Application of Consistent Contact Recreation Water Quality Standards Across Hydrological Extremes: Reasonable or Ridiculous?

Lucas F. Gregory, Texas A&M AgriLife Research, Texas Water Resources Institute
Stephen Muela, Texas A&M AgriLife Research, Texas Water Resources Institute
Kevin L. Wagner, Texas A&M AgriLife Research, Texas Water Resources Institute

Abstract:

Water quality standards are developed to protect and define when waterbodies support their designated uses. Recreational use categories may include activities that do not occur under similar hydrologic conditions making protection of all uses challenging. This paper presents a case study where *E. coli* concentrations were grouped by flow rate to demonstrate potential effects of developing use-specific water quality standards for contact recreation. Adopting this approach requires a shift from current water quality policy which applies to all hydrologic conditions. Implementing an alternative approach can still protect human health while minimizing costs taxpayers incur to restore impaired waterbodies.

I. Introduction:

Safeguarding water quality is essential to protect public health worldwide. Globally, the UN estimates that 780 million people do not have access to clean water and another 2.5 billion do not have adequate sanitation (UNICEF 2012). Deficient water treatment and natural phenomena can cause infectious doses of pathogens to be present in surface waters. When consumed, these pathogens can potentially cause water borne illnesses. Pathogen presence estimates commonly use fecal indicator bacteria (FIB) concentrations such as *Escherichia coli* due to cost considerations*. E. coli* occurs naturally in the intestinal tract of all endotherms and is closely associated with many human pathogens (Odonkor and Ampofo, 2013). Outside the host, its lifecycle is reasonably close to many bacterial pathogens but may be quite different from viral or protozoan pathogens, thus minimizing its utility as a FIB (Gerba, 2009). Many factors including low and high temperatures, limited moisture, low nutrition, salinity, solar radiation, soil properties, and predation affect the ability of *E. coli* to survive outside the host (Ishii and Sadowsky, 2008). However, recent research suggests that *E. coli* are able to persist for extended periods and potentially grow outside the host under suitable environmental conditions (Byappanahalli et al., 2012, Fujioka et al., 1998).

E. coli and associated pathogens arrive in streams through direct deposition (point sources or defecation into the stream) or indirectly via runoff (nonpoint source pollution). Nonpoint *E. coli* sources undergo various fate and transport processes before arriving in streams (Ferguson et al., 2003) thus affecting *E. coli* and pathogen quantities entering the stream. Regardless of transport mechanism, sediment provides an environmental niche where *E. coli* can persist for extended periods of time (Garzio-Hadzick et al., 2010) and potentially grow (Solo-Gabriele et al., 2000). This challenges water managers as extended persistence and growth can yield *E. coli* populations that may not be associated with recent contamination events (Anderson et al., 2005) and potentially diminish relationships between *E. coli* concentration and human health risk. It may also lead to impaired waterbody statuses and significant financial investments to correct perceived pollution issues (Wagner et al., 2016).

Known effects of flow rate on sediment transport further confound this issue. Research has demonstrated normal and high streamflow induced releases of streambed bacteria. In southeast Texas, up to 90% of observed instream *E. coli* load was derived from sediment under baseflow conditions (Brinkmeyer et al., 2015). This deviates from conventional thought that resuspension only occurs during high-flow events (Jamieson et al., 2005). Using artificial floods, Muirhead et al. (2004) demonstrated a two order of magnitude increase in *E. coli* concentrations that were a direct result of flow rate induced sediment resuspension. This is not surprising, considering that a literature review by Pachepsky and Shelton (2011) noted that *E. coli* concentrations can be 1 to 2,200 times greater in sediments than in the water column. However, they found that correlations between *E. coli* concentrations in overlying water and sediment are typically very weak. Regardless of correlation, inclusion of high-flow influenced samples in water quality assessments can affect results.

Surface water quality standards are established to protect designated waterbody uses and provide the basis for permitting, compliance, and assessments. Standards include defined designated uses, water quality criteria, and antidegradation policies. Once in place, water quality management decisions are largely based on these standards. Therefore, appropriately developing and applying these standards is critical because future management actions and the financial resources they require can be significant (Wagner et al., 2016).

Water quality standards established for contact recreation uses based on long-term FIB concentrations aim to protect human health during contact recreation. In work conducted by USEPA (1986), gastrointestinal illnesses contracted by swimmers a defined bathing beaches were correlated to *E. coli* concentrations. It was determined that increased *E. coli* concentrations resulting from recent fecal contamination (point source discharges of treated wastewater effluent) related to a quantified human health risk. A point to make regarding this study was that all work was conducted in lake settings that were influenced by wastewater treatment plant discharge. Their results formed the basis for development of primary contact recreation standards in many states and countries (Ishii and Sadowsky, 2008).

Water quality standards are often applied to flowing water bodies and all flow conditions (TCEQ, 2010). Various flow conditions present different inherent risks to those choosing to engage in contact recreation. Rational thinking suggests that activities such as swimming, wading by children, and tubing should not occur during high-flows due to increased drowning risks However, whitewater activities such as kayaking, canoeing, and rafting commonly occur during these conditions. Whitewater recreation is inherently risky and increased flow rates that occur during or shortly after storms greatly increase these recreation opportunities in areas where whitewater streams are not common (Daniel, 2004). The existence of these activity types have justified maintaining contact recreation standards at all flow conditions. However, arguments for applying water quality standards at high-flows (floods) are misguided due to the natural pollutant flushing that occurs and the inability to effectively manage pollutant sources during these conditions. Further, Dorevitch et al. (2011) found that kayakers typically consume 35-40% less water than swimmers. Thus, an opportunity to evaluate other water quality assessment and standards development approaches that could minimize potential financial burdens to society without substantially affecting human health risks exists. This paper will evaluate the effects of considering *E. coli* samples collected during high-flow events differently in water quality assessment results and discuss policy implications of flow rate and risk-based water quality standards.

II. Methods:

Site Description

Water quality monitoring was conducted on the Navasota River in east central Texas, USA (Figure 1) from December 12, 2014 through August 30, 2016. The Navasota River spans approximately 200 km from its headwaters to its confluence with the Brazos River. Average annual precipitation in the watershed ranges from 864 to 1,118 mm. Cool, wet winters and hot, dry summers typify local conditions. The watershed is predominantly rural with undeveloped land encompassing >92% of the land area. Grazing land and forests are the dominant land covers. Flood control and water supply is provided by three reservoirs impounding the river in its upper reaches. Lake releases mostly occur in response to rainfall runoff thus making it difficult to distinguish the effects of dam releases from precipitation and runoff into the watershed (Gregory et al., 2015).

Three monitoring sites were selected based on geographic location, accessibility, and availability of historic data at each point. For the assessment presented here, only the data collected from station 11877 were utilized. This site is located in the upper portion of the river approximately 27.4 km downstream of the largest reservoir. All sites were upstream of the urban areas. US Geologic Survey stream gage 08110500 is collocated at this site and records water levels at 15-minute increments. Monitoring occurred biweekly except when high-flows created hazardous sampling conditions or prevented station access. Approximately 25 storm events occurred during the monitoring period. Flow rates above 28.3 m^3/s produced hazardous conditions and monitoring was postponed. Missed events were rescheduled as soon as possible. Monitoring techniques followed procedures required by the Texas Commission on Environmental Quality (TCEQ, 2012). Large storm events routinely produced discharges of ~300 m^3/s, which are considered major flood events. Typical bankfull discharge is approximately 30 m^3/s at this point in the Navasota River.

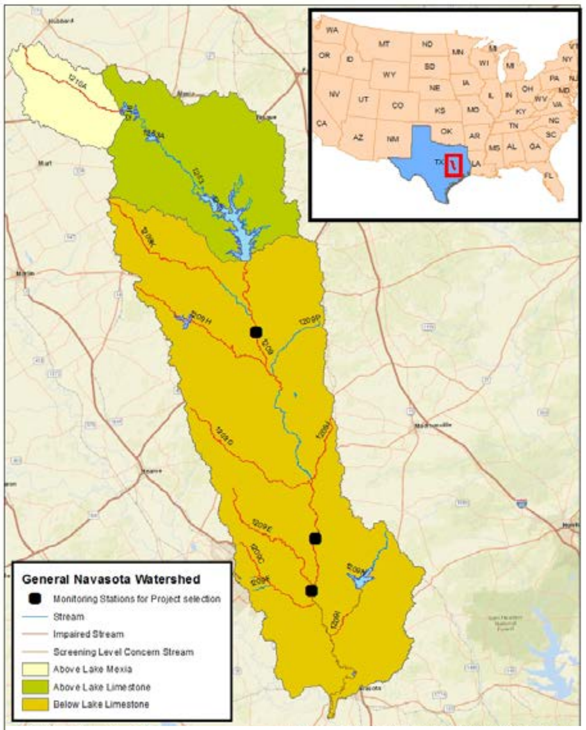

Figure 1. Navasota River watershed in Central Texas, USA

Flow volume was recorded using a Sontek ADV (Acoustic Doppler Velocimeter) Flowtracker® or a Sontek RiverSurveyor® M9 Doppler boat. Concurrent pH, water temperature, DO (dissolved oxygen), and specific conductance measurements were recorded with a YSI EXO1 Multiparameter Sonde. Water samples were collected from the centroid of flow into sterile 200 mL WhirlPak® bags and were transported in ice within 6 hours to the Soil and Aquatic Microbiology Lab at Texas A&M University for *E. coli* quantification. *E. coli* quantification in the lab was performed using the EPA 1603 method, a modified thermotolerant membrane filtration approach. Turbidity was determined using a HACH 2100Q field turbidity unit.

Statistical Analysis

Differences in median *E. coli* concentrations between safe, unsafe, and all flow conditions were evaluated using the non-parametric Mann-Whitney and Kruskal-Wallis tests. Data were non-normally distributed according to Kolmogorov-Smirnov testing. Significance for all analyses was determined using $\alpha=0.05$, thus p values ≤ 0.05 were considered statistically significant. All statistical analyses were conducted using Minitab 17 software (Minitab Inc., State College, PA).

III. Results

In order to recognize instances in which sediment resuspension and nonpoint sources cause elevated *E. coli* concentrations, flow events were separated into safe and unsafe conditions for swimming and wading by children (Table 1). Biweekly monitoring and sampling over the course of two years captured the *E. coli* concentrations and flow volumes for multiple storm events and baseflow conditions. Based on recorded flow velocity and stream depths, a discharge of 2.12 m^3/s at the monitoring location was assumed to be the upper flow-volume limit that allows for safe swimming and wading. All data were aggregated for evaluation to represent the current assessment approach.

Table 1. *E. coli* concentration descriptive statistics by flow category

E. coli concentrations CFU/100mL	*N*	*Median*	*Standard Deviation*	*Geometric Mean*
Safe flows	32	110	163.1	106.4
Unsafe flows	9	290	1835.7	510.4
All flows	41	124	978.9	150.1

Statistically, median *E. coli* concentrations were not equal between flow categories (p=0.001). Between individual categories, safe and unsafe conditions were found to be significantly different (p<0.001), but safe conditions and all flows combined were not (P=0.205). The presence of several outlier *E. coli* concentrations during high-flow events strongly influences the median and geometric means in each group (Figure 2). This demonstrates the typical increases in *E. coli* concentration that occur from instream sediment resuspension and nonpoint source pollutant contributions during high-flow events (Figure 3). Clearly, there are different potential human health risks under safe and unsafe flow conditions. These differing scenarios present an opportunity to create or apply multiple recreation water quality standards on the same waterbody that are based on flow condition and/or the amount and type of recreation that occurs.

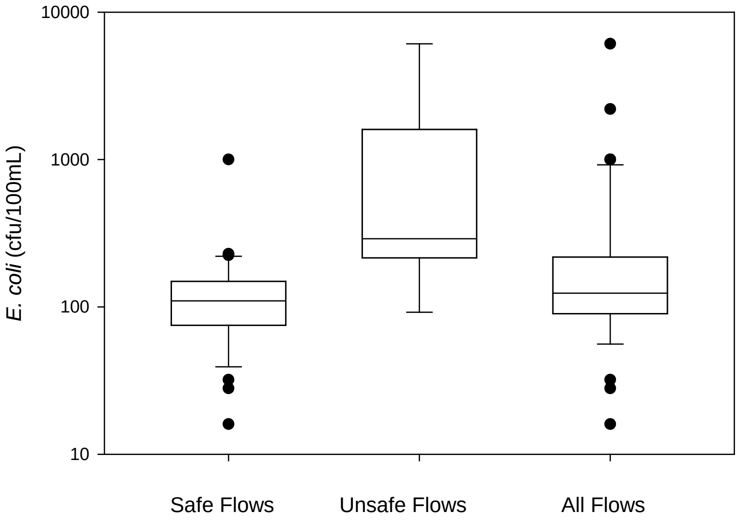

Figure 2. *E. coli* concentrations by flow condition

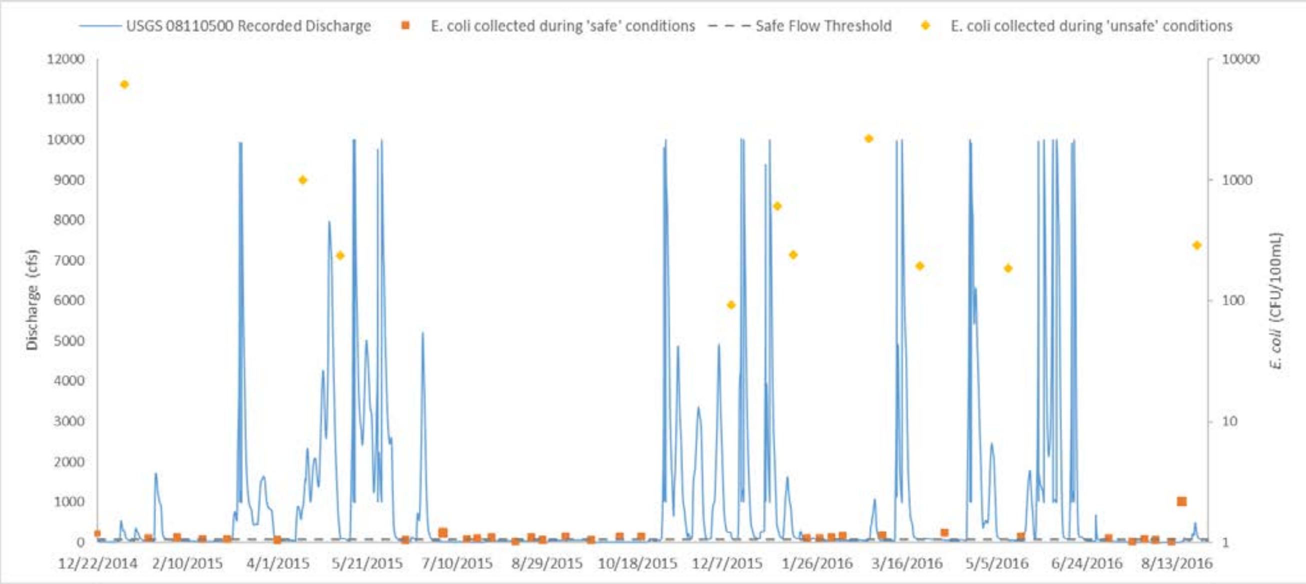

Figure 3: Hydrograph and *E. coli* concentrations at the monitoring station

IV. Policy Implications:

A singular numeric water quality standard for *E. coli* that a waterbody must meet to support recreation uses during all flow conditions is not practical. In Texas, this was acknowledged and addressed by developing specific standards for different waterbody uses listed below.

- primary contact 1 (126 cfu/100mL): uses presumed to involve a significant water ingestion risk including children wading, swimming, diving, surfing, water skiing, tubing, and whitewater kayaking, canoeing, or rafting
- primary contact 2 (206 cfu/100mL): uses are the same as primary contact 1 but are less frequent due to physical limitations of the waterbody and limited access
- secondary contact 1 (630 cfu/100mL): common activities with limited body contact including fishing, canoeing, kayaking, rafting, sailing, and motor-boating
- secondary contact 2 (1030 cfu/100mL): uses are the same as secondary contact 1 but are less frequent due to physical limitations of the waterbody and limited access
- non-contact (2060 cfu/100mL): contact is prohibited by law, or activities with no presumed water ingestion risk including hiking, biking, and birding

Although this is an improvement from a singular standard, the definition of primary contact recreation includes disparate activities not likely to occur in a waterbody under similar flow conditions. Whitewater sports require much higher flow velocity than swimming, wading by children, or diving. The latter are likely to occur under normal or low-flow conditions, while the former occur during high-flow and flood conditions. Therefore, water quality is likely worse when whitewater sports are likely to occur.

Whitewater sports are inherently dangerous due to adverse hydrologic conditions. Researchers documented whitewater kayaking fatality rates from 3 to 6 deaths per 100,000 kayaking days and injury rates at 4.5 per 1,000 kayaking days. They noted that self-guided paddling trips are significantly more dangerous than the commercial trips (Fiore and Houston 2001; Schoen and Stano 2002). Insurance companies also acknowledge the increased risk by routinely increasing policy premiums by $2 to $10 per $1,000 of coverage for frequent extreme sports participants. These persons assume increased risk during the activity thus logic suggests that a slight risk increase for contracting a gastrointestinal illness is appropriate. Implementing less restrictive water quality standards during natural high-flow conditions will adequately protect human health without imparting excessive financial burden to keep surface waters clean under all flow conditions.

A practical option for establishing an alternative contact use category that is applicable for more dangerous flow conditions combines flow rate-based thresholds and risk-based approaches. This will necessitate site-specific criteria establishment, but allows more appropriate water quality standards to be selected based on use. Utilizing site-specific criteria requires more detailed analysis of the recreational uses of a waterbody. Since waterbodies change throughout their course, it makes the most sense to do this assessment at the scale of assessment units (AUs) to ensure these standards are individually relevant and not overly broad. Flow rate-based standards can be used in situations where multiple uses occur at varying flow conditions. Under normal or “safe” flow conditions, primary contact uses may occur; but under higher flow or conditions, these uses become unsafe and are replaced by extreme uses like whitewater sports. Site-specific knowledge can be used to determine a flow threshold where swimming and wading become unsafe. In the case of the Navasota River, there were 15 instances where monitoring was abandoned due to hazardous wading conditions. The TCEQ surface water quality monitoring procedures prohibit wading in streams with a velocity of ~5 ft^2/s and a depth of only 2 ft. (TCEQ 2012). Once this threshold is established, the primary contact 1 standard would only apply to water quality samples collected below this flow threshold and excludes values collected above that level. The less restrictive standard applicable for flow conditions supporting extreme water sports should apply for all flow conditions including those above the flow threshold for safe flow conditions. Effectively, this standard applies for all contact recreation uses, but acknowledges the fact that natural hydrologic processes result in temporarily reduced water quality.

A risk-based approach to establishing alternative water quality standards can be used to set appropriate risk levels for differing thresholds. This approach considers the number of individuals contact recreating on an annual basis. Improvements documenting the quantity of contact uses and the flow conditions when they occur is necessary. For example, if 5,000 individuals swim in a waterbody in a given year under normal flow conditions and only 50 individuals engage in extreme whitewater sports under high-flow conditions, separate standards can be established to allow acceptable *E. coli* concentrations in the waterbody. Primary contact 1 described above predicts an illness rate of 8 people per 1,000 individuals and is based on the equation established by Dufour and Ballentine (1986):

$$\text{Illness rate per 1000 swimmers} = [\text{Log}(E.\ coli \text{ geometric mean}) - 1.249]/0.1064$$

At the assumed number of swimmers listed above and the primary contact 1 standard, 40 individuals per year may become ill. However, only 0.4 individuals of the extreme sports group may become ill at the same threshold. Increasing the water quality threshold for high-flow conditions to the secondary contact 1 use standard (630 cfu/100 mL) and applying it to individuals engaged in extreme sports results in 0.72 ill individuals out of the same 50 individuals during this one year period. This is a nominal illness increase relative to the increase in allowable *E. coli* concentrations in all flow conditions.

V. Conclusions:

The Navasota River provides an interesting case study representative of many low-use waterbodies. Its water quality is currently impaired under the required primary contact 1 standard. A recent use assessment indicates that primary contact uses occur, but at very limited levels. No instances of use during high-flow conditions were observed or noted in surveys. Grouping water quality data by flow threshold revealed significantly different results and demonstrates the potential for altering impairment designations by implementing flow rate-based standards with risk-based numeric criteria.

This approach requires more site-specific data collection prior to establishing flow rate-based thresholds and associated numeric criteria. However, it may reduce the number of impaired waterbodies by more accurately characterizing their use and allowing an appropriate standard to be selected. Problems alleviated with this approach have been acknowledged, but not entirely resolved. We realize that this is not a simple process, but one that has the potential to reduce management and restoration costs in waterbodies where significant primary contact uses do not occur at all flow conditions. This allows natural hydrological processes to occur that would prevent waterbodies from fitting into traditional standards categories based on use without causing water quality impairments.

It is not the intent of this paper to promote water quality standards reductions, but instead to propose improvements to current approaches. Stringent standards are quite important for protecting public health and conserving natural waters. However, water quality standards should incorporate the best available science and acknowledge different levels and types of uses that occur. Implementing variable condition standards will not compromise mandates to protect public health, but support a more targeted and reasonable approach that allows the limited restoration resources available to be applied where they are most needed.

Bibliography:

ANDERSON, K. L., WHITLOCK, J. E. & HARWOOD, V. J. 2005. Persistence and differential survival of fecal indicator bacteria in subtropical waters and sediments. *Applied and environmental microbiology,* 71**,** 3041-3048.

BRINKMEYER, R., AMON, R. M., SCHWARZ, J. R., SAXTON, T., ROBERTS, D., HARRISON, S., ELLIS, N., FOX, J., DIGUARDI, K. & HOCHMAN, M. 2015. Distribution and persistence of *Escherichia coli* and Enterococci in stream bed and bank sediments from two urban streams in Houston, TX. *Sci. Total Environ.,* 502**,** 650-658.

BYAPPANAHALLI, M. N., ROLL, B. M. & FUJIOKA, R. S. 2012. Evidence for occurrence, persistence, and growth potential of *Escherichia coli* and Enterococci in Hawaii's soil environments. *Microbes Environ.,* 27**,** 164-170.

DANIEL, S. H. 2004. *Texas Whitewater*, Texas A&M University Press.

DOREVITCH, S., PANTHI, S., HUANG, Y., LI, H., MICHALEK, A. M., PRATAP, P., WROBLEWSKI, M., LIU, L., SCHEFF, P. A. & LI, A. 2011. Water ingestion during water recreation. *water research,* 45**,** 2020-2028.

DUFOUR, A. & BALLENTINE, R. 1986. *Ambient Water Quality Criteria for Bacteria, 1986: Bacteriological Ambient Water Quality Criteria for Marine and Fresh Recreational Waters*, National Technical Information Service, Department of Commerce, US.

FERGUSON, C., HUSMAN, A. M. D., ALTAVILLA, N., DEERE, D. & ASHBOLT, N. 2003. Fate and transport of surface water pathogens in watersheds. *Crit. Rev. Env. Sci. Tec.,* 33**,** 299-361.

FUJIOKA, R., SIAN-DENTON, C., BORJA, M., CASTRO, J. & MORPHEW, K. 1998. Soil: the environmental source of *Escherichia coli* and Enterococci in Guam's streams. *J of Appl Microbiol.,* 85.

GARZIO-HADZICK, A., SHELTON, D. R., HILL, R. L., PACHEPSKY, Y. A., GUBER, A. K. & ROWLAND, R. 2010. Survival of manure-borne *E. coli* in streambed sediment: Effects of temperature and sediment properties. *Water Res.,* 44**,** 2753-2762.

GERBA, C. P. 2009. Indicator Microorganisms. *In:* MAIER, R. M., PEPPER, I. L. & GERBA, C. P. (eds.) *Environmental Microbiology.* Second ed. Boston: Academic Press.

GREGORY, L. F., GITTER, A. & LAZAR, K. 2015. Basin approach to address bacterial impairments in the Navasota River watershed. College Station, TX: Texas Water Resources Institute.

ISHII, S. & SADOWSKY, M. J. 2008. *Escherichia coli* in the environment: Implications for water quality and human health. *Microbes Environ.,* 23**,** 101-108.

JAMIESON, R. C., JOY, D. M., LEE, H., KOSTASCHUK, R. & GORDON, R. J. 2005. Resuspension of sediment-associated *Escherichia coli* in a natural stream. *J. Environ. Qual.,* 34**,** 581-589.

MUIRHEAD, R., DAVIES-COLLEY, R., DONNISON, A. & NAGELS, J. 2004. Faecal bacteria yields in artificial flood events: quantifying in-stream stores. *Water Res.,* 38**,** 1215-1224.

ODONKOR, S. T. & AMPOFO, J. K. 2013. Escherichia coli as an indicator of bacteriological quality of water: an overview. *Microbiology research,* 4**,** 2.

PACHEPSKY, Y. & SHELTON, D. 2011. Escherichia coli and fecal coliforms in freshwater and estuarine sediments. *Critical reviews in environmental science and technology,* 41**,** 1067-1110.

SOLO-GABRIELE, H. M., WOLFERT, M. A., DESMARAIS, T. R. & PALMER, C. J. 2000. Sources of *Escherichia coli* in a coastal subtropical environment. *Appl. Environ. Microb.,* 66**,** 230-237.

TCEQ 2010. Texas Administrative Code. *Texas Surface Water Quality Standards.* Austin, TX: TCEQ.

TCEQ 2012. Surface water quality monitoring procedures, volume 1: physical and chemical monitoring methods. *In:* DIVISION, W. Q. P. (ed.). Austin, TX: TCEQ.

USEPA 1986. Ambient Water Quality Criteria for Bacteria - 1986. Washington, DC.: Office of Water.

WAGNER, K. L., GREGORY, L. F. & BERTHOLD, T. A. 2016. Water Quality Management. *In:* CHEN, D. H. (ed.) *Sustainable Water Management and Technologies.* Boca Raton, FL: CRC Press.