot glass (20-30mL)," "a coffee cup (80-120mL)," or "a soda glass (170-210mL)." Overall, experienced sport divers, not wearing a mask, ingested the most water (approximately 100-250mL), followed by occupational divers (2-10mL), and then sport divers wearing masks (0-5mL).

Dorevitch *et al.* (2011) attempted to actually quantify the amount of water ingested during secondary recreation. Primary and secondary recreational users in the Chicago area were first asked to self-report estimated volumes. For actual quantification, Cyanuric Acid was added to the pool water as a tracer. Participant's urine was then analyzed for concentrations of the tracer. Less than two percent of participants reported swallowing approximately a teaspoon of water. Based on the study using the Cyanuric Acid tracer, less than 0.5 percent of participants swallowed a teaspoon or more.

Dose calculations for this study will be discussed further in Section 3.3.

2.3 Dose-Response Model Analysis

This section first provides the history of the United States recreational water quality guidelines. An analysis of several dose-response models is then presented. The analysis describes the theory and components of the Dufour risk model, the Fleisher risk model, Wymer and Dufour risk model, and the Wiedenmann model.

2.3.1 History of Recreational Water Quality Guidelines

This section summarizes the history and epidemiological studies used to develop the Recreational Water Guidelines in the United States.

2.3.1.1 United States Standards

The perennial question in the history of recreational water quality standards in the United States has been what to use as an indicator of the water's potential for inducing human illness. Historically, diseases of concern that were spread through water included cholera and typhoid fever. Both of these diseases are spread through fecal contamination. Testing for elevated concentrations of bacteria known to be associated with feces would potentially indicate sickness causing pathogens (Cabelli et al. 1983).

The first standards adopted by the US EPA for recreational water quality were put forth by the National Technical Advisory Committee (NTAC) to the Federal Water Pollution Control Administration in 1968. To properly assess location for possible recreational activities, the committee advised that five samples should be collected over a 30-day period, and the log mean fecal coliform concentration not exceed 200 per 100 mL. Another requirement was that no more than 10 percent of the samples taken should exceed 400 per 100 mL. The epidemiological evidence used to produce these guidelines was collected by the United States Public Health Service (USPH) from 1948-1950 (Dufour 1984). These guidelines were criticized by Cabelli (1983), who emphasized the need for recreational water quality guidelines that were supported with epidemiological evidence. Although rejecting the rationale of NTAC's suggested guidelines, Cabelli concurred that fecal coliform concentrations were the appropriate standard to use. Total coliforms were deemed insufficient as indicators because many bacteria belonging to the group are not fecal specific (Cabelli *et al.* 1983).

In 1979, the EPA launched a program with the intention of developing a recreational criteria for marine waters (Cabelli *et al.* 1983). The study was conducted at three locations: Coney Island Rockaways in New York, Levee Fontainebleau in Louisiana, and Revere and Nahant beaches in Massachusetts. Participants were found at these beaches on the weekends and were limited to family groups so as to limit exposure to one or two days. Water samples were collected during periods of maximum swimming activity and tested for concentrations of total coliforms. The concentrations were quantified using the most probable number procedure. Follow-up interviews were conducted by phone 8-10 days after the exposure to the marine waters. Participants were asked if they had experienced any GI symptoms. The swimming-associated GI symptoms per 1000 participants were plotted against indicator densities and analyzed using regression analysis. It was determined that of all the coliforms the samples were analyzed for, the fecal coliforms *enterococci* and *E. coli* had the strongest correlation to GI symptoms (Cabelli *et al.* 1983).

To determine freshwater recreational standards, Dufour (1984) used the same methodology as in the marine study (Cabelli *et al.* 1983). Dufour conducted his study at two locations: Keystone Lake near Tulsa and Oklahoma and Lake Erie near Erie, Pennsylvania. The only change between Cabelli (1983) and Dufour's (1984) study was how the follow-up interviews were conducted. In the initial interview, demographic information was collected from the participants as well as how long they swam, how many times they immersed their head and face, and finally, if they had had any GI symptoms in the previous week. Both *enterococci* and *E. coli* were used to assess water quality in this study. In the marine (Cabelli *et al.* 1983) study, only the correlation coefficient was used to assess "strength of association." In this study, the slope of the regression equation, the standard error and the correlation coefficient were all used to classify the "strength of association." It was determined that *E. coli* had the strongest relationship to swimming related GI.

Using both epidemiological studies, Dufour (1984) was able to develop recreational water criteria, as well as a model that relates recreational activity, illness and water quality. Dufour suggested the criteria shown in Table 2-1. The Dufour (1984) model will be discussed further in Section 2.3.2.Dufour Model

Table 2-1: Current EPA recreational water quality standards.

	Steady State Geometric Mean Indicator Density (Enterococci/100mL)	Single-Sample Maximum Allowable Density (Enterococi/100mL)			
		Designated Beach Area (upper 75% C.L.)	Moderate Full-Body-Contact Recreation (Upper 90% C.L.)	Lightly Used Full-Body-Contact Recreation (upper 90% C.L.)	Infrequently Used Full-Body-Contact Recreation (upper 95% C.L.)
Enterococci	33	61	78	107	151
E. Coli	126	235	298	409	575

Source:(Dufour 1984; US EPA 1986)

In 1986, the U.S. EPA (1986) adopted the criteria of water quality standards in found in Table 2-1.The EPA derived these criteria using an acceptable incremental risk of GI sickness was 0.8 percent. They used Dufour's (1984) equations to solve for the FIO concentration at which the incremental probability of GI was 0.8 percent. In addition to the FIO density guidelines, the EPA also recommended testing the recreational water of interest based on its intended frequency of usage. In peak season, the water should be tested weekly. During non-peak season, it is sufficient to test bi-weekly or monthly. Testing should also be done during dry weather to evaluate such conditions. These criteria are still in use today. These guidelines are, however, only relevant to full contact recreation (swimming). Many states use the "Moderate Full-Body-Contact Recreation" seen in Table 2-1 as the standard for secondary recreation that includes boating, fishing and wading. The "Designated Beach Area Single-Sample Maximum" is commonly used as the primary recreational standard (Dixon 2009).

2.3.2 Dufour Model

In both the marine (Cabelli et al. 1983) and freshwater (Dufour 1984) studies, participants were separated into two categories: those with highly credible GI (HCGI) symptoms, and those with total GI symptomatic illness. Both Dufour and Cabelli defined HGCI as any one of the following: vomiting, diarrhea with a fever requiring the individual to stay at home or refrain from usual activity or a stomach ache or nausea along with a fever. Dufour (1984) only used the data from the participants that claimed to have HGCI symptoms because the credibility of the data was better; however, the correlation between the indicators and the HCGI symptoms was less than the correlation between total GI symptoms and indicators.

Dufour (1984) plotted the concentrations of *Enterococci/E. Coli* versus the number of swimming-associated HCGI per 1000 swimmers, and used using log-linear regression to derive the relationships given below in Eq. 1 and 2.

$$P_i = -11.74 + 9.397(logC_{E.Coli}) \quad (1)$$

$$P_i = -6.28 + 9.40(\log C_{Enterococci}) \quad (2)$$

Where P_i = probability of GI

$C_{E.coli}$ = concentration of *E. coli.*

$C_{enterococci}$ = concentration of *enterococci*

Although Dufour's equations were the first to relate FIO with the probability of GI, they were criticized and deemed insufficient by others (Fleisher 1991; Wymer and Dufour 2002).

2.3.3 Fleisher Risk Model

In Fleisher's (1991) analysis of Dufour's dose-response models, he first criticized the methodology of Cabelli's (1983) epidemiological study from which the equations were derived. The main criticism was that the three study sites used in Cabelli's study were pooled as one when deriving the equations. The sites in Boston and New York are both marine waters, while Lake Pontchartrain is brackish. This is problematic because fecal indicator survival and salinity has an inverse relationship (Gerba et al. 1979). This also holds true for pathogenic organisms. Fleisher (1991) also claimed that because immunities among swimmers and pathogen composition varies with location, all three should not have been analyzed as one.

Fleisher (1991) agreed that the R^2 values, found by Cabelli, for the HCGI symptoms and total GI symptoms provided a reasonably good fit, 0.56 and 0.67 respectively. The HCGI symptoms were expected to be more credible, but never the less produced a less reliable R^2 value. Fleisher reevaluated the data from Cabelli's (1983) study and attempted to reproduce Dufour's analysis. Fleisher discovered that Dufour neglected three data points in the regression analysis for HCGI. Two were dropped by Dufour because the trials had no reported GI symptoms among non-swimmers and the third because it had an unusually low non-swimmer rate. Fleisher included these points in his analysis, and an R^2 value of 0.16 was determined for HCGI symptoms, which is not a good fit (Fleisher 1991).

Fleisher (1991) deduced the logistic regression relationship shown in Eq. 3.

$$P = \frac{1}{1+e^{-\alpha-\beta x}} \tag{3}$$

Where P = total probability of GI illness
x = $\log_{10}$(FIO density)
α,β = These terms are fitting parameters that shape the risk curve. They can be determined by fitting the risk curve to a specific site's data from an epidemiological study.

Fleisher (1991) separated the data from the three locations, but did not account for non-swimmer risk. Using the data from one of the three locations and plotting it, risk could be assessed for that specific site by fitting Eq. 3 to the data points. Fleisher concluded that the risk varied so greatly between the three locations, that the Dufour risk models and the standards set by the EPA for recreational water use were not sufficient or accurate (Fleisher 1991).

2.3.4 Wymer & Dufour Risk Model 2002

Wymer and Dufour (2002) reanalyzed the original equations derived by Dufour (Eq. 1, 2). Unlike Dufour (1984), they did account for non-swimmer risk.

$$\ln\left\{\frac{P(1-P)}{P_0/(1-P_0)}\right\} = \alpha + \beta x \tag{4}$$

Where P = total probability of GI
P_0 = non-swimmer risk of GI
x = $\log_{10}$(FIO density)
α,β = These are terms that shape risk curve. They can be determined by fitting the risk curve to a specific site's data from the epidemiological study.

The left side of Eq. 4 represents the odds ratio of contracting GI between a swimmer and a non-swimmer. In waters with low risk, the odds ratio of getting sick is almost equal between swimmers and non-swimmers.

Wymer and Dufour considered their model an improvement over the Dufour's (1984) original equations because it included the non-swimmer's risk of GI. Wymer and Dufour (2002) concluded that the background illness rates were the biggest variations between locations in the marine study and probably accounted for most of the discrepancy in the results.

2.3.5 Wiedenmann Model

Wiedenmann (2006) conducted an epidemiological study at a freshwater bathing site in Germany that was performed in an effort to provide an improved scientific basis for recreational water quality standards. Participants were recruited from the local population and randomly divided into bathers and non-bathers. Wiedenmann's study was the first to be both controlled and randomized. Those in the bathing category were required to submerge their head at least three times and were exposed to the water for 10 minutes. Water samples were collected from the site for microbiological analysis every twenty minutes. Wiedenmann developed no-observed-adverse-effect-levels (NOAEL's), which he defined as "the concentration of fecal indicator organisms below which the illness rates for recreational users is not significantly different than those of non-users." Wiedenmann suggested that "standards should be based on rates of compliance with NOAEL's rather than on attributable risks determined above NOAEL's, because the risks depend mainly on the unpredictable susceptibility of the cohorts." An attributable risk is the difference between the exposed population and the unexposed population. The NOAEL's developed by Wiedenmann, based on swimmer ingestion rates of 30 mL and are summarized in Table 2-2.

Table 2-2: NOAEL values from Wiedenmann's epidemiological study.

	Wiedenmann (2006) NOAEL's (FIO/100mL)
E. coli	100
Enterococci	25

Wiedenmann (2007) derived a statistical model based primarily on his epidemiological study to relate exposure risks to concentrations of indicator bacteria. This model incorporated more variables into the calculated risk than the three others discussed in Sections 2.3.2-2.3.4. This is the first model presented that considers the concentration of fecal indicators in the water as well as the volume of water ingested (Wiedenmann 2007) . The general equation for the Wiedenmann dose-response model is shown in Eq. 5.

$$Risk = (AR) * \{1 - [1 - p(1)]^z\} \quad (5)$$

Where $p(1)$ = The estimated risk of GI from ingesting a single pathogen organism
Z = Actual number of pathogen organisms ingested

The first part of the equation represents attributable risk (AR), which is the GI risk that is potentially directly associated with exposure to pathogens in the water.

$$AR = (MR - BR) \quad (6)$$

Where MR = the maximum rate of disease in the population if everyone was exposed.
For GI illness, MR = 0.1.
BR = the base rate (rate that the illness occurs naturally in the population)
For GI illness, the BR is 0.01-0.03.

Both the maximum rate and the base rate can vary between locations based on population susceptibility and immunities as well as pathogen variability (Wiedenmann 2007).

Single pathogen risk, or $p(1)$ in Eq. 5 is the risk of getting sick from ingesting a single pathogen. Water related diseases that can cause GI illness can be related to several types of pathogens. This term expresses the average single pathogen infectivity. The risk of infection from ingesting a quantity of z pathogens is defined as $p(z)$. The probability of not getting sick is calculated using Eq. 7.

$$Probability\ of\ Not\ Getting\ Sick = [1 - p(z)] \qquad (7)$$

According to Wiedenmann (2007), Eq. 7 can be transformed into Eq. 8.

$$Probability\ of\ Not\ Getting\ Sick = [1 - p(1)]^z \qquad (8)$$

Finally, setting Eq. 7 and 8 equal to each other, Eq. 9 is derived, which is the risk of getting sick from z pathogens, $p(z)$.

$$p(z) = \{1 - [1 - p(1)]^z\} \qquad (9)$$

Several parameters must be known in order to quantify z, shown in Eq. 10.

$$z = V_{in\_100mL} * x_{FIO/100mL} * PIR \qquad (10)$$

Where V_{in_100mL} = the number of 100 mL volumes of water ingested during the exposure event
PIR = Pathogen-Indicator Ratio, or the number of pathogenic organisms divided by the number of FIO
$X_{FIO/100mL}$= the number of FIO per 100 mL

The volume ingested must be expressed in 100 mL units so that it can be multiplied by the concentration of FIO, which is expressed as per 100 mL.
According to Wiedenmann (2007), it is difficult to quantify the PIR because of varying decay rates, disruption of aggregates and sedimentation. Eq. 11 relates FIO concentrations to pathogenic organism concentrations. This equation was derived through experimental observation (Wiedenmann 2007).

$$log_{10}\left(x\frac{PO}{100mL}\right) = a + b * log_{10}\left(x\frac{FIO}{100mL}\right) \qquad (11)$$

Eq. 11 is equivalent to Eq. 12.

$$\left(x\frac{PO}{100mL}\right) = 10^{a+b*\,log_{10}\left(\frac{FIO}{100mL}\right)} \qquad (12)$$

$PIR = \frac{\left(\frac{PO}{100mL}\right)}{\left(\frac{FIO}{100mL}\right)}$ and therefore is can now be substituted into Eq. 10, producing Eq. 13.

$$z = V_{in\_100mL} * x_{FIO/100mL} * \frac{\left(x\frac{PO}{100mL}\right)}{\left(x\frac{FIO}{100mL}\right)} \qquad (13)$$

Eq. 12 is then substituted into Eq. 13, which produces the final equation for the number of pathogens, z.

$$z = V_{in\_100mL} * 10^{a+b*\log_{10}\left(\frac{x_{FIO}}{100mL}\right)} \qquad (14)$$

Where a,b = site specific parameters indicating pathogenic presence
$C_{FIO/100mL}$= concentration of FIO (FIO/100mL)

Although variables *a* and *b* are supposed to be site specific parameters, most of the time the specific kinds of pathogens are in the water of interest are not known. This feature of the model can be very useful in customizing it to fit a specific location, but this data is difficult to collect and not very often available. Since these are not available, the default values were used in this model and are discussed further in Section 3.1.

In this study, a variety of exposure scenarios are evaluated with varying ingestion rates; therefore, through this analysis, it is clear that the Wiedenmann (2007) model is superior to the original Dufour (1984) model, the Fleisher (1991) risk model, and the Wymer and Dufour (2002) model. The Wiedenmann model will be used in this risk analysis and more specific information on the parameters used in this study can be found in Section 3.4.

3. Risk Analysis

This section follows the outline of a recreational risk assessment described in Section 1.6.

3.1 Site Characterization

As discussed in Section 1.6.1, site characterization involves the compilation of field data necessary to perform the risk assessment. In this study, the MWRA and MyRWA had databases of water quality sampling done on the Malden River. Data collection methods used by both organizations are discussed further in section 3.1.1. In this step, the field data are also analyzed. In this study, the two data sources were compared (Section 3.1.2), and also analyzed for the effect of precipitation on bacterial concentrations in the river.

3.1.1 Data Compilation

Bacterial data and rainfall data were compiled into a master spreadsheet, shown in Appendix D. The bacterial data came from the water quality sampling conducted regularly by MyRWA and the MWRA on the Malden River. Rainfall data was collected from the National Oceanic and Atmospheric Association.

MyRWA collects water quality data monthly from the shores of the Malden River just adjacent to the Medford Street Bridge (Adams and Larsen 2015). The location is labeled "MyRWA Testing Site" in Figure 3-1 below. While still at the testing site, the volunteers from MyRWA test the samples for temperature and turbidity. The water samples are then driven to MWRA's lab and tested by professionals for pH, dissolved oxygen, percent saturation, fecal coliform, specific conductance and *E. coli* concentrations. The *E. coli* concentrations are found using IDEXX Colilert kits (Herron 2014).

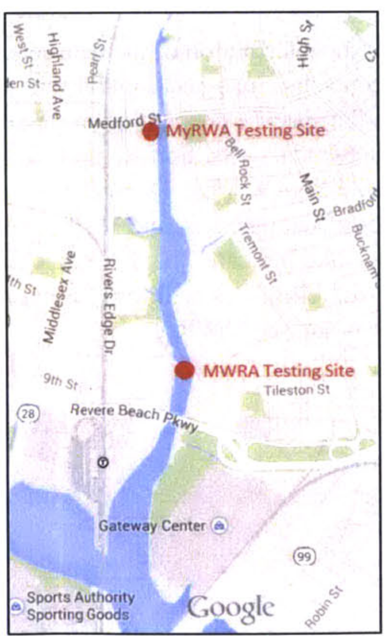


Figure 3-1: Testing sites used by the MWRA and MyRWA on the Malden River

The MWRA also collects water quality data monthly, but they do so from a boat in the center of the channel, downstream, towards the mouth of the Malden (Ducott 2015), as seen in Figure 3-1. They test for the same parameters as MyRWA; however, in addition to *E. coli*, they also quantify concentrations of *enterococci* which are quantified using Enterolert kits (Herron 2014).

NOAA collects hourly rainfall data at Logan Airport in Boston Massachusetts which was the closest location to the study site (NOAA 2014). Precipitation from the 24, 48, and 72 hours preceding the date of sample collection done by MyRWA and the MWRA was researched in the NOAA database and added to the master spreadsheet.

3.1.2 MyWRA-MWRA Data Comparison

The master spreadsheet compiled in this study contains more than 13 years of water quality data collected by MyRWA and the MWRA. In order to summarize all the data and give an idea of the distribution of the concentrations, a table of summary statistics has been provided in Table 3-1.

Table 3-1: Summary statistics of Malden River bacteria sampling.

Summary Statistics of Observations in River Water 2000-2014									
Source	Fecal Indicator	Mean	St. Dev	Minimum	25%tile	Median	Geometric Mean	75%tile	Maximum
MyRWA	Ecoli (FIO/100mL)	1598	9814	5	103	442	412	1598	71,000
MWRA	Ecoli (FIO/100mL)	260	2242	5	20	63	150	260	24,200
MWRA	Enterococci (FIO/100 mL)	295	1068	5	10	10	27	50	9,000

From the summary statistics, it apparent that on average MyRWA's *E. coli* data is significantly higher that the MWRA's and MyRWA's data set has a greater range. Because *Enterococci* is only collected by the MWRA (Section 3.3.2), *E. coli* will be used in all analyses to allow comparison between data sets. All *Enterococci* analyses can be found in the Appendix.

In order to get a better visualization of the distribution of the data sets, Figure 3-2 was created. The values on the horizontal axis are the *E. coli* concentrations on a logarithmic scale. The vertical axis gives the percent of concentrations greater than the specific concentration. Figure 3-2 indicates that the distribution is indeed significantly different for the two data sets. For example, at 100 FIO/100mL, MWRA has 40 percent of its data greater than that while MyRWA has 75 percent of its data greater. At 1000 FIO/100mL, MWRA has 13 percent of its data greater, and MyRWA has 35 percent greater. Figure 3-2 highlights the difference in distribution, and indicates that MyRWA's sampling location regularly has higher bacterial concentrations. This possibility was analyzed further by filtering the data set for samples taken on the same day by both MyRWA and the MWRA.

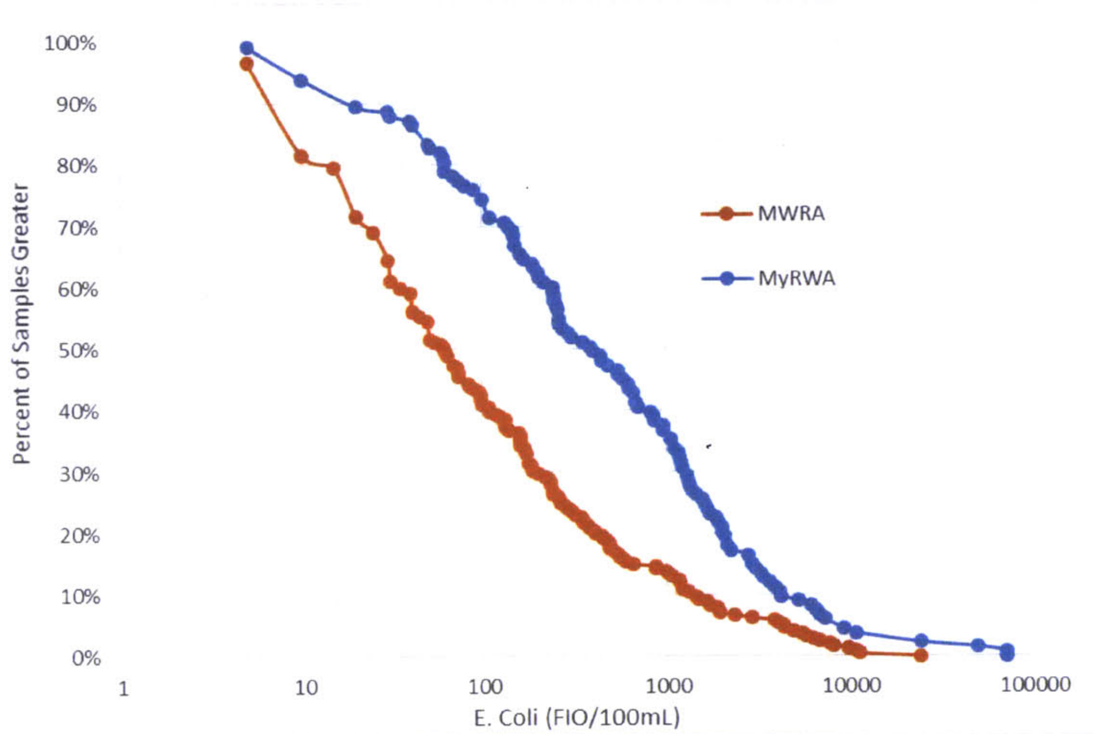


Figure 3-2: Frequency diagram of *E. coli* concentrations.

On ten days during 2002 to 2011, both the MWRA and MyRWA collected water quality samples on the same day. A comparison of the *E. coli* concentrations collected on these dates is shown in Figure 3-3.

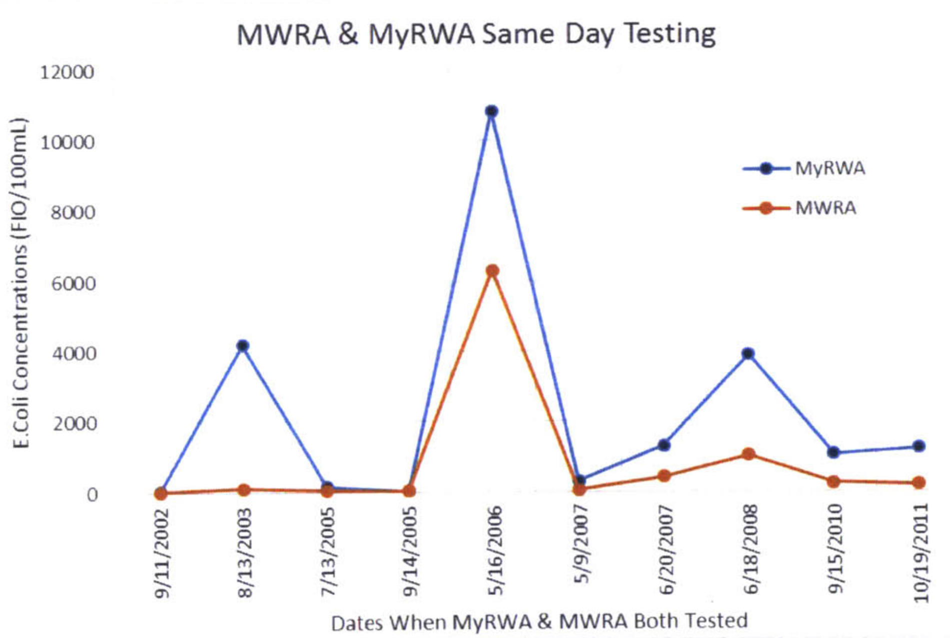


Figure 3-3: Difference in same day concentrations of *E.Coli* for MyRWA and MWRA.

Four out of the ten sampling dates have similar *E. coli* concentrations, with all of them being very close to the minimum of 5 FIO/100 mL. The remaining sample concentrations, all above 0 FIO/100 mL, do not seem to correlate well, with MyRWA always having significantly higher sample concentrations of *E. coli*.

After analyzing *E. coli* concentrations for same day testing, monthly and yearly variations of concentrations were then investigated. Figure 3-4 depicts monthly means of *E. coli*, excluding the winter months. The graph shows an upward trending pattern, with a spike in the fall months. MyRWA's mean concentration during some months are more than an order of magnitude greater than the MWRA mean concentration.

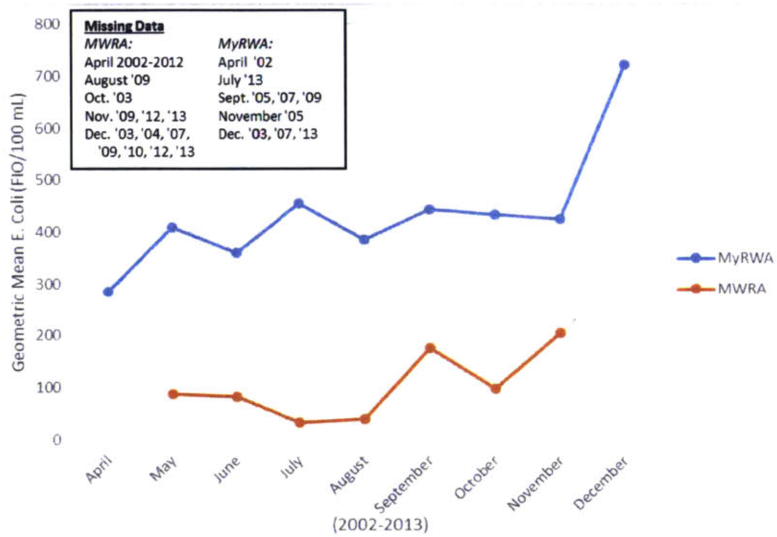


Figure 3-4: Monthly variations of *E.coli* geometric means, 2002-2013.

Figure 3-5 depicts annual geometric mean concentrations from 2002 to 2013. MyRWA's data points are again higher than the MWRA's, and both are generally trending upward.

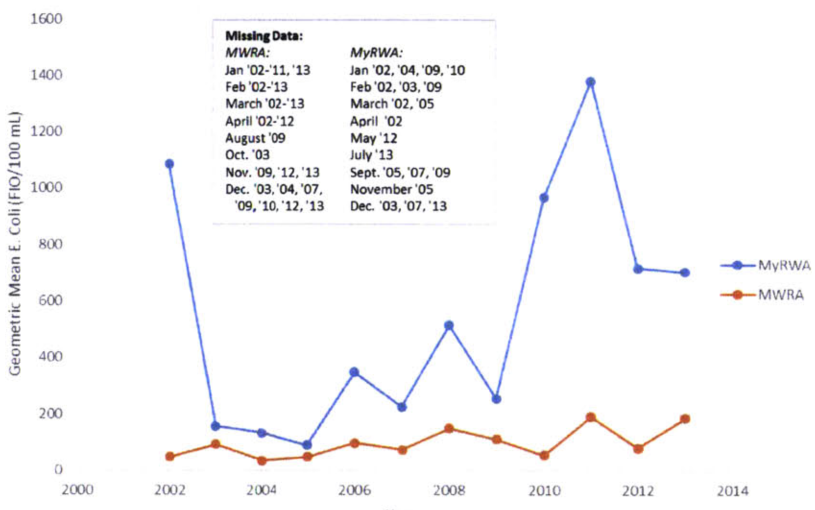


Figure 3-5: Annual variations in *E.coli* geometric mean, years 2002-2014.

3.1.3 Rainfall/Bacterial Concentration Evaluation

Section 2.1 described potential sources of bacterial contamination and how rainfall can mobilize and increase the concentrations of bacteria in waterbodies. This section analyzes bacterial concentrations in the Malden River after significant rainfall.

Figure 3-6 gives a visual summary of the relationship between significant rainfall, of greater than 0.5 inches, and elevated bacteria for the MyRWA and MWRA data sets. The first set of columns show the geometric mean of *E. coli* when there is rain only in the 24 hours prior to sampling, and no rainfall in the 24-72 hours preceding that. The second set of columns show the geometric mean of *E. coli* when there is precipitation in the 24-48 hours prior to sampling, and no rainfall in the 0-24 and 48-72 hours. The third set of columns show the geometric mean of *E. coli* when there is rain during the 48-72 hours prior to sampling, and no rainfall in the 0-48 hours before testing. The mean *E. coli* concentrations are highest when rain falls within 24 hours, then within 48-72 hours and the lowest being between 24-48 hours. These results indicate that when rain falls in the Malden River watershed, the run-off reaches the River quickly, accumulating bacterial contaminants along the way. When there is enough time between rainfall and testing, the bacteria concentrations decrease.

The last two sets of columns show the bacterial concentrations when there is precipitation anytime in the 72 hours prior to sampling and when there was absolutely no precipitation in the 72 hours prior to sampling. The lowest geometric mean of bacteria concentrations is when there is no rain in the 72 hours prior to sampling, demonstrating that rainfall does increase bacteria concentrations in the River.

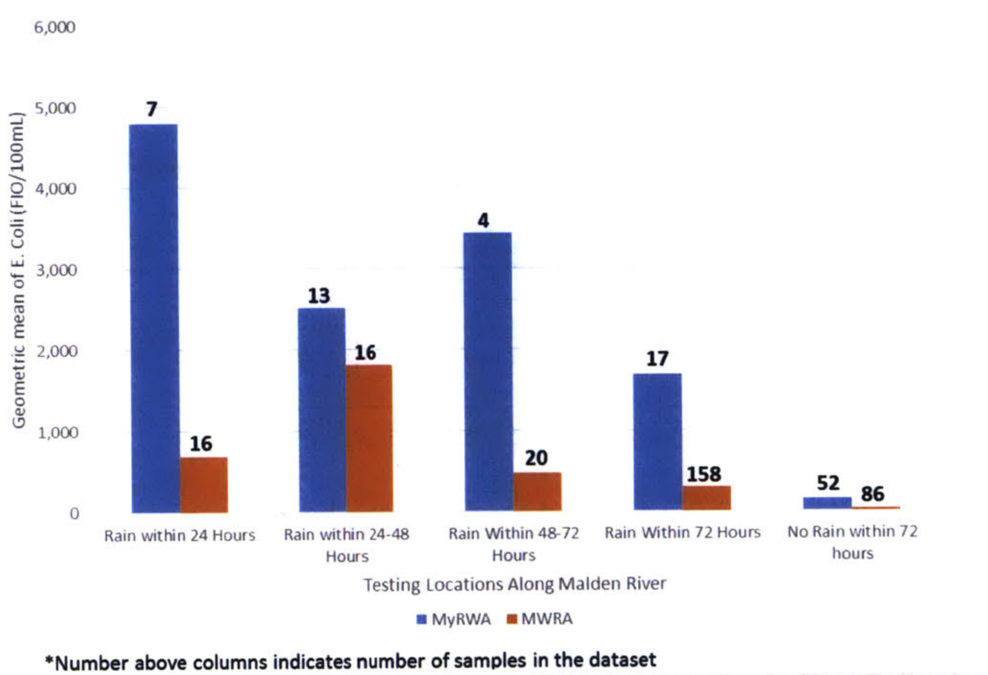


Figure 3-6: Geometric mean of *E. coli* concentrations compared with rainfall preceding sampling.
Note: All *E. coli* concentrations taken after precipitation of greater than 0.5 inches was included in the analysis.

In addition to the information about bacteria concentrations after rainfall, it is also important to again point out the differences in the concentrations of *E. coli.* MyRWA's geometric mean concentrations, shown in Figure 3-6, are all greater than that of the MWRA.

Due to the significant difference in concentration between the MyRWA and MWRA data sets, instead of combining these data sets into an integrated representation of FIO concentrations, I chose to perform two parallel sets of calculations, one for each of the data sets. At this time I have not determined the reasons for the substantial difference between the two data sets and suggest in Section 4.3 that additional data on bacterial concentrations may be useful.

3.2 Hazard Identification

As described in Section 1.6.2.1, concentrations of FIO's are used to identify potential pathogenic hazards in recreational risk assessments. High concentrations of FIO suggest the possibility of disease causing pathogens that cause gastro-intestinal illness (GI) in humans (Haas, Rose, and Gerba 1999). The bacteria that fit this criteria, and that are used in this study are *enterococci* and *Escherichia coli* (Sloat and Ziel 1992).

3.3 Exposure Characterization

As described in Section 1.6.2.2, the exposure routes of *E.coli* and *enterococci* are through ingestion, thus, it will be the only route of exposure considered in this study. The volumes of water ingested while participating in recreation, are shown below in Table 3-2. For this study, both primary contact (swimming) and secondary contact (boating and rowing) recreation are considered. Secondary recreational users have less direct contact with the water and therefore typically have less exposure. I assumed an exposure event in boating or rowing to be a practice or a race, and an exposure duration for swimming to be approximately 45 minutes in the water (US EPA 2011).

Table 3-2: Dose (mL) per event for primary and secondary contact recreation and volume of water ingested as they are put into the Wiedenmann (2007) risk equation.

Recreational Activity		V_{in} (mL)	V_{in_100mL}
Full Contact			
Swimming	Adult[1]	16	0.160
	Child[1]	37	0.370
Limited Contact			
Boating/Rowing	Adult[2]	2.8	0.028
	Child	6.4	0.064

Source:[1]*US EPA 2011,* [2]*MIT Crew Club Survey 2015*

The volume of ingestion during swimming came from the EPA (2011), specifically, page 3-7. The volume of ingestion during boating and rowing came from a survey done on the MIT Club Crew Team, approved by the MIT's Institutional Review Board, Committee on the Use of Human as Experimental Subjects. The complete survey and supplemental documents can be found in Appendix A.

Nine out of the ten rowers interviewed claimed that they ingested between 0.5-5 mL of river water per exposure event, regardless of whether it was a practice or a race. The mid-point of this range, 2.8 mL, was chosen to represent the volume of water that adults ingest per rowing event. Children were not interviewed to quantify the amount of water ingested. For swimming, the ingestion rate for children is 2.3 times higher than adults; therefore, I assumed that the ingestion rate for children rowing/boating was 6.4 mL. When the volumes of water ingested are inserted into the Wiedenmann (2007) equation, they must be transformed into 100mL units, also found in Table 3-2.

For this study, both primary contact (swimming) and secondary contact (boating and rowing) recreation are considered. Secondary recreational users have less direct contact with the water and therefore typically have less exposure. I assumed an exposure event in boating or rowing to be a practice or a race, and an exposure duration for swimming to be approximately 45 minutes in the water (US EPA 2011).

3.4 Dose-Response Model Parameters

The Wiedenmann (2007) dose-response model was discussed in detail in Section 2.3.5. The parameters and assumptions used in this study are shown in Table 3-3 below.

Table 3-3: Wiedenmann dose-response model inputs and parameters used for this study.

Inputs for Wiedenmann Model	Fecal Indicator	
	Intestinal Enterococci	Escherichia Coli
MR[1]	0.1	0.1
BR[1]	0.02	0.02
p(1)[1]	0.17	0.17
a[1]	-0.67	-2.17
b[1]	0.98	1.46
V_{intake}[2,3]	Refer to Table 3-2	
C_{FIO} (FIO/100mL)[4,5]	5-9000	5-71000

Source: [1]Wiedenmann 2007, [2]US EPA 2011, [3]MIT Club Crew Team Survey, Section 3.2, [4]MyRWA, [5]MWRA

Because there is no pathogen specific data on the Malden River, the default values were used for the *MR, BR, p(1), a,* and *b*. The quantities for the volume of medium ingested were discussed in Section 3.3.

3.5 Risk Characterization

Due to the variability between the two data sets, discussed in Section 3.1.2, risk analyses were done separately. This section analyzes overall risk, risk following significant precipitation, and seasonal risk.

The Wiedenmann (2007) risk model (Eq. 15) applied to the complete set of MWRA E. Coli measurements with the parameters discussed above (Tables 3-2 and 3-3) generates the curve shown in Figure 3-7, which represents the overall risk associated with recreational activity in the Malden River.

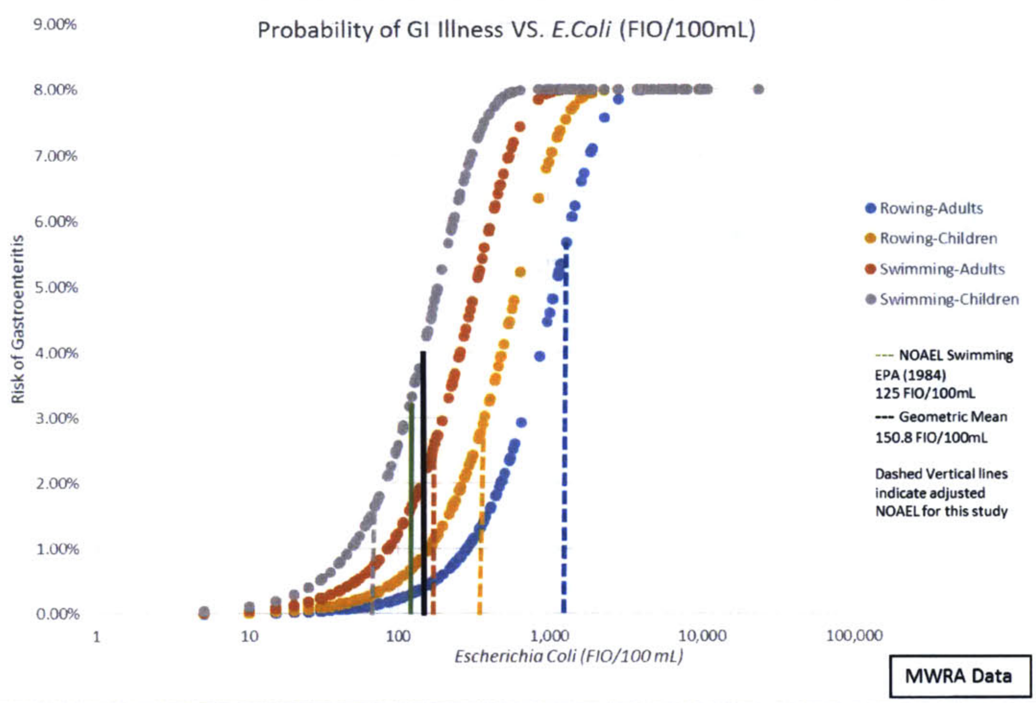


Figure 3-7: Risk curves showing probability of GI illness corresponding with the E. coli concentrations in the MWRA's data set.

$$Risk = (0.1 - 0.02) * \{1 - [1 - 0.17]^{\left(V_{in\_100mL} * 10^{-2.17 + 1.46 * \log_{10}\left(\frac{X_{FIO}}{100mL}\right)}\right)} \qquad (15)$$

Each curve represents a different ingestion rate for the respective recreational activity and user (found in Table 3-2).

An example of how to read this figure is as follows: First select one of the exposure scenarios represented in the figure, such as adult rowing, the blue curve. For adult rowing, if the *E. coli* concentration was at 1,000 FIO/100mL, the incremental risk of GI associated with an adult rowing would be approximately 5 percent. All of the curves in Figure 3-7 reach a maximum risk of 8 percent, which comes from the attributable risk parameter in the Wiedenmann (2007) model. The attributable risk parameter can be site specific, but in this case it is generic due to the lack of site-specific pathogen data.

I also show several reference concentrations on Figure 3-7. The solid green line in Figure 3-7 refers to the US EPA's *E. coli* guideline concentration for primary contact recreation (Section 2.3.1). The solid black line represents the geometric mean of the *E. coli* samples for the specific data set being analyzed. Four dashed lines represent the adjusted NOAEL's based from the Wiedenmann (2006) NOAEL for *E. coli* which is 100 FIO/100 mL. Wiedenmann describes the NOAEL as "the concentration of fecal indicator organisms below which the illness rates for recreational users is not significantly different than those of non-users." The NOAEL is basically a detection limit where Wiedenmann started to see a correlation between bacterial concentrations and GI in his epidemiological study. Below Wiedenmann's NOAEL, the risk becomes uncertain and may not be significantly different than zero. Weidenmann's NOAEL was calculated using an ingestion rate of 30 mL per swimming event. In this study, the ingestion rates are different, shown in As described in Section 1.6.2.2, the exposure routes of *E.coli* and *enterococci* are through ingestion, thus, it will be the only route of exposure considered in this study. The volumes of water ingested while participating in recreation, are shown below in Table 3-2. For this study, both primary contact (swimming) and secondary contact (boating and rowing) recreation are considered. Secondary recreational users have less direct contact with the water and therefore typically have less exposure. I assumed an exposure event in boating or rowing to be a practice or a race, and an exposure duration for swimming to be approximately 45 minutes in the water (US EPA 2011).

Table 3-2, and therefore NOAEL values were recalculated. The boating ingestion rate for a child is 4.7 times smaller than Wiedenmann's NOAEL for swimming. If the NOAEL increased accordingly, it would be 470 FIO/100 mL. This method of adjustment was applied to all the ingestion rates in this study, and are shown in Table 3-4.

Table 3-4: Wiedenmann (2006) NOAEL and the adjusted NOAEL's for this study.

Wiedenmann (2006)			
		Ingestion Rate (mL)	NOAEL (FIO/100 mL)
Swimming	Adult	30	100
Malden River Study			
		Ingestion Rate (mL)	Adjusted NOAEL (FIO/100 mL)
Swimming	Adult	16	188
	Child	37	81
Boating	Adult	2.8	1071
	Child	6.4	470

Figure 3-7 shows the overall geometric mean of the MWRA sample as 151 FIO/100mL. This is below all of the adjusted NOAEL's with the exception of the NOAEL for swimming children. The overall risk of GI illness for a child swimming is above that of a non-recreational user of the Malden River.

Figure 3-7 is shown here as an example set of results. Appendix B shows all of the risk curves and associated tables prepared as part of this evaluation.

3.5.1 Overall Risk

This section first analyzes the distribution of the samples and their corresponding risks, and then looks at the overall risk associated with recreational activity on the Malden River.

Figure 3-8 and Figure 3-9 show the distribution of calculated GI illness risks associated with the MyRWA data and the MWRA data, respectively. These figures were created using the following procedure:

- Empirical frequency distributions for each data set were calculated based on rank ordering the data and calculating a non-parametric frequency distribution using the equation n/(m+1), where n is the concentration rank and m is the number of data point. This produces an exceedance probability for each sample concentration.
- Each sample concentration may be associated with an incremental GI risk for a given exposure scenario using the risk assessment methods described here and illustrated in Figure 3-7.
- Plotting the incremental risk calculated for a given sample value against the associated exceedance probability produces Figure 3-8 and 3-9.

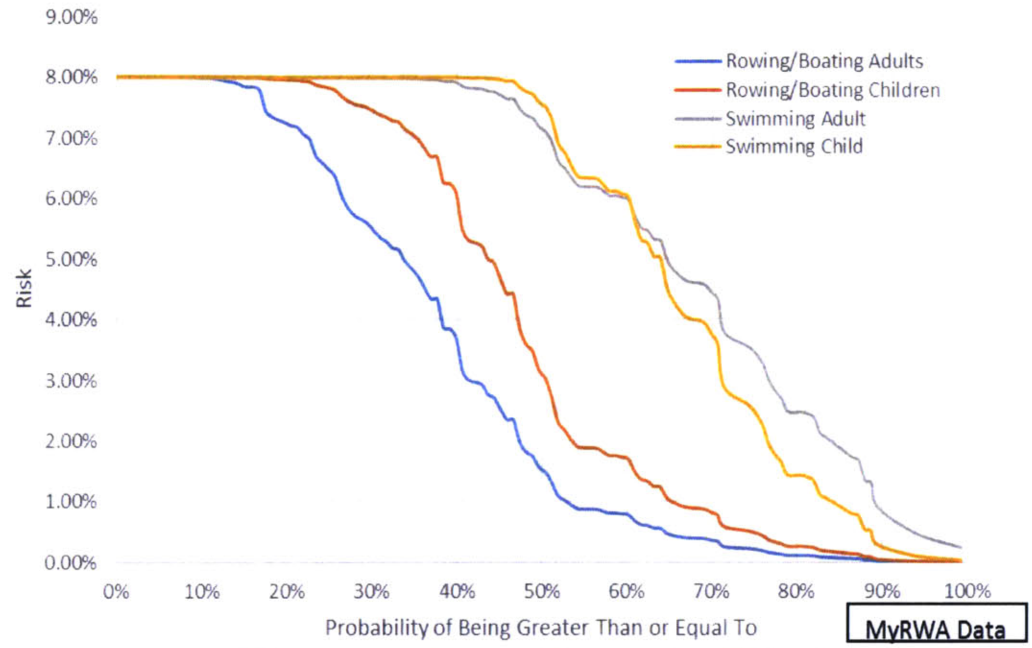


Figure 3-8: Probability distribution of overall incremental GI risk based on the MyRWA *E. Coli* data.

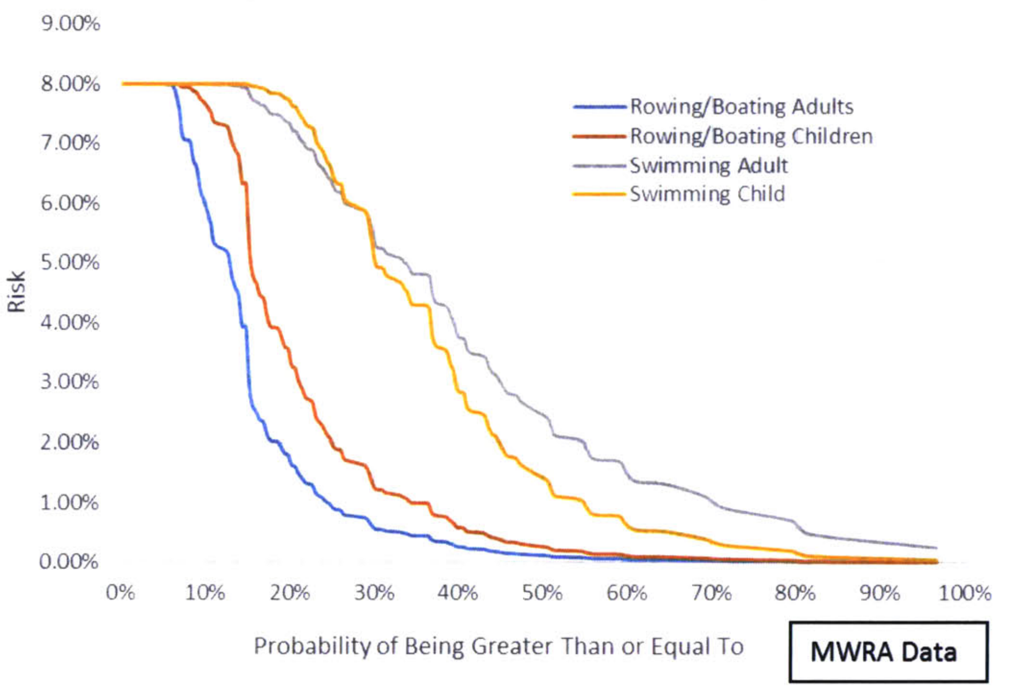


Figure 3-9: Probability distribution of overall incremental GI risk based on the MWRA *E. Coli* data.

Figure 3-2 allows one to determine the percentage of *E. coli* concentrations that are above the NOAEL's, seen in Table 3-5.

Table 3-5: Percent of *E.coli* concentrations that are above associated NOAEL's.

Data Set	Recreational Activity	Adjusted NOAEL (FIO/100 mL)	% of *E. coli* Concentrations Greater than NOAEL
MWRA	Adult-Swimming	188	38%
	Child-Swimming	81	47%
	Adult Boating	1071	12%
	Child Boating	470	25%
MyRWA	Adult-Swimming	188	71%
	Child-Swimming	81	78%
	Adult Boating	1071	32%
	Child Boating	470	53%

Table 3-6 shows the GI risks associated with the overall geometric mean of *E. coli* concentrations for both the MWRA and MyRWA. Table 3-6 also shows the adjusted NOAEL values as reference values. The NOAEL values do not impact the risk calculations, but as discussed earlier, the computed risks for FIO concentrations below the NOAEL are highly uncertain and may not be significantly different that zero. The geometric mean of the MWRA data is above the NOAEL for the child swimming exposure scenario. The geometric mean of the MyRWA data is above the NOAEL for both adult and child swimming exposure scenarios.

Table 3-6: Incremental risk of GI associated with the geometric mean of Malden River *E. Coli* concentrations.

	Organization	Activity	Age	Adjusted NOAEL (FIO/100 mL)	Geometric Mean of *E. coli* Concentrations (FIO/100mL)	Wiedenmann Risk at Geometric Mean
Overall Risk	MWRA	Swimming	Adult	188	151	2.2%
			Child	81		4.0%
		Rowing	Adult	1071		0.4%
			Child	470		1.0%
Overall Risk	MyRWA	Swimming	Adult	188	412	5.6%
			Child	81		7.0%
		Rowing	Adult	1071		1.0%
			Child	470		2.2%

3.5.2 Risk Following Significant Rainfall

Section 3.1.3 indicated that bacterial concentrations in the Malden River significantly respond to precipitation. This section evaluates the potential impacts of significant rainfall on GI risk for the same four exposure scenarios described above. During sampling that was preceded by at least a half an inch of rain, the overall geometric means of *E. coli* were 687 and 2009 FIO/mL for the MWRA and MyRWA, respectively. Table 3-7 shows that the risk posed to recreational users from the geometric mean E. Coli concentrations after greater than 0.5 inches of rain in the previous 72 hours is substantially higher than the overall risk based on the geometric mean of all sample concentrations (Table 3-6).

Table 3-7: Incremental risk of GI associated with the geometric mean of *E. coli* concentrations after 0.5 inches of rain or greater in the previous 72 hours.

	Organization	Activity	Age	Adjusted NOAEL (FIO/100 mL)	Geometric Mean of *E. coli* Concentrations (FIO/100mL)	Wiedenmann Risk at Geometric Mean
Risk After >0.5 inches Rain	MWRA	Swimming	Adult	188	687	6.5%
			Child	81		7.8%
		Rowing	Adult	1071		2.0%
			Child	470		3.9%
Risk After >0.5 inches Rain	MyRWA	Swimming	Adult	188	2009	8.0%
			Child	81		8.0%
		Rowing	Adult	1071		7.0%
			Child	470		7.8%

The geometric mean of *E. coli* concentrations for the MWRA samples exceed the NOAEL's for all evaluated activities except for an adult rowing. The MyRWA sample geometric mean exceeds the NOAEL's for every recreational activity. The risk of GI when rowing within 72 hours of a 0.5 inches of more of rain more than doubles when compared with the calculated overall risk (Section 3.5.1).

3.5.3 Seasonal Risk

Since water quality can vary significantly with time due to seasonal fluctuations of weather, it is often useful to analyze seasonal risk. The incremental GI risk posed to users of the Malden River associated with seasonal geometric mean *E. coli* concentrations is shown in Table 3-8. I excluded the winter months from this analysis because I assumed recreational activity would not take place during that time.

	Organization	Activity	Adjusted NOAEL (FIO/100 mL)	Age	Geometric Mean of *E. coli* Concentrations (FIO/100mL)	Wiedenmann Risk at Geometric Mean
Spring (March-May)	MWRA	Swimming	188	Adult	87	1.0%
			81	Child		2.1%
		Rowing	1071	Adult		0.2%
			470	Child		0.4%
Spring (March-May)	MyRWA	Swimming	188	Adult	302	3.2%
			81	Child		5.3%
		Rowing	1071	Adult		0.7%
			470	Child		1.4%
Summer (June-August)	MWRA	Swimming	188	Adult	51	0.4%
			81	Child		0.8%
		Rowing	1071	Adult		0.1%
			470	Child		0.2%
Summer (June-August)	MyRWA	Swimming	188	Adult	395	4.0%
			81	Child		6.3%
		Rowing	1071	Adult		1.0%
			470	Child		2.0%
Fall (Sept.-Nov)	MWRA	Swimming	188	Adult	142	2.2%
			81	Child		3.7%
		Rowing	1071	Adult		0.4%
			470	Child		1.0%
Fall (Sept.-Nov)	MyRWA	Swimming	188	Adult	497	4.0%
			81	Child		6.2%
		Rowing	1071	Adult		1.0%
			470	Child		2.2%

Table 3-8: Incremental risk of GI associated with seasonal geometric mean *E. coli* concentrations.

In the spring months, at the MWRA sampling location, the geometric mean of *E. coli* concentrations is only slightly above the NOAEL for a child swimming. The MyRWA location, however, had a geometric mean of *E. coli* that was greater than the NOAEL for all primary recreation.

In the summer months, the MWRA's geometric mean of *E. coli* concentrations that was less than all of the NOAEL's and all of the calculated risks were less than 1 percent. The MyRWA geometric mean of *E. coli* concentrations again exceed the NOAEL's for all primary recreation.

In the fall, the MWRA's geometric mean of *E. coli* concentrations was less than all of the NOAEL's with exception for the child swimming NOAEL. The MyRWA geometric mean of *E. coli* concentrations again exceed the NOAEL's for all primary recreation as well as the NOAEL for a child rowing.

A trend in all seasons analyzed is that the risks associated with the MyRWA sampling location were consistently at least twice that of the MWRA location.

4. Conclusions

This section summarizes the risk analysis and presents uncertainties in the study as well as suggestions for future work.

4.1 Risk Management and Communication

The goal of this study was to assess the microbial risk associated with using the Malden River for recreation. The initial analysis of the two data sets concluded that there is a significantly variation in the range of concentrations. The reasons for the variations are currently not known, but the data may study indicate that the microbial water quality conditions worsen as one travels upstream away from the junction with the Mystic River. Due to these differences, each data set was analyzed separately.

The examination of microbial populations in the Malden River after rainfall indicated that there is a significant bacterial response to rainfall, with the highest geometric mean of *E. coli* occurring in the first 24 hours after a rain event of greater than 0.5 inches. These results indicate that when rain falls in the Malden River watershed, the run-off reaches the River quickly, accumulating bacterial contaminants along the way. When there is enough time between rainfall and testing, the bacteria concentrations decrease.

The risk analysis provides insight to the risk of GI for recreational activity on the Malden River. The MyRWA sampling location very consistently has double the risk of GI associated with recreational activity in comparison to the MWRA location. The *E. coli* geometric means for the MyRWA location were consistently greater than the NOAEL's for primary recreation.

4.2 Uncertainties

Though the bacterial concentrations used in this study are based on real data, the other parameter selections for the Wiedenmann (2007) model are potentially subject to further development, which would then change the risk values.

4.3 Future Work

In order to determine if there is a significant spatial distribution of bacteria in the River, water sampling must be done at more locations in the River and more frequently. MyRWA is implementing a thorough bacterial study on the Malden in summer 2015 to determine specific areas of concern. The bacterial analysis and utilization of Greenberg's (2015) hydrological model of the Malden River watershed would be beneficial to implementing Smith's (2015) proposed BMP's and improve the water quality of the Malden River.

References

Adams, Kate, and Clay Larsen. 2015. MyRWA Water Quality Sampling.

ArcMap 10.2.2. 2010. Redlands, CA: ESRI (Environmental Systems Resource Institute).

Cabelli, V. J., A. P. Dufour, L. J. McCabe, and M. A. Levin. 1983. "A Marine Recreational Water Quality Criterion Consistent with Indicator Concepts and Risk Analysis." *Journal (Water Pollution Control Federation)* 55 (10): 1306–14.

Coughlin, Kelly. 2015. Sanitary Sewer Overflows.

Dixon, Cameron Chaffee. 2009. "Microbial Risk Assessment for Recreational Use of the Kranji Reservoir, Singapore." Thesis, Massachusetts Institute of Technology. http://dspace.mit.edu/handle/1721.1/51567.

Dorevitch, Samuel, Suraj Panthi, Yue Huang, Hong Li, Angela M. Michalek, Preethi Pratap, Meredith Wroblewski, Li Liu, Peter A. Scheff, and An Li. 2011. "Water Ingestion during Water Recreation." *Water Research* 45 (5): 2020–28. doi:10.1016/j.watres.2010.12.006.

Ducott, Laura. 2015. MWRA Water Sampling.

Dufour, Alfred. 1984. "Health Effects Criteria for Fresh Recreational Waters No. EPA-600/1-84-004." United States Environmental Protection Agency, Research Triangle Park, NC.

EPA. 2015. "What Is Non Point Source Pollution?" *EPA - Water*. Accessed May 5. http://water.epa.gov/polwaste/nps/whatis.cfm.

Fleisher, Jay M. 1991. "A Reanalysis of Data Supporting U.S. Federal Bacteriological Water Quality Criteria Governing Marine Recreational Waters." *Research Journal of the Water Pollution Control Federation* 63 (3): 259–65.

Gerba, C P, S M Goyal, R L LaBelle, I Cech, and G F Bodgan. 1979. "Failure of Indicator Bacteria to Reflect the Occurrence of Enteroviruses in Marine Waters." *American Journal of Public Health* 69 (11): 1116–19. doi:10.2105/AJPH.69.11.1116.

Greenberg, Sara. 2015. "Urban Hydrological Modeling of the Malden River Using the Storm Water Management Model (SWMM)." Cambridge, MA: Massachusetts Institute of Technology.

Haas, Charles, Joan Rose, and Charles Gerba. 1999. *Quantitative Microbial Risk Assessment*. New York: John Wiley & Sons, Inc.

Herron, Patrick. 2014. Malden River Water Quality Data.

Khweis, Majdolene. 2015. "Organic Sediment Analysis and Distribution on the Malden River." Senior Capstone Project, Massachusetts Institute of Technology.

MADEP. 2013. *Massachusetts Year 2012 Integrated List of Waters*. Commonwealth of Massachusetts: Mass DEP. http://www.mass.gov/eea/docs/dep/water/resources/07v5/12list2.pdf.

———. 2014a. *Massachusetts Surface Water Quality Standards. 314 CMR 4.00*. http://www.mass.gov/eea/docs/dep/service/regulations/314cmr04.pdf; http://water.epa.gov/scitech/swguidance/standards/wqslibrary/upload/mawqs_figures_tables.pdf.

———. 2014b. *Massachusetts Year 2014 Integrated List of Waters*. Commonwealth of Massachusetts: Mass DEP. http://www.mass.gov/eea/docs/dep/water/resources/07v5/14iwlistp.pdf.

———. 2015. "Malden SSO Database."

McLellan, S. L., and A. K. Salmore. 2003. "Evidence for Localized Bacterial Loading as the Cause of Chronic Beach Closings in a Freshwater Marina." *Water Research* 37 (11): 2700–2708. doi:10.1016/S0043-1354(03)00068-X.
MWRA. 2015. "Malden Watershed SSO Locations."
Nangle Associates. 2014. "Malden River Outfalls."
NOAA. 2014. "Hourly Precipitation Data Publication/Database." Database. *National Centers for Environmental Information*. December 13.
Oehmke, Theresa. 2015. "Potential for Sediment Re-Suspension and Transport in the Malden River." Senior Capstone Project, Massachusetts Institute of Technology.
Park, Allison. 2014. "Microbial Risk Assessment for Recreational Use of the Kallang Basin, Singapore." Cambridge, MA: Massachusetts Institute of Technology.
Pond, Kathy. 2014. "WHO | Water Recreation and Disease. Plausibility of Associated Infections: Acute Effects, Sequelae and Mortality." *WHO*. Accessed December 4. http://www.who.int/water_sanitation_health/bathing/recreadis/en/.
Salhotra, Atul. 2014. "Application of Risk Assessment for the Managment of Contaminated Sites." Massachusetts Institute of Technology, November 7.
Schijven, Jack, and Ana Maria de Roda Husman. 2006. "A Survey of Diving Behavior and Accidental Water Ingestion among Dutch Occupational and Sport Divers to Assess the Risk of Infection with Waterborne Pathogenic Microorganisms." *Environmental Health Perspectives* 114 (5): 712–17.
Shehane, S. D., V. J. Harwood, J. E. Whitlock, and J. B. Rose. 2005. "The Influence of Rainfall on the Incidence of Microbial Faecal Indicators and the Dominant Sources of Faecal Pollution in a Florida River." *Journal of Applied Microbiology* 98 (5): 1127–36. doi:10.1111/j.1365-2672.2005.02554.x.
Sloat, S, and C Ziel. 1992. "The Use of Indicator Organisms to Assess Public Water Safety." Hach Company.
Smith, Mia. 2015. "Evaluation of Stormwater BMP Alternatives in the Malden River Watershed." Cambridge, MA: Massachusetts Institute of Technology.
Stone, David, Anna Harding, Bruce Hope, and Samantha Slaughter-Mason. 2008. "Exposure Assessment and Risk of Gastrointestinal Illness Among Surfers." *Taylor & Francis Group, LLC*, no. 71: 1603–15.
Sylman, Shanasia. 2015. "Inorganic Contaminants in the Sediments of the Malden River: Distributions and Associated Risks." Senior Capstone Project, Massachusetts Institute of Technology.
U.S. Army Corps of Engineers. 2008. *Malden River Ecosystem Restoration: Detailed Project Report & Environmental Assessment*.
US EPA. 1983. *Results of the Nationwide Urban Runoff Program Volume 1 Final Report*. Washington D.C.: Water Planning Division U.S. Environmental Protection Agency.
———. 1986. "Bacterial Ambient Water Quality Criteria for Marine and Fresh Recreational Waters." US EPA.
———. 2011. "Exposure Factors Handbook: 2011 Edition." Office of Research and Development.
———. 2015a. "Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Interim." Policies & Guidance. Accessed May 13. http://www.epa.gov/oswer/riskassessment/ragse/.

US EPA, OW. 2014. "Sanitary Sewer Overflows and Peak Flows." Overviews & Factsheets. September 9. http://water.epa.gov/polwaste/npdes/sso/.

———. 2015b. "Clean Water Act, Section 502 General Definitions." Accessed May 14. http://water.epa.gov/lawsregs/guidance/wetlands/sec502.cfm.

Wiedenmann, Albrecht. 2007. "A Plausible Model to Explain Concentration – Response Relationships in Randomized Controlled Trials Assessing Infectious Disease Risks from Exposure to Recreational Waters." In *Statistical Framework for Recreational Water Quality Criteria and Monitoring*, edited by Larry J. Wymer, 153–77. John Wiley & Sons, Ltd. http://onlinelibrary.wiley.com.libproxy.mit.edu/doi/10.1002/9780470518328.ch9/summary.

Wiedenmann, Albrecht, Petra Krüger, Klaus Dietz, Juan M. López-Pila, Regine Szewzyk, and Konrad Botzenhart. 2006. "A Randomized Controlled Trial Assessing Infectious Disease Risks from Bathing in Fresh Recreational Waters in Relation to the Concentration of Escherichia Coli, Intestinal Enterococci, Clostridium Perfringens, and Somatic Coliphages." *Environmental Health Perspectives* 114 (2): 228–36.

Wymer, Larry J., and Alfred P. Dufour. 2002. "A Model for Estimating the Incidence of Swimming-Related Gastrointestinal Illness as a Function of Water Quality Indicators," 669–78.

Appendix A

MIT Club Crew Team Survey

Informal interview questions for "Microbial Risk Assessment for Recreational Use of the Malden River Study"

Investigator: Margaret Jacques, CEE, maggiej@mit.edu
Faculty Sponsor: David Langseth, CEE, langseth@mit.edu
COUHES number: 4725934

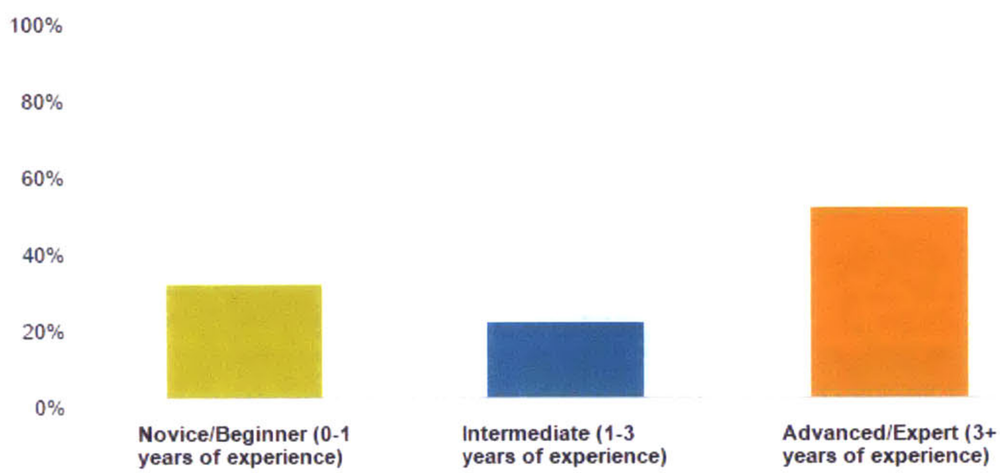
Members of the MIT rowing club will be asked a series of questions in survey relating to their experiences rowing on a river.

Below is the question bank for the informal interviews with the rowing team:

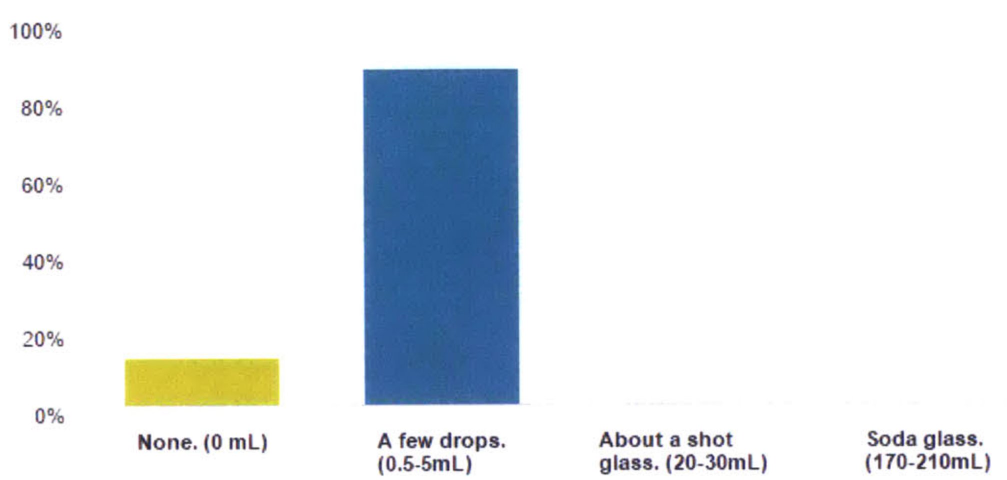
1. Please classify yourself as a rower:
    a. Novice/beginner (0-1 years experience)
    b. Intermediate (1-3 years experience)
    c. Advanced/Expert (3+ years experience)
2. On average, approximately how much water do you ingest per **practice**?
    a. None. (0 mL)
    b. A few drops. (0.5-5mL)
    c. About a shot glass. (20-30mL)
    d. Soda glass. (170-200mL)
3. On average, approximately how much water do you ingest per **race**?
    a. None. (0 mL)
    b. A few drops. (0.5-5mL)
    c. About a shot glass. (20-30mL)
    d. Soda glass. (170-200mL)
4. How many times have you fallen into the water in which your head was completely submerged?
    a. Never.
    b. Once.
    c. Twice.
    d. Three or more times.

Survey Responses

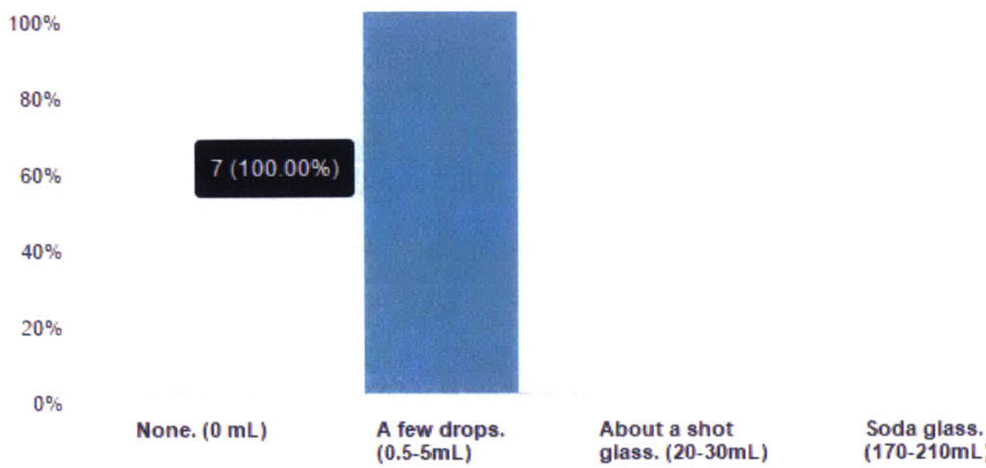
Please classify yourself as a rower:



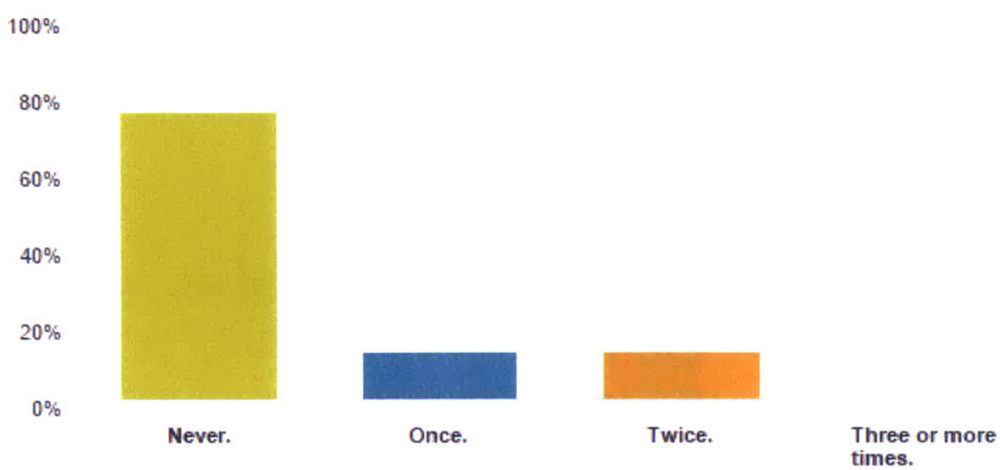
On average, approximately how much river water do you ingest per practice?



On average, approximately how much river water do you ingest during a race?



How many time have you fallen into the water in which your head was completely submerged?



IRB Application

	Massachusetts Institute of Technology Committee on the Use of Humans as Experimental Subjects	**Application #** (assigned by COUHES)	
		Date	

APPLICATION FOR APPROVAL TO USE HUMANS AS EXPERIMENTAL SUBJECTS (EXEMPT STATUS FORM)

Please answer every question. Positive answers should be amplified with details. You must mark N/A where the question does not pertain to your application. Any incomplete application will be rejected and returned for completion.

I. BASIC INFORMATION

1. Title of Study	
Microbial Risk Assessment for Recreational Use of the Malden River	
2. Investigator	
Name: Margaret Jacques	Building and Room #:1-143
Title: Graduate Student	Email: maggiej@mit.edu
Department: Civil and Environmental Engineering	Phone: (978) 471-2859
3. Faculty Sponsor. *If the investigator does not have PI Status (faculty, SRS or PRS) then a faculty sponsor must be identified and sign below.*	
Name: David Langseth	Email: langseth@mit.edu
Title: Lecturer	Phone: 781-254-6335
Affiliation: Civil and Environmental Engineering	
4. Collaborating Institutions. *If you are collaborating with another institution(s) then you must obtain approval from that institution's institutional review board, and forward copies of the approval to COUHES).*	
N/A	
5. Funding. *If the research is funded by an outside sponsor, the investigator's department head must sign this form. Please enclose one copy of the research proposal (draft is acceptable) with your application.* ***Do not leave this section blank. If your project is not funded check No Funding.***	
A. Sponsored Project Funding:	

☐ Current Proposal Sponsor ____________ Title ____________	Proposal #	____________
☐ Current Award Sponsor ____________ Title ____________	Account #	____________

B. Institutional Funding:

☐ Gift
☐ Departmental Resources
☐ Other (explain) ____________
☒ No Funding

6. Statement of Financial Interest

Does the principal investigator or any <u>key personnel</u> involved in the study have any <u>financial interest</u> in the research?

☐ Yes ☒ No

If yes then attach a **Supplement for Disclosure of Financial Interest** for each individual with an interest. *This supplement, together with detailed guidance on this subject and definitions of the highlighted terms, is available on the COUHES web.*

7. Human Subjects Training. *All study personnel in research MUST take and pass a training course on human subjects research. MIT has a web-based course that can be accessed from the main menu of the COUHES web site. COUHES may accept proof of training from some other institutions. List the name, MIT or outside affiliation and emails of all study personnel and indicate if they have taken a human subjects training course.*

David Langseth, langseth@mit.edu- Has completed the human subjects training course.

8. Anticipated Dates of Research

Start Date: April 20, 2015	Completion Date: April 25, 2015

II. STUDY INFORMATION

1. Purpose of Study. *Please provide a brief statement of the background, nature and reasons for the proposed study. Use non-technical language.*

The purpose of this study is to quantify the amount of river ingested by rowers or boaters per exposure event (practice, competition, outing). The amount fo river water ingested is referred to as the dose. This along with bacteria concentrations are inputs to the risk model which will predict the probability of gastrointestinal illness.

2. Study Protocol. *Please provide an outline of the proposed research. You should provide sufficient information for effective review by non-scientist members of COUHES. Define all abbreviations and use simple words. Unless justification is provided, this part of the application must not exceed 2 pages. Attaching sections of a grant application is **not** an acceptable substitute for the description requested here. Include copies of any questionnaire or standardized tests you* *plan to use. If your study involves interviews, submit an outline of the types of questions you will include. Your research outline should include a description of:*

A. Experimental procedures:

I will ask the MIT club rowing team a series of 4 questions:

1.) Please classify yourself as a rower
- **-novice/beginner**
- **-intermediate**
- **-expert/advanced**

2.) On average, how much water do you ingest per practice?
- **-None (0mL)**
- **-A few drops (0.5-5mL)**
- **-About a shot glass (20-30mL)**
- **-Soda glass (170-210mL)**

3.) On average, how much water do you ingest per race?
- **-None (0mL)**
- **-A few drops (0.5-5mL)**
- **-About a shot glass (20-30mL)**
- **-Soda glass (170-210mL)**

4.) How many times have you fallen into the water when your head has been completely submerged?
- **-Never**
- **-Once**
- **-Twice**
- **-Three or more times**

B. Type and number of subjects involved:

MIT Club Rowing Team- Approximately 20 rowers

C. Subject Compensation: (describe all plans to pay subjects in cash or other forms of payment i.e. gift certificate).

There will be no forms of compensation.

D. Method of recruitment *(attach recruitment materials flyer, poster, email message, Internet posting, etc.)*

Email

E. Length of subject involvement:

The survey will last about 5 minutes.

F. Location of the research:

Cambridge, MA

G. Procedures for obtaining informed consent *(if a waiver of written informed consent is requested an explanation of an alternative consent mechanism must be submitted):*

I am hoping that this reseach be deemed exempt, and the requirement for written informed consent be waived.

H. Procedures to ensure confidentiality:

Anonymous survey, names of those on MIT Club Rowing Team will not be identified in my thesis.

3. HIPAA Privacy Rule. *If you are in any way working with individually identifiable health* *information for a research study that is sponsored by MIT Medical, an MIT Health Plan or another healthcare provider, then the Health Insurance Portability and Accountability Act ("HIPAA") likely applies to your study and you must comply with HIPAA in the conduct of your study. However, we expect that if you are applying for exempt status, you will only receive de-identified health information from participants in connection with your study. If you expect to receive identifiable health information from or about research participants in your study, you should complete the standard COUHES application form rather than this application form. You may consult with COUHES staff if you have questions about the exempt/non-exempt status of your proposed research study.*

Signature of Investigator ______________________ **Date** __________

Signature of Faculty Sponsor ______________________ **Date** __________

Signature of Department Head E. E. Ad ______________________ **Date** __________

Print Full Name and Title ______________________________

The electronic file should be sent as an attachment to an e-mail: couhes@mit.edu. In addition, two hard copies (one with original signatures) should be sent to the COUHES office: Building E25-Room 143B.

COUHES Approval Documents

MIT Committee On the Use of Humans as Experimental Subjects

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
77 Massachusetts Avenue
Cambridge, Massachusetts 02139
Building E 25-143B
(617) 253-6787

To:	Margaret Jacques
From:	Leigh Firn, Chair COUHES
Date:	03/25/2015
Committee Action:	**Exemption Granted**
Committee Action Date:	03/25/2015
COUHES Protocol #:	1503007019
Study Title:	Microbial Risk Assessment for Recreational Use of the Malden River

The above-referenced protocol is considered exempt after review by the Committee on the Use of Humans as Experimental Subjects pursuant to Federal regulations, 45 CFR Part 46.101(b)(2) .

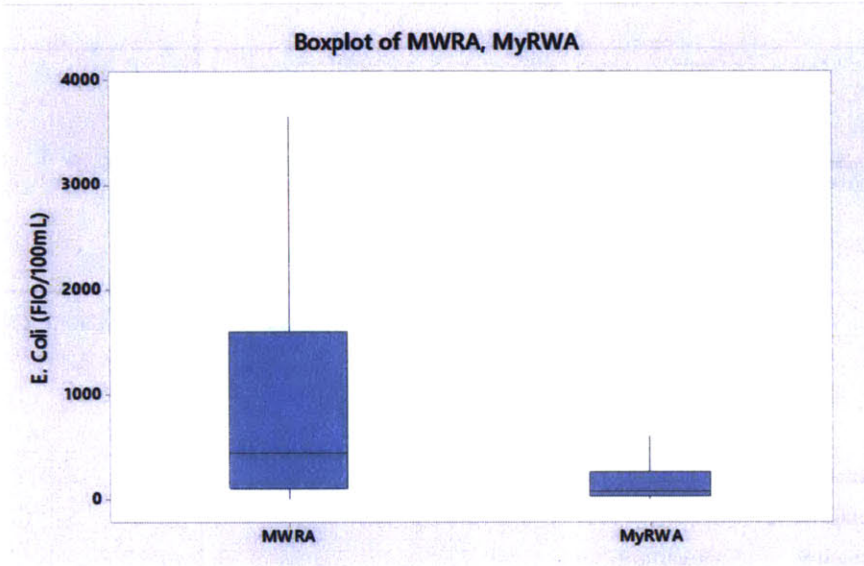
This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

If the research involves collaboration with another institution then the research cannot commence until COUHES receives written notification of approval from the collaborating institution's IRB.

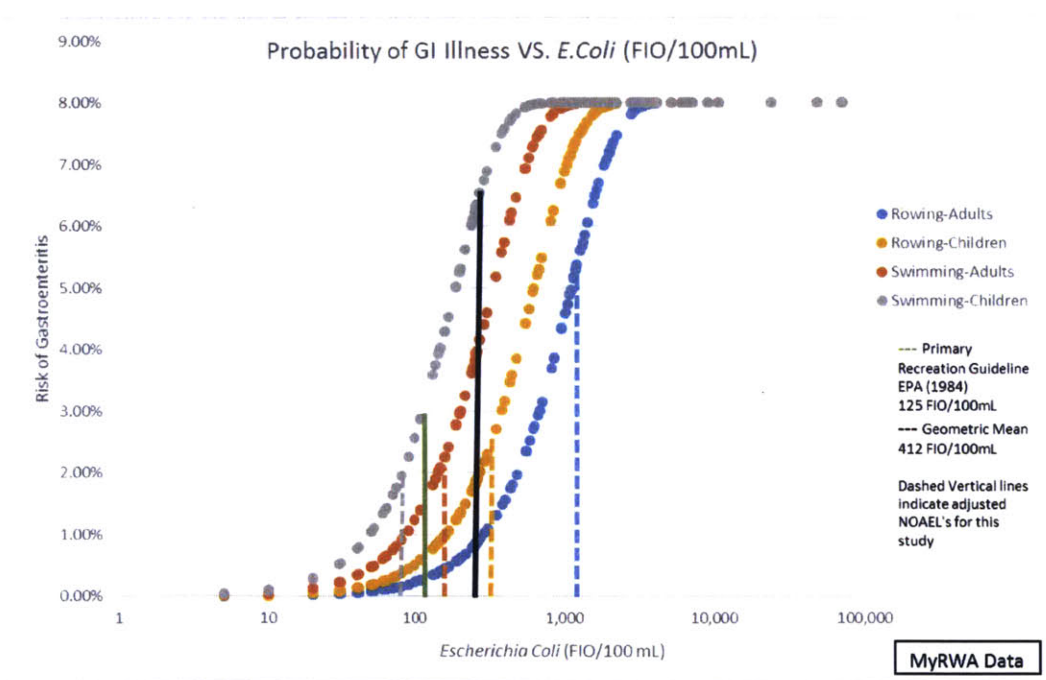
Any changes to the protocol that impact human subjects, including changes in experimental design, equipment, personnel or funding, must be approved by COUHES before they can be initiated. You should retain a copy of this letter for your records.

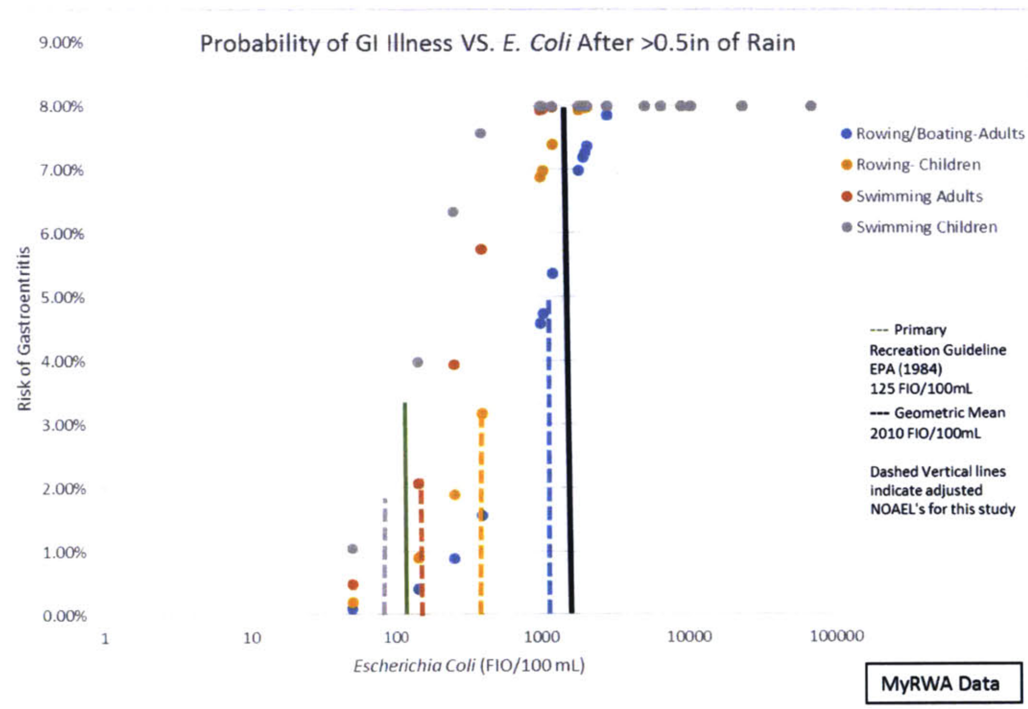
Appendix B

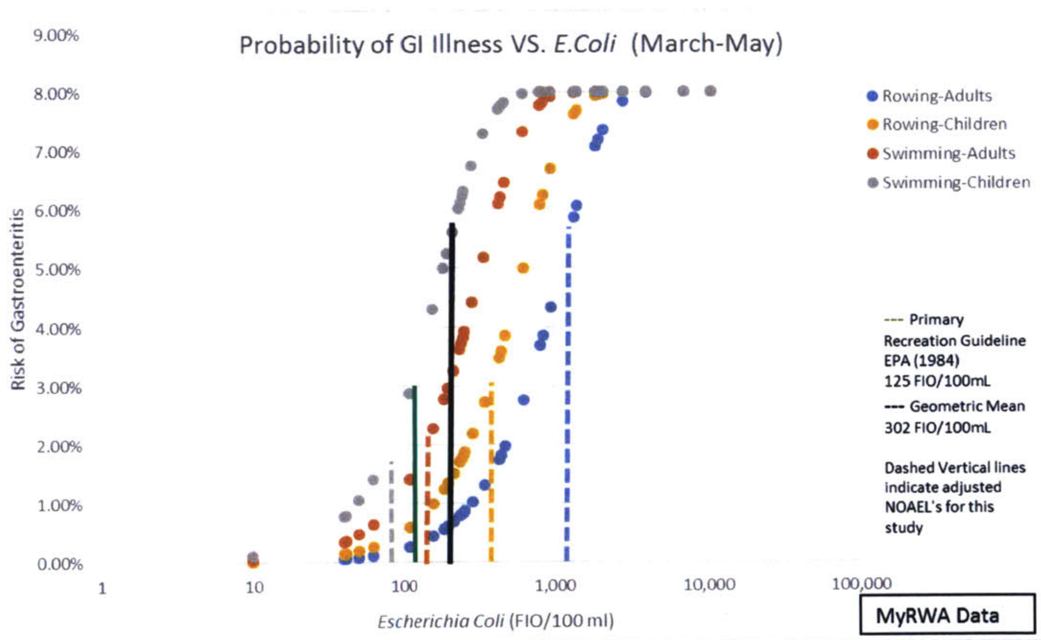
Comparison of Data Sets

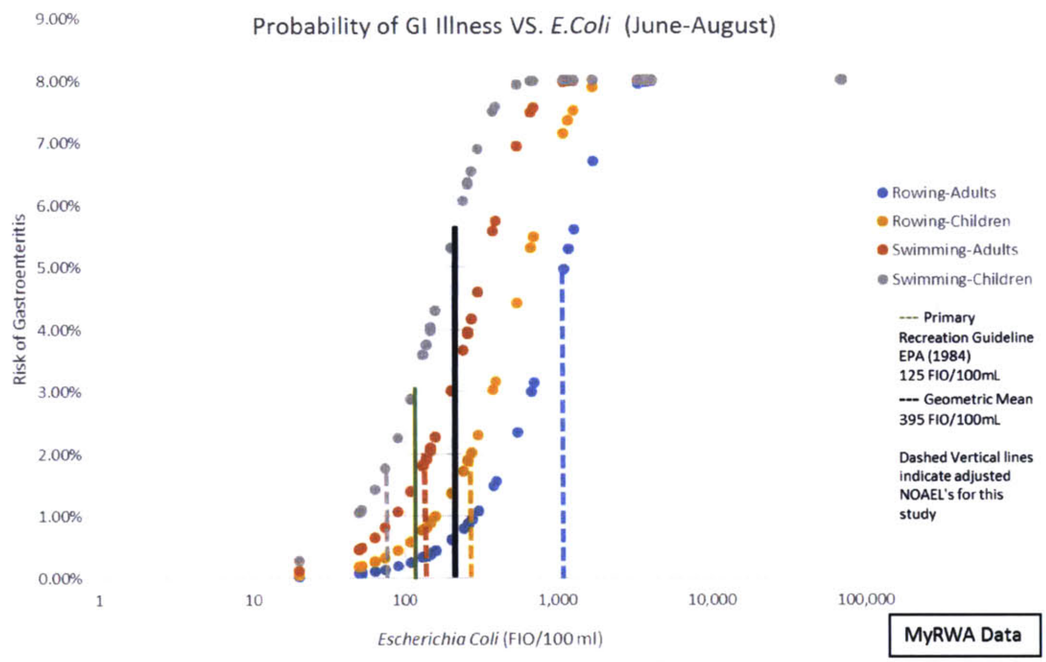


MyRWA E. coli Risk Curves

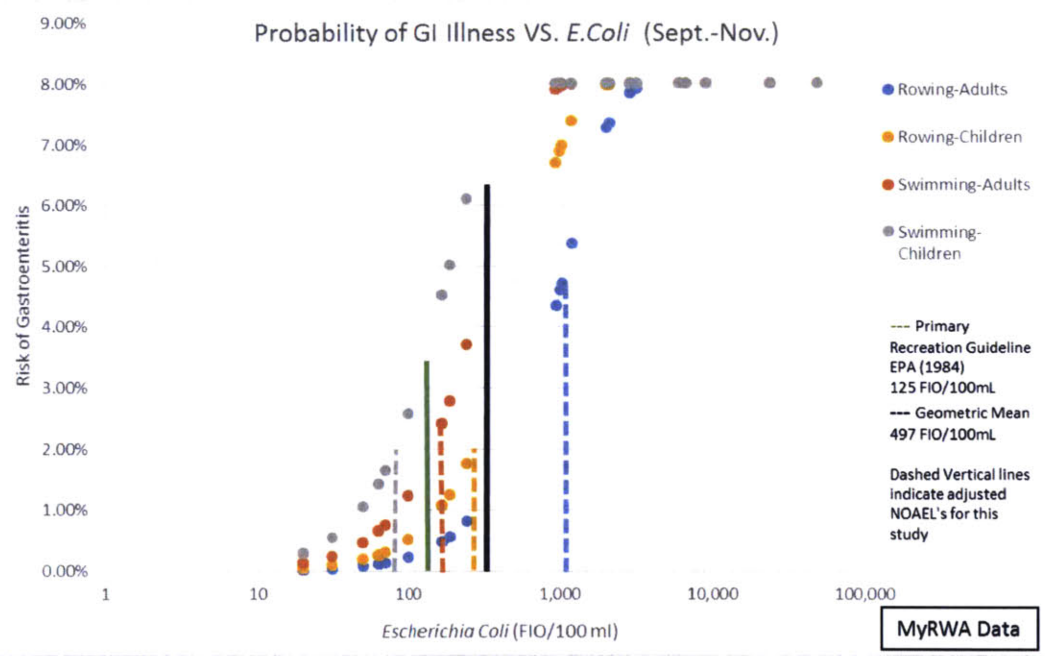



Probability of GI Illness VS. E. Coli After >0.5in of Rain
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
Risk of Gastroentritis
1
10
100
1000
10000
100000
Escherichia Coli (FIO/100 mL)
Rowing/Boating-Adults
Rowing- Children
Swimming Adults
Swimming Children
--- Primary Recreation Guideline EPA (1984) 125 FIO/100mL
--- Geometric Mean 2010 FIO/100mL
Dashed Vertical lines indicate adjusted NOAEL's for this study
MyRWA Data


Probability of GI Illness VS. E.Coli (March-May)
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
Risk of Gastroenteritis
1
10
100
1,000
10,000
100,000
Escherichia Coli (FIO/100 ml)
Rowing-Adults
Rowing-Children
Swimming-Adults
Swimming-Children
--- Primary Recreation Guideline EPA (1984) 125 FIO/100mL
--- Geometric Mean 302 FIO/100mL
Dashed Vertical lines indicate adjusted NOAEL's for this study
MyRWA Data

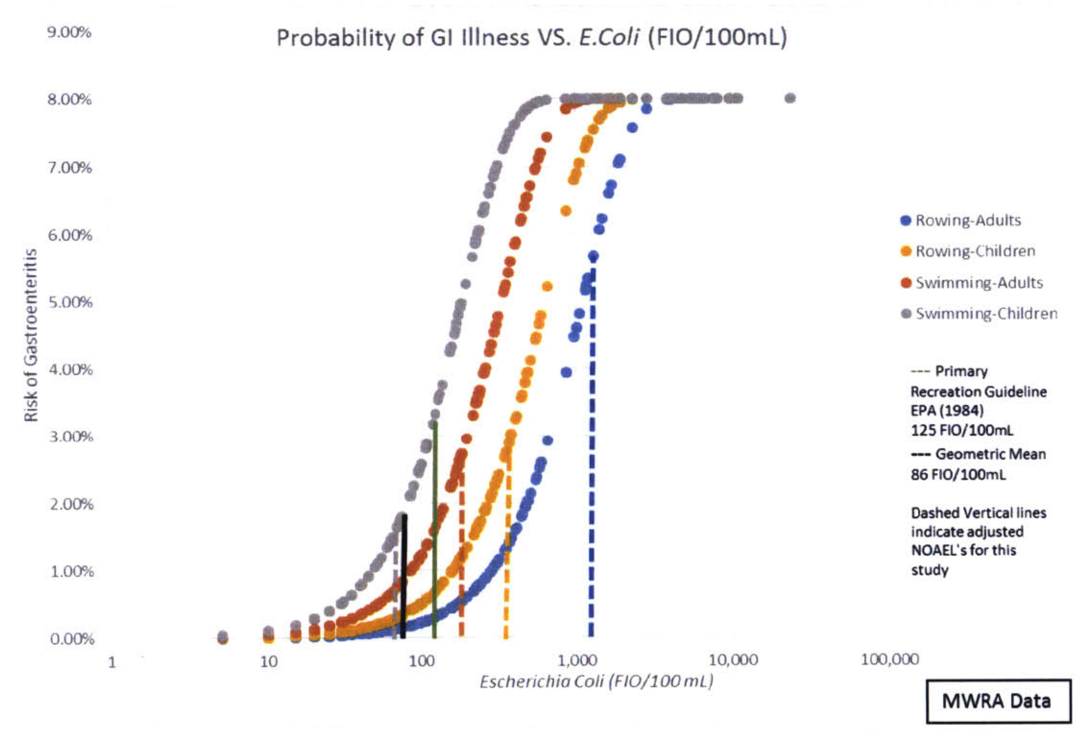


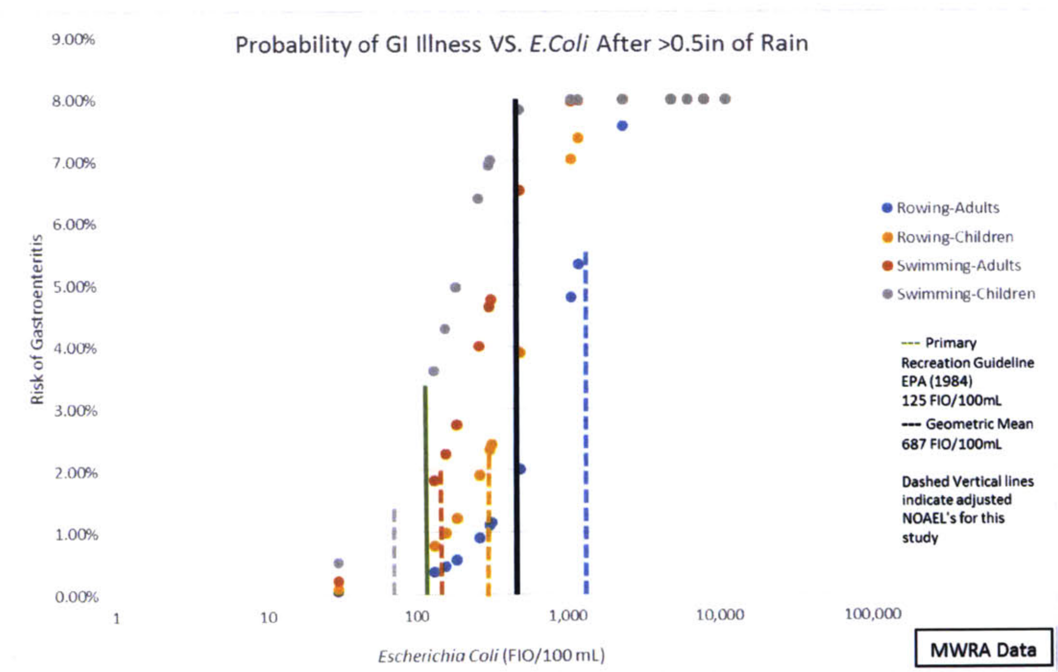
Probability of GI Illness VS. E.Coli (June-August)
Risk of Gastroenteritis
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
1
10
100
1,000
10,000
100,000
Escherichia Coli (FIO/100 ml)
Rowing-Adults
Rowing-Children
Swimming-Adults
Swimming-Children
--- Primary Recreation Guideline EPA (1984) 125 FIO/100mL
--- Geometric Mean 395 FIO/100mL
Dashed Vertical lines indicate adjusted NOAEL's for this study
MyRWA Data

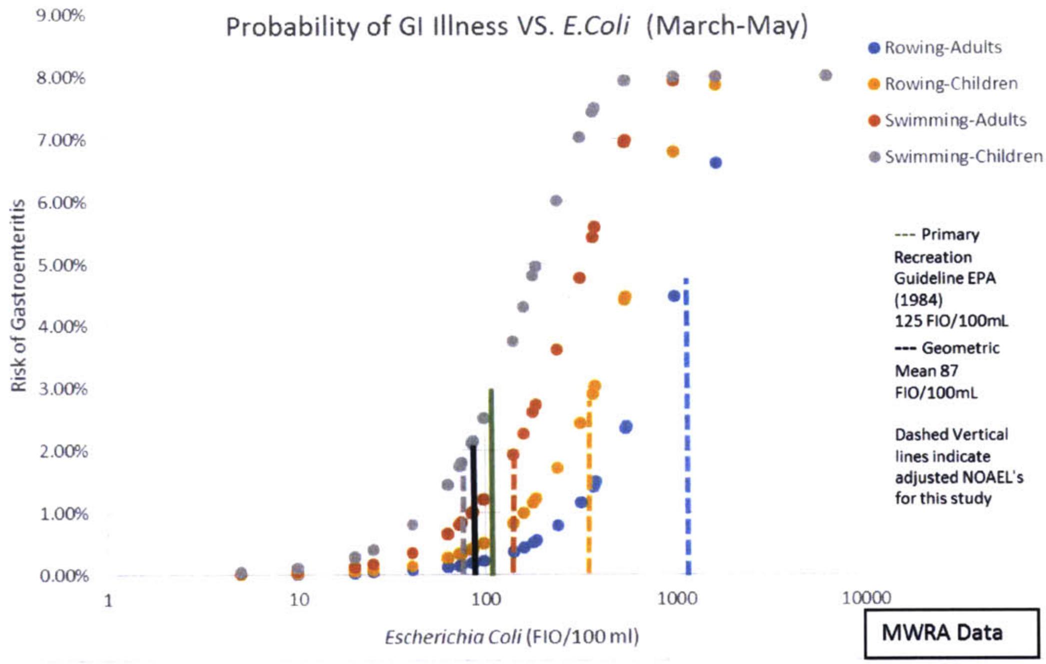


Probability of GI Illness VS. E.Coli (Sept.-Nov.)
Risk of Gastroenteritis
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
1
10
100
1,000
10,000
100,000
Escherichia Coli (FIO/100 ml)
Rowing-Adults
Rowing-Children
Swimming-Adults
Swimming-Children
--- Primary Recreation Guideline EPA (1984) 125 FIO/100mL
--- Geometric Mean 497 FIO/100mL
Dashed Vertical lines indicate adjusted NOAEL's for this study
MyRWA Data

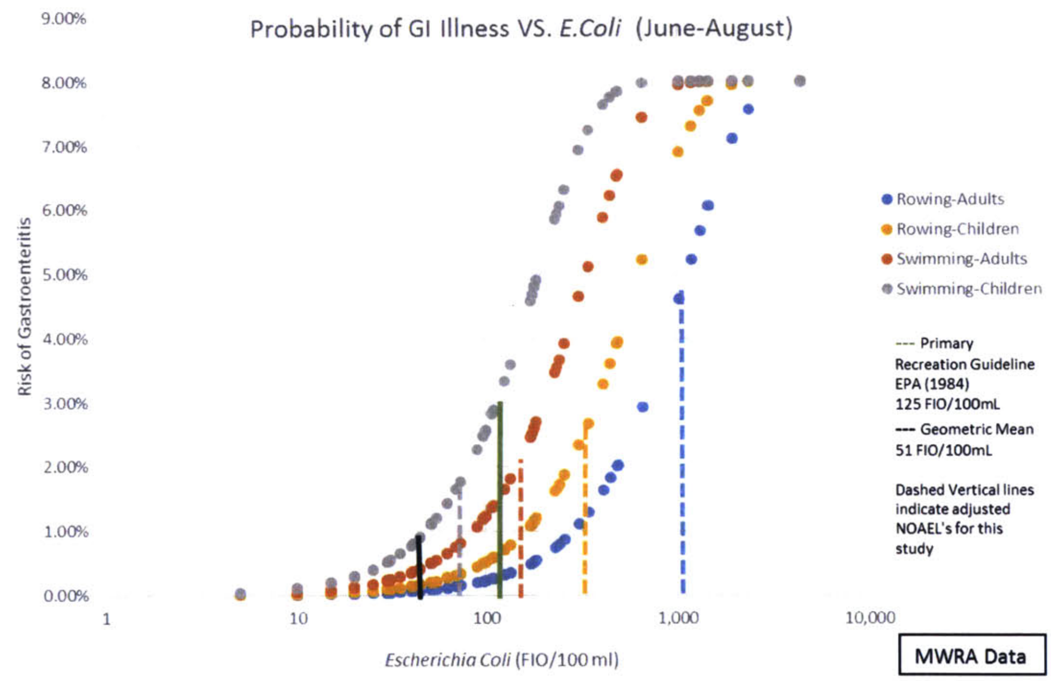
MWRA E. coli Risk Curves



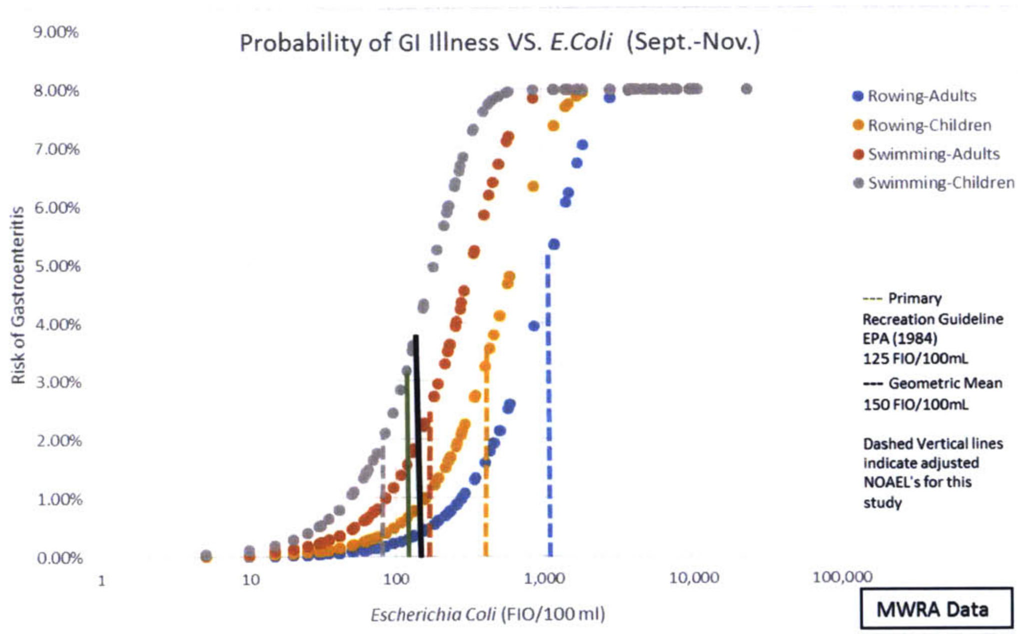




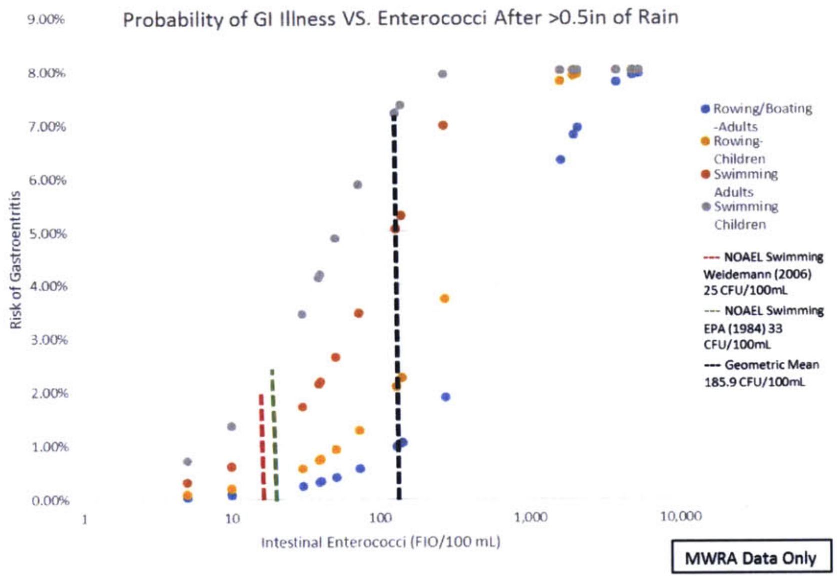
Probability of GI Illness VS. *E.Coli* (March-May)
Risk of Gastroenteritis
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
1
10
100
1000
10000
Escherichia Coli (FIO/100 ml)
Rowing-Adults
Rowing-Children
Swimming-Adults
Swimming-Children
--- Primary Recreation Guideline EPA (1984) 125 FIO/100mL
--- Geometric Mean 87 FIO/100mL
Dashed Vertical lines indicate adjusted NOAEL's for this study
MWRA Data

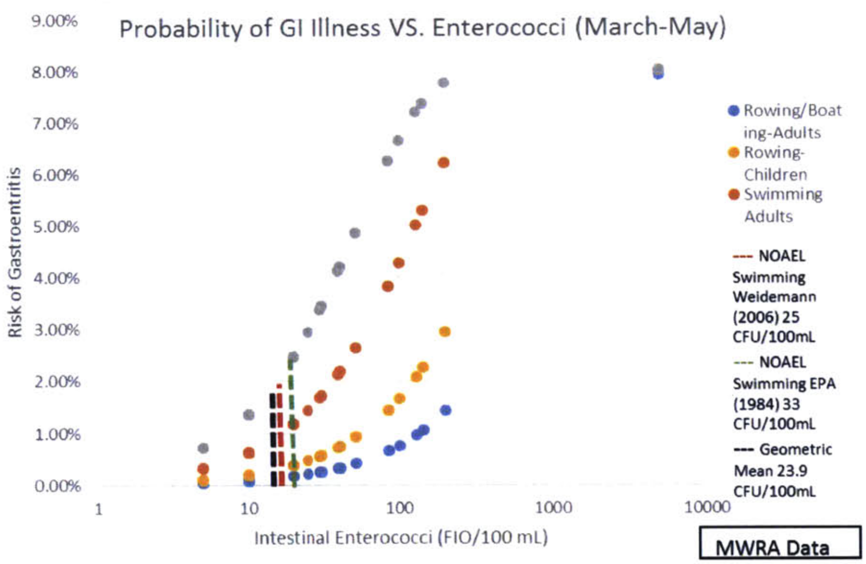


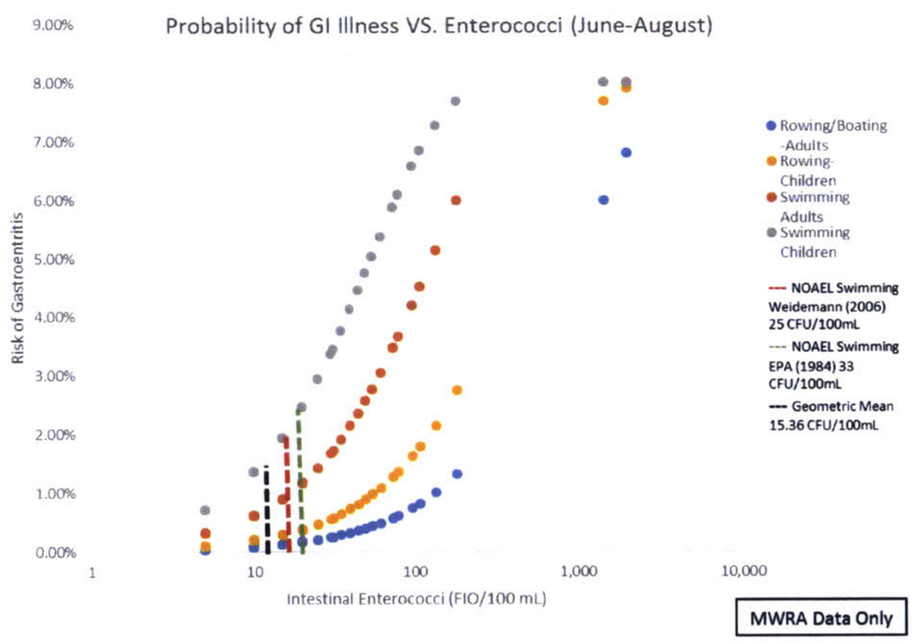
Probability of GI Illness VS. *E.Coli* (June-August)
Risk of Gastroenteritis
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
1
10
100
1,000
10,000
Escherichia Coli (FIO/100 ml)
Rowing-Adults
Rowing-Children
Swimming-Adults
Swimming-Children
--- Primary Recreation Guideline EPA (1984) 125 FIO/100mL
--- Geometric Mean 51 FIO/100mL
Dashed Vertical lines indicate adjusted NOAEL's for this study
MWRA Data

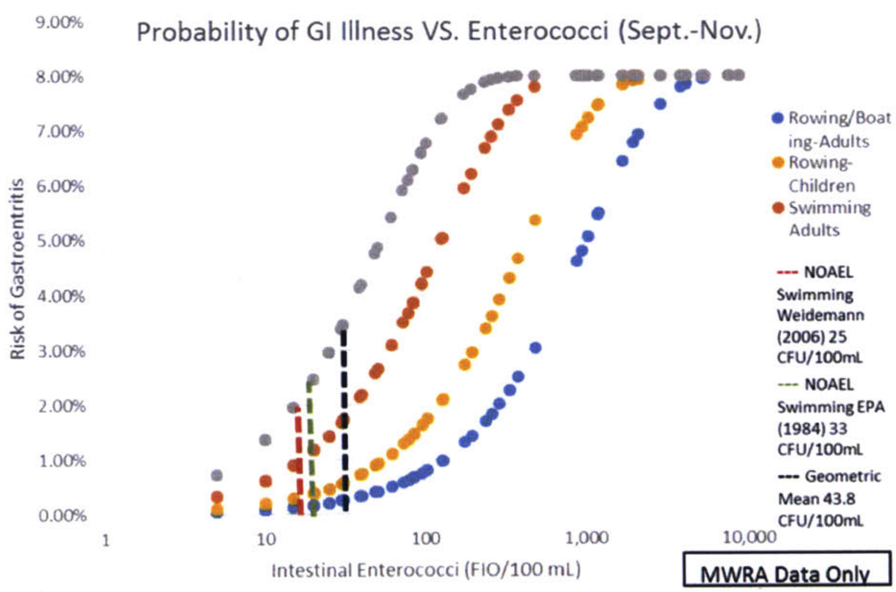

Probability of GI Illness VS. E.Coli (Sept.-Nov.)
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
Risk of Gastroenteritis
1
10
100
1,000
10,000
100,000
Escherichia Coli (FIO/100 ml)
Rowing-Adults
Rowing-Children
Swimming-Adults
Swimming-Children
--- Primary Recreation Guideline EPA (1984) 125 FIO/100mL
--- Geometric Mean 150 FIO/100mL
Dashed Vertical lines indicate adjusted NOAEL's for this study
MWRA Data

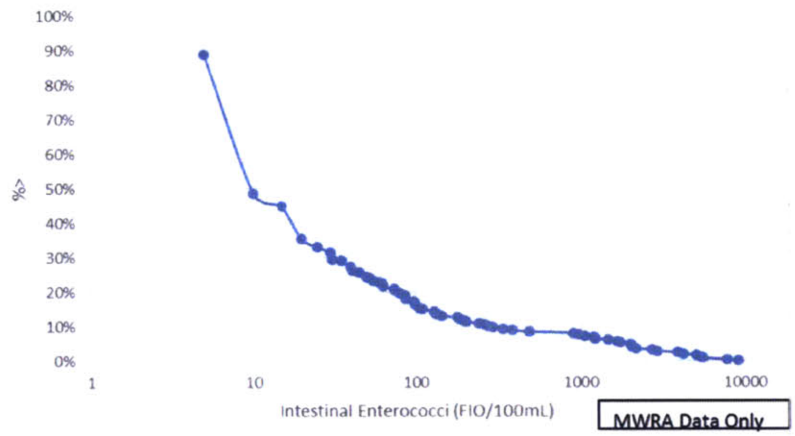
MWRA Enterococci Risk Curves



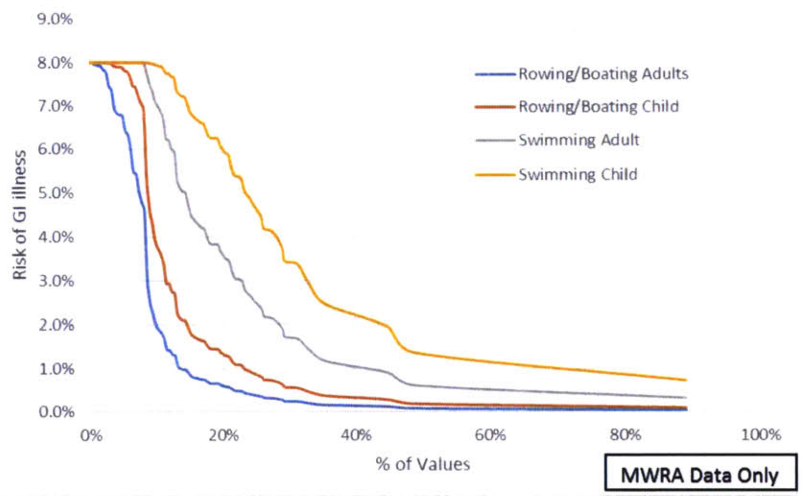



Probability of GI Illness VS. Enterococci (June-August)
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
Risk of Gastroenteritis
1
10
100
1,000
10,000
Intestinal Enterococci (FIO/100 mL)
Rowing/Boating -Adults
Rowing-Children
Swimming Adults
Swimming Children
--- NOAEL Swimming Weidemann (2006) 25 CFU/100mL
--- NOAEL Swimming EPA (1984) 33 CFU/100mL
--- Geometric Mean 15.36 CFU/100mL
MWRA Data Only


Probability of GI Illness VS. Enterococci (Sept.-Nov.)
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
Risk of Gastroenteritis
1
10
100
1,000
10,000
Intestinal Enterococci (FIO/100 mL)
Rowing/Boating-Adults
Rowing-Children
Swimming Adults
--- NOAEL Swimming Weidemann (2006) 25 CFU/100mL
--- NOAEL Swimming EPA (1984) 33 CFU/100mL
--- Geometric Mean 43.8 CFU/100mL
MWRA Data Only



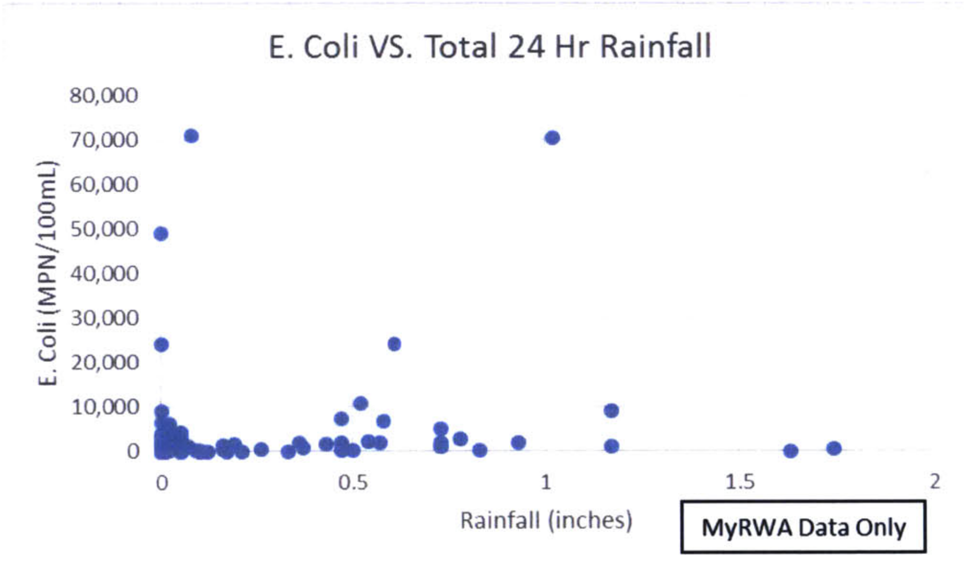
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
%>
1
10
100
1000
10000
Intestinal Enterococci (FIO/100mL)
MWRA Data Only

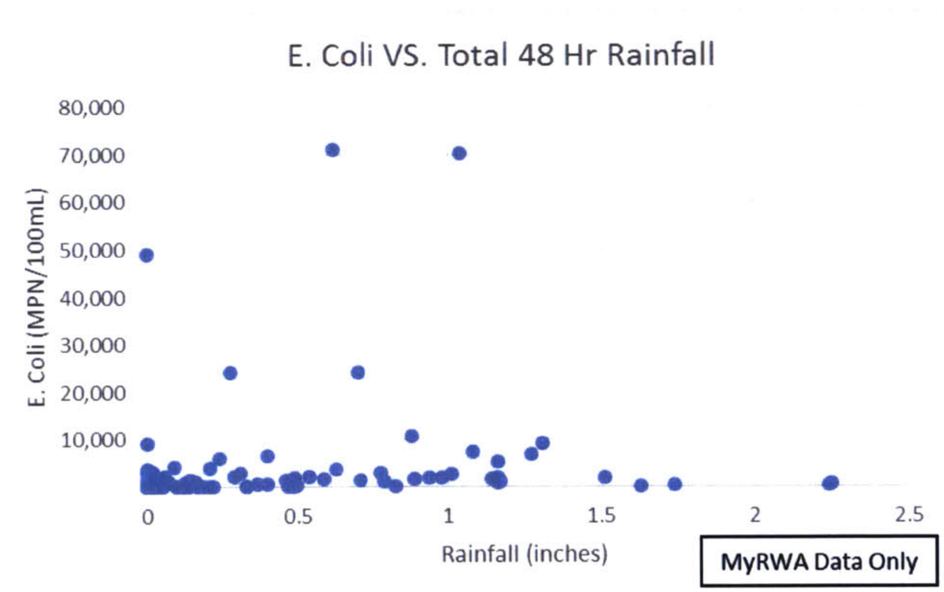


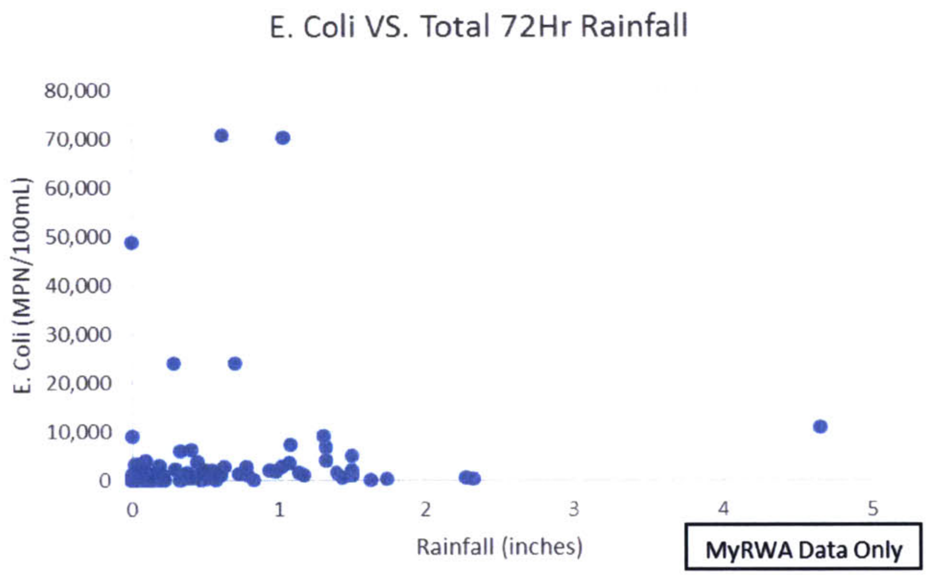
9.0%
8.0%
7.0%
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Risk of GI illness
Rowing/Boating Adults
Rowing/Boating Child
Swimming Adult
Swimming Child
0%
20%
40%
60%
80%
100%
% of Values
MWRA Data Only

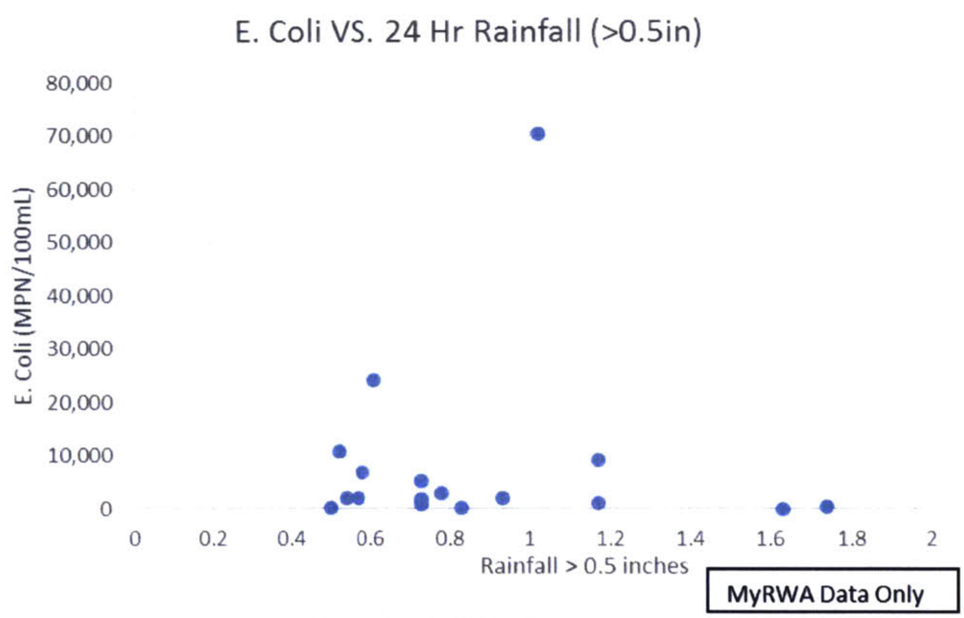
Appendix C

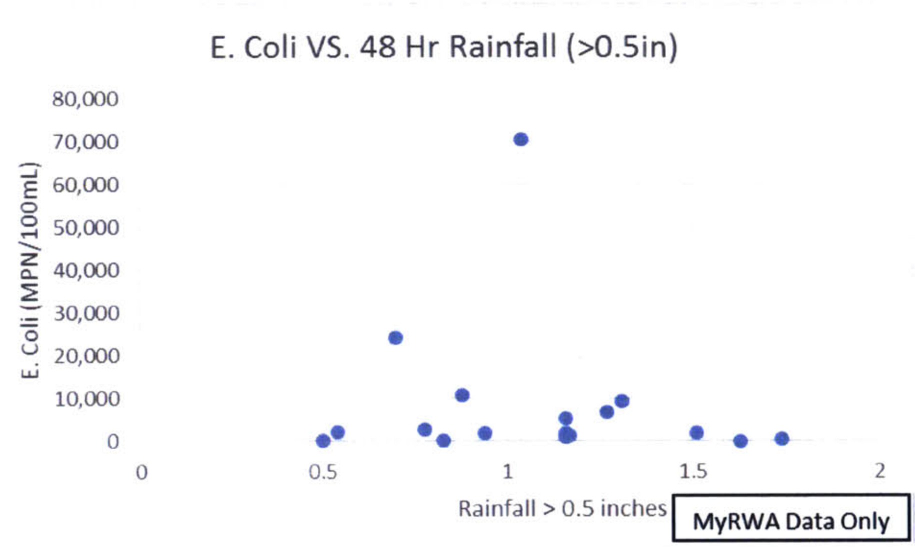
Additional Rainfall Analysis

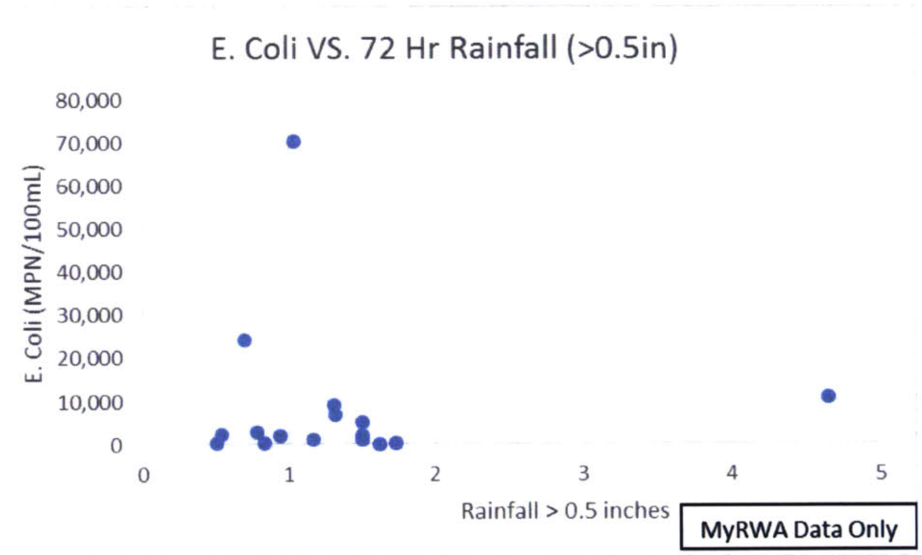


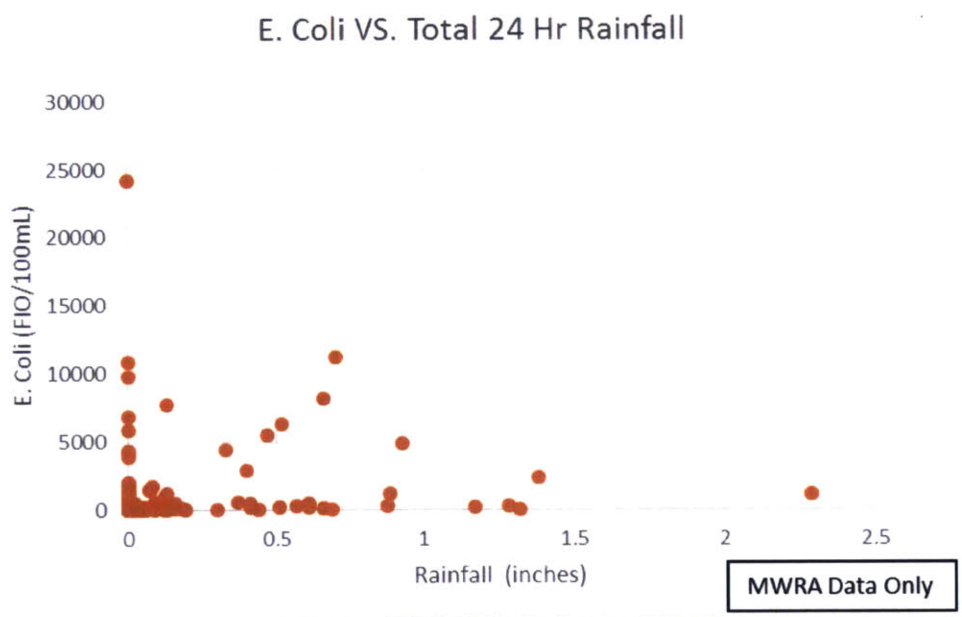


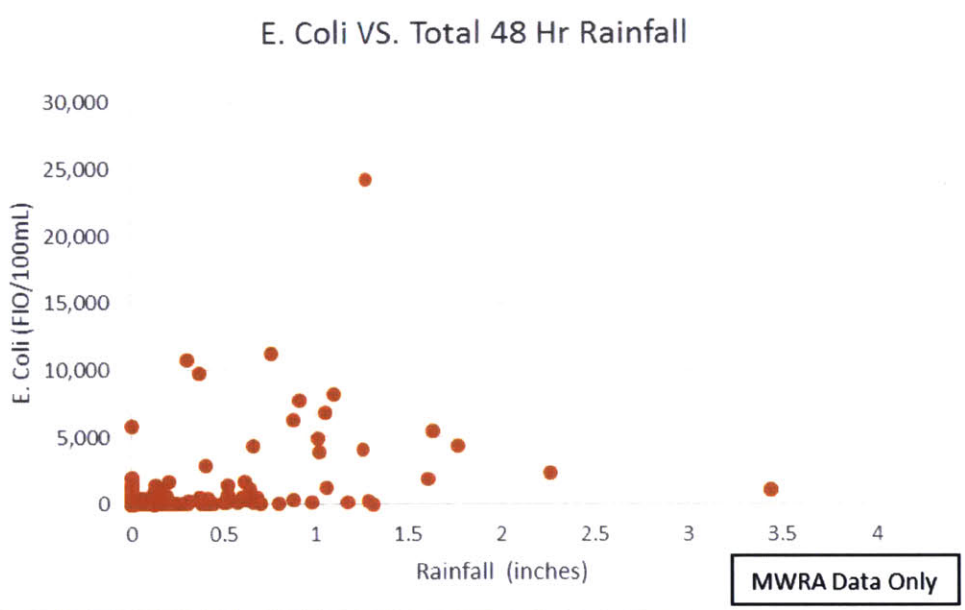

E. Coli VS. Total 72Hr Rainfall
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
E. Coli (MPN/100mL)
0
1
2
3
4
5
Rainfall (inches)
MyRWA Data Only

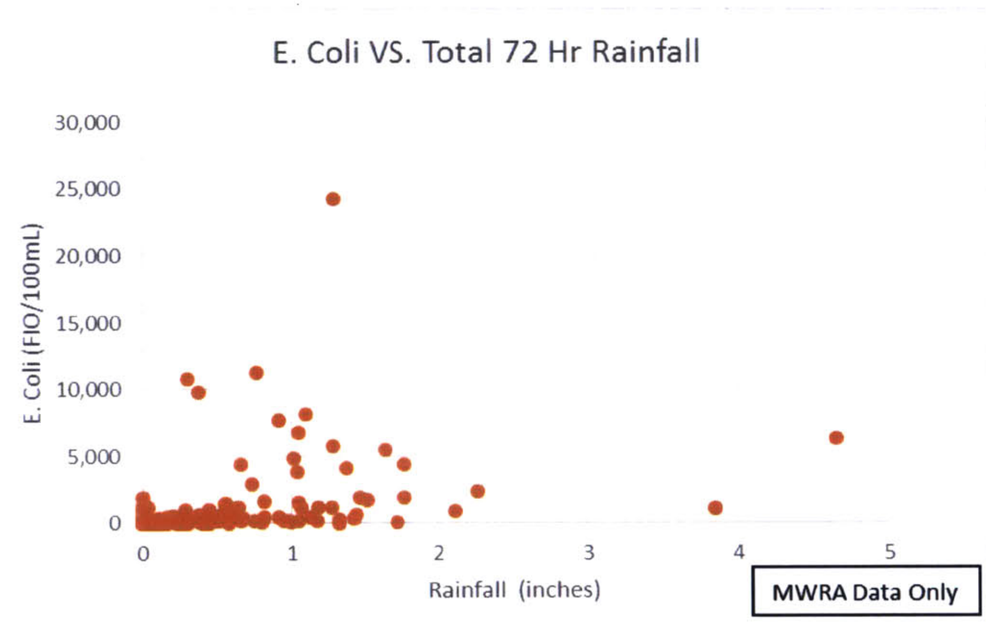

E. Coli VS. 24 Hr Rainfall (>0.5in)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
E. Coli (MPN/100mL)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Rainfall > 0.5 inches
MyRWA Data Only

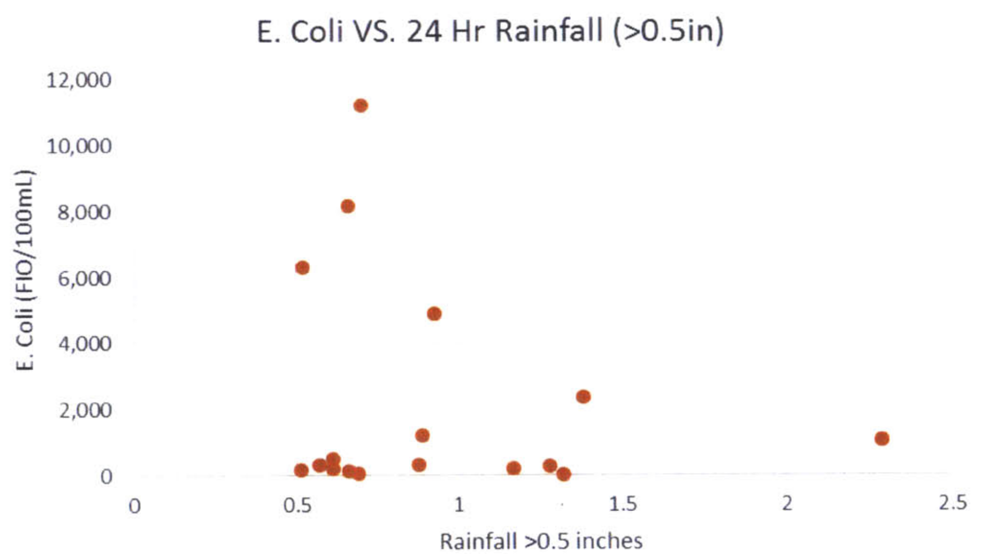

E. Coli VS. 48 Hr Rainfall (>0.5in)
E. Coli (MPN/100mL)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
0.5
1
1.5
2
Rainfall > 0.5 inches
MyRWA Data Only

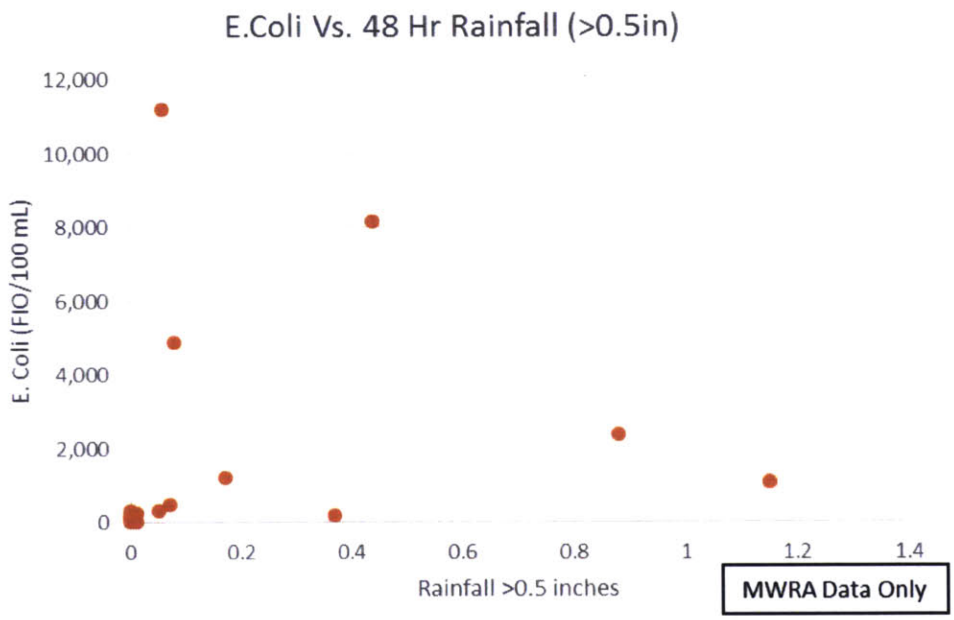

E. Coli VS. 72 Hr Rainfall (>0.5in)
E. Coli (MPN/100mL)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
1
2
3
4
5
Rainfall > 0.5 inches
MyRWA Data Only

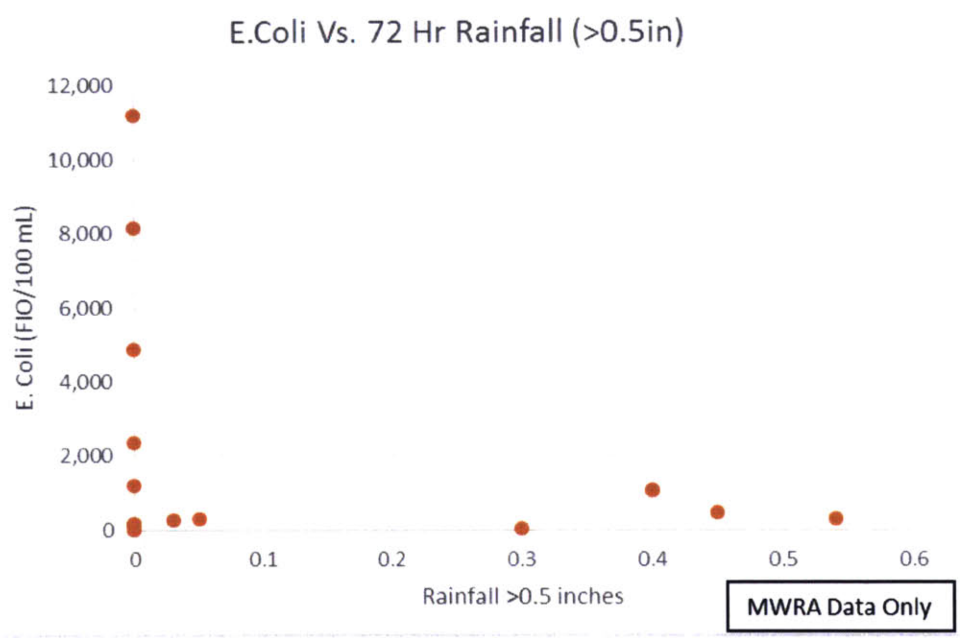

E. Coli VS. Total 24 Hr Rainfall
30000
25000
20000
15000
10000
5000
0
E. Coli (FIO/100mL)
0
0.5
1
1.5
2
2.5
Rainfall (inches)
MWRA Data Only

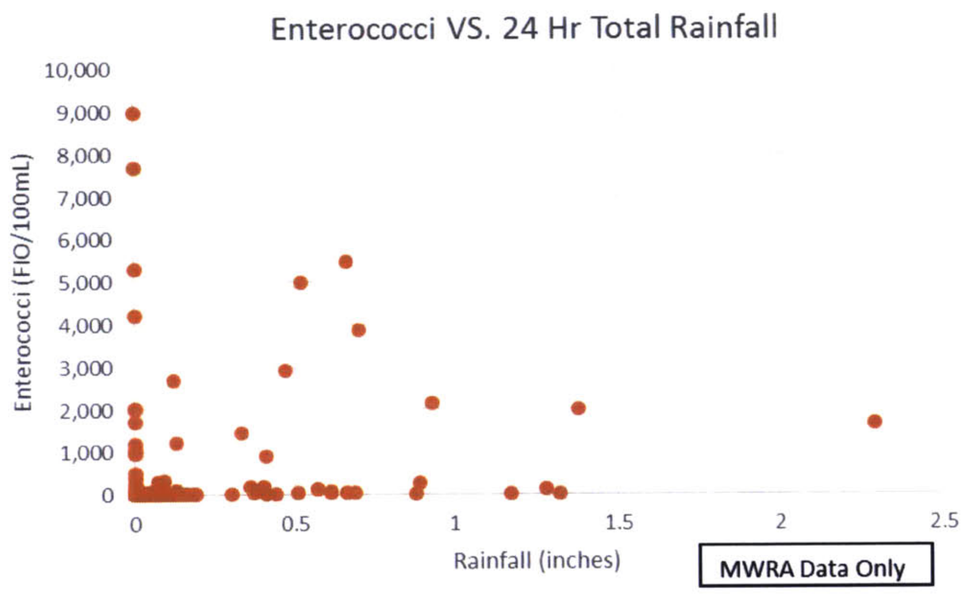

E. Coli VS. Total 48 Hr Rainfall
30,000
25,000
20,000
15,000
10,000
5,000
0
E. Coli (FIO/100mL)
0
0.5
1
1.5
2
2.5
3
3.5
4
Rainfall (inches)
MWRA Data Only


E. Coli VS. Total 72 Hr Rainfall
30,000
25,000
20,000
15,000
10,000
5,000
0
E. Coli (FIO/100mL)
0
1
2
3
4
5
Rainfall (inches)
MWRA Data Only

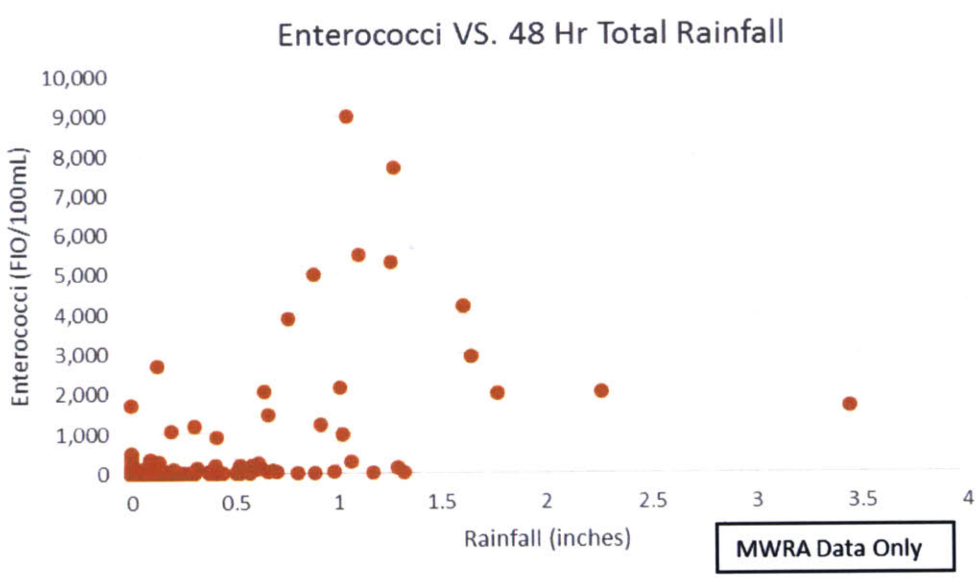

E. Coli VS. 24 Hr Rainfall (>0.5in)
12,000
10,000
8,000
6,000
4,000
2,000
0
E. Coli (FIO/100mL)
0
0.5
1
1.5
2
2.5
Rainfall >0.5 inches


E.Coli Vs. 48 Hr Rainfall (>0.5in)
E. Coli (FIO/100 mL)
12,000
10,000
8,000
6,000
4,000
2,000
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Rainfall >0.5 inches
MWRA Data Only

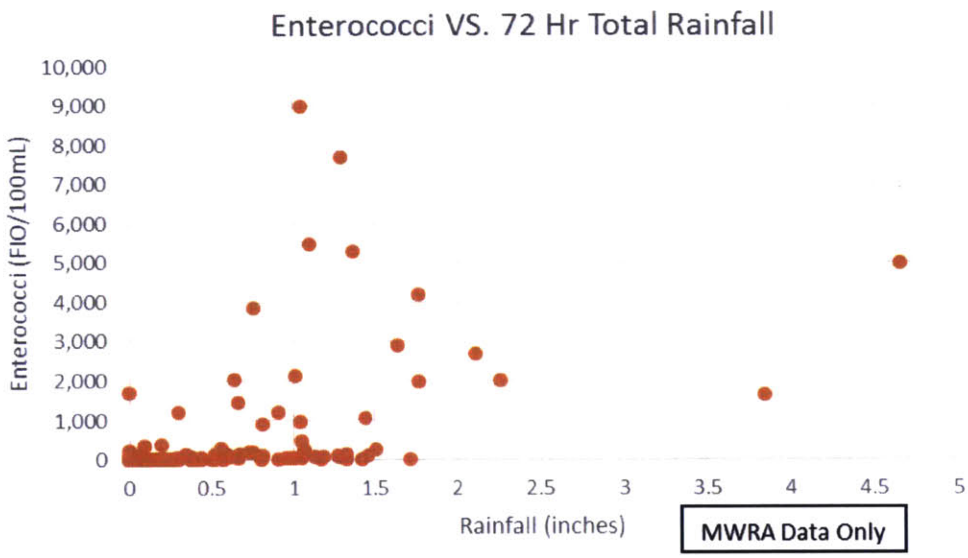

E.Coli Vs. 72 Hr Rainfall (>0.5in)
E. Coli (FIO/100 mL)
12,000
10,000
8,000
6,000
4,000
2,000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Rainfall >0.5 inches
MWRA Data Only

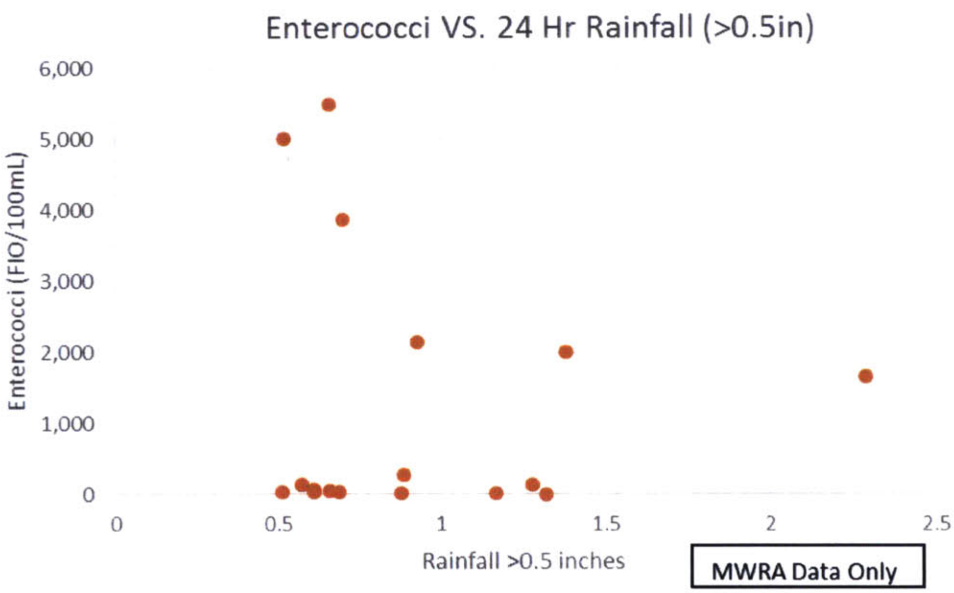


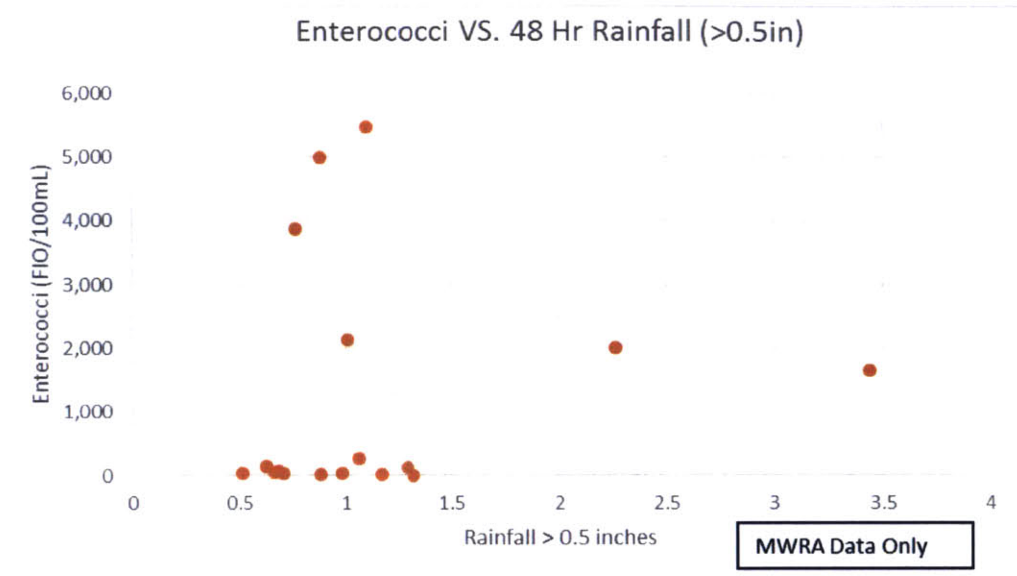
Enterococci VS. 24 Hr Total Rainfall
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Enterococci (FIO/100mL)
0
0.5
1
1.5
2
2.5
Rainfall (inches)
MWRA Data Only



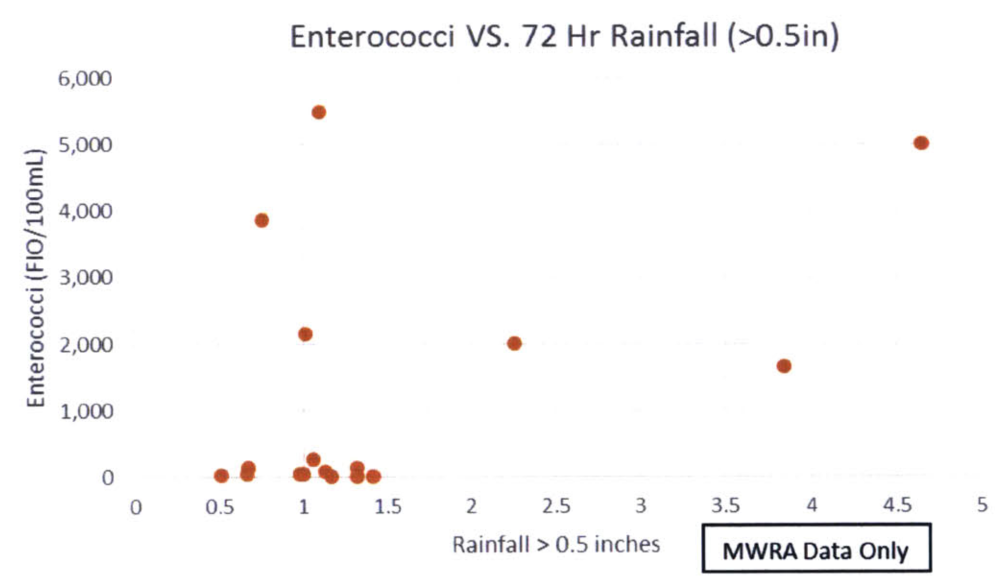
Enterococci VS. 48 Hr Total Rainfall
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Enterococci (FIO/100mL)
0
0.5
1
1.5
2
2.5
3
3.5
4
Rainfall (inches)
MWRA Data Only


Enterococci VS. 72 Hr Total Rainfall
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Enterococci (FIO/100mL)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Rainfall (inches)
MWRA Data Only


Enterococci VS. 24 Hr Rainfall (>0.5in)
6,000
5,000
4,000
3,000
2,000
1,000
0
Enterococci (FIO/100mL)
0
0.5
1
1.5
2
2.5
Rainfall >0.5 inches
MWRA Data Only



Enterococci VS. 48 Hr Rainfall (>0.5in)
Enterococci (FIO/100mL)
6,000
5,000
4,000
3,000
2,000
1,000
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Rainfall > 0.5 inches
MWRA Data Only



Enterococci VS. 72 Hr Rainfall (>0.5in)
Enterococci (FIO/100mL)
6,000
5,000
4,000
3,000
2,000
1,000
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Rainfall > 0.5 inches
MWRA Data Only

Appendix D

Master Spreadsheet

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MyRWA	5/16/2002	9:00 AM	MWRA176	ENT	40	0	0	0.3
MyRWA	1/11/2006	6:00 AM	MAR036	ECOLI	5	0.05	0.05	0.05
MyRWA	10/8/2003	7:00 AM	MAR036	ECOLI	10	0	0	0
MyRWA	6/26/2002	9:00 AM	MWRA176	ENT	20	0	0	0
MWRA	6/27/2002	9:31 AM	MWRA176	ENT	5	1.32	1.32	1.32
MyRWA	6/26/2002	9:00 AM	MWRA176	ECOLI	20	0	0	0
MWRA	6/27/2002	9:31 AM	MWRA176	ECOLI	0	1.32	1.32	1.32
MWRA	7/3/2002	7:46 AM	MWRA176	ENT	15	0	0	0
MWRA	7/3/2002	7:46 AM	MWRA176	ECOLI	30	0	0	0
MyRWA	2/11/2004	6:00 AM	MAR036	ECOLI	10	0	0	0
MWRA	7/17/2002	9:12 AM	MWRA176	ENT	5	0	0	0.05
MWRA	7/17/2002	9:12 AM	MWRA176	ECOLI	30	0	0	0.05
MWRA	7/18/2002	9:03 AM	MWRA176	ECOLI	30	0	0	0
MWRA	7/18/2002	9:03 AM	MWRA176	ENT	5	0	0	0
MWRA	8/6/2002	9:22 AM	MWRA176	ECOLI	20	0	0	0
MyRWA	3/10/2004	6:00 AM	MAR036	ECOLI	10	0.01	0.19	0.19
MyRWA	4/13/2005	6:00 AM	MAR036	ECOLI	10	0	0.03	0.03
MWRA	8/6/2002	9:22 AM	MWRA176	ENT	5	0	0	0
MWRA	9/11/2002	7:51 AM	MWRA176	ECOLI	10	0	0	0
MWRA	10/2/2002	9:46 AM	MWRA176	ECOLI	60	0	0	0
MWRA	9/11/2002	7:51 AM	MWRA176	ENT	5	0	0	0
MWRA	10/3/2002	9:33 AM	MWRA176	ECOLI	200	0.01	0.01	0.01
MyRWA	5/11/2005	6:00 AM	MAR036	ECOLI	10	0	0	0
MWRA	10/24/2002	9:28 AM	MWRA176	ECOLI	10	0	0.28	0.28
MWRA	10/25/2002	8:02 AM	MWRA176	ECOLI	10	0	0	0.28
MWRA	10/2/2002	9:46 AM	MWRA176	ENT	10	0	0	0
MyRWA	4/12/2006	6:00 AM	MAR036	ECOLI	10	0	0	0
MWRA	10/3/2002	9:33 AM	MWRA176	ENT	5	0.01	0.01	0.01
MWRA	11/19/2002	9:03 AM	MWRA176	ECOLI	600	0	0.19	1.44
MWRA	10/24/2002	9:28 AM	MWRA176	ENT	5	0	0.28	0.28
MWRA	11/20/2002	8:40 AM	MWRA176	ECOLI	240	0	0	0.19
MWRA	10/25/2002	8:02 AM	MWRA176	ENT	50	0	0	0.28
MyRWA	2/21/2007	6:00 AM	MAR036	ECOLI	10	0	0	0

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	12/16/2002	8:57 AM	MWRA176	ECOLI	870	0.12	0.12	2.11
MWRA	11/19/2002	9:03 AM	MWRA176	ENT	1050	0	0.19	1.44
MyRWA	9/11/2002	6:00 AM	MAR036	ECOLI	20	0	0	0
MyRWA	1/12/2005	6:00 AM	MAR036	ECOLI	20	0.1	0.49	0.57
MWRA	11/20/2002	8:40 AM	MWRA176	ENT	385	0	0	0.19
MyRWA	10/17/2007	6:00 AM	MAR036	ECOLI	20	0	0	0
MWRA	12/16/2002	8:57 AM	MWRA176	ENT	2700	0.12	0.12	2.11
MWRA	5/7/2003	9:28 AM	MWRA176	ECOLI	10	0	0.02	0.02
MWRA	5/7/2003	9:28 AM	MWRA176	ENT	5	0	0.02	0.02
MWRA	5/8/2003	9:00 AM	MWRA176	ECOLI	5	0.12	0.12	0.14
MWRA	5/8/2003	9:00 AM	MWRA176	ENT	10	0.12	0.12	0.14
MyRWA	11/14/2007	6:00 AM	MAR036	ECOLI	20	0	0.22	0.22
MWRA	6/4/2003	9:20 AM	MWRA176	ENT	40	0.03	0.03	0.03
MWRA	6/4/2003	9:20 AM	MWRA176	ECOLI	180	0.03	0.03	0.03
MWRA	6/5/2003	9:20 AM	MWRA176	ECOLI	100	0.13	0.16	0.16
MyRWA	11/19/2008	6:00 AM	MAR036	ECOLI	20	0	0	0
MWRA	6/25/2003	7:36 AM	MWRA176	ECOLI	90	0	0	0.03
MWRA	6/5/2003	9:20 AM	MWRA176	ENT	25	0.13	0.16	0.16
MWRA	6/26/2003	7:45 AM	MWRA176	ECOLI	45	0	0	0
MWRA	6/25/2003	7:36 AM	MWRA176	ENT	5	0	0	0.03
MyRWA	7/21/2010	6:00 AM	MAR036	ECOLI	20	0.05	0.05	0.05
MWRA	7/16/2003	9:11 AM	MWRA176	ECOLI	490	0.02	0.02	0.02
MyRWA	7/9/2003	6:00 AM	MAR036	ENT	30	0.1	0.1	0.1
MWRA	7/17/2003	8:46 AM	MWRA176	ECOLI	10	0	0.02	0.02
MWRA	6/26/2003	7:45 AM	MWRA176	ENT	5	0	0	0
MWRA	7/16/2003	9:11 AM	MWRA176	ENT	30	0.02	0.02	0.02
MWRA	8/13/2003	8:57 AM	MWRA176	ECOLI	110	0.05	0.09	0.09
MWRA	7/17/2003	8:46 AM	MWRA176	ENT	50	0	0.02	0.02
MyRWA	2/8/2006	6:00 AM	MAR036	ECOLI	30	0	0	0
MWRA	8/13/2003	8:57 AM	MWRA176	ENT	80	0.05	0.09	0.09
MWRA	8/14/2003	9:32 AM	MWRA176	ECOLI	40	0	0.05	0.09
MWRA	8/14/2003	9:32 AM	MWRA176	ENT	10	0	0.05	0.09
MWRA	9/3/2003	9:14 AM	MWRA176	ECOLI	10	0	0.4	0.4
MWRA	9/3/2003	9:14 AM	MWRA176	ENT	5	0	0.4	0.4
MWRA	9/4/2003	9:14 AM	MWRA176	ECOLI	445	0.41	0.41	0.81
MWRA	9/4/2003	9:14 AM	MWRA176	ENT	895	0.41	0.41	0.81
MyRWA	10/11/2006	6:00 AM	MAR036	ECOLI	31	0.33	0.33	0.33
MWRA	9/24/2003	8:56 AM	MWRA176	ENT	9000	0	1.05	1.05

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	9/24/2003	8:56 AM	MWRA176	ECOLI	6800	0	1.05	1.05
MWRA	9/25/2003	9:11 AM	MWRA176	ENT	490	0	0	1.05
MWRA	9/25/2003	9:11 AM	MWRA176	ECOLI	1500	0	0	1.05
MWRA	11/4/2003	8:44 AM	MWRA176	ENT	130	0.01	0.31	0.34
MyRWA	5/28/2002	7:00 AM	MAR036	ECOLI	40	0	0	0
MWRA	11/4/2003	8:44 AM	MWRA176	ECOLI	260	0.01	0.31	0.34
MWRA	11/5/2003	8:35 AM	MWRA176	ENT	40	0.69	0.7	1
MWRA	11/5/2003	8:35 AM	MWRA176	ECOLI	30	0.69	0.7	1
MyRWA	3/21/2012	6:00 AM	MAR036	ECOLI	41	0	0	0
MyRWA	3/12/2003	6:00 AM	MAR036	ECOLI	50	0	0	0
MyRWA	6/11/2003	6:00 AM	MAR036	ECOLI	50	0.21	0.21	0.21
MyRWA	6/9/2004	6:00 AM	MAR036	ECOLI	50	0.12	0.12	0.12
MWRA	5/5/2004	9:47 AM	MWRA176	ENT	100	0	0.2	0.81
MWRA	5/5/2004	9:47 AM	MWRA176	ECOLI	1660	0	0.2	0.81
MWRA	5/6/2004	9:06 AM	MWRA176	ECOLI	550	0	0	0.2
MyRWA	9/8/2004	6:00 AM	MAR036	ECOLI	50	1.63	1.63	1.63
MWRA	5/26/2004	9:18 AM	MWRA176	ECOLI	140	0.08	0.08	0.75
MWRA	5/6/2004	9:06 AM	MWRA176	ENT	25	0	0	0.2
MyRWA	7/16/2008	6:00 AM	MAR036	ECOLI	52	0	0	0.07
MWRA	5/26/2004	9:18 AM	MWRA176	ENT	200	0.08	0.08	0.75
MWRA	6/14/2004	9:41 AM	MWRA176	ECOLI	30	0	0	0
MWRA	6/17/2004	9:12 AM	MWRA176	ECOLI	5	0.01	0.01	0.01
MWRA	6/14/2004	9:41 AM	MWRA176	ENT	15	0	0	0
MWRA	6/17/2004	9:12 AM	MWRA176	ENT	135	0.01	0.01	0.01
MWRA	7/8/2004	9:28 AM	MWRA176	ECOLI	20	0.06	0.06	0.06
MWRA	7/9/2004	10:00 AM	MWRA176	ECOLI	15	0	0.06	0.06
MWRA	7/8/2004	9:28 AM	MWRA176	ENT	5	0.06	0.06	0.06
MyRWA	12/14/2005	6:00 AM	MAR036	ECOLI	60	0	0	0
MWRA	8/2/2004	9:39 AM	MWRA176	ECOLI	5	0	0	0
MWRA	7/9/2004	10:00 AM	MWRA176	ENT	25	0	0.06	0.06
MWRA	8/3/2004	8:17 AM	MWRA176	ECOLI	5	0	0	0
MyRWA	5/21/2008	6:00 AM	MAR036	ECOLI	62	0	0.33	0.33
MWRA	8/2/2004	9:39 AM	MWRA176	ENT	5	0	0	0
MWRA	8/23/2004	9:41 AM	MWRA176	ECOLI	180	0	0	1.05
MWRA	8/3/2004	8:17 AM	MWRA176	ENT	15	0	0	0
MWRA	8/24/2004	9:28 AM	MWRA176	ECOLI	100	0	0	0
MWRA	8/23/2004	9:41 AM	MWRA176	ENT	55	0	0	1.05
MyRWA	9/13/2006	6:00 AM	MAR036	ECOLI	63	0	0	0

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	9/14/2004	9:33 AM	MWRA176	ECOLI	50	0	0	0
MWRA	8/24/2004	9:28 AM	MWRA176	ENT	10	0	0	0
MWRA	9/15/2004	9:06 AM	MWRA176	ECOLI	70	0	0	0
MWRA	9/14/2004	9:33 AM	MWRA176	ENT	5	0	0	0
MWRA	10/7/2004	9:32 AM	MWRA176	ECOLI	30	0	0	0
MWRA	9/15/2004	9:06 AM	MWRA176	ENT	15	0	0	0
MWRA	10/8/2004	9:03 AM	MWRA176	ECOLI	5	0	0	0
MyRWA	10/15/2008	6:00 AM	MAR036	ECOLI	63	0	0	0
MWRA	10/27/2004	9:31 AM	MWRA176	ECOLI	30	0	0	0
MWRA	10/7/2004	9:32 AM	MWRA176	ENT	5	0	0	0
MWRA	10/28/2004	9:24 AM	MWRA176	ECOLI	10	0	0	0
MyRWA	8/19/2009	6:00 AM	MAR036	ECOLI	63	0	0	0
MWRA	10/8/2004	9:03 AM	MWRA176	ENT	10	0	0	0
MWRA	11/22/2004	10:39 AM	MWRA176	ECOLI	20	0	0.01	0.09
MWRA	10/27/2004	9:31 AM	MWRA176	ENT	10	0	0	0
MWRA	11/23/2004	10:42 AM	MWRA176	ECOLI	20	0	0	0.01
MWRA	10/28/2004	9:24 AM	MWRA176	ENT	10	0	0	0
MWRA	11/22/2004	10:39 AM	MWRA176	ENT	15	0	0.01	0.09
MyRWA	11/10/2004	6:00 AM	MAR036	ECOLI	70	0	0	0
MWRA	11/23/2004	10:42 AM	MWRA176	ENT	25	0	0	0.01
MyRWA	7/18/2007	6:00 AM	MAR036	ECOLI	74	0.17	0.17	0.17
MyRWA	2/9/2005	6:00 AM	MAR036	ECOLI	80	0	0	0
MyRWA	7/9/2003	6:00 AM	MAR036	ECOLI	90	0.1	0.1	0.1
MWRA	5/4/2005	8:18 AM	MWRA176	ENT	85	0	0	0.04
MWRA	5/4/2005	8:18 AM	MWRA176	ECOLI	75	0	0	0.04
MWRA	5/6/2005	7:57 AM	MWRA176	ECOLI	10	0.04	0.04	0.04
MyRWA	9/10/2003	7:00 AM	MAR036	ECOLI	100	0	0	0
MWRA	6/2/2005	9:44 AM	MWRA176	ECOLI	25	0	0	0.01
MWRA	5/6/2005	7:57 AM	MWRA176	ENT	5	0.04	0.04	0.04
MWRA	6/3/2005	10:01 AM	MWRA176	ECOLI	25	0	0	0
MWRA	6/2/2005	9:44 AM	MWRA176	ENT	40	0	0	0.01
MyRWA	11/12/2003	6:00 AM	MAR036	ECOLI	100	0	0.14	0.14
MWRA	6/20/2005	9:04 AM	MWRA176	ECOLI	15	0	0	0
MWRA	6/22/2005	9:21 AM	MWRA176	ECOLI	10	0.03	0.03	0.03
MyRWA	4/16/2008	6:00 AM	MAR036	ECOLI	110	0	0	0
MWRA	7/13/2005	9:25 AM	MWRA176	ECOLI	40	0	0	0
MWRA	6/3/2005	10:01 AM	MWRA176	ENT	15	0	0	0
MWRA	7/14/2005	9:40 AM	MWRA176	ECOLI	35	0	0	0

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	6/20/2005	9:04 AM	MWRA176	ENT	5	0	0	0
MWRA	6/22/2005	9:21 AM	MWRA176	ENT	15	0.03	0.03	0.03
MWRA	8/2/2005	9:43 AM	MWRA176	ECOLI	125	0.01	0.57	0.57
MWRA	8/3/2005	10:52 AM	MWRA176	ECOLI	15	0	0.01	0.57
MWRA	7/13/2005	9:25 AM	MWRA176	ENT	10	0	0	0
MyRWA	8/20/2008	6:00 AM	MAR036	ECOLI	110	0	0	0.02
MWRA	7/14/2005	9:40 AM	MWRA176	ENT	15	0	0	0
MWRA	8/24/2005	9:10 AM	MWRA176	ECOLI	5	0	0	0
MWRA	8/25/2005	9:46 AM	MWRA176	ECOLI	5	0	0	0
MWRA	8/2/2005	9:43 AM	MWRA176	ENT	20	0.01	0.57	0.57
MWRA	8/30/2005	7:54 AM	MWRA176	ECOLI	4400	0.33	0.66	0.66
MWRA	9/13/2005	7:47 AM	MWRA176	ECOLI	35	0	0	0
MWRA	8/3/2005	10:52 AM	MWRA176	ENT	5	0	0.01	0.57
MyRWA	9/14/2005	8:00 AM	MWRA176	ECOLI	25	0	0	0
MWRA	9/14/2005	8:24 AM	MWRA176	ECOLI	25	0	0	0
MWRA	8/24/2005	9:10 AM	MWRA176	ENT	10	0	0	0
MWRA	10/4/2005	7:44 AM	MWRA176	ECOLI	15	0	0	0
MWRA	8/25/2005	9:46 AM	MWRA176	ENT	20	0	0	0
MWRA	8/30/2005	7:54 AM	MWRA176	ENT	1460	0.33	0.66	0.66
MWRA	10/5/2005	8:50 AM	MWRA176	ECOLI	25	0	0	0
MyRWA	3/18/2009	6:00 AM	MAR036	ECOLI	110	0	0	0
MWRA	9/13/2005	7:47 AM	MWRA176	ENT	30	0	0	0
MWRA	10/26/2005	7:00 AM	MWRA176	ECOLI	4100	0	1.26	1.37
MWRA	11/1/2005	11:00 AM	MWRA176	ECOLI	50	0	0	0
MyRWA	9/14/2005	8:00 AM	MWRA176	ENT	20	0	0	0
MWRA	11/4/2005	9:55 AM	MWRA176	ECOLI	5	0	0	0
MWRA	9/14/2005	8:24 AM	MWRA176	ENT	20	0	0	0
MWRA	11/10/2005	8:39 AM	MWRA176	ECOLI		0.36	0.58	0.58
MWRA	11/21/2005	10:13 AM	MWRA176	ECOLI	70	0.16	0.16	0.16
MWRA	10/4/2005	7:44 AM	MWRA176	ENT	25	0	0	0
MWRA	11/23/2005	8:15 AM	MWRA176	ECOLI	1900	0	1.61	1.77
MWRA	10/5/2005	8:50 AM	MWRA176	ENT	80	0	0	0
MWRA	10/26/2005	7:00 AM	MWRA176	ENT	5300	0	1.26	1.37
MWRA	12/1/2005	9:35 AM	MWRA176	ECOLI	1160	0	0.64	0.64
MyRWA	6/17/2009	6:00 AM	MAR036	ECOLI	110	0	0	0
MWRA	11/1/2005	11:00 AM	MWRA176	ENT	75	0	0	0
MyRWA	6/20/2012	7:00 AM	MAR036	ECOLI	134	0	0	0
MyRWA	8/11/2004	6:00 AM	MAR036	ECOLI	140	0	0	0

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	11/4/2005	9:55 AM	MWRA176	ENT	5	0	0	0
MWRA	11/10/2005	8:39 AM	MWRA176	ENT	180	0.36	0.58	0.58
MyRWA	12/13/2006	6:00 AM	MAR036	ECOLI	146	0.1	0.1	0.1
MWRA	11/21/2005	10:13 AM	MWRA176	ENT	25	0.16	0.16	0.16
MyRWA	8/15/2012	6:00 AM	MAR036	ECOLI	148	0.83	0.83	0.83
MyRWA	7/13/2005	6:00 AM	MAR036	ECOLI	150	0	0	0
MWRA	5/16/2006	7:59 AM	MWRA176	ECOLI	6300	0.52	0.88	4.65
MyRWA	8/10/2005	6:00 AM	MAR036	ECOLI	150	0	0.02	0.02
MWRA	5/18/2006	8:11 AM	MWRA176	ECOLI	370	0	0	0.52
MWRA	5/31/2006	9:20 AM	MWRA176	ECOLI	25	0	0	0
MWRA	6/1/2006	9:21 AM	MWRA176	ECOLI	235	0.12	0.12	0.12
MWRA	11/23/2005	8:15 AM	MWRA176	ENT	4200	0	1.61	1.77
MyRWA	8/14/2002	6:00 AM	MAR036	ECOLI	160	0	0	0
MWRA	12/1/2005	9:35 AM	MWRA176	ENT	2040	0	0.64	0.64
MyRWA	5/12/2004	6:00 AM	MAR036	ECOLI	160	0	0	0
MWRA	5/16/2006	7:59 AM	MWRA176	ENT	5000	0.52	0.88	4.65
MWRA	6/27/2006	9:22 AM	MWRA176	ECOLI	180	0	0	0.95
MWRA	5/18/2006	8:11 AM	MWRA176	ENT	130	0	0	0.52
MWRA	6/28/2006	11:07 AM	MWRA176	ECOLI	185	0.05	0.05	0.05
MyRWA	9/18/2013	6:00 AM	MAR036	ECOLI	169	0	0	0
MWRA	7/19/2006	8:46 AM	MWRA176	ECOLI	30	0.19	0.41	0.41
MWRA	5/31/2006	9:20 AM	MWRA176	ENT	5	0	0	0
MWRA	6/1/2006	9:21 AM	MWRA176	ENT	5	0.12	0.12	0.12
MWRA	7/20/2006	8:27 AM	MWRA176	ECOLI	30	0	0.19	0.41
MWRA	8/7/2006	9:26 AM	MWRA176	ECOLI	45	0.04	0.04	0.04
MWRA	6/27/2006	9:22 AM	MWRA176	ENT	55	0	0	0.95
MWRA	8/8/2006	8:54 AM	MWRA176	ECOLI	10	0	0.04	0.04
MWRA	6/28/2006	11:07 AM	MWRA176	ENT	45	0.05	0.05	0.05
MyRWA	5/20/2009	7:00 AM	MAR036	ECOLI	189	0	0	0
MWRA	8/21/2006	9:16 AM	MWRA176	ECOLI	70	0	0.8	0.8
MWRA	7/19/2006	8:46 AM	MWRA176	ENT	5	0.19	0.41	0.41
MWRA	8/22/2006	8:38 AM	MWRA176	ECOLI	55	0	0	0.8
MWRA	7/20/2006	8:27 AM	MWRA176	ENT	5	0	0.19	0.41
MyRWA	10/13/2004	6:00 AM	MAR036	ECOLI	190	0	0.05	0.05
MWRA	9/14/2006	9:30 AM	MWRA176	ECOLI	15	0.3	0.3	0.3
MWRA	8/7/2006	9:26 AM	MWRA176	ENT	35	0.04	0.04	0.04
MWRA	9/15/2006	8:57 AM	MWRA176	ECOLI	10800	0	0.3	0.3
MWRA	10/2/2006	10:09 AM	MWRA176	ECOLI	70	0	0.38	0.38

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	8/8/2006	8:54 AM	MWRA176	ENT	5	0	0.04	0.04
MWRA	10/3/2006	9:12 AM	MWRA176	ECOLI	65	0	0	0.38
MWRA	8/21/2006	9:16 AM	MWRA176	ENT	20	0	0.8	0.8
MyRWA	4/9/2003	7:00 AM	MAR036	ECOLI	200	0.09	0.13	0.13
MWRA	10/16/2006	9:21 AM	MWRA176	ECOLI	20	0	0	0
MWRA	10/17/2006	8:45 AM	MWRA176	ECOLI	35	0.13	0.13	0.13
MWRA	8/22/2006	8:38 AM	MWRA176	ENT	5	0	0	0.8
MWRA	10/31/2006	8:38 AM	MWRA176	ECOLI	870	0	0	0
MWRA	11/1/2006	9:48 AM	MWRA176	ECOLI	280	0.09	0.09	0.09
MWRA	9/14/2006	9:30 AM	MWRA176	ENT	5	0.3	0.3	0.3
MyRWA	7/20/2011	7:00 AM	MAR036	ECOLI	203	0	0	0
MWRA	9/15/2006	8:57 AM	MWRA176	ENT	1200	0	0.3	0.3
MWRA	11/20/2006	10:05 AM	MWRA176	ECOLI	220	0	0	0
MWRA	10/2/2006	10:09 AM	MWRA176	ENT	50	0	0.38	0.38
MWRA	11/21/2006	9:20 AM	MWRA176	ECOLI	120	0	0	0
MyRWA	5/21/2014	6:00 AM	MAR036	ECOLI	218	0	0	0
MWRA	12/19/2006	8:55 AM	MWRA176	ECOLI	10	0	0.02	0.02
MWRA	10/3/2006	9:12 AM	MWRA176	ENT	15	0	0	0.38
MWRA	12/20/2006	8:58 AM	MWRA176	ECOLI	20	0	0	0.02
MyRWA	3/8/2006	6:00 AM	MAR036	ECOLI	240	0	0	0
MWRA	10/16/2006	9:21 AM	MWRA176	ENT	5	0	0	0
MWRA	10/17/2006	8:45 AM	MWRA176	ENT	10	0.13	0.13	0.13
MyRWA	7/15/2009	6:00 AM	MAR036	ECOLI	243	0	0	0
MWRA	10/31/2006	8:38 AM	MWRA176	ENT	1720	0	0	0
MWRA	11/1/2006	9:48 AM	MWRA176	ENT	340	0.09	0.09	0.09
MyRWA	3/19/2008	6:00 AM	MAR036	ECOLI	246	0.47	0.47	0.47
MyRWA	10/16/2013	6:00 AM	MAR036	ECOLI	246	0	0	0
MWRA	11/20/2006	10:05 AM	MWRA176	ENT	240	0	0	0
MyRWA	4/18/2012	6:00 AM	MAR036	ECOLI	253	0	0	0
MWRA	5/9/2007	9:42 AM	MWRA176	ECOLI	41	0	0	0
MWRA	11/21/2006	9:20 AM	MWRA176	ENT	105	0	0	0
MWRA	12/19/2006	8:55 AM	MWRA176	ENT	105	0	0.02	0.02
MWRA	5/10/2007	9:06 AM	MWRA176	ECOLI	20	0	0	0
MWRA	12/20/2006	8:58 AM	MWRA176	ENT	60	0	0	0.02
MWRA	6/6/2007	9:20 AM	MWRA176	ECOLI	1940	0	0	1.46
MWRA	6/7/2007	9:34 AM	MWRA176	ECOLI	231	0	0	0
MWRA	5/9/2007	9:42 AM	MWRA176	ENT	10	0	0	0
MWRA	6/20/2007	9:45 AM	MWRA176	ECOLI	413	0.16	0.16	0.16

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	5/10/2007	9:06 AM	MWRA176	ENT	20	0	0	0
MWRA	6/6/2007	9:20 AM	MWRA176	ENT	109	0	0	1.46
MyRWA	5/15/2013	6:00 AM	MAR036	ECOLI	259	0	0	0
MWRA	6/21/2007	9:21 AM	MWRA176	ECOLI	41	0.09	0.25	0.25
MWRA	7/10/2007	9:13 AM	MWRA176	ECOLI	10	0	0.23	0.25
MWRA	6/7/2007	9:34 AM	MWRA176	ENT	10	0	0	0
MWRA	6/20/2007	9:45 AM	MWRA176	ENT	10	0.16	0.16	0.16
MWRA	7/11/2007	9:26 AM	MWRA176	ECOLI	31	0	0	0.23
MWRA	6/21/2007	9:21 AM	MWRA176	ENT	10	0.09	0.25	0.25
MyRWA	6/8/2005	6:00 AM	MAR036	ECOLI	260	0.5	0.5	0.5
MWRA	8/1/2007	8:11 AM	MWRA176	ECOLI	30	0	0	1.72
MWRA	8/2/2007	7:50 AM	MWRA176	ECOLI	10	0	0	0
MWRA	7/10/2007	9:13 AM	MWRA176	ENT	10	0	0.23	0.25
MyRWA	6/14/2006	6:00 AM	MAR036	ECOLI	260	0	0	0
MWRA	8/22/2007	9:40 AM	MWRA176	ECOLI	10	0	0	0
MWRA	7/11/2007	9:26 AM	MWRA176	ENT	10	0	0	0.23
MWRA	8/23/2007	9:09 AM	MWRA176	ECOLI	20	0	0	0
MWRA	8/1/2007	8:11 AM	MWRA176	ENT	10	0	0	1.72
MWRA	9/11/2007	9:03 AM	MWRA176	ECOLI	265	1.28	1.29	1.32
MWRA	9/12/2007	7:35 AM	MWRA176	ECOLI	24200	0	1.28	1.29
MWRA	9/13/2007	9:24 AM	MWRA176	ECOLI	5790	0	0	1.28
MWRA	8/2/2007	7:50 AM	MWRA176	ENT	20	0	0	0
MWRA	10/2/2007	9:51 AM	MWRA176	ECOLI	10	0	0	0
MWRA	10/3/2007	9:22 AM	MWRA176	ECOLI	10	0	0	0
MWRA	8/22/2007	9:40 AM	MWRA176	ENT	10	0	0	0
MyRWA	6/18/2014	5:00 AM	MAR036	ECOLI	262	0	0.02	0.02
MWRA	8/23/2007	9:09 AM	MWRA176	ENT	10	0	0	0
MWRA	9/11/2007	9:03 AM	MWRA176	ENT	131	1.28	1.29	1.32
MWRA	10/24/2007	9:33 AM	MWRA176	ECOLI	63	0.04	0.05	0.05
MWRA	10/25/2007	9:23 AM	MWRA176	ECOLI	74	0.01	0.05	0.06
MWRA	9/12/2007	7:35 AM	MWRA176	ENT	7700	0	1.28	1.29
MWRA	11/13/2007	9:28 AM	MWRA176	ECOLI	10	0.19	0.22	0.22
MWRA	9/13/2007	9:24 AM	MWRA176	ENT	86	0	0	1.28
MyRWA	6/16/2010	6:00 AM	MAR036	ECOLI	275	0.02	0.02	0.02
MyRWA	5/9/2007	6:00 AM	MAR036	ECOLI	292	0	0	0
MWRA	10/2/2007	9:51 AM	MWRA176	ENT	10	0	0	0
MyRWA	6/14/2006	6:00 AM	MAR036	ECOLI	305	0	0	0
MWRA	10/3/2007	9:22 AM	MWRA176	ENT	10	0	0	0

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	10/24/2007	9:33 AM	MWRA176	ENT	10	0.04	0.05	0.05
MyRWA	4/15/2009	6:00 AM	MAR036	ECOLI	350	0	0	0
MWRA	10/25/2007	9:23 AM	MWRA176	ENT	97	0.01	0.05	0.06
MyRWA	8/21/2013	6:00 AM	MAR036	ECOLI	384	0	0	0
MyRWA	7/18/2012	6:00 AM	MAR036	ECOLI	399	1.74	1.74	1.74
MWRA	11/13/2007	9:28 AM	MWRA176	ENT	10	0.19	0.22	0.22
MyRWA	3/24/2010	6:00 AM	MAR036	ECOLI	435	0.02	2.24	2.32
MyRWA	4/21/2010	7:00 AM	MAR036	ECOLI	448	0	0	0
MyRWA	4/17/2013	6:00 AM	MAR036	ECOLI	479	0	0	0
MWRA	5/14/2008	9:38 AM	MWRA176	ENT	10	0	0	0
MWRA	5/14/2008	9:38 AM	MWRA176	ECOLI	20	0	0	0
MWRA	5/15/2008	8:54 AM	MWRA176	ECOLI	10	0	0	0
MWRA	5/15/2008	8:54 AM	MWRA176	ENT	10	0	0	0
MyRWA	6/12/2002	6:00 AM	MAR036	ECOLI	550	0.16	0.4	0.4
MWRA	6/2/2008	9:30 AM	MWRA176	ENT	20	0	0	0.02
MWRA	6/2/2008	9:30 AM	MWRA176	ECOLI	10	0	0	0.02
MWRA	6/3/2008	9:20 AM	MWRA176	ENT	74	0	0	0
MWRA	6/18/2008	8:30 AM	MWRA176	ENT	31	0	0	0.44
MWRA	6/3/2008	9:20 AM	MWRA176	ECOLI	63	0	0	0
MWRA	6/18/2008	8:30 AM	MWRA176	ECOLI	1020	0	0	0.44
MWRA	6/19/2008	9:08 AM	MWRA176	ENT	10	0	0	0
MyRWA	1/8/2003	7:00 AM	MAR036	ECOLI	550	0	0	0.03
MWRA	7/7/2008	8:27 AM	MWRA176	ENT	10	0	0	0.01
MWRA	6/19/2008	9:08 AM	MWRA176	ECOLI	345	0	0	0
MWRA	7/7/2008	8:27 AM	MWRA176	ECOLI	63	0	0	0.01
MWRA	7/8/2008	8:32 AM	MWRA176	ENT	10	0	0	0
MWRA	7/8/2008	8:32 AM	MWRA176	ECOLI	10	0	0	0
MyRWA	12/16/2009	6:00 AM	MAR036	ECOLI	583	0.01	0.01	0.01
MWRA	7/29/2008	7:32 AM	MWRA176	ENT	20	0	0	0.19
MWRA	7/29/2008	7:32 AM	MWRA176	ECOLI	31	0	0	0.19
MWRA	7/30/2008	7:56 AM	MWRA176	ECOLI	20	0	0	0
MyRWA	12/14/2011	6:00 AM	MAR036	ECOLI	620	0	0	0
MWRA	7/30/2008	7:56 AM	MWRA176	ENT	10	0	0	0
MWRA	9/11/2008	10:37 AM	MWRA176	ENT	10	0	0	0.28
MyRWA	4/14/2004	6:00 AM	MAR036	ECOLI	630	0.26	2.25	2.27
MWRA	9/11/2008	10:37 AM	MWRA176	ECOLI	471	0	0	0.28
MWRA	9/12/2008	7:33 AM	MWRA176	ENT	10	0.11	0.11	0.11
MWRA	9/12/2008	7:33 AM	MWRA176	ECOLI	354	0.11	0.11	0.11

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	9/29/2008	8:16 AM	MWRA176	ENT	262	0.08	0.61	1.51
MWRA	9/29/2008	8:16 AM	MWRA176	ECOLI	1720	0.08	0.61	1.51
MWRA	9/30/2008	10:08 AM	MWRA176	ECOLI	240	0	0.08	0.61
MWRA	9/30/2008	10:08 AM	MWRA176	ENT	63	0	0.08	0.61
MWRA	10/9/2008	8:55 AM	MWRA176	ECOLI	31	0.01	0.01	0.01
MWRA	10/10/2008	7:29 AM	MWRA176	ECOLI	41	0	0.01	0.01
MWRA	10/9/2008	8:55 AM	MWRA176	ENT	10	0.01	0.01	0.01
MyRWA	11/18/2009	6:00 AM	MAR036	ECOLI	663	0	0	0
MWRA	10/10/2008	7:29 AM	MWRA176	ENT	20	0	0.01	0.01
MWRA	10/28/2008	10:15 AM	MWRA176	ENT	199	0.4	0.4	0.73
MWRA	10/28/2008	10:15 AM	MWRA176	ECOLI	2910	0.4	0.4	0.73
MWRA	10/30/2008	9:54 AM	MWRA176	ECOLI	301	0	0	0.4
MWRA	11/18/2008	9:40 AM	MWRA176	ECOLI	583	0	0	0.37
MWRA	10/30/2008	9:54 AM	MWRA176	ENT	10	0	0	0.4
MyRWA	8/15/2007	6:00 AM	MAR036	ECOLI	677	0	0	0
MWRA	11/18/2008	9:40 AM	MWRA176	ENT	86	0	0	0.37
MWRA	11/20/2008	9:45 AM	MWRA176	ECOLI	161	0	0	0
MWRA	11/26/2008	7:59 AM	MWRA176	ECOLI	4350	0	1.77	1.77
MWRA	11/20/2008	9:45 AM	MWRA176	ENT	31	0	0	0
MWRA	11/26/2008	7:59 AM	MWRA176	ENT	1990	0	1.77	1.77
MWRA	12/12/2008	8:23 AM	MWRA176	ECOLI	1070	2.29	3.44	3.84
MWRA	12/12/2008	8:23 AM	MWRA176	ENT	1660	2.29	3.44	3.84
MyRWA	1/16/2013	6:00 AM	MAR036	ECOLI	677	0.37	0.37	0.37
MyRWA	8/17/2011	6:00 AM	MAR036	ECOLI	706	0	0.01	1.44
MyRWA	3/19/2014	6:00 AM	MAR036	ECOLI	816	0	0	0
MWRA	5/11/2009	9:47 AM	MWRA176	ENT	10	0	0	0.19
MWRA	5/11/2009	9:47 AM	MWRA176	ECOLI	98	0	0	0.19
MWRA	5/13/2009	9:15 AM	MWRA176	ECOLI	160	0	0	0
MyRWA	5/14/2003	6:00 AM	MAR036	ECOLI	850	0.04	0.07	0.18
MWRA	5/13/2009	9:15 AM	MWRA176	ENT	10	0	0	0
MWRA	6/1/2009	9:41 AM	MWRA176	ENT	20	0	0.03	0.17
MWRA	6/1/2009	9:41 AM	MWRA176	ECOLI	243	0	0.03	0.17
MWRA	6/3/2009	8:55 AM	MWRA176	ECOLI	10	0	0	0
MWRA	6/15/2009	9:43 AM	MWRA176	ECOLI	74	0	0.2	0.2
MWRA	6/3/2009	8:55 AM	MWRA176	ENT	10	0	0	0
MWRA	6/16/2009	9:18 AM	MWRA176	ECOLI	52	0	0	0.2
MWRA	6/15/2009	9:43 AM	MWRA176	ENT	20	0	0.2	0.2
MyRWA	2/20/2008	6:00 AM	MAR036	ECOLI	855	0	0	0

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	6/30/2009	9:17 AM	MWRA176	ECOLI	1440	0.07	0.52	0.55
MWRA	6/16/2009	9:18 AM	MWRA176	ENT	20	0	0	0.2
MWRA	7/1/2009	9:47 AM	MWRA176	ECOLI	487	0.61	0.68	1.13
MyRWA	3/21/2007	6:00 AM	MAR036	ECOLI	959	0	0.02	0.07
MWRA	6/30/2009	9:17 AM	MWRA176	ENT	183	0.07	0.52	0.55
MWRA	7/20/2009	10:12 AM	MWRA176	ECOLI	52	0	0	0.24
MWRA	7/1/2009	9:47 AM	MWRA176	ENT	74	0.61	0.68	1.13
MWRA	7/22/2009	10:28 AM	MWRA176	ECOLI	663	0	0.52	0.52
MWRA	7/20/2009	10:12 AM	MWRA176	ENT	10	0	0	0.24
MWRA	8/10/2009	10:14 AM	MWRA176	ECOLI	20	0.01	0.01	0.01
MWRA	7/22/2009	10:28 AM	MWRA176	ENT	10	0	0.52	0.52
MWRA	8/11/2009	10:25 AM	MWRA176	ECOLI	10	0.05	0.06	0.06
MyRWA	10/21/2009	7:00 AM	MAR036	ECOLI	960	0	0	0
MWRA	9/2/2009	9:17 AM	MWRA176	ECOLI	31	0	0	0
MWRA	8/10/2009	10:14 AM	MWRA176	ENT	10	0.01	0.01	0.01
MWRA	9/3/2009	10:34 AM	MWRA176	ECOLI	62	0	0	0
MWRA	8/11/2009	10:25 AM	MWRA176	ENT	10	0.05	0.06	0.06
MWRA	9/22/2009	10:04 AM	MWRA176	ECOLI	31	0	0	0
MWRA	9/23/2009	9:55 AM	MWRA176	ECOLI	52	0	0	0
MWRA	9/2/2009	9:17 AM	MWRA176	ENT	10	0	0	0
MWRA	10/5/2009	10:26 AM	MWRA176	ECOLI	1210	0	0	1.18
MWRA	9/3/2009	10:34 AM	MWRA176	ENT	10	0	0	0
MWRA	10/6/2009	9:13 AM	MWRA176	ECOLI	160	0	0	0
MyRWA	2/6/2008	12:00 PM	MAR036	ECOLI	1017	0.73	1.16	1.51
MWRA	9/22/2009	10:04 AM	MWRA176	ENT	10	0	0	0
MWRA	10/27/2009	9:13 AM	MWRA176	ECOLI	1210	0	0	0.03
MWRA	10/28/2009	9:17 AM	MWRA176	ECOLI	135	0.66	0.66	0.66
MWRA	9/23/2009	9:55 AM	MWRA176	ENT	10	0	0	0
MWRA	10/5/2009	10:26 AM	MWRA176	ENT	86	0	0	1.18
MyRWA	9/21/2011	6:00 AM	MAR036	ECOLI	1020	0	0.13	0.13
MyRWA	2/6/2008	1:00 PM	MAR036	ECOLI	1050	0.73	1.16	1.51
MyRWA	9/15/2010	6:00 AM	MAR036	ECOLI	1050	0	0.05	0.15
MWRA	10/6/2009	9:13 AM	MWRA176	ENT	10	0	0	0
MyRWA	1/17/2007	6:00 AM	MAR036	ECOLI	1090	0	0.06	0.6
MWRA	10/27/2009	9:13 AM	MWRA176	ENT	41	0	0	0.03
MWRA	10/28/2009	9:17 AM	MWRA176	ENT	52	0.66	0.66	0.66
MyRWA	6/15/2011	6:00 AM	MAR036	ECOLI	1110	0	0.04	0.09
MWRA	5/5/2010	9:22 AM	MWRA176	ECOLI	85	0	0.02	0.04

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	5/7/2010	8:43 AM	MWRA176	ECOLI	240	0	0	0
MWRA	5/5/2010	9:22 AM	MWRA176	ENT	10	0	0.02	0.04
MyRWA	1/15/2014	6:00 AM	MAR036	ECOLI	1110	0	0.79	0.79
MWRA	5/25/2010	9:09 AM	MWRA176	ECOLI	20	0	0	0
MWRA	5/7/2010	8:43 AM	MWRA176	ENT	10	0	0	0
MWRA	5/27/2010	8:42 AM	MWRA176	ECOLI	10	0.05	0.11	0.11
MWRA	5/25/2010	9:09 AM	MWRA176	ENT	10	0	0	0
MyRWA	12/11/2002	7:00 AM	MAR036	ECOLI	1160	0.07	0.07	0.07
MWRA	6/23/2010	9:10 AM	MWRA176	ECOLI	134	0.06	0.06	0.06
MWRA	5/27/2010	8:42 AM	MWRA176	ENT	10	0.05	0.11	0.11
MWRA	6/25/2010	8:36 AM	MWRA176	ECOLI	20	0	0.05	0.11
MWRA	6/23/2010	9:10 AM	MWRA176	ENT	10	0.06	0.06	0.06
MWRA	7/20/2010	9:06 AM	MWRA176	ECOLI	31	0	0	0
MWRA	6/25/2010	8:36 AM	MWRA176	ENT	20	0	0.05	0.11
MyRWA	1/16/2008	6:00 AM	MAR036	ECOLI	1170	0	0	0.55
MWRA	7/20/2010	9:06 AM	MWRA176	ENT	10	0	0	0
MWRA	7/21/2010	8:43 AM	MWRA176	ECOLI	10	0.05	0.05	0.05
MWRA	7/21/2010	8:43 AM	MWRA176	ENT	10	0.05	0.05	0.05
MWRA	8/2/2010	8:56 AM	MWRA176	ECOLI	52	0	0	0
MWRA	8/2/2010	8:56 AM	MWRA176	ENT	10	0	0	0
MWRA	8/4/2010	9:03 AM	MWRA176	ECOLI	10	0	0	0
MyRWA	8/18/2010	7:00 AM	MAR036	ECOLI	1200	0	0	0.21
MWRA	8/4/2010	9:03 AM	MWRA176	ENT	10	0	0	0
MWRA	8/31/2010	9:52 AM	MWRA176	ECOLI	20	0	0	0
MWRA	8/31/2010	9:52 AM	MWRA176	ENT	10	0	0	0
MWRA	9/1/2010	9:45 AM	MWRA176	ECOLI	10	0	0	0
MyRWA	10/19/2011	6:00 AM	MAR036	ECOLI	1220	1.17	1.17	1.17
MWRA	9/1/2010	9:45 AM	MWRA176	ENT	10	0	0	0
MWRA	9/15/2010	10:00 AM	MWRA176	ECOLI	233	0	0.05	0.15
MWRA	9/15/2010	10:00 AM	MWRA176	ENT	10	0	0.05	0.15
MWRA	9/16/2010	9:41 AM	MWRA176	ECOLI	96	0.14	0.14	0.19
MWRA	9/16/2010	9:41 AM	MWRA176	ENT	10	0.14	0.14	0.19
MWRA	10/4/2010	9:35 AM	MWRA176	ENT	31	0.51	0.51	0.51
MWRA	10/4/2010	9:35 AM	MWRA176	ECOLI	160	0.51	0.51	0.51
MWRA	10/5/2010	9:51 AM	MWRA176	ECOLI	512	0.09	0.6	0.6
MyRWA	6/20/2007	6:00 AM	MAR036	ECOLI	1290	0.16	0.16	0.16
MWRA	10/21/2010	8:56 AM	MWRA176	ECOLI	85	0.02	0.02	0.02
MWRA	10/5/2010	9:51 AM	MWRA176	ENT	98	0.09	0.6	0.6

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	10/22/2010	10:42 AM	MWRA176	ECOLI	10	0	0.02	0.02
MWRA	11/10/2010	12:05 PM	MWRA176	ECOLI	1440	0.07	0.13	0.56
MWRA	10/21/2010	8:56 AM	MWRA176	ENT	10	0.02	0.02	0.02
MWRA	11/12/2010	12:29 PM	MWRA176	ECOLI	63	0	0	0.07
MyRWA	2/15/2012	7:00 AM	MAR036	ECOLI	1290	0	0	0
MWRA	10/22/2010	10:42 AM	MWRA176	ENT	10	0	0.02	0.02
MWRA	11/10/2010	12:05 PM	MWRA176	ENT	294	0.07	0.13	0.56
MyRWA	1/18/2012	6:00 AM	MAR036	ECOLI	1310	0	0.14	0.15
MyRWA	2/20/2013	6:00 AM	MAR036	ECOLI	1330	0.03	0.46	0.46
MWRA	11/12/2010	12:29 PM	MWRA176	ENT	63	0	0	0.07
MyRWA	4/20/2011	6:00 AM	MAR036	ECOLI	1370	0	0.15	0.15
MyRWA	3/20/2013	6:00 AM	MAR036	ECOLI	1440	0	0.71	0.73
MyRWA	12/19/2012	6:00 AM	MAR036	ECOLI	1560	0	0.89	1.4
MWRA	5/3/2011	9:34 AM	MWRA176	ENT	10	0	0	0
MWRA	5/3/2011	9:34 AM	MWRA176	ECOLI	10	0	0	0
MWRA	5/5/2011	9:41 AM	MWRA176	ENT	31	0.01	0.38	0.38
MWRA	5/5/2011	9:41 AM	MWRA176	ECOLI	63	0.01	0.38	0.38
MyRWA	12/15/2010	7:00 AM	MAR036	ECOLI	1610	0	0	0.38
MWRA	5/23/2011	9:26 AM	MWRA176	ENT	10	0.11	0.11	0.11
MWRA	5/23/2011	9:26 AM	MWRA176	ECOLI	63	0.11	0.11	0.11
MWRA	5/25/2011	9:24 AM	MWRA176	ENT	20	0	0.17	0.28
MWRA	5/25/2011	9:24 AM	MWRA176	ECOLI	987	0	0.17	0.28
MWRA	6/7/2011	9:03 AM	MWRA176	ENT	10	0	0	0
MWRA	6/7/2011	9:03 AM	MWRA176	ECOLI	97	0	0	0
MWRA	6/8/2011	9:47 AM	MWRA176	ENT	10	0	0	0
MWRA	6/8/2011	9:47 AM	MWRA176	ECOLI	10	0	0	0
MyRWA	1/19/2011	7:00 AM	MAR036	ECOLI	1660	0.19	1.14	1.14
MWRA	6/28/2011	9:21 AM	MWRA176	ENT	10	0	0	0
MWRA	6/28/2011	9:21 AM	MWRA176	ECOLI	20	0	0	0
MWRA	6/29/2011	9:30 AM	MWRA176	ENT	10	0.18	0.18	0.18
MWRA	6/29/2011	9:30 AM	MWRA176	ECOLI	108	0.18	0.18	0.18
MyRWA	7/14/2004	7:00 AM	MAR036	ECOLI	1710	0.43	0.59	0.59
MWRA	7/27/2011	9:00 AM	MWRA176	ECOLI	10	0	0.01	0.16
MWRA	7/27/2011	9:00 AM	MWRA176	ENT	10	0	0.01	0.16
MWRA	7/28/2011	8:39 AM	MWRA176	ECOLI	20	0	0	0.01
MyRWA	2/6/2008	2:00 PM	MAR036	ECOLI	1860	0.73	1.16	1.51
MWRA	8/30/2011	9:22 AM	MWRA176	ECOLI	450	0	0	0.91
MWRA	7/28/2011	8:39 AM	MWRA176	ENT	10	0	0	0.01

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	8/30/2011	9:22 AM	MWRA176	ENT	30	0	0	0.91
MWRA	8/31/2011	9:09 AM	MWRA176	ECOLI	175	0	0	0
MWRA	9/13/2011	9:27 AM	MWRA176	ECOLI	41	0	0	0
MWRA	8/31/2011	9:09 AM	MWRA176	ENT	10	0	0	0
MWRA	9/14/2011	9:38 AM	MWRA176	ECOLI	63	0.08	0.08	0.08
MWRA	9/13/2011	9:27 AM	MWRA176	ENT	10	0	0	0
MyRWA	4/16/2014	6:00 AM	MAR036	ECOLI	1920	0.36	0.98	0.98
MWRA	9/26/2011	9:15 AM	MWRA176	ECOLI	350	0	0	0.43
MWRA	9/14/2011	9:38 AM	MWRA176	ENT	10	0.08	0.08	0.08
MWRA	9/28/2011	9:00 AM	MWRA176	ECOLI	109	0	0	0
MWRA	10/12/2011	9:38 AM	MWRA176	ECOLI	134	0.08	0.08	0.08
MWRA	9/26/2011	9:15 AM	MWRA176	ENT	31	0	0	0.43
MWRA	10/13/2011	9:25 AM	MWRA176	ECOLI	4880	0.93	1.01	1.01
MWRA	9/28/2011	9:00 AM	MWRA176	ENT	10	0	0	0
MWRA	10/19/2011	8:52 AM	MWRA176	ECOLI	187	1.17	1.17	1.17
MWRA	10/12/2011	9:38 AM	MWRA176	ENT	20	0.08	0.08	0.08
MyRWA	5/10/2006	6:00 AM	MAR036	ECOLI	2000	0.57	1.51	1.51
MWRA	10/13/2011	9:25 AM	MWRA176	ENT	2140	0.93	1.01	1.01
MWRA	10/20/2011	9:07 AM	MWRA176	ECOLI	5470	0.47	1.64	1.64
MWRA	10/19/2011	8:52 AM	MWRA176	ENT	10	1.17	1.17	1.17
MWRA	10/28/2011	9:44 AM	MWRA176	ECOLI	3870	0	1.02	1.04
MWRA	10/20/2011	9:07 AM	MWRA176	ENT	2910	0.47	1.64	1.64
MyRWA	12/17/2008	6:00 AM	MAR036	ECOLI	2020	0.47	0.49	0.49
MWRA	11/17/2011	10:21 AM	MWRA176	ECOLI	7700	0.13	0.91	0.91
MWRA	10/28/2011	9:44 AM	MWRA176	ENT	959	0	1.02	1.04
MWRA	11/30/2011	9:19 AM	MWRA176	ECOLI	11200	0.7	0.76	0.76
MyRWA	11/17/2010	7:00 AM	MAR036	ECOLI	2060	0.93	0.94	0.94
MWRA	11/17/2011	10:21 AM	MWRA176	ENT	1220	0.13	0.91	0.91
MWRA	12/22/2011	12:15 PM	MWRA176	ECOLI	168	0.41	0.5	0.5
MWRA	11/30/2011	9:19 AM	MWRA176	ENT	3870	0.7	0.76	0.76
MyRWA	3/16/2011	9:00 AM	MAR036	ECOLI	2140	0.54	0.54	0.54
MWRA	1/27/2012	12:38 PM	MWRA176	ECOLI	1210	0.89	1.06	1.06
MyRWA	10/17/2012	6:00 AM	MAR036	ECOLI	2140	0	0.06	0.08
MyRWA	11/14/2012	6:00 AM	MAR036	ECOLI	2250	0	0.29	0.29
MWRA	12/22/2011	12:15 PM	MWRA176	ENT	10	0.41	0.5	0.5
MWRA	1/27/2012	12:38 PM	MWRA176	ENT	275	0.89	1.06	1.06
MyRWA	12/8/2004	6:00 AM	MAR036	ECOLI	2810	0.03	1.01	1.02
MWRA	5/17/2012	9:05 AM	MWRA176	ECOLI	384	0	0.06	0.56

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	5/17/2012	9:05 AM	MWRA176	ENT	52	0	0.06	0.56
MWRA	5/18/2012	8:43 AM	MWRA176	ECOLI	63	0	0	0.06
MWRA	6/4/2012	9:36 AM	MWRA176	ECOLI	1180	0.13	0.14	1.27
MWRA	5/18/2012	8:43 AM	MWRA176	ENT	20	0	0	0.06
MWRA	6/4/2012	9:36 AM	MWRA176	ENT	97	0.13	0.14	1.27
MWRA	6/6/2012	9:20 AM	MWRA176	ECOLI	171	0	0.13	0.26
MyRWA	5/18/2011	6:00 AM	MAR036	ECOLI	2910	0.05	0.31	0.63
MWRA	6/20/2012	10:03 AM	MWRA176	ECOLI	41	0	0	0
MWRA	6/6/2012	9:20 AM	MWRA176	ENT	10	0	0.13	0.26
MWRA	6/21/2012	9:33 AM	MWRA176	ECOLI	98	0	0	0
MWRA	6/20/2012	10:03 AM	MWRA176	ENT	62	0	0	0
MWRA	7/9/2012	9:19 AM	MWRA176	ECOLI	10	0	0	0
MWRA	6/21/2012	9:33 AM	MWRA176	ENT	10	0	0	0
MWRA	7/10/2012	8:50 AM	MWRA176	ECOLI	10	0	0	0
MWRA	7/9/2012	9:19 AM	MWRA176	ENT	10	0	0	0
MyRWA	11/16/2011	6:00 AM	MAR036	ECOLI	2910	0.78	0.78	0.78
MWRA	7/10/2012	8:50 AM	MWRA176	ENT	10	0	0	0
MWRA	8/8/2012	8:52 AM	MWRA176	ECOLI	30	0	0	0
MWRA	8/8/2012	8:52 AM	MWRA176	ENT	10	0	0	0
MWRA	8/9/2012	8:23 AM	MWRA176	ECOLI	52	0	0	0
MyRWA	11/20/2013	6:00 AM	MAR036	ECOLI	3080	0	0	0.18
MWRA	8/9/2012	8:23 AM	MWRA176	ENT	10	0	0	0
MWRA	8/22/2012	8:25 AM	MWRA176	ECOLI	31	0	0	0
MWRA	8/22/2012	8:25 AM	MWRA176	ENT	10	0	0	0
MWRA	8/23/2012	9:26 AM	MWRA176	ECOLI	10	0	0	0
MWRA	8/29/2012	8:31 AM	MWRA176	ECOLI	52	0	0.15	0.15
MWRA	8/23/2012	9:26 AM	MWRA176	ENT	10	0	0	0
MWRA	8/30/2012	8:43 AM	MWRA176	ECOLI	10	0	0	0.15
MWRA	8/29/2012	8:31 AM	MWRA176	ENT	10	0	0.15	0.15
MWRA	9/4/2012	8:41 AM	MWRA176	ECOLI	10	0.44	0.44	0.44
MWRA	8/30/2012	8:43 AM	MWRA176	ENT	10	0	0	0.15
MWRA	9/5/2012	9:07 AM	MWRA176	ECOLI	8160	0.66	1.1	1.1
MyRWA	10/20/2010	7:00 AM	MAR036	ECOLI	3260	0.02	0.02	0.02
MWRA	9/26/2012	9:22 AM	MWRA176	ECOLI	85	0	0	0
MWRA	9/4/2012	8:41 AM	MWRA176	ENT	10	0.44	0.44	0.44
MWRA	9/5/2012	9:07 AM	MWRA176	ENT	5480	0.66	1.1	1.1
MWRA	9/27/2012	8:58 AM	MWRA176	ECOLI	41	0	0	0
MWRA	10/3/2012	8:23 AM	MWRA176	ECOLI	288	0.08	0.11	0.11

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	9/26/2012	9:22 AM	MWRA176	ENT	10	0	0	0
MWRA	10/4/2012	8:15 AM	MWRA176	ECOLI	158	0.03	0.11	0.14
MWRA	9/27/2012	8:58 AM	MWRA176	ENT	20	0	0	0
MyRWA	8/9/2006	6:00 AM	MAR036	ECOLI	3360	0	0	0.04
MWRA	10/3/2012	8:23 AM	MWRA176	ENT	10	0.08	0.11	0.11
MyRWA	6/19/2013	6:00 AM	MAR036	ECOLI	3650	0.01	0.63	1.07
MyRWA	6/18/2008	6:00 AM	MAR036	ECOLI	3870	0	0	0.44
MyRWA	4/18/2007	7:00 AM	MAR036	ECOLI	4110	0.05	0.21	1.32
MWRA	10/4/2012	8:15 AM	MWRA176	ENT	20	0.03	0.11	0.14
MyRWA	8/13/2003	6:00 AM	MAR036	ECOLI	4200	0.05	0.09	0.09
MyRWA	2/6/2008	11:00 AM	MAR036	ECOLI	5209	0.73	1.16	1.51
MWRA	4/25/2013	8:36 AM	MWRA176	ENT	10	0.03	0.03	0.16
MyRWA	10/12/2005	6:00 AM	MAR036	ECOLI	6100	0.02	0.24	0.33
MWRA	5/8/2013	8:53 AM	MWRA176	ENT	30	0.37	0.37	0.37
MWRA	4/25/2013	8:36 AM	MWRA176	ECOLI	86	0.03	0.03	0.16
MWRA	5/9/2013	9:13 AM	MWRA176	ENT	41	0.61	0.98	0.98
MWRA	5/8/2013	8:53 AM	MWRA176	ECOLI	556	0.37	0.37	0.37
MWRA	5/20/2013	9:04 AM	MWRA176	ENT	41	0.04	0.21	0.21
MWRA	5/9/2013	9:13 AM	MWRA176	ECOLI	187	0.61	0.98	0.98
MyRWA	2/17/2010	7:00 AM	MAR036	ECOLI	6490	0	0.4	0.4
MWRA	5/24/2013	8:01 AM	MWRA176	ENT	143	0.57	0.62	0.67
MWRA	6/10/2013	9:01 AM	MWRA176	ENT	10	0.88	0.88	1.42
MWRA	5/20/2013	9:04 AM	MWRA176	ECOLI	73	0.04	0.21	0.21
MWRA	5/24/2013	8:01 AM	MWRA176	ECOLI	318	0.57	0.62	0.67
MWRA	6/10/2013	9:01 AM	MWRA176	ECOLI	309	0.88	0.88	1.42
MWRA	6/11/2013	8:30 AM	MWRA176	ENT	2010	1.38	2.26	2.26
MWRA	6/11/2013	8:30 AM	MWRA176	ECOLI	2360	1.38	2.26	2.26
MyRWA	11/13/2002	7:00 AM	MAR036	ECOLI	6800	0.58	1.27	1.32
MWRA	7/16/2013	8:48 AM	MWRA176	ENT	20	0.01	0.01	0.01
MWRA	7/16/2013	8:48 AM	MWRA176	ECOLI	31	0.01	0.01	0.01
MWRA	7/18/2013	8:59 AM	MWRA176	ECOLI	259	0	0	0.01
MWRA	7/18/2013	8:59 AM	MWRA176	ENT	10	0	0	0.01
MWRA	8/13/2013	9:01 AM	MWRA176	ECOLI	1940	0	0	0
MWRA	8/13/2013	9:01 AM	MWRA176	ENT	10	0	0	0
MWRA	8/14/2013	8:42 AM	MWRA176	ECOLI	1310	0	0	0
MyRWA	5/19/2010	6:00 AM	MAR036	ECOLI	7270	0.47	1.08	1.08
MWRA	8/14/2013	8:42 AM	MWRA176	ENT	10	0	0	0
MWRA	8/28/2013	8:54 AM	MWRA176	ECOLI	20	0	0.01	0.02

Data Source	Date Sample Taken	Time of Sample	Location ID	FIO	(FIO/ 100mL)	Rainfall (current day), in.	Rainfall (current day + previous day), in.	Rainfall (current day + previous 2 days), in.
MWRA	8/29/2013	8:47 AM	MWRA176	ECOLI	52	0	0	0.01
MWRA	8/28/2013	8:54 AM	MWRA176	ENT	20	0	0.01	0.02
MWRA	9/10/2013	8:45 AM	MWRA176	ECOLI	160	0.03	0.03	0.03
MWRA	9/11/2013	9:27 AM	MWRA176	ECOLI	132	0	0.03	0.03
MyRWA	11/8/2006	6:00 AM	MAR036	ECOLI	9210	1.17	1.31	1.31
MWRA	8/29/2013	8:47 AM	MWRA176	ENT	10	0	0	0.01
MWRA	9/23/2013	8:53 AM	MWRA176	ECOLI	9800	0	0.37	0.37
MWRA	9/25/2013	9:42 AM	MWRA176	ECOLI	408	0	0	0
MyRWA	2/16/2011	7:00 AM	MAR036	ECOLI	9210	0	0	0
MWRA	9/10/2013	8:45 AM	MWRA176	ENT	10	0.03	0.03	0.03
MWRA	10/21/2013	9:33 AM	MWRA176	ECOLI	10	0	0	0
MWRA	9/11/2013	9:27 AM	MWRA176	ENT	20	0	0.03	0.03
MWRA	10/22/2013	9:06 AM	MWRA176	ECOLI	41	0	0	0
MWRA	9/23/2013	8:53 AM	MWRA176	ENT	10	0	0.37	0.37
MWRA	10/31/2013	9:25 AM	MWRA176	ECOLI	20	0.03	0.08	0.08
MWRA	9/25/2013	9:42 AM	MWRA176	ENT	10	0	0	0
MyRWA	5/16/2006	6:00 AM	MAR036	ECOLI	10810	0.52	0.88	4.65
MWRA	10/21/2013	9:33 AM	MWRA176	ENT	10	0	0	0
MyRWA	9/10/2008	6:00 AM	MAR036	ECOLI	24200	0	0.28	0.28
MWRA	10/22/2013	9:06 AM	MWRA176	ENT	10	0	0	0
MyRWA	9/19/2012	6:00 AM	MAR036	ECOLI	24200	0.61	0.7	0.7
MyRWA	10/9/2002	6:00 AM	MAR036	ECOLI	49000	0	0	0
MyRWA	7/12/2006	6:00 AM	MAR036	ECOLI	70400	1.02	1.04	1.04
MyRWA	7/10/2002	7:00 AM	MAR036	ECOLI	71000	0.08	0.62	0.62
MWRA	10/31/2013	9:25 AM	MWRA176	ENT	10	0.03	0.08	0.08