Joint Work Group Meeting:
Research, Monitoring, and Watershed Outreach
DRAFT Meeting Agenda
Thursday, March 7, 2013
10:00 AM to noon
H-GAC Conference Room C, Second Floor

Call to Order/Welcome/Introductions

Review Notes from Last Year

Update on I-Plan Approval Process

- TCEQ approval: January 30, 2013
- Summary of changes to the relevant sections

Review Annual Report format

Review Implementation Progress--Items identified in the discussions will be included in the annual report.

Implementation Strategy 9.0: Monitoring and I-Plan Revision

- Activities
    - 9.1: Continue to Utilize Ambient Water Quality Monitoring and Data Analysis
        - 9.1.1: Continue to Utilize Clean Rivers Program
        - 9.1.2: Test for additional indicators
    - 9.2: Conduct and Coordinate Non-Ambient Water Quality Monitoring
        - 9.2.1: Create and use a regional non-ambient QAPP
        - 9.2.2: Create and use a regional non-ambient monitoring database
    - 9.3: Create and Maintain a Regional Implementation Activity Database (Rachel will provide a report)
    - 9.4: Assess Monitoring Results and Modify I-Plan (This activity will be discussed in-depth at the Coordination & Policy workgroup meeting on March 28, 2013.)

Implementation Strategy 10.0: Research

- Research Priorities:
    - 10.1: Evaluate the Effectiveness of Stormwater Implementation Activities
    - 10.2: Further Evaluate Bacteria Persistence and Regrowth
    - 10.3: Determine Appropriate Indicators
    - 10.4: Additional Research Topics

Implementation Strategy 11.0: Geographic Priority Framework

- Activity:
    - 11.1: Consider Recommended Criteria When Selecting Geographic Locations for Projects

Identify Activities on Which to Focus Efforts

Identify Possible Revisions to the I-Plan—The work group may choose to recommend changes to the I-Plan for consideration by the BIG at its annual meeting.

Confirm Recommendations to the BIG for Annual Report

The workgroup must make recommendations to the BIG regarding activities related to the work group. Using a sample form conceptually approved by the BIG, meeting participants will consider the following:

- Status of activities (not started/in progress/complete, ahead/on/behind schedule)
- Progress
- Achievements
- Focus
- Revisions

Adjourn

BIG Annual Meeting: Tuesday, May 14, 2013
Coordination & Policy work group meeting: March 28, 2013, 10:00 AM

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Implementation Strategy 9.0:
Monitoring & I-Plan Revision

Work Group Recommendations

Meeting March 7, 2013. XX attendees, including X BIG members and X alternates.

Progress	Progress has been adequate. Activity has begun and is ongoing for each of the implementation activities.
Achievements	Ambient water quality monitoring has continued, and analysis capabilities have grown. A non-ambient QAPP has been drafted. HCFCD continues to develop their non-ambient BMP database. H-GAC has developed and tested a regional implementation database. [Overall, bacteria levels have continued to decline.]
Focus	Focus in the coming year will on continuing ambient water quality monitoring and analysis and strengthening implementation tracking a coordinating non-ambient efforts.
Revisions	The work group does not recommend changes to the I-Plan.

Implementation Strategy 10.0: **Research**

Work Group Recommendations

Meeting March 7, 2013. XX attendees, including X BIG members and X alternates.

Progress	Progress has been adequate. Activity has begun or is ongoing for each of the research priorities.
Achievements	H-GAC has applied for grant funding to look at bacteria persistence and regrowth. The HCFCD's BMP database shows promise for looking at stormwater BMP effectiveness. H-AC has been able to begin to analyze the relationship between *E. coli* and Enterococcus as a means to look at appropriate indicators.
Focus	Focus in the coming year will be on continuing existing programs and projects and on securing funding for additional projects.
Revisions	The work group does not recommend changes to the I-Plan.

Implementation Strategy 11.0: **Geographic Priorities**

Work Group Recommendations

Meeting March 7, 2013. XX attendees, including X BIG members and X alternates.

Progress	Progress has been adequate. Activity has begun and is ongoing.
Achievements	Seven-year geometric means for each of the assessment units identified in the 2012 "Most Wanted List" (of stations with the highest bacteria levels) have gone down, some significantly. Stakeholder response has been positive and action-oriented.
Focus	Focus in the coming year will be on continuing to address the "Most Wanted List," building on the momentum of stakeholders to address specific problem areas, and on beginning to address the "Most Likely to Succeed List" (MLSL, stations with bacteria levels closest to meeting the standards). Most of the MLSL stations saw increase bacteria levels.
Revisions	The work group does not recommend changes to the I-Plan.

General Topics

Francy, Donna S. et al. 2013. Predictive Models for *Escherichia coli* Concentrations at Inland Lake Beaches and Relationship of Model Variables to Pathogen Detection. Applied and Environmental Microbiology 79, 1676-1688.

Predictive models, based on environmental and water quality variables, have been used to improve the timeliness and accuracy of recreational water quality assessments, but their effectiveness has not been studied in inland waters. Sampling at eight inland recreational lakes in Ohio was done in order to investigate using predictive models for *Escherichia coli* and to understand the links between *E. coli* concentrations, predictive variables, and pathogens. Based upon results from 21 beach sites, models were developed for 13 sites, and the most predictive variables were rainfall, wind direction and speed, turbidity, and water temperature. Models were not developed at sites where the *E. coli* standard was seldom exceeded. Models were validated at nine sites during an independent year. At three sites, the model resulted in increased correct responses, sensitivities, and specificities compared to use of the previous day's *E. coli* concentration (the current method). Drought conditions during the validation year precluded being able to adequately assess model performance at most of the other sites. Cryptosporidium, adenovirus, eaeA (*E. coli*), ipaH (Shigella), and spvC (Salmonella) were found in at least 20% of samples collected for pathogens at five sites. The presence or absence of the three bacterial genes was related to some of the model variables but was not consistently related to *E. coli* concentrations. Predictive models were not effective at all inland lake sites; however, their use at two lakes with high swimmer densities will provide better estimates of public health risk than current methods and will be a valuable resource for beach managers and the public.

Duris, Joseph W.,et al. 2013. Factors related to occurrence and distribution of selected bacterial and protozoan pathogens in Pennsylvania streams. Water Research 47, 300-314.

The occurrence and distribution of fecal indicator bacteria (FIB) and bacterial and protozoan pathogens are controlled by diverse factors. To investigate these factors in Pennsylvania streams, 217 samples were collected quarterly from a 27-station water-quality monitoring network from July 2007 through August 2009. Samples were analyzed for concentrations of Escherichia coli (EC) and enterococci (ENT) indicator bacteria, concentrations of Cryptosporidium oocysts and Giardia cysts, and the presence of four genes related to pathogenic types of EC (eaeA, stx2, stx1, rfbO157) plus three microbial source tracking (MST) gene markers that are also associated with pathogenic ENT and EC (esp, LTIIa, STII). Water samples were concurrently analyzed for basic water chemistry, physical measures of water quality, nutrients, metals, and a suite of 79 organic compounds that included hormones, pharmaceuticals, and antibiotics. For each sample location, stream discharge was measured by using standardized methods at the time of sample collection, and ancillary sample site information, such as land use and geological characteristics, was compiled. Samples exceeding recreational water quality criteria were more likely to contain all measured pathogen genes but not Cryptosporidium or Giardia (oo)cysts. FIB and Giardia density and frequency of eaeA gene occurrence were significantly related to season. When discharge at a sampling location was high (>75th percentile of daily mean discharge), there were greater densities of FIB and Giardia, and the stx2, rfbO157, STII, and esp genes were found more frequently than at other discharge conditions. Giardia occurrence was likely related to nonpoint sources, which are highly influential during seasonal overland trans- port resulting from snowmelt and elevated precipitation in late winter and spring in Pennsylvania. When MST markers of human, swine, or bovine origin were present, samples more frequently carried the eaeA, stx2, stx1, and rfbO157 genes, but no genes were related exclusively to an individual MST marker. The human source pharmaceuticals (HSPs) acetaminophen and caffeine were correlated with Giardia, and the presence of HSPs proved to be more useful than MST markers in distinguishing the occurrence of Giardia. The HSPs caffeine and carbamazepine were correlated with the sum total of pathogen genes detected in a sample, demonstrating the value of using HSPs as an indicator of fecally derived pathogens. Sites influenced by urban land use with less forest were more likely to have greater FIB and Giardia densities and sum of the array of pathogen genes. Sites dominated by shallow carbonate bedrock in the upstream catchment were likely to have greater FIB densities and higher sum totals of pathogen genes but no correlation with Giardia detection. Our study provides a range of specific environmental, chemical, geologic, and land-use variables related to occurrence and distribution of FIB and selected bacterial and protozoan pathogens in Pennsylvania streams. The information presented could be useful for resource managers in understanding bacterial and protozoan pathogen occurrence and their relation to fecal indicator bacteria in similar settings.

Gonzalez, Raul A., et al. 2012. Application of empirical predictive modeling using conventional and alternative fecal indicator bacteria in eastern North Carolina waters. Water Research 46, 5781-5882.

Coastal and estuarine waters are the site of intense anthropogenic influence with concomitant use for recreation and seafood harvesting. Therefore, coastal and estuarine water quality has a direct impact on human health. In eastern North Carolina (NC) there are over 240 recreational and 1025 shellfish harvesting water quality monitoring sites that are regularly assessed. Because of the large number of sites, sampling frequency is often only on a weekly basis. This frequency, along with an 18e24 h incubation time for fecal indicator bacteria (FIB) enumeration via culture-based methods, reduces the efficiency of the public notification process. In states like NC where beach monitoring resources are limited but historical data are plentiful, predictive models may offer an improvement for monitoring and notification by providing real-time FIB estimates. In this study, water samples were collected during 12 dry (n ¼ 88) and 13 wet (n ¼ 66) weather events at up to 10 sites. Statistical predictive models for *Escherichia coli* (EC), enterococci (ENT), and members of the Bacteroidales group were created and subsequently validated. Our results showed that models for EC and ENT (adjusted R2 were 0.61 and 0.64, respectively) incorporated a range of antecedent rainfall, climate, and environmental variables. The most important variables for EC and ENT models were 5-day antecedent rainfall, dissolved oxygen, and salinity. These models successfully predicted FIB levels over a wide range of conditions with a 3% (EC model) and 9% (ENT model) overall error rate for recreational threshold values and a 0% (EC model) overall error rate for shellfish threshold values. Though modeling of members of the Bacteroidales group had less predictive ability (adjusted R2 were 0.56 and 0.53 for fecal

Bacteroides spp. and human *Bacteroides* spp., respectively), the modeling approach and testing provided information on Bacteroidales ecology. This is the first example of a set of successful statistical predictive models appropriate for assessment of both recreational and shellfish harvesting water quality in estuarine waters

Viau, Emily J. et al. 2011. Bacterial pathogens in Hawaiian coastal streams – Associations with fecal indicators, land cover, and water quality. Water Research 45, 3279 - 3290.

This work aimed to understand the distribution of five bacterial pathogens in O'ahu coastal streams and relate their presence to microbial indicator concentrations, land cover of the surrounding watersheds, and physical-chemical measures of stream water quality. Twenty-two streams were sampled four times (in December and March, before sunrise and at high noon) to capture seasonal and time of day variation. Salmonella, Campylobacter, Staphylococcus aureus, Vibrio vulnificus, and V. parahaemolyticus were widespread -12 of 22 O'ahu streams had all five pathogens. All stream waters also had detectable concentrations of four fecal indicators and total vibrio with log mean ± standard deviation densities of 2.2 ± 0.8 enterococci, 2.7 ± 0.7 *Escherichia coli*, 1.1 ± 0.7 Clostridium perfringens, 1.2 ± 0.8 F(+) coliphages, and 3.6 ± 0.7 total vibrio per 100 ml. Bivariate associations between pathogens and indicators showed enterococci positively associated with the greatest number of bacterial pathogens. Higher concentrations of enterococci and higher incidence of Campylobacter were found in stream waters collected before sunrise, suggesting these organisms are sensitive to sunlight. Multivariate regression models of microbes as a function of land cover and physical-chemical water quality showed positive associations between Salmonella and agricultural and forested land covers, and between S. aureus and urban and agricultural land covers; these results suggested that sources specific to those land covers may contribute these pathogens to streams. Further, significant associations between some microbial targets and physical-chemical stream water quality (i.e., temperature, nutrients, turbidity) suggested that organism persistence may be affected by stream characteristics. Results implicate streams as a source of pathogens to coastal waters. Future work is recommended to determine infectious risks of recreational waterborne illness related to O'ahu stream exposures and to mitigate these risks through control of land-based runoff sources.

Blaustein, R.A., et al. 2013. *Escherichia coli* survival in waters: Temperature dependence. Water Research, 47, 569-578.

Knowing the survival rates of water-borne Escherichia coli is important in evaluating microbial contamination and making appropriate management decisions. *E. coli* survival rates are dependent on temperature, a dependency that is routinely expressed using an analogue of the Q10 model. This suggestion was made 34 years ago based on 20 survival curves taken from published literature, but has not been revisited since then. The objective of this study was to re-evaluate the accuracy of the Q10 equation, utilizing data accumulated since 1978. We assembled a database of 450 *E. coli* survival datasets from 70 peer- reviewed papers. We then focused on the 170 curves taken from experiments that were performed in the laboratory under dark conditions to exclude the effects of sunlight and other field factors that could cause additional variability in results. All datasets were tabulated dependencies “log concentration vs. time.” There were three major patterns of inactivation: about half of the datasets had a section of fast log-linear inactivation followed by a section of slow log-linear inactivation; about a quarter of the datasets had a lag period followed by log-linear inactivation; and the remaining quarter were approximately linear throughout. First-order inactivation rate constants were calculated from the linear sections of all survival curves and the data grouped by water sources, including waters of agricultural origin, pristine water sources, groundwater and wells, lakes and reservoirs, rivers and streams, estuaries and seawater, and wastewater. Dependency of *E. coli* inactivation rates on temperature varied among the water sources. There was a significant difference in inactivation rate values at the reference temperature between rivers and agricultural waters, wastewaters and agricultural waters, rivers and lakes, and wastewater and lakes. At specific sites, the Q10 equation was more accurate in rivers and coastal waters than in lakes making the value of the Q10 coefficient appear to be site-specific. Results of this work indicate possible sources of uncertainty to be accounted for in watershed-scale microbial water quality modeling.

Lopez-Roldan, et al. 2012. On-line bacteriological detection in water. Trends in Analytical Chemistry 12, 46-57.

Microorganism contamination is a permanent concern in a wide range of fields, including the water-treatment, food and pharmaceutical industries, in which fast detection is critical to prevent microbial outbreaks. In water monitoring, current procedures for water-quality analysis are based on periodic sampling and detection by culture methods, which are slow, requiring 24–48 h for completion, so that, when first results reach the decision-takers and trigger an alarm, significant time has already passed and the population may have been exposed to a health hazard. There is a need for rapid, reliable detection of contaminants in a broad spectrum of water-management situations. For real-time detection, on-line monitoring seems to be the ideal approach, but the need to adjust the available techniques to autonomous operation and the optimization of response time are substantial challenges. This review presents the findings of an identification study about the state-of-the-art of technologies and commercial devices for on-line biomonitoring of water quality, specifically for the detection of fecal contamination. We also include studies dealing with verification or use of these devices.

Surbeck, Christine Q., et al. 2012. Ecological control of fecal indicator bacteria in an urban stream. Environmental Science and Technology 44, 631-677.

Fecal indicator bacteria (FIB) have long been used as a marker of fecal pollution in surface waters subject to point source and non-point source discharges of treated or untreated human waste. In this paper, we set out to determine the source(s) of elevated FIB concentrations in Cucamonga Creek, a concrete-lined urban stream in southern

California. Flow in the creek consists primarily of treated and disinfected wastewater effluent, mixed with relatively smaller but variable flow of runoff from the surrounding urban landscape. Dry and wet weather runoff contributes nearly 100% of FIB loading to Cucamonga Creek, while treated wastewater contributes significant loading of nutrients, including dissolved organic carbon (DOC), phosphorus, nitrate, and ammonium. FIB concentrations are strongly positively correlated with DOC concentration in runoff (Spearman's F g 0.66, P e 0.037), and microcosm studies reveal that the survival of *Escherichia coli* and enterococci bacteria in runoff is strongly dependent on the concentration of both DOC and phosphorus. Below threshold concentrations of 7 and 0.07 mg/L, respectively, FIB die off exponentially (die-off rate 0.09 h-1). Above these thresholds, FIB either grow exponentially (growth rate 0.3 h-1) or exhibit a periodic steady-state in which bacterial concentrations fluctuate around some mean value. The periodic steady-state pattern is consistent with a Lotka-Volterra predator-prey oscillation model, and the clearance rate (20 µL predator-1 h-1) obtained by fitting the model to our data is consistent with the hypothesis that predacious protozoa regulate FIB concentrations in runoff at high DOC concentrations. Collectively, these results indicate that FIB impairment of Cucamonga Creek is best viewed as an ecological phenomenon characterized by both bottom- up and top-down control.

Enns, Amber A. et al. 2012. Spatial and temporal variation in indicator microbe sampling is influential in beach management decisions. Water Research 46, 2237-2246.

Fecal indicator microbes, such as enterococci, are often used to assess potential health risks caused by pathogens at recreational beaches. Microbe levels often vary based on collection time and sampling location. The primary goal of this study was to assess how spatial and temporal variations in sample collection, which are driven by environmental parameters, impact enterococci measurements and beach management decisions. A secondary goal was to assess whether enterococci levels can be predictive of the presence of Staphylococcus aureus, a skin pathogen. Over a ten-day period, hydrometeorologic data, hydrodynamic data, bather densities, enterococci levels, and S. aureus levels including methicillin-resistant S. aureus (MRSA) were measured in both water and sand. Samples were collected hourly for both water and sediment at knee-depth, and every 6 h for water at waist-depth, supratidal sand, intertidal sand, and waterline sand. Results showed that solar radiation, tides, and rainfall events were major environmental factors that impacted enterococci levels. S. aureus levels were associated with bathing load, but did not correlate with enterococci levels or any other measured parameters. The results imply that frequencies of advisories depend heavily upon sample collection policies due to spatial and temporal variation of enterococci levels in response to environmental parameters. Thus, sampling at different times of the day and at different depths can significantly impact beach management decisions. Additionally, the lack of correlation between S. aureus and enterococci suggests that use of fecal indicators may not accurately assess risk for some pathogens.

Nova, Ana, ,et al. 2013. Antibiotic resistance, antimicrobial residues and bacterial community composition in urban wastewater. Water Research 47, 1875-1887

This study was based on the hypothesis that the occurrence of antimicrobial residues and antibiotic resistant bacteria in the sewage could be correlated with the structure and composition of the bacterial community and the antibiotic resistance loads of the final effluent. Raw and treated wastewater composite samples were collected from an urban treatment plant over 14 sampling dates. Samples were characterized for the i) occurrence of tetracyclines, penicillins, sulfonamides, quinolones, triclosan, arsenic, cadmium, lead, chromium and mercury; ii) antibiotic resistance percentages for tetracycline, sulfameth- oxazole, ciprofloxacin and amoxicillin and iii) 16S rRNA gene-DGGE patterns. The data of corresponding samples, taking into account the hydraulic residence time, was analyzed using multivariate analysis. Variations on the bacterial community structure of the final effluent were significantly correlated with the occurrence of tetracyclines, penicillins, sulfonamides, quinolones and triclosan in the raw inflow. Members of the class Epsilonproteobacteria presented positive correlations with those antimicrobials, whereas negative correlations were observed with Beta and Gammaproteobacteria and Firmicutes. Antibiotic resistance percentages presented different trends of variation in heterotrophs/enterobacteria and in enterococci, varied over time and after wastewater treatment. Antibiotic resistance was positively correlated with the occurrence of tetracyclines residues and high temperature. A relationship between antibiotic residues, bacterial community structure and composition and antibiotic resistance is demonstrated. Further studies, involving more wastewater treatment plants may help to elucidate this complex relationship.

Bacteria in Stormwater

Rowny, Jakob G. and Jill R. Stewart. 2012. Characterization of nonpoint source microbial contamination in an urbanizing watershed serving as a municipal water supply. Water Research 46,6143-6153.

Inland watersheds in the southeastern United States are transitioning from agricultural and forested land uses to urban and exurban uses at a rate greater than the national average. This study sampled creeks representing a variety of land use factors in a rapidly urbanizing watershed that also serves as a drinking water supply. Samples were collected bimonthly under dry-weather conditions and four times during each of three storm events and assessed for microbial indicators of water quality. Concentrations of fecal indicator bacteria (FIB) including fecal coliforms and *Escherichia coli* were measured using standard membrane filtration techniques. Results showed that FIB concentrations varied between 100 and 104 colony forming units (CFU) per 100 mL. An analysis of variance (ANOVA) showed that FIB were generally higher in more developed watersheds ($p < 0.01$). Concentrations were also significantly greater during storm events than during dry- weather conditions ($p < 0.02$), although concentrations demonstrated both intra and inter-storm variability. These results indicate that the magnitude of microbial contamination is influenced by intensity of watershed development, streamflow and antecedent precipitation. Dry-weather FIB loads showed considerable seasonal variation, but the average storm event delivered contaminant loads equivalent to months of dry-weather loading. Analysis of intra-storm loading patterns provided little evidence to support “first-flush” loading of either FIB, results that are consistent with environmental reservoirs of FIB. These findings demonstrate that single sampling monitoring efforts are inadequate to capture the variability of microbial contaminants in a watershed, particularly if sampling is conducted during dry weather. This study also helps to identify timing and conditions for public health vulnerabilities, and for effective management interventions.

McCarthy,D.T., et al. 2012. Intra-event variability of *Escherichia coli* and total suspended solids in urban stormwater runoff. Water Research 46, 6661-6670.

Sediment levels are important for environmental health risk assessments of surface water bodies, while faecal pollution can introduce significant public health risks for users of these systems. Urban stormwater is one of the largest sources of contaminants to surface waters, yet the fate and transport of these contaminants (especially those microbiological) have received little attention in the literature. Stormwater runoff from five urbanized catchments were monitored for pathogen indicator bacteria and total suspended solids in two developed countries. Multiple discrete samples were collected during each storm event, allowing an analysis of intra-event characteristics such as initial concentration, peak concentration, maximum rate of change, and relative confidence interval. The data suggest that a catchment's area influences pollutant characteristics, as larger catchments have more complex stormwater infrastructure and more variable pollutant sources. The variability of total suspended solids for many characteristics was similar to *Escherichia coli*, indicating that the variability of *E. coli* may not be substantially higher than that of other pollutants as initially speculated. Further, variations in *E. coli* appeared to be more commonly correlated to antecedent climate, while total suspended solids were more highly correlated to rainfall/runoff characteristics. This emphasizes the importance of climate on microbial persistence and die off in urban systems. Discrete intra-event concentrations of total suspended solids and, to a lesser extent *E. coli*, were correlated to flow, velocity, and rainfall intensity (adjusted by time of concentrations). Concentration changes were found to be best described by adjusted rainfall intensity, as shown by other researchers. This study has resulted in an increased understanding of the magnitude of intra-event variations of total suspended solids and *E. coli* and what physical and climatic parameters influence these variations.

Sidhu, J.P.S., et al. 2012. Prevalence of human pathogens and indicators in stormwater runoff in Brisbane, Australia. Water Research 46, 6652-6660.

Elevated numbers of enteric pathogens in the receiving waters following a storm event can be a serious public health concern. The purpose of this study was to conduct a preliminary investigation into the presence of human pathogens of concern in urban stormwater runoff. The involvement of a human sewage as a potential source of contamination was also investigated by using microbial source tracking methods. Water samples (20 L) were collected after storm events and during the dry weather from six sites in Brisbane, Australia. Collected samples were analyzed for fecal indicator bacteria (FIB), and then concentrated using hollow fiber ultrafiltration followed by molecular detection of selected enteric pathogens. The levels of FIB were found to frequently exceed the upper limit of Australian guidelines for managing risks in recreational water, during the dry periods and by further several orders of magnitude in the stormwater runoff. *Enterococcus* spp. Numbers as high as 3 x 104 100 mL-1 were detected in the stormwater runoff at the Fitzgibbon site. Human adenovirus and polyomavirus were frequently detected from all six sampling sites during wet and dry weather conditions suggesting their wide spread presence in the urban aquatic environments. Campylobacter jejuni, Campylobacter coli and Salmonella enterica were also detected during both dry and wet weather conditions. Presence of human-specific HF183 Bacteroides marker in most of the samples tested suggests ubiquitous sewage contamination in the urban environment. Since stormwater runoff routinely contains high numbers of FIB and other enteric pathogens, some degree of treatment of captured stormwater would be required if it were to be used for non-potable purposes

__Microbial Source Tracking and Alternative Indicators__

Yiping,Cao et al. 2013. Effect of platform, reference material, and quantification model on enumeration of *Enterococcus* by quantitative PCR methods. Water Research 47,233-241.

Quantitative polymerase chain reaction (qPCR) is increasingly being used for the quantitative detection of fecal indicator bacteria in beach water. QPCR allows for same-day health warnings, and its application is being considered as an option for recreational water quality testing in the United States (USEPA, 2011. EPA-OW-2011-0466, FRL-9609-3, Notice of Availability of Draft Recreational Water Quality Criteria and Request for Scientific Views). However, transition of qPCR from a research tool to routine water quality testing requires information on how various method variations affect target enumeration. Here we compared qPCR performance and enumeration of enterococci in spiked and environmental water samples using three qPCR platforms (Applied Biosystem StepOnePlus™, the BioRad iQ™5 and the Cepheid SmartCycler® II), two reference materials (lyophilized cells and frozencells on filters) and two comparative CT quantification models (DCT and DDCT). Reference materials exerted the biggest influence, consistently affecting results by approximately 0.5 log10unit. Platform had the smallest effect, generally exerting <0.1 log10 unit difference in final results. Quantification model led to small differences (0.04e0.2 log10 unit) in this study with relatively uninhibited samples, but has the potential to cause as much as 8-fold (0.9 log10 unit) difference in potentially inhibitory samples. Our findings indicate the need for a certified and centralized source of reference materials and additional studies to assess applicability of the quantification models in analyses of PCR inhibitory samples.

Nguyet-Minh Vuong, et al. 2013. Fecal source tracking in water using a mitochondrial DNA microarray. Water Research 47, 16-30.

A mitochondrial-based microarray (mitoArray) was developed for rapid identification of the presence of 28 animals and one family (cervidae) potentially implicated in fecal pollution in mixed activity watersheds. Oligonucleotide probes for genus or subfamilylevel identification were targeted within the 12S rRNA e Val tRNA e 16S rRNA region in the mitochondrial genome. This region, called MI-50, was selected based on three criteria: 1) the ability to be amplified by universal primers 2) these universal primer sequences are present in most commercial and domestic animals of interest in source tracking, and 3) that sufficient sequence variation exists within this region to meet the minimal requirements for microarray probe discrimination. To quantify the overall level of mitochondrial DNA (mtDNA) in samples, a quantitative-PCR (Q-PCR) universal primer pair was also developed. Probe validation was performed using DNA extracted from animal tissues and, for many cases, animal-specific fecal samples. To reduce the amplification of potentially interfering fish mtDNA sequences during the MI-50 enrichment step, a clamping PCR method was designed using a fish-specific peptide nucleic acid. DNA extracted from 19 water samples were subjected to both array and independent PCR analyses. Our results confirm that the mitochondrial microarray approach method could accurately detect the dominant animals present in water samples emphasizing the potential for this methodology in the parallel scanning of a large variety of animals normally monitored in fecal source tracking.

Sims, Atreyee, et al. 2013. Toward the development of microbial indicators for wetland assessment. Water Research 47,1711-1725.

Wetland assessment tools are being developed and employed in wetland monitoring and conservation based on physical, chemical and biological characterization. In wetland biological assessment, various ecological functions have been described by biological traits of an entire species pool that adapts to different types of wetland environments. Since microorganisms play a key role in wetland biogeochemical processes and respond quickly to environmental disturbances, this review paper describes the different macro indicators used in wetland biological monitoring and expands the potential use of microbial indicators in wetland assessment and management. Application of molecular microbial technologies paves the path to an integrated measure of wetland health conditions. For example, the ratio of ammonia-oxidizing archaeal and bacterial populations has been proposed to serve as a microbial indicator of wetland nutrient conditions. The microbial indicators coupled with physical, chemical and other biological parameters are vital to the development of multi-metric index for measuring wetland health conditions. Inclusion of microbial indicators will lead to a more comprehensive wetland assessment for wetland restoration and management practices.

Colford, John M. et al. 2012. Using rapid indicators for *Enterococcus* to assess the risk of illness after exposure to urban runoff contaminated with marine water. Water Research 46, 2176-2186.

BACKGROUND: Traditional fecal indicator bacteria (FIB) measurement is too slow (>18 h) for timely swimmer warnings. OBJECTIVES: Assess relationship of rapid indicator methods (qPCR) to illness at a marine beach impacted by urban runoff. METHODS: We measured baseline and two-week health in 9525 individuals visiting Doheny Beach 2007-08. Illness rates were compared (swimmers vs. non-swimmers). FIB measured by traditional (*Enterococcus* spp. by EPA Method 1600 or Enterolert™, fecal coliforms, total coliforms) and three rapid qPCR assays for *Enterococcus* spp. (Taqman, Scorpion-1, Scorpion-2) were compared to health. Primary bacterial source was a creek flowing untreated into ocean; the creek did not reach the ocean when a sand berm formed. This provided a natural experiment for examining FIB-health relationships under varying conditions. RESULTS: We observed significant increases in diarrhea (OR 1.90, 95% CI 1.29-2.80 for swallowing water) and other outcomes in swimmers compared to non-swimmers. Exposure (body immersion, head immersion, swallowed water) was associated with increasing risk of gastrointestinal illness (GI). Daily GI incidence patterns were different: swimmers (2-day peak) and non-swimmers (no peak). With berm-open, we observed associations between GI and traditional and rapid methods for *Enterococcus*; fewer associations occurred when berm status was not considered. CONCLUSIONS: We found increased risk of GI at this urban runoff beach. When FIB source flowed freely (berm-open), several traditional and rapid indicators were related to illness. When FIB source was weak (berm-closed) fewer illness associations were seen. These different relationships under different conditions at a single beach demonstrate the difficulties using these indicators to predict health risk.

Tambalo, Dinah D, et al. 2012. Persistence of host-associated Bacteriodales gene markers and their quantitative detection in an urban and agricultural mixed prairie watershed. Water Research 46,2891-2904.

Microbial source tracking is an emerging tool developed to protect water sources from faecal pollution. In this study, we evaluated the suitability of real time-quantitative PCR (qPCR) Taqman assays developed for detection of host-associated Bacteroidales markers in a prairie watershed. The qPCR primers and probes used in this study exhibited high accuracy (88-96% sensitivity and ≥ 99% host specificity) in detecting Bacteroidales spp. that are associated with faeces from humans, ruminants, bovines, and horses. The ruminant- and human-associated markers were also found in high concentrations within individual faecal samples, ranging from 3.4 to 7.3 log(10) marker copy numberg(-1) of individual host faeces. Following validation of host sensitivity and specificity, the host-associated Bacteroidales markers were detected in the Qu'Appelle Valley watershed of Saskatchewan, Canada which experiences a diversity of anthropogenic inputs. Concentrations of the ruminant marker were well-correlated with proximity to cattle operations and there was a correlation between the marker and *Escherichia coli* concentrations at these sites. Low concentrations of the human faecal marker were measured throughout the sampling sites, and may indicate a consistent influx of human faecal pollution into the watershed area. Persistence of each of the Bacteroidales host-associated marker was also studied in situ. The results indicated that the markers persist for shorter periods of time (99% decay in <8 days) compared with the conventional *E. coli* marker (99% decay in >15 days), suggesting they are effective at detecting recent faecal contamination events. The levels of Bacteroidales markers and *E. coli* counts did not correlate with the presence of the pathogenic bacteria, Salmonella spp. or Campylobacter spp. detected in the Qu'Appelle Valley. Collectively, the results obtained in this study demonstrated that the qPCR approach for detecting host-associated Bacteroidales spp. markers can be a useful tool in helping to determine host-specific impacts of faecal pollution into a prairie watershed.

Green, Hyatt C., et al. 2011. Differential decay of human faecal *Bacteriodes* in marine and freshwater. Environmental Microbiology 13, 3235-3249.

Genetic markers from Bacteroides and other faecal bacteria are being tested for inclusion in regulations to quantify aquatic faecal contamination and estimate public health risk. For the method to be used quantitatively across environments, persistence and decay of markers must be understood. We measured concentrations of contaminant molecular markers targeting *Enterococcus* and Bacteroides spp. in marine and freshwater microcosms spiked with human sewage and exposed to either sunlight or dark treatments. We used Bayesian statistics with a delayed Chick-Watson model to estimate kinetic parameters for target decay. DNA- and RNA-based targets decayed at approximately the same rate. Molecular markers persisted (could be detected) longer in marine water. Sunlight increased the decay rates of cultured indicators more than those of molecular markers; sunlight also limited persistence of molecular markers. Within each treatment, Bacteroides markers had similar decay profiles, but some Bacteroides markers significantly differed in decay rates. The role of extracellular DNA in persistence appeared unimportant in the microcosms. Because conditions were controlled, microcosms allowed the effects of specific environmental variables on marker persistence and decay to be measured. While marker decay profiles in more complex environments would be expected to vary from those observed here, the differences we measured suggest that water matrix is an important factor affecting quantitative source tracking and microbial risk assessment applications.

Bae, S. and S. Wurtz. 2012. Survival of host-associated bacteroidales cells and their relationship with *Enterococcus* spp., Campylobacter jejuni, Salmonella enterica serovar Typhimurium, and adenovirus in freshwater microcosms as measured by propidium monoazide-quantitative PCR. Applied and Environmental Microbiology 78, 922-32.

The ideal host-associated genetic fecal marker would be capable of predicting the presence of specific pathogens of concern. Flowthrough freshwater microcosms containing mixed feces and inocula of the pathogens Campylobacter jejuni, Salmonella enterica serovar Typhimurium, and adenovirus were placed at ambient temperature in the presence and absence of diurnal sunlight. The total *Enterococcus* DNA increased during the early periods (23 h) under sunlight exposure, even though cultivable *Enterococcus* and DNA in intact cells, as measured by propidium monoazide (PMA), decreased with first-order kinetics during the entire period. We found a significant difference in the decay of host-associated Bacteroidales cells between sunlight exposure and dark conditions (P value < 0.05), whereas the persistence of host-associated Bacteroidales DNA was comparable. The 2-log reduction times of adenovirus were 72 h for sunlight exposure and 99 h for dark conditions with similar decay rate constants (P value = 0.13). The persistences of fecal Bacteroidales cells and Campylobacter cells exposed to sunlight were similar, and host-associated Bacteroidales DNA and waterborne pathogen DNA were degraded at comparable rates (P values > 0.05). Overall, the ratio of quantitative PCR (qPCR) cycle threshold (C(T)) values with and without PMA treatment was indicative of the time elapsed since inoculation of the microcosm with (i) fecal material from different animal sources based on host-associated Bacteroidales and (ii) pure cultures of bacterial pathogens. The use of both PMA-qPCR and qPCR may yield more realistic information about recent sources of fecal contamination and result in improved prediction of waterborne pathogens and assessment of health risk.

Staley, Christopher. 2012. Assessment of sources of human pathogens and fecal contamination in a Florida freshwater lake. Water Research 46, 5799-5812.

We investigated the potential for a variety of environmental reservoirs to harbor or contribute fecal indicator bacteria (FIB), DNA markers of human fecal contamination, and human pathogens to a freshwater lake. We hypothesized that submerged aquatic vegetation (SAV), sediments, and stormwater act as reservoirs and/or provide inputs of FIB and human pathogens to this inland water. Analysis included microbial source tracking (MST) markers of sewage contamination (*Enterococcus faecium* esp gene, human-associated Bacteroides HF183, and human polyomaviruses), pathogens (Salmonella, Cryptosporidium, Giardia, and enteric viruses), and FIB (fecal coliforms, Escherichia coli, and enterococci). Bayesian analysis was used to assess relationships among microbial and physicochemical variables. FIB in the water were correlated with concentrations in SAV and sediment. Furthermore, the correlation of antecedent rainfall and major rain events with FIB concentrations and detection of human markers and pathogens points toward multiple reservoirs for microbial contaminants in this system. Although pathogens and human-source markers were detected in 55% and 21% of samples, respectively, markers rarely coincided with pathogen detection. Bayesian analysis revealed that low concentrations (<45 CFU x 100 ml-1) of fecal coliforms were associated with 93% probability that pathogens would not be detected; furthermore the Bayes net model showed associations between elevated temperature and rainfall with fecal coliform and enterococci concentrations, but not *E. coli*. These data indicate that many under-studied matrices (e.g. SAV, sediment, stormwater) are important reservoirs for FIB and potentially human pathogens and demonstrate the usefulness of Bayes net analysis for water quality assessment.

Gordon, Katrina V. et al. 2013. Relationship of human-associated microbial source tracking markers with Enterococci in Gulf of Mexico Waters. Water Research 47, 996-1004.

Human and ecosystem health can be damaged by fecal contamination of recreational waters. Microbial source tracking (MST) can be used to specifically detect domestic sewage containing human waste, thereby informing both risk assessment and remediation strategies. Previously, an inter-laboratory collaboration developed standardized PCR methods for a bacterial, an archaeal, and a viral indicator of human sewage. Here we present results for two subsequent years of field testing in fresh and salt water by five laboratories across the U.S. Gulf Coast (two in Florida and one each in Mississippi, Louisiana and Texas) using common standard operating procedures (SOPs) developed previously. Culturable enterococci were enumerated by membrane filtration, and PCR was used to detect three MST markers targeting domestic sewage: human-associated Bacteroides (HF183), Methanobrevibacter smithii and human polyomaviruses BK and JC (HPyVs). Detection of sewage markers in surface waters was significantly associated with higher enterococci levels and with exceedance of the recreational water quality standard in four or three regions, respectively. Sewage markers were frequently co-detected in single samples, e.g., M. smithii and HF183 were co-detected in 81% of Louisiana samples, and HPyVs and M. smithii were co-detected in over 40% of southwest Florida and Mississippi samples. This study demonstrates the robustness and inter-laboratory transferability of these three markers for the detection of pollution from domestic sewage in the waters impacting the Gulf of Mexico over a coastal range of over 1000 miles.

Chase,E., J.Hunting, C.Staley,V.J. Harwood. 2012. Microbial source tracking to identify human and ruminant sources of faecal pollution in an ephemeral Florida river. Journal of Applied Microbiology 113, 1396-1406.

Aims: Levels and sources of faecal indicator bacteria (FIB) in an ephemeral Florida river were assessed under different rainfall/flow patterns to explore the effects of rainfall on water quality. Methods and Results: Quantitative PCR for sewage markers [human- associated Bacteroides HF183 and human polyomaviruses (HPyVs)] and PCR for ruminant faecal markers were used to explore contamination sources. *Escherichia coli*, faecal coliform and enterococci levels consistently exceeded recreational water quality criteria, and sediment FIB levels were about 100-fold higher compared with water. HPyVs detections cooccurred with HF183, which was frequently detected near septic systems. Ruminant markers were detected only in livestock-grazing areas. Significantly greater faecal coliform and *E. coli* concentrations were observed under no-flow conditions and the levels of faecal coliforms in water column and sediments were negatively correlated with duration since last rain event. Conclusions: Septic systems and cattle grazing in this watershed contributed to the formation of FIB reservoirs in sediments, which were persistent following prolonged rainfall. Significance and Impact of the Study: Ephemeral water bodies that flow only under the direct influence of recent rainfall are rarely studied. FIB levels in the New River in Florida were greater during dry weather than wet weather, which contrasts with most observations and may be attributed to bacterial reservoirs formed in still pool, sediments and water-saturated soils in this subtropical environment.

Gentry-Shields, Jennifer, et al. 2012. HuBac and nifH source tracking markers display a relationship to land use but not rainfall. Water Research 46, 6163-6174.

Identification of the source of fecal pollution is becoming a priority for states and territories in the U.S. in order to meet water quality standards and to develop and implement total maximum daily loads. The goal of this research was to relate microbial source tracking (MST) assay concentrations to land use and levels of impervious surfaces in order to gauge how increasing development is associated with human fecal contamination in inland watersheds. The concentrations of two proposed MST markers, targeting nifH of *Methanobrevibacter smithii* and HuBac of *Bacteroides* sp., were positively correlated with increasing anthropogenic development and impervious surfaces. Higher concentrations of these MST markers in more urbanized watersheds suggest that increasing development negatively affects water quality. Neither MST marker concentration was correlated with antecedent rainfall levels, and detection of markers did not differ between dry weather and rain events. Water samples were also analyzed for norovirus and enterovirus, but these enteric viruses were rarely detected. These MST results differ from previous studies that have found correlations between traditional fecal indicator bacteria (FIB) and antecedent rainfall. This difference suggests that the MST markers used in this study may be more specific for recent, land-based contamination events as opposed to resuspension of particle-associated organisms in waterways. HuBac was detected in 98% of samples, correlating with fecal coliform and *Escherichia coli* concentrations. The ubiquity of the HuBac marker in our samples suggests that this marker does not provide sufficiently different or additional information than FIB, and it is likely this marker was amplifying non-human targets. The nifH marker was detected in 30% of samples. Less than half of the nifH-positive samples contained levels of fecal coliforms or *E. coli* above regulatory thresholds, suggesting that nifH would be more useful when utilized simultaneously with FIB than in a tiered monitoring strategy. The results of this research suggests that land use factors play an important role in characterizing and mitigating fecal contamination in watersheds.

Korajkic, A., B.D. Badgley, M.J. Brownell and V.J. Harwood. 2009. Application of microbial source tracking methods in a Gulf of Mexico field setting. Journal of Applied Microbiology 107:1518-1527.

Aims: Microbial water quality and possible human sources of faecal pollution were assessed in a Florida estuary that serves shellfishing and recreational activities. Methods and Results: Indicator organisms (IO), including faecal coliforms, *Escherichia coli* and enterococci, were quantified from marine and river waters, sediments and oysters. Florida recreational water standards were infrequently exceeded (6–10% of samples); however, shellfishing standards were more frequently exceeded (28%). IO concentrations in oysters and overlaying waters were significantly correlated, but oyster and sediment IO concentrations were uncorrelated. The human-associated esp gene of *Enterococcus faecium* was detected in marine and fresh waters at sites with suspected human sewage contamination. Lagrangian drifters, used to determine the pathways of bacterial transport and deposition, suggested that sediment deposition from the Ochlockonee River contributes to frequent detection of esp at a Gulf of Mexico beach. Conclusions: These data indicate that human faecal pollution affects water quality in Wakulla County and that local topography and hydrology play a role in bacterial transport and deposition. Significance and Impact of the Study: A combination of IO enumeration, microbial source tracking methods and regional hydrological study can reliably inform regulatory agencies of IO sources, improving risk assessment and pollution mitigation in impaired waters.

Korajkic, A., M.J. Brownell and V.J. Harwood. 2010. Investigation of human sewage pollution and pathogen analysis at Florida Gulf coast Beaches. Journal of Applied Microbiology 110, 174-183.

Aims: Water quality at two Florida beaches was compared using faecal indicator bacteria measurements, microbial source tracking (MST) methods for detecting human source pollution and the assessment of pathogen presence. These values were also compared before and after remediation of wastewater infrastructure at one beach.

Methods and Results: Faecal coliforms, Escherichia coli and enterococci were enumerated in estuarine water and sediment samples. PCR assays for the human-associated esp gene of *Enterococcus faecium* and human polyomaviruses (HPyVs) were used to detect human sewage. Culturable Salmonella and enteric viruses were also analysed. MST identified human sewage contamination at one beach, leading to repair of a sewer main and relocation of portable restrooms. Exceedances of Florida recreational water regulatory standards were significantly reduced after remediation (by 52% for faecal coliforms and 39% for enterococci), and the frequency of detection of MST markers decreased. Coxsackie virus B4 and HPyVs were codetected following a major sewage spill, but Salmonella was not detected during the study. Conclusions: These data indicate that infrastructure remediation significantly reduced pollution from human sewage at the impacted beach. Significance and Impact of the Study: A comprehensive microbial water quality study that can identify contamination sources through the use of MST markers and close collaboration with local ⁄ and state agencies can result in tangible actions to improve recreational water quality and safety

Wu, J., P. Ree and S.Dorner. 2011. Variability of *E. coli* density and sources in an urban watershed. Journal of Water and Health 9, 94-106.

The objective of this study was to characterize the variability of *Escherichia coli* density and sources in an urban watershed, particularly to focus on the influences of weather and land use. *E. coli* as a microbial indicator was measured at fourteen sites in four wet weather events and four dry weather conditions in the upper Blackstone River watershed. The sources of *E. coli* were identified by ribotyping. The results showed that wet weather led to sharp increases of *E. coli* densities. Interestingly, an intense storm of short duration led to a higher *E. coli* density than a moderate storm of long duration

($p<0.01$). The ribotyping patterns revealed microbial sources were mainly attributed to humans and wildlife, but varied in different weather conditions and were associated with the patterns of land use. Human sources accounted for 24.43% in wet weather but only 9.09% in dry weather. In addition, human sources were more frequently observed in residential zones (>30% of the total sources), while wildlife sources were dominant in open land and forest zones (54%). The findings provide useful information for developing optimal management strategies aimed at reducing the level of pathogens in urban watersheds.

Naturalized Fecal Indicator Bacteria

Wanjugi, Pauline and Valerie J. Harwood. 2013. The influence of predation and competition on the survival of commensal and pathogenic fecal bacteria in aquatic habitats. Environmental Microbiology 15, 517-526

The role of fecal indicator bacteria (FIB) in water quality assessment is to provide a warning of the increased risk of pathogen presence. An effective surrogate for waterborne pathogens would have similar survival characteristics in aquatic environments. Although the effect of abiotic factors such as sunlight and salinity on the survival of FIB and pathogens are becoming better understood, the effect of the indigenous microbiota is not well characterized. The influence of biotic factors on the survival of non- pathogenic *Escherichia coli*, *Enterococcus faecalis*, and *E. coli* O157:H7 were compared in fresh (river) water and sediments over 5 days. Treatments were (i) disinfection (filtration of water and baking of sediments) to remove indigenous protozoa (predators) and bacteria (competitors), and (ii) kanamycin treatment to reduce competition from indigenous bacteria. The disinfection treatment significantly increased survival of *E. coli*, *E. coli* O157:H7 and *Ent. faecalis* in the water column. In sediments, survival of FIB but not that of *E. coli* O157:H7 increased in disinfected treatments, indicating that the pathogen's survival was unaffected by the natural microbiota. Location (water or sediment) influenced bacterial survival more than species/type in the disinfection experiment. In the competition experiments where only the natural bacterial flora was manipulated, the addition of kanamycin did not affect the survival of *Ent. faecalis*, but resulted in greater survival of *E. coli* in water and sediment. Species/type influenced survival more than the level of competition in this experiment. This study demonstrates the complexity of interactions of FIB and pathogens with indigenous microbiota and location in aquatic habitats, and argues against over- generalizing conclusions derived from experiments restricted to a particular organism or habitat.

Meric, Guillaume,et al. 2013. Phylogenetic distribution of traits associated with plant colonization in *Escherichia coli*. Environmental Microbiology 15, 487-501.

Plants are increasingly considered as secondary reservoirs for commensal and pathogenic *Escherichia coli* strains, but the ecological and functional factors involved in this association are not clear. To address this question, we undertook a comparative approach combining phenotypic and phylogenetic analyses of *E. coli* isolates from crops and mammalian hosts. Phenotypic profiling revealed significant differences according to the source of isolation. Notably, isolates from plants displayed higher biofilm and extracellular matrix production and higher frequency of utilization of sucrose and the aromatic compound p-hydroxyphenylacetic acid. However, when compared with mammalian-associated strains, they reached lower growth yields on many C-sources commonly used by *E. coli*. Strikingly, we observed a strong association between phenotypes and *E. coli* phylogenetic groups. Strains belonging to phylo- group B1 were more likely to harbour traits indicative of a higher ability to colonize plants, whereas phylo- group A and B2 isolates displayed phenotypes linked to an animal-associated lifestyle. This work provides clear indications that *E. coli* phylogroups are specifically affected by niche-specific selective pressures, and provides an explanation on why *E. coli* population structures vary in natural environments, implying that different lineages in *E. coli* have substantially different transmission ecology

Brian D. Badgley,, Florence I. M. Thomas, Valerie J. Harwood, 2010. The effects of submerged aquatic vegetation on the persistence of environmental populations of *Enterococcus* spp. Environmental Microbiology 12, 1271-1281.

Enterococcus spp. are utilized worldwide as faecal indicator bacteria, but certain strains exhibit extended survival in environmental habitats and the factors influencing their persistence are poorly understood. We used flowing freshwater mesocosms to explore the effect of submerged aquatic vegetation (SAV) on the persistence of natural enterococci populations from a subtropical lake. The highest mean densities of culturable enterococci over 2 weeks occurred in SAV [8.6 × 102 colony-forming units (cfu) per 100 g wet weight], followed by sediments (1.3 × 102 cfu per 100 g) and water (18 cfu per 100 ml). However, due to relative differences in the total mass of each substrate in the entire system (water > sediments > SAV), SAV-associated enterococci represented only a minor proportion of the total population. Vegetated mesocosms harboured significantly higher mean cfu per mesocosm and cfu densities in sediments compared with their unvegetated counterparts, suggesting that SAV indirectly facilitates persistence in aquatic habitats. Populations were dominated (> 96%) by a single *Enterococcus casseliflavus* strain according to BOX-PCR genotyping, which did not change over the 10-month study and strongly suggests bacterial replication in the lake.

The presence of such strains in the environment may represent highly competitive, naturalized and reproducing indicator bacteria populations that are not directly related to pollution events.

Implementation Strategy 9.0: Monitoring and I-Plan Revision

In order to assess progress toward reducing bacterial loading, the BIG will need to evaluate, on a regular basis, the results of ongoing monitoring. This evaluation will be used to determine any changes that are necessary to this I-Plan.

The I-Plan is to address a period of 25 years. However, given the many unknowns pertaining bacteria sources, the cost-effectiveness of management activities, and the availability of resources for implementation, this time frame is provisional. As such, it will be important to continually track both actions taken and instream bacteria levels to gauge the rate of progress and adapt the strategy accordingly.

Monitoring and annual evaluation will determine if the I-Plan or any of its parts are complete, must address a longer time frame, or require revision. Every five years, as resources are available and with stakeholder participation, a more in-depth evaluation will be completed.

Monitoring of both ambient and non-ambient water quality, as well as the implementation activities in this plan, will form the basis for an annual report to be prepared by H-GAC. Conclusions derived from post-implementation water quality monitoring data will be an important indicator of whether implementation activities are resulting in the desired reduction of bacteria loading. The contents of the report will be reviewed by the BIG to determine strategic changes that are necessary to the I-Plan in order to improve progress.

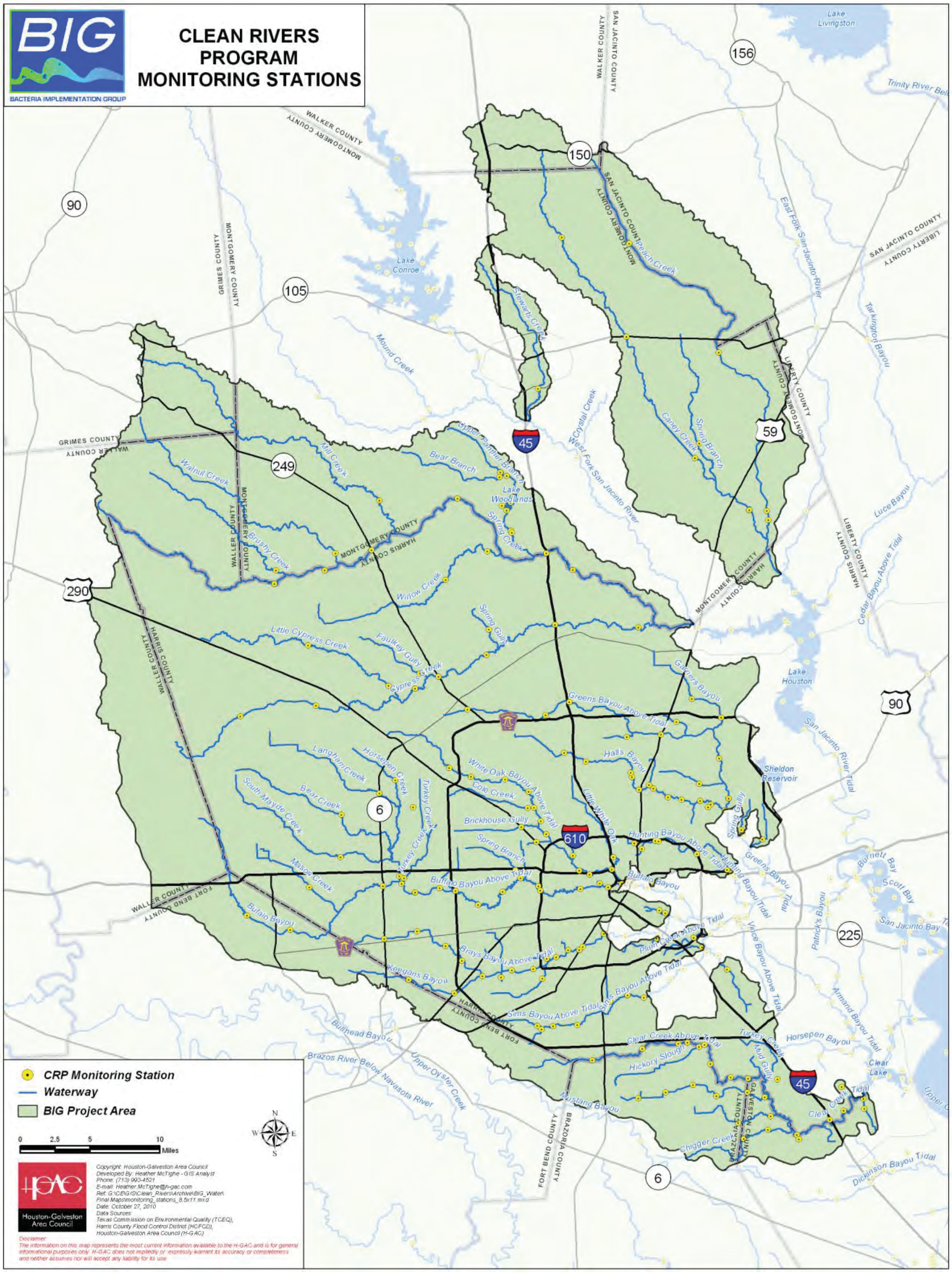
Implementation Activity 9.1: Continue to Utilize Ambient Water Quality Monitoring and Data Analysis

The results of monitoring and evaluating ambient water quality can help determine whether waterways are meeting standards for bacteria. The results will also identify trends of improvement and degradation that need to be addressed. This activity includes two elements: continuing the existing ambient water quality monitoring program and encouraging the use of two indicator organisms in sampling.

9.1.1: Continue to Utilize Clean Rivers Program

Ambient water quality monitoring within the BIG area is primarily the responsibility of the Clean Rivers Program, administered by H-GAC and the TCEQ in conjunction with local partner agencies. This program is ongoing and does not require additional funding for its current efforts. (See Figure 8 for locations of monitoring stations in the BIG project area. More detailed information regarding monitoring data can be found on H-GAC's Water Resources Information Map, or WRIM, which can be found at http://webgis2.h-gac.com/CRPflex/).

Figure 8: Map of Clean Rivers Program Monitoring Stations



The Clean Rivers Program is comprehensive, collecting samples region-wide, and should remain the primary source of data for ambient water quality.[105] This monitoring network includes over 300 sites and provides long-term data accredited by NELAC[106] for the evaluation of ambient conditions in the region's waterways. Monitoring sites are strategically chosen to give the greatest degree of coverage while also attempting to isolate individual waterways or their smaller units to allow for the accumulation of data with direct relevance to local conditions. Monitoring is conducted under a regional Quality Assurance Project Plan (QAPP).[107] Any new ambient monitoring by local partners shall be coordinated with the Clean Rivers Program and shall utilize the regional QAPP.

The Basin Summary Report,[108] produced every five years, evaluates at least seven years of data for each assessment unit and identifies statistically significant change. Along with the general benefit of coordinated regional data, these trend indicators will help guide I-Plan revisions and serve to verify the impact of implementation activities.

The local Clean Rivers Program steering committee meets regularly to discuss ways to improve the ambient water quality monitoring program. Local efforts are coordinated with those statewide to ensure consistency of data and to identify appropriate program improvements, which has already allowed for changes to facilitate this I-Plan. Specifically, monitoring reports now contain standardized information about any recreation that is observed at the sampling site.

9.1.2: Test for Additional Indicators

The presence of *E. coli* or Enterococcus species in water is a commonly employed indicator of the presence of enteric pathogens. Generally, TCEQ guidance and the location of the water sample determine which of the indicators is used. As resources are available, the abundance of both *E. coli* and Enterococcus species should be evaluated at freshwater sampling locations, to ensure a greater ability to correlate impacts of implementation activities on water quality. Additional parameters should be monitored, as deemed necessary and feasible, to target specific activities or sources for which the general correlation between indicators is not precise enough to show impacts. Additional testing may require a new or amended QAPP, and should take into account any existing or ongoing research on correlating current indicator bacteria with pathogens of concern. (See Research Priority 10.3.)

[105] (Houston-Galveston Area Council 2010a)

[106] NELAC, National Environmental Laboratory Accreditation Conference, provides accreditation of environmental labs.

[107] (Houston-Galveston Area Council 2010b)

[108] (Houston-Galveston Area Council 2006)

Implementation Activity 9.2: Conduct and Coordinate Non-Ambient Water Quality Monitoring

While the established ambient monitoring program will form the base of the data, some implementation activities, including monitoring plans for specific implementation activities, may require targeted sampling that may be site or contaminant specific. Because of requirements of the quality assurance plan,[109] this non-ambient program should be separate from the existing ambient program. As such, non-ambient monitoring should be facilitated through four activities.

9.2.1: Create and use a regional non-ambient QAPP

H-GAC will work with the TCEQ to establish a regional QAPP for non-ambient monitoring activities. Applicable sections of existing monitoring efforts, such as Harris County Flood Control District's wet weather monitoring for wet bottom detention basins, should be adopted and incorporated into a regional QAPP, as applicable and practicable.

9.2.2: Create and maintain a regional non-ambient monitoring database

Individual stakeholders will be responsible for implementing activities in their jurisdictions. However, to serve the combined purpose and interests of this I-Plan, the monitoring of non-ambient water quality data will be combined in a regional non-ambient monitoring database. This database could be compatible and coordinated with similar related databases, including the International Stormwater BMP Database[110] and the regional BMP effectiveness database being developed by the Harris County Flood Control District. This database could serve as a clearinghouse for non-ambient or targeted water quality monitoring data from across the region, to ensure availability and coordination of all related efforts. The database will be created in consultation with stakeholders and maintained by H-GAC and will be made available online. The coordinated approach to data acquisition will allow stakeholders, even when working separately, to benefit from their shared experiences. Evaluation of implementation activity effectiveness for one stakeholder can help other stakeholders make more informed decisions concerning the suite of measures they implement to meet the strategies of this I-Plan. Additional data sources that could be incorporated into the database include wet/dry weather monitoring data from MS4 permit holder annual reports, outfall monitoring, and pertinent data (including current and incoming monitoring requirements) from WWTF Discharge Monitoring Reports. This database shall be integrated with the database for tracking implementation activities, described in Implementation Activity 9.3. An ad hoc committee will be invited to participate in the creation of the database. This activity is not intended to create an additional reporting or liability burden for stakeholders.

[109] (Houston-Galveston Area Council 2010b)

[110] (Developed by Wright Water Engineers, Inc. and Geosyntec, Consultants 2010)

9.2.3: Implement targeted monitoring

Targeted monitoring should be implemented in those places where an entity needs to determine the direct impact of an implementation activity or BMP at a site where ambient monitoring will be unable to indicate changes to water quality as a result of the activity. Targeted monitoring may address sampling needs such as:

- Conditions during or differences in loading during dry and wet weather,
- Changes in instream bacteria levels throughout the day,
- Bacteria levels and loading during high-flow and low-flow regimes, and
- Locations specific to implementation activities, such as stormwater BMPs, or potential bacteria sources, such as the evaluation of bacteria levels in water coming from an outfall pipe.

Targeted monitoring of this type is already underway in the BIG area, as conducted by MS4 Phase I entities as part of stormwater permit requirements. These efforts should continue as practicable. Additionally, other entities, regardless of MS4 status, should consider or continue targeted monitoring as needed to evaluate implemented measures. The data collections efforts they undertake should be coordinated as part of the regional QAPP and monitoring database developed for non-ambient water quality in the region.

Implementation Activity 9.3: Create and Maintain a Regional Implementation Activity Database

Implementation tracking provides information that can be used to determine if progress is being made toward meeting the goals of the TMDL. Tracking also allows stakeholders to evaluate actions taken, identify those which may not be working, and make any changes that may be necessary to keep the I-Plan on track. The implementation activity database will contain information on implementation activities conducted by the stakeholders. Each stakeholder will be provided a list of the implementation activities designated under this I-Plan. Each year, the individual stakeholders will provide a report on the activities they implement during the year, and any related information regarding the activities. The BIG, through the H-GAC, will provide a reasonable reminder to each stakeholder prior to the due date, compile the individual reports in the database, and publish a summary as part of an annual I-Plan report. As an incentive to report in a timely manner and in addition to a list of implementation activities undertaken, the report will identify communities that either did not report or did not undertake implementation activities.

While there will be additional paperwork requested of stakeholders, the intent is not to increase reporting requirements unduly. Thus, copies of or access to existing reports or records can be submitted as part of the annual report to the BIG.

Implementation Activity 9.4: Assess Monitoring Results and Modify I-Plan

9.4.1: Assess Data

The information contained in the three databases (ambient, non-ambient, and implementation activity) shall be used to assess progress toward meeting the goals of this I-Plan. Annually, H-GAC shall assess information in the reports to identify whether progress is being made. In particular, H-GAC shall evaluate the following:

1. Does ambient water quality monitoring data indicate that bacteria levels are changing? If so, are the bacteria levels improving or degrading?
2. Do non-ambient water quality monitoring data indicate that implementation activities are reducing bacteria loading?
3. Are implementation activities and controls being undertaken as described in this I-Plan? Which activities have been implemented and which have not?

9.4.2: Communicate results

The information identified through the assessment process will form the basis for an annual report. H-GAC shall compile the annual report and shall present this information to stakeholders through various channels, including e-mail, web publication, presentations, and at an annual meeting.

9.4.3: Continue the BIG

The BIG shall continue to be the decision-making body for this I-Plan, as identified in its ground rules.

9.4.4: Update the I-Plan

The BIG shall review the annual report and, as appropriate, update the I-Plan. As it evaluates the I-Plan, the BIG shall consider reported activities and whether identified milestones are being met, changes in bacteria levels in waterways, changes to surface water quality standards or other regulations, and research. While progress shall be evaluated annually, a more rigorous evaluation should be conducted every five years. At the end of five years, the BIG shall identify costs for the implementation activities.

In its document titled, "Clarification Regarding Phased Total Maximum Daily Loads,"[111] the EPA describes adaptive implementation as "an iterative implementation process that makes progress toward achieving water quality goals while using any new data and information to reduce uncertainly and adjust implementation activities." It is under these auspices that the BIG shall approach updates to the I-Plan. H-GAC shall provide support for these efforts.

[111] (U.S. Environmental Protection Agency, Best-Wong, B. 2006)

9.4.5: Expand the geographic scope of the I-Plan as appropriate

As other watersheds in the vicinity of the BIG project area have TMDLs adopted by the TCEQ, stakeholders from those watersheds may petition the BIG to consider incorporating those watersheds into the I-Plan. These requests shall be considered by the BIG as part of its annual review of the I-Plan. Communities and stakeholders within the region are encouraged to participate in I-Plan activities, either informally and voluntarily, or formally upon incorporation by the BIG into the I-Plan. Voluntary action is particularly encouraged in those watersheds with streams that are impaired for bacteria but which do not yet have adopted TMDLs.

Implementation Strategy 10.0: Research

Bacterial contamination of waterways is a concern for the BIG project area, as reflected in the TMDL studies that this I-Plan addresses. The studies provide a general overview of the extent and character of the presence of bacteria, but they are not sufficient to determine the most cost-effective courses of action to achieve contact recreation standards. A dynamic process is required where affected entities continually expand their knowledge of bacteria sources and effects and where various management approaches are tested and refined. This section identifies potential research topics that will be critical to this undertaking.

Recognizing that many of these topics would be area-specific, the BIG was asked to prioritize those which would have the greatest impact on management actions across the area. Three topics emerged. These topics are pertinent to the entire BIG area, are intended to be implemented as resources are available, and may be superseded as necessary for research needs that are specific to individual stakeholders. Research would be conducted using appropriate methodology and quality assurance that have been developed in consultation with the TCEQ and the EPA. In the following text, although the research priorities are presented in a numerical order, this is not a rank order.

The I-Plan's stakeholders identified three priority research topics which address the following:

- Effectiveness of stormwater activities
- Bacteria persistence and regrowth
- Appropriate indicators

Additional topics were identified and, although important, were not identified as top priorities. Many of these topics are related to the three research priorities. As funding is available, these additional research topics should be considered.

A variety of funding sources should be pursued, with a variety of partners. It is unlikely that any one local entity will find it appropriate to conduct this research. Given the large-scale character of the undertakings, entities should look to coordinate efforts with the various academic institutions of the greater Houston area, federal and state agencies like the EPA, Center for Disease Control and Prevention, and Department of State Health Services, water and environmental research groups like Water Environment Research Foundation and Water Environment Association of Texas, and similar potential partners. A shared project, the result of an inter-local agreement or similar instrument, may allow local entities to feasibly investigate these issues. However, the more practical avenue is likely to be the BIG group as a whole advocating for a national or state-level entity to address research priorities.

Research Priority 10.1: Evaluate the Effectiveness of Stormwater Implementation Activities

Additional monitoring of current and future stormwater projects in the planning area will help provide an area-specific set of data on the relative effectiveness of different management practices. This effort would draw from current and proposed activities undertaken by Phase I MS4 permitted entities. The effectiveness studies would include both structural measures and behavioral measures. Structural measures might be based on both traditional drainage engineering, such as specifications for stormwater outfalls, and sustainable infrastructure design methodologies, such as Green Infrastructure and Low Impact Development. Behavioral measures, such as public outreach, public reporting of illicit discharges, and efforts aimed at changing behaviors. The data collected and the results from the comparative evaluations should be made available to all stakeholders through the monitoring databases described in Implementation Strategy 9.0.

Research Priority 10.2: Further Evaluate Bacteria Persistence and Regrowth

To better understand the extent of human contributions to bacterial loading in waterways, the underlying base layer of background or endemic bacteria should be studied in greater detail. Previous studies of water bodies in the region, including evaluations of Buffalo and Whiteoak bayous in Harris County,[112] indicated that naturally occurring bacteria are prevalent and persistent in our slow-moving waterways. While these naturally occurring bacteria are certainly supplemented with bacteria from human activities and other sources, the relationship and relative percentages of each should be studied in greater detail. Additionally, the character and cycle of bacteria in the waterway pertaining to regrowth potential requires further evaluation. More realistic and comprehensive simulations are required to more fully grasp the nature of bacterial behavior in the waterways. Implementing agencies that choose to conduct these studies for specific projects will make their data available for the rest of the stakeholders through the monitoring databases (or through H-GAC as a facilitator). The results could be used to provide more precise predictions of bacterial loading by following the impact of loading over time within the waterway.

Research Priority 10.3: Determine Appropriate Indicators

An indicator species is an organism whose presence is highly correlated to the presence of another organism (or group of organisms). *E. coli* or *Enterococcus* are used as indicator bacteria based on their pervasiveness and correlation between their presence and the presence of a wide range of potential microbial pathogens. However, that general correlation may not be precise enough to justify their exclusive use in monitoring for this I-Plan. While these indicators are generally accepted nationwide,

[112] (Brinkmeyer, Amon and Schwarz 2008) and (NSF International Engineering & Research Services 2007)

they may not reflect the unique balance of microbial pathogens and water quality characteristics of the region's semi-tropical urban bayous and local water bodies. Many studies, including the data used to formulate the 1986 EPA guidance on bacteria limits for recreational waters,[113] were conducted in areas and water bodies greatly different from the BIG area. The potential need for alternate, supplemental, or multiple indicators should be determined to refine the I-Plan's monitoring approach and further assist stakeholders in identifying sources.

The EPA is currently studying the question of appropriate indicators. The results of their inquiry, due in October of 2012,[114] should be incorporated into future revisions of this I-Plan. Additional consideration of the best indicator(s) for the area could help supplement their findings by providing a more specific understanding of local correlations between indicators and pathogens. Stakeholders are encouraged to participate in EPA's discussion of indicators and to encourage the EPA to consider environments similar to those in the Houston region.

Research Priority 10.4: Additional Research Topics

A variety of additional research topics were identified by stakeholders. The following list gives a brief description of broad groups of research topics and some possible research questions. Research addressing these topics should be conducted as resources are available.

- *WWTFs:* Studies should examine the correlation between bacteria levels in effluent and in-stream bacteria levels. Have in-stream bacteria levels changed as a result of the TCEQ's new rules that limit bacteria levels in effluent? Research may also be conducted to identify how other constituents in wastewater effluent may influence in-stream bacteria levels. How are in-stream bacteria levels influenced by sludge discharges, nutrients, and stormwater discharges from WWTFs?
- *Health risks:* The studies should include cumulative review of epidemiological studies, collection of new epidemiological data, and/or microbial risk assessment efforts aimed at determining human health risks from recreational activities in, on, or near bayous in the BIG region. What is the relationship between the levels of pathogens and indicators in different watersheds?
- *Recreational use:* Generally, eight or more illnesses above the background level are considered problematic. Does the rate of illness from contact recreation in impaired waterways in the project area exceed this threshold? What is the level of recreation on the waterways?
- *Land use:* Research could analyze the correlations between land use, turbidity, and in-stream bacteria levels. Some land use types may lead to increased turbidity, and may be associated with increased bacteria levels. Consideration should be given to evaluating the per-capita

[113] (U.S. Environmental Protection Agency 1986)

[114] (U.S. Environmental Protection Agency 2010c)

contribution of bacteria in relative compact mixed use developments versus lower density developments. Historical land use prior to development may also influence in-stream bacteria levels. Is there a correlation between impervious surfaces and in-stream bacteria levels?

- *Modeling:* The document, "Bacteria Total Maximum Daily Load Task Force Final Report,"[115] contains summary information about the selection and application of various water quality models for use in Texas. However, many questions were raised by the authors regarding how well the models work, how they can be improved to be more accurate, and how well they function as predictive models. Research could be done to provide answers to the questions raised in the report. One particular input for which further information could be done is to improve the flow data available for classified stream sections.
- *Unimpaired waterways:* A minority of sampled waterways in the project area are *not* considered impaired for bacteria. Why do these assessment units have relatively low bacteria levels? How could this information be applied to lower bacteria levels in impaired waterways?
- *Nutrients and other constituents:* Waterways in the project area contain constituents such as nutrients, fine particles, sediment, soil, and other solid materials. Studies and research should examine how such constituents influence instream bacteria levels.

[115] (Jones, et al. 2007)

Implementation Strategy 11.0: Geographic Priority Framework

In order to achieve state standards for contact recreation in the BIG region's waterways, all stakeholders will need to be responsible for some aspects of implementation. Some Implementation Activities, such as those described in Implementation Activity 1.1, will be implemented throughout the BIG Project Area. Others, such as Implementation Activity 3.1, will be implemented in targeted areas. It is this second group of IAs, those that are geographically targeted, that need a framework for prioritization. The framework described here provides guidance to communities in setting local implementation priorities.

Implementation Activity 11.1: Consider recommended criteria when selecting geographic locations for projects

As a community prioritizes actions within its watersheds it should consider five main categories of concern: bacteria level, accessibility, use level, implementation opportunities, and future land use changes. Table 8 lists criteria included in these categories. Communities may want to gather input from residents when setting priorities. This can be accomplished through public meetings or surveys. However, an ordered approach needs to be considered as well, such as targeting specific watersheds or suspected sources.

Table 8: Criteria to be considered when selecting geographic priorities

Category	Criteria to Consider
Bacteria Level	• Is the 7-year bacteria geometric mean for the waterway above the water quality criteria for bacteria? If yes, what is the magnitude of the exceedance? • Based on land use surrounding the waterway, is the source of bacteria more likely human or animal? • Is the flow in the waterway primarily effluent from wastewater treatment facilities? • How many impaired stream segments could be affected by the transport of bacteria downstream from the waterway?
Accessibility	• Is there a large population within 0.25 miles of the waterway? [Note: The meaning of the phrase "large population" can differ from community to community.] • Are there public access points (ramps, bridges, trails, developed parks) to the waterway?

Category	Criteria to Consider
Use Level	• Is contact recreation occurring in the waterway? • If the waterway is not currently used for recreation, would the waterway be used for recreation if the bacteria level were low? • Is the waterway part of a drinking water supply? • Are there signs that the waterway is being used for recreation (rope swings, fishing debris, beer cans, or graffiti)? • Is there an existing group that promotes protection and improvement of the waterway as a community asset? • Are the characteristics of the waterway such that individuals could use it for recreation (appropriate flow, depth, natural or man-made banks)?
Implementation Opportunities	• Are there existing groups to partner with for implementation? • Is there political will to lower a particular waterway's bacteria level? • What funds are available? • Can funding be leveraged with funding from upstream or downstream jurisdictions to expand spatial extent of an IA? • What are initial construction or installation costs? • What are estimated long-term maintenance costs? • Is there a waterway that could easily meet the standard? • Can a specific source of bacteria be singled out to better target IAs? • How much land is available to develop stormwater treatment facilities?
Future Land Use Changes	• What development is expected in the watershed? • Is the waterway threatened, but not yet listed as impaired? [Note: H-GAC Clean Rivers Program staff periodically analyzes water quality data to determine trends and can provide this information to interested communities. Additionally, raw data is available for download from the H-GAC website.]

Monitoring and Plan Revision Workgroup
Meeting Notes
December 6, 2011
10:00 am to noon
H-GAC Conference Room B

Attendees

Jonathan Holley (HCFCD), Robert Snoza (HCFCD), Kristi Corse (H-GAC), Rachel Powers (H-GAC), Todd Running (H-GAC), Jean Wright (H-GAC)

Discussion

Overview

The Implementation Plan was still undergoing internal review at TCEQ. TCEQ had not yet made any formal requests to change the plan. Informally, TCEQ requested modification to the inside cover pages, which were made without changes to content.

The annual report will contain information about progress on activities identified in the Implementation Plan. The workgroup will be an important means for collecting information about implementation.

The annual meeting in May 2012 will be an opportunity to recommend changes to the I-Plan, if the workgroup feels it is merited.

Review Progress

Implementation Activity 9.1: Continue to Utilize Ambient Water Quality Monitoring and Data Analysis

9.1.1: Continue to utilize Clean Rivers Program

Kristi Corse gave a brief overview of activities related to the **Texas Stream Team**. The Texas Stream Team is a statewide network of volunteer water quality monitors that is administered statewide by the Texas Rivers Institute at Texas State and locally by H-GAC. The monitoring is done under a Quality Assurance Protection Plan (QAPP). The data is used to augment professional monitoring data, but is not regulatory in nature. Data is also used to screen sites to see if professional monitoring is required.

The H-GAC program involves about 45 active volunteers, four of whom have been active for over 8 years. Volunteers monitor 42 sites in ten watersheds with nine new sites having been added in November 2011. Galveston Bay Foundation and Bayou Preservation Association have signed on to help recruit and manage volunteer efforts. The volunteers are beginning to look at nitrate and nitrogen in advance of state standards for nutrients. Data from monitoring efforts will soon be available online. For safety reasons, volunteers do not test for flow. Five people sample for bacteria.

Jean Wright gave a brief overview of activities related to the Clean Rivers Program. Professional monitors from eight organizations sample at about 400 sites. She displayed a map of 2011 and 2012 coordinated monitoring sites. This year, the number of parameters has changed. CRP is focusing on nutrients and eliminating non-essential lab parameters. For example, all partners will be collecting TKN samples on a quarterly basis but dropping parameters such as fluoride, TOC, and TDS. Jean provided two handouts: 'Coordinated Monitoring Meeting 2011 Summary Notes' and 'Measurement Performance Specifications for Field and Lab Parameters.' While overall funding remained relatively stable, many adjustments needed to be made at the programmatic level, which was successfully done. One notable accomplishment this year is the updated version of the Water Resources Information Map, the on-line map and database with water quality monitoring data: http://arcgis02.h-gac.com/wrim/.

9.1.2: Test for Additional Indicators

Jean reported that the Clean Rivers Partners have added quarterly sampling for *Enterrococcus* bacteria at all freshwater sites. H-GAC will share any information about conclusions or patterns as it becomes available.

Implementation Activity 9.2: Conduct and Coordinate Non-Ambient Water Quality Monitoring

9.2.1: Create and use a regional non-ambient QAPP

Todd reported that H-GAC had received funding to develop a regional non-ambient water-quality monitoring database. H-GAC submitted the template for a QAPP to TCEQ for review and is awaiting comments. H-GAC hopes that the QAPP will be complete by the end of the fiscal year (August 31, 2012).

HCFCD indicated that they would like the QAPP to be able to accommodate monitoring related to Low Impact Development. H-GAC intends that the QAPP will be able to accommodate such monitoring.

9.2.2: Create and maintain a regional non-ambient monitoring database

This activity is pursuant to the development of a regional non-ambient QAPP for water quality monitoring.

9.2.3: Implement targeted monitoring

This activity is pursuant to the development of a regional non-ambient QAPP for water quality monitoring and the development of a regional non-ambient water-quality monitoring database. The participants did not discuss any targeted monitoring that might be occurring in the project area.

Implementation Activity 9.3: Create and maintain a regional implementation activity database

Rachel reported that H-GAC had begun collecting information about which implementation activities have been undertaken. For example, H-GAC requested and received NOIs and Annual Reports for each of the MS4 operators in the BIG project area. The information contained in the reports will be compiled, along with information about other activities, in order to inform the development of the annual report and to help guide the BIG as it deliberates possible changes to the I-Plan.

Implementation Activity 9.4: Assess Monitoring results and modify I-Plan

H-GAC will be meeting and communicating with the workgroups to try to identify progress on implementation activities. H-GAC has also continued to assess water-quality monitoring data—this year in the Basin Summary report and annually in the Basin Highlights report. This information will be compiled and presented to the BIG at the annual meeting. Based on the information and recommendations from the workgroup, the BIG will make decisions about how to proceed.

9.4.1: Assess data

9.4.2: Communicate results

9.4.3: Continue the BIG

9.4.4: Update the I-Plan

9.4.5: Expand the geographic scope of the I-Plan as appropriate

H-GAC's contract with TCEQ includes stakeholder involvement for the development of TMDLs for waterways that were added to the list of impaired waterways. We anticipate that most of the newly listed waterways are tributaries within existing watersheds and the I-Plan already applies to them. Neither the Cedar Bayou Watershed Protection Plan stakeholder group nor the Upper Oyster Creek TMDL I-Plan stakeholder group have chosen to 'sign on' to the I-Plan. The Oyster Creek Plan, which is further along than Cedar Bayou, has chosen to include many of the activities in the plan and to indicate support and collaboration rather than formally adopting the BIG I-Plan. Later this year, TCEQ may start developing TMDLs for additional waterbodies in the Lake Houston watershed. At that time those areas might be added to the BIG at the discretion of stakeholders.

Identify Priorities

Priorities include the following:

- In the first year, we will focus on identifying baseline conditions against which progress can be measured.
- Stakeholders can participate in the annual Regional Coordinated Monitoring Workgroup, which will be meeting on April 3, 2012.

- Recommendations in the past have included monitoring for *Enterrococcus* bacteria at all freshwater monitoring sites and for including codes for tracking recreation use or evidence thereof. CRP has acted on both of these recommendations, as has begun collecting *Enterro* and is awaiting guidance from TCEQ for the collection of recreation information.
- Workgroup participants identified sampling and analysis to determine whether diurnal patterns exist in bacteria levels. The Harris County Flood Control District is interested in this possibility and is funding a related study involving changes in bacteria during the day.

Discuss Annual Plan Format

Rachel asked for input on the format and content for the annual report. In general, it will contain summary information about bacteria data, information about which implementation activities have been undertaken and by whom, and any conclusions that can be drawn from the information.

Rachel indicated that she anticipates two formats that will be used. Rachel showed a few examples.

- H-GAC will produce an at-a-glance report on one page that contains high level summary information.
- H-GAC will also produce a more in-depth narrative version with graphs and pictures.

Workgroup participants had no objections to the proposal.

Discuss Revision Process

Rachel briefly reviewed the revision process:

- Phase I: Discussion, draft by H-GAC, review by workgroup
- Phase II: Repeat as necessary until consensus is reached
- Phase III: Present to BIG as part of annual meeting
- Every five years, provide a more in-depth revision

Discuss Potential Changes to the I-Plan

The workgroup participants did not anticipate recommending any changes to the I-Plan until TCEQ has completed the review process.

Wrap-up

Rachel will provide notes for the meeting.

BIG Annual Meeting: May 22, 2012.

Adjourn

Research Work Group
Meeting Notes
January 12, 2012
10:00 am to noon
H-GAC Conference Room B, Second Floor

Attendees

Linda Broach (TCEQ), Michael Bloom (Geosyntech), Ralph Calvino (AECOM), Richard Chapin (City of Houston, on phone), Robert Snoza (HCFCD), Steven Johnston (GBEP/TCEQ), Rachel Powers (H-GAC)

Discussion

Overview

The Implementation Plan was still undergoing internal review at TCEQ. TCEQ had not formally requested any changes to the document. Informally, TCEQ requested modification to the inside cover pages, which were made without changes to content.

The annual report will contain information about progress on activities identified in the Implementation Plan. The workgroup will be an important means for collecting information about implementation.

Review Current Research

Rachel provided a handout listing several articles relevant to BIG research priorities. (Many thanks to Bill Hoffman for putting the list together.)

Research Priority 10.1: Evaluate the effectiveness of storm water implementation activities

- The National Stormwater BMB Database: In December 2010, the database published the "Pollutant Category Summary: Fecal Indicator Bacteria," which examined and summarized findings included within the database. The document is available on-line: http://www.bmpdatabase.org/Docs/BMP%20Database%20Bacteria%20Paper%20Dec%202010.pdf. [In general, conclusions are that more data and analysis is needed, retention (wet) ponds and various media are probably the category of BMPs most likely to be effective. Source controls and volume reduction may be effective at reducing bacteria loads.]
- Harris County and Harris County Flood Control District are undertaking an analysis of Clean Rivers Program water quality data to identify possible correlations between bacteria levels and other water quality parameters such as total suspended solids or nutrients. A final report is not available.

- Harris County, Harris County Flood Control District, and H-GAC are conducting sampling to better describe diurnal patterns in bacteria levels.
- University of Houston – Clear Lake has recently installed a wetland on campus designed to treat stormwater from the 19-acre campus. They are sampling bacteria levels of the water going into the wetland and coming out to see if the wetland effectively reduces bacteria levels. During dry weather, to maintain the wetland, they are pumping water from Horsepen Bayou. This may provide an opportunity to determine whether 'offline' treatment might be able to reduce in-stream bacteria levels.
- University of Houston – Clear Lake is working on a study of nutrients. (???need more detail??)
- The City of League City received a 319 grant to develop green infrastructure within a park.
- The City of Houston is implementing an erosion control project in Memorial Park, and is hopeful that erosion control might reduce bacteria loading. The City is sampling both water and sediment to see if there are changes in bacteria levels that correlate to the project.
- Geosyntech has received a grant from the Water Environment Research Foundation to examine 'advanced' green infrastructure that responds to real-time data. For example, they are installing equipment on rainwater harvesting facilities that can query local rainfall predictions to determine release rates for the facilities, and thus maximize the effectiveness of the harvesting.

Research Priority 10.2: Further evaluate bacteria persistence and regrowth

- The handout includes a paper by Konstantinidis et all in 2011 that describes research into distinguishing gene sequences of commensal versus environmentally adapted straing of e. coli. H-GAC is developing a grant proposal to work with him to analyze samples from local waterways.
- Rachel will check with Robin Brinkmeyer to see if any of her current or recent research is related to this topic.

Research Priority 10.3: Determine appropriate indicators

- H-GAC's Clean Rivers Program will be collecting entero samples to supplement *E. coli* samples in freshwater.
- EPA has recently published draft information pertaining to recreational water quality standards (http://water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/upload/recreation_document_draft.pdf) for the purpose of soliciting scientific views. Highlights include:
    - A qPCR method as a rapid analytical technique for the detection of enterococci in recreational water

- EPA is introducing a new term, Statistical Threshold Value (STV), as a clarification and replacement for the term single sample maximum (SSM). In addition there are no longer recommendations for different use intensities.
- EPA is providing information on tools for assessing and managing recreational waters, such as predictive modeling and sanitary surveys.
- EPA is providing information on tools for developing alternative RWQC on a site-specific basis, including epidemiological studies and the development of quantitative microbial risk assessment (QMRA)

- The group discussed whether it might wish to submit comments ("scientific reviews") on the EPA report. The work group felt that it would be appropriate to review the bibliography to make sure that appropriate studies have been included. ("Please include these studies in analysis, and if not, why not?") The group encourages individual stakeholders to submit comments and to let other people know that they are submitting comments. Harris County and Harris County Flood Control District are preparing comments.
- Michael Bloom, Catherine Elliott, and Linda Pechacek attended the EPA listening session last year in New Orleans pertaining to the recreational criteria process. In general, the meeting was disappointing in that EPA was proposing few changes and few specifics.

Identify Priorities

The group did not recommend any priorities and felt that the current approach, which combines research by BIG stakeholders with a review of research by others, seemed appropriate.

Potential additions to the annual report and modifications to the I-Plan

The workgroup did not wish to recommend changes to the research section.

The workgroup expressed an interest in making sure that the annual report, and possibly the implementation activity database, included a bibliography and/or information about current research efforts.

The research section of the annual report is intended to serve two functions. First, for the purpose of sharing information, it will contain a bibliography of recent research pertaining to the BIG's research priorities. Second, it will describe activities being undertaken by BIG stakeholders for the purpose of documenting efforts being undertaken.

Wrap-up

Rachel will provide notes for the meeting.

BIG Annual Meeting: May 22, 2012.

Adjourn

Watershed Outreach Work Group
Meeting Notes
Wednesday, August 29, 2012
2:00 pm to 3:30 pm
H-GAC Conference Room B, Second Floor

Participants

Linda Broach (TCEQ), Diana Jones (HCPID), Marty Kelly (TCEQ), Alisa Max (HCPID), Linda Pechacek (LDP), Rachel Powers (H-GAC), Mary Purzer (AECOM), Thushara Ranatunga (H-GAC), Jim Robertson (CCFCC)

Call to Order/Welcome/Introductions

Rachel Powers welcomed participants, initiated self-introduction, and reviewed the agenda.

Discussion

- **Overview**

Rachel explained that the TCEQ is still coordinating internally with other staff to prepare the plan for consideration by the Commission for approval. Many stakeholders are implementing activities described in the plan.

The implementation strategy developed by the Watershed Outreach Work Group consists of a framework of criteria that can be used by various stakeholders as appropriate to their situation. Criteria fall into five categories: bacteria level, accessibility, use level, implementation opportunities, and future land use changes.

A full-scale model for using all of the criteria has not been developed, although some of the criteria have been more-fully defined and used by various stakeholders. In particular, the draft annual report for the BIG includes two lists: “Most Wanted” & “Most Likely to Succeed.” The most wanted list describes the assessment units with the monitoring stations with the highest reported bacteria levels, which range from 5807 cfu/100ml to 2178 cfu/100ml (the state standard is 126 cfu/100ml). The most wanted list represents opportunities to make big changes in bacteria levels. The most likely to succeed list includes the assessment units with the monitoring stations with the lowest reported bacteria levels that are still impaired, which range from 127 cfu/100ml to 185 cfu/100ml (the state standard is 126 cfu/100ml). H-GAC has been and will continue to use those lists to target outreach efforts.

A draft annual report was presented to the BIG at its annual meeting in May. The BIG asked H-GAC to revise the annual plan format in coordination with an ad hoc committee. The ad hoc committee met in July and revisions to the plan are being made in response to discussions at that meeting. A revised report will be shared at the BIG mid-year meeting in October.

- **Harris County Prioritization Plan**

Alisa Max gave a brief presentation about how Harris County might use the framework to prioritize areas where they might undertake location-specific implementation activities. Harris County has preliminarily identified drinking water supply, 5-year geometric mean bacteria level, physical characteristics, downstream stream segments, and source of bacteria as criteria of concerned that could be scored to prioritize locations. Each of these criteria can be incorporated in GIS to develop comparative scores for various locations. The project is still conceptual and will need to undergo testing prior to use. Harris County is open to receiving comments on their methodology.

- **Most Wanted/Most Likely to Succeed lists**

Rachel briefly described how interns at the Bayou Preservation Association looked at assessment units on the most wanted and most likely to succeed lists. In particular, they examined monitoring data and conducted visual inspections at sites along Buffalo Bayou, Schramm Gully, and Hunting Bayou (and continued studies started last year of Cypress Creek and Little Cypress Creek). They identified potential sources of bacteria loading and are following up with appropriate authorities to see if the sources can be confirmed and addressed.

- **Identify Priorities & Discuss Next Steps**

The group did not identify any changes to the plan section to recommend to the BIG.

While the group expressed interest in trying to develop a model in GIS that could be used by stakeholders to develop their own priorities, participants also indicated that the two lists were good tools for directing efforts towards areas of concern. H-GAC will continue to focus on involving stakeholders in addressing assessment units on the two lists, and will continue to provide support for local efforts to set geographic priorities.

<u>Wrap-up</u>

BIG Mid-Year Meeting: October 16, 2012, 1:30 to 3:30

Next work group meeting will be in 2013.

<u>Adjourn</u>

Monitoring and Plan Revision

Main Summary

The BIG recommended that the BIG review progress on an annual basis and determine whether changes need to be made to the I-Plan or its implementation. The review is to be based on answers to the following questions:

1) Do ambient water quality monitoring data indicate that bacteria levels are changing? If so, are the bacteria levels improving or degrading?
2) Do non-ambient water quality monitoring data indicate that implementation activities are reducing the load of bacteria?
3) Are implementation activities and controls being undertaken as described in this I-Plan? Which activities have been implemented, and which have not?

The Clean Rivers Program continues to provide ambient water quality data that can be reviewed. H-GAC and BIG stakeholders have begun developing the capacity to collect non-ambient water quality data. H-GAC has also been working with stakeholders to gather information from stakeholders that can be used as a baseline for future comparisons.

[Brief statement about conversation at annual meeting.]

Review Progress

Continue to Utilize Ambient Water Quality Monitoring and Data Analysis

The BIG recommended that stakeholders continue the Clean Rivers Program in the BIG project area, which is being done. In the BIG project area, H-GAC manages the Clean Rivers Program, a statewide program for monitoring surface water quality. H-GAC coordinates 8 program partners who conduct sampling and lab analysis under a regional quality assurance project plan (QAPP) for ambient water quality monitoring. Professional monitors from those eight organizations sample ambient water quality at over 370 sites. While overall funding has remained relatively stable, H-GAC made adjustments to program elements, eliminating non-essential lab parameters and adding more parameters, such as nutrients. The Clean Rivers Partners have added quarterly sampling for *Enterrococcus* bacteria at all freshwater sites, to supplement *E.coli* sampling. H-GAC will share any information about conclusions or patterns as it becomes available. H-GAC's Clean Rivers Program has also acted on the recommendation to include codes in the sampling information for recording contact recreation and evidence thereof. The recommendations for tracking contact recreation is being considered by the state.

As part of its responsibilities for administering the local program of the statewide Texas Stream Team volunteer monitoring program, H-GAC oversees 45 active volunteers at 42 sites in ten watersheds. Five of the volunteers sample for bacteria. Galveston Bay Foundation and Bayou Preservation Association help recruit and manage volunteers. All of the volunteer monitoring is conducted under a quality assurance project plan (QAPP). The data is used to augment professional monitoring data, but is not regulatory in nature. Data is also used to screen sites to see if professional monitoring is required.

The Basin Highlights Report, an annual report on the Clean Rivers Program, provides additional information about the ambient water quality monitoring program. Additional data are available in the Water Resources Information Map, the on-line map and database with water quality monitoring data (http://arcgis02.h-gac.com/wrim/) and a free I-Phone application ("How's the Water?").

Conduct and Coordinate Non-Ambient Water Quality Monitoring

H-GAC applied for and received funding to develop a regional non-ambient water-quality monitoring database. After working with BIG stakeholders and Clean Rivers Program partners, H-GAC drafted a template for a QAPP. H-GAC has submitted the draft to TCEQ for review and is awaiting comments. The QAPP will be able to accommodate non-ambient monitoring, monitoring during stormwater events and measuring the effectiveness of implementation activities or policies such as low impact development. Once a QAPP has been approved, H-GAC will seek funding and partners to conduct non-ambient water quality monitoring under the QAPP.

Create and maintain a regional implementation activity database

H-GAC began collecting information about which implementation activities have been undertaken. For example, H-GAC requested and received NOIs and Annual Reports for each of the MS4 operators in the BIG project area. The information contained in the reports will be compiled, along with information about other activities, in order to inform the development of the annual report and to help guide the BIG as it deliberates possible changes to the I-Plan. A database is being developed to organize and share the information, and link activities to any available non-ambient water quality monitoring data.

Assess Monitoring Results and Modify I-Plan

The BIG recommends that it assess progress towards meeting the goals of the I-Plan. H-GAC has compiled information in this annual report, with input from the workgroups, that is intended to facilitate the BIG's assessment of progress.

[More information here about results of discussions at the annual meeting regarding changes to the I-Plan and progress.]

Expand the geographic scope of the I-Plan as appropriate

H-GAC's contract with TCEQ includes stakeholder involvement for the development of TMDLs for waterways that were added to the list of impaired waterways. Most of the newly listed waterways are tributaries within existing watersheds and the I-Plan already applies to them.

- Clear Creek watershed: Assessment Units 1101A_01, 1101C_01, 1101E_01, and 1102G_01

- Houston Metro and Buffalo/Whiteoak watersheds: Assessment Units 1007T_01, 1007U_01, 1007S_01, 1007V_01, 1017C_01 and 1007A_01
- Lake Houston watershed: Assessment Units 1008B_01, 1008B_02, 1008C_01, 1008C_02, 1008E_01, and 1011_01

TCEQ will be developing additional TMDLs for assessment units within the Lake Houston watershed but outside of the current BIG project area:

- Lake Houston watershed (outside current BIG project area): Assessment Units 1002_06, 1003_01, 1003_02, 1003_03, 1004_01, 1004_02, and 1004D_01

Once TMDLs for the assessment units have been adopted by the TCEQ, stakeholders from these watersheds may petition the BIG to incorporate the watersheds into the I-Plan. The BIG shall consider such requests at its annual meeting. In the next year, stakeholders within the watersheds will be approached to determine whether they intend to participate in the BIG I-Plan.

Neither the Cedar Bayou Watershed Protection Plan stakeholder group nor the Upper Oyster Creek TMDL I-Plan stakeholder group have chosen to 'sign on' to the I-Plan, largely because they address more than bacteria impairments. The Oyster Creek Plan, which is further along than Cedar Bayou, has chosen to include many of the activities in the plan and to indicate support and collaboration rather than formally adopting the BIG I-Plan.

Implementation Strategy 10.0: Research

Main Summary

A lack of meaningful data was a recurring discussion theme during the BIG planning process. As a result, the BIG explicitly identified research and support for research as key strategies to pursue. Research topics focus on the effectiveness of stormwater implementation activities, bacteria persistence and regrowth, and appropriate indicators to denote health risk presented by contact recreation.

Some research on these topics is being done locally and is described below, along with descriptions of national efforts and selected research publications. Abstracts for the research articles are available on the BIG's research workgroup page.

Local participation will be key to making sure that national research efforts apply to the BIG project area and that BIG priorities are addressed. In particular, the Research Work Group encourages individual stakeholders to participate in the EPA's recreational criteria process, which is examining appropriate indicators to denote health risk.

Evaluate the Effectiveness of Stormwater Implementation Activities

In December 2010, the National Stormwater BMP Database published the "Pollutant Category Summary: Fecal Indicator Bacteria," which examines and summarizes findings included within the database. The document is available on-line at: http://www.bmpdatabase.org/Docs/BMP%20Database%20Bacteria%20Paper%20Dec%202010.pdf. In general, conclusions indicate that more data and analysis are needed. Based on current data, the category of BMP most likely to be effective is retention (wet) ponds. Source controls and volume reduction may also be effective at reducing bacteria loads.

University of Houston – Clear Lake has recently installed a wetland on campus designed to treat stormwater from the 19-acre campus. UH-CL is sampling bacteria levels of the water going into and coming out of the wetland to see if the wetland effectively reduces bacteria levels. Water from Horsepen Bayou is pumped into the system during dry weather to maintain the wetland. The introduction of bayou water to the wetland may provide an opportunity to determine whether 'offline' treatment might be able to reduce in-stream bacteria levels.

The City of League City recently received a Nonpoint Source Program grant to examine stormwater BMPs in a park setting. Practices to be installed in the park may include: swales, rain gardens, pervious pavement, rainwater harvesting, and vegetated buffers. The features will serve as examples for the public and will be monitored for effectiveness. Ultimately, the results will be used to evaluate and develop stormwater ordinances and to encourage retrofits of commercial, residential, and public properties.

The City of Houston is implementing an erosion control project in Memorial Park and is hopeful that minimizing soil erosion might reduce bacteria loading. The City is sampling both water and sediment to see if there are changes in bacteria levels that correlate to the project.

Geosyntech has received a grant from the Water Environment Research Foundation to examine 'advanced' green infrastructure that responds to real-time data. For example, they are installing equipment on rainwater harvesting facilities that can query local rainfall predictions to determine release rates from the facilities and thus maximize the effectiveness of harvesting.

Further evaluate bacteria persistence and regrowth

E. coli has been considered a reliable indicator of fecal pollution because it was believed to live primarily within the gastrointestinal tract of warm-blooded organisms (commensal) and could not survive for an extended period outside this environment. Recent evidence suggests that some strains have adapted to other environments. A team of researchers affiliated with several institutions has sequenced the genomes of nine strains of *E. coli* that have adapted to the environment and cannot be distinguished from commensal *E. coli* by standard culture-based methods such as Colilert®. Knowledge of the genomes of these environmental strains will allow development of molecular assays to quantify commensal and environmental strains and to more accurately assess the extent of fecal pollution in aquatic systems. (http://www.sciencedaily.com/releases/2011/04/110411152527.htm)

H-GAC is developing is seeking funding to investigate naturalized populations of *E. coli* in local waterways. If funded, H-GAC would work with a team at the Georgia Institute of Technology headed by Dr. Konstantin Konstantinidis. Along with other researchers, he has sequenced the genomes of many naturalized strains of *E. coli* and are developing a molecular assay to quantify the relative contributions of environmental and fecal sources. (See Selected Research Articles for further information.)

A significant proportion of bacterial loading in our waterways comes from a variety of nonpoint sources. Knowledge of the relative contributions of various sources to the total load can increase the effectiveness of TMDL and Watershed Protection Plans. The Texas Water Resource Institute/Texas A&M Institute of Renewable Natural Resources sponsored a conference in Feburary 2012 on bacterial source tracking (BST) to acquaint the environmental and regulatory community with new technologies, current research strategies, and significant findings. Most presenters were cautiously optimistic about the potential of BST, noting some successes and many contradictory and counterintuitive results. Orin Shanks of the EPA Office of Research and Development averred that most of the PCR methods are not ready for broad application, although the cost of PCR analysis is falling rapidly. At present, regulatory acceptance of BST methods is limited. The conference drew participants from throughout the United States, including many from organizations in the BIG area (City of Houston, TCEQ Region 12, AECOM, H-GAC). Presentations can be viewed or downloaded at http://texasbst.tamu.edu/2012-conference/.

Selected Publications:

- Konstantinidis et al. 2011. "Genome sequencing of environmental Escherichia coli expands understanding of the ecology and sequencing of the model bacteria species." Proceedings of the National Academy of Sciences. www.pnas.org/cig/doi/10.1073/pnas.1015622108
- Satoshi Ishii,1 Winfried B. Ksoll,3 Randall E. Hicks,3 and Michael J. Sadowsky. 2006. Presence and Growth of Naturalized Escherichia coli in Temperate Soils from Lake Superior Watersheds. Applied and Environmental Microbiology 72(1): 612-621
- Beth L. Mote,a Jeffrey W. Turner,a,b* and Erin K. Lippa. 2012.Persisitence and Growth of the Fecal Indicator Bacteria Enterococci in Detritus and Natural Estuarine Plankton Communities. Applied and Environmental Microbiology 78(8):2569-2577
- [Placeholder: Brinkmeyer research]

Determine appropriate indicators

EPA has recently published draft information pertaining to recreational water quality standards (http://water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/upload/recreation_document_draft.pdf) for the purpose of soliciting scientific views. Highlights include discussions of new analytical techniques involving quantitative polymerase chain reactions, new statistical terminology, predictive modeling, sanitary surveys, epidemiological studies, and the development of quantitative microbial risk assessment (QMRA). The research, the impetus for which was a settlement agreement and consent decree, is meant to inform an update to the recreational water quality criteria in late 2012. BIG stakeholders have participated in the process and submitted technical comments on the draft report.

Harris County and Harris County Flood Control District are undertaking an analysis of H-GAC's Clean Rivers Program water quality data to identify possible correlations between bacteria levels and other water quality parameters such as total suspended solids or nutrients. A final report is expected this year.

H-GAC's Clean Rivers Program will be collecting enterococci samples to supplement *E. coli* samples in freshwater. Once sufficient samples have been created, the data will be analyzed to determine correlations between the data.

Harris County Flood Control District, in cooperation with H-GAC and the City of Houston Public Works Department, are conducting sampling to better describe diurnal patterns in bacteria levels.

- Selected Publications:

- Toothman , Byron R. , Lawrence B. Cahoon , Michael A. Mallin. 2009. Phosphorus and carbohydrate limitation of fecal coliform and fecal enterococcus within tidal creek sediments*Hydrobiologia* 636:401-412.
- Surbeck,C.Q., S.C. Jiang, S.B. Grant. 2010. Ecological Control of Fecal Indicator Bacteria in an Urban Stream. *Environmental Science and Technology* 44:631-637.
- Zhang et al. 2012. Development of predictive models for determining enterococci levels at Gulf Coast beaches. Water Research 46 (2012): 465-474
- Maraccini et al. 2012. Diurnal Variation in Enterococcus Species Composition in Polluted Ocean Water and a Potential Role for the Enterococcal Carotenoid in Protection against Photoinactivation. Applied and Environmental Microbiology 78(2): 305-310
- Rogers, et al. 2011. Decay of Bacterial Pathogens, Fecal Indicators, and Real-Time Quantitative PCR Genetic Markers in Manure-Amended Soils. Applied and Environmental Microbiology 77(17):4839-4848
- Flood et al. 2011. Lack of correlation between enterococcal counts and the presence of human specific fecal markers in Mississippi creek and coastal waters. Water Research 45(2):872-878
- Sauer, et al. 2011. Detection of the human specific Bacteroides genetic marker provides evidence of widespread sewage contamination of stormwater in the urban environment. Water Research 45(2011):4081-4091.
- Noble, et al. 2010. Comparison of Rapid Quantitative PCR-Based and Conventional Culture-Based Methods for Enumeration of Enterococcus spp. and *Escherichia coli* in Recreational Waters. Applied and Environmental Microbiology 76(22):7437-7443

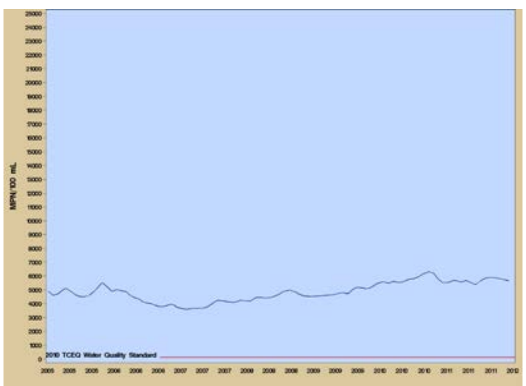
Maps and Graphics

- UH Clear Lake Wetlands
- Sampling
- League City park photo/drawing
- Memorial Park Construction

Ten Assessment units with the stations with the **highest** *E. coli* geometric means

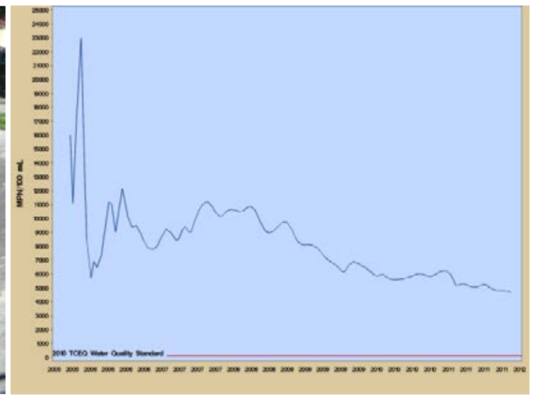
(1) Assessment Unit 1013C_01: Glennwood Cemetery (5807)

- Station 16675.
- Geomean for 65 *E. coli* samples: 5807.
- Geomean relative to standard: 46 times the standard.
- Description: An unnamed tributary of Buffalo Bayou at Glennwood Cemetery, not far from the intersection of Lubbock and Sawyer Streets just upstream of downtown Houston. Adjacent to the Houston Police Officers Memorial and Eleanor Tinsley Park. This assessment unit is the most upstream assessment unit for this waterbody. The area is undergoing construction currently to upgrade the biking and running trails along the Bayou.
- KM 493K.
- First listed in 2002.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/16675s.jpg
-



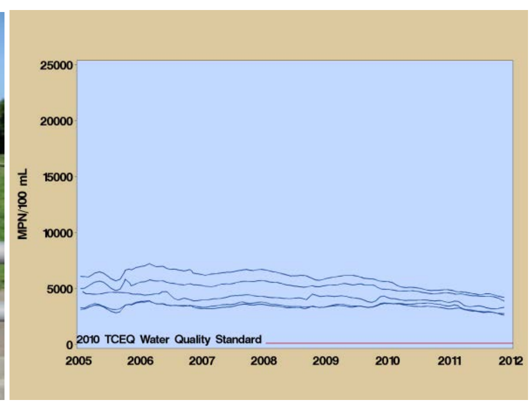
(2) Assessment Unit: 1007T_01: Bintliff Ditch

- Station 18690.
- Geomean for 55 *E. coli* samples: 5107.
- Geomean relative to standard: 41 times the standard.
- Description: A tributary of Brays Bayou near the intersection of Bissonet at Fondren in southwest Houston. This assessment unit is the most upstream assessment unit for this waterbody. May be showing improvement.
- KM 530Q.
- First listed in 2010.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/18690s.jpg



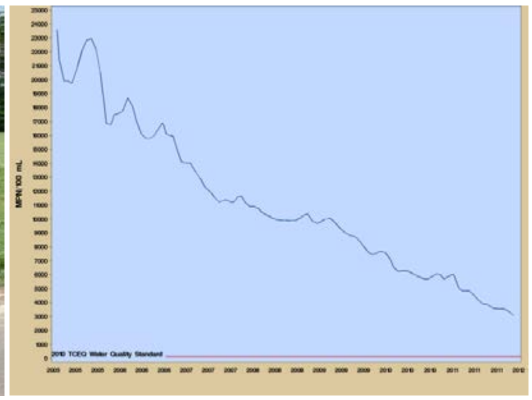
(3) Assessment Unit 1007B_01: Brays Bayou

- Five monitoring stations, from the Meyerland area outside the 610 Loop east to Hermann Park: 15854, 15853, 11138, 15859, 15855.
- First listed in 2002.
- Station 15854:
  - Geomean for 66 *E. coli* samples: 4410.
  - Geomean relative to standard: 35 times the standard.
  - Description: Brays Bayou at South Rice Ave.
  - KM 531U.
  - May be showing improvement.
- Station 15853:
  - Geomean for 65 *E. coli* samples: 4218.
  - Geomean relative to standard: 33 times the standard.
  - Description: Brays Bayou at Hillcroft.
  - KM 531S.
  - May be showing improvement.
- Station 15859:
  - Geomean for 66 *E. coli* samples: 2964.
  - Geomean relative to standard: 24 times the standard.
  - Description: Brays Bayou at Greenbriar.
  - KM 532M.
- Station 15855:
  - Geomean for 66 samples: 2931.
  - Description: Brays Bayou at Stella Link Road.
  - Geomean relative to standard: 23 times the standard.
  - KM 532N.
- Station 11138:
  - Geomean for 65 *E. coli* samples: 3510.
  - Geomean relative to standard: 28 times the standard.
  - Description: Brays Bayou at Almeda Road.
  - KM 533F.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/15854s.jpg



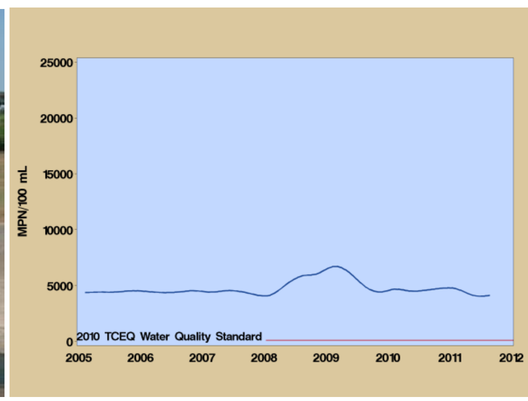
(4) Assessment Unit 1007R_01: Schramm Gully

- Station 15869
- Geomean for 66 *E. coli* samples: 4397
- Geomean relative to standard: 35 times the standard.
- Description: Tributary of Hunting Bayou at Cavalcade St. in northeast Houston.
- KM 454X.
- First listed in 2002.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/15869s.jpg



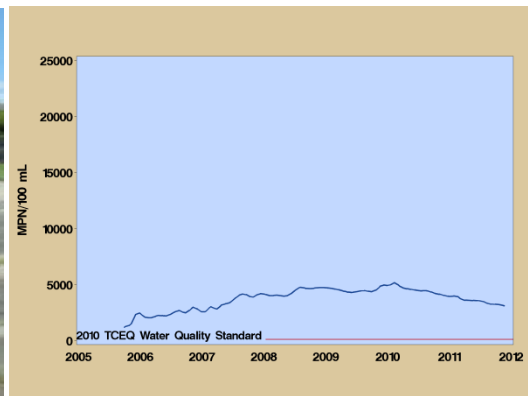
(5) Assessment Unit 1017_04: White Oak Bayou

- Two monitoring stations, one downstream of Heights Blvd, the other at West TC Jester, both northwest of downtown Houston: 11387, 16637.
- First listed in 1996.
- Station 11387:
    - o Geomean for 26 *E. coli* samples: 4130.
    - o Geomean relative to standard: 33 times the standard.
    - o Description: Whiteoak Bayou at Heights Blvd.
    - o KM 493E.
- Station 16637:
    - o Geomean for 27 *E. coli* samples: 3637.
    - o Geomean relative to standard: 33 times the standard.
    - o Description: Whiteoak Bayou at Heights Blvd.
    - o KM 493E.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/11387s.jpg



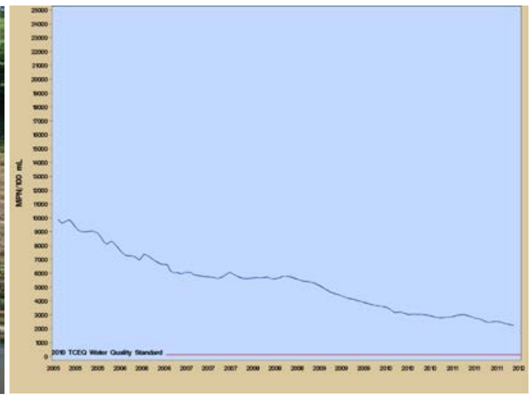
(6) Assessment Unit 1007U_01: Mimosa Ditch

- Station 18691.
- Geomean for 56 *E. coli* samples: 3613.
- Geomean relative to standard: 29 times the standard.
- Description: Tributary of Brays Bayou at Newcastle Drive near the south boundary of Bellaire.
- KM 531R.
- First listed in 2010.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/18691s.jpg



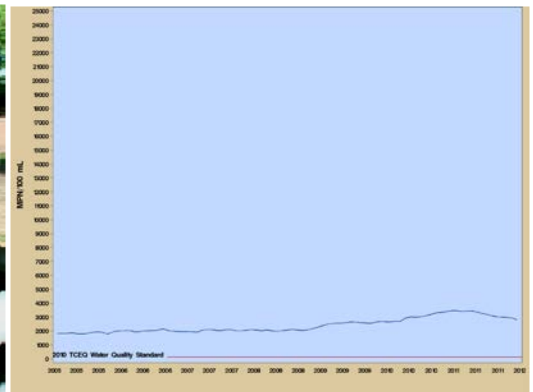
(7) Assessment Unit 1013A_01: Little White Oak Bayou

- Station 11148.
- Geomean for 66 *E. coli* samples: 3478.
- Geomean relative to standard: 28 times the standard.
- Description: Little White Oak Bayou at Trimble Street/North Edge of Hollywood Cemetery north of downtown Houston.
- KM 453Y.
- First listed in 2002.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/11148s.jpg



(8) Assessment Unit 1016D_01: Unnamed Tributary of Greens Bayou

- Station 16676.
- Geomean for 66 *E. coli* samples: 3336.
- Geomean relative to standard: 26 times the standard.
- Description: Unnamed Tributary of Greens Bayou at Smith Rd in Northeast Houston.
- KM 375X.
- First listed in 2002.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/16676s.jpg



(9) Assessment Unit 1006D_02: Halls Bayou at Airline

- Station 17490.
- Geomean for 66 *E. coli* samples: 2416.
- Geomean relative to standard: 19 times the standard.
- Description: Halls Bayou at Airline Road in North Houston.
- KM 375X.
- First listed in 2002.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/17490s.jpg

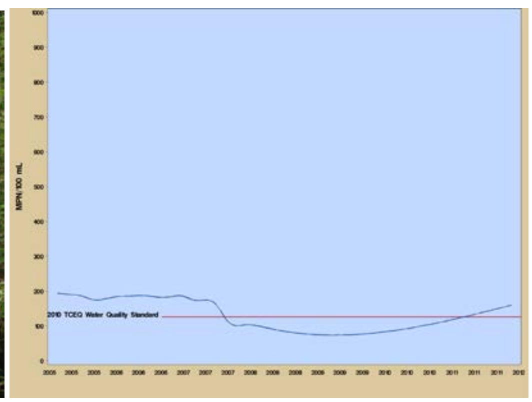
(10) Assessment 1007C_01: Keegans Bayou

- Station 11169.
- Geomean for 65 *E. coli* samples: 2178.
- Geomean relative to standard: 17 times the standard.
- Description: Keegans Bayou at Roark Road near US 59 just southwest of Houston City Limits
- KM 469C.
- First listed in 2002.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/11169s.jpg

Ten Assessment units with the stations with the **lowest** *E. coli* geometric means

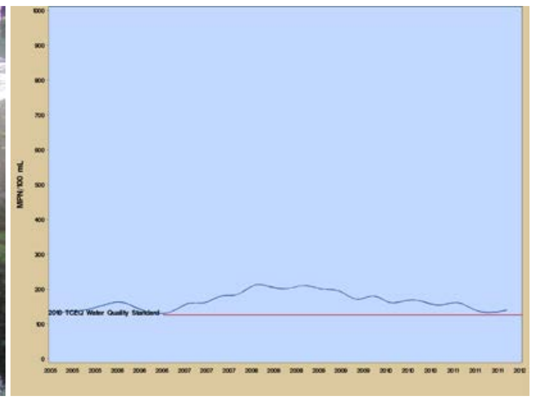
(1) Assessment Unit 1102C_01: Hickory Slough

- Station 17068.
- Geomean for 20 *E. coli* samples: Geometric Mean: 127.
- Geomean relative to standard: 1.01 times the standard.
- Description: Hickory Slough, a tributary of Clear Creek above tidal at Robinson Drive in Pearland.
- KM 615B.
- First listed in 2008.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/17068s.jpg



(2) Assessment Unit 1008B_01: Upper Panther Branch

- Station 16629.
- Geomean for 27 *E. coli* samples: Geometric Mean: 138.
- Geomean relative to standard: 1.1 times the standard.
- Description: Upper Panther Branch at Research Forest Dr. in the Spring Creek watershed.
- KM 217T.
- First listed in 2010.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/16629s.jpg



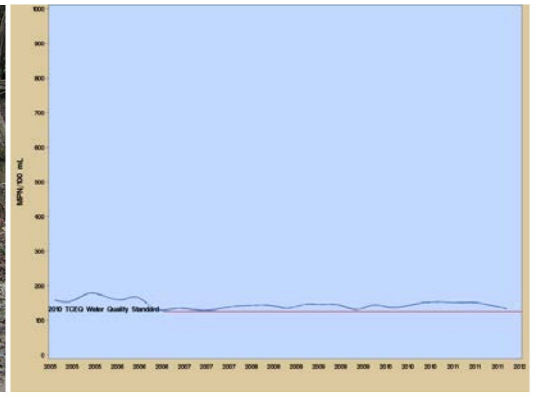
(3) Assessment Unit 1011_01: Peach Creek

- Station 16625.
- Geomean for 24 *E. coli* samples: Geometric Mean: 133.
- Geomean relative to standard: 1.1 times the standard.
- Description: Peach Creek at Old HWY 105.
- KM 192C.
- First listed in 2010.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/16625s.jpg

The watershed is dominated by forested land with the Sam Houston National Forest in the upper reach. Peach Creek flows into the East Fork San Jacinto River approximately two miles upstream from Lake Houston, the major drinking water supply for the region. Several small communities including Splendora, Patton Village, Roman Forest, and Woodbranch are located in the lower reach of the watershed. These residential communities are growing quickly especially along the U.S. Highway 59 corridor.

(4) Assessment Unit 1008C_02: Lower Panther Branch and

- Station 16627:
- Geomean for 27 *E. coli* samples: 147.
- Geomean relative to standard: 1.2 times the standard.
- Description: Lower Panther Branch at Sawdust Road in the Spring Creek Watershed.
- KM 251U.
- First listed in 2010
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/16627s.jpg



This segment continues to experience rapid development. Commercial and residential growth is flourishing in the northeastern and middle portions of the watershed. The areas around Spring, The Woodlands, Shenandoah, and Oak Ridge North have been growing for quite some time but development around the cities of Tomball and Magnolia, located in the middle of the watershed, has escalated in the past five years. Between I-45 to the west and U.S. Highway 59 to the east, most of Spring Creek has been preserved as a greenbelt to help minimize flooding. The primary land cover west of Tomball is agricultural and cultivated land. Grass, hay and pasture related to cattle and horse ranches are common. The forested areas in the middle and northwest portion of the watershed are interspersed by subdivisions platted with lots ranging from 0.5 to 5 acres in size. Ranchettes and hobby ranches are also common in that portion of the watershed. On-site sewage facilities are the primary means of waste disposal in those areas.

(5) Assessment Unit 1008_04: Spring Creek at Roberts Cemetery Road West in Spring Creek Watershed

- Station: 18868
- Geomean for 18 *E. coli* samples: Geometric Mean: 148.
- Geomean relative to standard: 1.2 times the standard.
- Description: Peach Creek at Old HWY 105.
- KM 285M.
- First listed in 2010.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/No_Image_Available.jpg

This segment continues to experience rapid development. Commercial and residential growth is flourishing in the northeastern and middle portions of the watershed. The areas around Spring, The Woodlands, Shenandoah, and Oak Ridge North have been growing for quite some time but development around the cities of Tomball and Magnolia, located in the middle of the watershed, has escalated in the past five years. Between I-45 to the west and U.S. Highway 59 to the east, most of Spring Creek has been preserved as a greenbelt to help minimize flooding. The primary land cover west of Tomball is agricultural and cultivated land. Grass, hay and pasture related to cattle and horse ranches are common. The forested areas in the middle and northwest portion of the watershed are interspersed by subdivisions platted with lots ranging from 0.5 to 5 acres in size. Ranchettes and hobby ranches are also common in that portion of the watershed. On-site sewage facilities are the primary means of waste disposal in those areas.

(6) Segment ID 1101_03 Clear Creek Tidal at SH 3

- Station 11446
- Geomean for 57 Enterrococci samples: Geometric Mean: 44.
- Geomean relative to standard: 1.2 times the standard.
- Description: Clear Creek Tidal at SH3 near Webster.
- KM 658D.
- First listed in 2010.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/11446s.jpg

(7) Segment ID: 1010_03 Caney Creek at Firetower Road, Caney Creek Watershed

- Station 20452.
- Geomean for 16 *E. coli* samples: Geometric Mean: 167.
- Geomean relative to standard: 1.3 times the standard.
- Description: Caney Creek at Firetower Road, Caney Creek.
- KM 221V.
- First listed in 2010.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/20452s.jpg

(8) Segment 1007R_03 Hunting Bayou at North Loop East, in Houston Ship Channel/Buffalo Bayou Tidal

- Station 11129.
- Geomean for 66 *E. coli* samples: Geometric Mean: 170.
- Geomean relative to standard: 1.4 times the standard.
- Description: Hunting Bayou at North Loop East.
- KM 455Y.
- First listed in 2010.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/11129s.jpg

(9) Segment ID 1102_02 Clear Creek at Telephone Road, Clear Creek Watershed

- Station 11452.
- Geomean for 44 *E. coli* samples: Geometric Mean: 182.
- Geomean relative to standard: 1.4 times the standard.
- Description: Clear Creek at Telephone Road.
- KM 575W.
- First listed in 2010.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/11452s.jpg

Folder of station photos: \\ntfs05\media\CommunityEnvironmental\Photos\Program Areas\Water Resources\Regional Monitoring\Monitoring Photos by Organization\Misc Stations

The Clear Creek Above Tidal watershed has continued to experience rapid residential and commercial development especially along FM518 though Friendswood and Pearland. The around FM 518 and Hwy 288 south of Beltway 8 in Pearland is also highly developed. There are still scattered areas of open space throughout the watershed that are likely to be developed as growth continues south and west. There are also some agricultural areas in the south and western parts of the watershed. The majority of the area and most of the new development is on sanitary sewer, but there are still several areas on-site sewer facilities scattered throughout the watershed.

(10) Segment ID 1008C_01: Lower Panther Branch at Sawdust

- Station 16628.
- Geomean for 27 *E. coli* samples: Geometric Mean: 185.
- Geomean relative to standard: 1.5 times the standard.
- Description: Garners Bayou at Old Humble Road.
- KM 251U.
- First listed in 2010.
- Photo: http://arcgis02.h-gac.com/Reference/WRIM/StationPics/16628s.jpg

BIG Most Wanted Most Likely to Succeed
Comparison of 2012 and 2013 lists

The SAS System

Monitoring Station	Parameter	Earliest Date in	Most Recent Date	samples	gm	ratio	au_id	List	Rank Last Year	Rank This Year	Ratio last year	Note
16675	E. Coli	9/29/2005	8/13/2012	68	5291.29	41.9944	1013C_01	Most Wanted	1	1	46	Glennwood Cemetery
18690	E. Coli	9/19/2005	8/8/2012	67	4498.17	35.6997	1007T_01	Most Wanted	2	2	41	Bintliff Ditch (Brays)
15854	E. Coli	9/28/2005	8/8/2012	69	3939.78	31.2681	1007B_01	Most Wanted	3	3	35	Brays (1 of 5)
15853	E. Coli	9/28/2005	8/8/2012	68	3792.75	30.1012	1007B_01	Most Wanted	3	3^	33	Brays (2 of 5)
11387	E. Coli	2/8/2006	11/27/2012	26	3767.5	29.9008	1017_04	Most Wanted	5	4	33	White Oak (1 of 2)
15828	E. Coli	2/8/2006	11/27/2012	27	3389.56	26.9013	1017_04	Most Wanted	addition	4^		White Oak NEW
11138	E. Coli	9/30/2005	8/14/2012	68	3146.31	24.9707	1007B_01	Most Wanted	3	3^	28	Brays (3 of 5)
11347	E. Coli	12/6/2001	8/26/2008	39	3023.29	23.9943	1013_01	Most Wanted	NEW	5		NEW Buffalo Tidal (1 of 2)
11309	E. Coli	9/30/2005	8/1/2012	68	2948.42	23.4002	1007B_01	Most Wanted	addition	3^		Brays NEW
18691	E. Coli	9/28/2005	8/14/2012	68	2893.61	22.9652	1007U_01	Most Wanted	6	6	29	Mimosa Ditch (Brays)
16676	E. Coli	9/27/2005	8/14/2012	69	2828.01	22.4445	1016D_01	Most Wanted	8	7	26	Unnamed Trib of Greens
17490	E. Coli	9/14/2005	8/23/2012	69	2633.69	20.9023	1006D_02	Most Wanted	9	8	19	Halls
11389	E. Coli	9/13/2005	8/9/2012	67	2599.96	20.6346	1017_04	Most Wanted	addition	4^		White Oak NEW
11345	E. Coli	11/19/2002	10/27/2009	27	2498.62	19.8304	1013_01	Most Wanted	NEW	5^		NEW Buffalo Tidal (1 of 2)
15869	E. Coli	9/29/2005	8/13/2012	69	2473.63	19.632	1007R_01	Most Wanted	4	9	35	Schramm Gully
15855	E. Coli	9/28/2005	8/14/2012	69	2468.92	19.5946	1007B_01	Most Wanted	3	3^	23	Brays (5 of 5)
16661	E. Coli	9/12/2005	8/2/2012	69	2373.1	18.8341	1007F_01	Most Wanted	NEW	10		NEW Berry Bayou
11148	E. Coli	9/13/2005	8/9/2012	69	2365.41	18.7731	1013A_01	Most Wanted	7		28	Little White Oak Bayou
16658	E. Coli	9/12/2005	8/2/2012	68	2306.71	18.3072	1007I_01	Most Wanted	NEW			NEW Plum Creek
11140	E. Coli	9/19/2005	8/8/2012	76	2191.61	17.3937	1007B_01	Most Wanted	addition			Brays NEW
11139	E. Coli	8/23/2005	8/14/2012	97	2027.3	16.0896	1007B_01	Most Wanted	addition			Brays NEW
11188	E. Coli	9/27/2005	8/7/2012	69	2003.31	15.8993	1014N_01	Most Wanted	NEW			NEW Rummel Creek
11169	E. Coli	9/19/2005	8/15/2012	69	1998.56	15.8616	1007C_01	Most Wanted	10		17	Keegans Bayou
11452	E. Coli	11/9/2005	10/2/2012	36	278.1	2.2071	1102_02	Most Likely	9		1.4	Clear Creek
11446	Enterococci	10/6/2005	10/2/2012	47	62.96	1.7988	1101_03	Most Likely	6		1.2	Clear Creek Tidal
16625	E. Coli	8/17/2005	7/12/2012	25	205.9	1.6341	1011_01	Most Likely	3		1.1	Peach Creek
16628	E. Coli	7/21/2005	7/5/2012	29	199.88	1.5864	1008C_01	Most Likely	10		1.5	Lower Panther Branch
16493	E. Coli	7/5/2005	7/2/2012	32	190.13	1.509	1101B_01	Most Likely	NEW			Chigger Creek
20730	E. Coli	10/8/2009	8/27/2012	27	189.13	1.5011	1008H_01	Most Likely	NEW	10		Willow Creek
20453	E. Coli	10/4/2007	8/9/2012	20	175.97	1.3965	1010_02	Most Likely	NEW	9		Caney Creek
11129	E. Coli	9/29/2005	8/13/2012	76	173.39	1.3761	1007R_03	Most Likely	8	8	1.4	Hunting (tidal?)
20452	E. Coli	10/4/2007	8/10/2012	20	163.88	1.3006	1010_04	Most Likely	7	7	1.3	Caney Creek
17068	E. Coli	8/29/2005	7/2/2012	19	156.13	1.2391	1102C_01	Most Likely	1	6	1.01	Hickory Slough
16629	E. Coli	7/21/2005	7/5/2012	29	152.71	1.212	1008B_01	Most Likely	2	5	1.1	Upper Panther Branch
18868	E. Coli	5/16/2007	8/2/2012	22	152.24	1.2082	1008_04	Most Likely	5	4	1.2	Spring Creek
16627	E. Coli	7/21/2005	7/5/2012	29	150.97	1.1982	1008C_02	Most Likely	4	3	1.2	Lower Panther Branch
20456	E. Coli	10/1/2007	8/2/2012	20	150.36	1.1934	1009E_01	Most Likely	NEW	2		Little Cypress Creek
16589	E. Coli	9/27/2005	8/14/2012	69	144.96	1.1504	1016A_02	Most Likely	NEW	1		Garners Bayou