science for a changing world

Coastal Processes Influencing Water Quality at Great Lakes Beaches

The overall mission of this work is to provide science-based information and methods that will allow beach managers to more accurately make beach closure and advisory decisions, understand the sources and physical processes affecting beach contaminants, and understand how science-based information can be used to mitigate and restore beaches and protect the public.

The U.S. Geological Survey (USGS), in collaboration with many Federal, State, and local agencies and universities, has conducted research on beach health issues in the Great Lakes Region for more than a decade. The work consists of four science elements that align with the USGS Beach Health Initiative Mission: real-time assessments of water quality; coastal processes; pathogens and source tracking; and data analysis, interpretation, and communication. The ongoing or completed research for coastal processes is described in this fact sheet.

Why do Scientists Study Coastal Processes?

Processes such as sediment transport, turbulence associated with currents and wave action, changes in lake and groundwater levels, and surface-water inputs can affect water quality at beaches. Additionally, beach sands and algae (*Cladophora*) can accumulate, harboring fecal indicator bacteria (FIB) and pathogens that can later be reintroduced into lake water and consequently impair swimming access. USGS scientists are working to characterize the transfer of FIB and pathogens to nearshore waters by way of these processes.

In a series of studies examining the interaction between water movement and bacteria concentrations, several contributing processes have been identified: nearshore **sediment resuspension**, nearshore current and wave actions, **lakebed shear stress**, daily fluctuations of bacteria concentrations (caused by **sunlight inactivation** during the day, followed by recovery overnight), and bacteria entrapment inside of **embayed beaches**.

Recognizing large-scale lake characteristics is essential in assessing beach water quality. USGS scientists identified simultaneous FIB fluctuations at multiple beaches along the coastline, identifying the importance of development of regionalized **nowcast models** for selected nonpoint-source beaches.

Wave Height and Resuspension of Sediments in Nearshore

In a study exploring bacteria loading from beach sand and sediments, wave action on the sand was identified as an important mechanism for washing bacteria into the nearshore water (Ge and others, 2010). Factors associated with the transport of bacteria from sand to water (**lakebed shear stress** and **wave run-up**) were calculated to describe the mobilizing mechanism at the beach. Resuspension is particularly important at **embayed beaches**, where beach sand tends to concentrate *Escherichia coli (E. coli)*. It was found that during high-wave events, beach water received the majority of *E. coli* loading from foreshore sand and submerged sediments (fig. 1).

Figure 1. Wave action and associated sediment resuspension lead to increased concentrations of bacteria in nearshore water.

However, higher bacteria loading was not always retained at the beach area, because longshore currents considerably facilitated bacteria exchange from outside to inside of the embayment. Finally, the occurrence of sediment resuspension in the beach water coincided with distribution of bacteria at the different depths. Collectively, nearshore hydrodynamics and *E. coli* transport involve multiple processes interacting with one another, which impact **microbial water quality** at swimming areas.

Daily Pattern and FIB Transport in Nearshore

A distinct daily pattern has been observed for FIB at the swimming areas, which encompasses decrease throughout daylight hours and rebound after dark. Thus, a theoretical model was developed to determine that some of the nightly increase of *E. coli* could be attributed to **wave-induced mass transport** (Ge and others, 2012a). The combination of this transport and nearshore sand **resuspension** effectively accounts for the increase in *E. coli* concentrations overnight. *E. coli* concentrations tended to increase by nearly three times overnight, and then decreased from the morning to the afternoon, mostly owing to **solar inactivation** and transport by currents. The nighttime replenishment of *E. coli* in nearshore water owing to **wave-induced mass transport** can be disturbed by lake-current activities. In coastal waters, however, current velocity is low; thus, wave action is an important mechanism for bacteria transport (fig. 2). These findings are of particular importance for water-monitoring programs and for protection of public health.

Figure 2. Measurements of current velocities using water-quality probes deployed in shallow water help scientists track bacteria transport in swimming areas.

The Effects of Sunlight on Bacterial Densities

The USGS conducted a 24-hour field experiment to study bacterial decay in the daytime and recovery at night at the Ogden Dunes beaches of Lake Michigan. USGS scientists simultaneously observed *E. coli* concentrations in the ambient water and in **mesocosms** in darkened and transparent bags, which helped separate the effects of bacterial death, **inactivation** owing to **sunlight**, and recovery during overnight hours, from the effects of fluid mixing and settling. The decay of *E. coli* was observed throughout the day as the **sunlight** caused **inactivation** or die-off of bacteria concentrations. The recovery of *E. coli* concentrations was noted during nighttime, as some of the inactivated cells were able to recover in the absence of sunlight. Secondarily, it was found that **sunlight inactivation** was variable, depending on the degree of water contamination; higher amount of suspended particles in the water diminishes the effect of sunlight. These findings have implications for beach managers, as they emphasize the importance of *E. coli* fluctuations during the day affecting sampling time for beach-monitoring practices. Also, although **sunlight inactivation** of water bacteria is widely accepted, this process differs depending on the contamination level of the nearshore water.

Embayments as FIB “Traps”

The 63rd Street Beach in Chicago, Illinois, is an **embayed beach** subject to high concentrations of *E. coli* throughout the summer. Sand has been identified as a significant source of *E. coli* to the beach water at this location (Whitman and Nevers, 2003), but the transport mechanism for this process has not been adequately described. In a study to characterize this process mathematically, water-quality instruments were deployed at the beach to develop wave and current profiles. These data were compared to *E. coli* concentrations in the foreshore and submerged sediment and in the beach water. Additional variables associated with the transport of bacteria from sand to water (**lakebed shear stress** and **wave run-up**) also were calculated, confirming the importance of these processes in bacteria loading and the concentration of *E. coli* in beach water. These processes are particularly important at **embayed beaches** (fig. 3), where beach sand tends to concentrate *E. coli*, and high-wave events result in elevated concentrations in the monitored swimming water (Ge and others, 2012b). Ongoing work is being done to explore the circulation patterns within these **embayed beaches** to determine bacteria-transport patterns following **resuspension**.

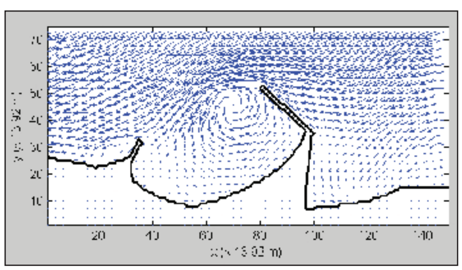

Figure 3. Embayed beach reduces water exchange and may re-circulate contaminated water within the enclosure causing impaired water quality.

Coastal Processes Integrated into Predictive Modeling

USGS scientists have explored the integration of coastal-process models (**mechanistic models**) with management-oriented predictive models (**nowcasts**) to explore the impact of sediment and contaminant discharges from rivers or river plumes on the dynamics of FIB at beaches. In an extensive examination of a plume-affected beach on the southern coast of Lake Michigan, USGS scientists deployed numerous current, wave, and water-quality profiling instruments to fully characterize the interaction of the river plume and beach water (fig. 4). It was found that microbial water quality at Ogden Dunes beach was significantly influenced by plumes coming out of Burns Ditch, about 1 mile east of the beaches, which tends not to be substantially diluted. Subsequently, refinements to Project SAFE (Swimming Advisory Forecast Estimate, first introduced in 2005; Nevers and Whitman, 2005) were applied, which improved the accuracy of the predictive model, made predictions on a real-time basis, and made the data available to the public. This integration of **mechanistic** and management-oriented predictive models will have an important influence on future applications of **nowcasts** and accurate estimates of human health risk.

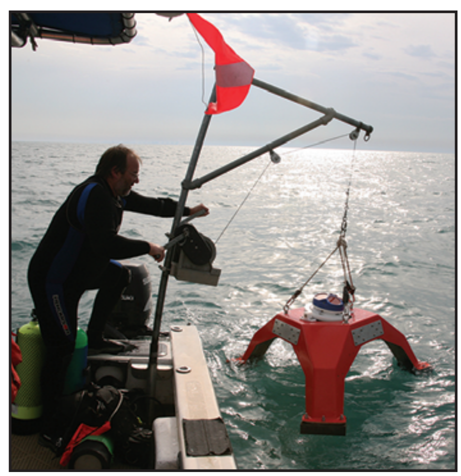

Figure 4. Instruments that collect continuous measurements of current and wave activities, helping scientists build more precise predictive models.

Tracking River Flow Into Lake Michigan and Onto Adjacent Beaches

In 2008, USGS scientists, along with Michigan State University researchers, performed a dye study at Burns Ditch (fig. 5) to track the movement of contaminants that could affect the adjacent beaches (Thupaki and others, 2010). Studies like this help answer the following questions: (1) What is the relative importance of various physical and biological processes influencing the fate and transport of *E. coli*? (2) How much contamination from the river plume is diluted as it enters Lake Michigan? (3) How does the river plume affect the total ***E. coli* budget** in the nearshore? Using numerical models, scientists found that currents in the nearshore are characterized by a strong alongshore component and a relatively weak cross-shore component; thus, contaminant plumes in southern Lake Michigan often lengthen along multiple beaches (fig. 6). Further, vertical turbulent mixing in the water column and cross-shore exchanges are significant in overall *E. coli* transport. The results have important implications for modeling *E. coli* at recreational beaches affected by river outfalls.

E. coli Fluctuations along Illinois and Indiana Coastline

USGS scientists have determined that there is a persistent background concentration of *E. coli* in the nearshore waters of Lake Michigan affecting multiple beaches (Nevers and Whitman, 2008; Whitman and Nevers, 2008) (fig. 7). The **background *E. coli* concentration** interacts with local sources of *E. coli* at specific beaches, and these local and background sources influence overall *E. coli* concentrations and therefore beach-monitoring results. Simultaneous fluctuations of other FIB and markers of various types of contamination with *E. coli* concentrations are being explored, so that immediate and persistent sources can potentially be eliminated. Further research will expand into regional detection of different genetic and fecal markers present in beach samples, so that the influence of large-scale lake processes on beach water quality can be determined.

Figure 5. Dye released into Burns Ditch helped track the movement of contaminants into Lake Michigan.

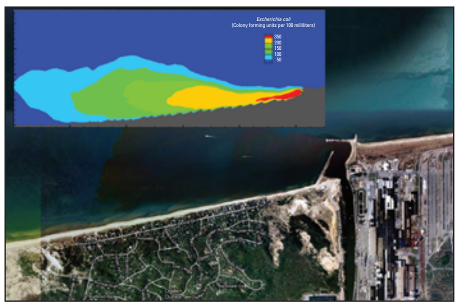

Figure 6. Numerical models simulate the fate of the river plume and potential effects on nearshore water quality.

Figure 7. Regional sources may influence water quality resulting in similar *Escherichia coli* concentrations at multiple neighboring beaches.

Twenty-Three Chicago Beaches

USGS scientists have explored *E. coli* data collected over 5 years from 23 Chicago beaches and found patterns linking beaches on a regional scale. Temporal fluctuations were evident by comparing highs and lows in bacteria concentrations throughout the summer seasons. Spatially, beaches located closer together had higher correlations in *E. coli* levels. Variables identified for use in a regional predictive model were day of the year, wave height, and barometric pressure. The model explained up to 40 percent of the variation, which is comparable to individual, site-specific models. The study by Whitman and Nevers (2008) concluded that the regional modeling approach helps understand large-scale processes affecting fluctuations of *E. coli* concentrations.

Twelve Indiana Beaches

USGS scientists simultaneously examined *E. coli* fluctuations at 12 beaches along 35 kilometers of Indiana's Lake Michigan coastline and built an empirical model, which included 2 variables: wave height and an interactive term comprised of wind direction and creek turbidity (Nevers and Whitman, 2008). Regional modeling results were similar to previously obtained models for individual beaches. The advantage of extending the coastline distance for modeling purposes is to see broader-scale changes in bacteria concentrations over time and space (fig. 8).

Figure 8. Water-quality signs inform swimmers in Indiana about potential risk associated with swimming at the beach.

Glossary

background concentration of *E. coli* Ambient concentration of *E. coli* bacteria in the environment from unspecified sources.

***E. coli* budget** Quantitative expression of *E. coli* input and removal.

embayed beach Usually curved shape beach with breakwalls present that limit water exchange.

lakebed shear stress The force applied to parallel area of lake bottom.

mechanistic models Mathematical models which use the laws of physics and an understanding of the behavior of a system's components to predict particle movement.

mesocosms Controlled studies set up to mimic natural conditions.

microbial water quality Water-quality assessment based on microbial organisms.

nowcast models Mathematical models that use quickly obtained measurements to predict *E. coli* concentrations in real time.

resuspension of sediments Stirring up settled particles from the lake bottom into the water column.

solar inactivation Bacterial decay during the day caused by ultraviolet solar activity.

turbidity A measure of light scattering in the water caused by suspended particles.

wave-induced mass transport The movement of bacteria from intermediate water depths to shallow depths as a result of wave motion.

wave run-up Maximum vertical extent of waves on a beach shore.

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Program Information

Funding for USGS beach projects and research in the Great Lakes comes from a variety of sources including the Ocean Research Priorities Plan, the USGS, the Great Lakes Restoration Initiative, the EPA, the NOAA Center for Great Lakes and Human Health, and many State and local partner agencies and organizations throughout the region.

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