California Stormwater Quality Association®

Dedicated to the Advancement of Stormwater Quality Management, Science and Regulation

Human Fecal Waste Sources of Bacteria: Abatement Strategies for Municipal Stormwater Agencies

September 2024

Preface

ADVANCING SUSTAINABLE STORMWATER MANAGEMENT

The California Stormwater Quality Association (CASQA) is a nonprofit corporation that advances sustainable stormwater management protective of California water resources. With well over 2,000 members, CASQA's membership is comprised of a diverse range of stormwater quality management organizations and individuals, including cities, counties, special districts, federal agencies, state agencies, ports, universities and school districts, wastewater agencies, water suppliers, industries, and consulting firms throughout the state. Collectively, CASQA represents over 34 million people in California.

CASQA's *Vision for Sustainable Stormwater Management*[1] (Vision) defines the actions needed to manage stormwater as an essential component of the state's water resources, support human and ecological needs, protect water quality, and enhance and restore California's waterways. There are four guiding principles to achieve this Vision. Like the legs of a chair, each Principle is essential and all four must be in place to support the whole.

> **Principle #1: Program Implementation:** Projects and programs that use stormwater as a resource, protect water quality and beneficial uses, and efficiently minimize pollution are critical for sustainable stormwater management. Stormwater capture and true source control (identifying and mitigating a pollutant at its source) are the primary drivers of these solutions, with effective Best Management Practices (BMPs) providing an important supportive role.
>
> **Principle #2: Permits, Regulations, and Legislation:** Permits, regulations, and legislation need to focus on effectiveness and desired outcomes to support sustainable stormwater management. Regulatory and legislative actions must align with and support the other components of the Vision – advancing stormwater capture, true source control, and effective BMPs, increasing public education and awareness focused on stormwater as a resource, and securing funding to support these solutions.
>
> **Principle #3: Public Education:** Public awareness, understanding, and support is essential to sustainable stormwater management. The key shift is viewing stormwater as a resource that must be protected and integrated into overall water resource management.
>
> **Principle #4: Funding:** Significant financial investment is required to achieve sustainable stormwater management. Stormwater is the most underfunded portion of the water sector and substantial funding is needed to bring these solutions forward.

GOALS AND CONTEXT FOR THIS REPORT

This report, *Human Fecal Waste Sources of Bacteria: Abatement Strategies for Municipal Stormwater Agencies,* advances Principle 1. CASQA has identified bacteria as a Water Quality Priority, requiring solutions at a statewide scale. In September 2022, the State Water Resources Control Board and CASQA co-hosted a statewide summit on bacteria to create an engaged information sharing and discussion platform. During the summit, CASQA committed to

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[1] https://www.casqa.org/wp-content/uploads/2022/10/final_-_vision_for_sustainable_stormwater_management_-_10-07-2020.pdf

creating a resource for municipalities who may want to proactively identify and abate human fecal sources. This document was developed to meet that commitment.

Acknowledgements

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Introduction

In 2019, the California Stormwater Quality Association (CASQA) identified bacteria as a statewide water quality priority. In September 2022, the State Water Resources Control Board (State Water Board) and CASQA co-hosted a statewide summit on bacteria to create an engaged information sharing and discussion platform with the following goals:

- Develop a common understanding of the evolution of the standards and science relevant to defining and achieving waters that are safe to swim and shellfish that are safe to eat,
- Review current source reduction and regulatory tools,
- Identify what's working well, what may be falling short, and potential improvements or opportunities to effectively reach our goals,
- Identify needed regulatory actions and research for achieving waters that are safe to swim and shellfish that are safe to eat, and
- Discuss a process for implementing those actions, including immediate next steps.

The summit resulted in the following key takeaways and principles to be considered moving forward, as described in the Day 3 summary[2]:

- Goal remains the same to get to the point where it is safe to swim and shellfish are safe to eat
- Risk-based perspective takes a lot of forms, but is something that came out clearly in the summit
- Fecal contamination source type matters as not every source of indicator bacteria has the same level of risk
- There are some opportunities to use and improve standards
    - Current objectives are most indictive of risk when there are high levels of human and cattle sources and may not be as appropriate when the primary fecal contamination source types are less risky.
    - Risk modeling, such as Quantitative Microbial Risk Assessment (QMRA), could be useful tools and could support site-specific objectives. A framework for how to do the studies and interpret the results would be helpful.
    - Consideration of tribal and subsistence beneficial uses.
- For implementation:
    - Control the controllable sources and prioritize source control for fecal contamination source types with the greater illness risk.
    - Accountability is important.
    - A framework for defining the actions needed would be helpful.
- Collective action, partnering and messaging are critical and important to everything that has been discussed. Examples include:
    - Joint fact finding,
    - Partnering with public health experts,
    - Working with expert panels and scientists,
    - Highlighting successes and learning from existing studies and monitoring, and
    - Communicating to the public so they can understand the risks more in real time.

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[2] See the Summary for all takeaways at https://www.casqa.org/wp-content/uploads/2023/04/California-Bacteria-Summit-Short-Summary-03-27-2023.pdf

- For monitoring, data, and tools, need to ensure that data are consistent and comparable and to support upcoming needs like source tracking and rapid, real-time data.

In the Day 1 and Day 2 summaries, takeaways that provide additional detail that can help inform implementation actions for municipal stormwater agencies include[3]:

- Fecal contamination source type matters as not every source of indicator bacteria has the same level of risk:
    - In waters impacted by human sources, viruses most likely to make people sick.
    - In waters not impacted by human fecal sources, viruses likely not present.
    - Nature and magnitude of source(s) are important in determining the risk of illness.
    - The riskiest sources are human and cattle, but other sources if present in high concentrations can cause illness.
- Distinguishing the sources is important for identifying what actions to take, and
- Source not only matters for risk, but it also matters for implementation to determine if our actions are removing the risk.

The takeaways related to the different levels of risk associated with different sources of indicator bacteria from the 2022 Bacteria Summit align with the conclusions from the United States Environmental Protection Agency's (EPA) 2nd 5-year review of the National Recreational Water Quality Criteria (EPA, 2023c). The review includes a plan to explore new methods to determine whether a waterbody is contaminated with human feces, as this type of contamination poses the greatest risk of illness in recreational waters.

To advance the principles for implementation identified in the 2022 Bacteria Summit Day 3 key takeaways and to provide stormwater agencies with actionable tools to address high-risk sources, CASQA committed to supporting municipal stormwater agencies by sharing success stories and best practices and identifying tools to conduct effective human source identification studies. This document was developed to meet that commitment and provide a summary of approaches and tools stormwater agencies can use to reduce the discharge of human fecal waste sources of FIB[4].

This document is one of a number of resources developed by CASQA to support agencies with addressing bacteria, with a focus on addressing high risk sources. Other, related resources include:

- A report on the regulatory and technical challenges associated with the current FIB objectives for recreational waters (CASQA, 2020). This report provides an in-depth discussion of the background of the

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[3] See the Summary for all takeaways at https://www.casqa.org/wp-content/uploads/2023/04/California-Bacteria-Summit-Short-Summary-03-27-2023.pdf

[4] The document is not intended to assess the ability of any of the potential strategies to meet individual discharger permit requirements. It is also not intended to evaluate or recommend a relationship between levels of human fecal waste and risk, suggest the level of reduction of human fecal waste sources necessary to meet acceptable risk thresholds, or imply that risk reduction is needed in all waterbodies or under all conditions. The report also does not address evaluations of risk associated with limited exposure (e.g., during wet weather events, low flows, inaccessible creeks, or smaller waterbodies) that could potentially be addressed through regulatory changes (e.g., use attainability analyses). The report is intended to provide strategies for stormwater agencies that have identified a need to implement control measures to reduce human health risks.

current FIB objectives and situations in which those objectives may not be directly linked to risk to recreators in California waterbodies. The report also discusses the technical challenges and significant costs associated with implementing actions to meet the FIB objectives. Given the identified uncertainties in applying the FIB objectives in California and the significant costs involved in meeting the FIB objectives, the need to explore alternative ways to assess the actual risk during recreation and strategies to address risk above acceptable levels when present was identified.

- A resource document, developed by CASQA in collaboration with the California Association of Sanitation Agencies (CASA), which focuses on joint actions and collaboration strategies between wastewater and stormwater agencies to address human fecal waste sources of bacteria in waterbodies (CASQA, 2024).

These documents contribute to a shared goal – to help create solutions to ensure waters are safe to swim and harvest shellfish. Most of the information presented in this document is based on data and strategies designed to protect recreation (i.e., “safe to swim”). However, actions focused on addressing human fecal waste sources are likely to support protection of other beneficial uses, such as harvesting of shellfish and tribal beneficial uses.

Background

Currently, the driver for implementation related to bacteria is based primarily on exceedances of fecal indicator bacteria (FIB) objectives. However, implementation actions designed to reduce FIB concentrations and loads to meet FIB objectives, do not necessarily reduce risk. The uncertainty regarding the ability of FIB targeted actions to address risk is due to the following factors[5]:

- Implementation actions have often been assessed for their ability to remove FIB concentrations or loads, but little data exists about their ability to remove pathogens, which are often viral and much smaller than bacteria (e.g., Rugh et al., 2022) and may result in reduced removal. FIB concentrations are indicators of pathogens, but pathogens (typically viruses) are the drivers of illness and risk.
- Implementation actions to address FIB objective exceedances generally do not consider the source of bacteria and may therefore be less effective in controlling human fecal waste sources of bacteria. For example, treatment of surface runoff would not address below ground sources of human fecal waste.
- Implementation actions to address FIB objectives are typically not designed or located to prioritize capture of human fecal waste sources of bacteria. Instead, dictated by requirements to reduce FIB loading, implementation actions often target high FIB concentrations which are often caused by less risky sources of bacteria (e.g., trash and pet waste).

As a result of these factors, an implementation approach focused on reducing FIB concentrations without consideration of the source of the FIB and risk of those sources may not effectively reduce the risk, even if FIB concentrations and loads are reduced.

A risk-based approach differs from the traditional FIB-based approach in that consideration of human fecal waste and other high-risk sources will guide implementation strategies, which will result in implementation actions to reduce identified human health risk rather than just FIB loading. This approach is expected to be more protective of public

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[5] An expanded rationale for a risk-based approach is included in Appendix A.

health during recreation and/or shellfish harvest activities and support more targeted and effective implementation approaches for stormwater agencies.

To date, the most common approach taken to address risk has been through source control, typically identified as a human fecal waste source investigation and abatement approach.[6] The next section of the document summarizes the typical steps in a human fecal waste source investigation and abatement approach and identifying resources that agencies can use to implement their own programs. For simplicity, the discussion focuses on human fecal waste sources, but the same steps can be used to investigate and abate cattle sources if desired.

In addition, the document identifies conditions when structural control measures may be useful in a risk-based implementation approach and considerations when implementing structural control measures that may help maximize risk reduction.

Human Fecal Waste Source Investigation and Abatement Program

A human fecal waste investigation and abatement program is a structured implementation approach that is designed to consider and prioritize human health risk when developing implementation actions by identifying locations where high-risk sources of FIB exist and implementing targeted actions to address the identified sources when possible.

The approach relies on monitoring data, a range of source investigation tools, and strategies to abate identified high risk sources to reduce risk in discharges from the storm drain system. If used as an implementation approach, the program is iterative and ongoing, continually assessing potential risk in waterbodies and implementing actions to address the risk when identified. The approach consists of monitoring, investigation, and abatement actions, as summarized in **Figure 1**.

The following sections provide a general discussion of each of these steps, an overview of approaches that have been used by other agencies to implement these steps, things to consider, and resources and examples that can be used when developing a program.

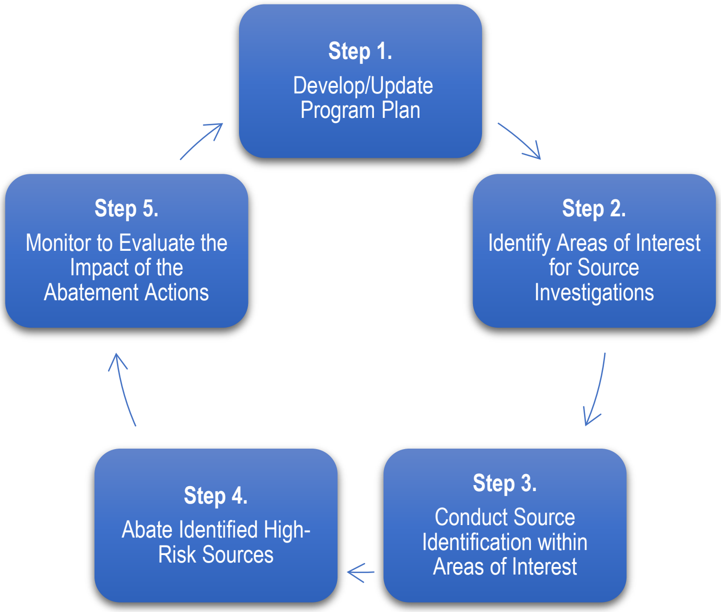

Figure 1. Human Fecal Waste Source Investigation and Abatement Approach Overview

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[6] It is important to note that while these strategies have been shown to be successful in small case studies (i.e., identifying and abating human fecal waste sources and reducing HF183 concentrations), to date implementation has been limited in scale and effectiveness has not been evaluated on a watershed scale (i.e., a measured reduction in pathogens or risk in the recreational waterbody).

STEP 1. DEVELOP / UPDATE PROGRAM PLAN

The first recommended step is to develop a plan for implementing the program that is specific to the watershed and the potential high-risk sources that could be present in the watershed. The plan should include a monitoring plan and strategies for conducting the source investigations at a minimum. The plan can also include potential methods for abating identified high risk sources, if desired.

Because the program is an iterative, ongoing program, the program plan should be updated as needed to incorporate information learned from the source investigations and any new tools or changes to the approach that occur as the program is implemented.

Gather Background Information

The first recommended action in developing the program plan is to gather background information on the watershed for the waterbodies of interest. The background information will help with identifying a monitoring approach that leverages existing data and monitoring programs and supports prioritized monitoring and source investigation actions. Examples of the types of background information that may be useful to collect are shown in **Table 1**.

Table 1. Types of Background Information to Support Program Plan Development

Information Category	Types of Data/Information
Monitoring Programs and Plans	• Existing monitoring sites • FIB data • Human and non-human markers
Source Information	• Location, age and condition of storm drain and sanitary sewer infrastructure • Locations of communities of people experiencing homelessness • Locations of historical sanitary sewer overflows • Locations of septic tanks • Land use information
Studies	• Source investigation studies • Sanitary surveys • Watershed characterizations • Relevant scientific literature

It can also be useful to establish a stakeholder group at this time to help gather the background information, gain knowledge of potential sources, and serve as a resource for supporting implementation of the program.

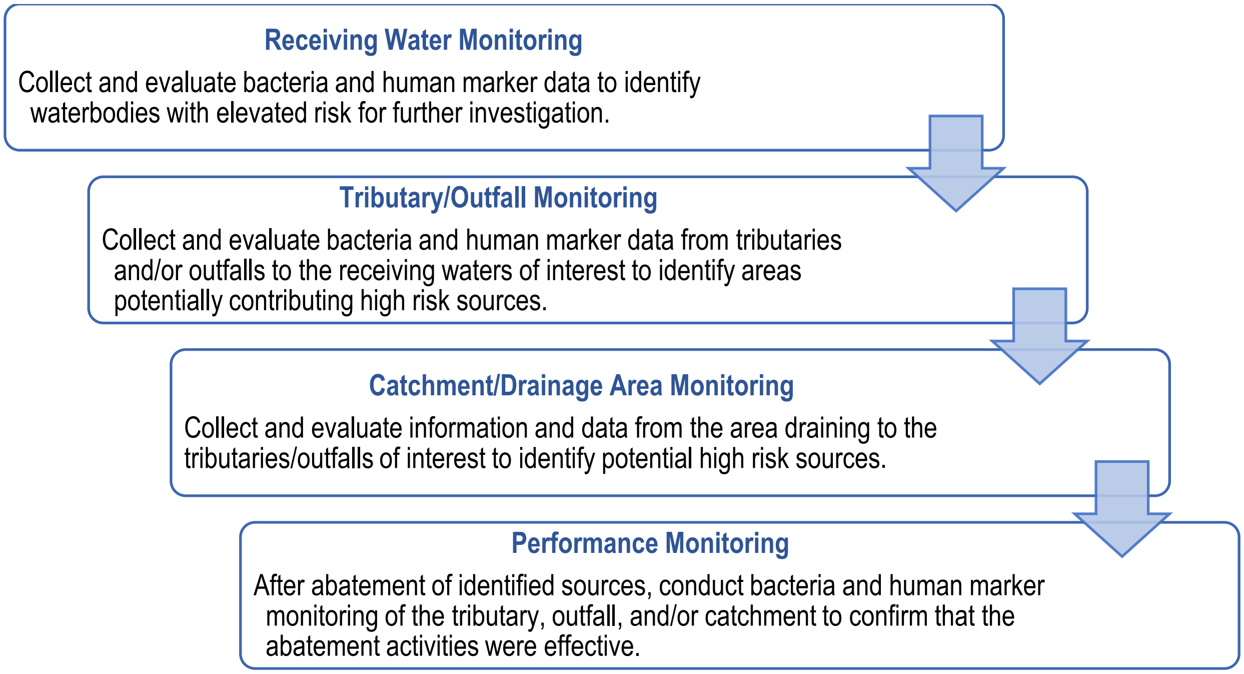
Develop Monitoring Plan

A typical human fecal waste source investigation and abatement program will contain some or all of the monitoring elements shown in **Figure 2.**

The monitoring plan should consider including monitoring questions to clarify the goals of the monitoring, monitoring methods, timing for the monitoring and investigations (e.g., wet weather or dry weather or both), and the indicators to be analyzed for each of the elements shown in **Figure 2**. Specific monitoring locations can be included in the plan or identified through implementation of the program.

Monitoring Questions: Some examples of monitoring questions that have been employed in studies include:

- Are conditions protective of beneficial uses?
- What are the major sources of FIB and human marker sources in the watershed?
- Are there areas of higher risk of human fecal waste from MS4 Permittees discharges that should be targeted for subsequent mitigation and elimination?
- Are management actions effective at mitigating human health risk?



Receiving Water Monitoring

Collect and evaluate bacteria and human marker data to identify waterbodies with elevated risk for further investigation.

Tributary/Outfall Monitoring

Collect and evaluate bacteria and human marker data from tributaries and/or outfalls to the receiving waters of interest to identify areas potentially contributing high risk sources.

Catchment/Drainage Area Monitoring

Collect and evaluate information and data from the area draining to the tributaries/outfalls of interest to identify potential high risk sources.

Performance Monitoring

After abatement of identified sources, conduct bacteria and human marker monitoring of the tributary, outfall, and/or catchment to confirm that the abatement activities were effective.

Figure 2. Human Fecal Waste Source Reduction Strategy with Tiered Monitoring Approach.

Adapted from "A Framework for Monitoring and Assessment in the San Diego Region" (San Diego RWQCB, 2012); and "Comprehensive Human fecal waste Source Reduction Strategy Work Plan" (Orange County MS4 Permittees, 2020).

Monitoring Timing: The timing for monitoring should be identified and include both the season and the condition (dry or wet weather). The selection of the seasons and conditions to be monitored will depend on which conditions are of potential concern for the waterbody. This can be determined by reviewing the historic monitoring data gathered as part of the background information. If wet weather conditions are investigated, it is recommended to perform dry weather investigations and abatement prior to wet weather, since dry weather sources also contribute during wet weather and elimination of dry weather sources may reduce and simplify wet weather investigations.

Indicators: The monitoring plan should at a minimum include the relevant bacteria indicators based on the type of waterbody (marine or inland). Agencies desiring to incorporate risk-based indicators into their monitoring plan could include human markers (typically HF183), coliphage, or specific viruses of potential concern. Both the indicators to be used and the monitoring methods associated with the indicators should be included. Potential questions to consider in identifying the indicators for the plan include:

- Are there any conditions that could impact the selection of the monitoring parameters? For example, certain indicators may not be feasible in a watershed for reasons that may include sample matrix inhibition of analysis method (e.g., Polymerase Chain Reaction (PCR) inhibition), the existence of HF183 in recycled water, or laboratory capabilities. If there are potential conditions of concern, pilot studies can be conducted prior to initiating the full monitoring program to test the viability of the selected approach.
- Are other sources of FIB of interest? Some monitoring programs may want to consider adding non-human markers to the program to help identify other sources of FIB to the waterbody. This may be of interest if a non-human source is expected to be contributing to high concentrations of FIB that may increase the risk from that source (e.g., birds).
- Is there a desire to incorporate monitoring that would support modeling to quantify risk and develop site-specific objectives, typically done through a Quantitative Microbial Risk Assessment (QMRA)? If so, collection of viruses and other data needed as inputs to the model may be of interest.

Monitoring Locations: In most cases, municipalities will already have an existing monitoring program that monitors FIB. The monitoring locations that have historically exceeded FIB objectives in data collected by existing monitoring programs can provide a starting point for the initial monitoring efforts. Agencies desiring to take a more risk-based approach to monitoring location selection can consider selecting monitoring locations in areas with a higher likelihood of riskier sources based on gathered background information on sources and/or consider areas with uses potentially impacted by pathogens (e.g., swimming or known shellfish harvesting locations).

Source Investigation Toolbox

The program plan can also include a summary of the tools that will be used to support the source investigations and, if desired, the situations in which the tools will be used. A summary of potential tools that could be considered is included in **Table 2**. It can also be helpful for the program plan to identify the approach that will be used to determine where source investigations will be conducted. Action thresholds and an adaptive management approach can be helpful to include in the program plan to help target areas for source investigations.

Table 2. Types of Source Investigation Tools to Support Program Development

Category	Tools
Desktop	• GIS-based potential source evaluation
Observational	• Visual Surveys • Sanitary Surveys • Inspections/Complaint investigations
Monitoring	• Flow • Human fecal waste specific markers • Chemical indicators of human fecal waste (caffeine, pharmaceuticals, etc.) • Biofilms
Infrastructure Testing	• CCTV • Dye testing (basic and rhodamine) • Smoke test
Other approaches	• Canine scent testing

Action Thresholds: A typical approach for prioritizing an outfall/catchment for monitoring and/or source investigation is to use an "action threshold" based on the collected monitoring data. The action thresholds are generally designed to prioritize outfalls with the greatest potential to contribute high risk sources to the waterbody. When developing the thresholds, agencies should consider whether different action thresholds are needed for dry and wet weather, type of location (e.g., MS4 outfall or receiving water), and type of waterbody (e.g., inland or marine). Methods for developing the threshold include:

- Using a percentile of historical monitoring data (or initial outfall screening data if available),
- Using risk-based literature values for HF183[7], and
- Using a percentage of detected values or values quantified above a selected threshold.

Adaptive Management Approach: The program should define how the monitoring results will be used to determine when additional abatement activities are needed and if additional outfalls/catchment areas need to be prioritized for source investigation and abatement.

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[7] Risk-based literature values that have been considered include:

1. Boehm (2015; 2018) includes a threshold of 1,000 copies/100 ml for freshwater receiving waters.
2. Boehm et al 2018 includes a threshold of 4,100 copies/100ml for freshwater tributaries and MS4 discharge outfalls.
3. Boehm and Soller, 2020 suggests a risk-based water quality threshold of 525 HF183 copies/100 mL as most representative of conditions described in the 2012 RWQC.

Resources for Developing a Program Plan

Publicly available resources that can help with gathering background information:

- California Integrated Water Quality System (CIWQS) https://ciwqs.waterboards.ca.gov/ciwqs/index.jsp
- Sanitary Sewer Systems General Order https://www.waterboards.ca.gov/water_issues/programs/sso/index.html
- California Environmental Data Exchange Network (CEDEN) Query Tool Filters https://ceden.waterboards.ca.gov/Home/AqtTool
- Stormwater Multiple Application and Report Tracking System (SMARTS) https://smarts.waterboards.ca.gov/smarts/faces/SwSmartsLogin.xhtml
- Biogeographic Information Observation System (BIOS) Viewer https://apps.wildlife.ca.gov/bios6/?al=Hydrography:1
- California Open Data Portal https://data.ca.gov/
- Heal the Bay's Beach Report Card https://beachreportcard.org/
- Heal the Bay's River Report Card https://healthebay.org/riverreportcard/
- National Water Quality Monitoring Council's Water Quality Portal (WQP) https://www.waterqualitydata.us/
- EPA's Enforcement and Compliance History Online (ECHO) https://echo.epa.gov/
- EPA's Permit Compliance System (PCS) and Integrated Compliance Information System (ICIS) Database https://www.epa.gov/enviro/pcs-icis-search
- EPA's WATERS Mapping Services https://www.epa.gov/waterdata/waters-mapping-services#Description
- EPA's Beach Advisory and Closing On-line Notification (BEACON 2.0) https://watersgeo.epa.gov/beacon2/
- EPA's Assessment and Total Maximum Daily Load Tracking and Implementation System (ATTAINS) https://www.epa.gov/waterdata/get-data-access-public-attains-data
- USDA Geospatial Data Gateway https://datagateway.nrcs.usda.gov/
- USGS Water-Quality Data for the Nation https://waterdata.usgs.gov/nwis/qw
- Groundwater Ambient Monitoring and Assessment Program (GAMA) https://www.waterboards.ca.gov/gama/
- State Water Resources Control Board's GeoTracker https://geotracker.waterboards.ca.gov/

Examples of monitoring plans that have incorporated risk-based approaches:

- Lower American River Bacteria Study – Data Summary of Phase 1 Source Identification Results https://www.beriverfriendly.net/wp-content/uploads/2021/12/Lower-American-River-Bacteria-Study.pdf
- Lower American River Bacteria Study – Preliminary Summary of Phase 2 Monitoring Results https://www.waterboards.ca.gov/centralvalley/water_issues/swamp/lar_ph2_21.pdf

- Central Valley Regional Water Quality Control Board (RWQCB) E. *coli* Monitoring Results: Lower American River https://waterboards.maps.arcgis.com/apps/webappviewer/index.html?id=1d02f001ac9143ca856125b436bb5905&extent=-13532752.25%2C4662456.4393%2C-13520522.3254%2C4670845.4032%2C102100
- Santa Ana River Watershed Bacteria Monitoring Program – Monitoring Plan https://sawpa.gov/wp-content/uploads/2022/06/FINAL-2022-Revised-SAR-Monitoring-Plan-w-Attch-6-6-2022.pdf

Examples of guidance and study plans that include source investigation tools:

- Quantifying Sources of Human Fecal Contamination Loading to the San Diego River – A Conceptual Workplan developed by the Southern California Coastal Water Research Project https://www.waterboards.ca.gov/sandiego/water_issues/programs/san_diego_river_io/docs/Fecal_Loading_Workplan_20190314.pdf
- The California Microbial Source Identification Manual: A Tiered Approach to Identifying Fecal Pollution Sources to Beaches by the Southern California Coastal Water Research Project https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/804_SIPP_MST_ManualPag.pdf
- City of Santa Barbara. Tools for Tracking Human Fecal Pollution in Urban Storm Drains, Creeks, and Beaches https://www.riverkeeper.org/wp-content/uploads/2015/03/TrackingGuide112712.pdf
- Colorado *E. coli* Toolbox: A Practical Guide for Colorado MS4s https://mhfd.org/wp-content/uploads/2019/12/Denver-E-coli-Toolbox-08-5-2016.pdf
- Pathogens in Urban Stormwater Systems https://www.asce-pgh.org/Resources/EWRI/Pathogens%20Paper%20August%202014.pdf
- Application of a microbial community sequencing approach to identify contamination from sewers in an urban watershed (Appendix D of Summary of Technical Research: Quantifying Sources of Human Fecal Pollution in the Lower San Diego River Watershed) https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1380_FecalPollutionSanDiegoRiver.pdf

STEP 2. IDENTIFY AREAS FOR SOURCE INVESTIGATIONS

Once a plan has been developed, the next step is to begin implementation of the plan by identifying areas to conduct source investigations. The goal of this step is to identify outfalls and/or catchment areas that have a high likelihood of containing sources of human fecal waste that are being discharged to the receiving water. The approach taken to identify the areas will depend on the size of the catchment being investigated and the amount of background information available to inform identification of the areas. Two approaches are commonly used for this step: 1) monitoring approach or 2) desktop approach. A combination of the two approaches can also be used.

Monitoring Approach to Identifying Areas for Source Investigations

A monitoring approach to identify areas of interest for source investigations consists of progressively monitoring upstream in a watershed until an outfall or catchment area has been identified that has high concentrations of indicator bacteria and human markers of waste, if used. A typical monitoring approach includes:

- **Conduct receiving water monitoring to identify waterbodies with elevated concentrations of the monitored indicators identified in the monitoring plan.** Identified receiving water locations would typically be at the base of the watershed or major tributaries. Ideally, water collected at receiving water locations will be analyzed for both FIB and human fecal indicators (e.g., HF183) to identify receiving waters with a higher likelihood of containing riskier sources. However, due to the cost of HF183 analysis, receiving water monitoring may just include FIB or HF183 analysis may be run just for samples with elevated FIB concentrations. Existing monitoring programs may be used for the receiving water monitoring.
- **Conduct monitoring upstream of identified receiving water sites in tributaries and/or outfalls.** This step includes monitoring at outfalls or catchments[8] for FIB and a human marker, such as HF183, though other indicators may be considered depending on the monitoring questions identified for the program (e.g., if a QMRA is being considered, specific viruses may be of interest, or non-human markers may be included). Programs often include a method for prioritizing tributaries and outfalls for monitoring. If included, the prioritization typically considers historical FIB and flow data, with outfalls with higher FIB concentrations and flows being monitored first. It should be noted that outfalls with flow, even if the FIB concentrations are not elevated, should still be evaluated as part of the program as they may contain human fecal waste sources.

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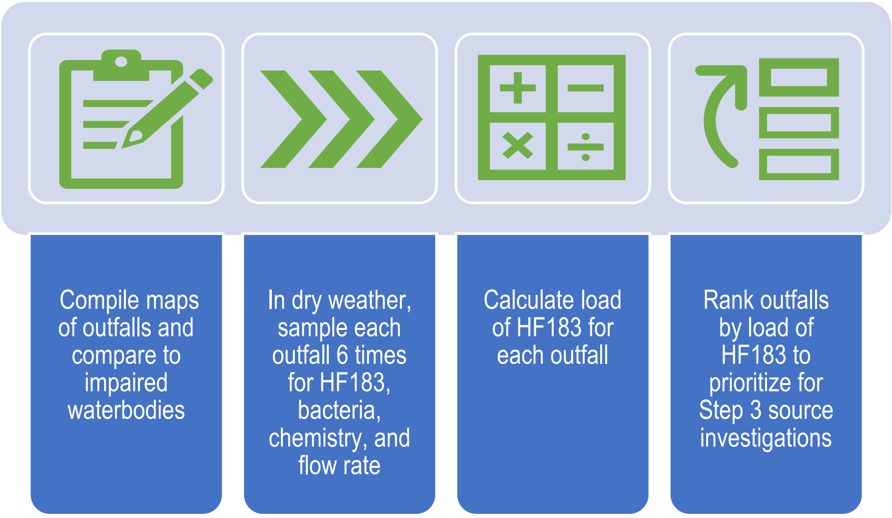
[8] Some programs include receiving waters in locations upstream of the monitoring locations in Step 1 as part of Step 2 to help narrow down the outfalls that need to be monitored.

Example of a Monitoring Approach for Step 2: Identify Areas for Source Investigation



When identifying the monitoring to be conducted in Step 2, agencies can consider the following questions:

- Based on historical FIB monitoring data, have areas of potential concern already been identified? If not, a broader receiving water monitoring program may be needed to identify areas for source investigation.
- Are identified areas of concern geographically small enough to be able to conduct source investigations? If not, upstream or outfall monitoring may be needed to identify areas for source investigations. An adaptive management approach may be implemented to prioritize subwatersheds for upstream/outfall monitoring and program implementation over time.
- Has historical monitoring identified a ubiquitous problem throughout a waterbody or region? If so, additional receiving water monitoring may not be very useful. Moving directly to tributary/outfall monitoring may be more productive.

Once monitoring has been completed, source investigation (Step 3) is then conducted in the drainage areas where the outfalls/catchments exceed the action thresholds defined in the program plan.

Desktop Approach to Identifying Areas for Source Investigations

A desktop analysis is typically included in this step to help identify the areas that are most likely to contribute human fecal waste sources to waterbodies of interest. The desktop analysis can support prioritization of outfalls/catchments for monitoring and support the source investigations in Step 3. The analysis could also be done as part of Step 3 only for the drainage area to an outfall/catchment rather than for the whole drainage area to the receiving water of interest, particularly if the monitoring approach is being used to identify areas for source investigations.

A desktop analysis typically consists of identifying potential sources of human fecal waste, including:

- Where sanitary sewers could potentially contribute to the MS4 system (crossing or adjacent lines and laterals, particularly when storm drain is at lower elevation than sewer and sanitary sewer lines with potential defects).
- Known locations of unhoused encampments or unauthorized recreational vehicle (RV) parking.

- Known locations of septic systems.
- Known areas of historical sanitary sewer overflows.
- Previously identified potential sources from Illicit Discharge Detection and Elimination (IDDE) investigations and/or sanitary surveys.[9]

Using a desktop approach, outfalls or catchments with known or suspected high-risk sources are prioritized for source investigations in Step 3.

Agencies can also use a combination of a desktop analysis and monitoring approach. The combination approach consists of using the desktop analysis to help prioritize areas for upstream tributary and outfall monitoring. Additionally, the desktop analysis can help identify where recycled water distribution could potentially create a misleading human marker signal. In these areas, indicators of human fecal waste other than HF183 may need to be used for monitoring.

Resources for Implementing a Program Plan to Identify Areas for Source Investigation

- San Diego River Water Quality Improvement Plan (WQIP) https://projectcleanwater.org/download/san-diego-river-sdr-water-quality-improvement-plan-wqip/
- South Orange County Water Quality Improvement Plan (WQIP) https://www.southocwqip.org/
- San Diego Bay Water Quality Improvement Plan (WQIP) 2021-2022 Annual Report https://projectcleanwater.org/download/san-diego-bay-wqip-2021-2022-annual-report/

STEP 3. CONDUCT HUMAN FECAL WASTE SOURCE INVESTIGATION

The process for conducting human fecal waste source investigation will be specific to each drainage area and could include a wide range of tools depending on available information and site-specific conditions. This section provides an inventory of potential tools and a list of resources that can be used to implement a program that is appropriate for the agency and site conditions.

Desktop Analysis. The desktop analysis conducted in Step 2 can optionally be used to help target potential sources for investigation in the drainage areas to the outfalls/catchments identified for source investigation. The desktop analysis provides information on potential locations of sources that can be prioritized for field reconnaissance and helps to define the appropriate approach to conducting the investigation based on the potential sources. The approach could range from a simple analysis identifying the potential human fecal waste sources present in the source investigation area to a more complicated catchment level prioritization analysis based on available data. The Newport Bay Source Investigation Study Design[10] includes a process for developing a catchment level prioritization to guide source investigations that includes the following steps:

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[9] Toilet paper, undigested food, wipes, sewage biofilm and sewage smells are examples of findings from these programs that would indicate potential human fecal waste sources.

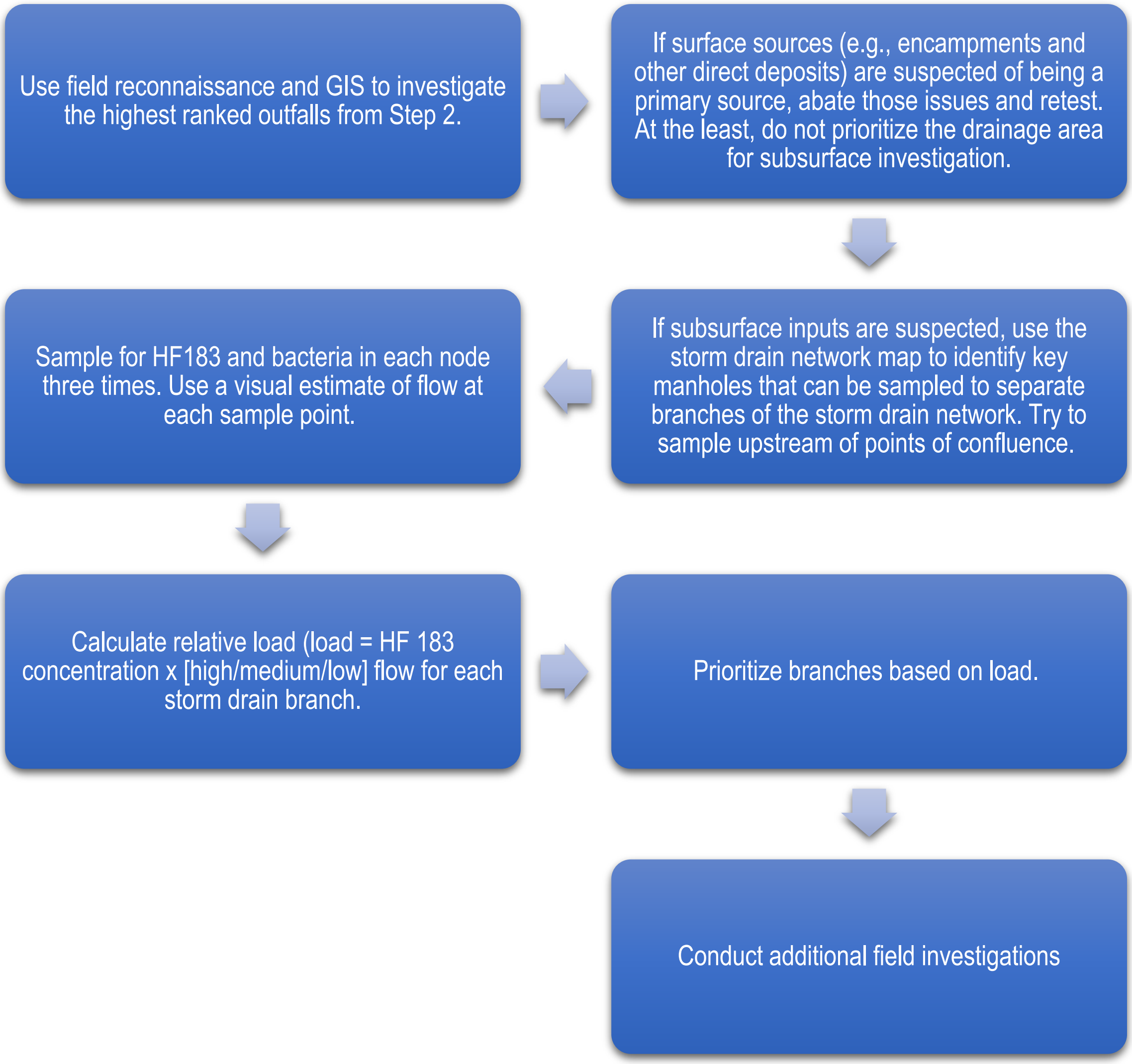
[10] "Source Investigation Final Report TSO 2019-0050 Task 3b" (Orange County MS4 and Newport Bay Watershed Permittees, 2023)

- Utilize Geographic Information System (GIS) to merge geo-coded information (e.g., private lateral spills, sewer infrastructure, MS4s, septic systems, etc.), watershed information (e.g., land use, soil properties, etc.), sewer infrastructure characteristics (e.g., age, material, size, depth, etc.), and other relevant information (e.g., unsheltered homeless population);
- Develop algorithm and scoring criteria based on selected metrics and water quality data; and
- Create a prioritization map to guide and select locations for the field reconnaissance.

Field Reconnaissance. Field investigations involve driving or walking through the drainage area to the outfall looking for potential sources of flow and pollutants to the receiving water. Field investigations can include:

- Visual inspections of the drainage area and potential above-ground sources (e.g., RV or unhoused encampments, visual evidence of dumping, etc.).
- Sanitary surveys to visually inspect for fecal contamination sources using EPA guidance (EPA, 2023b).
- Flow tracking - identify what portion of the MS4 is wetted to isolate the location where human fecal contamination may be entering the storm drain.
- Sampling FIB and HF183 and/or chemical sewage indicators in the storm drain system to:
    - Distinguish portions of the storm drain network with and without human fecal contamination,
    - Evaluate decreasing/increasing patterns in human signal to isolate potential entry point of contamination, and
    - Bracket potential points of entry identified by desktop analysis.
- Using closed-circuit television (CCTV) to evaluate storm drains and collection systems to identify where flow is entering the storm drain system. This is typically used for storm drain segments identified as potential entry points for contamination based on storm drain system sampling.
- Basic dye testing / smoke testing can be used if a cross connection or sanitary source is suspected. Use distance measured from CCTV and a rolling tape measure to approximate the point of input to the storm drain. Use liquid dye or dye tabs (commonly used by the wastewater crews) to test nearby yard and parking lot drains, laterals and bathrooms. If a lateral leak is suspected, work with the property manager to put dye in every sink and toilet - often just one is plumbed incorrectly. Use a flashlight at the next downstream manhole to wait for dye.
- Advanced dye testing and fluorometric loggers are used when exfiltration from the sanitary sewer is suspected. Dye is added to the sanitary sewer pipe and a logger is placed in the storm drain.
- Flow gauges and flow-triggered sampling can be used where periodic inputs are suspected.
- Employing emerging or unique tools such as canine scenting or biofilm microbial community evaluation.

Example of an Approach for Step 3: Conduct Human Fecal Waste Source Identification



Use field reconnaissance and GIS to investigate the highest ranked outfalls from Step 2.

If surface sources (e.g., encampments and other direct deposits) are suspected of being a primary source, abate those issues and retest. At the least, do not prioritize the drainage area for subsurface investigation.

If subsurface inputs are suspected, use the storm drain network map to identify key manholes that can be sampled to separate branches of the storm drain network. Try to sample upstream of points of confluence.

Sample for HF183 and bacteria in each node three times. Use a visual estimate of flow at each sample point.

Calculate relative load (load = HF 183 concentration x [high/medium/low] flow for each storm drain branch.

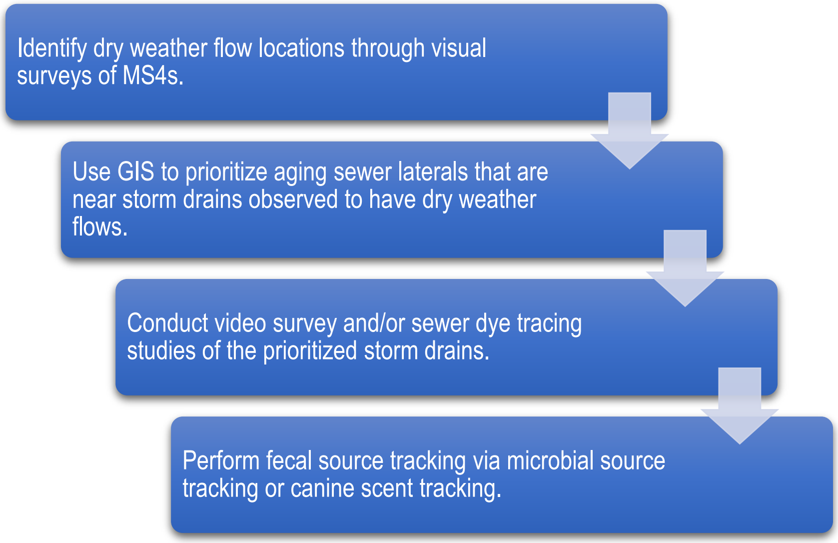
Prioritize branches based on load.

Conduct additional field investigations

As an alternative to developing a new source investigation program, may be a possibility to modify an agency's existing IDDE Program to incorporate the steps noted above.

If human fecal waste sources are identified from the source investigation, strategies to abate the identified sources can be implemented. Examples of potential abatement strategies of human fecal waste sources are included in Step 4.

Incorporating Source Investigations into IDDE Programs



Identify dry weather flow locations through visual surveys of MS4s.

Use GIS to prioritize aging sewer laterals that are near storm drains observed to have dry weather flows.

Conduct video survey and/or sewer dye tracing studies of the prioritized storm drains.

Perform fecal source tracking via microbial source tracking or canine scent tracking.

Resources for Conducting Source Investigation

Examples of human fecal waste source investigation programs, procedures and results:

- South Orange County Comprehensive Human Source Reduction Strategy (CHWSRS) Work Plan https://www.southocwqip.org/pages/chwsrs
- South Orange County Water Quality Improvement Plan (WQIP) 2021-22 Annual Report https://ocgov.app.box.com/v/2021-22WQIPAnnualReport
- Quantification of Sources of Fecal Pollution at Mule Creek https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1186_MuleCreekFecalPollution.pdf
- Los Coches Creek Microbial Source Tracking Study https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1087_LosCochesMST.pdf
- San Diego Bay Water Quality Improvement Plan (WQIP) 2021-22 Annual Report https://projectcleanwater.org/download/san-diego-bay-wqip-2021-2022-annual-report/

STEP 4. ABATE HUMAN FECAL WASTE SOURCES

Ideally, the end result of Step 3 is the identification of a human fecal waste source that can be abated. Human fecal waste sources can generally be grouped into two categories: wastewater system related or direct deposits. Wastewater system related sources include sanitary sewer overflows, leaking sanitary sewer collection system (mains and private laterals), malfunctioning septic systems, cross connections of sanitary sewer lines to the storm drain system, and boat pump-out facilities. Wastewater system related sources typically result from a malfunctioning system and can often be corrected by repairing the malfunction. To abate these sources, stormwater agencies often have to rely on wastewater or collection system agencies to correct the identified problem. Direct deposit sources result from any individual, company or group directly discharging human fecal waste to the receiving water, storm drain systems, or a surface that can be washed into either receiving waters or storm drain systems. Direct deposits occur in many ways, but common sources identified in the source investigation resources include illegal dumping to the storm drain (e.g., RVs or porta potties), unhoused encampments, and individual deposits outside bathroom facilities. Direct deposit sources are more challenging to address as they can be harder to identify and can require more complex solutions that may be beyond a stormwater agency's ability to implement on their own.

While addressing the identified sources will be specific to the situation, it can be helpful for a program to identify ahead of time the potential abatement strategies that may be used based on the identified source. **Table 3 i**ncludes potential abatement strategies for common human fecal waste sources. The majority of these strategies are source control strategies that have been found to be successful in reducing or eliminating human markers from the storm drain system.

Table 3. Source Control Strategies for Human Fecal Waste Source Abatement

Source	Potential Strategies[1]
Sanitary Sewer Overflows [2]	• Improved coordination with wastewater agencies. • Clear protocols for cleaning high-priority storm drain systems after a spill has occurred.
Leaking sewer mains (public/special districts) [2]	• Improved coordination with wastewater agencies for investigation procedures to identify leaking sanitary sewer lines. • Improved coordination with wastewater agencies for development of long-term asset management plans and implementation of needed repairs.
Leaking sewer laterals (private) [2]	• Improved coordination with sanitation agencies for development of educational and incentive programs to encourage homeowners and private entities to inspect and repair aging and leaking laterals. • Requirements for inspections and repairs of private sewer laterals periodically, for example prior to property sale. • Education and incentive programs to encourage homeowners to inspect and repair aging and leaking laterals.

Source	Potential Strategies[1]
Septic Systems	• Improved coordination with local Environmental Health Departments and Building & Safety Departments to identify potentially failing septic systems. • Support for implementation of the SWRCB's On-Site Wastewater Treatment System (OWTS) Policy (April 2023) and referral for enforcement, if needed. • Education and incentive programs to encourage homeowners to inspect and repair failing septic systems.
Marinas and pump-out facilities	• Regular inspections of facilities and repairs if leaks are found. • Education and outreach to boat owners regarding proper disposal of waste. • Enforcement for improper disposal of waste.
RV dumping	• Public outreach to educate that dumping to storm drain system is illegal. • Reporting hotline for responding to illegal dumping. • Ordinances to prohibit dumping and provide authority for progressive enforcement of violations. • Increased number of locations for RV services and waste disposal. • Incentive programs for proper disposal of waste and/or no-fee services for waste disposal. • Education and/or enforcement for improper disposal of waste. • Security camera to identify license plate of suspected repeat offender. Follow up enforcement.
Illegal discharges and dumping	• Public outreach to educate that dumping to storm drain system is harmful to downstream waters and illegal. • Reporting hotline for responding to illegal dumping. • Ordinances to prohibit dumping and provide authority for progressive enforcement of violations. • Education and/or enforcement for improper disposal of waste.
Direct human deposits of waste	• Support of municipal shelters and services to reduce homelessness. • Periodic cleanup of unhoused encampments near streams and waterbodies, particularly prior to the rainy season. • Evaluation of needs for and coordinate with owners of recreational, commercial, or other frequently visited areas to provide public restroom facilities and services. • Education and, if needed, enforcement regarding proper disposal of waste. • Partnering with non-governmental organizations to address homelessness. • Providing accessible services for proper disposal of human fecal waste.

<u>Notes:</u>

[1] Specific examples of how agencies have implemented many of these strategies can be found in the examples cited in previous sections. Annual reports for agencies in coastal counties (Santa Barbara, Ventura, Los Angeles, Orange and San Diego) are good resources for specific examples of strategies that have been implemented.

[2] In partnership, CASQA and CASA developed "A Roadmap for Stormwater and Wastewater Agencies to Collaboratively Reduce Human Fecal Sources of Bacteria in Waterbodies" that provides more detail and specific ideas for improving coordination with wastewater agencies and proactive strategies to prevent discharges from these sources (CASQA and CASA, 2024).

STEP 5. MONITOR TO EVALUATE THE IMPACT OF ABATEMENT ACTIONS

Once sources have been abated, follow-up monitoring should be conducted to evaluate if the abatement actions were effective. At a minimum, monitoring at the outfalls should be conducted to determine if the indicators have fallen below action thresholds. If the indicators are still above defined action thresholds, additional source investigation and abatement should be conducted to address other sources that are present in the drainage area.

Receiving water monitoring data should also be evaluated to determine if the goals of the program have been achieved. If the receiving water data is not meeting the defined goals of the program, additional outfalls/catchment areas need to be prioritized for source investigation and abatement.

If water quality concerns remain in the receiving water after identified sources in outfall drainage areas exceeding the action thresholds have been abated and discharge from outfalls meets the action thresholds, source investigations in other additional outfalls that do not meet the thresholds may need to be conducted until the receiving water quality is meeting the defined goals of the program.

SUMMARY AND EXAMPLE OF THE HUMAN FECAL WASTE SOURCE INVESTIGATION AND ABATEMENT PROGRAM

The program described above for human fecal waste control is an iterative process that includes both monitoring and desktop analysis approaches and involves a continual process of evaluation, prioritization, investigation, and abatement of identified sources. Permittees can rely on historical and current monitoring data to inform and prioritize sources and contributing sites, and to support identifying areas with potential human fecal waste sources. Based on this data, upstream tributaries can be monitored, and through an iterative process, areas with higher-risk sources can be identified. Identified sources can then be abated and follow-up monitoring conducted to assess whether additional source investigation is needed to abate additional sources.

An example of an overall workflow for the program is provided in **Figure 3** for dry weather and **Figure 4** for wet weather, modified from the Source Investigation Final Report submitted to the Santa Ana Regional Water Quality Control Board (Santa Ana RWQCB) by the County of Orange MS4 and Newport Bay Watershed Permittees (Orange County MS4 Permittees, 2023). The dry weather source investigation includes dry weather receiving water monitoring for marine and freshwater bacteria indicators, discharge outfall prioritization, outfall investigation/monitoring, and source investigation/elimination. In comparison, the wet weather source investigation process is event driven. It includes wet weather outfall monitoring/prioritization, monitoring of prioritized outfalls, outfall investigation, and source investigation/elimination. As stated above, it is recommended to perform dry weather investigations and abatement prior to those for wet weather.

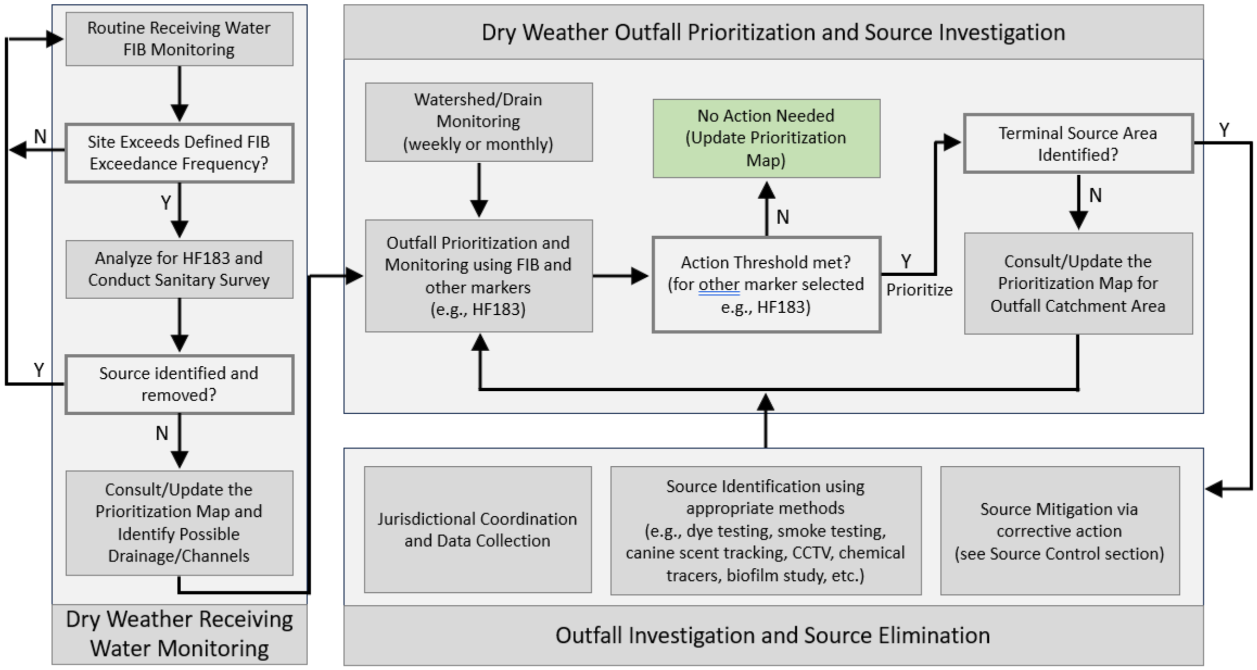


Figure 3. Dry Weather Workflow. Adapted from “Source Investigation Final Report TSO 2019-0050 Task 3b” (Orange County MS4 and Newport Bay Watershed Permittees, 2023)

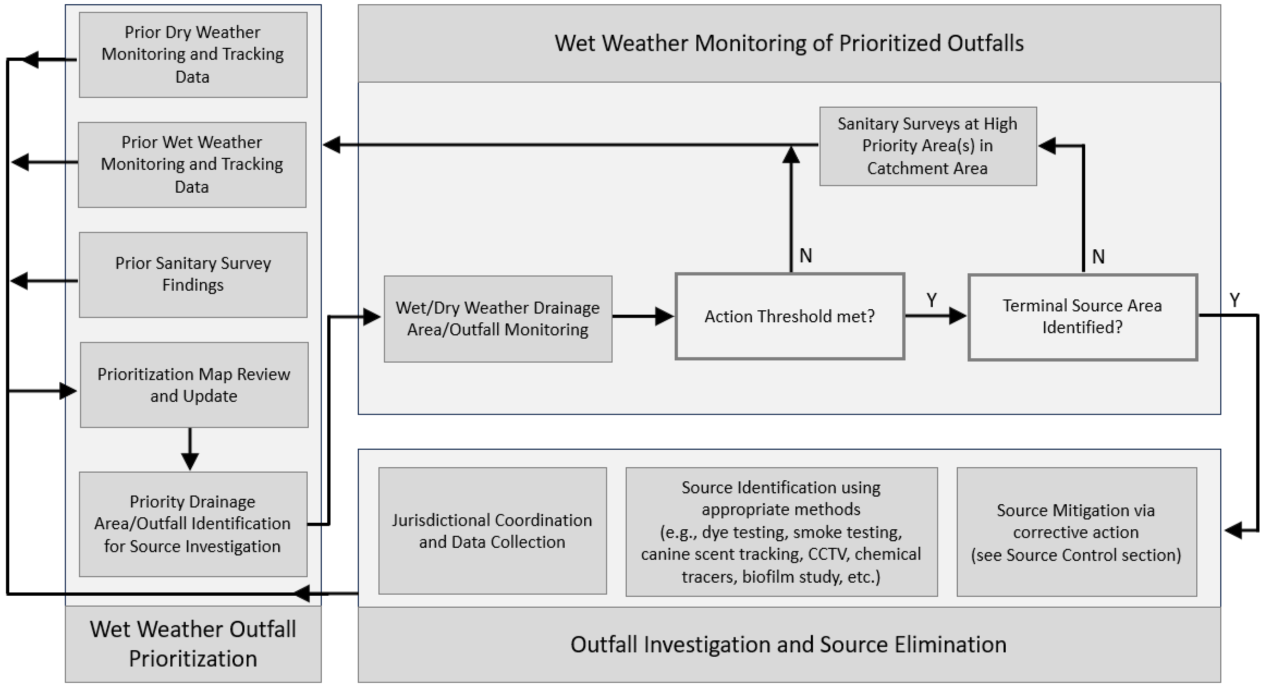


Figure 4. Wet Weather Workflow. Modified from “Source Investigation Final Report TSO 2019-0050 Task 3b” (Orange County MS4 and Newport Bay Watershed Permittees, 2023)

Other Approaches for Risk-Based Implementation

As discussed in the background section, traditional control measure implementation based on reducing FIB concentrations may or may not be effective in addressing risk from FIB sources. As noted above, source control strategies that are focused on addressing human fecal waste sources are often more effective as they directly address the source of the risk. However, the iterative and adaptive source control approach outlined in the previous section can be time and resource intensive and specific human fecal waste sources may be challenging to identify and abate. As a result, structural control measures may be a useful tool to consider as part of a risk-based implementation strategy.

For example, if human fecal waste is identified in nuisance flows or stormwater runoff, but the actual source cannot be identified or mitigated, flow diversion or implementation of a regional project to capture and treat high risk flows could be used after investigation efforts and attempts to eliminate sources are exhausted. A watershed approach employing projects to target multiple pollutants of concern, and located to address areas with the highest risk, also may be an efficient treatment strategy to improve water quality. The implementation of structural control measures may also offer additional benefits to communities such as improvement of the aging flood control infrastructure or supplementation of water supply.

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APPENDIX A
Expanded Rationale for a Risk-Based Implementation Approach

Background

Currently, the driver for implementation related to Fecal Indicator Bacteria (FIB) is based primarily on exceedances of FIB objectives. However, implementation actions designed to reduce FIB concentrations and loads to meet FIB objectives, do not necessarily reduce risk. The uncertainty regarding the ability of FIB targeted actions to address risk is due to the following factors:

1. Implementation actions have often been assessed for their ability to remove FIB concentrations or loads, but little data exists about their ability to remove pathogens, which are often viral and much smaller than bacteria (e.g., Rugh et al., 2022) and may result in reduced removal. FIB concentrations are indicators of pathogens, but pathogens (typically viruses) are the drivers of illness and risk.
2. Implementation actions to address FIB objective exceedances generally do not consider the source of FIB and may therefore be less effective in controlling human fecal waste sources of bacteria. For example, treatment of surface runoff would not address below ground sources of human fecal waste.
3. Implementation actions to address FIB objectives are typically not designed or located to prioritize capture of human fecal waste sources of bacteria. Instead, dictated by requirements to reduce FIB loading, implementation actions often target high FIB concentrations which are often caused by less risky sources of bacteria (e.g., trash and pet waste).

As a result of these factors, an implementation approach focused on reducing FIB concentrations without consideration of the source of the FIB and risk of those sources may not effectively reduce the risk, even if FIB concentrations and loads are reduced.

A risk-based approach differs from the traditional FIB-based approach in that consideration of human fecal waste and other high-risk sources will guide implementation strategies, which will result implementation actions to reduce identified human health risk rather than just FIB loading. This approach is expected to be more protective of public health during recreation and/or harvest activities and support more targeted and cost-effective implementation approaches for stormwater agencies.

Recognizing that some agencies may require additional background information and rationale to support implementing a risk-based approach, this attachment compiles available literature to support the reasons why actions targeted at FIB may not also address risk.

Reduction of Pathogens by Structural Control Measures

The stormwater capture control measures that reduce runoff volumes will also reduce loading of pollutants including bacteria and pathogens from urban runoff (Clary et al., 2020). Runoff volumes can be effectively reduced by capturing stormwater for retention and subsurface infiltration, or to some extent by diversion to wastewater treatment facilities. The challenge for other common control measures is that FIB and pathogens may persist outside of a warm-blooded host for extended periods of time. The nature-based processes for bacteria and pathogen removal are highly complex and difficult to mimic in the cities and other urbanized areas.

Typical Best Management Practice (BMP) types have been assessed for reduction of FIB; however additional research is needed to determine their effectiveness to reduce pathogens. The efficacy of passive structural controls for wet weather FIB load reduction in stormwater is highly variable by BMP type and FIB type, but the potential impact on BMP efficacy from the type of source (e.g., human vs. non-human), if any, is not yet understood (Clary et al., 2020).

Most BMP types are unable to consistently reduce bacteria concentrations to primary contact recreation receiving water standards, though some demonstrate statistically significant reductions of one or more types of FIB (i.e., E. coli, Enterococcus, and fecal coliform) including bioretention, media filters, retention (wet) ponds, wetland basins and detention ponds (Clary et al., 2020). However, green infrastructure (GI) retrofitting can only capture and treat, or infiltrate loads from a fraction of urban watersheds. The current scientific literature lacks pilot studies, even at a mini watershed scale, where GI has been deployed and either FIB standard attainment or pathogen reduction has been demonstrated.

Active treatment controls (e.g., low flow diversions to wastewater treatment facilities or with disinfection) are proven to reduce dry weather FIB concentrations at the point of treatment (Clary et al., 2020) and are typically selected when FIB concentrations cannot be controlled at the source in highly urbanized and developed areas where infiltration opportunities are not available. Diversions are more likely to address risk as all water is prevented from entering the waterbody, preventing the discharge of both FIB and pathogens, assuming pathogens are present. However, many discharges with high FIB concentrations have been shown to have little or no human fecal waste signals. The use of diversions is generally limited to dry weather low flows or possibly the initial part of a storm event (first flush). They are less likely to be able to be used as a strategy for wet weather discharges and may not be feasible in areas without nearby sewer infrastructure, with sewer capacity constraints, or requirements to maintain environmental flows.

Challenges with Addressing Riskier Sources Through Typical BMP Implementation Approaches that Do Not Consider the Source of FIB

Typical structural BMP implementation focuses on capturing the runoff from FIB sources present on land surfaces. However, except for illicit discharge/dumping and Sanitary Sewer Overflows (SSOs), these sources of FIB are often not associated with human fecal waste but are more likely to be associated with natural sources, pet waste, trash and wildlife, which pose a lower risk. Human fecal waste may also come from below ground sources such as leaking septic tanks and sewer infrastructure. **Table A-1** defines fecal sources based on their relationship to human activity and provides examples.

Table A-1. Sources of Human and Non-human Fecal Contamination in Receiving Waters

↑ Human Health Risk

Classification	Description	Source Examples
"Human fecal waste sources"	Human fecal waste only	Illegal discharges and dumping, illicit connections, leaks and overflows from sewage collection systems, vessel waste, unhoused encampments, failing septic systems
"Anthropogenic, Non-human sources"	A result of human activities, but not originating from the human body	Agricultural runoff, pet waste, landscaping manure and compost, trash related sources, commercial and industrial facilities
"Non-anthropogenic sources"	Independent of human activity	Wildlife, regrowth, naturalized sources in the environment (soil/sediment, beach wrack, vegetation, biofilms)

Figure A-1 shows the challenges with trying to address human fecal waste sources of FIB with typical structural BMP implementation. As shown in the figure, green infrastructure will typically only capture bacteria sources that are on the land surface. While some of the sources present on the land surface, such as unhoused encampments and illegal dumping, may contain human fecal waste sources, non-human fecal waste sources of bacteria are likely to predominate. Many of the most likely sources of human fecal waste occur below ground. Regional projects have more potential to capture the below ground sources such as leaking wastewater infrastructure, as long as they are located downstream of those sources and designed in a way that has a higher likelihood of treating or capturing the sources. If the locations and design of regional projects are selected without consideration of the sources of the bacteria, they may not capture or address below ground sources.

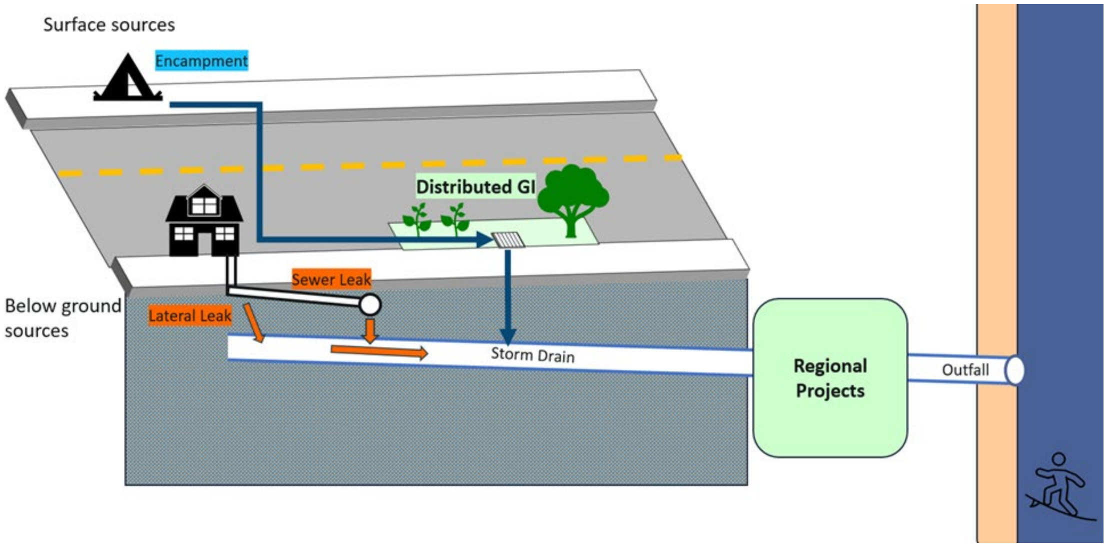

Figure A-1. Conceptual Diagram of the Relationship between Typical Structural BMP Implementation and Locations of Human fecal waste Sources (e.g., Lateral Leak, Sewer Leak, Encampment).

Support for Focusing on Risk Rather than FIB Concentrations in Implementation

According to the cost-benefit analysis conducted for the San Diego Region in 2017, human fecal waste source control is the most cost-effective strategy to address risk and increase recreational opportunities following rain events, measured as avoided illnesses (or additional beach days) per million dollars (San Diego Region CBA Steering Committee, 2017). This study compared multiple implementation strategies for managing FIB including compliance schedule changes, stream restoration improvements, and the prioritization of human fecal waste sources. Each was compared to default BMP strategies identified in Water Quality Improvement Plans (WQIPs) which target bacteria reductions in stormwater and dry weather runoff to achieve wet weather TMDL compliance. Human sources were categorized into high, medium, and low priority for treatment based on storm drain/stream distance, soil types, pipe diameter, and sanitary sewer pipe age. The high priority human sources had the highest soil permeability, smallest sanitary sewer pipe diameter, oldest pipe age, and were closest to storm drains/streams. As shown in **Figure A-2** and **Figure A-3,** over the 65-year analysis period, per $1 million invested, high priority human fecal waste control strategies avoided 994 infectious illnesses and gained 6,513 additional beach days, as compared to 44 and 604 for default WQIP BMP strategies, respectively. For human fecal waste controls that include high, medium, and low priority sites, avoided illnesses per $1 million spent was considerably greater than all other scenarios. Overall, a risk-based prioritization approach to address fecal contamination provides more risk-reduction per dollar spent than traditional methods.

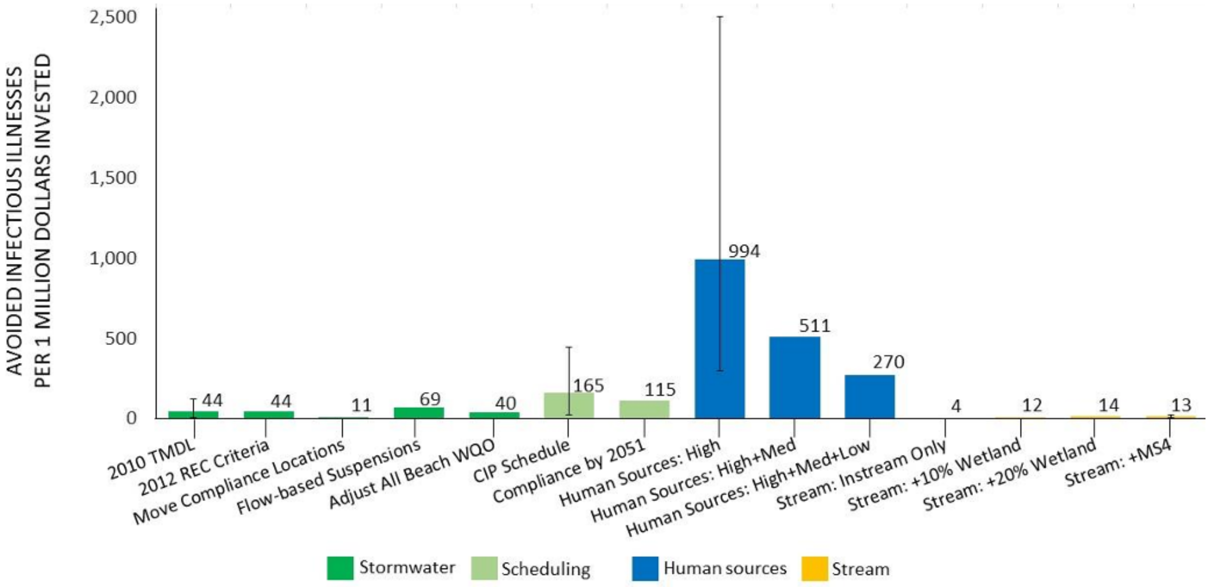

Figure A-2. Public Health Cost-effectiveness by Implementation Approach: Infectious Illnesses Avoided through 65-year Analysis Period per Million Dollars Invested. Reprinted from "Cost-Benefit Analysis San Diego Region Bacteria Total Maximum Daily Loads" (San Diego Region CBA Steering Committee, 2017).

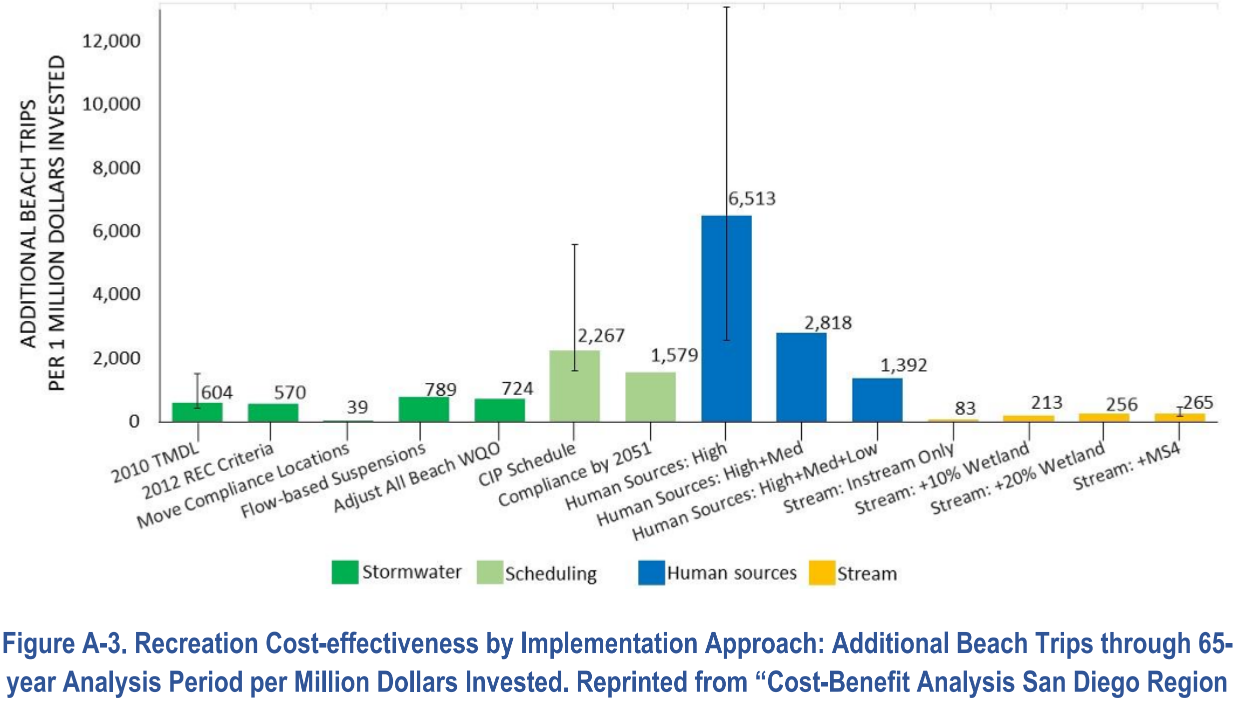

Figure A-3. Recreation Cost-effectiveness by Implementation Approach: Additional Beach Trips through 65-year Analysis Period per Million Dollars Invested. Reprinted from "Cost-Benefit Analysis San Diego Region Bacteria Total Maximum Daily Loads" (San Diego Region CBA Steering Committee, 2017).

References

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