Water quality modelling - Part 2
Pathogen simulation

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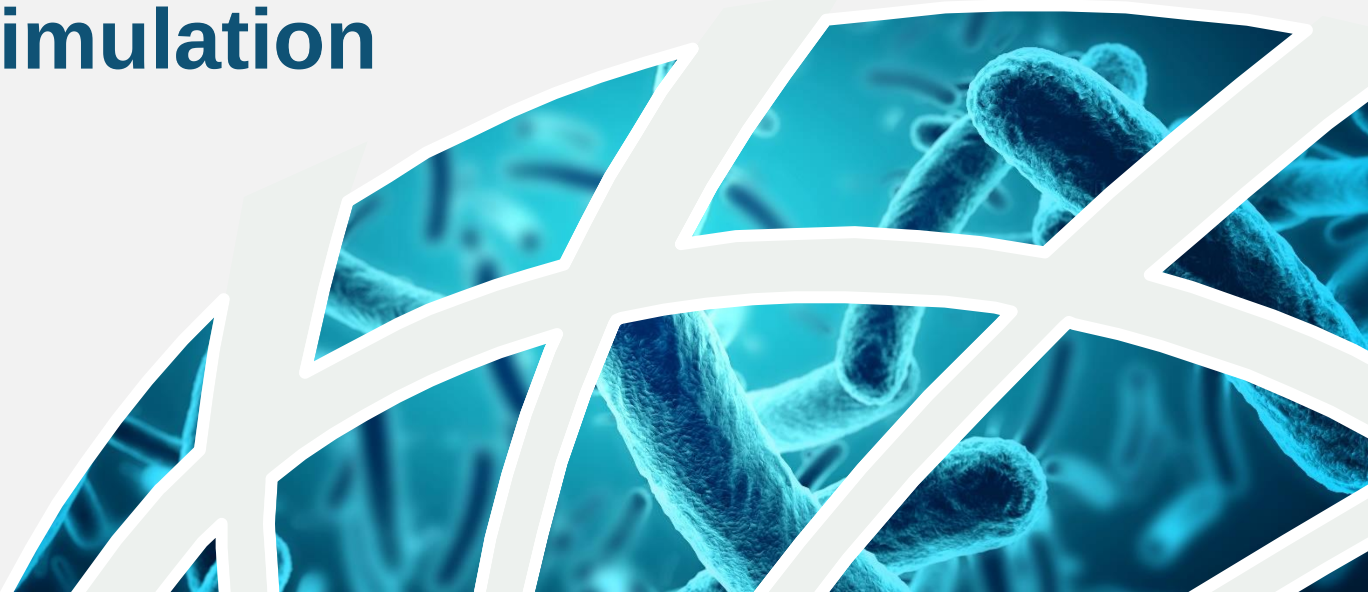
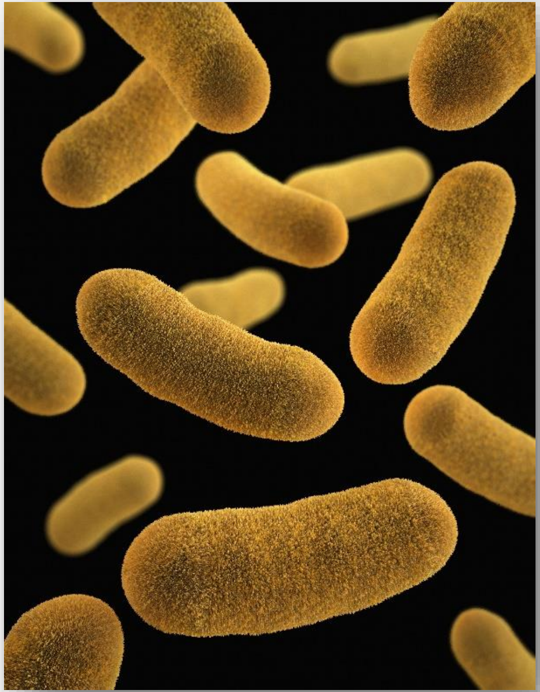


Overview

Today we'll cover

- What are pathogens?
- Why are pathogens of interest?
- How do we model pathogens?
- Example model



What are pathogens?

Pathogens are

- Microbes (not all microbes are pathogens)
  - Viruses, bacteria, single and multi-cell eukaryotes
  - Beneficial and harmful
- Everywhere on Earth!
  - Estimated to be 10^{31} organisms
  - Ten billion times the number of stars in the universe
  - Each human carries 30 trillion

What are pathogens?

Pathogens are

- Some familiar examples
  - Measles, smallpox, zika, Ebola, SARS, COVID
- Some common aquatic environment examples
  - Cryptosporidium or “crypto” (not the currency!)
  - Escherichia coli or “E. coli”
  - Norovirus
  - Campylobacter

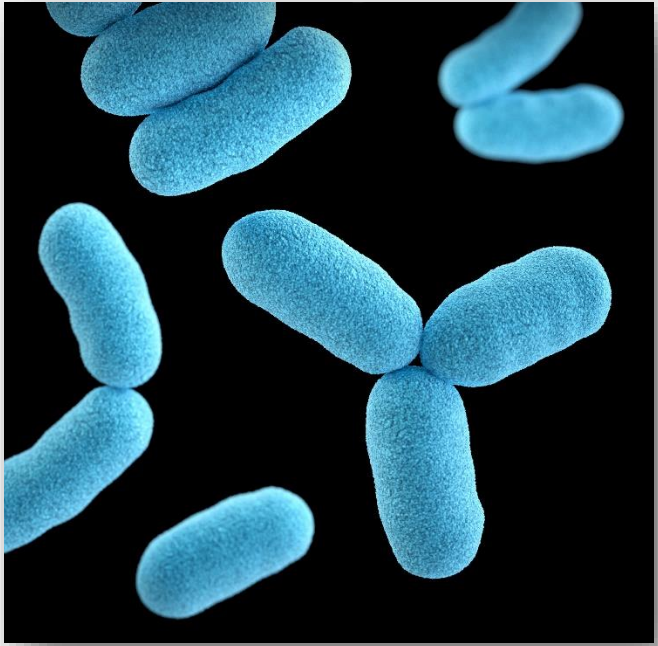
Why are pathogens of interest?

Pathogens are of interest because they

- Can cause human disease
- Can be fatal – up to 20% of global deaths in 2019
- Human and economic cost
  - US$1bn annually

Our concern today

- Environmental waterborne pathogens



Why are pathogens of interest?

Common environmental sources

- Human waste
  - Sewers, combined sewers (CSOs) and onsite treatment systems
- Mammalian waste (agricultural and urban)

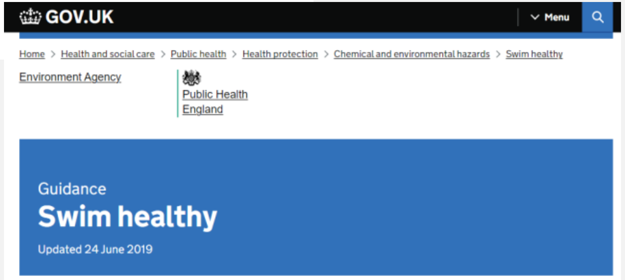
Common environmental receivers

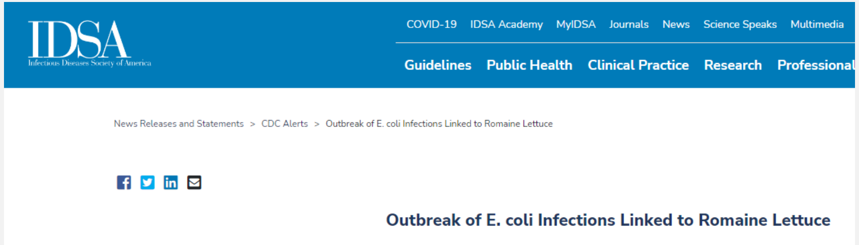
- Freshwater creeks, streams, rivers and lakes
- Reservoirs (including water supply), natural and urban lakes
- Coastal oceans

Why are pathogens of interest?

Environmental pathways to humans

- Ingestion of contaminated drinking water
  - Water supply contamination
- “Primary contact” with contaminated water
  - e.g. swimming, bathing, diving, water skiing
- “Secondary contact” with contaminated water
  - e.g. boating, fishing, canoeing
- Consumption of contaminated food

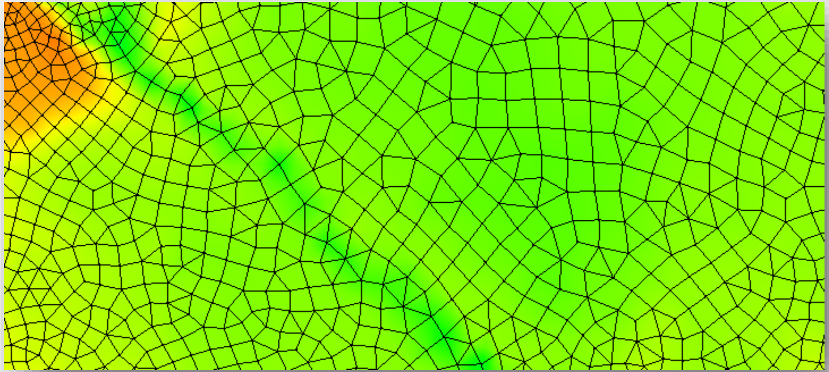


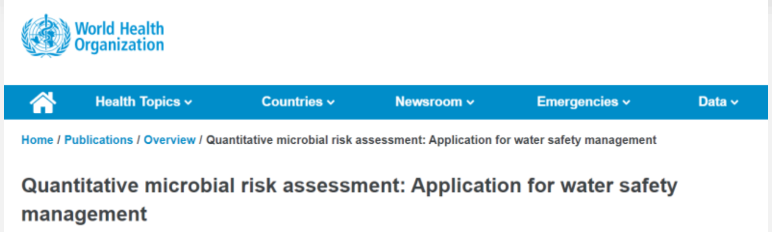


Why are pathogens of interest?

Aquatic environmental

- Look to numerical modelling
  - Risk elimination / minimisation
  - Public health
- QMRAs
  - Quantitative microbial risk assessment

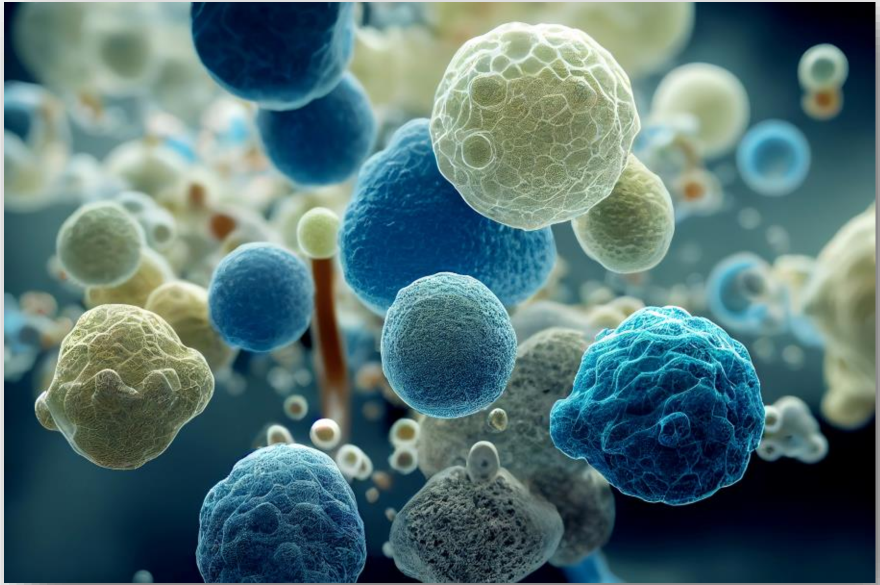




How do we model pathogens?

On waterborne release, pathogens transform via

- Natural mortality
- Light inactivation
- Settling
- Growth
- Predation
- Attachment / detachment to sediment

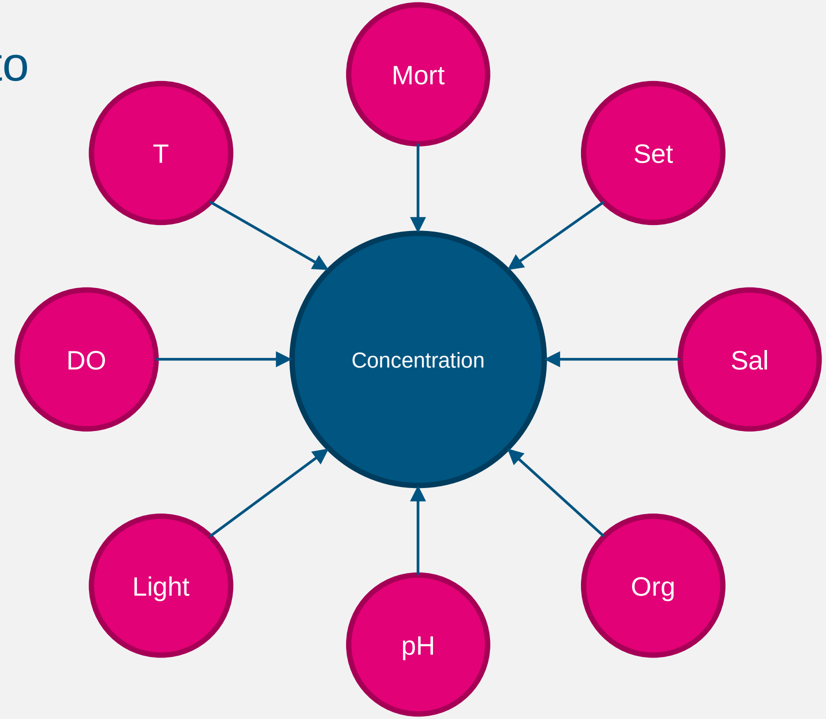


How do we model pathogens?

On waterborne release, pathogens respond to

- Temperature
- Light (visible, UV-A, UV-B, infrared)
- Salinity
- Oxygen
- pH
- Organic material

Not pretending this is straightforward!



How do we model pathogens?

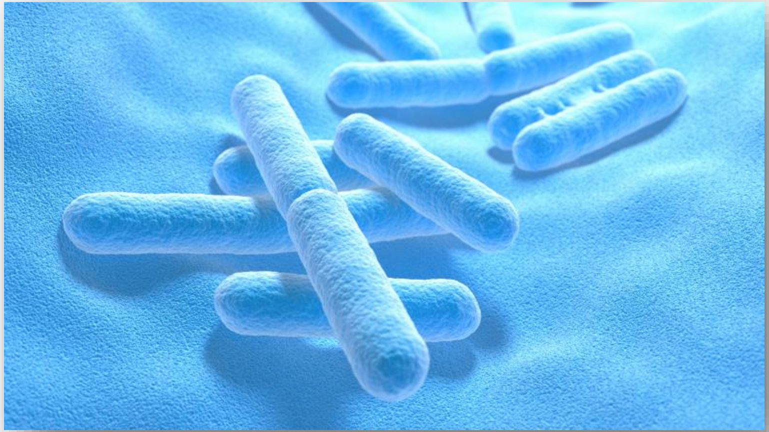
Inputs - concentrations

- Initial conditions
- Boundary inflows
  - Diffuse sources (e.g. catchment inflows)
  - Point sources (e.g. sewage outfalls)

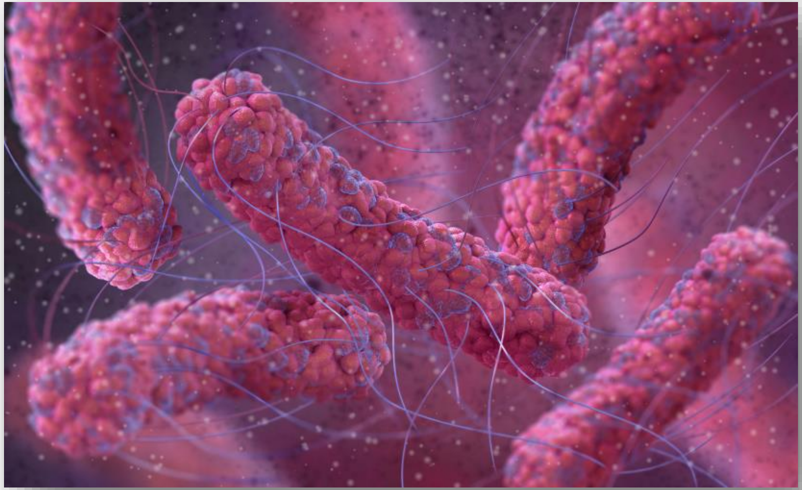
Inputs - parameters

- Many!

```
! Pathogens
pathogen model == attached, crypto
    alive min max == 0.0, 1e7
    mortality == 0.048, 0.0, 6.1, 1.0, 1.14
    visible inactivation == 0.0, 0.0667, 0.1
    uva inactivation == 0.01, 0.00667, 0.1
    uvb inactivation == 0.02, 0.00667, 0.1
    settling == -0.01, -0.2
    target attached fraction == 0.5
end pathogen model
```



How do we model pathogens?



Outputs - concentrations

- Transformation under environmental modification
- Concentrations are the result of multiple processes

Outputs – diagnostics (fluxes)

- Which processes dominate? Why?
- Ultimately seek understanding, not just concentrations

Lets look at an example

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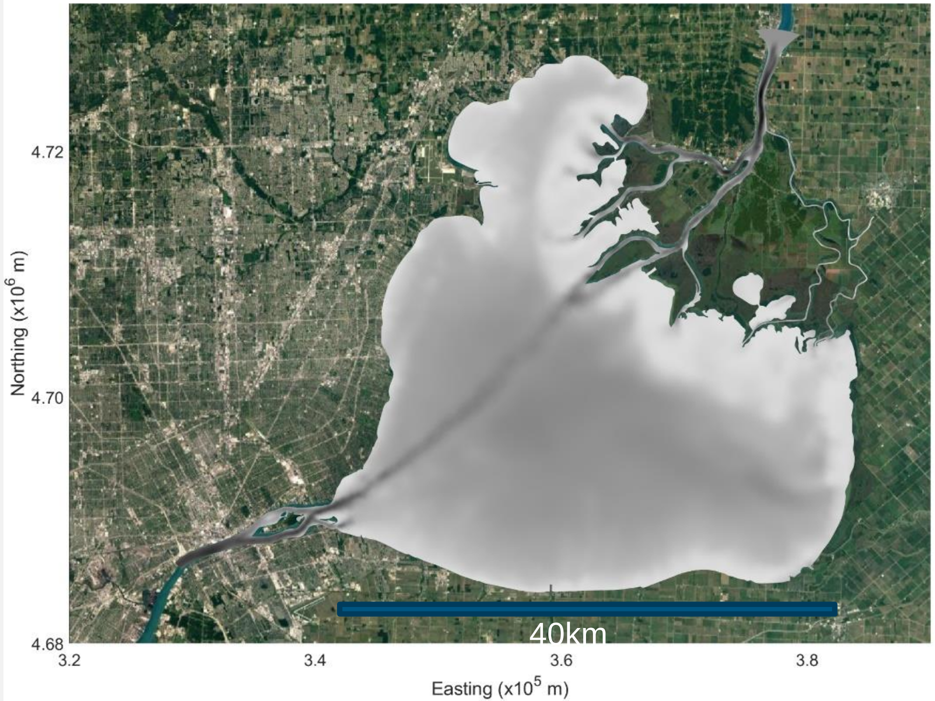
Large North American lake

- ~40 kilometres at widest
- ~10 metres at deepest
- ~1,200 km^2 area
- Bathymetry is grey
  - Darker is deeper
  - Lighter is shallower



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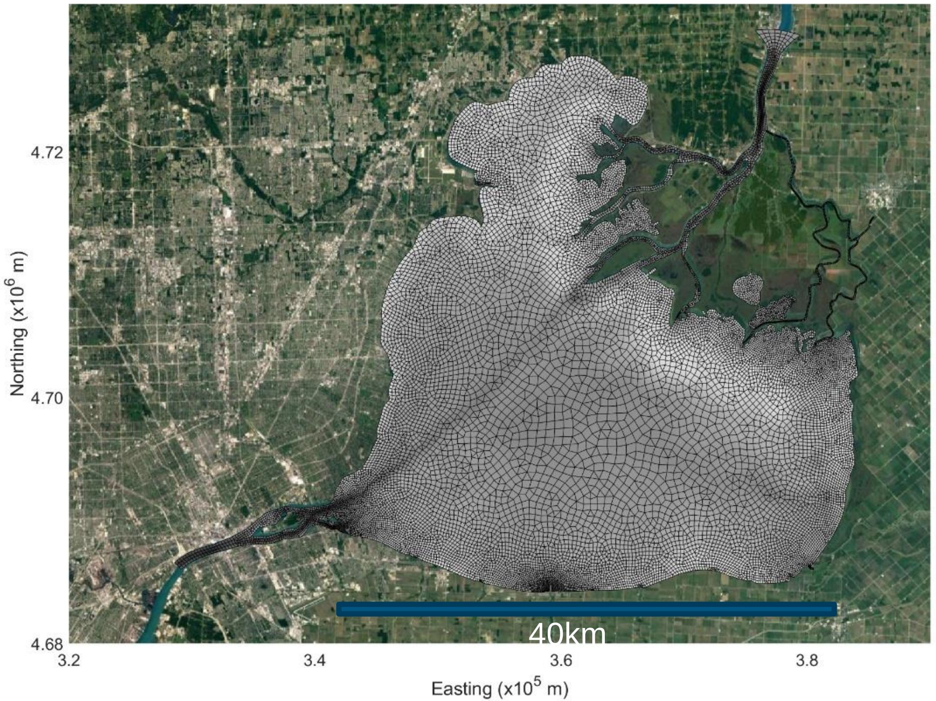
Model

- TUFLOW FV
  - Hydrodynamics
  - Advection dispersion
  - 3D
  - Water quality



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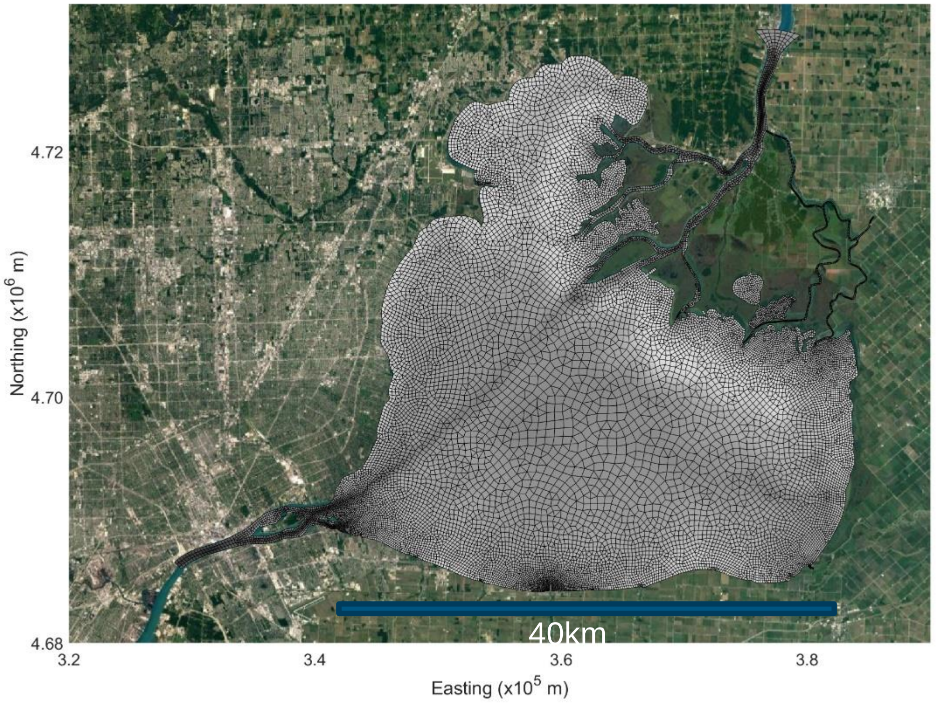
Model

- ~21,000 2D cells
- Developed by University of Windsor, Ontario
- Used with the kind permission of Dr Mohammad Madani



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Environmental setting

- Receives pathogens from
  - Upstream inflows
  - Fringing catchments
- Sees some recreational use
  - Boating
  - Fishing
  - Water sports

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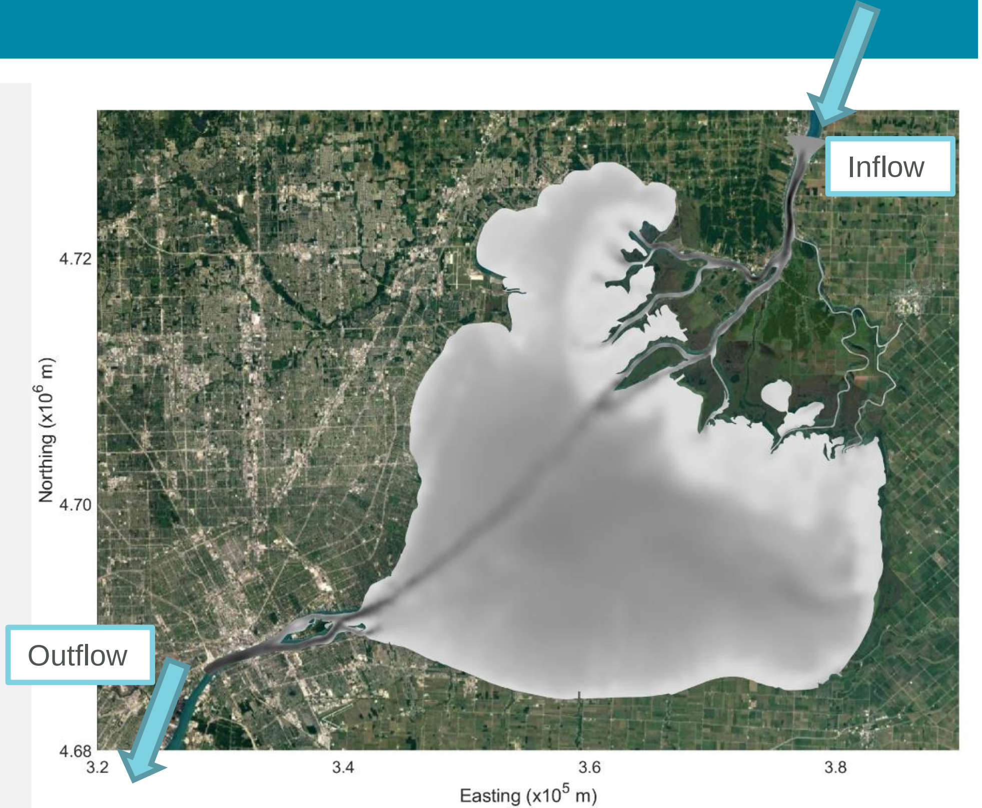
Simulation

- ~1 month
- Examine pathogen concentrations
  - Surface alive (active)
  - Surface dead (inactive)
- Entirely hypothetical
  - Not a real case - example only
- Included light and natural mortality



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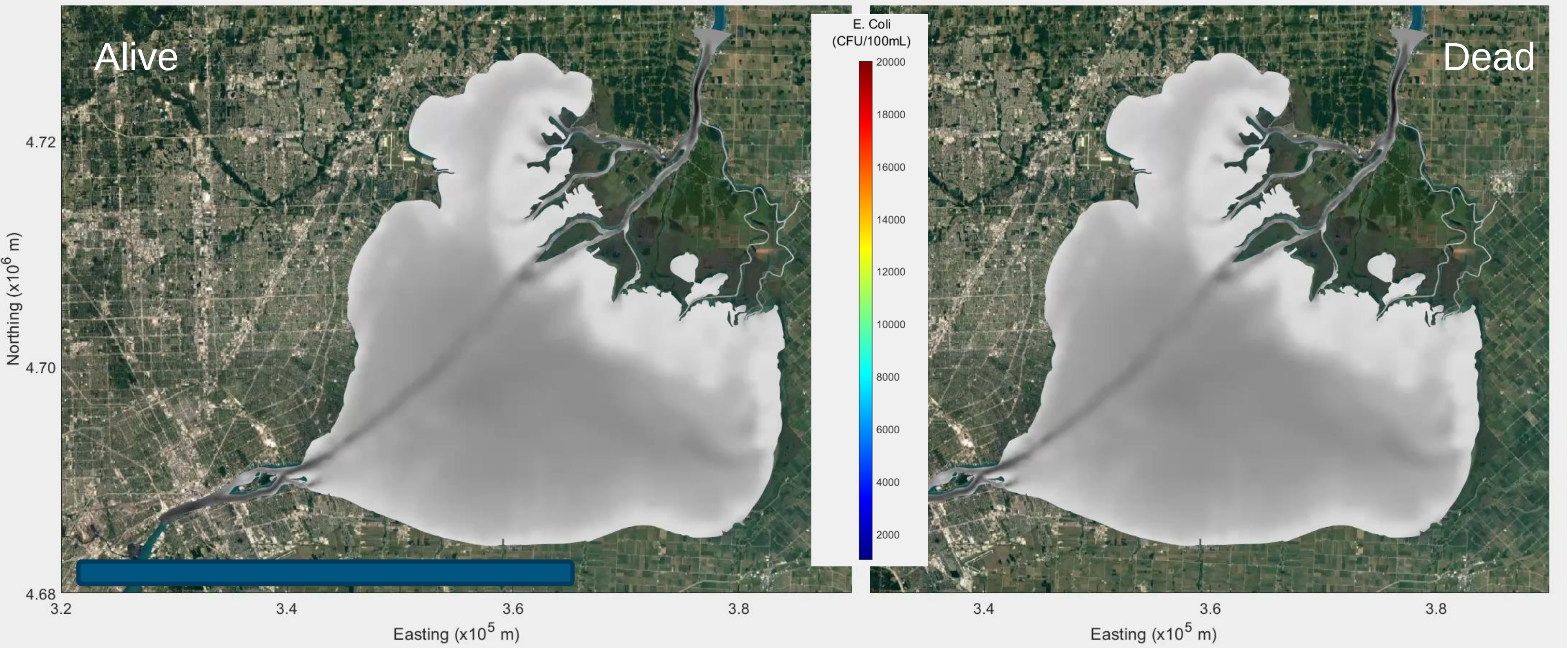

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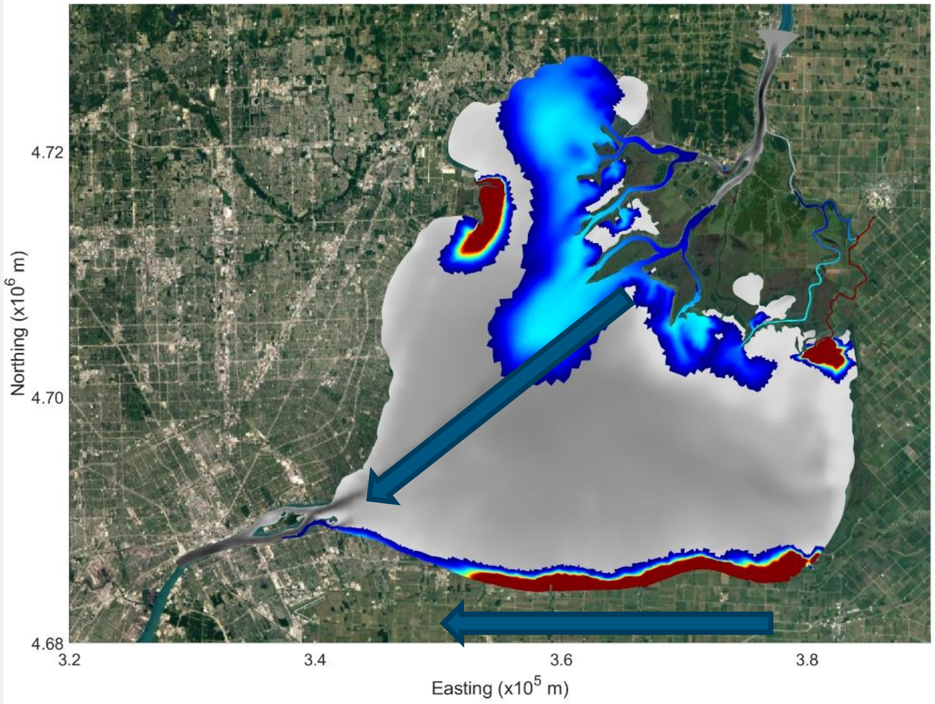
Qualitatively

- Alive pathogens do not persist
- Dead pathogens accumulate
- Long shore east to west transport
- But what process dominates
  - Natural mortality?
  - Light deactivation?
  - …?



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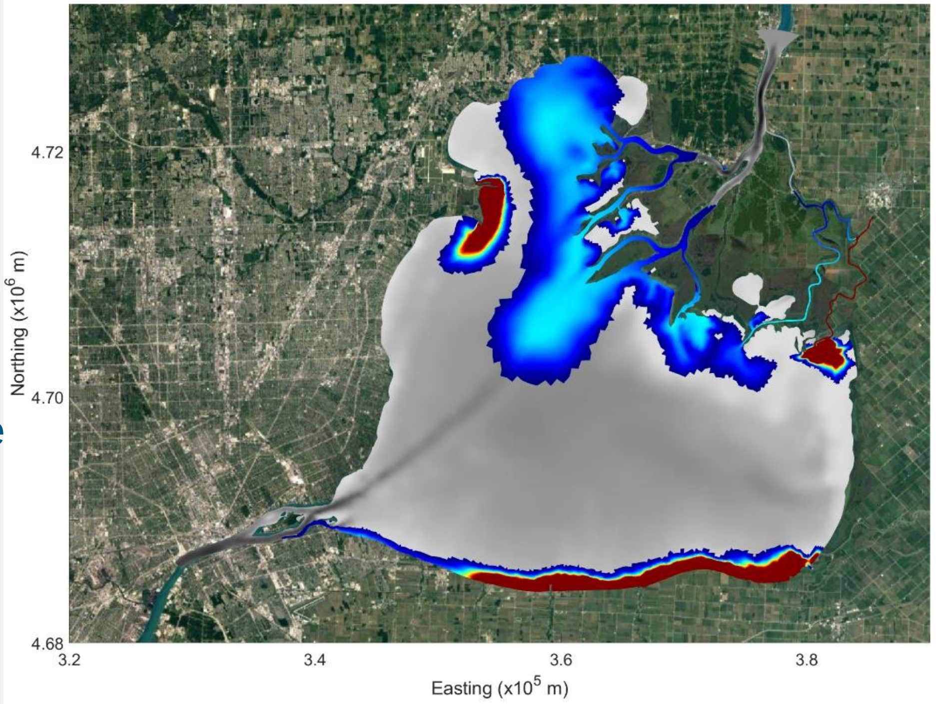
Diagnostics (fluxes)

- Same ~1 month
- Examine fluxes
  - Light deactivation and natural mortality
- Surface contours of fluxes
  CFU / 100 mL /day on same colour scale
  - A positive flux is from alive to dead
- Not presenting concentrations



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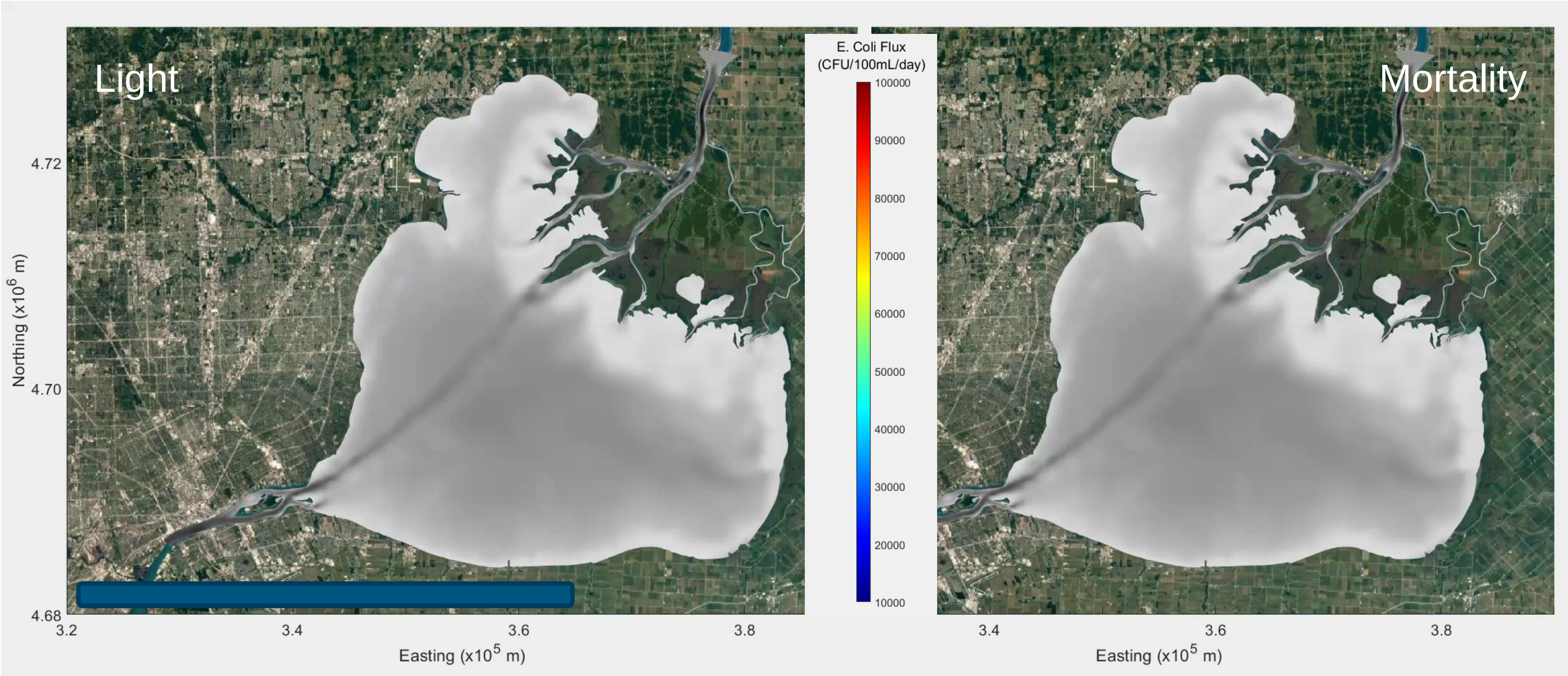

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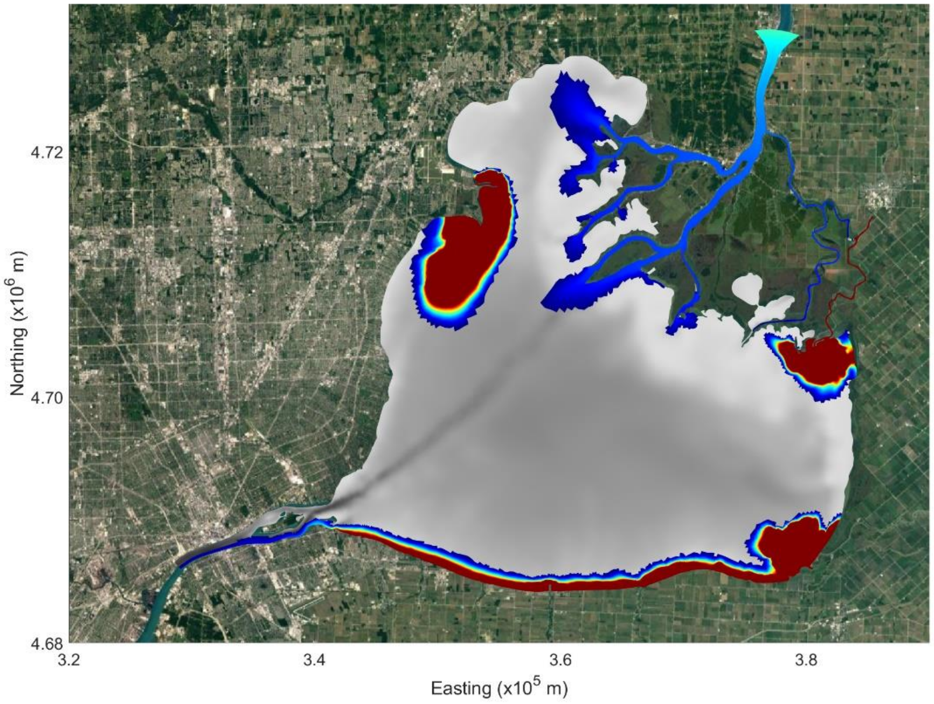
Qualitatively

- Light inactivation fluxes dominate
  - Obviously diurnal (night and day)
- Natural mortality less so

Quantitatively

- Light inactivation orders of magnitude greater than natural mortality
- Dominant flux pathway
  - Check and support parameterisation



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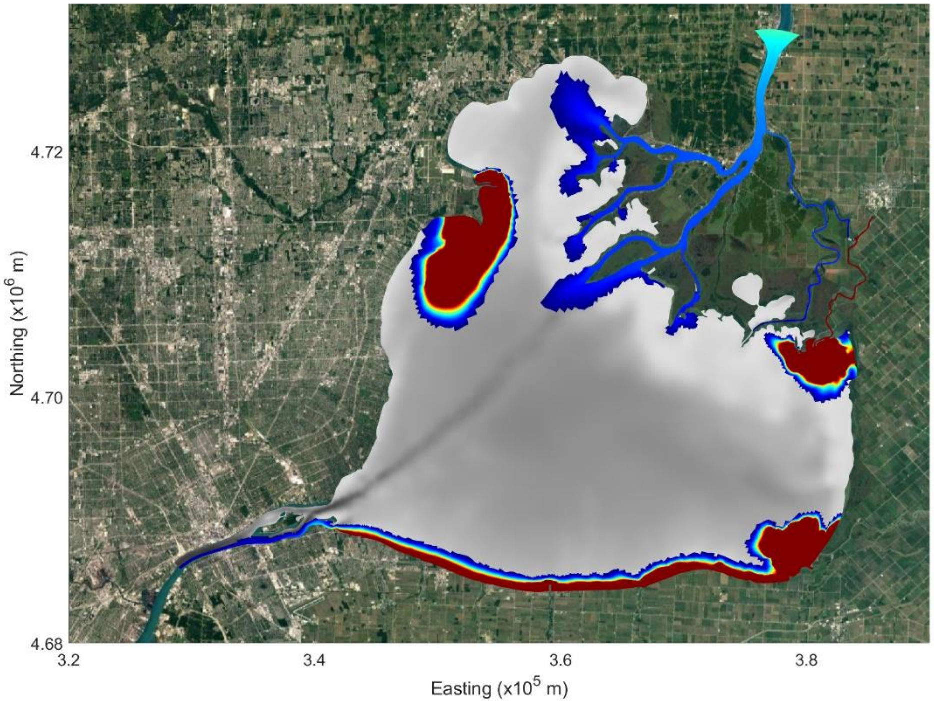
What about settling?

- Set typical settling rate
  - Alive and dead pathogens
- No resuspension
- Compare with light inactivation
- Positive flux is from water column to bed



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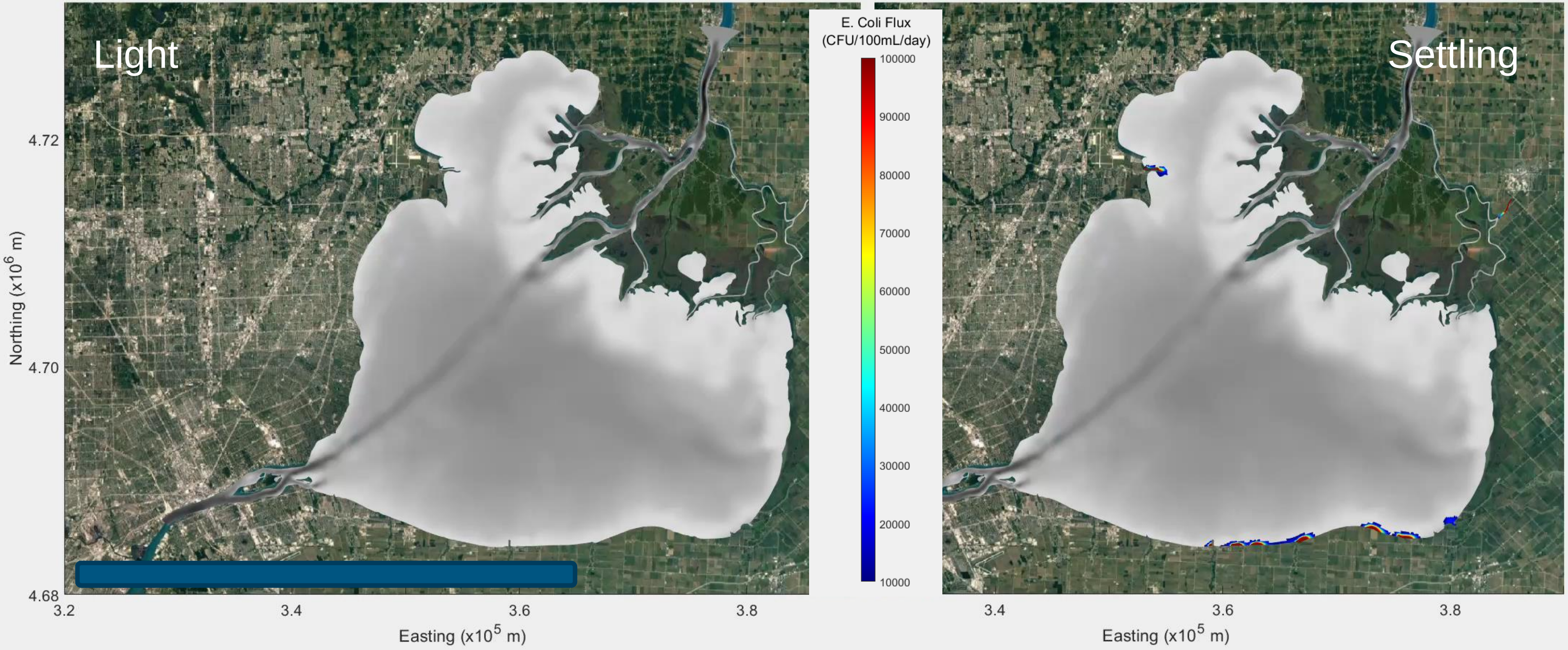

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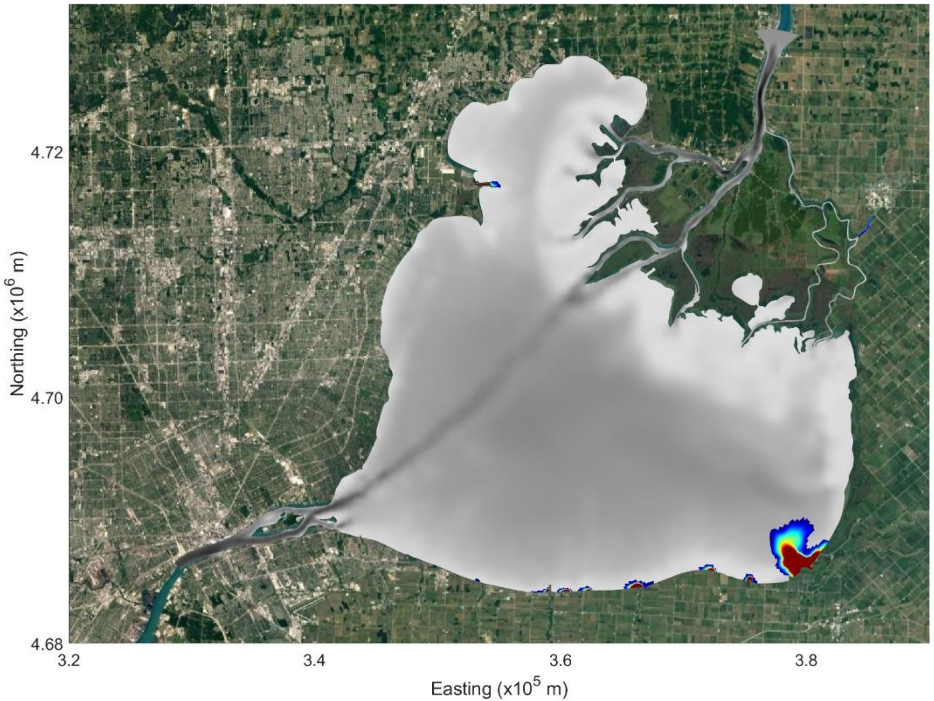
What about settling?

- Is not comparable in flux to light inactivation
- But more quantitatively
  - Use additional TUFLOW FV outputs
  - Total masses summed across the entire model domain in time



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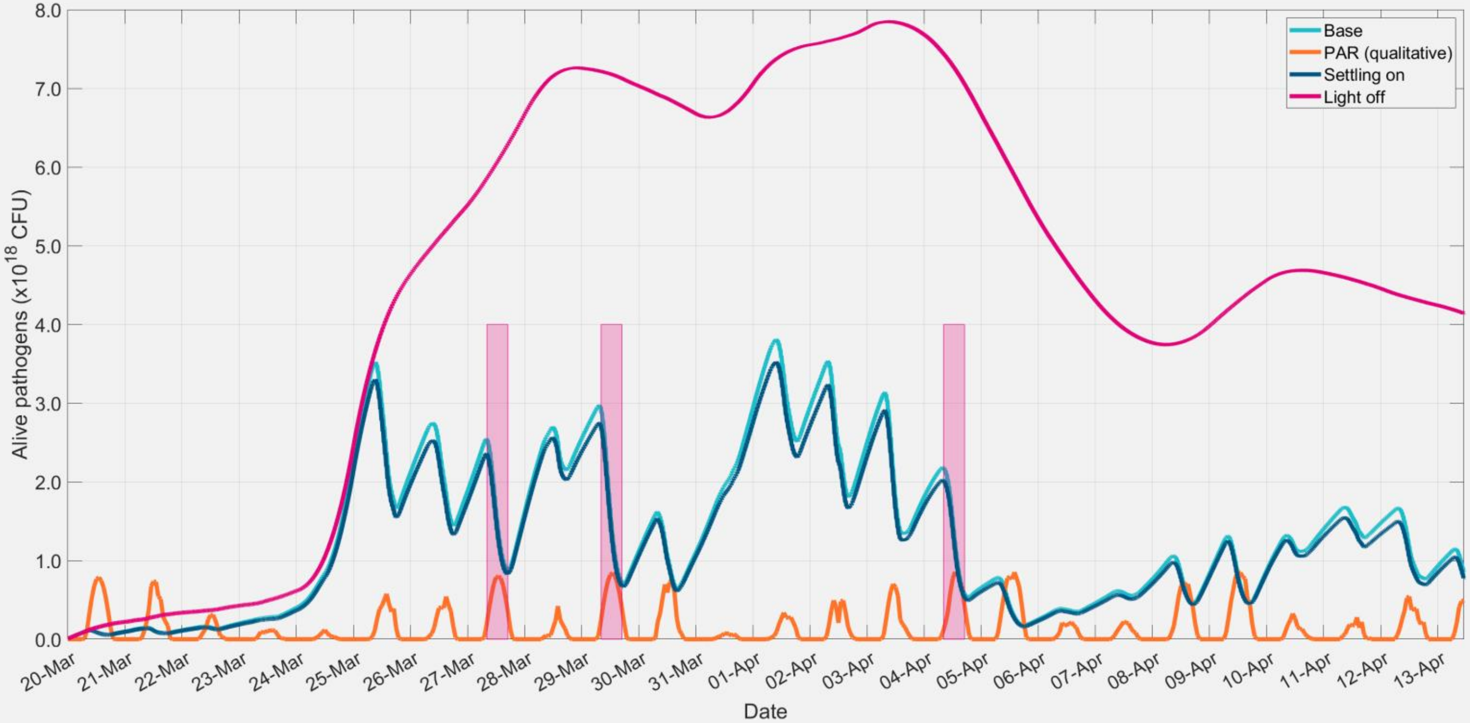
Quantitatively

- Different scale



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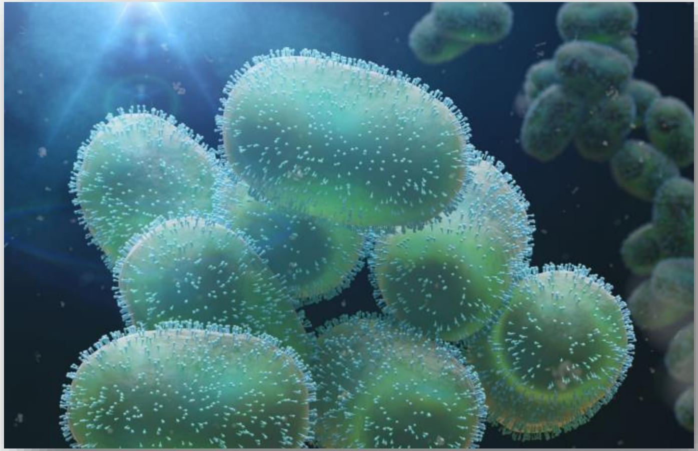
What have we learned?



- Light inactivation is clearly the dominant process in this system
- To promote understanding, we have used
  - TUFLOW FV water quality module diagnostics / fluxes
  - TUFLOW FV mass reporting
  - Multiple lines of evidence beyond trying to interpret concentrations
- Is a general technique for expediting water quality model calibration
  - Do not guess: understand!

Summary

Modelling environmental pathogens

- No simple task!
- Usually report concentrations (benchmarks)
- But: explore fluxes / diagnostics
  - Seek understanding
  - Why? To support What?
- Applies equally to large and small systems
  - Urban wetlands

Questions?