Modelling tanker ballast water dispersion in ports

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Introduction

- Saline ballast water (pH of 5.6) is ejected by tankers into fresh water at river ports such as Brisbane
- This is carried by the current away from the tanker
- Turbulent mixing likely
- River environment affected by the saline water, which has lower pH than river water
- Extent of ballast plume unknown

Computational fluid dynamics (CFD) can be used to model this situation.

Problem metrics

- Tanker is 300m long, with a draught of 20m
- Port is 30-35m deep
- Current has max. speed of ~1 m/s
- River water has 2 ppt salinity, and density of 1000 kg/m^3
- Ballast water is ejected for 18 hours at 6.12 m^3/s near rear of tanker
- Ballast water has a salinity of 35 ppt

Model specification

- Channel
  - Quasi-2D problem: channel ~3km x 35m (depth)
  - Vertical velocity profile at inlet (max. flow speed at top)
  - Quadratic bottom drag $C_D = 0.043$ (roughness length 0.4m)
  - Salinity 2 ppt, density 1000 kg/m^3
  - Salinity contraction coefficient 7.5 x 10^{-4}
  - Temperature 20℃
- Ballast outlet
  - Flow rate 6.12 m^3/s
  - Outlet boundary salinity 35ppt
  - Temperature 20℃

Model specification (2)

- Simulation
  - Uses finite-element CFD to resolve flow with Boussinesq approximation to drive convection
  - Mesh resolution ~5m (at tanker) to ~8m (>1km from tanker)

(zoomed view of mesh)

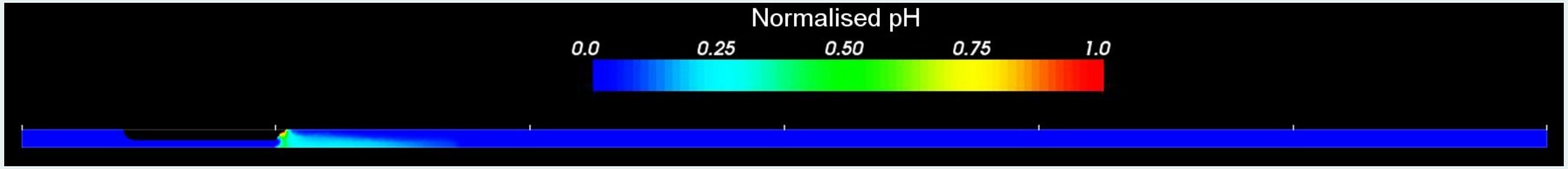
  - LANS turbulence modelling
  - Time-step 2.5 s
  - Simulation time ~ 18 hrs.
  - Two simulation studies run:
    1) peak flow speed u=0.4 m/s
    2) peak flow speed u=0.8 m/s
  - Normalised salinity specified as

$$\alpha = \frac{pH - pH_b}{pH_0 - pH_b}$$

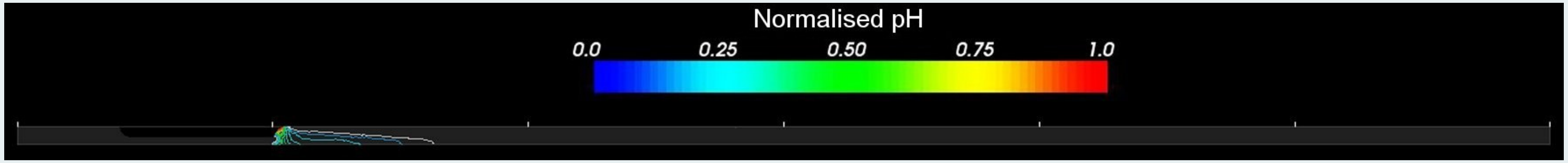
pH_b : the background pH of port water
pH_0: the pH of Ballast water in the tanker

Results :: u=0.4 m/s

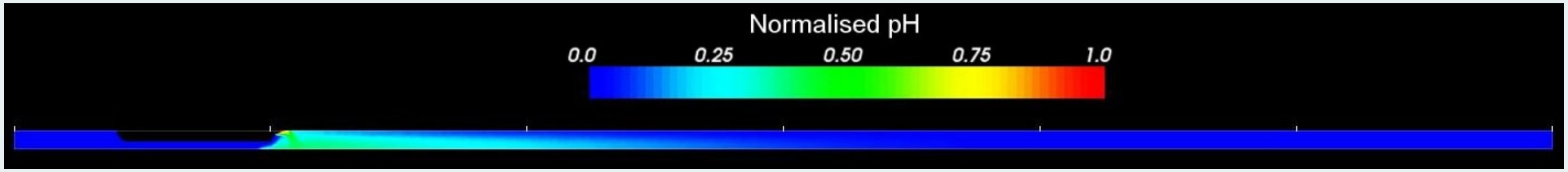
t=15 mins – coloured plot, white markers every 500m

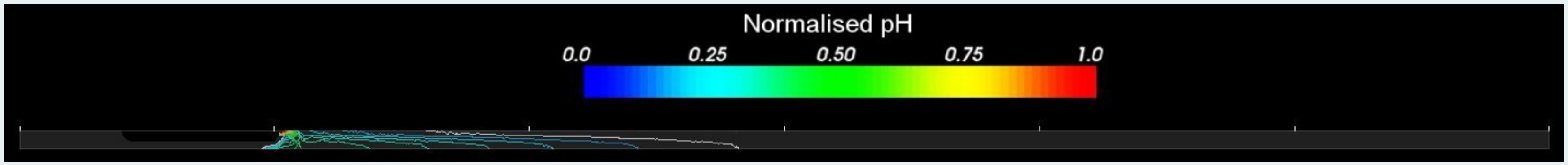


Contour plot, from 0.1 (white contour) to 1 in intervals of 0.05



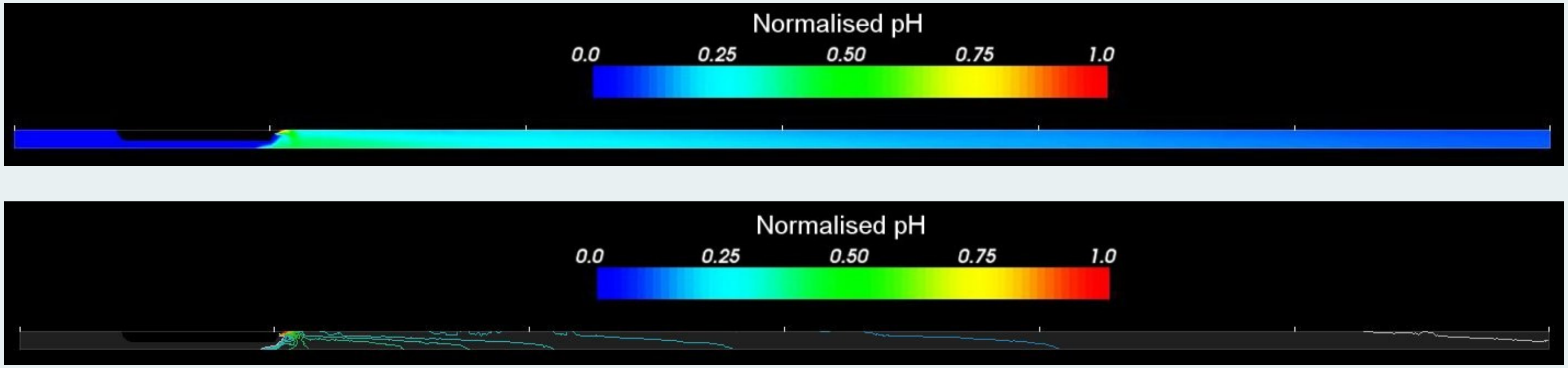
t=1 hour



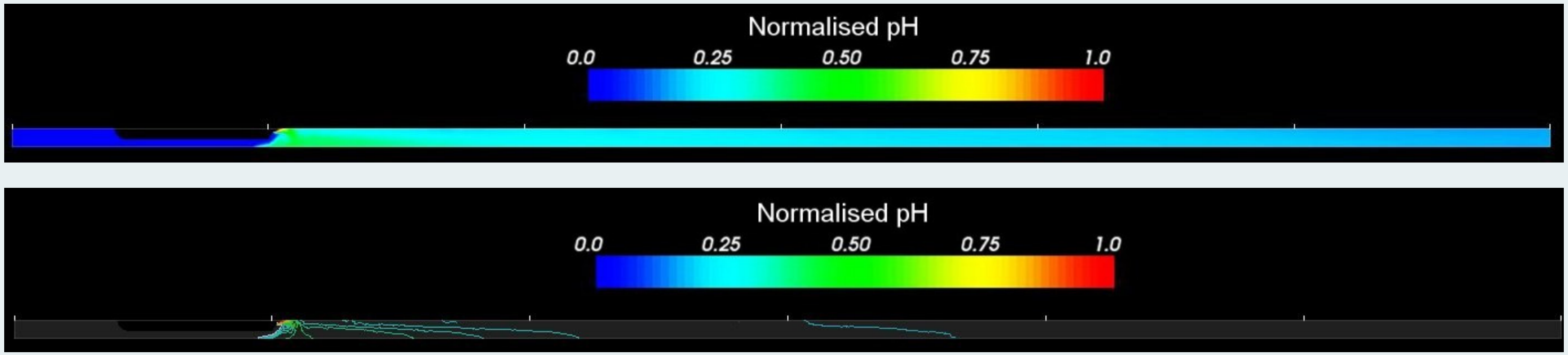


Results :: u=0.4 m/s (2)

t=6 ½ hours – plume extent passes 2.5km downstream

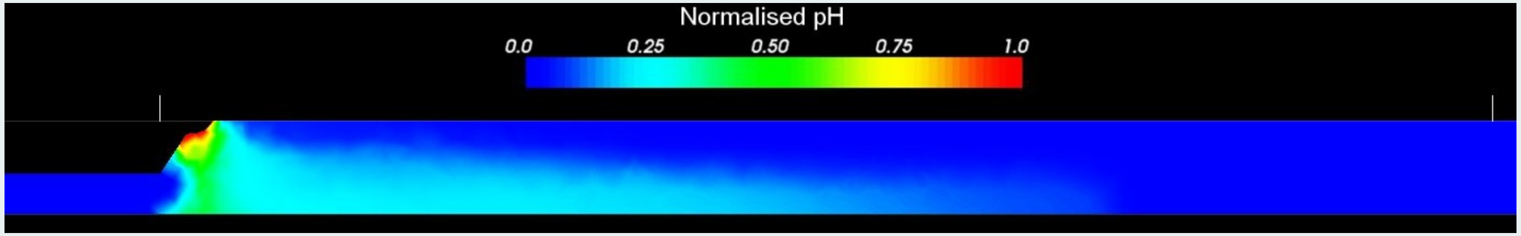


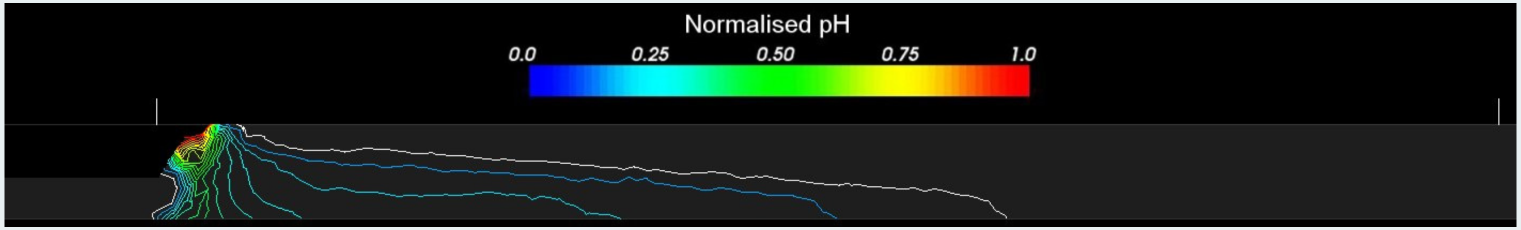
t=14 hours – plume has reached steady state



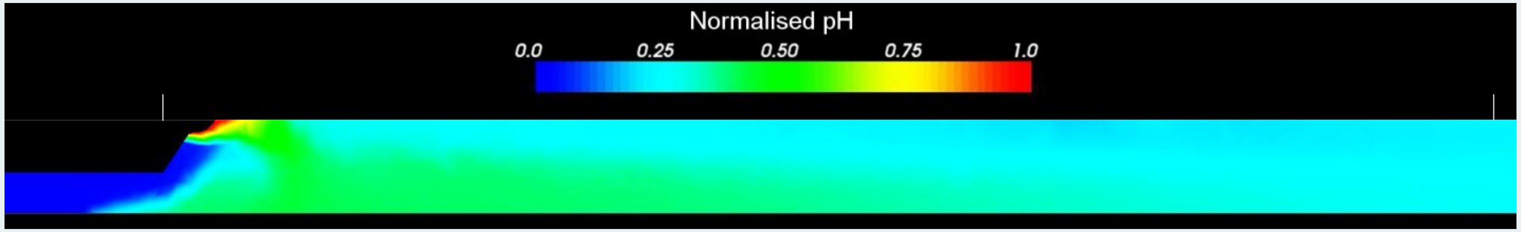
Results :: u=0.4 m/s (3)

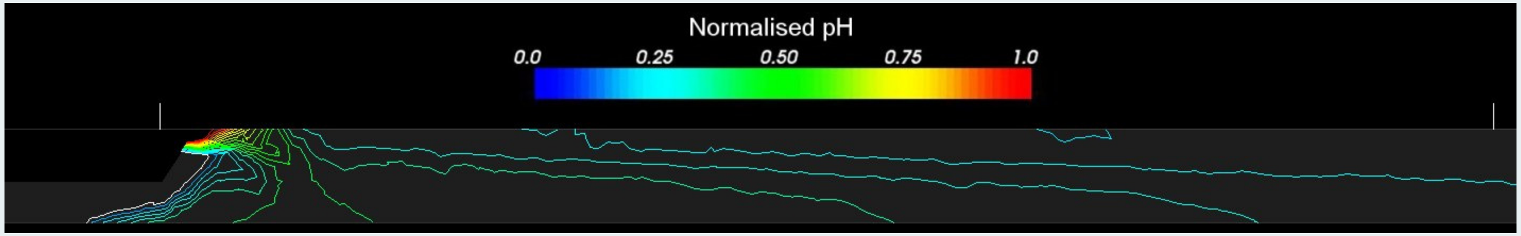
t=15 mins – zoomed to stern





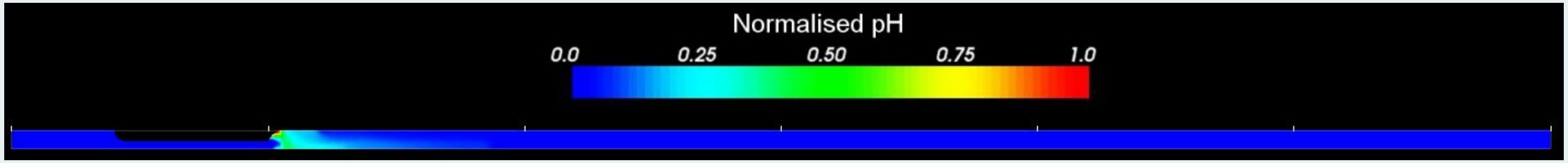
t=14 hours – zoomed to stern

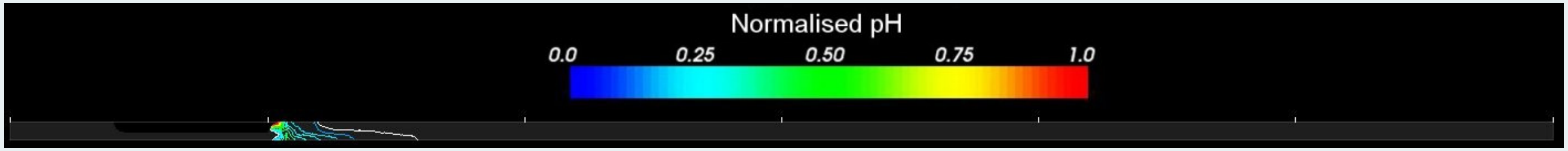




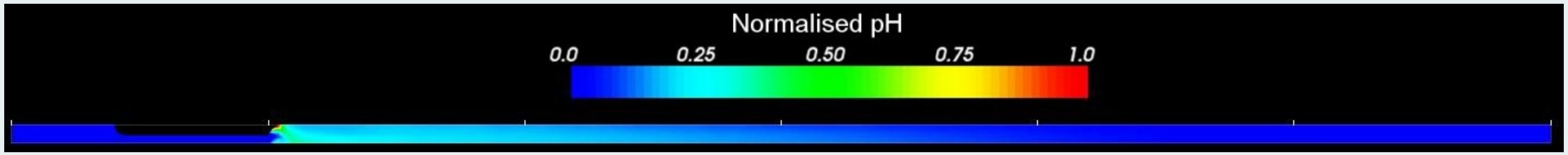
Results :: u=0.8 m/s

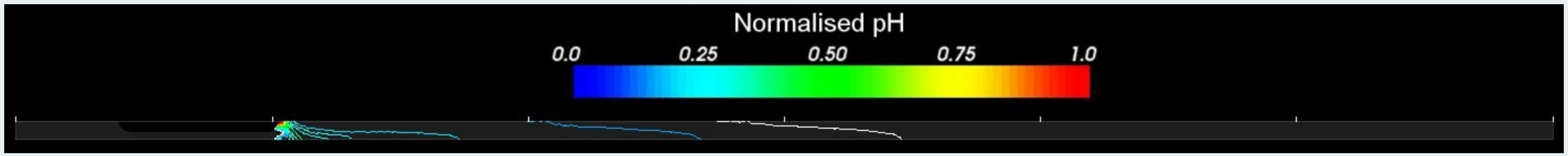
t=15 mins





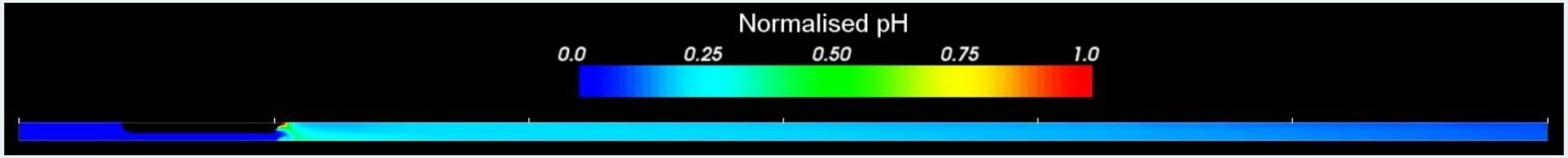
t=1 hour – plume extent ~400m greater than at u=0.4 m/s

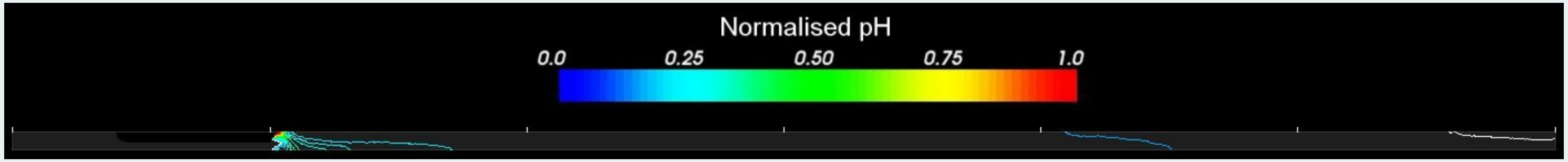




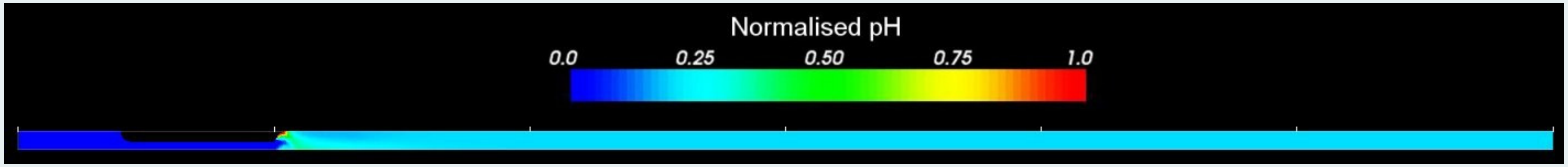
Results :: u=0.8 m/s (2)

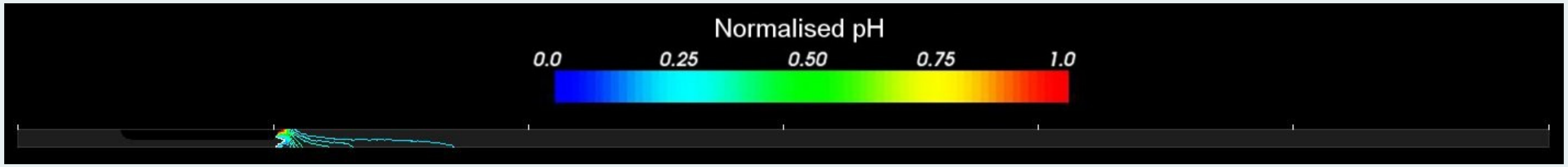
t=2 ¼ hours – plume extent passes 2.5km downstream





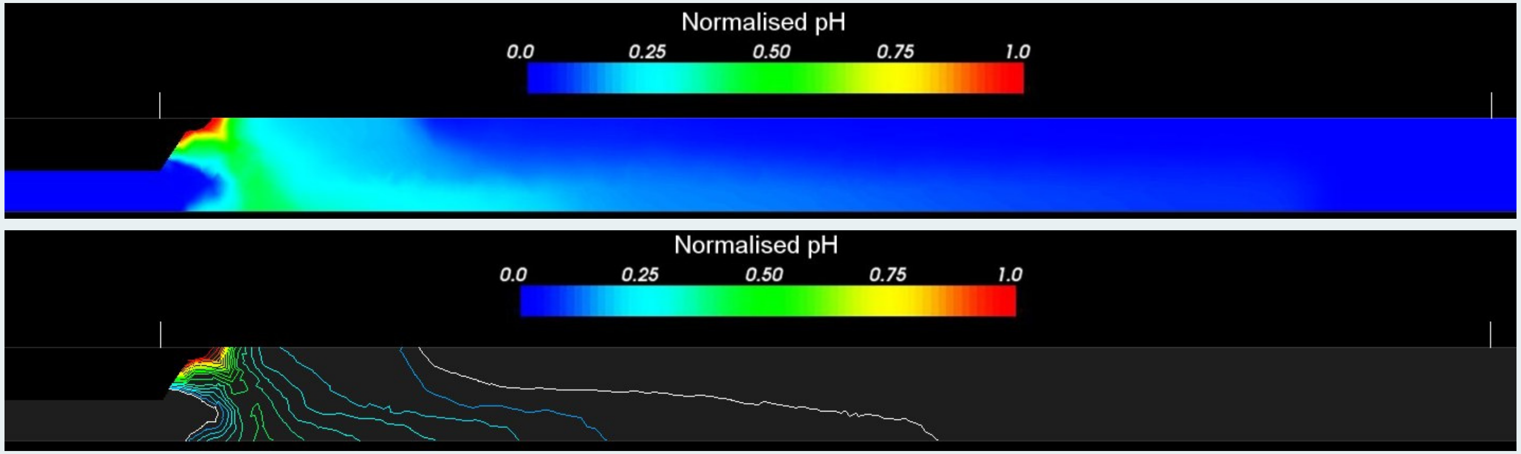
t=9 hours – plume has reached steady state



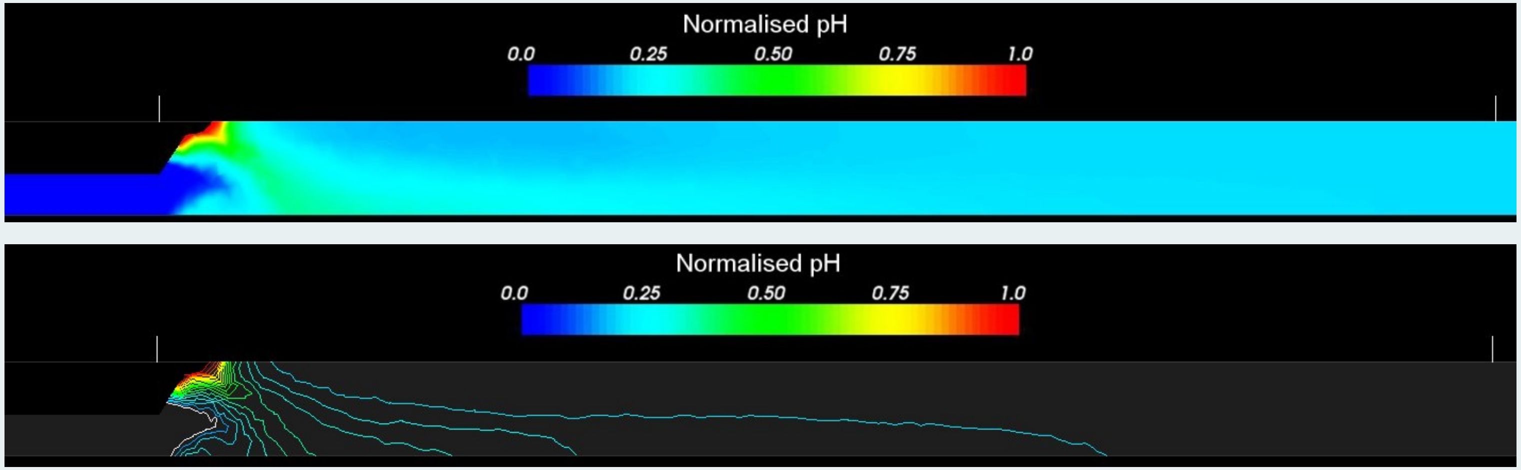


Results :: u=0.8 m/s (3)

t=15 mins – already the plume shape differs from the u=0.4m/s case

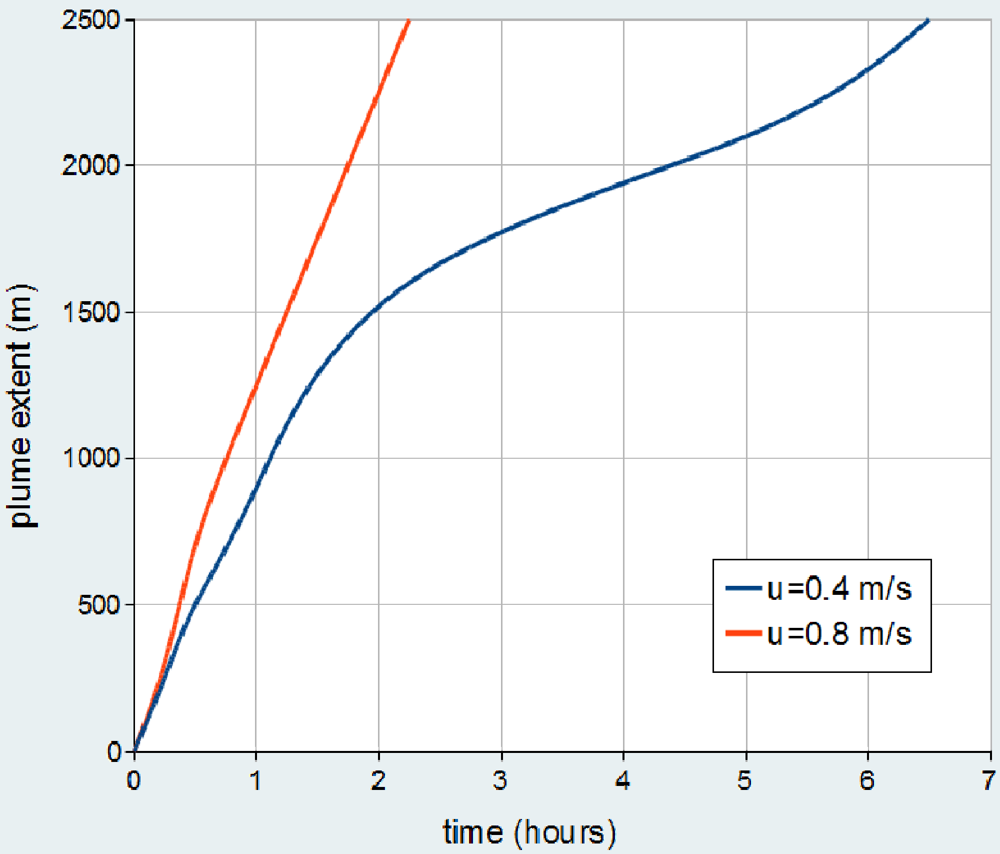


t=9 hours



Results :: comparison

- Plume development of low and high speed flows compared



Analysis

- Plumes extend several km downstream
- Doubling of peak flow speed shortens plume travel time:
  6 ½ hours at 0.4 m/s, to 2 ¼ hours at 0.8 m/s
- **These are worst case scenarios:** 2D problem ignores lateral turbulent mixing with river water
- A 3D model would allow lateral mixing, so ballast water concentration downstream would be lower than 2D cases

Conclusion

- 2D model can simulate saline/fresh water mixing and buoyancy plumes over large (>1 km) distances
- Shortcomings of 2D apparent in high plume concentrations downstream
- Requires three dimensional model for accurate simulation

- **Future work** – model can be extended to include 3D flow features, including:
  - Timed operation of below-water and above-water ballast outlets
  - Lateral flow dispersal and mixing
  - Complex 3D objects such as ship hulls, quays
  - Bathymetric features, eg. variable channel depth
  - Free surfaces
  - Spatially and time-varying tidal currents