# U.S. beach water quality monitoring

ASBPA Science & Technology Committee

*By*

Angelos Hannides,[1] Nicole Elko,[2] Tiffany Roberts Briggs,[3] Sung-Chan Kim,[4]
Annie Mercer,[5] Kyeong Park,[6] Brad Rosov,[7] Ryan Searcy,[8] and Michael Walther[9]

*1) Department of Marine Science, Coastal Carolina University, P.O. Box 261954, Conway, SC 29528*
*2) American Shore and Beach Preservation Association, P.O. Box 1451, Folly Beach, SC 29439*
*3) Department of Geosciences, Florida Atlantic University, 777 Glades Road, SE 470, Boca Raton, FL 33431*
*4) US Army Corps of Engineers, Engineer Research and Development Center, Coastal and Hydraulics Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180*
*5) American Shore and Beach Preservation Association, 1509 George II Hwy SE, Bolivia, NC 28422*
*6) Department of Marine and Coastal Environmental Science, Texas A&M University at Galveston, P.O. Box 1675, Galveston, TX 77553*
*7) Coastal Protection Engineering of North Carolina Inc, 4038 Masonboro Loop Road, Wilmington, NC 28409,*
*8) Department of Civil & Environmental Engineering, Stanford University, 473 Via Ortega, Stanford, CA, 94305*
*9) Coastal Tech–G.E.C., Inc., 3625 20th Street, Vero Beach, FL 32960*

**ABSTRACT**

Coastal water quality is an important factor influencing public health and the quality of our nation's beaches. In recent years, poor water quality has resulted in increased numbers of beach closures and corresponding negative impacts on tourism. This paper addresses some of the issues surrounding the management challenge of coastal water quality, in particular, beach water quality monitoring. For this effort, data on beach water quality monitoring activities conducted by states were assessed and synthesized. In total, 29 states were surveyed: 16 reported information for seawater; six reported for freshwater only; eight reported for both seawater and freshwater. Thresholds for advisories and closure vary nationally; however, all 29 states have established an online presence for their monitoring programs and display advisories and closures in real time, most often on spatial information (GIS) portals. Challenges in monitoring, prediction, and communication are assessed and discussed. Based on this assessment, the committee offers the following recommendations, as detailed in the text:

- Standardization of water quality data and the distribution medium;
- Enhanced public access to water quality monitoring data;
- Consistent thresholds for swim advisories;
- Water quality regulation reviews with stakeholder participation;
- Enhanced predictive models incorporating rapid testing results;
- Holistic water quality monitoring that includes indicators beyond fecal indicator bacteria;
- Managing contaminants of emerging concern through identification, monitoring and control; and
- Funding for water quality monitoring and reporting -- from federal, state, and local governments.

The American Shore and Beach Preservation Association (ASBPA) has polled coastal stakeholders (i.e. practitioners) to identify their top coastal management challenges (Elko and Briggs 2020). Informed by two annual surveys, a multiple-choice online poll was conducted in 2019 to evaluate stakeholders' most pressing problems and needs, including what they felt most ill-equipped to deal with in their day-to-day duties and which tools they most need to address these challenges.

Overall, the prioritized coastal management challenges identified by the survey were:

- **Deteriorating ecosystems** leading to reduced (environmental, recreational, economic, storm buffer) functionality,
- **Increasing storminess** due to climate change (i.e. more frequent and intense impacts),
- **Coastal flooding**, both
  — Sea level rise and associated flooding (e.g. nuisance flooding, King tides), and
  — Combined effects of rainfall and surge on urban flooding (i.e. episodic, short-term),
- Chronic **beach erosion** (i.e. high/increasing long-term erosion rates), and
- Coastal **water quality**, including harmful algal blooms (e.g. red tide, *Sargassum*).

This paper addresses some of the issues surrounding the management challenge of coastal water quality. Coastal regions include important human communities and ecosystems that support tourism, recreation, economics, and environmental resources; all of which are directly influenced by water quality. For example, recreational beach users and the quality of fisheries are affected by varying water quality. Restoring and preserving coastal water quality into the future is critical, yet challenging for many reasons, such as the decline in overall coastal water quality due to ubiquitous contamination of waters by microbial pathogens, fertilizers, pesticides, heavy metals (Halpern *et al.* 2012), and other pollutants. Major U.S. governmental agencies (National Institutes of Health, National Science Foundation, National Oceanic and Atmospheric Administration, Environmental Protection Agency (EPA), U.S. Army Corps of Engineers, and U.S. Geological Survey) have recognized that the link between the coastal oceans and human and ecosystem health is of critical importance (e.g. Nearshore Processes Community 2015).

The social relevance of water quality management cannot be ignored. Bacterial pathogens have been found to persist in ocean waters (Yamahara *et al.* 2007; Goodwin and Pobuda 2009, Halliday and Gast 2011) and Great Lakes beach sand (Ge *et al.* 2010; 2012), likely posing a human health risk (Heaney *et al.* 2012). Annually, gastrointestinal illness from exposure to microbial pathogens in polluted U.S. coastal waters is estimated to cost $300 million (Ralston *et al.* 2011). Harmful algal blooms caused by *Karenia brevis* or "red tides" too frequently affecting southwest Florida and the Gulf coast can cause human respiratory illness and eye irritation through suspension of toxins in the air and neurotoxic shellfish poisoning through consumption of contaminated seafood (NOAA 2021; National HAB Office 2021). A review by Fleming *et al.* (2011) found *Karenia brevis*-related emergency room costs in Sarasota County, Florida, ranged from $0.5 to $4 million U.S. dollars based on the severity of the bloom. It is estimated each bloom costs lifeguard agencies directly and indirectly $3,000 due to absenteeism and may affect a lifeguard's attentiveness or ability to identify and react to emergencies (Fleming *et al.* 2011). Beach closures due to poor water quality have increased dramatically over the past few decades (Dorfman and Stoner 2012) with a corresponding negative impact on beach tourism (Hanemann *et al.* 2001).

This paper introduces the topic of coastal water quality and explores in detail how beach water quality is monitored on a national scale to provide information to coastal managers, practitioners, elected officials, and the public interested in support of protecting public health and safety. The information provided may be helpful in prioritizing research investments in the topic area. This paper will also assist ASBPA in its role as the National Operator of the U.S. Blue Flag Beaches program, which considers beach water quality in a number of eligibility criteria. In particular, the paper brings to light challenges in managing a national-scale program given the diversity in U.S. states' monitoring protocols.

### *Beach water quality parameters*

Water quality parameters are used to characterize water body health, identify trends and problems, determine the efficacy of water pollution preventative measures, identify emerging issues, and respond to emergencies such as floods and spills. Depending on the goals and objectives, a water quality monitoring program can utilize a wide range of physical, chemical and biological parameters to assess water quality and to support modeling efforts to predict contamination events. A brief description of these parameters follows.

#### *Physical parameters*

**Temperature** is a master variable that affects living and non-living processes, such as water oxygen levels, metabolic rates of aquatic organisms including photosynthesis and respiration, the sensitivity of these organisms to pollution, parasites and disease, and the rates of chemical reactions. Inputs of freshwater such as stormwater runoff, cooling water discharges, etc. may substantially change beach water temperature. **Salinity or conductivity**, a measure of the amount of salt ions dissolved in water, may indicate when freshwater input has been substantial. Both temperature and conductivity/salinity are easily measured on site with affordable handheld devices, and are important components of monitoring programs and contamination modeling efforts (e.g. Nevers and Whitman 2008, Thoe *et al.* 2014).

**Turbidity** is defined as the concentration of particulates suspended in water. It is commonly monitored in the context of water quality as an indicator of living particles, e.g. microbial plankton contributing to an existing eutrophic bloom. It should be noted that fine soil particles washed from the surrounding land or dissolved organic matter in blackwater rivers may interfere with the use of turbidity as a water quality indicator and, in those cases, its use is contraindicated (Bricker *et al.* 1999).

#### *Chemical parameters*

Dissolved **oxygen** levels in water are a crucial indicator of the health of an aquatic system, since animals require it for respiration. Major sources for water oxygen are photosynthesis by aquatic plants and plant-like microbes, as well as exchange with the atmosphere which is increased by winds, waves, and currents. Overgrowth of photosynthesizers, known as eutrophication, and/or supply of organic material from land may result in increased respiration and drop in water oxygen levels, a phenomenon referred to as hypoxia. Eutrophication can occur naturally but in coastal regions, is most commonly anthropogenically driven (e.g. fertilizers) as a result of excessive **nutrient** loading. Therefore, nutrient concentrations are, in some instances, routinely measured and used as a quantitative indicator of the degree of water quality degradation (e.g. Bricker *et al.* 1999).

**Organic and metal contaminants**, such as oil, pesticides, and mercury, have been of concern for several decades. Their discharge and presence in the environment have been regulated both nationally (e.g. with the U.S. EPA Clean Water Act) and internationally (e.g. the MARPOL Convention). There is also a class of contaminants of emerging concern (CECs), such as compounds used in cosmetics or pharmaceuticals, whose distribution in the environment and their impact upon organisms and ecosystems isn't known but is considered potentially harmful (Sauvé and Desrosiers 2014; USGS 2021).

**Acidification** of water bodies, which is the increase of protons ($H^+$ ions), has now been a concern in both marine and freshwater settings for several decades. Fossil fuel combustion is one of the primary drivers behind human-driven acidification, through the release of gas contaminants. **Nitrogen and sulfur dioxides**, when dissolved in rainwater, will produce acids, leading to the phenomenon known as acid rain. Regulation of these two atmospheric pollutants (e.g. by the Clean Air Act in the U.S.) has already led to noticeable improvement of the acid content of freshwater bodies (Garmo *et al.* 2014; Kaushal *et al.* 2018). **Carbon dioxide**'s ability to acidify water and soil is considered the major driver behind estuarine and ocean acidification. This interferes with the shell-building ability of many marine organisms, including coral and bivalves (Ries *et al.* 2009), the latter having important consequences for the production of commercially important species (e.g. in the Pacific Northwest, Feely *et al.* 2010).

#### *Biological parameters*

**Chlorophyll** is the most common sunlight-trapping pigment found in photosynthesizers like plants and plant-like microbes. Its water concentration is an indicator of planktonic (free-floating) photosynthesizer abundance and biomass

**Table 1.**
**Summary of thresholds/criteria for advisories.**

| Seawater | | Freshwater | |
|---|---|---|---|
| 60-70 CFU/100 mL | 3 states | 185 CFU/100 mL | 1 state |
| 104 CFU or MPN /100 mL | 16 states | 235 CFU/100 mL | 9 states |
| 110-130 CFU or MPN /100 mL | 4 states | 300-410 CFU/100 mL | 4 states |

and as such it is considered a primary "symptom" of eutrophication in water bodies such as estuaries and the coastal ocean (CENR 2003; Bricker *et al.* 2007).

Fecal Indicator Bacteria (FIB) include members of two bacteria groups, **coliforms** and **fecal streptococci**. They are typically used as indicators of possible sewage contamination because they are common within the feces of warm-blooded animals including humans (USEPA 2012a). Although not harmful themselves, they indicate the possible presence of pathogenic (disease-causing) organisms and viruses. Sources of fecal contamination to surface waters include wastewater treatment plants, on-site septic systems, domestic and wild animal manure, and stormwater runoff. Their presence in water bodies suggests that pathogenic microorganisms might also be present causing a human health risk for those recreating or consuming shellfish from within those waters. Rather than testing directly for the presence of a large variety of pathogens, water samples are commonly obtained and tested for these indicator bacteria instead. The most commonly tested FIBs are:

- **Fecal coliforms**, which reside in the feces of most species of warm-blooded animals,
- ***Escherichia coli***, a species of fecal coliform bacteria specific to fecal material from humans and other warm-blooded animals,
- **Fecal streptococci**, which generally occur in the digestive system of warm-blooded animals, and
- **Enterococci**, a subgroup of fecal streptococci that is typically more human-specific, and distinguished by their ability to survive in salt water.

In 2012, the EPA recommended criteria that defined statistical thresholds for advisories/closures of recreational waters. Specifically, the EPA recommended the use of members of the genus *Enterococcus* (the Enterococci) for both "marine and fresh" recreational waters and of *Escherichia coli*, a member of the fecal coliform group, as an indicator organism for freshwater recreational waters (USEPA 2012a), as quantified by EPA Methods 1600 and 1603, respectively (USEPA 2014a; b). Both these methods require processing and culture times that translate into a lag of 18-48 hours between sampling and test results. In 2014, the EPA elaborated further on performance criteria (USEPA 2014c), including a description of a tiered monitoring system, the use of the rapid (2-3 h) qPCR (i.e. quantitative polymerase chain reaction) enumeration Method 1611 for *Enterococcus* species in "marine and fresh" waters (USEPA 2012b), and Beach Action Values (BAV) that incorporate thresholds for either one of the three aforementioned methods.

The laboratory testing of the chemical, biological, and physical parameters above are not uniform at the national level in their methodology nor level of accreditation. The EPA does not require seawater testing laboratories to be accredited as with drinking water. Instead, EPA focuses on approving the testing methodology used to collect seawater samples through review of Quality Assurance Project Plans (QAPP) (USEPA 2012a).

States and local authorities have control over setting their chosen parameters and methodologies. EPA recommends testing for Enterococci in seawater, but states can require additional parameters be measured (USEPA 2012a). For example, California tests for total coliform, *E. coli*, and Enterococci. Moreover, states may petition the EPA to establish their own regulatory thresholds if special conditions warrant it. In 2016, the Alaska Department of Environmental Conservation (AK DEC) successfully petitioned the U.S. EPA to establish a regulatory threshold of 130 CFU/100ml (Enterococci) and applicable BAV due to geographic location, water temperature, type of recreational water use, contribution of non-human sources, and length and extent of exposure. Finally, states are the responsible party for the accreditation of private, public, or academic laboratories providing the testing of seawater samples. For example, in South Carolina the Coastal Carolina University (CCU) Environmental Quality Lab has been issued such a certificate by the South Carolina Department of Health and Environmental Control per the state's Regulation 61-81 (CCU 2020a, b).

The National Environmental Laboratory Accreditation Conference (NELAC) Institute (TNI) operates the National Environmental Laboratory Accreditation Program (NELAP) which publishes requirements for accreditation bodies among other things (The NELAC Institute 2020). States can apply to be water quality testing accreditation bodies through TNI or independent companies can perform the accreditations. Lacking a state level accreditation, labs can be held to recognized international standards such as the International Organization for Standards (ISO) 17025 for testing and calibration laboratories (ISO 2017).

### *Beach water quality monitoring practices*

For this paper, data on beach water quality monitoring activities conducted by states were gathered from official web portals maintained by the responsible authorities. State authorities were subsequently contacted to vet public information through a structured questionnaire and update or amend the results as determined appropriate. In total, 29 states were surveyed: 16 reported information for seawater; six reported for freshwater only; eight reported for both seawater and freshwater. The information was tabulated on a spreadsheet and entries under each question were categorized as described in the sections below in order to synthesize and present them as succinctly as possible. The summary of the entries presented below is provided in Appendix A.

### *Advisories and closures*

All 29 states included in this analysis maintain thresholds at or above which they issue swim advisories for their beaches. The most common threshold of Enterococci in seawater samples in 16 of 23 states is 104 MPN (Most Probable Number) or CFU (Colony Forming Units) per 100 mL, while nine of 14 states use a threshold of 235 *E. coli* CFU per 100 mL in freshwater (Table 1). Both of these thresholds are in agreement with the early USEPA (2012a) guidance; however, the stricter thresholds of more recent USEPA (2014c) guidance have been implemented in some, but not all, states.

Provisions for beach closure exist in 16 states surveyed. Closure provisions can be in the form of numerical thresholds or other, more qualitative criteria as summarized in Table 2. All 29 states have established an online presence for their monitoring programs and display advisories and closures in real time, most often on spatial information (GIS) portals.

**Table 2.**
**Summary of beach closure provisions and thresholds/criteria for closure.**

| | Seawater | Freshwater |
|---|---|---|
| No closure | 12 states | 3 states |
| Closure with numerical thresholds | 5 states | 6 states |
| Typical threshold values (CFU/100 mL) | 60, 104, 130 | 130, 235, 320, 1000 |
| Closure with other criteria | 6 states | 4 states |
| Used criteria | Human causes, sewage spills, other types of pollution, natural disasters | |

***Monitoring period and frequency***

Monitoring period and frequency vary not just between states but also within a state, depending on the existence of a tiered system that categorizes beaches by popularity, use, history of water quality issues, accessibility, etc. The most extensively used monitoring period by a state is identified as it applies to the most significant portion of their monitored beaches or sites. Similarly, monitoring frequency categories encompass not just the stated time range but also patterns within that range (e.g. sampling every two or three weeks is included in the weekly-monthly category).

The period during which beach water monitoring occurs varies from year-round (nine states) to the period between Memorial Day and Labor Day (13 states), often defining the swimming or bathing season, and other periods in-between (Figure 1). Assigning how monitoring periods are distributed across geographical regions, following similar delineation as in similar ASBPA analyses (e.g. Elko and Briggs 2020), reveals that year-round monitoring is performed in states with climates favorable for recreational activities on the water throughout the year. At least 15 states survey their beaches daily or weekly during their monitoring period based on location, while eight states do so on a weekly or less frequent basis (Table 3).

***Beach or site density***

The number of monitored beaches or sites (laterally extensive beaches may contain multiple sites) for every mile of coastline may suggest the degree of importance states ascribe to beach water quality, but also (less frequently) the extent of beach use, potential issues or concerns caused by humans or natural disasters, and accessibility. A metric of testing site density was calculated using actual beaches or sites the states have monitored within the past two years, and publicly accessible beach lengths reported by the states to the EPA (USEPA 2021). The data indicate that 14 of 29 states monitor 1-10 stations per mile of publicly accessible beaches, while another 11 have a station for every 1-10 miles of publicly accessible beaches (Figure 2).

***Harmful Algal Blooms (HAB)***

States were asked about monitoring of harmful algal blooms (HAB) and whether they have systems for alerts, advisories, or closures in place. Provisions for alerts or advisories by all or some of their waters were in place for 19 of 29 states, while authorities in nine of 29 states have provisions for closures. It should be noted that several of the states with no current provisions are in the process of drafting HAB policies.

## CHALLENGES IN MONITORING AND PREDICTION

***Temporal/spatial variability in FIB***

Monitoring programs are often insufficient to capture the spatial and temporal variability of water quality at a beach. Beach water quality monitoring is often conducted weekly (Table 3) at discrete locations. The most popular methods to enumerate FIB are culture-based methods that take nearly 24 hours to provide results. FIB concentrations can vary daily or even hourly and at different locations at the beach and in the water column (Boehm 2007; Nevers and Whitman 2008; Gronewold *et al.* 2013). Boehm (2007) reports that, after sampling Huntington State Beach, CA, at a 10-minute sampling interval, FIB was observed to "change by 60% on average between consecutive samples, and by as much as 700%," which often is much greater than the magnitude of the California State standard.

Using an infrequent, single sample to manage a beach often leads to the provision of incorrect information to beachgoers. This means that a beach can be posted or even closed when water quality is actually good, or a beach can be left unposted when water quality is poor (Francy 2009). In a study involving 25 California beaches and six years of water quality monitoring data at those sites, the use of a single sample to warn beachgoers of poor water quality was shown to be correct on average 30% of the time (Thoe *et al.* 2015).

**Table 3.**
**Summary of monitoring frequencies employed by states.**

| Monitoring frequency | No. of states |
|---|---|
| Daily-weekly | 8 |
| Weekly | 7 |
| Daily-monthly | 6 |
| Weekly-monthly | 7 |
| Weekly-quarterly | 1 |

The most obvious solution to the temporal and spatial variability issue is to conduct more frequent sampling at more locations. This is often infeasible due to constrained resources, but there remain additional options for agencies to employ. For example, rather than basing a management decision on a single sample, the geometric mean has been used to smooth out spikes in water quality data and provide a broader view of water quality at a site (Wymer and Wade 2007). The downside to this option is that it can result in longer advisories because of the number of samples required to mediate an extreme spike.

The culturing methods for Enterococci and *E. coli* employed by most states yield results one to two days after sampling. In 2012, the EPA (USEPA 2012a) stated that: "New technologies may provide alternative ways to address methodological considerations, such as rapidity, sensitivity, specificity, and method performance." Since then, qPCR techniques have become more prominent in recreational water quality monitoring, including BAV definitions (USEPA 2014c) and, more recently, microbial source-tracking methods (USEPA 2019a). This latter development aims to pinpoint human

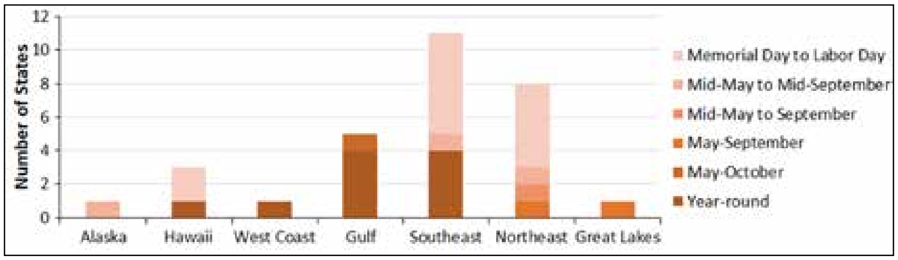


**Figure 1. Monitoring period across the country's major regions.**

fecal pollution, rather than generic fecal pollution, using qPCR EPA Methods 1696 and 1697 (USEPA 2019b; c) which are still not formally approved by specific EPA regulations. Such rapid and specific diagnostic methods, along with predictive models that assimilate real-time physical data such as precipitation, wave conditions, and salinity (see next section) will greatly improve the speed and certainty with which entities can make appropriate determinations for warnings, advisories and closures.

At present, advisory thresholds vary widely (Table 1), in part due to the gradual adoption of the more recent and stricter thresholds proposed in 2014 (USEPA 2014c). Moreover, closure thresholds are often qualitative (Table 2) due to the long incubation times of the culture methods 1600 and 1603 (USEPA 2014a; b). Adoption of the more rapid diagnostic methods may lead to convergence towards the stricter 2014 thresholds, more quantitative closure standards, and greater harmonization of policies across states and local entities.

Rapid testing methods that employ molecular techniques have increased in popularity, are approved by the US EPA (2012a) and can provide results within hours (Shanks *et al.* 2012). Finally, the use of predictive water quality models can provide more frequent and accurate water quality information to beachgoers to help reduce risk.

### *Predictive models*

Water quality predictions enable beachgoers to weigh risk prior to traveling to the beach and beach managers to conduct targeted sampling programs to learn more about what modulates water quality at their beaches. The EPA's Water Quality Criteria endorses the use of predictive models (USEPA 2012a) and programs in California (Heal the Bay 2021), North Carolina, South Carolina (USC 2020), Florida, and the Great Lakes (Francy *et al.* 2013), among other locations around

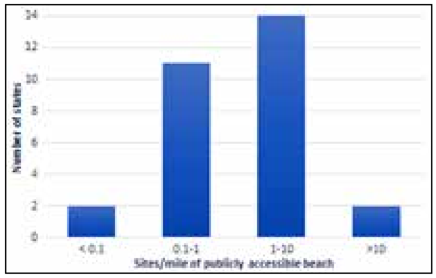


**Figure 2. Testing site density. Sites states monitored (2019-2020) per mile of publicly accessible beaches.**

the U.S., currently implement predictive modeling systems for public notification during the swim season.

Statistical and machine learning models (also known as "data-driven" models) take advantage of the correlation between FIB or harmful algae and environmental surrogates (including mean water level, significant wave height, solar radiation, wind speed, recent precipitation, etc.). They are typically calibrated on years of historical data (Francy *et al.* 2019) and validated by comparing model predictions to observations from the calibration datasets (Thoe *et al.* 2015; Searcy *et al.* 2018; Francy *et al.* 2019). Once validated, models are used to make future predictions of FIB or HABs using new environmental data as they become available. Past works have shown that data-driven models can predict poor water quality more accurately than the present method of relying on a single, days-old sample (Francy 2009; Thoe *et al.* 2015; Brooks *et al.* 2016) and provide more frequent water quality information to augment water quality monitoring programs (Shively *et al.* 2016; Searcy *et al.* 2018).

Extensive mechanistic modeling studies, on top of stochastic models delineating parametric relations, have been conducted to understand the transport and fate of FIB in the water column and provide decision-support information for effective public health management (Collins and Rutherford 2004; Cho *et al.* 2016). Various mechanistic water quality models based on a mass-balance equation for FIB have been applied for predicting the bacterial conditions in different water bodies (e.g. de Brauwere *et al.* 2014; Gao *et al.* 2015; Islam *et al.* 2018). The mass-balance equation solves physical (advective and turbulent diffusive) transport and bacteria-specific biogeochemical processes. The water quality models are typically coupled with hydrodynamic models that provide information for physical processes that transport bacteria in an aquatic system. A number of biogeochemical, both biotic and abiotic, processes affect bacterial concentration, but many models opt to have an overall removal rate (mostly first-order) to represent the combined effect of all biogeochemical processes (Bowie *et al.* 1985; Thomann and Mueller 1987; Liu *et al.* 2006).

A typical objective of modeling of FIB is to establish the level of bacterial pollution and potential pathogen contamination (Bowie *et al.* 1985). The usual approach is to simulate disappearance and estimate bacterial levels as a function of initial loading and the removal rate, which in turn is a function of time or distance of travel from the source(s) and environmental conditions such as temperature, salinity, wind speed and direction, and light intensity (e.g. Francy *et al.* 2013; Cho *et al.* 2016). The water quality models are validated using bacterial data from water quality monitoring programs and/or surveys for an ad hoc event. In applying these models, the largest uncertainties tend to be in the estimation of the model parameter (removal rate) and the bacterial loading; new studies have been conducted to propose new methods for parameter estimation and loading (Shen and Zhao 2010; Du *et al.* 2020; Yu *et al.* 2021).

For HAB predictions, Anderson *et al.* (2015) summarizes the models running from empirical nature to mechanistic nature. The HAB models in general deal with longer time scales than other water quality models, needing closer integration with observations such as time series data and remote sensing data.

### *Communication challenges*

Data discoverability is an issue water quality monitoring and public notification programs encounter. Some methods that agencies currently employ to communicate new sampling results include posting beach warning signs and updating the agency's website or telephone hotline. Press releases have been less effective and confusing, sometimes leading to misinformation on social media about larger stretches of beach, or even entire beach towns, being closed. Beach signs with clear imagery, current sample date, and multiple languages can directly provide water quality information to beachgoers. However, signs might be the least effective form of public notification because they require beach managers to constantly place and remove them as new data become available; they are easy to steal and deface; and they do not warn beachgoers of water quality issues prior to traveling to the beach (Pratap *et al.* 2013). Agency websites and telephone hotlines alleviate some of the issues with beach signs, but are ineffective if constituents are unaware of their availability.

Additional water quality monitoring may be conducted by local advocacy groups who have broad reach in their communities. For example, the Surfrider Foundation's Blue Water Task Force program is a volunteer-run program that tests for FIB at nearly 450 sampling sites across the country (Surfrider 2020). Such programs are intended to provide water quality information at sites that agencies do not routinely test, or to provide additional samples at currently monitored sites. These groups, which often represent thousands of members, often post their data on websites, social media, and mobile applications (e.g. CAWQMC 2020; Surfrider 2020; Swim Drink Fish Canada 2020). Due to inconsistent data standardization and testing quality concerns, some community-science groups may find it challenging for their data to be accepted for use beyond public notification (e.g. for regulatory purposes).

## RECOMMENDATIONS

This section describes recommendations by the ASBPA Science & Technology Committee for federal, state, and local government actions to collect and report coastal water quality data into the future to specifically support public health and ultimately promote the sustainability of coastal ecosystems. Implementation of these recommendations would yield public benefits by (a) identifying water quality conditions that may adversely affect public health, (b) providing a basis for the public to avoid unsafe waters, and (c) increasing public awareness of water quality issues affecting both public health and coastal ecosystems. Recommendations are summarized in Table 4 and described below.

**Table 4.**
**Recommendations**

| | |
|---|---|
| 1 | Standardization of water quality data and the distribution medium |
| 2 | Enhanced public access to water quality monitoring data |
| 3 | Consistent thresholds for swim advisories |
| 4 | Water quality regulation reviews with stakeholder participation |
| 5 | Enhanced predictive models incorporating rapid testing results |
| 6 | Holistic water quality monitoring that includes indicators beyond fecal indicator bacteria |
| 7 | Managing contaminants of emerging concern through identification, monitoring and control |
| 8 | Additional funding for beach water quality monitoring from federal, state and local governments |

### *Standardization*

This paper highlights significant variability in the U.S. states' approach to water quality testing data and information sharing. A national standard is lacking. States do not uniformly test the same water quality constituent, or at the same water depth. State monitoring agencies implement different systems for displaying test results and agency interpretations relative to public health. National standards for water quality testing and reporting would be useful to inform swimmers and more generally guide public use of coastal waters. Reporting would ideally provide internet links to raw data and maps to allow for more robust review and analysis of data. Results from water quality tests should be posted as the raw value with a user-friendly color code or emoji-based legend to indicate when advisories or closures are warranted. Swim Drink Fish in Canada has created an open data exchange standard (Swim Drink Fish Canada 2017), which could be considered as a potential model.

### *Enhanced public access to information*

For many public beaches, the ambient water quality is not evident to people who make recreational use of the beaches. To increase public awareness, the following measures might be undertaken:

- A summary of water quality testing results and interpretations might be posted at public beach access locations — perhaps via digital beach signs — particularly to provide warning during periods of poor water quality.
- Collaborative networks might be formed between testing agencies and community groups to promote resource sharing and enhance data broadcasting.
- Water quality testing and sampling methods, frequency, number of sites, and thresholds for advisory or closure might be posted on the local government's main beach monitoring page in language digestible to the public with links to supporting data and documentation.
- Community science-based groups can post agency data via their own chosen media.
- Government agencies can enhance data quality by providing certified lab services to community groups who lack them (e.g. CAWQMC 2020), but are able to collect samples.
- Water quality data can also be provided directly to beach user-groups, including local businesses, lifeguards, and beach camps.
- Leveraging technology (machine-to-machine data transfers) can help make data available to multiple platforms (websites, with web services for mobile apps, automated tweets, and Facebook posts, SMS, etc.).

### *Consistent thresholds*

U.S. coastal states and local governments vary in their threshold (see Tables 1 and 2) and response to condition that may pose a threat to public health. National consistency in swim advisory thresholds is desirable to (a) uniformly provide for public health, and (b) allow for comparison of the relative heath associated with alternative venues for recreational use of coastal waters. For example, all states might adopt the same threshold to trigger a no swimming advisory or develop thresholds specific to human fecal pollution using microbial source-tracking methods (USEPA 2019a). However, it is understood that extreme conditions due to geographic location, water temperature, type of recreational water use, contribution of non-human sources, and length and extent of exposure, may necessitate different thresholds, as in the aforementioned case of Alaska's successful petition to the EPA.

### *Water quality regulation reviews*

Overall trends within the U.S., and generally around the world, are towards the decreasing quality of coastal waters. Water quality regulations are reviewed triennially by state enforcement (USEPA 2014d). Local decision makers, health professionals, and monitors could be involved in the process formally. Such reviews could identify pollutant sources and formulate regulations and public actions to improve and sustain water quality. The review periods could be broadly advertised and publicly noticed to encourage active participation of experts, practitioners, and stakeholders.

### *Enhanced predictive models*

Rapid and specific diagnostic methods including predictive models exist that can assimilate real-time physical data such as precipitation, wave conditions, salinity, etc., to predict water quality conditions and their suitability for public recreational use. Increased monitoring data assimilation in these predictive models could greatly improve the speed and certainty with which local government entities can make appropriate determinations for "safe waters," warnings, advisories and closures. Such efforts require material support to sustain them, including computing resources and data collection programs, especially if models are applied to specific beaches. Modeling expertise is often not found in entities conducting data collection, therefore synergies between government agencies or government-academia-consulting consortia are desirable.

### *Holistic water quality monitoring*

The term water quality is understood by many to refer specifically to various coliform indicators such as cited in this paper. However, there are numerous other indicators that capture other major water quality issues such as eutrophication, hypoxia, acidification, etc., that are recognized to significantly affect coastal ecosystems. Such indicators may be monitored already by separate entities that often operate "in silos" without data sharing. All water quality monitoring entities are encouraged to work towards broader recognition of water quality parameters and, consequently, towards a more holistic and synergistic collective water quality monitoring program. Such a synergy may resolve often inexplicable substantial temporal variability of specific water-quality indicators at a given site (e.g. Boehm 2007) and may also facilitate the recognition of the role both point and non-point sources play in indicator fluctuations and more effective management of those sources. Broadening the definition and monitoring of water quality will further encourage and strengthen science-based policy by better describing the health of aquatic ecosystems.

### *Managing contaminants of emerging concern (CECs)*

While the most robust monitoring programs in the country pertain to microbial water quality, increasing attention should be paid to contaminants of emerging concern (CEC). CECs are chemicals and pollutants that enter aquatic systems and for which there is evidence of human and ecosystem health impacts after prolonged exposure (SCCWRP 2020; USEPA 2020; USGS 2021). Examples of CECs include microplastics, pesticides, and pharmaceuticals, all of which can be carcinogenic or act as endocrine disruptors. Because such effects are typically not acute, CECs have traditionally been difficult for water quality agencies to manage. New tools are being developed to rapidly test for CECs and their effects on biological systems. Government agencies are encouraged to work with local research institutions to identify CECs that affect their local waters and develop management plans that provide for identification and monitoring of CECs, and measures to reduce/abate all contaminants within coastal waters that adversely affect public health and coastal ecosystems.

### *Funding*

Each of the above recommendations cited above require public funding to implement. Additional funding by federal, state, and local governments is necessary to reliably provide (a) for public health in concert with recreational use of coastal waters, and (b) a basis for public investment to sustain coastal ecosystems.

## SUMMARY

This paper presents the results of a national-scale investigation into how states collect, manage, and communicate beach water quality monitoring results in support of protecting public health and safety. The work was motivated by ASBPA members and similar stakeholders that identified coastal water quality as one of the nation's most pressing management challenges (Elko and Briggs 2020). While various water quality parameters are discussed, the focus of coastal states' monitoring programs is on Fecal Indicator Bacteria (FIB), which includes members of two bacteria groups, **coliforms** and **fecal streptococci**. Although not harmful themselves, FIBs indicate the possible presence of pathogenic (disease-causing) organisms and viruses.

The EPA recommended threshold criteria for advisories/closures of recreational waters (USEPA 2012a; 2014c). While EPA recommends testing for Enterococci in seawater, states have control over setting their chosen parameters and methodologies. There is no U.S. federal level accreditation body for beach water quality testing laboratories. States, private industry, and non-governmental organizations handle lab accreditation in the U.S.

Twenty-nine states were surveyed for this paper. State beach water quality monitoring periods vary nationally, but are generally conducted during the swimming or bathing season for each state. Fourteen of 29 states monitor 1-10 stations per mile of publicly accessible beaches, while another 11 have a station for every 1-10 miles of publicly accessible beaches. Sixteen (16) reported information for seawater, six reported for freshwater only, and eight reported for both seawater and freshwater. Sixteen of 23 states use a threshold for Enterococci in seawater samples of 104 CFU per 100 mL, while nine of 14 states use a threshold of 235 *E. coli* CFU per 100 mL in freshwater. Both of these thresholds are in agreement with the early USEPA (2012a) guidance; however, the stricter thresholds of more recent USEPA (2014c) guidance have been implemented in some, but not all, other states. All 29 states have established an online presence for their monitoring programs and display advisories and closures in real time, most often on spatial information (GIS) portals.

A review of the above results, as well as a discussion of the challenges in monitoring, prediction, and communication led the committee to offer the following recommendations:

- Standardization of water quality data and the distribution medium;
- Enhanced public access to water quality monitoring data;

- Consistent thresholds for swim advisories;
- Water quality regulation reviews with stakeholder participation;
- Enhanced predictive models incorporating rapid testing results;
- Holistic water quality monitoring that includes indicators beyond fecal indicator bacteria;
- Managing contaminants of emerging concern through identification, monitoring and control;
- Additional funding from federal, state and local governments.

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## Appendix A.

**Summary of state beach water-quality monitoring activities presented in this study.**

| | ALERTS/ADVISORIES — THRESHOLDS | | CLOSURES | | MONITORING | | HAB | |
|---|---|---|---|---|---|---|---|---|
| State/region | Marine | Freshwater | Y/N | Threshold/ criterion | Period/ frequency | Sites/ mi | Alerts | Closures |
| AK — Alaska | >130 CFU/100 mL | | Y | 130 CFU/100 mL | MidMay-MidSep Weekly-biweekly | 0.05 | N | N |
| AL — Gulf | >104 CFU/100 mL | | N | | Year-round Daily-monthly | 0.88 | N | N |
| CA — West Coast | >110 CFU/100 mL | | Y | Range of thresholds | Year-round Weekly | 1.81 | Y | Y |
| CT — Northeast | >104 CFU/100 mL | >235 CFU/100 mL | Y | Other | Memorial-Labor Weekly | 1.36 | Y | Y |
| DE — Northeast | >104 CFU/100 mL | >185 ETCOC CFU/100 mL | N | | MidMay-MidSep Daily-weekly | 0.45 | Y | N |
| FL — Gulf/SE | >70 CFU/100 mL | | N | | Year-round Biweekly | 0.25 | Y | Y |
| GA — Southeast | >70 CFU/100 mL | | N | | Year-round Weekly-quarterly | 0.19 | Y | N |
| HI — Hawaii | >130 CFU/100 mL | | N | | Year-round Weekly-monthly | 0.63 | N | N |
| IL — Great Lakes | | >235 CFU/100 mL | Y | 235 CFU/100 mL | May-Sep Daily-biweekly | 14.04 | N | N |
| IN — Great Lakes | | >235 CFU/100 mL | Y | 235 CFU/100 mL | Memorial-Labor Daily | 1.44 | Y | Y |
| LA — Gulf | >104 MPN/100 mL | | Y | Other: natural or manmade disasters | May-Oct Weekly | 1.10 | N | N |
| MA — Northeast | >104 CFU/100 mL | >235 CFU/100 mL | N | | Memorial-Labor Daily-monthly | 7.71 | Y | N |
| MD — Northeast | >104 CFU/100 mL | >235 CFU/100 mL | Y | Other: sewage | Memorial-Labor Weekly-monthly | 9.18 | Y | N |
| ME — Northeast | >104 MPN/100 mL | | Y | Other | Memorial-Labor Daily-monthly | 2.26 | Y | N |
| MI — Great Lakes | | >300 CFU/100 mL | Y | 130 CFU/100 mL 30 d-GM | Memorial-Labor Weekly | 0.51 | N | N |
| MS — Gulf | >104 CFU/100 mL | | Y | Other: sewage or other pollution | Year-round Weekly | 0.61 | N | N |
| NC — Southeast | >104 CFU/100 mL | | N | | Year-round Weekly-monthly | 0.54 | N | N |
| NH — Northeast | >104 CFU/100 mL | | N | | Memorial-Labor Daily-weekly | 6.63 | Y | N |
| NJ — Northeast | >104 CFU/100 mL | >320 CFU/100 mL | Y | 104 CFU or 320 CFU/100 mL | MidMay-Sep Daily-weekly | 1.08 | Y | Y |
| NY — Northeast | >104 CFU/100 mL | >235 CFU/100 mL | Y | Other | May-Sep Daily-weekly | 2.82 | Y | Y |
| OH — Great Lakes | | >235 CFU/100 mL | N | | Memorial-Labor Daily-weekly | 0.80 | Y | N |
| OR — West Coast | >130 MPN | | N | | Memorial-Labor Three weeks | 0.31 | Y | Y |
| PA — Great Lakes | | >235 CFU/100 mL | Y | 1000 CFU/100 mL | Memorial-Labor Daily-weekly | 9.62 | Y | Y |
| RI — Northeast | >60 CFU/100 mL | | Y | 60 CFU/100 mL | Memorial-Labor Daily-monthly | 22.33 | Y | N |
| SC — Southeast | >104 CFU/100 mL | | N | | Year-round Daily-biweekly | 1.34 | Y | N |
| TX — Gulf | >104 CFU/100 mL | | N | | Year-round Weekly-biweekly | 0.49 | Y | N |
| VA — Southeast | >104 MPN/100 mL | >410 CFU/100 mL | Y | Other | MidMay-MidSep Weekly | 1.26 | Y | Y |
| WA — West Coast | >104 CFU/100 mL | | N | | Memorial-Labor Weekly | 0.06 | N | N |
| WI —Great Lakes | | >235 CFU/100 mL | Y | 1000 CFU/100 mL | Memorial-Labor Daily-weekly | 1.94 | N | N |

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