Forecasting Recreational Water Quality Standard Violations with a Linked Hydrologic-Hydrodynamic Modeling System

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Background

There is a clear need in the public health and water resource management communities to develop modeling systems which provide robust predictions of water quality and water quality standard violations, particularly in coastal communities. These predictions have the potential to supplement, or even replace the conventional beach closure decision strategies based on day-old fecal indicator bacteria monitoring results.

Here, we present a coupled modeling system which builds upon recent advancements in watershed-scale hydrological modeling and coastal hydrodynamic modeling, including the evolution of the Huron-Erie Connecting Waterways Forecasting System (HECWFS), developed through a partnership between NOAA's Great Lakes Environmental Research Laboratory (GLERL) and the University of Michigan Cooperative Institute for Limnology and Ecosystems Research (CILER).

To what extent may a linked hydrologic-hydrodynamic model be useful?

Assumptions, Challenges, and Potential

A linked hydrologic-hydrodynamic model for use as a nearshore water quality forecasting tool assumes that the watershed makes a significant contribution to the nearshore water quality. Specifically, it assumes that pollution introduced to the nearshore environment directly from the landscape (i.e. waterfowl droppings on the beach and directly into the lake) is negligible relative to the contribution from the watershed introduced via river(s).

One of the greatest challenges associated with the development of this forecasting system is obtaining the high spatial and temporal monitoring data which is required to calibrate and verify models. Nearshore water quality samples are typically collected seasonally and rarely collected beyond the extent of a beach. In order to calibrate and verify a forecasting system such as this, the entire reach of shoreline must be monitored routinely.

The goals of this pilot study are to investigate the validity of assumptions, overcome challenges, and explore the potential feasibility and utility of a linked hydrologic-hydrodynamic model for nearshore bacterial water quality forecasting and beach closure management. Our study is based on applying this modeling system to a popular beach in the metro Detroit (Michigan, USA) area and implementing a routine shoreline monitoring program to help assess model forecasting skill. This research presents an important stepping stone towards the application of similar modeling systems in frequently-closed beaches throughout the Great Lakes region.

Methodology

Site Description

The Clinton River drains 1965 km^2 of southeast Michigan including significant portions of Macomb and Oakland counties as well as smaller portions of St. Clair and Lapeer counties. The Clinton River empties into Lake St. Clair near Mt. Clemens, Michigan at two places – the mouth of the natural channel and the mouth of a spillway. Our study area includes the 7 miles of near-shore between the mouths of the natural Clinton River channel and the spillway (Figure 1). Located at the approximate center between the natural and spillway mouths is Lake St. Clair Metropark Beach, locally referred to as 'Metro Beach'.

Nearshore water quality monitoring

Routine water samples were collected on a weekly basis starting in June, during which time rainfall event samples were also collected. All water samples were analyzed for *E. coli* using both membrane filtration (EPA Method 1603: *Escherichia coli* (*E. coli*) in water by membrane filtration using modified membrane thermotolerant *Escherichia coli agar* (modified m-TEC)) and the EPA approved IDEXX Colilert® method.

Watershed pollutant fate and transport modeling

While a number of models (i.e. SWAT, SPARROW, HSPF) have been developed in recent years to simulate pollutant load, many of these numerical models require extensive, detailed data inputs which are impractical to obtain. Instead, we use a simple, process-based watershed pollutant fate and transport model with the same algorithm in order to provide loads to the hydrodynamic model. Unlike leveraging tools such as the EPA BIT or the Bacteria Source Load calculator developed at Virginia

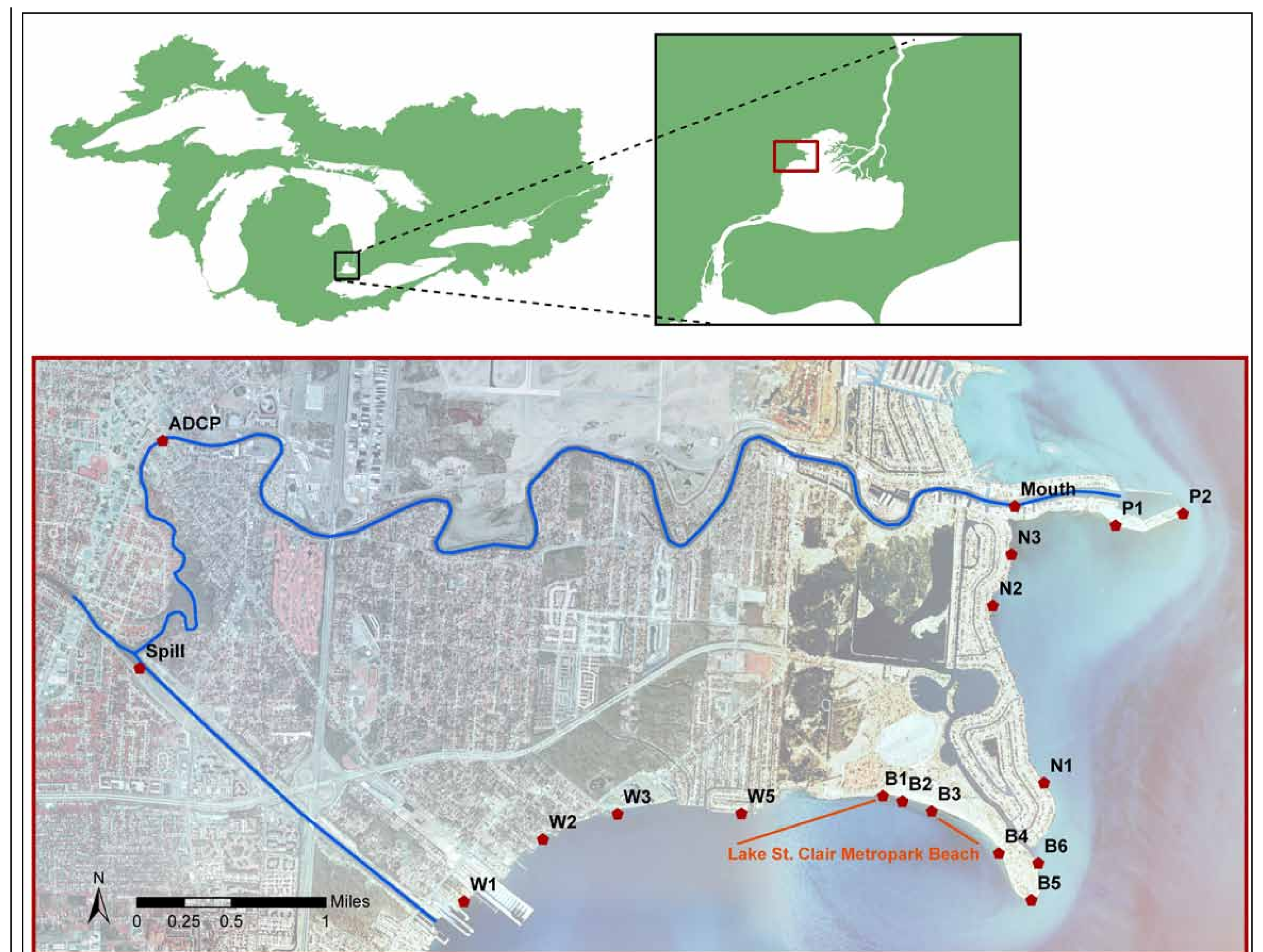

Figure 1. Location map of the Clinton River and nearshore Lake St. Clair along which water quality sampling were collect (nearshore monitoring locations and Lake St. Clair Metropark Beach also shown).

Tech, this model requires only land use and rainfall data to simulate and predict bacterial loads (equation 1, below).

$$\frac{dL}{dt} = N - k(T)L_t - \alpha r_t^{\beta} L_t$$

where
$L(t)$ = number of FIB organisms on landscape at time t
N = seasonal FIB deposition rate (organisms/day), a function of land use
$k(t)$ = 1st order terrestrial decay rate
α,β = washoff coefficients
$r(t)$ = effective rainfall rate (inches)

Nearshore hydrodynamic modeling

Currently the Huron-Erie Connecting Waterways Forecasting System (HECWFS) provides real-time nowcasts and 48-hour forecasts for wind speed, water temperature, surface currents, and water levels. Using HECWFS, a plume of the Clinton River is simulated into Lake St. Clair with a conservative tracer (Figure 2). This hydrodynamic model provides a very strong framework for which loading estimates can be provided and the conservative tracer replaced with an appropriate bacterial decay.

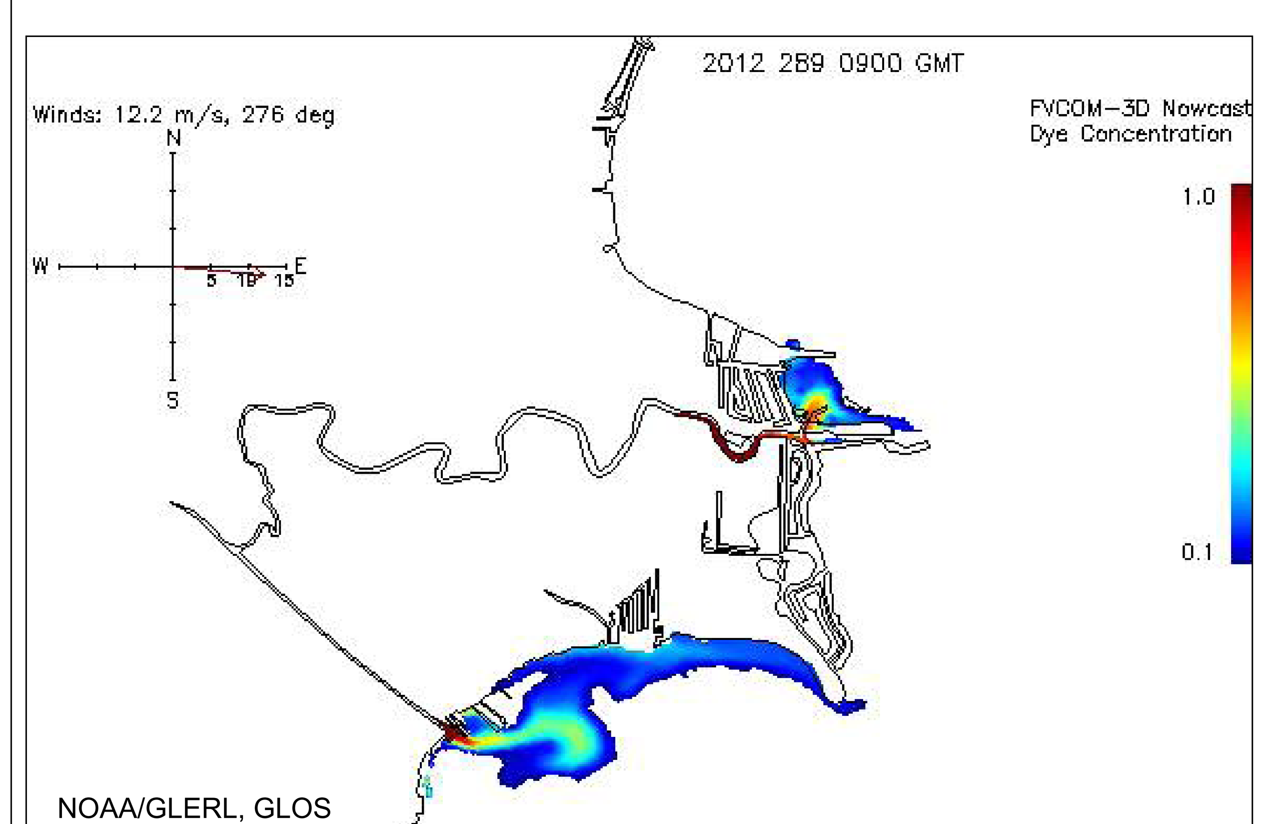

Figure 2. Model simulated tracer of the Clinton River plume representing the relative distribution of Clinton River water as it enters and mixes with Lake St. Clair.

Results and Conclusions

There are three critical take away messages from this study to date. First, this study demonstrates that it is essential to understand and acknowledge variability. Second, the pilot study of the Clinton River/nearshore Lake St. Clair area suggests that it may be appropriate to link a hydrologic-hydrodynamic model for forecasting nearshore bacterial water quality.

Understanding and acknowledging uncertainty

It is critical to the integrity of a water quality assessment that sources of uncertainty be understood and addressed. The preparation of various dilutions illustrates this concept. Using the 'spill' location on September 17th as an example, four preparations were prepared; each yielded a different concentration between 50 and 200 org/100 mL (Figure 3). While no single piece of monitoring data can provide the true concentration, each piece of data available, regardless of method or dilution, can contribute valuable information as to what the true concentration is. We propose a Bayesian hierarchical framework in which both measurement and *in situ* variability can be explicitly accounted for. Utilizing this framework, the 95% credible interval of the true concentration is indicated by red bars in Figures 3 and 4.

Linking a hydrologic-hydrodynamic model for forecasting nearshore bacterial water quality

This case study suggests that under some conditions, at some locations, a linked hydrologic-hydrodynamic model may work very well, however at other times and in different situations, an empirical model may be more valuable. On September 17th, a linked model may be appropriate. Observed nearshore bacterial concentrations generally follow the spatial pattern expected based on the simulated river plume. On this date, bacterial concentrations were generally higher at sites where the tracer concentration was also high, while the bacterial concentration was generally lower where tracer concentration was relatively low (Figure 3). Although September 17th supports the utility of using a linked hydrologic-hydrodynamic model for nearshore bacterial water quality forecasting, the simulations for the following week do not provide the same support. For September 24th, the generalized, expected pattern of high bacterial concentrations with high tracer concentrations, low bacterial concentrations with low tracer concentrations is not followed. Figure 4 illustrates that at locations where tracer concentrations were lowest on September 24th, observed bacterial concentrations were high; where bacterial concentrations were relatively low, tracer concentrations were high.

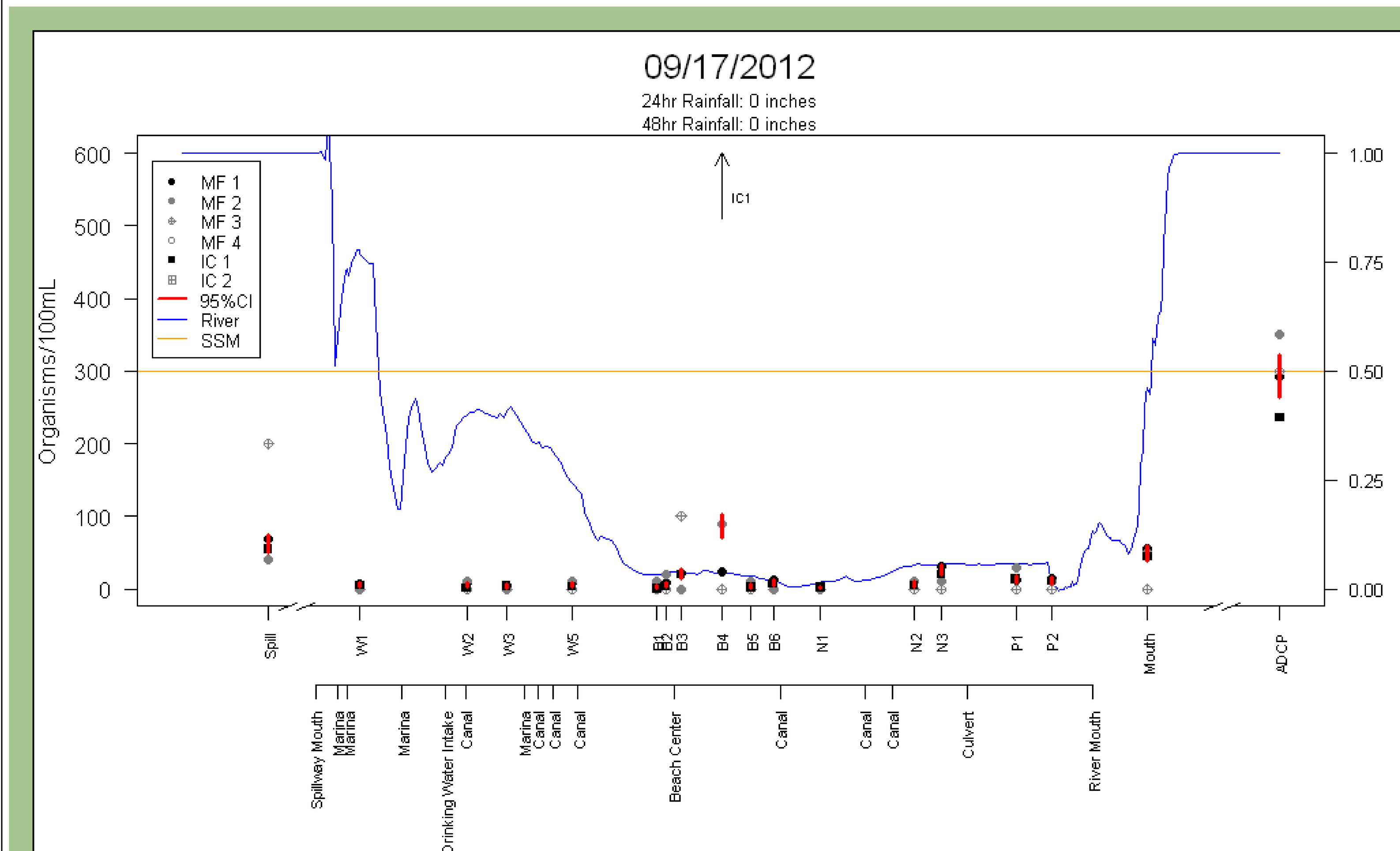

Figure 4. Plot of observed bacterial and (conservative) river tracer concentrations on September 24, 2012. Red vertical bars indicate the 95% credible interval of the true bacterial concentration.

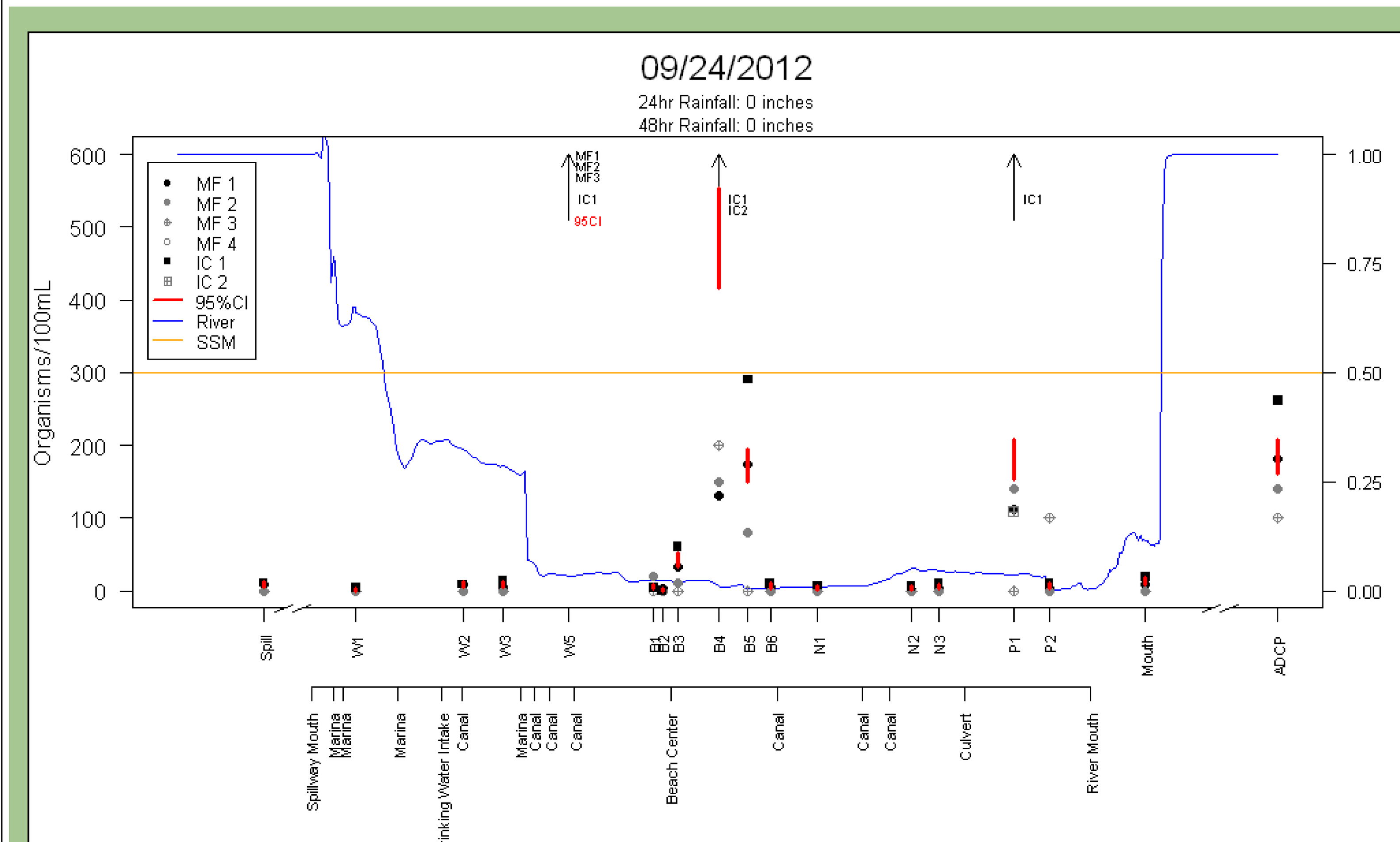

Figure 3. Plot of observed bacterial and (conservative) river tracer concentrations on September 17, 2012. Red vertical bars indicate the 95% credible interval of the true bacterial concentration.

Next steps

Next steps for this project include calibration of a pollutant fate and transport model, providing loads to the hydrodynamic model thereby replacing the simulated tracer, and continuing the effort to understand the strengths and weakness of this process-based forecasting system and how it can be used most valuably by the management community amongst current models and monitoring efforts. Ultimately the goal is to transition this pilot study into an operational framework.

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