RECREATIONAL BEACH BACTERIA MODELING AND FORECASTING AND THE CONSEQUENCES TO PUBLIC HEALTH AND ECONOMIC VITALITY

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Abstract. The South Carolina Department of Health and Environmental Control (SCDHEC), in conjunction with local governments, routinely monitor the bacterial water quality of South Carolina's ocean bathing beaches. These monitoring data are used to post swimming advisories with the goal of allowing the public to make informed decisions concerning recreating in waters presenting a potential for adverse health effects. SCDHEC tests for the bacterial indicator, enterococcus, to determine bacterial water quality and issue water quality swimming advisories. The method used to determine enterococcus concentration requires a 24-hour incubation period before results can be read. Decision makers are therefore issuing and lifting advisories based on the previous day's water quality. To further protect public health, preemptive rainfall advisories are issued at the discretion of the SCDHEC regional program manager. Preemptive advisories are a method used to notify the public of the likelihood of higher levels of bacterial contamination at certain times. SCDHEC uses preemptive advisories as a means to further protect public health by issuing the advisory without waiting 24-hours for sample results. However, because these advisories are issued solely at the discretion of the regional program manager without sampling results, decision errors can occur. Type I errors, or errors of commission, occur when water quality meets standards, but an advisory has been issued. Type I errors could cause loss of revenue or a poor public image, by unnecessarily advising the beach. Type II errors, or errors of omission, occur when water quality does not meet standards, but an advisory has not been issued. Type II errors compromise public health by failing to warn of contamination. Therefore there is a strong need for scientifically-justified decision tools that will aid SCDHEC in making accurate and defensible preemptive advisory issuance decisions. To improve advisory decision making, forecast modeling can provide a more reliable indication of whether an advisory should be issued for a beach area. A collaborative academic, state agency, private sector partnership has collaborated in developing, validating, calibrating and implementing decision support models to improve preemptive beach advisory accuracy. Model operation is in two phases. Phase 1 generates predictions based on updated regression equations and split criteria using currently used data sources and intervention analysis results. Predictions are generated in a spreadsheet using the equations and split criteria coded as a series of if:then statements. The current suite of developed models used by SCDHEC use this mechanism to develop daily predictions from both regression equations and regression trees. These predictions are classified into low, medium, and high risk, based on bacteria concentration criteria established by EPA.

INTRODUCTION

In the southeastern U.S., near-real-time data have proven essential in the management of bacterial contamination of surface waters, which is important foremost because of the associated human health concerns with fecal pollution (Johnson 2007). Beach recreation areas can also be affected by advisories designed to protect the public from health hazards associated with ingesting water or primary contact in contaminated areas. However, while beach swimming advisories are designed to protect public health, they may have important, and often negatively perceived, economic and social impacts (Kelsey, 2006).

In collaboration with local governments, the South Carolina Department of Health and Environmental Control (SCDHEC) routinely tests the bacterial water quality of South Carolina's ocean bathing beaches through the Beach Monitoring Program. Monitoring data are utilized to post swimming advisories, with the goal of allowing the public to make informed decisions concerning recreation in waters that may present potential adverse health effects (SCDHEC, 2004). In the early days of beach monitoring efforts in 1999, sampling sites were located every one to two miles along the beachfront area. Through the years, additional beach sites were added in order to better capture the spatial variability in water quality for areas with storm water pipes and swashes (areas where storm water outfalls discharge onto the beach). SCDHEC sampling results demonstrated that following rainfall events runoff from these pipes and swashes are often highly contaminated.

Beaches in South Carolina are ranked on a three-tier scale, based on intensity of use and potential disease risk (SCDHEC, 2004). Currently, SCDHEC and local municipalities collect routine samples once per week from 40 water quality monitoring stations along Tier 1 beaches. Additional samples are collected following rainfall events. Results of water quality sampling are used to post and lift swimming advisories, based on bacterial water quality criteria established by the United States Environmental Protection Agency (USEPA) and SCDHEC.

Because of the difficulty and expense of comprehensive testing for specific pathogens, bacterial proxies are used to provide evidence of fecal contamination, and the concomitant potential presence of pathogenic organism that threaten human health (USEPA, 2002). USEPA favors the use of enterococcus as the prime bacterial indicator for marine waters (USEPA, 2002), and SCDHEC tests for enterococcus to determine the water quality of recreational beaches, and assess the need to issue swimming advisories when enterococcal counts exceed current standards.

SCDHEC utilizes two beach advisory thresholds recommended by USEPA for Tier 1 beaches:

1) Two nonconsecutive samples greater than or equal to 104 Most Probable Number per 100 ml (MPN/100 ml), or
2) One single sample greater than or equal to 500MPN/100 ml (SCDHEC, 2004).

After issuing an advisory, SCDHEC collects repeat samples daily; advisories are lifted when sample results are below the 104 MPN/ 100 ml threshold level. However, the culture method used to determine enterococcus concentration requires a 24-hour incubation period before results can be ascertained (SCDHEC, 2001). Because of this lag time between sampling and results, beach advisories are issued based on 24-hour-old contamination information, which is a poorly related to current contamination conditions (Kim and Grant, 2004; Morrison et al. 2003).
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In an additional effort to protect public health, SCDHEC regional program managers can issue preemptive rainfall advisories at their discretion. These advisories are a tool used to notify the public of the likelihood of higher levels of bacterial concentrations due to specific occurrences, such as rainfall or extreme weather or pollution events (USEPA, 2002). Because SCDHEC data from specific monitoring stations routinely demonstrate elevated concentrations of enterococcus in these areas following rainfall events, SCDHEC can issue preemptive advisories at those times, for those sites (SCDHEC, 2004). Water samples are taken to confirm or lift the preemptive advisory. Again, regional program managers must issue advisories at their discretion, as sampling results, provide only after-the-fact confirmation.

Thus, advisories issued based on either Tier 1 Beach water sampling or preemptive rainfall advisories are subject to error. Further, no individual decision can be defended on firm science grounds, because there is no specific protocol directing the decision-making process, and because correlations between advisory issuance and adverse conditions have not been demonstrated.

Two main types of decision errors are of concern. An error of *commission* (a false positive) occurs when water quality results actually do meet standards, but an advisory had been issued. Commission (false positive) errors can have serious economic consequences, because an unnecessary advisory can result in lost tourist revenue, as well as erode public confidence in and compliance with advisories. An error of *omission* occurs when water quality results do not meet standards, but no advisory was issued (a false negative). Omission (false negative) errors, including failing to issue an advisory in a timely manner when one is warranted, can compromise public health. Direct economic consequences include treatment of illness; indirect costs include tourism downturns associated with the resulting poor public perception of beach safety.

METHODS

To improve advisory decision making, forecast modeling can provide a more reliable indication of whether an advisory should be issued for a swimming beach area (Johnson, 2007; Kelsey, 2006; McDonals, 2008). The University of South Carolina initiated collaboration with SCDHEC in implementing decision support models to improve beach advisory accuracy. Johnson (2007) studied Tier 1 beaches (those that have a high volume of use or present a high potential risk to public health) at North Myrtle Beach, Briarcliffe Acres, Arcadia Beach, Myrtle Beach, Springmade Beach, Myrtle Beach State Park and Surfside Beach (Fig. 1), in order to develop

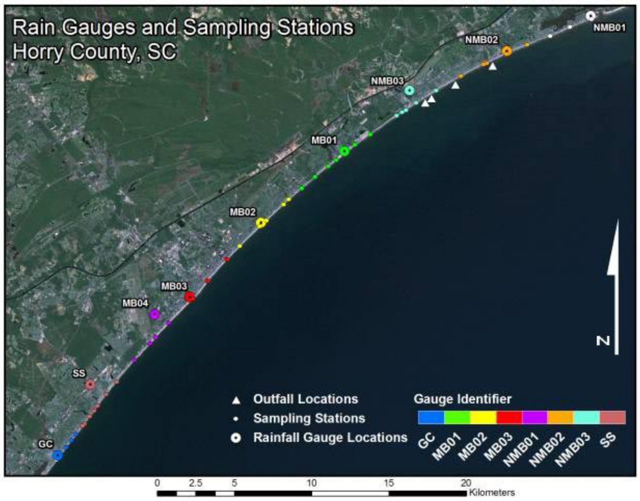

Figure 1. South Carolina Coastal Tier 1beaches, with their associated rain gauges, stormwater outfall, and water quality sampling locations.

Table 1. Variables used in the three levels of models for predicting bacterial concentrations in swimming beach waters.

Variables Included:	Model Level Category: Level One	Level Two	Level Three
Cumulative Rainfall	X	X	X
Rain Intensity	X	X	X
Preceding Dry Days	X	X	X
Weather	X	X	X
Tidal Range	X	X	X
Moon Phase	X	X	X
Station	X	X	X
Wind Speed		X	X
Wind Direction		X	X
Current			X
Salinity			X

statistical models that predicted enterococcus concentrations following rainfall events, based on a suite of explanatory variables (Table 1). Modeling efforts were evaluated at three levels. Level One models include only variables that can be obtained from the SCDHEC program manager's office, on a daily basis, with minimal retrieval effort. Level Two models additionally incorporate daily average wind speed and direction variables, which require additional time and effort to download and format. Level Three models further add variables that can be retrieved via the installation of remote equipment or on-site sampling.

This work demonstrated that Level Three models tended to have the lowest misclassification rates. Rainfall alone is not the best predictor for bacterial water quality, and that current speed, current direction, and salinity (Level Two and Three variables) were the most important predictors for enterococcus concentrations at most sites. Because Level Three models tended to be more laborious due to the need of extra data collection, Johnson recommended the implementation of Level One models when a site visit is not feasible. Where feasible, Level 2 and Level 3 models should be utilized in determining if additional sites should be placed under an advisory.

RESULTS

The most accurate models required on-site visits to access salinity, current speed, and current direction. However, it is often impractical or too costly for personnel to be tasked with these assessments. This led MacDonald (2008) to investigate using near-real-time data from the NOAA Integrated Ocean Observing System (IOOS®; www.ioos.gov), which are available online, to serve as a surrogate for on-site data collection. MacDonald (2008) evaluated three groups of models for enterococcus advisory predictions: IOOS-based models (using only data derived from IOOS buoys), SCDHEC-based models (containing no IOOS-related variables), and COMBINATION models (utilizing variables included in both modeling efforts). All models primarily focused on the coastal area encompassing Long Bay (Fig. 2). The IOOS and COMBINATION models utilized some key rainfall variables that were used in the SCDHEC models, but also incorporated physical and chemical oceanographic variables, including: salinity, current speed, and current direction. Both had similar misclassification rates and for both, those rates were lower than those of SCDHEC models.

These results validated what Johnson (2007) found in the higher level modeling efforts: the most accurate models were those that included the additional IOOS variables. Several studies have confirmed that in addition to rainfall, variables such as salinity, temperature, wind speed, wind direction, and tides, are important factors in determining bacterial concentrations (Boehm et al., 2003; Chapra, 1997; Francy et al., 2006).The success of the IOOS and COMBINATION models in lowering mis-classification rates indicated that IOOS data have potential for improving predictive capabilities, if it could be assimilated into the existing models. Additional research by Kelsey et al. (2004) has also suggested that rainfall estimates obtained by radar and averaged over

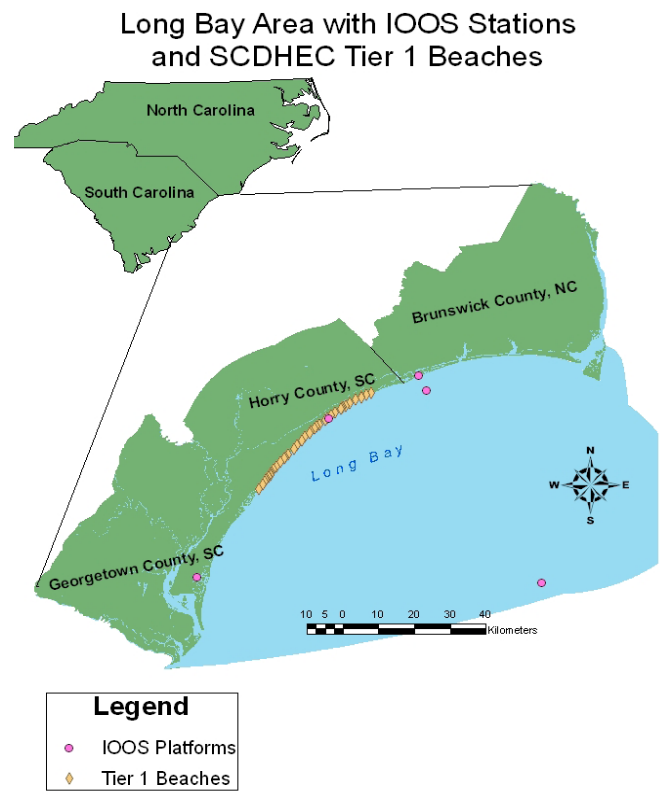

Figure 2. Long Bay coastal and ocean monitoring stations.

relevant areas may be better predictors of bacteria concentration than rainfall estimates obtained by rain gauges. The addition of more spatially appropriate rainfall estimates obtained by radar sources are currently being incorporated in the bacterial models.

CONCLUSIONS

These modeling efforts have demonstrated that predictive models effectively serve the essential purpose of providing a decision support tool for issuing preemptive advisories (Johnson, 2007), and SCDHEC began utilizing this tool in May 2008. Prior to this, beach advisories in South Carolina were based on the occurrence of rainfall, and best professional judgment. Current additional modeling efforts are underway to better address Type I and Type II errors and to account for changes in local practices for managing stormwater runoff.

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