Environmental Factors Associated with Recreational Beach Water Quality in Toronto and Niagara Region

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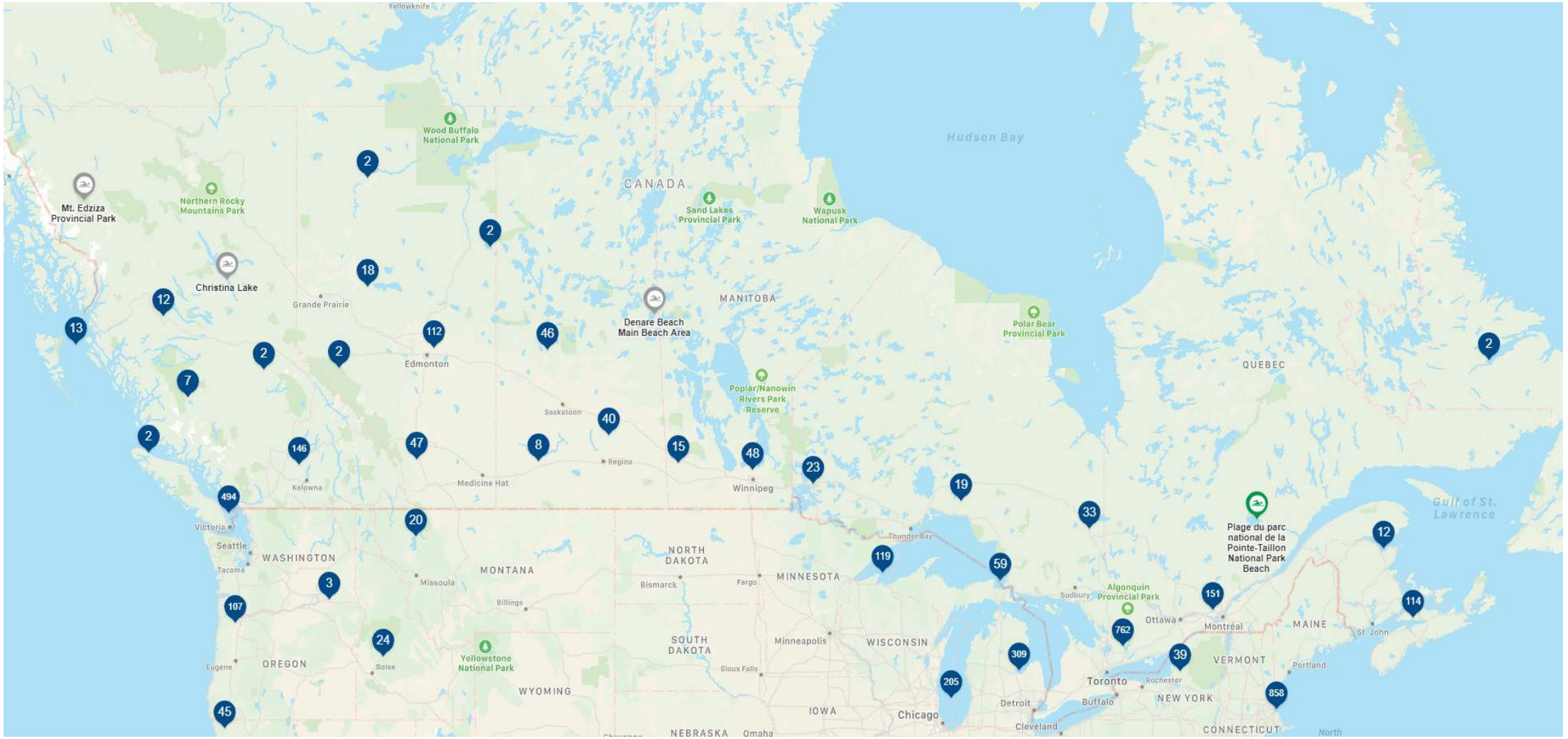
Introduction

- Swimming at public beaches is an increasingly popular recreational activity among Canadians, particularly during the pandemic
- Other popular recreational water activities include kayaking, paddleboarding, waterskiing and canoeing
- Poor recreational water quality represents a risk of acute gastrointestinal illness (AGI) for those engaging in recreational water activities; however, it is highly undetected and underreported
- AGI risk is higher in children 0-10 years of age
- Bacterial, protozoal and viral waterborne pathogens are the primary etiological agents of concern in beaches – *Escherichia coli (E. coli), Enterococcus, Salmonella, Campylobacter, Giardia,* and *Cryptosporidium*
- Beach managers monitor the presence of *E. coli,* which is a fecal indicator bacteria to indicate the presence of water pathogens
- Environmental factors are involved with affecting water quality levels
- Our research aims to understand the environmental factors associated with *E. coli* concentration in freshwater beaches

Outline

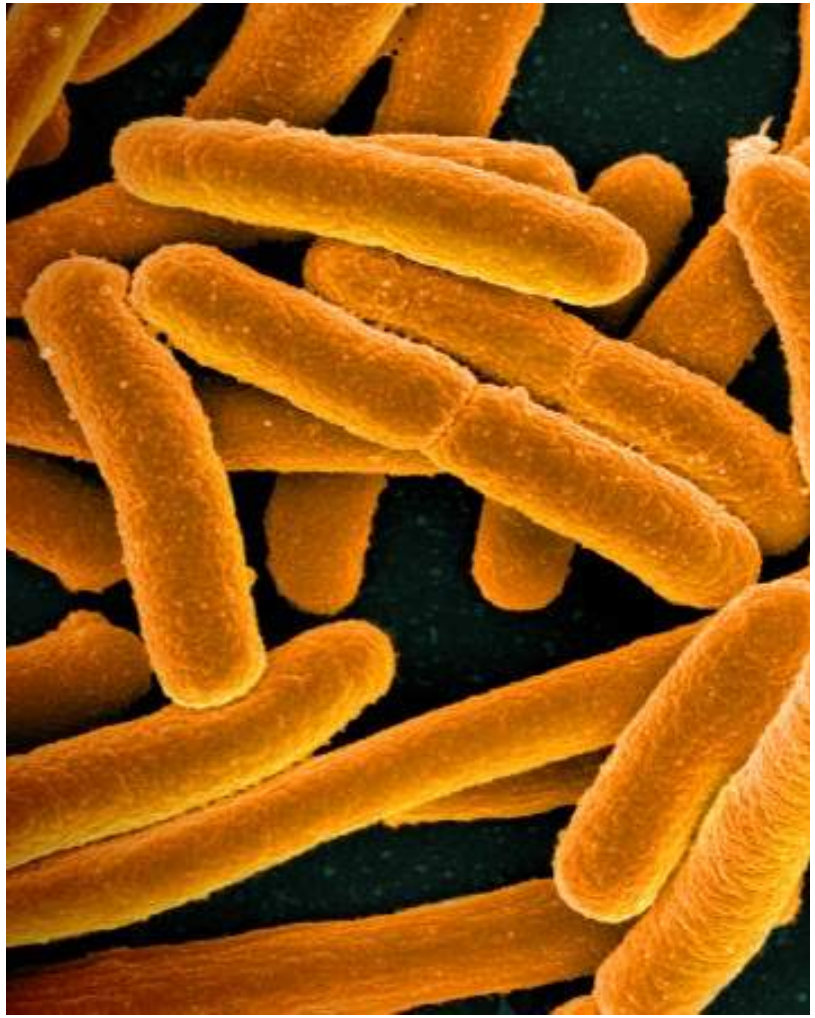
- Background
- Research Objectives
- Study Setting
- Data
- Analysis Methods
- Results
    - Niagara Path Analysis
    - Telehealth analysis
    - Regional analysis
- Discussion/Conclusions
- Questions

Canadian Beaches



(Swim Drink Fish, 2021)

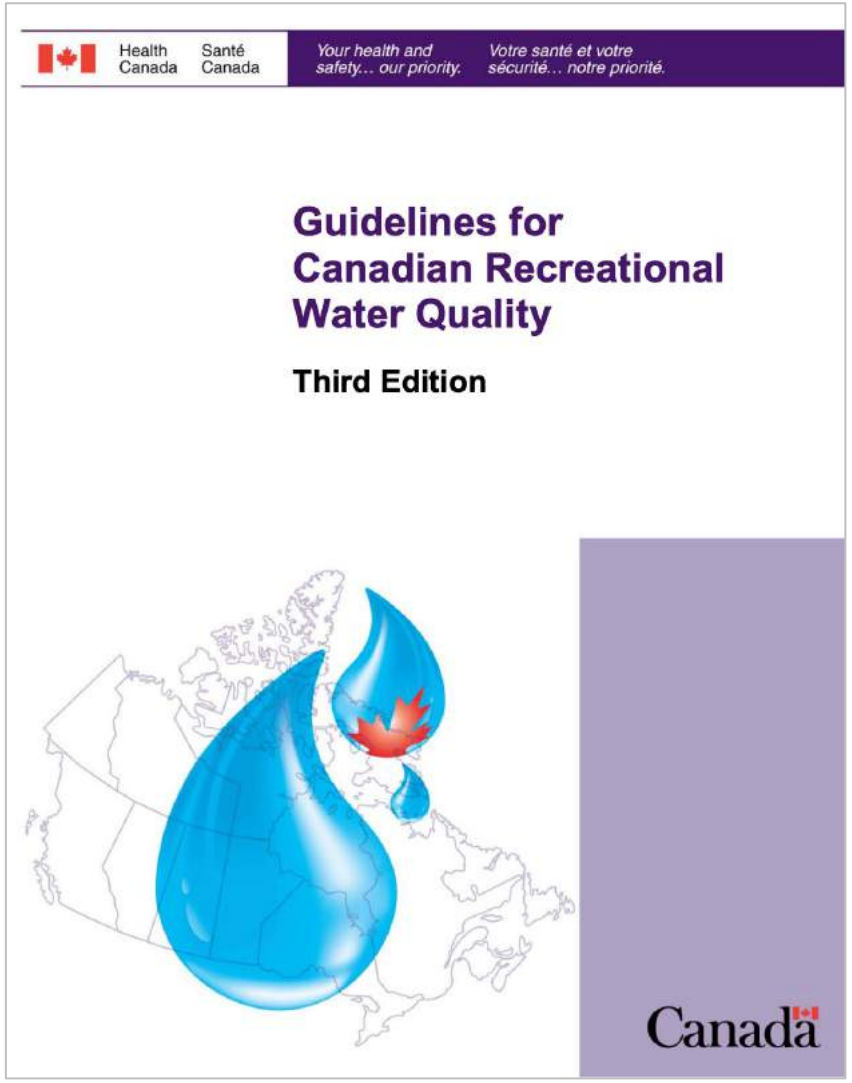
Fecal Indicator Bacteria (FIB)



- The presence of these bacteria are an indication of fecal material in the water
- *Escherichia coli* concentration is the indicator suggested for freshwater recreational water
- Enterococcus is the suggested FIB for marine waters
- This research focuses on *E. coli* concentration in freshwater beaches

Guidelines for Canadian Recreational Water Quality

- Published in 2012
- Threshold levels have been developed to suggest an acceptable and low risk of gastrointestinal illness
- In fresh waters, guidelines recommend *Escherichia coli* geometric mean concentration of ≤200 colony-forming units (CFU)/100 mL OR a single sample maximum concentration of ≤400 CFU/100mL
- Geometric mean = calculated from a minimum of 5 samples



Beach Monitoring

- Recreational water quality monitoring falls under provincial and territorial jurisdiction
- In Ontario, beaches are regularly monitored by public health authorities through water sampling during the summer season
- Communication of water quality risk to the public is determined by each jurisdiction and may include a sign or flag directly posted on the beach or on the public health authority website

Water Sampling

- The 2018 Ontario Operational Approaches for Recreational Water Guideline recommends that water be collected where depth is 1-1.5m deep
- Samples are obtained 15-30 centimetres below the water surface
- Sample collected using sterile bottles used by Public Health Ontario Laboratory
- For consistency, water samples are collected from the same general locations at 5 sites across the beach

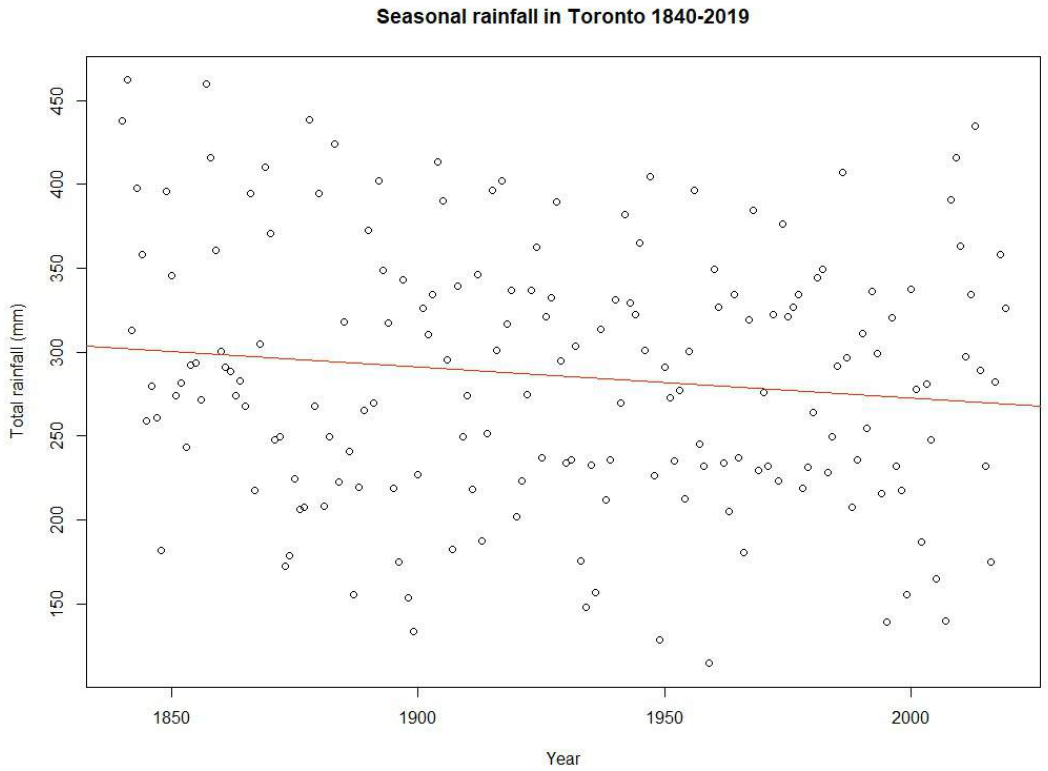
Limitations

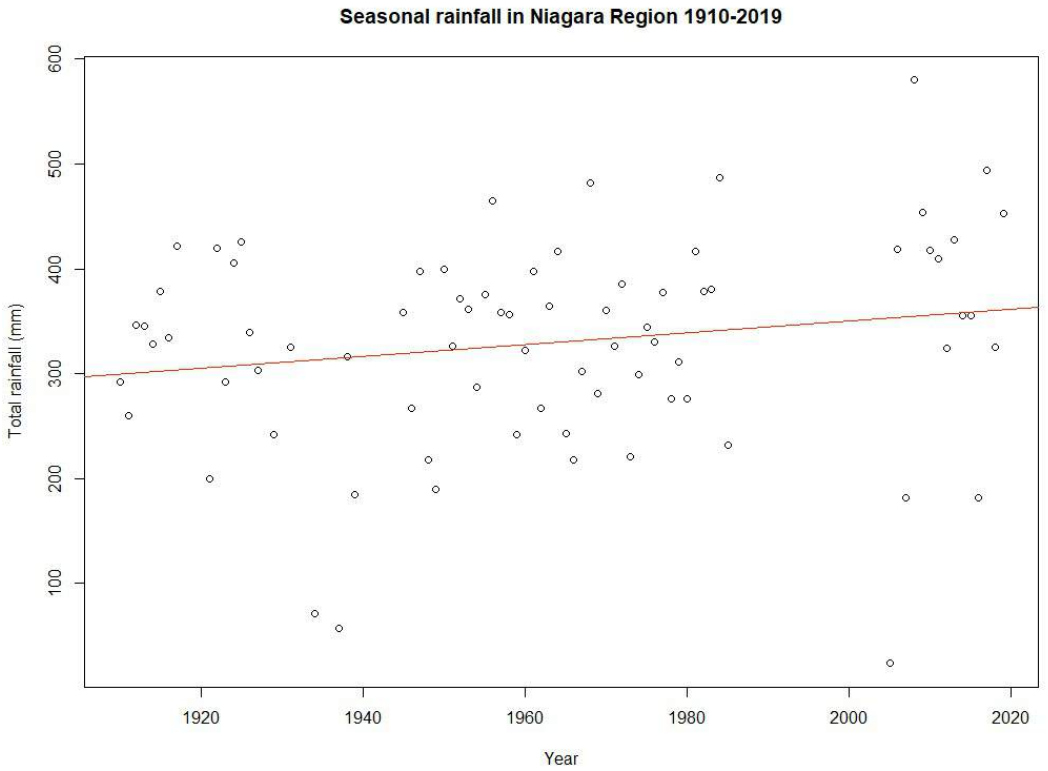
- Culture based methods can take 18-24 hours to process
- Decisions about beach posting status are based on previous day *E. coli* concentration
- Delays can result in risk to swimmers as changes in environmental conditions can affect water quality in hours
- Understanding environmental factors associated with water quality can inform beach monitoring programs

Environmental Factors

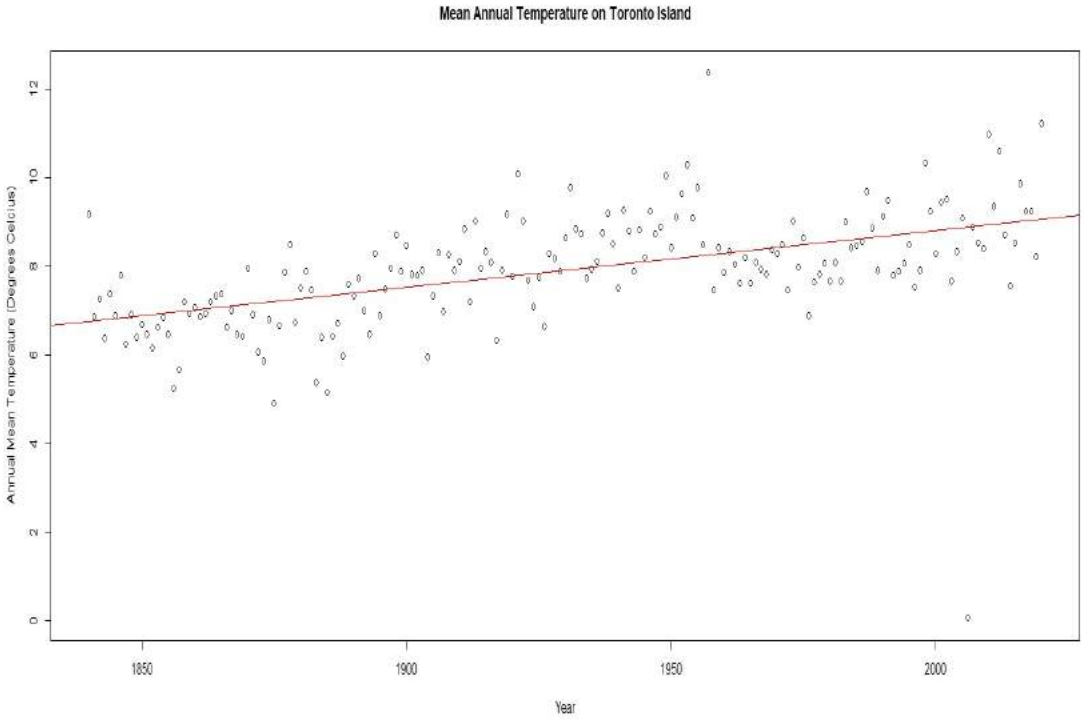
- Rainfall
- Air temperature
- Water temperature
- Stream discharge
- Wave height
- Wind speed
- Ultraviolet radiation
- Turbidity

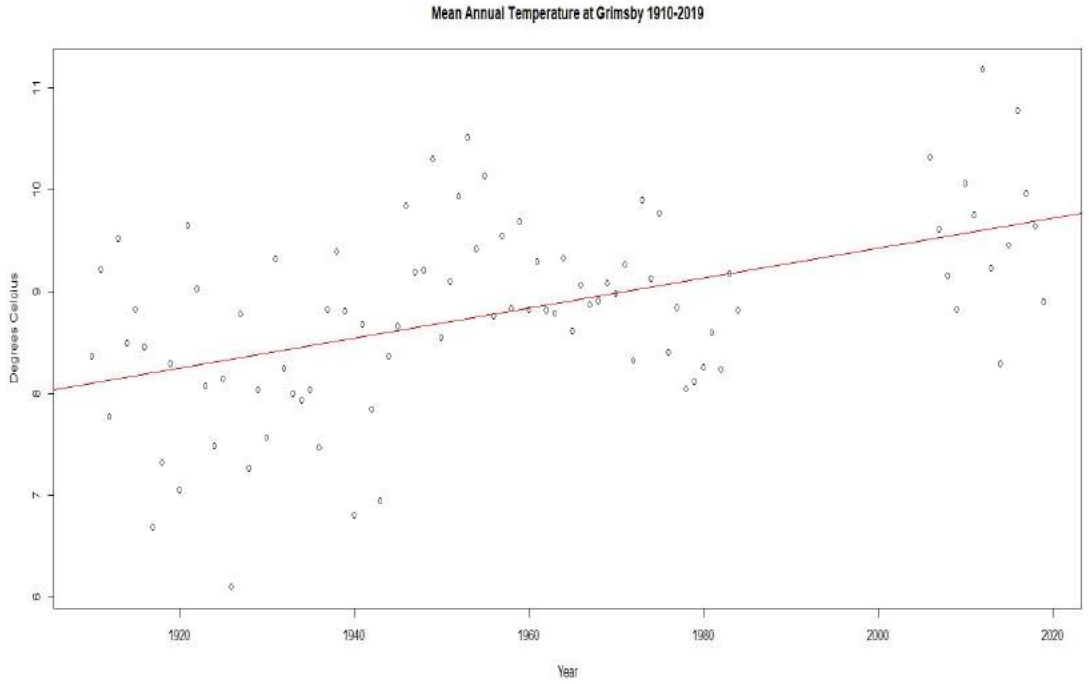
Rainfall


Seasonal rainfall in Toronto 1840-2019
Total rainfall (mm)
150
200
250
300
350
400
450
1850
1900
1950
2000
Year


Seasonal rainfall in Niagara Region 1910-2019
Total rainfall (mm)
100
200
300
400
500
600
1920
1940
1960
1980
2000
2020
Year

Air Temperature Trends





Research Objectives

1. Determine which climate- and weather-related factors are associated with higher levels of *E. coli* in public bathing beaches over time.

2. Develop user-friendly predictive models, using a novel Bayesian network approach, for selected beaches to assist public health authorities in their risk management decisions.

Study Setting

Toronto

- Largest city in Canada
- 5,429,254 (urban) million people
- 11 beaches included in the study

Niagara Region

- Large region consisting of several municipalities
- 14 million tourists annually
- 8 beaches included in the study

Data

- 5,149 *E. coli* observations from Niagara Region
- 14,324 *E. coli* observation from Toronto
- Linked to publicly available environment data from Environment Canada's and the conservation authority's historical data repository

Variable	Toronto	Niagara
Years of data	**2007-2019**	**2011-2019**
E. coli value	Beach	Beach
Rainfall	Weather Station	Weather Station
Water Temperature	Buoy	Buoy, Beach
Air Temperature	Weather Station	Weather Station, Beach
Wave Height	Buoy	Buoy, Beach
Wind Speed	Buoy	Buoy
Stream Flow	River sensor	River sensor
Water Level	Buoy	Buoy
Turbidity	NA	Beach

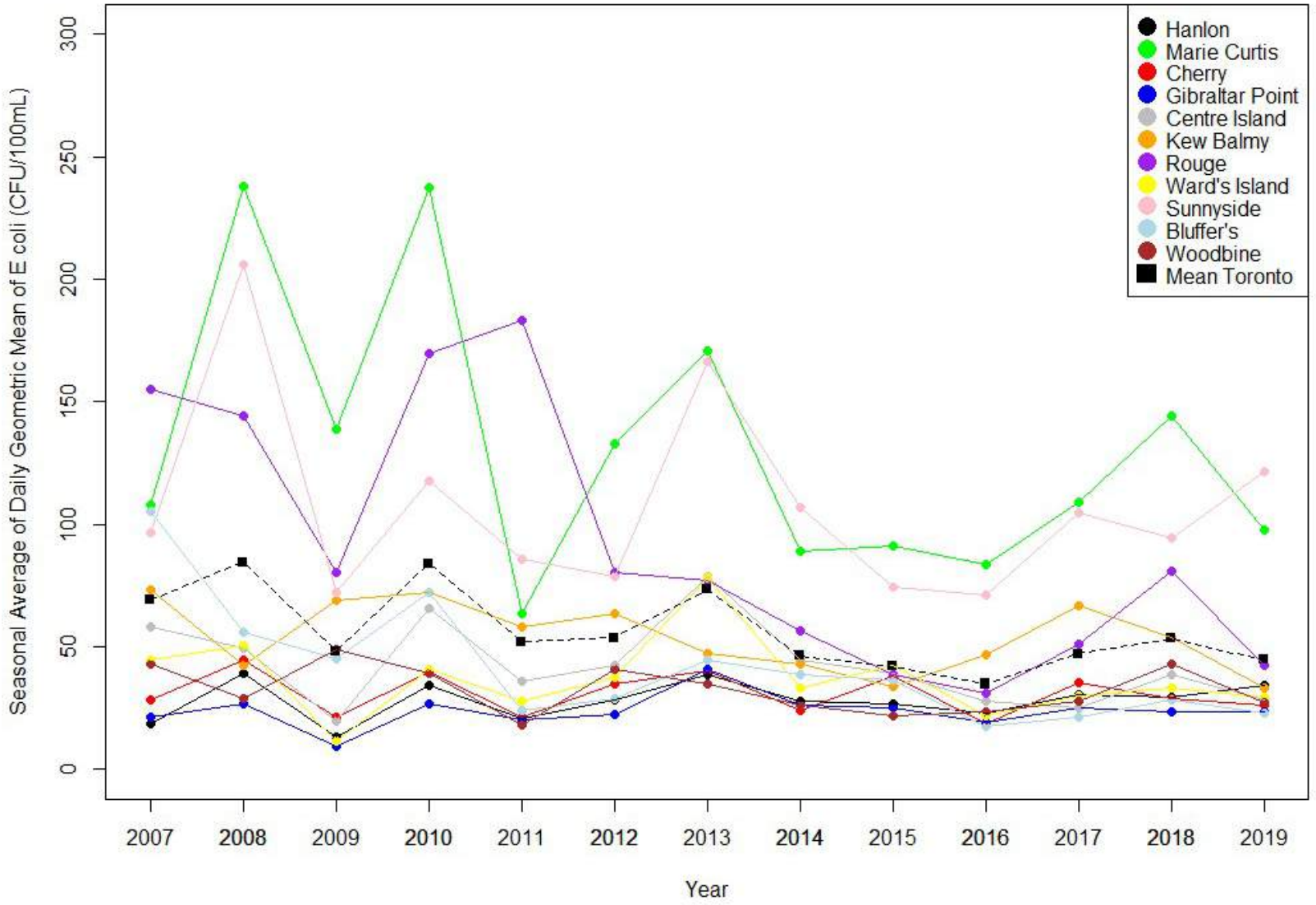
Toronto

- 11 beaches on Lake Ontario
- Grimsby buoy
- Streamflow data – 3 rivers
- UV station TRCA

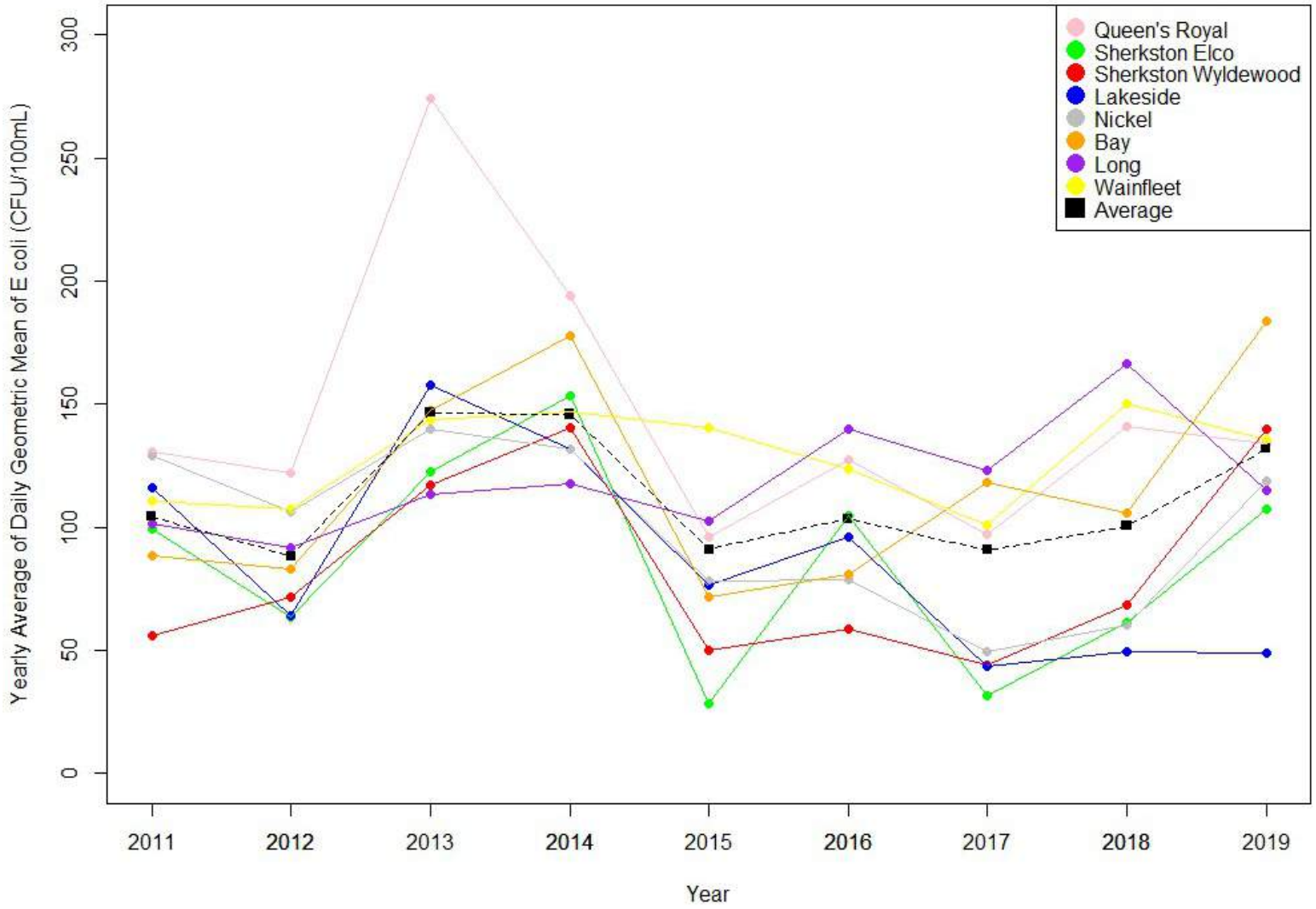
Niagara Region

- 2 beaches on Lake Ontario
- 6 beaches on Lake Erie
- 2 buoys
- Streamflow data – Welland Canal and Niagara River
- UV station Buffalo

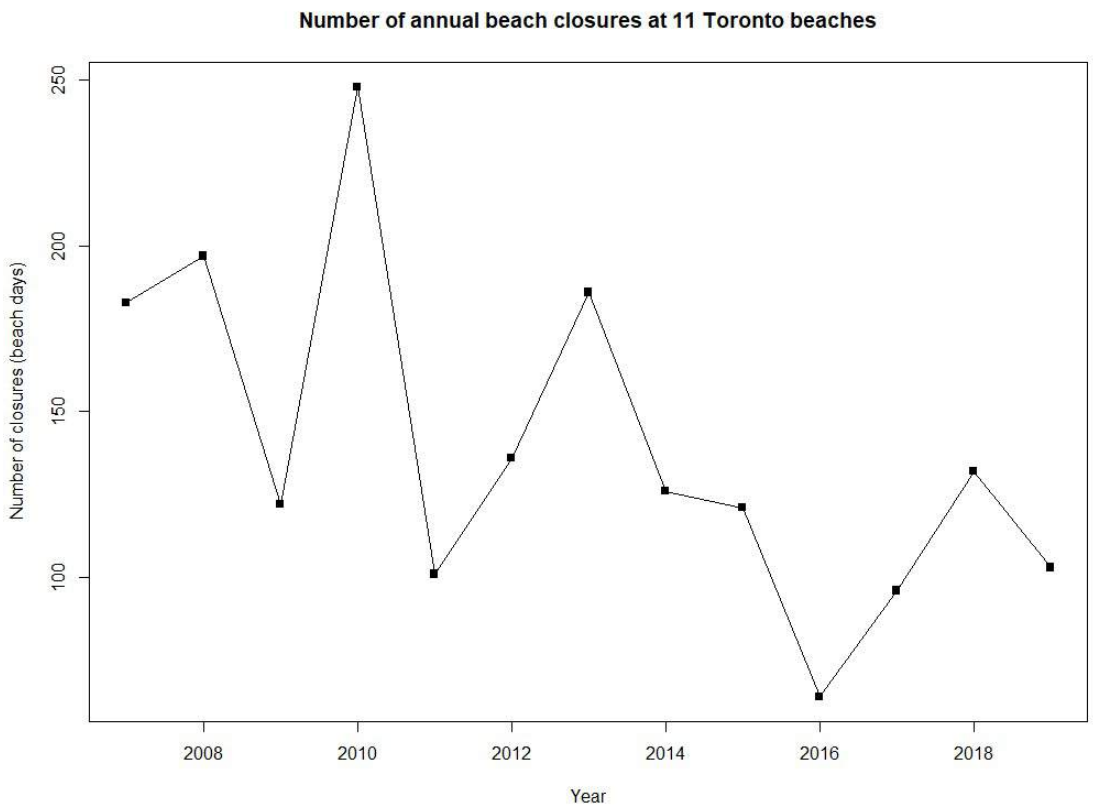
Mean annual *E. coli* mean at Toronto beaches, 2007-2019

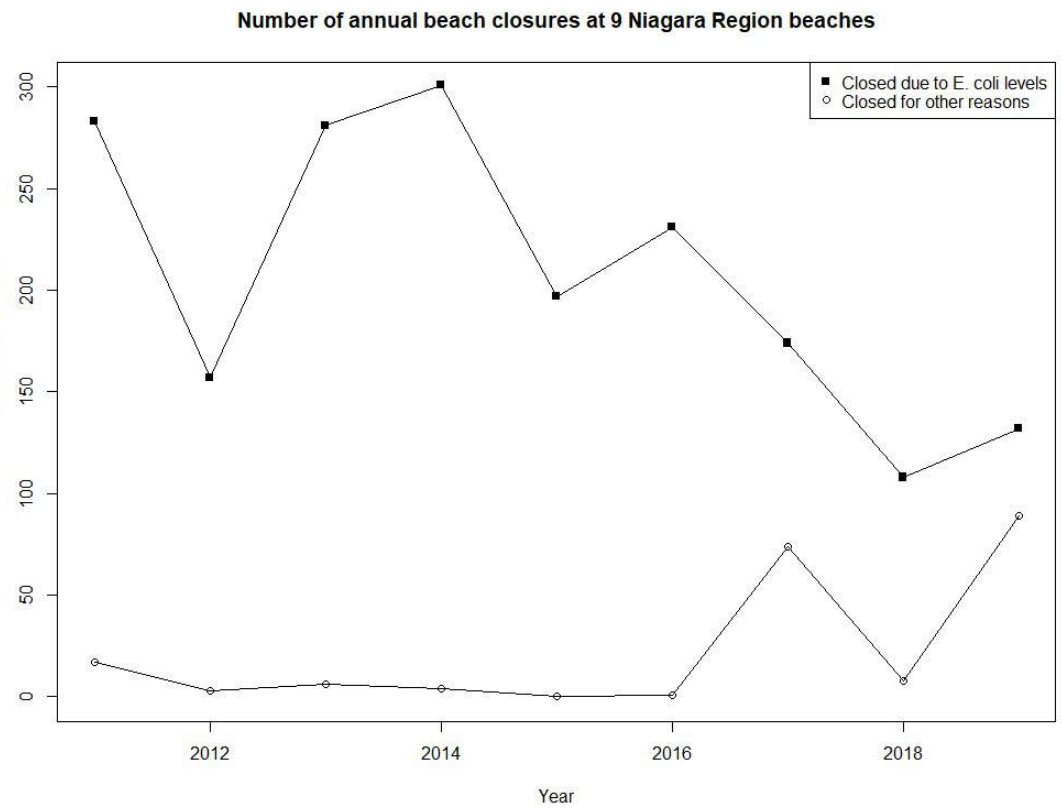


Mean annual *E. coli* mean at Niagara Region beaches, 2011-2019



Beach Posted as Unsafe for Swimming





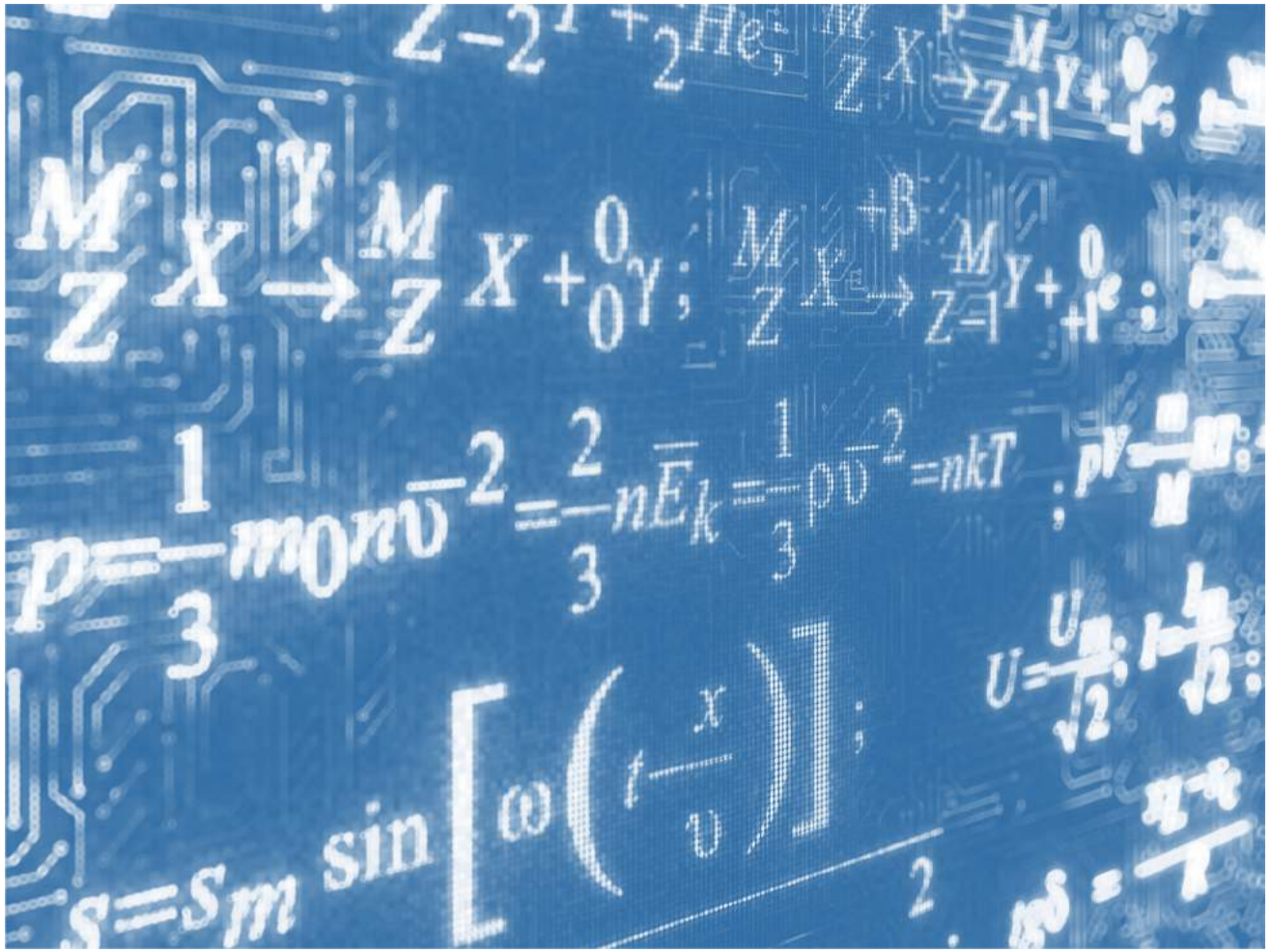
Analysis Methods

Path analysis

- Conducted in the Niagara Region
- Allows us to examine the relationship between variables

Multilevel modelling

- Examine beach-specific and geographic-specific effects

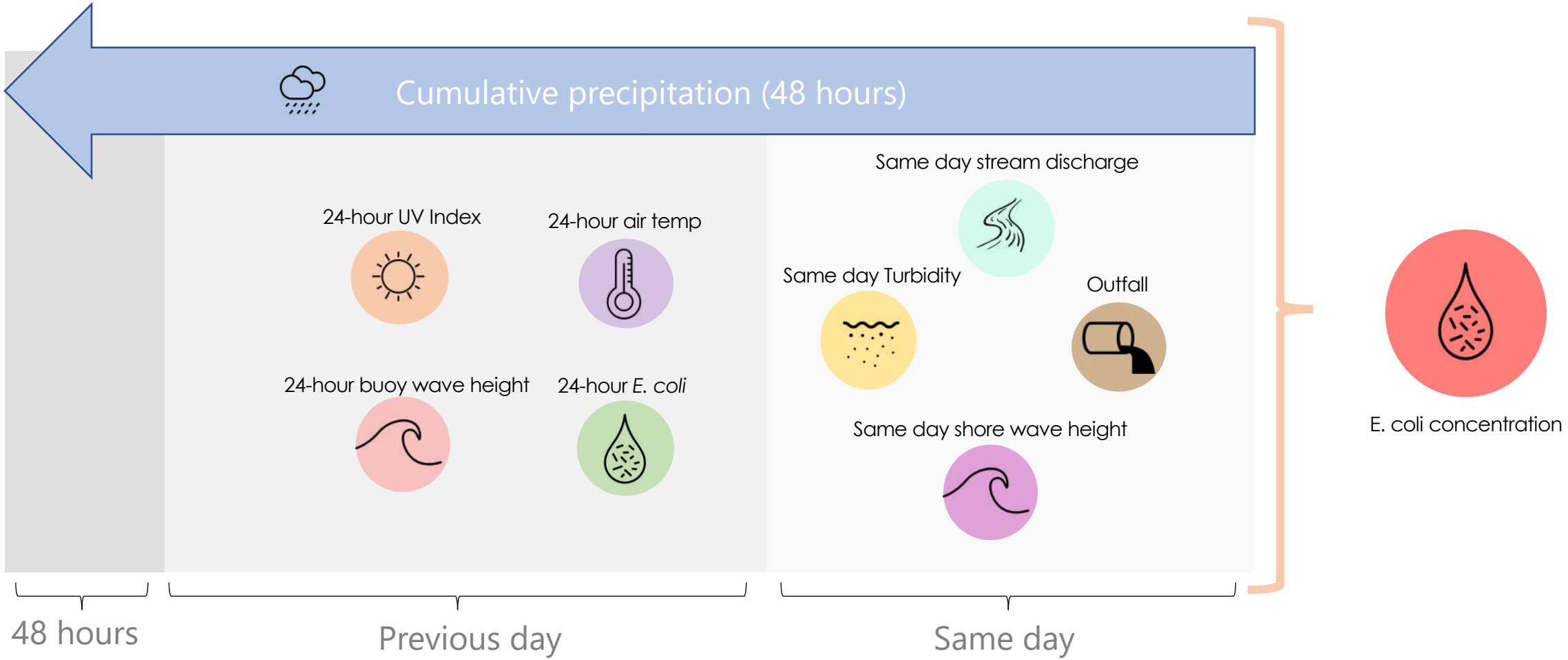


Niagara Region Path Analysis

- Niagara Region public health authorities collected several parameters locally – turbidity, outfall, shore wave height
- Turbidity was collected from the 3rd water sampling location and tested on site – the availability of this data allowed for the examination of relationships between variables
- Outfall *E. coli* sampling was conducted weekly from the water runoff outflow source on the beach, at a subset of beaches

Variable	Toronto	Niagara
Years of data	2007-2020	2011-2020
E. coli value	Beach	Beach
Rainfall	Weather Station	Weather Station
Water Temperature	Buoy	Buoy, Beach
Air Temperature	Weather Station	Weather Station, Beach
Wave Height	Buoy	Buoy, Beach
Wind Speed	Buoy	Buoy
Stream Flow	River sensor	River sensor
Water Level	Buoy	Buoy
Turbidity	NA	Beach
Outfall	NA	Beach

Environmental variables

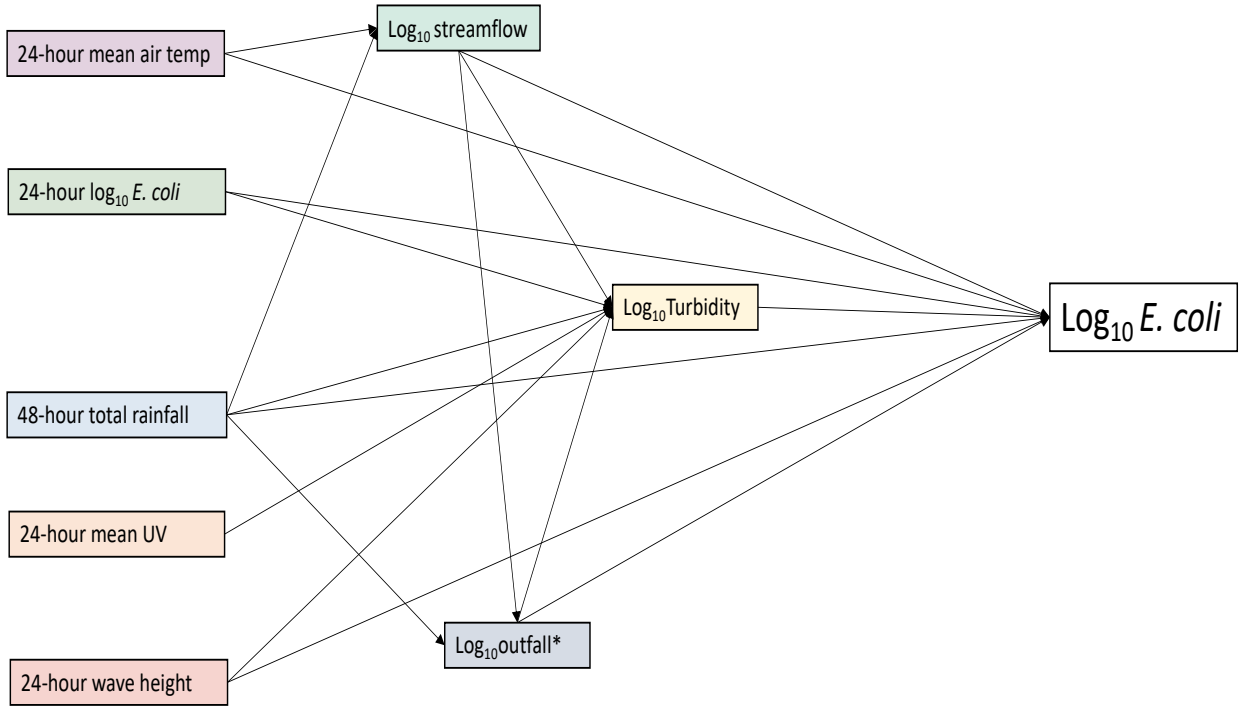


Niagara Region Path Analysis

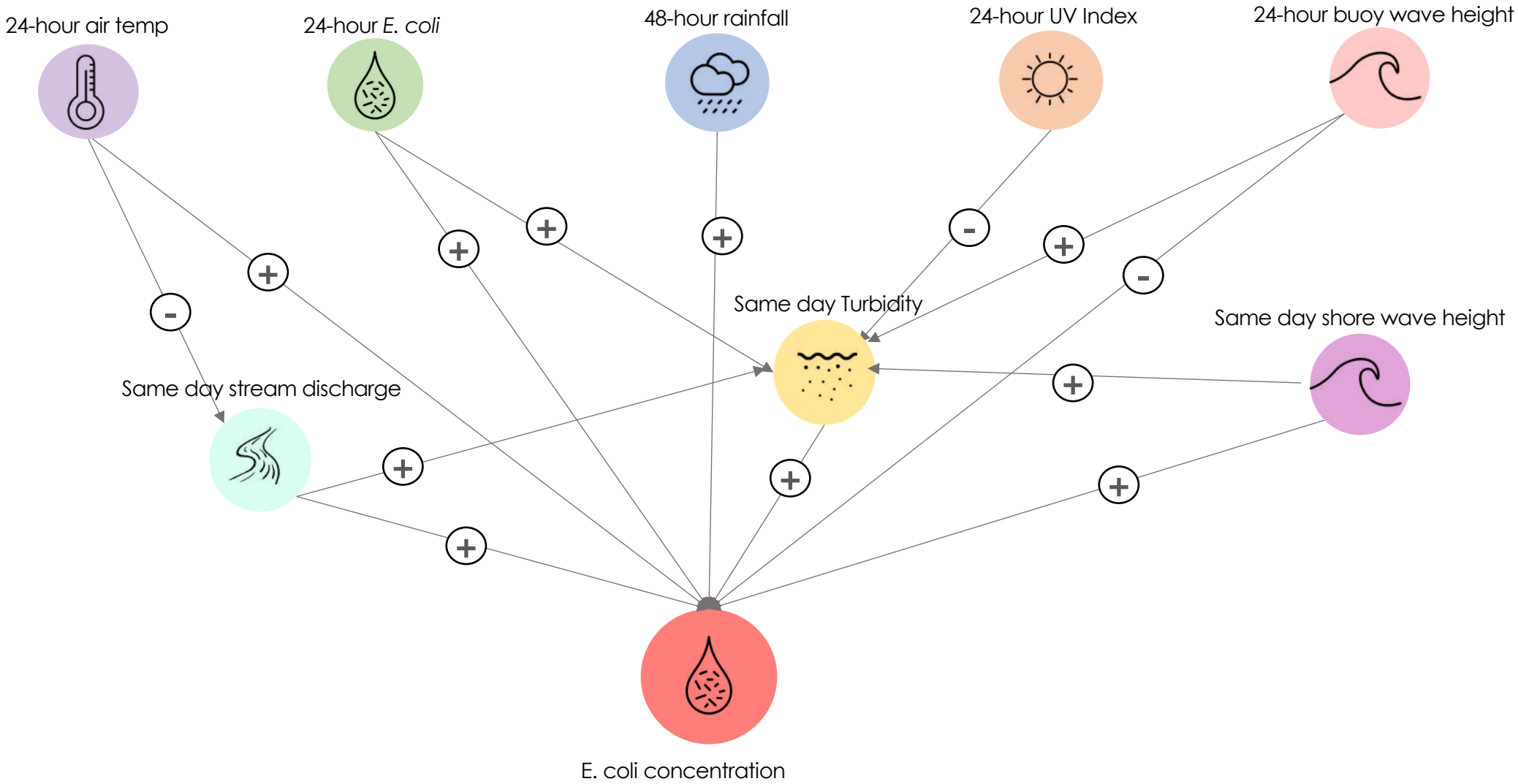
- Path analysis is a powerful statistical method for examining causal patterns among variables, which is useful in understanding the relationships between variables

- To our knowledge this is the first application of this methodology to examine predictors of freshwater quality

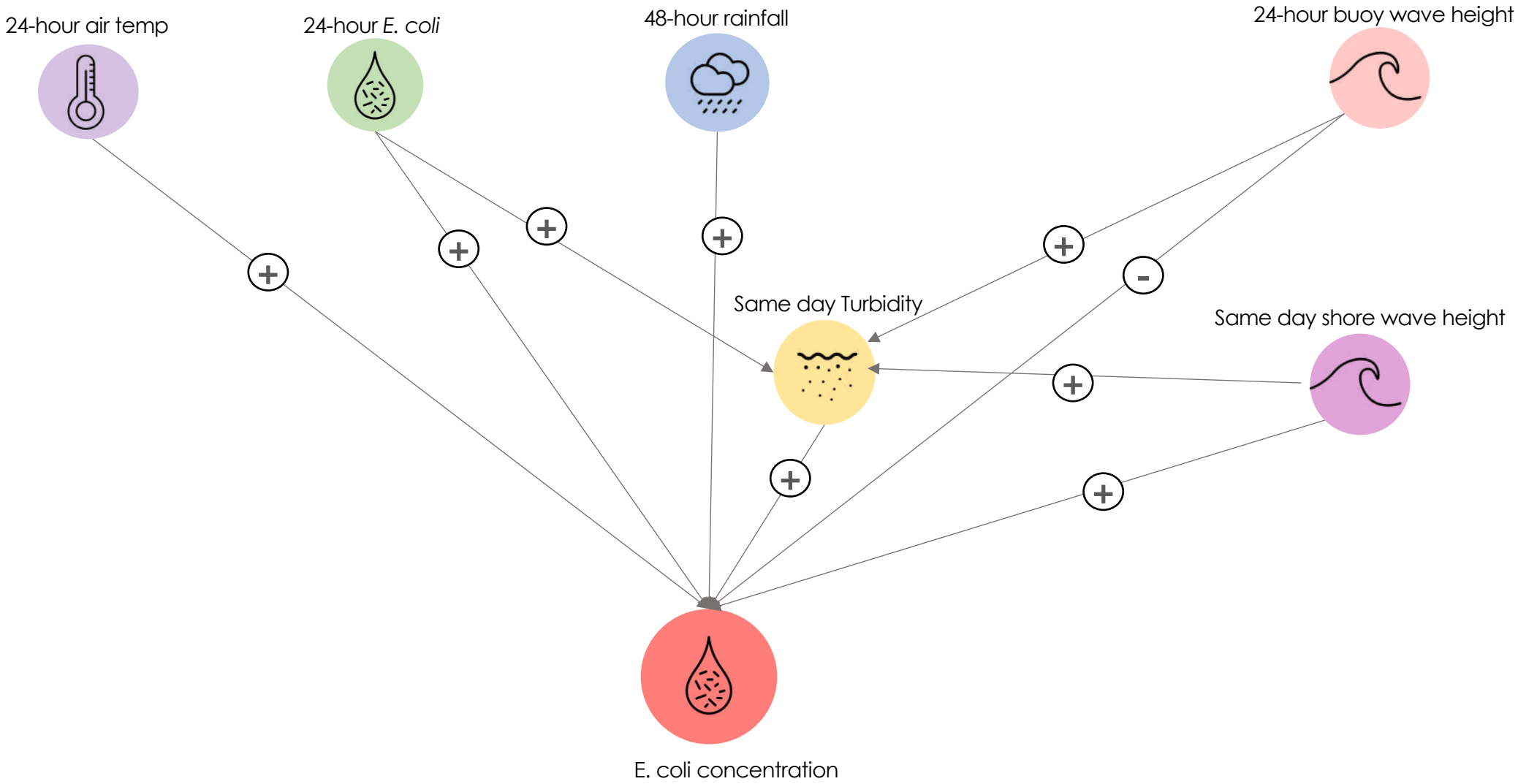
Conceptual Path Diagram



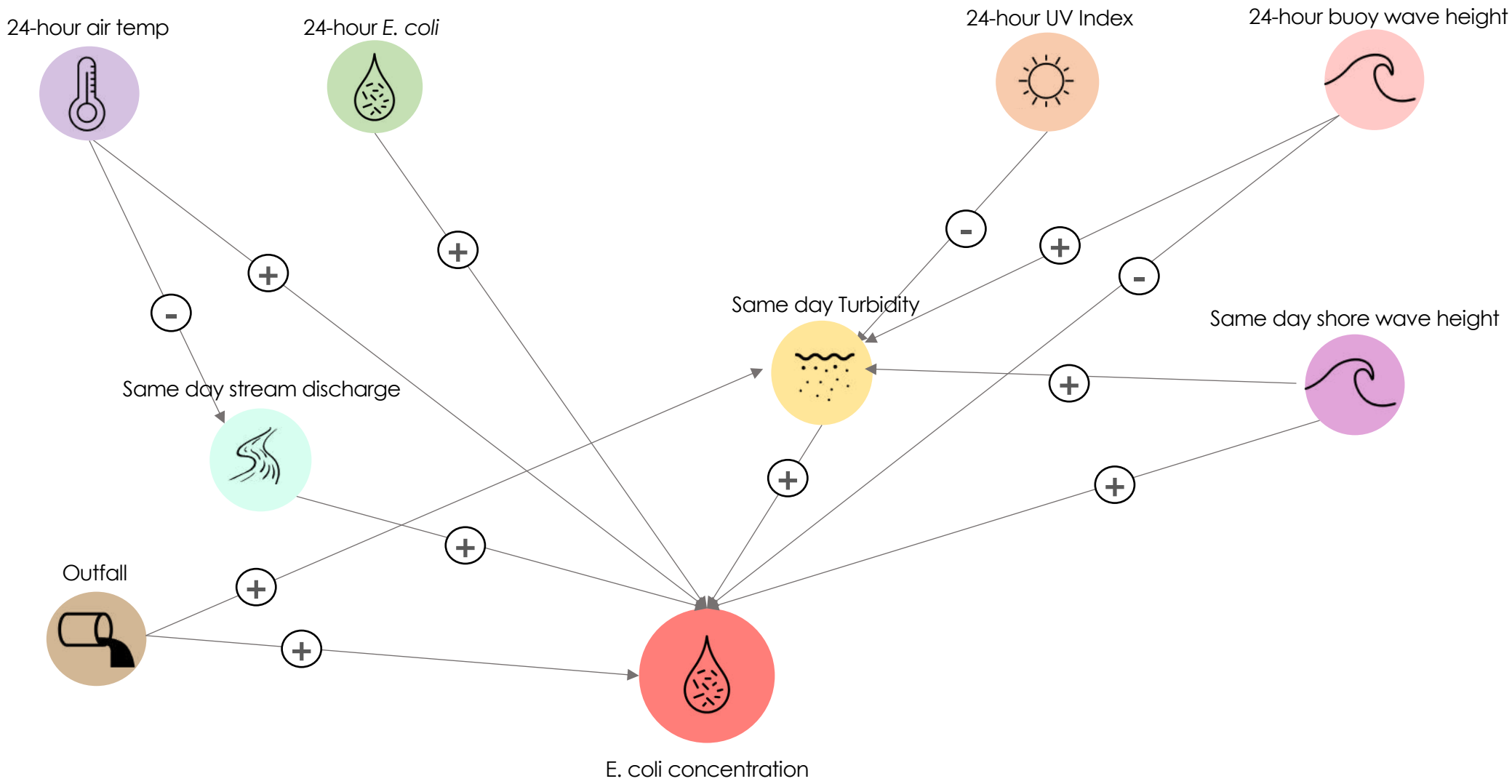
Overall Path Analysis Results



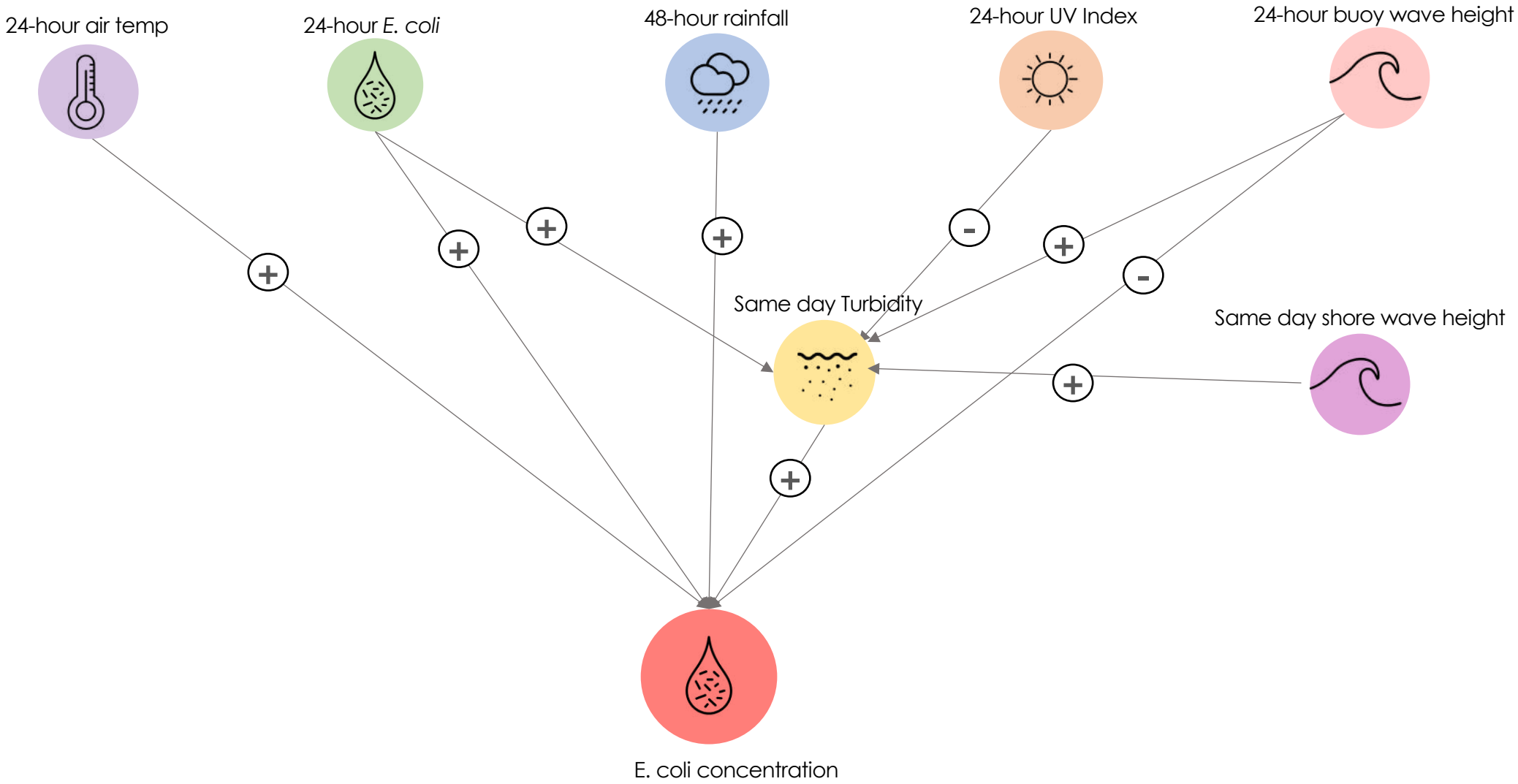
Bay Beach Analysis Results



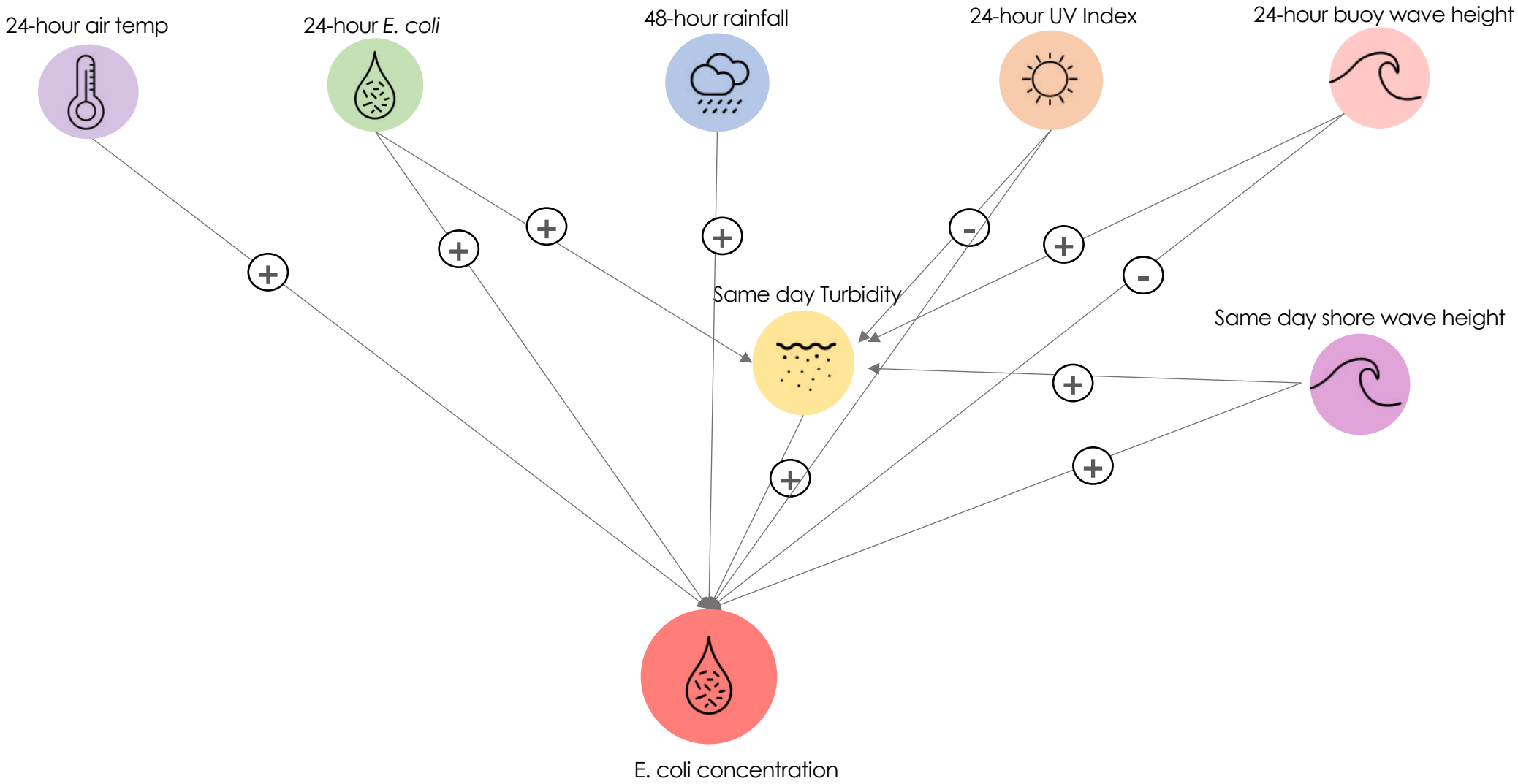
Bay Beach Analysis Results (OUTFALL)



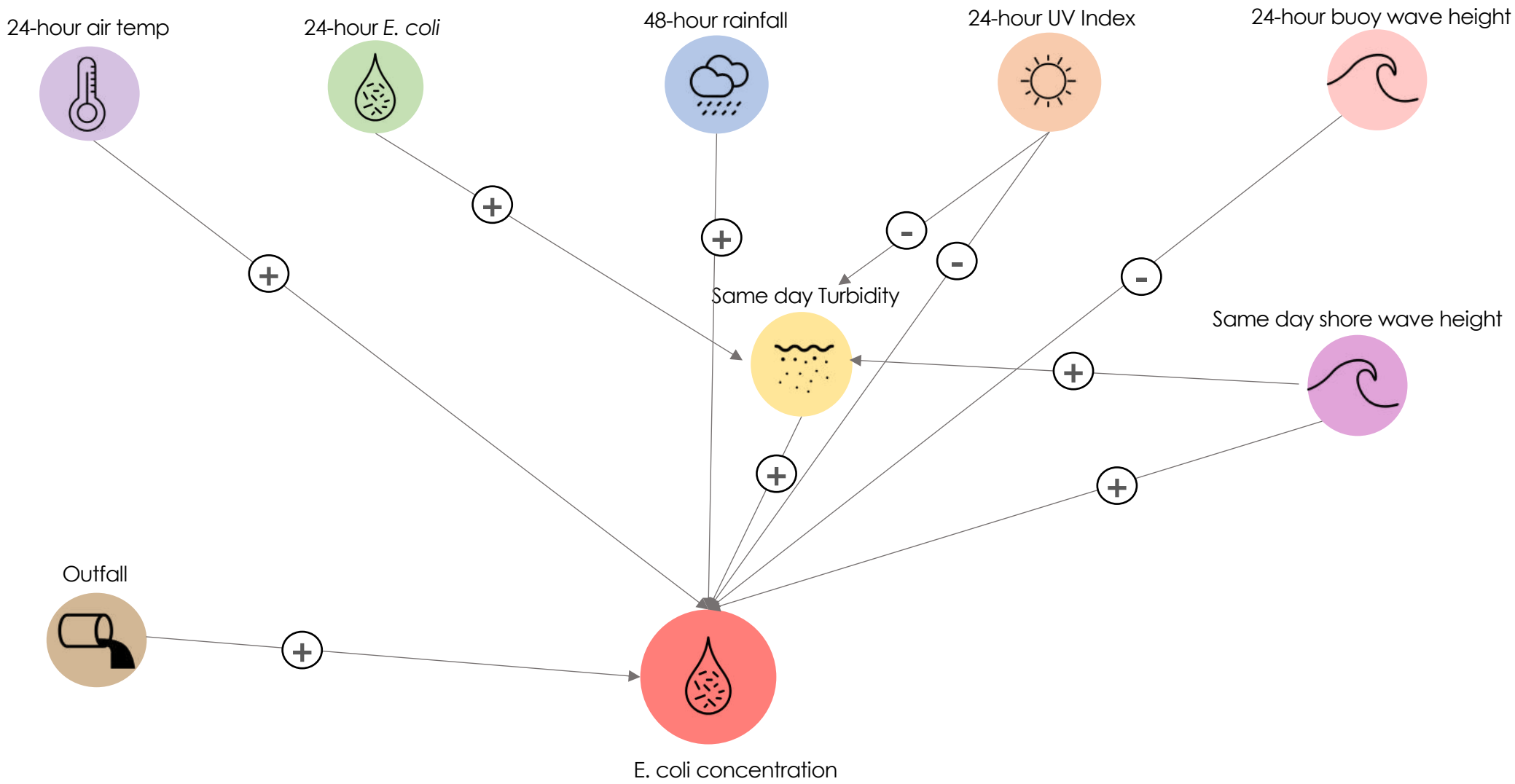
Lakeside Beach Analysis Results



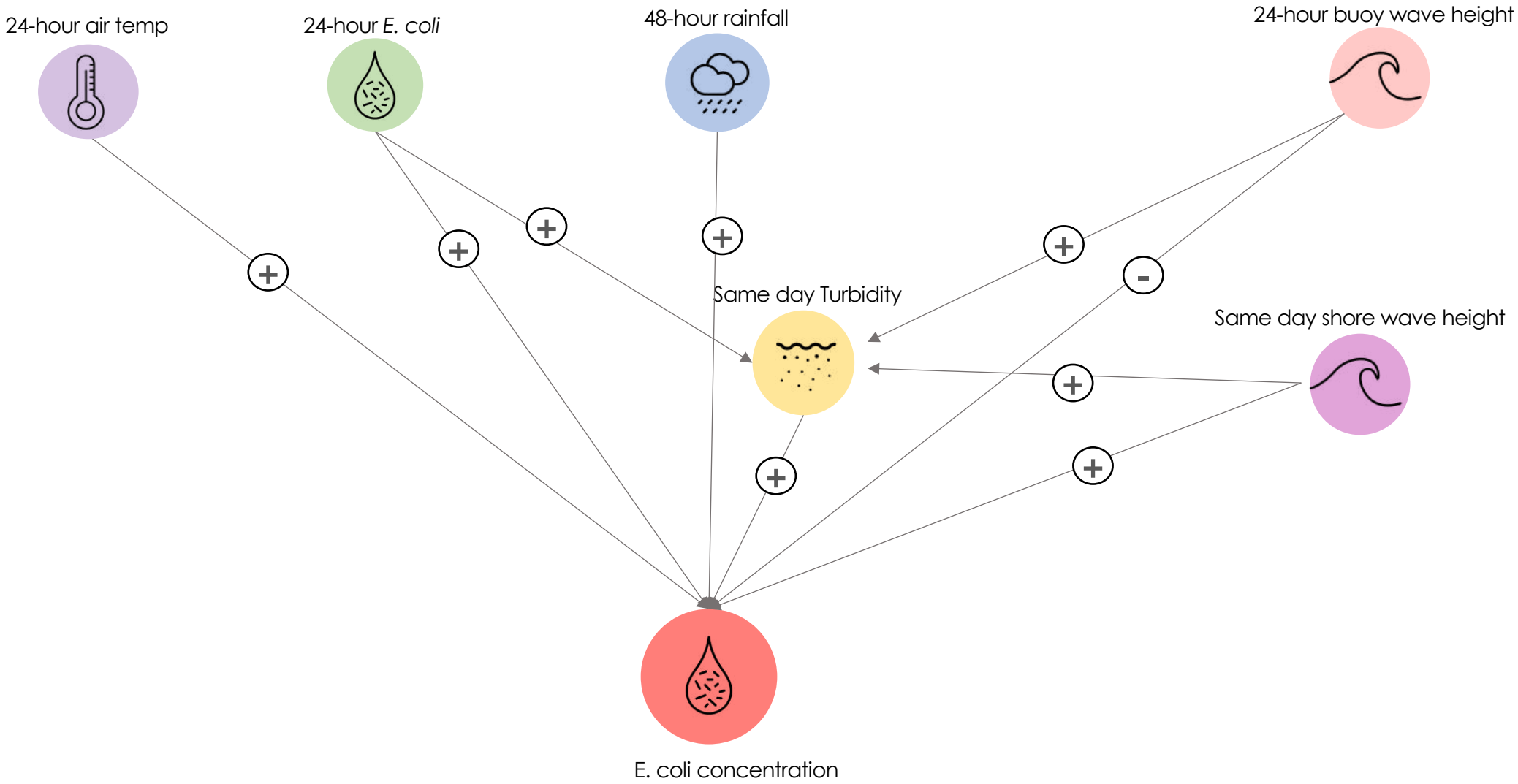
Long Beach Analysis Results



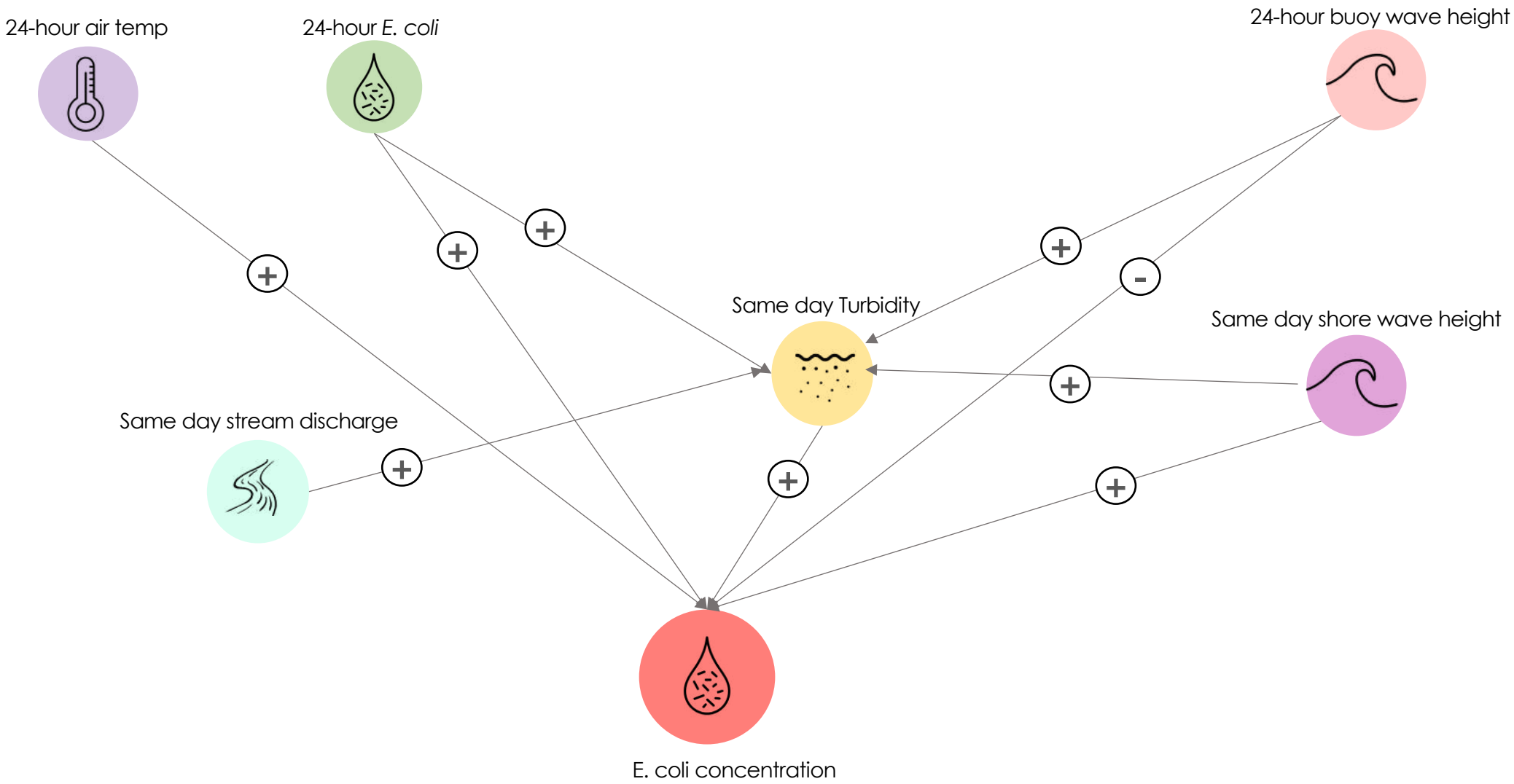
Long Beach Analysis Results (OUTFALL)



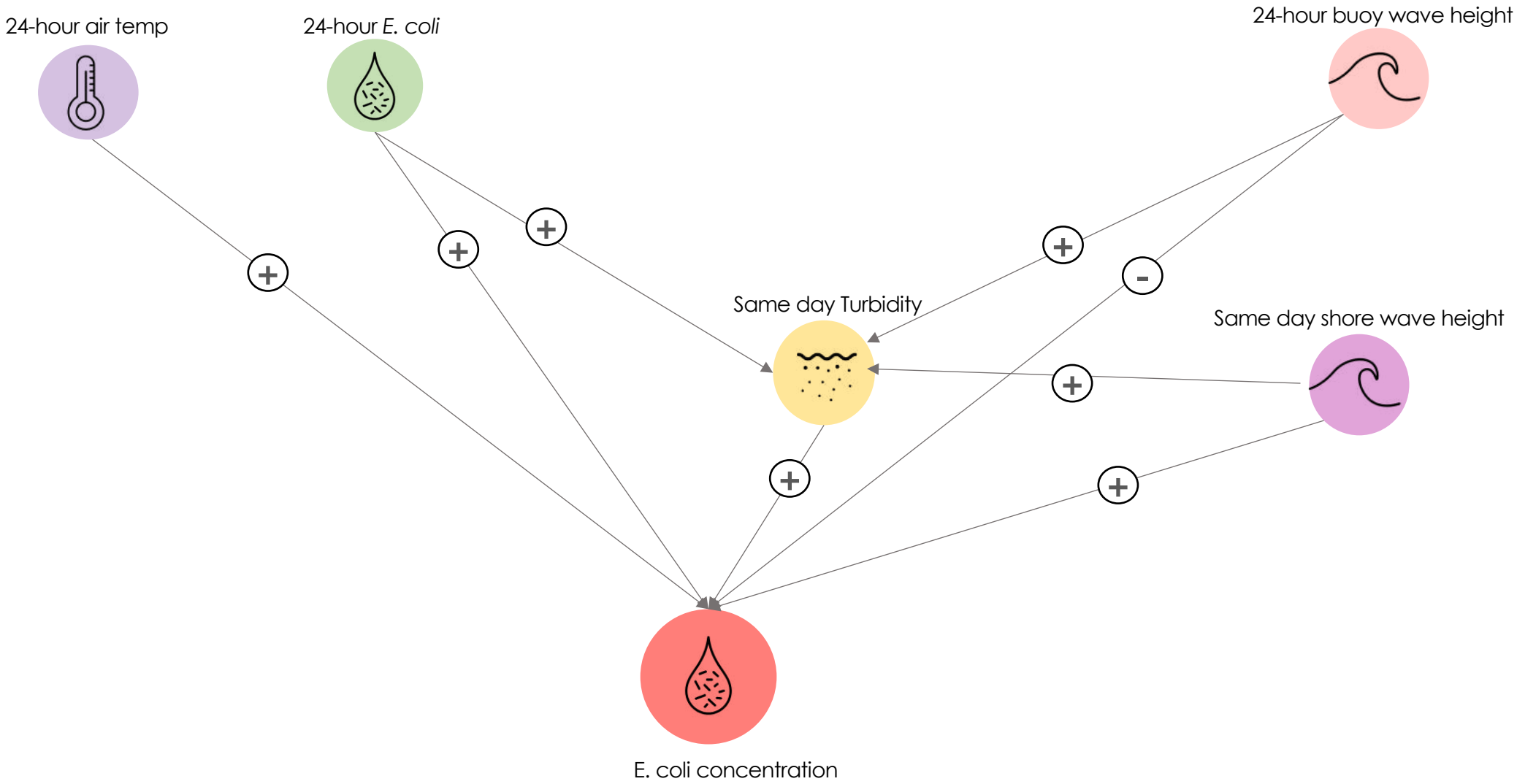
Nickel Beach Analysis Results



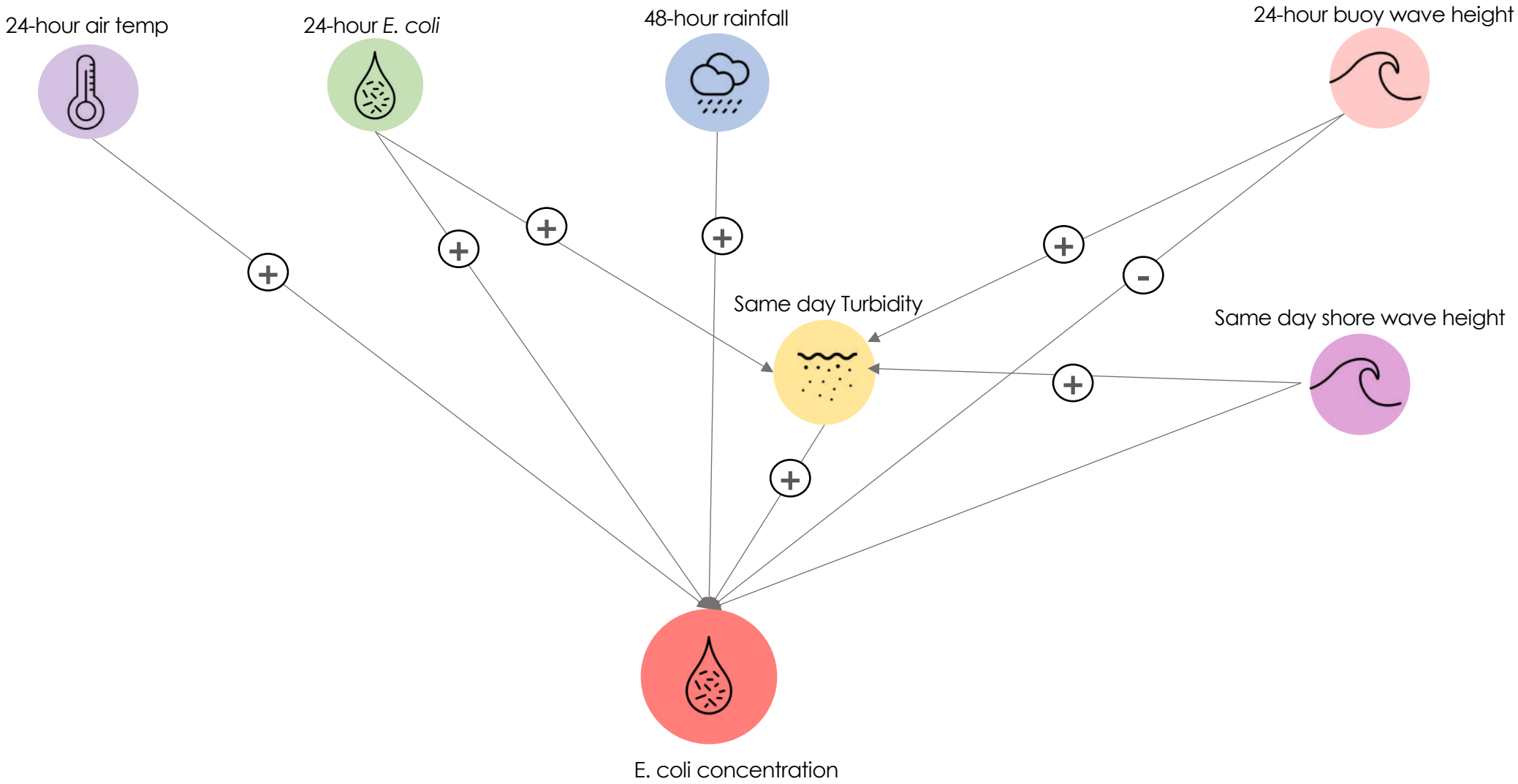
Sherkston Elco Beach Analysis Results



Sherkston Wyldewood Beach Analysis Results



Wainfleet Beach Analysis Results



Key Findings

Same day Turbidity

Turbidity was found to be an important mediator for the indirect effect of environmental predictors overall and in all beach-specific models.

48-hour rainfall

Rainfall was an important direct predictor for *E. coli* in most models except the two Sherkston beaches.

24-hour air temp

Previous day air temperature and E. coli had direct and indirect effects on *E. coli* concentrations.

24-hour *E. coli*

24-hour buoy wave height

Shore wave height had a positive effect on *E. coli* while off-shore wave height had a negative effect on *E. coli*

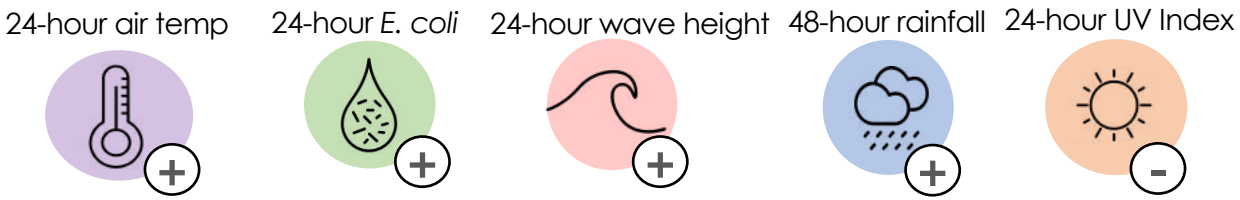
Same day shore wave height

Linear Mixed Effects Regression Modelling

- Preliminary Toronto models identified several environmental factors were **positively** associated with E. coli levels, including previous day air temperature, previous day geometric mean, wave height, and 48-hour cumulative rainfall.

- UV index was **negatively** associated with E. coli levels at Toronto beaches.

- Air temperature, wave height, UV index, streamflow had significant **beach-specific effects**, suggesting unique contamination sources and factors that affect E. coli levels



LMER Modelling – Lifeguard Variables

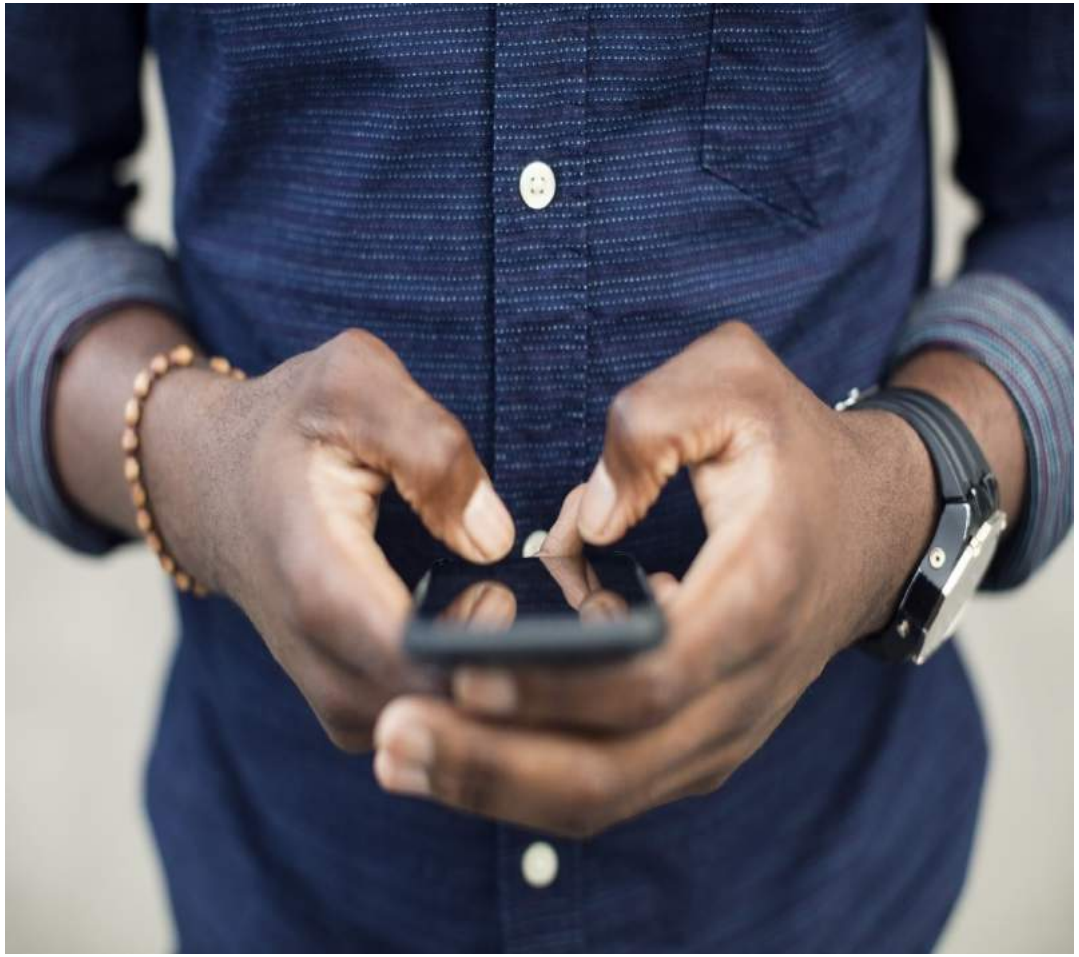
- Lifeguards collect several additional observational variables
- Water Quality: Clear, Mixed, Murky
- Water fowl: Estimated count
- Included in models. Both were statistically significant and positively associated with increased *E. coli* concentration

Telehealth Analysis

- To evaluate associations between preceding rainfall and beach water E. coli levels in our two study regions and rates of acute gastrointestinal illness (AGI) we linked our beach data with historical Telehealth Ontario data

- Telehealth Ontario is a free 24-hour phone line for Ontario residents to speak with a registered nurse about possible illness, as a first point of contact in the healthcare system.

- It represents an early warning syndromic surveillance system for AGI.



Telehealth Analysis - Methods

- Developed distributed lag non-linear models to evaluate associations between average beach *E. coli* levels, preceding extreme rainfall, and AGI (diarrhea and/or vomiting) rates in the two study regions during summer months
- *E. coli* data were lagged 10 days prior to illness, and rainfall was lagged 12 days to account for its influence on beach water quality.
- We also controlled for other environmental variables – air temperature, stream discharge, and mean UV index – all were lagged 11 days to account for influence on beach water quality

Telehealth Analysis – Preliminary Results

- **Toronto:** increased previous day cumulative rainfall and extreme rainfall (99th percentile) in the preceding 12 days was associated with increased rates of AGI calls among adults. In children, beach E. coli levels and heavy rainfall (95th percentile) were associated with higher AGI rates.

- **Niagara**: rainfall levels were higher and a preceding heavy rainfall (95th percentile) was associated with increased rates of AGI calls in both adults and children. Beach E. coli levels (specifically at lag periods of 6-7 days) were also associated with AGI in adults and children.

Preliminary results suggest a relationship between preceding rainfall, beach water quality, and AGI in our study regions.

Conclusions

- Using several advanced statistical methods, we aimed to further understand the relationship between environmental and climatic factors and *E. coli* concentration at freshwater beaches in two of the Great Lakes.
- We identified key environmental variables associated with water quality and gained a better understanding of the inter-variable relationships.
- We aim for the results of this study to be used to inform beach monitoring programs and reduce the burden of water-borne disease.
- We identified relationships between the variables and the various indirect effects on *E. coli*.

Conclusions

- Turbidity data was regularly collected in the Niagara Region and was found to be an important predictor for E. coli concentration as well as an important mediator for the indirect effect of other environmental predictors.
- Cumulative rainfall in the previous 48 hours was positively associated with increased E. coli concentration in both Toronto and Niagara.
- Previous day mean temperature, geometric mean, wave height, UV index, and same day streamflow were associated with E. coli concentration, in various models.
- Beach-specific effects were important and identified in our various modelling approaches
- Heavy rainfall was associated with increased rate of AGI telehealth calls in both adults and children in both regions.

Future Direction

- Finalize and publish results of various analyses
- Research objective 2 – develop predictive models using novel approach
- Prospective cohort study to determine the incidence and burden of RWI in these regions.

Acknowledgements

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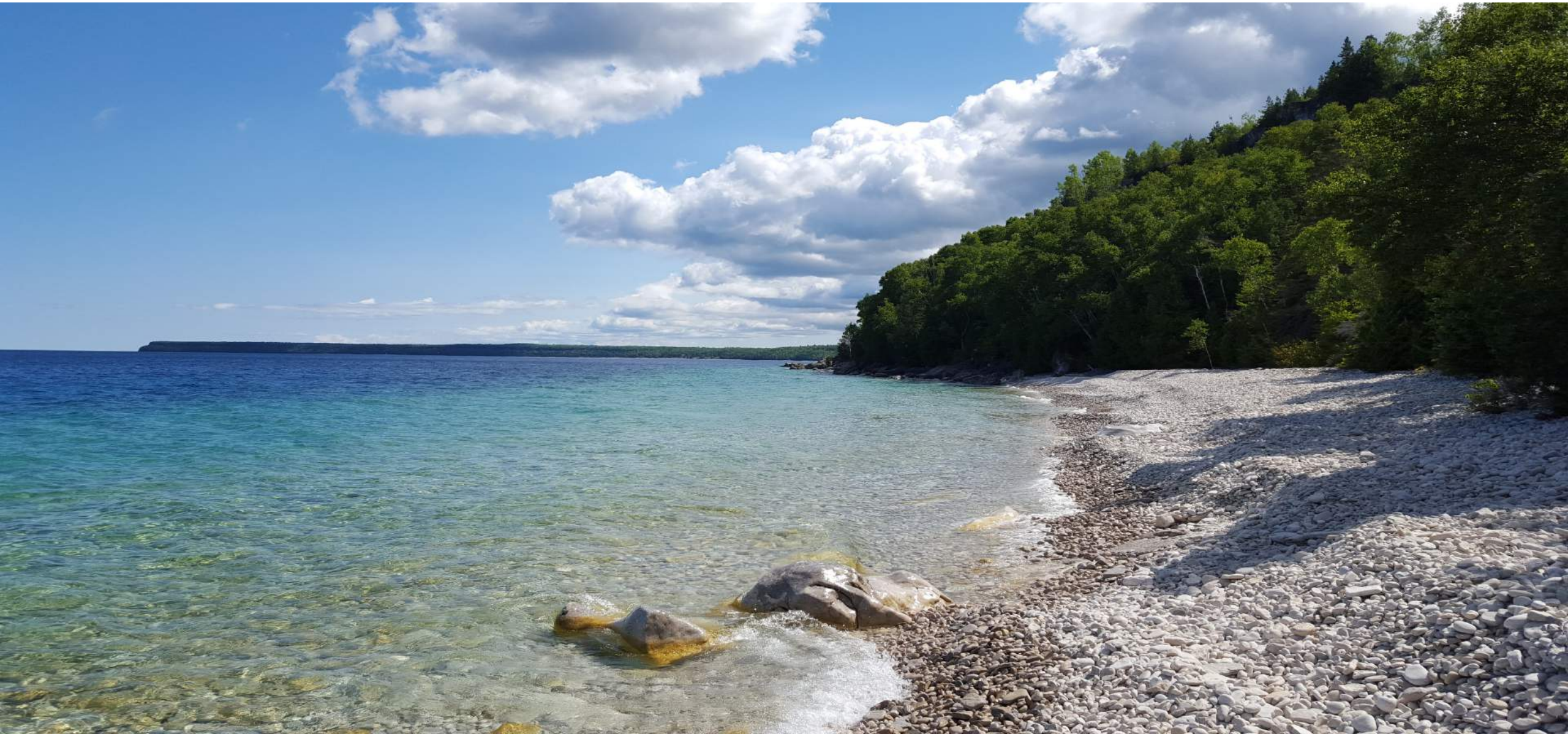
Toronto Public Health: Mahesh Patel

We also thank everyone involved in the data collection and management at each public health unit.

Funding: Public Health Agency of Canada

Thank you!



Questions

For those representing public health units, do your unit currently use predictive modelling for beach posting status?

Do you think predictive modelling would be a useful tool for recreational water quality?

For those representing public health units, does your unit collect turbidity data?