WHITE PAPER

Identifying Sources of Fecal Bacteria Loadings: A First Step towards Attaining Recreational Water Quality Standards for Fecal Bacteria in the Milwaukee River Basin

Prepared by the Southeastern Wisconsin Watersheds Trust's
Science Advisory Committee, Bacteria Workgroup
March 14, 2020

www.swwtwater.org

ABOUT THE SCIENCE ADVISORY COMMITTEE AND BACTERIA WORK GROUP

The Science Advisory Committee of the Southeastern Wisconsin Watershed Trust ('Sweet Water') formed a Bacteria Work Group in response to impairments in the region's waterways due to fecal bacteria pollution and the newly drafted TMDLs for the Milwaukee River Basin. The Work Group is comprised of members from Sweet Water's Science Advisory Committee whose professional backgrounds and personal interests complement the Work Group's scope of work. Members include individuals from local and regional non-profit organizations, scientists and water professionals from public and private sectors, engineers, land conservation departments, WDNR, and regional planning staff.

The group met periodically from June 2017 to April 2019. They collected research regarding bacteria TMDLs nationwide, invited speakers who have been testing waterways and implementing proven methods for identifying and prioritizing bacteria sources, and engaged in dozens of hours of discussions. The information from those discussions was further developed in September/October 2019 and incorporated into an elementary operational framework under which fecal bacteria pollution can be identified and ultimately remediated. This straight forward framework is advanced in this White Paper: *Identifying Sources of Fecal Bacteria Loadings: A First Step towards Attaining Recreational Water Quality Standards for Fecal Bacteria in The Milwaukee River Basin.*

ABOUT SWEET WATER

Sweet Water collaborates with diverse stakeholders in efforts to secure healthy and sustainable water resources in the Greater Milwaukee watersheds. Sweet Water bases recommendations on sound science, taking a watershed approach that bridges jurisdictional and social boundaries while recognizing that how the land is managed affects drainage areas, water quality and the overall health of water resources of the region.

NOTE TO READERS

Sweet Water, members of the Bacteria Work Group and the organizations they represent make no claims as to the completeness or the usefulness of the material covered in this White Paper. The intention of the White Paper is to serve as a starting point when beginning to identify sources and/or evaluate measures to control waterborne fecal bacteria contamination. The information and recommendations contained herein were created using best practices and science available at the time of its development; however, it is important to note the paper and details within should be considered a living document. Members of the Bacteria Work Group encourage audiences to use the White Paper as a tool which they can learn from and adapt to fit their needs. The details presented are for informational purposes and should be view as discretionary, non-compulsory suggestions and/or methodologies when considering any fecal bacteria reduction program.

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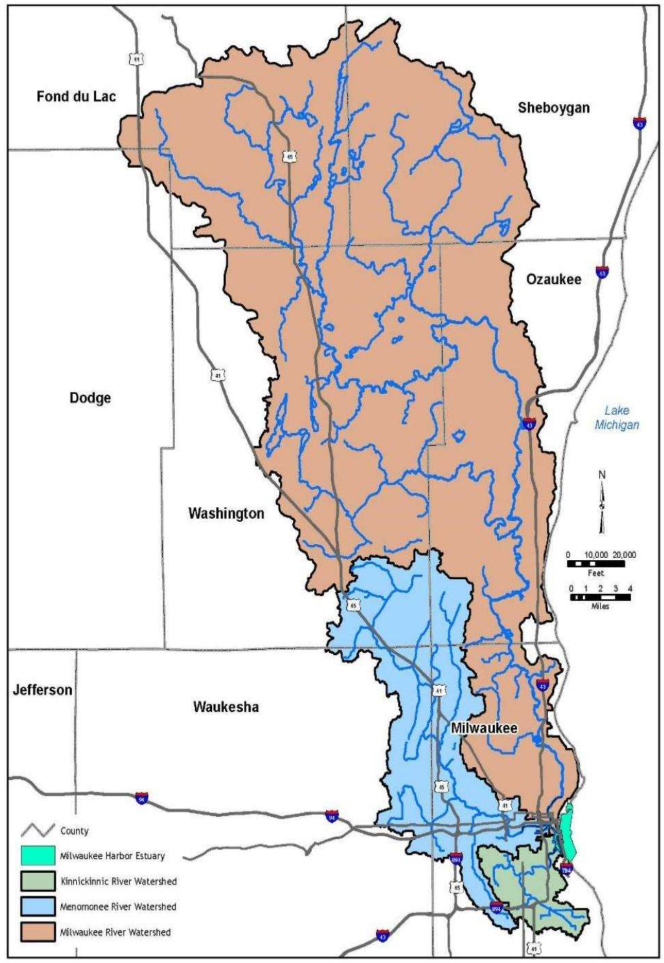
INTRODUCTION

The Milwaukee River Basin includes the Milwaukee River, the Menomonee River, the Kinnickinnic River, their tributaries and the Milwaukee Harbor Estuary (Figure 1). This represents an 839 square mile drainage area that collectively discharges into Milwaukee's Outer Harbor and ultimately to Lake Michigan. These watersheds are associated with a significant portion of Wisconsin's largest population centers and are largely accessible to the public for whole (full) or partial body recreational contact. The Clean Water Act (CWA) requires promulgation of water quality criteria to support designated uses. These include recreational standards to allow whole body contact with waters (swimmable goal) without fear of illness or infection from pathogenic organisms. State regulatory agencies, in our case Wisconsin Department of Natural Resources (WDNR), are delegated to implement requirements of the CWA. When monitoring indicates that instream conditions do not meet water quality criteria that support designated uses, those water bodies are listed as impaired for the specific pollutant causing impairment in accordance with Section 303(d) of the CWA.

Figure 1: Map of Milwaukee River Basin



Final Report, Total Maximum Daily Loads for Total Phosphorus, Total Suspended Solids, and Fecal Coliform Milwaukee River Basin, Wisconsin.

Many segments of the Menomonee, Kinnickinnic and Milwaukee Rivers, as well as the Milwaukee Harbor Estuary, are on the State's Impaired Waters List 303(d) due to fecal coliform concentrations (and other pollutants) that exceed the current recreational (and other water quality) standards. The WDNR examines current water quality conditions and updates the 303(d) list every two years. The Clean Water Act requires that where water quality standards are not attained, a Total Maximum Daily Load (TMDL) study be conducted to identify sources of pollutants causing the impairments and identify reductions needed for water quality goals and designated uses to be achieved. A TMDL for fecal coliform bacteria, phosphorus and suspended solids has been completed for the Milwaukee River Basin and was approved by U.S. EPA on March 9, 2018.

Recreation Standards for Swimmable Waters

Water quality recreational use standards are based on a statistical measurement of fecal bacteria organisms, that may indicate the presence of pathogens associated with human fecal waste at a concentration which heightens risk of illness if water is ingested. Fecal coliform bacteria and *Escherichia coli* (*E. coli)*, collectively fecal indicator bacteria, are used as microbiological indicators of safety for drinking water and swimming.

The presence of fecal indicator bacteria indicates contamination originating from the intestinal tract of warm-blooded animals, including humans. The occurrence of bacterial, viral, protozoan and possibly fungal organisms, which are either pathogens or possess the potential to infect humans, is associated with the presence of the fecal indicator bacteria. Illness occurs when a person ingests a sufficient amount (infective dose) of the pathogenic organism. Examples of waterborne pathogens that can accompany fecal indicator bacteria (fecal coliform and *E. coli*) contamination in waterbodies are indicated in Table 1.

Table 1. Types of Pathogenic Waterborne Microorganisms associated with Fecal Pollution

Viruses	Bacteria	Protozoa
Rotavirus	*E. coli* (Limited subspecies)	*Cryptosporidium parva*
Adenovirus	Salmonella spp	*Cryptosporidium hominus*
Coxsackievirus	Shigella spp	*Giardia lamblia*
Hepatitis A & E	*Aeromonas hydrophila*	
Norovirus	Legionella	

The concentration of fecal bacteria present is indicative of the degree of human health risk associated with using the water for drinking, swimming or recreational whole-body contact. The State of Wisconsin defines recreational standards in Wisconsin Administrative Code NR 102.04(6). Under existing bacteria criteria based on fecal coliform, recreational standards are met if fecal coliforms are found at a geometric mean of no more than 200 colony forming units (cfu) per 100 ml, based on a minimum of five samples per month, with no more than 10% of samples exceeding 400 cfu/100 ml. NR 102.04(5) states that all surface waters shall be suitable for supporting recreational use. However, the WDNR is proposing revisions to the bacteria criteria to use *E. coli* as the pathogen indicator in place of fecal coliforms, which are expected to be promulgated in 2020 (see discussion later in this section and Table 4). It should be noted that *E. coli* has been used as a recreational water quality standard for Great Lake beaches since 2002.

Wisconsin Administrative Code Variance, a Less Restrictive Standard for Certain Waterway Segments

Variances were promulgated in the 1970s with the initial creation of water quality standards as required by the Clean Water Act. In Wisconsin, NR 104.06(2) has provided a variance from the recreational standard for certain stream segments in the Milwaukee River Basin because at that time they were impacted by combined sewer and sanitary sewer overflows of untreated or partially treated sanitary wastewater mixed with stormwater runoff caused by excessive rainfall induced infiltration and inflow into the sanitary sewer system (Table 2). It was also recognized that these segments of rivers were in highly urbanized areas and were at the downstream end of large drainage areas that accumulated and concentrated the pollutants from entire (upper and lower) watershed drainage areas.

Table 2. Former Stream Segments with Fecal Coliform Variances

1. Underwood Creek in Milwaukee and Waukesha counties below Juneau Boulevard
2. Indian Creek in Milwaukee County (tributary to the Milwaukee River)
3. Honey Creek in Milwaukee County (tributary to the Menomonee River)
4. Menomonee River in Milwaukee County below the confluence with Honey Creek
5. Kinnickinnic River
6. Lincoln Creek (tributary to the Milwaukee River)
7. Milwaukee River downstream from North Avenue dam (Dam now removed)
8. South Menomonee canal and Burnham canal (partially remediated and converted to a wetland)

The variance sets a fecal coliform standard for the first six stream segments as a geometric mean based on a minimum of five samples per month of 1000 cfu/100 ml with no more than 10% of samples exceeding 2000 cfu/100 ml. The latter two stream segments are required to meet the 1000 cfu/100 ml. The latter two stream segments are required to meet the 1000 cfu/100 ml geometric mean standard only. With the completion of the Milwaukee Metropolitan Sewerage District's (MMSD) Inline Storage System (Deep Tunnel) in 1995, local and Interceptor System sewer improvements and expansion of the two major water reclamation facilities, Milwaukee's waterways no longer experience the high rate of overflows they once received when this variance was first established. According to the *Final Report, Total Maximum Daily Loads for Total Phosphorus, Total Suspended Solids, and Fecal Coliform Milwaukee River Basin, Wisconsin-2018*, Milwaukee's waterways experience approximately two overflows per year from combined sewer overflows and one overflow every five to ten years from neighboring separate sanitary sewer systems. Wet weather flow in the Combined Sewer Area is now over 99% captured and treated. Analysis of data in the MMSD 2010 Facilities Plan and the update of the Water Quality Management Plan (collaboratively prepared by SEWRPC with the MMSD 2020 Facilities Plan) determined that exceedance of fecal coliform water quality standards persists in the Milwaukee River Basin, both within the MMSD sewer service area and outside of it. However, impairment is rarely caused by identified combined or separate sewer system overflows. Thus, the justification for a relaxed standard (variance) for stream segments is no longer present. Because these outdated variances no longer apply to the stream segments listed in Table 2, the TMDL analysis used the recreational standard (NR 102.04(6)) uniformly throughout the Milwaukee River Basin study area (no variance consideration). The WDNR submitted a proposal to the legislature in late 2019 that, if passed, would repeal these fecal coliform variances in 2020.

Fecal Coliform and Escherichia coli (E.coli) as Indicator Organisms

Recreational standards are intended to protect whole body recreational use of surface waters, minimizing risk from ingestion or infection of human pathogens. Accordingly, TMDL implementation should prioritize identification of human sources, such as unidentified sanitary sewer connections to storm sewers, remaining overflows and failing septic tanks. Stormwater runoff to surface waters may also contribute significant loadings of fecal bacteria, but not necessarily of human origin. The University of Wisconsin-Milwaukee (UWM) School of Freshwater Sciences has demonstrated through several years of genetic testing that observed *E. coli* bacteria may originate from waterfowl, other birds, wildlife, cattle or other domestic animals (pets).

Fecal coliform and *E. coli* bacteria are not precise indicators of human pathogen presence. Virtually all warm-blooded animals excrete fecal coliforms and *E. coli*, so the presence of fecal coliforms and *E. coli* may or may not be indicative of human source contamination, which poses the greatest health risk to people. U.S. EPA has prepared guidance, first in 1986 and more recently in 2012, with a recommendation that the recreational standard be revised to use *Escherichia coli* (*E. coli)*, a more precise organism of the coliform group, or enterococci to indicate the presence of human sanitary waste. While *E. coli* is a better fecal bacteria indicator, the presence of either *E. coil* or fecal coliform detected in water does not necessary correlate with or equate to the presence of enteric viruses and parasites. Additionally, it's important to take into consideration that *E. coli* can regrow or regenerate in the environment if temperature and nutrient conditions are favorable, confounding true source concentration levels and originating source identification. U.S. EPA proposed that states look at two different risk levels for revised recreational standards (Table 3). The U.S. EPA document initially evaluated, but ultimately rejected, a tiered recreational use risk level for different degrees of contact. Therefore, the current guidance document does not propose a standard for less than whole body contact. Moreover, the TMDL for the Milwaukee River Basin evaluated needed bacterial reductions for fecal coliform compliance absent the previously mention variances, (i.e. all surface waters would support whole body contact -Section 3.2.3. TMDL).

Table 3. 2012 U.S. EPA Recommendations Utilizing *E.coli* and Enterococci as Indicator Organisms

CRITERIA ELEMENTS	Recommendation 1 Estimated Illness Rate 36/1,000		Recommendation 2 Estimated Illness Rate 32/1,000	
Indicator	GM (cfu/100 mL)	STV (cfu/100 mL)	GM (cfu/100 mL)	STV (cfu/100 mL)
Enterococci (marine & fresh)	35	130	30	110
E. coli (fresh)	126	410	100	320

Note that GM is geometric mean of a minimum of 5 samples in 30 days. STV is statistical threshold value; 10% of values can exceed the STV to conform to the risk level identified in the U.S. EPA Guidance.

Source: U.S. EPA, Office of Water 820-F-12-058 Recreational Water Quality Criteria

The WDNR submitted updated recreational standards for E. coli bacteria to the legislature in late 2019 based on the 2012 USEPA Guidance document, and if passed the new E. coli criteria would be promulgated in place of the previous fecal coliform criteria sometime in 2020. The draft recreational standard update (7-18-2019) was published for comment until August 20, 2019. The TMDL also evaluated potential compliance with proposed recommendations for *E. coli* bacteria as presented in Table 4.

The updated standards reflected in the EPA's 2012 guidance and the TMDL recommendations are wholly consistent with MMSD's goal of total overflow elimination within its service area by 2035 and reduced potential for human health risk from exposure during recreational contact.

Table 4. Updated Wisconsin Recreational Standard Utilizing *E. coli* as the Indicator Organism

***E. coli* (counts[1] per 100 mL)**	
Geometric Mean [2]	**Statistical Threshold Value [3]**
126	**410**
1. For determining attainment or compliance, counts are considered equivalent to either colony forming units or most probable number.	
2. The geometric mean shall not be exceeded in any rolling 90-day period during the recreation season.	
3. The statistical threshold value shall not be exceeded more than 10 percent of the time during any rolling 90-day period during the recreation season.	

Source: https://WDNR.wi.gov/news/input/documents/rules/WY1715DraftRule2.pdf.

The Recreational Standard rule update also includes the following:

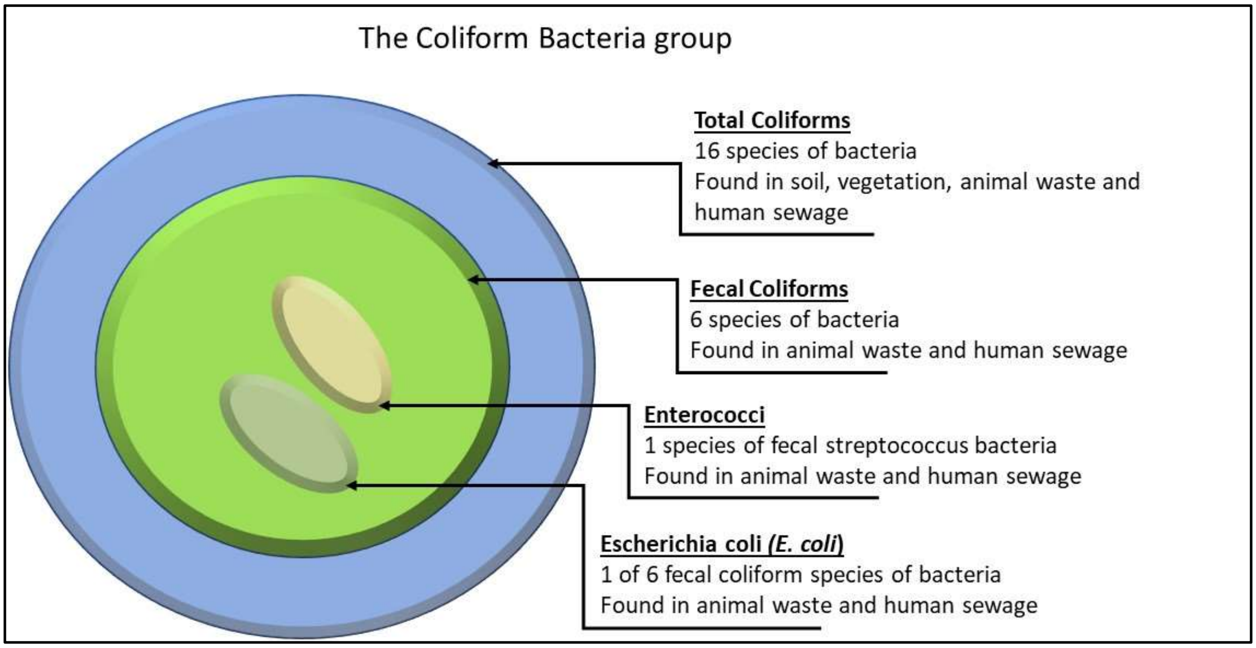
- NR 104.06 is also modified to eliminate variances to the recreational water quality standards previously found.
- WPDES effluent limits and approved lab methods are updated. *E. coli* limits would typically apply from May to September, unless the water body is a drinking water source, in which case either *E. coli* or fecal coliform limits would apply for the remainder of the year.

This White Paper assumes that stream segments impaired for fecal coliform will also be similarly impaired for *E. coli*. It also assumes that activities to identify fecal coliform sources and reduce fecal coliform discharges to Milwaukee River Watershed segments will also similarly reduce *E. coli* concentrations since *E. coli* is a subset of the fecal coliform bacteria group (Figure 2). It is anticipated that the updated rule will not be in place and appropriate data assembled to be used in the next 303(d) listing of impaired waters (2020), so fecal coliform data will be referenced. It is anticipated that the 303(d) listing for 2022 will be based on *E. coli* data.

Assurance that Milwaukee River Watershed Segments are Safe for Recreational Activity - Attainment of Recreational Standards

The amount of fecal pollution that is entering local waterways must be reduced in order to attain Clean Water Act and State of Wisconsin water quality standards, protect human health, allow for safe water related recreation, and remove those waterways from the Impaired Waters 303(d) List. Sources of fecal pollution can include wastewater treatment plant discharges, sewage overflows, leaky sewer laterals and cross connections, leaky septic tanks, urban stormwater runoff, non-point source runoff from farm fields, wildlife, domestic livestock operations (farm animals), various waterfowl and household pets.

Figure 2. Diagram depicting the Relationship between Total Coliform, Fecal Coliform, Enterococci and *E. coli.*



Adapted from: www.mfe.govt.nz/fresh-water/tools-and-guidelines/microbiological-guidelines-recreational-water

In the Milwaukee River Basin, the exact location of these sources have not been identified, with roughly 90% of all fecal pollution coming from unknown sources according to the *Final Report, Total Maximum Daily Loads for Total Phosphorus, Total Suspended Solids, and Fecal Coliform Milwaukee River Basin, Wisconsin – 2018.* The Milwaukee River Basin's Watersheds impaired segments for fecal coliform bacteria are listed in Table 5.

Because there is so little known about fecal bacteria sources, a systematic approach to identifying, locating and prioritizing fecal pollution sources in terms of "human health" risk is a critical necessity for genuinely reducing the amount of fecal pollution in the waterways of the Milwaukee River Basin. This White Paper, prepared by the Bacteria Work Group and formed under the Science Advisory Committee of the Southeastern Wisconsin Watersheds Trust, provides a series of generalized flow charts and descriptive text which postulates logical considerations, pathways and exposure routes for identifying various sources of fecal bacteria loading in the Milwaukee River Basin.

Effective and widespread utilization of such protocols would provide crucial foundational steps towards implementing a well-tailored strategy to achieve TMDL recommended reductions in fecal bacteria loading in the Milwaukee River Basin and attaining the Clean Water Act's recreational standard. Achieving recreational standards ensures that the Milwaukee River Basin's waters are safe for whole (full) body contact (i.e. swimming) and other public recreational purposes.

Table 5. Approved 2014 303(d)-Listed Segments for Fecal Bacteria Contamination Included in the Milwaukee River Basin TMDLs

Water Body	Description [1]	Representative TMDL Reach(es)	Pollutants	Impairments	Current Status [2]	Designated Use [3]
Menomonee River Watershed						
Butler Ditch	Mile 0-2.90	MN-08	Fecal Coliform	Recreational Restrictions – Pathogens	FAL – Supporting	Default FAL
Goldenthal Creek	Mile 0-3.50	MN-03	Fecal Coliform	Recreational Restrictions – Pathogens	FAL – Not Assessed	Default FAL
Honey Creek	Mile 0-8.96	MN-15	Fecal Coliform, Total Phosphorus	Recreational Restrictions – Pathogens, Degraded Biological Community	FAL – Not Supporting	Default FAL Variance
Lilly Creek	Mile 0-4.70	MN-07	Fecal Coliform	Recreational Restrictions – Pathogens	FAL – Not Supporting	Default FAL
Little Menomonee River	Mile 0-9	MN-09	Fecal Coliform, Total Phosphorus	Recreational Restrictions – Pathogens, Degraded Biological Community	WWSF – Not Supporting	Default FAL
Menomonee River	Mile 2.2-2.67	MN-16	E. coli, Fecal Coliform, Total Phosphorus	Recreational Restrictions – Pathogens, Low DO	FAL – Not Supporting	Default FAL Variance
Menomonee River	Mile 2.66-6.27	MN-16	Fecal Coliform	Recreational Restrictions – Pathogens	WWSF – Fully Supporting	Default FAL Variance
Nor-X-Way Channel	Mile 0-4.90	MN-05	Fecal Coliform, Total Phosphorus	Recreational Restrictions – Pathogens, Water Quality Use Restrictions	FAL – Not Supporting	Default FAL
Underwood Creek	Mile 0-2.84	MN-12	Fecal Coliform	Recreational Restrictions – Pathogens, Degraded Biological Community	FAL – Not Supporting	Default FAL Variance
Underwood Creek	Mile 2.84-8.54	MN-11, MN-12	Fecal Coliform	Recreational Restrictions – Pathogens, Degraded Biological Community	FAL – Not Supporting	Default FAL Variance
West Branch Menomonee River	Mile 0-2.45	MN-02	Fecal Coliform	Recreational Restrictions – Pathogens	FAL – Not Assessed	Default FAL
Willow Creek	Mile 0-2.80	MN-04	Fecal Coliform	Recreational Restrictions – Pathogens	FAL – Supporting	Default FAL
Kinnickinnic River Watershed						
Cherokee Creek	Mile 0-1.60	KK-6	Fecal Coliform	Recreational Restrictions – Pathogens	LAL – Supporting	Default FAL
Holmes Avenue Creek	Mile 0-1.80	KK-5	Fecal Coliform	Recreational Restrictions – Pathogens	LAL – Supporting	Default FAL

Water Body	Description [1]	Representative TMDL Reach(es)	Pollutants	Impairments	Current Status [2]	Designated Use [3]
Kinnickinnic River	Mile 2.4-2.83	KK-7	E. coli, Fecal Coliform, Total Phosphorus	Recreational Restrictions – Pathogens, Low DO, Degraded Biological Community	FAL – Not Supporting	Default FAL Variance
Kinnickinnic River	Mile 2.84-9.94	KK-1, KK-2, KK-7	Fecal Coliform, Total Phosphorus	Recreational Restrictions – Pathogens, Degraded Biological Community	LAL – Not Supporting	Default FAL Variance
South 43rd Street Ditch	Mile 0-1.16	KK-3	Fecal Coliform, Total Phosphorus	Recreational Restrictions – Pathogens, Degraded Biological Community	LAL – Not Supporting	Default FAL Variance
Wilson Park Creek	Mile 0-3.5	KK-4	Fecal Coliform	Recreational Restrictions – Pathogens	LAL – Fully Supporting	Default FAL
Wilson Park Creek	Mile 3.5-5.5	KK-4	Fecal Coliform	Recreational Restrictions – Pathogens	FAL – Not Assessed	LFF
Milwaukee River Watershed						
Milwaukee River	Mile 3.1-19.35	MI-27, MI-32	E. coli, Total Phosphorus	Recreational Restrictions – Pathogens, Impairment Unknown	FAL – Not Supporting	WWSF
Milwaukee River	Mile 19.35-29.33	MI-17, MI-25	E. coli	Recreational Restrictions – Pathogens	FAL – Supporting	WWSF
Milwaukee Harbor Estuary						
Menomonee River	Mile 0-2.2	Estuary	E. coli , Fecal Coliform, Total Phosphorus	Recreational Restrictions – Pathogens, Low DO	FAL – Not Supporting	Default FAL Variance
Kinnickinnic River	Mile 0-2.4	Estuary	E. coli , Fecal Coliform, Total Phosphorus	Recreational Restrictions – Pathogens, Low DO, Degraded Biological Community	FAL – Not Supporting	Default FAL Variance
Milwaukee River	Mile 0-2.9	Estuary	E. coli , Total Phosphorus	Recreational Restrictions – Pathogens, Low DO	WWSF – Not Supporting	Default FAL Variance
Milwaukee River	Mile 2.9-3.1	Estuary	E. coli, Total Phosphorus	Recreational Restrictions – Pathogens, Impairment Unknown	FAL – Not Supporting	WWSF
Outer Harbor	Mile 0-0.32	Estuary	E. coli	Recreational Restrictions – Pathogens	FAL – Not Supporting	Default FAL

1) Description corresponds with assessment units. In some cases, more than one assessment unit maybe covered within the listed mileage.
2) FAL = Fish and Aquatic Life, WWSF = Warm Water Sport Fish, LAL = Limited Aquatic Life, LFF = Limited Forage Fish
3) Variances are either for Fecal Coliform or Dissolved Oxygen and are listed in chapter NR 102, Wisconsin Administrative Code.

Source: Final Report, Total Maximum Daily Loads for Total Phosphorus, Total Suspended Solids, and Fecal Coliform Milwaukee River Basin, Wisconsin.

FRAMEWORK for ACHIEVING RECREATIONAL WATER QUALITY STANDARDS

Fecal bacteria contamination has been a problem in the Milwaukee River Basin for decades. Total Maximum Daily Load (TMDL) analysis for fecal coliform bacteria in the Milwaukee River Basin identified the need to reduce fecal indicator bacteria loading (thereby decreasing the risk of exposure to pathogens) to improve water quality and meet recreational water quality criteria. It is expected that the TMDLs will be one of the motivating factors for stakeholders to locate, prioritize, and reduce the amount of fecal pollution in the various waterways of the region.

Moving forward, the indicator organism for achieving compliance with recreational standards will be *E. coli*. Hence, a robust instream *E. coli* data set should be assembled to assess continued impairment against recreational water quality criteria and allowing for statistical analysis of risk by defined stream segments. Data should be collected over a range of hydrological conditions to assist in the characterization of sources and per the updated rules (NR 102.04(6). If wildlife are the suspected source of elevated *E. coli* concentrations, then a site-specific criteria could also be developed to reflect a lesser risk to human health.

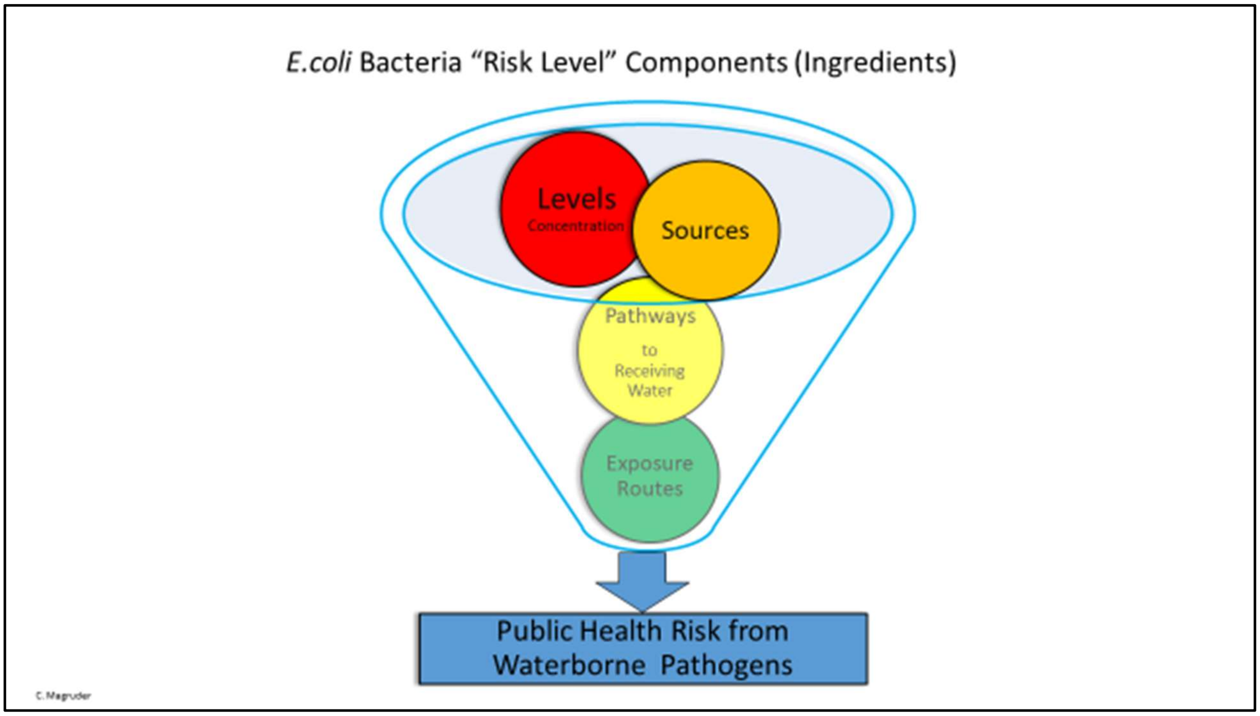
With respect to source identification, the Bacteria Work Group recommends using the approved TMDL momentum to develop and promote a series of *generalized decision-tree type flowcharts* to enhance the general understanding of sources of fecal contamination, bacterial load (concentration), mechanisms of transport, exposure routes (contact) and host susceptibility (likelihood of infection in exposed individuals) ultimately resulting in waterbody impairment within the Milwaukee River Basin. This approach is purely optional but represents a potentially effective course of action in lieu of costly, and sometimes ambiguous, analytical source identification techniques, which require extremely rigorous molecular/ genetic testing in addition to routine, regulatory monitoring. The empirical ability to identify the most likely sources of *E. coli* could be informative to the differentiation of human vs non-human sources, equating to greater or lesser public health risk. While non-compulsory, the following suggestions and/or methodologies may serve as a starting point when beginning to identify sources and evaluate measures to control fecal contamination to surface waters.

The simplified *E. coli* bacterial “Risk Level” components/ingredients (Figure 3) illustrates the four main components (ingredients) that, working in conjunction, can result in enhanced risk to public health as a result of exposure to waterborne pathogens. There is an understanding that all four components/ingredients work in various combinations to produce a relative public health risk level, with some combinations having higher risks than others. This concept is discussed in further detail below.

The first component in this simplified illustration is the “level” or concentration of *E. coli* present in the waterbody. The most elementary considerations are whether the *E. coli* concentration is above the adopted recreational water quality standard, how often this occurs (frequency), and when (i.e. wet weather vs dry weather or both). The likelihood of exposure and illness may increase as the concentration increases, depending on the source.

The second component is the “source” or origin of *E. coli*, i.e. whether it’s from human or non-human sources? As explained previously, *E. coli*, as an indicator organism (or surrogate), represents the potential for human pathogens to be present. *E. coli* originating from human sources are considered of greater risk than non-human sources from the standpoint that there is an inherently greater probability of human pathogens being associated/present in human sources of fecal contamination.

Figure 3. *E.coli* Bacteria "Risk Level" Components (Ingredients)



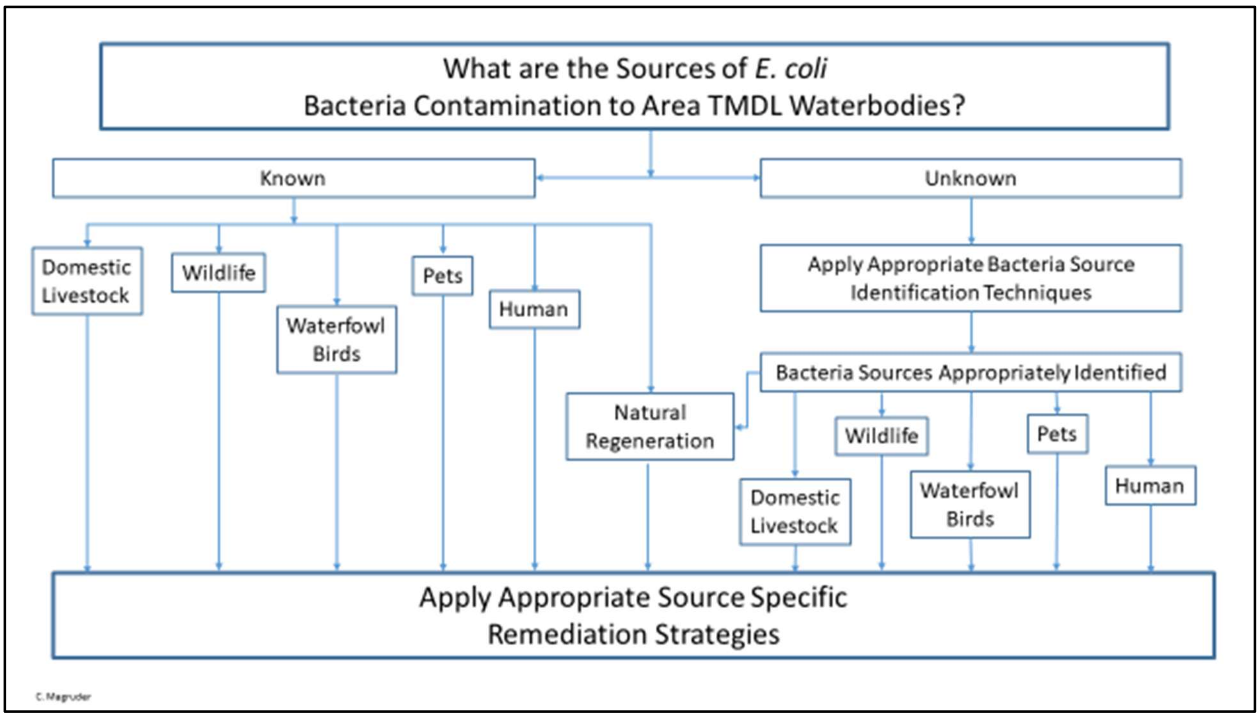
The third component is the *"pathway"*, in which the *E. coli* moves from its point of origin through the environment, ultimately being deposited into a receiving water. For example, fecal indicator bacteria and associated waterborne pathogens can move through the environment via stormwater runoff, storm sewers and groundwater, flowing through and to ditches, streams and rivers, ponds, lakes and lagoons as well as infiltrating into underground aquifers (drinking water source). Understanding the multitude of potential pathways and mechanisms of transport can assist in/is critical for identifying effective mitigation and management, with the goal of reducing human exposure risk.

The fourth component is the *"exposure route"*, i.e. how humans come in contact with *E. coli* that has been transported to a receiving water. Public health risk changes as a function of the load (concentration), method of exposure (i.e. how the person is exposed) and susceptibility of the exposed person to illness (i.e. small children, the elderly and those with compromised immune systems will be more susceptible to infection than healthy adults). For example, public health risk increases as exposure goes from minimal human contact with a drainage ditch/canal to full body contact from swimming to even greater contact from ingestion (i.e. contamination of drinking water supplies). There is an understanding that all four components/ingredients work in various combinations to produce a relative public health "risk level". The risk of illness associated with waterborne human pathogens increases depending on the "level" (concentration), "source" (origin) of the fecal indicator bacteria (i.e. fecal coliform, *E. coli)* and "exposure route" (how humans come in contact). For example, low *E. coli* concentrations may produce a "high risk of illness" if the originating source is human sewage and the exposure route is drinking water or a public swimming beach. Conversely, high *E. coli* concentrations may produce a "lower risk of illness" if originating source is non-human, e.g. domesticated pet waste, and the route of exposure is non-consumptive/non-immersive, i.e. secondary or incidental non-full body contact, such as wading in a stream or canoeing.

Generalized Decision-tree Type Flowcharts

Various potential sources of *E. coli* bacteria are illustrated in the "sources" flow chart (Figure 4). Sources of *E. coli* fall into the same six main categories whether the originating source is known at the outset of the investigation or unknown, requiring the application of source identification techniques. These categories include humans, pets, waterfowl/birds, wildlife, and domestic livestock as the originating sources but also, importantly, the natural regeneration of *E. coli* bacteria in the environment.

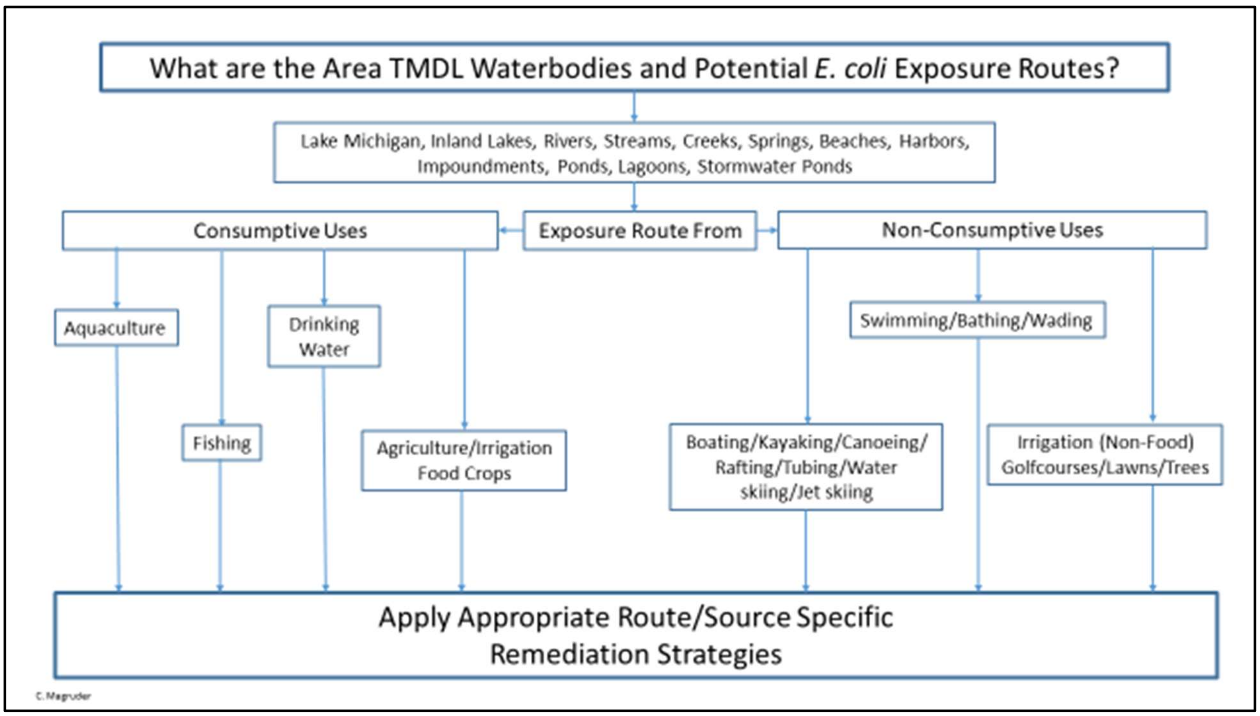
Figure 4. Originating Sources *E. coli* Bacteria Contamination



Source specific remediation strategies can be implemented once the specific source category, or categories, is known. However, approximately 90% of the originating source categories in the Milwaukee River Basin are currently unknown. Determining the source of fecal contamination will require extensive and appropriate *E. coli* source identification techniques be applied. This could require highly sophisticated molecular-genetic testing. However, some source categories could be eliminated immediately, or at least logically ruled out, with inferences and deductions drawn from using the various generalized flow chart diagrams described below. Using readily available information, this decision tree approach characterizes and postulates the most likely sources of *E. coli* through inference, including possible categorization of contamination as human vs non-human source origin. Recognizing the role that hydro-meteorological conditions play in fecal bacteria contamination of waterbodies is fundamental to understanding potential source loadings.

Even when the origin of fecal pollution sources has been identified, the determination of exposure routes are necessary to gauge the level of human health risk. Potential exposure routes can be defined as *"consumptive"* or "*non-consumptive"* (Figure 5). Consumptive exposure routes, i.e. those uses resulting in direct ingestion of waterborne pathogens (e.g. drinking water), would theoretically carry a higher degree of risk. While ingestion can occur as a result of non-consumptive uses, such as swimming, the exposure is of a more incidental nature. Incidental exposure may carry a lesser health risk, depending on the nature of the pathogen, infective dose (concentration/load), length of contact and susceptibility of the exposed individual. There are many different enteric pathogens (i.e. bacteria, viruses and parasites derived from the intestines) that can be transmitted through water. Those of human origin (e.g. sewage), as previously stated, are more likely to result in human infection.

Figure 5. *E.coli* Bacteria Contamination Exposure Routes

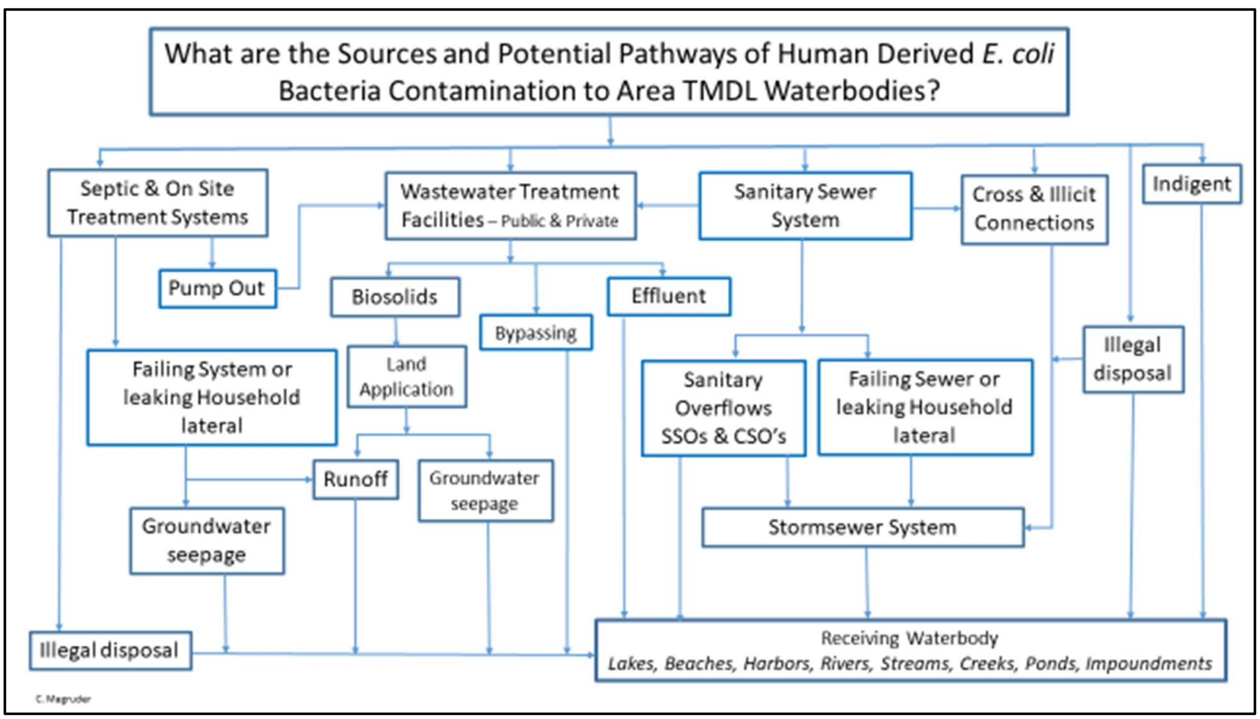


Consumptive uses would include things like drinking water, agricultural irrigation of food crops, aquaculture for human consumption, fishing for human consumption. Non-consumptive uses could include swimming, wading, boating, canoeing and other water related recreational activities or irrigation of non-food items such as golf courses, lawns and trees. Knowing the exposure pathways or how humans use or come in contact with various water resources that are contaminated fecal bacteria and knowing when those bacteria levels are most likely to be elevated can help with reducing health risk by both minimizing contact with that water body and reducing or eliminating the originating bacteria source. As example, if exposure is from a swimming beach, then making sure there are no illicit sanitary sewer connections to storm sewers or storm sewers themselves that drain to or near the beach area, minimize overland runoff/flow and monitoring *E. coli* bacteria levels during use (both dry and wet weather) would be vital in reducing human exposure and health risk levels to enteric pathogens.

The most plausible pathways by which various sources of fecal pollution (Figure 4) reach regional water resources are illustrated in generalized pathway flowcharts (Figures 6-10). These flow chart source categories are to assist with inferences and deductions that can be made to characterize the most likely sources of *E. coli* (human vs non-human). The various pathways determine where exposure is most plausible to occur and ultimately what potential public health risk may be present. There are many ways for pathogens to move through the environment so understanding the mechanisms of transport (pathways) is critical for identifying effective reduction strategies.

Some of the potential sources and pathways of human derived *E. coli* bacteria contamination to area waterways are represented in Figure 6 flow chart.

Figure 6. Potential Sources of Human Derived *E.coli* Bacteria



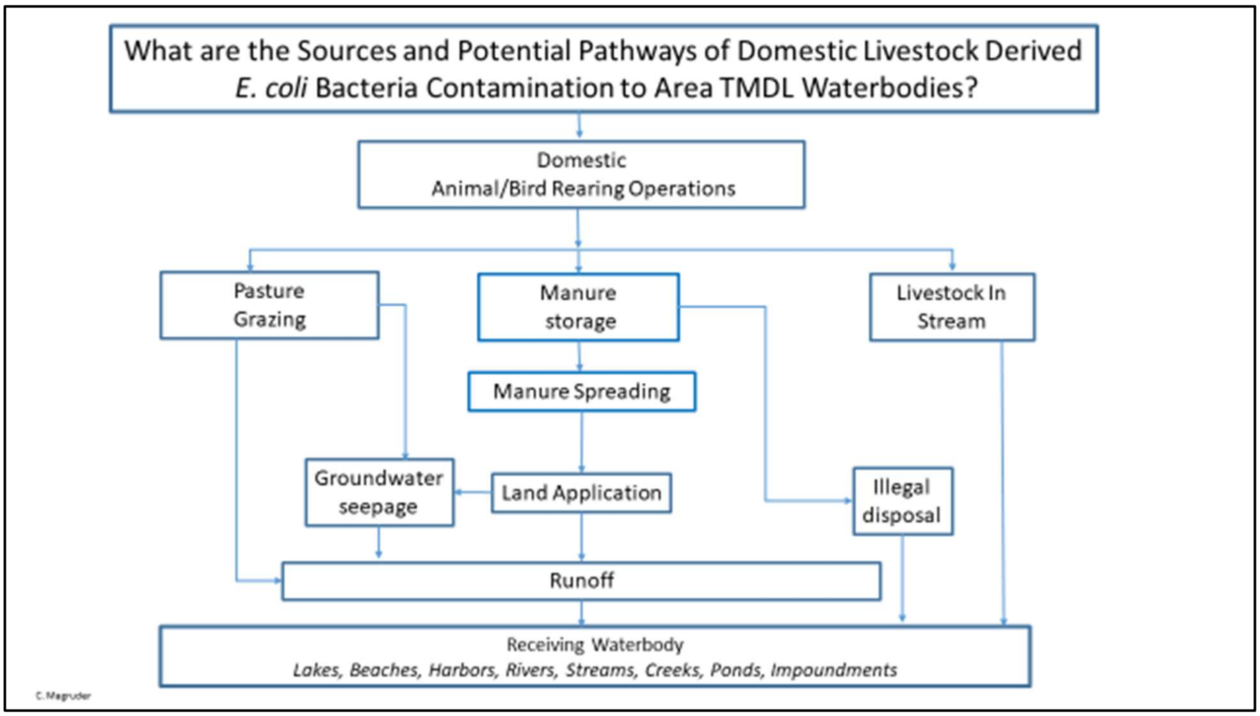
Septic and on-site wastewater treatment systems, wastewater treatment facilities (both public and private), sanitary sewer overflows, cross connections, illicit connections and discharges of sanitary waste often contribute to human derived *E. coli* contamination. Failing septic systems and/or leaking household laterals can also, either directly or indirectly, lead to contamination of receiving water resources. Human derived *E. coli* bacteria is of the greatest concern, and therefore, must be prioritized to have the greatest emphasis for elimination.

Agricultural environments may be an additional source of pathogens if domestic livestock (e.g. cattle) are excreting bacteria, viruses or parasites with their fecal waste. Domestic livestock derived *E. coli* is of concern as human infections with *E. coli* pathotypes and other enteric pathogens have been documented. A variety of pathways capable of delivering domestic livestock derived E. coli to area waterways is depicted in Figure 7.

Contamination of waterways with domestic livestock *E. coli* bacteria can result from a variety of domestic animal/bird rearing operations and transport. The most likely source contamination arises from mismanagement of manure waste, manure spreading/land application with mobilization of fecal waste being associated precipitation (rainfall or snowfall) runoff and pasture grazing of livestock also with runoff or livestock actually entering waterways (streams or rivers).

In addition there can be accidental spills or illegal disposal of animal waste which ends up getting into a receiving water creating the risk of human exposure depending on where, when and how this occurs.

Figure 7. Potential Sources of Domestic Livestock Derived *E.coli* Bacteria

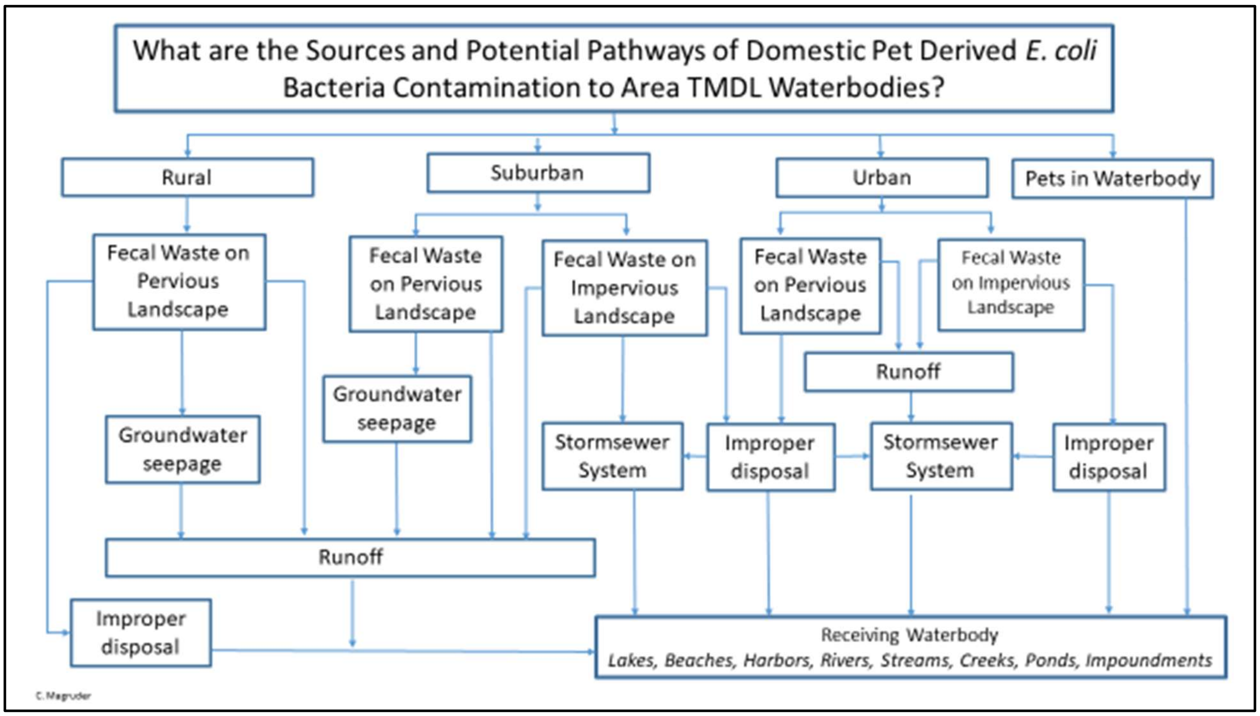


Another source of fecal contamination arises from domestic pets derived *E. coli*. Transport pathways of pet waste to regional waterways occurs in a variety of ways, as depicted in Figure 8. It can originate from stormwater runoff of fecal waste on rural, suburban or urban landscapes.

Pet waste deposited on pervious surface generally breaks down, infiltrating into the surrounding soil, where *E. coli* can enter groundwater. Pet waste deposited on impervious surfaces will also break down, however *E. coli* will mobilize with stormwater and snow melt runoff if not removed immediately. Once mobilized, improperly disposed of *E. coli* can be conveyed (transported) by surface runoff or via the storm sewer conveyance system, finding its way into nearby receiving waters. Consequently, it's important that pet owners pick up pet waste as quickly as possible and dispose of it in a proper manner to reduce fecal loading and the risk of human exposure to potential pathogens; especially true in the urban environment.

Fecal bacteria contamination originating from pet waste should, in theory, be one of the easiest sources of *E. coli* bacteria to manage. Since it comes down to education and modifying human behavior, a fundamental shift in mindset and routine practices must occur, such that pet owners take responsibility for management of their own pet's fecal waste.

Figure 8. Potential Sources of Domestic Pet Derived *E.coli* Bacteria



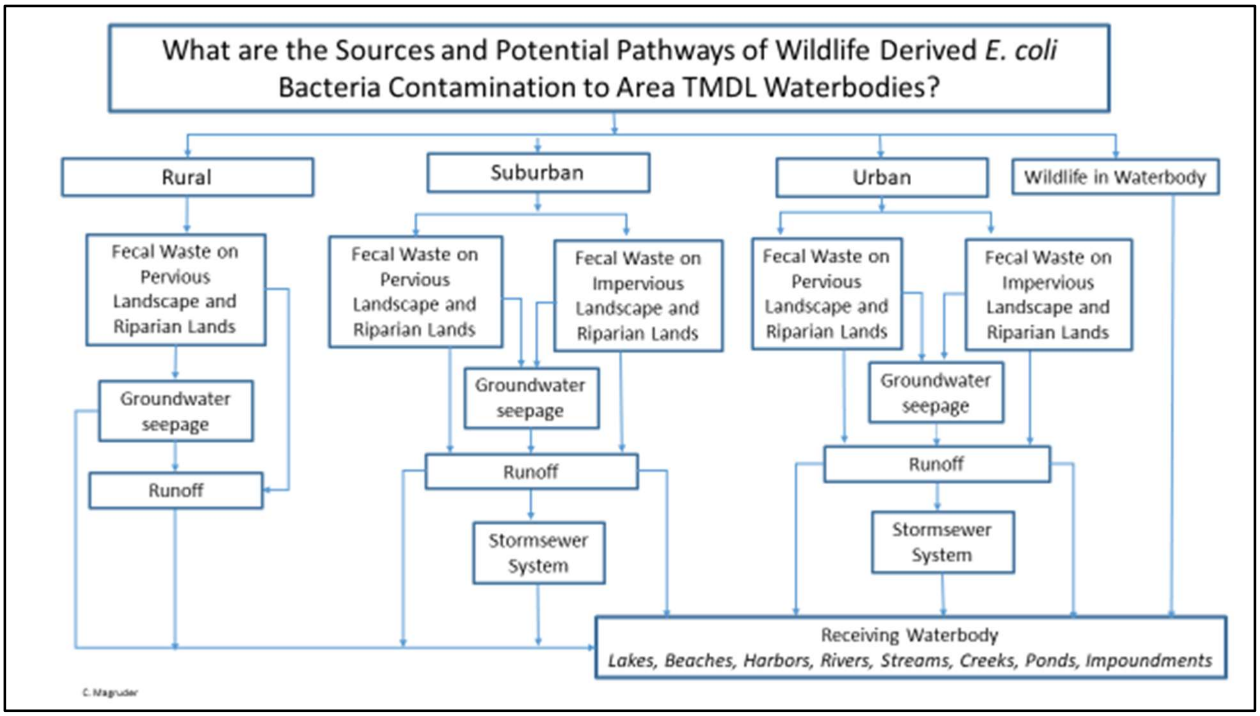
The potential pathways of *E. coli* bacteria entering area waterways from wildlife are very similar to that of pet fecal waste. Wildlife fecal waste can be found on both pervious and impervious landscapes as depicted in Figure 9.

There is a natural element to wildlife waste in the rural and suburban environment, where waste on pervious surfaces generally decomposes into the soil. However, wildlife, like domestic livestock, can contaminate area waterways with *E. coli* bacteria through direct deposition as they live in, enter and/or utilize water resources. Likewise, *E. coli* can enter groundwater and seep into waterways where large wildlife populations, with a heavy fecal waste burden, occur. In the urban environment it is far more likely to have *E. coli* contamination resulting from wild animals such as raccoons, opossums and rodents that utilize storm sewers as habitat, which allows their fecal waste to undoubtedly directly enter area waterways through these man-made stormwater conveyance systems.

Additionally, urban stormwater detention and retention systems can encourage wildlife and waterfowl to use and live in close proximity to these man-made water features. In doing so, they contaminate them not only with *E. coli* but also with other potential human pathogens like giardia and cryptosporidium.

Unlike pet waste, wildlife feces is usually not associated with direct human interactions or behaviors. However, there are exceptions, especially in the urban environment where the presence of human-derived trash and garbage may become a food source for wildlife creating a nuisance situation. Humans are not typically responsible for managing wildlife fecal waste, therefore, mitigating sources of wildlife fecal waste is both problematic and a characteristically low priority in any community.

Figure 9. Potential Sources of Wildlife Derived *E.coli* Bacteria



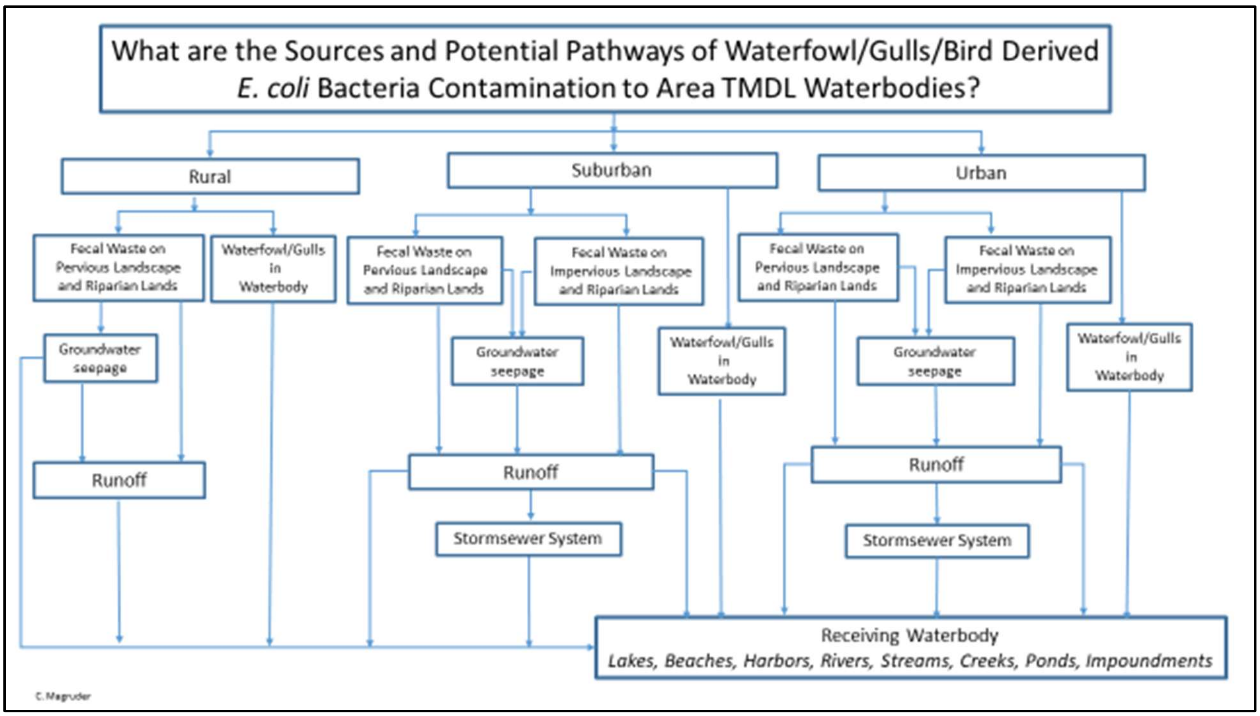
The potential pathways of waterfowl/gull/bird derived *E. coli* entering area waterways are very similar to that as wildlife fecal waste. Waterfowl/gull/bird fecal waste can be found on both pervious and impervious surfaces and landscapes as depicted in Figure 10.

Because birds are highly mobile and often highly gregarious there are numerous ways in which their fecal waste, containing *E. coli* and associated potential pathogens (i.e. *Shigella spp*, *Salmonella spp*), can contaminate waterways.

Bird derived *E. coli* bacteria loads can become mobilized from impervious surfaces and riparian lands as a result of stormwater runoff and drainage from parking lots, rooftops, street gutters, down spouts and storm drains. Gulls, Canada geese, common terns and various ducks commonly share nesting colonies containing dozens, even hundreds of nesting pairs. These large congregations of gulls and waterfowl, such as duck and geese, can seriously contaminate and degrade public swimming beaches, ponds, streams, and lagoons.

A single gull dropping is capable of containing as many as 340 million *E. coli* bacteria per gram, these and other birds can also be vectors for salmonella. Here again, human activities and behaviors, especially in the urban environment, oftentimes foster nuisance situations in which large flocks of birds congregate at beaches, lagoons, stormwater ponds, parks, and parkways because of readily available food sources (human related garbage/trash, food waste and/or feeding) or circumstances that create preferred environmental niche or habitat conditions.

Figure 10. Potential Sources of Waterfowl/Gulls/Bird Derived *E.coli* Bacteria



SUMMARY OF SOURCE IDENTIFICATION FRAMEWORK

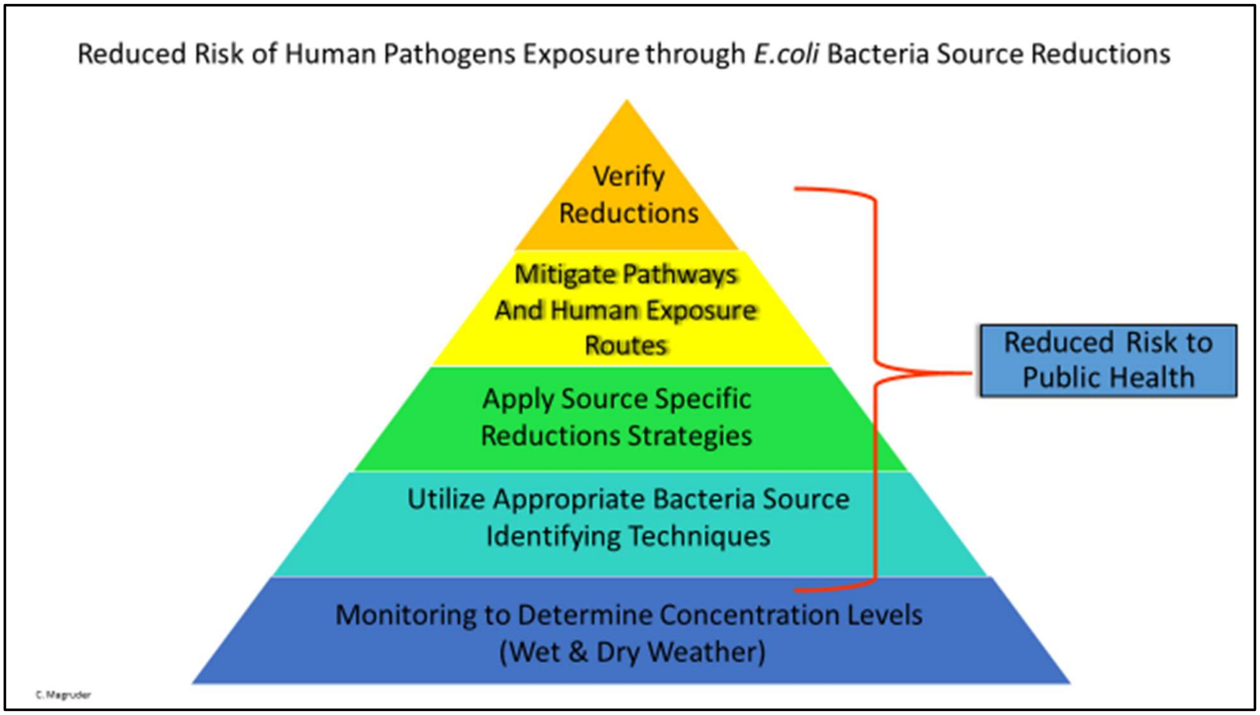
In summary, reducing the risk of human contracted illnesses due to exposure to pathogens can be achieved through *E. coli* bacteria source identification and reductions, understanding and mitigating transport pathways and exposure mechanisms. This requires a strategic approach that utilizes logical deductions to evaluate (rule in or out) specific sources, applies appropriate bacteria source identifying techniques, includes environmental monitoring to determine concentration levels during both wet and dry weather since precipitation generated stormwater runoff is a major driver of pathogen transport and delivery to waterbodies in the Milwaukee River Basin (Figure 11).

The Clean Water Act requires that sanitary sewer systems be maintained such that there are no cross connections diverting sanitary wastewater from full treatment, Municipal Separate Storm Sewer System

(MS4) permits require testing for illicit connections, and failing private septic systems must also be corrected so as reduce sources of human waste entering the nation's waterways. Priority therefore should be given source specific reduction strategies in regards to human derived *E. coli* bacteria and mitigating the transport pathways to waterways and lowering or eliminating the human exposure component to contaminated waterways.

Utilizing the information contained within this White Paper can help elected officials make meaningful decisions, will empower rural and urban municipalities/governments to take corrective actions, and will

Figure 11. Reducing Health Risk from Pathogens by reducing *E.coli* Bacteria Exposure



encourage environmental organizations to act on their findings. Ranking these originating source of *E. coli* fecal bacteria from high to low risk and then prioritizing corrective actions based on the sources, pathways and exposure to pathogenic risk to human health should be prepared. Once these mitigating and correct of actions are in place monitoring would be necessary to verify reductions in *E. coli* bacteria levels. All these together can reduce the risk to public health by keeping humans waste out of waterways and keeping human exposure to that waste at a minimum.

RECOMMENDATIONS FOR IDENTIFYING SOURCES OF EXCESS FECAL BACTERIA

Sweet Water's Bacteria Work Group suggests a six step protocol be followed by local groups and agencies to identify the sources of elevated bacteria in the Milwaukee River Watershed. These steps can be rolled into any future fecal bacteria reduction programs, however, the steps should be regarded as completely discretionary suggestions for identifying sources and/or evaluating measures to control waterborne fecal bacteria contamination. Future fecal bacteria reduction programs can be tailored to the specific and unique circumstances of the highly diverse communities contained within Milwaukee River Basin boundaries. Precise details for each component of individual fecal bacteria reduction programs can be modified and/or expanded during the creation of explicit *Fecal Bacteria Reduction Program Guides* for areas that have adequate stakeholder input and discussions if desired. Again, this is at the discretion of the various stakeholders and collaborators throughout any evaluation.

Throughout 2020-2023 responsible parties should be identified and engaged for developing the expanded *E. coli* bacteria database. This will involve correlating and analyzing the data for newly collected *E. coli* data to advance the knowledge of problem areas and the need specific *fecal bacteria source reduction* practices. Clearly, municipalities are responsible for the sanitary waste collection system and its maintenance and MS4 for illicit connections, but who will be responsible/motivated to collect the instream data, follow-through with the data analysis and then apply the results to the various decision flow charts (trees) to determine which fecal bacteria source problem areas still needs to be ascertained? This will be a meticulous process that will require 2-3 years of careful review and planning. As always, funding availability will be crucial for developing and implementing successful *bacteria source reduction programs*. Identifying funding sources/grants should begin in earnest in 2020 and continue throughout the lifetime of the various fecal bacteria source reduction programs. It is imperative that local, State and/or Federal funding opportunities be aggressively sought out over the next five to ten years (2020-2030). Without ample and proper funding it will be difficult to move forward with meaningful bacteria source reduction programs or make measurable progress towards meeting Clean Water Act goals and State of Wisconsin recreational use objectives.

Six Steps for a Fecal Bacteria Reduction Programs (2020-2030)

1. GATHERING DATA

The data needed to identify and prioritize sources and pathways of fecal bacteria, specifically *E. coli* will vary depending on the specific location in which a *Bacteria Reduction Program Guide* can or should be used. Possible types of data are listed below (Table 6), but this list is not exhaustive. If there are gaps in data, the *Bacteria Reduction Program Guide* should develop step-by-step instructions as to how to fill those gaps and specific resources that can provide support in doing so. These steps can be tailored to each set of circumstances but can also be general and flexible enough in that their uses can cover a wide variety of scenarios and locations.

2. ANALYZING DATA

Analyzing data helps determine relationships, narrowing bacteria pollution originating sources and estimate relative contributions from areas or sites with multiple sources will be necessary. It is also helpful to identify how, when and why the waterways are most impacted (dry or wet weather). A *Bacteria Reduction Program Guide* can or should provide examples, scenarios and instructions for identifying those relationships, revealing trends, and making cause and effect correlations.

3. CONDUCTING SITE ASSESSMENTS

Site assessments may be conducted by municipalities (wastewater and MS4 permit holders), MMSD, watershed organizations/concerned citizens, or colleges/universities. Site assessments help determine sources and include visual assessments of the site, physical assessments, sanitary surveys, and biofilm assessments. An example of a physical site assessment developed by the City of Racine, WI is shown in Appendix 1, (Figure 12). A *Bacteria Reduction Program Guide* should provide instructions on how to conduct various site assessments and develop templates to document field observations. Advances in field screening tests may allow more rapid identification elevated bacteria levels, the conditions when they occur, allowing discernment of potential sources at an economical cost.

Table 6. Examples of Data Types

Urban Sites, Upstream Milwaukee River	Rural Sites, Upstream Milwaukee River	Urban Sites within the MMSD Service Area
1. Water quality monitoring records for 10 years 2. Fecal coliform and *E. coli* monitoring data for wet and dry weather conditions 3. DMR disinfection reports 4. SSO occurrences – reported or not 5. Basement backups reports 6. Sewer rehabilitation projects 7. Locations of septic systems now sewered 8. Remaining septic systems in municipal boundaries 9. Illicit connections	1. Water quality monitoring records for 10 years 2. Fecal coliform and *E. coli* monitoring data for wet and dry weather conditions 3. Locations of septic and mound systems with proximity to channels and tiled fields 4. Inspections of septic systems at sale reports 5. Animal operations with access to streams 6. Fields with manure application 7. Conformance reports to seasonal application restrictions and proximity to watercourses 8. Fields used for septage spreading 9. Manure hauler practices and documentation	1. Water quality monitoring records for 5 years 2. Fecal coliform and *E. coli* data for wet and dry weather 3. Storm sewer or open channel discharges to stream segments where elevated bacteria concentrations have been observed

4. IDENTIFYING SITE-SPECIFIC SOLUTIONS

A *Bacteria Reduction Program Guide* should include descriptions of green infrastructure and other best management practices (BMPs) that could help reduce bacteria loadings. BMP recommendations could include rain gardens, bio-retention, stream stabilization, buffer strips, repairs to infrastructure, or changes in policy. Detailed descriptions for each practice, scenarios for using each practice, and resources for implementing and funding those practices could be included as well.

5. UTLIZING A DECISION TREE MATRIX AND FECAL BACTERIA SOURCE FLOW CHARTS

Risk management is embedded in the decision tree matrix via prioritization of sites. High priority sites are those most likely resulting from human sanitary waste and waters with elevated bacteria levels that are also utilized for whole body recreational uses. Non-human sources that are controllable (such as domestic animals) will then be identified for control. In many cases, the matrix may recommend green infrastructure or other localized measures to mitigate run-off. In the highest priority cases, however, further investigation and elimination of the source of bacteria will be required. Municipalities could use GIS or work with their engineering partners to assess risk exposure to high priority sources to prioritize multiple high priority sites. An example decision tree successfully used by the City of Racine Health Department is shown in Appendix 1. This model (Figure 13) can serve as a template that can be modified and adapted for the numerous communities and varied situations found within the Milwaukee River Basin.

6. HOW AND WHERE TO TAKE WATER QUALITY SAMPLES

Safeguarding the integrity of taking water samples is crucial to successfully identifying sources of fecal bacteria. A *Bacteria Reduction Program Guide* should include a water quality assurance plan (WQAP), which provides instructions on how, when and where to properly take water samples. Additionally, it should include a list of resources that can help complete genetic marker testing to distinguish human from non-human sources of fecal pollution, specifically *E. coli* bacteria. Protocols should be included in the Guidance for selecting sample locations to identify instream concentrations from potential bacteria sources. Samples should be collected under varying hydrologic conditions. And results should be shared so stakeholders throughout the watershed are aware of identified sources and more efficiently apply findings to their location.

CONCLUSIONS

As confirmed by water quality monitoring undertaken in the Milwaukee River Basin over several years, the presence of fecal coliform, including in particular from human waste, at numerous sites within the Basin violates the recreational standards for surface waters set out in the Clean Water Act and corresponding Wisconsin law. While the existence of this health risk is widely acknowledged, the exact location of over 90% of the sources of contamination have not been identified.

A systematic approach to locating and prioritizing sources of fecal pollution is a critical step towards implementing a well-tailored strategy to remove this public health risk and ensure that the Milwaukee River Basin's waters are safe for drinking, swimming and other recreational purposes. Communities with stormwater permits and sewerage treatment plants, county health and conservation departments, city engineers and technicians, private engineering companies and non-profit organizations all have a shared interest in reducing the amount of fecal pollution found in our watersheds' waterways, but many lack the resources or know-how to do so in a most cost-effective way. This White Paper summarizing the findings and recommendations of the Bacteria Work Group set up by the Science Policy Committee of the Southeastern Wisconsin Watersheds Trust to explore and address this problem.

The White Paper provides a series of generalized decision flowcharts that provide clear understanding in the recognition of pathogen risk levels, assists in evaluating likely sources, helps determine potential exposure possibilities and probabilities and fecal pollution pathways (routes) to the varieties of waterbodies with the Milwaukee River Basin. It provides a detailed summary description of a protocol developed for identifying the sources of bacteria loading in an urban setting that could be modified in other communities in the Milwaukee River Basin and recommends that over the next five –ten years (2020 -2030) that (1) sustainable funding be sought immediately, (2) the production of a user-friendly *Bacteria Reduction Program Guide* be developed highlighting various protocols and how they could be implemented, (3) test piloting the use of a *Bacteria Reduction Program Guide* utilizing the recommended six step protocol in strategically identified settings and (4) begin to apply what is learned from test pilot programs to widely the Milwaukee River Basin where appropriate and feasible.

The development and testing of a *Bacteria Reduction Program Guide(s)* will depend upon the procurement of funding for this purpose. Funding availability will be key for developing and implementing any bacteria source reduction programs and is crucial to the overall success of such source reduction programs.

Appendix 1

A guide/model of a more advanced and comprehensive *E. coli* bacteria source identification and source elimination strategy has been utilized the City Racine, Wisconsin. A decision tree has been created by the City of Racine Health Department to identify human related sources of *E. coli* through the wastewater, sanitary and stormwater sewer systems. The program provides step-by-step instructions for responsible parties to complete the tasks described below. Many of these tasks were identified as critical steps in the City of Racine's successful efforts to locate and prioritize sources of pollution, (Presentation: A Systematic Framework to Identify and Prioritize Sources of Bacteria, Julie Kinzelman).

Test-Pilot Locations

The Bacteria Work Group recommends test-piloting the first of *Bacteria Reduction Program Guides* when fully developed and to do so over the next five to ten years (2020-2030), for use in four locations within the Milwaukee River Basin that are known to be problematic, have high levels of fecal pollution using the following criterion: access to financial and staff resources, type of pollution (point vs nonpoint) and potential sources of fecal pollution (human, domestic, farm and wildlife).

Suggested Locations

1. A rural, upper Milwaukee River site, primarily in an agriculture area.
2. A small municipality along the Milwaukee River or one of its tributaries that has a stormwater permit and is located outside of the MMSD service area.
3. A neighborhood along the Milwaukee River or one of its tributaries that relies primarily on septic systems for waste disposal.
4. An urban municipality having a stormwater permit within the MMSD service area.

Each location would require a partner who would champion the process and give feedback to the Work Group about the Bacteria Reduction Program Guide ease of use, challenges encountered, suggestions for improvement, and recommendations on how to best use the *Bacteria Reduction Program* six step protocol basin-wide.

Strategies for basin-wide implementation could include short-term actions for immediate changes needed due to human health concerns as well as long-term planning such as incorporation of bacteria-mitigating measures into Stormwater Management Plans, Illicit Detection and Discharge Programs, and Stormwater Utility Funds. The specific strategies adopted will be informed by learning developed through the test-pilot locations and will ultimately depend upon the priorities and resources of the communities in which high-risk to human health sites are located. Likewise, the extent to which the municipalities utilize the Bacteria Reduction Program Guide, following the pilot phase, will largely depend upon its cost-effectiveness. Therefore, feedback in relation to cost and other local capacity issues will be a key focus of the pilot studies.

Figure 12. Site Assessment Sample

Location and surrounding area:

Located on the western branch of the river which splits around the Park. Land to the west is residential and to the east is open space/parkland mainly grass.

Stream bank conditions:

Stream banks are in good condition with recent restoration work undertaken on the east bank adjacent to site and approximately 120m u/s.

Infrastructure:

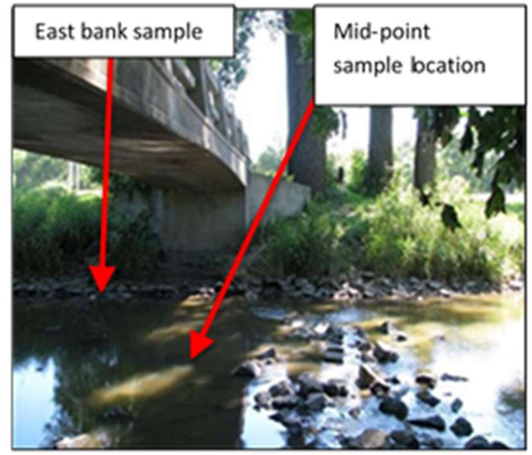
Outfall adjacent to footbridge and sample locations exhibits a constant dry weather flow.

Other comments:

This outfall is suspected of contributing to the high levels of E-coli at the sample site.

Source: Presentation: A Systematic Framework to Identify and Prioritize Sources of Bacteria, Julie Kinzelman

View south, downstream, from the footbridge. Both banks are in good condition.

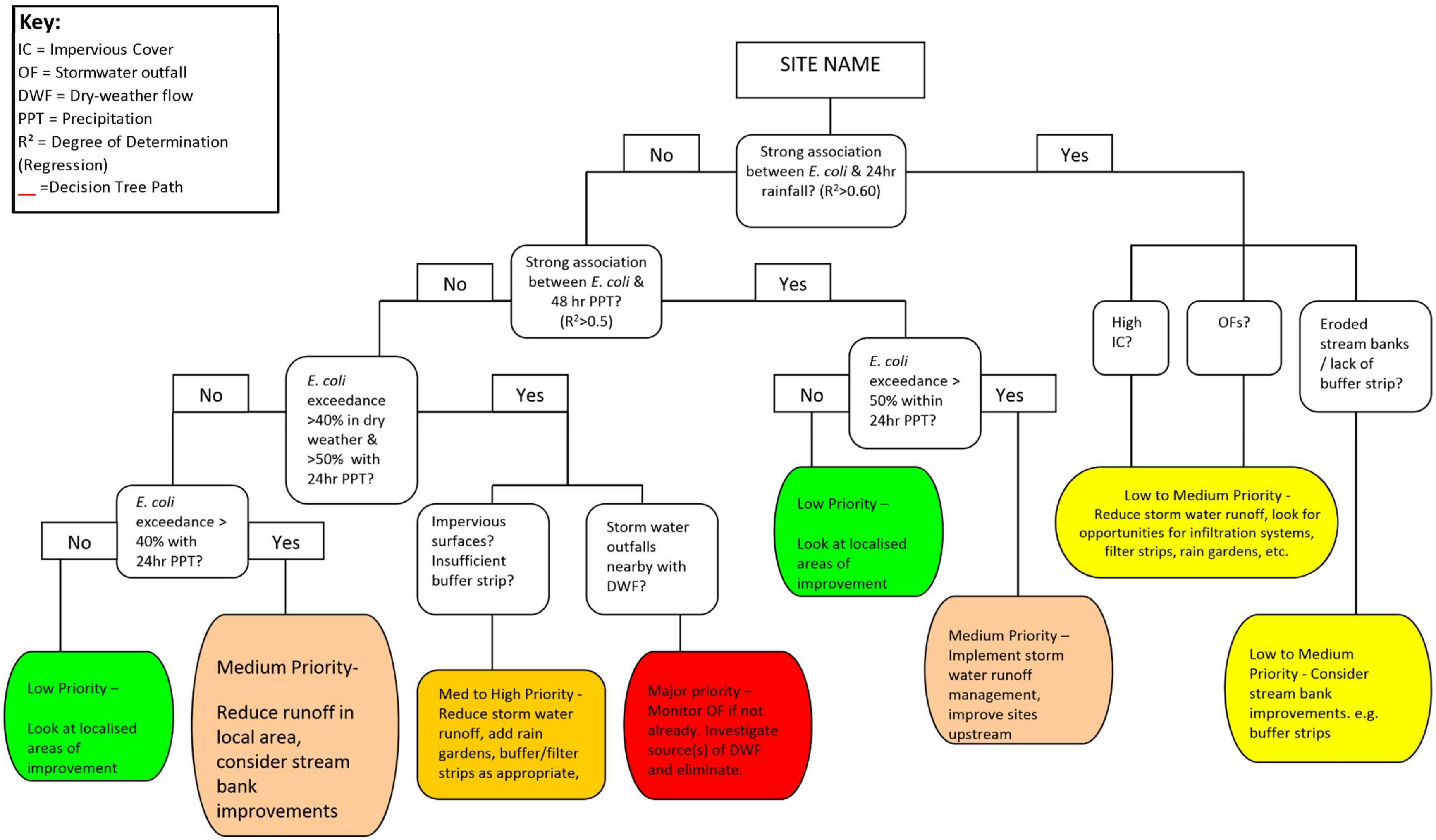


View from the west bank across to the east bank sample location.

View of outfall exhibiting dry weather flow.

View looking north from footbridge at east bank. Conditions = high grass and little sign of erosion.

Figure 13. Decision Tree Matrix Sample



Source: Presentation: A Systematic Framework to Identify and Prioritize Sources of Bacteria, Julie Kinzelman.