
Summary: This report describes grant-funded work undertaken by the Wisconsin Department of Natural Resources in close collaboration with the City of Racine and Ozaukee County health departments, the U.S. Environmental Protection Agency’s Office of Research and Development, and the U.S. Geological Survey’s Wisconsin Water Science Center. We developed real-time predictive water-quality models (“nowcasts”) for five high-priority beaches in southeastern Wisconsin. We also worked to build capacity among local health departments to operate and maintain these models over time. This report describes the work we undertook, documents the deliverables produced, and presents case studies and lessons learned to improve future beach modeling and nowcasting efforts. This document also fulfills final reporting requirements for our grant agreement.

This project was funded by the Wisconsin Coastal Management Program and the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resources Management under the Coastal Zone Management Act, Grant #NA09NOS4190107. Points of view expressed in this report do not necessarily reflect the views or policies of the Wisconsin Coastal Management Program or National Oceanic and Atmospheric Administration. Mention of trade names and commercial products does not constitute endorsement of their use.



Cover Illustrations: Clockwise from upper left: North Beach, Racine, Wisconsin; operating a nowcast model; screen capture of *Virtual Beach* model prediction tab; real-time data link developed as part of the grant-funded work. Photos by Adam C. Mednick.

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Building Operational “Nowcast” Models for Predicting Water Quality at Five Lake Michigan Beaches

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September 2012

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Introduction

The objectives of this project were to facilitate the establishment of water-quality “nowcasts” (real-time predictive models) at high-priority beaches in southeastern Wisconsin and to build capacity among local health departments to operate and maintain these models over time. The Wisconsin Department of Natural Resources (Wisconsin DNR) coordinates the state’s Great Lakes Beach Program, with the objective of reducing swimmers’ risk of exposure to water-borne pathogens and improving water quality at coastal beaches. As part of the federal BEACH Act¹, the Wisconsin DNR annually funds local health departments to conduct regular water-quality monitoring and notification at 114 beaches on the Lake Michigan and Lake Superior coastlines. Under this program, health departments or their sub-contractors collect and test water samples one to five days per week, depending on a beach’s priority level. Swim advisories are posted whenever the nearshore concentration of the fecal-indicator bacterium *E. coli* exceeds the recreational water-quality criterion of 235 colony-forming units (CFUs)/100 mL. Beaches are closed when *E. coli* levels exceed 1,000 CFUs/100 mL. In addition to signs at the beach (Figure 1), advisories and closures are posted on the *Wisconsin Beach Health* website (www.wibeaches.us).

Because standard monitoring entails transporting samples to a laboratory and culturing for *E. coli*, decisions on whether or not to post an advisory are typically made using information that is a day or more old – the so-called “persistence model”. Nearshore *E. coli* levels, however, can fluctuate over relatively short periods of time (Whitman et al. 2004), such that the standard approach frequently produces Type I errors (false exceedances), as well as Type II errors (false non-exceedances) (Nevers and Whitman 2005). Routine monitoring errors increase swimmers’ exposure to potentially unhealthy conditions on days when advisories should have been posted, while negatively impacting coastal economies on days when beaches are unnecessarily posted. Mednick and Watermolen (2009) report that over 40% of advisories and 60% of closures posted in Wisconsin between 2003 and 2009 were unnecessary, while over 10% of non-advisory beach days should either have been posted with an advisory or closed. Had all Type I and II errors associated with the state’s closure guideline been avoided during that period, beach closures would have been reduced by a third.



Figure 1. Public notification signage used at beaches.

¹ Beaches Environmental Assessment and Coastal Health Act of 2000; see: <http://water.epa.gov/lawsregs/lawguidance/beachrules/act.cfm>.

Nowcasts that use multivariate statistical models to predict current *E. coli* concentrations or the probability of exceeding water-quality standards are one of three options available to beach managers looking to post more timely advisories. The first option is to post advisories based on recent rainfall, although rainfall alone has been shown to be a poor predictor of water quality (Sampson et al. 2006). Standardized sanitary surveys have shown that many other variables influence water quality at beaches (e.g., Chase and Richmond 2007). The second option is quantitative polymerase chain reaction (qPCR), a rapid lab-based method that can reduce the wait time between sample collection and analytical results from roughly one day to just two to four hours. The City of Racine Health Department is the first local jurisdiction in the U.S. to use qPCR for routine beach monitoring. Implementing qPCR, however, requires significant start-up costs and highly-skilled operators.

A number of studies have demonstrated that nowcast models routinely produce more accurate estimates of current water quality than the persistence model (e.g., Nevers and Whitman 2005, Francy and Darner 2007, Frick et al. 2008). Local jurisdictions have been slow to adopt this third method, however, in part because they lack the technical capacity to build and operate models (Francy 2009). Prior to 2008, nowcast systems were operational at just nine beaches across the Great Lakes. Three beaches were covered by the Lake County (Illinois) Health Department’s *Swimcast*² system, which relies on expensive, onsite, hydro-meteorological stations. Two beaches were covered by the *Ohio Nowcast*³ developed and operated by the U.S. Geological Survey (USGS); and four more were covered by the since-discontinued *Project S.A.F.E.*⁴, which was also developed and operated by the USGS. In 2008, the Ozaukee County Public Health Department initiated its own *Rainflow* model, which posted advisories based on a mathematical combination of rainfall, stream-flow, and turbidity values.

In an effort to make nowcast modeling a more feasible alternative for local beach managers, the Wisconsin DNR conducted a technology-transfer study (Mednick and Watermolen 2009), as part of a U.S. Environmental Protection Agency (EPA)-led Advanced Monitoring Initiative project on beach water-quality forecasting. The Wisconsin DNR study entailed intensive beta-testing and evaluation of the modeling software *Virtual Beach*⁵ (Frick et al. 2008), two hands-on workshops for targeted local users, and summer field-testing in cooperation with the Ozaukee County Public Health Department. From this, the Wisconsin DNR provided the *Virtual Beach* development team within the U.S. EPA’s Ecosystem Research Division with structured feedback and suggestions on how to make the software more useful and user-friendly, with an emphasis on practical considerations for local operations. The study resulted in five broad recommendations related to the accessibility, enhancement, and integration of modeling tools, supporting data, and online data infrastructure, as well as training and technical assistance for local users. The current project was initiated in response to the findings of this earlier study.

² www.lakecountyl.gov/Health/want/Pages/SwimCast.aspx

³ www.ohionowcast.info

⁴ www.glsc.usgs.gov/ProjectSAFE.php

⁵ www.epa.gov/ceampubl/swater/vb2/

2. Project Description

2.1. Project Sites

Project sites included five public beaches along the Lake Michigan shoreline (Figure 2), including North Beach and Zoo Beach in the City of Racine, Upper Lake Park Beach in Port Washington, and Harrington Beach State Park “North” and “South” beaches in the Town of Belgium⁶. The Wisconsin DNR designates all of these sites as high-priority beaches on account of their high levels of visitation, although they vary considerably in terms of their physical and community characteristics. Detailed descriptions of each site can be found in the case studies included in the Appendices.

Project cooperators included the two local health departments responsible for the monitoring and public notification of water-quality conditions at the beaches: The Racine Health Department for North and Zoo beaches; and the Ozaukee County Public Health Department for the Upper Lake Park and Harrington beaches. Both departments have a wealth of experience in beach management and were seen as promising candidates to assume a greater role in the development and long-term operation and maintenance of nowcast models.

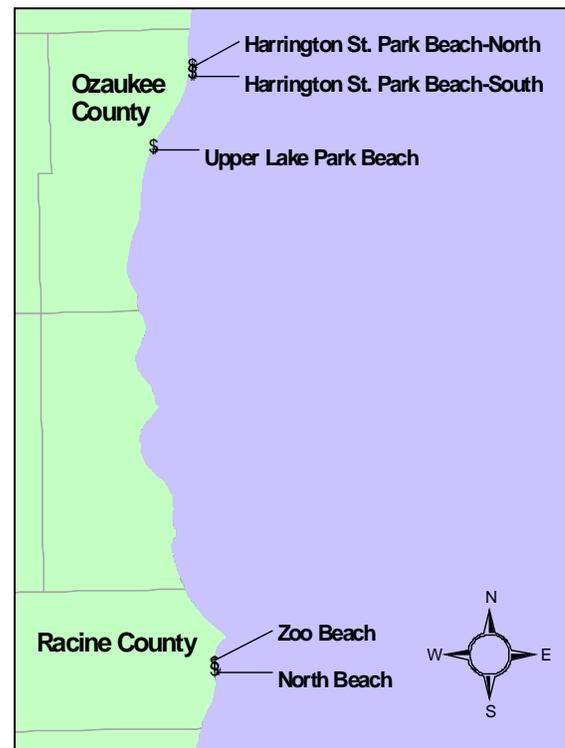


Figure 2. Location of project sites.

2.2. Field Visits

Wisconsin DNR project staff conducted field visits to each of the project beaches in July 2010, accompanying local health department personnel on their sampling rounds and consulting with them afterwards. Through these visits project staff acquired insights into the potential sources and mechanisms of *E. coli* contamination at each beach, including nearshore, onshore, and hydro-meteorological conditions. Contamination sources and mechanisms vary from beach to beach (e.g., Figure 3; see also the case studies in the Appendices). Field notes taken during the initial and subsequent beach visits proved useful during the development, evaluation, and refinement of the nowcast models, including the decisions on which variables to consider, add, or remove from the various models.

Also during the field visits, project staff observed and consulted with health department staff regarding their daily procedures for beach monitoring and public notification, including process steps, timing, and logistics. From this, valuable insights were gained on how to integrate nowcast operation within existing beach management routines and workflow. Project staff made return visits to Racine and Ozaukee County in August 2011 to observe local operation of the nowcast models established for North Beach (Racine)

⁶ In actuality, there are seven beaches. The two Harrington Beach State Park sites (“North” and “South”) each have adjacent beach sites (“County Highway D Beach” to the north and “Cedar Road Beach” to the south) that are designated by the U.S. EPA as separate public beaches. In 2010, the Ozaukee County Public Health Department resumed the protocol of maintaining and testing separate samples for each beach site, as opposed to compositing the paired samples collected at the two northern beaches and two southern beaches, respectively.

and Upper Lake Park Beach (Port Washington), including sampling rounds at all of the project beaches. Through these return visits, project staff acquired additional information and insights into the beaches, as well as the process of operating the nowcast models.



Figure 3. *Cladophera* algae, Harrington Beach State Park-North.

2.3. Training and Technical Assistance

Over the course of the project, Wisconsin DNR staff provided comprehensive training and technical assistance to beach monitoring staff at the two cooperating local health departments. Hands-on workshops, one-on-one instruction, and direct support (scheduled and on-call) were employed at different times to train local staff on how to operate nowcast models that had already been developed, as well as the more detailed process of building the models. For the 2011 beach season, training and technical assistance focused entirely on model operation. Project staff first developed step-by-step instructions on how to make and interpret nowcast predictions using *Virtual Beach 2.0*. The example used was a Wisconsin DNR-developed nowcast model for Upper Lake Park Beach in Port Washington. Following the limited release of *Virtual Beach 2.1* in early 2011, project staff updated these instructions, this time using a newly-created model for North Beach in Racine as the example. Detailed instructions on how to access online data for model inputs were added and the full set of instructions were compiled into an illustrated training module, which was used in a hands-on training workshop held on May 5 at the Johnson Foundation’s Wingspread facility in Racine (Figure 4). Conducted by project staff in conjunction with a two-day “Lake Michigan Beach Health” conference organized by the Wisconsin Coastal Management Program, this two and a-half hour workshop was attended by beach monitoring staff from the Racine and Ozaukee County health departments, among others. Participants worked through the training module and made their own real-time prediction of North Beach water-quality conditions.



Figure 4. Hands-on training workshop, Racine, May 5, 2011.

For the 2012 beach season, project staff provided training and technical assistance in model-building as well as nowcast operation. As with predictive models in general, beach nowcasts must be re-calibrated over time to ensure that they account for changing conditions. Nowcast models are rebuilt each year during the off-season, incorporating data collected during the recently completed monitoring season. The updated dataset is used to build a new model for the upcoming beach season. Ideally, local health departments will take increasing responsibility for rebuilding nowcast models for their beaches, thereby freeing Wisconsin DNR staff to expand model-building and technical assistance activities to cover more beaches around the state. Project staff created detailed training modules on: (1) data processing/model set-up, and (2) model-building/evaluation using *Virtual Beach 2.1*. These modules were used in a day-long training workshop for Racine and Ozaukee County beach monitoring staff, held at Racine City Hall on December 5, 2011. The example used for the modules was Upper Lake Park Beach; however, project staff helped beach monitoring staff from Racine to work through the exercises with data from their own beaches and by the end of the session had completed an initial 2012 nowcast model for North Beach.

Throughout the 2011 and 2012 beach seasons, project staff corresponded regularly with both of the cooperating health departments, by phone and electronically, assisting beach monitoring staff with the regular operation of nowcast models that the Wisconsin DNR had built and provided – or in the case of the Racine Health Department in 2012, that local staff had taken the lead in building. This included, on several occasions, project staff running nowcast models remotely, using data provided by local cooperators, in order to confirm that models were being run correctly, to test possible replacement models, and to trouble-shoot various aspects of model operation, including problems accessing automated model inputs through various web data services. Project staff provided on-call, live support, as well as scheduled technical assistance. In addition, project staff traveled to Racine and Ozaukee County each during the 2011 and 2012 beach seasons to provide on-site instruction and technical assistance, and to observe local operation of the various nowcasts. These visits allowed project staff to evaluate the integration of the modeling into routine monitoring and public notification processes, which in Racine includes the use of qPCR analysis to estimate cell-based equivalents of *E. coli* concentrations in near-real-time (2 hours), as well as the standard persistence method. These observations informed a number of enhancements to *Virtual Beach* and the *Wisconsin Beach Health* website to help further integrate nowcasting into routine procedures.

2.4. Data Assembly

In addition to training and technical assistance, project staff provided direct service to the cooperating local health departments, beginning with the assembly of historical datasets required for model-building. As is often the case with environmental modeling projects, data assembly proved to be among the most time-consuming aspects, although critical online data infrastructure made this task more manageable. The *Wisconsin Beach Health* website⁷, maintained and operated by the USGS Wisconsin Water Science Center, provided an archive of historical data on *E. coli* lab results and concurrent field conditions (e.g., wave height, water clarity, and algae levels), which are uploaded by local personnel as part of routine monitoring and sanitary surveys. Project staff accessed these data through separate queries of monitoring and sanitary survey archives and downloaded them as comma-separated value (.CSV) tables. For nowcast model-building, Francy and Darner (2006) recommend a minimum of 120 observations over two or more beach seasons, to account for both inter- and intra-seasonal variation. The assembled datasets generally exceeded these guidelines. For Upper Lake Park Beach in Port Washington and Zoo Beach in Racine, three seasons’ worth of data were assembled. For North Beach, four seasons’ worth of data were assembled and then filtered to exclude all days for which there had been no rainfall recorded during the previous 48 hours. This was done at the suggestion of local health department staff because there are typically only three or four exceedances per summer, occurring only after significant rain events. Filtering the data enhanced the *E. coli* signal thereby increasing the sensitivity of the eventual models to the occasional exceedance. For the Harrington beaches, three years’ data were initially downloaded, but data from 2009 and earlier were later excluded due to a significant change in monitoring in 2010. Prior to then, samples were composited from multiple monitoring stations; afterwards, they were analyzed individually.

The paired .CSV tables of monitoring and sanitary survey data were merged by date-and-time, converted to MS Excel, and formatted to conform to the various input requirements of *Virtual Beach*. For example, date-and-time and *E. coli*, respectively, were made the first two columns of each table and all sub-detection *E. coli* results (reported as “<10”) were converted from text strings to numeric values of 5. Similarly, categorical text measures of beach conditions were converted to binomial (presence/absence) or ordinal (ranked) variables. For example, the four-category measure of *water clarity* (“clear,” “somewhat turbid,” “turbid,” and “opaque”) was converted into four binomial variables, one for each category, with a value of 1 if the condition is present and 0 if otherwise. Categorical measures of *algae on beach* and *algae in water* (“none,” “low,” “moderate,” and “heavy”), alternatively, were converted to ordinal variables with numeric values of 0, 1, 2, and 3.

Additional data assembly and formatting were conducted in order to incorporate “automated” hydro-meteorological data and model estimates available online from the USGS and National Oceanic and Atmospheric Administration (NOAA). Prior to the opening of the 2011 beach season, project staff worked with staff at the NOAA Great Lakes Environmental Research Laboratory and the Great Lakes Commission to help finalize and deploy an operational web service for the Great Lakes Coastal Forecast System (GLCFS)⁸, which provides location-specific, hourly hydrodynamic model inputs and outputs across the Great Lakes. These include air and water temperature, cloud cover, wind speed and direction, surface current speed and direction, wave height and direction, and wave period. Project staff assembled additional data, including location-specific rainfall and river discharge data, from other NOAA and USGS online data portals.

For the 2011 nowcasts, project staff accessed and downloaded data directly from their individual sources. As detailed in the report *Accessing Online Data for Building and Evaluating Real-Time Models to Predict Beach Water Quality* (Mednick 2009), this process involved a complex and time-intensive set of

⁷ <http://www.wibeaches.us>

⁸ <http://data.glos.us/glcfs/>

procedures. Data “stations” – both physical stations and GLCFS grid cells – were selected for each beach using online or desktop geographic information system analyses. Depending on the source, data were downloaded as a number of different file types, requiring considerable formatting before project staff could assemble them, along with the tables of *E. coli* lab results and field conditions, into a dynamic database within MS Access. Final model-building tables for each of the project beaches were created using MS Access queries, as well as MS Excel “VLOOKUP” functions, using date-and-time as the common attribute.

For the 2012 nowcasts, different parts of the data assembly work described above were accomplished using the beta version of an online data portal called the *Environmental Data Discovery and Transformation* (ENDDAT)⁹ system, also developed by the USGS Wisconsin Water Science Center. ENDDAT enables users to access location-specific NOAA and USGS data through a map-based interface. Extracted data can be filtered to temporally match sample dates-and-times uploaded to the system by the user. ENDDAT fulfills a key recommendation of the Wisconsin DNR technology transfer study on predictive modeling tools (Mednick and Watermolen 2009) and is expected to significantly cut the time necessary for data assembly in advance of future beach seasons.

2.5. Model Set-up

Following the completion of data assembly and formatting tasks, project staff began model set-up for the different beaches using *Virtual Beach*. For the 2011 nowcasts, project staff used a limited-release version (“2.1”) that represented a significant redesign, including a number of changes made in response to detailed suggestions provided by project staff in early 2011. These enhancements generally sought to enable collaboration between two types of users: (1) centralized “model builders,” and (2) distributed “model operators.” Additional enhancements were made with guidance from project staff prior to the public release of *Virtual Beach 2.2* in March 2012. Both versions follow the same basic file-management and sharing scheme, including “project” files (.VBPX) and “model” files (.VBMX), both of which are self-contained and portable. Model files essentially contain all that is needed to operate a nowcast; i.e. model coefficients and an input/output interface. Project files save/archive all of the model set-up; i.e. the historical data used to build the model, along with the user-specified data processing, manipulation, and variable transformations.

Virtual Beach project files were created for each beach. As a first step, the Beach Orientation utility within the “Beach Location” tab was used to determine each site’s shoreline orientation, or angle, with a default of 0 degrees representing a straight north-south shoreline (Figure 5). This was followed by a series of data processing, manipulation, and transformation steps using the various utilities within *Virtual Beach*’s “Data Processing” tab (Figure 6). Assembled data tables were imported and scanned for missing cells or non-readable (i.e. text) values using the Validate utility. Wherever these “anomalous” values were identified, project staff removed either the row (i.e. the observation) or the column, depending on the extent of the missing data and whether or not the potential independent variable was deemed likely to influence *E. coli* levels. Such determinations were based on an evaluation of bivariate scatter plots and correlation coefficients, as well as the earlier field visits and discussions with health department staff. Once the imported table was cleared of all anomalous data, the dependent variable (i.e. *E. coli*) was log-transformed to ensure linear relationships with independent variables. Paired variables of magnitude and direction (e.g., wind velocity and wind direction) were processed into alongshore (A) and onshore (O) vectors based on beach orientation (Figure 5) using *Virtual Beach*’s Compute A, O utility.

⁹ <http://cida.usgs.gov/enddat/>

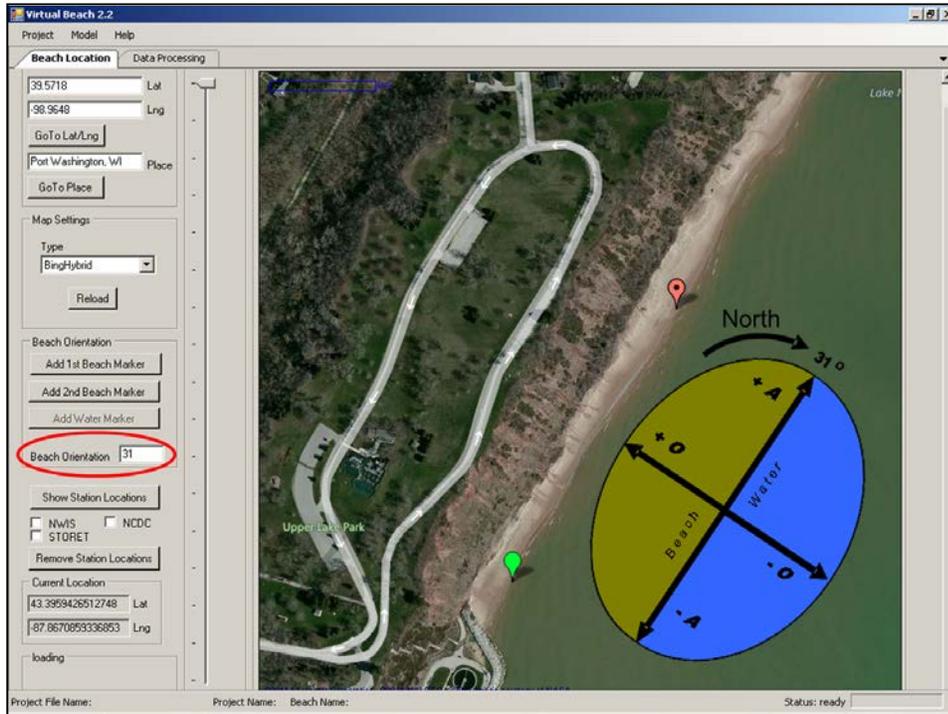


Figure 5. Virtual Beach’s “Beach Location” tab, with added schematic of +/- alongshore (A) and onshore (O) vectors, given a 31° shoreline orientation, Upper Lake Park Beach, Port Washington.

Date	EColi	SampleTime	PreJun21	Jun21Jul15	Jul16Aug10	PostAug10
06/04/2008	127.4	06/04/2008 8:50...	1	0	0	0
06/05/2008	1733	06/05/2008 11:4...	1	0	0	0
06/06/2008	435.2	06/06/2008 8:40...	1	0	0	0
06/07/2008	139.6	06/07/2008 8:50...	1	0	0	0
06/08/2008	686.7	06/08/2008 7:40...	1	0	0	0
06/09/2008	1414	06/09/2008 8:50...	1	0	0	0
06/10/2008	2419	06/10/2008 9:00...	1	0	0	0
06/11/2008	106.7	06/11/2008 9:00...	1	0	0	0
06/12/2008	52	06/12/2008 8:40...	1	0	0	0
06/13/2008	2419	06/13/2008 9:00...	1	0	0	0
06/14/2008	2419	06/14/2008 8:40...	1	0	0	0
06/15/2008	56.3	06/15/2008 8:40...	1	0	0	0
06/16/2008	17.5	06/16/2008 7:30...	1	0	0	0
06/17/2008	7.3	06/17/2008 9:20...	1	0	0	0
06/18/2008	0.5	06/18/2008 8:30...	1	0	0	0
06/19/2008	1	06/19/2008 9:00...	1	0	0	0
06/20/2008	7.4	06/20/2008 9:00...	1	0	0	0
06/21/2008	2	06/21/2008 7:50...	0	1	0	0
06/22/2008	5.2	06/22/2008 8:20...	0	1	0	0
06/23/2008	5.2	06/23/2008 8:30...	0	1	0	0
06/24/2008	4	06/24/2008 9:00...	0	1	0	0
06/25/2008	22.7	06/25/2008 7:30...	0	1	0	0
06/26/2008	17.5	06/26/2008 9:49...	0	1	0	0
06/27/2008	7.4	06/27/2008 8:40...	0	1	0	0
06/28/2008	58.8	06/28/2008 8:45...	0	1	0	0

Figure 6. Virtual Beach’s “Data Processing” tab.

At Upper Lake Park Beach in Port Washington and North and Zoo beaches in Racine, *E. coli* lab results are actually composites of samples collected at more than one monitoring station, although field conditions like water temperature and algae are measured separately at each station. To address this, project staff used *Virtual Beach*'s Manipulate utility to combine station-specific measurements into composite variables (e.g., average water temperature). The same utility also was used to take the product of all possible pairings of quantitative variables in order to create “interaction terms” (e.g., rainfall x wave height). Several interaction terms were included in the 2011 nowcast for North Beach; however, this practice was discontinued in 2012, out of concern that including multiple interaction terms (without a strong conceptual basis) could result in “over-fitting” model predictions to extremely narrow conditions. The practice of compositing multi-station data was also discontinued after 2011, in favor of selecting a single station as identified by health department staff. The difference between station-specific values and their average was determined to be too small to warrant the extra data processing. Project staff did continue to use the Manipulate utility, however, to sum certain pairs of categorical variables in order to erase the fuzzy boundaries between them and enhance their combined data signal. For example, the binomial variables for the subjective water clarity categories of “turbid” and “opaque” were summed to create a new binomial variable, receiving a value of 1 if *either* condition is reported and 0 if not.

The last model set-up task was the mathematical transformation of potential independent variables (columns) in the data table. Using *Virtual Beach*'s Transform utility, project staff initiated seven pre-set mathematical operations plus a custom operation (exponent), for a total of eight different transformations applied to each of the potential variables. Transformations included taking the log10, natural log, inverse, square, square-root, cube-root, quad-root, and polynomial of the native (i.e. untransformed) variables – both “main-effect” (i.e. single) variables and combined variables. For each variable, the transformation with the highest linear correlation to $\log(E. coli)$ – in some cases the un-transformed variable itself – was recommended by *Virtual Beach* as the optimal transformation to use in model-building. In most cases, project staff selected the recommended transformations for inclusion; however, in some they manually overrode the default selections in favor of other transformations, often the transformation with the *second*-highest correlation coefficient, based on visual inspection of the bivariate scatter plots (Figure 7) or other considerations. Finally, project staff resaved the .VBPX files to complete model set-up.

2.6. Model Building

For the 2011 nowcasts, all of the model-building tasks described below were conducted exclusively by Wisconsin DNR project staff. For the 2012 nowcasts, the Racine Health Department assumed primary responsibility for building models for North and Zoo beaches, with Wisconsin DNR staff playing a technical support role. This transition occurred midway through the project, following hands-on training conducted in fall 2011. Project staff, however, maintained responsibility for data assembly and model set-up, providing health department staff with completed *Virtual Beach* project (.VBPX) files, from which they built nowcast models. Project staff also maintained responsibility for model-building for the three Ozaukee County beaches. This was due to the limited staff time available from the Ozaukee County Public Health Department. In contrast to Racine, which has several permanent and seasonal health department staff engaged in beach-related research and management activities, Ozaukee County has one staff member dedicated part-time to beach monitoring, plus a part-time summer intern. In this respect, Ozaukee County is more reflective of the typical coastal community. Their staff, however, continued to operate nowcast models and provided invaluable guidance and feedback to project staff on the models, their performance, and the practical strengths and weaknesses of the operational nowcast systems including *Virtual Beach* and the real-time component of the ENDDAT system. This split in nowcast responsibilities between the different project partners is discussed further under “Project Outcomes.”

After completing model set-up for each beach, various utilities within *Virtual Beach*'s “Modeling” tab (Figure 8) were used to generate potential nowcast models from among the vast number of possible combinations of independent variables. With each additional independent variable available for a given beach, the number of possible models doubles, plus one. If there are only two potential independent variables, for example, there will be three possible models. If, however, there are 20 potential independent variables, there will be over 1 million possible models. For most beaches, there are tens- to hundreds-of-millions of possible models, making exhaustive model-building and evaluation impossible. *Virtual Beach*'s Genetic Algorithm utility, however, provides a virtually comprehensive model-optimization routine that required minimal computer processing and staff time. Within the Genetic Algorithm, potential models are treated as individuals (i.e. unique combinations of independent variables) within a user-defined population. The Genetic Algorithm simulates the evolution of the potential models over a user-specified number of generations. New models (individuals) are created through the recombination of variables plus random mutation, leading over time to increased “fitness” as defined by a user-selected criterion. For the 2011 nowcasts, project staff selected the predicted residual sum of squares (PRESS) statistic, a form of “leave-one-out” cross-validation assumed to be a good indicator of models' eventual predictive power.

Depending on the number of independent variables selected for inclusion in the Genetic Algorithm (from among the full set of available independent variables), the automated process generally took less than two minutes to run using the default population size (100) and number of generations (100). The result of the Genetic Algorithm was an ordered list of the top ten “best fit” models for each beach, according to the user-selected fitness criterion (i.e. PRESS), together with various statistical measures of model performance and graphical displays of predicted versus observed $\log(E. coli)$ (Figure 9). Reported model statistics included Akaike information criterion (AIC), corrected AIC, Bayesian information criteria (BIC), the coefficient of determination (R-squared), adjusted R-squared, PRESS, root mean square error (RMSE), Type I errors, Type II errors, sensitivity (the percent of exceedances correctly predicted), specificity (the percent of non-exceedances correctly predicted), and accuracy (the percent of exceedances and non-exceedances correctly predicted).

Typically, different models among the top ten list ranked higher or lower according to different statistics. Considerable manual effort, therefore, was devoted to evaluating and comparing the top ten models in order to determine which among them were more or less likely to improve water-quality predictions in an operational capacity. The process for this was semi-structured and dynamic, relying on modelers' best judgments and assumptions, informed by field observations and input from project collaborators. As a general practice, models were evaluated and compared according to more than one statistic, with an emphasis on the visual inspection of four-quadrant scatter plots of predicted-versus-observed $\log(E. coli)$ (Figure 9). Priority was given to models with the lowest number of overall prediction errors (Type I and Type II) with respect to the 235 CFU/100 mL water-quality threshold (log-transformed). These statistics and scatter plots, however, were for the historical period (i.e. the “training” dataset) as opposed to actual predictions (i.e. the “validation” dataset). *Virtual Beach*'s Cross Validation utility was therefore used for an additional evaluation and comparison among the top ten models. Cross Validation measures a model's ability to correctly predict a randomly removed subset of the historical observations, which act as a simulated validation dataset. Within this automated process, each of the top ten models was re-run 500 times with one-quarter to one-third of the total number of observations randomly removed. The top ten models were then ranked according to the sum of square prediction errors over the removed portions. In most cases, cross-validation reinforced manual selections already made by the modelers. In some cases, however, cross-validation resulted in the modeler selecting a different model as the preferred nowcast.

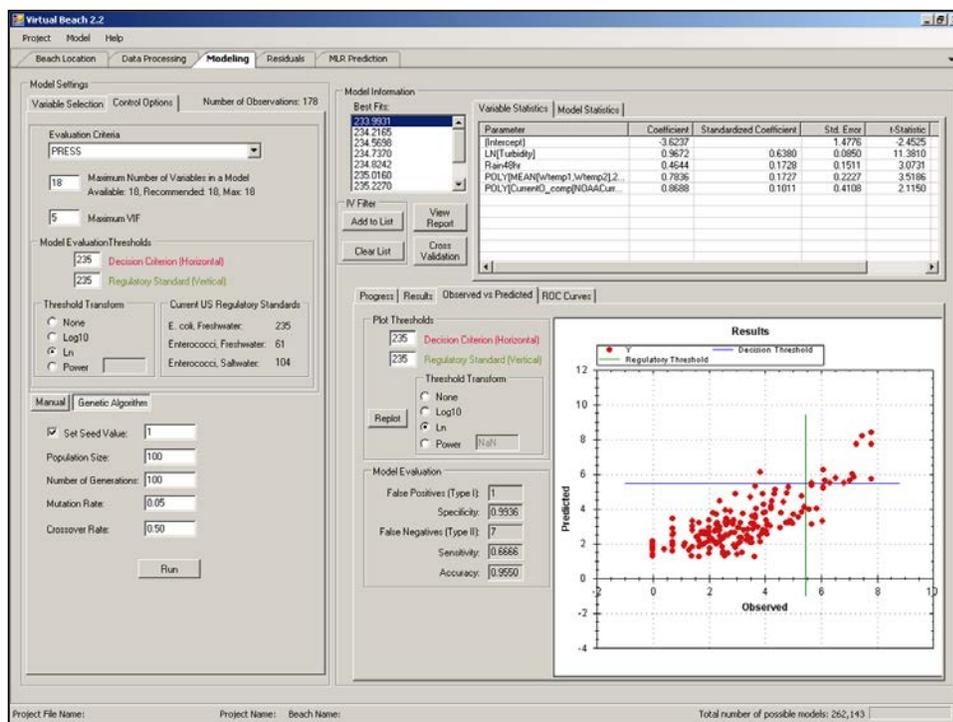


Figure 9. *Virtual Beach’s “Modeling” tab, showing example “best fit” model, with variable statistics and graphical display.*

In advance of the 2012 beach season, Wisconsin DNR project staff worked with staff at the Racine Health Department and collaborating scientists at U.S. EPA’s Office of Research and Development and the USGS Wisconsin Water Science Center to begin the process of formalizing guidelines and “rules-of-thumb” for model building, evaluation, and final selection. This was done partly in response to the expanded number of potential independent variables made available by the new ENDDAT system. One resulting change in practice was the use of *Virtual Beach’s* IV Filter utility in combination with the Genetic Algorithm to narrow the initial set of potential independent variables. In the first step of this process, the Genetic Algorithm was run for the entire set of possible independent variables using AIC as the fitness criterion, rather than PRESS. Among the ten criteria available, AIC is moderately restrictive, in terms of the degree to which it penalizes large models and less significant independent variables. The IV Filter was then used to reduce the set of potential independent variables to just those contained in at least one of the top ten models according to AIC. If the number of remaining independent variables was 15 or less, *Virtual Beach’s* Manual model-building utility was used to evaluate *all* possible combinations of these independent variables, based on PRESS, to identify a final group of top ten models assumed to have relatively good predictive power. If, on the other hand, more than 15 independent variables remained, the Genetic Algorithm and IV Filter utilities were run a second time, using the more highly-restrictive BIC statistic to further narrow the set of independent variables before using *Virtual Beach’s* Manual utility. In a separate set of analyses, the Genetic Algorithm was used to identify the maximum attainable accuracy levels with respect to correctly-predicted exceedances and non-exceedances for each beach. In these analyses, the Genetic Algorithm was run for all possible independent variables using sensitivity, specificity, and accuracy as the respective fitness criteria. No consideration was given to model size, goodness-of-fit, or the statistical significance of independent variables. The results of these analyses revealed the absolute upper limits of model accuracy, as well as the lowest possible number of Type I and Type II errors, respectively, and the different “optimal” balances that could be achieved between the two.

Modelers used these pieces of information as guideposts, or targets, when conducting the final (mostly manual) phase of model comparison and selection.

Once the final (preferred) model had been selected for each beach, the utilities within *Virtual Beach*’s “Residuals” tab were used to test ordinary least-square (OLS) assumptions and to identify and remove influential outliers from the historical dataset. *Virtual Beach*’s DFFITS utility was used to identify potential outliers within the model-building dataset, remove them one at a time, and re-estimate the model until a default or user-specified threshold DFFITS¹⁰ value was achieved. The result of these processes was a list of “Reduced” models, each containing the same independent variables but with different coefficients, reflecting successive re-estimation of the preferred model, each with one more observation removed. Similar to the dynamic process used to select the preferred model from among the top ten list in the “Modeling” tab, the reduced versions of the model were compared according to their model statistics and four-quadrant scatter plots (Figure 10), with an emphasis on increasing model accuracy relative to water-quality standards. In general, the removal of successive data points improved model fit and accuracy over the model-building (historical) dataset. Given the risk of removing important variability from the dataset, however, care was taken to remove only a small number of data points. For the 2012 beach season, the following guidelines were instituted: (1) individual observations were only removed if their absolute DFFITS values were greater than or equal to 1, or if they were otherwise clearly shown to be data anomalies, and (2) no more than 5% of the total number observations were removed.

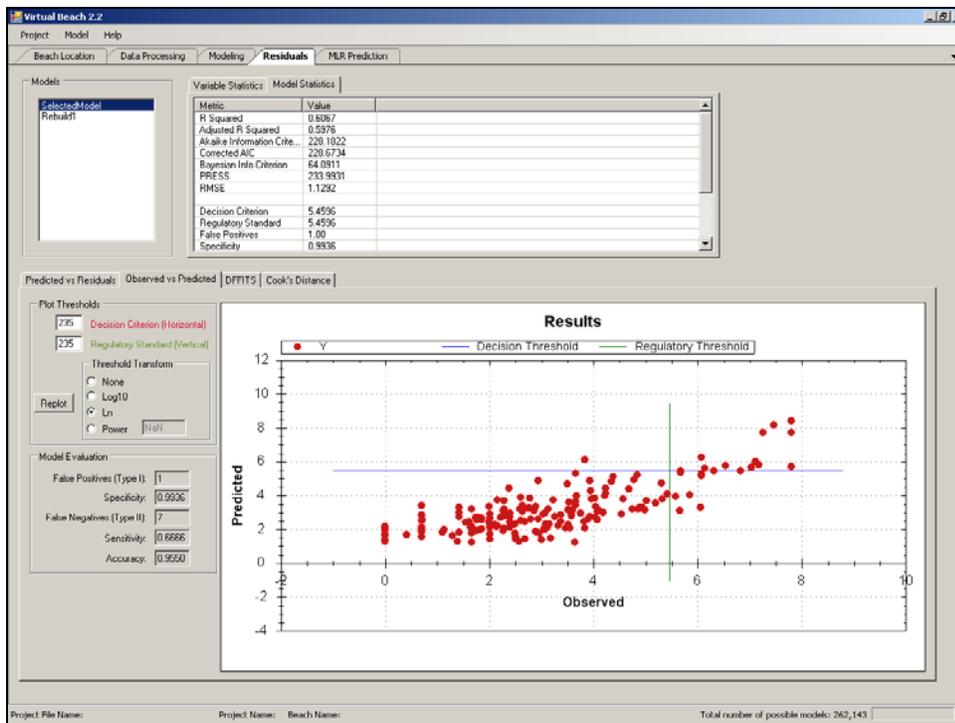


Figure 10. *Virtual Beach*’s “Residuals” tab, with example “Reduced” model.

¹⁰ DFFITS, or the “Difference in Fit, Standardized” is the resulting change in the predicted value of a data point (i.e. *E. coli* on a given day) when the corresponding observation is left out of the model. The difference is standardized across the dataset by dividing each value by the estimated standard deviation of the model fit at that point.

At the conclusion of the model-building process, the selected nowcast models for each beach were reviewed in the “Prediction” tab and saved as fully self-contained and portable *Virtual Beach* model (.VBMX) files (Figure 11). For the 2011 beach season, Wisconsin DNR project staff shared the .VBMX files for North Beach and Upper Lake Park Beach, respectively, with the Racine Health Department and the Ozaukee County Public Health Department. For the 2012 beach season, project staff shared .VBMX files with Ozaukee County for Upper Lake Park Beach, Harrington Beach-North, and Harrington Beach-South, as well as their respective adjacent beaches at County Highway D and Cedar Road. The 2012 .VBMX files for North Beach and Zoo Beach were created by the Racine Health Department.

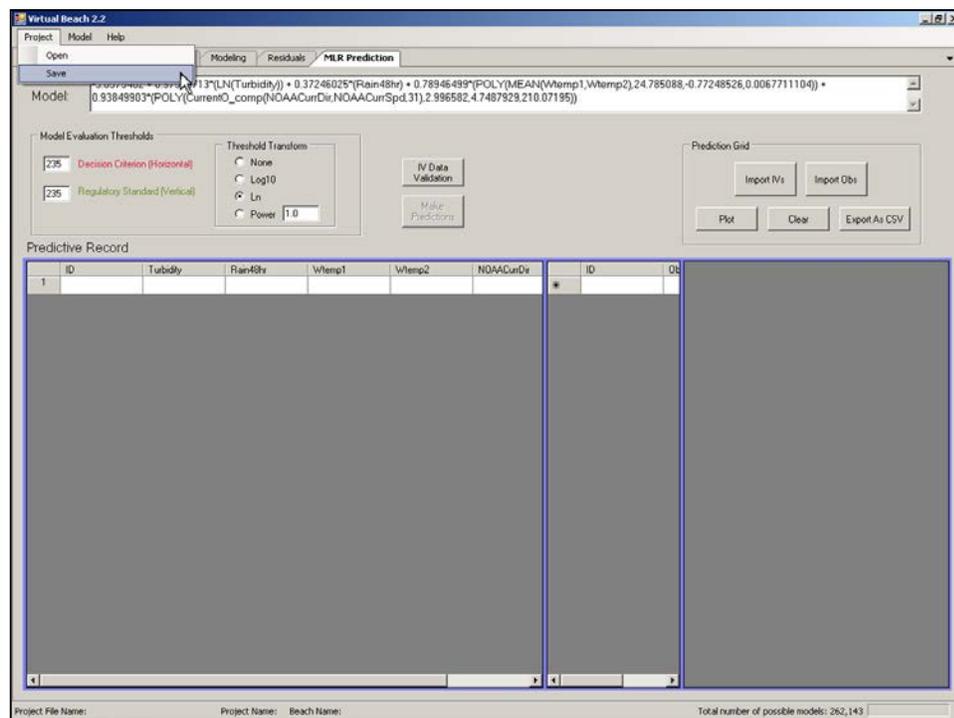


Figure 11. *Virtual Beach*’s “MLR Prediction” tab showing a model file (.VBMX) being saved.

2.7. Model Operation

Beach nowcasts were operated by local health department staff with technical support provided by Wisconsin DNR. The process of running a nowcast model typically took local operators five minutes or less per day on top of their routine monitoring and public notification activities. Nowcast model runs followed the completion of beach water sampling and routine sanitary survey measurements, once monitoring personnel returned to their office. The typical procedure was to open the .VBMX model file for a given beach and enter the particular input data into the Prediction Form within *Virtual Beach*’s “MLR Prediction” tab (Figure 12), while simultaneously (or shortly thereafter) entering the day’s sanitary survey results into a web data entry form for upload or transfer to the *Wisconsin Beach Health* online database. Most models had 12 or fewer input variables. None had more than five variables that were field-measured; i.e. sanitary survey data. Before being entered, some of the sanitary survey data needed to be manually translated from text-based categories (e.g., water clarity=“clear”) into numeric values (either binary or ranked/ordinal). In 2011, nowcast models also included “stage-of-season” variables, for which operating staff entered either a 1 or 0 depending on the date.

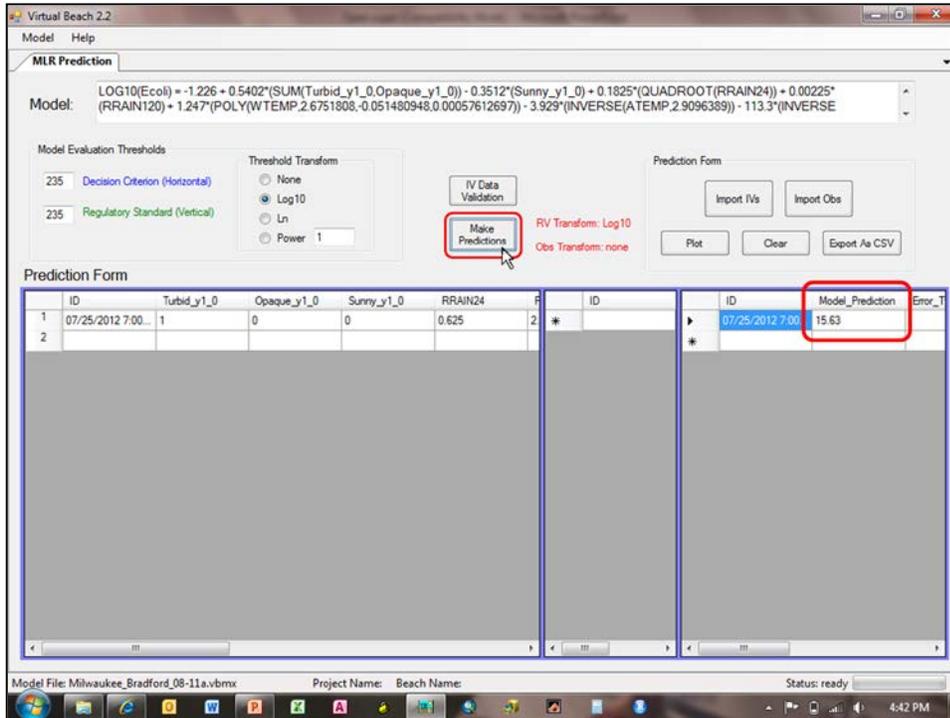


Figure 12. *Virtual Beach’s “MLR Prediction” tab, showing how to make a prediction.*

All of the models included “automated” data inputs (i.e. near real-time, hydro-meteorological data or estimates from NOAA or USGS) that operating staff accessed via the web. For the 2011 season, these inputs were accessed via web-links included in beach-specific “real-time” data access pages¹¹ created by project staff and posted on the *Wisconsin Beach Health* website. Automated inputs in 2011 included the most recent data on 24-hour antecedent rainfall (from the nearest airport or NOAA cooperating weather station), instantaneous discharge from USGS-gauged tributary streams, and GLCFS surface current speed and direction. These web-links allowed operating staff to copy and paste the values for input variables included in the models into the “MLR Prediction” tab. For the 2012 nowcasts, project staff used the ENDDAT system to create single URLs, including beach-specific rainfall (radar-estimated), stream discharge, and various GLCFS inputs (e.g., cloud cover and wind) and outputs (e.g., waves) aggregated or composited over various time windows. When launched, these custom URLs would download a one-row .CSV table of the most recent values for *all* of the automated input variables. Operating staff would then import the table into the Prediction Form, populating all of the automated data inputs, before manually-entering the remaining (field-measured) data.

Once the Prediction Form was completely filled-in with valid numeric data, operating staff would click “Make Predictions” to run the model. This output predicted water-quality conditions in the right side of the Prediction Form (Figure 12). Outputs included the estimated concentration of *E. coli* as well as the statistical probability of exceeding the 235 CFU/100 mL water-quality standard. Health department staff then used these outputs to help determine whether or not to post a water-quality advisory. For more information on the nowcast procedures used at different project beaches, see the case studies included in the Appendices.

¹¹ <http://www.wibeaches.us/apex/f?p=181:3:988138247379641::NO::>

2.8. Mid-season Evaluation and Model Rebuilding

During the course of the 2012 beach season, multiple nowcast models were built, tested, and implemented for project beaches in Ozaukee County. In addition to the advent of the ENDDAT system, which significantly increased the number of available variables, the 2012 beach season itself presented a new challenge as reflected by sustained extreme weather and lake conditions. These included prolonged heat waves and drought, little or no discharge from tributary streams, and extreme high water temperatures. At the core of any nowcast model is the basic assumption that underlying system conditions (including climate) are generally stable from year to year. This fundamental assumption was challenged during the 2012 beach season, which saw numerous dry weather *E. coli* elevations, along with reported increases in *Cladophora* and suspected mussel die-offs attributed to extreme water temperatures. As the season progressed, it became apparent that the parameters estimated using data from several previous beach seasons had changed and that the models needed to be revisited. In response, project staff conducted intensive model evaluation and rebuilding for the nowcasts at Upper Lake Park Beach and Harrington Beach State Park (North and South).

Compared to the initial model-building process, evaluating and rebuilding nowcasts mid-season was a much more conceptual, iterative, and manual process, and was therefore considerably more labor-intensive. The first step of the process was to open the saved *Virtual Beach* project (.VBPX) files for these beaches and run the Genetic Algorithm and IV Filter using the less-restrictive PRESS statistic to narrow the potential independent variables. Rather than conducting an exhaustive search of the remaining independent variables, however, project staff manually selected different combinations of independent variables and used *Virtual Beach*'s Manual (non-exhaustive) model-building utility to create one model at a time. For each individual model, project staff ignored the statistics and scatter plots in the “Modeling” tab (i.e. how well the model predicted previous years' conditions) and proceeded to the “Prediction” Tab, where they imported a table of current-season (validation) data and evaluated the model according to *actual* predictive power; that is, the number of Type I and Type II prediction errors during current beach season (Figure 13). Project staff repeated this process numerous times, gradually identifying which independent variables were more or less predictive of *E. coli* exceedances and non-exceedances, and recombining them accordingly until it was decided that the refined models could not be substantially improved upon. Typically, the process took the equivalent of two full staff-days per beach.

Relative to the historical datasets, each of the newly rebuilt models had considerably lower model fit values (e.g., R-square) and somewhat lower accuracy (i.e. sensitivity and specificity). In other words, the automated model-building process used prior to the beach season could not have identified the combinations of independent variables selected for the rebuilt models. These findings suggest that the underlying parameters did indeed change in 2012. They also highlight the importance of conducting mid-season evaluation and rebuilds if necessary and the need to make certain enhancements to *Virtual Beach* and the existing online systems for beach data in order to make this process less labor intensive.

3. Project Outcomes

3.1. Operational Nowcasts

The principal objective of the project, the establishment of operational nowcasts at the five project beaches, was achieved in stages. During the 2011 beach season, nowcasts were used to inform local swim advisories at two of the five beaches: Upper Lake Park Beach in Port Washington and North Beach in Racine. One reason for this was the concurrent evolution of the U.S. EPA’s *Virtual Beach* software and the online data infrastructure used to build and operate the nowcasts. The spring 2011 release of *Virtual Beach* version 2.1 coincided with the launch of the GLCFS web service, which enabled nowcast models to be built and operated with location-specific hydrodynamic estimates. Due to the timing of these changes, project staff and the cooperating health departments decided to focus initial implementation on one site per jurisdiction. This allowed for the collection and assembly of a second season’s worth of single-sample *E. coli* data for the eventual nowcast models for the Harrington Beach State Park sites, which had switched from composite sampling to individual sampling the summer before.

Operational nowcasts were instituted at the remaining three beaches over the course of the 2012 beach season. The Racine Health Department implemented the Zoo Beach nowcast in June of 2012 and the Ozaukee County Public Health Department began testing nowcasts for Harrington Beach State Park (North and South) the following month. The final Harrington Beach models, however, were not implemented until the last week of the 2012 season, after intensive evaluation and significant revisions to the models to better predict dry-weather *E. coli* elevations. Notification of advisories and beach closures were posted on-site via standard signage, as well as electronically via the *Wisconsin Beach Health* website, subscriber email alerts, and RSS feeds. Starting in 2012, the reason for these actions (i.e. “nowcast prediction”) was included in all of the electronic notices (Figure 14) with links to more detailed explanations (Figure 15). Signage at the beach, however, did not include the reason for posting.

3.2. Reduced Monitoring Errors

The longer-operating nowcast models at Upper Lake Park and North Beach affected measurable reductions in the number of monitoring errors that would otherwise have occurred in their absence. At Upper Lake Park Beach, the 2011 and 2012 nowcasts correctly predicted four water-quality exceedances (two each season), triggering swim advisories that otherwise would have been missed. In addition, the models predicted three non-exceedances on days when the beach otherwise would have been posted with an advisory (based on the previous day’s lab results) plus an additional non-exceedance on a day when the beach otherwise would have been closed. At North Beach in 2011, the nowcast correctly predicted non-exceedances on two days that would otherwise have been posted with swim advisories. Both of these were confirmed by rapid qPCR. Since the nowcasts only took a few minutes to run, their results typically preceded those of the qPCR analysis and on at least three occasions helped to determine that qPCR results were incorrectly in exceedance of water-quality thresholds (later confirmed by 18-hour, quanti-tray enumeration). In general, nowcast-estimated exceedance probabilities (as opposed to predicted *E. coli* levels) were used by Racine Health Department staff as one of several lines of evidence for posting accurate advisories, including qPCR and observed conditions. For North Beach, this combined approach resulted in two advisories and one closure that otherwise would have been missed in 2012, two non-advisories when an advisory otherwise would have been posted, and one non-advisory when the beach otherwise would have been closed. Similarly, at Zoo Beach in 2012, this approach resulted in two closures and one advisory that otherwise would have been missed, plus one non-advisory when the beach otherwise would have been posted with an advisory and one when it otherwise would have been closed.

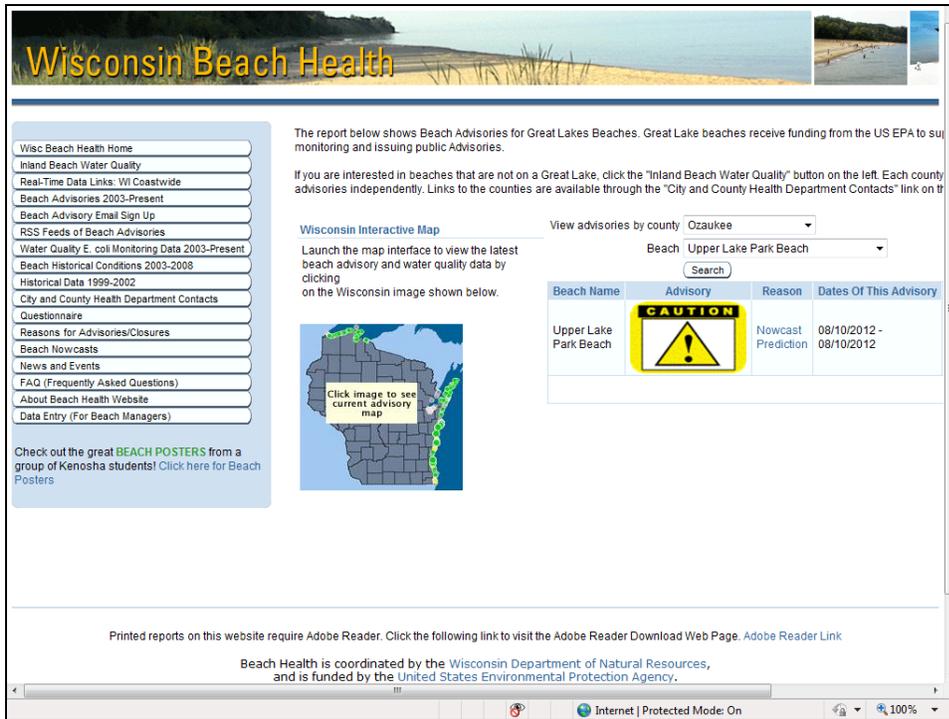


Figure 14. Wisconsin Beach Health web-notification of a nowcast-based advisory for Upper Lake Park Beach, August 10, 2012. (next day lab results: 416 CFU/100 mL).



Figure 15. Wisconsin Beach Health website showing reasons for advisories.

3.3. Enhanced Local Capacity

During the course of the project, local capacity to operate nowcast models increased considerably in both the City of Racine and Ozaukee County. In addition to receiving training and technical assistance, individual staff members in the respective health departments developed expertise on nowcast operation based on first-hand experience over two beach seasons. Among other things, this allowed project staff to devote additional time in 2012 to pre-season technical assistance and guidance on model-building (for beaches in Racine) and intensive, mid-season model evaluation and rebuilding (for Ozaukee County beaches). Changes made to *Virtual Beach* (version 2.2) and the creation of the ENDDAT system prior to the 2012 beach season required continued technical support on nowcast operation, but health department staff adapted to the new procedures without significant additional training.

Enhancing local capacity not only to operate nowcast models that already had been developed, but to build new models, proved more challenging. After receiving training in 2011, beach monitoring staff at the Racine Health Department were able to build the 2012 nowcast models for North and Zoo beaches; however, Wisconsin DNR staff conducted all of the data assembly and model set-up work beforehand. Project staff provided local cooperators with completed *Virtual Beach* project (.VBPX) files for each beach, as well as technical assistance. Ozaukee County Health Department staff also participated in the day-long training on model-building, but did not have the time needed to take over the lead role in model-building on top of other job tasks that go beyond beach monitoring. Given the limited staff time and resources available to most local health departments, it is not clear that the responsibility for creating and maintaining operational nowcasts can be handed over to local operators without some level of continued technical assistance from a centralized agency that can benefit from economies of scale. That said, any extra responsibility taken by local operators, will make it easier for the Wisconsin DNR, USGS, and others to expand nowcast model-building and technical assistance to more beaches in Wisconsin and throughout the Great Lakes.

4. Literature Cited

- Chase, S.M and N.L. Richmond. (2007). Wisconsin's Great Lakes beach sanitary survey report: beach Season 2007. Madison, WI: Bureau of Watershed Management, Wisconsin Department of Natural Resources
- Francy, D.S. (2009). Use of predictive models and rapid methods to nowcast bacteria levels at coastal beaches. *Aquatic Ecosystem Health and Management* 12(2):177-182.
- Francy, D.S. and R.A. Darner (2006). Procedures for developing models to predict exceedances of recreational water-quality standards at coastal beaches. Reston, Virginia, U.S. Geological Survey: 34.
- Francy, D.S. and R.A. Darner (2007). Nowcasting beach advisories at Ohio Lake Erie beaches. Reston, Virginia, U.S. Geological Survey: 13.
- 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(13):4818-4824.
- Mednick, A.C. (2009). *Accessing Online Data for Building and Evaluating Real-time Models to Predict Beach Water Quality*. Madison, WI: Bureau of Science Services, Wisconsin Department of Natural Resources.
- Mednick, A.C. and D.J. Watermolen (2009). *Beach Pathogen Forecasting Tools: Pilot Testing, Outreach, and Technical Assistance*. Madison, WI: Bureau of Science Services, Wisconsin Department of Natural Resources.
- Nevers, M.B. and R.L. Whitman (2005). Nowcast modeling of *Escherichia coli* concentrations at multiple urban beaches of Southern Lake Michigan. *Water Research* 39(20): 5250-5260.
- Sampson, R.W., S.A. Swiatnicki, C.M. McDermott, and G.T. Kleinheinz. (2006). The effects of rainfall on *Escherichia coli* and total coliform levels at 15 Lake Superior recreational beaches. *Water Resources Management* 20:151-159.
- Whitman, R.L., M.B. Nevers, G.C. Korinek, and M.N. Byappanahalli. (2004). Solar and temporal effects on *Escherichia coli* concentration at a Lake Michigan swimming beach. *Applied and Environmental Microbiology* 70(7):4276-4285.

5. Acknowledgments

I am especially grateful to Kyle Minks and Kimberly Ness, both formerly with the Wisconsin DNR, for their work on this project. I am also grateful for the collaboration and expertise provided by members of the participating health departments: Dan Ziegler of the Ozaukee County Public Health Department and Dr. Julie Kinzelman, Adrian Koski, and Stephan Kurdas of the Racine Health Department. A number of researchers and technicians at partner agencies provided key assistance with data and modeling systems – from the U.S. EPA: Dr. Michael Cyterski, Mike Galvin, Dr. Rajbir Parmar, and Kurt Wolfe; from the U.S. Geological Survey: David Blodgett, Rebecca Carvin, Steven Corsi, Laura De Cicco, Jessica Lucido, Alice McCarthy, Susan Phillips, and David Sibley; from the National Oceanic and Atmospheric Administration: Gregory Lang; and from the Great Lakes Commission: Guan Wang. Within the Wisconsin DNR, Donalea Dinsmore, Robert Masnado, Theresa Nelson, Jerry Sullivan, and Dreux Watermolen provided valuable guidance and assistance. And finally, many thanks to Todd Breiby, Michael Friis, and Anne Iwata of the Wisconsin Coastal Management Program for their active support. This project was funded by the Wisconsin Coastal Management Program and the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resources Management under the Coastal Zone Management Act, Grant #NA09NOS4190107.

Notes

Appendices: Beach Water-quality Nowcast Model Case Studies

- A. North Beach, Racine, Wisconsin
- B. Zoo Beach, Racine, Wisconsin
- C. Upper Lake Park Beach, Port Washington, Wisconsin
- D. Harrington Beach State Park-South
- E. Harrington Beach State Park-North

Beach Water-quality Nowcast Model Case Study

North Beach, Racine, Wisconsin

Located just north of Racine's harbor, North Beach (Figure 1) is among the most popular beaches on the Great Lakes and has been the focus of a long-term applied research program that has resulted in a series of innovations in the testing, management, and restoration of recreational water quality. These innovations have resulted in dramatic improvements in water quality over the past decade, reduced public health risk, and fewer beach closures. Since 2004, North Beach has been certified as a Blue Wave beach by the national Clean Beaches Council, the first beach in Wisconsin and second on the Great Lakes to be so recognized.



Figure 1. North Beach, Racine, Wisconsin.

Racine's Parks, Recreation, and Cultural Services Department maintains North Beach and is responsible for daily beach grooming, beach improvements, and lifeguard services throughout the summer. Based on daily counts by lifeguards in 2010 and 2011, total annual visits to North Beach are estimated at between 70,000 and 90,000. Major annual events include the two-day "Spike 'n Splash," which generates 200 hotel room stays, and the Ironman Racine Triathlon, which attracts 2,000 athletes from around the country. The city administration has estimated that these activities, coupled with regular visitation, generate as much as \$5 million each year for the local economy¹.

¹ Garret, Ronnie. 2012. "A Day at the Beach." *Corporate Report Wisconsin*. 2623(August). Available online: <http://crwmag.com/issue/august-2012/article/a-day-at-the-beach>.

Beach Water-quality Nowcast Model Case Study

Responsibility for monitoring water quality falls with the Racine Health Department, which sends monitoring personnel to collect samples five days per week (Monday through Friday) at four fixed stations along 1,980 ft. of shoreline (Figure 1). Samples are composited and tested for the bacterium *E. coli* in the health department's laboratory. Tests include both the standard 18-hour, colilert analysis and a 2-hour, quantitative polymerase chain reaction (qPCR) analysis. Racine is the only jurisdiction to date approved by the U.S. EPA to use qPCR for operational water-quality testing. Racine is also the first jurisdiction to employ a standardized beach sanitary survey to identify likely sources and pathways of microbial contamination. Sanitary surveys entail intensive spatiotemporal sampling of water quality and measurements of associated nearshore, onshore, and hydro-meteorological conditions over the course of one or more beach seasons.

In 2004, North Beach was posted with 21 swim advisories and three beach closures. By 2010, there was just one advisory and in 2011 there were only three. Sanitary surveys have informed several beach improvements and best management practices contributing to these reductions, including beach re-grading, improved grooming practices, dune stabilization, and the redesign of the English Street stormwater outfall. During most rainfall events, stormwater flowing into the redesigned system is routed through two "vorceptors" (which settle debris and particulates) followed by a series of wetland cells before discharging into the lake via an outlet at Zoo Beach to the north. During large rainfall events, excess stormwater bypasses the bio-filtration system and discharges into the lake at the northern extent of the beach (Figure 1). Depending on the speed and direction of the nearshore current, large rainfall events can cause high *E. coli* levels at the beach.

Nowcast Models

Separate nowcast models were developed for North Beach for the 2011 and 2012 beach seasons, respectively. The 2011 nowcast model was built by the Wisconsin DNR using *Virtual Beach 2.1* with input and suggestions provided by beach monitoring staff at the Racine Health Department. The finished model was provided as a *Virtual Beach* model (.VBMX) file, for operation using that software. For the 2012 nowcast, Wisconsin DNR staff conducted data assembly, formatting, and model set-up, while Racine Health Department staff took the lead on building the model from a shared *Virtual Beach* project (.VBPX) file. The full process of data assembly, model set-up, and model-building is described in detail in the report *Building Operational "Nowcast" Models for Predicting Water Quality at Five Lake Michigan Beaches*².

The 2011 North Beach nowcast model was specified as:

$$\begin{aligned} \text{LN}(E\text{coli}) = & 0.3824 - 0.116*(\text{PROD}(\text{Rain}24,\text{Rain}48)) + 0.6694*(\text{SQUAREROOT}(\text{Rain}48)) - \\ & 10.72*(\text{PROD}(\text{Rain}48,\text{CurrentEast})) + 4.062*(\text{PROD}(\text{Rain}48,\text{CurrentNorth})) + \\ & 0.000448*(\text{PROD}(\text{Discharge},\text{Cloudy})) - 0.4114*(\text{Sunny}) + 0.4737*(\text{WaveHeight_ft}) - \\ & 0.1971*(\text{PROD}(\text{Rain}24,\text{WaveHeight_ft})) + 0.03915*(\text{WaterTemp_F}) - 0.7231*(\text{ClearWater}) - \\ & 2.886*(\text{PROD}(\text{CurrentNorth},\text{ClearWater})) + \\ & 0.9655*(\text{QUADROOT}(\text{PROD}(\text{Rain}24,\text{Pre_June}21))) + \\ & 0.1446*(\text{QUADROOT}(\text{PROD}(\text{Discharge},\text{June}21_July15))) + \\ & 1.32*(\text{QUADROOT}(\text{PROD}(\text{Rain}24,\text{July}16_Aug10))) + \\ & 0.3075*(\text{QUADROOT}(\text{PROD}(\text{WaterTempF},\text{Post_Aug}10))) \end{aligned}$$

² Mednick, A.C. 2012. *Building Operational "Nowcast" Models for Predicting Water Quality at Five Lake Michigan Beaches*. PUB-SS-1098. Bureau of Science Services, Wisconsin Department of Natural Resources, Madison.

Beach Water-quality Nowcast Model Case Study

The 2012 North Beach nowcast model was specified as:

$$\begin{aligned} \text{LOG10}(\text{Ecoli}) = & -4.377 + 0.2074*(\text{July16_Aug10}) - 0.1271*(\text{Sunny}) - 0.312*(\text{ClearWater}) - \\ & 0.3463*(\text{AlgBch_None}) + 1.257\text{e-}06*(\text{SQUARE}(\text{Gulls})) - 136.4*(\text{INVERSE}(\text{DOY},59.5)) + \\ & 0.7114*(\text{POLY}(\text{RRAIN24},1.2171673,0.048945098,-0.00066772263)) + \\ & 2.949*(\text{POLY}(\text{Q168},1.3845188,-0.00012402325,8.6777287\text{e-}08)) + \\ & 1.376*(\text{POLY}(\text{Q504},1.3083821,0.00075025842,-7.3351447\text{e-}07)) - \\ & 23.84*(\text{INVERSE}(\text{Qmax672},19.5)) + 0.7337*(\text{WaveO_comp}(\text{WVHT},\text{WVDIR},-17.35)) \end{aligned}$$

Where:

Ecoli = *E. coli* (MPN/ 100mL) — Measured by the Racine Health Dept.
AlgBch_None = Algae on beach? (n=0/ y=1) — Measured by the Racine Health Dept.
Cloudy = Sky condition (y=1/ n=0) — Measured by the Racine Health Dept.
ClearWater = Water “clear”? (y=1/ n=0) — Measured by the Racine Health Dept.
CurrentEast = Surface Water Velocity towards 90° (meters/sec) — GLCFS, NOAA
CurrentNorth = Surface Water Velocity towards 0° (meters/sec) — GLCFS, NOAA
Discharge = Root River Discharge, instantaneous (ft³/sec) — USGS Gage
DOY = Day of year (1-365)
Gulls (count of birds) — Measured by the Racine Health Dept.
June21_July15 = Between these dates? (y=1/ n=0)
July16_Aug10 = Between these dates? (y=1/ n=0)
Post_Aug10 = After to August 10th? (y=1/ n=0)
Pre_June21 = Prior to June 21st? (y=1/ n=0)
Q168 = Root River Discharge, 7-day mean (ft³/sec) — USGS Gage
Q504 = Root River Discharge, 21-day mean (ft³/sec) — USGS Gage
Qmax672 = Root River Discharge, 28-day max (ft³/sec) — USGS Gage
RAIN24 = Rainfall, 24 hours (in) — Racine Batten Airport
RAIN48 = Rainfall, 48 hours (in) — Racine Batten Airport
RRAIN24 = Rainfall, 24 hours (mm) — Radar Est. from the North Central River Forecasting Center, NOAA
Sunny = Sky condition (y=1/ n=0) — Measured by the Racine Health Dept.
WaveHeight_ft = Wave Height (ft.) — Estimated by the Racine Health Dept.
WaveO_comp = Onshore Waves (meters) — Derived from:
 Significant Wave Height (meters) — GLCFS, NOAA
 Wave Direction (from 0-360 deg.) — GLCFS, NOAA
WaterTemp = Water Temperature (deg. F) — Measured by the Racine Health Dept

And where:

LOG10 = logarithm, base 10
LN = natural logarithm
POLY = polynomial transformation (a + bX + cX²)
PROD = X1 * X2
QUADROOT = X^{1/4}
SQUARE = X²
SQUAREEROOT = X^{1/2}

Beach Water-quality Nowcast Model Case Study

Nowcast Model Operation

Racine Health Department staff members operate the North Beach nowcast. The process of running the nowcast generally takes the operator five minutes or less on top of daily beach monitoring and public notification activities. Nowcast model runs are conducted after monitoring personnel return to the health department lab from collecting water samples and taking routine sanitary survey measurements at the beach (Figure 2). In some cases the nowcast operator will have conducted the field work. On most days, however, other staff members conduct the field work and provide the nowcast operator with the needed input values recorded on standardized paper forms. During the 2011 beach season, routine sampling and sanitary surveys took place around 11:00 a.m. During the 2012 beach season, these activities were moved forward to around 07:00 a.m., in order to allow time for samples to be returned to the lab, prepped for qPCR analysis, and run through the 2-hour process before posting an advisory (if deemed necessary based on the results) by mid-morning (In previous years, sampling was conducted at noon, with the aim of getting samples to the lab in time to conduct the standard 18-hour culture method to post advisories by mid-morning *the next day*.)



Figure 2. Measuring water temperature during sample collection.



Figure 3. Opening a Virtual Beach model (.VBMX) file.

In 2011, the procedure for running the nowcast was for the operator to open the *Virtual Beach* model (.VBMX) file on their PC (Figure 3) and manually enter the day's input values into the *Virtual Beach* "MLR Prediction" tab. This was often done at, or around, the same time as the day's sanitary survey measurements and lab results were uploaded to the *Wisconsin Beach Health* website. Manually entered data included measurements that had just been taken in the field: *WaterTemp* (degrees F), *WaveHeight_ft* (estimated feet), *ClearWater* (1 if water "clear", 0 if not), *Sunny* (1 if sky "sunny"...), and *Cloudy* (1 if the sky "cloudy"...), as well as stage-of-season markers: *Pre_June21* (1 if before June 21st...), *June21_July15* (1 if between these dates...), *July16_Aug10*, and *Post_Aug10*. Input data also included *RAIN24* and *RAIN48* (inches of rain recorded at Batten Airport over the 24 and 48 hours prior to 07:00 a.m.), as well as *CurrentEast* (Velocity of surface water movement towards [+], or away from [-], 90° due East, estimated by NOAA-GLCFS) and *CurrentNorth* (Velocity of surface water movement towards [+], or away from [-], 0° due North...). The nowcast operator accessed these last four data inputs via the web, using beach-specific links posted on the *Wisconsin Beach Health* website (Figure 4), and copied the values into the MLR Prediction tab. Once all of the input values were entered, the operator executed the model.

Beach Water-quality Nowcast Model Case Study

Real-Time Data Links for:
North Beach
 Racine County EPA ID: WI721390

Weather <http://glos.us/obs/station/11-190.html>
 Conditions: (Default time zone is GMT. Can change to CDT.)
 RACINE/JOHN H BATTEN

24-hr. Rainfall: <http://www.crh.noaa.gov/product.php?site=MKX&product=HYD&issuedby=MKX>
 RACINE/JOHN H BATTEN (Search for: " RAC ")

Lake Level: http://tidesandcurrents.noaa.gov/data_memu.shtml?stn=9087057_Milwaukee,WI&type=Great+Lakes+Water+Level+Data
 MILWAUKEE

Surface Current and Waves: http://michigan.gln.net:8080/glcfs/glcfsps.glos?lake=michigan&j=87.76109&j=42.74095&v=uc_vc_vvh&h=1&latest=3&tzf=5&f=rss&u=m&pv=1&order=dec
 Nearest GLCFS Cell
 Lat: 42.74095
 Lon: -87.76109

Tributary Discharge: http://waterdata.usgs.gov/nwis/tv?cb_00060=on&format=html&period=1&site_no=04087240
 ROOT RIVER AT RACINE, WI

Note: The Web links listed above represent the nearest stations that regularly report real-time data. Distances between the beach and stations varies from site to site. "Surface Current and Waves" are model estimates from the Great Lakes Coastal Forecast System (GLCFS): www.glerl.noaa.gov/res/glcfs/

[Return to Wisconsin Beach Health main page](#)

Figure 4. Real-time data links for North Beach, posted on the Wisconsin Beach Health website (http://www.wibeaches.us/real_time_data_links/RTD_Racine_North.html).

Virtual Beach 2.2

Model Help

MLR Prediction

Model: $\text{LOG}_{10}(\text{Ecoli}) = -1.226 + 0.5402(\text{SUM}(\text{Turbid}_{y1_0}, \text{Opaque}_{y1_0}) - 0.3512(\text{Sunny}_{y1_0}) + 0.1825(\text{QUADROOT}(\text{RRAIN24})) - 0.00225(\text{RRAIN120}) + 1.247(\text{POLY}(\text{WTEMP}, 2.6751808, -0.051480948, 0.00057612697)) - 3.929(\text{INVERSE}(\text{ATEMP}, 2.9096389)) - 113.3(\text{INVERSE}(\text{ATEMP}, 2.9096389)))$

Model Evaluation Thresholds: 235 Decision Criterion (Horizontal), 235 Regulatory Standard (Vertical)

Threshold Transform: None, Log10, Ln, Power 1

IV Data Validation: RV Transform: Log10, Obs Transform: none

Prediction Form:

ID	Turbid_y1_0	Opaque_y1_0	Sunny_y1_0	RRAIN24	P	ID	Model_Prediction	Error_T
1	07/25/2012 7:00...	1	0	0	0.625	*	07/25/2012 7:00	15.63
2						*		

Model File: Milwaukee_Bradford_08-11a.vbmx Project Name: Beach Name: Status: ready 4:42 PM

Figure 5. Virtual Beach's "MLR Prediction" tab.

Beach Water-quality Nowcast Model Case Study

The procedure for running the 2012 nowcast model was somewhat different, allowing for additional “automated” data inputs via the U.S. Geological Survey’s *Environmental Data Discovery and Transformation* (ENDDAT) system³. The operator used a custom ENDDAT web URL (developed by Wisconsin DNR staff) to download a one-row table of the most recent values of several model inputs, including: *Q168* and *Q504* (7-day and 21-day average Root River discharge, ft³/sec mean), *Qmax672* (28-day maximum Root River discharge, ft³/sec), *RRAIN24* (millimeters of rain estimated by radar over the past 24 hours), and *Significant Wave Height* (meters) and *Direction* (0-360 degrees), as well as *DOY* (day of year, 1-365). The daily ENDDAT table was then imported into the *Virtual Beach* MLR Prediction tab, leaving the operator to manually-enter the remaining values: *AlgBch_None* (1 if there is any algae on the beach, 0 if none), *Gulls* (estimated number of gulls present), *ClearWater* (1 if water “clear”...), *Sunny* (1 if sky “sunny”...), and *July16_Aug10* (1 if between these dates...). Once all of the input values were entered, the operator executed the model to make a prediction (Figure 5).

Outputs of the nowcast included the estimated concentration of *E. coli*, as well as the statistical probability of exceeding the 235 CFU/100 mL water-quality standard. Health department staff used these outputs together with qPCR and sanitary survey results as multiple lines of evidence for determining whether or not to post a water-quality advisory or close the beach. The nowcast was generally conducted while qPCR analysis was in progress. Whereas the process of conducting the nowcast takes five minutes or so, the process of conducting qPCR typically takes two hours, including sample preparation, system operation, and output interpretation (Figure 6). As they are completed, nowcast predictions, 18-hour lab results, and qPCR are displayed alongside one another for daily comparison and validation (Figure 7).



Figure 6. Conducting qPCR analysis. clockwise from top left: sample preparation (A-B), setting-up a qPCR run (C), and displayed results (D).

³ <http://cida.usgs.gov/enddat/>

Beach Water-quality Nowcast Model Case Study

August 2011 E.coli - North Beach							
	Virtual Beach	coliform 24 AM	total MTEC AM	qPCR AM	coliform 18 PM	total MTEC PM	qPCR PM
1	6.545 0.02%	10	10	0-31	<10	0	0-23
2	12.32 0.18%	10	0	0	<10	0	0
3	64.49 11%	97	260	0*	683	250	703-1187
4	111.5 23%	146	120	40-200	41	30	22-32
5	17.95 0.53%	63	80	0-49	30	N/A	Fri
8		74	60	0-118 56-73*	74	80	219-221 *
9	26.76 1.6%			64-134			0-45
10	33.44 2.7%			0			

Figure 7. Daily comparison of Virtual Beach results to standard lab and qPCR results.

Nowcast Results

The 2011 North Beach nowcast was operated from June 10 through September 6. During that period, the model correctly predicted *non-exceedances* on 2 days when North Beach would otherwise have been posted, based on the previous days' 18-hour lab results. Both of these decisions were confirmed by qPCR results. For the 2012 beach season, the Racine Health Department was granted special permission by the U.S. EPA to use qPCR results for regulatory purposes; i.e. posting swim advisories or issuing beach closures. The 2012 nowcast was operated simultaneously with qPCR from June 28 through August 31. Rather than using nowcast-predicted concentrations of *E. coli* as the basis for posting advisories, the health department used model-estimated exceedance probabilities in conjunction with qPCR results – and in some cases, field-observed beach conditions such as strong onshore winds following rainfall – as multiple lines of evidence for posting advisories. On two occasions during the summer of 2012, nowcast exceedance probabilities indicated that qPCR results were incorrectly in exceedance of 235 CFU/100 mL advisory threshold. This was confirmed by secondary qPCR analysis and the following days' 18-hour lab results. This combined approach resulted in the posting two swim advisories and one beach closure that otherwise would have been missed, two *avoided* advisories that otherwise would have been posted, and one *avoided* closure that otherwise would have been issued.

Beach Water-quality Nowcast Model Case Study



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Miscellaneous Publication PUB-SS-1100 2012

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This project was funded by the Wisconsin Coastal Management Program and the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resources Management under the Coastal Zone Management Act, Grant #NA09NOS4190107. Points of view expressed in this report do not necessarily reflect the views or policies of the Wisconsin Coastal Management Program or National Oceanic and Atmospheric Administration.

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Beach Water-quality Nowcast Model Case Study

Zoo Beach, Racine, Wisconsin

Located near the Racine Zoo and lakefront park, Zoo Beach (Figure 1) is a smaller and quieter neighbor to the popular North Beach, which lies just to the south. Like North Beach, Zoo Beach is maintained by Racine's Parks, Recreation, and Cultural Services Department, which is responsible for regular beach grooming and lifeguard services throughout the summer. Based on daily counts by lifeguards in 2010 and 2011, total annual visits to Zoo Beach are estimated at between 3,700 and 4,700.

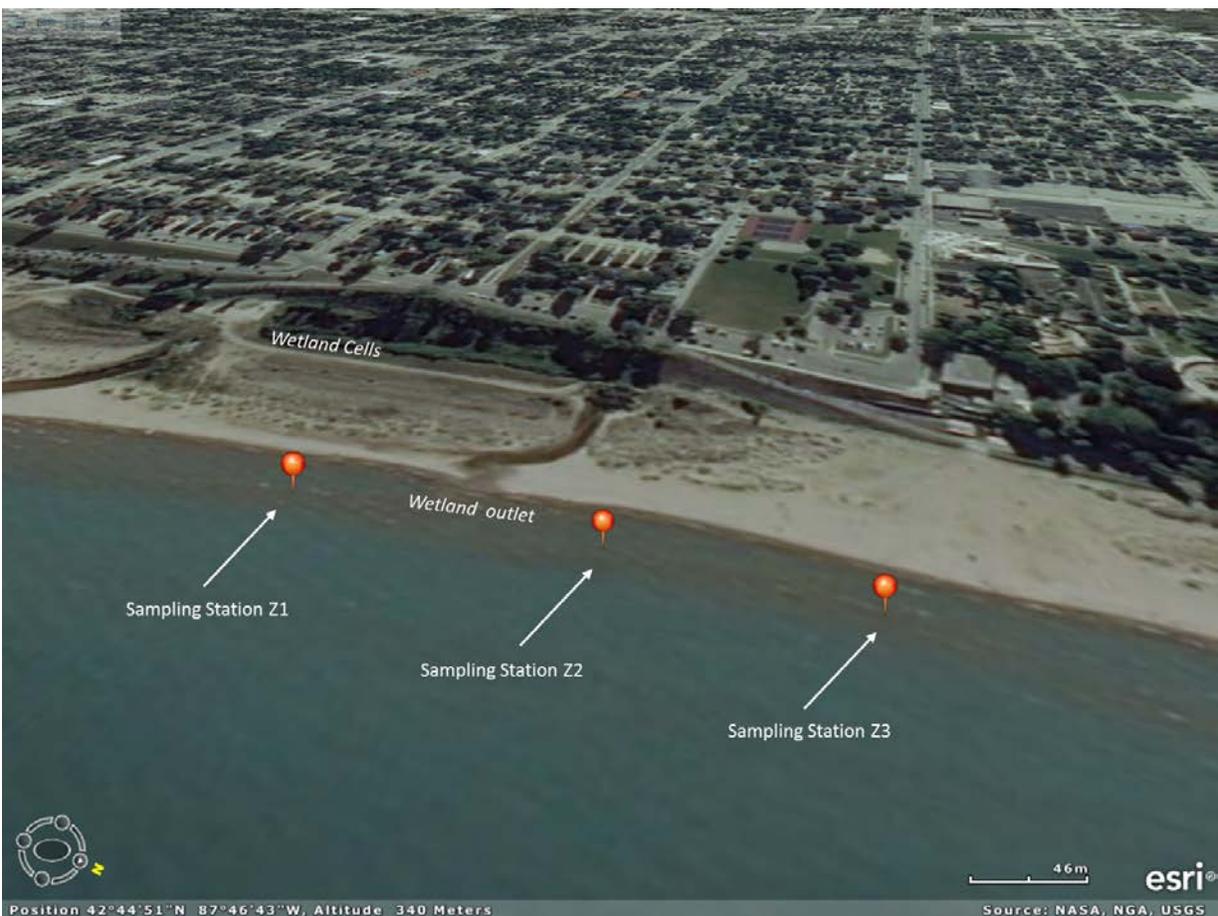


Figure 1. Zoo Beach, Racine, Wisconsin.

Responsibility for monitoring water quality falls with the Racine Health Department, which sends monitoring personnel to collect samples five days per week (Monday through Friday) at three fixed stations along 1,180 ft of shoreline. Because they are located next to one another along the same stretch of shoreline, North and Zoo beaches are monitored one after the other by the same personnel, with all of the samples transported to the health department lab for testing. Tests include both the standard 18-hour, colilert analysis and a 2-hour, quantitative polymerase chain reaction (qPCR) analysis. Individual samples are composited before being tested.

In 2004, Zoo Beach was posted with 13 swim advisories and four beach closures. By 2010, advisories had been reduced to four, with no closures. In 2011, there were five advisories. Like neighboring North Beach, Zoo Beach has been the subject of long-term sanitary surveys, including intensive water-quality

Beach Water-quality Nowcast Model Case Study

monitoring at multiple locations and concurrent measurements of nearshore, onshore, and hydro-meteorological conditions. This monitoring has informed several best management practices and beach improvements, including the redesign of the English Street outfall, effectively the boundary between Zoo and North beaches. During most rainfall events, stormwater flowing into the redesigned system passes through two “vorceptors” (which settle debris and particulates) and is then routed through a series of wetland cells before discharging at Zoo Beach (Figure 1). The higher number of advisories at Zoo Beach relative to North Beach may be related to the location of the wetland outlet, which has a low flow on most days and larger flows during rainfall events. In contrast, the southern bypass outlet (at the site of the original outfall) only discharges to the lake during heavy rainfall events.

Nowcast Models

The 2012 beach season was the first with an operational nowcast at Zoo Beach. Although Wisconsin DNR staff conducted the data assembly, formatting, and model set-up, Racine Health Department staff built the model from a shared *Virtual Beach* project (.VBPX) file. The full process of data assembly, model set-up, and model-building is described in detail in the report *Building Operational “Nowcast” Models for Predicting Water Quality at Five Lake Michigan Beaches*¹.

The 2012 Zoo Beach nowcast model was specified as:

$$\begin{aligned} \text{LOG}_{10}(\text{Ecoli}) = & 0.2516 + 0.3805 * (\text{SQAREROOT}(\text{Wave_Height_ft})) - \\ & 0.676 * (\text{QUADROOT}(\text{RRAIN1})) + 0.3209 * (\text{POWER}(\text{RRAIN6}, 0.3333333)) + \\ & 0.09746 * (\text{SQAREROOT}(\text{RRAIN48})) + 0.3751 * (\text{POWER}(\text{CLDCV}, 0.3333333)) - \\ & 6.203 * (\text{INVERSE}(\text{ATEMP}, 3.28725)) + 0.06553 * (\text{QUADROOT}(\text{Qmax672})) + \\ & 0.3889 * (\text{POLY}(\text{CurrentA_comp}(\text{CSPD}, \text{CDIR}, -5.41), 1.1815802, -0.21025639, 12.837678)) + \\ & 0.003368 * (\text{SQUARE}(\text{WindO_comp}(\text{WSPD}, \text{WDIR}, -5.41))) \end{aligned}$$

Where:

Ecoli = *E. coli* (MPN/ 100mL) — Measured by the Racine Health Dept.
ATEMP = Air Temperature (degrees C) — GLCFS, NOAA
CurrentA_comp = Alongshore Current (meters/sec) — Derived from:
 Surface Current Velocity (meters/sec) — GLCFS, NOAA
 Surface Current Direction (toward 0-360 deg.) — GLCFS, NOAA
CLDCV = Cloud Cover (percent) — GLCFS, NOAA
Qmax672 = Root River Discharge, 28-day max (ft³/sec) — USGS Gage
RRAIN1 = Rainfall, 1 hour (mm) — Radar Est. from the North Central River
 Forecasting Center, NOAA
RRAIN6 = Rainfall, 6 hours (mm) — Radar Estimate... NOAA
RRAIN48 = Rainfall, 48 hours (mm) — Radar Estimate... NOAA
WaveHeight_ft = Wave Height (ft.) — Estimated by the Racine Health Dept.
WindO_comp = Onshore Wind (meters/sec) — Derived from:
 Wind Velocity (meters/sec) — GLCFS, NOAA
 Wind Direction (from 0-360 deg.) — GLCFS, NOAA

¹ Mednick, A.C. 2012. *Building Operational “Nowcast” Models for Predicting Water Quality at Five Lake Michigan Beaches*. PUB-SS-1098. Bureau of Science Services, Wisconsin Department of Natural Resources, Madison.

Beach Water-quality Nowcast Model Case Study

And where:

LOG10 = logarithm, base 10
INVERSE = $1/X$
POLY = polynomial transformation ($a + bX + cX^2$)
POWER = $X^{1/3}$
PROD = $X1 * X2$
QUADROOT = $X^{1/4}$
SQUARE = X^2
SQUAREROOT = $X^{1/2}$

Nowcast Model Operation

Racine Health Department staff members operate the Zoo Beach nowcast. The process of running the nowcast generally takes the operator five minutes or less per day, on top of routine beach monitoring and public notification activities. Nowcast model runs are conducted after monitoring personnel return to the health department lab from collecting water samples and taking routine sanitary survey measurements at the beach. Beach monitoring generally takes place around 07:00 a.m., in order to allow time for samples to be returned to the lab, prepped for qPCR analysis, and run through the 2-hour process before posting an advisory (if deemed necessary based on the results) by mid-morning. In some cases the nowcast operator will have conducted the field work. On most days, however, other staff members conduct the field work and provide the nowcast operator with the needed input values recorded on standardized paper forms (Figure 2).

The procedure for running the Zoo Beach nowcast was for the operator to first access and download “automated” data inputs via the U.S. Geological Survey’s *Environmental Data Discovery and Transformation* (ENDDAT) system² using a custom ENDDAT web URL developed by Wisconsin DNR staff. Launching the URL downloads a one-row table of the most recent values of several model inputs including: *CLDCV* (percent cloud cover), *Qmax672* (28-day maximum Root River discharge, ft³/sec), *RRAIN1*, *RRAIN6*, and *RRAIN47* (millimeters of rain estimated by radar over the past 1, 6, and 48 hours), *Significant Wave Height* (meters) and *Direction* (0-360 degrees), and *Surface Current Velocity* (meters/sec) and *Direction* (0-360 degrees). Next, the operator opened the *Virtual Beach* model (.VBMX) file and imported the daily ENDDAT table into the MLR Prediction tab, leaving the operator to manually enter a single value: *WaveHeight_ft* (estimated wave height in feet). Once all of the input values were entered, the operator executed the model to make a prediction (Figure 3).

Outputs of the nowcast included the estimated concentration of *E. coli*, as well as the statistical probability of exceeding the 235 CFU/100 mL water-quality standard. Health department staff used these outputs together with qPCR and sanitary survey results as multiple lines of evidence for determining whether or not to post a water-quality advisory or close the beach. The nowcast was generally conducted while qPCR analysis was in progress. Whereas the process of conducting the nowcast takes five minutes or so, the process of conducting qPCR typically takes two hours, including sample preparation, system operation, and output interpretation (Figure 4). As they are completed, nowcast predictions, 18-hour lab results, and qPCR are displayed alongside one another for daily comparison and validation.

² <http://cida.usgs.gov/enddat/>

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GREAT LAKES BEACHES ROUTINE ON-SITE SANITARY SURVEY

Name of Beach: North Beach Zoo Beach
 Beach ID: WI721390 (North) WI988510 (Zoo)
 Survey Date: 08/11/2011 Survey Start Time: 7:00
 Surveyor Name(s): J. Granite
 Sampling Station(s)/ID: N1-N4 *(206,207,135,136) 21-23 *(127,208,209)
 Surveyor Affiliation: RHD
 STORET Organizational ID: 21WIBCH
 * last three digits of STORET ID which are preceded by 10138.

PART I - GENERAL BEACH CONDITIONS

Air Temperature: 16 °C °F Wind Speed (mph): 6 Wind Direction (e.g. E or 90°): W
 24-hr Rainfall (inches): [] Rainfall Intensity: Misty Light Rain Steady Rain Heavy Rain Other
 Sky Conditions: Sunny Mostly Sunny Partly Sunny Mostly Cloudy Cloudy/Overcast
 Wave Height: 1.5 FT Est. Actual
 Wave Intensity: Calm Normal Rough
 % Cloud Cover: 8 Barometric Pressure: 29.97 in. Hg hPa UV Index(0-16): 2
 Dew Point Temperature: 10.6 °C °F Long-shore current speed: [] m/s ft/s
 Long-shore current direction (e.g. S or 180°): []
 Comments/Observations: []

Figure 2. Routine sanitary survey form for Zoo Beach, Racine.

Virtual Beach 2.2
 Model Help
MLR Prediction

Model:
$$\text{LOG}_{10}(\text{Ecoli}) = -1.226 + 0.5402 * (\text{SUM}(\text{Turbid}_{y1_0}, \text{Opaque}_{y1_0})) - 0.3512 * (\text{Sunny}_{y1_0}) + 0.1825 * (\text{QUADROOT}(\text{RRAIN24})) + 0.00225 * (\text{RRAIN120}) + 1.247 * (\text{POLY}(\text{WTEMP}, 2.6751808, -0.051480948, 0.00057612697)) - 3.929 * (\text{INVERSE}(\text{ATEMP}, 2.9096389)) - 113.3 * (\text{INVERSE}(\text{ATEMP}, 2.9096389)))$$

Model Evaluation Thresholds: 235 Decision Criterion (Horizontal), 235 Regulatory Standard (Vertical)
 Threshold Transform: None Log10 Ln Power 1
 IV Data Validation: []
 Prediction Form:
 RV Transform: Log10, Obs Transform: none

Make Predictions (highlighted)

ID	Turbid_y1_0	Opaque_y1_0	Sunny_y1_0	RRAIN24	Model_Prediction	Error_T
1	07/25/2012 7:00...	1	0	0	0.625	2
2						

Model File: Milwaukee_Bradford_08-11a.vbmx Project Name: Beach Name: Status: ready
 4:42 PM

Figure 3. Virtual Beach's "MLR Prediction" tab.

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Figure 4. Conducting qPCR analysis. clockwise from top left: sample preparation (A-B), setting-up a qPCR run (C), and displayed results (D).

Nowcast Results

The 2012 Zoo Beach nowcast was operated from June 28 through August 31. That season, for the first time, the Racine Health Department was granted permission by the U.S. EPA to use qPCR results for regulatory purposes; i.e., posting swim advisories or issuing beach closures. The 2012 nowcast was operated simultaneous with qPCR. Rather than using nowcast-predicted concentrations of *E. coli* as the basis for posting advisories, the health department used model-estimated exceedance probabilities in conjunction with qPCR results – and in some cases, field-observed beach conditions such as strong onshore winds following rainfall – as multiple lines of evidence for posting advisories. On one occasion, the nowcast exceedance probability indicated that qPCR results were incorrectly in exceedance of the 1,000 CFU/100 mL beach closure guideline. This was confirmed by secondary qPCR analysis and the following day's 18-hour lab results. This combined approach resulted in the posting two swim advisories and one closure that would have otherwise been missed, 1 avoided advisory that otherwise would have been posted, and 1 avoided closure.

Beach Water-quality Nowcast Model Case Study



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Miscellaneous Publication PUB-SS-1101 2012

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This project was funded by the Wisconsin Coastal Management Program and the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resources Management under the Coastal Zone Management Act, Grant #NA09NOS4190107. Points of view expressed in this report do not necessarily reflect the views or policies of the Wisconsin Coastal Management Program or National Oceanic and Atmospheric Administration.

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Beach Water-quality Nowcast Model Case Study

Upper Lake Park Beach, Port Washington, Wisconsin

Located just north of downtown Port Washington, Upper Lake Park Beach comprises the waterfront portion of Upper Lake Park (Figure 1). The city's Parks and Recreation Department maintains the beach, which is approximately 1,700 ft long and situated beneath a large bluff. In 2010, stairs were constructed from the park proper to the beach and the city now regularly grooms the beach. No lifeguards are posted and daytime visitor counts are not made; however, anecdotal information and reports from monitoring personnel indicate that visitation is moderate to heavy during the summer months.



Figure 1. Upper Lake Park Beach, Port Washington, Wisconsin.

The Ozaukee County Health Department is responsible for water-quality monitoring and public notification. Samples are collected four days per week (Thursday-Sunday) from two fixed stations (see Figure 1). Although two separate samples are collected, they are composited before being tested by the city drinking water utility for *E. coli*, using the standard 18-hour colilert analysis. The entire beach is posted with an advisory if the composite results exceed water-quality guidelines. In 2010, Upper Lake Park Beach was posted with two advisories and one closure. In 2011, four advisories were posted.

Beach Water-quality Nowcast Model Case Study

In 2007, the county conducted a standardized sanitary survey of Upper Lake Park Beach to determine, in part, whether *E. coli* elevations at the beach were caused by effluent discharge from the nearby Port Washington wastewater treatment plant. Intensive spatiotemporal sampling and testing revealed that the treatment plant was not contributing to contamination events and that the principal source was stormwater discharge from Valley Creek, which outfalls just to the south of the plant (Figure 1). Microbial water quality was shown to be strongly correlated with rainfall and turbidity, as well as creek flow. Based on these findings, the health department instituted the first multi-variate, early-warning system for beach water quality in Wisconsin, known as the “Rainflow” system. Rainflow recommended whether or not to post advisories based on whether threshold levels of measured rainfall, creek flow, and turbidity were exceeded. Ozaukee County is unique among local health departments in its routine operation of a stream gage to measure flow levels in the creek discharging near Upper Lake Park, as well as an in-house turbidity meter to quantitatively measure nearshore turbidity as part of its sanitary survey work. Turbidity is the most influential factor in water-quality exceedances at Upper Lake Park, and has been shown to be highly correlated to *E. coli* levels at beaches around the Great Lakes.

Midway through the 2009 season, the Rainflow system was replaced with a statistical nowcast model developed by the Wisconsin DNR using the U.S. EPA’s *Virtual Beach* version 1. This system was an updated version of the original research-and-development software and had significant limitations related to conducting operational nowcasts. For example, running daily predictions required a custom spreadsheet-based system to operate the model. Experience gained through the field-testing of this combined system proved invaluable in terms of the guidance provided to the Wisconsin DNR and U.S. EPA on how future versions of *Virtual Beach* should function to better facilitate operational nowcasting. A re-vamped *Virtual Beach* version 2.0 was released in 2010; however, it was not in time for the beach season. The original hybrid system was employed for the 2010 nowcast.

Nowcast Models

Separate nowcast models were developed for Upper Lake Park Beach for the 2011 and 2012 beach seasons, respectively. 2011 marked the first year in which the re-vamped *Virtual Beach* was used as the stand-alone system for nowcasting water quality. Both years’ models were built by the Wisconsin DNR using the updated software (version 2.1 in 2011; version 2.2 in 2012). Beach monitoring staff at the Ozaukee County Public Health Department provided expert guidance and suggestions, based on their ongoing sanitary surveys. The finished models were provided as *Virtual Beach* model (.VBMX) files for local operation using the software. The full process of data assembly, model set-up, and model-building is described in detail in the report *Building Operational “Nowcast” Models for Predicting Water Quality at Five Lake Michigan Beaches*¹.

The 2011 Upper Lake Park Beach nowcast model was specified as:

$$\begin{aligned} \text{LN}(Ecoli) = & -2.734 + 0.0745 * (\text{LN}(\text{PROD}(\text{CreekFlow}, \text{WaterTemp}_F))) + 0.4303 * (\text{Rain48}) + \\ & 0.9432 * (\text{LN}(NTU)) + 0.0519 * (\text{WaterTemp}_F) - 0.345 * (\text{PROD}(\text{WaveHeight}_ft, \text{Sunny})) + \\ & 0.176 * (\text{QUADROOT}(\text{PROD}(\text{AirTemp}_F, \text{Post_Aug10}))) + \\ & 0.5388 * (\text{SQUAREROOT}(\text{WaveHeight}_ft)) - 2.946 * (\text{CurrentNorth}) \end{aligned}$$

¹ Mednick, A.C. 2012. *Building Operational “Nowcast” Models for Predicting Water Quality at Five Lake Michigan Beaches*. PUB-SS-1098. Bureau of Science Services, Wisconsin Department of Natural Resources, Madison.

Beach Water-quality Nowcast Model Case Study

The 2012 Upper Lake Park Beach nowcast model was specified as:

$$\begin{aligned} \text{LOG10}(\text{Ecoli}) = & -3.23 + 0.06899*(\text{WaveHeight_ft}) + 0.5437*(\text{POWER}(\text{NTU},0.3333333)) + \\ & 0.4524*(\text{POLY}(\text{Gulls},1.1391227,-0.0088228638,9.7708626e-05)) + \\ & 1.035*(\text{POLY}(\text{CurrentO_comp}(\text{CSPD},\text{CDIR},31.71),1.0632748,-1.1696592,59.751572)) + \\ & 0.0003058*(\text{PROD}(\text{NTU},\text{RRAIN48})) + 0.3368*(\text{SQUAREROOT}(\text{WTEMP})) + \\ & 0.351*(\text{WaveO_comp}(\text{WVHT},\text{WVDIR},31.71)) + 0.0001457*(\text{SQUARE}(\text{WaterTemp_F})) - \\ & 0.01177*(\text{QUADROOT}(\text{RRAIN24})) + 0.3087*(\text{AlgBch_high1_0}) \end{aligned}$$

Where:

Ecoli = *E. coli* (MPN/ 100mL) — Measured by the Ozaukee Co. Pub. Health Dept.
AirTemp_F = Air Temperature (deg. F) — Measured by Ozaukee Co. Pub. Health
AlgBch_high1_0 = Algae on beach “high”? (y=1/ n=0) — Ozaukee Co. Pub. Health
CreakFlow = Valley Creek flow (100 gal/day) — Ozaukee Co. Public Health Dept.
CurrentNorth = Surface Water Velocity towards 0° (meters/sec) — GLCFS, NOAA
CurrentO_comp = Onshore Current (meters/sec) — Derived from:
 Surface Current Velocity (meters/sec) — GLCFS, NOAA
 Surface Current Direction (toward 0-360 deg.) — GLCFS, NOAA
Gulls (count of birds) — Ozaukee Co. Pub. Health Dept.
NTU = Turbidity (NTU) — Ozaukee Co. Pub. Health Dept.
Post_Aug10 = After to August 10th? (y=1/ n=0)
RAIN48 = Rainfall, 48 hours (in) — Port Washington Wastewater Treatment Plant
RRAIN24 = Rainfall, 24 hours (mm) — Radar Est. from the North Central River
 Forecasting Center, NOAA
RRAIN48 = Rainfall, 48 hours (mm) — Radar Estimated... NOAA
Sunny = Sky condition (y=1/ n=0) — Measured by the Ozaukee Co. Pub. Health Dept.
WaveHeight_ft = Wave Height (ft.) — Measured by the Ozaukee Co. Pub. Health Dept.
WaveO_comp = Onshore Waves (meters) — Derived from:
 Significant Wave Height (meters) — GLCFS, NOAA
 Wave Direction (from 0-360 deg.) — GLCFS, NOAA
WaterTemp_F = Water Temp. (deg. F) — Measured by Ozaukee Co. Pub. Health Dept.
WTEMP = Water Temperature (deg. C) — GLCFS, NOAA

And where:

LOG10 = logarithm, base 10
LN = natural logarithm
POLY = polynomial transformation (a + bX + cX²)
PROD = X1 * X2
QUADROOT = X^{1/4}
SQUARE = X²
SQUAREROOT = X^{1/2}

Beach Water-quality Nowcast Model Case Study

Nowcast Model Operation

Beach monitoring staff at the Ozaukee County Health Department operate the Upper Lake Park Beach nowcast. The process of running the nowcast generally takes the operator five minutes or less per day, on top of routine beach monitoring and public notification activities. Nowcast model runs are conducted after monitoring personnel return to the health department office after collecting water samples and taking routine sanitary survey measurements at the beach (Figure 2) and recording flow in the nearby Valley Creek. On many days the nowcast operator is the same staff person who has conducted the field work. For parts of the season, summer interns may conduct the fieldwork and provide the nowcast operator with the needed input values recorded on standardized paper forms. Routine sampling and sanitary surveys take place around 07:00 a.m. CDT, allowing for ample time to run the model and post an advisory, if deemed necessary, by mid-morning. One additional step that is conducted for Upper Lake Park Beach is the measurement of actual turbidity, as opposed to a visual/subjective estimation of water clarity. A turbidity meter (Figure 3) is used to quantitatively measure the turbidity of water in nephelometric turbidity units (NTU).

In 2011, the procedure for running the model was for the operator to open the *Virtual Beach* model (.VBMX) file on their PC and manually enter the day's input values into the *Virtual Beach* MLR Prediction tab. This was often done at, or around, the same time as the day's sanitary survey measurements and/or lab results were uploaded to the *Wisconsin Beach Health* website (Figure 4). Manually entered data included measurements that had just been taken in the field: *WaterTemp* (degrees F), *AirTemp* (degrees F), *WaveHeight_ft* (estimated ft), *NTU* (turbidity), and *Sunny* (1 if sky "sunny"...), as well as a stage-of-season marker: *Post_Aug10* (1 if after August 10th, 0 if not). Input data also included *RAIN24* and *RAIN48* (inches of rain recorded at the Port Washington water treatment plant over the 24 and 48 hours prior to 07:00 a.m. CDT), as well as *CurrentNorth* (velocity of surface water movement towards [+] or away from [-] 0° due north, estimated by NOAA-GLCFS). The nowcast operator accessed these last three data inputs via the web, using beach-specific links posted on the *Wisconsin Beach Health* website (Figure 5), and copied the values into the MLR Prediction tab. Once all of the input values were entered, the operator executed the model.

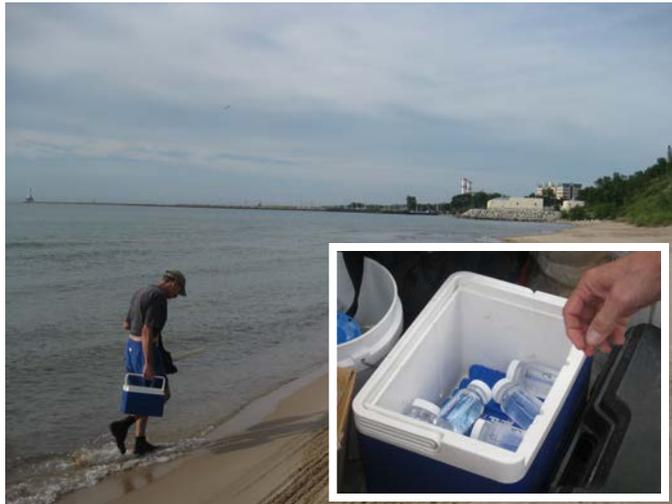


Figure 2. Transporting water-quality samples, Upper Lake Park Beach, Port Washington.



Figure 3. Turbidity meter used by Ozaukee County Public Health Department.

Beach Water-quality Nowcast Model Case Study

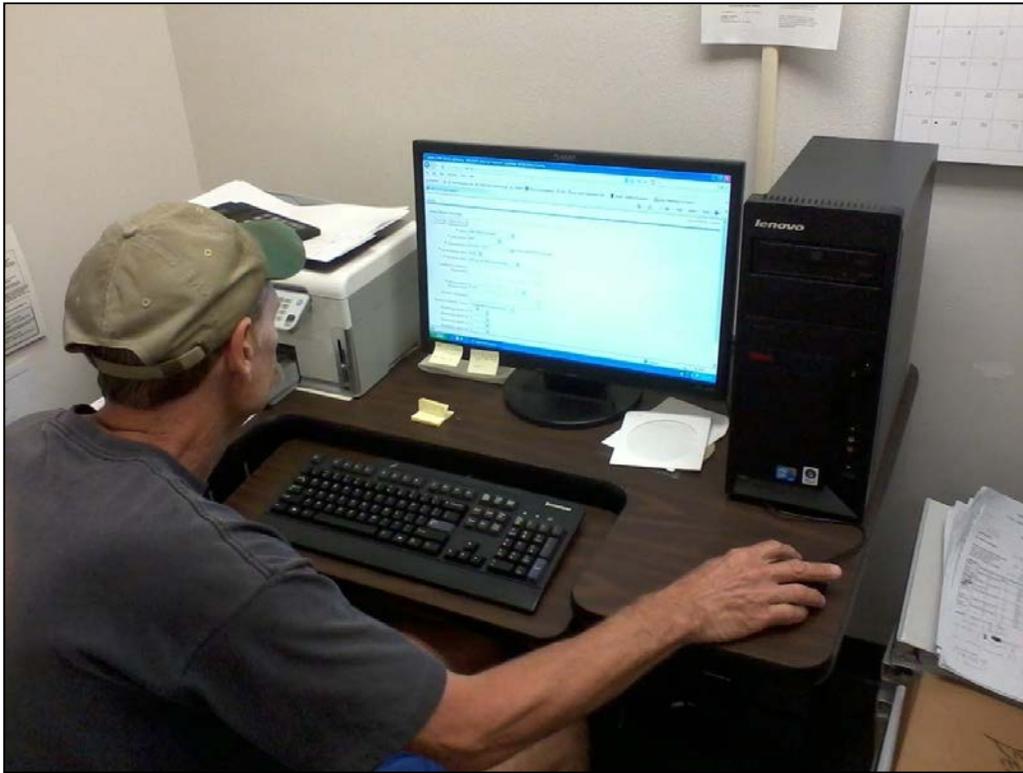


Figure 4. Uploading routine sanitary survey data to the Wisconsin Beach Health website.

Real-Time Data Links for:
Upper Lake Park Beach
Ozaukee County EPA ID: WI652173

Weather <http://glos.us/obs/station/3-22.html>
Conditions: (Default time zone is GMT. Can change to CDT.)
PORT
WASHINGTON

24-hr. Rainfall: <http://www.crh.noaa.gov/product.php?site=MKX&product=HYD&issuedby=MKX>
PORT WASHINGTON
(Search for: "PTW3")

Lake Level: http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=9087057_Milwaukee,WI&type=Great+Lakes+Water+Level+Data
MILWAUKEE

Surface Current and Waves: http://michigan.glerl.noaa.gov/glcfs/glcfsps_glos?lake=michigan&i=87.84885&j=43.38675&v=uc,vc,vvh&h=1&latest=3&tzf=-5&f=rss&cu=m&pv=1&order=dec
Nearest GLCFS Cell
Lat: 43.38675
Lon: -87.84885

Tributary Discharge: http://waterdata.usgs.gov/nwis/tv?cb_00060=on&format=html&period=1&site_no=04086000
SHEBOYGAN RIVER AT
SHEBOYGAN, WI

Note: The Web links listed above represent the nearest stations that regularly report real-time data. Distances between the beach and stations varies from site to site. "Surface Current and Waves" are model estimates from the Great Lakes Coastal Forecast System (GLCFS):
www.glerl.noaa.gov/res/glcfs/

[Return to Wisconsin Beach Health main page](#)

Internet | Protected Mode: On 100%

Figure 5. Real-time data links for Upper Lake Park, posted on Wisconsin Beach Health website (www.wibeaches.us/real_time_data_links/RTD_Ozaukee_Upper%20Lake%20Park.html).

Beach Water-quality Nowcast Model Case Study

The procedure for running the 2012 nowcast model was somewhat different, allowing for additional “automated” data inputs via the U.S. Geological Survey’s *Environmental Data Discovery and Transformation* (ENDDAT) system². The nowcast operator used a custom ENDDAT web URL (developed by Wisconsin DNR staff) to download a one-row table of the most recent values of several model inputs, including: *RRAIN24* (millimeters of rain estimated by radar over the past 24 hours), *Significant Wave Height* (meters) and *Direction* (0-360 degrees), and *DOY* (day of year, 1-365). The daily ENDDAT table was then imported into the *Virtual Beach* MLR Prediction tab, leaving the operator to manually-enter the remaining values: *AlgBch_None* (1 if there is any algae on the beach, 0 if none), *Gulls* (estimated number of gulls on the beach), *ClearWater* (1 if water “clear”...), *Sunny* (1 if sky “sunny”...), and *July16_Aug10* (1 if between these dates...). Once all of the input values were entered, the operator executed the model to make a prediction (Figure 6).

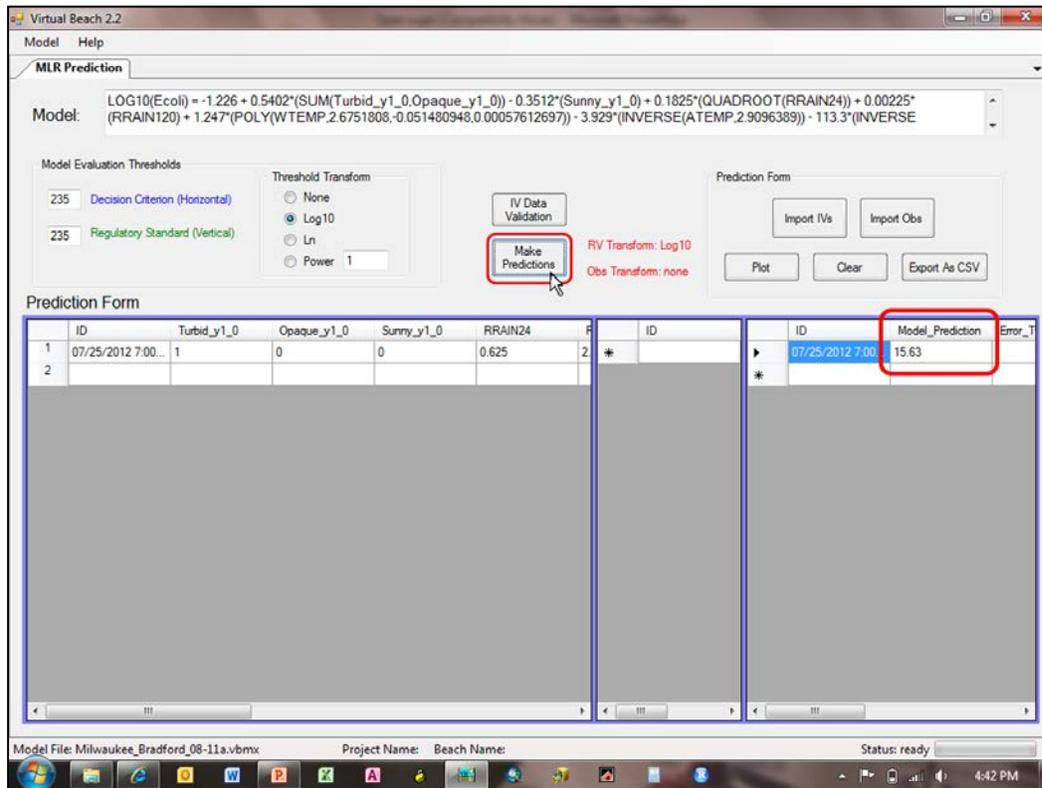


Figure 6. Virtual Beach’s “MLR Prediction” tab.

Outputs of the nowcast included both the estimated concentration of *E. coli* and the statistical probability of exceeding the 235 CFU/100 mL water-quality standard. Health department staff primarily used the estimated *E. coli* concentrations to determine whether or not to post swim advisories or closures at the beach.

² <http://cida.usgs.gov/enddat/>

Beach Water-quality Nowcast Model Case Study

Nowcast Results

The 2011 Upper Lake Park Beach nowcast was operated from June 23 through September 5. During that period, the model correctly predicted water-quality exceedances resulting in the posting of two swim advisories that otherwise would have been missed. In addition, the model predicted non-exceedances resulting in one avoided advisory and one avoided closure that otherwise would have been issued (based on the previous day's lab results). The 2012 nowcast was only run in operational mode from August 11 through September 3, having performed poorly (in evaluation mode) during the early part of the season, before being rebuilt to account for extreme hydro-meteorological conditions and to improve sensitivity to dry-weather/clear-water *E. coli* elevations. During this shortened period of operation, however, the model predicted water-quality exceedances resulting in the posting of two swim advisories that otherwise would have been missed. In addition, the model predicted non-exceedances resulting in two avoided swim advisories that otherwise would have been posted (based on the previous day's lab results).



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Miscellaneous Publication PUB-SS-1102 2012

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This project was funded by the Wisconsin Coastal Management Program and the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resources Management under the Coastal Zone Management Act, Grant #NA09NOS4190107. Points of view expressed in this report do not necessarily reflect the views or policies of the Wisconsin Coastal Management Program or National Oceanic and Atmospheric Administration.

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Beach Water-quality Nowcast Model Case Study

Beach Water-quality Nowcast Model Case Study

Harrington Beach State Park-South, Wisconsin

Located in the Town of Belgium, Harrington Beach State Park is a 715-acre unit within the Wisconsin State Park System. Annual visitation is estimated at 125,000, with the heaviest use occurring during the summer. In 2010, Harrington Beach was converted from a day-use only park to an overnight facility, with the construction of a 69-unit campground. Overall, the park has 1.1 miles of beach shoreline, which is divided into north and south sections (Harrington Beach-North and Harrington Beach-South, respectively) by a peninsula near the midpoint. There are no lifeguards and the beaches are not regularly groomed.

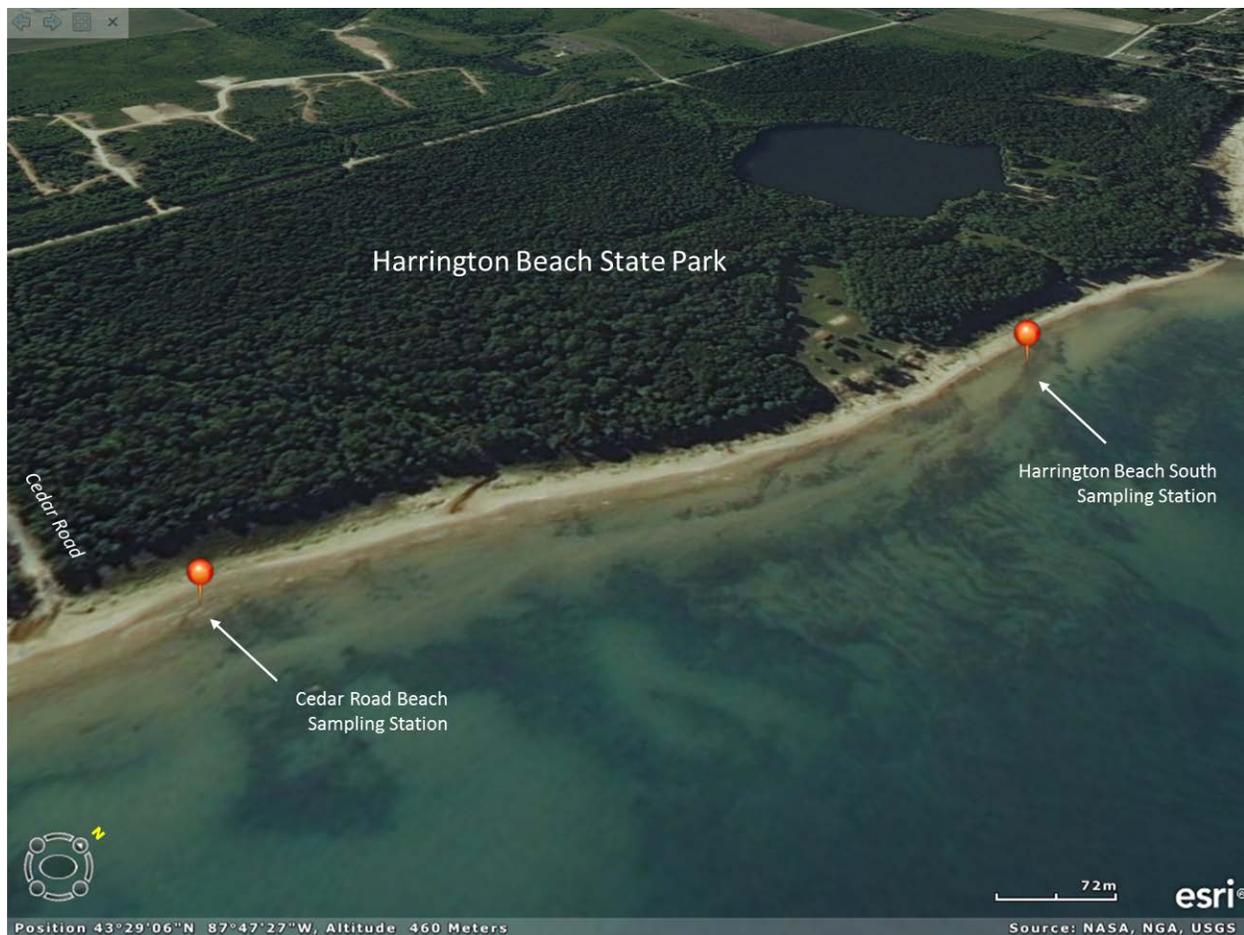


Figure 1. Harrington Beach State Park “South” and “Cedar Road Beach”.

Figure 1 shows the portion of Harrington Beach State Park from the southern boundary at Cedar Road to the mid-point peninsula (approximately 3,300 ft; Harrington Beach-South). The Ozaukee County Public Health Department monitors water quality and collects samples at two fixed stations four days per week (Thursday through Sunday). Officially, the U.S. EPA recognizes the shoreline associated with each of the two stations as separate beaches. The southernmost stretch is known as “Cedar Road Beach”. In 2008 through 2009, samples collected from the two stations were composited before being transported to the Port Washington drinking water utility lab for *E. coli* testing using the standard 18-hour, colilert analysis. From a management standpoint, they constituted a single beach. Beginning in 2010, the county resumed its earlier procedure of maintaining and testing separate samples for the two sites.

Beach Water-quality Nowcast Model Case Study

Harrington Beach-South has seen an increase in advisories and closures in recent years, both in absolute terms, and since the resumption of single sample testing, in comparison to Cedar Road Beach. In 2010, there were 23 posted advisories and four closures at Harrington Beach-South (compared with nine advisories and four closures at Cedar Road). In 2011, there were 20 posted advisories and one closure at Harrington Beach-South (compared with eight advisories and one closure at Cedar Road). Although an intensive sanitary survey has never been conducted at Harrington Beach, the disparity in advisories suggests that there is considerable spatial variation in the sources and pathways of *E. coli* contamination. Routine observation and reporting of beach conditions suggests that water quality is heavily influenced by wave height, wave direction, and the level of *Cladophora* algae (large fields of which are visible offshore in Figure 1) on the beach and in the water column.

Nowcast Model

The 2012 beach season was the first with a nowcast model at Harrington Beach–South. For most of the season, however, the nowcast was operated in test-mode only as it proved difficult to predict numerous dry weather exceedances. We could not account for these difficulties, but they appeared to be related to high levels of *Cladophora*, extreme high water temperatures, and observed mass die-offs of mussels, possibly related to the unusually warm water. Eventually, the model was rebuilt to increase its sensitivity to these unusual conditions. Both versions of the model were built by the Wisconsin DNR using *Virtual Beach 2.2*. Beach monitoring staff at the Ozaukee County Public Health Department provided expert guidance and suggestions based on their long-term observations. The finished models were provided as *Virtual Beach* model (.VBMX) files for local operation using the software. The full process of data assembly, model set-up, and model-building, as well as mid-season evaluation and rebuilding, is described in detail in the report *Building Operational “Nowcast” Models for Predicting Water Quality at Five Lake Michigan Beaches*¹.

The 2012 Harrington Beach–South nowcast model was specified as:

$$\begin{aligned} \text{LOG}_{10}(\text{Ecoli}) = & -1.027 + 0.531 * (\text{POLY}(\text{RRAIN120}, 1.4356084, -0.011799177, 0.00042613486)) + \\ & 0.02823 * (\text{RRAIN24}) + 0.487 * (\text{SUM}(\text{Turbid_y1_0}, \text{Opaque_y1_0})) + \\ & 0.2756 * (\text{SUM}(\text{AlgBch_mod1_0}, \text{AlgBch_high1_0})) + \\ & 0.7276 * (\text{POLY}(\text{WaveA_comp}(\text{WVHT}, \text{WVDIR}, 15.45), 1.3582417, 0.11702918, 1.917174)) + \\ & 0.001636 * (\text{SQUARE}(\text{WTEMP})) \end{aligned}$$

Where:

Ecoli = *E. coli* (MPN/ 100mL) — Measured by the Racine Health Dept.
AlgBch_high1_0 = Algae on beach “high”? (y=1/ n=0) — Ozaukee Co. Pub. Health
AlgBch_mod1_0 = Algae on beach “moderate”? (y=1/ n=0) — Ozaukee Co. Pub. Health
Opaque_y1_0 = Water “opaque”? (y=1/ n=0) — Ozaukee Co. Pub. Health
RRAIN24 = Rainfall, 48 hours (mm) — Radar Est. from the North Central River Forecasting Center, NOAA
RRAIN120 = Rainfall, 5 days (mm) — Radar Estimate.... NOAA
Turbid_y1_0 = Water “turbid”? (y=1/ n=0) — Ozaukee Co. Pub. Health
WTEMP = Water Temperature (degrees C) — GLCFS, NOAA

¹ Mednick, A.C. 2012. *Building Operational “Nowcast” Models for Predicting Water Quality at Five Lake Michigan Beaches*. PUB-SS-1098. Bureau of Science Services, Wisconsin Department of Natural Resources, Madison.

Beach Water-quality Nowcast Model Case Study

$WaveA_comp$ = Alongshore Wind (meters/sec) — Derived from:
Significant Wave Height (meters) — GLCFS, NOAA
Wave Direction (from 0-360 deg.) — GLCFS, NOAA

And where:

LOG10 = logarithm, base 10

INVERSE = $1/X$

POLY = polynomial transformation ($a + bX + cX^2$)

POWER = $X^{1/3}$

PROD = $X1 * X2$

QUADROOT = $X^{1/4}$

SQUARE = X^2

SQUAREROOT = $X^{1/2}$

Nowcast Operation

The Harrington–South nowcast was run alternatively by beach monitoring staff at the Ozaukee County Health Department and staff at the Wisconsin DNR using daily data uploaded to the *Wisconsin Beach Health* website. The process of running the nowcast took the operator five minutes or less, on top of routine beach monitoring and public notification activities. Nowcast model runs were conducted after monitoring personnel returned to the health department office from collecting water samples and taking routine sanitary survey measurements at the beach (Figure 2). Routine sampling and sanitary surveys took place around 06:00 a.m.

The nearshore water at Harrington Beach-South was classified subjectively as “clear,” “somewhat turbid,” “turbid,” or “opaque,” following the routine sanitary survey protocol. On most days, however, beach monitoring personnel also used a turbidity tube (Figure 3) to derive a simple quantitative measure of water clarity (i.e. centimeters of visibility). This measure will likely be used in place of the subjective categories in future nowcasts.

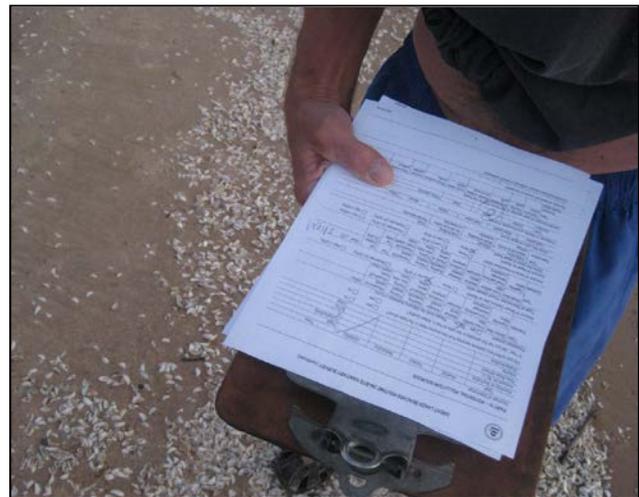


Figure 2. Beach conditions entered on a routine sanitary survey form.



Figure 3. Using a turbidity tube to measure water clarity.

Beach Water-quality Nowcast Model Case Study

The procedure for running the model was for the operator to first access and download “automated” data inputs via the U.S. Geological Survey’s *Environmental Data Discovery and Transformation* (ENDDAT) system² using a custom ENDDAT web URL developed by Wisconsin DNR staff. Launching the URL downloads a one-row table of the most recent values of several model inputs, including: *WTEMP* (water temperature in degrees C), *RRAIN24*, and *RRAIN120* (millimeters of rain estimated by radar over the past 24 and 120 hours), *Significant Wave Height* (meters), and *Direction* (0-360 degrees). Next, the operator opened the *Virtual Beach* model (.VBMX) file and imported the daily ENDDAT table into the MLR Prediction tab, leaving the operator to manually-enter *AlgBch_high1_0* (algae on beach “high” [1] or not [0]), *AlgBch_moderate1_0* (algae on beach “moderate” [1] or not [0]), *Turnbid_y1_0* (water “turbid” [1] or not [0]), and *Opaque_y1_0* (water “opaque” [1] or not [0]). Once all of the input values were entered, the operator executed the model to make a prediction (Figure 4).

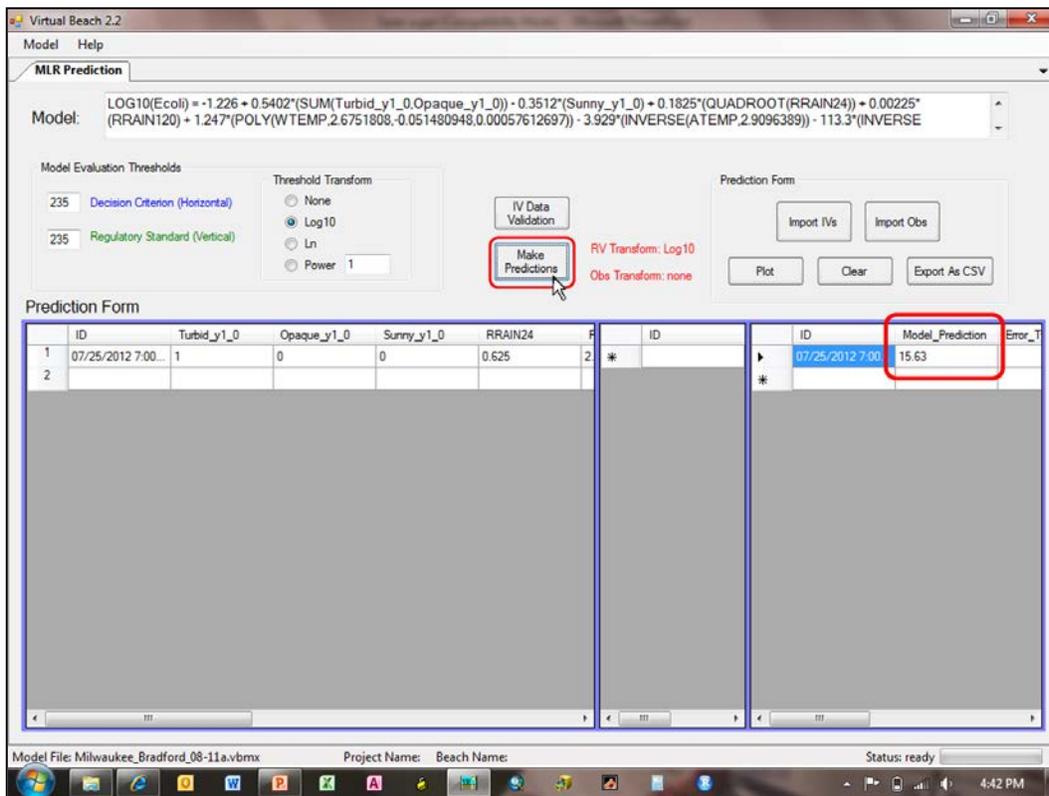


Figure 4. Virtual Beach, making a prediction.

Outputs of the nowcast model included both the estimated concentration of *E. coli* and the statistical probability of exceeding the 235 CFU/100 mL water-quality standard. As discussed above, the revised nowcast model for Harrington Beach-South did not become operational until the final week of the 2012 beach season. Applied retroactively over the full season, the model proved to be 76% accurate in predicting water-quality exceedances and non-exceedances, compared to 72% for the “persistence method” (i.e. the previous day’s lab results).

² <http://cida.usgs.gov/enddat/>

Beach Water-quality Nowcast Model Case Study



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Miscellaneous Publication PUB-SS-1103 2012

Author: Adam C. Mednick
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Beach Water-quality Nowcast Model Case Study

Beach Water-quality Nowcast Model Case Study

Harrington Beach State Park-North, Wisconsin

Located in the Town of Belgium, Harrington Beach State Park is a 715-acre unit within the Wisconsin State Park System. Annual visitation is estimated at 125,000, with the heaviest use occurring during the summer. In 2010, Harrington Beach was converted from a day-use only park to an overnight facility, with the construction of a 69-unit campground. Overall, the park has 1.1 miles of beach shoreline, which is divided into north and south sections (Harrington Beach-North and Harrington Beach-South, respectively) by a peninsula near the midpoint. There are no lifeguards and the beaches are not regularly groomed.

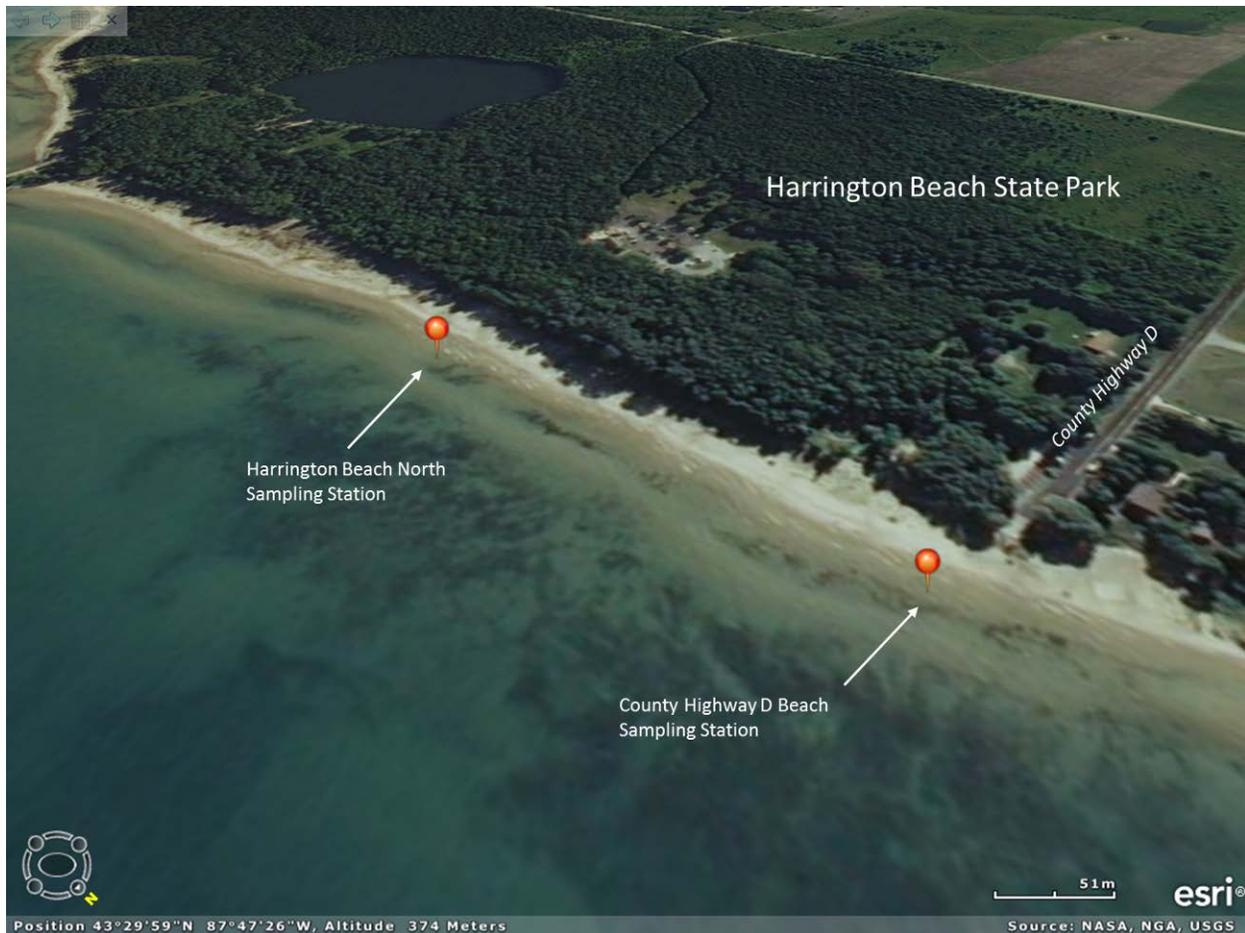


Figure 1. Harrington Beach State Park “North” and “County Highway D Beach”.

Figure 1 shows the northern portion of Harrington Beach State Park, running south from the park boundary at County Highway D to the peninsula at the near mid-point of the shoreline (approximately 2,500 ft; Harrington Beach-North.). The Ozaukee County Public Health Department monitors water quality and collects samples at two fixed stations (Figure 1) four days per week (Thursday through Sunday). Officially, the northernmost portion is recognized by the U.S. EPA as a separate beach (“County Highway D Beach”). The northernmost sampling station corresponds with this site. From 2008 through 2010, samples from the two sites were composited prior to being transported to the Port Washington drinking water utility lab to be tested for *E. coli* using the standard 18-hour, colilert analysis. The county resumed its earlier practice of maintaining separate samples in 2011.

Beach Water-quality Nowcast Model Case Study

Water quality at Harrington Beach-North has improved in recent years. Since the resumption of single sample testing, however, the improvement at County Highway D has been less pronounced. In 2010, there were eight posted swim advisories and no closures at Harrington Beach-North (compared with ten advisories and one closure at County Highway D). In 2011, there were just three posted advisories at Harrington Beach-North (compared with six advisories at County Highway D). Although an intensive sanitary survey has never been conducted at Harrington Beach, the disparity in advisories suggests that there is considerable spatial variation in the sources and pathways of *E. coli* contamination. Routine observation and reporting of beach conditions suggests that water quality is heavily influenced by wave height, wave direction, and the level of *Cladophora* (large fields of which are visible offshore in Figure 1) on the beach and in the nearshore water column.

Nowcast Model

The 2012 beach season was the first with a nowcast model at Harrington Beach–North. For most of the season, however, the nowcast was operated in test-mode only as it proved difficult to predict numerous dry weather exceedances. We could not account for these difficulties, but they appeared to be related to high levels of *Cladophora*, extreme high water temperatures, and observed mass die-offs of mussels, possibly related to the unusually warm water. Eventually, the model was rebuilt to increase its sensitivity to these unusual conditions. Both versions of the model were built by the Wisconsin DNR using *Virtual Beach 2.2*. Beach monitoring staff at the Ozaukee County Public Health Department provided expert guidance and suggestions based on their long-term observations. The finished models were provided as *Virtual Beach* model (.VBMX) files for local operation using the software. The full process of data assembly, model set-up, and model-building, as well as mid-season evaluation and rebuilding, is described in detail in the report *Building Operational “Nowcast” Models for Predicting Water Quality at Five Lake Michigan Beaches*¹.

The 2012 Harrington Beach–North nowcast model was specified as:

$$\text{LOG}_{10}(\text{Ecoli}) = 1.068 + 1.008\text{e-}05 * (\text{SQUARE}(\text{DOY})) - 0.4291 * (\text{ClearWater_y1_0}) - 56.2 * (\text{INVERSE}(\text{WaterTemp_F}, 24)) + 0.1606 * (\text{POWER}(\text{RRAIN24}, 0.33333333)) + 0.0001106 * (\text{SQUARE}(\text{RRAIN120})) + 0.745 * (\text{POLY}(\text{WaveA_comp}(\text{WVHT}, \text{WVDIR}, -11.67), 1.1339497, -0.64205924, 2.2847268)) - 0.001594 * (\text{INVERSE}(\text{CLDCV}, 0.0061)) + 0.1343 * (\text{SQUARE}(\text{AlgBeach_0-3}))$$

Where:

Ecoli = *E. coli* (MPN/100mL) — Measured by the Racine Health Dept.

AlgBeach_0-3 = Algae on beach (0“none” – 3“high”) — Ozaukee Co. Pub. Health

CLDCV = Cloud Cover (percent) — GLCFS, NOAA

ClearWater = Water “clear”? (y=1/n=0) — Measured by the Ozaukee Co. Pub. Health

DOY = Day of year (1-365)

RRAIN24 = Rainfall, 24 hours (mm) — Radar Est. from the North Central River Forecasting Center, NOAA

RRAIN120 = Rainfall, 5 days (mm) — Radar Estimate.... NOAA

WaterTemp_F = Water Temperature (degrees F) — Ozaukee Co. Pub. Health

¹ Mednick, A.C. 2012. *Building Operational “Nowcast” Models for Predicting Water Quality at Five Lake Michigan Beaches*. PUB-SS-1098. Bureau of Science Services, Wisconsin Department of Natural Resources, Madison.

Beach Water-quality Nowcast Model Case Study

$WaveA_comp$ = Alongshore Wind (meters/sec) — Derived from:
Significant Wave Height (meters) — GLCFS, NOAA
Wave Direction (from 0-360 deg.) — GLCFS, NOAA

And where:

LOG10 = logarithm, base 10
INVERSE = $1/X$
POLY = polynomial transformation ($a + bX + cX^2$)
POWER = $X^{1/3}$
PROD = $X1 * X2$
SQUARE = X^2

Nowcast Operation

The Harrington Beach–North nowcast was run alternatively by beach monitoring staff at the Ozaukee County Health Department and staff at the Wisconsin DNR, using daily data uploaded to the *Wisconsin Beach Health* website. The process of running the nowcast took the operator five minutes or less, on top of routine beach monitoring and public notification activities. Nowcast model runs were conducted after monitoring personnel returned to the health department office from collecting water samples and taking routine sanitary survey measurements at the beach (Figure 2). Routine sampling and sanitary surveys take place around 06:00 a.m.

The nearshore water at Harrington Beach-North was classified subjectively as “clear,” “somewhat turbid,” “turbid,” or “opaque,” following the routine sanitary survey protocol. On most days, however, beach monitoring personnel also used a turbidity tube (Figure 3) to derive a simple quantitative measure of water clarity (i.e. centimeters of visibility). This measure will likely be used in place of the subjective categories in future nowcasts.

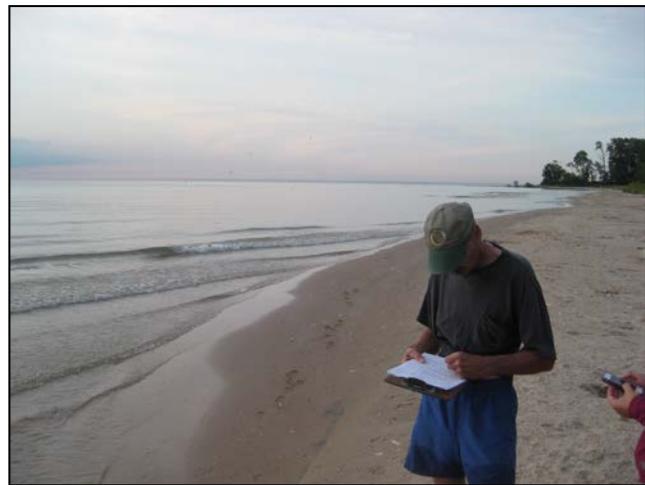


Figure 2. Beach conditions entered on a routine sanitary survey form.



Figure 3. Using a turbidity tube to measure water clarity.

Beach Water-quality Nowcast Model Case Study

The procedure for running the model was for the operator to first access and download “automated” data inputs via the U.S. Geological Survey’s *Environmental Data Discovery and Transformation* (ENDDAT) system² using a custom ENDDAT web URL developed by Wisconsin DNR staff. Launching the URL downloads a one-row table of the most recent values of several model inputs, including: *RRAIN24* and *RRAIN120* (millimeters of rain estimated by radar over the past 24 and 120 hours), *CLDCV* (percent cloud cover), *DOY* (day of year, 1-365), and *Significant Wave Height* (meters), and *Direction* (0-360 degrees). Next, the operator opened the *Virtual Beach* model (.VBMX) file and imported the daily ENDDAT table into the MLR Prediction tab, leaving the operator to manually-enter three additional values: *WaterTemp_F* (water temperature, degrees F), *ClearWater* (water clarity category is “clear” [1] or not [0]), and *AlgBeach_0-3* (amount of algae on beach, ranging from “none” [0] to “high” [3]). Once all of the input values were entered, the operator executed the model to make a prediction (Figure 4).

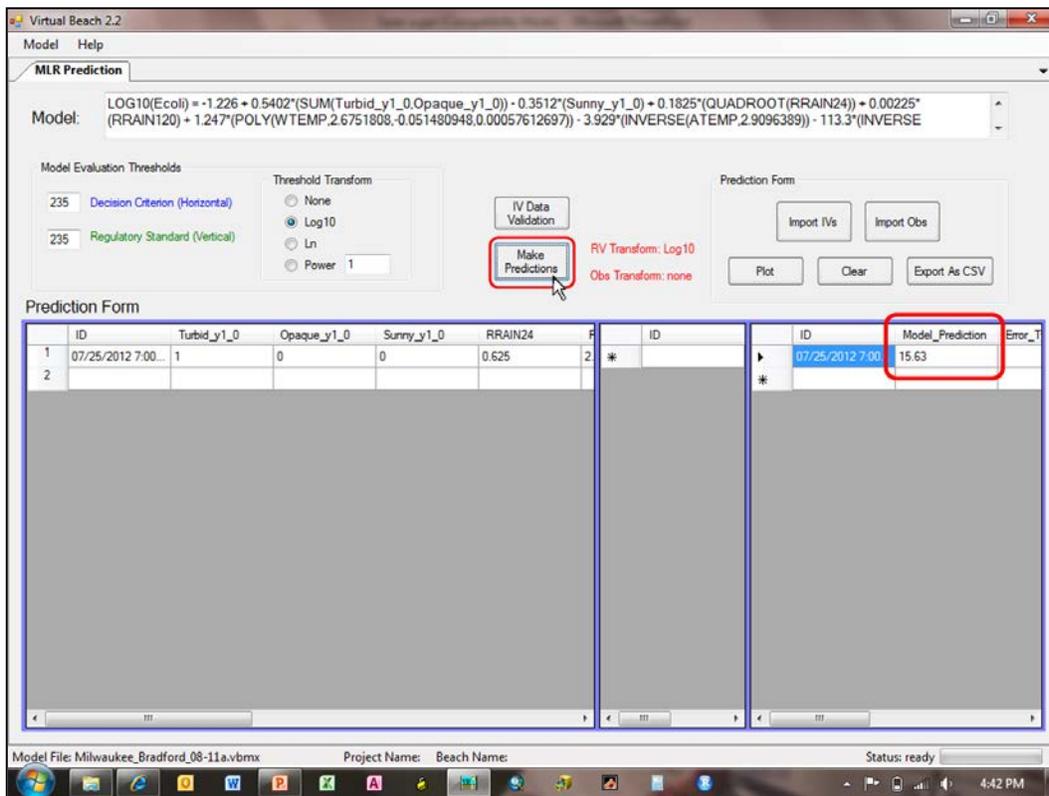


Figure 4. Virtual Beach, making a prediction.

Outputs of the nowcast included both the estimated concentration of *E. coli* and the statistical probability of exceeding the 235 CFU/100 mL water-quality standard. As discussed above, the revised nowcast model for Harrington Beach-North did not become operational until the final week of the 2012 beach season. Applied retroactively over the full season, the model proved to be 77% accurate in predicting water-quality exceedances and non-exceedances, compared to 66% for the “persistence method” (i.e. the previous day’s lab results).

² <http://cida.usgs.gov/enddat/>

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Miscellaneous Publication PUB-SS-1104 2012

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This project was funded by the Wisconsin Coastal Management Program and the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resources Management under the Coastal Zone Management Act, Grant #NA09NOS4190107. Points of view expressed in this report do not necessarily reflect the views or policies of the Wisconsin Coastal Management Program or National Oceanic and Atmospheric Administration.



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