Evaluation of Predictive Modeling for Parlee Beach

FUSS & O'NEILL

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Executive Summary

The recently completed Parlee Beach Water Quality Final Report (April 2018) included a recommendation to explore the use of developing a tool for predicting water quality, based on relevant environmental and meteorological data, which could be used by the Medical Officer of Health (MOH) to issue No Swimming Advisories at Parlee Beach. Currently, the standard culture methods used to determine water quality at most beaches in Canada and the United States to measure concentrations of the fecal indicator bacteria (FIB) *Enterococcus* and *E.coli* take at least 18–24 hours before results are available (Francy et al. 2013). When culture methods are used, water quality conditions, and any advisory postings, are determined by the previous day's bacteria concentration. A tool such as a predictive model would offer forecasting opportunities that would address concerns with public exposure to elevated bacteria concentrations that potentially exist due to the time lag between water quality sampling and receipt of laboratory results reporting concentrations of *Enterococcus* or *E.coli*. The goal of this study was to address the feasibility of predictive modeling for Parlee Beach and related questions about the current water quality monitoring program and the use of the antecedent rainfall threshold currently used for advisories.

How is Parlee Beach Water Quality?

In 2017 and 2018, water samples were collected at five (5) locations along Parlee Beach and analyzed for the FIB *Enterococcus* and *E.coli* for comparison with the guidelines for Canadian recreational water quality (Health Canada, 2012). Exceedance of the geometric mean guidelines were 5% for *Enterococcus* and <1% for *E.coli* for the 2017-2018 period of record. Similarly, exceedances of the single sample maximum for *Enterococcus* were 3% of all the observations at the five beach monitoring locations over the period of record. These results represent conditions of good beach water quality. For comparison, the U.S. Environmental Protection Agency (USEPA) identified 16% of samples exceeding a recreational water quality standard as indicative of "poor water quality"(Zepp et al., 2010) and the Natural Resources Defense Council (NRDC) in their 2014 Testing the Waters report on United States beaches (Dorfman et al., 2014) identified beaches with 2% or less of the samples exceeding the relevant standard or guideline as having exceptional water quality (i.e., "superstars"). On the opposite end of the spectrum, when 25% or more of the samples exceed the relevant standard or guideline, a beach is considered to have chronic water quality problems (Dorfman et al., 2014). Overall, 10% of all samples collected by the 30 states reporting data to the USEPA and cited in the NRDC report exceeded the relevant water quality standard. Using the benchmarks of 2%, 10%, and 25%, Parlee Beach falls just short of exceptional water quality, shows slightly fewer exceedances than typically observed at U.S. beaches, and is far below the levels that would lead it to be characterized as having poor water quality or chronic water quality problems. It is interesting and important to note that the analysis detailed in **Section 2** showed that the majority of the exceedances of the recreational water quality guidelines at Parlee Beach occurred in the months of July, August and September, regardless of rainfall.

Is a Rainfall Threshold a Useful Preemptive Advisory Criterion?

Use of a threshold amount of rainfall as a basis for issuing an advisory is a widely-used empirical approach in which elevated indicator bacteria concentrations, and hence potential waterborne pathogens, are typically associated with some threshold value of rainfall. This empirical model relies on the conceptual model of rainfall and subsequent runoff as being transport mechanisms for indicator bacteria to nearshore recreational waters. Because daily water quality samples are collected at Parlee Beach, it is possible to test the accuracy of the rainfall threshold as a predictive tool.

An analysis of *Enterococcus* data for the current threshold of 10 mm of rainfall in the prior 24-hours presented in **Section 3**, shows that the threshold would correctly predict approximately 38% of the days (5 of the 13 days in 2017-2018) that exceeded the geometric mean of 35 MPN/100 ml. However, 18 additional days would have advisories posted with this threshold when the indicator bacteria concentrations subsequently indicated values below the guidelines (i.e., false positives). If the threshold were raised to 25 mm, only 2 of the 13 days (15%) would be accurately posted, while an additional 7 days would experience unwarranted advisories and 11 days would not have advisories despite indicator bacteria concentrations exceeding the geometric mean guideline. It is also notable that of the four days in the period of record with the highest geometric mean *Enterococcus* concentrations, only 1 would have been correctly predicted as an advisory day by either the 10 mm or 25 mm rainfall threshold. Similarly, if all five monitoring stations are considered and compared to the single sample maximum guideline value of 70 MPN/100 ml for *Enterococcus*, the 10 mm threshold would predict approximately 30% of the total observations (not beach days) that exceeded the guideline and the 25 mm threshold would predict approximately 19%. In short, a rainfall threshold is an unreliable predictor of water quality at Parlee Beach. While a rainfall threshold provides some decision-making rationale, for the 10 mm and 25 mm thresholds it does so at the cost of nearly three times more advisories than the actual water quality would warrant, while failing to identify over half of the days when water quality would indicate advisories should be posted.

Are there Recommended Modifications to Current Beach Monitoring?

Collection of daily data provides a useful tool for monitoring and tracking recreational water quality and should be continued at this time if at all possible. While both *E.coli* and *Enterococcus* can be used as indicator organisms, *Enterococcus* is generally recognized as a more robust indicator organism in marine or estuarine waters (USEPA, 2004). Therefore, if one indicator bacteria were to be used for monitoring, *Enterococcus* would be recommended. Turbidity is recommended as an additional onsite water quality parameter because of its history as a useful indicator of water quality and a potentially important variable in predictive models (Francy and Darner, 2006). Francy and Darner (2006) recommend that turbidity should be measured onsite by use of a field turbidimeter or in situ by use of a water-quality meter. If turbidity is measured by laboratory analysis, the samples should be kept on ice during transport to the laboratory. Anderson (2005) recommends that the same type of instrument be used for measurement of turbidity since turbidity instruments of different designs may not yield equivalent results. More information on handheld turbidity meters can be found in **Section 2** of the report. Collection of basic weather data – rainfall and wind direction – should continue to be monitored. Any individuals collecting water quality or environmental data should be trained annually at the start of the beach season to ensure that consistent collection methods are used that allow for comparison of data across years. Use of checklists and development of guidance documents can be useful tools for training and to maintain consistency across seasons and among different individuals collecting data.

Is Parlee Beach a Candidate for Predictive Models?

The study considered the development of multiple linear regression (MLR) models to predict indicator organism concentrations. Exploratory data analysis described in **Section 2** suggested that development of robust, statistically significant models for Parlee Beach would be unlikely because of the relatively low number of exceedances of the indicator bacteria concentrations relative to the water quality guidelines. Typically, approximately 20-30% of the data exceeding the water quality guidance value of interest is needed for a model to have robust predictive capability across a range of values. MLR models were developed in the Virtual Beach version 3.0.6 (VB3.0.6) modeling software. It should be noted that a MLR model can be valid, i.e., meet all the requirements for MLR, but not provide robust predictive capability for the variable of interest.

The model development focused on predicting both single sample and geometric mean values of *Enterococcus* using a suite of meteorological and environmental candidate independent variables (IVs). IVs that emerged as statistically significant as predictors included: 24-hour antecedent rainfall, days since rainfall, water surface elevations, wind direction, and change in wind direction. Models developed to predict indicator bacteria concentrations during the latter part of the beach season (July-September) were generally better predictors as measured by adjusted R-squared. However, adjusted R-squared values were generally low, with the best performing model having a moderate adjusted R-squared of 0.4954, indicating that approximately half of the variability in the FIB data could be explained by the independent variables in the model. The MLR models were characterized by generally low sensitivity, meaning they did not perform well in terms of identifying true exceedances of the recreational water quality guidelines. As evaluated by sensitivity, the best performing MLR model had a sensitivity value of 0.25 and utilized July through September 24-hr antecedent rainfall and number of days since rain as the independent variables. However, the MLR models generally resulted in fewer false positives, as demonstrated by the higher specificity of those models (i.e., ability to correctly predict values below the guideline value) compared to 10 mm threshold antecedent precipitation. Overall, the predictive models developed as part of this study do not show robust performance in terms of ability to predict exceedances of the geometric mean or single sample water quality guidance. If modeling were to be piloted at Parlee Beach, models described in **Section 3** for the period July-September would be recommended.

Because of the low number of exceedances of the recreational water quality guidelines, and the limitations this presents for predictive modeling, other methods of rapid assessment of microbial water quality conditions should not be eliminated from consideration. Quantitative polymerase chain reaction, or qPCR, is a rapid method that is in use at several recreational water bodies in the U.S. and has been accepted by the U.S. EPA for assessment of recreational water quality conditions at both fresh and marine water beaches. A combination of a MLR model or the antecedent rainfall threshold and qPCR could also be considered. For example, the current rainfall threshold for preemptive advisories tends to over-estimate days when water quality actually exceeds the guideline, i.e., it produces many false negatives. If a 24-hour rainfall value, which is also a forecastable meteorological variable, were used as a screening tooling, then when rainfall is over the threshold value, qPCR testing could be run on the samples collected. This would allow the development of a forecast for water quality that could guide the use of qPCR analysis in a targeted, cost-effective way, especially during the period of July-September, and potentially reduce the number of “false positives” resulting from the use of the rainfall threshold alone.

Section 1 - Parlee Beach Existing Data

1.1. Existing Data

As discussed in the Parlee Beach Water Quality Final Report (2018), many factors have the potential to influence water quality at Parlee Beach as measured by concentrations of the fecal indicator bacteria (FIB) *E.coli* and *Enterococcus*. These different factors include the sources of bacteria from activities upstream or upwind in the beachshed, from sediment resuspension, and from bather, boater, and wildlife activities at the beach, as well as environmental variables like rainfall, wind and tides that influence the fate and transport of bacteria.

A first step in understanding the potential relationships among bacteria concentrations and environmental variables is the collection and summary of data to understand what information is present, the completeness of the information and what temporal data gaps exist that might impact the feasibility of developing a predictive model or otherwise assessing relationships among FIB and other, more readily measured or estimated environmental data.

The existing data for Parlee Beach has been identified based on discussions with the Department of Environmental and Local Government and the Office of the Chief Medical Officer of Health, reviewed for completeness, and summarized in a series of tables. **Table 1-1** provides a concise summary of all the data subject to ongoing collection or measurement during the typical beach season (May to October). Data collected as part of a stand-alone investigation of potential bacteria sources are summarized separately in **Table 1-2**. Individual types of data sets are discussed in more detail and this section concludes with the identification of overlapping time frames for environmental variable collection in the 2017 and 2018 beach seasons.

Table 1-1. Summary of Existing Parlee Beach Data Sets

Data Set	Parameters	Frequency	Period of Record	Source	Gaps
Parlee Beach Weather Station	Rain (mm)	Hourly	2017-06-05 to 2017-10-10 2018-06-18 to 2018-09-15	Dept of Environment and Local Government	2017-09-04 to 2017-09-09 2018-06-24 to 2018-06-28
	Rain Duration (10 sec/count)				
	Rain Intensity (mm/hr)				
	Wind Direction (deg)				
	Wind Speed (km/hr)				
	Mean Wind Speed (km/hr)	Daily	2017-06-05 to 2017-10-10		2017-09-04 to 2017-09-09
Lifeguard Observations	Air Temp (°C)	Twice Daily	2017-06-06 to 2017-08-19 2018-06-03 to 2018-08-25	Lifeguard Daily Checklist Department of Tourism, Heritage and Culture	2017-06-17
	Water Temp (°C)				
	Water Quality				
	Sand Quality				
	# of Beachgoers				
	# of Bathers in water				
	# of birds	Daily			
	Wind Direction				
	Wind Strength				
	# of Boats anchored				
	Tide level				
	# of boats passing by				
	Cloud Cover				
Coal Branch River (01BS001)	Mean Water Surface Elevations (m)	Daily	2017-01-01 to 2018-12-31	Water Survey of Canada/Environment and Climate Change Canada	None
Petitcodiac River (01BU002)	Mean Water Surface Elevations (m)	Daily	2017-01-01 to 2018-12-31	Water Survey of Canada/Environment and Climate Change Canada	None

Table 1-1 (cont'd). Summary of Existing Parlee Beach Data Sets

Data Set	Parameters	Frequency	Dates of Coverage	Source	Gaps
Parlee Beach Water Quality	Antecedent 24 hr Rainfall (mm)	Daily	2017-05-17 to 2018-10-10	Dept of Environment and Local Government	None
	E.coli (MPN)		2017-05-15 to 2017-10-09		2017-10-02, 2017-05-27
	E.coli (counts)		2018-05-22 to 2018-10-08		2018-06-02, 2018-06-03, 2018-06-14, 2018-08-18, 2018-09-19
	Enterococcus		2017-05-15 to 2017-10-10, 2018-05-22 to 2018-10-08		2017-05-27, 2017-10-02, 2017-10-10, 2018-06-02, 2018-06-03, 2018-06-14, 2018-08-18, 2018-09-19

Note that the sampling locations referenced in **Table 1-2** can be found in the report entitled, Parlee Beach Water Quality Final Report (2018), available at https://www2.gnb.ca/content/dam/gnb/ Departments/eco-bce/Promo/Parlee_Beach/pdfs/parlee_beach_water_quality_finalreport-e.pdf.

Table 1-2. FIB Data Collected from Discrete Watershed Sampling Events

<table>
<tr><th>Indicator</th><th>Units</th><th>Sampling Location</th><th>Dates of Sampling</th><th>Media</th></tr>
<tr><td>Enterococcus</td><td>MPN/100 ml</td><td>Lac des Boudrea Mudflats
Wetland between Cap-Brule and The Bluff
Pond south of Parlee Beach
Parlee Beach brook outlet North of St. John St.
South Cove Estuary</td><td rowspan="2">2017-09-06,
2017-09-07,
2017-10-30</td><td>Sediment</td></tr>
<tr><td>E.coli</td><td>MPN/100 ml</td><td>Lac des Boudrea Mudflats
Wetland between Cap-Brule and The Bluff
Pond south of Parlee Beach
Parlee Beach brook outlet North of St. John St.
South Cove Estuary</td><td>Sediment</td></tr>
<tr><td>E.coli (ETF)</td><td>MPN/100 ml</td><td>Shediac A, Shediac B, Shediac C, Shediac E
Shediac G, Shediac H
WQ1, WQ2
WQ3, WQ4
WQ5, WQ6
WQ7, WQ8
WQ9, WQ10
WQ11</td><td>2017-06-22,
2017-07-19,
2017-08-22,
2017-09-20,
2017-10-18</td><td>Water</td></tr>
<tr><td>E.coli (WRP)</td><td>MPN/100 ml</td><td>AG1, AG2, AG3, FW1, FW2, FW3, FW4, FW5, FW6, FW7, FW8, FW9, FW10, FW11, E1, E2, E2B, E3, E4,M1, M2, M3, M4, M6, SED1, SED2, SED3, SED4, SED5, SW1, SW2, SW3, SW4, SW5, SW6, SW7, SW8</td><td rowspan="2">2017-07-27,
2017-08-09,
2017-08-10,
2017-08-21,
2017-09-07,
2017-09-21,
2017-10-11,
2017-10-27</td><td>Water</td></tr>
<tr><td>Enterococcus (WRP)</td><td>MPN/100 ml</td><td>AG1, AG2, AG3, FW1, FW2, FW3, FW4, FW5, FW6, FW7, FW8, FW9, FW10, FW11, E1, E2, E2B, E3, E4,M1, M2, M3, M4, M6, SED1, SED2, SED3, SED4, SED5, SW1, SW2, SW3, SW4, SW5, SW6, SW7, SW8</td><td>Water</td></tr>
</table>

1.2 Fecal Indicator Bacteria Data

Measurement of the fecal indicator bacteria *E.coli* and *Enterococcus* was performed daily at Parlee Beach throughout the 2017 and 2018 beach seasons (**Table 1-3**). The locations and details of sampling can be found in the Parlee Beach Water Quality Final Report (2018). The change in units in the reporting of *E.coli* indicates a change in the method of laboratory enumeration from the 2017 to 2018 seasons. This change should have minimal impact on the comparison or use of data from the two years and can be used together for further data analysis and modeling.

Gaps in the data record are minimal in 2017, with only 3 days of missing *Enterococcus* and 2 days of missing *E.coli* data. Although 5 days of data for both *E.coli* and *Enterococcus* are missing in 2018, this represents less than 4% of the 2018 data record.

Table 1-3. Summary of Fecal Indicator Bacteria Data

Indicator	Units	Frequency	Period of Record	Source	Gaps
Enterococcus	MPN/100 ml	Daily	2017-05-15 to 2017-10-10, 2018-05-22 to 2018-10-08	Dept of Environment and Local Government	2017-05-27, 2017-10-02, 2017-10-10, 2018-06-02, 2018-06-03, 2018-06-14, 2018-08-18, 2018-09-19
E.coli (MPN)	MPN/100 ml	Daily	2017-05-15 to 2017-10-09		2017-10-02, 2017-05-27
E.coli (counts)	CFU/100 ml	Daily	2018-05-22 to 2018-10-08		2018-06-02, 2018-06-03, 2018-06-14, 2018-08-18, 2018-09-19

1.3 Meteorological Data

Meteorological data for the Parlee Beach area is available from three (3) data sets (**Table 1-4**). Daily measurement of precipitation in the prior 24-hour period was recorded daily and reported with measurements of FIB concentrations during both the 2017 and 2018 beach seasons. Lifeguards at Parlee Beach recorded air and water temperature twice daily during June, July and August of the 2017 and 2018 beach season. Rainfall amount, duration and intensity, as well as wind direction and wind speed were recorded hourly by the Parlee Beach Weather Station during the 2017 and 2018 beach seasons, although the accuracy of the rainfall data has not been confirmed[1]. Coverage in both data sets is very good, with 6 days or less of missing data in each. Daily mean wind speed was also reported in 2017 by the weather station.

Table 1-4. Meteorological Data

Variable	Frequency	Period of Record	Source	Gaps
24 hr Antecedent Rainfall (mm)	Daily	2017-05-17 to 2018-10-10	Parlee Beach Water Quality Data	None
Air Temp (°C)	Twice Daily	2017-06-06 to 2017-08-19 2018-06-03 to 2018-08-25	Lifeguard Daily Checklist - Department of Tourism, Heritage and Culture	2017-06-17
Water Temp (°C)				
Rain (mm)	Hourly	2017-06-05 to 2017-10-10 2018-06-18 to 2018-09-15	Parlee Beach Weather Station	2017-09-04 to 2017-09-09 2018-06-24 to 2018-06-28
Rain Duration (10 sec/count)				
Rain Intensity (mm/hr)				
Wind Direction (deg)				
Wind Speed (km/hr)				
Mean Wind Speed	Daily			

[1] Although the rainfall data is reported here, communication with the Department of the Environment and Local Government indicated that the rainfall data has not been confirmed and the 24-hour antecedent rainfall data reported with the fecal indicator bacteria should be used for subsequent statistical and modeling analyses.

1.4 Environmental Data

Other environmental data (i.e., not continuous meteorological data) collected coincident with beach water quality monitoring consists of two types of data – categorical and continuous. Categorical data is data that can be described by two or more categories and often includes some subjectivity on the part of the data gatherer. For Parlee Beach, observations recorded by lifeguards provide information on several categorical variables that describe conditions at the beach (**Table 1-5**). Although limited to June, July, and August, there are few gaps in the period of record and this data set provides the only readily available information on tides, cloud cover, and visual assessment of water quality.

Table 1-5. Categorical Environmental Data

Variable	Categories	Frequency	Period of Record	Source	Gaps
Water Quality	Bad, Poor, Good, N/A	Twice Daily	2017-06-06 to 2017-08-19 2018-06-03 to 2018-08-25	Lifeguard Daily Checklist	2018-06-17
Sand Quality	Good, OK	Twice Daily			
Wind Direction	Directions	Daily			
Wind Strength	Strong Mild Weak Numbers	Daily			
Tide Level	High Low N/A	Daily			
Cloud Cover	Clear All Day Rain Sunny # of hours	Daily			

Additional continuous environmental data was also collected in the 2017 and 2018 beach seasons (**Table 1-6**). Water surface elevation data is recorded at two nearby river gaging stations, the Coal Branch River (Station 01BS001) and the Petitcodiac River (Station 01BU002), both are maintained by the Water Survey of Canada/Environment and Climate Change Canada. Data is only readily available online in real-time format for dates after 2017. Provisional data for 2017 and 2018 was obtained from the Water Survey of Canada/Environment and Climate Change Canada and was used in this analysis.

The daily lifeguard data provides some additional information on beachgoers and bathers in the water, which are a potential source of fecal shedding. Although only available for June, July, and August, there are few gaps in the available data.

Table 1-6. Continuous Environmental Data

Variable	Frequency	Dates of Coverage	Source	Gaps
Coal Branch River (01BS001) Mean Water Surface Elevation (m)	Daily	2017-01-01 to 2018-12-31	Water Survey of Canada/Environment and Climate Change Canada	None
Petitcodiac River (01BU002) Mean Water Surface Elevation (m)	Daily	2017-01-01 to 2018-12-31	Water Survey of Canada/Environment and Climate Change Canada	None
# of Beach-goers	Twice Daily	2017-06-06 to 2017-08-19 2018-06-03 to 2018-08-05	Lifeguard Daily Checklist	None
# of Bathers	Daily	2017-06-06 to 2017-08-19 2018-06-03 to 2018-08-05	Lifeguard Daily Checklist	None

1.5 Data Gaps

Figure 1-1 summarizes the period of record coverage for the data sets described above. In order to assess relationships between Parlee Beach FIB concentrations and meteorological and environmental data, the period of record of the data sets must overlap. The orange rectangles indicate the areas of overlap in 2017 and 2018, respectively. For example, for all the types of data collected in 2018 to be used in the development of predictive models, the time period of modeling would be limited to June through August 2018. This subset contains 84 days of data, only 30% of the number of beach days with FIB data records in 2018. Similar conditions exist in the 2017 data.

If the lifeguard data is excluded, the period of record for the meteorological data from the Parlee Beach Weather Station corresponds to 87% of the 2017 FIB data and 67% of the 2018 FIB data periods of record. The three parameters whose periods of record coincide with the FIB data period of record are 24-hour antecedent precipitation data and water surface elevation data in the Coal Branch and Petitcodiac Rivers.

1.6 Conclusions and Recommendations

Available data for microbial water quality, meteorological, and other environmental data was reviewed to summarize the available data and identify possible temporal gaps in the data. The following key observations were made:

- The data coverage over the period of record for FIB concentrations, 24-hour antecedent rainfall, and nearby river water surface elevations is excellent.

- There was a change in the laboratory method used to quantify *E.coli* and although the results from each method should be comparable and capable of being used together, this change should be kept in mind in reviewing subsequent analyses.
- Within individual data sets, there is generally very good coverage over the period of record for the data set, with few missing values.
- For both the 2017 and 2018 beach seasons, the available meteorological data covers a shorter time period than the period of record for FIB sampling, limiting the full use of the FIB data for comparisons with meteorological data other than 24-hour antecedent rainfall.
- Categorical variables introduce potential for inconsistency in describing data conditions.
- Water and sediment sampling in the beachshed and surrounding area of Parlee Beach provide "snap shots" of conditions. While these may provide useful in developing theories of bacteria sources to Parlee Beach, the limited amount of data does not allow their use for detailed statistical analysis or development of predictive models.

Based on this initial analysis, the following recommendations are also made:

- To the extent practicable, the time periods of lifeguard and weather station data collection should be coincident with the collection of water samples for FIB analysis. Analysis described in **Section 2** and **Section 3** indicates that meteorological data is more critical in terms of potential relationships with FIB concentrations and a fairly extensive overlap in the periods of record already does exist between those variables and FIB data collection.
- Lifeguards should be given careful detailed guidance about the recording of categorical data so that there is consistency in the data reported.

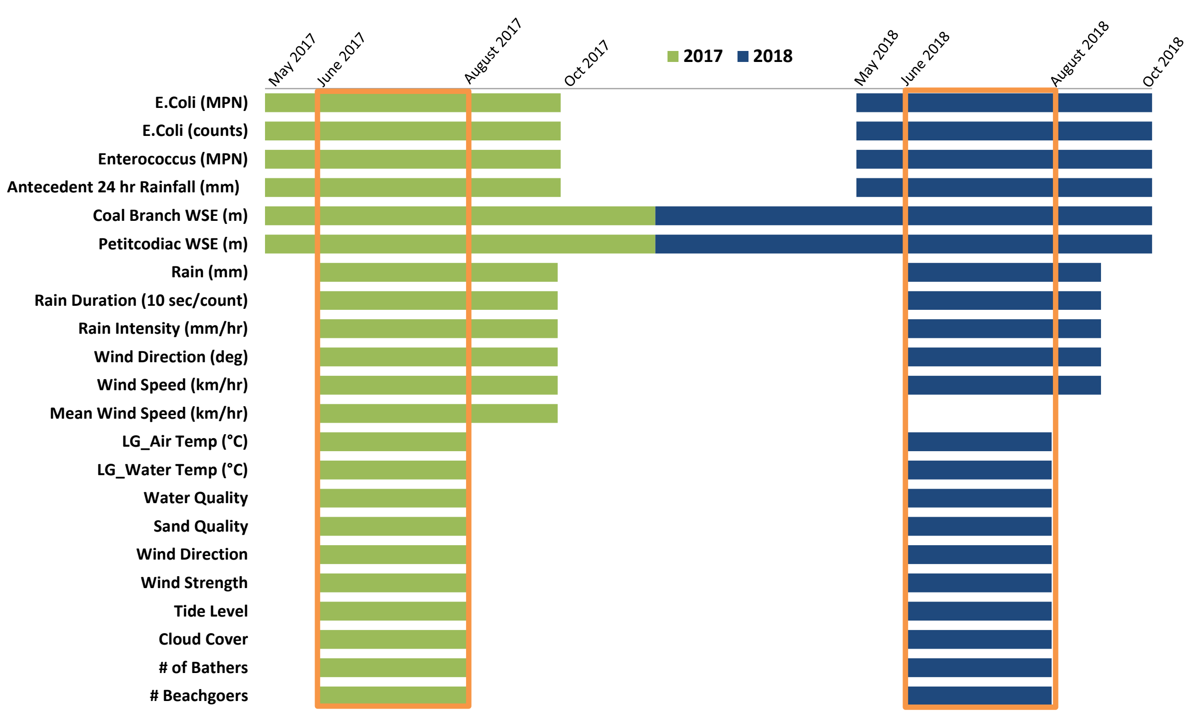


Figure 1-1. Period of Record Coverage for Parlee Beach Data

Section 2 - Parlee Beach Exploratory Data Analysis

2.1 Purpose and Objectives

Preliminary data analysis is a useful initial step to identify potentially significant relationships between fecal indicator bacteria (FIB) such as *Enterococcus* and *E.coli* and independent variables that characterize meteorological or other environmental conditions. The understanding of potential relationships both aids the process of selecting variables for predictive model building and also informs data collection efforts. Meteorological or other environmental variables that show little relationship with FIB or relationships that are not statistically significant have less value in terms of identifying conditions under which FIB concentrations are elevated. This information can be helpful in the prioritization of data collection efforts. The analysis described in this report includes both graphical and statistical analysis and utilizes Microsoft Excel, Minitab 18, and Virtual Beach version 3.0.6 (VB3.0.6). Data used in the analysis are summarized in **Section 1**.

2.2 Summary of Fecal Indicator Bacteria

Figure 2-1 and **Table 2-1** provide a graphical and tabular summary of the *Enterococcus* and *E.coli* concentration data collected in 2017 and 2018. *Enterococcus* data is relatively consistent in both 2017 and 2018 in terms of mean and median values as well as the percentage of days the geometric mean exceeded the recreational water quality guideline of 35 MPN/100 ml. The small interquartile range (i.e., the difference between the 1st and 3rd quartile visually expressed as the height of the box in **Figure 2-1**), indicates that the majority of the data falls within a small range of values. Not surprisingly given the "left censored" data resulting from a reporting limit of 10 MPN/100 ml, **Figure 2-1** shows that the data has a positive skew.

Table 2-1. Summary Statistics for Fecal Indicator Bacteria (2017-2018)

Fecal Indicator Bacteria		n	Mean	Standard Deviation	Min	1st Quartile	Median	3rd Quartile	Max	% Exceedance[2]
Enterococcus[1] (MPN)	2017	146	13.54	14.94	10.00	10.00	10.00	11.49	144.52	5.5%
	2018	135	17.57	33.77	10.00	10.00	10.00	12.54	331.36	4.4%
	All	281	15.48	25.80	10.00	10.00	10.00	11.49	331.36	5%
Enterococcus[3] (MPN)	2017	726	17.90	72.92	10.00	10.00	10.00	10.00	1616.00	1.9%
	2018	675	26.16	102.97	10.00	10.00	10.00	10.00	1850.00	4.2%
	All	1401	21.40	88.72	10.00	10.00	10.00	10.00	1850.00	3%
E.coli[1] (MPN or Counts)	2017	146	16.00	36.59	1.00	1.42	3.20	11.44	234.33	1.4%
	2018	135	7.09	18.01	2.00	2.00	2.64	4.70	187.41	0%
	All	281	11.72	29.47	1.00	2.00	2.64	7.52	234.33	0.7%

[1]Geometric mean; [2]Relative to the GM guideline of 35 MPN/100 ml or SSM guideline of 70 MPN/100 ml; [3]Single sample value.

The *E.coli* data show some differences between 2017 and 2018, with higher mean, median, maximum values and interquartile range in 2017, as indicated in **Figure 2-1** by the height of the box for the 2017 data. The percentage of values exceeding the guideline, while low overall, was also higher in 2017 than 2018. While both FIB are assessed in this analysis, it is useful to keep in mind that *Enterococcus* is generally considered to be a preferable indicator for marine or estuarine waters since *Enterococcus* has demonstrated greater resistance to certain environmental stresses in recreational waters, such as conditions of sunlight and salinity.

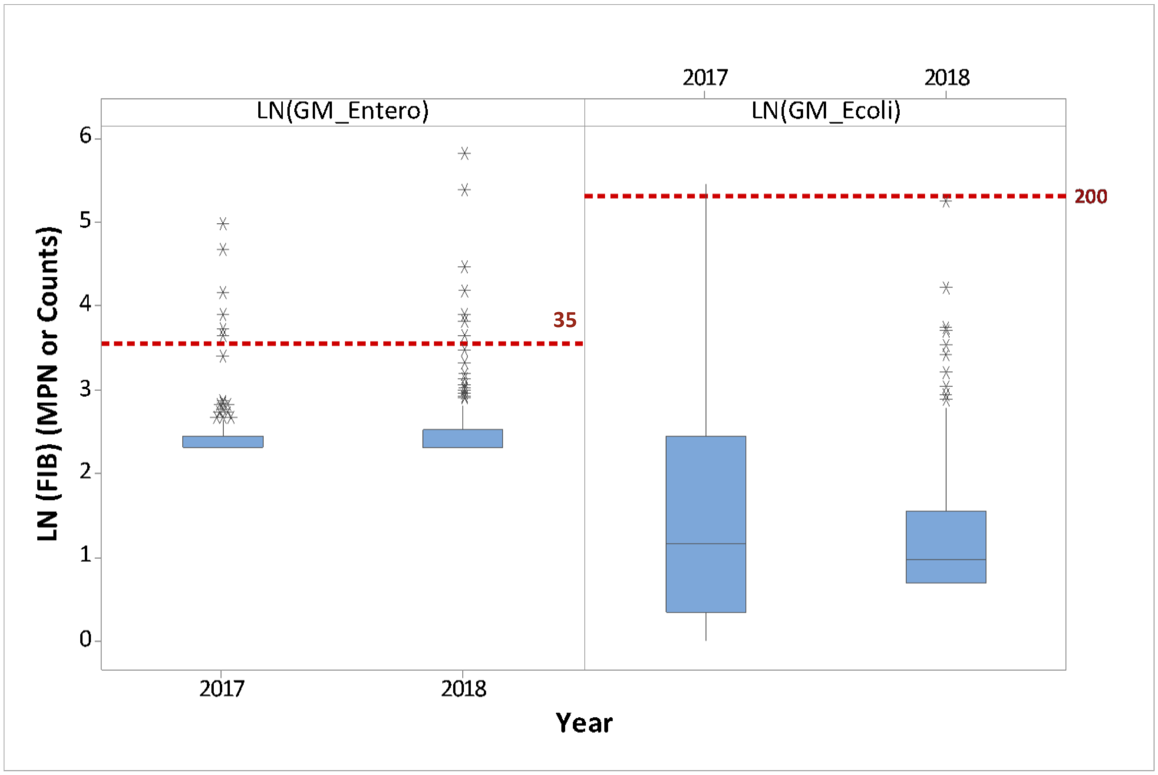


Figure 2-1. Boxplots of Natural Log-Transformed Geometric Mean *Enterococcus* and *E.coli* Data

2.3 Data Preprocessing

The existing Parlee Beach data was preprocessed in order to modify the data to a format to facilitate analysis of relationships between data and also prepare the data for predictive model building.

As described in the Parlee Beach Water Quality Final Report (2018), *E.coli* and *Enterococcus* samples were collected at five separate sampling locations. To produce a single comparable modeling variable for predicting geometric mean (GM) FIB concentrations, the GM of the five measurements was calculated and recorded. The geometric mean indicates a central value of a set of numbers utilizing the product of their values, and thus cannot be calculated if any numbers in the set has a value of 0. To account for this, when an individual station in the set of sampling locations had a bacteria count of 0 it was replaced with a value of 1 to allow for calculation of a geometric mean. Computed GM values were compared against and confirmed with those reported at https://beaches.gnb.ca/en/SamplingLocation/Details/5882. In addition, *Enterococcus* concentrations identified as a less than value (i.e., <10) were set equal to the value of the reporting threshold (i.e., <10 was set to 10 for *Enterococcus*).

Hourly meteorological data was converted to daily averages to allow for direct comparison with FIB data in daily format. Additionally, because of observations in the Parlee Beach Water Quality Final Report (2018) about the potential influence of wind direction on FIB concentrations, the newly averaged daily wind direction was lagged one day to create a new dataset called "Prior Day Wind Direction." A variable describing the change in wind direction compared to the prior day was also created.

Categorical data is data that can be described by two or more categories and often includes some subjectivity on the part of the data gatherer. For Parlee Beach, observations recorded by lifeguards provide information on several categorical variables that describe conditions at the beach. Tide, water quality, and sand quality categorical data was assigned a numeric value (1, 2, or 3) based on their respective category. Wind direction recorded by lifeguards in cardinal direction (N, E, S, W) was converted to degrees (N=0°, S=180°, W=270° etc.).

The daily lifeguard data provides some additional information on beachgoers and bathers in the water, which are a potential source of fecal shedding. For many days in the period of record, the lifeguards presented recorded data in the form of a range (e.g.: 300-500 bathers). In these instances, the upper end of the range is used in the analysis.

2.4 Graphical Analysis

A combination of time series plots, scatterplots and boxplots were used to investigate relationships among data. Graphical analysis is a useful step in overall data evaluation because it can reveal non-linear relationships among variables that are not apparent in the linear correlation analysis described below.

Time Series Plots

Figures 2-2 and 2-3 show time series plots of daily *Enterococcus* or *E.coli* concentration along with daily average temperature, morning water temperature as measured by lifeguards, and 24-hour antecedent precipitation. **Figures 2-4 and 2-5** show time series plots of water surface elevation in the Coal Branch and Petitcodiac Rivers and *Enterococcus* in the 2017 and 2018 beach seasons. These plots are helpful to assess temporal changes in FIB coincident with the environmental variables plotted.

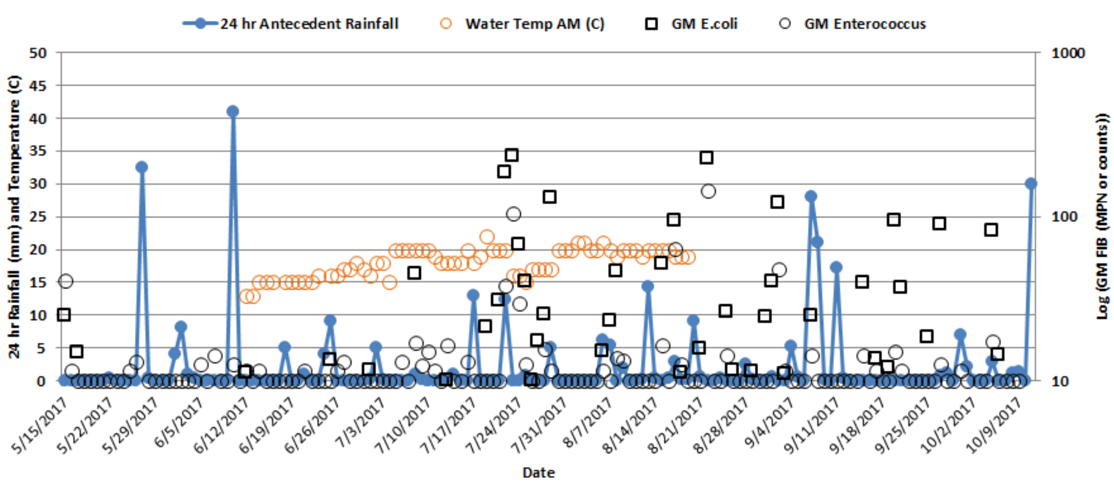


Figure 2-2. 2017 Time Series Plot of FIB, Morning Temperature and 24-hr Antecedent Rainfall

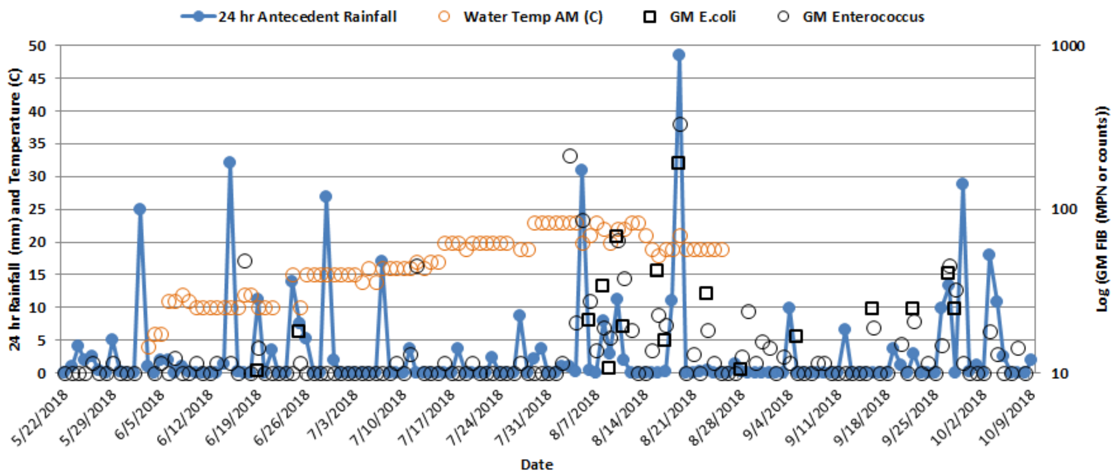


Figure 2-3. 2018 Time Series Plot of FIB, Morning Temperature and 24-hr Antecedent Rainfall

Several observations are immediately noticeable from the time series plots in **Figures 2-2 and 2-3**. First, the highest FIB concentrations are typically observed from late July to late August, although higher *E.coli* concentrations were observed into October in 2017. This time period coincided with a period of increased water temperature due to normal seasonal increases in air temperature. However, FIB concentrations do not appear to show variation with temperature. For example, even when water temperatures drop following a rainfall event (i.e., July 22, 2017, August 8, 2018), FIB concentrations remain elevated.

While FIB concentrations do appear to show some response to 24-hr antecedent rainfall, there does not appear to be an entirely consistent relationship between the magnitude of rainfall and the magnitude of FIB concentration, especially in the earlier part of the beach season. (This observation is explored more fully in **Section 3**.) For example, in **Figure 2-2** and **Figure 2-3**, rainfall events on May 27, 2017 and June 10, 2017 were not followed by increases in FIB. Lower magnitude rainfall events in July and August 2017 were coincident with the highest FIB concentrations observed in 2017. Similarly, 25 mm and 26.8 mm rainfall events on June 2, 2018 and June 29, 2018, respectively, did not coincide with increases in FIB concentrations. However, the highest *E.coli* and *Enterococcus* geometric mean concentrations observed in 2018 coincide with the highest magnitude 24-hr antecedent rainfall event on August 19, 2018. These observations suggest that other factors beyond just rainfall magnitude are influencing FIB concentrations.

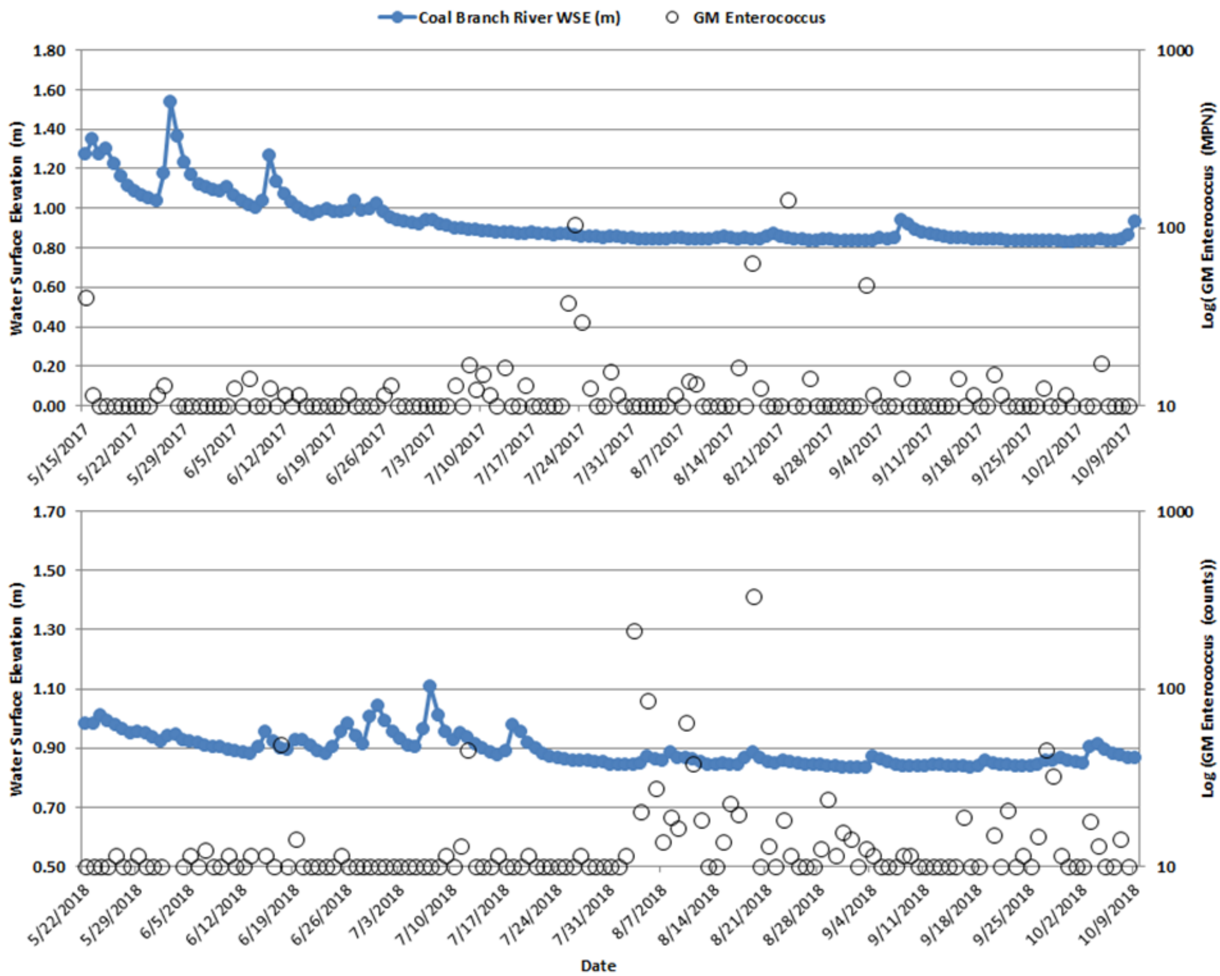


Figure 2-4. Time Series Plot of *Enterococcus* and Coal Branch River Water Surface Elevation 2017 (top) and 2018 (bottom)

Enterococcus was used for comparison with water surface elevation (WSE) in the Coal Branch and Petitcodiac Rivers. **Figure 2-4** indicates little coincident change in *Enterococcus* concentrations with water surface elevation (WSE) in the Coal Branch River with elevated *Enterococcus* concentrations occurring during a period of summertime low flow. The Petitcodiac River appears to be more responsive to precipitation events, but as with precipitation in **Figures 2-2 and 2-3**, there is little early season coincidence between higher WSE and elevated *Enterococcus*. It is notable that the nearly 50 mm rainfall event in August 2018, which is nearly half of the average monthly total rainfall for August, produced both elevated WSE and *Enterococcus* values (**Figure 2-5**), suggesting that very large, infrequent summertime rain events may be coincident with elevated *Enterococcus* at Parlee Beach.

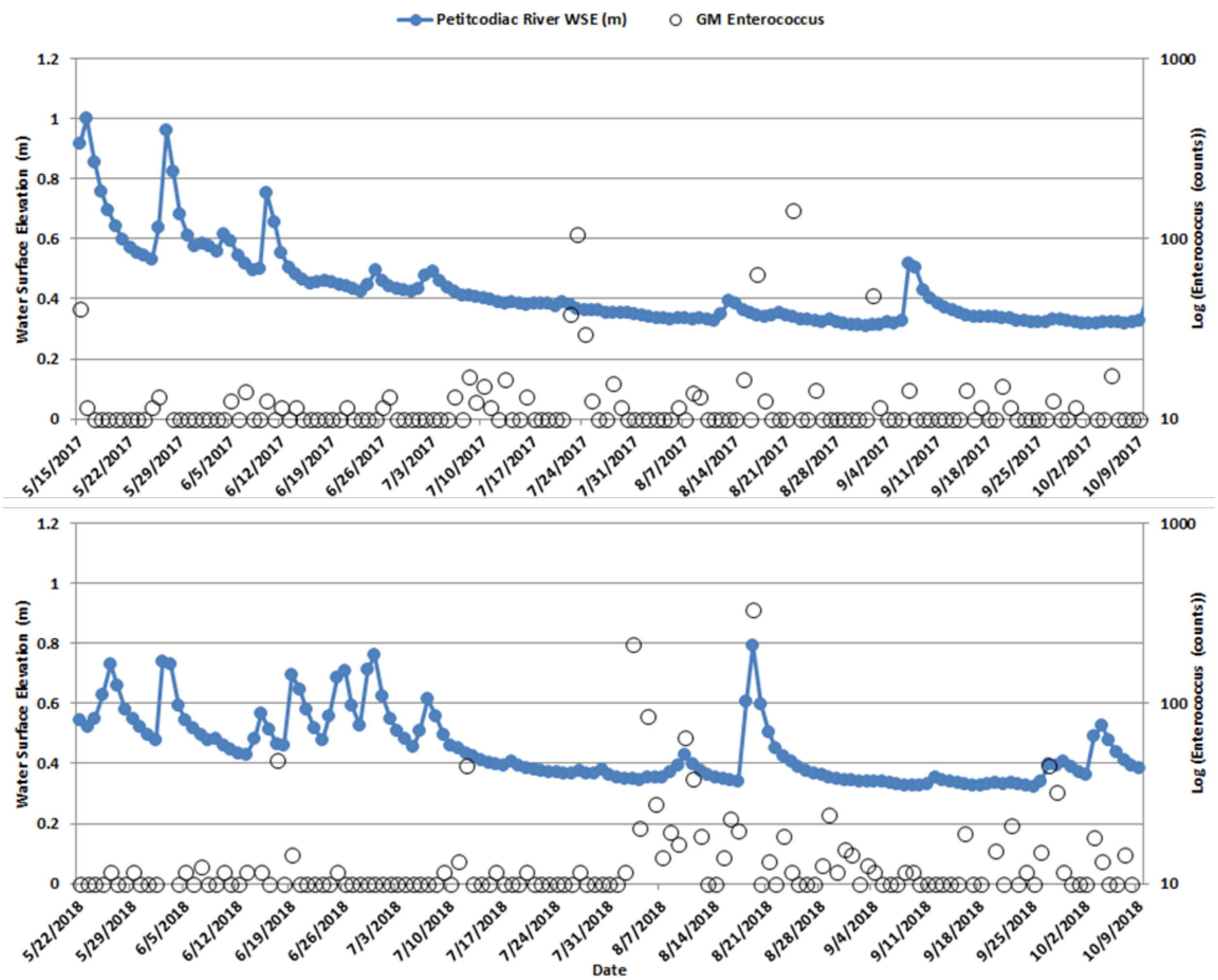


Figure 2-5. Time Series Plot of *Enterococcus* and Petitcodiac River Water Surface Elevation 2017 (top) and 2018 (bottom)

Scatter Plots

Scatter plots shown in matrix format provide a rapid visual assessment of the potential relationship between variables, as well as the absence of any visually discernable relationship. For predictive modeling, a linear relationship between FIB and an independent variable shows the most potential for use. In several of the figures, logarithmic transformations of the data were used, which is a helpful transformation for skewed data to make patterns in the data more visible when plotted.

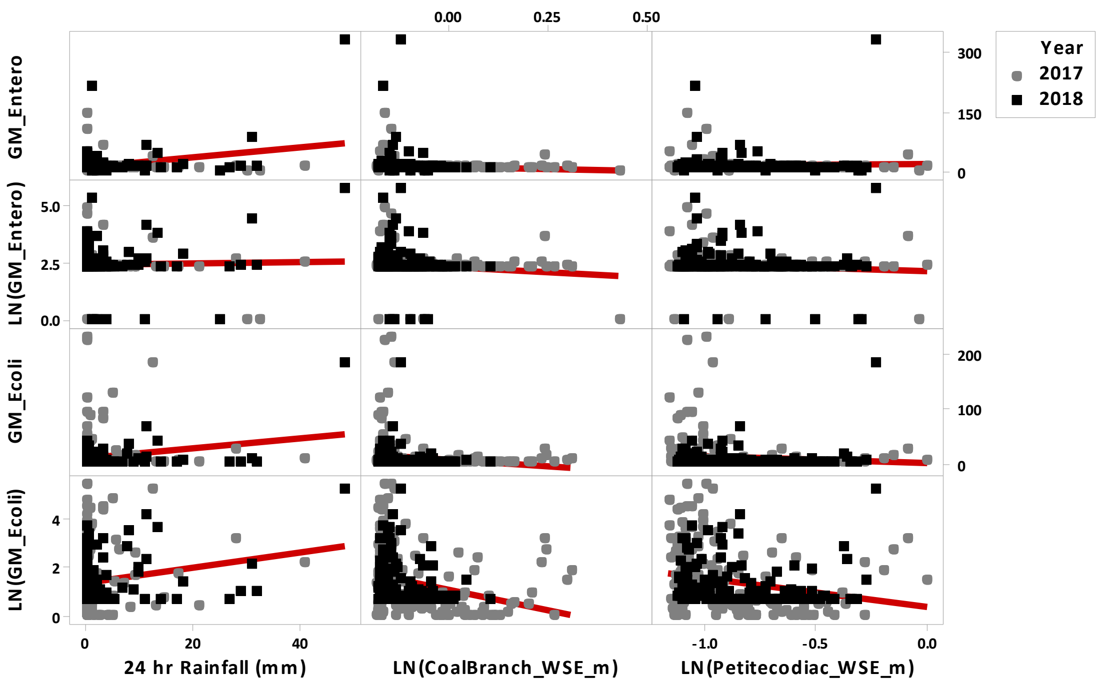


Figure 2-6. Matrix Scatter Plots with Regression line – Rainfall and Water Surface Elevation

The scatter plots in **Figure 2-6** show a slight positive relationship with rainfall, with elevated FIB concentrations associated with higher amounts of 24-hour antecedent rainfall. Consistent with the water surface elevation time series, FIB concentrations show a slightly negative relationship with WSE, with higher values of WSE generally associated with lower values of FIB, especially for *E.coli* in 2018.

Figure 2-7 shows that higher FIB concentrations are generally observed when water temperature is higher. This observation does not necessarily imply a causative relationship although warmer water temperatures likely create better survival conditions for FIB and are coincident with water conditions more attractive to beachgoers and bathers, increasing the potential for fecal shedding from beachgoers. However, matrix scatter plots of FIB concentrations versus numbers of beachgoers and bathers (**Figure 2-8**) shows no strong positive relationship (i.e., increasing number of bathers does not coincide with increasing FIB concentrations).

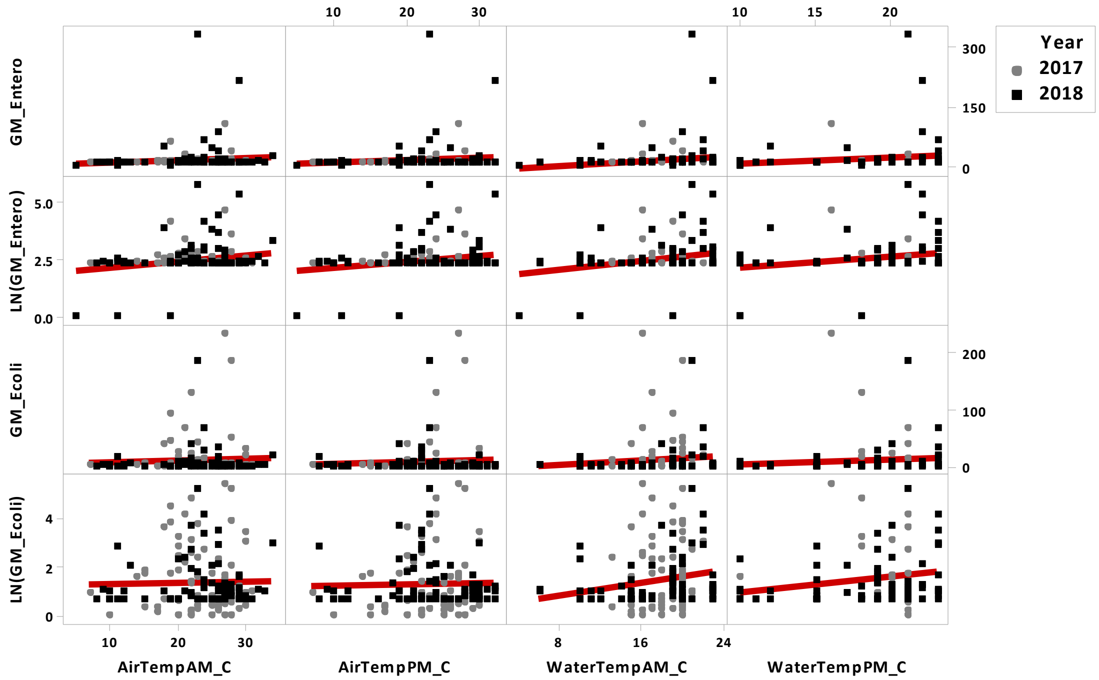


Figure 2-7. Matrix Scatter Plots with Regression line – Air and Water Temperature

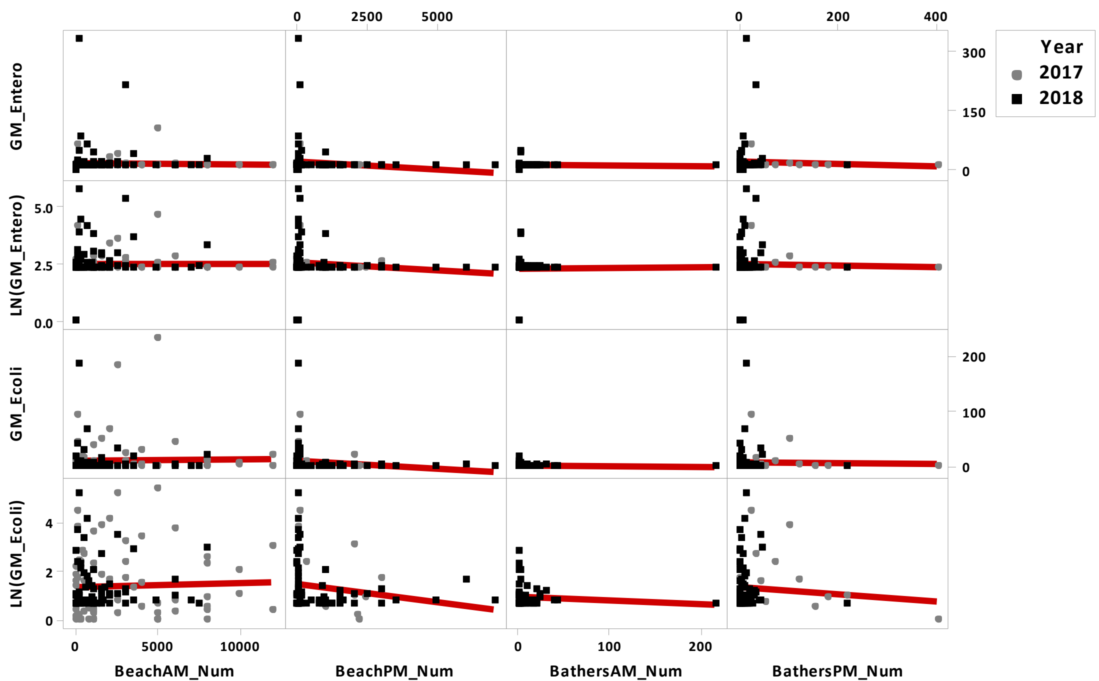


Figure 2-8. Matrix Scatter Plots with Regression line – Beachgoers and Bathers

Scatter plots can also be useful to check on agreement between measurements from two different sources. **Figure 2-9** shows wind direction from the Parlee Beach Weather Station plotted against lifeguard observations of wind direction. There is little agreement between the two data sets (R-squared less than 10%). While this may be the result of variability in wind direction throughout the day, it also illustrates the potential difference in a value that can result from different sources of data and highlights that the source used for model development must be used for subsequent model implementation.

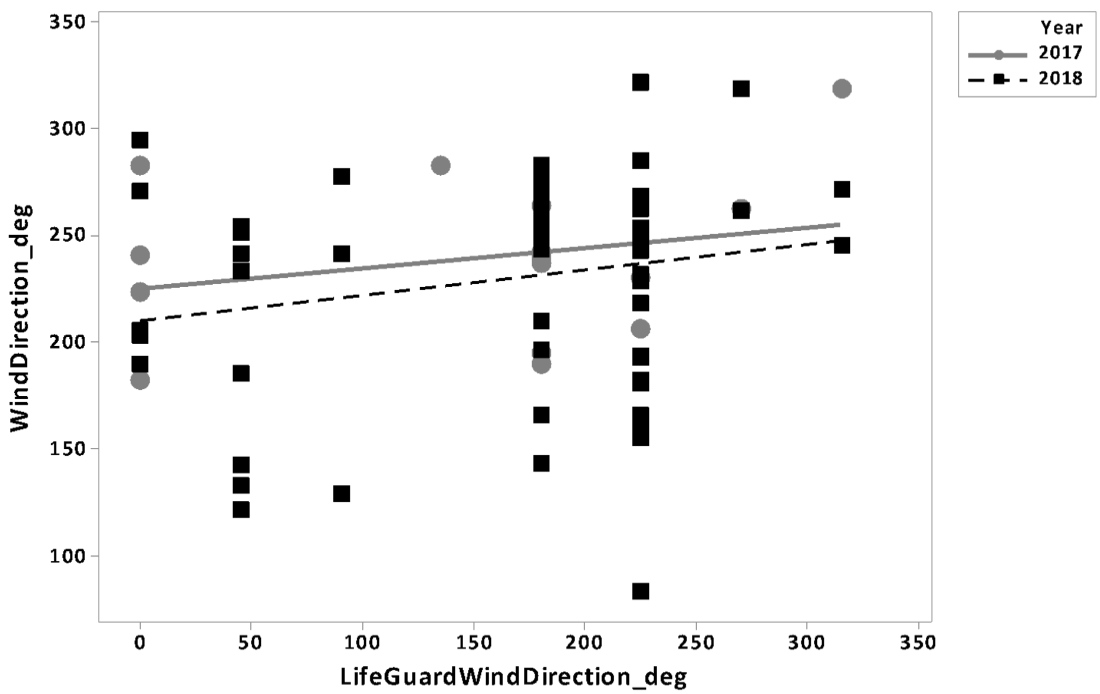


Figure 2-9. Scatter plot with Regression line - Lifeguard and Weather Station Wind Direction for 2017 and 2018

Boxplots

Boxplots (also called box and whisker plots) were used for categorical variables to visually assess differences in FIB concentrations for different categories of the variable of interest. Reference lines for the *Enterococcus* (35 MPN/100 ml) and *E.coli* (200 MPN/100 ml) geometric mean water quality criteria are also included in each plot. Tide level (**Figure 2-10**), water quality (**Figure 2-11**), sand quality (**Figure 2-12**), and wind direction (**Figure 2-14**) as recorded by lifeguards at Parlee Beach is shown in the boxplots below. With the exception of the tide data, which was uniformly recorded in 2017 and 2018, there is quite a bit of variability in the way in which information is reported by the lifeguards. For example, while three categories were used for water quality in 2017, additional categories were used in 2018. Similarly, categories used vary from year to year for recording of sand quality.

Figure 2-10 shows FIB concentration by tide category for both the 2017 and 2018 beach season. While few exceedances of the water quality criteria are reported in either beach season, FIB concentrations show the greatest variability at low tide. Exceedances of the *Enterococcus* criteria were also observed at high tide, with no exceedances and the least variability for either FIB at the "medium tide" category. The increased variability at the low tide condition suggests that at low tide, the beachshed influences water quality and there is less potential dilution from the incoming tide. As with other parameters, the differences between 2017 and 2018 *E.coli* concentrations are notable.

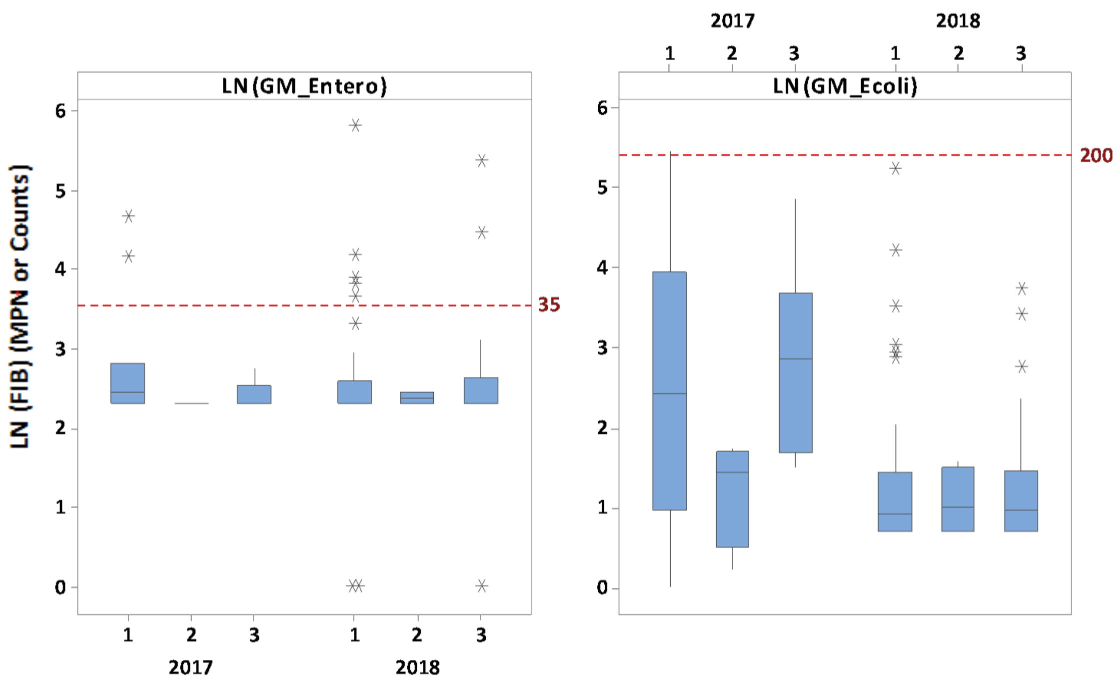


Figure 2-10. Boxplot of FIB Concentration by Tide Category
(1 = Low, 2 = Medium, 3 = High)

Although there are year to year differences in the number of categories, the lifeguard recording of "poor" or "bad" water quality conditions does coincide with higher FIB concentration (**Figure 2-11**). This indicates that visual assessment is a useful tool. However, there are some days when water quality criteria were exceeded even when "good" water quality conditions were recorded by the lifeguards. This highlights the challenge with assessing microbial water quality since visual appearance does not always provide a reliable predictor.

Lifeguard recording of sand water quality shown in **Figure 2-12** seems to have little relationship to FIB concentrations with "good" being assigned to almost all days. The value of sand quality recording appears limited in its usefulness relative to water quality given the data plotted in **Figure 2-12**.

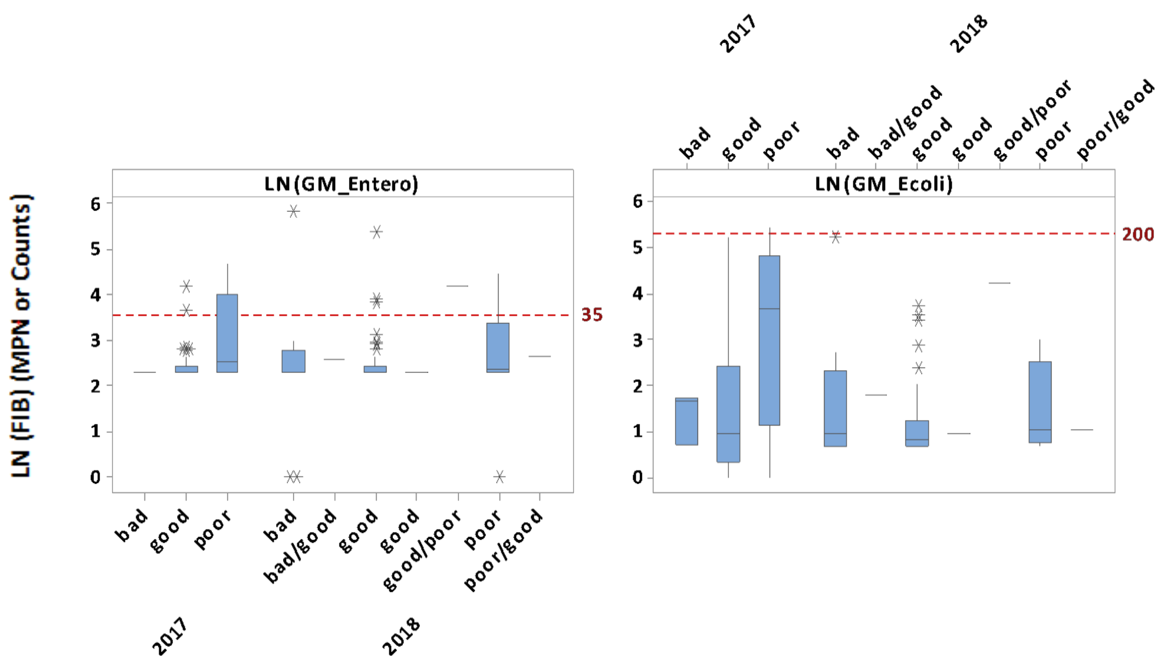


Figure 2-11. Boxplot of FIB Concentration by Water Quality Category

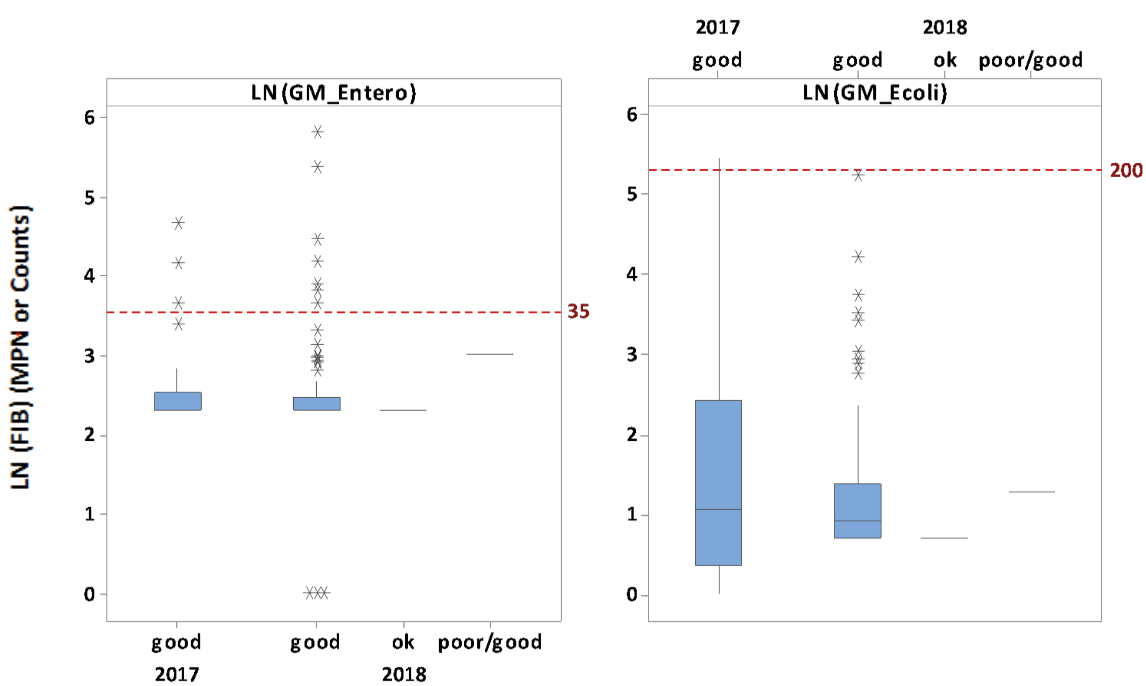


Figure 2-12. Boxplot of FIB Concentration by Sand Quality Category

The following observations can be drawn from the lifeguard reports summarized in the boxplots in **Figure 2-13**. The greatest variability in *Enterococcus* concentrations are observed with north and southwest winds, with exceedances of the recreational water quality criteria coincidence with north, northeast, and southwest winds. *E.coli* concentrations show the highest concentrations when southwest and north-northeast winds are reported. For both FIBs, the least variability is observed with south and west winds.

These results appear to be counter to the observation reported in the Parlee Beach Water Quality Final Report (2018) which states the following regarding wind direction, "These data suggest that when the wind is blowing from the southwest (between 180 and 270 degrees), water quality at Parlee Beach is acceptable. But when the wind shifts to the northwest (between 270 and 360 degrees) there is often an increase in test values." To further explore this issue, the Parlee Beach Weather Station wind direction data was divided into four quadrants (0-90 degrees = NE, 91-180 degrees = SE, 181-270 degrees = SE, 271-360 degrees = NW). **Table 2-2** presents the counts, mean and maximum values, as well as the standard deviation (StDev) and interquartile range (IQR) of the data to describe variability for each quadrant observed in 2017 and 2018. Of the wind direction observations recorded, the majority are from the southwest (an offshore wind). These data were also used to generate boxplots of FIB by quadrant (**Figure 2-14**). While **Table 2-2** and **Figure 2-14** indicate that the highest *E.coli* concentrations were observed coincident with a northwest wind, exceedances of the *Enterococcus* water quality criteria were observed coincident with winds from all directions except the northeast (which only had two observations in the period of record). To better understand the percentage of observations exceeding the standard, cumulative distribution curves of *Enterococcus* concentrations were plotted for NW, SE, and SW winds (**Figure 2-15**). While all three quadrants have exceedances, the NW quadrant has the highest percentage of values (~15%) above the water quality criteria, followed closely by SE. Southwest winds are least often associated with exceedances of the *Enterococcus* criteria. While southwest winds are offshore winds, northwest and southeast winds are alongshore, moving water parallel to the beach and potentially acting as a transport mechanism for bacteria to the beach from other locations to the northwest or southeast.

Table 2-2. FIB Characteristics by Wind Quadrant Reported at the Parlee Beach Weather Station

Variable	Wind Quadrant	N	Percent	Mean	StDev	Maximum	IQR
GM_Entero	NE	2	0.69	10.00	0.00	10.00	*
	SE	26	8.93	25.30	62.90	331.40	2.2
	SW	147	50.52	13.80	19.16	214.15	1.49
	NW	32	11.00	20.79	28.99	144.52	6.24
GM_Ecoli	NE	2	0.69	6.410	0.72	6.92	*
	SE	26	8.93	13.40	36.42	187.41	6.34
	SW	143	49.14	11.80	25.07	186.07	6.52
	NW	32	11.00	27.00	58.30	234.30	15.0

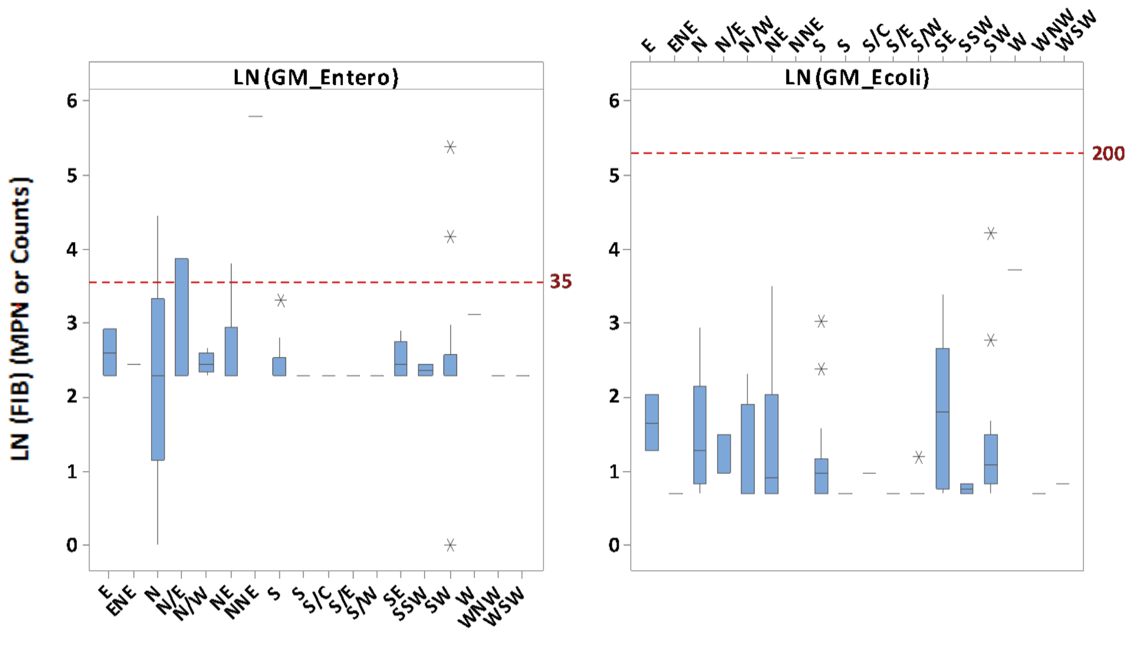


Figure 2-13. Boxplot of FIB Concentration by Lifeguard Reported Wind Direction (2018)

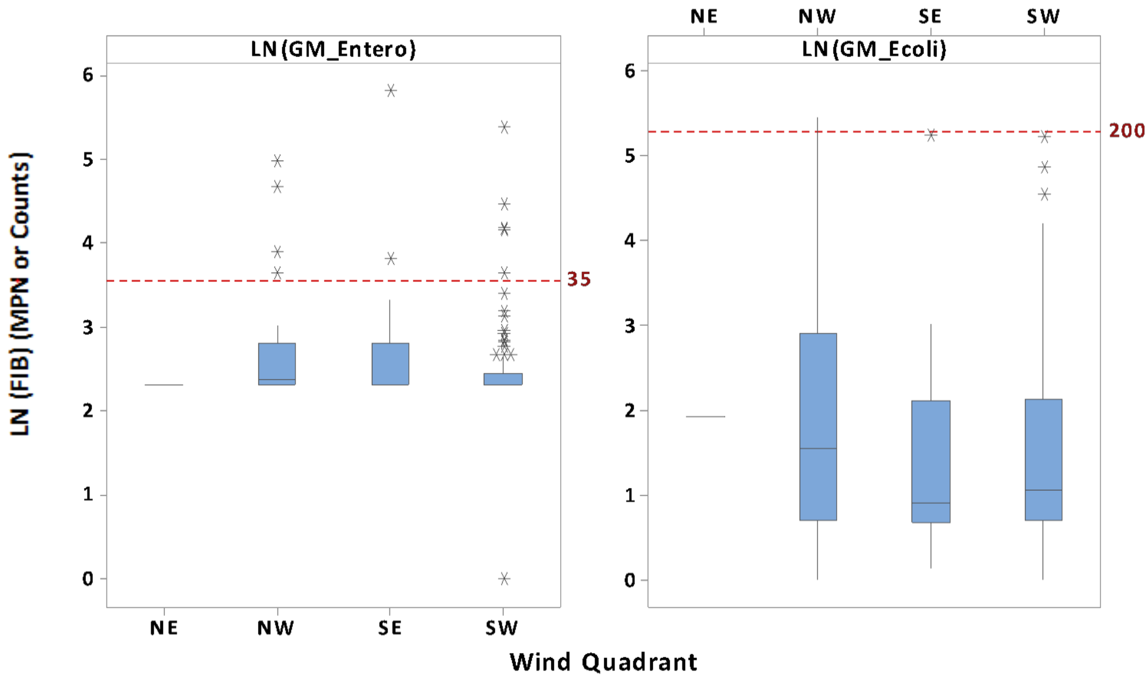


Figure 2-14. Boxplot of FIB Concentration by Parlee Beach Weather Station Wind Direction Quadrant

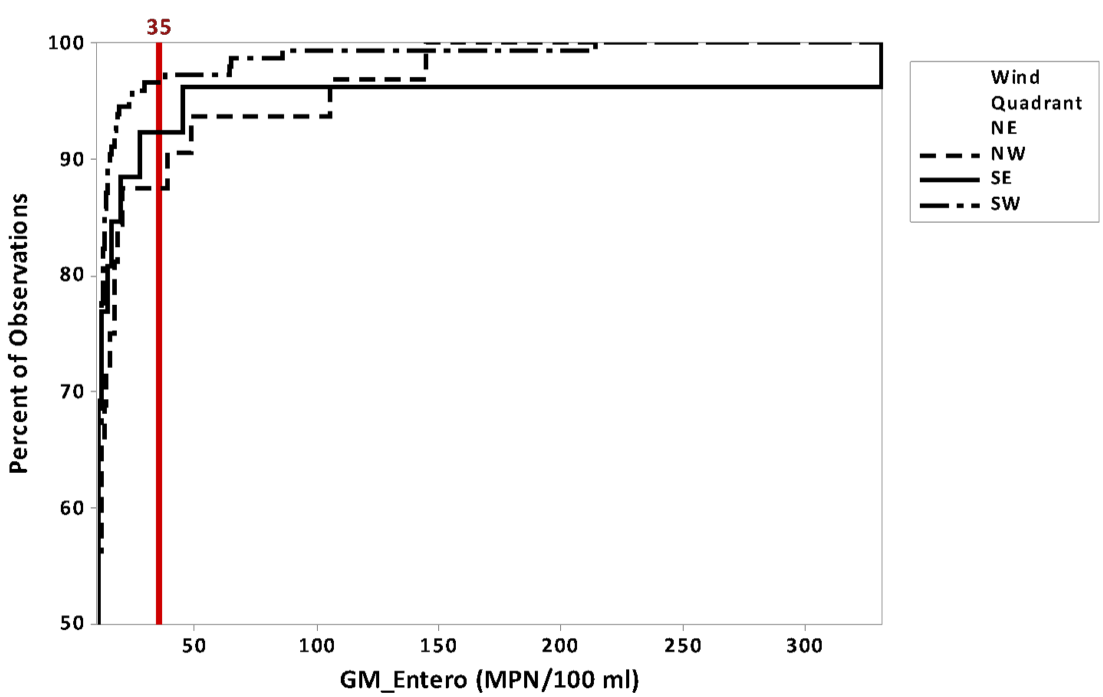


Figure 2-15. Cumulative Distribution of *Enterococcus* Concentrations by Wind Direction Quadrant (2017 and 2018)

2.5 Statistical Analysis

Statistical analysis followed the methods outlined in Guidance for Developing Predictive Models for Ontario Beaches (Mas and Baker, 2011). First, exploratory statistical analysis of the relationships between *E.coli* or *Enterococcus* and independent meteorological or environmental variables was performed. Using VB3.0.6, Pearson linear correlation coefficients were computed for the untransformed and natural log-transformed daily geometric mean (GM) *E.coli* and *Enterococcus*. The correlation coefficient measures the co-variation of two variables. The independent non-categorical meteorological and environmental variables were analyzed given the following transformation conditions:

- untransformed,
- natural log,
- log base 10,
- square, and
- square root.

VB3.0.6 has a useful automatic selection process for correlation analysis. The transformations with the strongest statistically significant correlation were selected and recorded, unless that correlation was not a 20% improvement[2] from untransformed correlation. In those instances, the untransformed correlation was selected and recorded. Geometric means for FIB were analyzed as one combined dataset (2017 and 2018 beach seasons) as well as individual years in order to explore temporal differences or differences in measurement methodology. All statistically significant correlations (p-value <0.05, 95% confidence level) are presented in the tables below. It should be noted that while the rainfall-related data from the Parlee Beach weather station was included in the analysis, the validity of the rainfall data has not been confirmed. Therefore, those results are shown in grey to indicate the conditional nature of the correlation. In addition, as discussed in the Parlee Beach Data Review, the data coverage and, therefore the number of data pairs available for correlation, vary with the parameter. 24-hr antecedent rainfall and water surface elevation data have the longest periods of record overlapping. In comparison, lifeguard data is limited to June through August or approximately 60% of the FIB period of record.

Table 2-3. Statistically Significant (p<0.05) Correlations with LN (GM *Enterococcus*) or GM *Enterococcus* (2017-2018 Beach Seasons)

Explanatory Variable	Correlation (p-value)
SQ (24hr Rainfall @ Parlee Beach Provincial Park)*	0.5260*

[2] This change of 20% in the strength of the correlation is recommended in VB3.0.6 as the threshold to use for selection of the transformed IV over the untransformed IV for model development.

	(0.000)
24hr Rainfall @ Parlee Beach Provincial Park	0.3127 (0.000)
SQ (Rainfall @ Parlee Beach Weather Station)*	0.2257* (0.001)
Rain Intensity @ Parlee Beach Weather Station)*	0.1963* (0.0051)
LN (Prior Day Wind Direction @ Parlee Beach)*	-0.2009* (0.004)

*Correlation with untransformed GM *Enterococcus*; SQ = square of the value in parentheses; LN = natural log of the value in parentheses.

Table 2-3 shows that 24-hr antecedent rainfall is the environmental variable consistently and most strongly correlated with *Enterococcus* concentrations for the entire period of record (2017 and 2018). The correlation is stronger (r = 0.5260) for *Enterococcus* compared to *E.coli* (r=0.2377). The positive correlation is consistent with the concept that rainfall influences FIB concentrations by transporting bacteria to the beach during runoff-producing events. However, it is important to note that correlation describes the degree to which the two variables co-vary (i.e. one variable increases or decreases as the other increases). Correlation between two variables does not provide evidence that there is a causal relationship between the two variables (Helsel and Hirsch, 2002). Multiple linear regression (discussed in **Section 3**) seeks to determine and quantify the extent to which one variable can predict the variation in the other.

Table 2-4. Statistically Significant (p<0.05) Correlations with LN (GM *E.coli*) or GM *E.coli* (2017-2018 Beach Seasons)

Explanatory Variable	Correlation (p-value)
SQ (24hr Rainfall @ Parlee Beach Provincial Park)*	0.2377* (0.0001)
24hr Rainfall @ Parlee Beach Provincial Park	0.1659 (0.006)
Rain Duration @ Parlee Beach Weather Station	-0.1438 (0.041)
Water Surface Elevation @ Coal Branch River*	-0.1484* (0.013)
Water Surface Elevation @ Coal Branch River	-0.2648 (0.000)
Water Surface Elevation @ Petitcodiac River	-0.1947 (0.001)

*Correlation with untransformed GM *E.coli*; SQ = square of the value in parentheses; LN = natural log of the value in parentheses.

Notably, no statistically significant correlations between 24-hour rainfall and *E.coli* concentrations in 2017 were found (**Table 2-5**). In addition, there exist other notable differences between the 2017 and 2018 *E.coli* correlations. While *Enterococcus* has no significant correlation with any of the lifeguard observed variables over the period of record for 2017 and 2018, lifeguard observed afternoon water and morning air temperatures, afternoon beach attendees, as well as prior day wind directions all have significant, strong negative correlations with 2018 *E.coli* while having no significant correlations in 2017 (**Table 2-6**). This is an unexpected result since it suggests that warmer temperatures and higher numbers of beachgoers are correlated with lower FIB concentrations, while these are conditions that are counterintuitive to the conceptual ideas of potential increased fecal shedding from beachgoers and increased FIB survival in warmer temperatures. To explore this further, prior day lifeguard observations were also checked (i.e., do beach conditions the day before influence FIB concentrations?) and no significant correlations were found for either FIB for either 2017 or 2018.

This variation in the relationships between 2017 and 2018 for *E.coli* and the unexpected negative correlations with *E.coli* in 2018 may be the result of differences also observed in the summary statistics of the *E.coli*. Data analysis revealed some statistical differences between the two fecal indicator bacteria (FIB) (see **Table 2-1**) concentrations that may be linked to the laboratory method used to measure *E.coli* concentrations. Regardless, the low percentage of exceedances in *E.coli* data suggest it has limited use as an indicator compared to *Enterococcus*.

Water surface elevations at Coal Branch and Petitcodiac Rivers have moderate negative correlations with *E.coli* concentrations (both combined dataset and individual years) and no significant correlation with *Enterococcus*. Coal Branch, located north of Parlee Beach (**Figure 2-16**), has a stronger negative correlation with *E.coli* concentrations than the Petitcodiac River. The negative correlations with water surface elevation indicate that during times of high flow, *E.coli* concentrations are lower. This is consistent with the time series plots (**Figures 2-4 and 2-5**). Because the beach season also coincides with summer which is traditionally a lower streamflow (i.e., drier) season, this correlation may not be causative in nature but rather illustrate the seasonal covariation that exists.

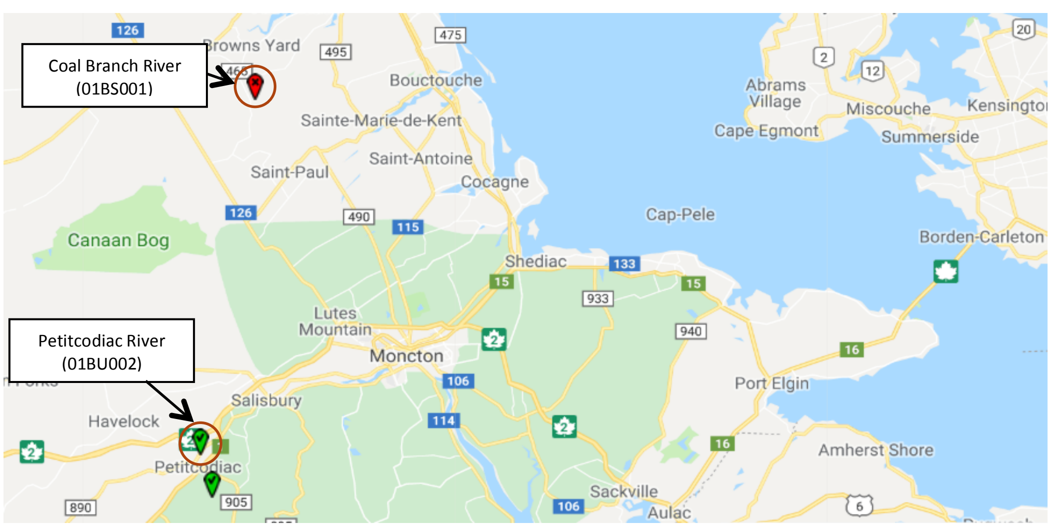


Figure 2-16. Location of Coal Branch River and Petitcodiac River Gages

Table 2-5. Statistically Significant ($p<0.05$) Correlations with LN (GM *E.coli*) or GM *E.coli* (2017 Beach Season)

Explanatory Variable	Correlation (p-value)
Rain Duration @ Parlee Beach Weather Station*	-0.2011* (0.028)
Wind Direction @ Parlee Beach Weather Station*	0.2479* (0.006)
Rain @ Parlee Beach Weather Station	-0.1913 (0.037)
Rain Duration @ Parlee Beach Weather Station	-0.2436 (0.007)
Rain Intensity @ Parlee Beach Weather Station	-0.1849 (0.044)
Water Surface Elevation @ Coal Branch River*	-0.1981* (0.017)
Water Surface Elevation @ Petitcodiac River*	-0.1779* (0.032)
Water Surface Elevation @ Coal Branch River	-0.2997 (0.0002)
Water Surface Elevation @ Petitcodiac River	-0.2461 (0.003)

*Correlation with untransformed GM *E.coli*; SQ = square of the value in parentheses; LN = natural log of the value in parentheses.

Table 2-6. Statistically Significant (p<0.05) Correlations with LN (GM *E.coli*) or GM *E.coli* (2018 Beach Season)

Explanatory Variable	Correlation (p-value)
SQ (Rainfall @ Parlee Beach Provincial Park)*	0.6949* (0.000)
24h Rainfall @ Parlee Beach Provincial Park)	0.3184 (0.0002)
Rain @ Parlee Beach Weather Station*	0.6407* (0.000)
Rain Duration @ Parlee Beach Weather Station*	0.2384* (0.030)
Rain Intensity @ Parlee Beach Weather Station*	0.7328* (0.000)
Rain @ Parlee Beach Weather Station	0.2449 (0.026)
Lifeguard Morning Air Temperature*	-0.5135* (0.003)
Lifeguard Afternoon Water Temperature*	-0.3973* (0.0269)
LN (Lifeguard Afternoon Beach Attendees)*	-0.3574* (0.048)
Lifeguard Morning Air Temperature	-0.4649 (0.008)
Rain Intensity @ Parlee Beach Weather Station	0.3248 (0.003)
Water Surface Elevation @ Petitcodiac River*	0.2267* (0.008)
Water Surface Elevation @ Coal Branch River	-0.2702 (0.002)
LN (Prior Day Wind Direction @ Parlee Beach)*	-0.4136* (0.0001)
LN (Prior Day Wind Direction @ Parlee Beach)	-0.2421 (0.028)

*Correlation with untransformed GM *E.coli*; SQ = square of the value in parentheses; LN = natural log of the value in parentheses.

2.6 Conclusions and Recommendations

Exploratory data analysis identified the follow key findings regarding the characteristics of the FIB data collected during the 2017 and 2018 beach seasons and the relationships between *E.coli* and *Enterococcus* and independent environmental variables concurrently collected in 2017 and 2018:

- The percentage of FIB concentrations exceeding the geometric mean recreational water quality guideline (35 MPN/100 ml) was low for both *Enterococcus* (~5%) and *E.coli* (<1%). Similarly, the percentage of *Enterococcus* data exceeding the single sample maximum value of 70 MPN/100 ml was low (~2-4%). This indicates overall good water quality as measured by the FIB and also suggests that development of robust, statistically significant predictive models may be unlikely since there are relatively few examples of high FIB values to successfully map the empirical relationship between FIB concentrations and other variables.
- Values for some variables are available from multiple sources (i.e., weather station and lifeguard data), but those data values do not necessarily agree. A comparison of wind direction data from the lifeguard observations and the Parlee Beach

Weather Station shows that there is little agreement between the two data sets (R-squared less than 10%). While this may be the result of variability in wind direction throughout the day, it also illustrates the potential difference in a value that can result from different sources of data and highlights that the source used for model development must be used for subsequent model implementation.

- For several of the categorical variables, there is quite a bit of variability in the way in which information is reported by the lifeguards. Standardization of categories and their meanings is critical if variables are to be used for multi-season comparisons or model development and implementation.
- The results of this analysis reinforced the earlier finding that northwest winds are often associated with elevated FIB concentrations. However, it is important to note that all quadrants except the northeast have exceedances, although the northwest quadrant has the highest percentage of values (~15%) above the water quality criteria, followed closely by southeast. Southwest winds are least often associated with exceedances of the *Enterococcus* criteria. While southwest winds are offshore winds, northwest and southeast winds are alongshore, moving water parallel to the beach and potentially acting as a transport mechanism for bacteria to the beach from other locations to the northwest or southeast.
- Correlation analysis shows that the following variables are likely candidates for predictive model development:
    - 24-hour antecedent rainfall
    - Prior day wind direction
    - Wind direction
    - Water surface elevation at the Coal Branch River gage
- Other variables that may have utility, but were only observed to be corrected with the 2018 *E.coli* data include:
    - Air temperature
    - Water temperature
    - Afternoon Beach Attendance

Based on the exploratory data analysis, the following recommendations are also made:

- While both FIB were assessed in this analysis, *Enterococcus* should be used for monitoring going forward since it is generally considered to be a preferable indicator for marine or estuarine waters. *Enterococcus* has demonstrated greater resistance to certain environmental stresses in recreational waters, such as conditions of sunlight and salinity.
- Lifeguards should be given careful detailed guidance about the recording of categorical data so that there is consistency in the data reported.
- It will likely not be possible to substitute data from one source with data from another. For example, it is unlikely that a predictive model developed using weather station wind direction will be able to successfully utilize lifeguard observations of wind direction, nor could a multi-season statistical analysis use data from different sources.
- Lifeguard observations of sand quality appear to have little relationship with water quality and could be eliminated without impact to prediction of water quality.

- Turbidity should be considered as field measurement to be added to the data collection/monitoring program for Parlee Beach because of its history as a useful indicator of water quality and a potentially important variable in predictive models (Francy and Darner, 2006). This would require purchase or rental of a handheld turbidity meter (i.e., turbidimeter) that is meets performance criteria as specified by ISO 7027 (DIN EN 27027) method and is compliant with ASTM D6855-03. A measurement range of 0-1000 NTU would be sufficient for beach monitoring purposes. Anderson (2005) recommends that the same type of instrument be used for measurement of turbidity since turbidity instruments of different designs may not yield equivalent results. Suitable meters usually cost approximately $1300[3] and are factory-calibrated, but require monthly calibration with calibration solutions. Calibration solutions typically need to be replaced approximately once per year and cost approximately $70. Having extra sample vials used for the analysis is also recommended; they have a cost of approximately $70 for a package of 3. The meters are relatively straightforward to use and readings are obtained quickly and would require minimal training for a field sampler. Turbidity samples could be collected with daily beach water quality samples and are estimated to add an additional 10-15 minutes maximum of sampling time per station for sample collection, analysis and data recording. Many turbidimeters also provide internal data logging so that measurements can be downloaded following sampling and potential transcription errors avoided. Francy and Darner (2006) recommend that turbidity should be measured onsite by use of a field turbidimeter or in situ by use of a water-quality meter. If turbidity is measured by laboratory analysis, the samples should be kept on ice during transport to the laboratory. While turbidity can be measured in the laboratory, onsite measurement is recommended if the results are to be used as part of a predictive modeling program or if turbidity is to be used as a "real time" indicator of water quality because onsite measurement provides immediate results compared to the lag time associated with laboratory analysis.

[3] Canadian Dollars

Section 3 - Preliminary Model Development & Evaluation

3.1 Introduction

A primary goal of this study was to identify the feasibility and limitations of using empirical or data-driven predictive water quality models for Parlee Beach. Predictive models can provide a useful tool for forecasting or nowcasting beach water quality conditions. Multiple linear regression (MLR) is a well-established tool for model development. While MLR requires that linear relationships exist between the untransformed or transformed dependent or target variable and any independent or explanatory variables, it is a highly transparent and easily reproducible modeling approach. Previously conducted exploratory data analysis indicated the presence of a linear correlation between fecal indicator bacteria (FIB) and environmental variables (i.e., rainfall, river stage, etc.), supporting the feasibility of MLR. One limitation presented by the Parlee Beach data set is the relatively few number of daily FIB values that exceed the water quality guidance for recreational beaches. Generally, for models to be successful at predicting exceedances of a criteria value it is recommended that at least 20% of the available data for model development include values that exceed the criteria value. Given that the combined 2017-2018 Parlee Beach data set contains less than 6% of values that exceed the *Enterococcus* guidelines value and less than 2% that exceed the *E.coli* criteria value, development of models that successfully predict values above the recreational water quality guidelines of interest was anticipated to present a challenge.

Using Virtual Beach version 3.0.6 (VB3.0.6), the objective of this task was to begin with the suite of candidate variables identified in **Section 2** to generate regression-based models that meet the underlying assumptions for linear regression as outlined in Guidance for Developing Predictive Models for Ontario Beaches (i.e., coefficients are significant, residuals appear homoscedastic, independent and normally distributed, etc.). In addition to considering multiple explanatory variables, the use of rainfall data alone was also evaluated and the usefulness of the preemptive advisory value of 10 mm assessed.

3. 2 Modeling Approach

In addition to the independent (explanatory) variables (IVs) discussed in **Section 2 - Explanatory Data Analysis**, additional IVs were created and added to the datasets used for model development, consisting of: the previous 48 and 72 hour rainfall amounts, numerical month and day of the year value, absolute value of change in wind direction, number of days since last rain event, and number of days since last rain event multiplied by absolute value in change in wind.

As noted in **Sections 1 and 2**, the IVs used for model development have varying ranges of data coverage. In order to create a model, VB3.0.6 must have a complete dataset (i.e., a dataset with no missing values). Within the VB3.0.6 data validation process, if any day within the dataset is missing data for a single variable, that entire day will be automatically removed for all variables. In order to account for this potential removal of data, before using VB3.0.6, IVs were ranked by length of data coverage and grouped in datasets by decreasing data coverage iteratively. For example, "Dataset A" would be the fecal indicator bacteria (FIB) and the IV with the longest data coverage. "Dataset B" would be "Dataset A" plus the IV with the 2nd longest coverage, etc. This ensured that VB3.0.6 is given the greatest number of observations possible for any given combination of IVs.

In addition, another VB dataset was created where all of the data was split into two temporal groupings (May through July and August through September) before undergoing the iterative process described above in order to investigate differences in behavior occurring early in the beach season versus late in the beach season. These data sets were subject to the same statistical analysis described in **Section 2** in order to investigate linear relations between untransformed or transformed FIB, and untransformed or transformed IVs.

VB3.0.6 has multiple methods of statistical modeling including Multiple Linear Regression, Partial Least Squares, and Generalized Boosted Regression. As described in Guidance for Developing Predictive Models for Ontario Beaches (Mas and Baker, 2011), multiple linear regression (MLR) models are a common water quality modeling technique utilized at various beach locations. The goal of MLR is to explain as much as possible the variation in the response or target variable (FIB in this case) given a set of explanatory or independent variables (IVs). The MLR component of VB3.0.6 finds the best possible MLR models based on criteria defined by the user. As the number of IVs included for modeling increases, the number of possible models describing their linear relation increases exponentially, so careful consideration of these criteria is critical.

The user must first set the maximum number of variables in a model. A general rule of thumb is to have at least 10-20 observations per estimated parameter in a model; otherwise the model can be over-fit and as a result have poor estimation. Following the guidance described in the Virtual Beach 3.0.6: User's Guide, maximum allowable limit of IVs = $\frac{number\ of\ observations}{5}$ was set to avoid overfitting.

The VB3.0.6 MLR component automatically handles multi-collinearity among predictor variables. Multi-collinearity occurs when two explanatory variables in a MLR model are highly related to each other. Explanatory variables should be independent and this correlation could cause issues when the model is fit or interpreted. A Variance Inflation Factor (VIF) is used within VB3.0.6 to discard models containing variables with a high degree of multi-collinearity. A VIF of 1 is ideal. If any IV in a model has a VIF exceeding the user defined VIF threshold (VIF>5 in this study), that model was excluded.

In addition, adjusted R-squared was selected as the evaluation criteria for the fit of the model, and models with an adjusted R-squared of 0.1 or greater were retained. Adjusted R-squared is a measure of the variation in FIB concentration that is explained by the explanatory variables. Because low adjusted R-squared values indicate poor ability to produce precise predictions, the 0.1 threshold was set since models with adjusted R-squared values below that threshold were unlikely to be useful for the purposes of this study. Adjusted R-squared is a modified version of R-squared that considers the number of predictors in a regression model and thus is better suited as an evaluation criterion comparing various linear regression models containing differing numbers of predictors. If p is defined as the number of parameters in a model, n as the number of observations in the dataset, RSS as the residual sum of squares for a model, and TSS as the total sum of squares for a model, the evaluation criteria for any model can be defined as:

$$R^2 = 1 - \frac{RSS}{TSS} \text{ and } Adjusted\ R^2 = 1 - (1 - R^2)\frac{(n-1)}{(n-p-1)}$$

Models for which the p-values of the coefficients of both the intercept and IVs were less than 0.05 were retained as statistically significant. If one or more of the coefficients had p>0.05, the models were dropped from further consideration. A p-value less than or equal to 0.05 indicates strong evidence that the coefficient is less than zero and is a standard value used in multiple linear regression.

Models were further evaluated based on three additional criteria: Accuracy, Specificity, and Sensitivity. These criteria compare observed and model predicted results to a criterion (typically a water quality standard or guideline) so that true/false positives and true/false negatives can be defined. The criteria were set to 35 for *Enterococcus* and 200 for *E.coli* for modeling geometric mean values and 70 MPN/100 ml for modeling single sample *Enterococcus* concentrations. Model predictions above this threshold are considered exceedances/positives, and model predictions below this value are considered non-exceedances/negatives. The closer to the value of 1 (one) for these criteria, the better the model performance.

$$Accuracy = \frac{(true\ positives + true\ negatives)}{n}$$

$$Specificity = \frac{true\ negatives}{(true\ negatives + false\ positives)}$$

$$Sensitivity = \frac{true\ positives}{(true\ positives + false\ negatives)}$$

Also, although **Section 2** highlighted some concerns about the *E.coli* data given the characteristics of the 2017 versus the 2018 data set, but both the *Enterococcus* and *E.coli* data sets were used for geometric mean model development.

3. 3 Preliminary Model Evaluation

Tables 3-1 and 3-2 summarize the best performing models that were developed from the entire 2017-2018 period of record using the methodology described above. Where models included the same IV, but with transformation of IVs or FIB, the best performing model as measured by adjusted R-squared, specificity and sensitivity is shown. Model development for *E.coli* was particularly challenging because of the lack of exceedances of the water quality criteria (i.e., *E.coli* >200 counts or MPN/100 ml). As a result, of the few models that did meet the criteria for MLR, none were able to predict any of the exceedances of the water quality criteria, resulting in a sensitivity of zero. Despite this, antecedent rainfall, wind direction, and water surface elevation in the Coal Branch River were independent variables in the models that emerged, a finding that is consistent with the conceptual model of bacteria transport to Parlee Beach.

Table 3-1. MLR Models Predicting Geometric Mean *E.coli* at Parlee Beach (2017-2018)

Target Variable	Independent Variables	Adjusted R-squared	False Positives	Specificity	False Negatives	Sensitivity	Accuracy
GM(*E.coli*)	24-hr Antecedent Rain, Coal Branch WSE, Wind Direction	0.1223	0	1	2	0	0.9009
LN(GM(*E.coli*))	24-hr Antecedent Rain, Coal Branch WSE	0.1296	0	1	2	0	0.99277

LN(GM(*E.coli*))	24-hr Antecedent Rain, Petitcodiac WSE	0.1084	0	1	2	0	0.99277

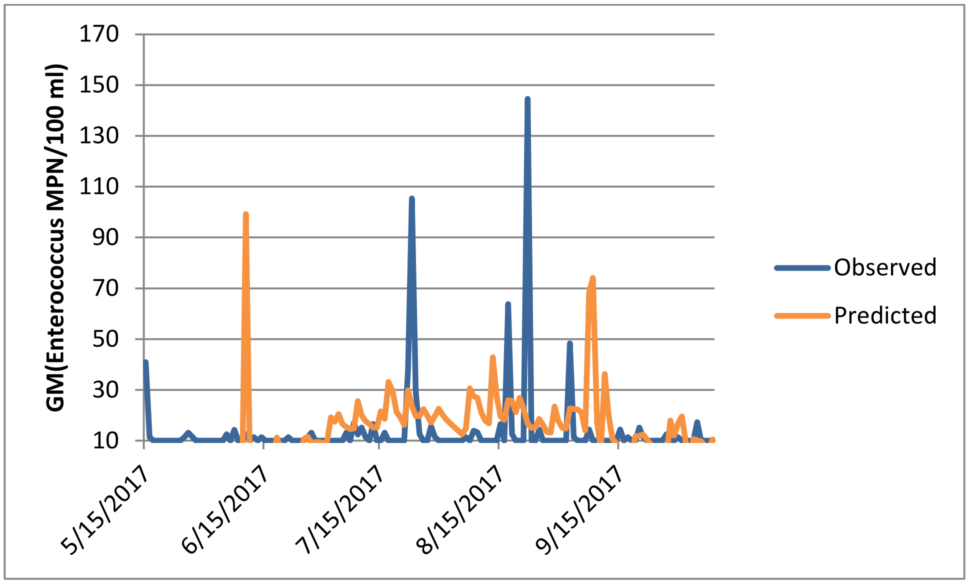
The MLR models in **Table 3-2** demonstrate a slight improvement in the reduction of false negatives, and have an increased number of false positives, but overall, have limited predictive capability. The model that best balances false positives and negatives (**Eqn 1**) is one with IVs consisting of rainfall, water surface elevation, day of the year and days since rain. Although this model would not be suitable for operational implementation, the IVs used are consistent with anecdotal observations that time of year and the amount of time since last rain have some relationship with FIB concentrations at the beach.

Table 3-2. MLR Models Predicting Geometric Mean *Enterococcus* at Parlee Beach (2017-2018)

Target Variable	Independent Variables	Adjusted R-squared	False Positives	Specificity	False Negatives	Sensitivity	Accuracy
GM(*Enterococcus*)	24-hr Antecedent Rain, Coal Branch WSE	0.1608	10	0.96212	10	0.23076	0.92779
GM(*Enterococcus*)	SQ(24-hr Antecedent Rain), Coal Branch WSE, SQ(Petitcodiac WSE)	0.3046	6	0.97727	11	0.15384	0.93862
GM(*Enterococcus*)	SQ(24-hr Antecedent Rain), SQ(48-hr Antecedent Rain), Coal Branch WSE, LOG10(Day of Year), SQRT(Days Since Rain)	0.4854	5	0.97297	9	0.18181	0.92857
LN(GM(*Enterococcus*))	24-hr Antecedent Rain, Coal Branch WSE	0.1262	0	1	12	0.07692	0.95667

GM_Entero_MPN =
494.2 + 0.07906*(SQUARE(24-hr AntecedentRainfall_mm)) + 0.01454*(SQUARE(48-hr Antecedent Rainfaill_mm)) - 211.6*(CoalBranch_WSE_m) - 123.2*(LOG10(DayOFYear)) - 5.915*(SQUAREROOT(DaysSinceRain)) (Eqn 1)

Figure 3-1 shows time series plots for the 2017 and 2018 seasons, respectively, calculated from **Equation 1**. Model performance appears better in the 2018 season, especially in late-August in response to a large (48.5 mm) rainfall event. A scatterplot of observed versus predicted *Enterococcus* concentrations calculated from **Equation 1** (**Figure 3-2**) shows a line of perfect fit (i.e., if predicted and observed concentrations were in perfect agreement). From this plot, it is evident that the high overall accuracy is driven by the relative large numbers of observations below the 35 MPN/100 ml threshold criterion.



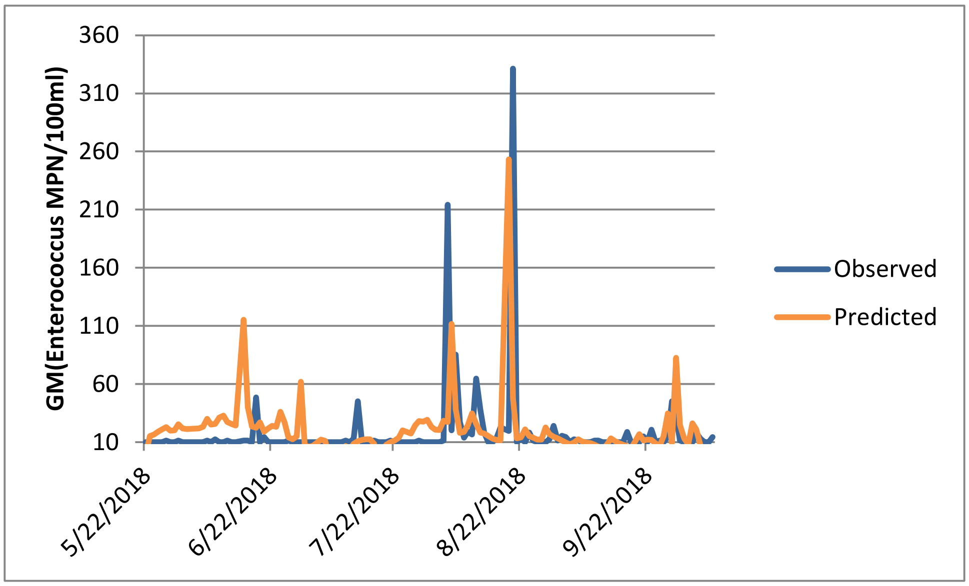


Figure 3-1. Time Series Plots of Predicted and Observed Geometric Mean *Enterococcus* Concentrations for 2017 (top) and 2018 (bottom)

Based on conversations with New Brunswick Department of Environment and Local Government and Office of the Chief Medical Officer of Health staff, the data set was also broken into two time periods – May-July and August-October. While the May-July data did not produce any statistically significant models, the August-October data set did produce models that met the requirements of statistical significance using 24-hour antecedent rainfall, days since rain and day of the year as IVs. Despite the fact that model predictive performance was still not at a level that would recommend operational implementation, the result supports two findings that have emerged through this preliminary model development and the analysis of rainfall data alone that is described in the next section – factors influencing FIB concentrations at Parlee Beach appear to change through the recreational season and the time since rainfall, in addition to the amount of rainfall, is an important factor.

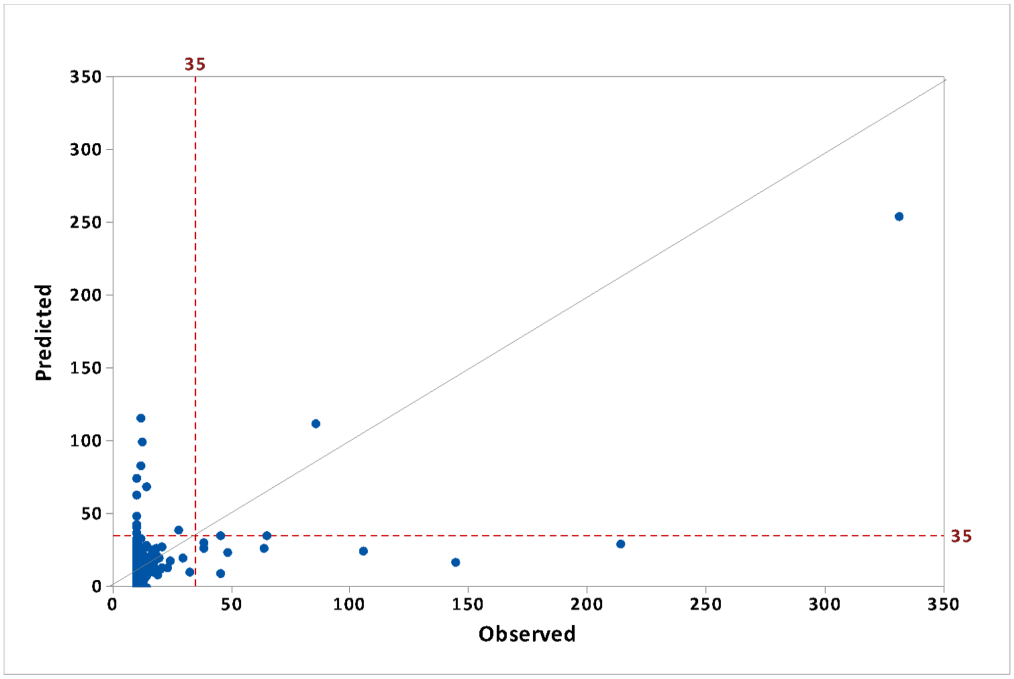


Figure 3-2. Scatterplot of Observed and Predicted (Eqn 1) *Enterococcus* with Perfect Fit Diagonal Line and Recreational Water Quality Criterion Reference Lines

3. 4 Antecedent Rainfall Models

An observed rainfall of 10 mm or more in the prior 24 hours is currently used as a preemptive advisory criterion for Parlee Beach. This is a widely-used empirical approach that states that elevated FIB concentrations are typically associated with some threshold value of rainfall and rely on the conceptual model of rainfall and subsequent runoff as being transport mechanisms for FIB to nearshore recreational waters. In the Parlee Beach Water Quality Final Report (2018) there was some questioning of the usefulness of the 10 mm rainfall threshold as a useful indicator of elevated bacteria concentrations. One objective of this study was to assess the usefulness of the currently used criteria and determine if additional recommendations could be made regarding the use of a rainfall threshold for preemptive advisories. *Enterococcus* was the FIB used for this assessment because of the increased number of values exceeding the criterion for *Enterococcus* and the consistency in *Enterococcus* data throughout the period of record.

The initial step in the analysis was plotting antecedent 24-hr antecedent rainfall versus *Enterococcus* concentrations. As **Figure 3-3** and **Figure 3-4** show, the use of the 10 mm threshold results in a relatively large number of false positives as well as several false negatives. For example, in **Figure 3-3** while the use of the 10 mm threshold value resulted in 5 days where *Enterococcus* concentrations were above the 35 MPN/100 ml criteria and a swimming advisory would have been correctly posted, there were nearly double the number of days when use of antecedent rainfall alone would have left the beach open for swimming despite *Enterococcus* concentrations above the recommended criteria. Even more frequent is the number of days when rainfall alone would have recommended a preemptive beach postings and subsequent FIB testing indicated concentrations below the level of concern for recreational exposure.

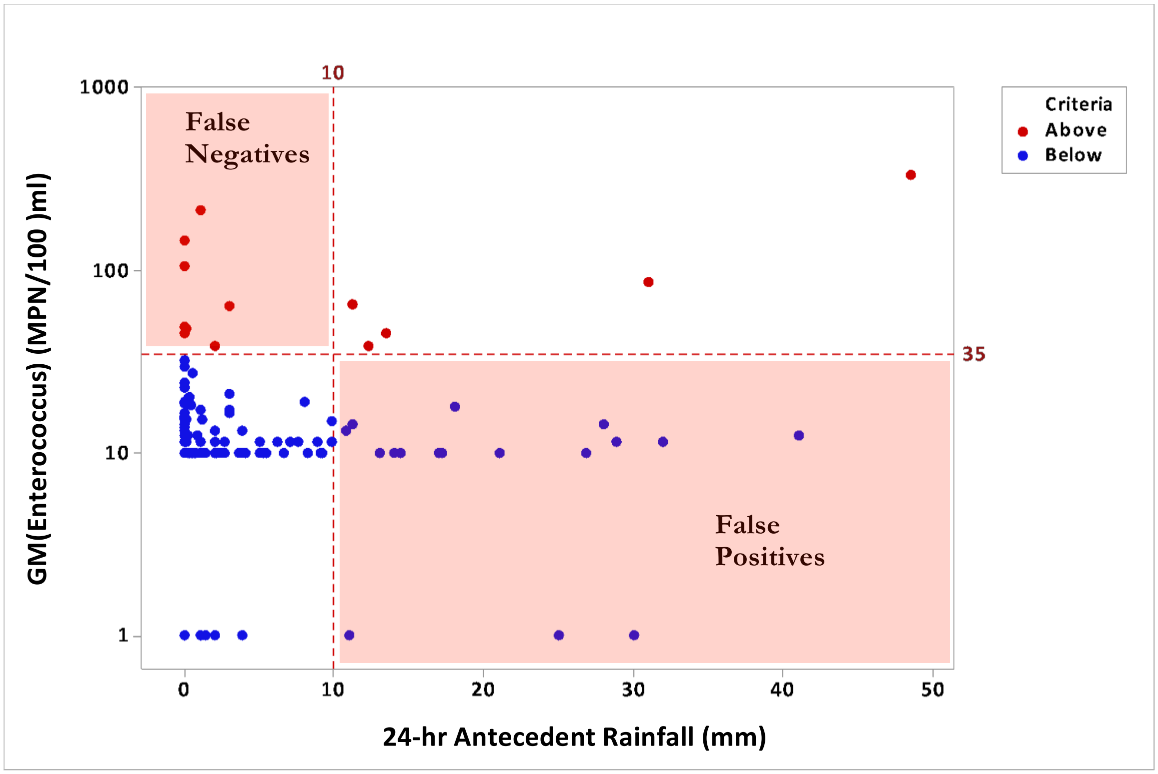


Figure 3-3. Scatterplot of Geometric Mean *Enterococcus* and 24-hr Antecedent Rainfall (2017-2018)

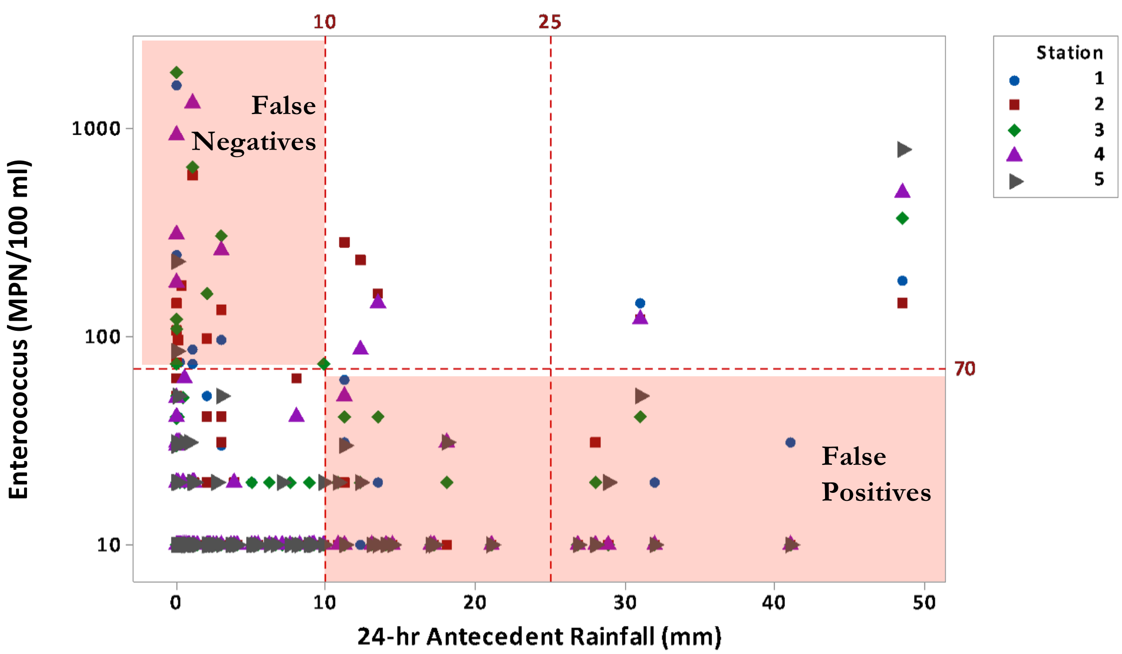


Figure 3-4. Scatterplot of *Enterococcus* and 24-hr Antecedent Rainfall (2017-2018)

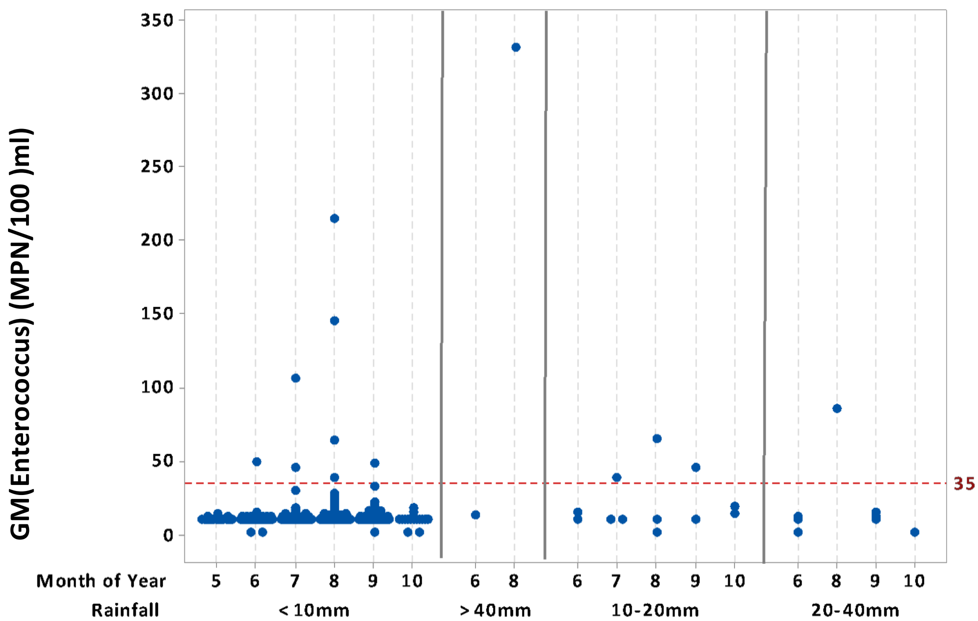


Figure 3-5. Individual Value plot of Geometric Mean *Enterococcus* Concentrations by Month and Associated 24-hr Antecedent Rainfall (2017-2018)

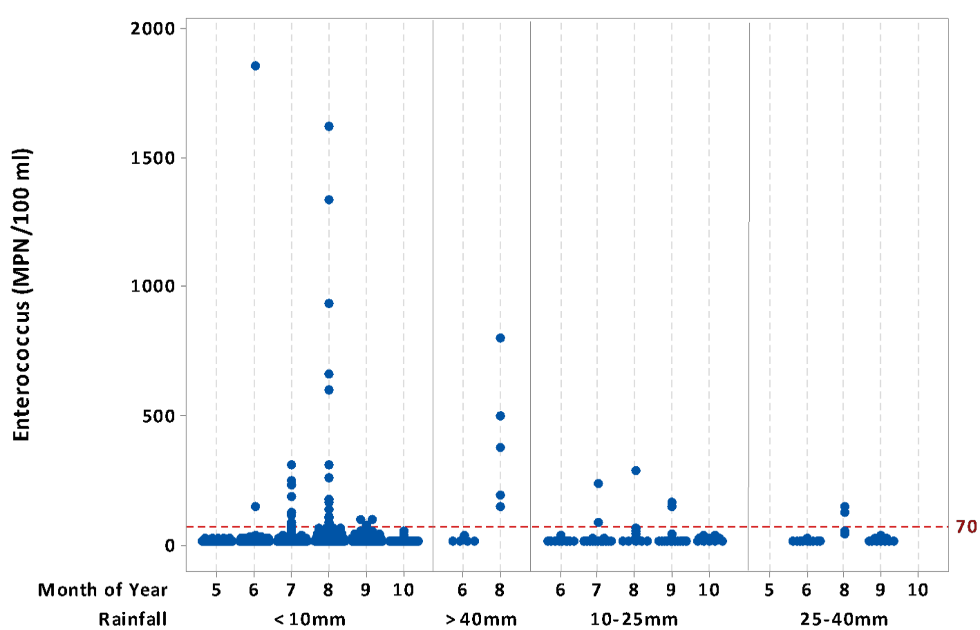


Figure 3-6. Individual Value plot of Single Sample *Enterococcus* Concentrations by Month and Associated 24-hr Antecedent Rainfall (2017-2018)

In order to better understand the potential behavior of antecedent rainfall as a predictor of microbial water quality, the *Enterococcus* data was assigned a rainfall category (<10 mm, 10-20 mm, 20-40 mm, and >40 mm) and plotted by month (**Figure 3-5** and **Figure 3-6**). The pattern of data in both figures reveals several useful observations. First, more observations of *Enterococcus* concentrations above 35 MPN/100 ml (**Figure 3-5**) or 70 MPN/100 ml (**Figure 3-6**) have occurred in the 2017-2018 recreation seasons when antecedent rainfall is actually below 10 mm compared to any other rainfall value. Even when rainfall values are above 10 mm, *Enterococcus* concentrations are more likely than not to be below the recreational water quality criteria. In addition, it is notable that elevated rainfall is more likely to be a predictor from July to September, although this is also a time when exceedances of the water quality criteria are likely to occur, regardless of rainfall amount.

Table 3-3 shows that the threshold would correctly predict approximately 38% of the days (5 of the 13 days) that exceeded the geometric mean of 35 MPN/100 ml. However, 18 additional days would have advisories posted with this threshold, when the indicator bacteria concentrations subsequently indicated values below the guidelines (i.e., false positives). If the threshold were raised to 25 mm (**Table 3-4**), only 2 of the 13 days (15%) would be accurately posted, while an additional 7 days would experience unwarranted advisories and 11 days would not have advisories despite indicator bacteria concentrations over the geometric mean guideline. It is also notable that of the four days in the period of record with the highest geometric mean *Enterococcus* concentrations, only 1 would have been correctly predicted as an advisory day by either the 10 mm or 25 mm rainfall threshold.

Similarly, if all five monitoring stations are considered and compared to the single sample maximum guideline value of 70 MPN/100 ml, the 10 mm threshold would predict approximately 30% of the total observations (not beach days) that exceeded the guideline and the 25 mm threshold would predict approximately 19% (**Table 3-4**). In the absence of any other data, the rainfall threshold provides some decision-making rationale, but for the 10 mm and 25 mm thresholds it does so at the cost of nearly three times more advisories than the actual water quality would warrant, while failing to identify over half of the days when water quality would indicate advisories should be posted. It is worth noting that a 25 mm rainfall threshold would offer little increase in specificity, but would substantially decrease sensitivity.

Table 3-3. Summary of Rainfall Threshold Performance for Geometric Mean *Enterococcus* (2017-2018)

Rainfall Threshold	n	True Positives	True Negatives	False Positives	False Negatives	Sensitivity	Specificity	Accuracy
10 mm	285	5	254	18	8	0.3846	0.9338	0.9088
25 mm	285	2	265	7	11	0.1538	0.9743	0.9368

Table 3-4. Summary of Rainfall Threshold Performance for Single Sample *Enterococcus* (2017-2018)

Rainfall	n	True	True	False	False	Sensitivity	Specificity	Accuracy

Threshold		Positives	Negatives	Positives	Negatives			
10 mm	1385	13	1261	82	29	0.3095	0.9389	0.9199
25 mm	1385	8	1316	27	34	0.1905	0.9799	0.9559

Although the use of a threshold value is basically an empirical model as discussed above, the relationship between rainfall and *Enterococcus* concentrations was formalized with two types of regression analysis. First, multiple linear regression was used to look at the relationship between geometric mean *Enterococcus* and rainfall and days since rainfall for the entire period of record (Equations A and B) and for the period July-September (Equations C and D). The results of that analysis using VB3.0.6 for transformed and untransformed *Enterococcus* and independent variables indicate that the best performing models are:

GM_Entero = 13.71 + 0.08533*(SQUARE(24-hr AntecedentRainfall_mm)) (Eqn A)

GM_Entero =
22.2087+0.0835*SQUARE[24-hr AntecedentRainfall_mm]–6.8765*SQUAREROOT[DaysSinceRain] (Eqn B)

GM_Entero (July-Sept) = 13.57 + 0.09939*(SQUARE(24-hr AntecedentRainfall_mm)) (Eqn C)

GM_Entero (July-Sept) =
19.55 + 0.09631*(SQUARE(24-hr AntecedentRainfall_mm))
- 4.806*(SQUAREROOT(DaysSinceRain)) (Eqn D)

Table 3-5. Rainfall Only MLR Models Predicting Geometric Mean *Enterococcus* at Parlee Beach

Equation	Adjusted R-squared	False Positives	Specificity	False Negatives	Sensitivity	Accuracy	n
A	0.3697	3	0.98378	9	0.18182	0.93878	196
B	0.4002	3	0.98378	9	0.18182	0.93878	196
C	0.4298	5	0.97076	10	0.16666	0.91803	183
D	0.4442	6	0.96491	9	0.25	0.91803	183

These results (**Table 3-5**) suggest that about 30-40% of the variability in the FIB can be explained by the antecedent rainfall and days since last rain. Surprisingly, although the number of days since rainfall did emerge as a factor in two of the four models in **Table 3-5**, the coefficient for days since last rain is negative. This result is counterintuitive to the idea that a longer period of dry weather would allow a build-up of bacteria that would be transported to the beach in the subsequent rainfall event. Nevertheless, the MLR analysis reveals that the number of days, especially in the July-September time period is a variable that helps to explain the observed variability in the FIB concentrations. Although the models' ability to predict lower concentrations and the large number of values less than 35 MPN/100 ml make the accuracy of the models high (>90%), the large number of false negatives illustrates the relatively poor performance of the models in predicting exceedances of the criteria value. Because the number of observations used to develop the equations in **Table 3-5** is smaller than the total number of observations available and used in the analysis presented in **Table 3-3**, a direct comparison is limited (i.e., not all the same data is contained in each calculation of specificity and sensitivity). However, based on data used for each, compared to the MLR models, it does appear that the 10 mm rainfall threshold is more likely to produce false positives, and the 25 mm threshold offers no improvement compared to MLR models and a decline compared to the 10 mm threshold, to predict *Enterococcus* values above the recreational water quality guidelines.

Use of the single sample values of *Enterococcus* increases the size of the data set available for model development, but due to the low percentage of values exceeding the water quality guideline of 70 MPN/100 ml, the MLRs developed are also characterized by low sensitivity (**Table 3-6**), i.e., limited ability to predict exceedances of the recreational water quality guideline of 70 MPN/100 ml. Adjusted R-squared values are even lower than the MLRs developed using the geometric mean *Enterococcus* data. Based on the performance of these models, they would not be recommended for use in an operational setting.

LN(Entero) =
5.813 + 0.04242*(24-hr AntecedentRainfall_mm) + 0.01006*(Rainfaill_mm_48hr)
+ 4.48e-06*(SQUARE(WindDirection_deg)) + 1.708e-05*(SQUARE(ChangeWindDirection_deg))
- 0.04143*(DaysSinceRain) - 3.62*(CoalBranch_WSE_m) - 8.507e-06*(SQUARE(DayOFYear)) (Eqn E)

LN(Entero) =
5.754 + 0.05236*(24-hr AntecedentRainfall_mm) + 1.715e-05*(SQUARE(ChangeWindDirection_deg))
- 0.05086*(DaysSinceRain) + 4.124e-06*(SQUARE(WindDirection_deg)) - 8.31e-06*(SQUARE(DayOFYear))
- 3.497*(CoalBranch_WSE_m) (Eqn F)

LN(Entero) =
10.37 + 0.03894*(24-hr AntecedentRainfall_mm) + 0.007361*(Rainfall_mm_72hr)
+ 2.584e-06*(SQUARE(WindDirection_deg)) - 0.1038*(SQUAREROOT(DaysSinceRain))
- 3.677*(CoalBranch_WSE_m) - 0.8801*(LN(DayOFYear)) (Eqn G)

Table 3-6. MLR Models Predicting Single Sample *Enterococcus* Concentrations at Parlee Beach

Equation	Adjusted R-squared	False Positives	Specificity	False Negatives	Sensitivity	Accuracy	Time Period	n
E	0.1984	3	1	31	0.13888	0.96287	July-Sept	835
F	0.1933	0	1	31	0.1388	0.9629	July-Sept	835
G	0.1825	5	1	31	0.13888	0.96836	May-October	980

As an alternative to MLR, binary logistic regression (BLR) was also explored. BLR models the relationship between a set of predictors and a binary response, which is a response with two possible outcomes. In this case, the outcomes are that the geometric mean FIB value is above (greater than) or below (less than) the recreational water quality criteria. The Minitab 18 statistical software was used for the development of BLR equations. For the BLR, a probability of exceeding the threshold (i.e., 50% probability, 25% probability) is set and then the prediction for one of the two binary responses is evaluated. The best performing model was generated when both antecedent precipitation and the number of days since rainfall are included as predictors. Two probability levels are included for comparison – 25% and 50%. A 50% value means that if the model predicts the probability of exceeding the threshold of 35 MPN/100 ml is 50% or higher, the binary result assigned is that *Enterococcus* is above the standard. Although BLR can sometimes be helpful to predict an "over/under" value compared to an exact value, the use of BLR appears to offer little reduction in the number of false negatives and may not offer substantial improvement over the use of a MLR model for rainfall (**Table 3-7**).

The equation for the BLR is:

Probability (GM_Entero>35) = **exp(Y')/(1 + exp(Y'))**

Where:
Y' = -2.004 + 0.0856*24-hr AntecedentRainfall_mm - 0.887*DaysSinceRain (Eqn 2)

Table 3-7. Rainfall Only BLR Models Predicting Geometric Mean *Enterococcus* at Parlee Beach

Probability Threshold	False Positives	Specificity	False Negatives	Sensitivity	Accuracy	n
0.25	3	0.9769	9	0.3333	0.9402	183
0.50	0	0.9885	10	0.1666	0.9457	183

3. 5 Conclusions and Recommendations

Preliminary model development and analysis of antecedent rainfall identified the following key findings regarding the use of predictive models and rainfall thresholds for potential management of recreational access at Parlee Beach:

- While several valid predictive models were developed from the available 2017-2018 data sets, none showed robust performance that would indicate they were strong candidates for operational implementation at Parlee Beach. Independent variables in the models most often included 24-hr antecedent rainfall, water surface elevation at the Coal Branch River, and days since rain. The frequency of antecedent rainfall as an IV is consistent with findings of the previous exploratory data analysis.
- Wind direction or change in wind direction did not appear as an important IV for modeling the geometric mean concentration, with only wind direction being present in one of the valid models. This may be due in part to the predominance of southwest winds and/or a general lack of observations exceeding the water quality guideline for recreational waters. Wind direction and change in wind direction did appear as IVs in modeling predicting the single sample value of *Enterococcus*.
- While valid models were identified, adjusted R-squared values were generally low, with the best performing modeling having a moderate adjusted R-squared of 0.4954.
- The MLR models were characterized by generally low sensitivity, meaning they did not perform well in terms of identifying true exceedances of the recreational water quality guidelines. As evaluated by sensitivity, the best performing MLR model

had a sensitivity value of 0.25 and utilized July through September 24-hr antecedent rainfall and number of days since rain as the predictive variables.

- Binary logistic regression (BLR) was also tested as an alternative to MLR. Performance was similar to MLR, with a relatively low probability of occurrence of exceeding the criteria needed to achieve sensitivity consistent with the best MLR models. In practice, use of a low probability of occurrence threshold diminishes the meaningfulness of the model.

Based on the preliminary model development and analysis of rainfall data for preemptive advisory postings for Parlee Beach, the following recommendations are also made:

- Based on the relatively low number of exceedances of the recreational water quality guidelines for *Enterococcus* and *E.coli*, development of robust predictive models suitable for operational use will be unlikely. If modeling were to be piloted for the 2019 season, the models shown in **Equation 1** or **Equation B** for the entire beach season or in **Equation D** for the period July-September would be recommended based on the analyses conducted. Even so, robust prediction is unlikely and the models should not be used as the sole decision-making tool for advisories.
- Because of the low number of exceedances of the recreational water quality criteria, and the challenge this presents for predictive modeling, other methods of rapid assessment of microbial water quality conditions should not be eliminated from consideration. Quantitative polymerase chain reaction, or qPCR, is a rapid method that is in use at several recreational water bodies in the U.S. and has been accepted by the U.S. EPA for assessment of recreational water quality conditions at both fresh and marine water beaches.
- An antecedent rainfall amount of 10 mm has not been demonstrated to be a reliable predictor of microbial water quality at Parlee Beach, based on data collected during the 2017 and 2018 beach seasons.
- Measurement of turbidity as a field water quality parameter is a recommended addition for 2019 with subsequent assessment of the parameter as a surrogate indicator and/or an additional independent variable in predictive modeling. (See **Section 2.6** for additional detail.)
- Although the 2017-2018 data indicates that more exceedances of the water quality criterion office in the late summer, routine use of qPCR may actually be most helpful for the protection of public health in the early summer (May, June) the time period within the recreational season when rainfall appears to be an even less effective indicator of water quality.
- A combination of a MLR model or the antecedent rainfall threshold and qPCR could also be considered. For example, the current rainfall threshold for preemptive advisories tends to over-estimate days when water quality actually exceeds the guideline, i.e., it produces many false positives. If a 24-hour rainfall value, which is also a forecastable meteorological variable, were used as a screening tooling, then when rainfall is over the threshold value, qPCR testing could be run on the samples collected. This would allow the development of a forecast for water quality that could guide the use of qPCR analysis in a targeted, cost-effective way, especially during the period of July-September, and potentially reduce the number of "false positives" resulting from the use of the rainfall threshold alone.

Glossary

Glossary

Accuracy – A measurement of the closeness of the computed values to the true value. In this study, accuracy is measured relative to a computed (i.e., modeled or estimated) value being above or below a criterion of interest (i.e., a recreational water quality guideline).

$$Accuracy = \frac{(true\ positives + true\ negatives)}{n}$$

Adjusted R-squared – An adjusted R-squared value is a measure of how well the data matches the model, or in other words, the percentage of data explained by the model. This is a variation of the R-squared value that better compensates for data sets with multiple variables (See **R-squared**). If p is defined as the number of parameters in a model and n as the number of observations in the dataset, the evaluation criteria for any model can be defined as:

$$Adjusted\ R^2 = 1 - (1 - R^2)\frac{(n-1)}{(n-p-1)}$$

Correlation – Correlation is a measure the strength and direction of the association between two variables. Correlation describes the degree to which the two variables co-vary (i.e., one variable increases or decreases as the other increases). Correlation between two variables does not provide evidence that there is a causal relationship between the two variables (i.e., does not mean that variation in one variable is caused by the other variable).

False positive – In this study, a false positive is a predicted value of a bacteria concentration above the water quality guideline concentration when the measured concentration was below the guideline concentration.

False negative – In this study, a false negative is a predicted value of a bacteria concentration below the water quality guideline concentration when the measured concentration was above the guideline concentration.

Independent or Explanatory variable – The value of an independent variable does not depend upon another variable. Independent variables (in this study, rainfall, temperature, etc.) are used to predict the value of another variable, the dependent or response variable (in this study, *Enterococcus* or *E.coli* concentration).

Left-censored data – Left-censored data refers to a data set where data values are not available below a given threshold. In this study, data may be reported as a bacteria concentration below a concentration (i.e., <10 MPN/100 ml), but it cannot determine exactly how far below the threshold the actual concentration is.

Multiple Linear Regression (MLR) – MPR is a statistical method used to determine a mathematical relationship between multiple independent variables and one dependent variable (in this study, *Enterococcus* or *E.coli* concentration).

Over-fit model – Overfitting happens when a regression model becomes tailored to fit characteristics of a specific sample set rather than the overall population of data. Typically an over-fit model may match the given data well but fail to accurately predict future data.

p-value – In MLR, the p-value reflects the strength of evidence against the hypothesis that the coefficient of a linear regression model is not statistically different from zero (i.e., the null hypothesis).

R-squared – A measure of how well the data matches the model, or in other words, the percentage of data explained by the model (See **Adjusted R-squared**). Using RSS as the residual sum of squares for a model, and TSS as the total sum of squares for a model, the evaluation criteria for a model can be defined as:

$$R^2 = 1 - \frac{RSS}{TSS}$$

Sensitivity – Sensitivity is a measure of the percentage of positive results correctly identified to be positive results. In this study, sensitivity is measured relative to a computed (i.e., modeled or estimated) value being above or below a criterion of interest (i.e., a recreational water quality guideline).

$$Sensitivity = \frac{true\ positives}{(true\ positives + false\ negatives)}$$

Specificity – Specificity is a measure of the percentage of negative results correctly identified to be negative results. In this study, specificity is measured relative to a computed (i.e., modeled or estimated) value being above or below a criterion of interest (i.e., a recreational water quality guideline).

$$Specificity = \frac{true\ negatives}{(true\ negatives + false\ positives)}$$

Statistically significant – Significantly significant is a term used to describe data when the probability of the results occurring purely by chance is below a given threshold.

References

Anderson, C.W., 2005. Turbidity: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6., section 6.7, available at: http://pubs.water.usgs.gov/twri9A6/

Dorfman, M., Haren, A. and Devine, J., 2014. Testing the Waters. A Guide to Water Quality at Vacation Beaches NRDC.

Francy, D.S., Brady, A.M.G., Carvin, R.B., Corsi, S.R., Fuller, L.M., Harrison, J.H., Hayhurst, B.A., Lant, J., Nevers, M.B., Terrio, P.J., and Zimmerman, T.M., 2013. Developing and implementing predictive models for estimating recreational water quality at Great Lakes beaches: U.S. Geological Survey Scientific Investigations Report 2013–5166, 68 p., http://dx.doi.org/10.3133/sir20135166/.

Francy, D. and Darner, R., 2006. Procedures for Developing Models to Predict Exceedances of Recreational Water Quality Standards at Coastal Beaches—Techniques and Methods 6-B5. US Geological Survey, Reston, VA.

Health Canada, 2012. Guidelines for Canadian Recreational Water Quality – Third Edition. Available at: https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-recreational-water-quality-third-edition.html

Helsel, D.R. and R. M. Hirsch, 2002. Statistical Methods in Water Resources Techniques of Water Resources Investigations, Book 4, chapter A3. U.S. Geological Survey. Available at: https://pubs.usgs.gov/twri/twri4a3/pdf/twri4a3-new.pdf

Mas, D. and Baker, K. 2011. Guidance for Developing Predictive Models for Ontario Beaches.

Steering Committee for Parlee Beach Water Quality. 2018. Parlee Beach Water Quality, Shediac, New Brunswick Final Report. Available at: https://www2.gnb.ca/content/dam/gnb/Departments/eco-bce/Promo/Parlee_Beach/pdfs/parlee_beach_water_quality_finalreport-e.pdf

USEPA, 2004. Water Quality Standards for Coastal and Great Lakes Recreation Waters; Final Rule. Available at: https://www.govinfo.gov/content/pkg/FR-2004-11-16/pdf/04-25303.pdf

Zepp, R.G., Cyterski, M., Parmar, R., Wolfe, K., White, E.M. and Molina, M., 2010. Predictive Modeling at Beaches Volume II: Predictive Tools for Beach Notification. US EPA National Exposure Research Laboratory, Washington, DC, USA.

End of Report