



# Coastal Water Quality Modelling 101

Michael Barry



# Coastal water quality modelling

## Overview

- What is coastal water quality?
- Drivers for water quality management
- What to do?
- Three common issues
- Data needs



**What is coastal  
water quality?**

# Coastal water quality modelling

## What is coastal water quality?

- Familiar with water movement and physics
  - Tides, currents, salinity and temperature
- We like “good quality” or “healthy” water

Healthy waters



# Coastal water quality modelling

## What is coastal water quality?

- We don't like “poor quality” or “unhealthy” water
- Some common pollutants/poor water quality
  - High turbidity
    - Light cutting and discolouration
  - Red, green and bluegreen algal blooms
    - “Red tides” that have an odour and are often toxic
  - Ballast water releases of exotic plant and animals
  - Low dissolved oxygen
    - Toxic to biota
  - Pollutants discharged from pipes
    - Sewage, brine, stormwater



# Coastal water quality modelling

## What is coastal water quality?

- How we describe impacts of concern
  - Acute toxicity
    - Immediate, e.g. fish swimming through a pollutant plume
  - Chronic toxicity
    - Long term, e.g. depletion of seagrass
  - Human health
- End result
  - Loss of biodiversity
  - Human health concerns

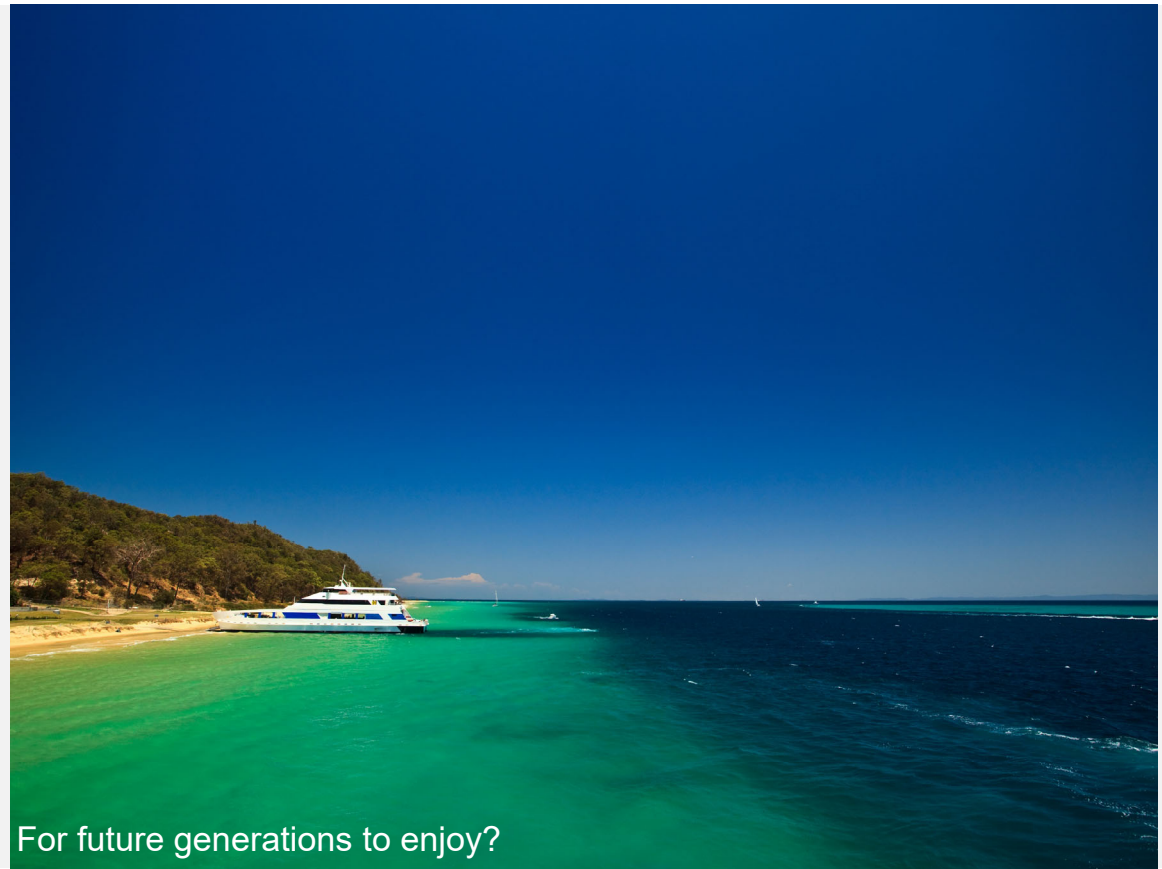


# Drivers for water quality management

# Coastal water quality modelling

## Drivers for water quality management

- Environmental conservation (the carrot)
  - Custodianship
  - Intergenerational conservation





# Coastal water quality modelling

## Drivers for water quality management

- Regulation (the stick)
  - Varies from country to country
  - Proposed developments of scale generally require environmental impact assessment
  - Varying levels of detail
    - Environmental review to full impact statement
  - Varying levels of government
    - Local / county / municipality (bylaws)
    - State (law)
    - Federal (law and international treaties)
  - No environmental approvals = no development
  - Making money vs conserving natural assets



## Environment Protection and Biodiversity Conservation Act 1999

No. 91, 1999

### Compilation No. 56

**Compilation date:** 28 March 2021

**Includes amendments up to:** Act No. 129, 2020

**Registered:** 19 April 2021

This compilation is in 2 volumes

**Volume 1:** sections 1–266  
**Volume 2:** sections 266B–528  
Schedule  
Endnotes

Each volume has its own contents

**This compilation includes commenced amendments made by Act No. 13, 2020**

**What to do?**

# Coastal water quality modelling

## What to do?

- Undertake environmental assessment
- Multipronged
  - Data collection and synthesis
  - Research
  - Stakeholder engagement
  - Expert opinion
  - Numerical modelling
- Modelling is only one (but important) part of the story

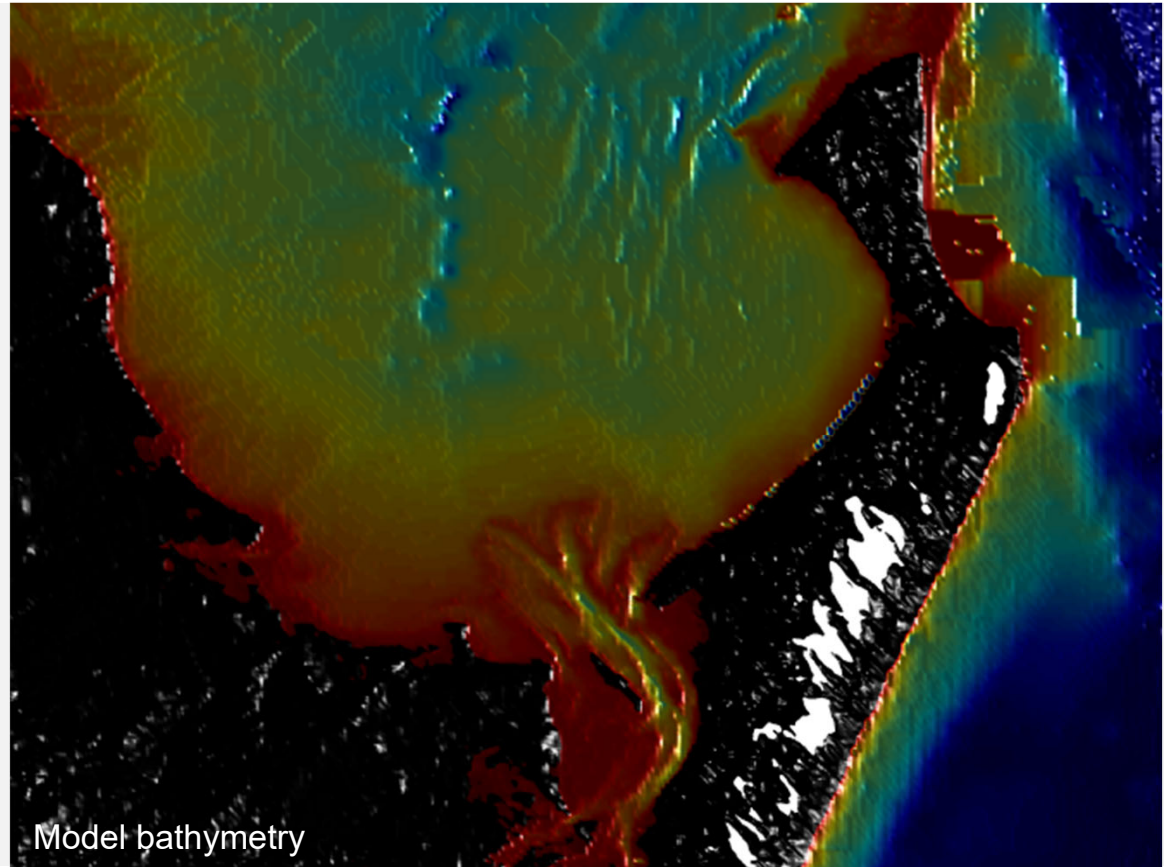


Aquaculture operation

# Coastal water quality modelling

## What to do?

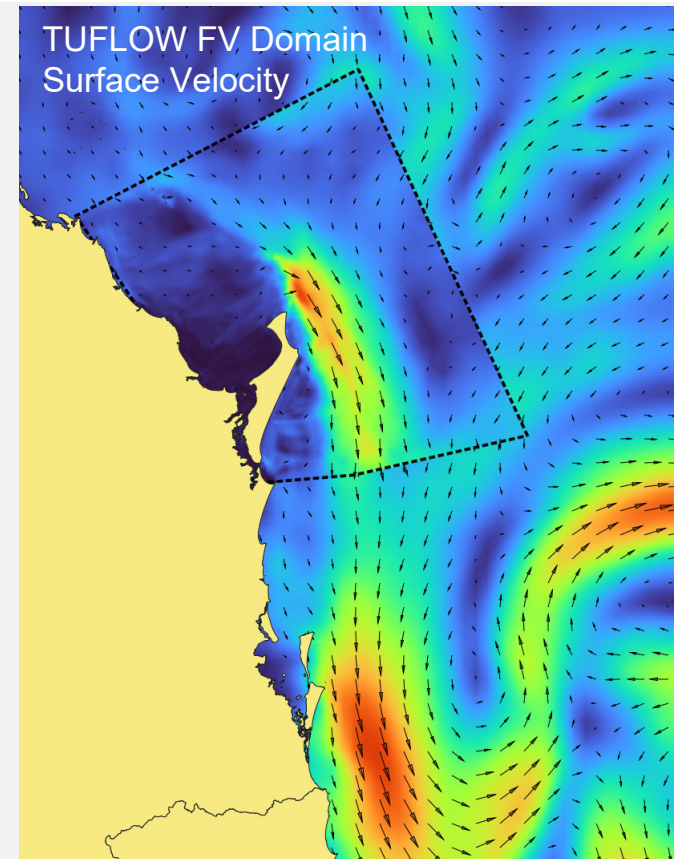
- How are models used in this context?
- Illustrate by three common issues
- Use a subset of the TUFLOW suite of tools
  - TUFLOW FV
    - Hydrodynamics (HD)
    - Sediment transport module (STM)
    - Water quality module (WQM)
    - Particle tracking module (PTM)
  - Finite volume scheme (flexible mesh)
  - Fully three dimensional
  - Previously presented (3D coastal modelling)



# Coastal water quality modelling

## What to do?

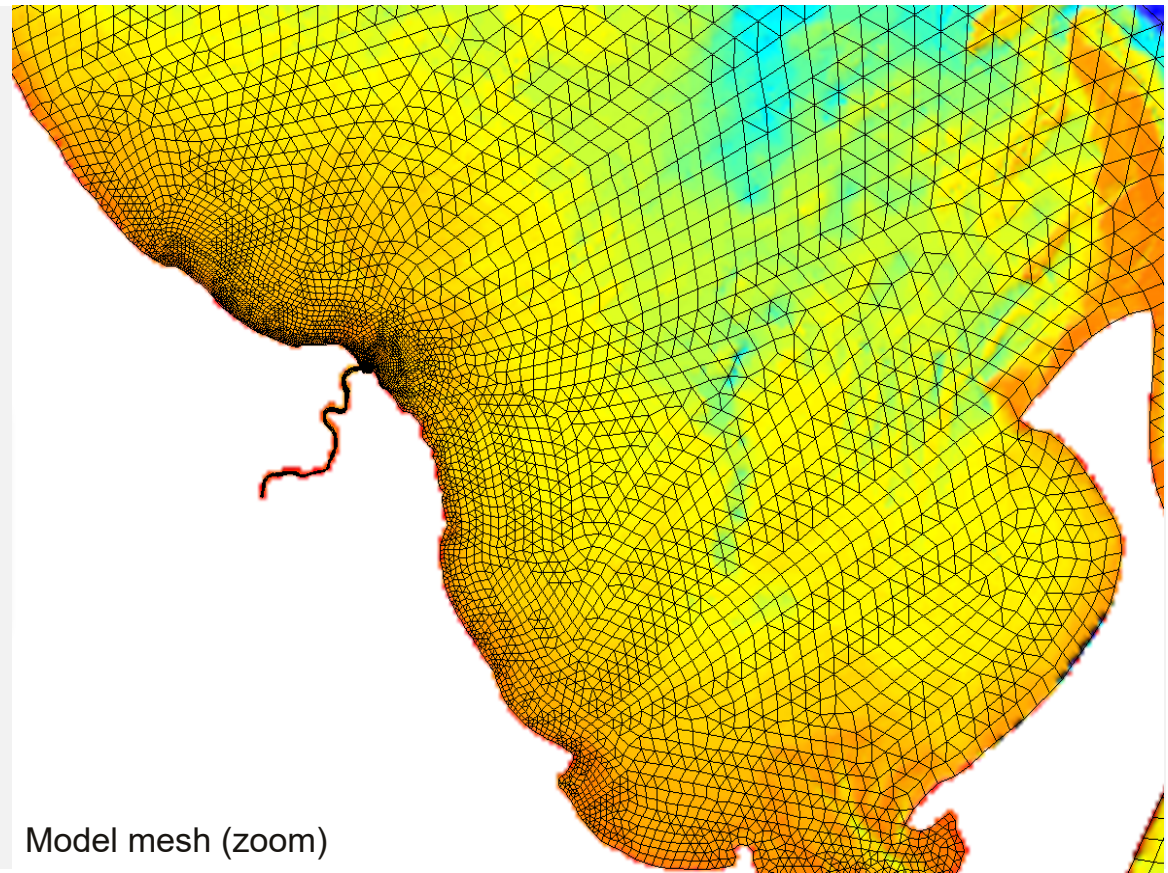
- Hydrodynamics (HD)
- Model on the east coast of Australia
  - 13,547 2D cells and 199,649 3D cells
  - 50 vertical layers in a hybrid scheme
  - Parallelised GPU compute
  - Full meteorological forcing
- Simulates
  - Water level
  - Current speed and direction
  - Temperature
  - Salinity
  - Light



# Coastal water quality modelling

## What to do?

- Hydrodynamics (HD)
- Model on the east coast of Australia
  - 13,547 2D cells and 199,649 3D cells
  - 50 vertical layers in a hybrid scheme
  - Parallelised GPU compute
  - Full meteorological forcing
  - Simulates
    - Water level
    - Current speed and direction
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    - Salinity
    - Light



Model mesh (zoom)

# Coastal water quality modelling

## What to do?

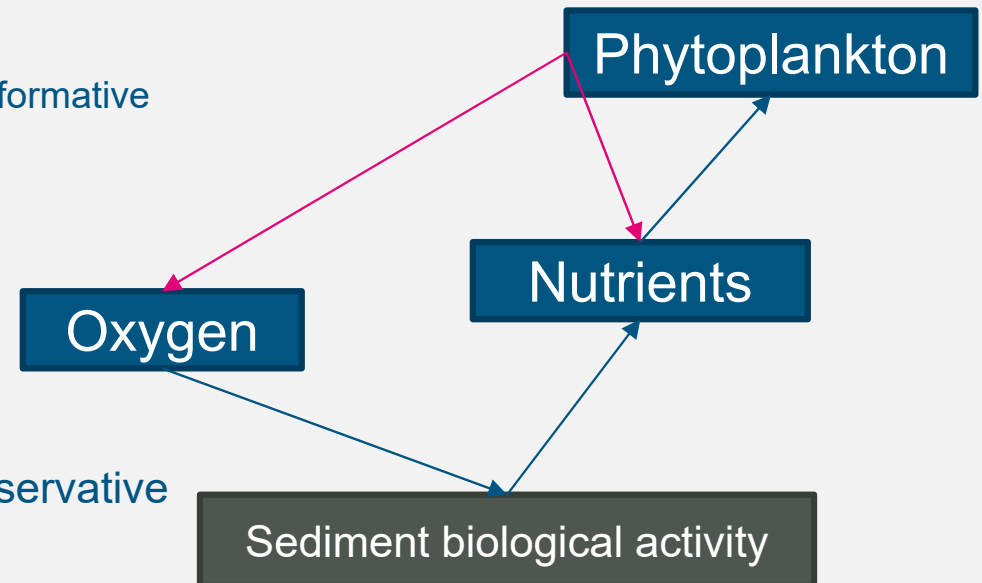
- Sediment transport module (STM)
  - One sediment fraction
  - Settling
  - Flocculation
  - Deposition
  - Resuspension
  - Bedload



# Coastal water quality modelling

## What to do?

- Water quality module (WQM)
- Why not just use passive tracers and an advection dispersion model?
  - Tracers are conservative
  - Water quality processes are not conservative: they are transformative
- Example: sediment biological activity
  - Sediments consume oxygen
  - Sediments produce nutrients
  - Nutrients support phytoplankton growth
  - Phytoplankton feed back to oxygen and nutrients
- These processes are mutually dependent and not conservative
- Beyond simple conservative dilution and advection

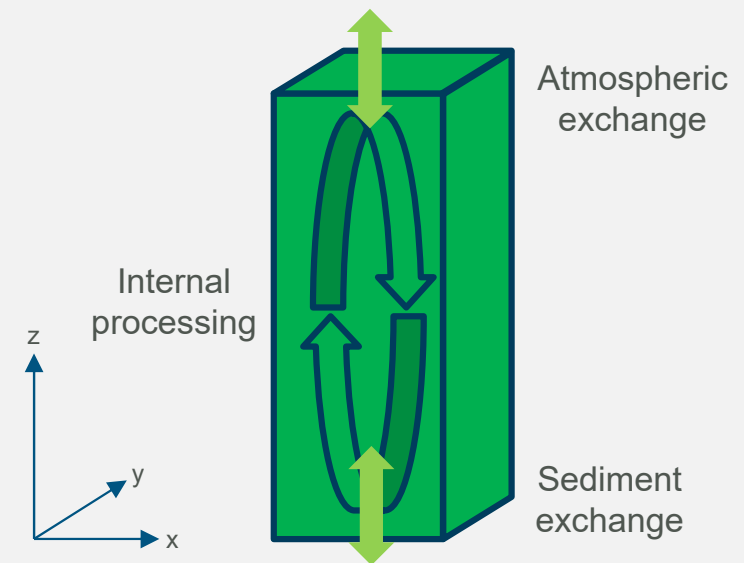




# Coastal water quality modelling

## What to do?

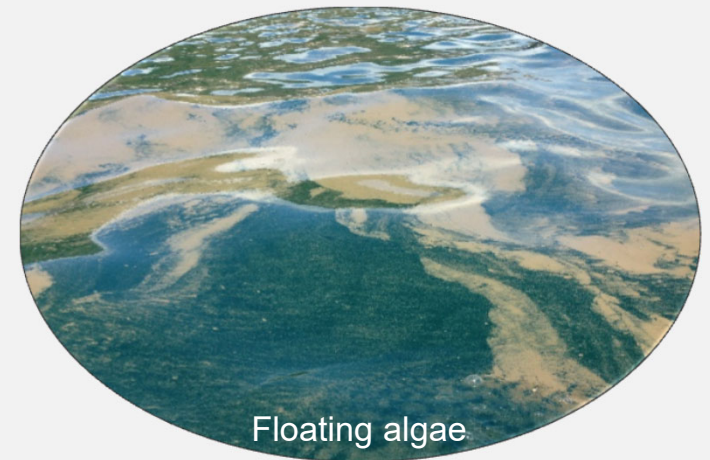
- Water quality module (WQM)
- Transformative (non-conservative) processes simulated
  - Atmospheric exchange of oxygen, nitrogen and phosphorus
  - Sediment (bed) exchange of oxygen, silicate and nutrients
  - Internal processing
    - Transformations between organic and inorganic nutrients
    - Phytoplankton growth and respiration
- Basic premise: to numerically simulate ecologically relevant transformative processes and pathways to support environmental management



# Coastal water quality modelling

## What to do?

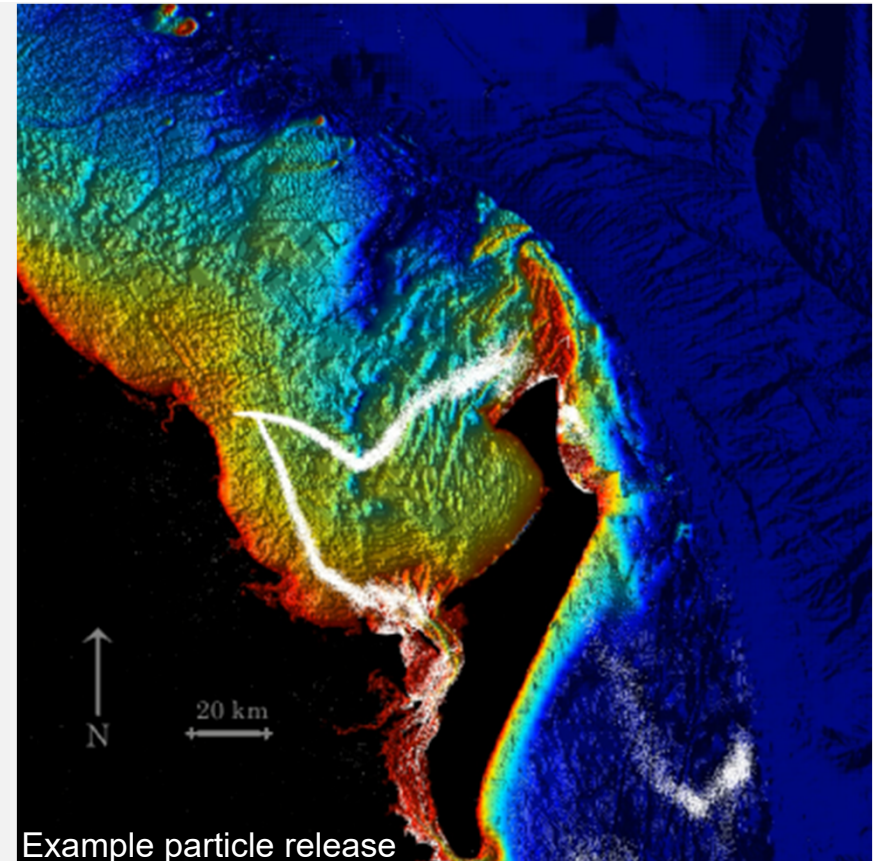
- Water quality module (WQM)
- Constituents:
  - Dissolved oxygen
  - Silicate
  - Inorganic nitrogen (ammonium and nitrate)
  - Inorganic phosphorus (free reactive and adsorbed)
  - Particulate and dissolved organic matter (carbon, nitrogen and phosphorus)
    - Labile (ecologically available)
    - Refractory (ecologically unavailable)
  - Phytoplankton (any number of species)



# Coastal water quality modelling

## What to do?

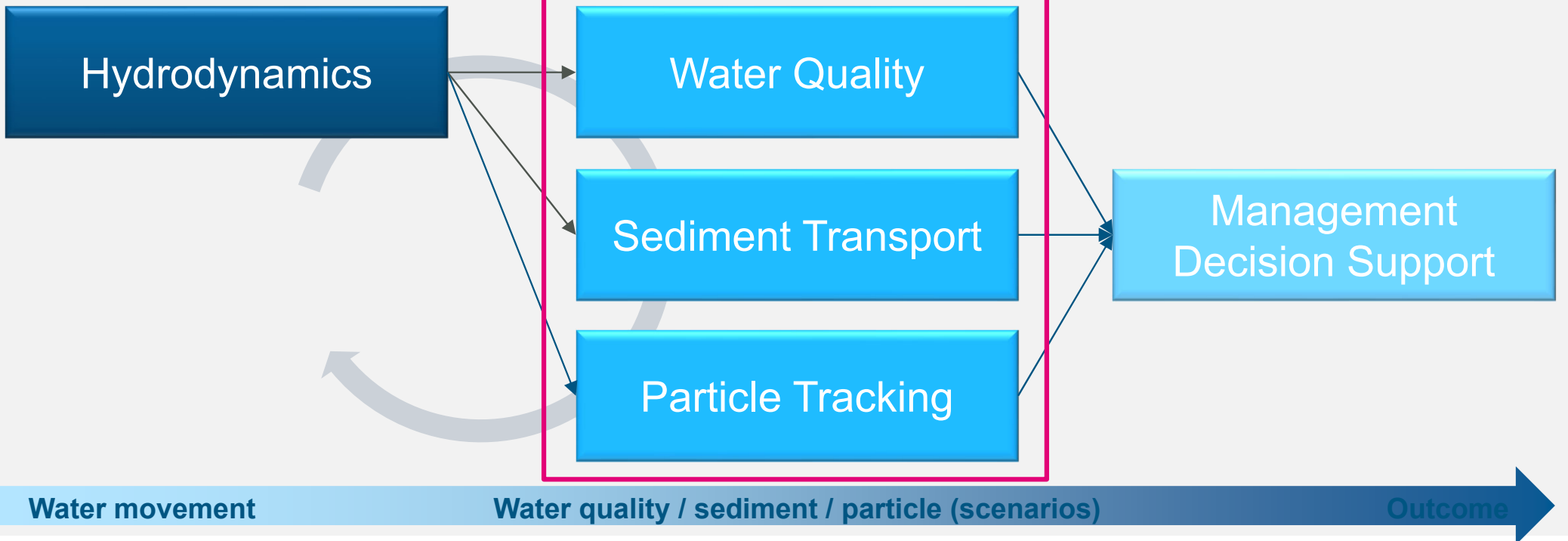
- Particle tracking module (PTM)
- Simulate non-dissolved environmental or ecological quantities
  - Solid waste
  - Marine plant and animal pests
  - Turtles
  - Shrimp
  - Large plastic waste
  - Many others



# Coastal water quality modelling

## What to do?

- TUFLOW FV workflow

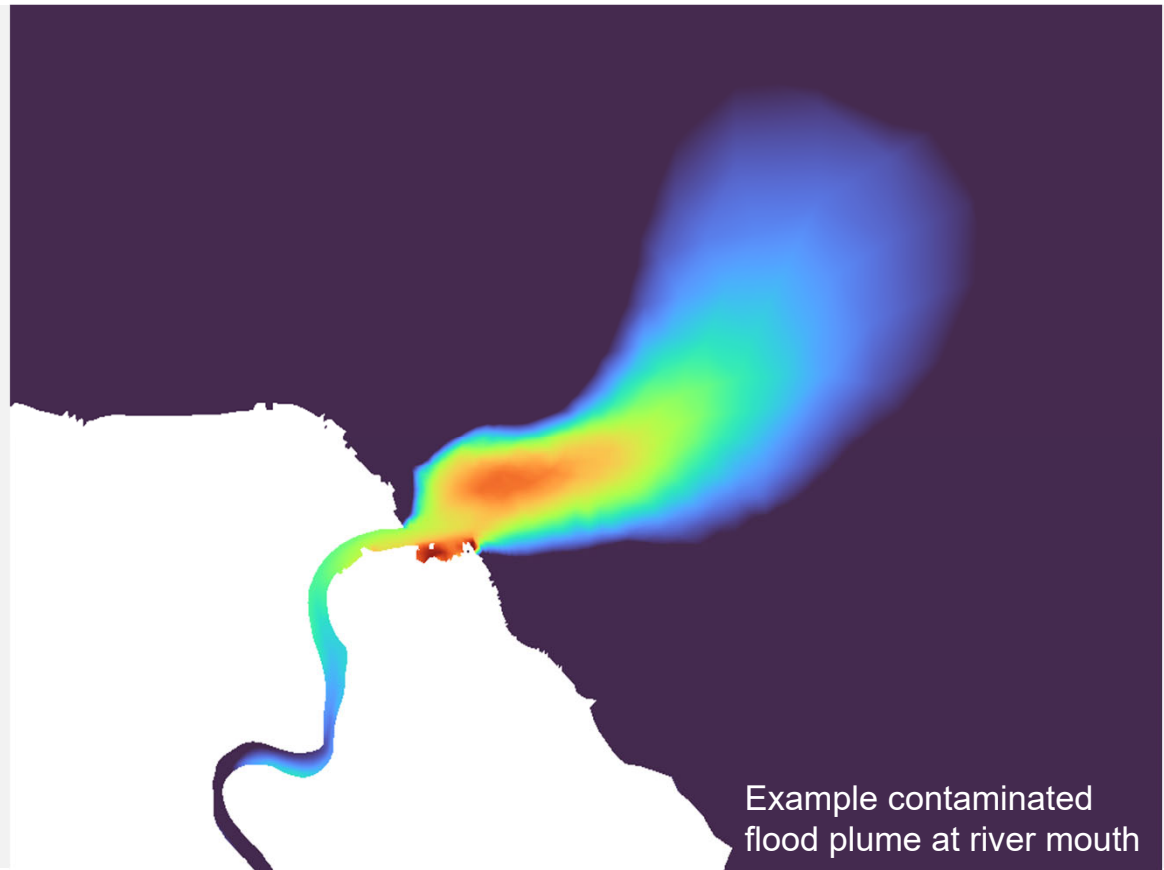


# Three common issues

# Coastal water quality modelling

## Three common issues

- There are many coastal water quality issues
- Often project/proposal specific
- Three today
  1. Riverine delivery of catchment derived pollutants to the coastal zone
  2. Release of exotic marine plant or animal pests from ship ballast
  3. A proposed aquaculture farm
- All are hypothetical

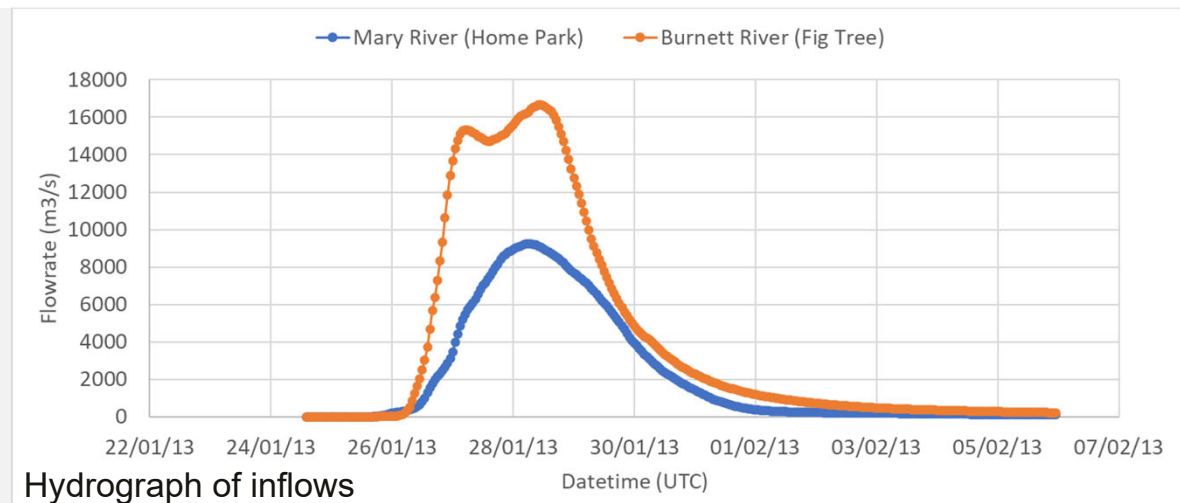


# Coastal water quality modelling

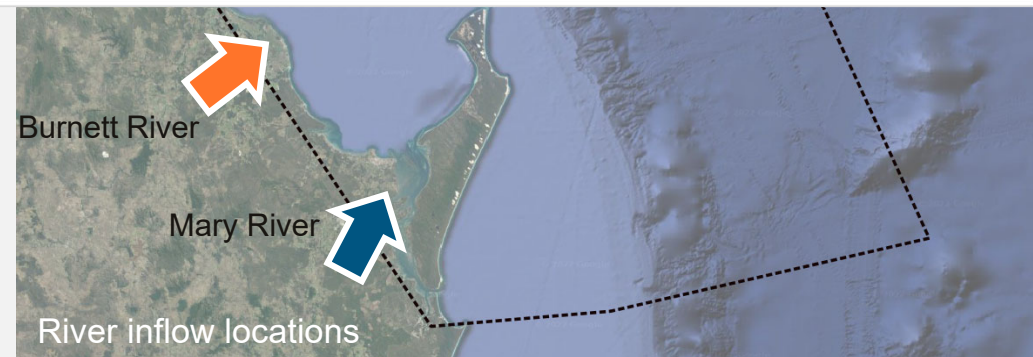
## Three common issues

### 1. Riverine pollutant delivery

- Scenario
  - A marine authority wishes to better understand the impact of large riverine inflows on both local biota and human health
- Two (fresh) inflows simulated (there are others)
- Uses 3D HD, STM and WQM over 9 days
- January 2013 - ex tropical cyclone Oswald
  - Large flood event
  - Burnett River and Mary River
- Riverine inputs
  - Fresh water (HD)
  - Nutrients (WQM)
  - Sediment (STM)



Hydrograph of inflows

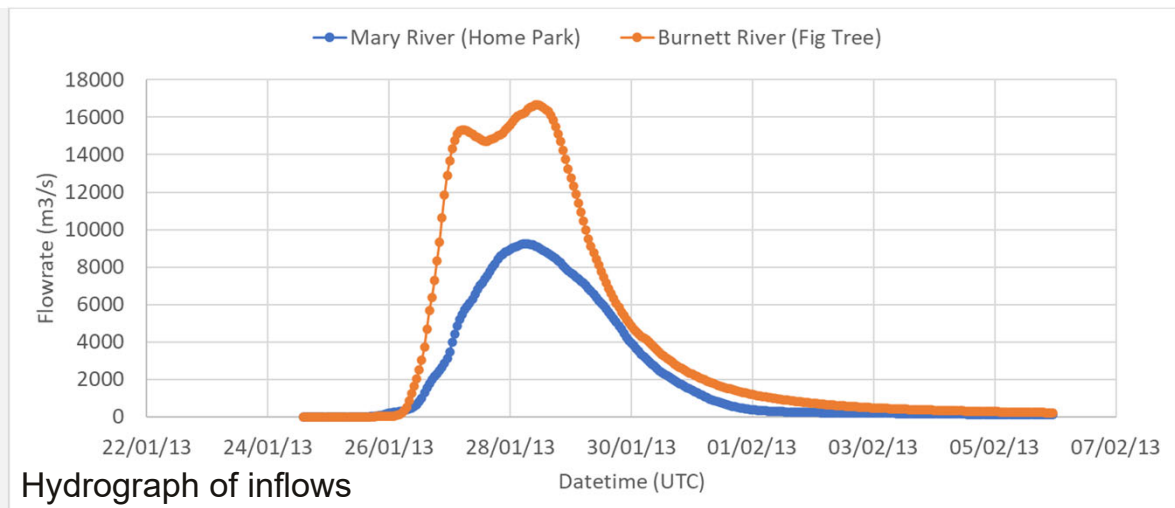


# Coastal water quality modelling

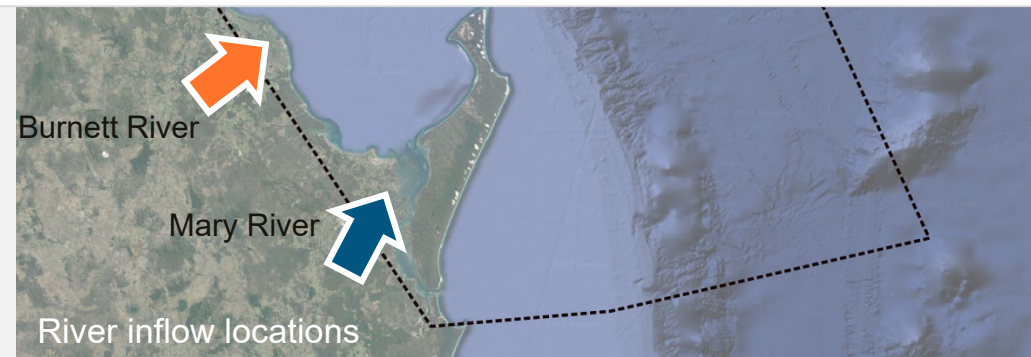
## Three common issues

### 1. Riverine pollutant delivery

- Scenario
  - A marine authority wishes to better understand the impact of large riverine inflows on both local biota and human health
- Two (fresh) inflows simulated (there are others)
- Uses 3D HD, STM and WQM over 9 days
- January 2013 - ex tropical cyclone Oswald
  - Large flood event
  - Burnett River and Mary River
- Four outputs
  - Salinity (HD)
  - Light (HD)
  - Sediment (STM)
  - Chlorophyll a (WQM)



Hydrograph of inflows





# Coastal water quality modelling

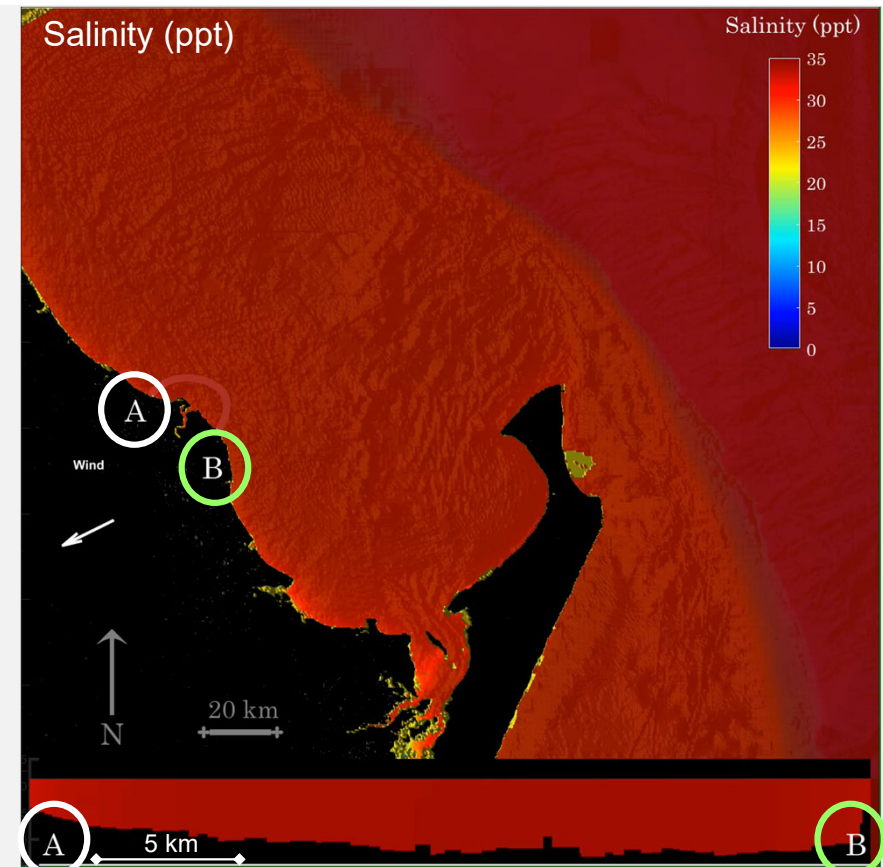
## Three common issues

### 1. Riverine pollutant delivery

- Animation
  - Colour contours are salinity (ppt)
  - Surface sheet and curtain synchronised
  - Curtain runs from A to B (left to right)
- Salinity
  - Surface overflow (fresher)
  - Defined plume
  - Concentrations increase from the source
  - Ultimately behaves as longshore drift

Surface values

Vertical curtain



# Coastal water quality modelling

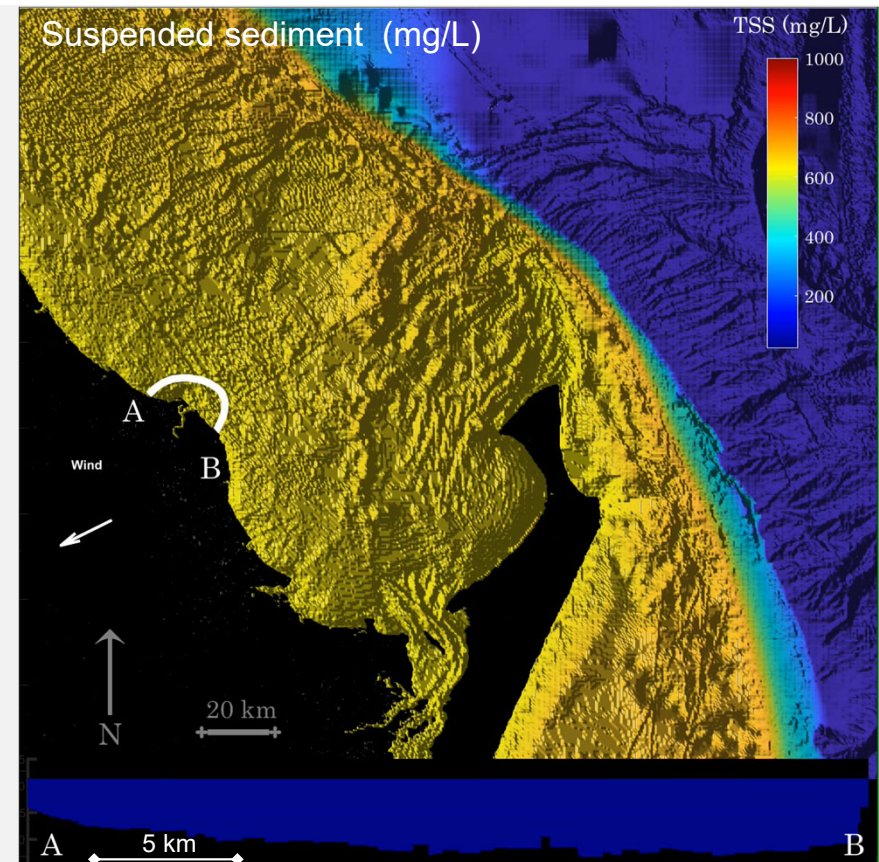
## Three common issues

### 1. Riverine pollutant delivery

- Animation
  - Colour contours are suspended sediment (mg/L)
  - Surface sheet and curtain synchronised
  - Curtain runs from A to B (left to right)
  - Sediment contours below 20 mg/L are removed in surface sheet
- Sediment
  - Surface overflow (salinity difference)
  - Defined plume
  - Concentrations decrease from the source
  - Ultimately behaves as longshore drift
  - Also can fall out / smother coral, seagrass etc

Surface values

Vertical curtain



# Coastal water quality modelling

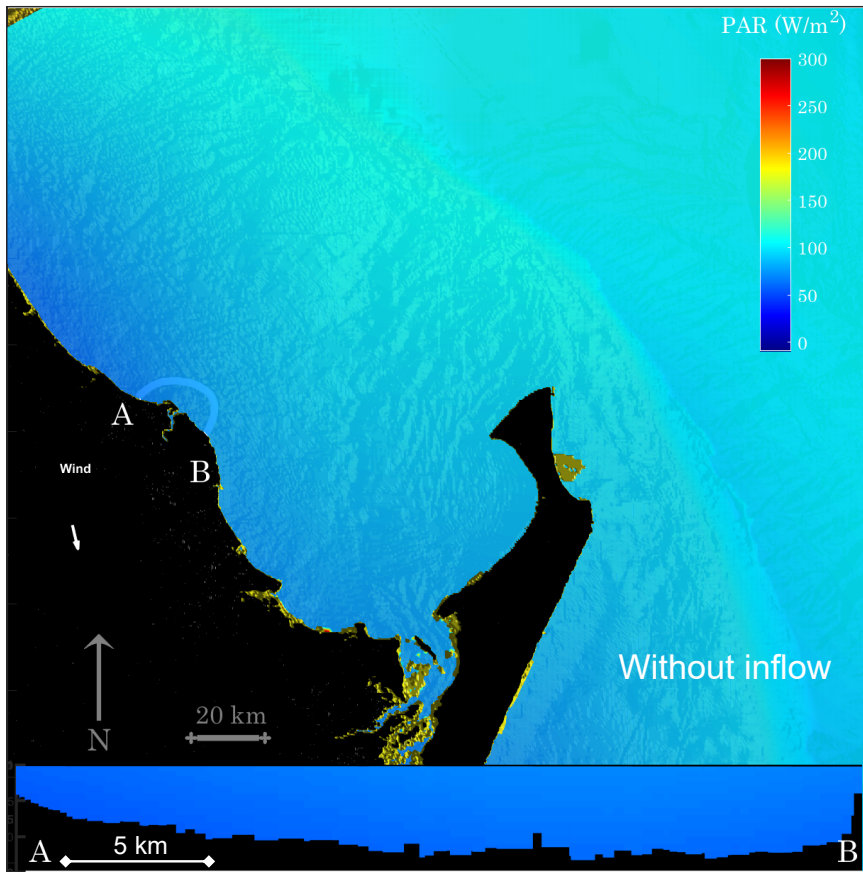
## Three common issues

### 1. Riverine pollutant delivery

- Photosynthetically active radiation (PAR,  $W/m^2$ )
  - The light we see: high during the day and zero at night
  - Plants and animals need light to live
  - Light naturally decreases from top to the bottom of a water column
  - But, suspended sediment absorbs more light and can increase shading of underlying waters
  - Plants and animals can be adversely affected
  - “Low visibility” diving conditions



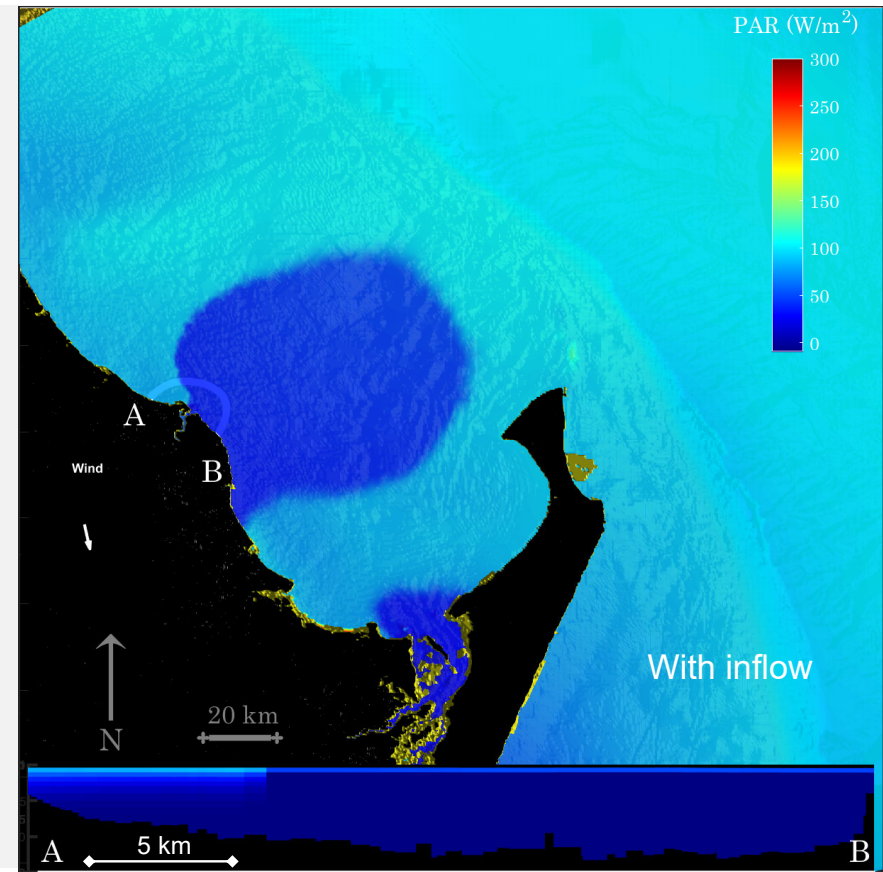
# Coastal water quality modelling



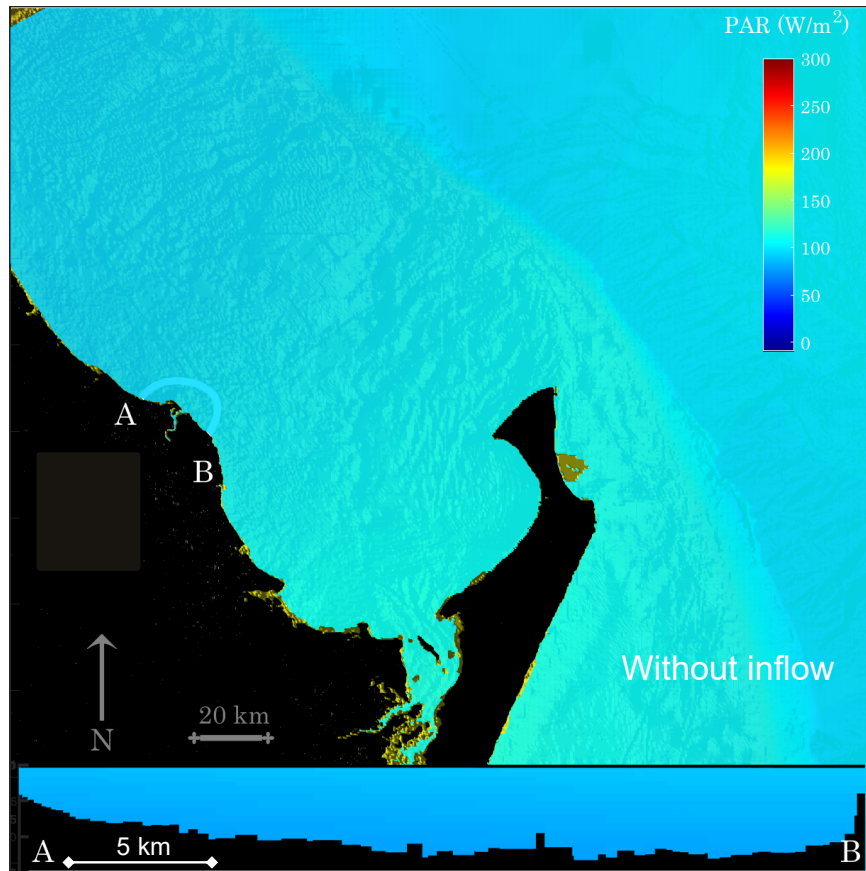
Photosynthetically  
active radiation ( $\text{W/m}^2$ ):  
mid simulation

Surface values

Vertical curtain



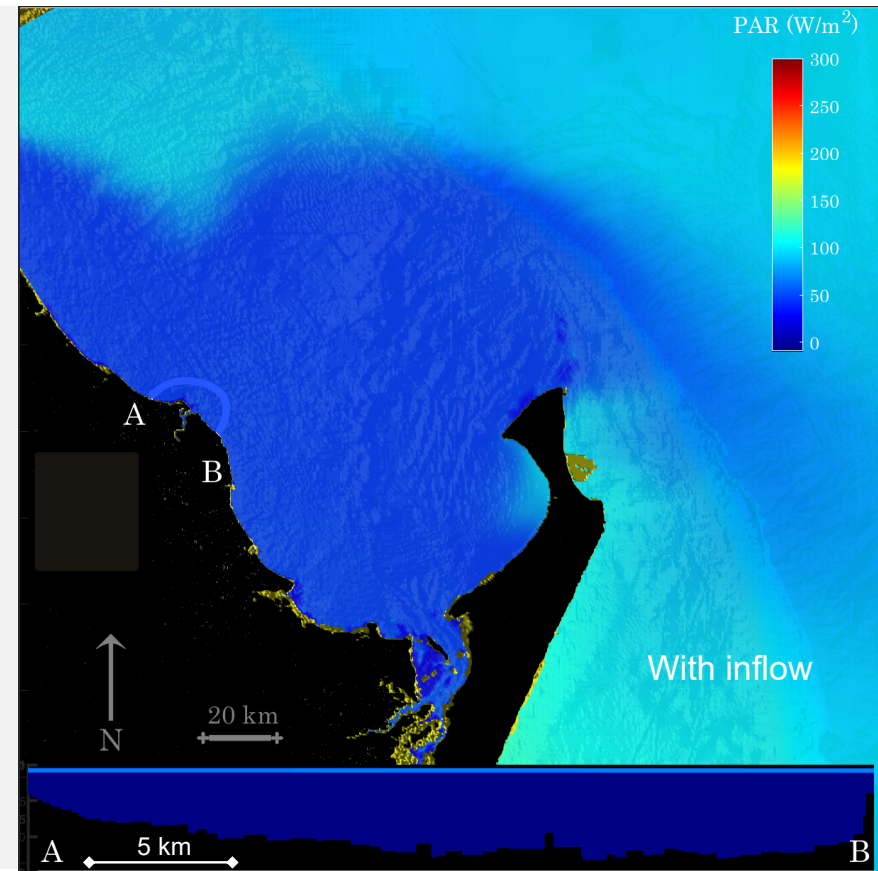
# Coastal water quality modelling



Photosynthetically  
active radiation ( $W/m^2$ ):  
end simulation

Surface values

Vertical curtain



# Coastal water quality modelling

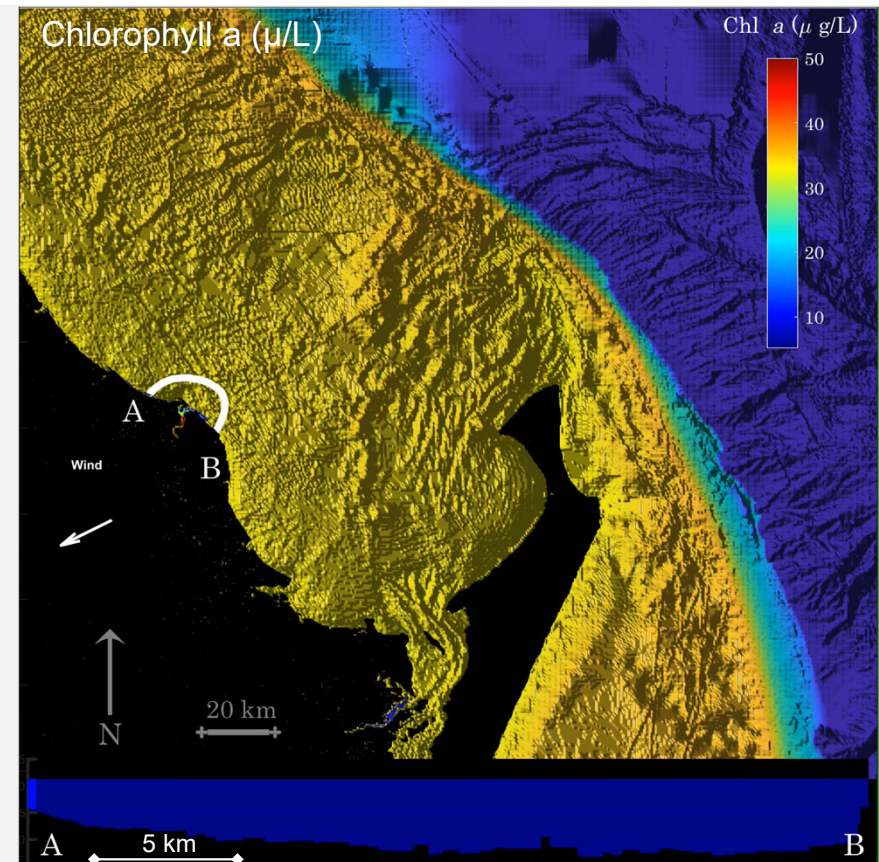
## Three common issues

### 1. Riverine pollutant delivery

- Animation
  - Colour contours are chlorophyll *a* ( $\mu\text{g/L}$ )
  - Surface sheet and curtain synchronised
  - Curtain runs from A to B (left to right)
  - Phytoplankton contours below  $5 \mu\text{g/L}$  removed in surface sheet
- Phytoplankton
  - Bloom on the outer edges of the plume
  - Concentrations increase from the source
  - Growth takes time and salinities are too low in the plume
  - Ultimately behaves as longshore drift
  - Phytoplankton washes up onto local beaches

Surface values

Vertical curtain

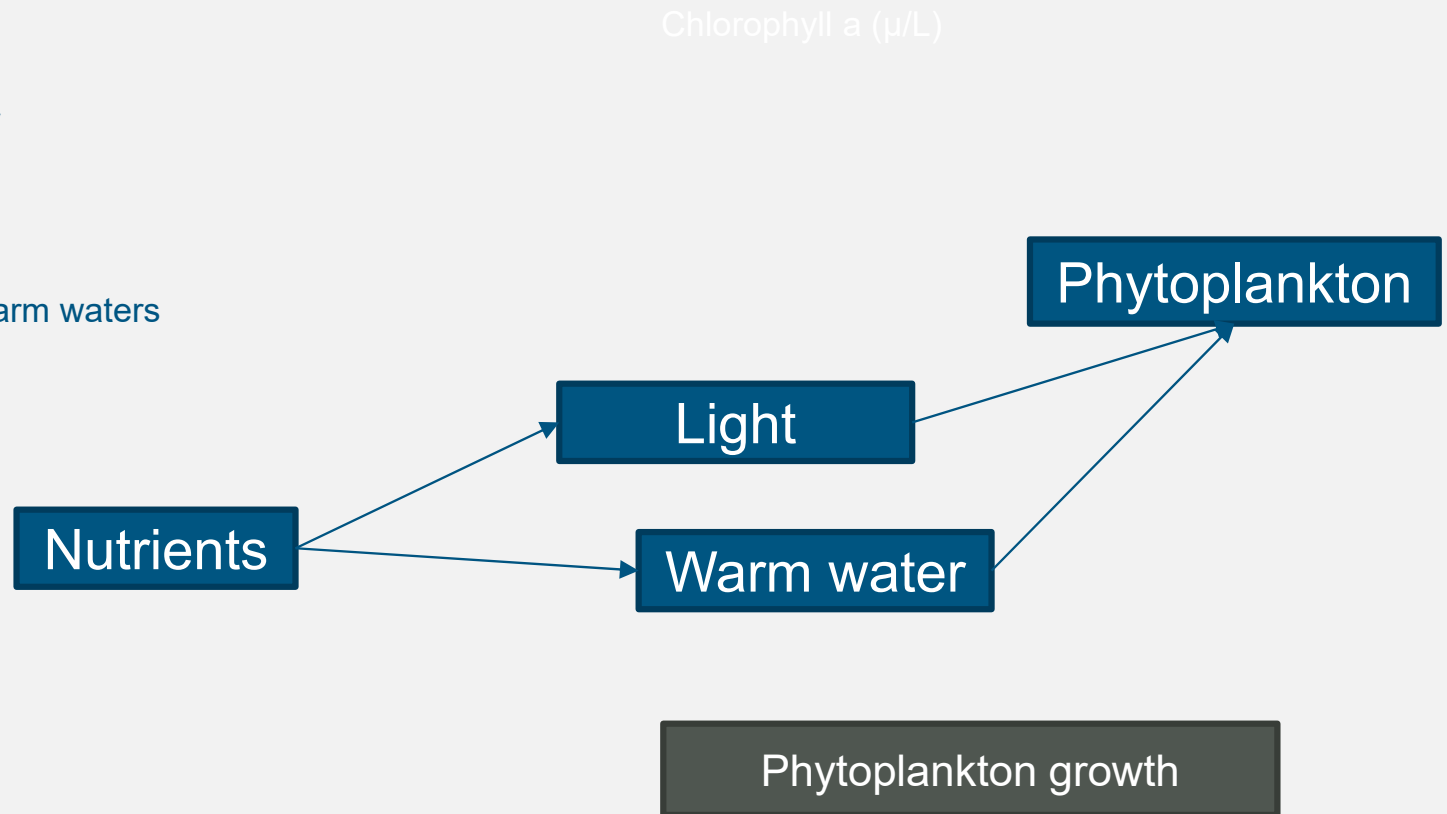


# Coastal water quality modelling

## Three common issues

### 1. Riverine pollutant delivery

- Phytoplankton
  - River delivered nutrients
  - Nutrients were advected to warm waters
  - Bloom was triggered



# Coastal water quality modelling

## Three common issues

### 1. Riverine pollutant delivery

- What do we advise the marine authority?
- Ecology
  - Prolonged shading of marine ecosystems is likely
  - Phytoplankton blooms are likely, and pronounced in warmer shallows
- Human health
  - Phytoplankton detritus is likely to interact with beaches - toxicity
  - Primary contact onshore or offshore (boating) may be problematic
- Conservative passive tracer simulation will not allow these sorts of transformative assessments



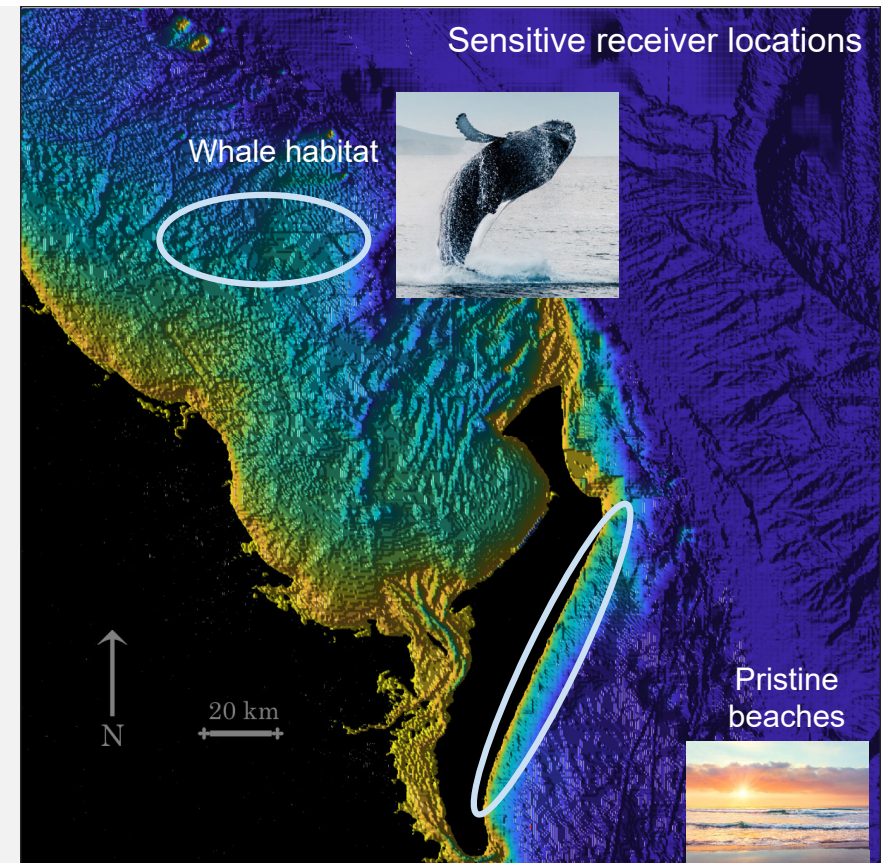


# Coastal water quality modelling

## Three common issues

### 2. Pests from ship ballast

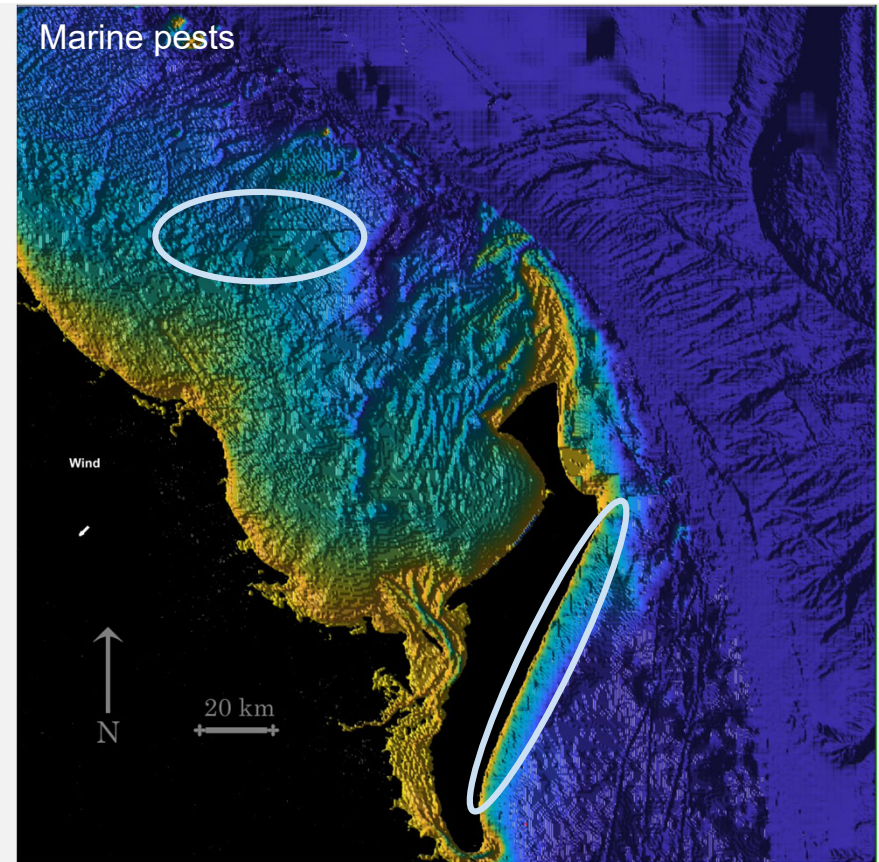
- Scenario
  - Federal government requires (by law) an Environmental Impact Statement (EIS) for a proposed major port development
  - The EIS terms of reference require investigation of the impact of ballast water pests on sensitive receivers
- Two vessels simulated entering port (initially) over 4 days
- Two scenarios with identical vessel tracks constantly releasing particles
  - Mix of N/SW/SE winds
  - Predominantly SE winds
- Outputs
  - Particle interactions with sensitive receivers



# Coastal water quality modelling

## Three common issues

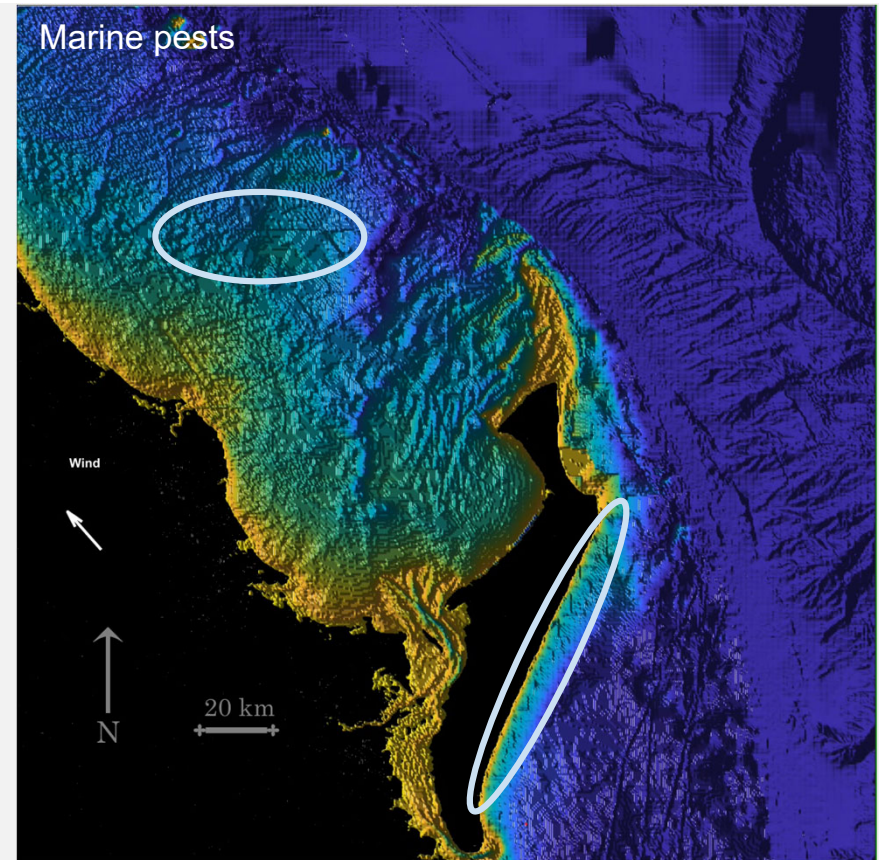
2. Pests from ship ballast
  - Mixed winds
  - Tides active



# Coastal water quality modelling

## Three common issues

2. Pests from ship ballast
  - Predominantly SE winds
  - Tides active



# Coastal water quality modelling

## Three common issues

### 2. Pests from ship ballast

- What do we write in the EIS for the Federal government?
  - Undertake many more simulations first
- Interaction of pests with local biota is likely strongly dependent on wind conditions
- Local winds, particularly southeasterlies, provide conditions that may result in adverse interactions
- What this might mean for whales and beach users



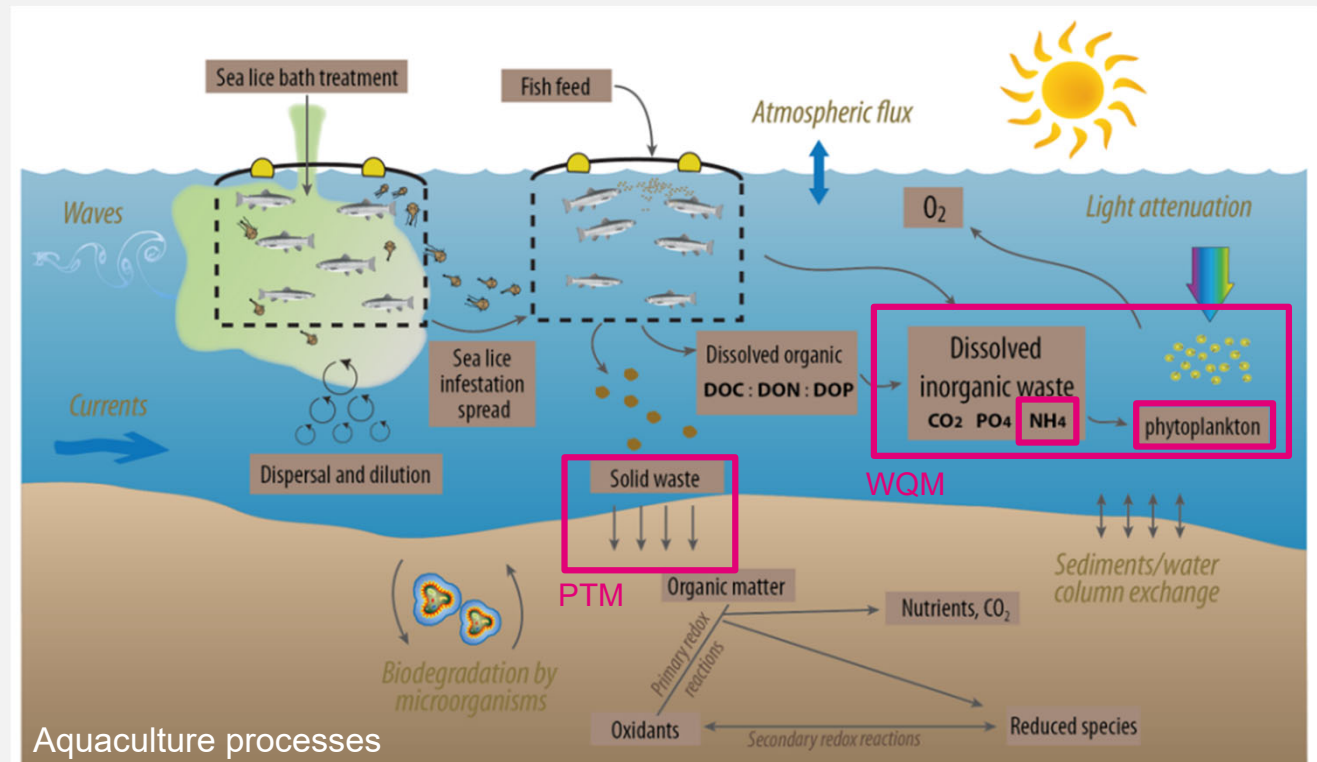
Marine pest

# Coastal water quality modelling

## Three common issues

### 3. Aquaculture

- Scenario
  - Global aquaculture consortium proposes to set up a sea cage fish operation
  - Four groups of cages
  - Federal, state and local governments require (separate) detailed environmental impact assessments to be undertaken
- Focus on impacts
  - Water column – ammonium and phytoplankton
  - Sediment – solid waste

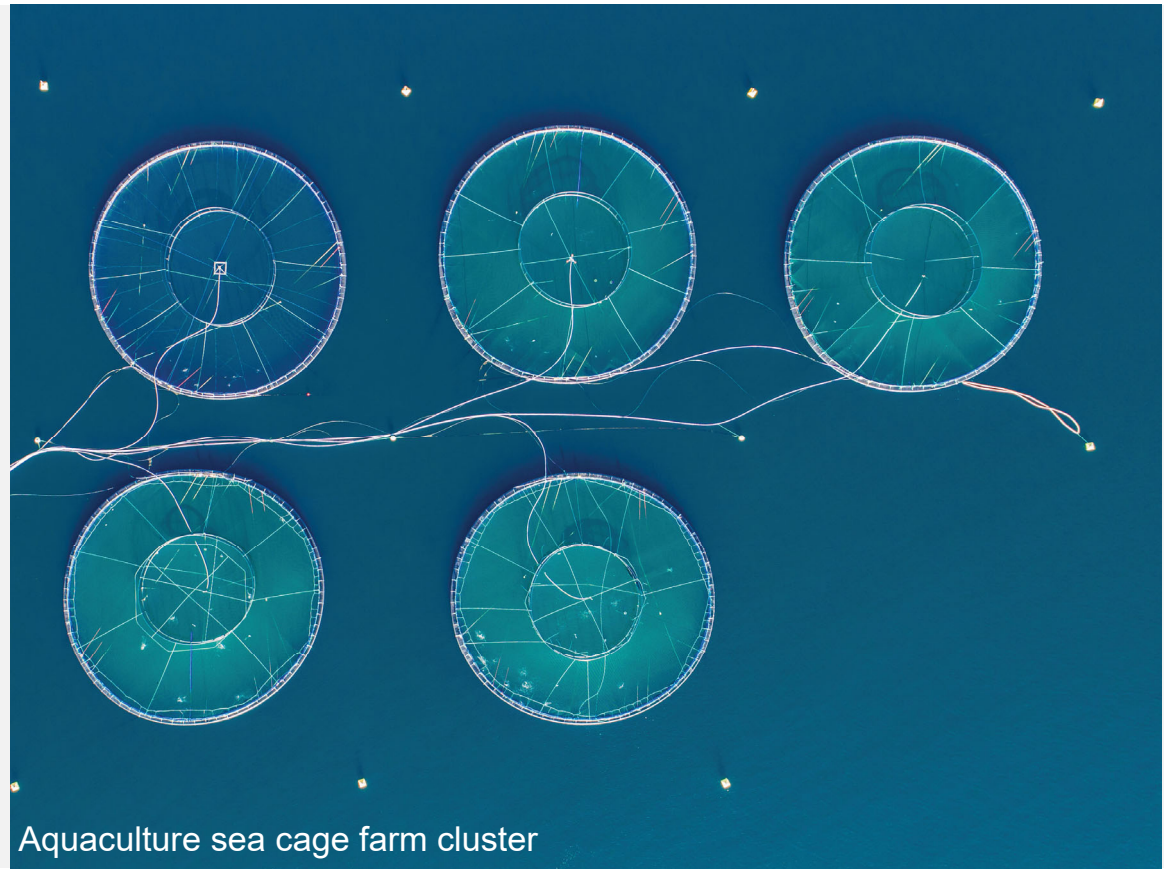


# Coastal water quality modelling

## Three common issues

### 3. Aquaculture

- Four sea cage farm clusters simulated
- Uses TUFLOW FV's PTM and WQM
- Inputs
  - Dissolved ammonium (dissolved waste/feed)
  - Particles (overfeed and waste)
- Three outputs over 18 days
  - Ammonium (WQM)
  - Chlorophyll a (WQM)
  - Particles reaching the sediment (PTM)



Aquaculture sea cage farm cluster

# Coastal water quality modelling

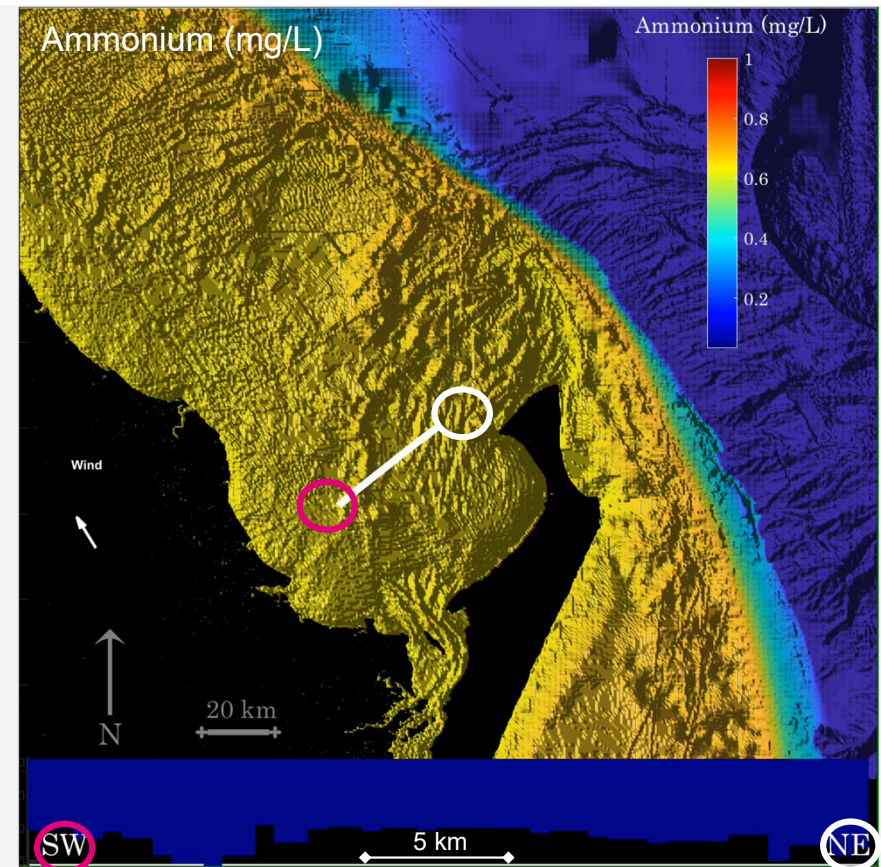
## Three common issues

### 3. Aquaculture

- Animation
  - Colour contours are ammonium (mg/L)
  - Surface sheet and curtain synchronised
  - Curtain runs from southwest (SW) to northeast (NE) (left to right)
  - Ammonium contours below 0.3 mg/L are removed in surface sheet
- Ammonium
  - Confined to the surface
  - Diluted and consumed by phytoplankton nearshore
  - Considerable concentrations and plume extent
  - Impacts are local

Surface values

Vertical curtain



# Coastal water quality modelling

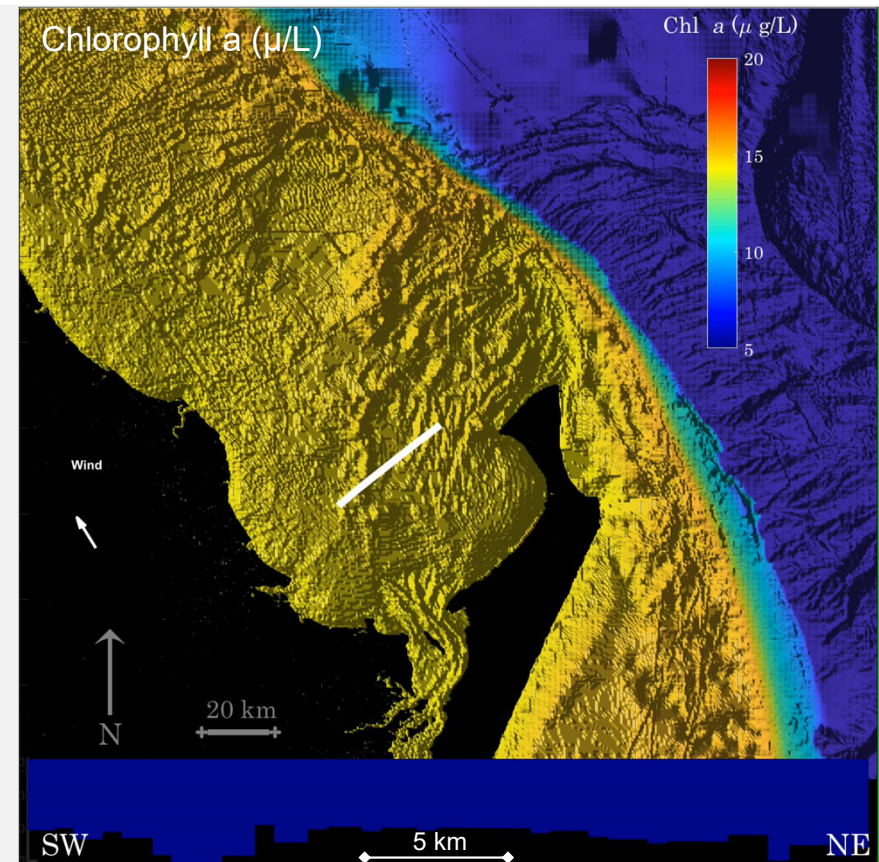
## Three common issues

### 3. Aquaculture

- Animation
  - Colour contours are chlorophyll *a* ( $\mu\text{g/L}$ )
  - Surface sheet and curtain synchronised
  - Curtain runs from A to B (left to right)
  - Chlorophyll *a* contours below  $5\ \mu\text{g/L}$  are removed in surface sheet
- Phytoplankton
  - Confined to the surface
  - Feeds on ammonium generated within farms
  - Considerable concentrations
  - Impacts are non-local

Surface values

Vertical curtain



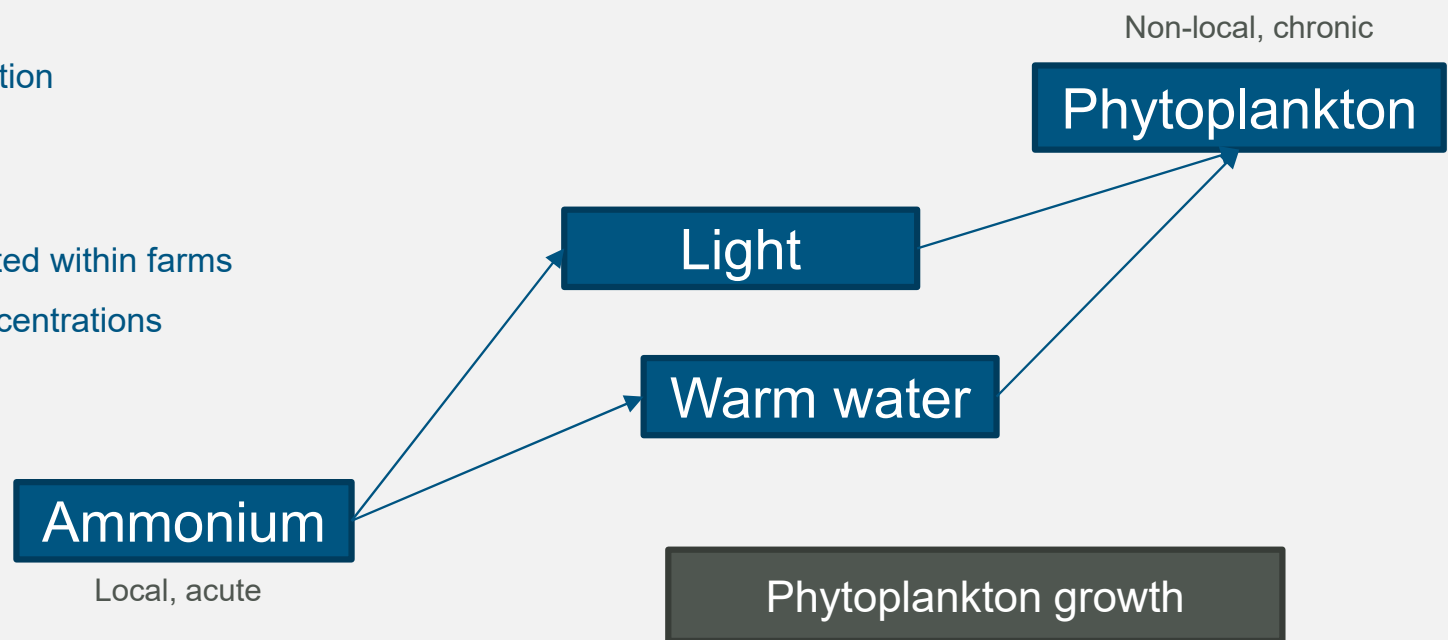


# Coastal water quality modelling

## Three common issues

### 3. Aquaculture

- Ammonium (acute)
  - Local release and transformation
  - Immediate potential effect
- Phytoplankton (chronic)
  - Feeds on ammonium generated within farms
  - Considerable near shore concentrations
  - Delayed potential effect

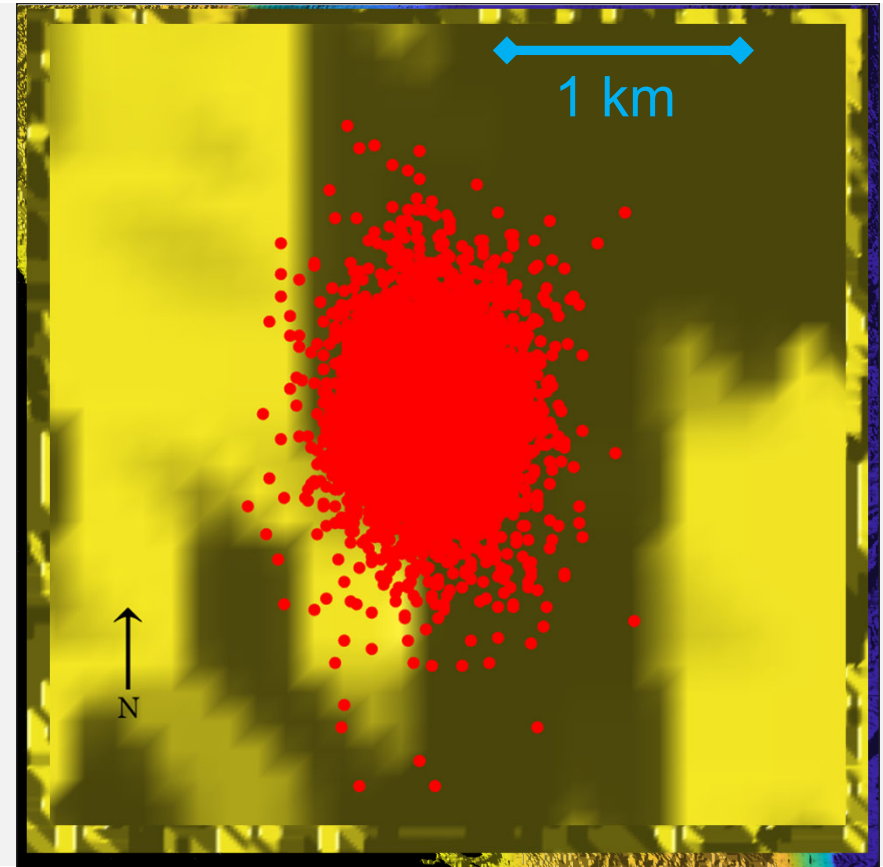


# Coastal water quality modelling

## Three common issues

### 3. Aquaculture

- Sediments
  - Confined to near cages
  - But still occupy a 2-3 km diameter area
  - Impacts are local, to scale of cages at least



# Coastal water quality modelling

## Three common issues

### 3. Aquaculture

- What do we report to the various levels of government?
- Acute toxicity (ammonium) is a potential but likely confined to local areas. Potentially also influence aquaculture
- Chronic issues may result around phytoplankton blooms, at locations away from the sea cages
- Or, we might report these to our customer (the proponent) and then use the model to investigate mitigation options to present to government
- Conservative passive tracer simulation will not allow these sorts of transformative assessments



Aquaculture sea cage

# Data needs

# Coastal water quality modelling

## Data needs - quantities

- Hydrodynamics
  - Water levels, currents/fluxes
  - Temperature and salinity
  - Sediment
- Water quality: what
  - Continuous
    - Dissolved oxygen, turbidity, fluorescence
  - Grabs
    - Nutrients
    - Phytoplankton species
  - Expensive!
    - Plans need to be targeted and robust



# Coastal water quality modelling

## Data needs - temporal

- Hydrodynamics
  - Spring neap cycles
  - Potentially short term (e.g. dredge plumes)
- Water quality: when
  - Seasonal
    - Warmer and cooler months
    - Wetter and drier months
  - Long term (chronic) vs short term (acute)



# Summary

# Coastal water quality modelling

## Summary

- Environmental impact assessment
  - Numerical models are tools to inform
    - Understanding
    - Risk elimination / mitigation
    - Predictions need to be used in conjunction with expert opinion and other avenues
  - Impacts can be
    - Direct or indirect
    - Benthic and/or pelagic
    - Acute or chronic
    - Local or non-local
  - Must use non-conservative water quality models





