Beach Monitoring and Predictive Modeling

Niagara Region Public Health
Ontario Public Health Standards:  
*Beach Management Protocol*

- Water Sampling at least weekly, a minimum of 5 sample sites per beach
- Geometric Mean calculated on (5 or more samples)
- Compare GM result with provincial standard of 100 E.coli/100 ml.
Persistence Model

- Persistence model assumes E. coli levels persist for 24-48 hours or more.
- However we know that sampling results may not reflect actual conditions at the time of posting.
- We also know that beach water-quality can change quickly.
Our Story

• As we happily sampled beaches once per week as outlined in the Provincial Beach Management Protocol, we felt confident that we were meeting the needs of the Province and the Protocol. But; were we meeting the needs of the public.

• In 2007 intense news media interest caused us to more seriously consider the appropriateness of the Persistence Model.

• In 2008 we sampled a number of beaches on multiple days; beyond the minimum standard of the Protocol.

• Analysis of multiple day sampling confirmed our suspicion that the Persistence Model was failing us.
Our Story cont’d

• Can We Do Better Than The Persistence Model?
• Research Other Jurisdictions
• Great Lakes Beach Association
• Meetings with key Regional staff, municipalities, Niagara Water Strategy etc.
• Rapid Testing (technology not there yet, but getting close)
• Daily sampling (still significant time lag)
• Predictive Modeling (not perfect but may be a good option)
Long Beach Conservation West 2010

E. Coli Geometric Mean

E. Coli
 Posted
 E. Coli Threshold

Niagara Region

FUSS & O’NEILL
Nickel Beach 2010

E. coli Geometric Mean

- E. coli
- Posted
- E. Coli Threshold
Nickel Beach 2011

E. Coli Geometric Mean

- E.coli
- posted
- E.Coli Threshold

Niagara Region
Nickel Beach 2011

E.Coli Geometric Mean

- E.coli
- posted
- E.Coli Threshold

24 hour rain fall totals for Nickel beach 2011

- mm of rainfall

Water turbidity (ntu) for Nickel beach 2011

- turbidity (ntu)

Wave height (inches) for Nickel beach 2011

- wave height (inches)
Our Story cont’d

• In 2009 we commenced a pilot project approved by our Board of Health to investigate the feasibility of Predictive Modeling. A system being used at a number of US beaches and other international beaches.

• In 2010 we honed our environmental data collection capabilities and hired a consulting firm Fuss and O’Neill to create ‘predictive models’ for 3 of our most popular beaches.
Predictive Modeling

• Predictive models can predict or estimate E.coli levels (or predict the probability of being above or below the Provincial standard) based on weather, environmental factors etc.

• Predictive models may be more accurate but certainly more timely than the persistence model.
Predictive Modeling

- Data we collect for predictive modeling includes:
  - rainfall
  - wind speed, wind direction
  - air and water temperature
  - sunlight and cloud cover (observational)
  - turbidity
  - wave height
  - other observational survey data (i.e., number of people at the beach, animals, birds, etc.)
Predictive Modeling
Process Models

- Physical
- Chemical
- Biological
Data-Driven Models

Environmental Variables ➔ E.coli

Explanatory ➔ Target
Approach

Data Acquisition and Compilation

Exploratory Data

Selection of Explanatory Variables and Model Development

Model Diagnostics

Model Performance Evaluation
Approach

- Improve posting accuracy
- Parsimonious models
- Sustainable - Data available for foreseeable future
Data Sources

- **Beach Specific**
  - Niagara Region staff

- **Weather**
  - Niagara Weather Information System (NWIS)
  - Environment Canada

- **Lake Level**
  - Fisheries and Oceans Canada

- **Buoy**
  - Fisheries and Oceans Canada
  - NOAA National Buoy Data Center
1: Bay Beach (Crystal)
2: Lakeside Beach
3: Nickel Beach

Observational Data Collection Stations

Legend:
- Beach
- Environment Canada Meteorological Station
- WWF Climate Station
- Busy Location
- Lake Level Station

Map References: Esri ArcGIS Online; Niagara Region Public Health; Niagara Region Waterford Conservation Authority, Environment Canada

Date: 12/31/2011
Graphical Analysis & Correlation

Continuous Variables

Pearson’s r Correlation

E. coli

Variable

ln(E. coli)

ln(Variable)

Categorical Variables

ANOVA

E. coli

Variable Category
Correlated Parameters

**Lakeside**
- Wave Height
- Turbidity
- Wind Speed
- Water Temp
- Conductivity
- TDS
- pH
- Precipitation
- Wind Gust
- Lake Level

**Nickel**
- *E. coli* Outfall
- *E. coli* Source
- Turbidity
- Lake Level
- Wind Speed
- Wave Height
- Algae
- Dead Fish
- Dead Birds
- Air Temp
- Dew Pt
- Precipitation

**Bay (Crystal)**
- Precipitation
- *E. coli* Outfall
- *E. coli* Source
- Turbidity
- Lake Level
- Wind Speed
- Wave Height
- Algae
- Dead Birds
- Dew Pt
- Precipitation
Model Development

Evaluate all Variables

2010 Data

Training

Testing

Evaluate Met/Hydro Data

2007-2010 Data

2007-2009

Training

2010

Testing

• Censored Data
Model Development

• Multiple Linear Regression
  – Continuous response
  – *E. coli* concentration

• Binary Logistic Regression
  – Discrete response
  – Above/Below standard
Multiple Linear Regression

- Widely used
- Successful at beaches on Great Lakes
- Purpose – explain variation in response or target given explanatory or input variables.
- Assumptions
  - Response variable is linearly related to explanatory variable
  - Data used to fit model are representative
Binary Logistic Regression

• Calculates the probability of a particular response
• Useful for binary responses – yes/no, post/don’t post
## Models - Lakeside

Table 2-5. Model Explanatory Variables at Lakeside Beach

<table>
<thead>
<tr>
<th>Model</th>
<th>Turbidity @ Beach</th>
<th>Dalhousie Station Precipitation</th>
<th>Water Temperature @ Beach</th>
<th>TDS @ Beach</th>
<th>Buoy #45139 West Wind</th>
<th>Dissolved Oxygen @ Beach</th>
<th>Dalhousie Station North Wind</th>
<th>Dalhousie Station East Wind</th>
<th>Wind Speed @ Beach</th>
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<tr>
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<td>✓</td>
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Models - Nickel

Table 2-7. Model Explanatory Variables at Nickel Beach

<table>
<thead>
<tr>
<th>Model</th>
<th>Turbidity @ Beach</th>
<th>Wave Height @ Beach</th>
<th>Buoy #45142 Wind Gust</th>
<th>Seaway Station Wind Speed</th>
<th>Buoy #45142 Wave Height</th>
<th>Seaway Station v-component wind (4-hour average)</th>
<th>Seaway Station Precipitation</th>
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*Developed using data from 2007 through 2009*
## Models – Bay (Crystal)

<table>
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<th>Model</th>
<th>Turbidity @ Beach</th>
<th>Port Colborne Lake Level</th>
<th>Wave Height @ Beach</th>
<th>Wind Speed @ Beach</th>
<th>Fort Erie Station Precipitation</th>
<th>Fort Erie Station v-component wind (4-hour average)</th>
<th>Fort Erie Air Temperature</th>
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</tbody>
</table>

*Developed using data from 2007 through 2009*
Performance

• Adjusted $R^2$, RMSE
• False/True Positives/Negatives
• Sensitivity
• Specificity
• Graphical
Performance

<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
<th>Observed</th>
<th>Time</th>
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<tr>
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E.coli

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<th>FN</th>
<th>TP</th>
<th>TN</th>
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</table>

Model #1

Model #2
Performance

Lakeside Beach 2010 Model Performance - Multiple Linear Regression

% True Negative  % True Positive  % False Negative  % False Positive

Prior Day  Actual Posting  MLR 1  MLR 2  MLR 3  MLR 4  MLR 5  MLR 6  MLR 7
Performance

Nickel Beach 2010 Model Performance - Multiple Linear Regression

% True Negative  % True Positive  % False Negative  % False Positive

Prior Day  Actual Posting  MLR 1  MLR 2  MLR 3  MLR 4
Performance

Nickel Beach 2010 Model Performance - Logistic Regression

- % True Negative
- % True Positive
- % False Negative
- % False Positive

Figure 3-5. LR Model Classification Performance at Nickel Beach
Performance

Bay/Crystal Beach 2010 Model Performance - Multiple Linear Regression

% True Negative  % True Positive  % False Negative  % False Positive

100%  90%  80%  70%  60%  50%  40%  30%  20%  10%  0%

Prior Day  Actual Posting  MLR 1  MLR 2  MLR 3  MLR 4  MLR 5  MLR 6  MLR 7
## Performance

<table>
<thead>
<tr>
<th>Beach</th>
<th>Overall Correct Classification</th>
<th>Specificity</th>
<th>Sensitivity</th>
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</thead>
<tbody>
<tr>
<td>Lakeside</td>
<td>Prior Day GM <em>E. coli</em></td>
<td>60%</td>
<td>70%</td>
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<tr>
<td></td>
<td>Models</td>
<td>72-85%</td>
<td>84-100%</td>
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<tr>
<td>Nickel</td>
<td>Prior Day GM <em>E. coli</em></td>
<td>68%</td>
<td>79%</td>
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<tr>
<td></td>
<td>Models</td>
<td>78-89%</td>
<td>84-100%</td>
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<td>Bay (Crystal)</td>
<td>Prior Day GM <em>E. coli</em></td>
<td>70%</td>
<td>87%</td>
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<tr>
<td></td>
<td>Models</td>
<td>75-86%</td>
<td>78-100%</td>
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</tbody>
</table>
Performance

Bay Beach (Crystal)

- Observed
- Prior Day Model
- MLR 6

GM = 100 CFU/100ml

ln (E. coli GM)
Challenges

• Transfer from Developer to Manager

• Timing of Data Availability

• Beach Suitability
“Despite the attractiveness of predictive models...it is likely that FIB fluctuations at some beaches defy simple prediction approaches.”

- Nevers et al., 2009
Key Points

• Assess Data Infrastructure
  • Precipitation, Streamflow, Wind Speed and Direction, Wave Height and Turbidity

• Better Candidates Beaches

• Low Exceedance
  • Decreasing False Positives
  • Less Likely to Improve True Positives

• Compared to Persistence Model?

• Ongoing “Maintenance” – Not Static
Identifying Candidate Beaches

1. Currently Unsatisfactory?

2. Sufficient Beach Data Quality, Timing, Quantity?

3. Consistent Water Quality Concerns?

4. Other Environmental Data?
Technical Bulletin:
Is Your Beach a Candidate for Predictive Modeling?

How is recreational water at beaches currently monitored?
Monitoring of E. coli levels is the common approach to beach water quality assessment and swimmer health protection in Ontario. If the provincial E. coli standard is exceeded, health unit staff work with the beach operator to assess the circumstances and take action, including posting of warning signs not to swim. Microbiological test results are typically received at least 24 hours after a water sample is taken. The delay in receiving the test results may not adequately reflect the conditions on subsequent days and actions, such as posting may not be appropriate. This method of using test data from previous days is known as the “Persistence Model”, because it assumes conditions “persist” over time. However, it is now known that some beaches have water quality that may vary dramatically over a 24 h period, and a better mechanism for making decisions for managing access to recreational water at public beaches is warranted. Recently several state and local authorities in the U.S., notably in Lake Michigan and Lake Erie, as well as a few health units in Ontario are moving towards a “Predictive Model” approach in order to better protect beach goers’ health.

What is predictive modeling?
Predictive modeling is a statistical technique used to predict beach water quality (E. coli concentrations) based on multiple predictor variables, primarily hydrologic or meteorological (e.g., rainfall, wind speed and direction, stream flow and water level, turbidity, temperature) and other site-specific data. This input data must be consistently available for the model to be successful. To be useful, the model should be easy to implement by beach operators. Also it should afford an improvement in public health protection and maximize access to the water by the public, compared with previous day E. coli counts.

Types of models to predict beach water quality
- Multiple Linear Regression (MLR)
  MLR takes a group of random variables and tries to find a mathematical relationship between those variables and E. coli concentrations. The model creates a relationship in the form of a straight line (linear) that best approximates all the individual data points. MLR can be used to predict E. coli concentrations as well as help assess causal factors for E. coli levels. For the model to be successful these variables must be linearly related and the data used to develop the model must be representative of site-specific conditions.
Current and Future Initiatives
Niagara Beach Sampling

• Sampling is carried out by 2 person teams of summer students or Public Health Inspectors. *(Health and Safety reasons)*

• Samples are collected at a depth of about .75m. or 2 ½ feet. *(Primarily for safety reasons)*

• Additional samples are collected at some beaches for research purposes.
Beach Studies 2010/2011/2012

- MST (Microbial Source Tracking) and DNA tracing studies carried out in 2010 at 15 beaches and another subset of these in 2011.
- Campylobacter and sand studies 2012.
Niagara Beach Sampling

• Beach assessment and survey data collected and input into our Hedgehog computer system.
• Data from Hedgehog is transferred to our Beaches Application.
• Beach application consists of 5 apps that allow quick retrieval, analysis and reporting of beach information.
• Website and hot-line are updated and beach owners are notified of postings and un-postings.
Niagara Beach Signage

- **WARNING**
  - Recent water sample test results indicate excessive levels of bacteria.
  - Water in this area may not be safe for swimming or bathing.

- **Welcome to the Beach**
  - Help keep our beaches clean
    - Don’t feed birds or other wildlife
    - Don’t use soap or shampoo in the water
    - Place garbage in bins or take with you
    - Use washroom facilities

These conditions can cause bacteria levels to rise:
- Large number of swimmers
- Wind and high waves
- Large number of bees
- Recent heavy rainfall
- Cloudy water

To see the current status of this beach, or find nearby beaches with swimming and washroom facilities, visit www.niagararegion.ca

This beach is part of the Niagara Region Water Quality Monitoring Program. Water quality is tested to protect beaches during the summer season for your health and safety.
Beaches of the Regional Municipality of Niagara

Lake Ontario

Niagara-On-The-Lake

Grimsby

St. Catharines

Lincoln

Niagara Falls

West Lincoln

Pelham

Thorold

Welland

Wainfleet

Port Colborne

Fort Erie

Lake Erie
Beach Website Future

- Water quality forecasts (above or below provincial standard)
- Water temperature
- Automated updates of E.coli data
- Water quality trends (charts or graphs)
Automating Environmental Data Collection at Beaches To Support Predictive Modeling
Beach Buoy Project

Environmental Data Buoy

Sonde
Weather Station
Target Beaches

- Lakeside Beach, St. Catharines
- Bay/Crystal Beach, Fort Erie
- Nickel Beach, Port Colborne
- Long Beach-Long Beach Conservation East-Niagara Public Access Beach, Wainfleet
Collaboration

• Our primary partners are beach owners/municipalities Niagara Region and Environment Canada.

• Help from primary partners include;
  – Installing buoys and weather stations.
  – Monitoring buoys and weather stations for security and damage etc
  – Maintaining buoys and weather stations as the need arises.
Environment Canada
YSI Sonde at Lakeside Beach, St. Catharines
Deployment
Environment Canada Data Buoy
Collaboration

• Other possible collaborators;
  – McMaster University
  – Brock University
  – Niagara College
  – Niagara Water Strategy
  – Ministry of Environment
  – Niagara Peninsula Conservation Authority
Potential Benefits to all Collaborators

- Access to ongoing data
- Increased knowledge on condition of beaches
- Information that can help mitigate beach water quality problems
- More timely posted warnings to public about beach water quality
- More accurate posting of beaches
- Beaches more often open to public use
- Posting of beaches when most necessary
- Public view of positive action being taken to protect beaches
- Other opportunities for related research efforts such as climate change research
Conclusion

• The ability to predict or forecast beach water quality, with improved timeliness of beach posting will help to prevent or reduce water-borne illness.
• More timely and appropriate posting of beaches will increase economic benefits of open beaches.
• Actively managing beaches will improve beach water quality and increase the enjoyment of beaches by the public.
‘Niagara Beach Cast’

Questions?