Utilizing DNA Markers and Pharmaceuticals to Identify Human Sources of Fecal Contamination in Stormwater Discharges

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Boston Water and Sewer Commission’s Collection Systems

- 206 Storm Drain Outfalls/Sub-catchments
- 18 Interconnections
- 30 Combined Sewer Overflow Outfalls
- Appx. 80% of Boston is served by separated sewers and storm drains
- Appx. 20% served by combined sewers
BWSC’s IDDE Program

- BWSC has been doing IDDE since late 1980’s
- Expanded 2000 with Stony Brook Investigation
- 4 more CWI Phases since 2000
- With each new phase
  - Expanded areas under investigation
  - Built on “lessons learned”
  - Added new “Tools in the Tool Box”
IDDE Methodology

- Small Storm Drain Pipe
- Storm Drain Manhole
- Juncture Manhole
Field Test Kits

- Quick
- Easy to use
- Inexpensive
- Immediate results
Illicits Found and Corrected 2000-2017

- 10,000 manholes investigated
- 21,500 dye tests performed
- 1,739 illicits corrected
  - 1,211 direct connect to drain
  - 230 internal (owner corrected)
  - 298 leaking laterals (most were owner corrected)
- 810,000 gpd sewage removed from drains
Consent Decree 2012

- Requires annual wet and dry weather screening of all storm drain/CSO outfalls and interconnects
- Prioritization of sub-catchments for IDDE investigation
- Deadlines for completion of IDDE investigation; ALL 254 sub-catchments must be completed by 2019
  - 35% inc. beaches were to be completed in 3 years (2015)
  - 35% completed by 2018
  - Remainder (30%) complete by 2019
Prioritization

- Ranked based primarily on outfall screening FIB results

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Priority 2</th>
<th>Priority 3</th>
<th>Priority 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. coli (CFU/100mL)</td>
<td>&gt;10,000</td>
<td>1,000 - 10,000</td>
<td>&lt;1,000</td>
</tr>
<tr>
<td>Enterococci (CFU/100mL)</td>
<td>&gt;5,000</td>
<td>500 - 5,000</td>
<td>&lt;500</td>
</tr>
</tbody>
</table>
But What Were We Missing?

- As of 8/23/2015 investigations in 105 sub-catchments were considered complete (40%)
- But despite eliminating dozens of illicits, FIB in some sub-catchments remained high
- There were isolated locations (drains) within sub-catchments where there was contamination but no source had been found
Urban Runoff WQ Study Primary Objectives

- **Objective 1:** Determine whether elevated FIB concentrations at representative outfalls are due to human fecal contamination or non-human sources
- **Objective 2:** Evaluate the relative contribution of FIB and phosphorus to the MS4 from various sources, particularly during wet weather
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Factor Tested</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Fecal Bacterial DNA Markers</td>
<td>Sub-catchments with corrective actions completed vs incomplete</td>
<td>Evaluate if corrective actions performed through the current IDDE program are eliminating human fecal contamination, to confirm existing IDDE program effectiveness or improve the screening process.</td>
</tr>
<tr>
<td>Human Fecal Bacterial DNA Markers</td>
<td>Wet vs dry weather in sub-catchments where corrective actions have been completed</td>
<td>Evaluate if aboveground human sources are contributing during wet weather, or if wet weather is flushing illicit discharges that do not reach the outfall during dry weather, to potentially improve the IDDE program.</td>
</tr>
<tr>
<td>FIB, Nutrients, and Surfactants</td>
<td>Human waste present vs absent</td>
<td>Evaluate if conventional parameters are reliable indicators of human fecal contamination, to potentially improve the IDDE program.</td>
</tr>
<tr>
<td>PPCPs</td>
<td>Human waste present vs absent</td>
<td>Evaluate if PPCPs could be used as a reliable additional line of evidence for human fecal contamination, to potentially improve the IDDE program.</td>
</tr>
<tr>
<td>Non-Human Fecal Bacterial DNA Markers</td>
<td>Human vs dog and goose fecal sources</td>
<td>Evaluate if non-human fecal management actions may be effective in certain sub-catchments.</td>
</tr>
<tr>
<td>Microbial Community DNA Analysis</td>
<td>Residential and open space vs urban sub-catchments</td>
<td>Evaluate if this analytical tool may be useful for identifying broader fecal and environmental sources.</td>
</tr>
<tr>
<td>FIB and Phosphorous</td>
<td>Aboveground vs belowground sources</td>
<td>Evaluate if TMDL compliance measures may be more effective targeting aboveground sources of FIB and phosphorous. Also to develop data to support watershed model calibration.</td>
</tr>
<tr>
<td>FIB and Phosphorous</td>
<td>Sediments</td>
<td>Evaluate if catch basin and storm drain cleaning may be effective in reducing FIB and phosphorous.</td>
</tr>
<tr>
<td>FIB and Phosphorous</td>
<td>Illicit sewage discharges</td>
<td>Evaluate FIB and phosphorous contributions from known illicit discharges.</td>
</tr>
<tr>
<td>FIB and Phosphorous</td>
<td>Season</td>
<td>Evaluate if seasonal management actions may be effective in reducing FIB and phosphorous. Also, to develop data to support watershed model calibration.</td>
</tr>
<tr>
<td>Group</td>
<td>Sampling Condition¹</td>
<td>Dry Weather Outfall FIB Concentration²</td>
</tr>
<tr>
<td>-------</td>
<td>---------------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>1-1a</td>
<td>Dry</td>
<td>High</td>
</tr>
<tr>
<td>1-1b</td>
<td>Wet</td>
<td>N/A (no flow)</td>
</tr>
<tr>
<td>1-1c</td>
<td>Wet</td>
<td>Low</td>
</tr>
<tr>
<td>1-2</td>
<td>Dry</td>
<td>High</td>
</tr>
<tr>
<td>1-3</td>
<td>Dry</td>
<td>High</td>
</tr>
</tbody>
</table>

1. Sub-catchments with a “Dry” sampling condition typically produce dry weather discharges while sub-catchments with a “Wet” sampling condition typically do not discharge during dry weather.
2. Based on bacteria screening levels in the Consent Decree, shown in Table 1. Exceedances of these criteria do not necessarily imply sewage contamination is present.
3. In accordance with the Consent Decree requirements, outfalls are sampled during wet weather only if there was no dry weather flow or concentrations of certain parameters in dry weather flows were below screening levels.

<table>
<thead>
<tr>
<th>Group</th>
<th>Description</th>
<th>Sampling Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>Stormwater surface runoff from representative land use types (e.g., residential, commercial, institutional, and mixed-use)³</td>
<td>Wet</td>
</tr>
<tr>
<td>2-2</td>
<td>Stormwater runoff in MS4 manholes²</td>
<td>Wet</td>
</tr>
<tr>
<td>2-3</td>
<td>Sediments in catch basins³</td>
<td>Dry</td>
</tr>
<tr>
<td>2-4</td>
<td>Illicit Discharges⁴</td>
<td>Dry</td>
</tr>
</tbody>
</table>

1. Collected prior to entering catch basins, composite sample of flow entering all accessible catch basins upstream of the manhole sampled in Group 2-2.
2. Collected downstream from locations sampled in Group 2-1.
3. Composite sample from catch basins sampled in Group 2-1.
4. Collected downstream from known illicit discharges.
Sample Parameters by Laboratory

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Analytical Labs</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIB (E. coli and Enterococcus) and DNA filtering</td>
<td>Northeast Environmental and Alpha Analytical</td>
</tr>
<tr>
<td>Phosphorous (total and dissolved) and TSS</td>
<td>Alpha Analytical</td>
</tr>
<tr>
<td>PPCPs(^1) (Acetaminophen, Atenolol, Azithromycin, Caffeine, Carbamazepine, Cotinine, Primidone and Sucralose)</td>
<td>Weck Laboratories (California)</td>
</tr>
<tr>
<td>DNA markers (Human ([HF183Taqman and HumM2])^2, Dog, and Goose)</td>
<td>Source Molecular (Florida)</td>
</tr>
<tr>
<td>DNA Community Analysis</td>
<td>U. New Hampshire Hubbard Center for Genome Studies</td>
</tr>
<tr>
<td>Salinity, Conductivity, pH, and Temperature</td>
<td>Field Probe</td>
</tr>
<tr>
<td>Surfactants, Ammonia, and Total Residual Chlorine(^3)</td>
<td>Field Kits</td>
</tr>
</tbody>
</table>

\(^1\) PPCPs were selected based on guidance from EPA New England’s draft source tracking protocol and the list of analytes recommended for analysis in the project RFP.

\(^2\) Human fecal bacterial DNA markers selected based on the California Microbial Source Identification Manual

\(^3\) A subset of samples was laboratory analyzed for surfactants, ammonia, and total residual chlorine at Alpha Analytical to validate the accuracy of field kit results. This analysis was performed for one (1) dry weather sampling event.
Sampling Program Summary

- 35 unique sampling locations
- 6 dry and 6 wet sampling events sampled
- 7/1/2016-7/31/2017 (Drought in 2016 required program extension)
- 378 samples collected in total
- Up to 25 different parameters analyzed resulting in 2,362 unique sample results
Preliminary Results

• The HM (HF183) was detected in all sub-catchments during dry weather regardless of IDDE program status.
• FIB were correlated with human marker results during dry weather, confirming the utility of FIB for dry weather outfall prioritization and screening.
• FIB were not effective in detecting human waste during wet weather, when a mixture of waste types and other FIB sources are conveyed.
Preliminary Results continued

- Acetaminophen, atenolol, and caffeine were correlated with the human marker in dry weather outfall flows.
- IDDE test kit parameters (ammonia, surfactants, and residual chlorine) in outfall flows were not correlated with human marker results, and were prone to false positive and false negative signals.* (based on OF screening data)
- Sewage (as indicated by the HM) was a significant source of TMDL pollutants (FIB and phosphorous) in discharges during dry weather, while non-sewage sources were more significant during wet weather.
Preliminary Recommendations
-Outfall Screening

- Consider discontinuing use of test kits in outfall screening and for prioritizing sub-catchments for IDDE
- Consider discontinuing use of wet weather FIB sampling data for sub-catchment prioritization (not indicative of human waste).
- Use only dry weather FIB data for prioritizing sub-catchments for IDDE
- Consider collecting multiple FIB dry weather samples from each outfall and geometrically average results for prioritization
Preliminary Recommendations - Network IDDE Investigations

- Consider discontinuing use of field test kits in field investigations and use FIB instead*
  - Requires delivery to lab within 6 hours
  - Must be kept on ice
  - Greater cost
  - Results can take up to weeks to be provided
  - *Not recommended by BWSC
- Use CCTV in storm drains to ID illicits and leaks
Does not solve the Fundamental Problem:

We have numerous methods for detecting human contamination in storm drains.

HM and Pharmaceuticals are additional “Tools in the Tool Box”.

However, if we still can’t find the source of the contamination we can’t eliminate it.
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Next Steps for BWSC

- Will continue using field test kits during outfall screening (required by Consent Decree)
- Will continue perform wet weather screening of outfalls (required by Consent Decree)
- Will continue using field test kits for network IDDE investigations - review existing data to determine validity of the ammonia vs. bacteria link
- Will consider sampling for FIBs during field investigation manhole inspections
- Will consider more piloting of HMs