# Expanded Beach "Nowcast" Modeling across Wisconsin

Bureau of Science Services
Wisconsin Department of Natural Resources
P.O. Box 7921
Madison, WI 53707-7921

Miscellaneous Publication PUB-SS-1142 2014

---

**Executive Summary:** With funding from the Great Lakes Restoration Initiative, the Wisconsin Department of Natural Resources successfully completed a three-year project to expand the use of real-time, predictive models (“nowcasts”) to improve the accuracy of monitoring at coastal beaches in Wisconsin. Major project tasks included the development of nowcast models using the Virtual Beach model-building and decision-support software, outreach and training to potential adopters in Wisconsin and throughout the Great Lakes region, technical assistance and on-demand support to local adopters, and the coordination of efforts with and among numerous federal, state, local, academic, and private partners, including the co-development of Virtual Beach version 3.0 with research and development teams at the U.S. Environmental Protection Agency and U.S. Geological Survey.

All of the project goals and objectives were met during the 2011, 2012, and 2013 beach seasons. Outcomes included: (1) the establishment of operational nowcast models at 21 coastal beaches in Wisconsin, including 12 high-priority beaches; (2) increased local awareness and capacity to use Virtual Beach through the training of 34 local beach managers, monitoring personnel, and researchers in the state of Wisconsin, plus 47 in other Great Lakes and maritime states and Ontario; (3) a reduction in monitoring errors; specifically, 39 fewer missed or unnecessary advisories and closures than would otherwise have occurred; (4) seven fewer beach closures than would otherwise have occurred; (5) the successful integration of EPA and USGS modeling tools and USGS’ Environmental Data Discovery and Transformation (EnDDaT) system; and (6) the development of a more cost-effective “two-tiered” approach to nowcast modeling that allows coastal communities to reduce the frequency of sampling and testing while effectively expanding their monitoring programs from intermittent to daily.

In order to ensure continued expansion and long-term sustainability of nowcast modeling, we recommend strategic investments in three areas: (1) improving the operational capacity of the EnDDaT system, (2) maintaining basic support for periodic updates and bug fixes to Virtual Beach, and (3) supporting nowcast training, technical support, and guidance.

**Cover photo:** North Beach, Port Washington, WI. Dan Ziegler

---



---

# Expanded Beach "Nowcast"

# Modeling across Wisconsin

**Adam C. Mednick** and **Dreux J. Watermolen**

Bureau of Science Services
Wisconsin Department of Natural Resources
101 South Webster Street
Madison, WI 53707

**August 2014**

## Contents

## Figures



## Tables

## The Problem: Traditional Beach Monitoring

The U.S. Great Lakes coast includes more than 1,000 beaches, spanning 675 miles of shoreline (U.S. EPA 2013). Combined, these beaches receive an estimated 8 million visitors per year, or 80 million visits (Austin et al. 2007). Under the federal BEACH Act, local health departments or other agencies routinely collect nearshore water-quality samples at 580 of these beaches and analyze the samples for concentrations of *E. coli* bacteria (Figure 1). Elevated levels of *E. coli* have been associated with increased incidences of gastro-intestinal illness (Wade et al. 2003) and attendant healthcare costs (Given et al. 2006). Swim advisories are posted when single-sample *E. coli* concentrations exceed the federal standard of 235 colony-forming units (CFU) per 100 mL. Depending on the state, beaches are closed when levels exceed higher concentrations; for example, 1,000 CFU/100 mL in Wisconsin.

Between 2008 and 2010, 14% of all samples collected at Great Lakes beaches exceeded the 235 CFU/100 mL standard. In a number of counties, more than 20% of samples exceeded this threshold (Figure 1). In addition to public health impacts, reductions in spending and overall economic value has been estimated at between \$15 and \$30 per visitor per beach closure or advisory (Murray et al. 2001, Rabinovici et al. 2004, Song et al. 2010, Shaikh 2012). Poor water quality at Great Lakes beaches has also been associated with lower property values (Ara 2007) and has been reported as aggravating issues of environmental justice (Evans and Kantrowitz 2002, Farquhar et al. 2005). Conversely, improving water quality and reducing the number of beach closures and advisories has been shown to be an important element of community redevelopment (Kinzelman and Hiller 2007).

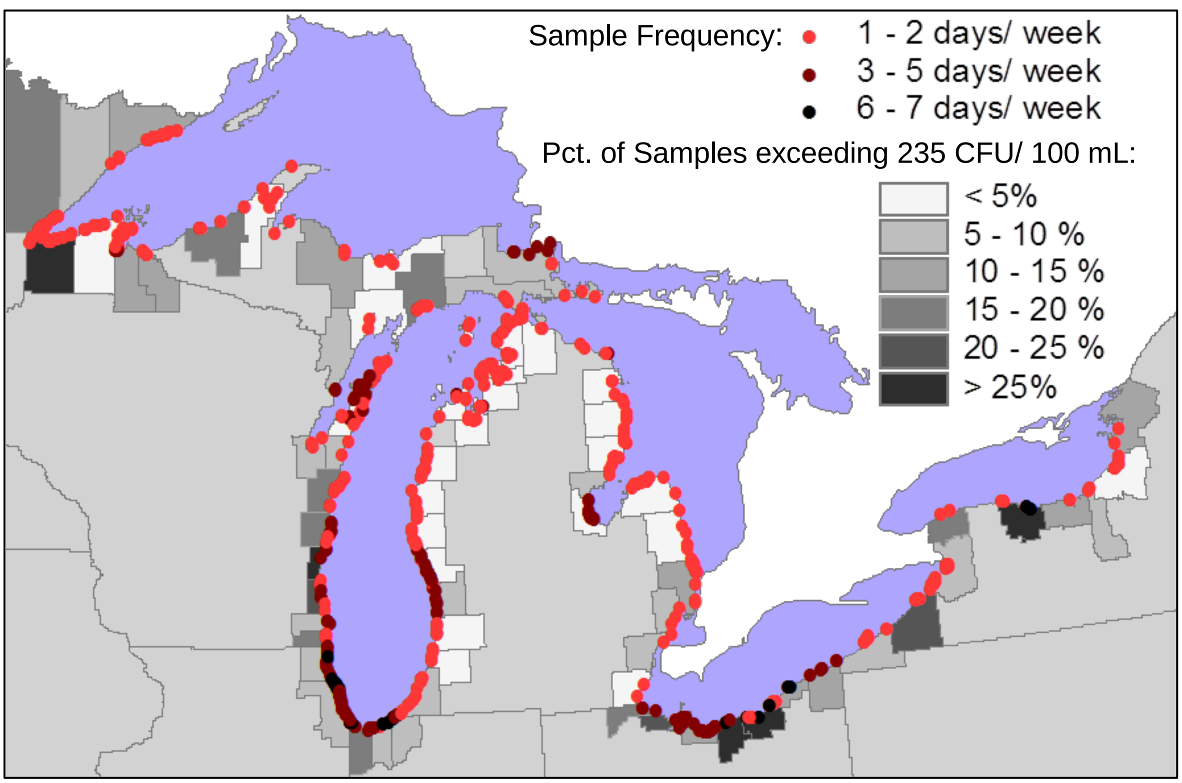



**Figure 1.** *Monitored beaches and per-county percentage of exceedances, 2008-2010.*

The negative consequences of impaired beach water quality are exacerbated by the standard method of monitoring, which entails collecting samples in waist-deep water, transporting them to a laboratory, and culturing them for *E. coli*. This process takes 18 to 24 hours, whereas *E. coli* levels fluctuate over much shorter intervals. As such, results are frequently not reflective of present conditions (Whitman et al. 1999). An analysis of advisories and closures posted at Great Lakes beaches between 2008 and 2010 (Table 1) reveals that two-thirds (nearly 3,000) were unnecessary; that is, *E. coli* levels were actually below 235 CFU/100 mL at the time of posting. Conversely, over 4,500 actual exceedances went undetected until the following day, leaving the beaches open and unposted during periods of heightened exposure risk. Changes in regional climate could further exacerbate this problem, as projected increases in extreme heat and storm events will likely increase both visitation (Loomis and Crespi 1999) and the risk of waterborne illnesses (Patz et al. 2008).

**Table 1.** *Decision-errors at Great Lakes beaches, 2008-2010*.*

| | **Sampled Advisories** | | **Sampled Beach-Open** | | **Combined, Sampled** | |
|---|---|---|---|---|---|---|
| | All | In-Error | All | In-Error | All | Total Errors |
| Illinois | 1,107 | 709 (64%) | 9,127 | 1,142 (13%) | 10,234 | 1,851 (18%) |
| Indiana | 716 | 452 (63%) | 3,881 | 555 (14%) | 4,597 | 1,007 (22%) |
| Michigan | 201 | 137 (68%) | 7,020 | 528 (8%) | 7,221 | 665 (9%) |
| Minnesota | 74 | 58 (78%) | 1,853 | 90 (5%) | 1,927 | 148 (8%) |
| New York | 467 | 260 (56%) | 2,322 | 440 (19%) | 2,789 | 700 (25%) |
| Ohio | 636 | 434 (68%) | 4,842 | 770 (16%) | 5,478 | 1,204 (22%) |
| Pennsylvania | 72 | 59 (82%) | 937 | 88 (9%) | 1,009 | 147 (15%) |
| Wisconsin | 1,225 | 849 (69%) | 9,868 | 951 (10%) | 11,093 | 1,800 (16%) |
| **Total** | **4,498** | **2,958 (66%)** | **39,850** | **4,564 (11%)** | **44,348** | **7,522 (17%)** |

* These statistics were computed from data reported to EPA (2013) and retrieved from the *Beach Advisory and Closing On-line Notification* (BEACON) system: http://watersgeo.epa.gov/beacon2/. The sample (n=44,348) includes all "beach days" (1 day x 1 beach=1) for which water-quality samples were collected between 2008 and 2010. This sample includes 25% of the total beach days during those three years at the 580 beaches monitored under the federal BEACH Act.

The use of multivariate statistical models to "nowcast" current water quality based on empirical relationships between *E. coli* and readily-measurable meteorological, nearshore, and onshore conditions has been shown to result in considerably fewer errors than either the culture-based "persistence model" or rainfall-only models (Francy and Darner 2007, Mednick and Watermolen 2009, Nevers and Whitman 2005, Olyphant and Whitman 2004). Local beach managers, however, have been slow to adopt nowcasting on account of limited funding and training opportunities, the lack of easy-to-use tools, and the lack of coordinated technical leadership (Francy 2009). In 2010, only one of 124 monitored coastal beaches in Wisconsin had a nowcast model in operation to inform advisory decisions. Across the other seven Great Lakes states, just five of approximately 450 monitored beaches had similar models in operation.

## Goals and Objectives

Building on lessons learned during an earlier technology transfer project (Mednick and Watermolen 2009), the Wisconsin Department of Natural Resources (Wisconsin DNR) applied for and secured Great Lakes Restoration Initiative (GLRI) funding to increase the number of beaches with nowcast models in operation. Wisconsin DNR's earlier effort had focused on version 1.0 of U.S. EPA's Virtual Beach (VB) decision-support software (Frick et al. 2008). VB can be used to develop, evaluate, and operate beach-specific nowcast models (Cyterski et al. 2013). Although the initial effort did not result in widespread adoption of VB 1.0, it did generate valuable feedback from targeted local users that resulted in a number of enhancements to VB 2.0. The GLRI nowcast project sought to accelerate this process through a combination of capacity-building and use-inspired enhancements to VB, as well as complimentary modeling tools and online data systems. As established by Wisconsin DNR's GLRI grant proposal and work plan, the goals of the project were:

> *To reduce the number of Type I and Type II monitoring errors [i.e., unnecessary and missed advisories] and the overall number of beach closures in Wisconsin...*
>
> *[T]o establish 20 operational nowcast models [in Wisconsin] by the summer of 2013, including 10 or more for high priority beaches.*

In order to achieve these goals, the principal investigator pursued the following objectives, as outlined in the GLRI grant proposal and work plan:

> *[1.] building initial nowcast models for candidate beaches using modeling tools and database systems developed by EPA and USGS;*
>
> *[2.] developing, testing, and refining step-by-step nowcast training modules;*
>
> *[3.] conducting five hands-on training workshops;*
>
> *[4.] providing technical assistance to beach managers and monitoring personnel engaged in operating, evaluating, or refining nowcast models;*
>
> *[5.] compiling and providing user-feedback and practical suggestions to EPA and USGS; and*

*[6.] helping to coordinate complimentary tool development and database integration efforts led by EPA, USGS, and others.*

### Measures of Success

All of the project's goals and objectives were met within a three-year timespan that included the 2011, 2012, and 2013 summer beach seasons. All quantifiable outputs and outcomes were tracked. Table 2 (page 5) summarizes these success measures, including benchmarks (where specified in the project proposal) and final tallies.

## Project Description

Project goals and objectives were met through a combination of nowcast model-development, outreach and capacity-building, and the integration and enhancement of VB and other tools that support operational nowcast modeling. The principal investigator managed and carried-out project tasks fulltime, with assistance from staff and supervisors within Wisconsin DNR's Bureau of Science Services and Water Division. As detailed later in this report, this project was highly collaborative, resulting in the coordination and leveraging of related projects, resources, and expertise among many federal, state, local, academic, non-profit, and commercial entities.

### Model Development

For model development, the principal investigator assembled and formatted data tables for each of 62 monitored beaches in Wisconsin for input into the VB model-building tabs. Data included historical *E. coli* concentrations and concurrent sanitary survey data, plus spatiotemporally-matched, hydro-meteorological data from various NOAA and USGS online databases (see Mednick 2009). This process included the development and execution of a customized geographic information system (GIS) protocol for identifying and assembling location-specific Web links to historical and real-time data feeds from all available weather stations, in-lake buoys, stream gages, and hydro-meteorological model outputs. The GIS protocol helped to inform the development of the Environmental Data Discovery and Transformation (EnDDaT) online portal (http://cida.usgs.gov/enddat) developed by the USGS Wisconsin Water Science Center (WIWS) and Center for Integrated Data Analysis (CIDA), which are co-located in Middleton, Wisconsin and were close project partners. In 2012, EnDDaT replaced the GIS-based protocol and significantly reduced the amount time and effort required to update input datasets for VB.

In coordination with USGS-WIWS, the principal investigator reached out to all of the state's coastal beach managers to determine the level of interest in establishing operational nowcast models at their respective beaches. Beaches were selected for modeling based on the expressed level of interest and preference, with an emphasis on modeling Tier I (high priority) beaches. Of the 62 beaches with assembled datasets, the principal investigator developed nowcast models for 25 beaches using VB versions 2.1, 2.2, and 3.0. USGS-WIWS developed nowcast models for another seven, plus three that were not originally identified on account of being neither Tier I nor listed as impaired. The principal investigator provided input data, VB training, and technical assistance to WIWS staff.

**Table 2.** *Project success measures.*

| Measure | Description | | Benchmark | Final |
|---|---|---|---|---|
| Beaches with operational nowcasts by 2013 | The number of coastal beaches in Wisconsin for which nowcast models were used to guide beach actions (i.e., the issuance or lifting of swim advisories or closures) in 2013: | | | |
| | | Tier I (High Priority) Beaches | 10 | 12 |
| | | Tier II (Medium Priority) Beaches | - | 7 |
| | | Tier III (Low Priority) Beaches | - | 2 |
| | | Total Beaches | 20 | 21 |
| Trainings conducted | The number of workshops conducted on how to develop and operate nowcast models using *Virtual Beach* (VB): | | | |
| | | For beach managers in Wisconsin | 3 | 4 |
| | | For beach managers elsewhere in the Great Lakes | 2 | 3 |
| Personnel trained | The number of personnel, researchers, or contractors involved in beach monitoring that received VB training, either in a workshop or one-on-one. Working in: | | | |
| | | Wisconsin | - | 34 |
| | | Illinois | - | 2 |
| | | Indiana | - | 1 |
| | | Michigan | - | 14 |
| | | Minnesota | - | 1 |
| | | New York | - | 1 |
| | | Ohio | - | 16 |
| | | Pennsylvania | - | 2 |
| | | Ontario | - | 4 |
| | | Maritime States (NH, OR, WA) | - | 3 |
| Reduction in monitoring errors | The net decrease in incorrect or unnecessary beach actions that would otherwise have occurred under standard monitoring. Based on retroactive lab results and the documented use of nowcast models (n = 174). * | | | |
| | | Missed Advisories: | - | –18 |
| | | Unnecessary Advisories: | - | –5 |
| | | Missed Closures: | - | –1 |
| | | Unnecessary Closures: | - | –8 |
| Reduction in closures: | | | - | –7 |

* “Model” was reported as the reason for 169 beach actions in Wisconsin between 2011 and 2013. An additional five actions were based on qPCR re-testing to corroborate nowcast results.

All of the models developed in 2011 and 2012 were multiple-linear regression (MLR) models, following the original method applied by Olyphant et al. (2003), Francy et al. (2003), Nevers and Whitman (2005), and Frick et al. (2008), which was the only option available in VB at the time. MLR models are limited in the number of predictive variables allowed, as well as the requirement that the relationships between these variables and *E. coli* must be independent and linear. VB 3.0 included two new options: partial least squares (PLS) and gradient-boosting machine (GBM) models. These options were added by USGS-WIWS (Brooks et al. 2013) in collaboration with the lead software developers at U.S. EPA's Office of Research and Development (EPA-ORD). PLS and GBM do not limit the number of variables included, nor do they require variable independence. As coded in VB 3.0, these options significantly reduce the time required to develop nowcast models. In 2013, the principal investigator used VB 3.0 to develop a pair of models for each beach: (1) a standard MLR model using a mix of field-measured and EnDDaT data and (2) an "all-automated" PLS or GBM model (whichever performed better) using only EnDDaT data.

## Outreach and Capacity Building

The principal investigator used a number of different communication channels and venues to reach out to the targeted community-of-practice for beach nowcasts; i.e., coastal health department managers, personnel, and sub-contractors directly involved in beach monitoring and public notification, not only in Wisconsin but in other Great Lakes states and provinces as well. This included direct emails and phone conservations, Wisconsin DNR's beach website, the Wisconsin Beach Health website (www.wibeaches.us), and the Beachnet list serve, as well as presentations at regional beach meetings in Wisconsin and each of the annual Great Lakes Beach Association conference between 2011 and 2013. The two-part objective was (1) to build awareness and interest in nowcast modeling and the VB software system, and (2) to build local capacity to operate and eventually develop nowcast models using VB.

**Table 3.** *Virtual Beach training workshops.*

| Location | Date(s) | Attendees | States/Provinces Represented |
|---|---:|:---:|---|
| Northland College<br>Ashland, WI | Apr. 27, 2011 | 5 | WI |
| University of Wisconsin<br>Oshkosh, WI | May 3, 2011 | 12 | WI |
| Johnson Foundation at Wingspread<br>Racine, WI | May 4, 2011 | 13 | WI, IL, MI |
| Blue Chip Casino<br>Michigan City, IN | Sept. 26, 2011 | 16 | IN, MI, MN, OH, ONT, OR, WA |
| City Hall<br>Racine, WI | Dec. 5, 2011 | 3 | WI |
| Ohio Water Science Center<br>Columbus, OH | Dec. 7-8, 2011 | 21 | IL, MI, NY, OH, PA, WI |
| Wisconsin Water Science Center<br>Middleton, WI | Jan. 16-17, 2013 | 14 | MI, OH, ONT, WI, NH |

Capacity-building took multiple forms as well. These included: (1) the development of illustrated, step-by-step training modules for developing, evaluating, and operating nowcast models using VB; (2) a series of hands-on training workshops conducted for potential nowcast adopters in and outside of Wisconsin (Table 3); (3) on-site training and technical assistance conducted during visits to communities adopting nowcast models; and (4) on-demand technical support for nowcast adopters, including guidance, assistance, and trouble-shooting on VB, EnDDaT, and other operational aspects of nowcasting. Technical support was provided by the principal investigator via telephone, email, Web conferencing, or in person, depending on the situation.

### Tool Enhancement and Integration

Substantial effort went into enhancing and integrating VB, EnDDaT, and related modeling and online data-access tools, in partnership with EPA-ORD and USGS WIWS/CIDA. The principal investigator regularly provided feedback and guidance on ways to enhance the tools based on their experience developing nowcast models and working with local operators. In particular, the Ozaukee County Public Health Department, Racine Health Department, and Cardinal Environmental, Inc. of Sheboygan provided a wealth of practical feedback and suggestions, which were incorporated into VB 2.1 and later VB 3.0. The principal investigator facilitated the partnership between EPA and USGS that resulted in the joint development of VB 3.0, including the direct integration of USGS' GBM and PLS modeling tools, which made the process of developing models more efficient, along with the capability to download automated data from EnDDaT directly into the VB Prediction tab, which made the process of running the models more user-friendly for local operators. Coordinating the previously separate efforts of EPA and USGS was an explicit goal of the project, as it increased the likelihood of more widespread adoption of nowcast modeling by leveraging the research and development teams' respective resources and expertise, avoiding the duplication of effort, and combining what would otherwise be competing tools into a single system. The principal investigator also worked with programmers at the NOAA Great Lakes Ecosystem Research Laboratory and the Great Lakes Commission to enhance and trouble-shoot the Great Lakes Coastal Forecasting System (GLCFS) Web service, which provides critical hydro-meteorological data used to develop and operate nowcast models.

### Evaluating Future User Needs and Transferability

During the third and final year of the project, Wisconsin DNR staff led or supported efforts aimed at evaluating future needs, as well as the potential for transferring the successful approach taken to develop and implement VB 3.0 to other decision-support systems. First, project staff collaborated with researchers at the University of Michigan Cooperative Institute for Limnology and Ecosystems Research (CILER) in developing and implementing an online "Beach Information Needs" survey, including a number of questions related to VB and nowcast modeling. This survey was conducted on behalf of the Beach Health Interagency Coordination Team (BHICT). Project staff assisted BHICT members in assembling a comprehensive list of the approximately 90 public health professionals, technicians, and researchers responsible for water-quality monitoring and public notification at the 580 Great Lakes beaches that are routinely monitored under the BEACH Act. In addition, project staff provided CILER with survey questions and technical assistance. The 50-question survey achieved a response rate of 84% (n=76) and provided a wealth of information on the community-of-practice and its needs for maintaining and improving water-quality monitoring, mitigation, and public notification in the face of diminishing federal support.

Following this, project staff at Wisconsin DNR conducted a series of semi-structured interviews of the relevant water-quality specialists and public health managers within five selected communities: three in Wisconsin and two in Michigan (which had no technical assistance program, such as the one funded by this grant). These interviews provided deeper insights into the various factors influencing coastal health departments' decisions to implement (or not implement) nowcast modeling. Lastly, project staff at Wisconsin DNR conducted a series of semi-structured interviews with the principal developers (past and present) of the various versions of VB. These interviews provided greater insights into which characteristics of the system's research and development process were most helpful in terms of developing a decision-support system that was actually adopted into community practice, where so many others go unused.

## Major Accomplishments

All of the project's primary goals and objectives were met within the three-year project period. These included the establishment of operational nowcast models at 20 beaches in Wisconsin, including 10 high-priority beaches, and the resulting reduction in advisory decision errors and overall beach closures. Additional accomplishments included increased local awareness and capacity to use VB, the leveraging of resources through partnership and collaboration, and the development of new tools and methods for more cost-effective beach management.

### Primary Outputs

#### *The Expansion of Operational Nowcasts*

In 2010, prior to the initiation of the project, one beach in Wisconsin had an operational nowcast in place. This was one of just six beaches with nowcast models in operation across the Great Lakes region. By 2013, nowcast models were used to make advisory decisions at 21 beaches in Wisconsin, out of 77 beaches Great Lakes-wide (Figure 2).

Figure 3 shows the number of coastal counties that had at least one nowcast model in use between 2005 and 2013. Outside of Wisconsin, the disproportionate increase in beaches in Illinois is based on the development of several real-time models by the USGS Great Lakes Water Science Center, covering a total of 25 beaches within the City of Chicago. Funded under a separate GLRI grant, these models use data buoys deployed offshore to measure model input variables. Of the remaining 31 beaches with nowcast models in place in 2013, 22 beaches were covered by models developed and/or operated by personnel trained by the principal investigator, including two beaches in Illinois, one in Indiana, two in Michigan, one in New York, 10 in Ohio, and six in Pennsylvania.

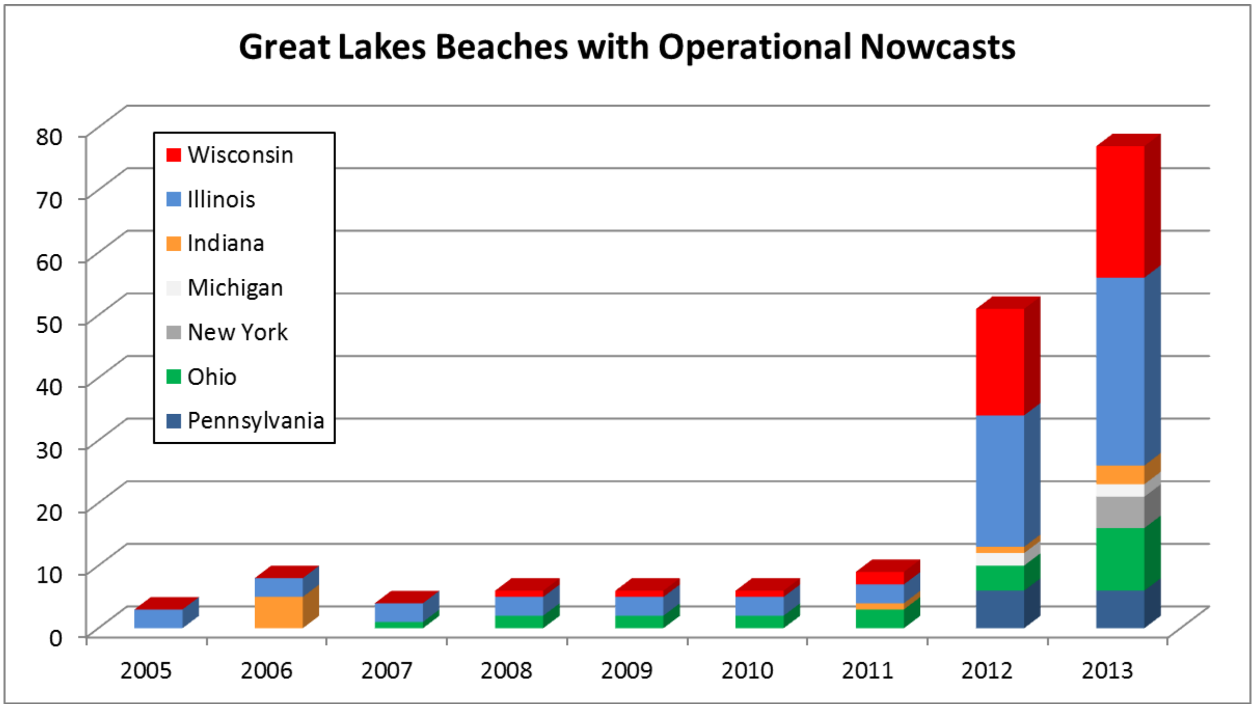



**Figure 2.** *Great Lakes beaches with operational nowcasts, 2005-2013.*

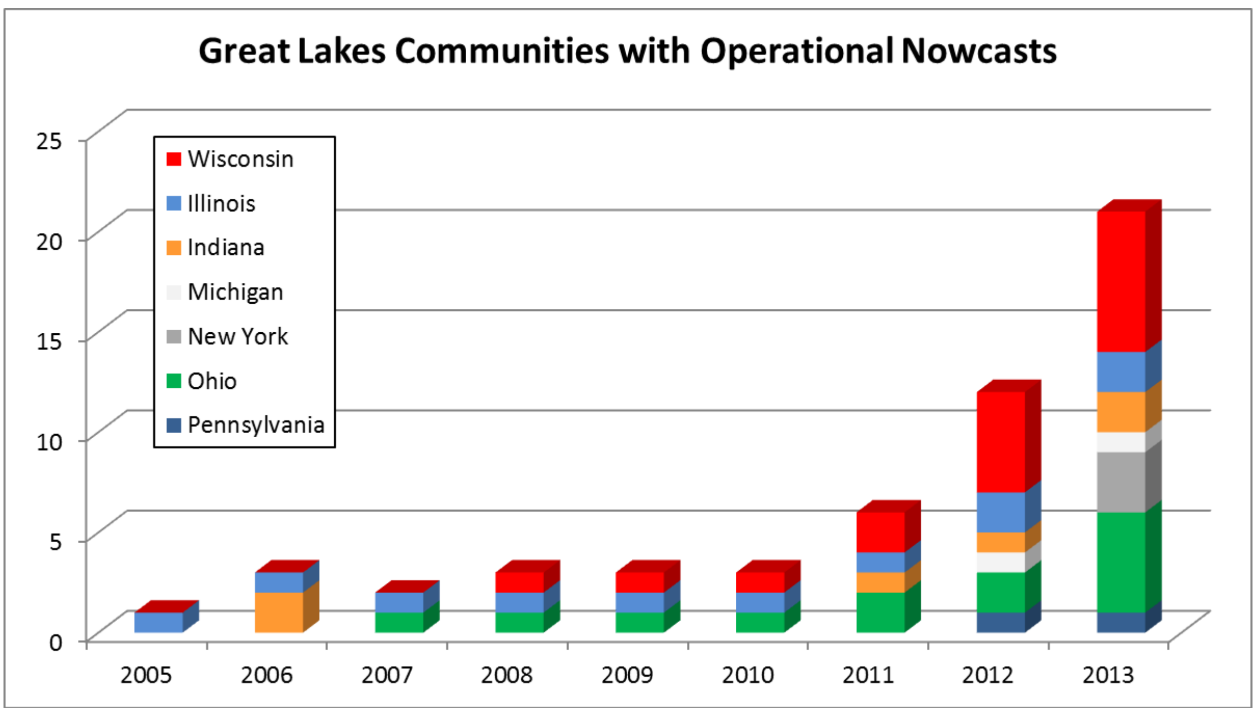



**Figure 3.** *Great Lakes counties with operational nowcasts, 2005-2013.*

### Reduction in Monitoring Errors

As summarized in Table 2 (page 5), the documented use of nowcast models resulted in the reduction in incorrect or unnecessary beach actions being taken in Wisconsin. Over the course of the project, local managers' decisions to issue or lift swim advisories, as well as beach closures, were correct 32 more times than would have been the case had only the standard, 18-hour lab test been used. This included 18 swim advisories and one closure that were necessary to protect public health but which would otherwise have been missed, in addition to the avoidance of five unnecessary advisories and eight closures that otherwise would have been issued.

With limited exceptions, only those beach actions for which the locally reported reason was listed as "Model" were counted in these tallies. The exceptions were five beach actions for which nowcast predictions are known to have informed the decision to re-test water quality using rapid qPCR analysis, subsequently resulting in a decision to issue or lift an advisory. In all, nowcast models are known to have informed 174 beach actions in Wisconsin during the project period. It is possible that additional beach actions were informed by nowcast models but were not reported as such; for example, in cases where a model prediction was one of several determinants, or when personnel mistakenly selected "Elevated Bacteria" as the reason for the decision when issuing an advisory via the Wisconsin Beach Health website.

### Reduction in Beach Closures

As anticipated, the use of nowcast predictions as the basis for beach actions led to the reduction in beach closures overall, through the avoidance of unnecessary closures posted the day after exceedances of the Wisconsin's closure threshold of 1,000 CFU of *E. coli*/100 mL. The documented use of nowcast models during the project period resulted in seven fewer beach closures than would have occurred if only the standard method of beach monitoring had been employed during the same period. This difference represents a 5% reduction in the number of closures for the 22 Wisconsin beaches that had a nowcast model in place for at least part of the three-year project period, and a 2% reduction in the number of beach closures in Wisconsin overall. Assuming the number of beaches with operational nowcasts and the proportion of beach actions taken according to their results continue to increase, the long-term result will be a substantial reduction in the number of beach closures in the Great Lakes region, simultaneous to a strengthening of public health protection through the reduction in the number of necessary advisories that are missed under the current standard practice.

## Secondary Outputs

### Increased Local Awareness and Capacity

Table 4 lists project presentations given by the principal investigator between 2011 and 2013. Table 3 (page 6) lists the VB training workshops conducted during the same period. According to the basin-wide survey conducted by CILER and the principal investigator, 18% of Great Lakes beach managers and monitoring personnel had used VB to develop, test, and/or operate a nowcast model as of the 2013 beach season. Of those who had not used VB, 78% reported that they were at least "somewhat familiar" with the software, with nearly half reporting that they were either "moderately familiar" (35%) or "very familiar"

(14%). Seventy percent reported being at least "moderately interested" in using the software themselves, including 15% who reported being "extremely interested" and 29% who reported being "very interested." Although similar data do not exist for the period prior to the project, it can be assumed that Wisconsin DNR's outreach and capacity-building efforts played a significant role in achieving these levels of interest and VB use.

**Table 4.** *Project presentations, 2011-2013.*

| Venue / Location | Date | Title | Authors |
|---|---|---|---|
| Lake Superior Beach Health Meeting – Ashland, WI | April 27, 2011 | Implementing nowcast models | Mednick, A.C. |
| Lake Michigan Beach Health Meeting – Racine, WI | May 4, 2011 | Implementing nowcast models | Mednick, A.C. |
| Coastal Zone 2011 – Chicago IL | May 3, 2011 | Predicting beach water quality: Operational "nowcasts" and long-term impact assessments | Mednick, A.C. |
| US EPA National Beaches Conference – Miami, FL | May 14, 2011 | Virtual Beach and other current approaches | Kinzelman, J.L.<br>Mednick, A.C. |
| US EPA National Beaches Conference – Miami, FL | Mar. 15, 2011 | Implementing predictive models on a broader scale: Current efforts in Wisconsin (Poster Presentation) | Mednick, A.C.<br>Kinzelman, J.L<br>Minks, K.R.<br>Ziegler, D.E. |
| Great Lakes Beach Association Conference – Michigan City, IN | Sept. 27, 2011 | Implementing predictive models on a broader scale | Mednick, A.C. |
| Midwest SDSS Partnership Annual Meeting – Chicago, IL | Jul. 9, 2012 | Implementation of Virtual Beach by local and county health departments | Mednick, A.C.<br>Watermolen, D.J. |
| Great Lakes Beach Association Conference – Mackinac Island, MI | Oct. 17, 2012 | Beach "nowcasting" in a post-BEACH Act world (Plenary Presentation) | Mednick, A.C. |
| International Association for Great Lakes Research Annual Conference – West Lafayette , IN | June 4, 2013 | Improving beach health through the integration of sanitary surveys, rapid methods, and mitigation: Coast-wide efforts in Wisconsin | Kinzelman, J.L.<br>Kleinheinz, G.<br>Mednick, A.C. |
| International Association for Great Lakes Research Annual Conference – West Lafayette , IN | June 4, 2013 | Advanced decision-support for coastal beach health: Virtual Beach 3.0 (Poster Presentation) | Cyterski, M.J.<br>Galvin, M.<br>Wolfe, K.L.<br>Brooks, W.R.<br>Corsi, S.R.<br>Roddick, T.<br>Mednick, A.C.<br>Rockwell, D. |
| Great Lakes Beach Association Conference – Sheboygan, WI | Oct. 17, 2013 | Wisconsin beach nowcast 2013: Results and lessons learned | Mednick, A.C. |

### *Increased Collaboration and Leveraging*

In addition to model development, training, and technical assistance, a substantial effort went into building partnerships with and among numerous federal, state, local, academic, and private entities involved in Great Lakes beach management, leading to greater collaboration and the leveraging of resources in pursuit of the expansion of nowcast modeling. Table 5 lists project cooperators, their roles, and the roles of Wisconsin DNR. Most notably, the principal investigator worked closely with research and development teams at EPA-ORD, USGS-WIWS, and USGS-CIDA to facilitate the joint development and release of VB 3.0, including the integration of GBM and PLS modeling capabilities and EnDDaT data-downloads into the software. Following the informal mode of partnership characterizing all aspects of the project, the joint development of VB 3.0 was non-contractual and entirely voluntary.

**Key** to letter codes used in **Table 5**, page 13.

| | |
|---|---|
| A | Develop/refine Virtual Beach |
| B | Develop/refine critical cyber-infrastructure (e.g., EnDDaT) |
| C | Develop/share nowcast models |
| D | Provide nowcast demonstration/training |
| E | Provide technical assistance |
| F | Collect/provide data |
| G | Implement operational nowcast models |
| H | Field test *Virtual Beach* |
| I | Field test critical cyber-infrastructure |
| J | Provide practical feedback on *Virtual Beach* |
| K | Provide practical feedback on critical cyber-infrastructure |
| L | Provide guidance/direction to *Virtual Beach* developers |
| M | Provide guidance/direction to developers of critical cyber-infrastructure |
| N | Provide interagency coordination |
| O | Provide expert input/review |
| P | Develop/provide case studies and examples of nowcast implementation |
| Q | Develop/propose new tools and methods for beach monitoring/management |
| R | Provide forums/channels for project communication |

**Table 5.** *Project cooperators and their respective roles.*

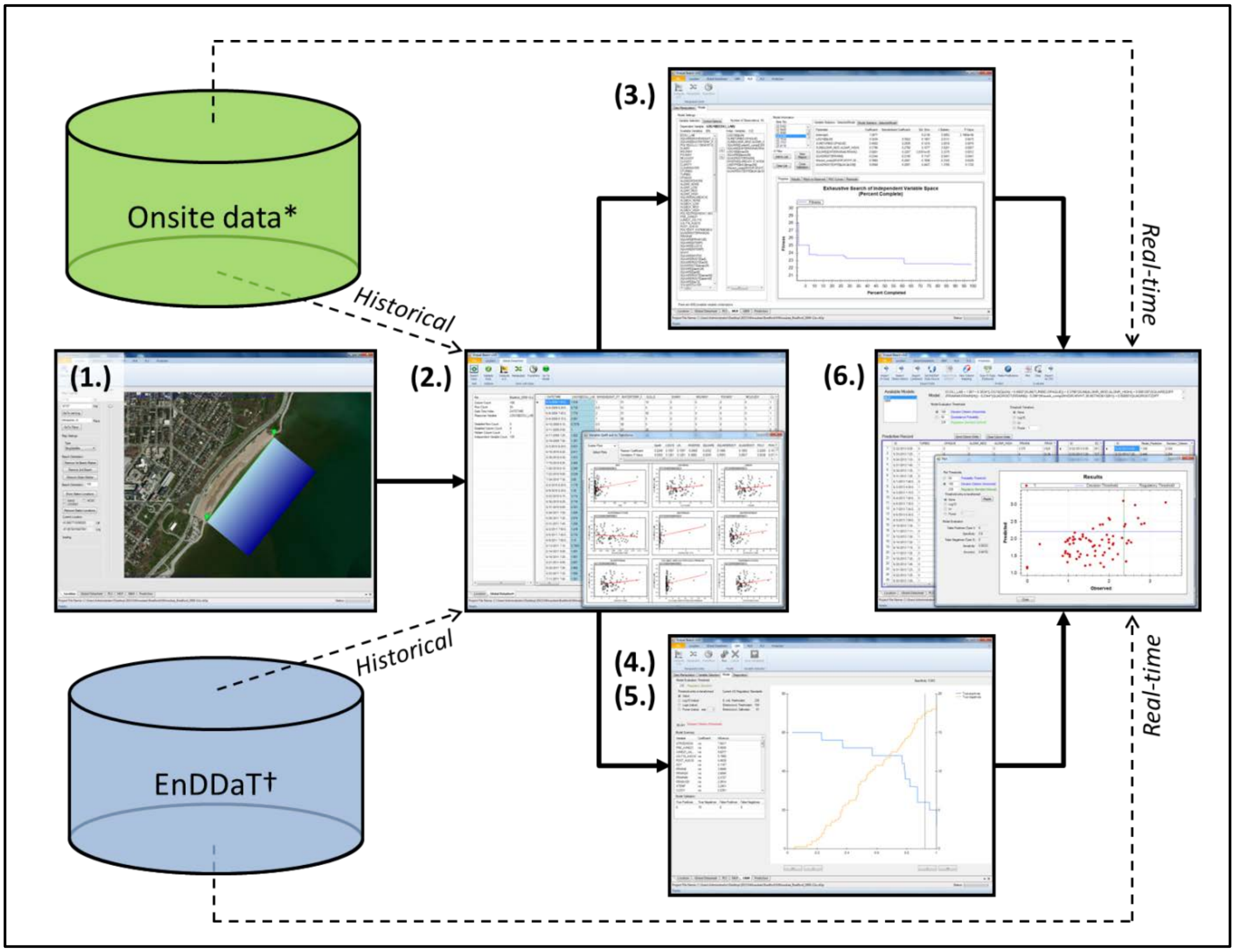
| Cooperator | Cooperator Roles* | Wisconsin DNR Roles* |
|---|---|---|
| **Federal** | | |
| USGS Wisconsin Water Science Center (WIWS) | A, C, D, E, H, O, Q | A, D, E, H, J, L, N, Q |
| EPA-ORD Ecosystem Research Division | A, D, E, O, Q | A, D, H, J, L, N, Q |
| USGS Center for Integrated Data Analysis (CIDA) | B, E, O, Q | D, I, K, M, N |
| USGS Ohio Water Science Center | D, E, H, O | D |
| NOAA Great Lakes Environmental Research Lab | B, E, O | I, K, N |
| National Weather Service - Milwaukee/Sullivan | B, E | I, K |
| EPA Great Lakes National Program Office | O | D, P, Q |
| EPA Office of Water | O | D, P, Q |
| **State** | | |
| Wisconsin Coastal Management Program | D, N, R | D, N, P, Q |
| Wisconsin Division of Health | N, R | D, N, Q |
| Michigan Department of Environmental Quality | O | E, Q |
| **Local** | | |
| Ozaukee County Public Health Department | F, G, H, I, J, K, O | C, D, E, N, P, Q |
| Racine Health Department | F, G, H, I, J, K, O | C, D, E, N, P, Q |
| Sheboygan County Health & Human Services | F, G, J | C, D, E, N, Q |
| Milwaukee Health Department | F, G, J | C, D, E, N |
| South Milwaukee Health Department | F, G, J | C, D, E, N |
| Ashland County Health & Human Services | F, G | D, N |
| Bayfield County Health Department | F, G | D, N |
| Manitowoc County Health Department | F, G | D, N |
| **Academic** | | |
| University of Wisconsin – Oshkosh | F, G, H, O | C, D, E, N |
| University of Wisconsin – Milwaukee | C, F, G, O | D, E, N |
| University of Michigan – CILER | C, H, J, L | D, E, N |
| **Private or Non-Profit** | | |
| Cardinal Environmental, Inc. | F, G, J | C, D, E, N |
| Alliance for the Great Lakes | F, Q | Q, D, E, N |
| Great Lakes Commission | B, R | I, K, M, N |
| Great Lakes Observing System | B | I, K, M, N |
| **Other** | | |
| Great Lakes Beach Association | D, R | D, P, Q |
| Midwest Decision-Support System Partnership | N, O | D, P, Q |
| Beach Health Interagency Coordinating Council | N, O | P, Q |

* Descriptions of roles played can be found on the previous page.

### *Cost-Effective Methods and Tools*

The collaboration between EPA, USGS, and Wisconsin DNR fostered an "agile" and "use-inspired" process of research and development, which made it possible to respond to changing needs and circumstances with new methods and tools. In particular, the proposed elimination of annual grants for beach monitoring and public notification from EPA's FY 2013 and FY 2014 budgets spurred the development of a new "two-tiered" method of nowcast modeling, by which sampling frequency can be reduced while the frequency of modeling can be expanded. A survey of all Great Lakes beach managers and monitoring personnel, with a response rate of over 70% (Rockwell et al. 2014), revealed that the overwhelming majority of coastal communities planned to either eliminate their monitoring programs altogether or to significantly reduce the number of beaches they monitor and/or the frequency at which they collect and test samples. Although funding was maintained under a continuing resolution in 2013 and restored by Congress for one year in 2014, the uncertainty and long-term outlook led the principal investigator to develop this approach as a more cost-effective means of monitoring. At the same time, the extreme heat wave and drought that occurred during the summer of 2012 showed that nowcast models need to be more robust under changing conditions in order to maintain public health protection and verify that GLRI-funded beach remediation projects remain effective.

The two-tiered approach to nowcast modeling (Figure 4, page 15, and Table 6, page 16) entails developing a pair of models for each beach: a Tier I ("standard") MLR model that uses a combination of filed-measurements and data downloaded from EnDDaT, and a Tier II ("all-automated") GBM or PLS model that exclusively uses EnDDaT data. Tier I models are operated on days when samples and sanitary-survey data are collected. Tier II models are operated on all other days. Prior to the development of VB 3.0, the barriers to implementing this approach were that it doubled the amount of time and effort required to develop models, while the process of inputting EnDDaT data into VB was confusing and required multiple steps. Cutting the time needed to develop VB models and enabling EnDDaT data to be downloaded directly into the VB were primary objectives during the final year of the project, and the principal developer worked with the research and development teams in EPA and USGS to make the necessary changes, routinely working onsite at USGS-WIWS directly with the principal programmer.




* Lab results and sanitary survey data (i.e., field-observed conditions). Ideally, these data will be digitally-archived and readily-accessible through a state or federal beach website; e.g., Wisconsin Beach Health (USGS 2003).

† The Environmental Data Discovery and Transformation Web portal (USGS 2013) enables users to access remotely-measured hydro-meteorological conditions, both historical and in near real-time, according to user-defined locations, time-windows, and data transformations.

**Figure 4.** *Two-tiered nowcasting with Virtual Beach 3.0. (See Table 6 [page 16] for descriptions of the specific functions in each tab.).*

**Table 6.** *Steps to two-tiered nowcast modeling with Virtual Beach 3.0.*

| **Step** (see Fig. 4) | **VB 3.0 Functions** |
|---|---|
| 1. Set Beach Orientation | a. Locate and view the target beach using standard maps and satellite imagery.<br>b. Set beach orientation (rotation in degrees from north-south) for subsequent processing of wind, current, and wave vector and magnitude data. |
| 2. Import and Process Historical Data | a. Import historical data; typically, 100 or more time-stamped (date-and-time) *E. coli* lab results, spanning two or more beach seasons, plus spatiotemporally matched data on as many potential explanatory variables as possible; e.g., wave height, water temperature, wind speed and direction, turbidity, gull counts, etc.<br>b. Rapidly scan and clean the data by identifying and removing (or correcting) missing or anomalous entries (by cell, row, column, or entire sheet).<br>c. View bivariate data plots to evaluate the relationship between the various potential explanatory variables and the bacterial response.<br>d. Decompose wind, current, and/or wave data (vector and magnitude) into “onshore” and “alongshore” components (velocity or height).<br>e. Combine potential explanatory variables via sum, difference, or product.<br>f. Manually or batch-transform (log, inverse, polynomial, power) potential explanatory variables.<br>g. Manually or batch-select the best transformations per potential explanatory variable according to default or user-defined thresholds. |
| 3. Develop MLR Model | a. Generate multiple-linear regression models through a genetic algorithm or exhaustive search of the variable space, optimized according to user-selected criteria: AIC, BIC, $R^2$, PRESS, sensitivity, specificity, or accuracy.<br>b. Perform cross-validation to simulate model performance in predictive mode.<br>c. Visually evaluate and select from among top-10 models according to dynamic plots of fitted-versus-actual values and statistical criteria (e.g., sensitivity).<br>d. Identify influential outliers using DFFITS and Cook’s distance and select from among the data-“reduced” models according to dynamic plots of fitted versus actual values and statistical criteria.<br>e. Graphically optimize decision thresholds; i.e. the point estimate or probability at which advisories are posted. |
| 4. Develop PLS Model | a. Generate partial-least squares models.<br>b. Graphically optimize decision thresholds. |
| 5. Develop GBM Model | a. Generate decision-tree models using a “gradient-boosting machine”.<br>b. Graphically optimize decision thresholds. |
| 6. Operate Models (Make Predictions) | a. Manually enter field-observed explanatory variables; e.g., water clarity.<br>b. Import remotely observed data from the EnDDaT Web portal; e.g., lake current speed and direction, antecedent rainfall, and sky conditions.<br>c. “Nowcast” (predict) current water quality conditions using the selected MLR, PLS, and/or GBM models. Includes a point-estimate of bacterial concentration and the probability of exceeding selected decision thresholds.<br>d. Evaluate model performance (sensitivity, specificity, accuracy) and decision thresholds using four-quadrant plots of predicted *E. coli* versus lab results. |

Because the process of developing VB 3.0 occurred up to and throughout the 2013 beach season, adoption of the two-tiered nowcast method was limited. Beta versions of VB 3.0 were used for this purpose at seven of the 21 beaches with operational models in 2013. Table 7 lists the validation results of the two-tier models developed for these beaches, plus models developed but not implemented at beaches that had traditional nowcast models in place in 2013. Significantly, both the Tier I and Tier II models outperformed traditional monitoring (i.e. the “persistence method”), as well as the hypothetical absence of monitoring (Figure 5). ***This approach effectively expands public health protection to seven days a week, while reducing the cost of sampling and testing.*** Wisconsin DNR’s efforts to develop and implement this method were recognized by the Environmental Council of States (ECOS) through its 2012 Innovation Award.

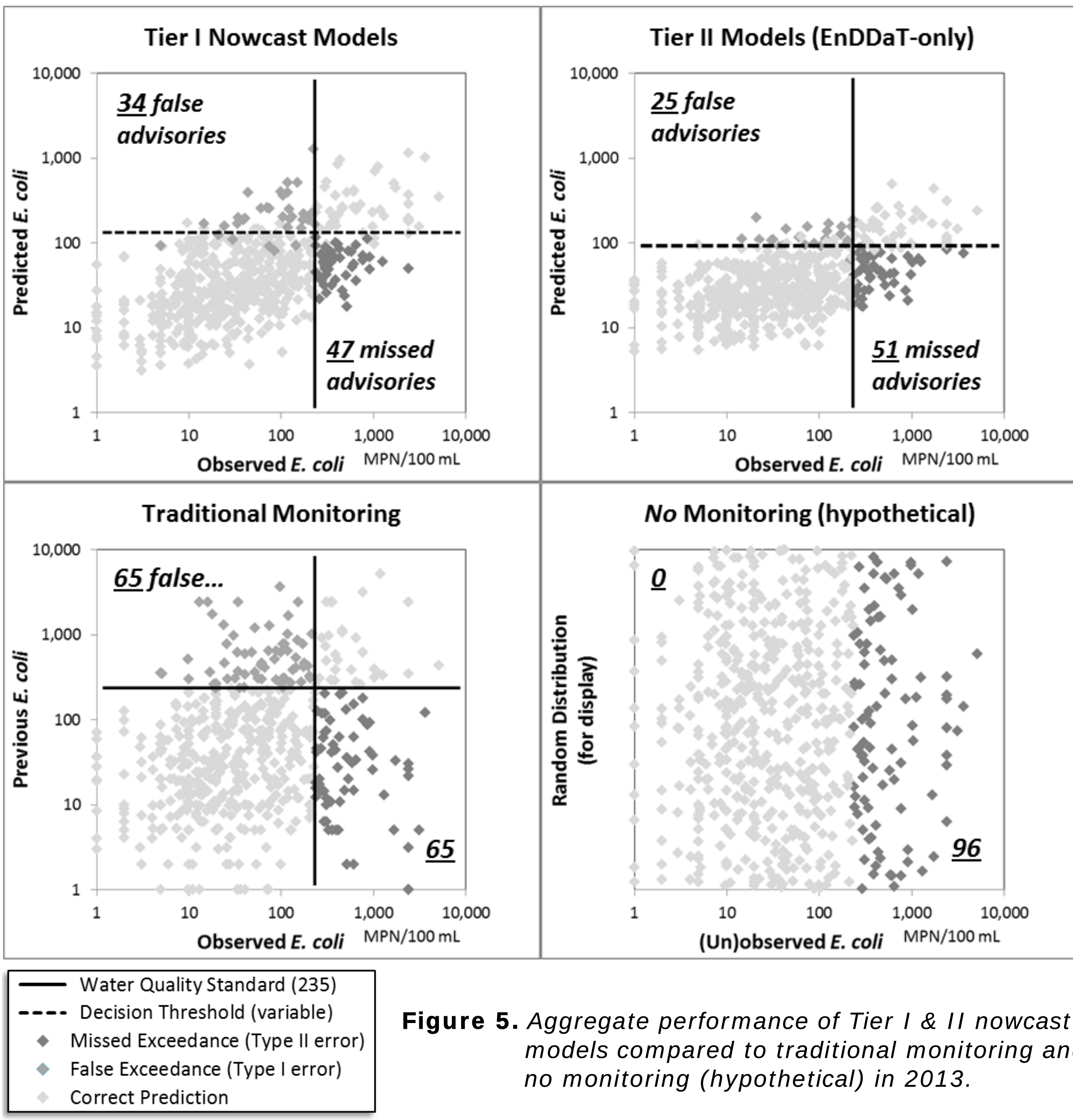



**Figure 5.** *Aggregate performance of Tier I & II nowcast models compared to traditional monitoring and no monitoring (hypothetical) in 2013.*

**Table 7.** *Season-wide validation of Tier I & II nowcast models, 2013.*

| Beach: | Decision- | Validation data (CFUs/ 100 mL): | | | | Precision: | | Decision support: | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Model type * | threshold | Samples | Pct. > 235 | Mean | Std. dev. | R-square | Mean error | Sensitivity | Specificity | Pct. Correct |
| **Aggregate:** | | n = 583 | 16% | 211 | 1,090 † | | | | | |
| Tier I (MLR) | Variable | | | | | 39% | +/- 183 | 52% | 93% | 86% |
| Tier II (PLS,GBM) | Variable | | | | | 32% | +/- 186 | 48% | 95% | 87% |
| Persistence | 235 CFU | | | | | 10% | +/- 319 | 30% | 87% | 77% |
| None (no monitoring) | | | | | | | | 0% | 100% | 84% |
| **Blue Harbor:** | | n = 29 | 10% | 146 | 390 | | | | | |
| Tier I (MLR) | 170 CFU | | | | | 54% | +/- 120 | 67% | 100% | 96% |
| Tier II (GBM) | 140 CFU | | | | | 63% | +/- 124 | 67% | 100% | 96% |
| Persistence | 235 CFU | | | | | 4% | +/- 253 | 0% | 92% | 82% |
| None (no monitoring) | | | | | | | | 0% | 100% | 90% |
| **Bradford:** | | n = 72 | 17% | 134 | 309 | | | | | |
| Tier I (MLR) | 160 CFU | | | | | 32% | +/- 117 | 64% | 90% | 86% |
| Tier II (GBM) | 90 CFU | | | | | 31% | +/- 99 | 64% | 92% | 87% |
| Persistence | 235 CFU | | | | | 4% | +/- 171 | 36% | 87% | 79% |
| None (no monitoring) | | | | | | | | 0% | 100% | 83% |
| **Cedar:** | | n = 59 | 27% | 244 | 478 | | | | | |
| Tier I (MLR) | 120 CFU | | | | | 25% | +/- 193 | 50% | 93% | 81% |
| Tier II (GBM) | 90 CFU | | | | | 28% | +/- 211 | 44% | 90% | 78% |
| Persistence | 235 CFU | | | | | 18% | +/- 245 | 56% | 83% | 76% |
| None (no monitoring) | | | | | | | | 0% | 100% | 73% |
| **County Highway D:** | | n = 53 | 13% | 127 | 345 | | | | | |
| Tier I (MLR) | 150 CFU | | | | | 27% | +/- 119 | 43% | 91% | 85% |
| Tier II (GBM) | 100 CFU | | | | | 33% | +/- 110 | 43% | 98% | 90% |
| Persistence | 235 CFU | | | | | 20% | +/- 187 | 14% | 87% | 77% |
| None (no monitoring) | | | | | | | | 0% | 100% | 87% |

* "Tier I" model = sampling-day nowcast. "Tier II" model = any time (automated) nowcast. "Persistence" model = standard monitoring (i.e., using previous days' *E. coli* to predict present water- quality conditions). MLR = multiple linear regression. PLS = partial least-squares. GBM = gradient boosted (decision tree) model.

† The sample set for which these statistics were calculated includes one lab result of >24,192 MPN (most probable number) per 100 mL. This is the maximum value possible for the IDEXX Colilert© test with a 1:100 sample dilution.

**Table 7.** *Season-wide validation of Tier I & II nowcast models, 2013 (continued).*

| **Beach:** | **Decision-** | **Validation data (CFUs/ 100 mL):** | | | | **Precision:** | | **Decision support:** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Model type ***** | **threshold** | Samples | Pct. > 235 | Mean | Std. dev. | R-square | Mean error | Sensitivity | Specificity | Pct. Correct |
| **Deland:** | | n = 29 | 3% | 33 | 51 | | | | | |
| Tier I (MLR) | 100 CFU | | | | | 34% | +/- 26 | 0% | 96% | 93% |
| Tier II (GBM) | 50 CFU | | | | | 0% | +/- 32 | 0% | 100% | 96% |
| Persistence | 235 CFU | | | | | 3% | +/- 49 | 0% | 96% | 93% |
| None (no monitoring) | | | | | | | | 0% | 100% | 97% |
| **General King:** | | n = 29 | 14% | 186 | 461 | | | | | |
| Tier I (MLR) | 100 CFU | | | | | 43% | +/- 157 | 50% | 96% | 89% |
| Tier II (GBM) | 100 CFU | | | | | 42% | +/- 148 | 75% | 92% | 89% |
| Persistence | 235 CFU | | | | | 3% | +/- 299 | 25% | 88% | 79% |
| None (no monitoring) | | | | | | | | 0% | 100% | 86% |
| **Grant:** | | n = 42 | 31% | 398 | 977 | | | | | |
| Tier I (MLR) | 170 CFU | | | | | 55% | +/- 313 | 67% | 93% | 85% |
| Tier II (PLS) | 120 CFU | | | | | 17% | +/- 353 | 42% | 100% | 83% |
| Persistence | 235 CFU | | | | | 9% | +/- 598 | 33% | 69% | 59% |
| None (no monitoring) | | | | | | | | 0% | 100% | 69% |
| **Harrington North:** | | n = 54 | 13% | 159 | 369 | | | | | |
| Tier I (MLR) | 130 CFU | | | | | 34% | +/- 142 | 43% | 91% | 85% |
| Tier II (PLS) | 80 CFU | | | | | 21% | +/- 139 | 29% | 96% | 87% |
| Persistence | 235 CFU | | | | | 15% | +/- 204 | 29% | 89% | 81% |
| None (no monitoring) | | | | | | | | 0% | 100% | 87% |
| **Harrington South:** | | n = 55 | 20% | 191 | 390 | | | | | |
| Tier I (MLR) | 120 CFU | | | | | 36% | +/- 157 | 55% | 93% | 85% |
| Tier II (GBM) | 90 CFU | | | | | 27% | +/- 162 | 36% | 88% | 78% |
| Persistence | 235 CFU | | | | | 9% | +/- 279 | 18% | 79% | 67% |
| None (no monitoring) | | | | | | | | 0% | 100% | 80% |

* “Tier I” model = sampling-day nowcast. “Tier II” model = any time (automated) nowcast. “Persistence” model = standard monitoring (i.e., using previous days’ *E. coli* to predict present water- quality conditions). MLR = multiple linear regression. PLS = partial least-squares. GBM = gradient boosted (decision tree) model.

† The sample set for which these statistics were calculated includes one lab result of >24,192 MPN (most probable number) per 100 mL. This is the maximum value possible for the IDEXX Colilert© test with a 1:100 sample dilution.

**Table 7**. *Season-wide validation of Tier I & II nowcast models, 2013 (continued).*

| **Beach:** | **Decision-** | **Validation data (CFUs/ 100 mL):** | | | | **Precision:** | | **Decision support:** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Model type ***** | **threshold** | Samples | Pct. > 235 | Mean | Std. dev. | R-square | Mean error | Sensitivity | Specificity | Pct. Correct |
| **North:** | | n = 54 | 17% | 563 † | 3,282 † | | | | | |
| Tier I (MLR) | 80 CFU | | | | | 63% | +/- 538 | 33% | 93% | 83% |
| Tier II (GBM) | 80 CFU | | | | | 65% | +/- 547 | 44% | 95% | 87% |
| Persistence | 235 CFU | | | | | 2% | +/- 1,054 | 11% | 86% | 74% |
| None (no monitoring) | | | | | | | | 0% | 100% | 83% |
| **Upper Lake Park:** | | n = 54 | 9% | 97 | 336 | | | | | |
| Tier I (MLR) | 180 CFU | | | | | 35% | +/- 82 | 40% | 100% | 94% |
| Tier II (PLS) | 90 CFU | | | | | 18% | +/- 89 | 40% | 100% | 94% |
| Persistence | 235 CFU | | | | | 0% | +/- 146 | 40% | 94% | 89% |
| None (no monitoring) | | | | | | | | 0% | 100% | 91% |
| **Zoo:** | | n = 53 | 15% | 193 | 483 | | | | | |
| Tier I (MLR) | 90 CFU | | | | | 44% | +/- 165 | 63% | 84% | 80% |
| Tier II (GBM) | 60 CFU | | | | | 54% | +/- 167 | 75% | 91% | 88% |
| Persistence | 235 CFU | | | | | 4% | +/- 288 | 25% | 91% | 80% |
| None (no monitoring) | | | | | | | | 0% | 100% | 85% |

* “Tier I” model = sampling-day nowcast. “Tier II” model = any time (automated) nowcast. “Persistence” model = standard monitoring (i.e., using previous days’ *E. coli* to predict present water- quality conditions). MLR = multiple linear regression. PLS = partial least-squares. GBM = gradient boosted (decision tree) model.

† The sample set for which these statistics were calculated includes one lab result of >24,192 MPN (most probable number) per 100 mL. This is the maximum value possible for the IDEXX Colilert© test with a 1:100 sample dilution.

## Lessons Learned

In conducting this project, Wisconsin DNR learned several critical lessons, which will guide future work by the agency and its partners in the face of continued uncertainty regarding federal funding for routine beach monitoring and public notification under the BEACH Act. These findings should be useful to the EPA, as well, as the agency continues to develop and refine its policy and technical guidance on beach monitoring, including rapid methods and modeling. More broadly, some of the lessons learned can inform parallel efforts to develop and transfer decision support-systems for sustainable community development and water resource management.

### Variable Local Capacity

Among the critical lessons learned over the course of this project is that coastal communities' capacity to implement nowcast modeling varies widely. Results of the online survey showed that nearly one-third of local health departments responsible for beach management reported having fewer than 10 staff members. Of the 21 local health departments responsible for more than five beaches, over three-quarters estimated that beach related work represented less than 10% of their overall staff time (the lowest possible category), while more than a third reported that summer interns carried out more than half of their departments' beach related workloads. These findings are not surprising, given that local health departments are typically responsible for a wide range of services, including routine and complaint-based inspections of restaurants, lodging, public and private wells, and other facilities, as well as immunizations, educational programs, community outreach, permitting, and clerical work. Coupled with the experience of project staff, interviews of practitioners in the five selected communities showed that those communities with the typical staff and resource constraints were able to operate nowcast models, but were unable to develop and maintain them on their own.

### Validation and Calibration

An important lesson learned during the course of this project was that nowcast models must be validated during the course of a beach season – not simply at the end of the season – as the underlying hydro-meteorological conditions may dramatically change under unusual weather conditions. This occurred during the summer of 2012, which was characterized by historically extreme water temperatures, prolonged periods of drought, low tributary flows, and abnormally large *Cladophera* blooms punctuated by a few large storm events. These conditions led project staff to manually re-calibrate the nowcast models that had been developed for three beaches in Ozaukee County. Relying on recent observations to optimize the models, this iterative process was largely manual and extremely time-intensive. Subsequent changes were made to VB and the Wisconsin Beach Health Web data archive to address these issues and make the process of mid-season validation and calibration significantly simpler and less time-consuming.

### "Use-Inspired" Research and Development

One of the most important lessons of this project was that it is possible to conduct research and development of model-based, decision-support systems in a manner that results in actual use and adoption at the local level. Over the past decade, the EPA has invested a considerable amount of resources and effort into developing and providing data and tools to help local communities to manage their growth and environmental resources more sustainably. These efforts, however, belie a 50-year history of extensive research and development of computerized, decision-support systems in various domains (see Shim et al. 2002, Arnott and Pervan 2005), including community development (see Geertman et al. 2013) and water resources management (see Hayes and McKee 2001, Giupponi et al. 2011). Unfortunately, the recent proliferation of such research and development efforts has not translated into widespread adoption of decision-support systems.

VB represents a rare case in which a decision-support system has been adopted widely by members of its targeted community-of-practice, at least in the Great Lakes region. The approach taken, of which Wisconsin DNR's project staff members were integrally involved, could be termed "use-inspired" research and development, in that it was highly flexible and responsive to the practical and operational needs of local users. In addition to the principal investigator's experience, interviews with members of the original and current research and development teams at EPA-ORD's Ecosystems Research Division in Athens, as well as the research and development teams at USGS WIWS/CIDA reveal several defining characteristics of the successful development and technology transfer of VB. These include the following:

- *Informal initiation of the research and development process*. The early work that led to the development of VB was not initiated at the request of the Office of Water, in response to the BEACH Act, but began as a low-level work effort within ERD. This meant that there was not immediately a set direction. It also engendered a strong sense of personal ownership on the part of original developers, and most importantly set the precedent that system development was to be conducted in-house by ERD staff, as opposed to outside contractors.

- *Open-ended prototyping*. A long period of low-level prototyping meant that different modeling and decision-support approaches could be experimented with before a formal directive was issued to create something like VB. This saved time and effort in the long run, as methods that may have appeared scientifically interesting, but would have proved operationally difficult (especially hydro-dynamic, as opposed to empirical modeling) had already been tested and ruled out.

- *The establishment of a system mandate*. When the formal directive for the development of VB did come, in 2008, it provided the needed "push" for the system to be developed and implemented.

- *A cooperative extension approach to user engagement*. Rather than the standard "involvement" of potential users through meetings, workshops, and/or Webinars, Wisconsin DNR's project followed a classical "extension" model of technology transfer. In this model, the principal investigator worked as a fulltime change-agent, dedicated to providing practitioners in coastal communities around the Great Lakes with information, training, and (in Wisconsin) on-demand technical assistance on VB, while simultaneously working with the research and development teams to enhance the system to meet the needs of users.

- *Agile software development*. Because VB was developed in-house at ERD and USGS – with project staff providing a channel of communication from users in the field – the development of the system was highly agile; that is, constantly responsive to feedback and suggestions from users. Had the system been developed by outside contractors, this level of responsiveness would not likely have been possible.

- *The incorporation of outside innovations*. Wisconsin DNR's project staff helped to facilitate collaboration between the research and development teams in EPA's ORD office in Athens, GA and USGS-WIWS in Middleton, WI. Eventually, the two teams decided to combine their respective efforts, leading to the incorporation of new modeling methods within VB and the direct integration of Web-based hydro-meteorological data from NOAA and USGS, via USGS' Environmental Data Discovery and Transformation (EnDDaT) system. This in turn, enabled the development of the more cost-effective 'two-tiered' nowcasting approach.

- *Adaptation to changing circumstances*. Lastly, the involvement of Wisconsin DNR's project staff in the development process helped to keep the research and development teams abreast of rapidly changing circumstances and needs within the community-of-practice, and adapt the system accordingly. Most notable, was the proposed elimination of BEACH Act funding and the ramifications that that had for states and their local cooperators. The integration of VB 3.0 with the EnDDaT system was a direct and rapid response to this circumstance. This not only maintained the system's relevance, it markedly increased interest among coastal communities looking for a cost-effective means of reducing sampling while maintaining (or improving) public health protection.

### The Role of Professional 'Change-Agents'

As suggested by the preceding discussion, perhaps the most important lesson learned from the project was the pivotal role played by professional change-agents, such as Wisconsin DNR's project staff, who were dedicated full-time to providing local practitioners with information, training, and on-demand technical assistance, while at the same time working closely with system developers to respond to the feedback and suggestions of the real-world users. Essentially, project staff functioned as cooperative extension agents to members of the community-of-practice of beach managers in Wisconsin. Using this classical and proven model of innovation-diffusion, Wisconsin DNR was able to achieve far greater technology transfer at equal or less cost than efforts in other states that focused on individual beaches or communities.

Interviews of practitioners within the three selected Wisconsin communities and two communities in Michigan suggested that project staff played two critical roles in increasing communities' ability and willingness to adopt nowcast modeling. One was to build local capacity and confidence. Interviewed practitioners emphasized that having the assistance of the change-agent built confidence in VB and nowcasting. The other was to make VB more operationally useful to practitioners by working with the VB research and development teams within EPA and USGS to make changes to the system's design and functionality – in order to best meet local users' practical needs. Related to this, project staff helped to bring about the collaboration between the EPA and USGS research and development teams and the eventual integration of their respective modeling and data tools into VB 3.0.

## Future Work: Institutionalizing Nowcast Modeling

Based on the lessons learned from this project, future work will concentrate on making nowcast modeling more institutionalized (i.e. self-sustaining) at the local level. To this end, Wisconsin DNR and the Wisconsin Coastal Management Program are sponsoring a University of Wisconsin Sea Grant initiative to develop key resources necessary to support the use of VB and the implementation of nowcast modeling over the long term, in the absence of the kind of centralized support that was provided previously with GLRI funding. In addition to building capacity for nowcasting, this effort will create guidance materials to address decision-making based on nowcast models, monitoring considerations, and model maintenance. The Sea Grant project will also invest in developing a Wisconsin Coastal beaches working group that provides a network to share best practices, addresses current issues or problems faced on the local level, brings consistency to implementation, and is led from within. Specific activities of this effort include:

- Developing guidance on nowcast operation to include initial calibration, validation, data quantity and quality, and decision criteria for local operators.
- Developing on-line training and help resources for nowcast developers and users.
- Conducting trainings for Wisconsin DNR staff, local users, and managers.
- Establishing a Wisconsin Coastal Beaches Working Group, including nowcast users who can share experiences and best practices.

## Recommendations

> *"Consider a research intervention that is conducted in a health organization, in which a new program is introduced and evaluated. After the research project is completed and special funding and expertise end, will the innovative program continue or will it be dropped?"*
>
> - Everett Rogers (2003) *Diffusion of Innovations*: page 429.

Building on the findings and lessons learned during the course of Wisconsin DNR's GLRI "nowcast" project, we offer the following recommendations to help ensure the continued expansion and long-term sustainability of nowcast modeling in the Great Lakes and elsewhere. The EPA encourages coastal states and locales to use predictive models through its revised recreational water quality criteria. Our experience, however, along with the results of the comprehensive survey and in-depth interviews of Great Lakes beach managers, suggests that the *region-wide* adoption and sustained use of nowcast modeling will require strategic investments in three critical areas: (1) online data infrastructure, (2) software maintenance, and (3) extension services. Investments in these three areas could enable a more timely transition from traditional (sample intensive) monitoring to the more accurate and *cost-effective* "two-tiered" modeling approach described earlier (page 14). This transition would ensure the continued protection of public health at Great Lakes beaches in the event that BEACH Act funding for traditional monitoring is in fact eliminated, as has been proposed in each of the past two federal budgets.

**1. Online Data Infrastructure.** *Provide targeted funding to improve the operational capacity of the Environmental Data Discovery and Transformation (EnDDaT) system.*

The integration of VB with the EnDDaT online data system not only has improved the ease and accuracy of nowcast-based decision-making, it has enabled local beach managers to expand their monitoring frequency from intermittent to daily – at a reduced cost. EnDDaT is the lynchpin of this approach. Without it, cost-effective daily nowcasts are not possible[1]. Developed by the USGS with funding from an early round of the GLRI, EnDDaT represents the leading-edge of real-time, online data infrastructure; however, its capacity to meet the growing demand for operational nowcast modeling is limited severely. In particular, it is vulnerable to data transmission failures when the volume of 'data calls' from users is high, and in instances when there are unreported interruptions or slow-downs in one or more of the Web data services that feed the system. Strategic project funding could improve EnDDaT's throughput and stability under high use conditions, and could enable automated performance tracking and outage notifications. Together with improvements being made to its contributing Web data services, a strategic investment in these improvements would help ensure that EnDDaT can support operational nowcasts at several hundred beaches on a daily basis.

[1] A few locales have deployed their own in-situ measuring stations (nearshore data buoys or sondes installed on drilled piers) to provide real-time input data to run nowcast models. These systems cost approximately $30,000 each, not including annual deployment and removal, storm repair, and maintenance. For the vast majority of coastal communities, these systems are cost-prohibitive.

**2. System Maintenance.** *Maintain basic support for periodic updates and bug-fixes to Virtual Beach.*

A key factor in the success of our GLRI nowcast project was the availability and willingness of software developers at the EPA to make user-requested updates and bug fixes to VB. Had the EPA not supported these efforts at several critical junctures, implementing operational nowcasts would have been largely impossible, resulting in the failure of the GLRI nowcast project. Moving forward, it is essential that there be at least some level of continued support for the EPA software developers to update VB to fix newly discovered or emerging problems; at a minimum, those problems caused by changes in operating systems, computing environments, etc.

**3. "Extension" Services.** *Support nowcast training, technical support, and guidance across the Great Lakes.*

The other critical factor in the success of Wisconsin DNR's GLRI nowcast project was the availability of a dedicated staff person to provide extension services, including training and technical support to local practitioners across the Great Lakes, as well as direction to the relevant research and development teams. This approach to "diffusing" innovations among practitioners in various domains has a long and proven track record of success (Rogers 2003). In contrast, projects that have relied on technical experts to develop and implement a few 'one-off' models, from start to finish, have proven to be inefficient and unsustainable. In Wisconsin, post-GLRI nowcast work is focusing on the establishment of a VB Users Group and online training materials with the aim of sustaining local adoption and use in the absence of dedicated extension staff. The ultimate effectiveness of this limited approach is yet to be seen. A complimentary approach with a far greater likelihood of success would be for the EPA to support at least one region-wide extension agent for nowcast modeling throughout the Great Lakes. This could be a full-time position, or part of one or more positions at EPA or an appropriate extension agency.

## Acknowledgements

Many individuals contributed to the success of this project. First and foremost was Richard Zdanowicz, U.S. EPA Region 5 (retired). In essence, this was his project. Within the Wisconsin DNR, a number of staff (past and present) provided assistance, including: Ron Arneson, Kate Barrett, Donalea Dinsmore, Sandy Duran, Karin Fassnacht, James Fowler, Lisa Helmuth, Bob Holsman, Sally Kefer, Kathy Koch, Mike Kvitrud, Gina LaLiberte, Ryan Marty, Bob Masnado, Kyle Minks, Linda Morgan, Kim Ness, Jordan Petchenik, Kim Peterson, Greg Pils, Chris Pracheil, Matt Rehwald, Deb Rohrbeck, Lisa Stacey, Jack Sullivan, Jerry Sullivan, Michelle Voss, Dougal Walker, Kim Walz, and Chris Welch.

The following scientists developed Virtual Beach and provided invaluable assistance and collaboration. From U.S. EPA's Ecosystem Research Division in Athens, Georgia: Mike Cyterski, Walt Frick, Mike Galvin, Zhongfu Ge, Rajbir Parmar, Candida West, Kurt Wolfe, and Richard Zepp. And from the USGS Wisconsin Water Science Center in Middleton, Wisconsin: Wesley Brooks, Becky Carvin, Steve Corsi, Mike Fienen, and Tonia Roddick.

Many individuals from a wide range of agencies provided critical data and technical support. From the USGS Center for Integrated Data Analysis in Middleton, Wisconsin, these included Dave Blodgett, Nate Booth, Laura De Cicco, Carolyn Emmanuelli, Jessica Lucido, Alice McCarthy, Susan Phillips, Morgan Schneider, and David Sibley. From NOAA's Great Lakes Environmental Research Laboratory, these included Greg Lang and David Schwab. From the Great Lakes Commission, these included Christine Manninen and Guan Wang. These also included Tad Slawecki from LimnoTech, Bill Kramer from EPA’s Office of Water, and Brian Hahn from the National Weather Service, Milwaukee/Sullivan, Wisconsin.

Guidance and timely support were supplied by additional federal and state personel. Within U.S. EPA, these included Tamara Anan'eva, Frank Anscombe, Judy Beck, Mike Bland, Tom Brody, John Dorkin, Elizabeth Hinchey-Malloy, Beth Leamond, Zenny Sadlon, Daniel Samardzich, John Wathen, Holly Wirick, and Gigi Zywicki. Within USGS, these included Amie Brady, Donna Francy, Sheridan Haack, Meredith Nevers, and Richard Whitman. Within Wisconsin state government, these included Anne Iwata, Todd Breiby, and Mike Friis of the Wisconsin Coastal Management Program and Mark Werner and Emelia Wollenburg of the Wisconsin Department of Health Services. Outside of Wisconsin, these included Shannon Briggs of the Michigan Department of Environmental Quality and Michelle Caldwell of the Indiana Department of Environmental Management.

David Rockwell of the University of Michigan's Cooperative Institute for Limnology and Ecosystems Research provided a wealth of guidance and support, as did Kim Busse, Reynee Kachur, Greg Kleinheinz, and Nilay Sheth of the University of Wisconsin-Oshkosh and Todd Brennan of the Alliance for the Great Lakes.

Most importantly, the success of this project is owed to the local health department personnel and contractors who implemented nowcasts: Kirsten Johnson and Dan Ziegler of the Ozaukee County Public Health Department; Joel Brunner, Julie Kinzelman, Adrian Koski, and Stephan Kurdas of the Racine Health Department; David Roettger, Shirley Rohde, and Bobbi Stauber of the Sheboygan County Department of Health and Human Services; Jon Gabrielse, Amanda Greuel, and Scott Hanson of Cardinal Environmental, Inc.; Terri Linder and Lindor Schmidt of the Milwaukee Health Department; John Hernandez, Todd Miller, and Chelsea Weirich of the University of Wisconsin at Milwaukee; and Marty Zabkowicz of the South Milwaukee Health Department.

## Sources Cited

Ara, S. (2007). *The Influence of Water Quality on the Demand for Residential Development around Lake Erie.* Unpublished Dissertation. Columbus, OH: Ohio State University.

Austin, J., Anderson, S., Courant, P., & Litan, R. (2007). *Healthy Waters, Strong Economy; The Benefits of Restoring the Great Lakes Ecosystem*. Washington, DC: The Brookings Institution.

Brooks, W.R., Fienen, M.N., & Corsi, S.R. (2013). Partial least squares for efficient models of fecal indicator bacteria on Great Lakes beaches. *Journal of Environmental Management* 114(0):470-475.

Cyterski, M., Brooks, W., Galvin, M., Wolfe, K., Carvin, R., Roddick, T., et al. (2013). *Virtual Beach 3: User's Guide*. Athens, GA: U.S. Environmental Protection Agency.

Evans, G.W., & Kantrowitz, E. (2002). Socioeconomic status and health: the potential role of environmental risk exposure. *Annual Review of Public Health* 23(1):303-331.

Farquhar, S.A., Parker, E., Schulz, A., & Israel, B. (2005). In their words: How Detroit residents perceive the effects of their physical environment. [Article]. *Local Environment* 10(3):259-274.

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., & Darner, R.A. (2007). *Nowcasting beach advisories at Ohio Lake Erie beaches* (No. Open File Report 2007-1427). Reston, VA: U.S. Geological Survey.

Francy, D.S., Gifford, A.M., & Darner, R.A. (2003). Escherichia coli *at Ohio Bathing Beaches: Distribution, Sources, Wastewater Indicators, and Predictive Modeling* (No. Water-Resources Investigations Report 02-4285). Columbus, OH: U.S. Geological Survey.

Frick, W.E., Ge, Z., & Zepp, R. (2008). Nowcasting and forecasting concentrations of biological contaminants at beaches: A feasibility and case study. *Environmental Science and Technology* 42(13):4,818-4,824.

Given, S., Pendleton, L., & Boehm, A.B. (2006). Regional public health cost estimates of contaminated coastal waters: A case study of gastroenteritis at Southern California beaches. *Environmental Science and Technology* 40(16):4,851-4,858.

Kinzelman, J., & Hiller, J. (2007). Incorporating education and outreach in the re-engineering of a storm water outfall impacting recreational water quality at two public bathing beaches on Lake Michigan. *Journal of Marine Education* 23(2):13-18.

Loomis, J.B., & Crespi, J. (1999). Estimated effects of climate change on selected outdoor recreation activities in the United States. In R. Mendelsohn & J.E. Neumann (eds.). *The Impact of Climate Change on the United States Economy* (pp. 289–314). Cambridge, UK: Cambridge University Press.

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., & Watermolen, D.J. (2009). *Beach Pathogen Forecasting Tools: Pilot Testing, Outreach, and Technical Assistance*. Madison, WI: Bureau of Science Services, Wisconsin Department of Natural Resources.

Murray, C., Sohngen, B., & Pendleton, L. (2001). Valuing water quality advisories and beach amenities in the Great Lakes. *Water Resources Research* 37(10):2,583-2,590.

Nevers, M.B., & Whitman, R.L. (2005). Nowcast modeling of *Escherichia coli* concentrations at multiple urban beaches of Southern Lake Michigan. *Water Research* 39(20):5,250-5,260.

Olyphant, G.A., Thomas, J., Whitman, R.L., & Harper, D. (2003). Characterization and statistical modeling of bacterial (*Escherichia coli*) outflows from watersheds that discharge into southern Lake Michigan. *Environmental Monitoring and Assessment* 81(1):289-300.

Olyphant, G.A., & Whitman, R.L. (2004). Elements of a predictive model for determining beach closures on a real time basis: The case of 63rd Street Beach Chicago. *Environmental Monitoring and Assessment* 98(1):175-190.

Patz, J.A., Vavrus, S.J., Uejio, C.K., & McLellan, S.L. (2008). Climate change and waterborne disease risk in the Great Lakes region of the US. *American Journal of Preventive Medicine* 35(5):451-458.

Rabinovici, S.J.M., Bernknopf, R.L., Wein, A.M., Coursey, D.L., & Whitman, R.L. (2004). Economic and health risk trade-offs of swim closures at a Lake Michigan beach. *Environmental Science and Technology* 38(10):2,737-2,745.

Rockwell, D., Joseph-Joshi, S, Mednick, A. & Wirick, H. (2014). *Beach Health Information Needs Assessment Nine Years Later: Results from Follow Up Survey* (No. NOAA Technical Memorandum GLERL-163). Ann Arbor, MI: NOAA Great Lakes Environmental Research Laboratory.

Rogers, E.M. (2003). *Diffusion of Innovations*, 5th ed. New York, NY: Free Press. 576 p.

Shaikh, S.L. (2012). *The value of beach visits and the effect of swim bans in Chicago*. Paper presented at the Delivering Healthy Water Workshop, University of Stirling. Retrieved from http://www.deliveringhealthywater.net/wp-content/uploads/2012/10/Sabina-Shaikh_REVISED.pdf

Song, F., Lupi, F., & Kaplowitz, M. (2010). *Valuing Great Lakes beaches.* Paper presented at the Agricultural and Applied Economics Association, 2010 AAEA,CAES, and WAEA Joint Annual Meeting, Denver, CO.

U.S. Environmental Protection Agency (EPA). (2013). BEACON 2.0 - Beach Advisory and Closing On-line Notification. Retrieved December 5, 2013, from http://watersgeo.epa.gov/beacon2/

Wade, T.J., Pai, N., Eisenberg, J.N.S., & Colford Jr., J.M. (2003). Do US Environmental Protection Agency water quality guidelines for recreational waters prevent gastrointestinal illness? A systematic review and meta-analysis. *Environmental Health Perspectives* 111(8):1,102.

Whitman, R.L., Nevers, M.B., & Gerovac, P.J. (1999). Interaction of ambient conditions and fecal coliform bacteria in Southern Lake Michigan beach waters: Monitoring program implications. *Natural Areas Journal* 19(2):166-171.

# Science Services

**Center for Excellence –**
**providing expertise for science-based decision-making**

---

**We develop and deliver science-based information, technologies, and applications to help others make well-informed decisions about natural resource management, conservation, and environmental protection.**

**Our Mission:** The Bureau of Science Services supports the Wisconsin Department of Natural Resources and its partners by:

- conducting applied research and acquiring original knowledge.
- analyzing new information and emerging technologies.
- synthesizing information for policy and management decisions.
- applying the scientific method to the solution of environmental and natural resources problems.
- providing science-based support services for management programs department-wide.
- collaborating with local, state, regional, and federal agencies and academic institutions in Wisconsin and around the world.

---