Environmental Factors Associated with Recreational Beach Water Quality in Canada

Johanna Sanchez, PhD
Binyam Desta, PhD

Agence de la santé publique du Canada
Public Health Agency of Canada
Toronto Metropolitan University

Introduction

Swimming at public beaches is an increasingly popular recreational activity among Canadians, particularly during the pandemic

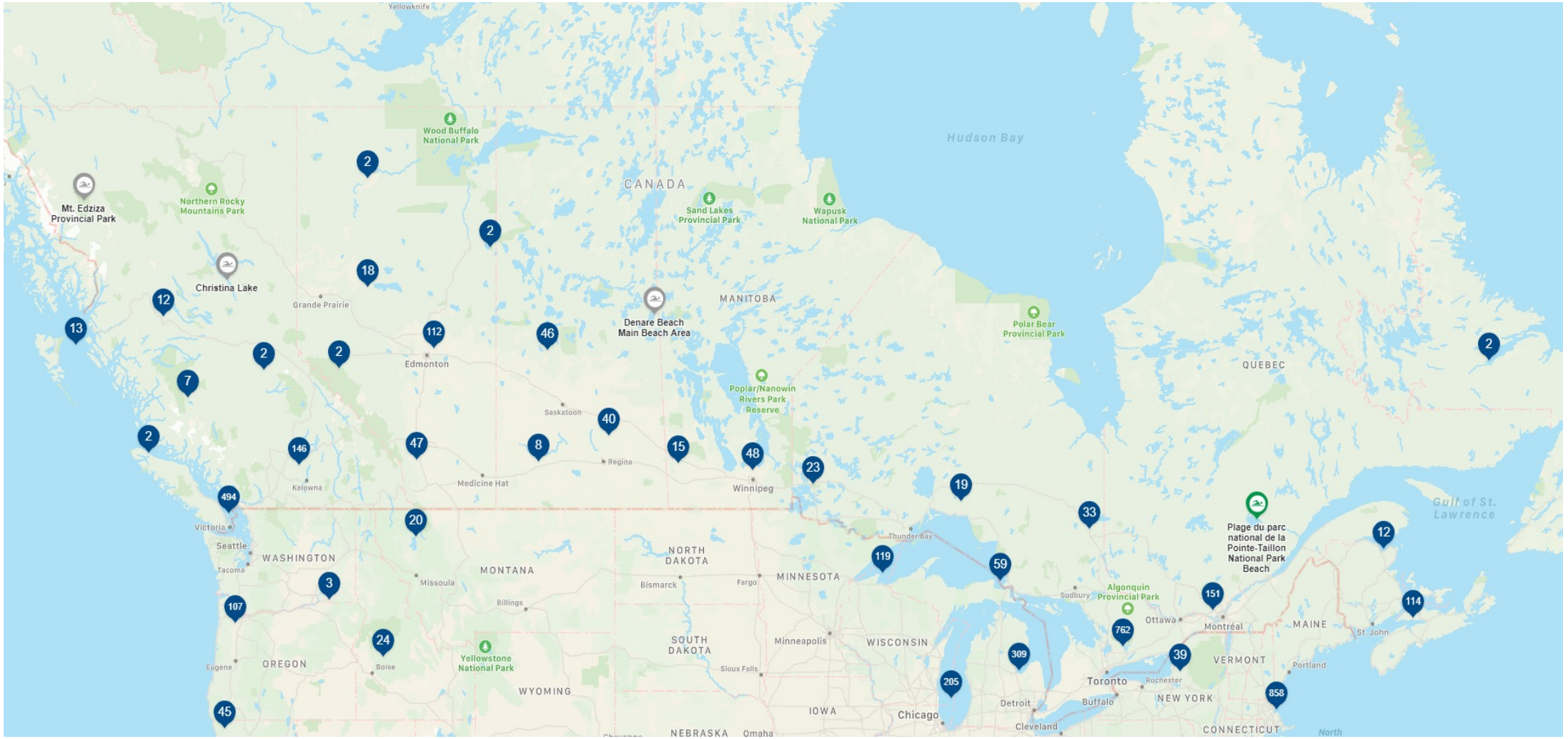
Other popular recreational water activities include kayaking, paddleboarding, waterskiing and canoeing

Outline

- Background
- Our Research Team
- Recreational Water Quality Projects
- Summary of Results
- Future Direction
- Questions

The Canadian Recreational Water Quality Research Group

Canadian Beaches



(Swim Drink Fish, 2021)

Water Quality

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 beach water quality

Research Team

Comprised of **public health researchers** at **Toronto Metropolitan University** specializing in epidemiology, burden of waterborne infection, and advanced analytic methods.

We work in close collaboration with participating public health units to generate knowledge about Canadian freshwater beaches and further inform current beach monitoring programs.

Dr. Ian Young

Associate Professor

Dr. Jordan Tustin

Associate Professor

Dr. Johanna Sanchez

Senior Research Associate

Dr. Binyam Desta

Postdoctoral Fellow

Rachel Jardine

Research Assistant

Projects

The Canadian Beach Water Research Group

1

Environmental predictors of recreational water quality

2

Canadian Beach Cohort Study

3

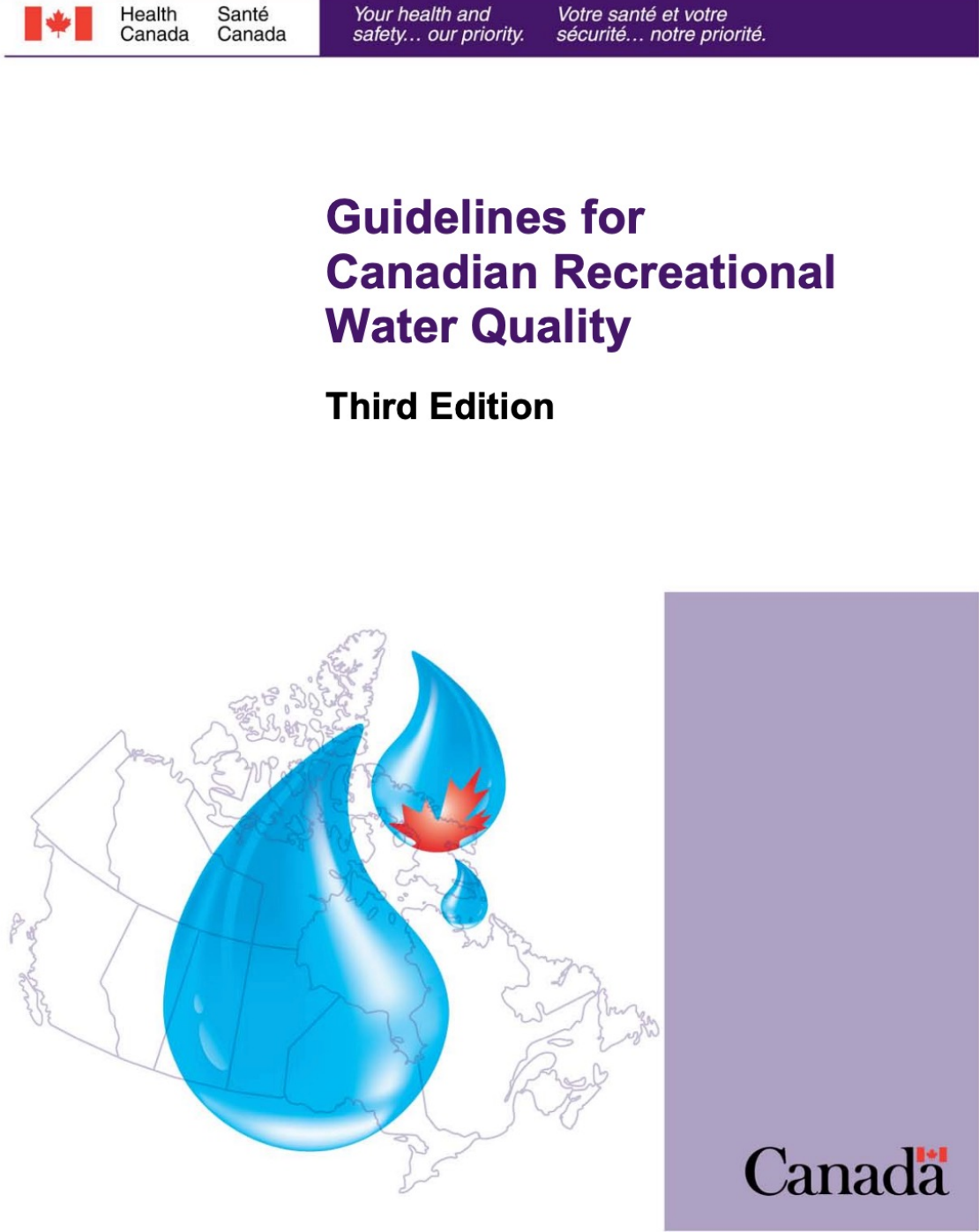
Canadian Algal Blooms in Recreational Waters

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

Guidelines for Canadian Recreational Water Quality

- 3rd edition published in 2012 is currently being revised
- Used by provinces/local public health authorities to guide beach surveillance policies/programs
- In 2012 edition, threshold values were developed to suggest an acceptable risk of gastrointestinal illness
  - *E. coli* single sample max. of 400 CFU/100mL
  - *E. coli* geometric mean of 200 CFU/100mL
- The new edition proposes to replace threshold values with "beach action values" (BAV):
  - *E. coli* single sample max. of 235 CFU/100mL



Beach Monitoring

- In Canada, beaches are regularly monitored by public health authorities through water sampling and beach assessments during the summer season
- Recreational water quality monitoring falls under provincial and territorial jurisdiction
- Sampling results are used to inform risk management and communication decisions, including beach postings or closures to reduce risks
- The frequency of water quality monitoring varies by jurisdiction and beach, and is determined based by various factors (e.g., popularity, historical results)

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

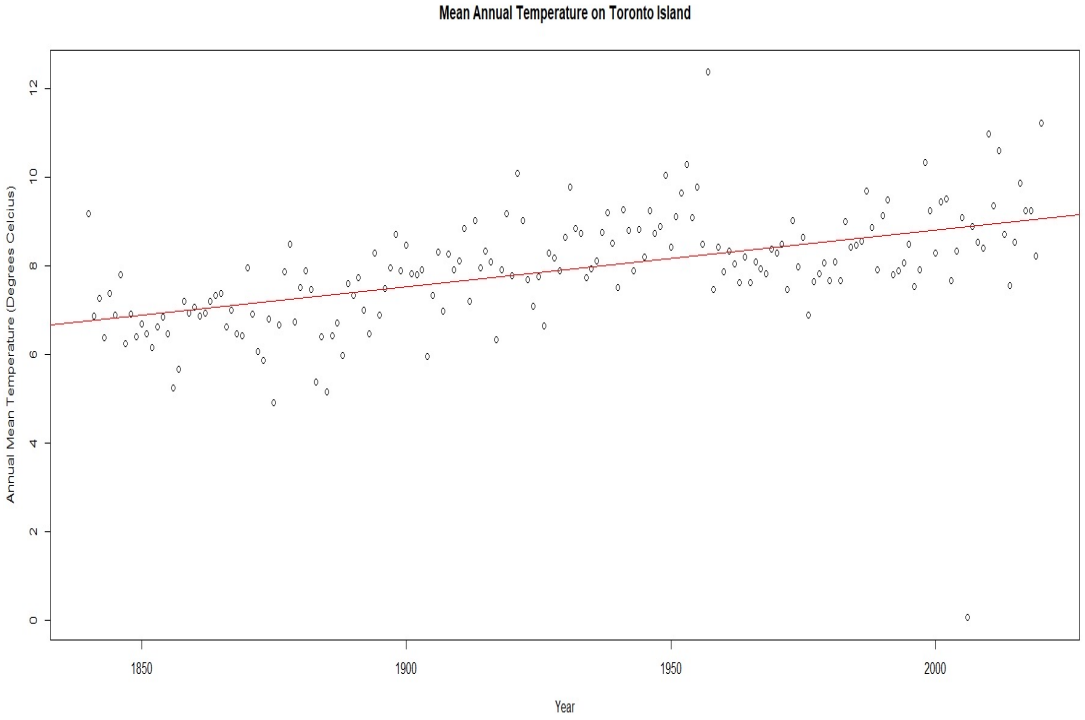
Ultraviolet radiation

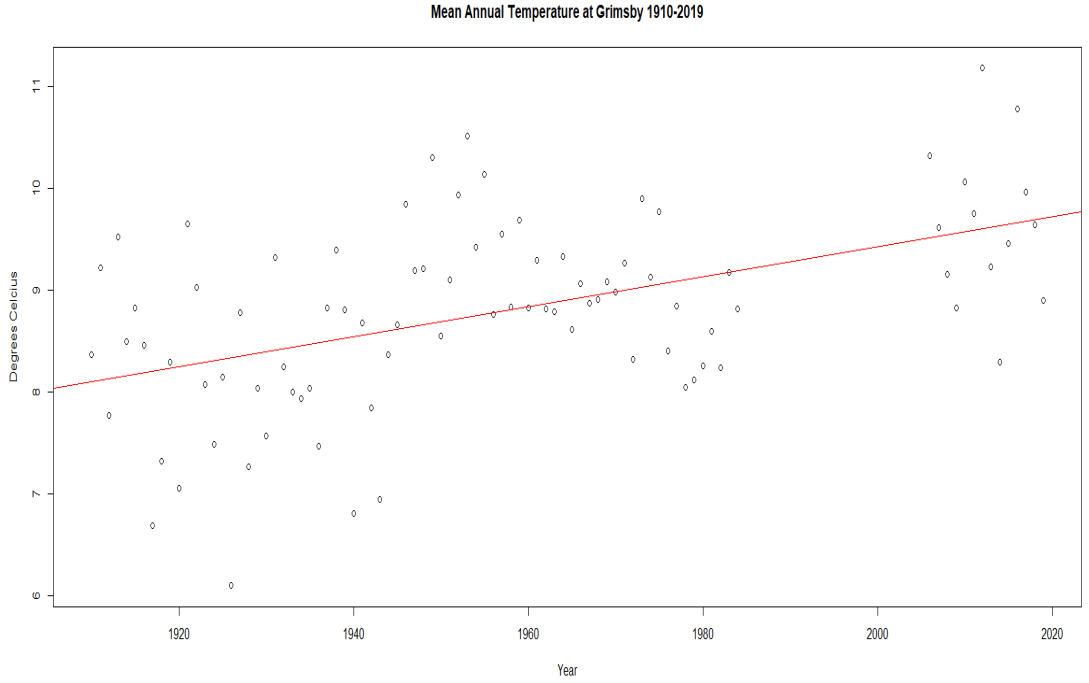
Turbidity

Salinity

Tides

Air Temperature





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.

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 Sites

Toronto Metropolitan University

Toronto

Largest city in Canada
Opportunity to study beaches in an urban setting in a Great Lake (Lake Ontario)

Niagara Region

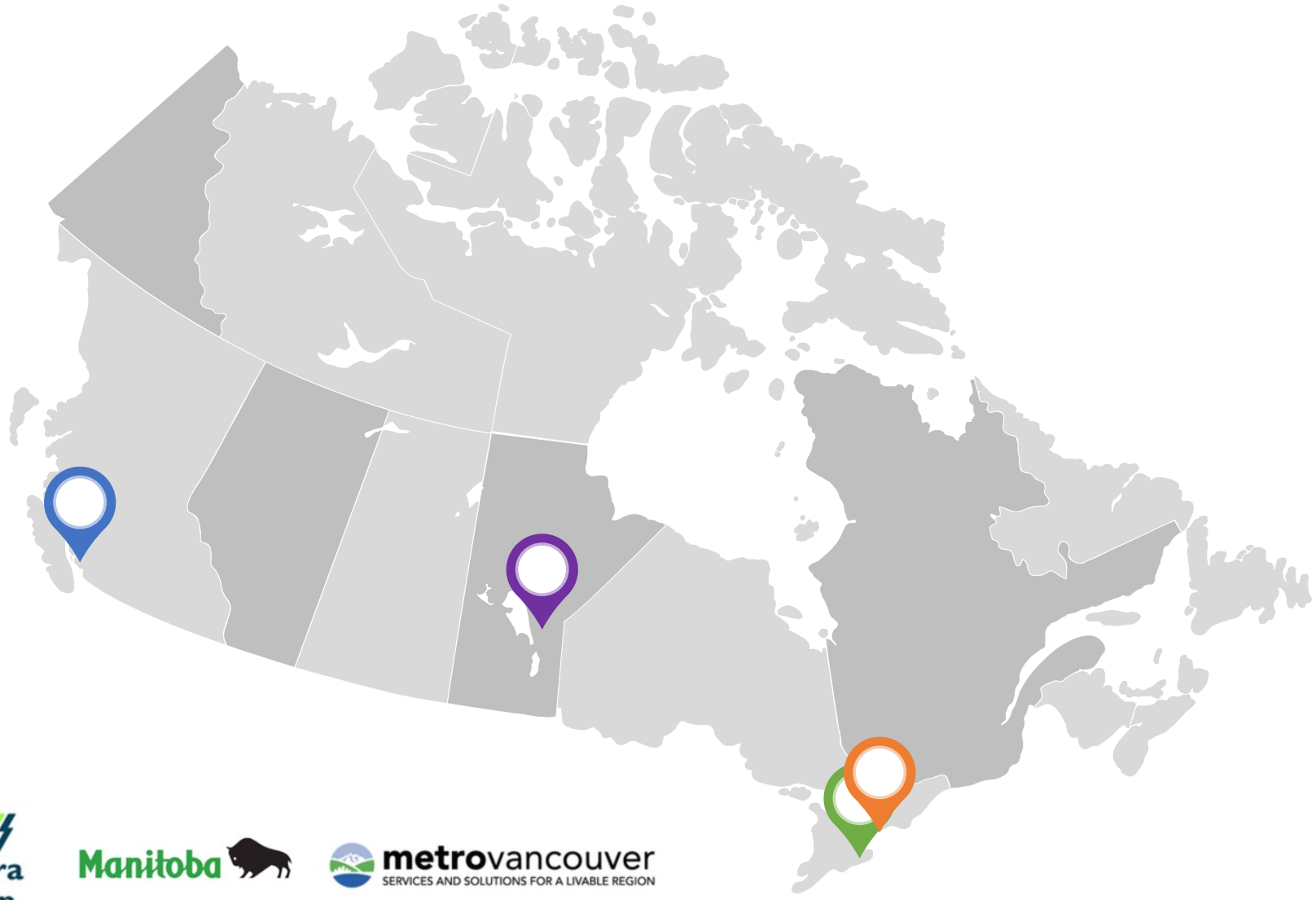
One of the most popular tourist areas
Large geographic area
Beaches in two great lakes

Manitoba

Lake Winnipeg
Sixth largest freshwater lake in Canada

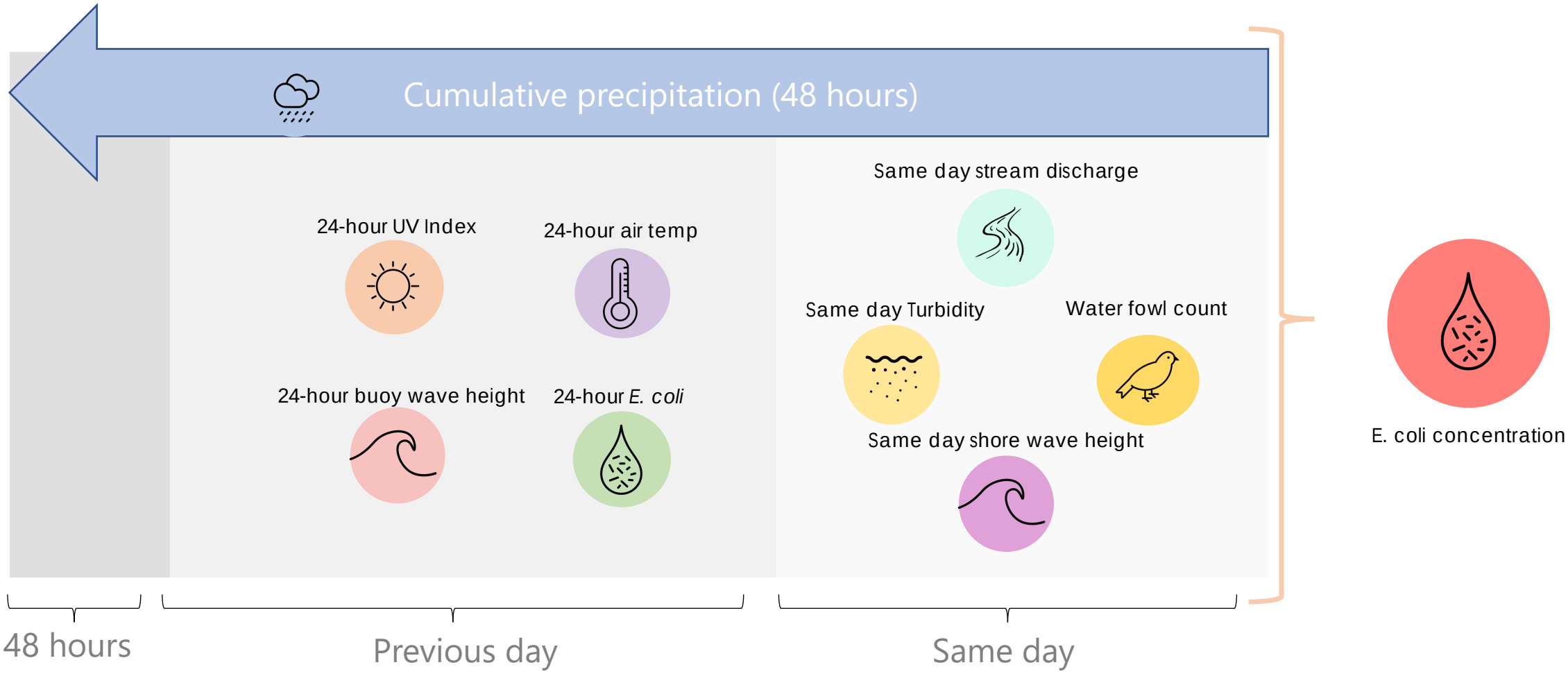
Vancouver

Coastal city (Pacific Ocean)
One of the largest cities in Canada.
Opportunity to explore marine beaches



Toronto Public Health
Vancouver Coastal Health
Niagara Region
Manitoba
metrovancouver
SERVICES AND SOLUTIONS FOR A LIVABLE REGION

Environmental variables



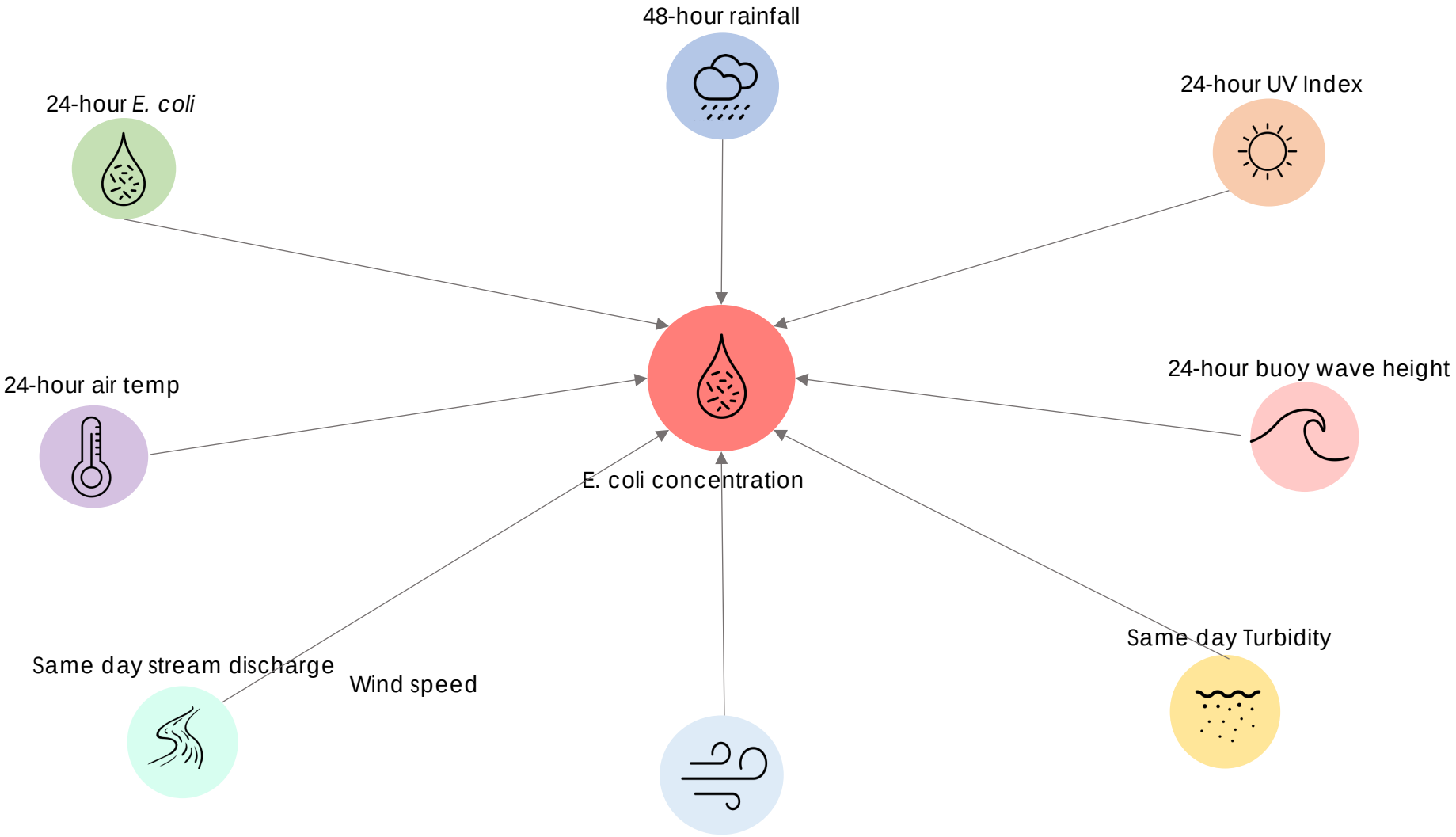
Toronto

- 11 beaches on Lake Ontario – 10 included in our study
- Grimsby buoy
- Streamflow data – 3 rivers
- UV station TRCA

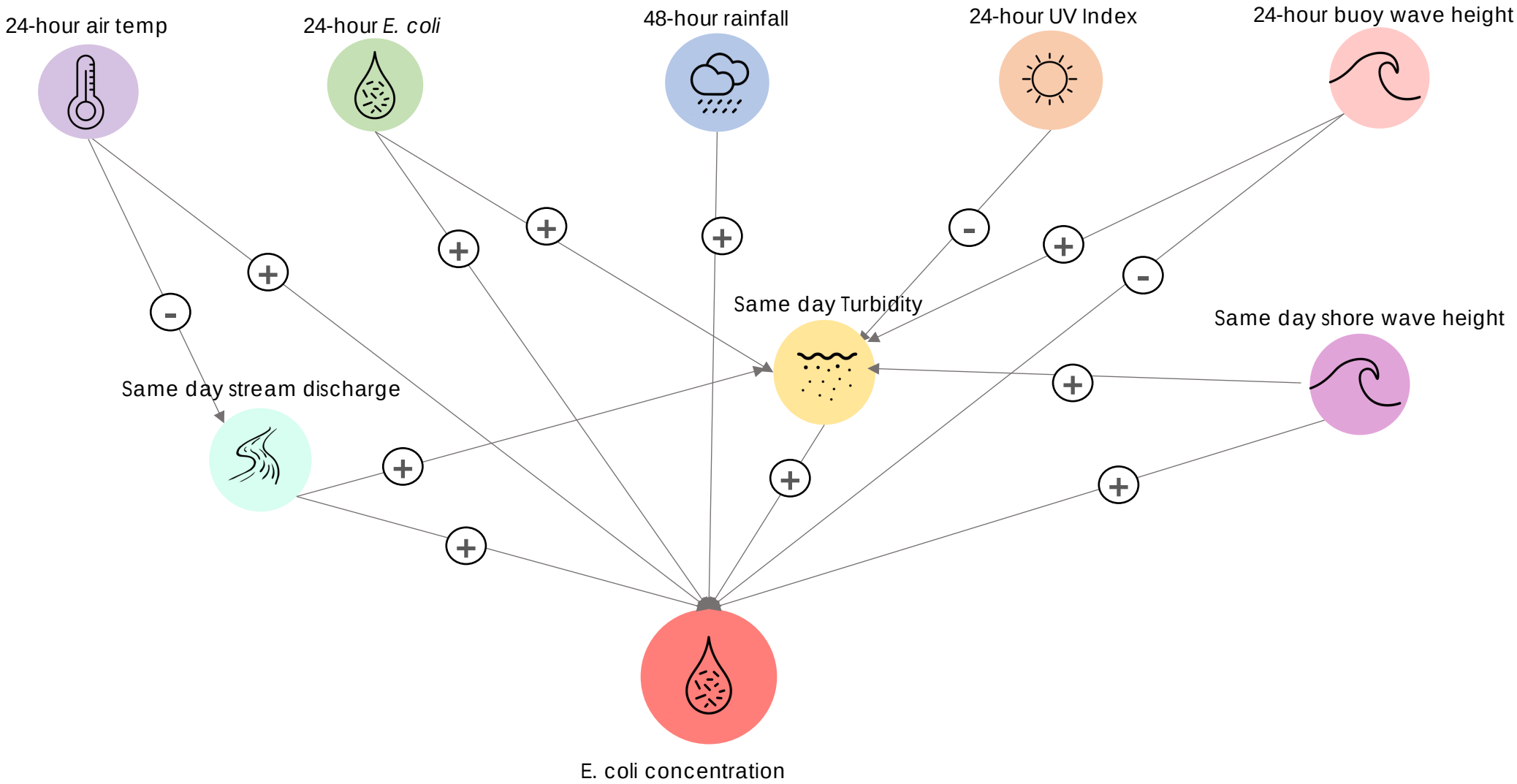
Niagara Region

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

Effect of Environmental Factors on E. coli



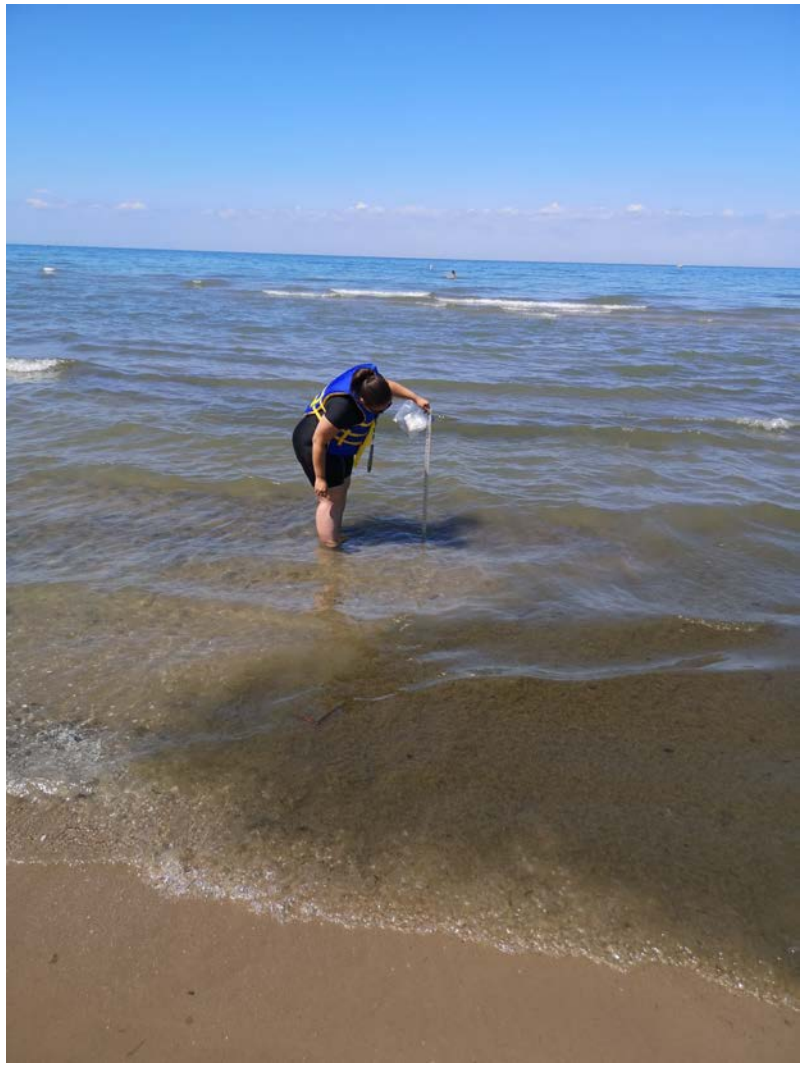
Overall Niagara Path Analysis Results



Key Findings

- Confirmed relationships between environmental factors.
- Beach-specific models had some difference but there were general trends.
- Turbidity was found to be an important mediator for the indirect effect of environmental predictors overall and in all beach-specific models

Niagara Region Path Analysis Results



Epidemiology and Infection

cambridge.org/hyg

Original Paper

Cite this article: Sanchez JJ, Young I, Heasley C, Kelly J, Habjan A, Waterhouse R, Tustin J (2021). Environmental factors associated with freshwater recreational water quality in Niagara Region, Ontario, Canada: A path analysis. *Epidemiology and Infection* **149**, e217, 1–11. https://doi.org/10.1017/S0950268821002120

Received: 4 May 2021
Revised: 13 September 2021
Accepted: 15 September 2021

Key words:
Epidemiology; food safety; food-borne zoonoses; meta-analysis; systematic review

Author for correspondence:
J. Johanna Sanchez,
E-mail: johanna.sanchez@ryerson.ca

Environmental factors associated with freshwater recreational water quality in Niagara Region, Ontario, Canada: A path analysis

J. Johanna Sanchez[1], Ian Young[1], Cole Heasley[1], Jeremy Kelly[2], Anthony Habjan[2], Ryan Waterhouse[2] and Jordan Tustin[1]

[1]School of Occupational and Public Health, Ryerson University, Toronto, Ontario, Canada and [2]Niagara Region Public Health, Thorold, Ontario, Canada

Abstract

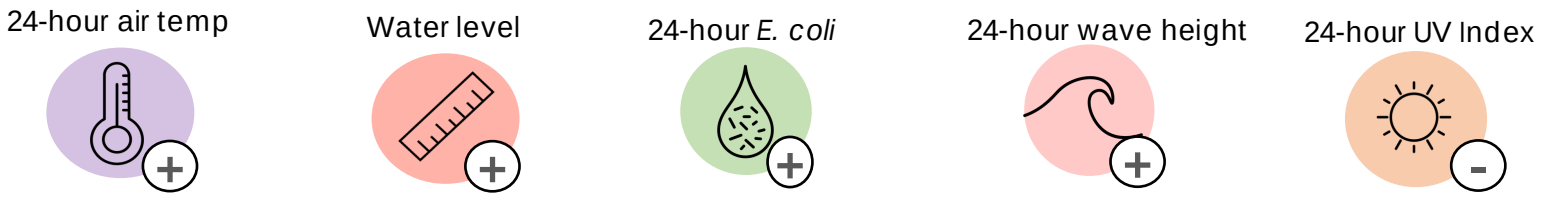
Escherichia coli concentration levels in recreational water are used by beach managers to evaluate the risk of gastrointestinal illness among beachgoers. We examined the relationship between specific environmental factors and *E. coli* concentration in recreational beaches in the Niagara Region. We analysed *E. coli* geometric means collected from eight beaches from two of the Great Lakes in the Niagara Region in Ontario, between 2011 and 2019. We applied path analysis to evaluate the relationship between the environmental factors and *E. coli* concentrations, including whether effects were direct or indirect via a mediator. Turbidity was found to be an important mediator for the indirect effect of environmental variables overall and in beach-specific models. Rainfall and streamflow had a positive indirect effect on *E. coli* via turbidity and a direct effect in five out of seven beach models. Streamflow was also a mediator for the indirect effect of previous day air temperature in five out of seven models. In three subset models, outfall *E. coli* concentration was a mediator for the effect of the environmental factors. Using a novel methodological approach, this study identifies important relationships and pathways that predict beach *E. coli* concentration in freshwater beaches located on two of the Great Lakes.

Introduction

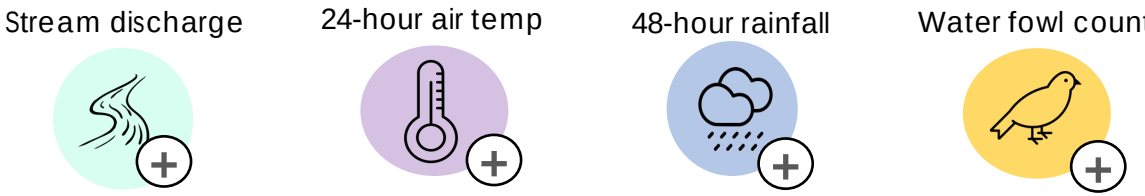
Poor recreational water quality, as indicated by a high concentration of pathogens, represents a risk of gastrointestinal illness for those engaging in water activities such as swimming [1, 2]. In Canada, beach water quality in freshwater bodies is regularly monitored by measuring faecal indicator bacteria (FIB) levels, most commonly *Escherichia coli (E. coli)*, as a surrogate for the presence of enteric pathogens and risk of gastrointestinal illness [3]. The Guidelines for

Toronto and Niagara Analysis

Overall relationship direction



Toronto



Niagara

Beach-specific effects suggest unique contamination sources and factors that affect E. coli levels

Toronto and Niagara Results

International Journal of
Environmental Research and Public Health

MDPI

Article

Region-Specific Associations between Environmental Factors and *Escherichia coli* in Freshwater Beaches in Toronto and Niagara Region, Canada

Johanna Sanchez [1,*], Jordan Tustin [1], Cole Heasley [1], Mahesh Patel [2], Jeremy Kelly [3], Anthony Habjan [3], Ryan Waterhouse [3] and Ian Young [1]

1 School of Occupational and Public Health, Ryerson University, Toronto, ON M5B 1Z5, Canada; jtustin@ryerson.ca (J.T.); cole.heasley@ryerson.ca (C.H.); iyoung@ryerson.ca (I.Y.)
2 Toronto Public Health, Toronto, ON M5B 2L6, Canada; mahesh.patel@toronto.ca
3 Niagara Region Public Health, Thorold, ON L2H 0G5, Canada; jeremy.kelly@niagararegion.ca (J.K.); anthony.habjan@niagararegion.ca (A.H.); ryan.waterhouse@niagararegion.ca (R.W.)
* Correspondence: johanna.sanchez@ryerson.ca

Abstract: Poor freshwater beach quality, measured by *Escherichia coli* (*E. coli*) levels, poses a risk of recreational water illness. This study linked environmental data to *E. coli* geometric means collected at 18 beaches in Toronto (2008–2019) and the Niagara Region (2011–2019) to examine the environmental predictors of *E. coli*. We developed region-specific models using mixed effects models to examine *E. coli* as a continuous variable and recommended thresholds of *E. coli* concentration (100 CFU/100 mL and 200 CFU/100 mL). Substantial clustering of *E. coli* values at the beach level was observed in Toronto, while minimal clustering was seen in Niagara, suggesting an important beach-specific effect in Toronto beaches. Air temperature and turbidity (measured directly or visually observed) were positively associated with *E. coli* in all models in both regions. In Toronto, waterfowl counts, rainfall, stream discharge and water temperature were positively associated with *E. coli* levels, while solar irradiance and water level were negatively associated. In Niagara, wave height and water level had a positive association with *E. coli*, while rainfall was negatively associated. The differences in regional models suggest the importance of a region-specific approach to addressing beach water quality. The results can guide beach monitoring and management practices, including predictive modelling.

Keywords: *Escherichia coli*; water quality; recreational water; environmental factors; fecal indicator bacteria

check for updates

Citation: Sanchez, J.; Tustin, J.; Heasley, C.; Patel, M.; Kelly, J.; Habjan, A.; Waterhouse, R.; Young, I. Region-Specific Associations between Environmental Factors and *Escherichia coli* in Freshwater Beaches in Toronto and Niagara Region, Canada. *Int. J. Environ. Res. Public Health* **2021**, *18*, 12841. https://doi.org/10.3390/ijerph182312841

Academic Editors: Paul B. Tchounwou and Ivone Vaz-Moreira

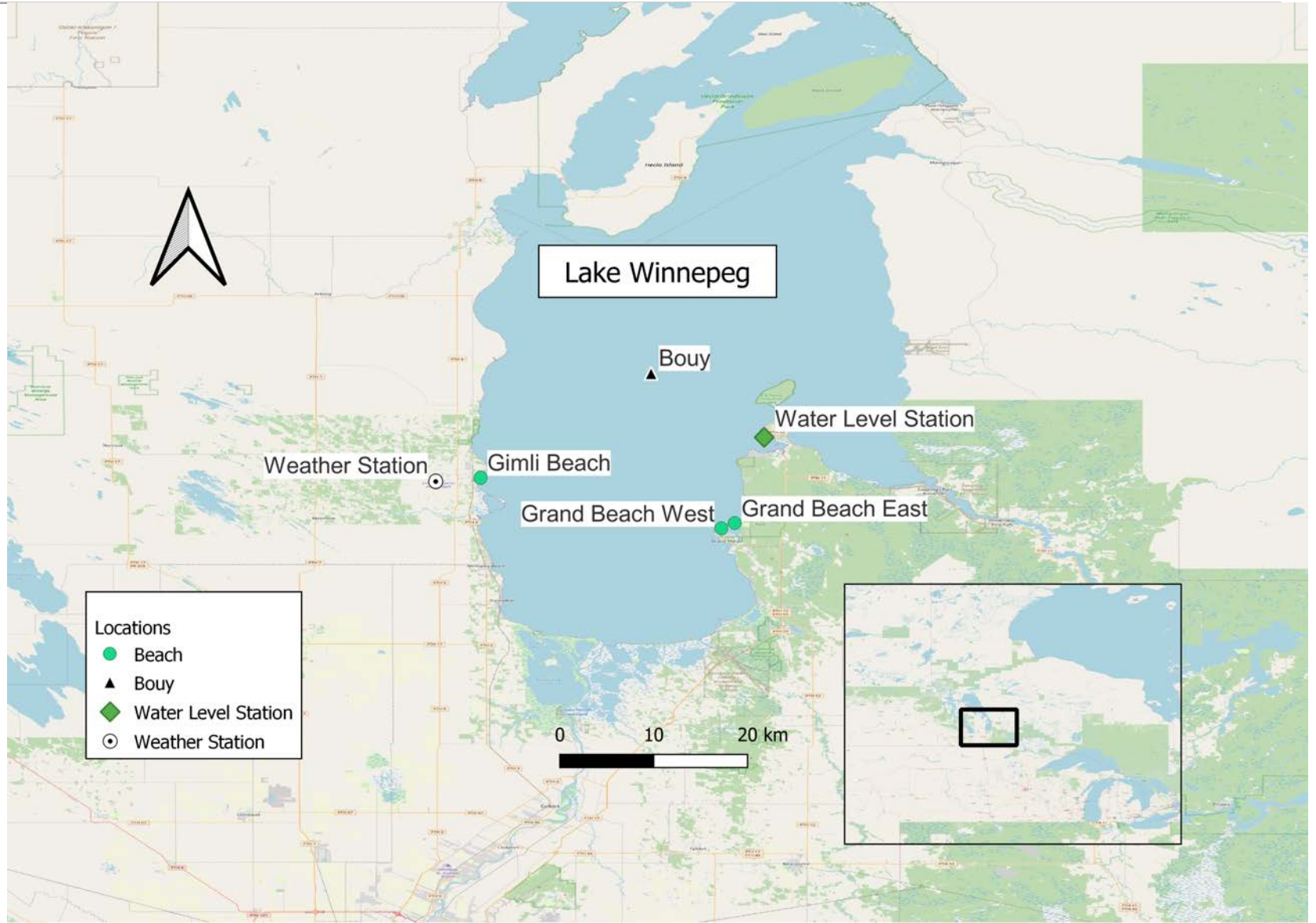
Received: 23 September 2021
Accepted: 29 November 2021
Published: 6 December 2021

1. Introduction

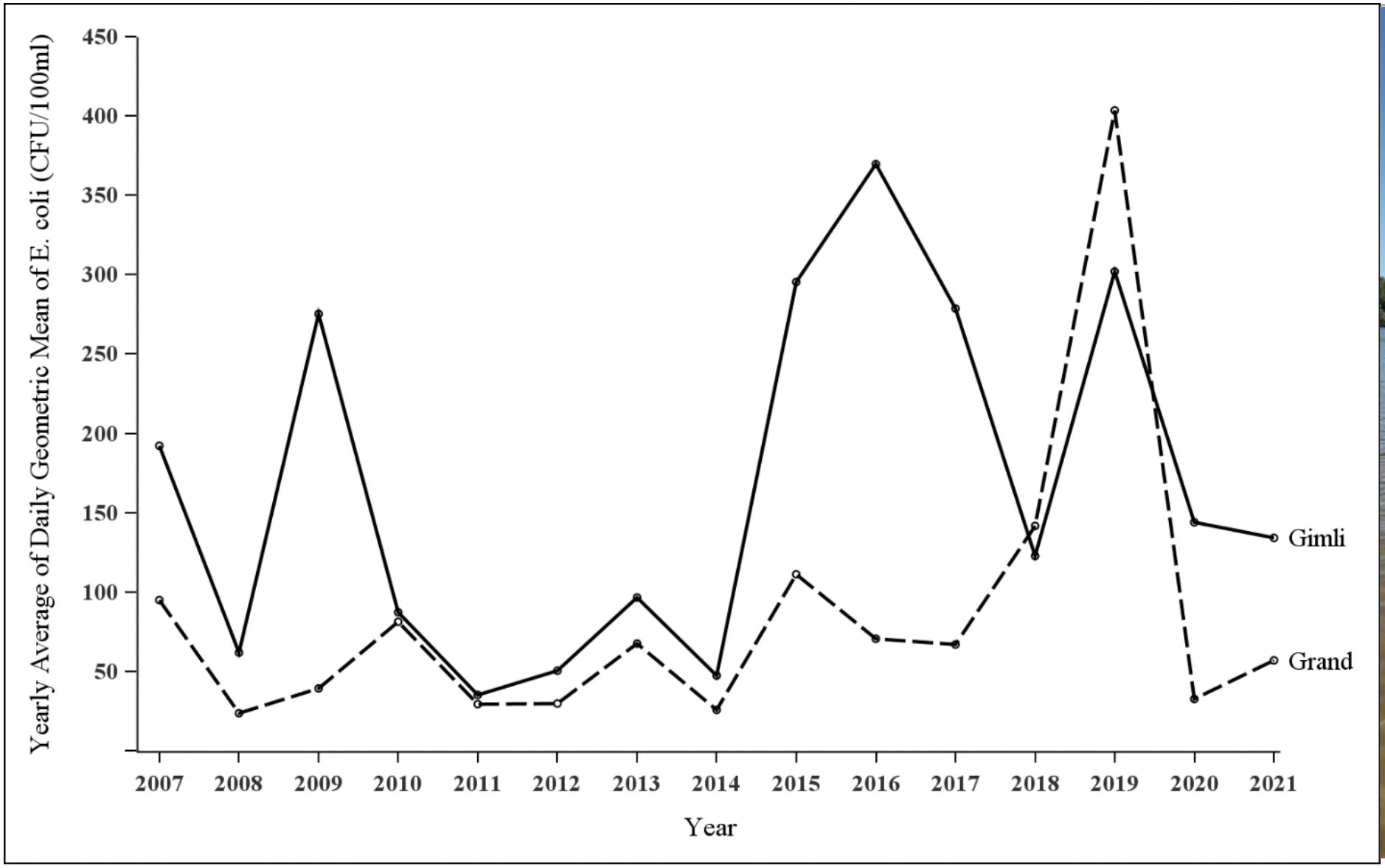
The concentration of *Escherichia coli (E. coli)* is used as an indicator of recent fecal pollution and signifies risks of recreational water illness in freshwater beaches [1]. Municipal beach monitoring programs routinely collect water samples to determine whether bacterial concentrations exceed guideline thresholds. Canadian guidelines implemented in 2012

Manitoba

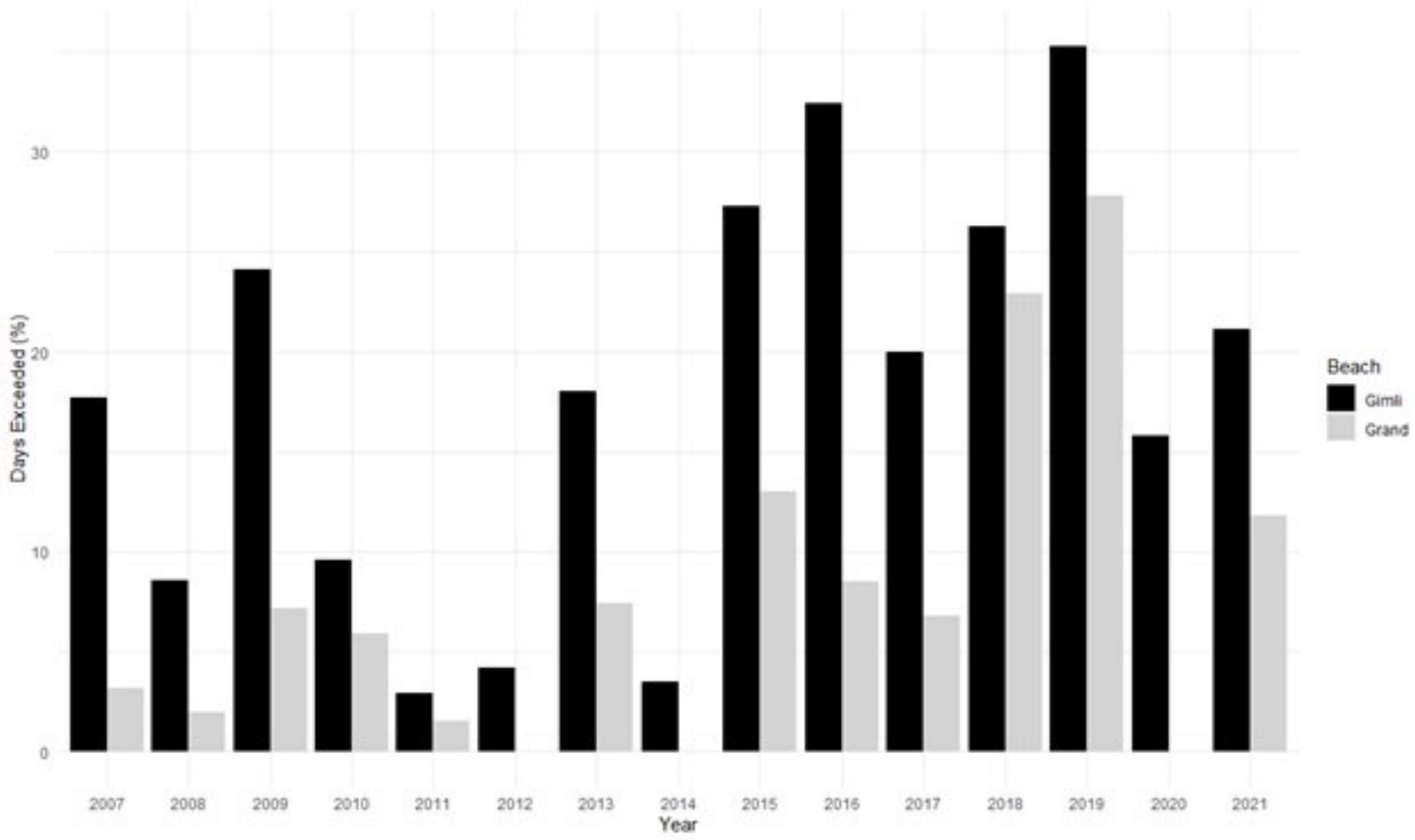
- 2 beaches on Lake Winnipeg
  - located on opposite sides
- 1 bouy
- 1 Weather station
- 1 Water level station



Mean annual *E. coli* mean at Manitoba Beaches, 2007-2021



Annual *E. coli* threshold exceedances (200 CFU/100 ml) at Manitoba Beaches



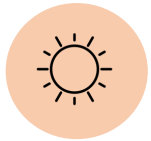
Data - Manitoba

Publicly Available Environmental Data

Air temp

Water level

UV Index



48-hour rainfall

Antecedent dry days

Manitoba

24-hour *E. coli*

Analytical Methods

Multilevel modelling

- Examined year-specific effects via two outcomes

Path analysis

- Allowed us to examine the relationship between variables

Manitoba Multilevel Modelling Analysis

Gimli

48-hour rainfall

24-hour mean air temp

24-hour *E. coli*

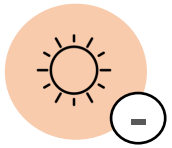
Grand

48-hour rainfall

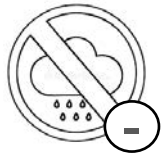
24-hour air temp

24-hour *E. coli*

24-hour UV Index

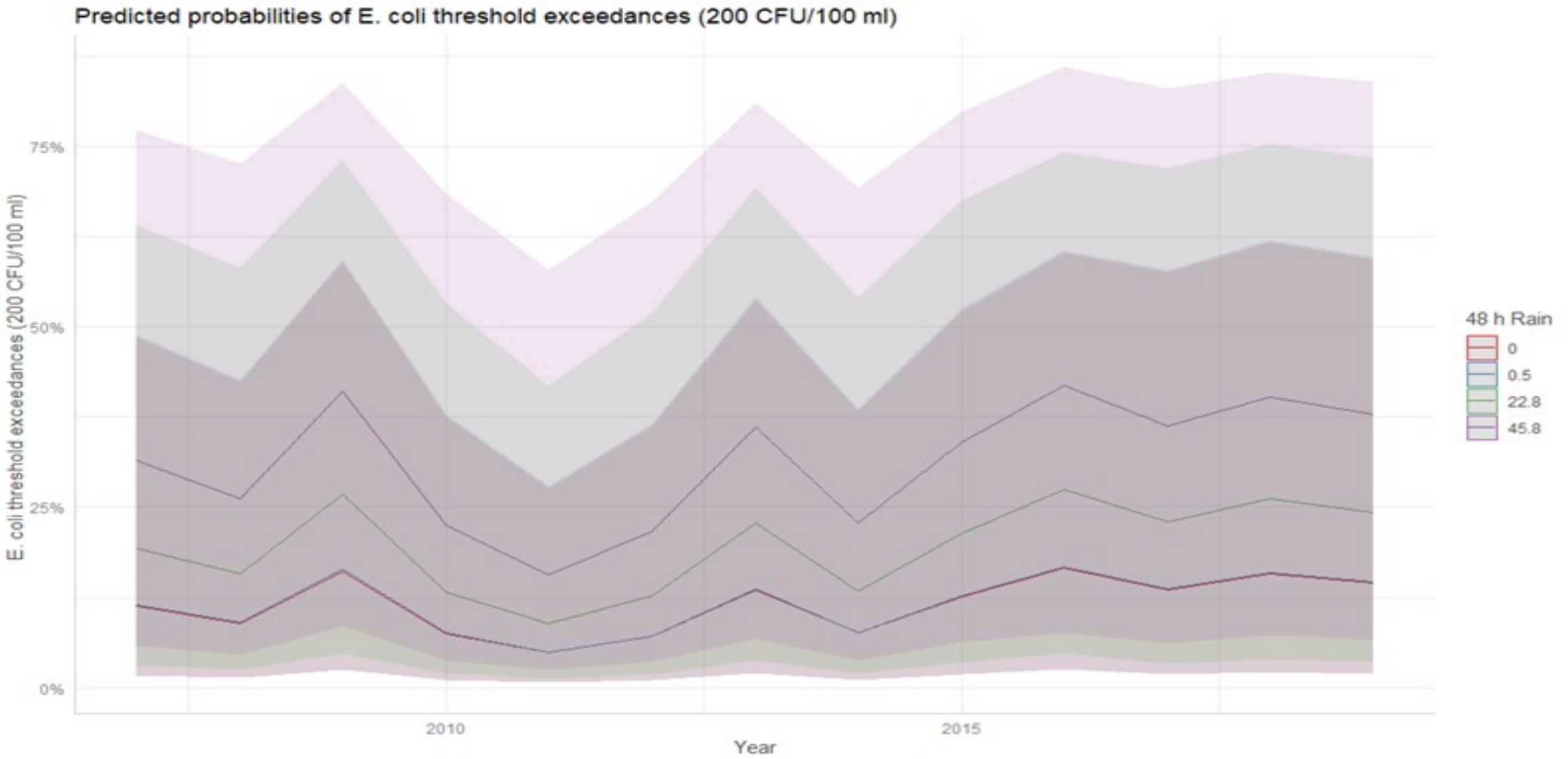


Antecedent dry days

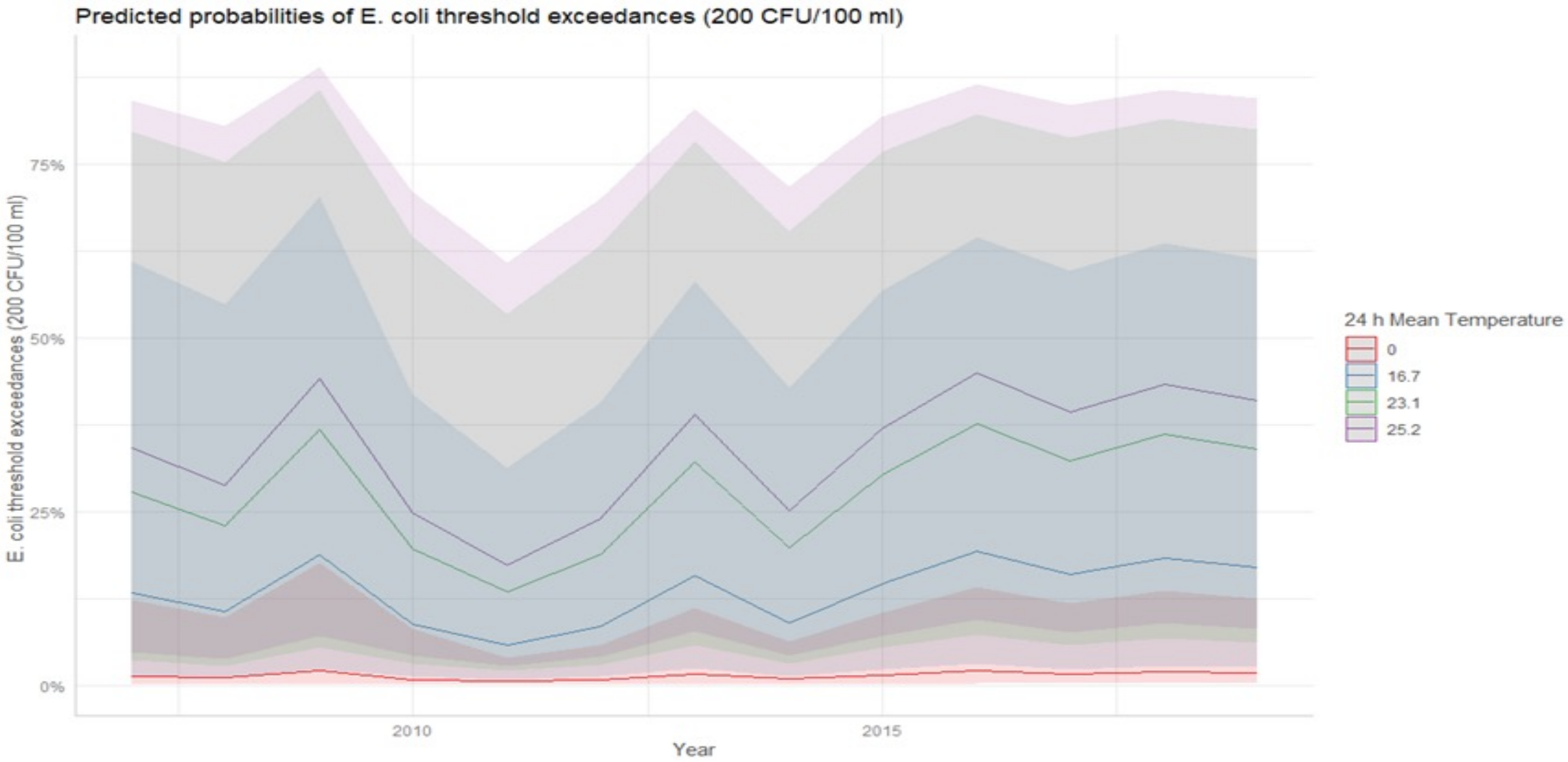


Year-specific effects were significant and suggest yearly-varying factors that affect E. coli levels.

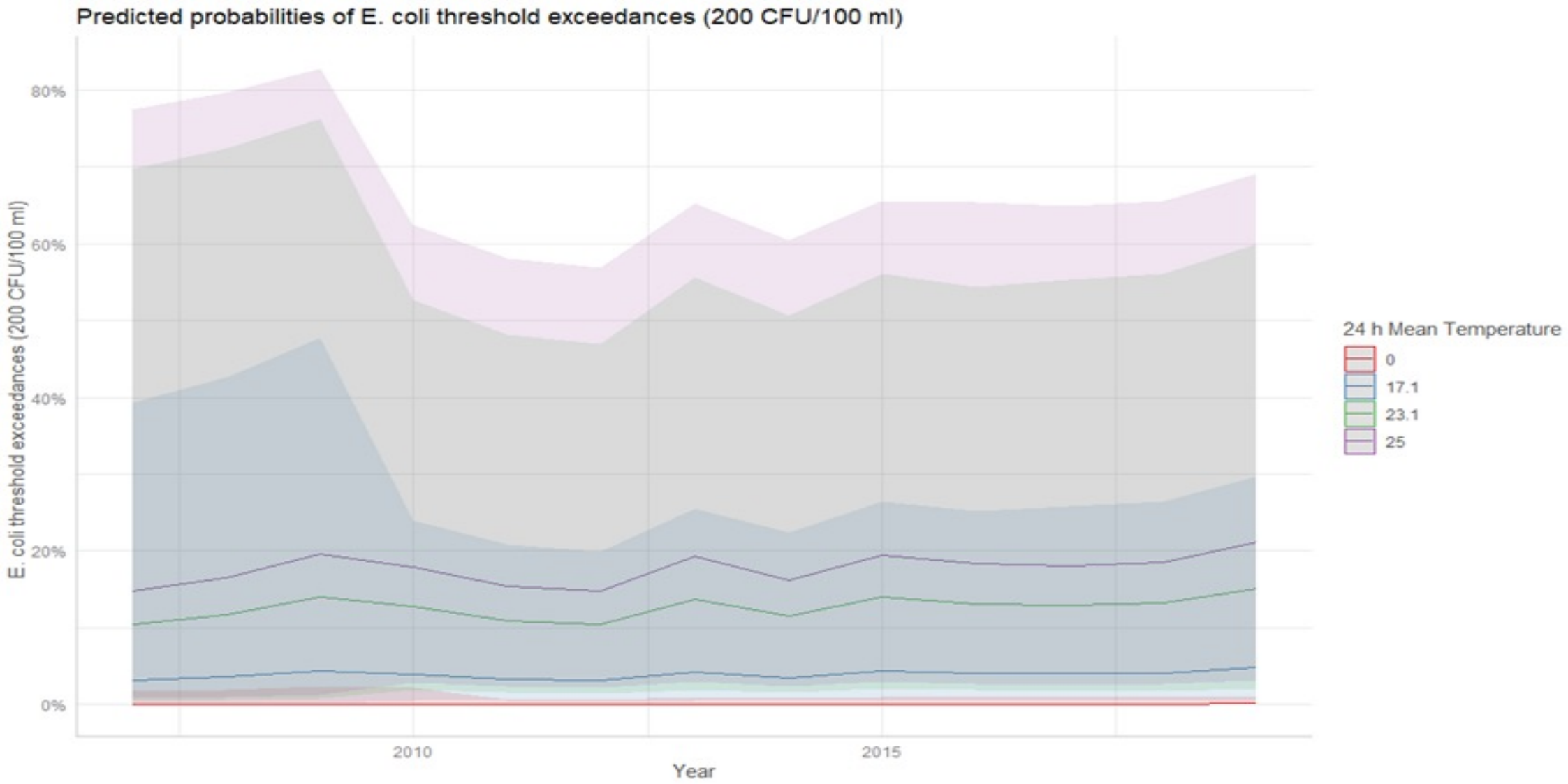
The predicted probability of exceeding the 200 CFU/100 *E. coli* threshold at four rain values – Gimli logistic model



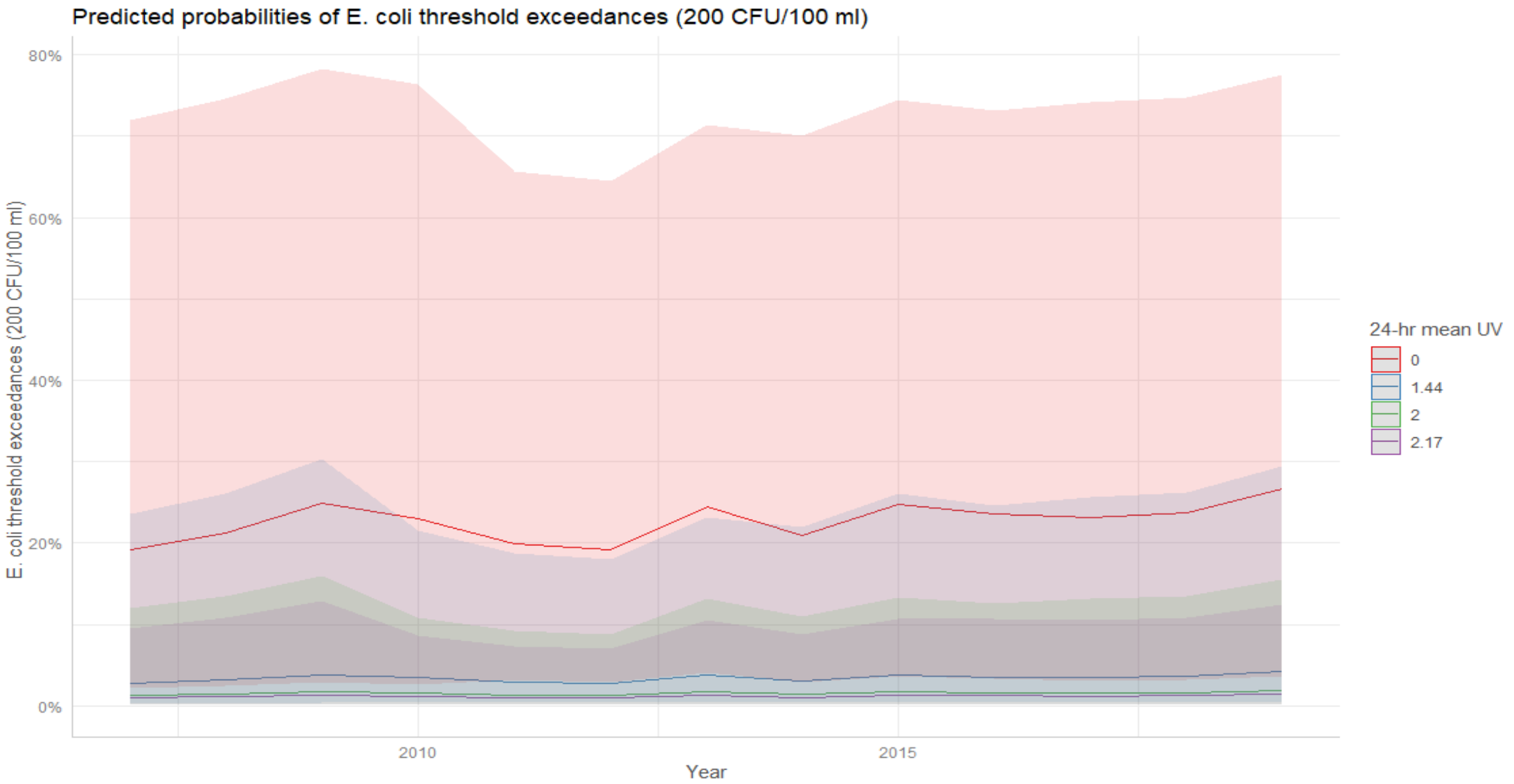
The predicted probability of exceeding the 200 CFU/100 *E. coli* threshold at four temp values – Gimli logistic model



The predicted probability of exceeding the 200 CFU/100 *E. coli* threshold at four temp values – Grand logistic model



The predicted probability of exceeding the 200 CFU/100 *E. coli* threshold at four UV values – Grand logistic model



Conclusion and Future Plan

1

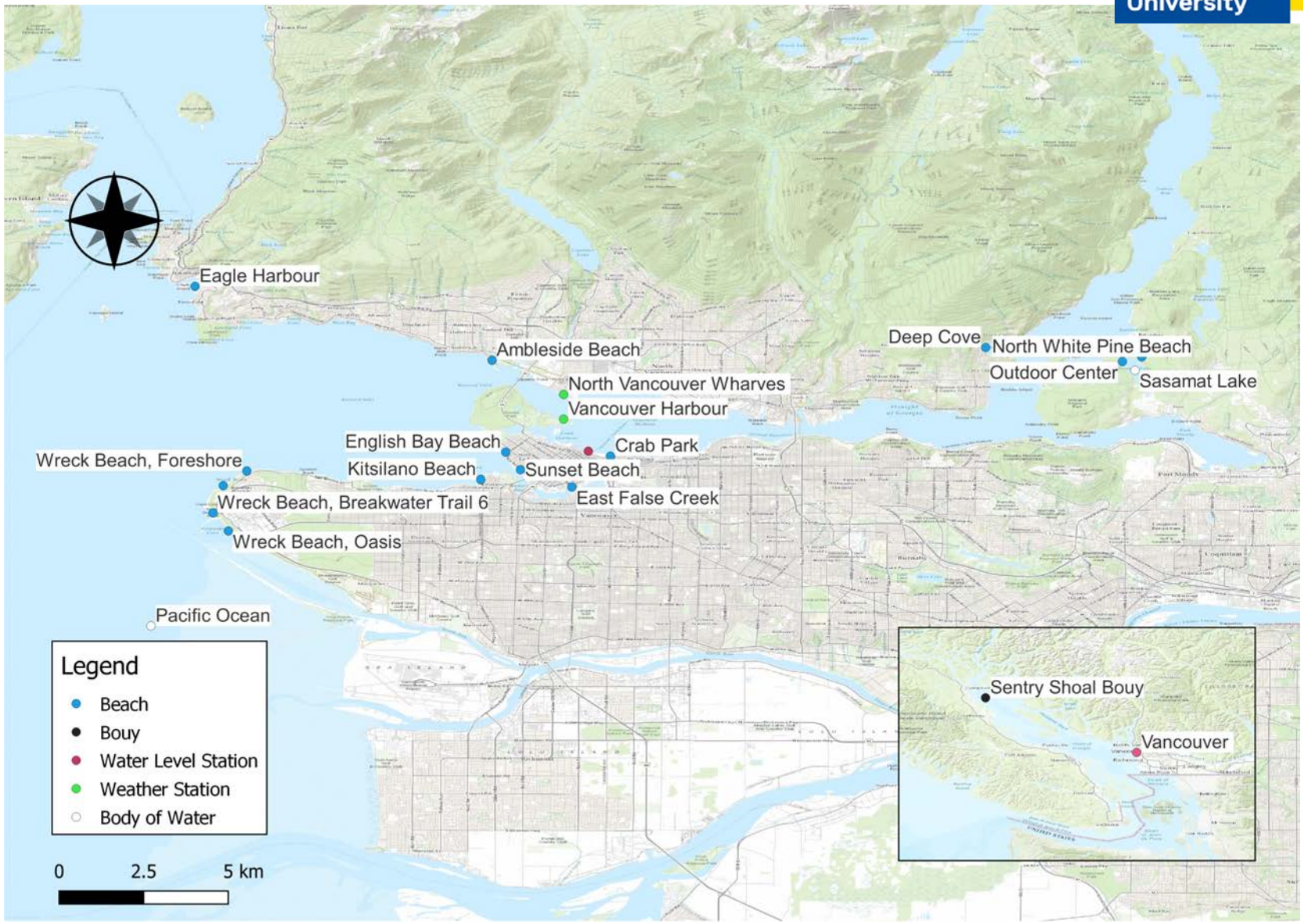
The need for enhancing beach monitoring programs for extreme weather events (climate change preparedness efforts)

2

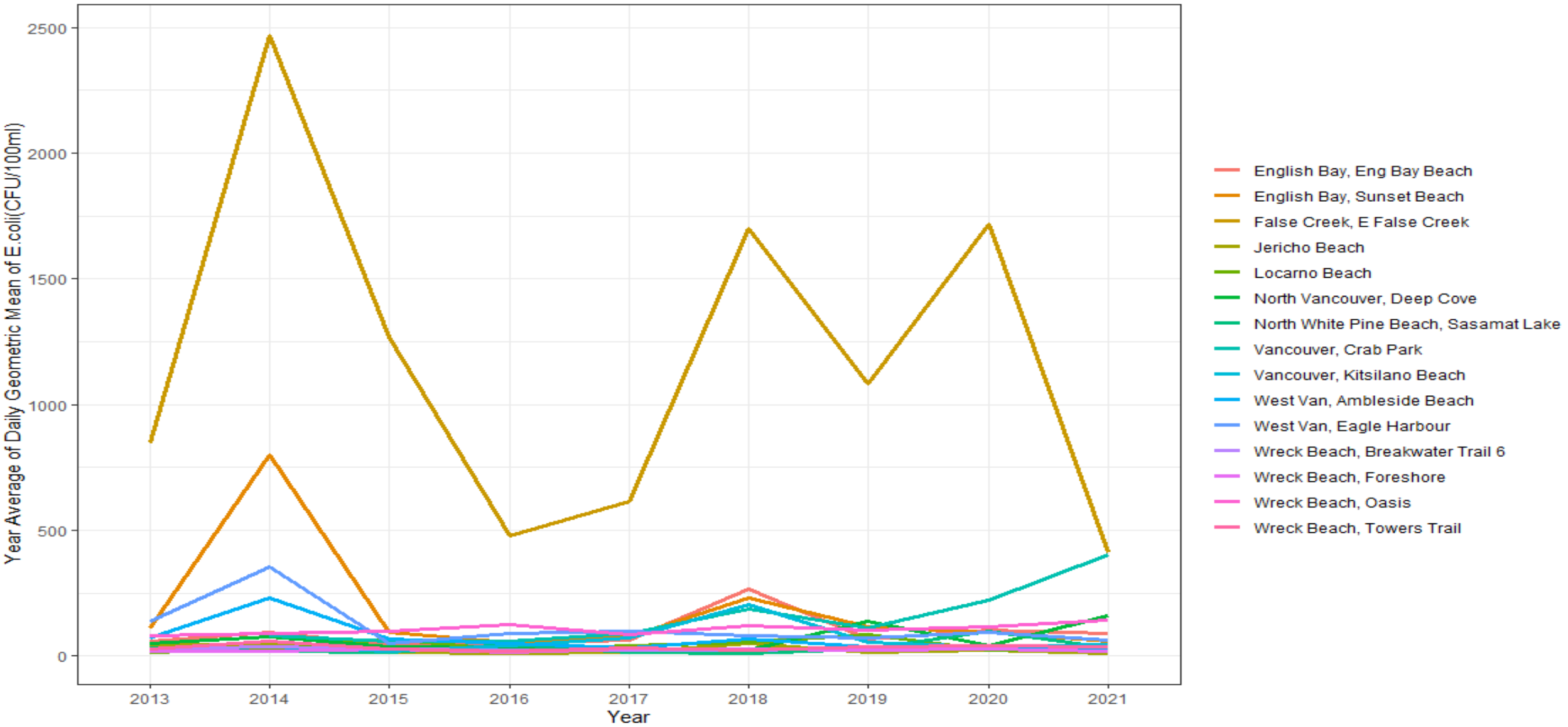
The findings will help develop real-time recreational water quality predictive models to allow more accurate beach management decisions

Vancouver

- 15 beaches on the Pacific Ocean
- 1 buoy
- 2 Weather station
- 1 Water level station



Mean annual *E. coli* mean at Vancouver Beaches, 2013-2021



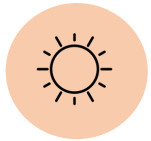
Data - Vancouver

Publicly Available Environmental Data

Air temp

Water level

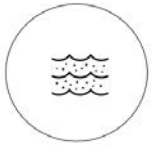
UV Index



48-hour rainfall

Antecedent dry days

Salinity



Vancouver

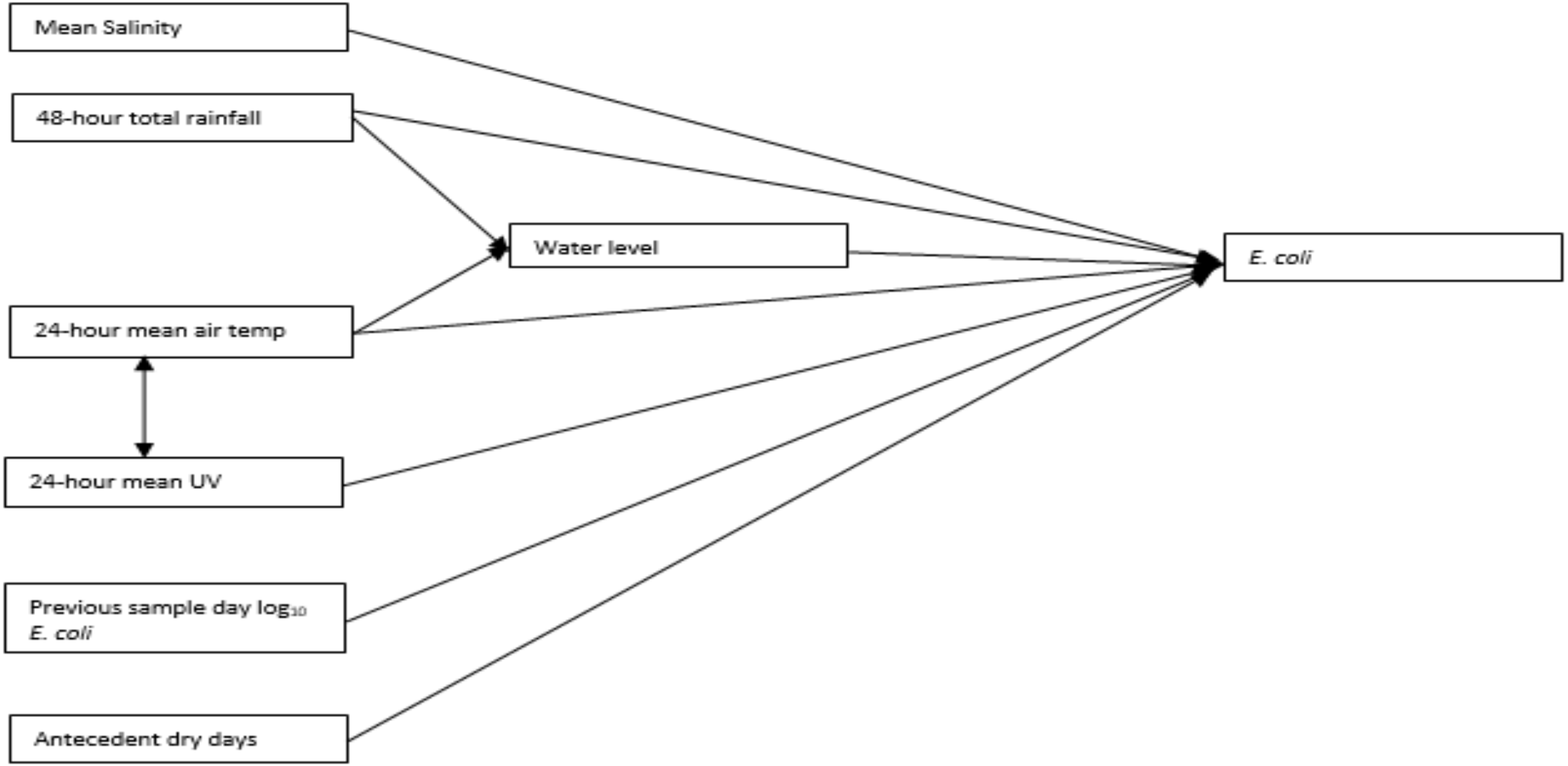
Previous sample day *E. coli*

Analytical Methods

Bayesian Mixed Effect Regression Modelling

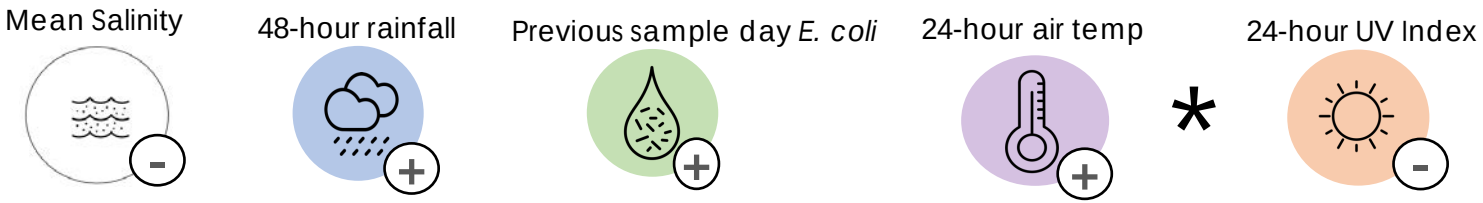
- Informed by our DAG
- Varying slope for each predictor variable for each beach (except for antecedent dry days)
- Keeping year a fixed effects
- Interaction between temp and UV

Directed Acyclic Graph (DAG) of the relationship between variables affecting E. coli



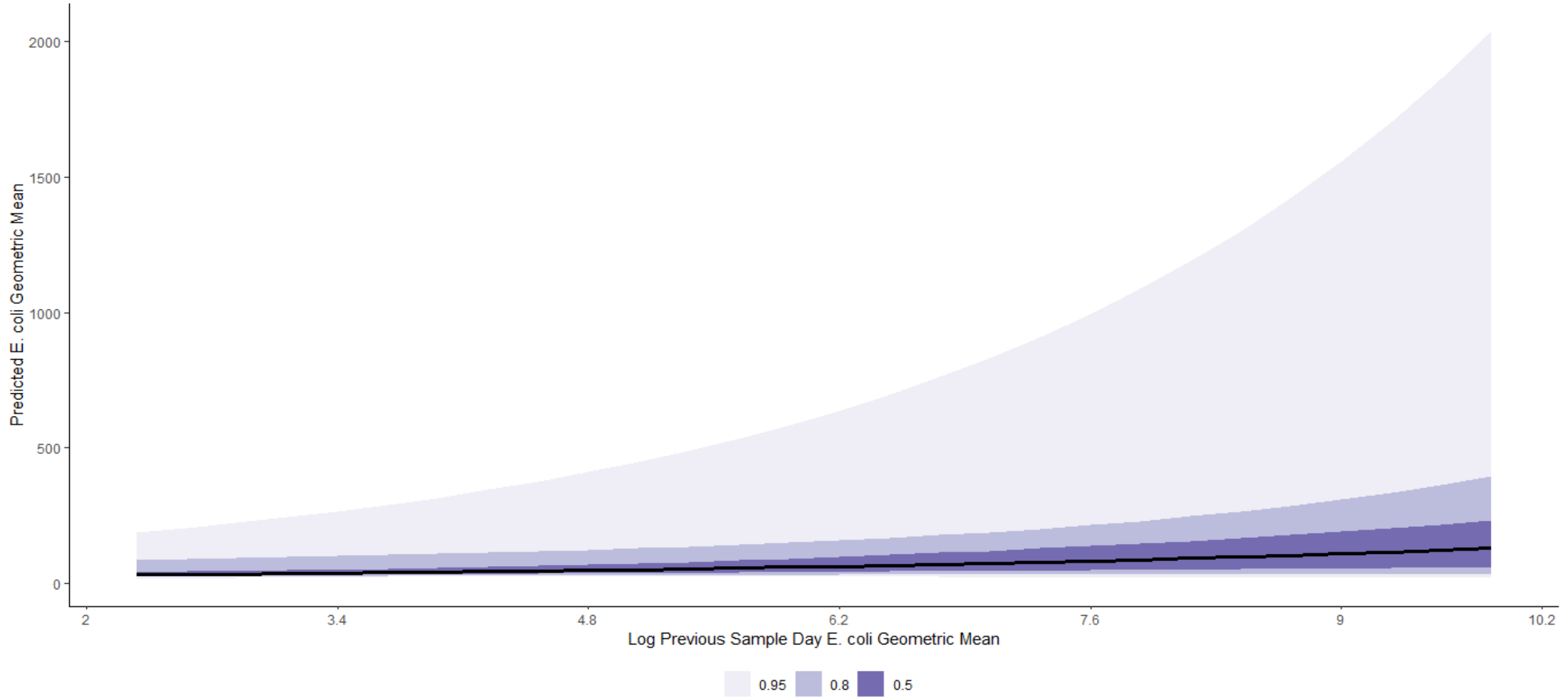
Vancouver Bayesian Mixed-effect Model

Overall relationship direction

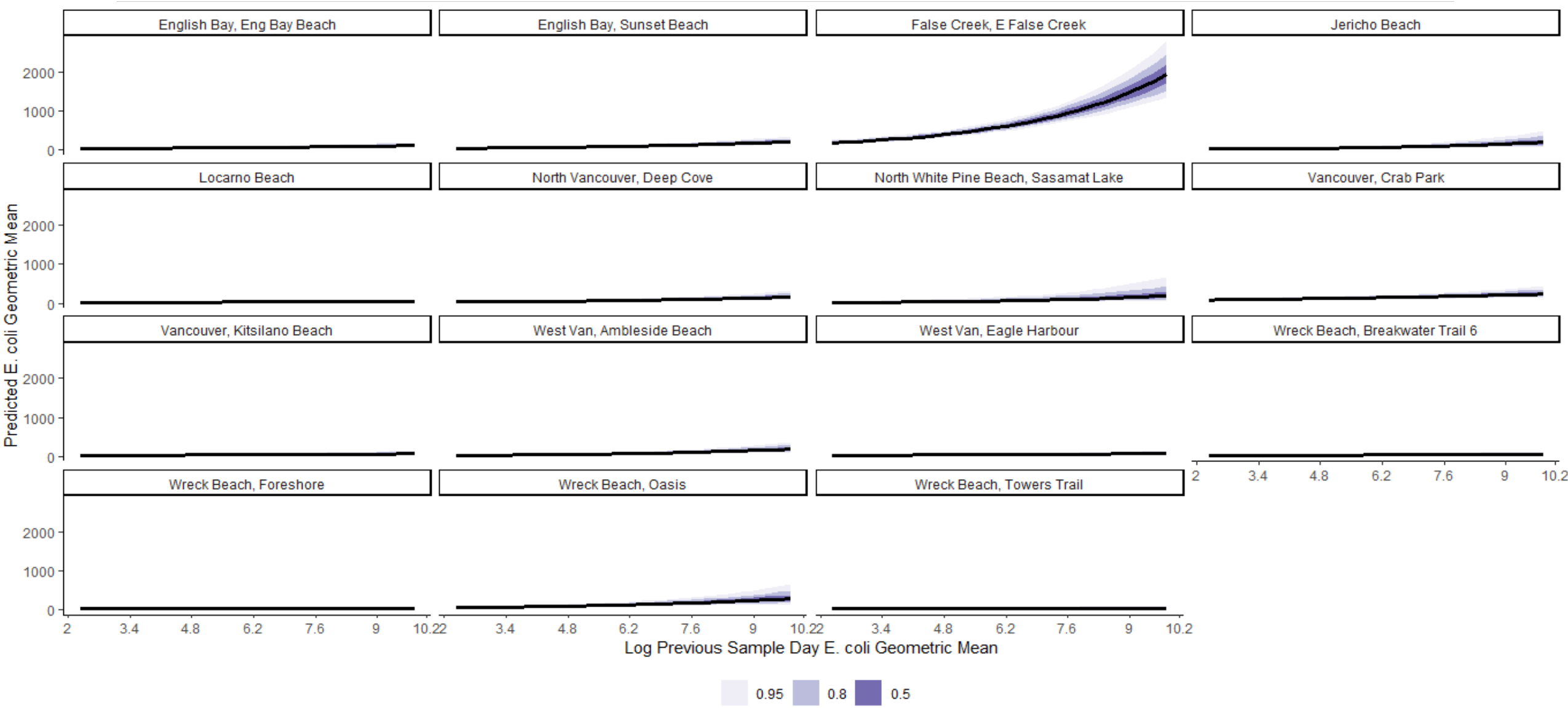


The average effects of the predictor variables varied by **beaches**

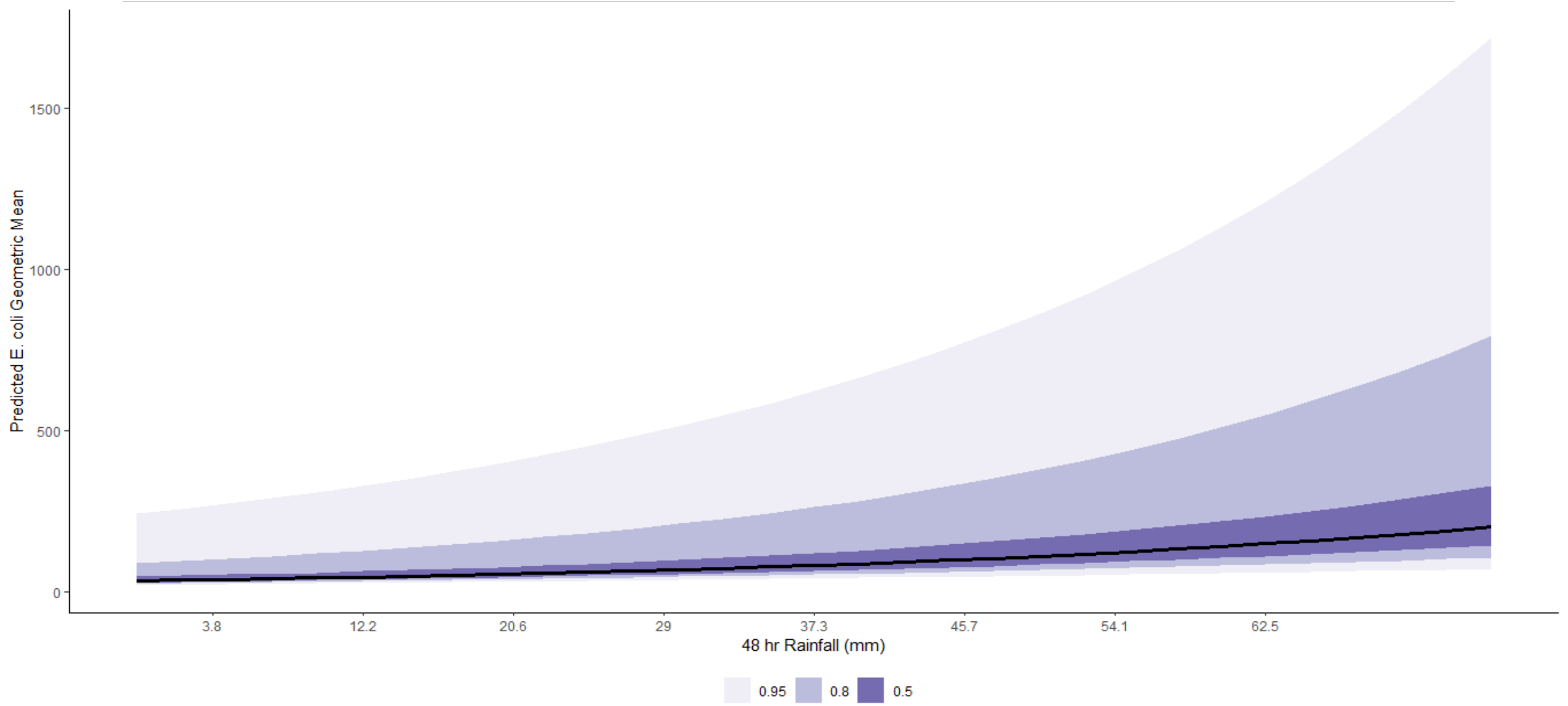
The predicted geometric *E. coli* concentration per values of previous sample day log geometric mean of *E. coli*



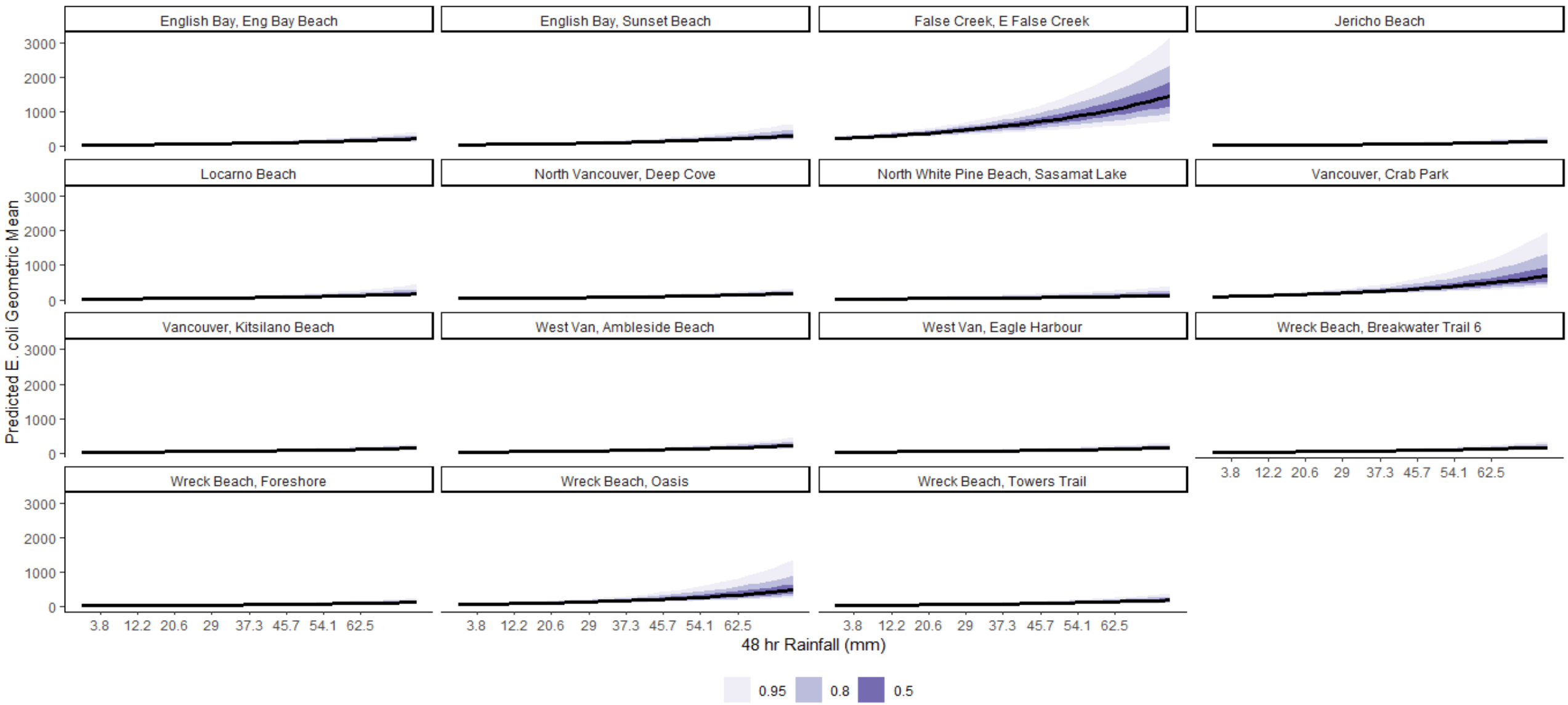
The beach-specific predicted geometric *E. coli* concentration per values of previous sample day log geometric mean of *E. coli*



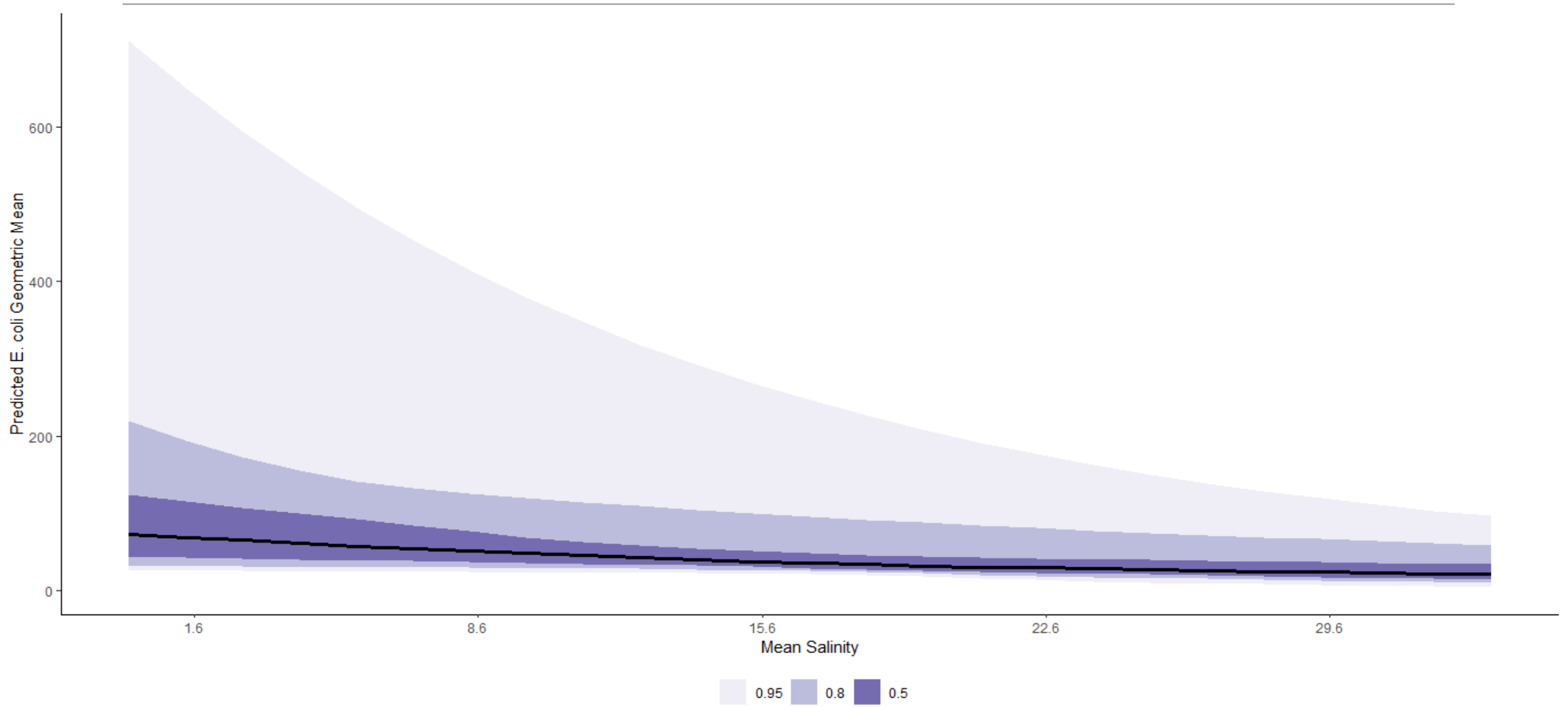
The predicted geometric *E. coli* concentration per value of 48-hr total rainfall



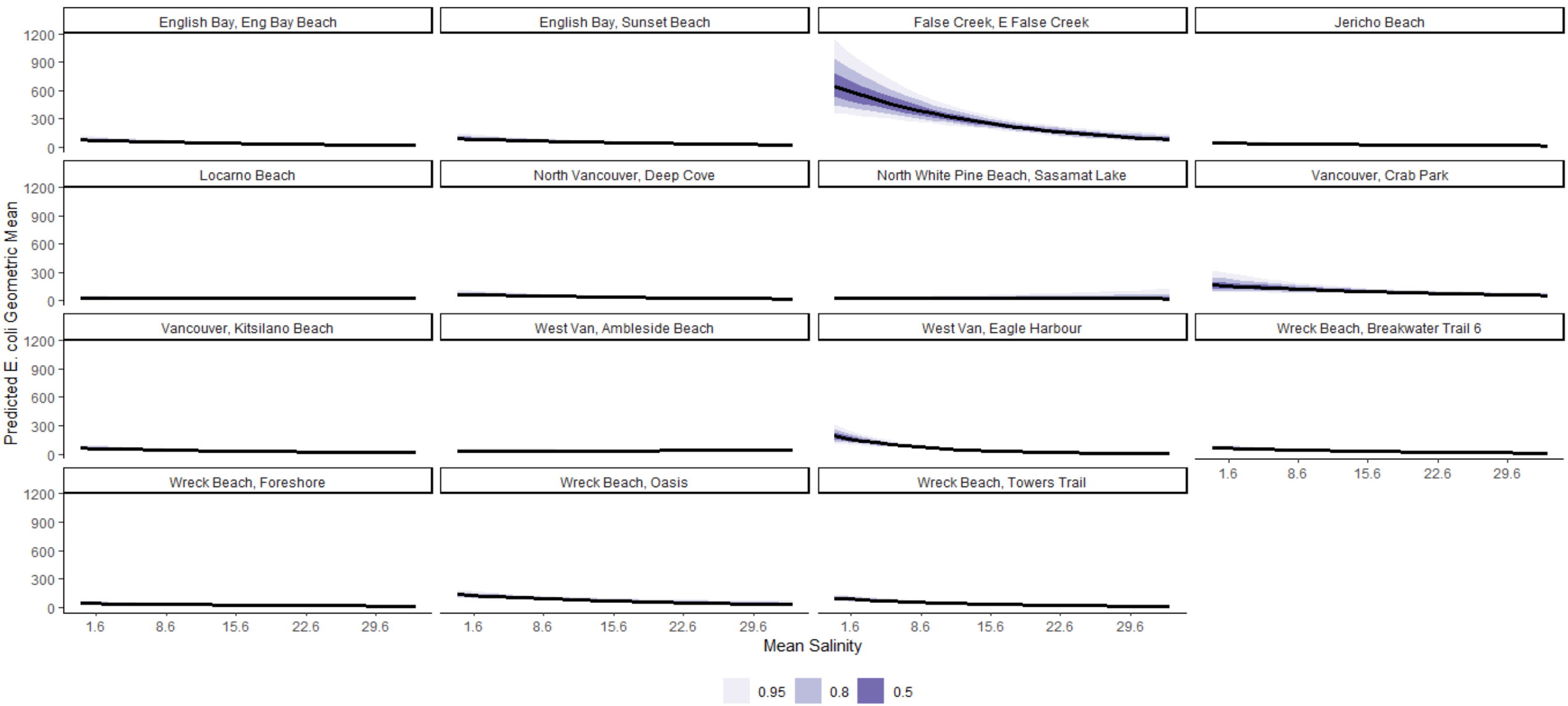
The beach-specific predicted geometric *E. coli* concentration per value of 48-hr total rainfall



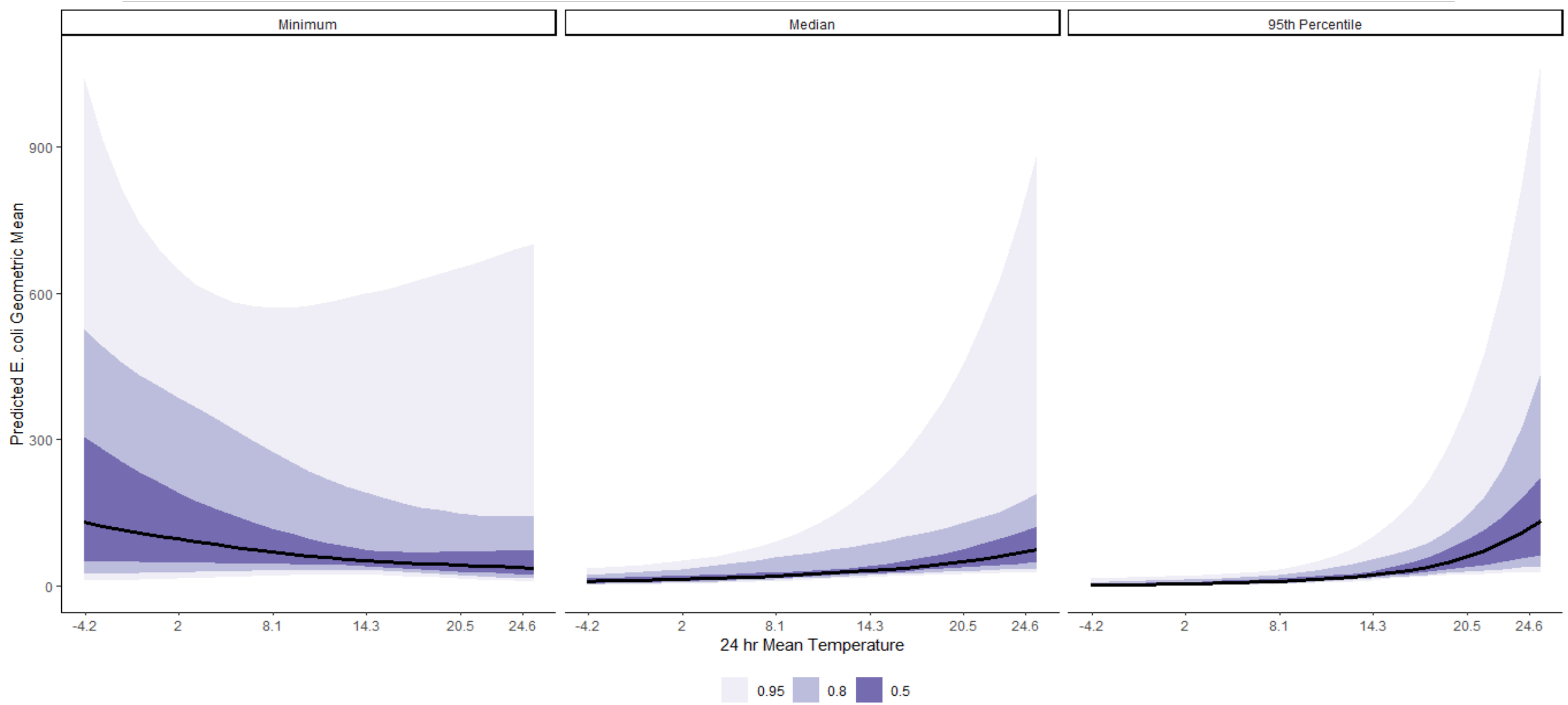
The predicted geometric *E. coli* concentration per values of mean salinity



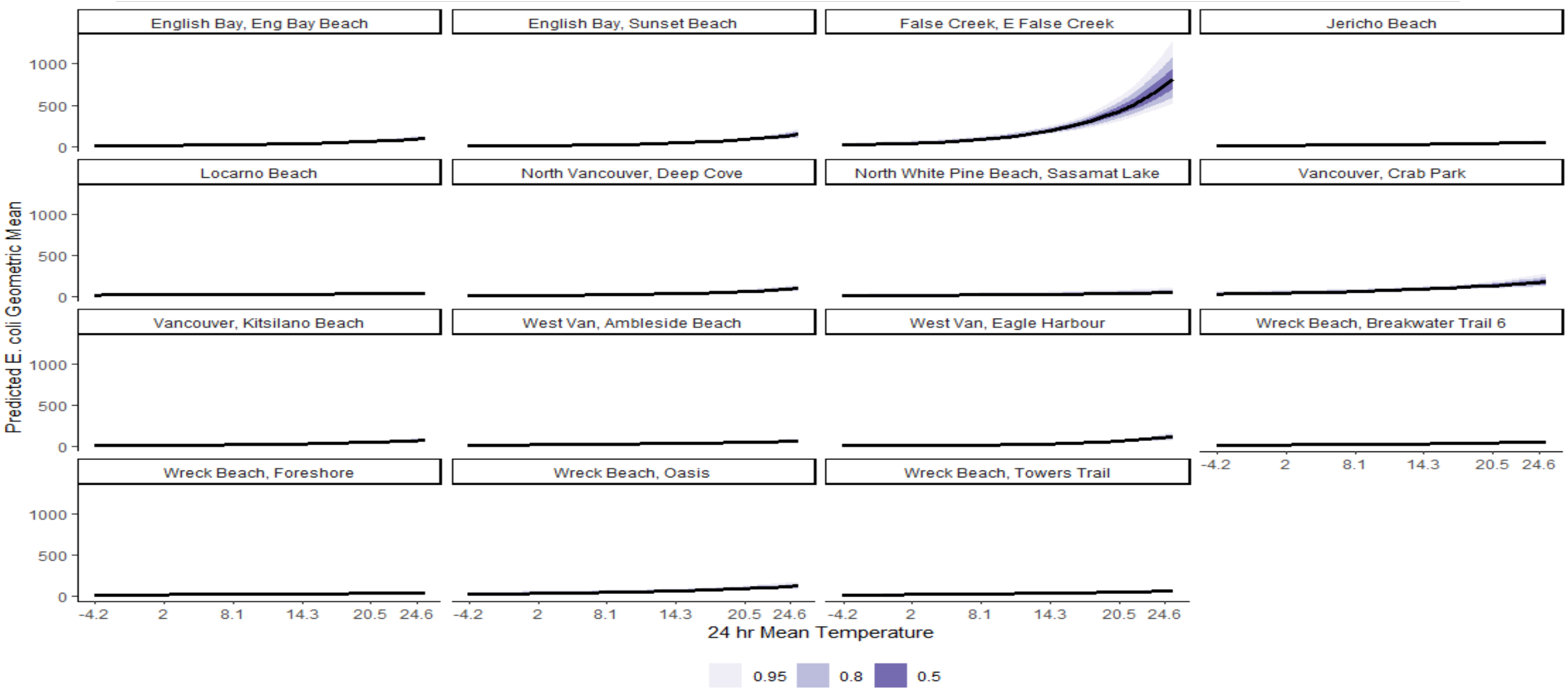
The beach-specific predicted geometric *E. coli* concentration per values of mean salinity



The predicted geometric *E. coli* concentration per 24 hr mean temperature at three values 24-hr mean UV index



The beach-specific predicted geometric *E. coli* concentration per 24 hr mean temperature at the median value of 24-hr mean UV index



Conclusion and Future Plan

1

Beach-specific approach to beach monitoring programs and predictive models is warranted in Vancouver

2

The findings will form the basis for building real-time predictive models of marine water quality to enable more accurate beach management decision-making

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.

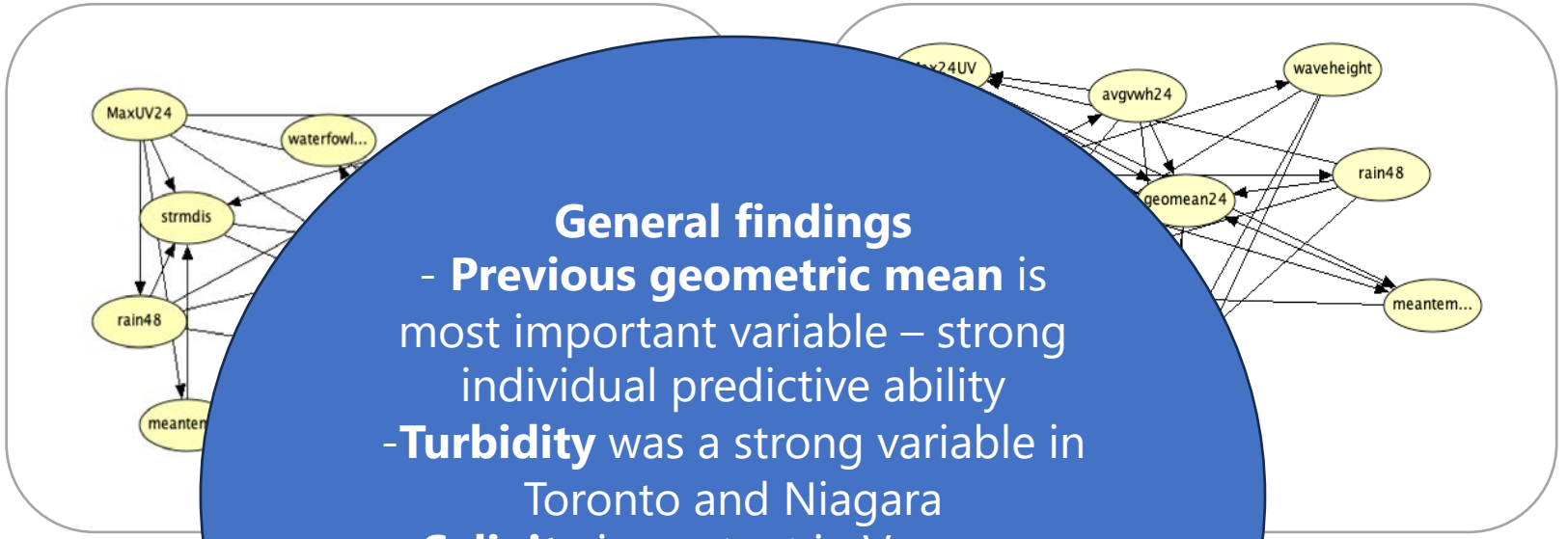
Predictive Bayesian Network Model

- We used information learned in Objective 1 analysis to guide the development of the Bayesian Network graphic models

- Type of Artificial Intelligence Graphical model that uses probability to determine the occurrence of an event

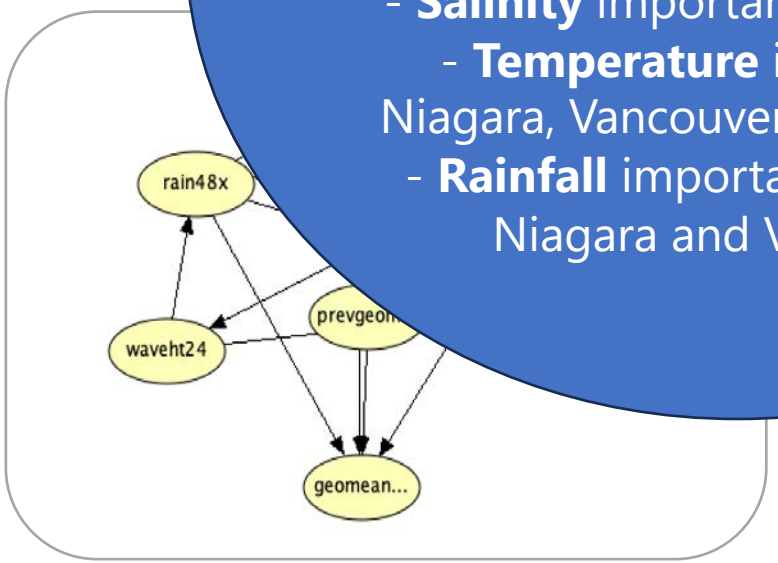
Bayesian Network Models

Toronto

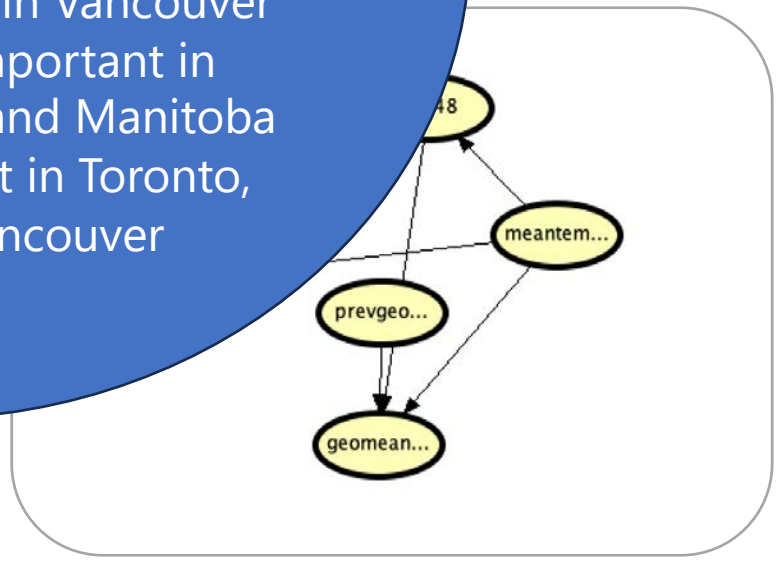


Niagara

Vancouver



Manitoba



General findings

- **Previous geometric mean** is most important variable – strong individual predictive ability
- **Turbidity** was a strong variable in Toronto and Niagara
- **Salinity** important in Vancouver
- **Temperature** important in Niagara, Vancouver and Manitoba
- **Rainfall** important in Toronto, Niagara and Vancouver

Future Direction

The Canadian Recreational Water Quality Research Group

Environmental predictors of recreational water quality

Prediction Web Application for Public Health Units

Canadian Beach Cohort Study

Canadian Algal Blooms in Recreational Waters

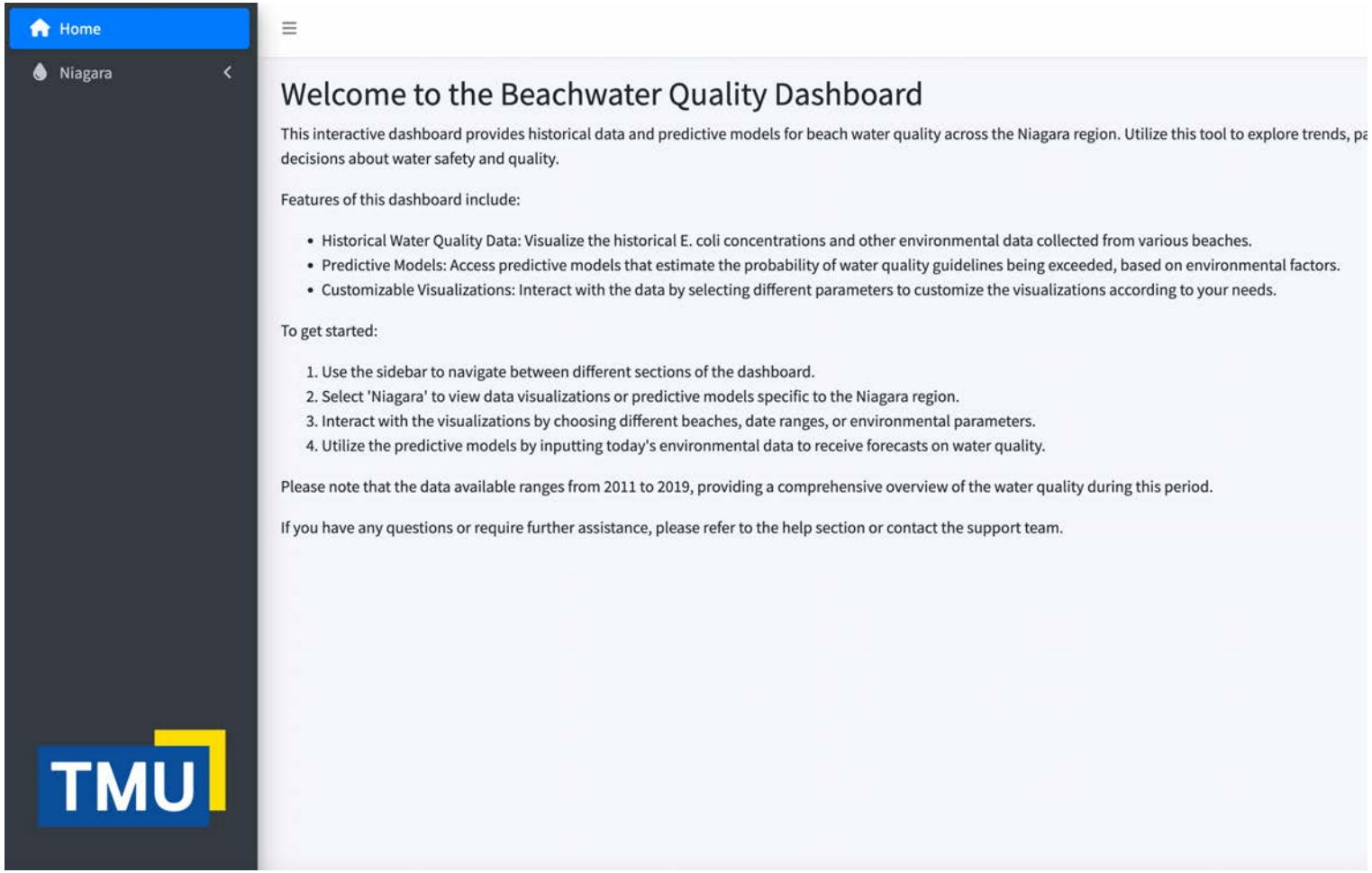
Rec Water R Shiny Application

- Interactive application/webpage for visualization of beach and weather data
- Home for the predictive models for daily threshold exceedance projections

Goal:

- User-friendly application
- Informative tool
- Accurate

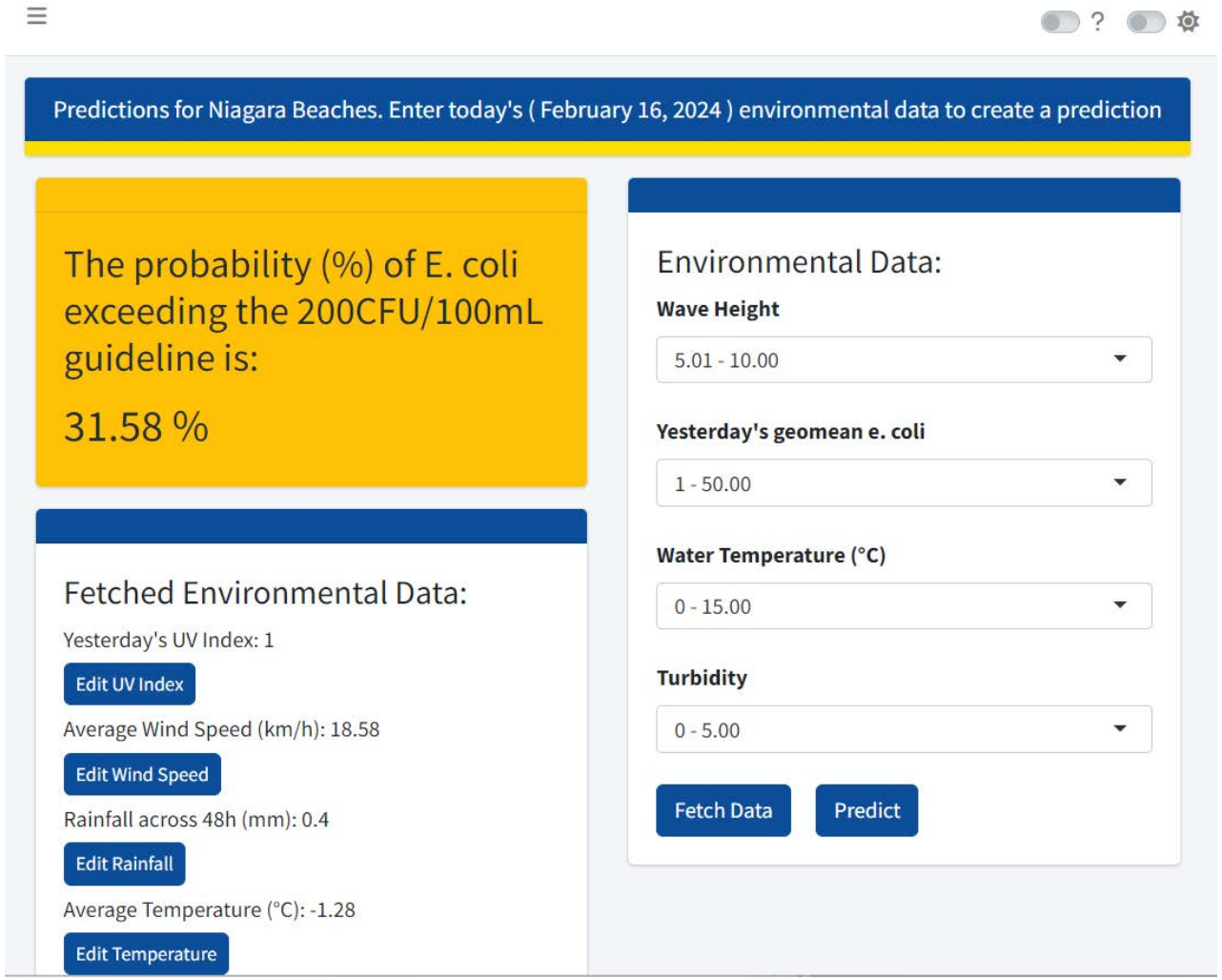
R Shiny App



Currently being finalized for testing with public health for summer 2024

Retroactively looking at 2023 data to look at predictive performance

R Shiny App


Predictions for Niagara Beaches. Enter today's (February 16, 2024) environmental data to create a prediction
The probability (%) of E. coli exceeding the 200CFU/100mL guideline is:
31.58 %
Fetched Environmental Data:
Yesterday's UV Index: 1
Edit UV Index
Average Wind Speed (km/h): 18.58
Edit Wind Speed
Rainfall across 48h (mm): 0.4
Edit Rainfall
Average Temperature (°C): -1.28
Edit Temperature
Environmental Data:
Wave Height
5.01 - 10.00
Yesterday's geomean e. coli
1 - 50.00
Water Temperature (°C)
0 - 15.00
Turbidity
0 - 5.00
Fetch Data
Predict

Canadian Beach Cohort Study

- 2022: Toronto Woodbine Beach Feasibility Study
- 2023: CIHR Bridge Funding - Marie Curtis and Sunnyside Beach (623 participants, 405 households)
  - ➢ Surveyed participants and conducted follow-up to determine AGI
  - ➢ Additional water sampling on recruitment days for microbial source tracking
- 2024: Received funding from CIHR for full study! Will add beaches in Vancouver and Manitoba and potentially other sites

Algal Blooms Project

- Research Title: Burden of recreational water illness due to cyanobacteria and their toxins in Canadian freshwater beaches
- Four years of funding from PHAC
- Examine the impact algal blooms have on human and animal health (exposed pets) – ONE HEALTH approach

Conclusions

- We applied different and novel analytic methods to understand the relationship of environmental factors on water quality at beaches across four regions in Canada (Objective 1)
- We learned which factors had an important effect
- We used knowledge gained to develop predictive model using a novel approach – Bayesian Networks model – an application of AI
- We are actively exploring the health burden of poor water quality levels and algal blooms

Application of Research

- Prediction models can be applied to global health contexts to understand water quality (drinking water, recreational waters, etc)
- A web application like R Shiny app could provide public health units with a tool for predicting water quality
- Information gained from our beach cohort and algal bloom projects can have widespread impact in the area

Acknowledgements

Co-authors: Dr. Ian Young, Dr. Jordan Tustin, Rachel Jardine

Collaborators

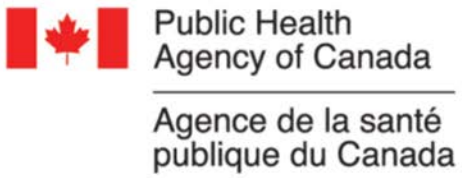
Toronto: Mahesh Patel

Niagara: Jeremy Kelly, Anthony Habjan, Ryan Waterhouse, Brendan Cooper

Vancouver: Dr. Michael Schwandt

Manitoba: Dylan Lyng

Funding:



For more information visit: canadianbeachwater.ca

Thank you!