NEW ENGLAND WATER ENVIRONMENT ASSOCIATION
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WORKING FOR WATER QUALITY

Geosyntec consultants

Evaluating Urban Water Quality in Boston's MS4

January 23, 2018

Boston Water and Sewer Comission

CDW

SC
UNIVERSITY OF NEW HAMPSHIRE
STORMWATER CENTER

Source Molecular
Leader in Microbial Source Tracking

THE UNIVERSITY OF ALABAMA

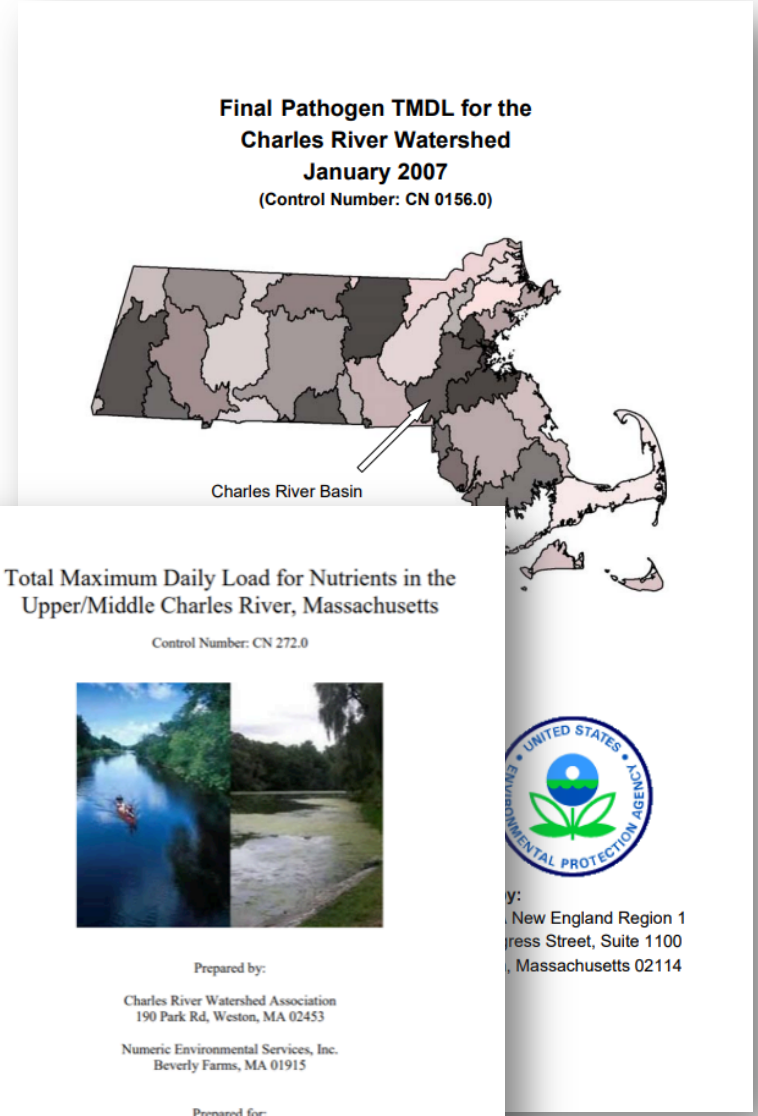
UCSB

Outline

- What was the motivation for this project?
- What is Microbial Source Tracking (MST)?
- What are the available tools for MST?
- How did we use these tools in Boston?
- What did we learn?
- How can we use the results to improve how we do IDDE?

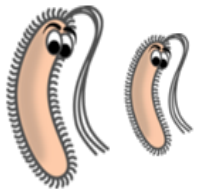
Project Impetus

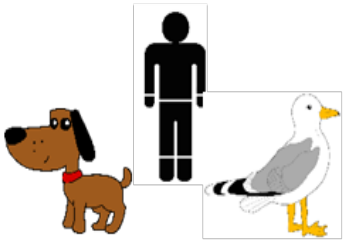
- High levels of fecal indicator bacteria and nutrients, have prompted "impaired" status designations and associated TMDLs
- To address this (and other MS4 permit requirements), the BWSC implements an IDDE program
- Having implemented rigorous and methodical IDDE procedures for ~30 years and *still finding high FIB at outfalls*, BWSC is now at a state of program maturity such that they have sought to test more sensitive and specific methods to identify remaining illicit sewage discharges into their MS4

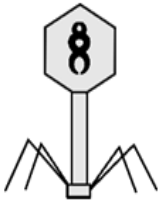


Fecal Indicator Presumptive Linkages

State of the science for fecal source determination







Fecal Indicator Bacteria (FIB) have been linked to an increased occurrence of gastrointestinal illness, however this linkage may not be appropriate for non-sewage impacted waters

<u>How to measure each step in this linkage:</u>

Culturable FIB	**Fecal DNA Markers (MST)**	Direct pathogen enumeration (needed for **QMRA**)	Epidemiology studies

Common Sources of FIB in Urban Stormwater ^ and Nutrients!

Primary below-ground targets for many IDDE programs

Common Human Waste Sources

- Sanitary Sewer Overflows (SSOs)
- Leaky Sewer Pipes (Exfiltration)
- Illicit Connections to MS4
- Leaky or Failing Septic Systems
- Porta-Potties
- Bathers and Open Defecation
- Boats and RVs
- Dumpsters and Trash Cans
- Garbage Trucks
- Illegal Dumping
- Illegal Discharges
- Gray Water Discharges

Common Non-Human Sources Related to Human Activities

- Pets (Dogs, Cats, etc.)
- Livestock (Horses, Cows, etc.)
- Rodents (Mice, Rats, etc.)
- Dumpsters and Trash Cans
- Garbage Trucks
- Animal Manure/Compost
- Washwater
- Green Waste
- Litter
- Grease Bins/Traps
- Irrigation Runoff

Common Non-Human Sources Independent of Human Activity

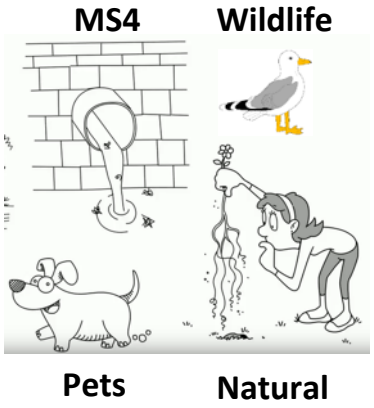
- Birds (Geese, Gulls, Pigeons, etc.)
- Wildlife (Raccoons, Birds, Deer, Coyote, etc.)
- Non-Fecal Sources:
  - Decaying Plants
  - Algae and Biofilms
  - Soil/Sediment

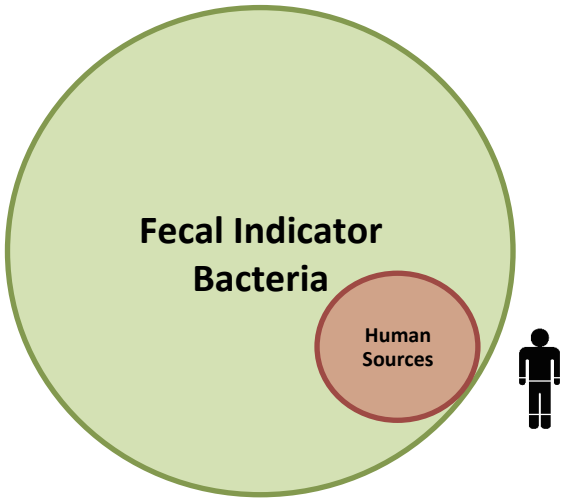
Non-fecal environmental sources may comprise a significant portion of FIB during wet weather!

References: ASCE *Pathogens in Urban Stormwater Systems*, and *Colorado E. coli Toolbox*

Bacteria (and Nutrient) Sources

In general, where contributions from human waste (e.g., sewer leaks, illicit connections, etc.) are small, the primary **sources of FIB and human waste markers differ**, so control strategies SHOULD differ too!





Recreational **illness risks vary by source**, so some sources are more important to control than others.

Similar issues for phosphorus bioavailability and contribution to eutrophication.

What is Microbial Source Tracking?

- MST is a systematic approach to identifying sources of fecal contamination
- MST utilizes multiple tools including:
  - conventional methods (e.g., ammonia, CCTV, dye testing) that have been used to identify illicit discharges for the past 20+ years
  - laboratory methods that **measure DNA specific to humans and other animals** (also known as “markers”)

Microbial Source Tracking

WHAT IS MICROBIAL SOURCE TRACKING?

Microbial source tracking (MST) is a systematic approach to identifying and locating sources of fecal contamination in urban waters. MST utilizes multiple tools including conventional methods (e.g., ammonia, CCTV, dye testing) that have been used to identify illicit discharges for the past 20+ years, as well as more recently developed laboratory methods that measure DNA specific to humans and other animals (also known as “markers”). By performing MST, potential waste sources are systematically tested and investigated to identify and locate the origin of fecal bacteria in contaminated waters.

MST is the most reliable means of identifying and locating sources of fecal waste

WHY DOES THE SOURCE OF FECAL BACTERIA MATTER?

Elevated levels of fecal indicator bacteria (FIB), including *E. coli* and *Enterococcus*, are one of the most common causes of water quality impairment in surface waters across the United States. FIB may originate from a variety of human and non-human sources, as well as non-fecal sources; however, these sources often cannot be distinguished using conventional methods and thus cannot be effectively controlled through management actions.

The health risk associated with exposure to water containing human waste is much greater than that of most non-human sources. Therefore, identifying the source(s) of fecal contamination (human versus non-human) in waters with elevated FIB is of critical importance to meet recreational water quality criteria and reduce human health risk. An MST investigation is often the most reliable means of distinguishing these sources.

Common Human Waste Sources
- Sanitary Sewer Overflows (SSOs)
- Leaky Sewer Pipes (Exfiltration)
- Illicit Connections to MS4
- Leaky or Failing Septic Systems
- Porta-Potties
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IDDE and Source Tracking Tools

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Outfall Screening
GIS
FIB
Basic Chemical Indicators
Canine Scent Tracking

$$

Dye Testing
Closed-Circuit Television

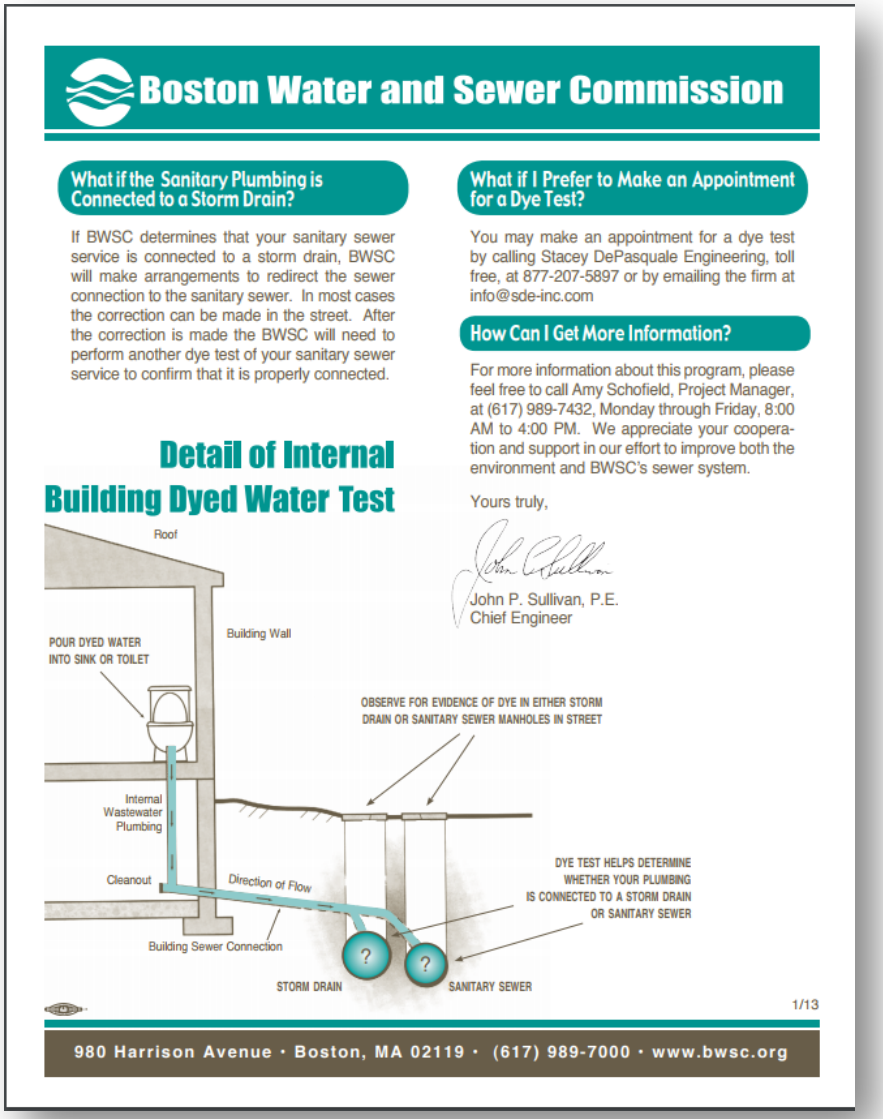
$$$

Advanced Chemical Indicators (PPCPs)
Human DNA Markers
Non-Human DNA Markers

Most sensitive and specific tool for quantifying magnitude of human waste in all water types (e.g., MS4 network or outfalls, surface receiving waters, and groundwater).

BWSC's IDDE Program

- BWSC has been doing IDDE since late 1980's
- Since 2000
  - 10,000 manholes investigated
  - Corrected > 1,700 illicit connections
  - Removed > 800,000 GPD of sewage



Boston Water and Sewer Commission

What if the Sanitary Plumbing is Connected to a Storm Drain?

If BWSC determines that your sanitary sewer service is connected to a storm drain, BWSC will make arrangements to redirect the sewer connection to the sanitary sewer. In most cases the correction can be made in the street. After the correction is made the BWSC will need to perform another dye test of your sanitary sewer service to confirm that it is properly connected.

What if I Prefer to Make an Appointment for a Dye Test?

You may make an appointment for a dye test by calling Stacey DePasquale Engineering, toll free, at 877-207-5897 or by emailing the firm at info@sde-inc.com

How Can I Get More Information?

For more information about this program, please feel free to call Amy Schofield, Project Manager, at (617) 989-7432, Monday through Friday, 8:00 AM to 4:00 PM. We appreciate your cooperation and support in our effort to improve both the environment and BWSC's sewer system.

Yours truly,

John P. Sullivan, P.E.
Chief Engineer

Detail of Internal Building Dyed Water Test

1/13

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BWSC's IDDE Program

- Outfall prioritization based on FIB outfall screening

Bacteria	Priority 2	Priority 3	Priority 4
E. coli (CFU/100mL)	>10,000	1,000 - 10,000	<1,000
Enterococci (CFU/100mL)	>5,000	500 - 5,000	<500

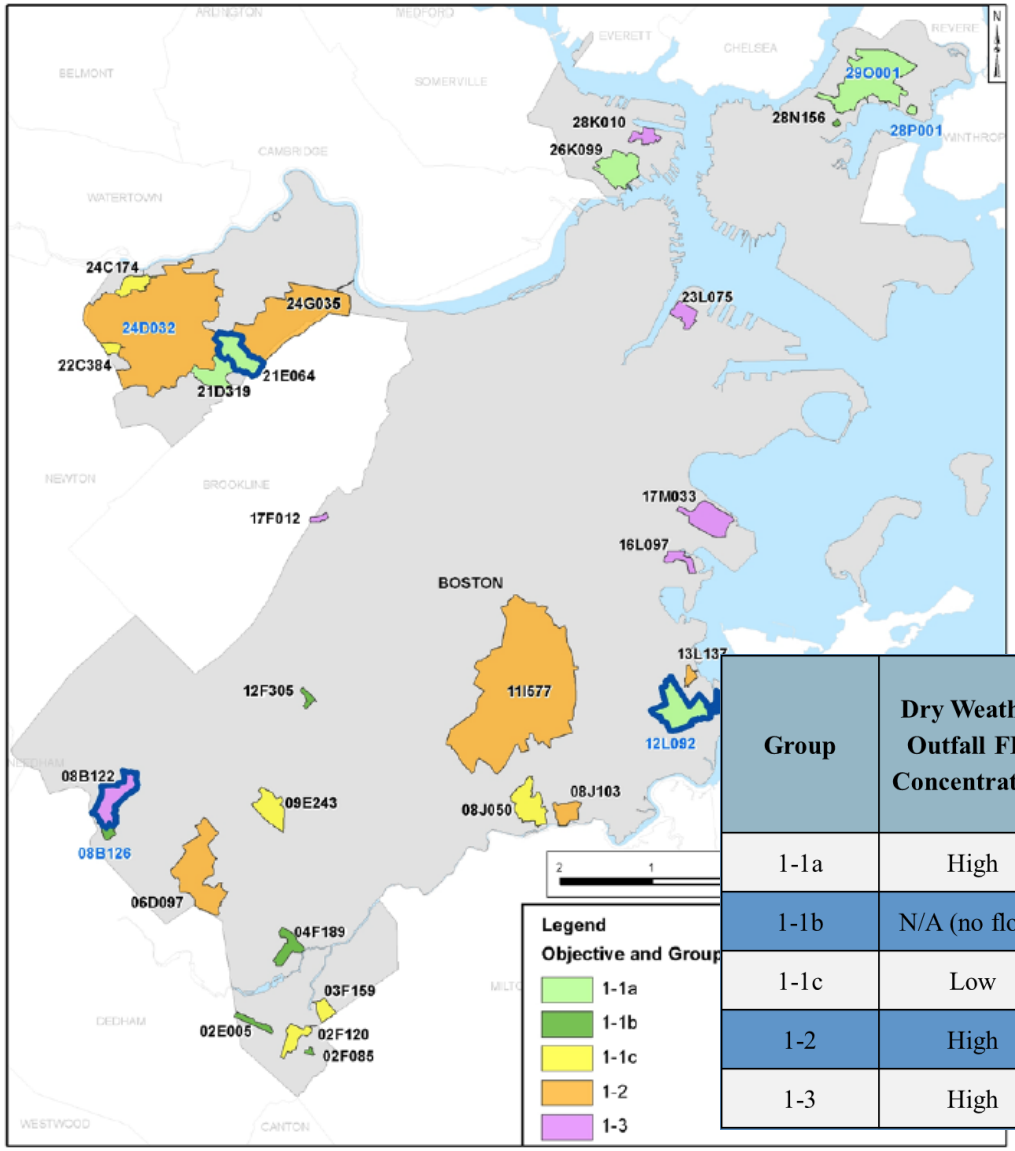
- In-network program utilizes Field Test Kits for ammonia, chlorine and surfactants
  - Quick
  - Easy
  - Inexpensive
  - Immediate results

Project Objectives

Human DNA Markers were used to:

- **Objective 1:**
  - Determine whether elevated FIB concentrations (and P) at representative outfalls are due to human fecal contamination or non-human sources
- **Objective 2:**
  - Evaluate the relative contribution of FIB and P to the MS4 from various sources, particularly during wet weather

Sampling Location Overview



A total of 378 samples were collected from 35 outfalls throughout Boston over a 1-year period. Sampling locations represented a mixture of drainage areas, land usage, and stages of IDDE implementation.

Group	Dry Weather Outfall FIB Concentration	Wet Weather Outfall FIB Concentration	Status of IDDE Investigation	Status of Corrective Actions	Sampling Condition
1-1a	High	Not Sampled	Complete	Complete	Dry
1-1b	N/A (no flow)	High	Complete	Complete	Wet
1-1c	Low	High	Complete	Complete	Wet
1-2	High	Not Sampled	Complete	Not Complete	Dry
1-3	High	Not Sampled	Not Complete	Not Complete	Dry

Analysis Summary

- Dry and Wet weather event samples
  - **FIB (*E. coli* and Enterococcus)**
  - **Phosphorous (total and dissolved)**
  - Total Suspended Solids
  - Field Parameters (salinity, conductivity, pH & temperature)
  - **Human DNA markers**
  - **Field test kits (Ammonia, Surfactants & Total Residual Chlorine)**
  - Catch basin sediment FIB and Phosphorus results (dry events)
  - Catch basin surface runoff FIB and Phosphorus results (wet events)
  - **PPCPs**
  - **Animal DNA Markers**
  - Community analysis results (UNH)

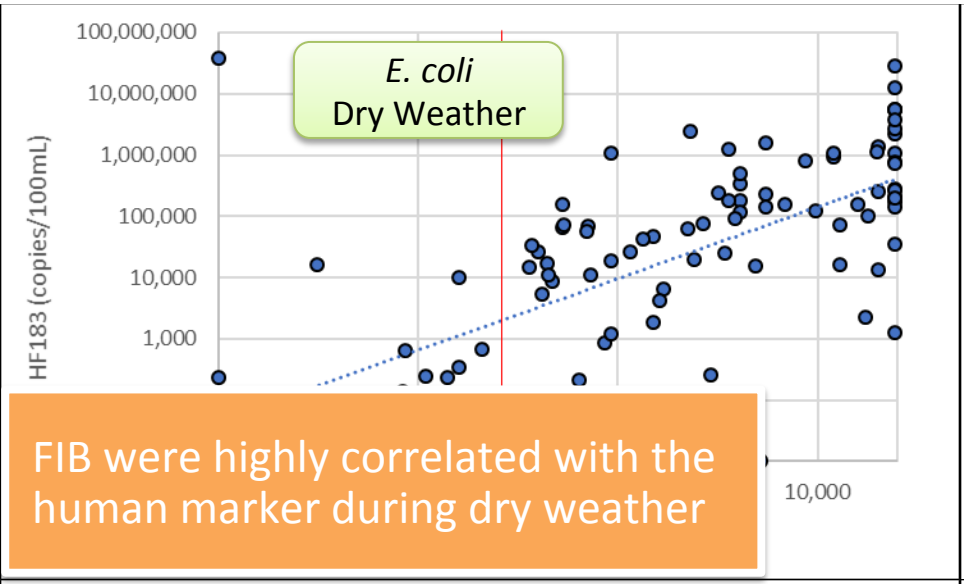
Did we achieve our project goals?

What did we learn?

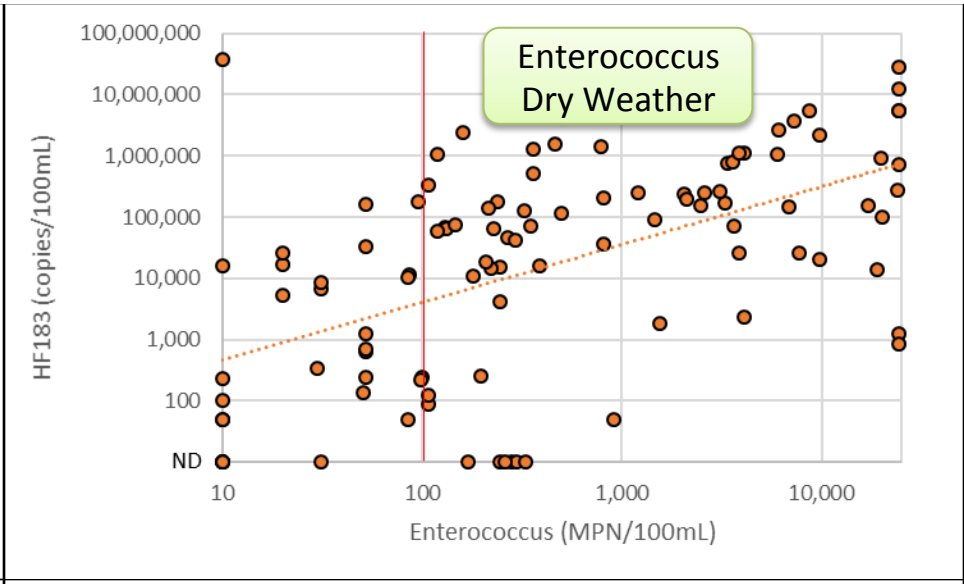
Overall Project Goals

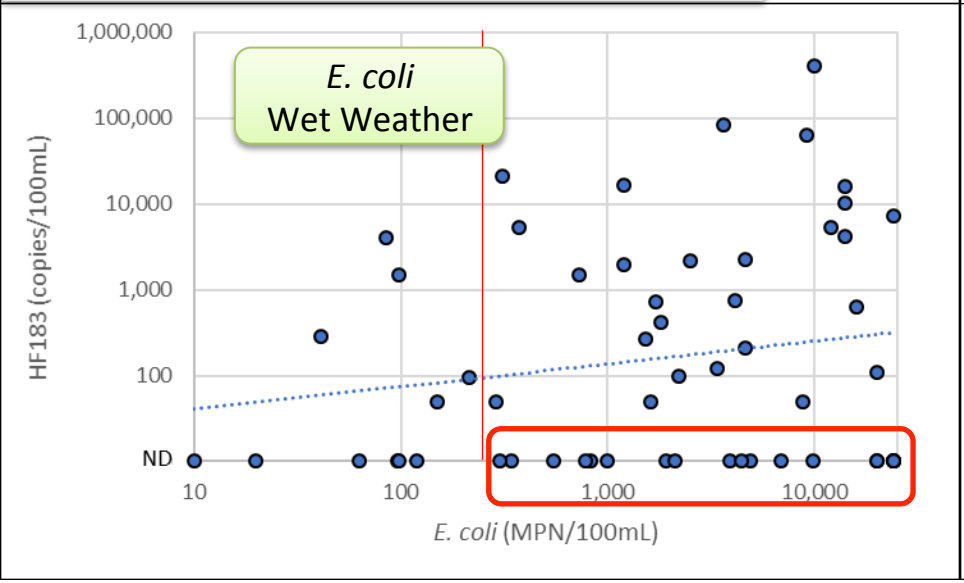
- Explore the use and effectiveness of alternative parameters and methods for determining whether bacteria in storm drains and outfalls may be from non-human sources
  - FIB's reliability was confirmed for indicating sewage presence in dry weather flows
  - DNA markers are preferable over PPCPs as "advanced" alternative parameters for indicating human waste

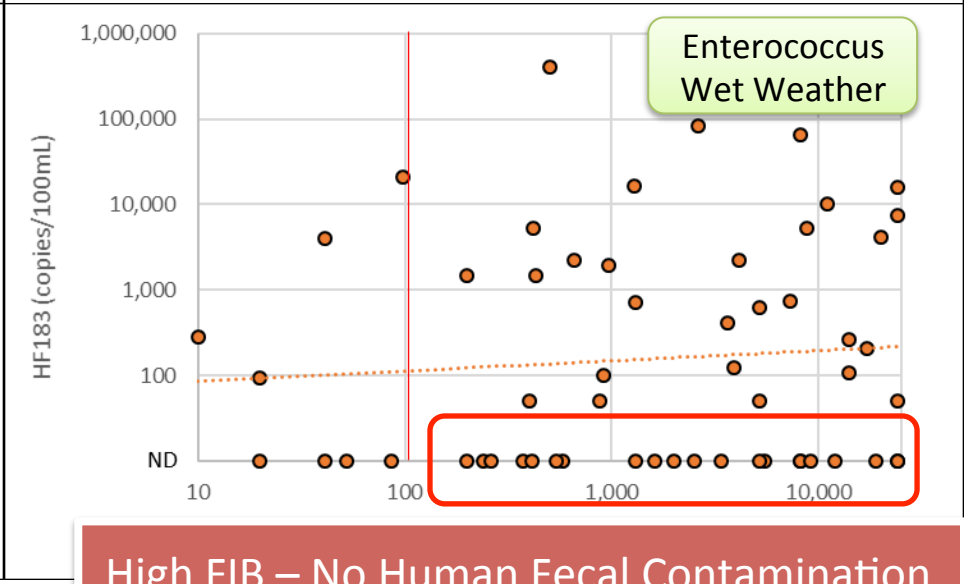
FIB vs. Human Marker (HF183)



FIB were highly correlated with the human marker during dry weather

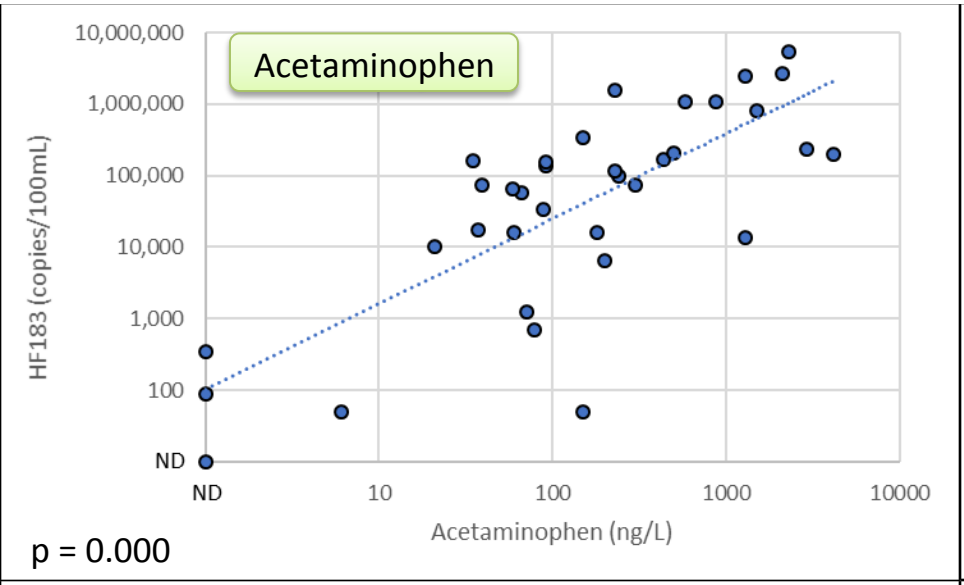




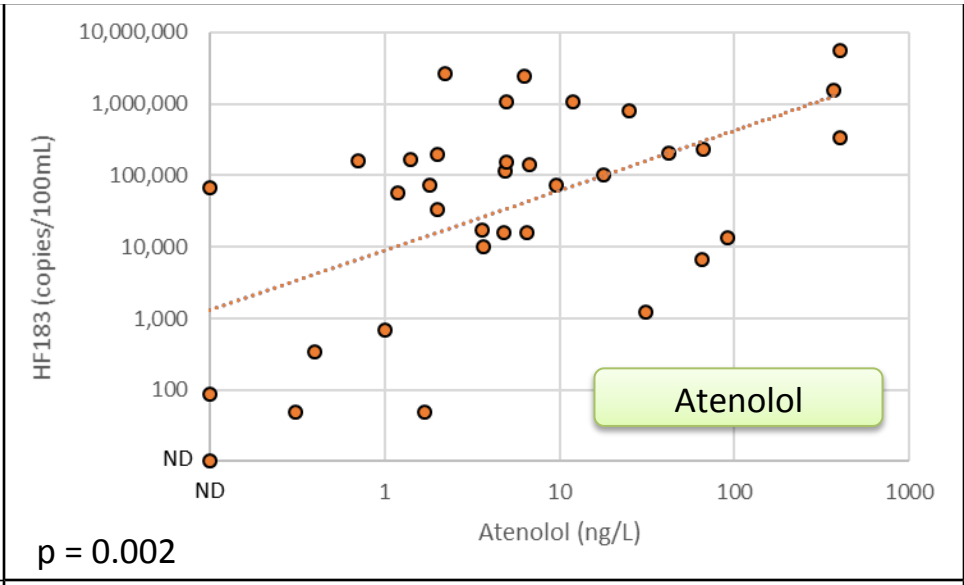


High FIB – No Human Fecal Contamination

PPCPs vs HF183 (dry weather outfalls)



p = 0.000



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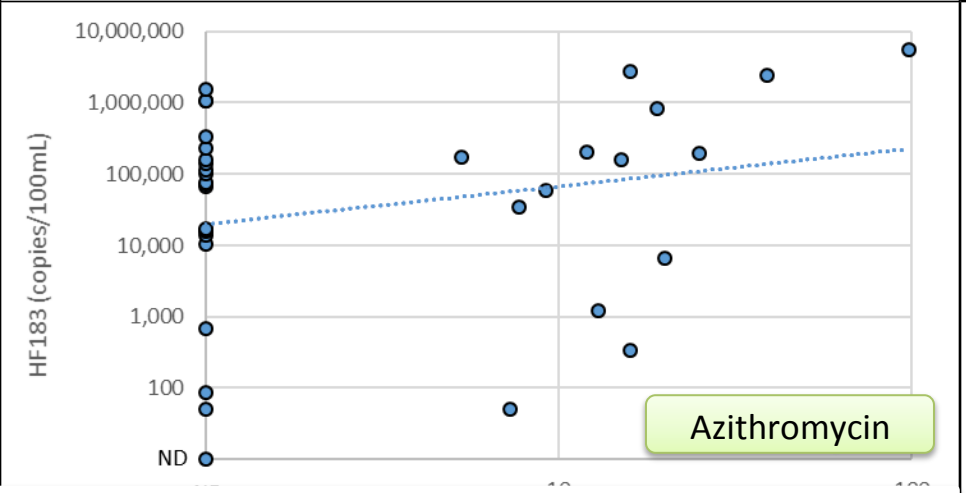
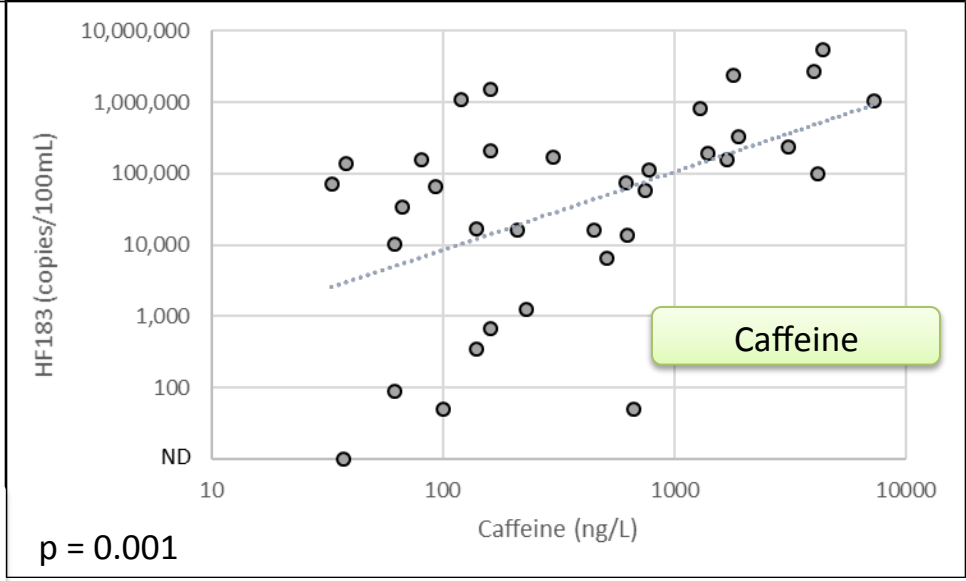




p = 0.001

A subset of PPCPs (acetaminophen, atenolol, and caffeine) were correlated with the human marker in dry weather

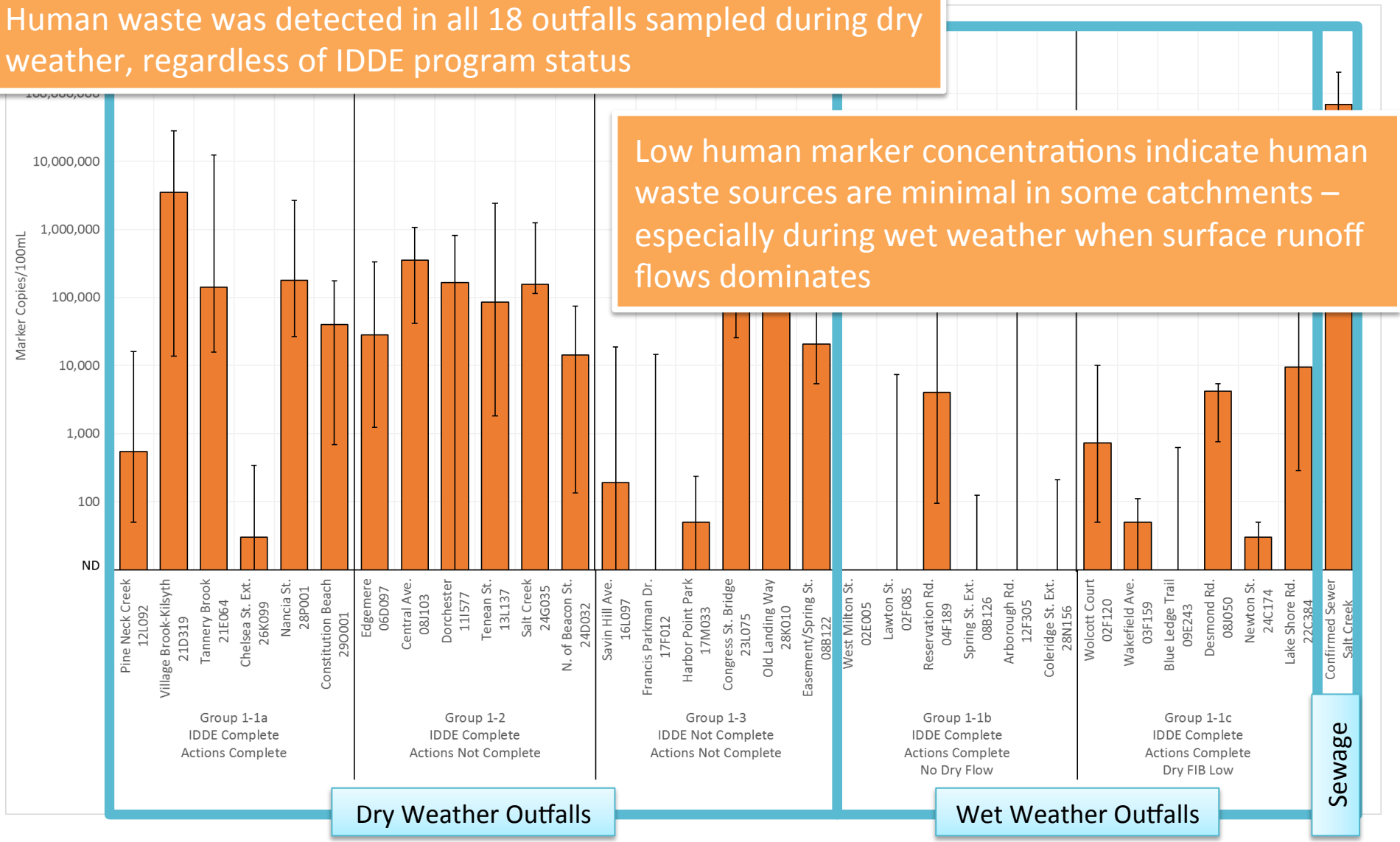
Overall Project Goals

- Determine where and to what extent non-human sources of bacteria and phosphorus may be contributing to contamination in the MS4
  - Human waste markers were measured at most sub-catchments tested during dry weather, even where IDDE and corrective actions has been completed
  - Human marker levels were low at several outfalls

Human Waste

Human waste was detected in all 18 outfalls sampled during dry weather, regardless of IDDE program status

Low human marker concentrations indicate human waste sources are minimal in some catchments – especially during wet weather when surface runoff flows dominates

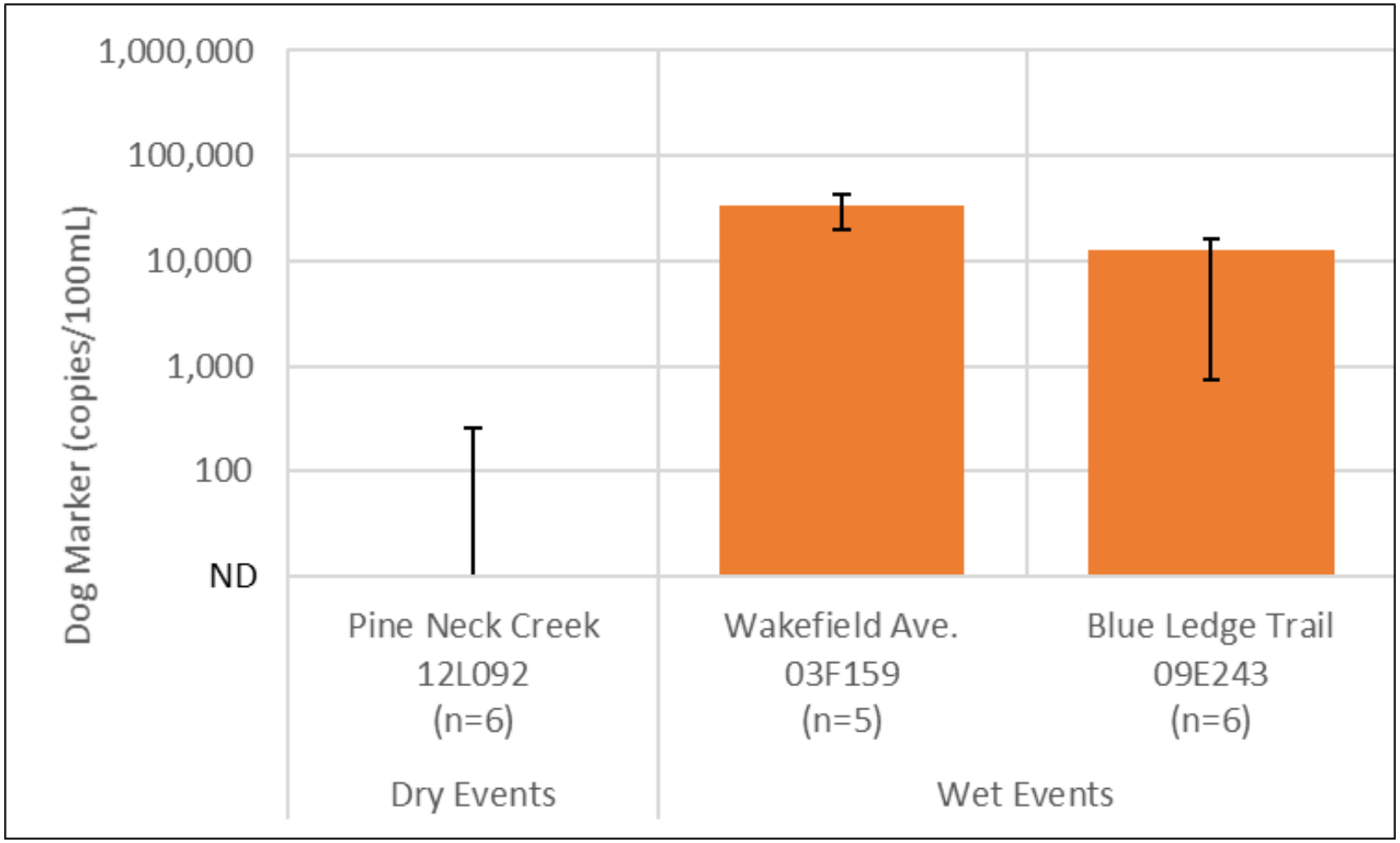


Overall Project Goals

- Determine where and to what extent non-human sources of bacteria and phosphorus may be contributing to contamination in the MS4 (cont.)
  - During wet weather, lower human marker and higher non-human (dog, not geese) marker concentrations were measured.
    - This explains the limited utility of FIB (for indicating sewage) during wet weather

Non-Human Waste

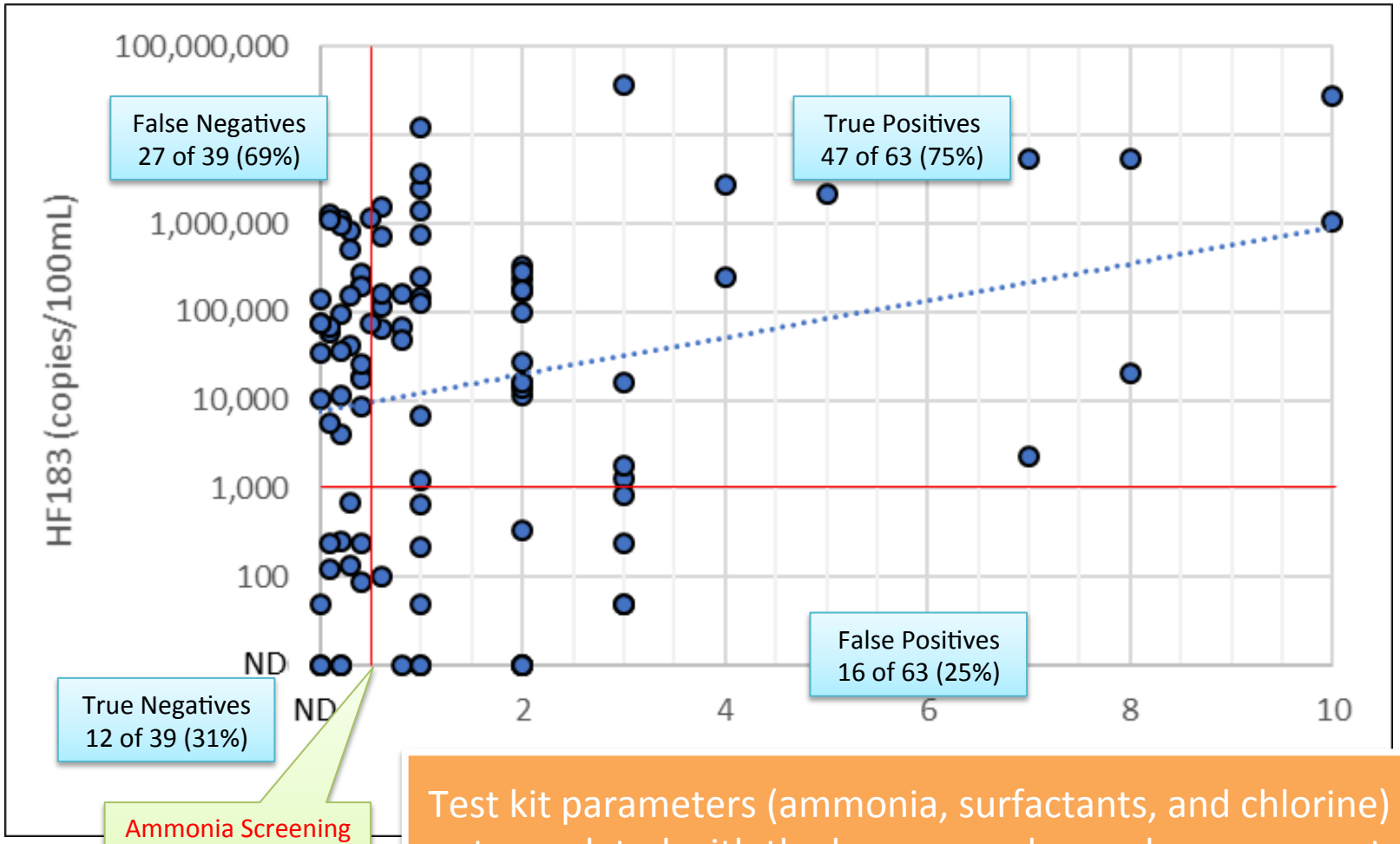
Dog waste was a source of FIB to the three outfalls investigated (particularly during wet weather)



Overall Project Goals

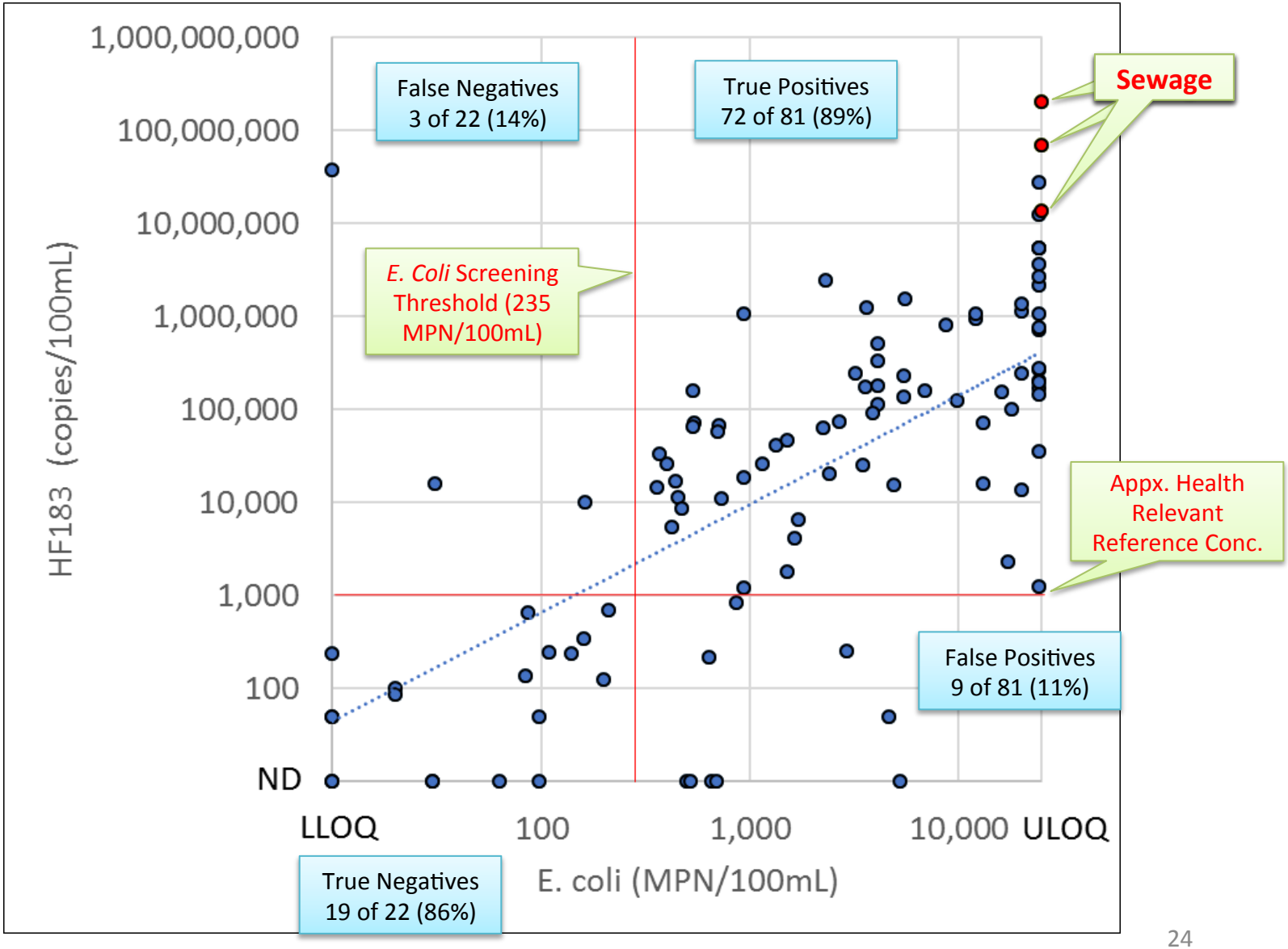
- Aid the Commission in prioritizing where (and how) future illicit discharge investigations should be directed (i.e., where human waste is present)
  - Where? Sub-catchments with dry weather flow and elevated (dry weather) FIB.
  - How? Pilot test recommended alternative network investigation procedures, which include using FIB along with CCTV and dye testing with fluorometers.

Ammonia vs HF183 (dry weather outfalls)



Test kit parameters (ammonia, surfactants, and chlorine) were not correlated with the human marker and were prone to false negative and false positive results at outfalls

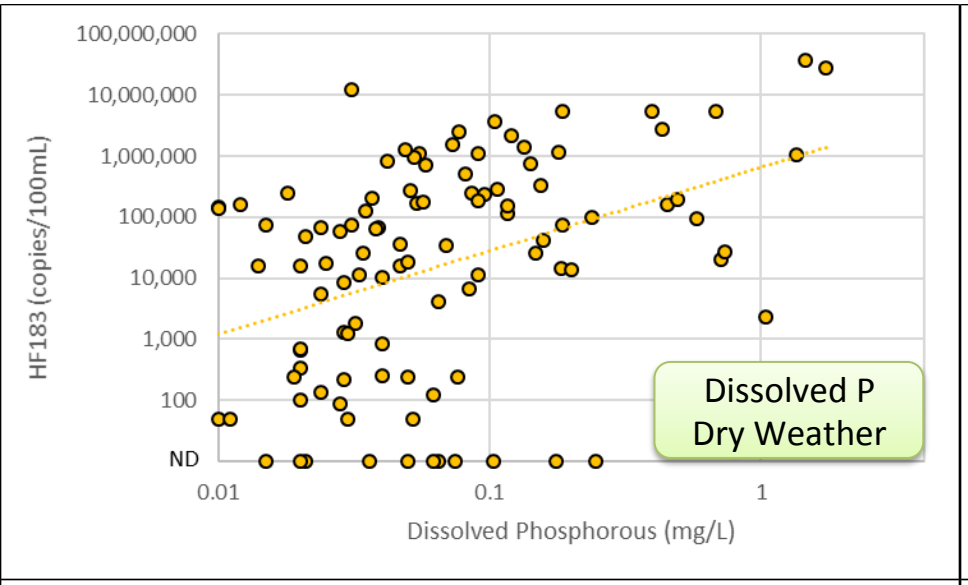
E. coli vs. HF183 (dry weather outfalls)

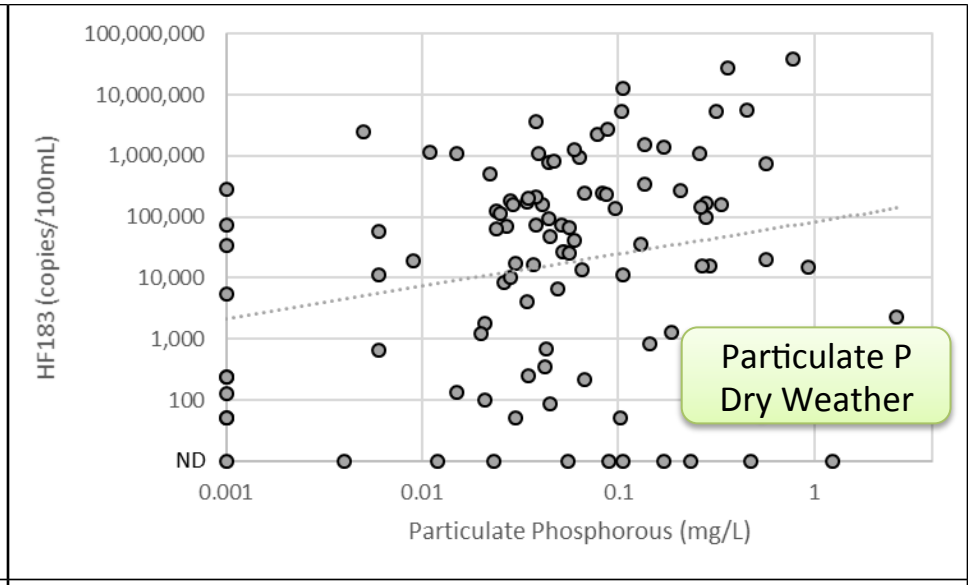


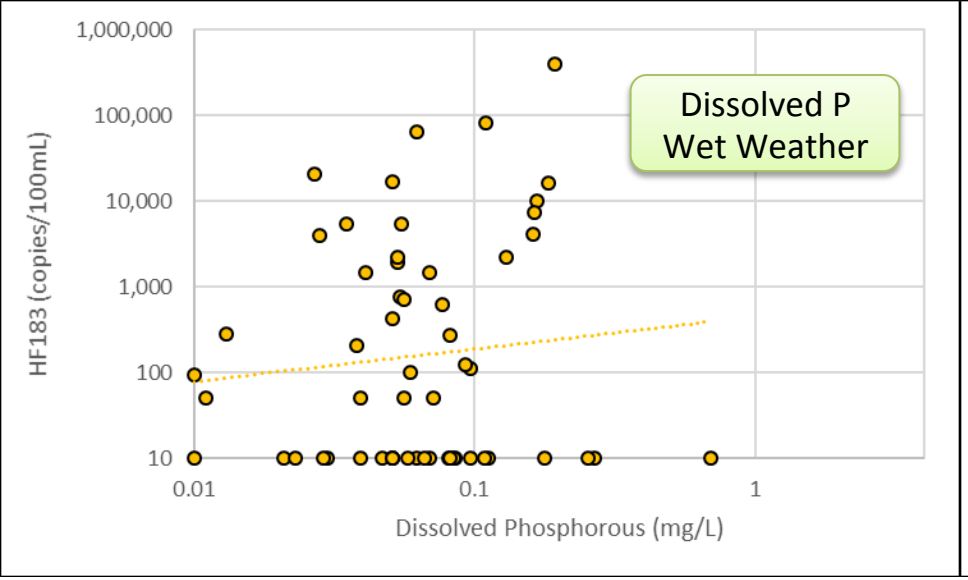
Major Project Finding

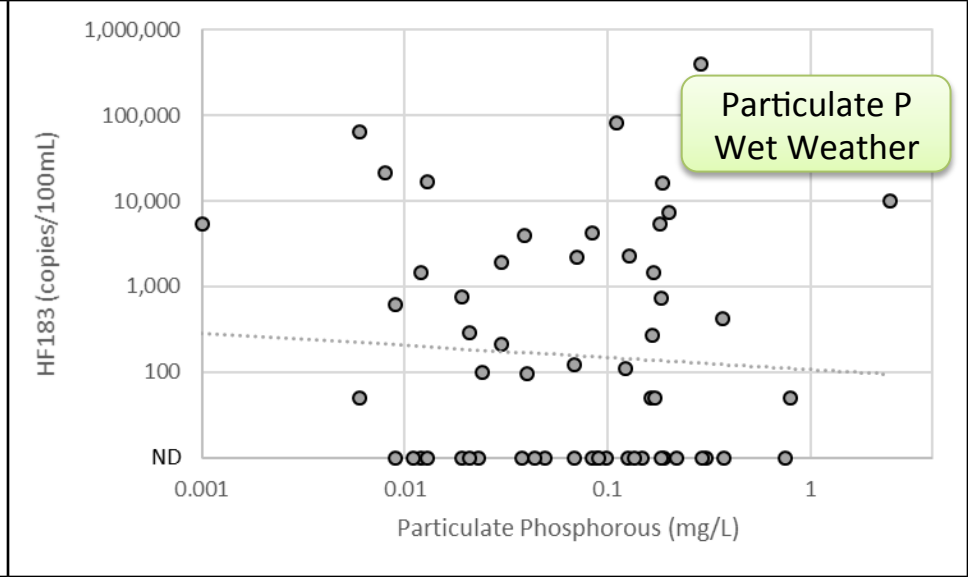
Human waste was a significant source of TMDL pollutants (FIB and phosphorous) in MS4 discharges during dry weather, while non-human sources were more significant during wet weather

Phosphorous vs HF183 (outfall correlations)









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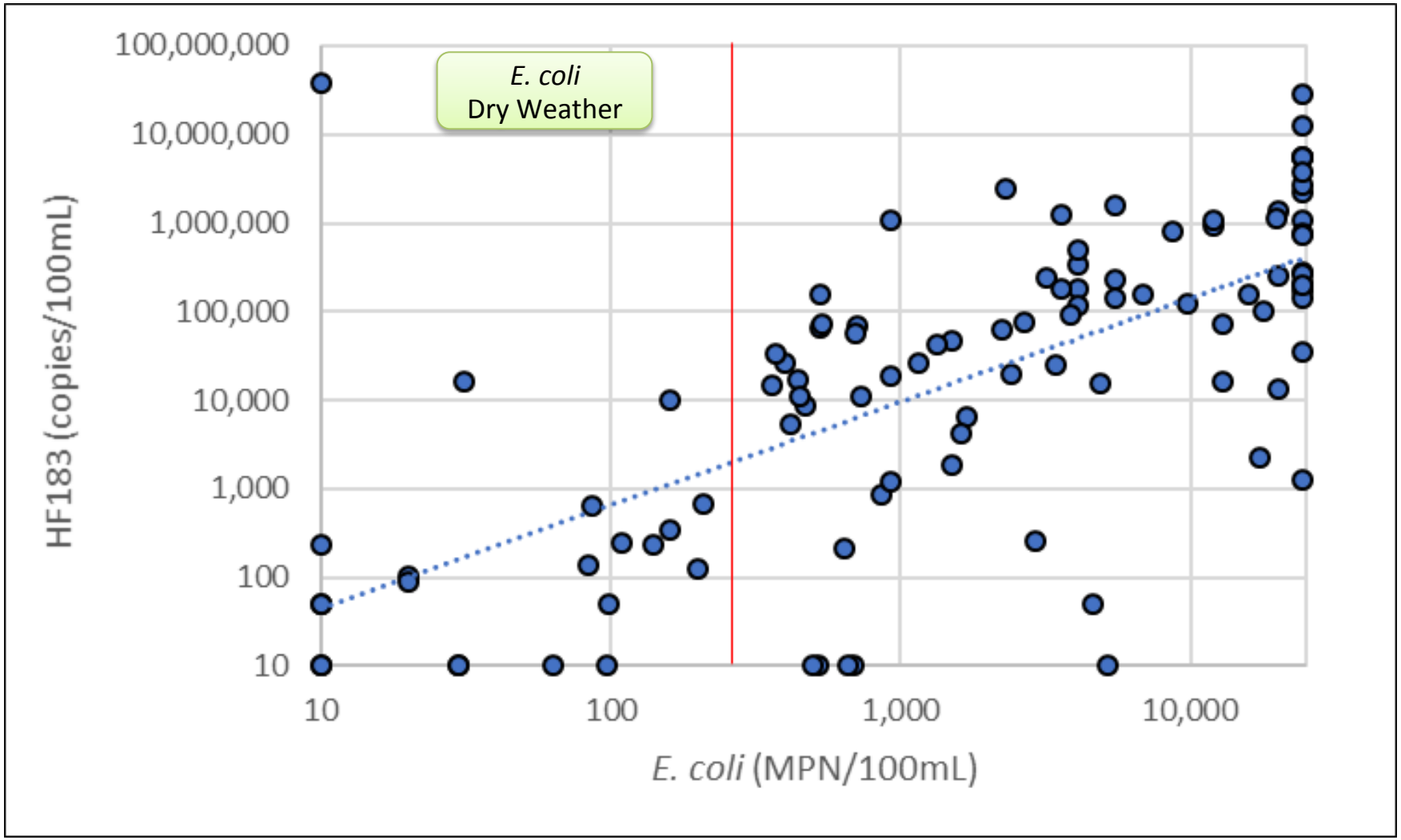


Overall Project Findings

- Human waste sources remain in many BWSC sub-catchments
- Use of alternative network investigation procedures could more efficiently locate the remaining sewage discharges
  - Pilot testing could confirm this
- Dry weather discharges containing human waste are a significant source of *TMDL pollutants*
  - Suggests low hanging fruit remains for achieving progress toward TMDL load reduction
- Elimination of remaining *human waste* can yield greater benefit in terms of illness risk and bioavailable phosphorous reduction than wet weather controls (e.g., GI)

Recommendations

How can we use these results to improve IDDE?

Bacteria and Nutrient Source Tracking Tools

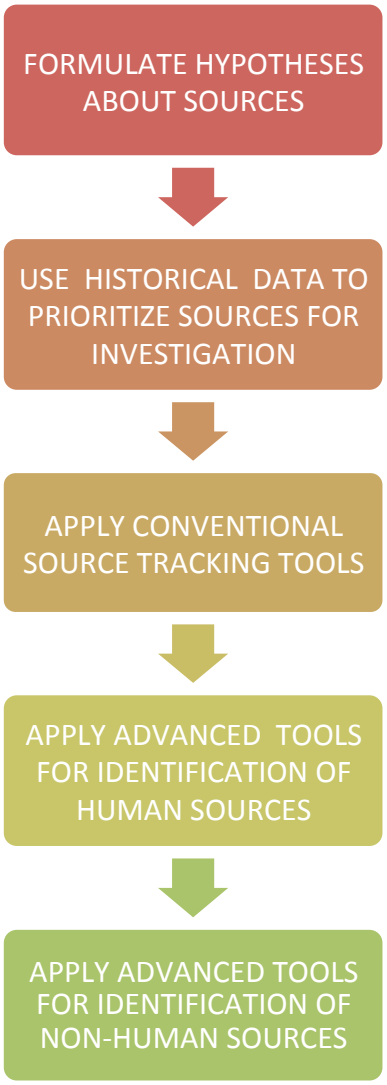
When to use each for advanced IDDE in MS4s

Tool	Reliable for Outfall Screening/ Prioritization?	Reliable for Network Investigation (Upstream of Priority Outfalls)?	Sensitivity for human waste?	Specificity to human waste?	Cost
Visual Surveys, Odors	As a start	YES (for bounding dry flows)	VERY LOW	VERY LOW	$
GIS		YES (for locating "at risk" crossings)			$/$$
FIB	Dry weather only, when sewage sources remain	Dry weather only, when sewage sources remain	LOW	LOW	$/$$
Basic Chemical Indicators (Test Kits)	Not really	More evaluation needed	LOW	LOW	$
Canine Scent Tracking	Not rigorously tested	Not rigorously tested	MEDIUM	MEDIUM	$/$$
Dye Testing		YES (especially w/ fluorometer)			$/$$
CCTV		YES (in MS4 not sewer)			$$
Advanced Chemical Indicators (PPCPs)	Possibly	Possibly	**HIGH (for some)**	**HIGH (for some)**	**$$$**
Human Markers	**YES**	**YES (targeted)**	**HIGH**	**HIGH**	**$$$**
Non-Human Markers					**$$$**
Stable Isotopes					**$$$**

Definitions: "sensitivity" refers to ability to detect low concentrations of waste
"specificity" refers to ability to differentiate human waste vs non-human

Recommendations for Advanced, Sewage-Focused IDDE and MST

1. Forget **PPCPs** – too high cost for limited accuracy
   - Though potentially useful for septic/groundwater studies (more mobile and conservative than human marker)
2. *Comprehensively* weigh **cost vs benefit**
   - FIB cost might be 10x test kits, and human marker might be 10x FIB, but also consider cost of false positives (investigating for illicit discharges that aren't there) and false negatives (missing ones that are there)
   - Confirm test kits and FIB accuracy through local human marker sampling
3. For **outfall prioritization**, use FIB for dry weather only
   - Wet weather mobilizes too many watershed sources for FIB to be indicative of human waste
4. For **network investigations** to locate sewage inputs, consider piloting new procedures:
   - Visual survey of outfalls and manholes to bound flowing segments
   - GIS to compare sewer-MS4 invert elevations and proximity
   - FIB sampling at key nodes (if FIB proven accurate)
   - CCTV flowing segments, with GIS maps in hand
   - Sewer dye testing (with fluorometers) where FIB elevated and CCTV indicates source of unknown flow
5. For proper study design tips, consult available guidance



Tiered Source Tracking Approach (adapted from Griffith, 2013)

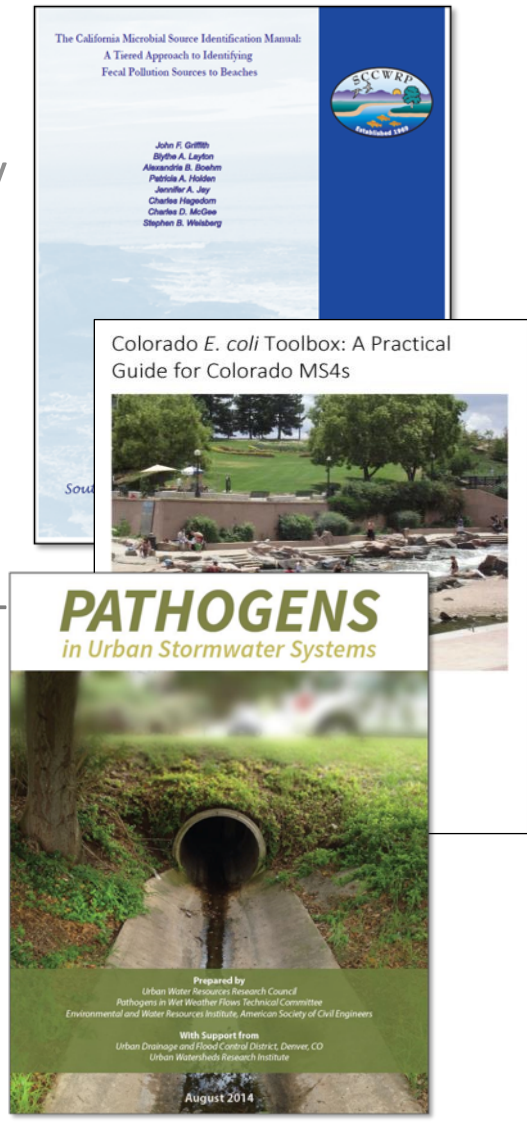
Recommendations for Advanced, Sewage-Focused IDDE and MST

6. Worry about **wet weather** only after completing dry weather program
   - But ask questions first: What is the expected benefit, or what hypothesized additional sources would this catch?
   - Challenge: wet weather introduces watershed-wide land surface sources and eliminates utility of FIB, meaning entire investigation (outfalls, networks) may need to rely on higher cost human marker
   - Wet weather can dilute markers, making signals lower (harder to chase)
7. When using **human DNA markers**, use validated lab, adhere to QAQC best practices, and involve an expert experienced with MST sampling design and results interpretation (and discussion with regulators)
   - Despite high interest in **non-human markers,** they're really most useful when FIB remains high and human markers low or ND… recommend not wasting $$ on them until this outcome reached
   - Other emerging **community based methods** are attractive yet they remain experimental/unproven… need this science to evolve and regulators to verify and accept (e.g., through a standard method)
8. For **TMDL implementation planning**, use models that support robust cost benefit analysis
   - May find that advanced IDDE results in substantial progress toward TMDL required load reduction, lessening GI need, and at much lower unit cost than wet weather controls
   - Consider data needs to allow baseline quantification (to support progress reporting over time) – e.g., outfall sampling paired with flow measurement

Conclusions

Successful source tracking of bacteria and nutrient sources can result in:

- Improved water quality outcomes that are directly connected to beneficial use endpoints – e.g., recreational public health protection through abatement of highest risk sources (human)
- Compliance with TMDL, MS4 permit and Consent Decree requirements, reduction of litigation risks (increasingly common), and access to alternative compliance pathways (e.g., site-specific criteria)
- Lower cost means of water quality improvement – greater bang for buck ($ per load reduction) to control waste sources than to capture/treat stormwater using Green Infrastructure
- Demonstrated commitment to solving water quality problems and leadership in applying innovative solutions – helps secure trust/ credibility with regulators and other stakeholders



Questions?

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