The Future of Water Quality Modelling

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Australian Water School Webinar

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Outline

What is water quality modelling?

What is particle tracking?

What is the status quo?

The Future - Advanced water quality modelling case studies

What is water quality modelling?

Different environmental water modelling disciplines use different tools, but most are some form of numerical model, or a combination thereof

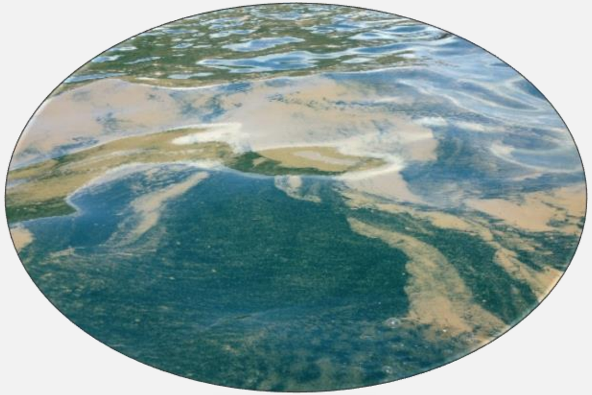
- Hydrologic (e.g. rainfall runoff prediction)
- Hydraulic (e.g. flood modelling)
- Hydrodynamic (e.g. estuarine tidal flows)
- Sediment transport (e.g. coastal environments)
- Waves (as additional stress to hydrodynamics)
- Groundwater (independent or linked to hydrodynamic/hydrologic models)
- Plumes (e.g. ocean outfalls)
- Combinations of one-, two- and three-dimensional models
- Not an exhaustive list…

Physics

What is water quality modelling?

When ecological process questions arise, an additional suite of models is required

- Simulate water chemistry and ecology, informed in part by physicals
- Used to examine the non-conservative fate and transport of ecologically significant constituents
  - Dissolved oxygen (core of many water quality and ecological models)
  - Nutrients (nitrogen and phosphorus)
  - Organic matter (nitrogen, phosphorus and carbon)
  - Phytoplankton (algae)
  - Zooplankton
  - Pathogens
  - Geochemistry
  - Many more



- Wide range of water quality constituents simulated to address different issues
- Basic premise: to simulate ecologically relevant processes and pathways
  that can be characterised by dissolved quantities to support environmental management

What is water quality modelling?

Typical questions that water quality models might be used to address (not exhaustive)

- What nutrient loading can an estuary accept from a wastewater treatment plant, before estuarine water quality fails to meet its objectives?
- What impact will catchment-based stormwater treatment have on the ecological function of a downstream creek?
- How might we best design a wetland to treat urban stormwater runoff?
- How might the frequency and severity of algae blooms change in a water supply reservoir if sediment nutrient release is suppressed?
- What risks are posed to the public by pathogens delivered to aquatic recreational areas?
- What is the likely geochemistry of a coal mine’s final void if it fills with water to form a lake?

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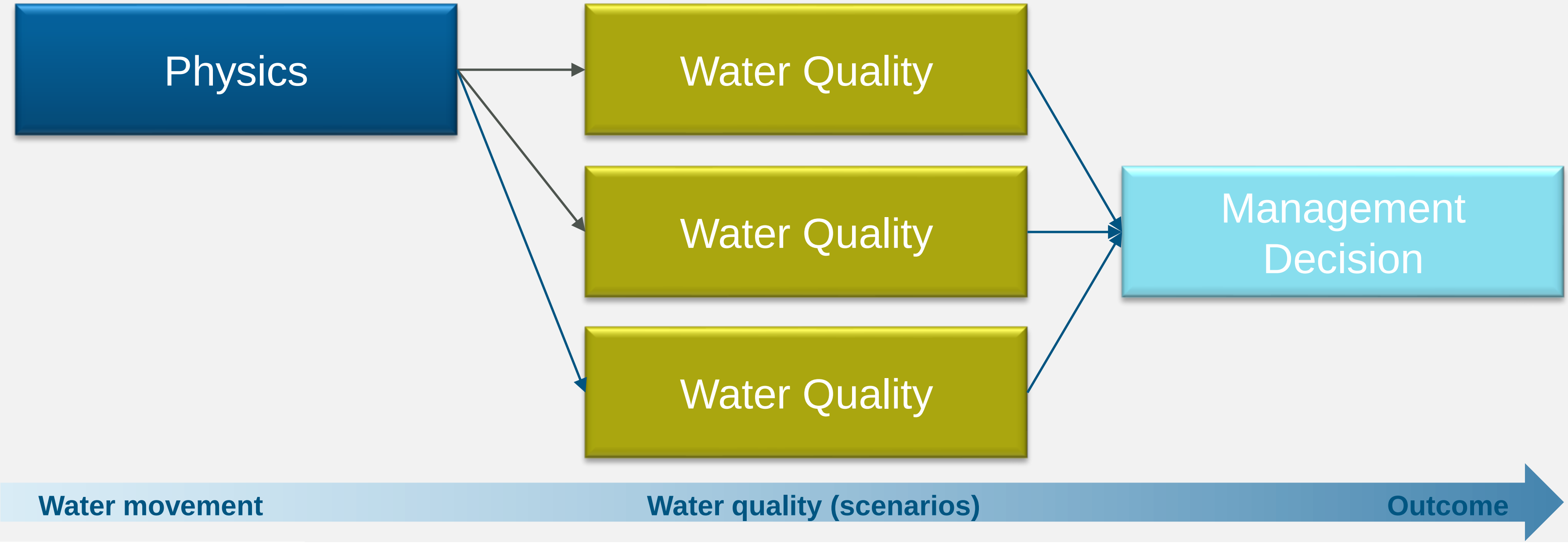
What is water quality modelling?

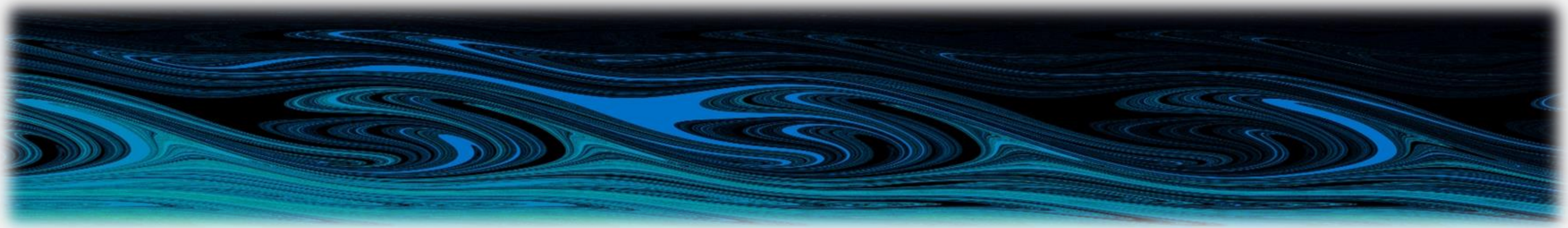
The historical approach to addressing these types of questions has typically been



What is water quality modelling?

Summary

- These assessments simulate concentration based quantities, also known as “Eulerian” or “cell” based quantities
- Relate primarily to dissolved quantities
- If not, they attempt to simulate non-dissolved quantities as water concentrations
  - Phytoplankton “concentration”, but phytoplankton are discrete entities
  - Shrimp or fish “concentration”, but these are also discrete entities
- Leads to particle modelling



What is particle modelling?

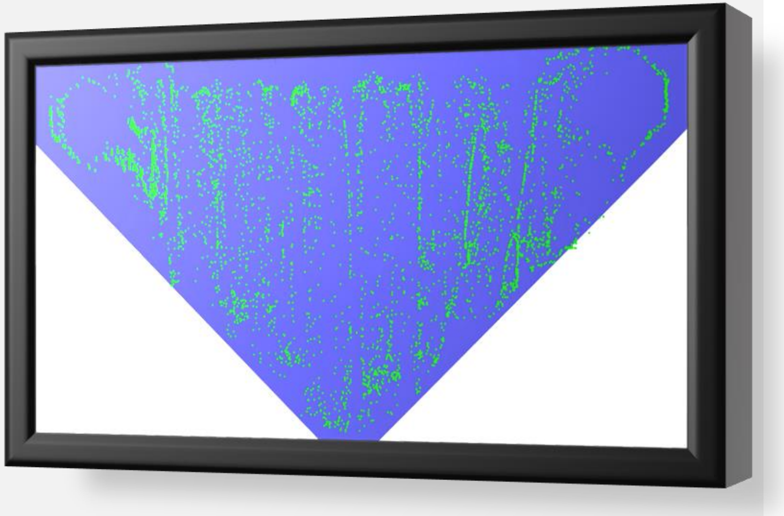
When discrete entity process questions arise, they can be simulated as particles

- Particle (or particle tracking) models simulate individual entities rather then dissolved quantities
- Individual entities might include
  - Fish or crustaceans
  - Shrimp (prawns)
  - Surface scum algal blooms
  - Fish larvae
  - Turtle hatchlings
  - Aquaculture feed pellets or waste
  - Over-boarded shipping containers
  - Solid oceanic waste / wreckage
  - Lost uncontrolled vessels
  - Many others

What is particle modelling?

Particles can be

- Transported by the flow field and/or wave and wind drift
- Modified by settling/buoyancy, decay, sedimentation and resuspension
- Dispersed horizontally and vertically
- Given motility behaviours over and above simple advection
- Set to crawl if on dry land
- Basic premise: to simulate processes and pathways that cannot be properly characterised by dissolved quantities to support environmental and other management efforts



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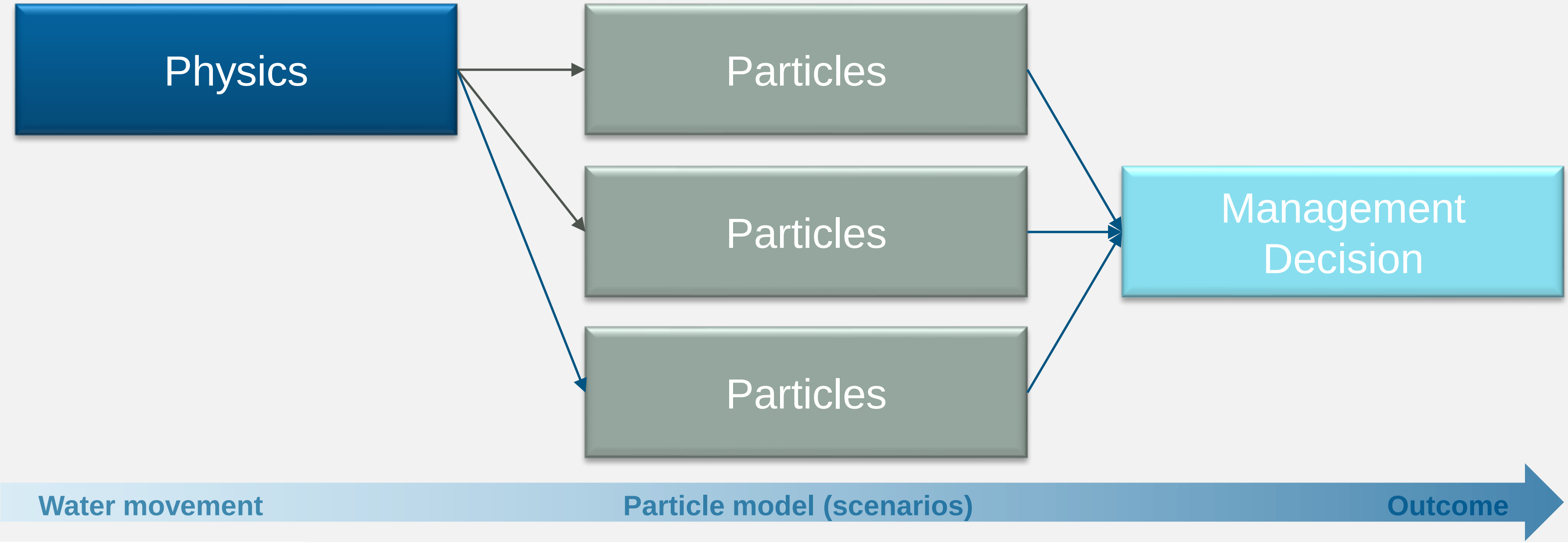
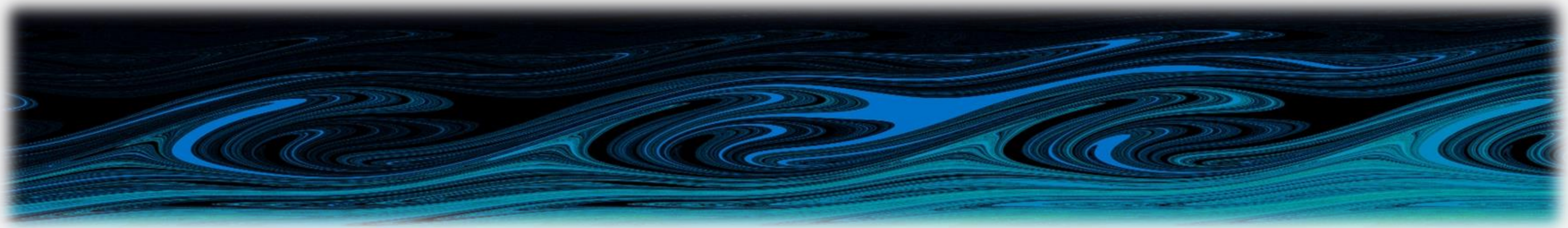


What is particle modelling?

Summary

- These assessments rely on particle based dynamics, also known as “Lagrangian” quantities
- Not dissolved quantities
- Moved by currents, waves, wind and potential organism-based motility



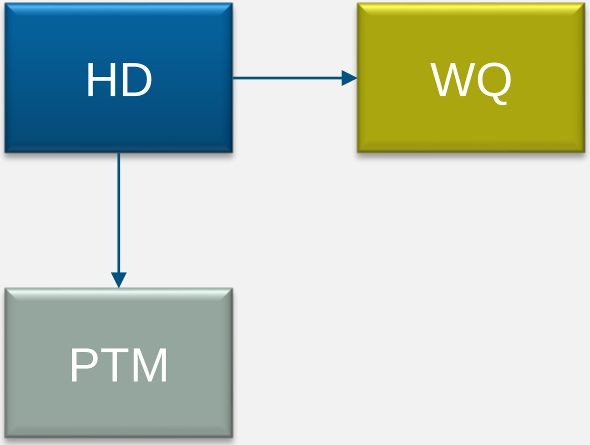
What is the status quo?

The past

- Both Eulerian and Lagrangian modelling tools have been used for decades, in increasing complexity
- Both have primarily (but not always) been driven only by hydrodynamics, and have themselves not been linked
- Restrictive in the issues that can be addressed

Most traditional analyses are one-way

- Water quality responds to hydrodynamics
- Particles respond to hydrodynamics
- Particles do not modify water quality
- Water quality does not modify particle behaviour
- Water quality does not alter hydrodynamics
- Some exceptions (WQ → HD, niche, often non-commercial)
  - Oil spill modelling (2D)
  - Phytoplankton shading
  - Fish kills



What is the status quo?

The past

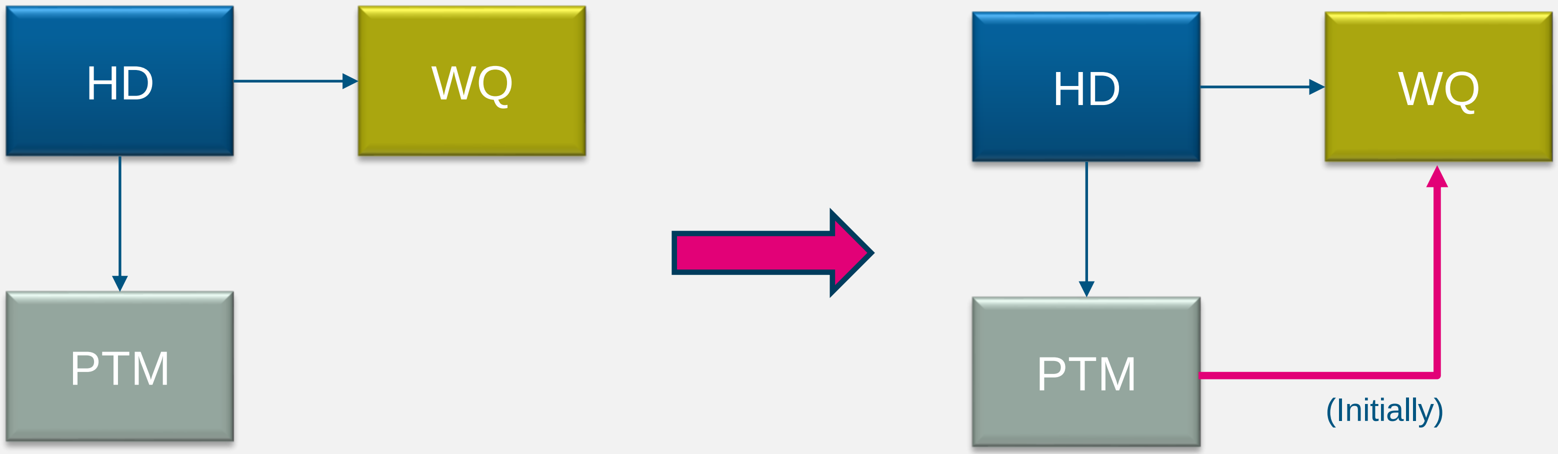
- Hydrodynamics
  - 1D hydrodynamic models were once the norm
- Understanding of our natural environment
  - Basic processes (e.g. total nutrients and generic phytoplankton)
- Compute power
  - CPU was once the norm
  - Desktop computers were once the norm

The present

- Hydrodynamics
  - 3D models are now expected
- Understanding of our natural environment
  - Multitrophics are increasingly well understood
- Compute power
  - GPU is now expected (or at least asked after)
  - Blade arrays and cloud compute options are the norm

What is the status quo?

The questions being asked of environmental models are increasing in scale and complexity



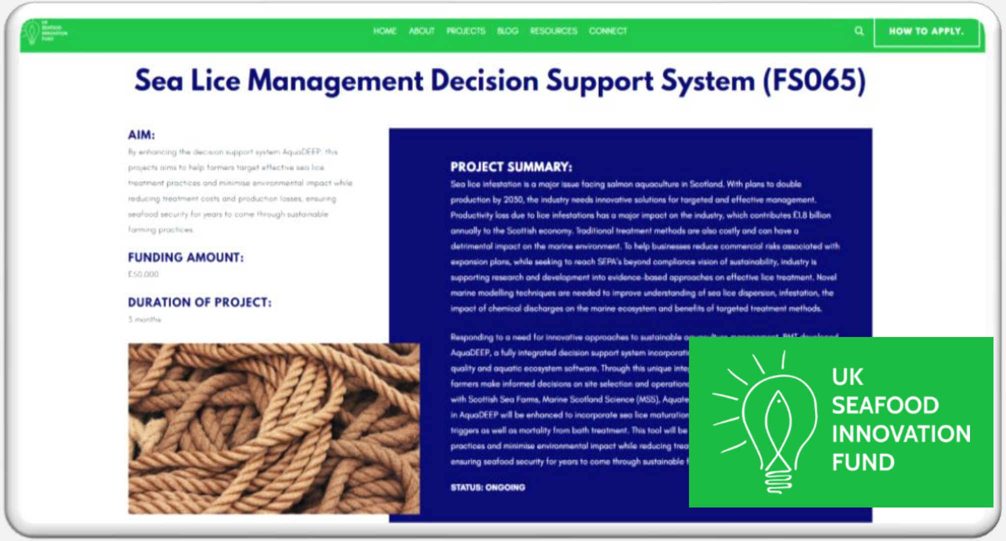
What is the status quo?

A glimpse of what is to come in TUFLOW

- Two way linking of HD / PT / WQ models
  - Management of dissolved oxygen in “shrimp” ponds
  - Migration of salmon

Already being applied in industry

- UK Seafood Innovation Fund project
- BMT, Scottish Sea Farms, Marine Scotland Science, Aquatera and Scottish Environment Protection Agency
- https://www.bmt.org/news/2020/bmt-to-support-scottish-seafood-industry/



Question 1: DO (dissolved oxygen) in shrimp ponds

The setting

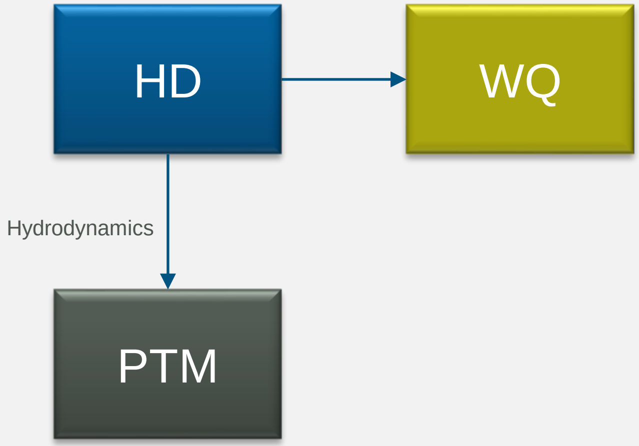
- Land based aquaculture uses grow out ponds to develop shrimp to saleable size
- Ponds are typically
  - Up to hundreds of metres in horizontal dimension, and
  - Several metres deep at their deepest
- Maintenance of oxygen in the ponds is critical
  - Shrimp consume oxygen via respiration
  - Shrimp waste and over-feed also consume oxygen when broken down
- For the purposes of this simple example case, “shrimp” migrate vertically on a diurnal cycle, seeking safety at depth during daylight hours

Key questions

- Does vertical shrimp migration lead to ongoing low dissolved oxygen at depth?
- If so, how might shrimp respond?

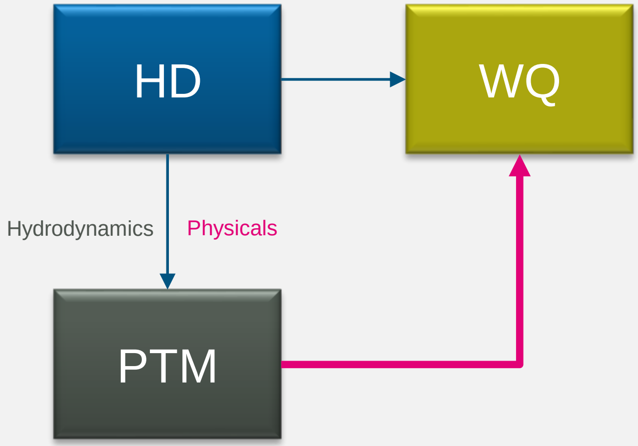
Question 1: DO in shrimp ponds

Historical assessments



- Make inferences around PTM-WQ linkage

Current needs



- Specifically simulate PTM-WQ linkage

Question 1: DO in shrimp ponds

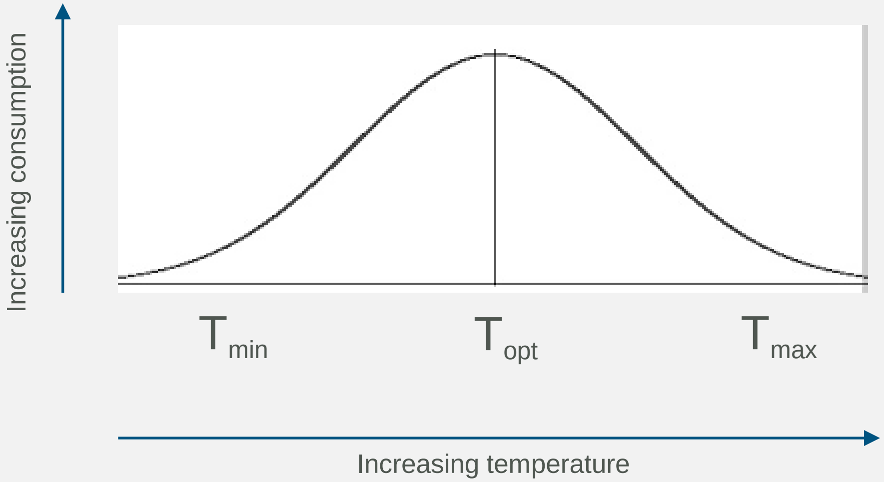
The requirement

- Particles are to respond to hydrodynamics, but also dynamically to
  - Temperature
  - Light (PAR)
- Particles are to consume oxygen at a user defined rate
- This will allow
  - Diurnal vertical migration
  - Interaction between PT and WQ models around oxygen

Question 1: DO in shrimp ponds

The implementation

- Particle tracking
  - Migrate downwards when a user defined ambient PAR threshold is exceeded
  - Stop migrating once the PAR threshold is no longer exceeded
  - Crawl downwards if they hit a pond's sloping sides
  - Freely migrate laterally at the pond base
- Oxygen consumption
  - Within a user defined temperature range
  - Scales with maximum mg O_2 per gram of shrimp biomass
  - User defined temperature dependence

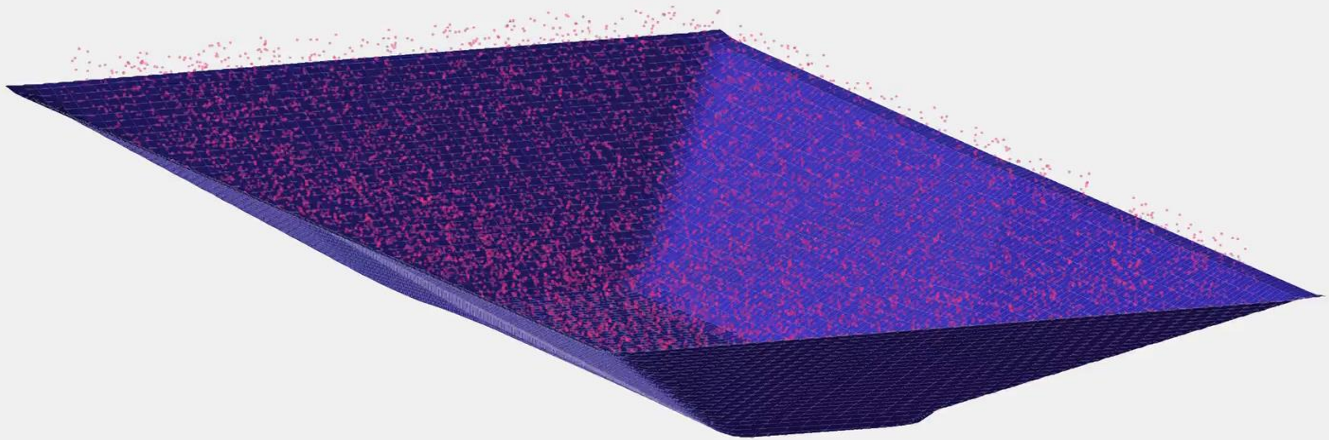


The example model

- 3D constructed shrimp farm pond

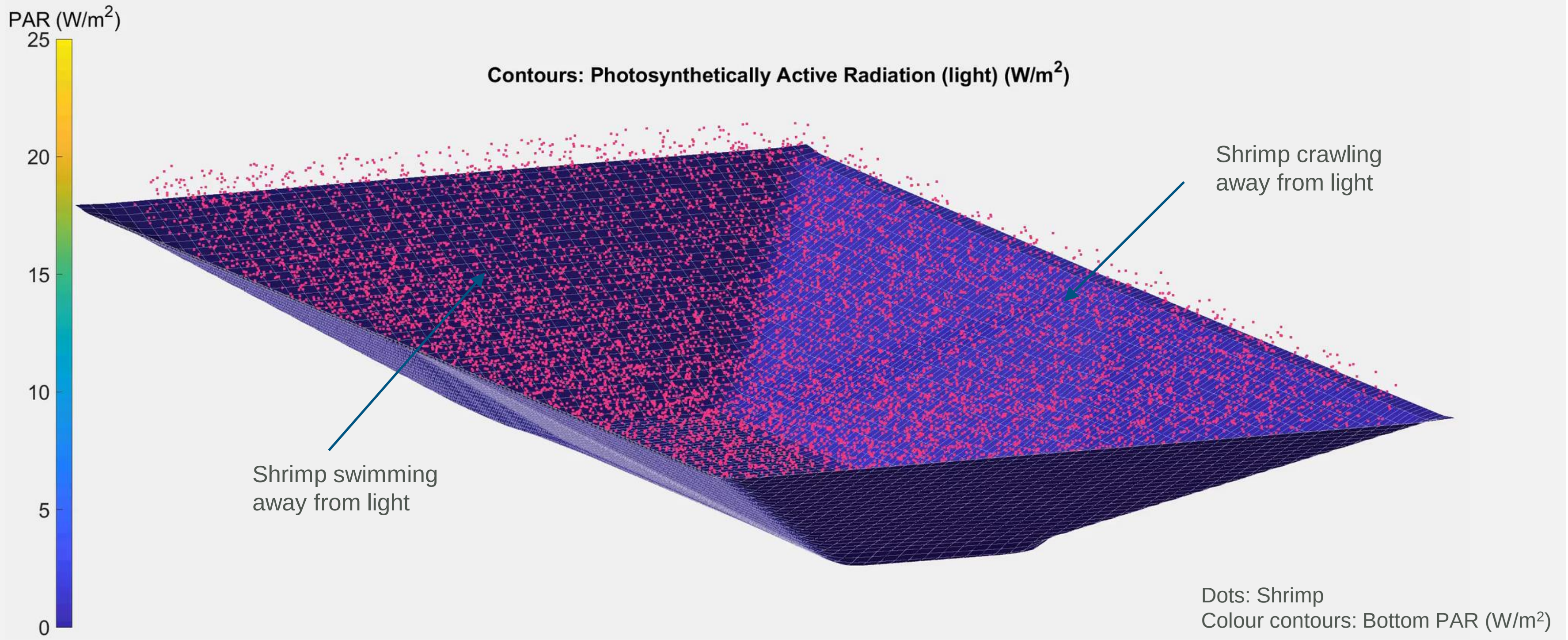
Question 1: DO in shrimp ponds

The 3D pond model



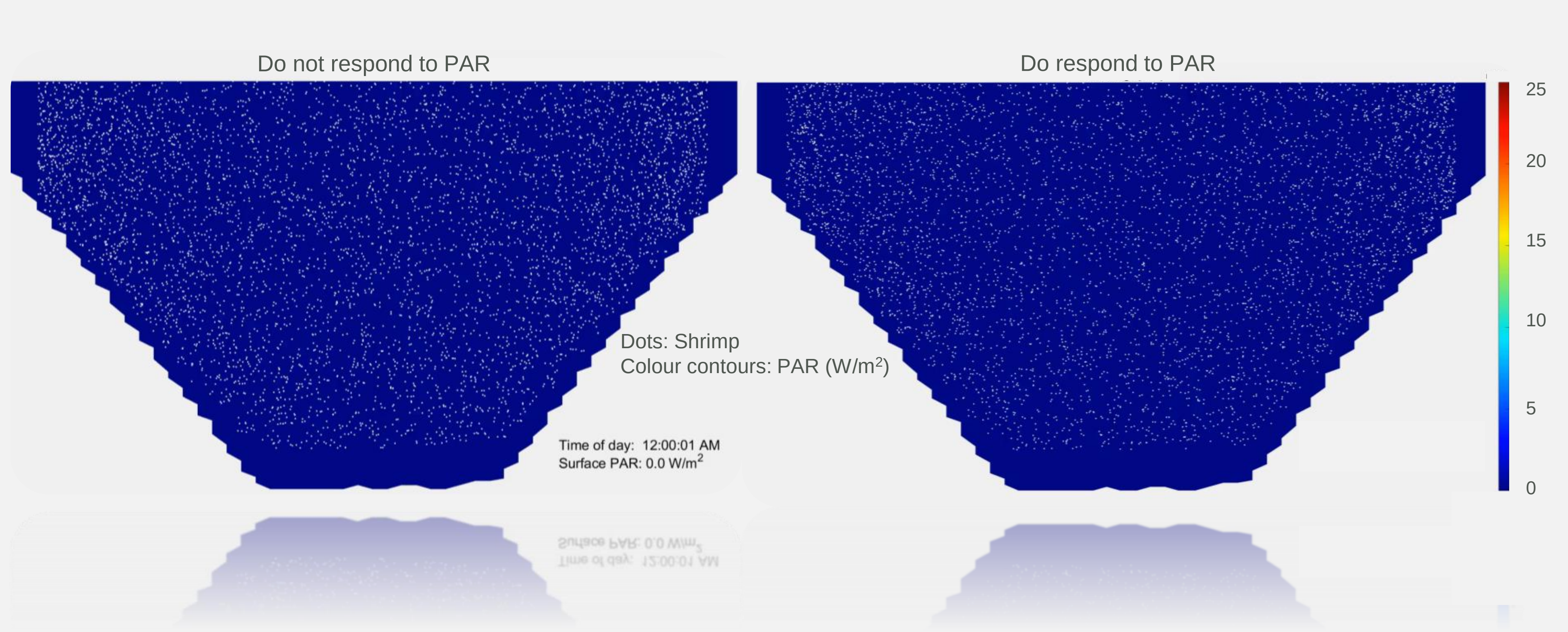
Dots: shrimp
Colour contours: bottom PAR

Question 1: DO in shrimp ponds



Dots: Shrimp
Colour contours: Bottom PAR (W/m2)

Question 1: DO in shrimp ponds



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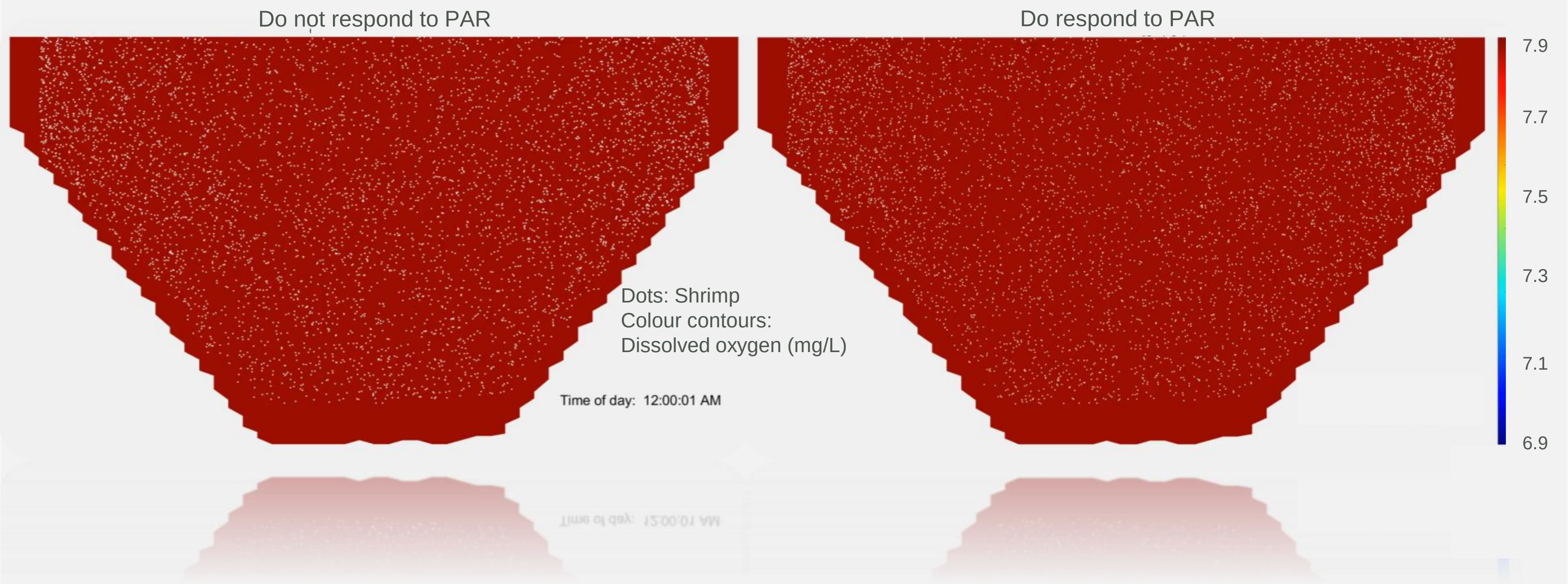
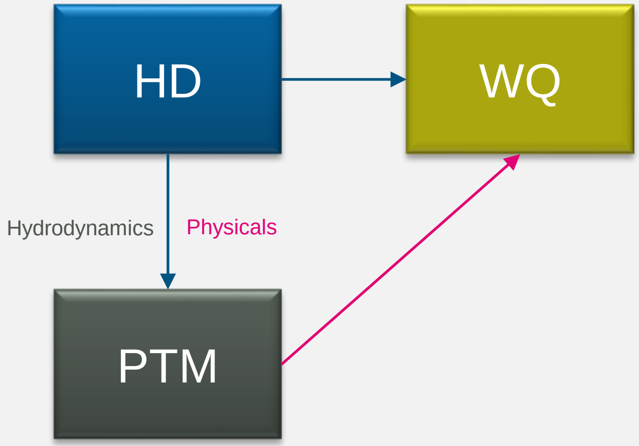


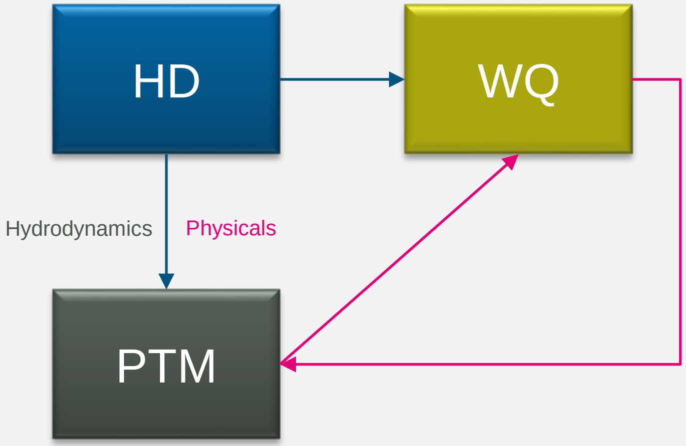
Question 1: DO in shrimp ponds

Current needs



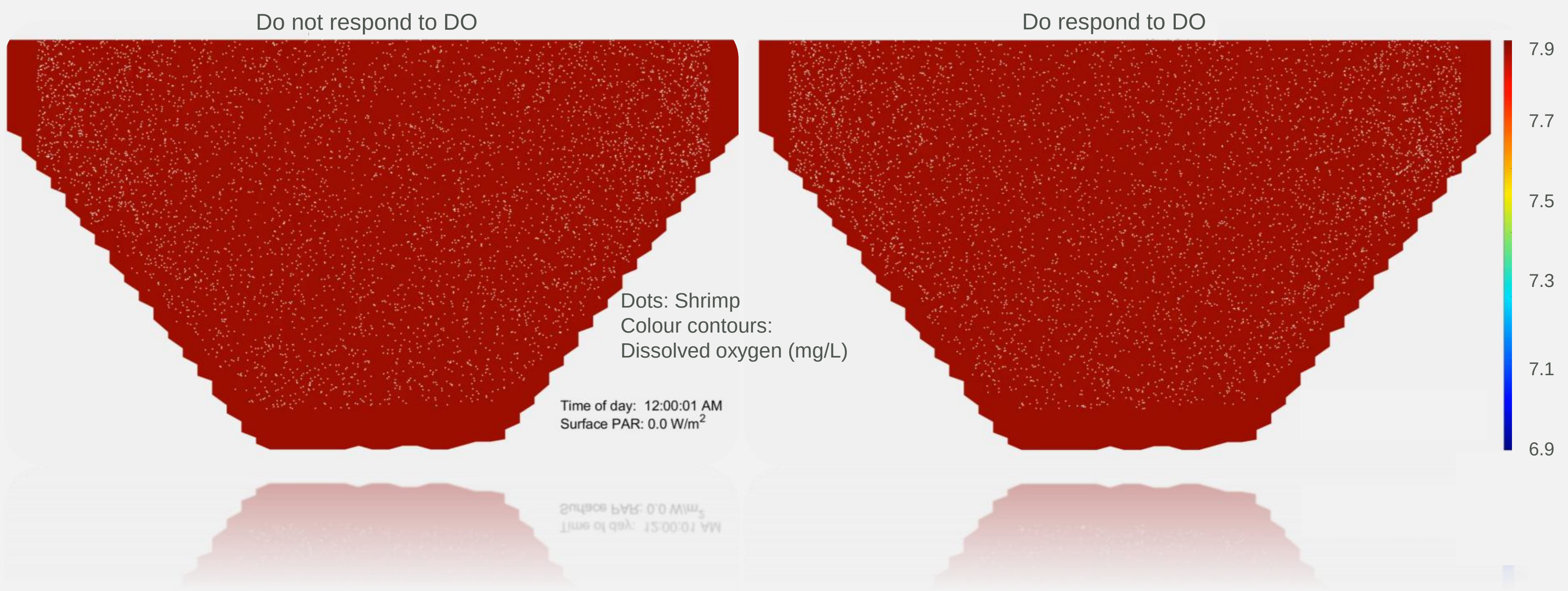
- Specifically simulate PTM-WQ linkage

Future needs



- Have WQ feed back to PTM
- Shrimp avoid low DO waters to survive

Question 1: DO in shrimp ponds



Question 1: DO in shrimp ponds

Where to next

- Customisation of algorithms to reflect different behaviours (real shrimp!)
- Management of ponds, shrimp, feed and waste

Example questions

- How can paddles be arranged to promote accumulation of waste in locations that are easy to access to clean, and to minimise a low DO footprint size?
- How do different types of feed/waste travel through the pond and influence dissolved oxygen?
- What thickness of waste is likely to collect at the bottom of a pond, and how often should it be cleaned, to optimise cleaning costs and avoid low DO?
- Is waste or overfeed resuspended and if so, what are its water quality dynamics?
- What are the carbon, nitrogen and phosphorus dynamics associated with pellet overfeed and waste and how can these be better managed to save money?
- And many more…

Question 2: Migrating salmon

The setting

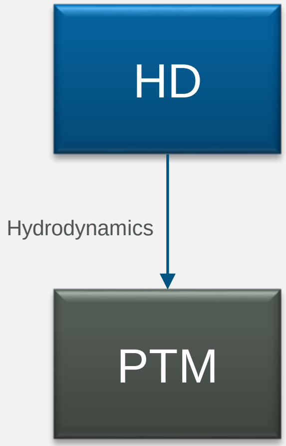
- Salmon migrate upstream
- They have various depth and temperature seeking behaviours
- They can become stressed due to higher water temperatures and so seek cold water refuges
- Creation of artificial refuges is being considered to assist migrating salmon

Key question

- How might a refuge be designed to maximise benefit to salmon?

Question 2: Migrating salmon

Historical assessments



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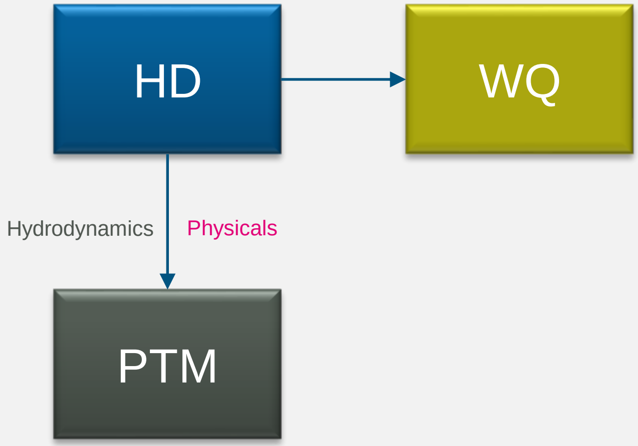
Current needs



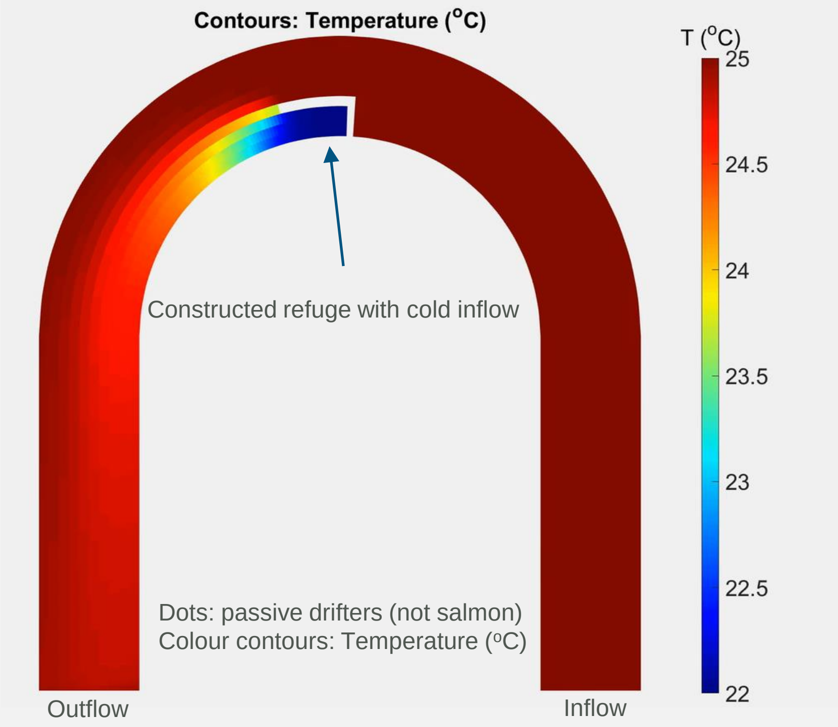
- Specifically simulate HD-PTM linkage

Question 2: Migrating salmon

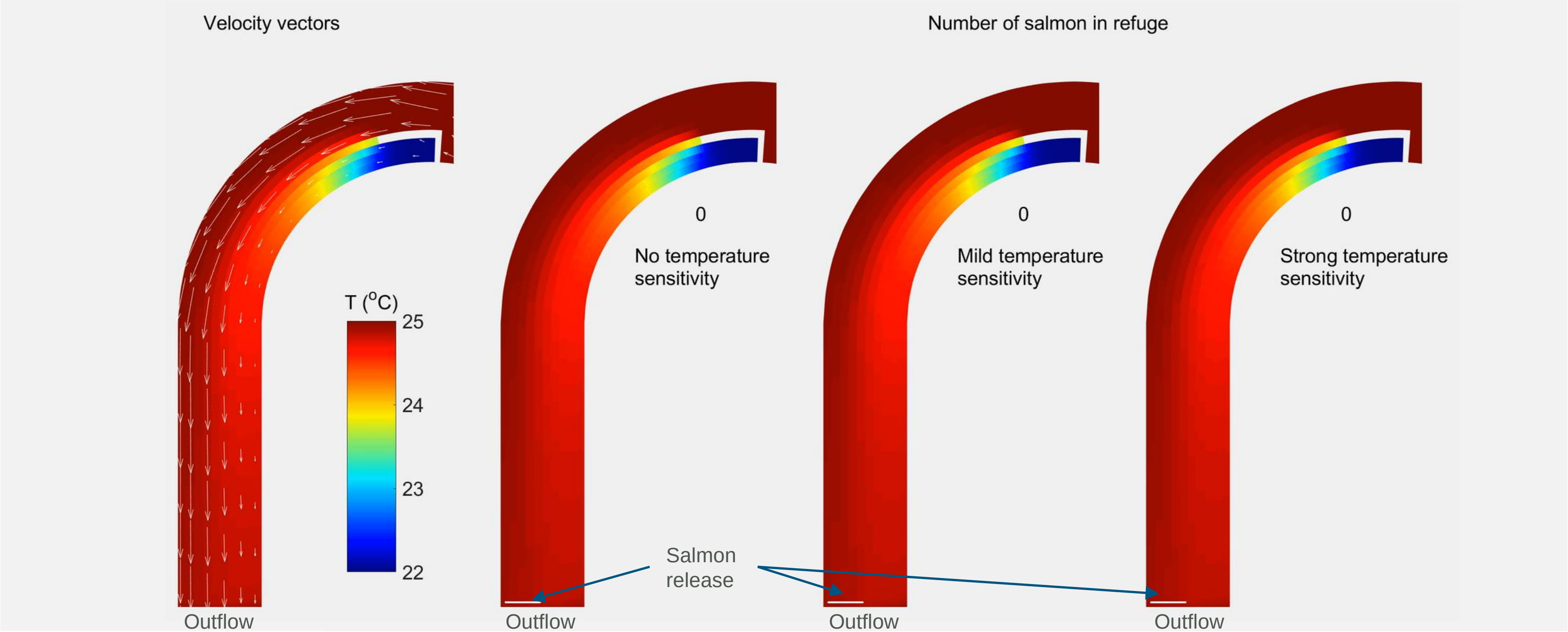
The requirement

- Particles are to respond to hydrodynamics
  - Swim against the current
- And also dynamically to
  - Local temperature gradients
- This will allow
  - Lateral deviation of upstream swimming to seek cooler waters
  - Assist in designing constructed refuges

Question 2: Salmon migration



Question 2: Salmon migration



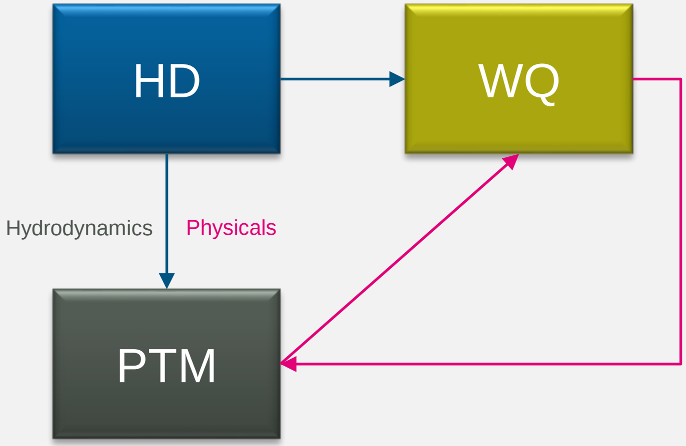
Summary

Past and present

- Requirements are becoming more demanding
- Historical approaches are no longer sufficient

The future

- As a matter of course:
  - Two–way interaction of HD, PT, WQ
  - Cloud and GPU compute



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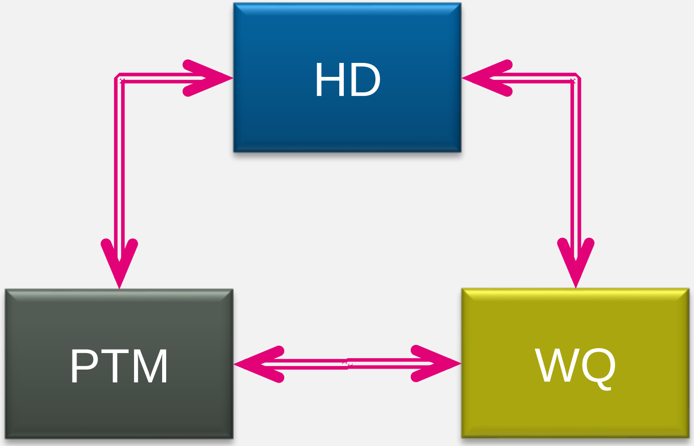

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