Predictive Modeling of a Fecal Indicator at a Subtropical Marine Beach

R. G. Zepp, E. M. White, M. Molina and M. Cyterski
US Environmental Protection Agency, NERL/ERD, 960 College Station Rd, Athens GA 30605-2700

Background

Fecal contamination is a major source of pathogens in recreational waters and both point and non-point sources are involved. Fecal indicator bacteria (FIB) such as enterococci have been used to assess contamination of marine recreational waters. Hobie Beach is a popular beach near downtown Miami, Florida. The beach has experienced episodic biological contamination that has been quantified using several FIB (2, 4). There are no known sources of sewage-derived contamination at Hobie Beach and past studies have indicated that non-point sources on the shore are important contributors to the FIB in the water (1, 4).

This presentation reports the results of a study at Hobie Beach that provided statistical models for predicting enterococci concentrations at the beach. Hobie Beach was selected in part because few modeling studies have been conducted at marine beaches in warm climates. This study is part of several research efforts designed to evaluate the applicability of statistical modeling to a variety of marine and freshwater beaches. Virtual Beach is a software tool used in the study to develop predictive models based on microbial data (dependent variables) and observations (independent variables, IVs) of the hydrometeorological and biogeochemical conditions at the beaches(3).

Study Protocol

An overview of the study site is provided in Figure 1. Water samples were collected by contractors from ERG Inc at shin-deep and waist deep sites in the swim area (three times a day, four days a week) for measurement of culturable enterococci during July through September. Filters were collected for subsequent enterococci qPCR analysis and archiving at EPA (Figure 2). Instruments were deployed at the beach to log data that were used to develop the models (Figure 2). The UV radiometer system equipped with two optical sensors, each measuring UV irradiance (305, 325, 340, and 380 nm) positioned at two different depths underwater (Figure 3). The instruments were deployed close to the beach site (Figure 4).

Experimental Results

In agreement with results from two one-day intensive sampling studies (4), results from this study showed that enterococci concentrations were consistently higher at shin-deep sites than at the waist-deep sites throughout the summer (Figure 5). Also, the concentrations at the shin-deep sites were influenced by the tides with higher concentrations observed during high tides (Figure 6). This tidal variability may be attributable to desorption and resuspension of the FIB from the shore region during high tides (4). Other IVs that significantly influenced enterococci levels at waist-deep sampling locations included wind speed, air temperature, dewpoint and pH.

Figure 1. Image showing locations of sampling and instrument sites at Hobie Beach

Dependent Variables (DV) Collected:
Culturable (Method 1600) and qPCR Enterococci

Independent Variables (IV) Collected:
UV Sensor
Irradiance and Attenuation Coefficients
ADCP
Current Speed and Direction; Water Depth; Wave Height and Direction
Met Station
Solar Radiation; PAR; Wind Speed; Wind Direction; Gust Speed; Rainfall; Air Temp; Relative Humidity; Dewpoint; Barometric Pressure
Sonde
Water Temp; Specific Conductivity; Salinity; Dissolved Oxygen; Water Depth; pH; Turbidity; Chlorophyll
Filtered Water Samples
Absorption coefficients; Dissolved Organic Carbon

Figure 2. Measurements made at Hobie Beach during study

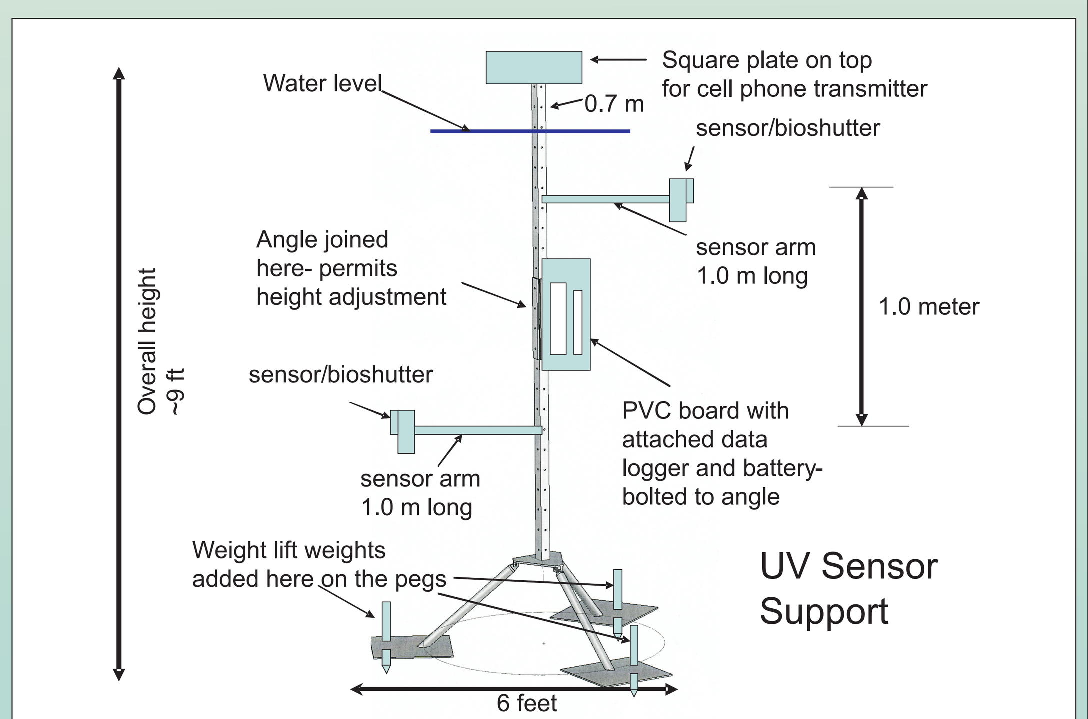

Figure 3. Schematic of tower structure used for UV measurements

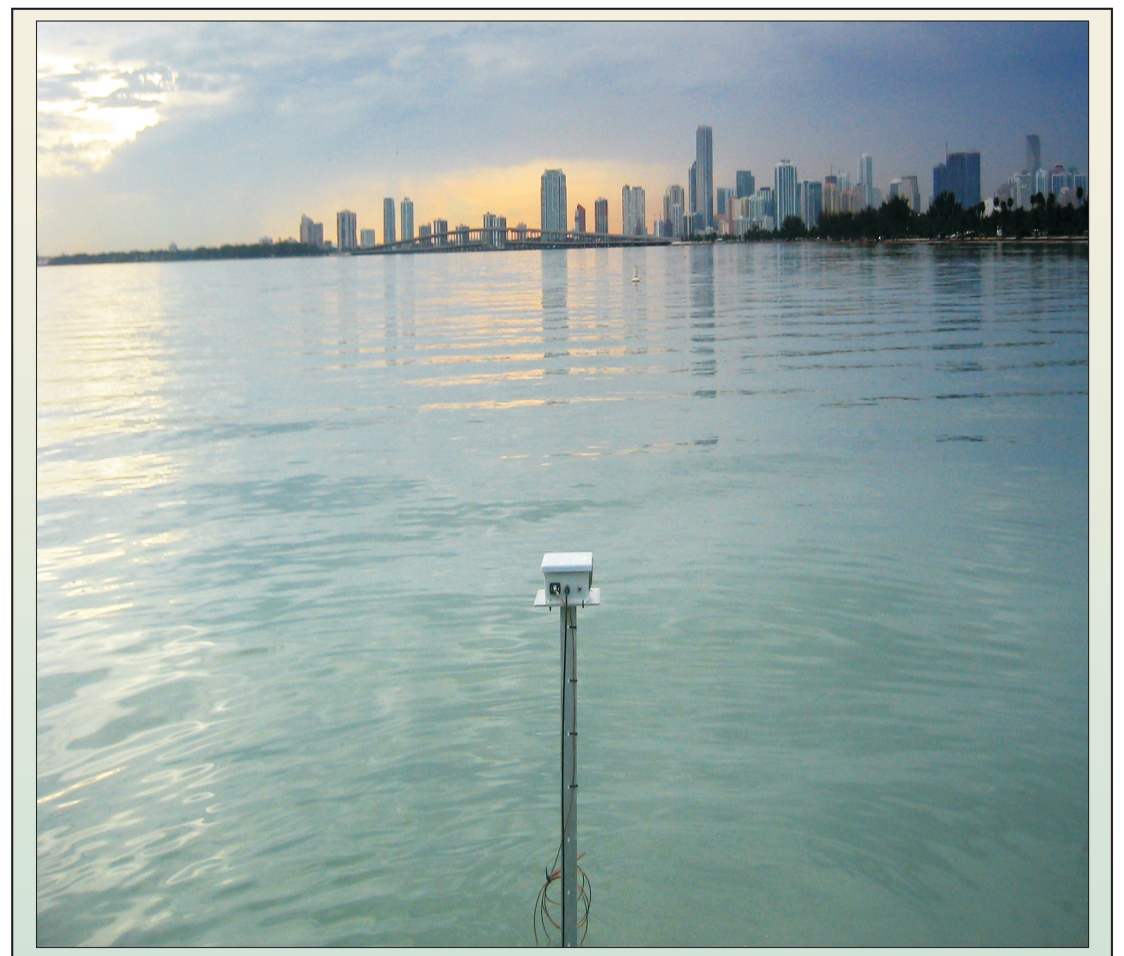
Figure 4. Picture of Hobie Beach with deployed tower in foreground

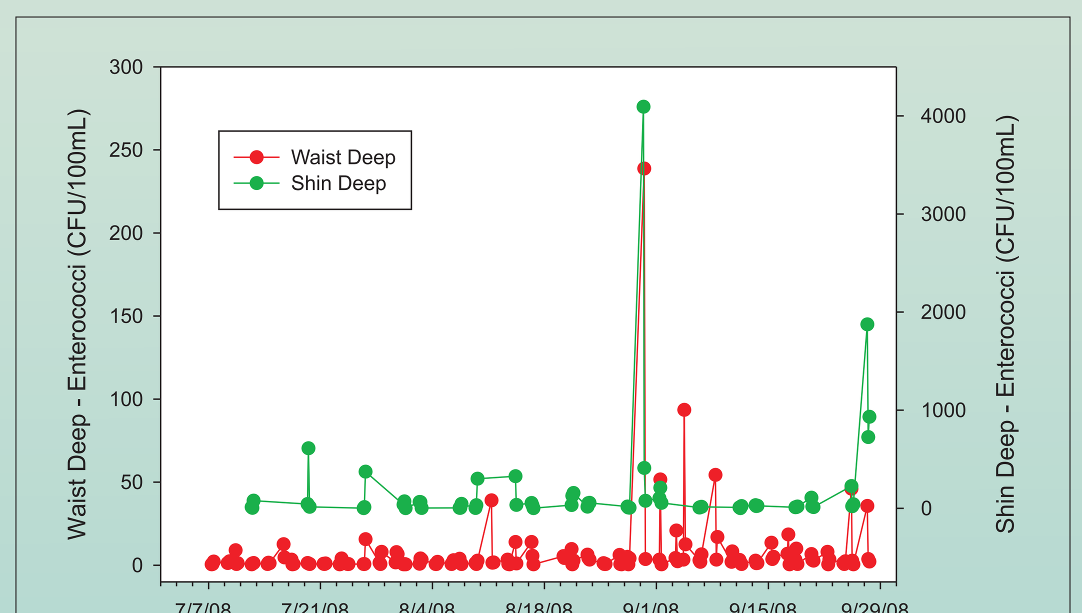

Figure 5. Comparison of enterococci concentrations at shin-deep and waist deep sampling sites

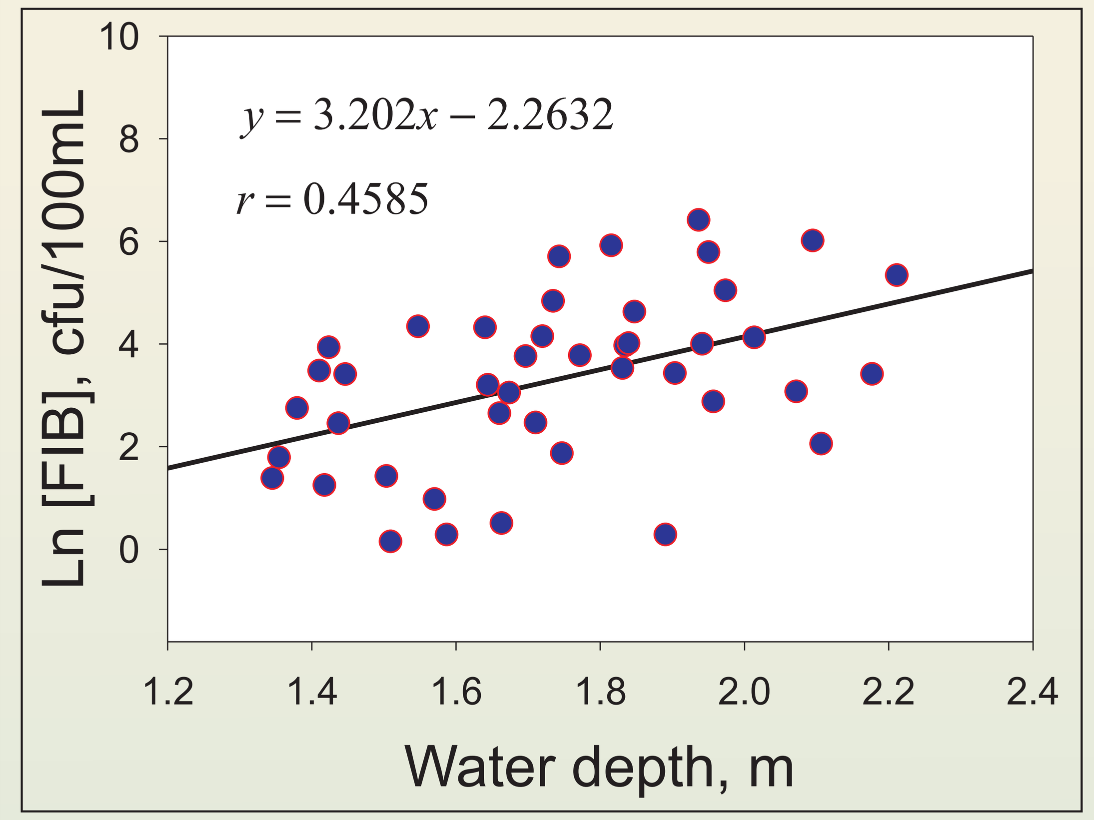

Figure 6. Enterococci concentrations vs tidal stage at shin-deep sites

- **Virtual Beach 1.0**
  Model Builder for developing multiple linear regression (MLR) models for indicator prediction and Beach Advisor for providing user friendly beach advisory decision support for non technical users
- **Virtual Beach 2.0**
  Under development: update software from Delphi to .Net; integrate Model Builder and Beach Adviser into single tool; add capabilities (e.g. neural networks, CART)

Figure 7. Summary of Virtual Beach features

135 observations
Significant IVs : PAR, Parallel Winds, Water Depth, pH, Chlorophyll
Adjusted R-square = 19%

Removal of Large* Outliers

GROUP 1 : 120 observations
Significant IVs : PAR, Parallel Winds, Water Depth, pH, Chlorophyll
Adjusted R-square = 49%

GROUP 2 : 15 observations
Significant IVs : Dewpoint, Water Depth
Adjusted R-square = 79%

Follow up with Discriminant Analysis:
Use IVs to predict if an observation is Type 1 or Type 2
72% Overall Success Rate (70% for Type 1, 80% for Type 2)

Adapted type of Hierarchical Bayesian method

*Standardized Residual > 2.0

Figure 8. Analyses of Hobie Beach data and approaches for model development

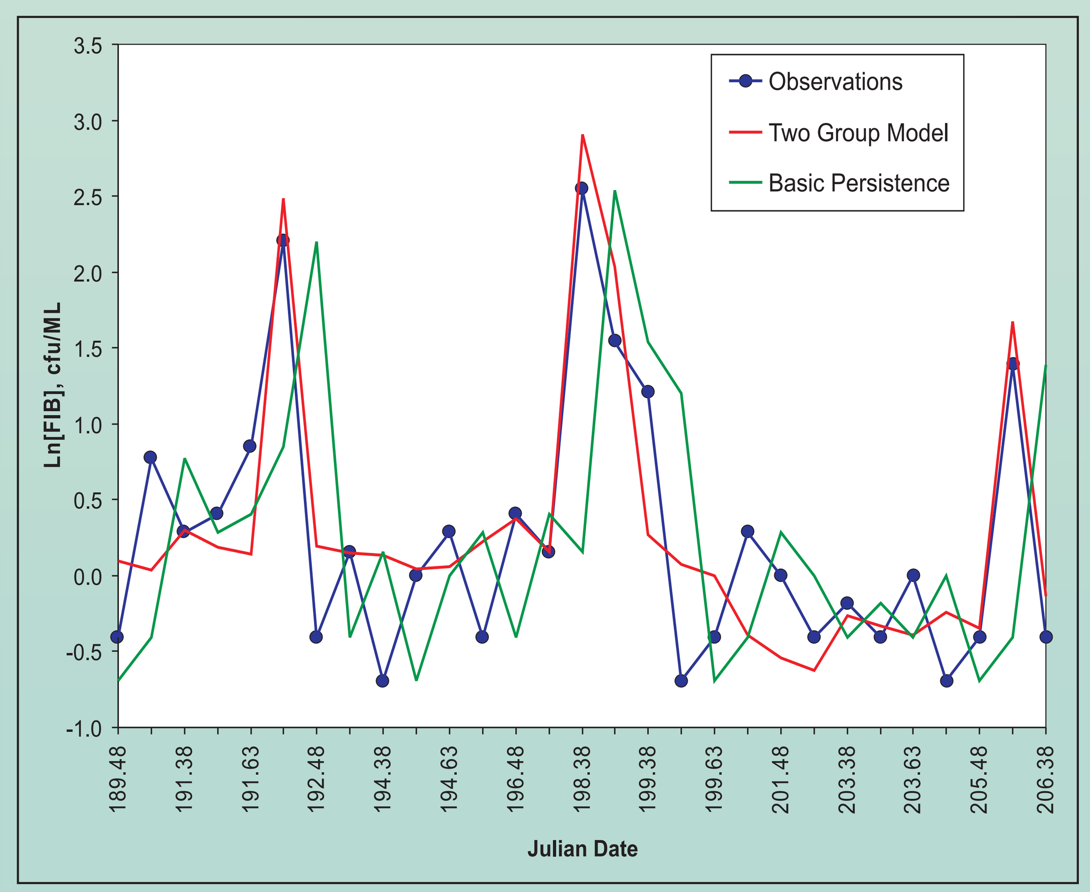

Figure 9. Comparison of observed enterococci concentrations with concentrations estimated using persistence approach and Baysian-type MLR model (two group)

Statistical Model Development

Statistical models were developed using a modified version of Virtual Beach as well as other software tools such as MiniTab. Steps used in model development were: (1) optimize the correlations (Spearman Rank) between the FIB concentrations and each IV based on a temporal "window" used to average the IVs (temporal synchronization analysis); (2) filter out IVs with too many missing data (i.e., those that would severely reduce the sample size if included in the analysis); (2) Box-Cox Transformation to normalize IVs; (3) Anderson-Darling test of normality to filter out IVs that are still egregiously non-normal; (4) Examine Pearson Correlation coefficients to filter out IVs that are too highly correlated with other IVs; (5) Put the remaining IVs into a statistical package for MLR data analysis. (6) Find the model with the lowest Mallows Cp (a combination of total variability explained and parsimony in parameter selection to prevent overfitting), to identify the best IVs from the array of potential variables available for fitting. Features of Virtual Beach are summarized in Figure 7 and the approach used to analyze the Hobie Beach data set is shown in Figure 8. The best results were obtained by a modified Hierarchical Bayesian Method in which the data were subdivided into two groups. Comparisons of the modeled and observed data are provided in Figure 9.

Acknowledgements

We gratefully acknowledge the efforts of Diana Aranda and Chris Sinigalliano in maintaining the equipment during the experiments and downloading some of the data. We also thank ERG Inc for their efforts in collecting the water samples and the FIB measurements, Erich Bartels and Jed Campbell for deploying and recovering the equipment, and Jon Wong for assisting with Virtual Beach analyses.

References

1. **Bonilla, T. D., K. Nowosielski, M. Cuvelier, A. Hartz, M. Green, N. Esiobu, D. S. McCorquodale, J. M. Fleisher, and A. Rogerson.** 2007. Prevalence and distribution of fecal indicator organisms in South Florida beach sand and preliminary assessment of health effects associated with beach sand exposure. Marine Pollution Bulletin **54**:1472-1482.
2. **Elmir, S. M., M. E. Wright, A. Abdelzaher, H. M. Solo-Gabriele, L. E. Fleming, G. Miller, M. Rybolowik, M. T. P. Shih, S. P. Pillai, J. A. Cooper, and E. A. Quaye.** 2007. Quantitative evaluation of bacteria released by bathers in a marine water. Water Research **41**:3-10.
3. **Frick, W. E., Z. Ge, and R. G. Zepp.** 2008. Nowcasting and forecasting concentrations of biological contaminants at beaches: A feasibility and case study. Environmental Science and Technology **42**:4818-4824.
4. **Shibata, T., H. M. Solo-Gabriele, L. E. Fleming, and S. Elmir.** 2004. Monitoring marine recreational water quality using multiple microbial indicators in an urban tropical environment. Water Research **38**:3119-3131.