Guidance for Developing Bacteria TMDL (Total Maximum Daily Load) Stormwater Wasteload Allocation (SW-WLA) Watershed Implementation Plans (WIPs)

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The objective of this guidance is to specify requirements and recommendations for permitted Phase I MS4 stormwater jurisdictions in Maryland in the development of their permit required Stormwater Wasteload Allocation (SW-WLA) implementation plans and subsequent progress reporting for bacteria total maximum daily loads (TMDL). This document draws heavily on the material presented and discussed at the February 7, 2020 Bacteria TMDL Implementation Workshop held at the Maryland Department of the Environment (MDE) and subsequent meetings with contributors.

Introduction

This document outlines the requirements and recommendations for Phase I municipal separate storm sewer system (MS4) permitted jurisdictions developing implementation plans for Bacteria TMDLs in Maryland. Bacterial water quality impairments pose a risk to human health via direct human contact with surface waters and shellfish consumption. The goal of Bacteria TMDLs and their associated stormwater wasteload allocation (SW-WLA) implementation plans is to ensure that fecal bacteria concentrations are low enough to provide full body contact recreation and shellfish harvesting in designated waterbodies. Sources of bacteria, however, can be difficult to trackdown and even if they are identified, remedial actions can be financially and politically difficult. Furthermore, public health data associated with bacteria impairments can be limited, making it sometimes difficult for practitioners to be proactive in planning for, and implementing Bacteria TMDLs. This document details the required and recommended datasets and water quality monitoring strategies that will enhance the ability of the Phase I MS4 jurisdictions to trackdown sources of bacteria, since identifying and eliminating fecal bacteria sources is key to meeting Bacteria TMDL SW-WLA goals.

This guidance document is linked to the requirements of major stormwater permits in Maryland, i.e., Phase I MS4 permits. However, the general principles and their respective recommendations outlined in this guidance can be applied across all watersheds in the State for any and all jurisdictions and watershed managers. This document addresses the evaluation and remediation of bacteria impairments from a data perspective. A great deal of infrastructure is and will continue to be overhauled in Maryland to meet load and wasteload allocations in TMDLs. This guidance encourages jurisdictions to evaluate their bacteria impaired waters beyond current conditions and to account for natural resource assets and risks to those assets to prioritize implementation (Soneja et al 2016). The primary question that this guidance attempts to assist jurisdictions with is: "how can implementation be prioritized given a diverse set of local resources and economies in order to protect human health?". The implementation strategy outlined by this guidance is the identification, and elimination of fecal bacteria sources across a watershed, prioritized based on impacts to resources related to human health, e.g., shellfish harvesting locations, designated beaches, etc. In connection, jurisdictions should establish in their plans any issues with using indicator bacteria, and how this presents a barrier(s) for accounting for implementation, if applicable. Lastly, jurisdictions should be aware and begin to consider integrating mutli-variate approaches to Bacteria TMDL implementation, with the understanding that harmful algal blooms (HABs; large scale cyanobacteria growth often associated with nutrient enrichment) can co-occur spatially where fecal bacteria issues persist. Emerging methodologies to potentially trace and differentiate between these different types of toxicity (i.e. chemical and biological) using chemical tracers are discussed in Section 6.

Maryland Department of the Environment (MDE), Watershed Protection, Restoration, and Planning Program (WPRPP) is working to link together datasets collected and managed by various programs within and outside MDE. MDE WPRPP is working to facilitate data sharing and make these data available to implementers (e.g., data that is usually generated from regulatory programs) for use to prioritize implementation. Jurisdictions should consider issues related to stormwater management in a watershed-wide context. Discussions should be framed based on watershed boundaries, because most watersheds have some degree of interjurisdictional management already in place due to the overlap in infrastructure. The information bases are designed to be linked in this manner. While not required, jurisdictions with wasteload allocations are encouraged to work cooperatively with other neighboring jurisdictions even if they do not have stormwater permits in developing their plans to start building multivariate databases as part of their source identification efforts.

In terms of collaboration, watershed managers should make use of available resources at the local level and State level to evaluate risk (identify potential sources) and identify appropriate best management practices (BMPs) to eliminate sources of fecal bacteria within their watershed. Leveraging the data and operational expertise provided by a defined group of stakeholders will increase the effectiveness of restoration efforts. Moreover, economic considerations of shellfish beds and beaches in the form of monetary production data would be useful to demonstrate investment versus return values for TMDL related implementation.

While this document does specify certain mandatory planning elements and reporting elements, it is not intended to be a comprehensive list of implementation requirements, but should instead serve as a starting point for planners and implementers to begin or add to existing implementation processes. As with Bacteria TMDL implementation plans themselves, this guidance document will be updated when better information becomes available, either due to advances in science or reports from successful monitoring and implementation efforts. Those using this document should coordinate directly with the Watershed Protection Restoration and Planning Program (WPRPP, formerly the Integrated Water Planning Program or "IWPP") at MDE, so that feedback can be integrated into this guidance to improve Maryland's performance in terms of water quality impairment reductions Statewide.

Bacteria TMDL Implementation Background

The Chesapeake Stormwater Network and the Urban Stormwater Workgroup of the Chesapeake Bay Program have summarized the state of Bacteria TMDL implementation across the Chesapeake Bay watershed including potential sources, standard BMPs and source elimination strategies, and typical issues that jurisdictions will encounter.

Research continues to find that bacteria levels are high in urban areas, and isolating the specific Fecal Indicator Bacteria (FIB) factors that cause them is confounding. Wet weather monitoring consistently shows that FIB levels are generally two to three orders of magnitude higher than the water quality standards established to protect human health. FIB levels during dry weather tend to be lower and less variable in most urban watersheds, although standards are still exceeded in local hotspots that are influenced by human waste. There is little hard evidence to show that FIB levels in urban watersheds have improved much in recent decades, except in situations where known sewage influences were successfully removed. A lot of investigative work is needed to find (and fix) the spills, leaks, discharges, and overflows that are polluting urban waters.

FIB can originate from humans and animals. Most science indicates that human waste is the most likely to cause illness – and this is the top priority for water quality management with regard to bacteria. Managers typically like to use land-use loading rates when developing watershed plans. However, land-use loading rate data is extremely variable for bacteria loads, both temporally and spatially. Growth, die-off and transport dynamics are very difficult to simulate. So, there are a lot of confounding variables, but general predictors of elevated FIB concentrations include high impervious cover, high sediment-yielding land-uses, and proximity to on-site disposal systems (OSDS or "septics").

The presence of high FIB concentrations is strongly associated with urban land-use in a watershed, but it is difficult to isolate the specific sub-watershed factors that produce them. As a result, assigning a reliable loading rate for FIB solely based on urban land-use is not currently supported by available science. This is unfortunate, since water resource managers often rely heavily on these land-use based models for implementing other local State-based TMDLs. The nutrient and sediment accounting framework behind the Chesapeake Bay TMDL is not currently appropriate for crafting local Bacteria TMDLs or implementation plans for bacteria impairments. Accurately simulating bacteria loading, delivery or treatment using the current generation of watershed simulation models is a challenge compared to other Chesapeake Bay pollutants.

Quantification of the bacterial removal efficiency of individual Best Management Practices (BMPs) also proves difficult.

- BMP performance research has been limited to just a few BMPs, and few field studies have been done with diverse methodologies. In addition, BMP efficiency is difficult to quantify, because there is a partition in the data that is difficult to create between removal and die-off.
- Most urban BMPs show some ability to reduce FIB, but not enough to meet water quality standards. Much less is known about how they work during dry weather conditions.
- Urban BMPs must perform at an extremely high level (99+ % removal efficiency) to consistently reduce bacteria concentrations from stormwater inflow, enough to meet water quality standards. Recent BMP performance data confirms that they cannot consistently meet such a high treatment standard (see Chesapeake Stormwater Network report for specific performance: https://chesapeakestormwater.net/2018/10/fecal-indicator-bacteria-management/).
- Local stormwater and wastewater agencies need to integrate their Illicit Discharge Detection and Elimination (IDDE), Infiltration/Inflow (I/I) and Sanitary Sewer Overflow (SSO) monitoring programs together to identify bacteria sources in their community.

Given the issues and inaccuracies associated with quantifying land-use loading rates and traditional BMP performance, this guidance uses an alternative approach to Bacteria TMDL implementation in Maryland. The approach is based on using spatial identification of potential bacteria sources on the landscape, and associated water quality monitoring to identify sources, track progress, and estimate trends.

Hotspots signify risk, in terms of traditional infrastructure, these include: sewer leaks, manhole overflows, sewage exfiltration, untreated waste releases, boat discharges, etc; and in terms of evaluations of residential practices: leaking septic tanks, illicit wastewater discharge from campers and homes, pet waste pick-up behavior, and mulching habits.

Most bacteria-related problems are rooted in untreated wastewater discharges that are difficult to pinpoint in the urban environment. Ways to overcome difficulties of pinpointing hotspots include:

- New bacteria source tracking methods and synoptic stream/storm drain sampling, which can identify bacteria hotspots causing the greatest public health risk in urban watersheds.
- Managers supplementing their tracking methodologies with detailed follow-up investigations to isolate sewage leaks and other individual bacteria sources causing the bacteria hotspots.

In contrast to nutrient and sediment TMDL implementation plan development, bacteria baseline and progress modeling is not required of the Phase I MS4 jurisdictions. This is because Bacteria TMDL implementation uses a source identification approach summarized in the preceding paragraphs. Furthermore, as also described in the preceding paragraphs, modeling is not required due to the significant uncertainty in the reduction potential of typical BMPs and the significant variability and range in fecal bacteria concentrations in receiving water bodies. For these same reasons, while MDE asks that local jurisdictions include timeframes with milestones for identifying and remediating sources of fecal bacteria across watersheds, jurisdictions are not being asked to specify final achievement dates for SW-WLAs, as is required for Nutrient and Sediment TMDL SW-WLA Implementation Plans.

Section 1: Summary of TMDL Modeling Methodologies

TMDLs provide the base framework for remediating fecal bacteria water quality impairments. These TMDLs lay the foundation for management, and therefore implementation. In Maryland, Bacteria TMDL watershed models are fairly simple and provide a general estimate of fecal bacteria sources by type, e.g., human source, domestic pets, livestock, and wildlife, and location. The modeling methodologies for these TMDLs are described below to provide context for the remainder of this guidance that outlines the specifics of the implementation approach. The TMDLs do not identify specific sources of fecal bacteria across the landscape, which is where the permit required implementation plans take over.

There are three types of water quality models used to simulate water column bacteria concentrations in response to variable watershed loads that are used to develop Bacteria TMDLs in Maryland's Shellfish harvesting waters: (1) a one-segment Tidal-Prism model, (2) a multiple-segment tidal-prism model, and (3) a HEM-3D model depending on the size of the water body. Maryland's fecal Bacteria TMDLs are not developed using mechanistic watershed models similar to nutrient and sediment models. Sources of bacteria are not as ubiquitous across landscapes like nutrients and sediments. Rather, they are highly localized (see Introduction - Bacteria TMDL Implementation Background), making the development of mechanistic models difficult. Maryland's TMDL methodology for fecal bacteria, uses observed bacteria concentrations and flows to back-calculate estimates of watershed loading inputs. Since the TMDLs do not simulate watershed processes as in a mechanistic model, they do not provide modeling information with regard to the potential sources of bacteria in the watershed. Therefore, source identification is one of the primary goals of Bacteria TMDL implementation. Applicable water quality models could be used by local jurisdictions to attempt to simulate impacts on water column fecal coliform concentrations in response to variable freshwater inputs and stormwater inputs; however, this is not recommended at this time.

Generally, the information needed for the delisting of a fecal coliform impairment in shellfish waters is not related to the Bacteria TMDL models themselves. Rather, the information needed for delisting is solely based on the fecal coliform monitoring data itself, and subsequent assessments using the numeric water quality criterion and mitigation of sources.

While the TMDL modeling tools may not provide a significant amount of information pertaining to source identification and potential implementation actions, the TMDL modeling can provide useful information with regard to the potential types of fecal bacteria sources in the watershed. Most of Maryland's Bacteria TMDLs and source sector allocations (i.e. wasteload allocations and load allocations) are informed by Bacteria Source Tracking (BST) data. Even though the State uses an older methodology, the data still provide estimates of variable sources of bacteria in a watershed.

Quick Take: Is the BST data that was used in the source assessment for the TMDLs still accurate? Does MDE have any plans to update the data?

At the moment, MDE does not have any plans to collect additional BST data, but there is a possibility this can be done in the future. Per this bacteria guidance, and the MS4 monitoring guidelines, jurisdictions are encouraged to collect new BST data to assess changes in microbial community sources. In addition, while watershed conditions have certainly changed in many of the approved Bacteria TMDL catchments (this would have an impact on BST results), the TMDL BST data still have utility in watersheds that have experienced little change, e.g., high density urban watersheds. There is certainly error associated with the original results, as with any measured values, but MDE believes the original BST data still provide an adequate breakdown of the major sources of fecal bacteria in a watershed.

Beaches and shellfish beds are individually considered in terms of their own unique water quality criteria. Therefore the model used for TMDL development depends on analyses of waterbody/pollutant dynamics, data available, and water quality criteria. Whether the most probable number (MPN) or colony forming unit (CFU) is used as the unit for the expression of the TMDL depends on the laboratory methodology used for estimating bacteria counts. For shellfish waters, only MPN is used to estimate the fecal coliform concentration, which applies for both assessment purposes and TMDL development. Bacteria TMDLs in shellfish waters use a Statistical Threshold Value (STV) methodology, as defined by the listing criteria:

- https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Documents/Assessment_Methodologies/Bacteria_Listing_Methodology_Final_2_23_2021.pdf.

Furthermore, all shellfish TMDL models use an inverse load estimation methodology, which uses water quality data to back-calculate pollutant watershed load.

The differences between the CFU and MPN expressions of fecal bacteria concentrations and laboratory methodologies used to determine those concentrations are complex. CFU is used with the membrane filtration method for determining concentration, and it represents a count of the bacterial colonies on the membrane after an incubation period. MPN is used when not counting a specific thing, but rather it is based on a probability used for the IDEXX method, or multiple fermentation tube method, when wells or tubes are negative or positive. The EPA CFU and MPN methodologies are discussed in the following documents:

- See Section: 4.4.1.1 Culture Methods in the *National Beach Guidance and Required Performance Criteria for Grants, 2014 Edition* *or* pages 4-17 in the *National Beach Guidance and Required Performance Criteria for Grants June 2002* (U.S. EPA 2002).

Section 2: Overview of MS4 Permit Requirements and Other Regulatory Requirements Informing Bacteria TMDL Implementation Plan Development

This section of the guidance provides a summary of the regulatory framework for the development of permit required Bacteria TMDL implementation plans. This regulatory framework includes: (1) the regulations and protocols used in determining whether a waterbody is impaired due to elevated fecal bacteria concentrations, and (2) the specific sections of the Phase I MS4 permit that dictate required elements of all TMDL implementation plans and required monitoring related to fecal bacteria. (1) not only reiterates the ultimate goal of Bacteria TMDL implementation (i.e., meeting fecal bacteria water quality criterion), but it also describes how a jurisdiction can implement a future monitoring plan that is consistent with State assessment methodologies for waterbody delisting purposes. (2) serves as a reminder to jurisdictions with regard to the required elements of their implementation plans, and it connects the permit required monitoring to the development of their plans.

Clean Water Act 303(d) Overview

MDE WPRPP develops TMDLs to address bacteria-impaired (i.e. Category 5) waters listed on Maryland's Integrated Report of Surface Water Quality. Category 5 waters are impaired and require a TMDL. Once a TMDL is developed for the combination of impaired water and pollutant, the waterbody will move to Category 4a; waters that have completed a TMDL. The ultimate goal will be for the waters to move "off the list" to Category 2 signifying that they are attaining the Water Quality Standard for that pollutant. Currently identified bacteria impairments are listed in the state's latest Integrated Report which can be found on MDE's website here (https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Pages/Combined_2020_2022IR.aspx) Local jurisdictions can search for specific impairments through the searchable Integrated Report Database (https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Pages/303d.aspx) or through the Water Quality Assessments (IR) and TMDLs map (https://mdewin64.mde.state.md.us/WSA/IR-TMDL/index.html) (MDE 2021a).

Watershed planners developing Bacteria TMDL implementation plans should be familiar with the following items in the Code of Maryland Regulations (COMAR):

1. Designated uses – COMAR 26.08.02.02
2. Water quality criteria specific to designated uses – COMAR 26.08.02.03-3
3. Surface water use designation – COMAR 26.08.02.07
4. Stream segment designations – COMAR 26.08.02.08
5. Anti-degradation policy

a. COMAR 26.08.02.04
b. COMAR 26.08.02.04-1
c. COMAR 26.08.02.04-2

Shellfish resources

The statutory authority for the Maryland shellfish program is in the Annotated Code of Maryland, Health-General Article, Title 21, Subtitles 1 – 3 and Natural Resources Article §4-742, and the regulatory authority is in the Code of Maryland Regulations (COMAR). Fecal bacteria are used as an indicator of potential pathogens that pose a risk to human health via either the consumption of shellfish or direct water contact. MDE continues to monitor in various shellfish harvesting waters (Use Class II) for indicator bacteria specified in the Code of Maryland Regulations (COMAR) for Use Class II waters (MDE 2021c).

MDE participates in the National Shellfish Sanitation Program. This program is designed to reduce the risk of human infection from consuming oysters and clams harvested from shellfish waters throughout the US. In Maryland, MDE is responsible for classifying shellfish harvesting waters and determining which waters are safe for direct harvest of shellfish (meaning oysters and clams). A significant responsibility and major part of the program relies on MDE to conduct shoreline surveys, where trained MDE staff walk the shoreline and look for pollution sources that would have a negative impact on shellfish waters, e.g., sources of human pathogens from untreated waste. Sources include failing septic systems, gray water (i.e. waste from homes where the laundry or kitchen is not hooked into the septic system), manure management on farms, run off from individual property owners who do not clean up after pets, small hobby farms, and wildlife, including animals and birds.

The surveys are not statewide, however, MDE staff survey hundreds of properties annually in areas adjacent to shellfish waters (shellfish waters include the Chesapeake Bay and the estuarine portions of its tributaries). These shoreline surveys and accompanying maps can be valuable datasets for jurisdictions in the development of their implementation plans. They can provide source information for future action. To acquire the surveys for an applicable waterbody, jurisdictions should contact Leaton Jones (leaton.jones@maryland.gov) of MDE's Environmental Assessments and Standards Program. Maps are compiled to summarize the Shellfish Certification Program's shoreline survey areas by county.

Beaches

MDE continues to monitor State designated beaches for indicator bacteria through the Maryland Beaches Program (MDE 2021d). This program is administered by MDE; however, the responsibility of monitoring and public notification of beach information is delegated to local health departments. On a less frequent basis, MDE has historically monitored non-tidal waters that are not specifically designated as bathing beaches. Even though these waters are not specifically designated as bathing beaches, all waters throughout the State must support the water contact recreation designated use. This monitoring resulted in non-tidal waters that are not designated bathing beaches being assessed as impaired on the Integrated Report. MDE works with local health departments to enhance beach water quality monitoring and maintain the public notification process for beach water quality in Maryland.

In October 2000, Congress passed the Beaches Environmental Assessment and Coastal Health (BEACH) Act and provided funding to the U.S. EPA to improve beach monitoring in coastal states. The Maryland Beaches Program was established to protect the health of Marylanders at public bathing beaches. The program has evolved further to comply with the requirements of the Federal BEACH Act of 2000. This program is administered by MDE; however, the responsibility of monitoring and public notification of beach information is delegated to the local health departments. To protect the health of citizens visiting beaches across Maryland, the Maryland Beaches Program within MDE is working to standardize and improve recreational water quality monitoring in the State.

The presence of human fecal contamination does not necessarily mean presence of pathogens, indicate pathogen type, or in which concentrations they may be present. The use of FIB is based on the epidemiological studies of the 90th percentile. The authors of these studies found the probability of swimmers becoming sick depended on the FIB concentrations in the recreational waters. The current regulatory value of 126 CFU/100 mL is the level of *E. coli* for the specific probability of getting sick (1 in 10,000). For enterococci, which is applied in marine/tidal water bodies, the regulatory threshold is 35 cfu/100 mL. Those epidemiological studies did not look at (a) what are the specific pathogens causing illnesses, and (b) where these pathogens are coming from.

Most, but not all researchers note that the presence of *Bacteroides* (a genus of Gram-negative, obligate anaerobic bacteria) is a sign of fresh (2-3 days) pollution. EPA has recognized Bacteroides as a potential indicator of human fecal pollution since the year 2000. Several studies were commissioned by EPA; however, concentration thresholds were never established such as those that exist for *E. coli*, fecal coliforms, or enterococci and are built into TMDLs (like 126 CFU/ 100 ML for *E. coli*). A possible reason may be the EPA philosophy on thresholds, as the agency has believed that those can be established only from epidemiological studies. The situation with pharmaceuticals is similar to the situation with *Bacteroides*. They indicate the presence of human or animal pollution sources, but there are no thresholds. The volume of literature on *Bacteroides* and water quality is useful, but is less than on *E.coli* and water quality. While the field is moving towards human-specific fecal indicators like HF183 and *E. coli* H8. These analyses are costly if trying to pay for outside analytical services, but HF183 may become more accessible in terms of hardware and available laboratories that can perform the methodology. Jurisdictions should review the U.S. *EPA National Beach Guidance and Required Performance Criteria for Grants (Beach Guidance* 2014 edition for relevant details (U.S. EPA 2014b).

Fecal Bacteria Water Quality Criterion and Integrated Report Assessments

As briefly described in the "TMDL Methodologies' Section, beaches and shellfish beds are individually considered in terms of their own unique water quality criteria. For shellfish waters, MPN is used for fecal coliform concentration. The bacterial water quality criterion for shellfish harvesting waters specify that both the median concentration and 90th percentile concentrations of fecal coliform must be less than 14 MNP/100 milliliters (ml) and 49 MNP/100 ml, respectively. Assessment of the criteria must include a minimum of 30 samples taken over a three year period. The criteria for the "Water Contact Recreation" designated use have both a geometric mean concentration and a Statistical Threshold Value (STV). Criteria concentrations, thresholds, and FIB differ depending on the indicator and tidal status of the waterbody. For the bacteria indicator enterococci, which is an indicator for Marine and Tidal or Freshwater Contact Recreation, the geometric mean concentration is less than 35 cfu/100 ml, and the STV is defined as no more than 10% of samples with a concentration greater than 130 cfu/100 ml. *E. coli* is an indicator used in freshwater only and the geometric mean (GM) must be less than 126 cfu/100 ml, and the STV is defined as no more than 10% of samples with a concentration greater than 410 cfu/100 ml. The duration and frequency for both indicators are that the waterbody GM should not be greater than the selected GM magnitude in any 90-day period. There should not be greater than a 10% excursion frequency of the STV magnitude in the same 90-day period. Assessment for both tidal and nontidal waters is performed using at a minimum, weekly sampling, and the "swimming" season, defined as Memorial Day through Labor Day is used as the primary 90-day period for assessment.

Once monitoring begins to show declines in bacteria concentrations (described further in Section 4), jurisdictions need to begin to develop more specific planning horizons and monitoring plans, e.g., moving to weekly sampling to match assessment requirements. Therefore, it is important for jurisdictions to understand methods that are used to list waters as impaired, once data indicate that new planning horizons and monitoring plans should be developed. The *Listing Methodology for Identifying Waters Impaired by Bacteria in Maryland's Integrated Report* written by MDE Environmental Assessment and Standards Program has more detail on how threshold exceedances are handled for the assessment (MDE 2020a). There is a brief discussion criteria formulation in Sections 3.6.2 and 3.6.3 of Office of Water 820-F-12-058 Recreational Water Quality Criteria and associated errata sheet (U.S. EPA 2014a, U.S. EPA 2012).

Phase I MS4 Permits

TMDL Stormwater Wasteload allocation (SW-WLA) Implementation Plans

40 CFR § 122.44(d)(1)(vii)(B), states that for National Pollution Discharge Elimination System (NPDES) permits, "Effluent limits developed to protect a narrative water quality criterion, a numeric water quality criterion, or both, are consistent with the assumptions and requirements of

any available wasteload allocation for the discharge prepared by the State and approved by EPA pursuant to 40 CFR 130.7." Consistent with this regulation, Maryland's Phase I Municipal Separate Storm Sewer System (MS4) NPDES Permits require jurisdictions to develop watershed implementation plans to meet their SW-WLA assigned in a TMDL. For bacteria impairments, the focus is on making progress toward the applicable water quality criteria, or achievement of the criteria at applicable scales or in the absence of other non SW-WLA sources (see "General Guidance for Phase I MS4 TMDL Implementation Plans" for further information). This guidance document provides recommendations for addressing the following requirements of Phase I MS4 permits:

Legal requirements for SW-WLA Watershed Implementation Plans (WIPs) include five basic elements, which can be found in further detail in Part IV "Standard Conditions" of the jurisdiction's stormwater permit. Jurisdictions without stormwater permits that are deciding to develop WIPs should also include these elements in their plans in some capacity.

1. Date that the TMDL or individual allocation is planning on being met, with a detailed schedule of projects and programs leading to attainment.
    - Note: for Bacteria TMDLs, where the focus of implementation is source identification and mitigation, no end date needs to be provided, since there is a lot of uncertainty regarding the path forward. However, detailed schedules of planned efforts and actions still need to be provided.
2. Detailed accounting of cost estimates for projects and programs.
3. Detailed list of Best Management Practices (BMPs), programmatic initiatives, or alternative water quality control practices to be implemented that have a solid scientific foundation for actions taken.
4. Specific adaptive management process that defines information feedback loops to evaluate implementation (specific permit references are identified and described below, following this bulleted list).
    - This process is further described in this guidance document as well as the "General Guidance for Phase I MS4 TMDL Implementation Plans". Specifically, further details are provided regarding how to establish numeric goals (that can be reassessed and adjusted if needed) and the development and incorporation of pollutant and resource monitoring plans.
5. A system of public engagement for accountability purposes
    - Further details are provided in the "General Guidance for Phase I MS4 TMDL Implementation Plans".

Applicable permit language in support of the iterative and adaptive requirements for the SW-WLA Plans includes:

> Part V.A.3
> "Because this permit uses an iterative approach to implementation, the County must continuously evaluate the effectiveness of its programs and report any modifications in

each annual report. Where programs are determined by the County to be ineffective, modifications shall be made within 12 months that effectively show progress toward meeting stormwater WLAs developed under EPA approved TMDLs."

Part V.B
"In order to assess the effectiveness of _______County's NPDES stormwater program for reducing the discharge of pollutants to the MEP and working toward meeting water quality standards, the permittee will cooperate with the Department during the review of annual reports, field inspections, and periodic requests for additional data to determine permit compliance"

The referenced program effectiveness should be appropriate based on the latest science and available information. Consequently, in order for jurisdictions to assess the effectiveness of programs, they need to use up-to-date data and information. The regulatory oversight that MDE provides allows jurisdictions to inquire about appropriate information, in order for methodologies to be verified and validated. This means that SW-WLA implementation plans should be adaptive, updated once a permit term, and incorporate any and all new information that allows for a more accurate assessment of programs.

Once approved by MDE, implementation plans are enforceable under the NPDES MS4 permit. A TMDL Implementation Plan is a technical planning-level document that identifies water quality-based strategies that a local jurisdiction intends to implement to control existing point and nonpoint pollutant sources in a degraded watershed. MDE allows flexibility in how local jurisdictions develop their TMDL SW-WLA implementation plans, provided that the approach is reasonable and that key elements intended to maximize the potential for achieving water quality standards within the impaired waterbody, as outlined within this guidance document, are met.

Assessment of Controls - BMP Effectiveness Monitoring

Permit required watershed restoration monitoring should be used to determine the effectiveness of generic watershed restoration efforts (i.e., stormwater management (SWM) facility retrofits, new SWM for previously untreated impervious surface, in-stream restoration, sanitary sewer repairs, septic system upgrades, etc.), on bacteria load reductions. Jurisdictions should be considering how to utilize the following permit required monitoring efforts in their bacteria implementation plans: (1) baseflow sampling, (2) storm event sampling, and (3) continuous monitoring.

Ideally, this sampling would be paired with identical sampling at a control site, but a cost-benefit analysis in terms of the usefulness of purchasing data is necessary. Permit required monitoring emphasizes time over space (i.e., before and after restoration), and does so by looking at concentrations/loads, benthic indices, habitat scores, and geomorphic conditions. Ideal monitoring programs would monitor more storms and do more frequent baseflow sampling beyond what is required to be attentive custodians of fisheries and bathing sites, but jurisdictions are empowered to consider their own cost-benefit scenarios.

Assessment of Controls - Watershed Assessment and Trend Monitoring (**new requirement in Phase 1 permit**)

For the Bacteria component of the Watershed Assessment and Trend Monitoring requirement of the Phase I permit, the purpose is to assess trends in concentrations/loads over time in bacteria impaired watersheds. Ideally, as jurisdictions find and eliminate bacteria sources, a decline in concentrations should be seen in the data. Monthly grab samples for at least one station in all Bacteria TMDL watersheds are required (more are encouraged, but again, this is a cost-benefit consideration).

Samples should be collected at roughly the same date/time every month. This includes recording precipitation amount and type for 72 hrs prior to monitoring. Flow should be recorded from the nearest USGS gaging station and appropriately scaled to the watershed area draining to the monitoring station. Microbial source tracking (MST) using qPCR methodologies is optional, but encouraged for stations with high concentrations and no known/identified sources upstream (MDE 2021b).

Quick Take: Does MDE currently do their own sampling and analysis of *E. coli* or *Enterococcus* on a regular basis?

- **Shellfish**: The MDE Shellfish Program collects routine samples, however, it is for fecal coliform for shellfish harvesting waters.
    - All bacteria samples are taken to MDH laboratories for analysis. The data is then used to classify those waters.
- The MDE Field Services Program does collect *E. coli* samples when needed for specific projects. These are usually an attempt to gauge the efficacy of BMP's on agricultural properties within the nonpoint source 319 program.
- **Beaches**: At all freshwater beaches, *E.coli* is monitored on a regular basis; and for marine beaches, *Enterococcus* is monitored on a regular basis. Technically, MDE does not actually collect the data, the local health departments do, but MDE oversees the data collection and the information is reported to MDE.

Section 3: Required and Recommended Datasets for Planning Spatially-based Implementation

As discussed in the introduction to this guidance document, the primary strategy for implementing Bacteria TMDLs in Maryland is source identification and remediation with consideration given to specific resources of interest. In order to identify and remediate sources of fecal bacteria, jurisdictions must make use of available spatial datasets in a desktop analysis and complement that analysis with field investigations and monitoring.

This section describes the variable datasets jurisdictions are required to include or should consider in their planning efforts to reduce sources of fecal bacteria to impaired waterbodies. These datasets represent potential sources of fecal bacteria to a waterbody (i.e., risks) and the resources of interest to prioritize and protect from pathogens in the water.

The following is a list of spatial datasets that MDE WPRPP is either requiring or recommending local jurisdictions use to target potential sources of bacteria to receiving surface waters. MDE WPRPP recommends including these datasets in a comprehensive spatial database. An example of how these datasets can be used for targeting purposes can be found in a study of the San Diego River in California (Geosyntec 2012). For all the datasets listed below, jurisdictions should subset these datasets to identify where any remedial actions have already occurred. For instance, jurisdictions should subset their spatial septic system database to identify systems that have been hooked up to a municipal sanitary sewer service, upgraded or repaired, etc. Typical remedial actions are described further in Section 5.

Once spatial datasets are in a catalog, it is recommended that potential sources that have been identified be investigated via source tracking monitoring, inspections, or other means; so that partnering numeric data exist (see Florida DEP 2018a). This will be a long-term process, but it will enable jurisdictions to find problem areas and address them directly. In addition, this will enable jurisdictions to start the process of accounting for their SW-WLA, while ultimately working to demonstrate attainment of water quality standards. The formal methodology for identifying whether a waterbody is impaired in Maryland's Integrated Report for fecal bacteria impairments is available on MDE's Integrated Report website (MDE 2021a). Some of the data sources enumerated below already exist in curated files, and some do not. For example, Shoreline Surveys are an existing data collection activity, but MDE WPRPP does not have the status of each individual watershed file.

Required and Recommend Datasets: Natural and Water Resource Assets and Risk to Those Assets

General (three categories of information)

1. Land-use **(Required for WIP development)**
    a. Potential source(s) of data: State or local jurisdiction
    b. Applies across multiple sources (see following sections for further details)
        i. State datasets:
            1. Maryland Department of Planning (MDP) *Land Use/Land Cover Land Use Map Update Project* (MDP 2020)
            2. Maryland Department of the Environment: Reclassed Chesapeake Conservancy land-cover
                a. Maryland Department of the Environment Reclassed Land Cover Dataset (MDE 2021)
                b. Original Chesapeake Conservancy land-cover datasets can be found here (Chesapeake Conservancy 2021).

2. Municipal Stormwater Infrastructure **(Required for WIP development)**
    a. Potential source(s) of data: NPDES stormwater permit holders
    b. Key Features/Data of interest:
        i. Canals
        ii. Ditches/Swales
        iii. Stormwater management (SWM) facilities
        iv. Pipes
        v. Outfalls
        vi. Inlets
        vii. All types of water control structures

3. MDE Shoreline Surveys **(Recommended for WIP development)**
    a. Potential source(s) of data: Inquire with local health departments. MDE is not permitted to distribute this information.
    b. These resources are referenced so that if jurisdictions consider using pre-cursor or derivative of the information from SSV3 **from their local health departments**, they will then be using like-terminology when they are referencing the information from SSV3 in their Bacteria TMDL implementation plans and at meetings.
    c. For specific information, send a formal request to Marcia Potter of MDE marcia.potter@maryland.gov or Kathy Brohawn of MDE kathy.brohawn@maryland.gov
    d. In order for Maryland (and other states) to sell shellfish to other states, they must be in accordance with the National Shellfish Sanitation Program (NSSP) Model

Ordinance (https://www.fda.gov/media/143238/download) (Sanitary Survey ordinance are in Chapter IV. Shellstock Growing Areas @.01 Sanitary Survey and Section IV Guidance Documents, Chapter II Growing Areas @.03).

e. The authority for MDE to restrict harvesting in shellfish growing areas is in the 2017 Annotated Code of Maryland, Natural Resources Article §4-742: https://codes.findlaw.com/md/natural-resources/md-code-nat-res-sect-4-742.html
f. The regulatory authorities for the designated use of shellfish harvest waters and for water quality criteria are in COMAR at 26.08.02.02-1 and 26.08.02.03-3.
g. MDE performs shoreline inspections of all classified shellfish harvesting areas. These surveys identify the potential sources of fecal bacteria to the harvesting area, and they are performed once every 10 years. While only performed for shellfish harvesting areas, the same processes can be of use for designated beaches and other areas of concern with respect to fecal bacteria concentrations.
h. To conduct these surveys, the local health department goes through a scoring methodology: identifies risk based on proximity of septic systems, animals, density of bathers, accessible bathrooms, etc. This can help categorizes beaches on a tier of risk of contamination (Schoen and Ashbolt 2010)
    i. Performing similar surveys at non-designated shellfish harvesting areas could be a training opportunity with local health departments.
    ii. For further information, see "Shoreline Survey Application shellfish areas SSv2 Instruction Packet" (MDE 2015)
i. Shoreline survey information is sent by the Public Health Program at MDE (Primary Contact: Kathy Brohawn) to local health departments with shellfish harvesting waters. Phase I MS4s should contact their local health department for the information, due to the fact that the shoreline surveys contain private information.
j. MDE conducts sanitary surveys of each shellfish harvesting area prior to its approval as a source of shellfish. The purpose of the sanitary survey is to identify and evaluate factors influencing the quality of a shellfish harvesting area. These factors may include sources of potential and actual pollution (failing septic systems, animal wastes from agricultural properties, wastewater treatment plants, industrial waste, surface-runoff from polluted areas), bacterial quality of the water and shellfish, hydrologic characteristics of shellfish harvesting areas, and general land-use patterns.
k. MDE has over 200 surveys in counties that are adjacent to shellfish harvesting waters of the Chesapeake Bay and tributaries. Surveys have boundaries and are identified by a unique number.
l. Shoreline surveys are not performed statewide, however, MDE staff survey hundreds of properties annually in areas adjacent to shellfish waters (shellfish waters include the Chesapeake Bay and the estuarine portions of its tributaries). A survey may include obtaining permission to dye test a home's septic system to determine if the system is operating properly or failing. It is important to note, that when an individual onsite septic system is operating properly, it may not be failing, but could still contribute to nutrient levels in groundwater. When a failure

or violation is identified or observed, staff report it to the local health department. Failure rates are on the decline in the areas surveyed for the Shellfish Sanitation Program. In some areas, where soils and high water tables do not support individual onsite septic systems, the surveys conducted by MDE have supported bringing sewer to communities. Properties are revisited every seven to ten years. Details on observed problems identified during the shoreline survey can be obtained by contacting MDE personnel listed under shellfish and beach contacts.

m. Maryland's Shellfish Harvesting and Closure Area Map https://mde.maryland.gov/programs/Marylander/fishandshellfish/Pages/shellfishmaps.aspx
n. EPA Guidance for Sanitary Surveys for Recreational Waters https://www.epa.gov/beach-tech/beach-sanitary-surveys#marine
o. Local health departments assess pollution sources at beaches each beach season in accordance with COMAR 26.08.09, and mitigate any sources of waste that can be addressed. Local health departments use Appendix 2A in the Guidance for County Recreational Water Quality Monitoring and Notification Programs to help them list sources and ascribe the appropriate "Tier" to the beach. This document is available on the link below: https://mde.maryland.gov/programs/Water/Beaches/Documents/MDBEACHrev2020.pdf
p. Please contact MDE if you need assistance finding the appropriate local health department contact information about water quality around a beach or water body.

Predominantly human sources (three categories of information)

While waterbody fecal bacteria from other sources such as domestic pets, livestock, and wildlife still present a risk of illness to humans, human source bacteria provides the highest level of risk and its identification and elimination should be prioritized above the other source categories.

1. Municipal Sanitary Sewer Infrastructure **(Required for WIP development)**
    a. Potential source(s) of data: utility, local jurisdiction, and private owner
    b. Areas of Biofilm accumulation/bacteria regrowth; for example, where settling may occur due to events like pump station failures or regular maintenance (Urban Water Resources Research Council 2014, Payne et al 2020, Peipoch et al 2019; Balzer et al 2020).
    c. Features/Data of Interest:
        i. Sanitary lines (sewage exfiltration)
            1. Attributes of Interest:
                a. Age
                b. Other Problem Areas
                    i. Build up of fats and oils, decaying plant matter, litter and sediment in the storm drain
        ii. Combined sewer overflows (CSO) locations regulated under NPDES/Long Term Control Plans (LTCP)

iii. Sanitary Sewer Overflow (SSO) locations
iv. Illicit Discharge Detection and Elimination (IDDE) location
v. Lift and pump stations
    1. Potential source(s) of data: as for spatial data for these lift stations, it is unlikely that any NPDES program will have the information, but jurisdictions should check Wastewater Treatment Plants (WWTPs) under NPDES (can be privately and publicly owned).
    2. For water/sewer conveyance pump stations serve different purposes, but share similar designs.
        a. A "lift station" is a special term given to a facility specifically designed for the pumping of sewage to a higher elevation
        b. A "pump station" is used more generically for those designed to raise water, not just sewage, to a higher elevation.
vi. Retrofit status - Sewer line repaired and/or lined, SSO eliminated, etc.

2. On-site Disposal Systems **(Required for WIP development)**
    a. Potential source(s) of data: Local health department, MDE Wastewater Permits Division
        i. Features/Data of interest:
            1. Best Available Technology (BAT) On-site Sewage Disposal Systems (OSDS)
            2. Mobile home parks and campgrounds
                a. On-site facilities and type
                b. RV dumping
            3. Identified or potential leaky or failing OSDS
                a. MDE WPRPP Chesapeake Bay Phase III WIP septics project will help in identifying likely failing systems (Available upon request from MDE WPRPP)
                    i. Age of parcel subdivision to gauge infrastructure integrity
                    ii. Parcel size-explanatory variable that could predict failures, (i.e., old development with small lots that are likely to have small treatment zones)
            4. Retrofit Status - Connected to a municipal sanitary sewer service, upgraded, and/or replaced.

3. Other potential human sources **(Recommended for WIP development)**
    a. Landfills
        i. Potential source(s) of data: MDE Wastewater Permits Division, local jurisdiction

            1. MDE Data: https://mde.maryland.gov/programs/LAND/SolidWaste/Pages/PermittedFacilities.aspx
                a. Operational
                b. Historic
                    i. U.S. EPA, Landfill Methane Outreach Program Landfill and Landfill Gas Energy Project Database
                        1. Includes larger operational and more recent closed, ~1980s+, facilities (U.S. EPA 2021)
                    ii. Maryland historic landfill initiative
                        1. https://mde.maryland.gov/programs/LAND/MarylandBrownfieldVCP/Pages/HistoricLandfillInitiative.aspx
    b. Locations of historical repetitive illegal dumping
    c. Homeless encampments
    d. Chemical toilet deployment
    e. Reclaimed water/gray water usage
    f. Open air markets

Predominantly non-human sources (four categories of information)

1. Domestic Pets **(Required for WIP development)**
    a. Potential Sources of data: MDP Land-Use/Land-Cover, local zoning and parcel data
    b. Waterbody fecal bacteria concentrations from domestic pets pose a risk of illness to human health via shellfish consumption and direct contact through recreation.
    c. Methods/data for identification of sources:
        i. Land-use or parcel data
            1. Potential source(s) of data: Maryland Department of Planning (MDP), local jurisdictions
            2. Methods: isolate residential areas, particularly medium to high density residential areas where there might be a higher density of pet ownership, and therefore a higher density of pet waste.
        ii. Pet vaccination records
        iii. Dog walk parks
            1. Official
            2. Unofficial
        iv. Businesses providing animal related services
            1. Commercial production and treatment
            2. Pet storage and treatment

2. Urban non-stormwater discharges that have the potential to mobilize wildlife and other FIB, and contribute to biofilm formation **(Recommended for WIP development)**

a. Potential source(s) of data: local Jurisdiction, tax codes, zoning records
b. Types:
    i. Dumpsters and transfer stations
    ii. Garbage truck routes
    iii. Food processing facilities
    iv. Outdoor dining
    v. Restaurant grease bins
    vi. Services of grease and biological waste
    vii. Bars/stairwells/washdown areas
    viii. Piers/docks
    ix. Food service businesses, fruit-processing facilities, seafood-processing facilities, bait shops, and restaurants
    x. Power washing
    xi. Excessive irrigation
    xii. Car washing
    xiii. Pools/hot tubs

3. Wildlife **(Recommended for WIP development)**
    a. Potential sources of data:
        i. Maryland Department of Natural Resources (MD DNR) population surveys (see appendices of fecal Bacteria TMDL documentation for further information)
            1. Birds
            2. Mammals
    b. Like domestic pet sources of fecal bacteria, wildlife source bacteria pose a risk of carrying pathogens that also pose a threat to human health.
    c. Types:
        i. Rodents/fecal vectors (e.g. rats, raccoons, squirrels, opposums)
        ii. Birds (e.g. pigeons, gulls, swallows)
        iii. Open spaces with flocking
        iv. Urban wildlife habitat corridors (e.g. deer, coyotes, foxes, beavers, feral cats)

4. Agricultural sources **(Recommended for WIP development)**
    a. Potential Sources of data: MDP Land-Use/Land-Cover, local zoning and parcel data, MDE permits, other
    b. Livestock source bacteria in a waterbody poses a risk to human health via pathogen exposure
    c. Note: Agricultural sources may not only include large scale farming operations, but also small parcel "ranchettes" inside MS4 permitted boundaries
    d. Methods/data for identification of sources:
        i. Animal feeding operation NPDES permits (CAFOs) (MDE 2021e)

        1. CAFOs have a SWM requirement indicating no discharge for a 25 year, 24 hour storm event (MDE 2021e). Identify CAFO Locations and associated SWM facility locations.
        2. Potentially most of them have wet stormwater management facilities as their "storage ponds".
    ii. Land-use or parcel data from Property Map Products MdProperty View Advanced Desktop GIS to use with ESRI's ArcGIS Software (Maryland Department of Planning 2021). Permitted jurisdictions will likely need to contact their partner SCDs to acquire this data, if they decide to include this in their planning efforts.
        1. Livestock operations
        2. Grazing without riparian buffer
        3. Manure storage
        4. Pasture
        5. Corrals
    iii. Manure spreading, pasture/crops
        1. Potential source(s) of data: Soil Conservation District (SCD), nutrient management plans
    iv. Municipal biosolids reuse
        1. Potential source(s) of data is the General Instructions for Completing a Sewage Sludge Utilization Permit Application database (MDE 2021f).
    v. Slaughterhouses
        1. Depending on wastewater treatment techniques, slaughterhouse wastewater contains various and high amounts of organic matter and possibly fecal bacteria (e.g., proteins, blood, fat and lard) (Bazrafshan et al. 2012).
        2. See the following SIC codes
            a. 0751 Livestock Services, Except Veterinary (this is custom slaughtering for individuals)
            b. 2011 Meat Packing Plants (everything except fish and poultry)
            c. 2015 Poultry Slaughtering and Processing
    vi. Irrigation water can be a source of bacteria (U.S. FDA 2017)
        1. Potential source(s) of monitoring data: Maryland Department of Agriculture, U.S. Food and Drug Administration
        2. Reclaimed water
        3. Impoundments used for crop irrigation could have elevated fecal bacteria concentrations based on contributing area characteristics
            a. Potential for elevated fecal bacteria concentrations may correlate with fertilizer/manure application rates within the contributing area
                i. If no details by lbs/acre, then look at crop type by district/County.

ii. SCD may have raw data

Natural resource areas (two categories of information)

1. MDE Designated Shellfish Harvesting areas (**Required for WIP development**)
    a. Potential sources of data: MDE's Shellfish Harvesting Programs
        i. Maryland Shellfish Advisory and Maps
            1. https://mde.maryland.gov/programs/Marylander/fishandshellfish/Pages/shellfishadvisory.aspx
            2. https://mdewin64.mde.state.md.us/WSA/Shellfish/index.html
        ii. Classifications
            1. Conditionally Approved Harvesting Areas
            2. Restricted Harvesting Areas
            3. Closed Safety Zones
            4. Approved Harvesting Areas
            5. Non-shellfish Waters

2. Beach locations **(Required for WIP development)**
    a. Potential source(s) of data: MDE, Local Jurisdiction
        i. Non-recognized beaches identified by stakeholders (Source: Local Jurisdiction)
        ii. Designated Beaches
            1. MDE's Healthy Beaches website:
                a. https://mde.maryland.gov/programs/Water/MHB/Pages/Current-Conditions.aspx
    b. Beach Evaluation and Classification Checklist for an Inventory and Prioritization of Recreational Bathing Areas (to be completed in Microsoft Excel) (MDE 2016).
        i. Inventory and Prioritization of Recreational Bathing Areas, can provide direction for deciding on WIP monitoring efforts
            1. Bather Use Level
            2. Historical Water Quality
            3. Pollution Threats: Human Fecal Matter Sources
            4. Pollution Threats: Animal Fecal Matter Sources
            5. Beach Structure and Ecological Factors

Section 4: Bacteria Monitoring - Source Identification, Tracking Progress, and Estimating Trends

The second component of fecal bacteria source identification and remediation are field investigations and water quality monitoring. Field investigations are typical procedures followed in a jurisdiction's Illicit Discharge Detection and Elimination (IDDE) program. Further details regarding these field investigations for an advanced IDDE program are described in Appendix 3, which documents Baltimore City's program for source identification. There are many publicly available water quality monitoring datasets collected by other entities that local jurisdictions should use in their source identification planning process; however, these datasets will need to be complimented by other observations collected specifically by local jurisdictions (the minimum requirements for which are outlined in a jurisdiction's permit). Water quality monitoring data will not only aid in source identification, but will also enable jurisdictions to monitor trends in fecal bacteria concentrations over time.

Stormwater permits can generate data and information related to bacterial water quality impairments that: (1) provide a minimum standard for monitoring in Bacteria TMDL watersheds, and (2) provide MDE and the jurisdiction with a dataset to identify sources and trends (e.g., tracking progress after implementation).

Under the new 2021 and 2022 Phase I MS4 permits, jurisdictions are required to develop bacteria monitoring programs for the purposes of source identification, tracking progress, and establishing trends. These new monitoring requirements are based on established monitoring programs in Baltimore City and Baltimore County that have demonstrated decreasing trends in bacteria concentrations and loads over the past decade. Further information on the specifics of these programs can be found in MDE's 2020 MS4 Monitoring Guidelines. This document provides specifics on lab methodologies consistent with the Integrated Report bacteria assessment (p.14; Mandatory Guidelines #1), frequency of sampling (p. 14; Mandatory Guidelines #2 and Recommended Guidelines #5), and procedures for distinguishing between flow regimes, which is helpful for subsequent trend analysis (MDE 2020b). Further information regarding other established bacteria monitoring programs from which jurisdictions can draw upon are identified below and included in the appendices to this guidance:

1. Appendix 1. ShoreRivers Approach to Monitoring for an exemplary approach to monitoring watershed hydrology that is predominantly composed of nonpoint sources.
2. Appendix 2. Anne Arundel Approach to Monitoring for an exemplary approach to monitoring in mixed non-point source and point source watersheds.
3. Appendix 3. Baltimore City Approach to Monitoring for an exemplary approach to monitoring watershed hydrology that is composed of predominantly point sources.
4. Florida DEP also has well established guidance on monitoring protocols for source identification. For further information, see section "2.5.2.1 Selecting Water Quality Sampling Station Locations" of Restoring Bacteria-Impaired Waters: A Toolkit to Help

Local Stakeholders Identify and Eliminate Potential Pathogen Problems for determining how to integrate specificity (Florida DEP 2018a).

While the sampling requirements specified in MDE's 2020 MS4 Monitoring Guidelines align with MDE Integrated Report assessment methodologies for fecal bacteria in terms of procedures and lab methodologies, the temporal resolution of the required sampling does not suffice for Integrated Report assessment methods. The permit required monitoring calls for monthly samples, while the Integrated Report method requires weekly samples during the beach season (Memorial Day through Labor Day). For the purposes of identifying trends of bacteria levels and helping with source identification in impaired watersheds, weekly sampling is not needed (MDE 2020b). However, MDE recommends that when trends in the monthly data indicate that concentrations are approaching numeric water quality criteria thresholds, jurisdictions should increase the temporal frequency of sample collection so that the data can be used for Integrated Report assessments. If the data indicates that water quality criteria are being met, it is probable that some degree of "maintenance" monitoring will be required; information regarding these requirements will be developed by MDE in the future.

Analysis of fecal bacteria monitoring data for source identification should follow the combination of several established methodologies. Jurisdictions should use traditional synoptic approaches that examine the distribution of concentrations across geographies to identify extreme outliers and statistical approaches based on sampling distribution for outlier identification. Analysis should also consider the frequency of numeric water quality criterion exceedances. Florida DEP has a ranking method that relies on the magnitude and frequency of criterion exceedances. This method is useful for jurisdictions looking for an established standardized method of prioritizing. See page 13 of the Restoring Bacteria-Impaired Waters: A Toolkit to Help Local Stakeholders Identify and Eliminate Potential Pathogen Problems (Florida DEP 2018a). Stakeholders should use this to determine how they might prioritize hot spots for further investigations. Baltimore City has an established methodology for source identification that can be followed as well, which is based on the permit required fixed station/interval monitoring, that is further described in Appendix C. Finally, MDE is continuing analysis of historic bacteria monitoring data and will be providing information in the future regarding recommended analytical approaches for analyzing trends.

Required and Recommend Datasets Relevant for Monitoring Bacteria

In addition to the bacteria monitoring data collected under the Phase I MS4 permit, there are several other relevant monitoring datasets that jurisdictions are required or recommended to utilize in order to identify potential sources, track progress, and establish trends of fecal bacteria. These include required Phase I MS4 Illicit Discharge and Detection Elimination (IDDE) monitoring, MDE's monitoring of shellfish harvesting areas, the monitoring of public beaches performed by local Health Departments, data collected under National Safe Drinking Water Act regulations, and datasets that primarily pertain to other designated uses but can be used as surrogate parameters, e.g., benthic macroinvertebrates. These datasets are described below.

1. Illicit Discharge Detection Elimination (IDDE) Monitoring (**Required for WIP development**)
2. MDE Shellfish Monitoring (**Required for WIP development**)
   a. MDE's shellfish monitoring program adheres to the National Shellfish Sanitation Program (NSSP) Guide for the Control of Molluscan Shellfish: 2019 Revision (U.S. FDA 2020). The guidance provides descriptions of the variable shellfish classifications (pages 3-10), has water quality standard descriptions for growing areas (pages 45-48), and has requirements of the classifications for growing areas (pages 48-55).
   b. The three different shellfish area classifications are "restricted", "conditionally approved", and "approved". NOAA has provided validation of MD's conditionally approved waters (Leight and Hood 2018). The designated shellfish harvesting areas and their status can be found here: https://mde.maryland.gov/programs/Marylander/fishandshellfish/Pages/shellfishmaps.aspx
   c. In order to demonstrate support of the shellfish harvesting designated use, the measured level of fecal coliform in water must have a median of less than 14 MPN/100 ml and a 90th percentile of less than 49 MPN/100 ml, calculated from a minimum of 30 samples usually taken over a three-year period. MDE conducts routine bacteria water quality sampling and pollution source surveys to assess shellfish harvesting areas so that waters can be assigned to one of three classifications used for protecting shellfish consumers. See Listing Methodology for Identifying Waters Impaired by Bacteria in Maryland's Integrated Report for more details (MDE 2020a).
   d. Current fecal coliform data and stations are on MDE's website. There is an interactive map where you can "click" on a station and get the last 30 samples of fecal coliform results and rainfall information. The link to the web site is: https://mdewin64.mde.state.md.us/WSA/Shellfish/index.html
   e. MDE Contact information for further details:

      Shellfish-Amy Laliberte
      410-537-3614
      Amy.laliberte@maryland.gov

3. Beaches Monitoring (**Required for WIP development**)
   a. The fecal bacteria thresholds used for recreational waters can be found in COMAR 26.08.02.03-3.

Designated Use	Bacteria Indicator	GM (cfu/100ml)	STV (cfu/100ml)
Marine & Tidal, or Freshwaters Contact Recreation	Enterococci	≤ 35	No more than 10% > 130
Freshwater Contact Recreation	E. coli	≤ 126	No more than 10% > 410
Duration and Frequency: The waterbody GM should not be greater than the selected GM magnitude in any 90-day period. There should not be greater than a ten percent excursion (i.e. an exceedance of the threshold.frequency of the STV magnitude in the same 90-day period.			

b. Water bodies are monitored at least weekly to evaluate the geometric mean (GM) and statistical threshold value (STV) during an annual 90-day assessment period, e.g., the beach season, which runs from Memorial Day through Labor Day. Further information can be found in MDE's Bacteria Listing methodology: https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Documents/Assessment_Methodologies/Bacteria_Listing_Methodology_Final_2_23_2021.pdf.
c. Historic beach data submitted to MDE by local Health Departments is stored in the Department's Ambient Water Quality Monitoring System (AWQMS) (MDE 2021g).
d. MDE Contact Information for further details:
    i. Leaton Jones
    410-537-3851
    Leaton.jones@maryland.gov
    ii. Heather Merritt
    410-537-3618
    Heather.merritt@maryland.gov

4. The Food Safety Modernization Act (FSMA) Produce Safety Rule (PSR) (**Recommended for WIP development)**
    a. FDA regulates microbial quality of irrigation water by looking for bacteria by borrowing from the 2012 EPA guidance and uses *E.coli* as FIB (U.S. FDA 2017).
    b. At the University of Maryland Dr. Rachel Rosenberg-Goldstein's laboratory has completed an analysis looking at whether or not collecting fewer samples (n = <20) for the baseline water quality assessment needed for the FSMA PSR affects results.
    c. Jurisdictions with irrigated agriculture should work to understand if the FDA program *The Food Safety Modernization Act (FSMA) Produce Safety Rule (PSR)* is generating information/data collected under this program in their jurisdiction; because there is a possibility it might be useful for Bacteria TMDL implementation planning and management. Maryland jurisdictions should pursue

these datasets as another variable to add to their watershed implementation models when assessing where implementation needs to be focused. In addition, delineating irrigation water supplies (i.e. “agricultural source water protection zones”) would provide additional water resource assets to consider in spatial planning.

i. This standard under development by FDA could be useful for developing implementation horizons for some jurisdictions in Maryland.
    1. The quantitative standard proposed by FDA is subject to change; the current proposed standard is: 126 MPN / 100 mL E. coli with an STV of 410 MPN/100 mL.
ii. The information generated from the FSMA PSR at a local level could be shared with stormwater jurisdictions in Maryland, if the jurisdiction requests the data.

5. National Primary Drinking Water Regulations and Monitoring Data (**Recommended for WIP development**)
    a. Data collected under the National Primary Drinking Water Regulations can serve as a useful complementary dataset to support a more comprehensive view of where bacteria loading is posing an immediate risk to water supply and to measure progress (U.S. EPA 2020a). This information is also collected based on regulations, so it will be available on a continual basis making it ideal for use in planning and decision making processes. However, it is important for jurisdictions to understand that drinking water data does not always have a “one-to-one relationship” with traditional approaches to bacteria source tracking because pollutants, chemical factors, and treatment byproducts can co-occur and may indicate bacteria loading is occurring in the vicinity of a drinking water plant’s source water and intake.
    b. Under the National Primary Drinking Water Regulations (NPDWR), U.S. EPA regulates the following:
        i. Microorganisms: Cryptosporidium, Giardia lamblia, Heterotrophic Plate Count, Legionella
        ii. Total coliform, fecal coliform, E. coli, turbidity, viruses
        iii. Disinfection byproducts: Bromate, Chlorite, Haloacetic Acids (HAA5), Total Trihalomethanes(TTHMs)
        iv. Disinfectants: Chloramines, Chlorine, Chlorine Dioxide
        v. Inorganic chemicals: Antimony, Arsenic, Asbestos, Barium, Beryllium, Cadmium, Chromium, Copper, Cyanide, Fluoride, Lead, Mercury, Nitrate, Nitrite, Selenium, Thallium
        vi. Organic chemicals (54)
        vii. Radionuclides
    c. NPDWRs set limits for each regulated contaminant
        i. Maximum Contaminant Level Goal (MCLG)

ii. Maximum Contaminant Level (MCL)
iii. If there is no reliable method that is economically and technically feasible to measure a contaminant at particularly low concentrations, a Treatment Technique (TT) is set rather than an MCL. A Treatment Technique is an enforceable procedure or level of technological performance which public water systems must follow to ensure control of a contaminant.

d. NPDWRs include:
    i. Acceptable techniques for treating contaminated water.
    ii. Acceptable limits for disinfection byproducts.
    iii. Schedules for compliance testing.
    iv. Compliance sample holding time/temperature.
    v. Prescribed methods for each contaminant that must be used for compliance analyses.
    vi. NPDWRs cover finished drinking water, and in some cases source water that will be used for drinking water (SWTR/LT2).
    vii. The SDWA gives individual states the opportunity to set and enforce their own drinking water standards if the standards are at least as stringent as EPA's national standards. So, there might be Maryland or site-specific standards that could be useful for planning for bacteria reductions.
e. Specific rules that are potential sources of data for jurisdictions to use in planning.
    i. Surface Water Treatment Rule (SWTR) Filtration Avoidance Criteria
    ii. Long Term 2 Enhanced Surface Water Rule (LT2)
    iii. Revised Total Coliform Rule (RTCR)
    iv. Ground Water Rule (GWR)

6. Benthic Macroinvertebrates (**Recommended for WIP development**)
    a. For jurisdictions that regularly collect macroinvertebrate samples.
    b. There is a basic negative relationship between bacteria presence and macroinvertebrate biodiversity (Jerves-Cobo et. al 2018). Jurisdictions are encouraged to consider the development of decision tree models based on bacteria growth stimulated by nutrients. Use of bioindicators in the "European Water Framework Directive" allow for combined observations of fecal coliform and macroinvertebrates species to locate proxy indicator species based on (1) presence/absence, (2) density, (3) ratio.

Section 5: Management Actions

Management strategies will be tailored to the individual needs and resources of jurisdictions as well as the potential sources of fecal bacteria identified using the datasets listed in Section 3 of this document and monitoring data as described in Section 4. However, the following are typical management strategies employed by local jurisdictions and the State to reduce fecal bacteria inputs. By no means is this list comprehensive. Rather, this list is only meant to provide examples of the types of management strategies that should result from the source identification targeting efforts.

- Human Sources
    - *Septic Connections, Upgrades, and Maintenance* - Failing septic systems are a typical source of fecal bacteria to impaired waterways. Most conventional systems, when operating properly, are not a major source of fecal bacteria to receiving waterbodies. However, when these systems are not properly maintained, or when these systems were not constructed based on current regulations and specifications, they can be significant sources of fecal bacteria to receiving waterbodies. MDE regulates and oversees septic installation in the State. Typical remediation strategies to address failing septic systems include connecting systems to sanitary sewer service, performing maintenance on systems to ensure that they are functioning properly, e.g., septic pumping, and upgrading systems to current specifications and/or advanced Best Available Technology (BAT) systems.
    - *Sanitary Sewer Repairs* - The sanitary sewer conveyance system can be a significant source of fecal bacteria to receiving waterbodies. Generally, municipal wastewater treatment significantly reduces fecal bacteria in designed discharges. However, the conveyance system itself, particularly in older systems, can often be a source of fecal bacteria to receiving waterbodies, whether through specific discharge points to deal with excess flows during rain events, cracks in the conveyance system, or back-ups due to excess flows and build-up within the system. There are many different types of repairs to the sanitary system, most of which are structural, but some may be non-structural (e.g., fats, oil, and grease (FOG) reduction programs to reduce clogs in the system). Structural repairs include the replacement and lining of old piping, eliminating cross connections with the storm sewer system, pumping station upgrades, and Sanitary Sewer Overflow (SSO) elimination.
    - *Illicit Discharge Elimination* - There are often illegal discharges to the storm sewer system that result in elevated fecal bacteria loads to receiving waterbodies. For instance, it is not uncommon for the sanitary sewer discharge from private residences and businesses are often mistakenly, or intentionally, hooked up to the storm sewer system, rather than the municipal sewer system. Phase I MS4 jurisdictions are required to implement Illicit Discharge Detection and

Elimination (IDDE) programs designed to identify and eliminate these illegal hook-ups.

- Domestic Pet Sources
  - *Pet Waste Outreach and Management* - Domestic pets can be a significant source of fecal bacteria to receiving waterbodies. While the risk to human health from domestic pet source fecal bacteria is lower than that of human source bacteria, some risk does still exist, and actions can be taken to remediate these sources. Typical management strategies that can be used to remediate fecal bacteria sources from domestic pets include pet waste outreach campaigns and installing pet waste stations in areas where residents typically walk their pets, or where pets can typically be found in large numbers (e.g., dog parks).
- Wildlife Sources
  - *Wildlife Abatement Programs* - While wildlife sources of fecal bacteria pose a lower risk to human health than human source bacteria, there is still some risk. Generally, wildlife sources are not considered to be controllable, but there are some actions that can be taken to remediate these sources. Wildlife populations themselves can be particularly problematic, particularly deer in suburban areas and rats in high density urban areas. Abatement programs to control these sources can be employed to reduce fecal bacteria contributions.
  - *Stormwater Management Facility Fencing* - Geese and other bird populations have a tendency to congregate around water features on the landscape, particularly impounded water features, which includes stormwater management facilities. Installing fencing around these facilities often deters bird populations from congregating and therefore can reduce fecal bacteria loads to receiving waters.

The above list only provides a sample of the variable management strategies that are typically employed by local jurisdictions to reduce fecal bacteria loads. For additional information regarding fecal bacteria management strategies, the Chesapeake Stormwater Network provides more complete summaries in their report entitled “Fecal Indicator Bacteria Management”, available on their website at:

- https://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2018/10/Bacteria-Management-Report_final.pdf.

Section 6: Reporting

Annual reporting requirements for Phase 1 Stormwater Permit for Bacteria TMDL SW-WLA implementation plans will be tailored to the individual jurisdictional and programmatic needs of water resource managers.

1. Permit Term Submissions
    a. Year 1
        i. Implementation Plan documentation describing the use of the datasets listed in Section 3 and monitoring data described in Section 4 to identify potential sources of fecal bacteria, the general and specific strategies for remediating these sources (see examples in Section 5 of this document), and the monitoring strategy for identifying new sources, confirming existing sources, assessing trends in fecal indicator bacteria, and evaluating impairment status, where and when applicable.
            - See Section 4 and the MS4 monitoring guidelines for further details on jurisdiction monitoring strategies
            - https://mde.maryland.gov/programs/Water/StormwaterManagementProgram/Documents/Final%20Determination%20Dox%20N5%202021/2021%20MS4%20Monitoring%20Guideline%20Final%2011%2005%202021.pdf.
        ii. The plan documentation should include a table similar to the example table provided below, which has been adapted from a template used by the Oregon Department of Environmental Quality (Oregon DEQ 2021). This table summarizes the various sources of fecal bacteria in the watershed and the strategies for remediating these sources. As described further below in annual reporting, the status of the various strategies should be updated on an annual basis and reported to MDE.
    b. Year 3
        i. MDE requests jurisdictions submit a geospatial data package or file reviewable in ESRI ArcPro GIS. The submission should contain information referenced above in Section 3 and be accompanied by data referenced in Section 4.
        ii. This will be required to be submitted to MDE prior to the end of the third year of the permit term. This spatial data package should be updated once a permit term and submitted to MDE. Ideally, jurisdictions should be updating this package on a continuous basis.
    c. Year 4
        i. In year four of the permit term one advanced spatial analysis needs to be performed using the spatial data submission from year three. This analysis will help rank potential sources for targeting remediation.

    ii. Advanced analyses can be done using pre-programmed evaluations found in many GIS programs or using a unique script/code that meets the jurisdictions needs for improving the sophistication of bacteria source trackdown and remediation.

2. Annual Reporting
    a. Annually, jurisdictions should report updates on any remedial actions outlined within their plan using a matrix/table as a reporting format such as the one from the Oregon Department of Environmental Quality included below (Oregon DEQ 2021). Reporting via a table similar to the one below should constitute the bulk of the narrative submitted to MDE on an annual basis starting in year two of the permit term.
        i. Using the table below as an example, the last column is necessary for annual reporting. This table is also able to be submitted as a linked submission to geospatial information described previously. The tables should be adapted as necessary to include any quantitative information associated with the strategy. For example, if a jurisdiction has a strategy of eliminating SSOs or lining sanitary sewer pipes, MDE would request that the quantity of SSOs that were eliminated or how many miles of sanitary sewer line were repaired be documented in the report.
        ii. This quantitative information should also be tracked spatially and added to the jurisdiction's map package that is submitted to MDE once a permit term.
    b. Monitoring data should be reported on an annual basis.
    c. Monitoring data collected by the jurisdictions and reported to MDE should follow the established reporting format outlined in the jurisdiction's MS4 geodatabase and MS4 monitoring guidelines:
        - https://mde.maryland.gov/programs/Water/StormwaterManagementProgram/Documents/Final%20Determination%20Dox%20N5%202021/2021%20MS4%20Monitoring%20Guideline%20Final%2011%2005%202021.pdf.

3. If jurisdictions have concerns about redundancies in exercises they are performing to meet Bacteria TMDL SW-WLAs between different programs within MDE, these concerns should be brought to MDE's attention during the first year of the permit term. This is essential for MDE to improve customer service with regard to data processing.

Reporting Example: TMDL Implementation Matrix Template, Pollutant: Bacteria (adopted from Oregon DEQ 2021)							
SOURCE What sources of this pollutant are under your jurisdiction?	**STRATEGY** What is being done, or what will you do, to reduce and/or control pollution from this source?	**HOW** Specifically, how will this be done?	**FISCAL ANALYSIS** What is the expected resource need? Are there existing resources budgeted? If not, where will the resources come from?	**MEASURE** How will you quantitatively or qualitatively demonstrate successful implementation or completion of this strategy?	**TIMELINE** When do you expect it to be completed?	**MILESTONE** What intermediate goals do you expect to achieve, and by when, to know progress is being made?	**STATUS** Include summary and date
Failing septic systems	Ensure repair of failing systems	Respond to reports of failing systems; work with homeowner to set a timeline for repair	Already funded; see specific program budget	Track # of reports, outcome of inspection (failing or not) and date of follow-up that confirmed repairs were made	Ongoing	N/A	
Bacteria carried to waterways in storm runoff	Address runoff problems from farms via SB 1010 plans (ODA)	Contact _____ when problems are identified	No additional resources needed.	Track # of referrals	Ongoing	N/A	

Quick Take: Outstanding issues related to reporting and compliance

- The following attempts to document reporting requirements that could be refined in the future and unanswered compliance questions:
  - When does a jurisdiction need to stop monitoring for bacteria?
  - How can information generated through applied science contribute to the legal reporting framework in order to measure jurisdictional progress?
    - Examples
      - Absolute concentration
      - % Exceedance of the criteria
      - Geomean; is used for bacteria assessment purposes, potential progress metric
    - Baltimore City: consider results based on COMAR. If there is a seasonal flux, but COMAR is based on 90 days, is it better to report in 90 day increments and not a yearly value?
    - Daily flux, seasonal variation, yearly fluctuations - which are most important to document?
  - What does contaminant load mean for bacteria load?
    - See page 40 "entity" refers to stakeholders with responsibilities for the items listed in the first column, ex. Cities, Sanitary Sewer Utilities, Counties.3.2.1 Summary of Potential Sources and Management Actions (Florida DEP 2018a).
  - How should the State of Maryland gauge a good bacteria "model"?
    - For example: at " X" density of on-site sewage disposal systems (OSDS) a chemical and/or biological signal can be detected; so, "Y" number of river miles should be sampled in areas with an "X" density of OSDS.
    - What stressors or resources should be quantified?
  - How does MST fit into the current reporting system?
    - Procedures that Baltimore City outlines (see below in Section 7 "Research Applications - Microbial source tracking (MST)"):
      - Look for all human sources that can be identified and eliminate them first.
      - Screen using an ammonia signal.
      - MST is conducted post implementation for all human sources.
    - Can MST be used to "recalilbrate" old(er) TMDLs?
    - Are heterogeneous land-use types the ones that have the greatest need for MST evaluations?
  - How can MST be linked to another planning process? Are land-use evaluations the planning process that most jurisdictions are most comfortable with?

Section 7: Current Research Applications and Future Research Needs

Bacterial water quality impairments pose a risk to human health via direct human contact with surface waters and shellfish consumption. These impairments are common throughout Maryland. However, sources of bacteria can be difficult to trackdown and even if they are identified, the remedial actions can be financially and politically difficult. Furthermore, public health data associated with bacteria impairments is not readily available, making it sometimes difficult for practitioners to be proactive in planning and implementing load reductions outlined in Bacteria TMDLs. The proactive approach, from a public health perspective, is to work toward preventing resource degradation in the first place. A way of doing this is to seek a "chemical**:**pathogen source" relationship.

This section discusses the current applied research that could be utilized for Bacteria TMDL implementation and future applied research that would be useful to undertake related to implementing Bacteria TMDLs in Maryland. One key area of future research is working toward correlating human source fecal bacteria presence and concentration to specific tracers that are easily analyzed and cost efficient. Current research indicates that emerging chemical tracers can be used to detect wastewater signals in surface waters. Of particular interest is the potential use of paraxanthine (a caffeine metabolite) as a chemical tracer indicative of human waste in surface waters. Research that screens for caffeine (which is rather degradable) and its metabolite product paraxanthine alongside bacteria during source tracking studies to develop a relationship between the two parameters would be beneficial (M.Gonsior, University of Maryland Center for Environmental Science, personal communication, February 23, 2021; also see Appendix 4. UMCES Tracer Outline).

The concurrent sampling of microbial and chemical tracers would enhance the identification of sources in impaired watersheds. Other chemical tracers of interest that researchers speculate could be correlated with fecal bacteria counts and sewage inputs to surface waters include highly soluble conservative tracers such as the artificial sweeteners, sucralose and acesulfame potassium, which do not readily break down in the natural environment. In addition to the labile, but often detectable tracers mentioned above, the pain relief and fever reducing pharmaceutical acetaminophen would be more likely only detected in sewage overflow and other direct contaminations caused by untreated effluent.

Research Applications - Chemical Tracers

While further research is still needed, particularly how tracers correlate with fecal bacteria counts, pathogens, and risk to human health, jurisdictions may consider investigating the use of these tracers to locate and remediate sources of fecal bacteria. In addition to providing local jurisdictions information with regard to potential stormwater and wastewater inputs to surface waters, any and all investigations will likely aid in the development of impairment source trackdown using chemical signals. There are many different tracers that researchers are currently exploring as indicators of wastewater inputs to surface waters.

Paraxanthine is a caffeine metabolite and is perhaps the most likely candidate for use by local jurisdictions in identifying potential sources. Sucralose can indicate that human source waste is present in a waterbody, but it can be common in the environment. Carbamazepine is a prescription drug that is persistent in the environment, and could be useful for monitoring larger waterbodies that receive consolidated wastewater from large population areas.

There is a need to be able to separate treated wastewater inputs from tracers used to detect non-treated wastewater. Some of the very labile wastewater tracers such as acetaminophen might be of use in this context. In addition, there is a need to integrate forthcoming stormwater studies to review the chemical composition of stormwater runoff. For example, MRI and x-ray contrast chemicals may be specifically indicative of hospital wastewater and potentially leaking sanitary pipes.

Current research shows chemical tracers and bacteria blooms are not necessarily directly correlated, possibly due to the patchy occurrence of bacteria blooms; however, source tracking based on chemical analysis can be undertaken and would establish a baseline of the likelihood of bacteria blooms to occur (James et al 2016). Linking chemical tracers to nutrient species can also be helpful to track the discharge of waste streams. Other emerging issues include per- and polyfluorinated compounds in drinking water and diverse surfactants remaining in treated effluent.

Sucralose, one of the key potential tracers, can be detected at sites with even very low septic impacts. Sucralose is a good tracer of source inputs, but because it is so “conservative”, it will be present even after most other emerging contaminants have degraded, nitrogen concentrations are at baseline levels, and no pathogenic bacteria remain. However, in an unpublished University of Maryland Center for Environmental Science (UMCES) study of septic-impacted first order streams, a strong correlation with nitrogen was observed, suggesting that at least in smaller streams and watersheds, it could be a good proxy for septic N-loading.

Carbamazepine is persistent in the environment, but not to the degree of sucralose and it is also a prescription drug and hence may not reflect septic system impact in small watersheds accurately. Another artificial sweetener, acesulfame potassium, is also very stable and both carbamazepine and acesulfame potassium ionize better than sucralose, so they are much easier to detect at very low concentrations.

There will always be some sort of signal from wastewater in a receiving waterbody, but the question becomes is that signal indicative of a problem (i.e, a pathogen contribution). Florida

DEP has also done some investigation into the use of chemical tracers as signals for wastewater inputs. They have conducted studies on acetaminophen, ibuprofen, carbamazepine, and sucralose and have compiled a workbook documenting the conclusions and relevance to wastewater tracking. The information was compiled using a wastewater study and available literature, as well as from best professional judgment from laboratory technicians that work with Florida DEP (Florida DEP 2018b; Subedi and Loganathan 2016). It would be useful to be able to establish applicable approaches as part of a methodology for bacteria source tracking and elimination here in Maryland.

Compounds such as acetaminophen, ibuprofen, caffeine, and paraxanthine can be good tracers with minimal laboratory-based processing, and can likely represent higher wastewater presence or wastewater with higher N-loading (i.e. a higher likelihood to be pathogenic). At least for acetaminophen, caffeine and paraxanthine, this is because they have been found to readily degrade under aerobic conditions (James et al 2016 [for caffeine and paraxanthine], Juying et al 2014 [for acetaminophen]). In the recent unpublished UMCES stream study, acetaminophen was essentially never detected, except for maybe appearing in one month (May) at the two highest septic system density sites below the quantification limit (indicating its fast degradation). However, it has been detected in untreated effluent entering the Patapsco River. Ibuprofen was detected year-round at the two highest septic system density sites, but the seasonal trends in concentrations were unclear. Caffeine and paraxanthine were mainly seen at low levels at two high septic system density sites and a stream in a seasonally visited park in June and July. Possible explanations for this seasonal pattern are higher effluent input in spring/summer, lower stream discharge in spring/summer, or possibly other reasons. This also appears to correlate with an increase in sucralose concentrations during this same time, but no data on bacteria was collected during this study.

The current research holds promise for using less expensive tracer studies to indicate where we have potential pathogens from wastewater inputs However, further research is still needed. For further information, see Appendix 4: UMCES Tracer Outline for an expanded discussion.

Research Needs - Tracers in General

The direct detection of pathogens and subsequent predictive modeling of pathogens and FIB is a challenge. Given that the predictive modeling of contaminants can be a powerful tool for planning, this represents another key research gap. However, there have been recent advances, which if built upon, could hold promise for the future. There is new research indicating that Coliphage (a type of bacteriophage, i.e viruses that infect *E.coli*) could serve as an alternative virus-based indicator of fecal contamination. Coliphage (somatic/male-specific) may better mimic the persistence of pathogenic viruses in the environment and wastewater treatment discharges compared to FIB. The Coliphage's development as an additional indicator has been associated with swimming related illness (U.S. EPA 2020b).

Other key areas of research are related to the data collection and sampling procedures themselves for fecal bacteria. For instance, the following questions and statements have been posed by key researchers:

1. Is it necessary to specify the appropriate depths at which samples should be taken?
2. When and where sampling occurs can have a large impact on fecal bacteria concentrations. For example, the edges of a pond show different bacteria impairment (due to the churning of water near the edge/shallow areas) compared to "at depth" samples.
3. Data shows the importance of the time of year/day that samples are collected has an effect on bacteria counts.
4. What are the relevance of new technologies in tracking microbial content of surface waters; for example: drone imagery, hyperspectral imagery, algae/HABs/algaecide use?

Furthermore, there are other research questions related to the implications of emerging chemical tracers, total bacteria counts, and microbial source tracking. These include questions such as:

1. How can a correlation between chemical tracers and bacteria loads be established? As conservative chemical tracers, can sucralose, acesulfame potassium, or carbamazepine be used to understand the microbial loading, since these contaminants are rather persistent?
2. How can MST and chemical tracer data be linked to total bacteria counts, since FIB is the established benchmark for assessing whether or not it is safe for humans to come in contact with surface waters?
3. Since many chemical tracers span different degradation times in surface waters, what does the presence or absence of these tracers indicate regarding the age of the bacteria/sewage inputs? What kind of co-contaminants (e.g. stormwater signature) are you seeing when you have an increase in total bacteria counts?
    a. How can *in-situ* sources of bacteria be identified, and how system specific does this information need to be?
    b. How long after a source of fecal bacteria is eliminated will impacts on bacteria regrowth occur and what is the fate and transport of associated pathogens?
4. What variables need to be more extensively monitored or what relationships need to be better understood in order for bacteria source trackdown to be more thorough in its application so remediation can be undertaken with a greater level of confidence?
    a. Where wildlife are known to congregate during certain seasons?
    b. Where is the microbial quality of irrigation water being monitored?
        i. What is the link between irrigation ponds and ambient water quality?
        ii. Do changes in farm pond bacteria counts occur due to inputs, not due to activity within the pond itself?

Research Applications - Microbial source tracking (MST)

MST can be used in conjunction with spatially based desktop studies and fecal bacteria monitoring to locate and remediate potential sources of pathogens across the landscape. Baltimore City has developed established methodologies for using MST in conjunction with source trackdown investigations and fecal bacteria monitoring and fixed sites/time intervals. These methods are further described in Appendix 3.

MST is a method designed to collect, isolate, identify, and measure a host organism specific identifier from an environmental sample (U.S. EPA 2018). However, standard methods have yet to be developed. Maryland and its partner research institutions can work to develop a standardized local method so that jurisdictions using MST are generating data that is comparable. MST is based on a hierarchy of source risks that have been researched and developed: (1) humans presenting the most risk, (2) livestock, (3) pets, and (4) birds. Livestock pathogens are not well studied yet.

MST is relatively accurate in determining the presence/absence of certain markers and in what amounts; however, it is not very accurate for calculating the percent breakdown of sources when a sample is very complex and therefore has its limitations in terms of decision making. Although FIB are not always a reliable guide for remediation, molecular MST can assist with: (1) targeted remediation projects, (2) the development and use of appropriate BMP's, (3) assessment of remediation/restoration projects, and (4) prioritization of remediation (Pecher 2018).

One of the main human markers is HF 183. HF 183 is a DNA fragment from the 16S rRNA gene of Bacteroides and is primarily associated with human fecal material. HF 183 indicates the presence of human fecal contamination. While the presence of HF 183 does not necessarily indicate the presence of pathogens, it does indicate that human source bacteria are present. And while total fecal bacteria counts do provide information regarding the likelihood of pathogens being present, it does not indicate anything specific regarding the source of those pathogens. Therefore, source tracking information complements the FIB concentration data, but cannot replace it. This is because they look at different aspects of microbial pollution.

While MST plays an important role in the management of bacterial impairments, fundamental questions with regard to its application in source identification still exist. These include:

1. In what circumstances and watersheds is MST ideal for identifying bacterial sources?
2. Is MST ideal in watersheds with heterogeneous landscapes?
3. What is the optimal design for implementing MST analysis? For instance, based on a given density of septic systems, what resolution of monitoring for MST analysis would be necessary to determine if there is a human source contribution? What is the optimal monitoring strategy for identifying specific sources of bacteria in a watershed and how

would such a monitoring strategy align with current regulatory datasets, such as bacteria monitoring at public beaches or shellfish harvesting areas?

Appendices

Appendix 1. ShoreRivers

Appendix 2. Anne Arundel County Report

Appendix 3. Baltimore City Report

Appendix 4. University of Maryland Center for Environmental Science (UMCES) Tracer Outline

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