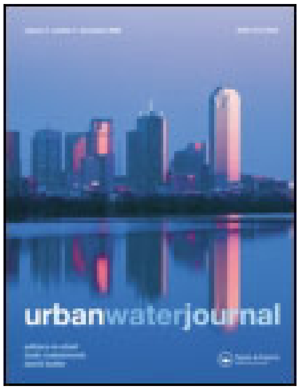

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RESEARCH ARTICLE

# Illicit discharge detection and elimination: Low cost options for source identification and trackdown in stormwater systems

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Permit regulations in the U.S. for Municipal Separate Storm Sewer Systems (MS4) require the MS4 to develop a program that detects and eliminates illicit discharges (e.g., improper wastewater connections) into the storm sewer system. Municipalities are interested in cost-effective methods to meet the permit requirements of this federal mandate. Our demonstration project with municipalities in Western New York State evaluated low cost options for illicit discharge trackdown. First, a visual reconnaissance was used to document flowing stormwater outfalls in dry weather. Subsequently, a sampling program was conducted, in combination with decision-making tools, to identify possible sources of illicit discharges. Colorimetric techniques were tested for a number of chemical parameters and the Coliscan Easygel® system was tested for E. coli analysis. Results from these various cost-effective analytical techniques were compared with analysis by standard methods. The E. coli test, in particular, had good precision and was useful in trackdown.

**Keywords:** illicit discharge; stormwater; MS4; outfall; E. coli

## 1. Introduction

### 1.1. *Background and regulatory need*

Over the past 30 years municipal stormwater management has experienced an important paradigm shift, evolving from an urban flood control function to an environmental protection and regulatory function (Tucker and Harrison 2006). Municipal stormwater management increasingly is thought of as an element of a comprehensive, integrated urban water resource management service that may have a watershed focus (Prince George's County 1999, U.S. EPA 2000, Clarkson 2003, Stark 2003, Tucker and Harrison 2006). Due to the concerns about stormwater quality and impacts on receiving waters, the U.S. EPA promulgated a Phase I stormwater program in 1990, followed by Phase II in 1999 (U.S. EPA 1999). Phase I required medium and large MS4 owners and operators with populations of 100,000 or more to obtain National Pollutant Discharge Elimination System (NPDES) permit coverage for their stormwater discharges. Phase II extended the regulations to small MS4s servicing populations under 100,000 within U.S. Census-defined Urbanized Areas ($>1000$ people/mi$^2$; $>1000$ people/2.59 km$^2$).

Regulated MS4 owners and operators in New York State are required to obtain a General Permit for their separate storm sewer system discharges from the state regulatory authority, the Department of Environmental Conservation. Under the General Permit, the MS4 must design a stormwater management program to reduce the discharge of pollutants to the "maximum extent practicable" and protect water quality. The stormwater management programs developed by the MS4s must include six minimum control measures (MCMs):

- Public Education and Outreach on Stormwater Impacts;
- Public Involvement/Participation;
- Illicit Discharge Detection and Elimination (IDDE);
- Construction Site Runoff Control;
- Post-construction Stormwater Management;
- Pollution Prevention/Good Housekeeping for Municipal Operations.

These complementary measures, when successfully implemented, are expected to reduce the volume of

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pollutants discharged into receiving bodies of water. However, the measures also represent an un-funded federal mandate off-loaded to municipalities and implementation of the measures, particularly the IDDE efforts (and associated analytical costs), can be a financial burden for the municipalities. The objective of this study therefore was to develop and demonstrate a cost-effective and robust protocol for small MS4s to detect, sample, and track down the source of illicit discharges to their storm sewer systems.

### *1.2. Western New York Stormwater Coalition*

In 2002, the regulated MS4s in two counties of Western New York State (Erie and Niagara), started meeting regularly and established the Western New York Stormwater Coalition (WNYSC). The primary objective of the WNYSC is to utilize intergovernmental cooperation to collectively meet the Phase II stormwater regulations. The WNYSC membership includes 29 regulated MS4s in Erie County, 10 regulated MS4s in Niagara County, two county agency MS4s and two non-traditional MS4s. Through participation in the WNYSC, the MS4s have worked cooperatively to develop and implement a stormwater management program that meets the Phase II stormwater regulations.

The Erie County Department of Environment and Planning (ECDEP) is lead agency for the WNYSC and in that capacity acts as administrator and coordinator. A detailed discussion of the WNYSC activities to address the six MCMs (including local ordinance development) is provided by Rossi *et al.* (2009). The IDDE requirement was the most costly and labor intensive measure of all the MCMs to implement. Prioritization of the tasks to develop an IDDE program dictated that first the stormwater outfalls must be mapped. The WNYSC bid out the mapping project and hired a single contractor to identify, inspect, and geocode over 5000 outfalls. The results of this effort were made available to the MS4s and general public through web-based mapping (http://gis1.erie.gov/ENSSO/) and the benefits of this collaborative effort were two fold: realization of significant savings based on economies of scale and fulfilment of the first round of inspections required by the Phase II regulations.

With the outfall mapping completed, the WNYSC turned its attention to developing an IDDE protocol. Buffalo State, State University of New York (Buffalo State) collaborated with the WNYSC on this task through a grant from the U.S. EPA. This collaborative project illustrates the approach that the WNYSC has successfully utilized to address Phase II regulations.

## 2. Methods

### *2.1. The demonstration project*

New York State's IDDE regulations require the MS4 to develop, implement, and enforce a program to detect and eliminate illicit discharges into the system managed by the MS4. Illicit discharges to storm sewer systems include illegal dumping, improper business/industrial connections, failing septic systems, recreational sewage, and wastewater connections. The regulations specifically suggest Pitt's (2004) *Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessment* and its Outfall Reconnaissance Inventory (ORI) tool be used for classification of outfalls. This document was valuable in developing the basic framework for our project, although local conditions required some variances to implementation. It was the intention of our project to take those national standards, apply them to a subset of municipalities in the WNYSC, and refine them as needed to provide an efficient and cost-effective program to successfully meet the regulations.

Of the 41 regulated MS4s in the WNYSC, six were selected to participate in the demonstration project. Selection was based on willingness to participate, as well as a desire to represent a range in socio-economic structure, urban development, and technical capability. Each of the six demonstration municipalities provided a list of at least 10 priority outfalls that would be included in an ORI as the first step in developing the illicit discharge trackdown protocol. The WNYSC developed guidelines to help the municipalities identify the priority outfalls. The guidance directed the MS4s to consider factors such as whether or not the outfall was known to experience dry weather discharges, the potential impact of the surrounding land use for an outfall, outfalls located in environmentally sensitive areas, and the age of the outfall and contributing area.

The study team met with representatives of each municipality once the priority outfalls had been identified to review general procedures for the assessment, review site locations on the municipal maps, develop a general schedule for the work, and ensure coordination of all efforts between the team and municipal staff.

### *2.2. Visual inspection of priority outfalls – completing the ORI field sheet*

Field work for the project commenced with visual inspections for the ORI. A 72 hour antecedent dry period was observed prior to the site visit to minimize the possibility of sampling stormwater runoff rather than illicit connections and it also acted to standardize conditions to facilitate between-site data comparisons. A 72 hour antecedent dry period also has been used to define the start of independent wet weather events in sampling done under several Long Term Control Plan (LTCP) studies for combined sewer overflow abatement in the city of Buffalo (e.g., Irvine *et al*. 2005). The 72 hour antecedent dry period criterion to initiate visual inspection and sampling therefore is consistent with other sewer studies done in the region.

At each site, the study team used a Garmin eTrex handheld Global Positioning System (GPS) unit to confirm the location of the outfall, originally inventoried under the web-based mapping effort (http://gis1.erie.gov/ENSSO/). The study team then conducted the visual inspection of the site, including completion of the ORI Field Sheet. The ORI Field Sheet piloted in this study was based on those developed by Pitt (2004). At the end of the two year field program and based on study team experience, the ORI Field Sheet was modified somewhat to reflect local conditions.

If flow at the outfall was observed, flow rate was measured using one of two methods. For smaller flows, a bucket was used to collect water for a timed period and the volume of water was measured in a graduated 1 L beaker. For larger flows, the velocity was measured using either a Marsh McBirney Model 2000 meter or a Global Water FP 101 meter, with the width and depth of flow being determined using a tape measure.

The ORI served two purposes. First, it provided a quality assurance check on the original mapping done under contract for the WNYSC. Second, it allowed a rapid determination of potential need for additional investigation of illicit connection. If flow was observed during the ORI survey, the site was categorized as having high potential for illicit connection. If other indicators of sanitary waste were observed during the ORI (e.g., toilet paper; oily sheen; odour), the site was categorized as having very high potential for illicit connection. If flow or the other indicators were observed, the outfall was scheduled for sample collection and potential trackdown.

### 2.3. *Sample collection at flowing outfalls*

For sample collection at flowing outfalls, the 72 hour antecedent dry period was again observed. Using a certified clean, 1 L amber glass bottle, a grab sample was collected directly from the flow and retained for laboratory analysis. In a separate, clean, 1 L amber glass bottle, a sample was collected for on-site analysis of pH, temperature, conductivity, and total dissolved solids using a Hanna Instruments HI9811 field meter. Because of the variety of outfall configurations and flow rates it sometimes was not possible to sample directly into the bottles. A clean, long-handled dipper was used if the flow could not be directly collected in the 1 L amber bottles. The dipper was conditioned with the flow (i.e., rinsed three times) prior to collecting a sample. In other cases it was necessary to "channel" the diffuse, shallow flow into the sample bottle using plastic roof gutter. Flow rate was measured and recorded again, per the methods described in Section 2.2.

From the "laboratory analysis" bottle, 1 mL of sample was extracted using a disposable, sterile, plastic pipette and dispensed into a Coliscan Easygel® (Micrology Laboratories, Goshen, IN) growth media screw-top plastic vial for the E. coli analysis. The 1 L amber glass sample bottle for the laboratory analysis and the Coliscan Easygel® growth media (containing the 1 mL water sample) were placed on ice for preservation in the field. All samples were processed within four hours of collection.

### 2.4. *Sample collection for trackdown*

Based on the results of the outfall sampling and the decision making tools (discussed in section 3.3), sampling was conducted progressively up-pipe for trackdown purposes. The within-sewer sample locations were considerably refined by first driving and walking the contributing area. The contributing area was defined based on discussions with municipal staff and guided by sewer drawings. Areas with no observed flow in the sewer pipes were eliminated from further consideration for the trackdown.

Typically, the trackdown sampling required the lifting of manhole covers. However, no confined space entry was done during the sampling; all sampling was done from the street surface. The sample collection method depended on the depth of flow and the size, depth, and configuration of the manhole access. Sampling was done using either a dipper, telescoping sampler, or a bailer that could be laid horizontally into shallow flow.

The sample handling and on-site parameter analysis at the trackdown sites was identical to that described for the outfalls (discussed in Section 2.3). Generally, two to three sites upstream of a particular outfall were selected for sampling and once the sample results were reviewed, either further sampling was done, or a decision regarding the source was determined.

### 2.5. *Receiving water body sampling*

Water samples were collected in five different receiving water bodies, Cayuga Creek (Niagara County), Scajaquada Creek, Niagara River, Two Mile Creek, and a tributary leaving Green Lake (Figure 1). The sample sites generally were located as an upstream and downstream pair. The Cayuga Creek site had a total of three permitted stormwater discharges between the upstream and downstream location; Niagara River had four permitted stormwater discharges between the upstream and downstream location; Two Mile Creek had five permitted stormwater discharges between the upstream and downstream location; and the tributary leaving Green Lake had one permitted stormwater discharge between the upstream and downstream location. All of the receiving water sites were sampled during dry weather flow. Scajaquada Creek receives not only stormwater discharges, but also combined sewer overflow (CSO) discharges from the City of Buffalo. Samples were collected at between two and four sites (Figure 2) on Scajaquada Creek for three storms that occurred on 24 July 2008, 1 October 2008, and 16 October 2008 in addition to dry weather samples. These sites were selected for sampling in association with the Buffalo Sewer Authority's CSO Long Term Control Plan Phase II Study.

Samples collected on Scajaquada Creek were collected either with a telescoping sampler or by wading into the creek and sampling directly into a bottle, depending on flow conditions. Samples for Cayuga Creek, Two Mile Creek, and the tributary leaving Green Lake were collected by wading into the creek and sampling directly into a bottle, while samples for the Niagara River were collected from the shoreline with a telescoping sampler. The sample handling and

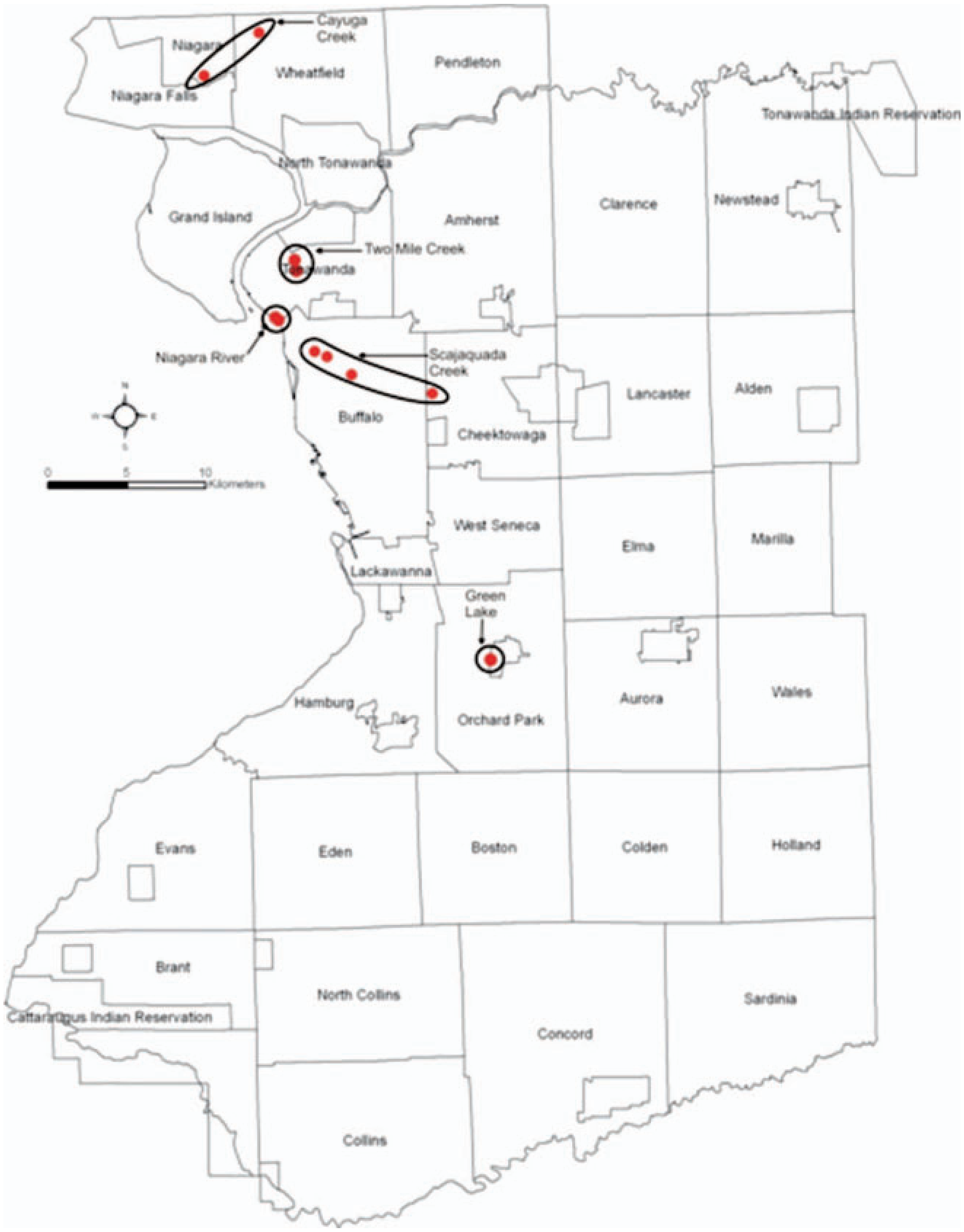

Figure 1. General location of receiving water samples.

Figure 2. Scajaquada Creek sample sites. The creek flows through an underground tunnel between sites 1 and 2.

on-site parameter analysis at the receiving water body sites was identical to that described for the outfalls (discussed in Section 2.3).

### 2.6. *Municipal tap water and local groundwater profiles*

To assist with the trackdown interpretation, samples of tap water were collected at two different locations in three of the participating MS4 communities. The sample handling and on-site parameter analysis for the tap water was identical to that described for the outfalls (discussed in Section 2.3). Supplementing the municipal tap water profile data were the Annual Drinking Water Quality Reports for the participating MS4 communities. The reports identify levels of various contaminants detected as well as fluoride concentrations.

Local groundwater data also were compiled to assist with the trackdown interpretation. The United

States Geological Survey's *Groundwater Quality in Western New York, 2006* (Eckhardt *et al.* 2008) was used to develop a geographical profile to characterize local groundwater quality for eight sites in Western New York's Urbanized Area.

### 2.7. *Analytical methods at Buffalo State*

Routine analysis of all samples was done in the Water Quality Laboratory, Department of Geography/Planning, Buffalo State. The sample parameters and analytical methods were selected through a review of Pitt (2004), Pomeroy *et al.* (1996), and through our own experience in evaluating water quality with community groups (e.g., http://www.buffalostate.edu/orgs/aqua/; Wills and Irvine 1996, Irvine *et al.* 2004). The guiding principle for our sampling program was that we wanted meaningful parameters that could be analyzed easily and cost-effectively (particularly important for municipalities with limited resources) with reasonable precision.

Parameters sampled for the study were nitrate, ammonia, total phosphorous, potassium, fluoride, total chlorine, chromium VI, copper, dissolved oxygen, $BOD_5$, detergents (anionic surfactants), phenols, general and carbonate hardness, total suspended solids, turbidity and E. coli. Analyses for nitrate, ammonia, total phosphorus, fluoride, total chlorine, chromium VI, and copper were done using a colorimetric approach with a Hanna Instruments (www.hannainst.com) C 200 multiparameter bench photometer. Samples were not filtered prior to analysis. In consideration of space, the analytical details are not provided here, but are presented in Irvine *et al.* (2009). Briefly, all analyses carefully followed the Standard Operating Procedures outlined in the Hanna Instruments *Instruction Manual C 99 & C 200 HI 83000 Series Multiparameter Bench Photometers*. The nitrate analysis used an adaptation of the cadmium reduction method and results were expressed as nitrate-nitrogen, which were multiplied by a factor of 4.43 to convert to nitrate ($NO_3^-$). The ammonia analysis used an adaptation of the Nessler method; total phosphorus analysis was an adaptation of the amino acid method; fluoride analysis was an adaptation of the SPADNS method; total chlorine analysis was an adaptation of the U.S. EPA DPD method; chromium VI analysis was an adaptation of the diphenylcarbohydrazide method; and copper analysis used the bicinchoninate reagent approach. Potassium was analyzed using an adaptation of the turbidimetric tetraphenylborate method using a Hanna Instruments HI 93750 single parameter photometer.

Dissolved oxygen was measured using a CHEMetrics, Inc. (www.chemetrics.com) visual test kit that employed the indigo carmine method (ASTM D 888–87) in which the reduced form of indigo carmine reacts in a sample, with dissolved oxygen forming a blue product. The kit comes with a graduated colour comparator with divisions of 1, 2, 3, 4, 5, 6, 8, 10, and 12 ppm. To determine $BOD_5$ the dissolved oxygen level measured in the field was compared with the dissolved oxygen measured in a BOD bottle held at room temperature, 5 days after sample collection.

Detergents (anionic surfactants) were measured using a CHEMetrics, Inc. (www.chemetrics.com) visual test kit that employed the methylene blue active substances method in which anionic detergents react with methylene blue to form a blue-coloured complex that is extracted into an immiscible organic solvent. Results are expressed in ppm as linear alkylbenzene sulfonate (LAS) equivalent weight 325. The intensity of the colour reaction is determined using a graduated colour comparator having divisions of 0, 0.25, 0.50, 0.75, 1.0, 1.5, 2.0, and 3.0 ppm.

The Coliscan Easygel® system from Micrology Labs (http://www.micrologylabs.com/Home), Goshen, IN, was used to determine E. coli levels. The medium/inoculums mix collected in the field was plated immediately upon return to the laboratory at Buffalo State. The poured samples were incubated at room temperature for 48 hours and after this period, all purple colonies were counted as E. coli. Pink colonies are coliform and teal green colonies are other types of bacteria that may include Salmonella spp. or Shigella spp. The pink and teal green colonies were not counted in this study.

Phenols were measured using a CHEMetrics, Inc. (www.chemetrics.com) visual test kit that employed the 4-aminoantipyrine (4-AAP) method in which phenolic compounds react with 4-AAP in alkaline solution in the presence of ferricyanide to produce a red reaction product. The intensity of the colour reaction is determined using a graduated colour comparator having divisions of 0, 5, 7.5, 10, 15, 20, 25, and 30 ppm. General and carbonate hardness were determined using a titration approach with reagents in the GH & KH General & Carbonate Hardness Test Kit available from Aquarium Pharmaceuticals (http://aquariumpharm.com/). Turbidity (NTU) was determined in the laboratory using an Oakton T-100 Portable Turbidity Meter.

### 2.8. *Quality assurance checks on routine analytical methodologies*

To check the calibration of the Hanna C 200 and HI 93750 photometers, certified, standard solutions of potassium, nitrate, fluoride, chromium VI, and copper were obtained from Ricca Chemical Co., Arlington, TX, and certified, standard solutions of phosphorus and ammonia were obtained from Pointe Scientific, Inc., Canton, MI. In addition to the standard solutions for

QA/QC of the Hanna Instruments photometers, several other QA/QC measures were taken to assess the reliability of the routine analytical methods employed for this study. First, a total of 11 receiving water samples and 12 samples from storm sewers were collected in duplicate and analyzed at Buffalo State and at a New York State Health Department certified laboratory. The parameters analyzed at Buffalo State and the certified laboratory were chromium VI, copper, potassium, ammonia, $BOD_5$, nitrate, total phosphorus, and total recoverable phenolics. All samples were refrigerated at 4°C until analysis was started. At the certified lab, chromium VI, copper, and potassium were analyzed using U.S. EPA method 200.7, ammonia was analyzed using U.S. EPA Method 350.1, nitrate was analyzed using U.S. EPA method 353.7, and total recoverable phenolics were analyzed using U.S. EPA method 420.4 (U.S. EPA 1983, 1991, 1992, 1993). Biochemical oxygen demand was analyzed using Standard Method 5210B and total phosphorus was analyzed using Standard Method 4500-P E (APHA 1998). Detection limits were: chromium – 0.004 mg/L; copper 0.01 mg/L; potassium – 0.5 mg/L; ammonia – 0.02 mg/L; $BOD_5$ – 2.0 mg/L; nitrate – 0.05 mg/L; total phosphorus – 0.01 mg/L; total recoverable phenolics – 0.01 mg/L. QA/QC measures (except for $BOD_5$) included matrix spikes, method blanks, and blank spikes for each batch of samples.

A total of 21 samples (10 receiving water and 11 storm sewer) were collected in duplicate and analyzed at Buffalo State and at the Erie County Public Health Laboratory for E. coli. The Erie County Public Health Laboratory analyzed E. coli using membrane filtration according to U.S. EPA Method 1603. Finally, a YSI 6920 datasonde was used to compare dissolved oxygen measurements with the CHEMetrics visual test kit measurements, as well as measurements of pH and conductivity with the Hanna Instruments HI9811 field meter.

## 3. Results

### 3.1. MS4 participants

Among the six MS4s that participated in the project, there were five traditional, land use control MS4s (i.e., municipally owned) and one non-traditional, non-land use control MS4 (college campus). The demographic characteristics of the MS4s (Table 1) offered diversity with the storm sewer system configurations, receiving water features, and population.

### 3.2. Outfall sampling

A total of 64 outfalls were investigated for the project, approximately ten per MS4. The first round of fieldwork for the project consisted of conducting an ORI for the 64 outfalls selected for the study. The ORI served to verify existing outfall data, confirm dry weather flow conditions, measure flow rates, and evaluate potential for an illicit discharge.

Once the ORIs were completed, fieldwork transitioned to outfall sampling and field measurements followed by lab analysis and interpretation. For each participating MS4, the ORI results were used to streamline the outfall sampling by prioritizing fieldwork toward flowing outfalls or those with compelling evidence of prior illicit discharges (i.e., intermittent, though not necessarily flowing at initial inspection).

To determine whether an outfall flowing during dry conditions was illicit, it was necessary to collect and analyze a sample. Samples were collected according to the methods detailed in Section 2.3, under 72 hour dry antecedent conditions.

### 3.3. Illicit discharge trackdown

#### 3.3.1. Determination of need

Lab results and field measurements determined whether or not a trackdown investigation was needed. The primary decision-making tools were a flow chart (Figure 3) and industrial benchmarks developed by Pitt (2004) and the New York State Department of Environmental Conservation's (NYSDEC) Part 703: Surface Water Quality Standards (NYSDEC 1999). In the absence of effluent limitation guidelines, the NYSDEC Standards provided a baseline value to determine tolerable levels for contaminants detected.

Table 1. Demographics of participating MS4s.

| MS4 | Population (2000 Census) | Area ($km^2$) | Length of Pipe (m) | Number of Outfalls | Length of Streams (m) | Land Use** |
|---|---|---|---|---|---|---|
| #1 | 12,575* | 0.47 | 17,320 | 6 | 1049 | Academic institution (urban area) |
| #2 | 18,621 | 66.6 | 64,370 | 331 | 120,500 | Low density residential |
| #3 | 22,458 | 81.5 | 167,400 | 175 | 168,800 | Medium density residential |
| #4 | 24,343 | 89.8 | 261,300 | 218 | 140,300 | Medium density residential |
| #5 | 61,729 | 43.1 | 458,700 | 62 | 45,690 | Light industrial; Commercial; High density residential |
| #6 | 45,920 | 46.6 | 159,000 | 278 | 96,830 | Light industrial; Medium density residential |

*represents number of students and full time faculty, fall, 2008; **predominant land use in the contributing area of the sampled outfalls in each MS4.

The Pitt (2004) flow chart values and the NYSDEC Standards as summarized in Table 2, allowed for a rapid determination as to whether or not a trackdown was necessary. Simply put, if a given parameter exceeded the Pitt values or the NYSDEC Standards, further investigation was warranted. The Pitt (2004) flowchart/industrial benchmarks were used to characterize the (possible) source of flow as sanitary wastewater, washwater, irrigation, tap water, groundwater, or industrial/commercial. Municipal tap water and ground water profiles (Eckhardt *et al.* 2008) also were used to determine a possible source in instances

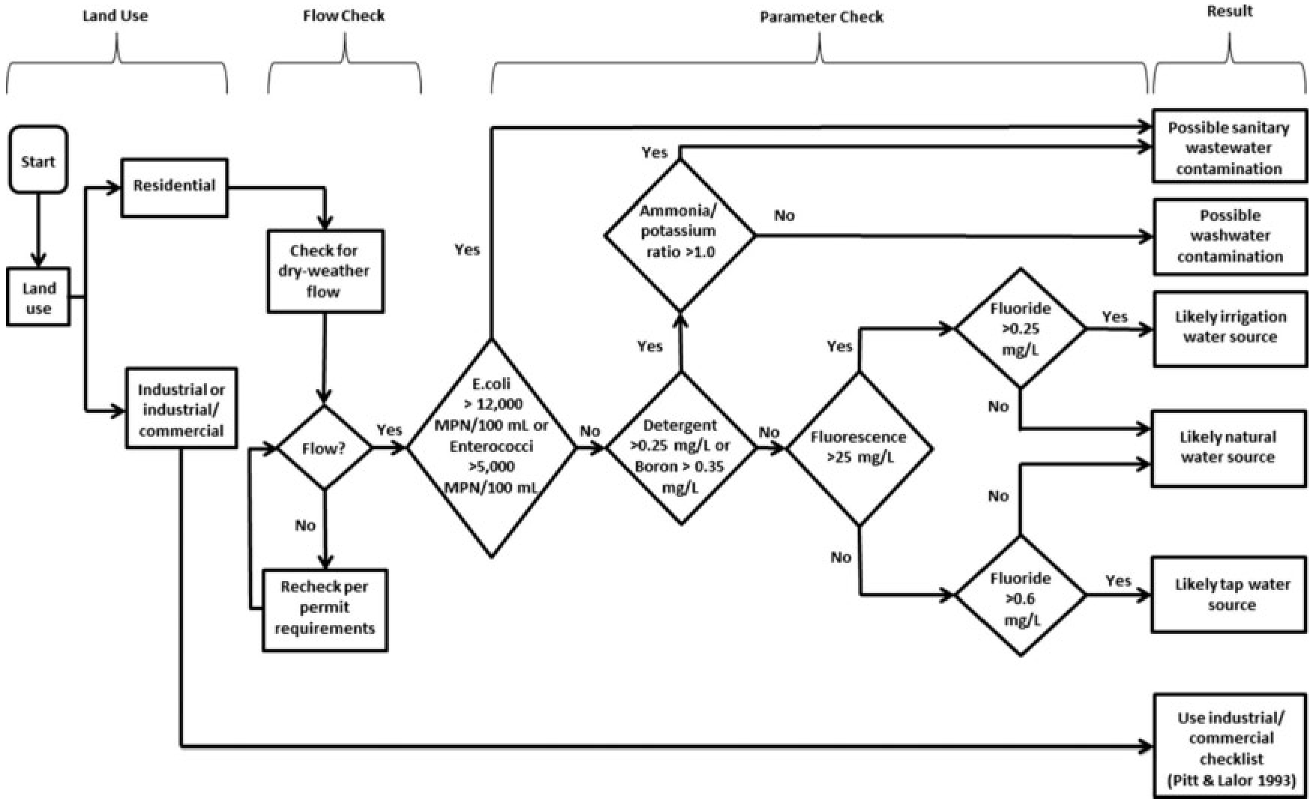

Figure 3. Flow chart for trackdown (after Pitt 2004).

Table 2. Summary of IDDE Guidance Manual Benchmarks (Pitt 2004) and NYSDEC Part 703: Surface Water & Groundwater Quality Standards (NYSDEC 1999).

| Contaminant | | NYS Standard | Pitt Benchmark | Possible Source |
|---|---|---|---|---|
| Ammonia | mg/L | 2 mg/L | Fingerprint Value* | Sewage |
| Detergents | ppm | | > 0.25 mg/L | Sewage; washwater; industrial/ commercial |
| E. coli | per 100 mL | | > 12,000 CFU/100 ml | Sewage |
| Conductivity | $\mu$S/cm | | Fingerprint Value* | Industrial |
| Fluoride | mg/L | 1.5 mg/L | Fingerprint Value* | Tap/irrigation water |
| Nitrate | mg/L | 10 mg/L | | Sewage; fertilizer |
| pH | | 6.5–8.5 | | Industrial |
| Potassium | ppm | | Fingerprint Value* | Sewage; industrial |
| Turbidity | NTU | 5 NTU | | Industrial |
| Ammonia Potassium Ratio | | | > 1.0 | Sewage |
| Other Indicators: | | | | |
| Phosphorous - Total | mg/L | | | Sewage; fertilizer |
| Chlorine - Total | mg/L | | | Tap/irrigation water |

*See Tables 48 and 49 of Pitt (2004).

where no pollutants were detected and no indicators were present for a flowing outfall.

### *3.3.2. Trackdown process*

Once an outfall sample indicated the possibility of an illicit discharge to a storm sewer system, the trackdown process was initiated. Field work first entailed a physical trackdown in the contributing area to determine points in the system where flow was present. In doing so, the various portions of the system where flow was absent could be eliminated from further consideration. With the contributing area defined, the source of the illicit discharge was identified more efficiently.

There are two possible approaches for tracking down the source of an illicit discharge: collect samples progressively up-pipe at manholes and other access points; or use a sewer camera. For the purpose of this project, source trackdown did not utilize a sewer camera because the majority of the MS4 project partners do not own or have access to a camera. However, the camera approach was recommended in some instances to quickly and specifically identify a discharge point.

Of the 64 outfalls evaluated through the ORI, a total of 24 were flowing at the time of inspection and were sampled. Fifteen of the outfalls required a trackdown investigation to identify a source of contamination. Sixty seven samples were collected and analyzed as part of the trackdown and recommendations for specific MS4 inspection to correct illicit connections were made for a total of seven outfalls. The inspections and subsequent corrective actions are facilitated by the local ordinance that the MS4s adopted as part of the WNYSC work (see Rossi *et al*. 2009). It was beyond the scope of this project to follow up with each MS4 to determine if corrective actions were completed. For the purpose of discussion, one outfall, known as Outfall #7, has been selected to describe the process, follow up reporting, and recommendations.

### *3.3.3. Case study – outfall #7*

Previous inspections at the outfall indicated flow was present in 2005 (GIS mapping survey, http://gis1.erie.gov/ENSSO/) and 2007 (ORI for this study). In spring 2008, Outfall #7 was revisited to collect a sample. Elevated levels of E. coli (21,600 CFU/100 ml), ammonia (3.9 mg/L) and fluoride (1.6 mg/L) were detected in the sample. Storm sewer and land use maps were obtained from the MS4 project partner for review and planning for additional trackdown sampling. Follow up sampling at the outfall confirmed elevated levels of: E. coli (14,000 CFU/100 ml), ammonia (4.5 mg/L) and nitrate (64 mg/L). At that time, a field assessment was conducted to define the contributing area for Outfall #7, confirm the accuracy of the sewer maps, and plan for trackdown sampling.

A trackdown was initiated on 8 July 2008. Once again, the outfall was sampled and E. coli levels remained high (28,000 CFU/100 ml), as did the ammonia (3.7 mg/L). The first upstream site sampled (#2 manhole, 68 m upstream of Outfall #7), exhibited a sharp increase in E. coli (49,000 CFU/100 ml), detergent (10 mg/L), and total phosphorus (25 mg/L). Nitrate (48 mg/L) and ammonia (3.8 mg/L) levels were elevated as well. At the #3 manhole site (148 m upstream of Outfall #7), E. coli levels (44,000 CFU/100 ml) and detergent (10 mg/L) remained high while nitrate and total phosphorus decreased substantially. Ammonia remained consistent with previous levels (4.0 mg/L). Still farther upstream, at the #4 manhole (238 m upstream of Outfall #7), the E. coli (43,000 CFU/100 ml) and ammonia (3.8 mg/L) levels remained high. Detergent levels, although slightly elevated, decreased substantially (1.25 mg/L). One additional upstream point was sampled on 6 August 2008. At this site, the #5 manhole (329 m upstream of Outfall #7), E. coli levels declined (12,500 CFU/100 ml) to near benchmark limits (12,000 CFU/100 ml as defined by Pitt 2004).

At the levels detected, E. coli contamination from Outfall #7 became a flag of concern. The elevated levels of E. coli alone were indicative of raw sewage contamination. The high ammonia concentrations were consistent with raw sewage and further reinforced it as the source of contamination. Similarly, in the presence of high ammonia concentrations, the elevated detergent levels provided credence to the suspected source. The trackdown investigation defined the geographic boundaries of the source of contamination as being downstream from the #5 manhole.

Further investigation by the MS4 to identify the source of E. coli contamination and eliminate it (using the newly established local stormwater ordinance) was recommended. It also was recommended the MS4 re-inspect this site one year after eliminating the E. coli source.

## **3.4. Receiving water body results**

### *3.4.1. E. coli in receiving waters*

High levels of pathogenic indicators, including E. coli, are a concern in many water bodies throughout the United States and this contamination frequently is the primary focus of watershed Total Maximum Daily Load (TMDL) studies (e.g., U.S. EPA 2001, He *et al*. 2007, Kay *et al*. 2007, U.S. EPA 2009). Water bodies in Erie and Niagara Counties are no exception to this concern and bacterial contamination along the Buffalo waterfront has been, and continues to be, a focus in the Buffalo Sewer Authority CSO Long Term Control Plan (NYSDEC 2005, Irvine *et al*. 2005, 2006a). As such, this section separately discusses the issue of E. coli levels in receiving waters.

### *3.4.2. E. coli characteristics, Cayuga Creek, Niagara County*

A total of 62 samples (21 dry weather days, 41 wet weather days) were collected at the upstream and downstream sites on Cayuga Creek between 27 July 2007 and 25 July 2008 for E. coli analysis and the results are summarized in Figure 4. The maximum measured E. coli level for a storm event at the upstream site was 18,900 CFU/100 mL and the maximum measured E. coli level for the downstream site was 11,500 CFU/100 mL. However, as shown in Figure 4 there was a general trend towards increasing E. coli levels in the downstream direction for both dry weather and storm event conditions. In general, the upstream site exhibited relatively low E. coli levels. Mean storm event levels were higher than dry weather flow at both sites.

Although the municipalities in the Cayuga Creek watershed were not participants in this demonstration project, there are three permitted stormwater outfalls (NI6, NI5, NI4) between the upstream and downstream sites (Figure 5). Samples were not collected at these outfalls during dry weather flow. However, samples were collected at most of the stormwater outfalls shown in Figure 5 in association with the storm event of 21 October 2008 (0.4 inches (10.1 mm) of rain). The geometric mean E. coli level at the outfalls for this event was 711 CFU/100 mL, which is taken as the "expected" level (Figure 6). Site NI4 (Figures 5 and 6), in particular, could be an important source of E. coli during storm events. There also may be other sources of E. coli to Cayuga Creek between the upstream and downstream sites, including failing septic systems and natural wildlife, and these various sources should be investigated further.

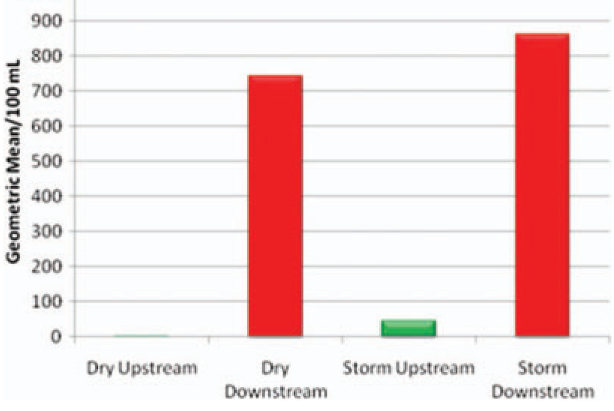

Figure 4. Geometric mean E. coli levels in Cayuga Creek.

### *3.4.3. E. coli levels at Niagara River, Two Mile Creek, and Green Lake Tributary sites*

Although two of four outfalls examined between the two Niagara River receiving water sites had E. coli levels in the range of 21,600–115,900 CFU/100 mL, there was no observable impact on the Niagara River downstream site. The two samples collected at the Niagara River upstream site had E. coli levels of 200 CFU/100 mL, while the two samples collected at the Niagara River downstream site had E. coli levels of 300 and 800 CFU/100 mL on 22 July 2008 and 13 August 2008. The high flow volume in the Niagara River was quite sufficient to dilute the small volume stormwater discharges. The E. coli levels at the upstream (0 CFU/100 mL) and downstream (600 CFU/100 mL) sites on the tributary from Green Lake also did not reflect significant impact from the single stormwater discharge point between them (150 CFU/100 mL).

E. coli levels at the upstream and downstream locations on Two Mile Creek may reflect inputs from the stormwater discharge points. For example, on 22 July 2008 E. coli levels at the upstream site were 2200/100 mL and the downstream site, were 4100 CFU/100 mL. One of the sampled outfalls between the two sites had an E. coli level of 9700 CFU/100 mL.

### *3.4.4. E. coli levels in Scajaquada Creek – storm event conditions*

Sampling was conducted during storm events at various combinations of the four sample sites on Scajaquada Creek, depending on team availability and storm duration. These sites were selected as being common to the Buffalo Sewer Authority's CSO Long Term Control Plan Phase II Study. Samples were collected for the storm events of 24 July 2008, 1 October 2008, and 16 October 2008 and the results are summarized in Table 3. The levels of E. coli observed in Scajaquada Creek for storm events generally were higher than those observed for Cayuga Creek. Several city of Buffalo CSOs discharge to Scajaquada Creek between sites 1 and 2 and CSO points also are located in the vicinity of sites 3 and 4.

Because of the likely contributions of CSOs to Scajaquada Creek during storm events it is difficult to separate contributions from stormwater discharges

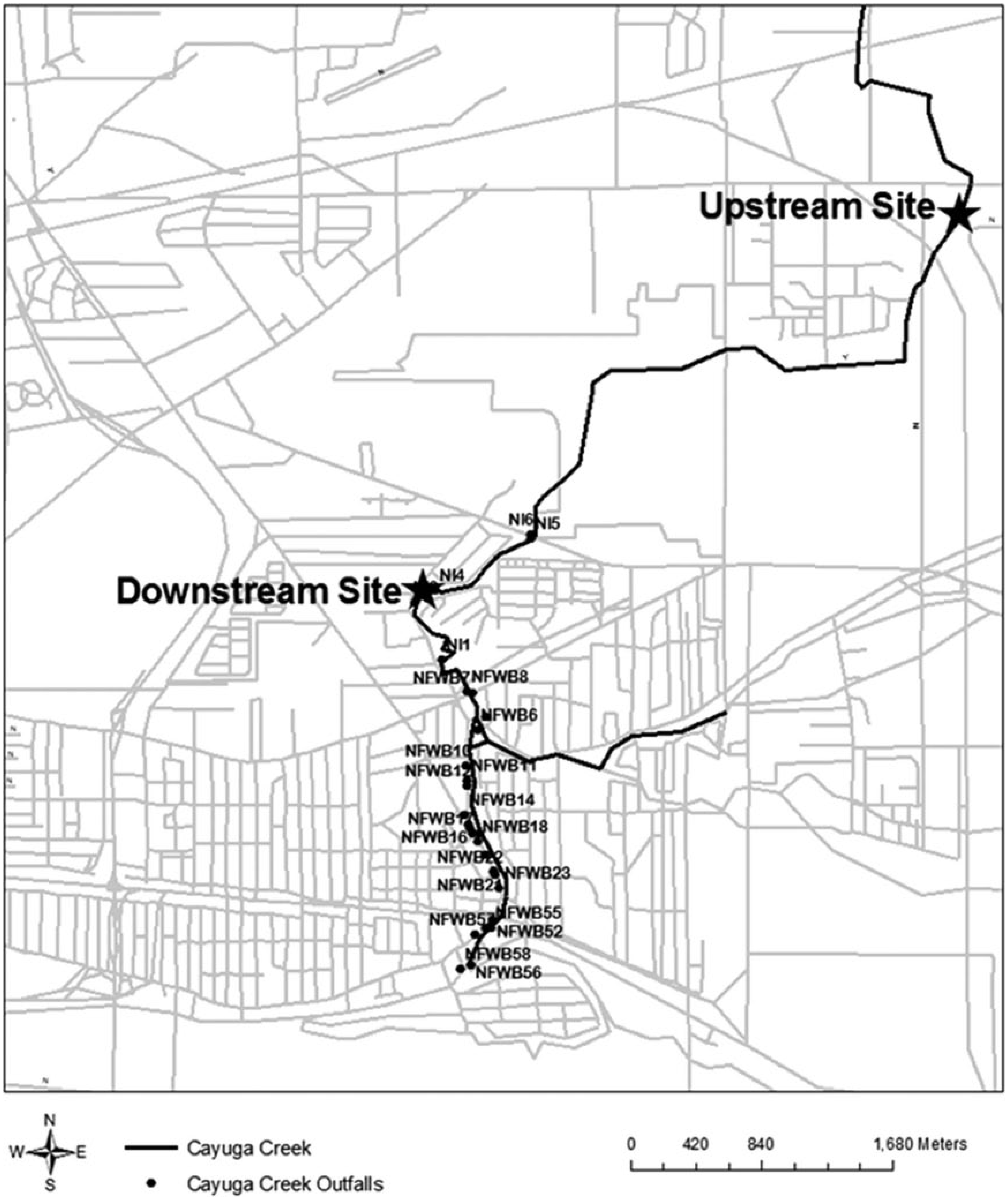

Figure 5. Permitted stormwater discharge locations, Cayuga Creek, Niagara County. NI6, NI5, and NI4 are between the upstream and downstream sample sites on Cayuga Creek.

and CSOs. For the 24 July 2008 event, three of four Buffalo State stormwater discharge points located between Scajaquada Creek sample sites 3 and 4 had E. coli levels of 2500–4200 CFU/100 mL, which were comparable to the levels observed in Scajaquada Creek. It also seems likely that the CSO impact was

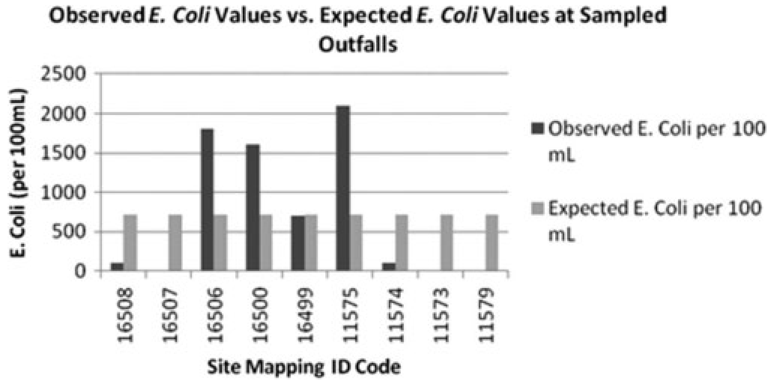

Figure 6. E. coli results for stormwater discharges to Cayuga Creek, event of 10/21/08. Site mapping ID codes for locations between the upstream and downstream sites in Cayuga Creek are: NI6 = 16508; NI5 = 16507; and NI4 = 16506.

Table 3. E. coli levels for storm events on Scajaquada Creek.

| Date | Time | Site | E. Coli CFU/100 ML | Comments |
|---|---|---|---|---|
| 24 July 2008 | 10:30 | 3 | 4,400 | Rain during and immediately prior to sampling totaled 8.6–10.2 mm (2 gauges) |
| | 11:20 | 4 | 6,500 | |
| | 13:20 | 2 | 35,800 | |
| 1 October 2008 | 8:20 | 3 | 23,200 | Rain around 23:00 the night before of ~ 4.8-10.2 mm (multiple gauges throughout the city; sewage odor at site 4, flow was turbid and visually higher than baseflow) |
| 1 October 2008 | 8:35 | 4 | 29,500 | |
| 16 October 2008 | 11:00 | 1 | 33,000 | Rain the previous night of ~20.1 mm |
| 16 October 2008 | 16:40 | 1 | 18,200 | |
| 17 October 2008 | 9:05 | 1 | 6,900 | |
| 16 October 2008 | 11:30 | 2 | 47,600 | |
| 16 October 2008 | 17:10 | 2 | 20,200 | |
| 17 October 2008 | 9:25 | 2 | 38,200 | |
| 16 October 2008 | 11:50 | 3 | 27,600 | |
| 16 October 2008 | 17:30 | 3 | 17,800 | |
| 17 October 2008 | 9:40 | 3 | 9,400 | |
| 16 October 2008 | 12:13 | 4 | 17,400 | |
| 16 October 2008 | 17:45 | 4 | 12,800 | |
| 17 October 2008 | 10:00 | 4 | 4,400 | |

observed at site 2 for the sample collected at 13:20 (35,800 CFU/100 mL), but the CSO discharge was not reflected in the samples collected at sites 3 and 4 earlier in the day. Further sampling and possible model application needs to be done to more adequately assess CSO vs. stormwater inputs.

For the storm event of 16 October 2008 a decrease in E. coli levels was observed through the event in association with a decreasing flow. Irvine *et al.* (2002) showed that fecal coliform levels were significantly correlated with suspended solids concentrations in local rivers and we expect E. coli would exhibit a similar relationship. As such, the E. coli and suspended solids from the various sources (including stormwater discharges, CSOs, and bed and bank sediment resuspension) will have flushed through the system earlier in the 16 October 2008 event and towards the end of the event also will start to settle out of the water column with the lower flow.

### *3.5. QA/QC results*

#### *3.5.1. E. coli analysis, Coliscan Easygel® vs. membrane filtration*

The results of the Coliscan Easygel® and membrane filtration analysis (Erie County Public Health Department) for receiving water (n = 11) and stormwater sewer samples (n = 12), combined (total n = 21), are shown in Figure 7. The samples represented a range of E. coli levels and the regression indicates there was good correspondence between the Coliscan Easygel® results and the standard, membrane filtration. The slope of the regression line between the Coliscan Easygel® results and membrane filtration was close to 1 and was significantly different from 0 ($\alpha = 0.05$), while the intercept was not significantly different from 0 ($\alpha = 0.05$).

Citizen's groups throughout the U.S. successfully have used the Coliscan Easygel® system in monitoring programs (e.g., Alabama Water Watch (1999); Virginia Citizen Water Quality Monitoring Program (2003);

Texas Watch (http://www.texaswatch.geo.txstate.edu/Newsletters/98–04.pdf ); Hoosier Riverwatch (http://www.in.gov/dnr//riverwatch/pdf/manual/Chap4.pdf); Alliance for the Cheaseapeake Bay Citizens Monitor (http://www.acb-online.org/pubs/projects/deliverables-87–1–2003.pdf); University of Vermont (2003)) and we have used the system for research projects in Cambodia and Thailand (e.g., Krueger *et al.* 2004, Gugino *et al.* 2006, Irvine *et al.* 2006b, Visoth *et al.* 2010). The Virginia Department of Environmental Quality approved the Coliscan Easygel® method for screening purposes and independent testing (e.g., Alabama Water Watch 1999, Deutsch and Busby 2000) has shown that Coliscan Easygel® results are comparable to standard methods. Our results also suggest that the Coliscan Easygel® system can be used to reliably and cost-effectively track down illicit connections and problem discharges.

### *3.5.2. Certified standard analysis with Hanna Instruments photometers*

Certified standards for potassium, nitrate, fluoride, chromium VI, copper, total phosphorus, and ammonia were analyzed in triplicate. All parameters except potassium were measured using the Hanna Instruments C 200 photometer. Potassium was measured using the Hanna Instruments HI 93750 photometer. Results of the mean of triplicate samples for potassium, nitrate, chromium VI, copper, and fluoride are shown in Figures 8–12. The Hanna Instruments C 200 photometer recorded a mean triplicate result of 1.03 mg/L for the total phosphorus standard of 1.0 mg/L. The Hanna Instruments C 200 photometer also recorded a mean triplicate result of 0.41 and 1.03 mg/L for the ammonia standard of 0.5 and 1.0 mg/L, respectively. Results of the certified standards analysis show that the Hanna Instruments photometers were capable of producing reliable results suitable for a trackdown study.

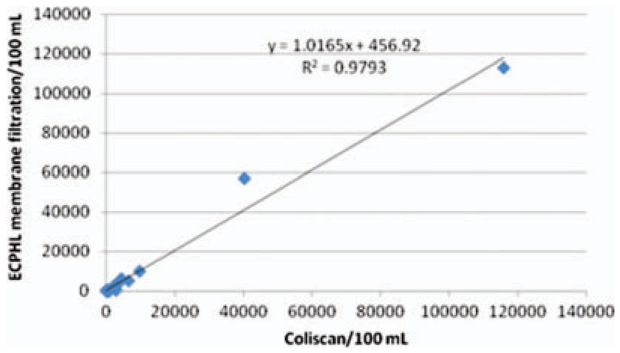

Figure 7. Comparison of E. coli levels determined using Coliscan Easygel® and membrane filtration, Erie County Public Health Lab (ECPHL).

### *3.5.3. Comparison of results between Hanna Instruments photometers and certified laboratory*

Results of the 11 receiving water samples and 12 storm sewer samples analyzed using the Hanna Instruments photometers and the New York State Health Department certified laboratory are summarized in Table 4. The mean level for all parameters was higher for the

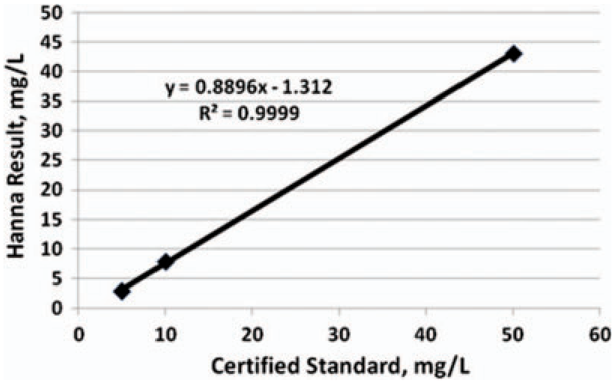

Figure 8. Potassium standards analysis with Hanna HI 93750 photometer. Each point is the mean of a triplicate analysis.

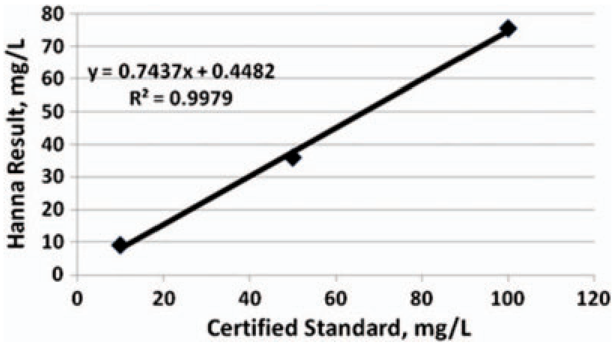

Figure 9. Nitrate as $NO_3^-$ standards analysis with the Hanna C 200 photometer. Each point is the mean of a triplicate analysis.

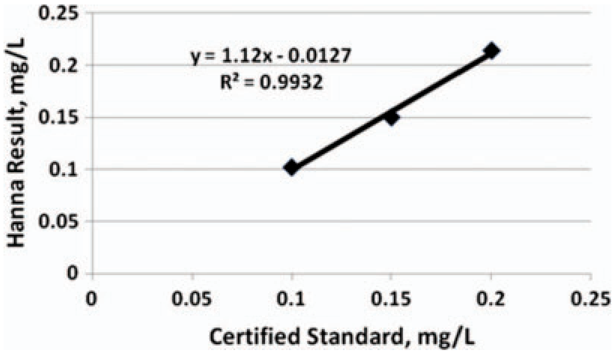

Figure 10. Chromium VI standards analysis with the Hanna C 200 photometer. Each point is the mean of a triplicate analysis.

Hanna Instruments photometers than the results obtained from the certified laboratory. In the case of chromium and copper, frequently the levels were near or below the detection limit for the certified laboratory. The standard deviations for the Hanna Instruments results were considerably higher than those for certified laboratory. Considering the good results of the Hanna Instruments photometers with the certified standards, the comparisons with certified laboratory were somewhat disappointing and should be investigated further. A review of the Hanna Instruments data indicated that individual sample results could be high. In the future, anomalous values should be flagged and re-done in triplicate. Furthermore, the samples were not filtered prior to analysis with the Hanna Instruments photometers. Higher suspended solids levels can result in interference with the photometric analysis and testing of both filtered and unfiltered environmental samples should be carried out. The samples for the certified laboratory were not filtered prior to analysis, so this rules out analytical differences as a result of different sample preparation.

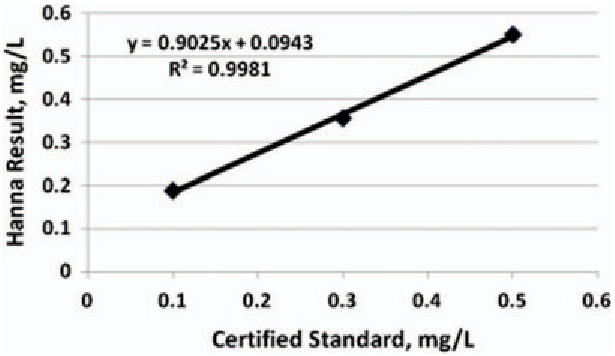

Figure 11. Copper standards analysis with Hanna C 200 photometer. Each point is the mean of a triplicate analysis.

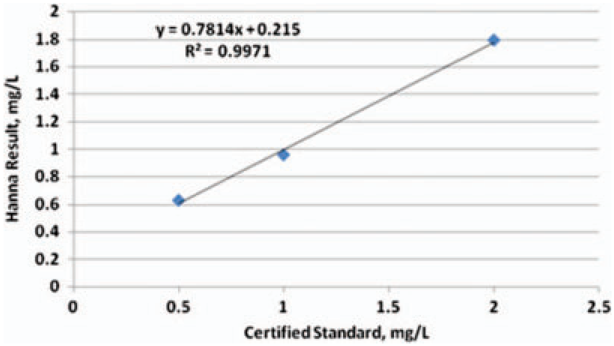

Figure 12. Fluoride standards analysis with Hanna C 200 photometer. Each point is the mean of a triplicate analysis.

Table 4. Mean values (standard deviation in brackets) of certified laboratory and Hanna photometer results.

| Parameter | Certified Lab | Hanna Photometer |
|---|---|---|
| chromium (mg/L) | 0.0024 (0.0013) | 0.0127 (0.0195) |
| copper (mg/L) | 0.008 (0.007) | 0.288 (0.310) |
| potassium (mg/L) | 3.9 (2.3) | 19.3 (16.3) |
| ammonia (mg/L) | 0.421 (0.977) | 2.13 (2.95) |
| nitrate (mg/L) | 0.574 (0.418) | 5.8 (7.9) |
| total phosphorus (mg/L) | 0.135 (0.198) | 14.3 (11.2) |

### 3.5.4. *Comparisons for dissolved oxygen and conductivity tests with YSI 6920 results*

The regression between the CHEMetrics visual test for dissolved oxygen and measurements made by a YSI 6920 datasonde is shown in Figure 13. The relationship is strong and some of the scatter occurred due to the coarser resolution of the visual test (0.5 mg/L). Given the ease of the visual test and its low relative cost, these results were quite encouraging.

The Hanna Instruments HI9811 field meter measurements of conductivity (project meter) were compared to the YSI 6920 datasonde measurements (Figure 14). The Hanna Instruments meter is a relatively low-cost unit but the results compared favourably with those provided by the YSI 6920.

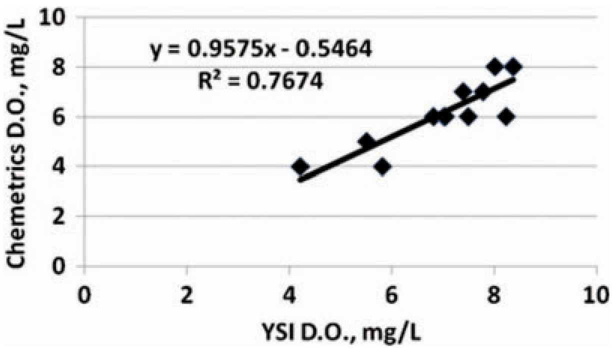

Figure 13. Regression between CHEMetrics and YSI dissolved oxygen measurement.

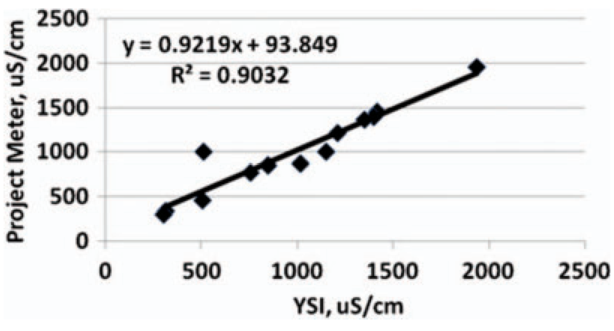

Figure 14. Hanna HI9811 (Project) conductivity measurements compared with the YSI 6920 measurements.

One pair of measurements exhibited some deviation from the regression line, where the HI9811 meter recorded a value of 1,000$\mu$ S/cm but the YSI 6920 recorded a value of 512 $\mu$S/cm. For this particular set of measurements, the flow from the outfall pipe was quite shallow and it was difficult to get the YSI 6920 sensor submersed in the flow. The HI9811 measurement was taken from a sample bottle and it is likely that the HI9811 reading more accurately reflected the true conductivity of the outfall.

## 4. Technology transfer

The primary objective of this project was to demonstrate a protocol for small MS4s to detect, sample, and track down the source of illicit discharges to their storm sewer systems. The MS4s of the WNYSC received a series of training workshops (sample collection and analysis; ORI; interpretation of trackdown results) and opportunities to provide feedback throughout the course of the project.

In March 2009, a final training workshop was held for all MS4s in the WNYSC. Based on the feedback and concerns voiced at the previous training workshops, the sampling protocol and trackdown procedures were streamlined to be an efficient, cost-effective process that is compliant with New York State's Phase II Stormwater regulations.

## 5. Cost comparisons

One of the objectives of this study was to identify cost-effective, robust, and accurate analytical methods for the trackdown studies. Two comparisons are offered here.

### 5.1. *E. coli*

- Erie County Public Health Lab = \$16.07/sample (note that this is a low price for a New York State Laboratory).
- Coliscan Easy Gel® - \$1.60 (materials) + \$3.33 (labour) = \$4.93/sample.

### *5.2. Suite of total phosphorus, nitrate, potassium, chromium, and copper*

- New York State Health Department certified laboratory = \$105/sample.
- Kit reagents (\$3.31) + \$13.33 (labour) + \$ 1.77 (Capital equipment costs) = \$18.41/sample.(Capital costs here assume new photometers every 500 samples, which is very conservative.)

Clearly, the analytical approaches examined in this project offer a cost-effective alternative to contract laboratory costs.

## 6. Conclusion

The outcome of this project was two-fold: a simple process to detect and eliminate illicit discharges to storm sewer systems; and, a reliable, cost-effective analytical method to perform the sampling and chemical analysis required to properly identify an illicit discharge.

The demonstration component of the project entailed sampling and analysis for a broad spectrum of parameters to determine a source for the contamination and/or flow. Initially, there were twenty analytical parameters measured for each sample. Each parameter was examined as an indicator to characterize the flow as illicit and to identify the source of flow (i.e., sanitary, washwater, industrial, groundwater, etc.). As the various flow identification and trackdown analyses were conducted, it soon became evident that a number of the parameters analyzed simply did not provide a hard indicator for source identification. In some instances, such as copper, detections at a wide range of concentrations were prevalent in all samples collected, tap water and groundwater included. In other cases, the parameter just did not come into play for source identification. Ultimately, twelve parameters were selected for the IDDE guidance document: temperature; pH; conductivity; E. coli; ammonia; nitrate; fluoride; total chlorine; potassium; detergents; phosphorous; and, turbidity.

To achieve the goal of determining cost-effective chemical analyses procedures, the project entailed use of simple kits and colorimetric approaches. The analytical methods were inexpensive and easy to use (detailed in Section 2.7). To confirm the reliability and accuracy of the analytical methods a variety of QA/QC assessments were applied and these indicated the methods provided a level of accuracy that was conducive to their application for illicit discharge detection and trackdown sampling purposes. The results were particularly encouraging for the E. coli analysis. Care should be taken with the photometric analyses and if extreme values are measured the sample should be re-analyzed in triplicate.

Following the success of the demonstration project, the WNYSC utilized grant funds to purchase equipment and supplies for outfall sampling and in-house chemical analyses for its entire membership. These outfall sampling kits are comprehensive in that everything required for an illicit discharge trackdown investigation is included.

Through its partnership with the WNYSC membership, the Erie County Department of Environment and Planning coordinated the purchase, assembly and delivery of the outfall kits. In addition, field training for MS4 staff on sampling procedures, laboratory training for sample analysis, results interpretation guidance, and trackdown and elimination strategies are currently underway. Erie County Department of Environment and Planning will continue to be a resource for the MS4 project partners for assistance with interpretation of analytical results, trackdown procedures, and source identification.

While the two primary objectives of the study were achieved, in reality it is often difficult to progress to the next level, that being effective elimination of the source of illicit connection. The foremost reason for this is a lack of financial resources for many of the MS4s. Socio-economic variability among and within the MS4 communities is considerable. At the municipal level, this translates into challenges to dedicate manpower and/or equipment, at a minimum. More costly constraints would be the need for large scale infrastructure improvements or re-construction projects to eliminate illicit discharges. On a smaller scale, similar financial limitations may exist for residential property owners when corrective action is the responsibility of a property owner. Simply put, medium-high density residential areas are common among MS4 communities and often have a large proportion of economically disadvantaged sections within them. Stormwater utilities have been successfully established in some states to help address financial concerns (e.g., Brisman 2001) but a recent study completed for the WNYSC found a general resistance to this approach at the MS4 and public levels in Western New York (Wendel Duchscherer *et al.* 2010). Specifically, public consultation suggested that a stormwater utility was perceived as another layer of government with increased fees and less local control.

Finally, although this study was site-specific to Western New York, in fact, many of the trackdown techniques discussed herein could be used at locations throughout North America and even globally since frequently there are common water quality concerns with respect to contaminant type and source. The laboratory methods used in this study were cost-effective and robust, making them particularly attractive for developing countries and we have applied these methods successfully in Cambodia, Thailand, and Malaysia. The trackdown approach also is flexible enough to accommodate local knowledge about specific contaminants of concern and these could be added, as needed, to help identify sources of illicit connections.

## Acknowledgements

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