LITERATURE REVIEW ON MICROBIAL SOURCE TRACKING WITH OPTICAL BRIGHTENERS

March 29, 2010

Steven Yergeau

Literature Review

The United States Environmental Protection Agency (USEPA) has reported there are over 44,000 impaired waters and over 75,000 associated water quality impairments in the country (USEPA 2008). Of these impairments, 10,662 are caused by pathogens (primarily bacteria). The Clean Water Act mandates that state agencies must develop a total maximum daily load (TMDL) and a watershed management plan for impaired water bodies to improve water quality (USEPA 1997). A TMDL is a calculation of the maximum pollution a water body can receive from the sum of point and non-point sources in the watershed and remain in compliance with water quality standards (USEPA 1991). For New Jersey, 270 TMDLs have been approved by the USEPA for fecal coliform pollution. Once a TMDL is established, a watershed protection plan must be developed and adopted to reduce contaminant sources in order to attain TMDL goals (USEPA 2008). This plan must include source identification and development of strategies for mitigation of these sources.

Source identification of pollutants in a watershed is accomplished via field sampling at several locations under various hydrological conditions within the area of concern, numerical simulations, or a combination of these. Field measurements can be used directly to identify sources, or to calibrate numerical simulations used to identify those sources. Field measurements, however, are often costly and cannot achieve spatial or temporal resolutions
necessary to accurately represent all watershed processes, nor may they be used to assess impacts due to mitigation activities.

Most often when determining pathogen contamination, indicator organisms are monitored (Simpson et al. 2002; Scott et al. 2002; Stoeckel and Harwood 2007). Fecal coliform or \textit{E. coli} are typically sampled to indicate the presence or absence of contamination from fecal matter. Using an indicator organism to solve fecal contamination problems in surface waters presents several challenges. First, fecal coliform is solely an indicator of fecal pollution and not a direct measure of fecal contamination. Other methods may be appropriate for determining actual concentrations of bacteria in surface waters. Second, fecal coliform does not identify sources of fecal pollution, only its presence. Therefore, it is imperative that prior to any remediation strategy, potential sources of pollution be identified. This will target efforts to efficiently use resources (time, effort, money) so that maximum benefits to water quality can be achieved and contamination effectively reduced.

There are a variety of sources from which fecal contamination can originate. Potential sources of fecal coliform contamination include failing sanitary sewer or septic systems, wildlife and waterfowl. Agricultural practices including the spreading of manure and its use as a fertilizer could potentially lead to runoff of fecal-related pathogens. Livestock access to waterways can also lead to direct introductions to streams. Improper disposal of domestic pet wastes is also a potential source of pathogen pollution. Recently, dumpsters have been recognized as a source of pathogens in stormwater runoff due to birds using dumpsters as feeding locations; this is also true of rodents (Central Coast Water Board 2006).

Microbial source tracking (MST) is a series of methods employed to determine sources of microbial pollution, whether from bacteria or other pathogens such as viruses and protozoans
MST is the concept of applying microbiological, genotypic (molecular), phenotypic (biochemical), and chemical methods (e.g., caffeine or optical brighteners) to identify the origin of fecal pollution (Simpson et al. 2002; Scott et al. 2002; Stoeckel and Harwood 2007). MST techniques typically report fecal contamination source as a percentage of targeted bacteria. One of the most promising targets for MST is \textit{Bacteroides}, a genus of obligately anaerobic, gram-negative bacteria that are found in all mammals and birds. \textit{Bacteroides} comprise 30\% to 40\% of the amount of bacteria in feces and 10\% of the fecal mass (Layton et al. 2006). Due to large quantities of \textit{Bacteroides} in feces, they are an ideal target organism for identifying fecal contamination (Layton et al. 2006). In addition, \textit{Bacteroides} have been recognized as having broad geographic stability and distribution in target host animals and are a promising microbial species for differentiating fecal sources (USEPA 2005; Dick et al. 2005; Layton et al. 2006). For more a more detailed discussion on MST methodology and its applications, see Simpson et al. (2002), Scott et al. (2002), and Stoeckel and Harwood (2007).

While reviews of MST methods have been performed, these have focused primarily on the microbiological, genotypic, and phenotypic methods of tracking fecal contamination and only barely touch upon the chemical methods. Hagedorn and Weisberg (2009) present the only known peer-reviewed assessment of chemical methods for fecal source tracking. Included in their review are source identification methods using pharmaceuticals and personal care products, fecal sterols/stanols, optical brighteners/fluorescent whitening agents, and caffeine. The various advantages and disadvantages to each method are presented, as well as evaluation criteria to determine if these compounds are ideal for use in source tracking of fecal pollution (Hagedorn and Weisberg 2009). Investigation into chemical methods of MST is required to track down
areas of detected human sources of pathogenic contamination so that point sources within a watershed can be adequately identified and addressed during the watershed planning process.

One promising chemical source tracking method to identify human bacterial contamination in surface water is the fluorometric detection of optical brighteners. Optical brighteners are compounds added to laundry detergents and soaps, and have no natural sources (Boving et al. 2004; Tavares et al. 2008). These compounds enter an excited state when exposed to UV light (360-365nm range) and emit light in the blue range (400-440nm) (Tavares et al. 2008). Fluorescence of these compounds can be measured with a fluorometer. Because household plumbing systems combine effluent from washing machines and toilets, optical brighteners are associated with human sewage in sewer lines, septic systems and wastewater treatment plants (Hartel et al. 2007). Their presence in surface water, therefore, can be an indicator of illicit connections, leaking pipes, or contamination from wastewater. Successful use of optical brighteners as a means of tracking sources of human fecal contamination has been used in North Carolina (Tavares et al 2008), Georgia (McDonald et al. 2006; Hartel et al. 2008), and Georgia and Puerto Rico (Hartel et al. 2007). There have been a few studies that show good correlation between optical brightener and fecal indicator bacteria (Hagedorn and Weisberg 2009). One characteristic of optical brighteners that make it attractive in source tracking is its low cost (McDonald et al. 2006; Hartel et al. 2007; Hartel et al. 2008). Optical brightener detection via fluorometry also has a high degree of sensitivity, accuracy and repeatability, when compared to other chemical methods of fecal source tracking (Hagedorn and Weisberg 2009).

There are a few issues that surround using optical brighteners in MST, however. Natural substances found in streams, such as humic acids, can also fluoresce which confounds interpretation of fluorescence data (Boving et al. 2004). In addition, the longevity of optical
brighteners within streams is unknown. A study in Rhode Island found that interference of humic acids in the stream limited the value of this method of source tracking to the local vicinity of the source (Boving et al. 2004). In California, decay of optical brighteners due to sunlight was evaluated for a variety of detergents (Cao et al. 2009). It was found that, depending on detergent manufacturer, after 30 minutes of exposure to UV light fluorescence was reduced by 13.2% to 71.7% (Cao et al. 2009). In addition, discharges that contain optical brighteners are non-continuous. Sporadic grab sampling may miss discharges from human sources and continuous monitoring may be necessary to accurately determine levels of optical brighteners present.

In order to overcome some of these concerns and gain a better understanding of the sources of contaminants of human origin, tiered approaches can be applied to source tracking studies. Tiered approaches study multiple levels, multiple scales, or measuring multiple parameters with increasing focus as one moves through each tier. This has been recommended by investigators as a successful means of tracking fecal contamination sources (Boehm et al. 2003; Stewart et al. 2003; Noble et al. 2006; Cao et al. 2009). The tiered approach can aid watershed management in abating the most significant sources of fecal bacteria (or other pollutant of concern) (Noble et al. 2006). Objectives and tasks are developed in this approach so that appropriate management practices are implemented and resources are allocated efficiently and economically throughout a watershed.

A short literature search has not found studies where a tiered approach was conducted using optical brighteners as one of the tiers. This represents a gap in the ability to track sources of fecal contamination. To help fill this need, a proposed scheme for determining human sources using optical brighteners as part of the Musquapsink Brook Watershed restoration plan is outlined below:
TITLE: Source Determination of Human-Related Fecal Contamination: A Tiered Approach for Watershed Management

Tier 1: Screening for fecal coliform contamination

- Surface water quality sampling performed during both wet and dry weather to determine the presence of fecal contamination.

Tier 2: Location of human and non-human fecal “hot spots”

- MST sampling using qPCR analysis to differentiate between human and non-human sources of bacterial loadings to surface waters.

Tier 3: Source tracking with optical brighteners

- Use fluorometric analysis to detect the presence of optical brighteners in the stream and possibly correlate with dissolved oxygen measurements in order to verify sewer/septic discharges.

Optical brighteners show promise as a method of MST in watershed restoration planning but additional field sampling and comparisons with other methods need to be conducted to determine their effectiveness in watershed management.
REFERENCES


Central Coast Water Board. 2006. Total Maximum Daily Loads for Pathogens in Aptos and Valencia Creeks, including Trout Gulch, Santa Cruz, California. San Luis Obispo, CA.


