Transport and Retention Processes and Their Water Quality Implications in the Middle–Lower Rappahannock River

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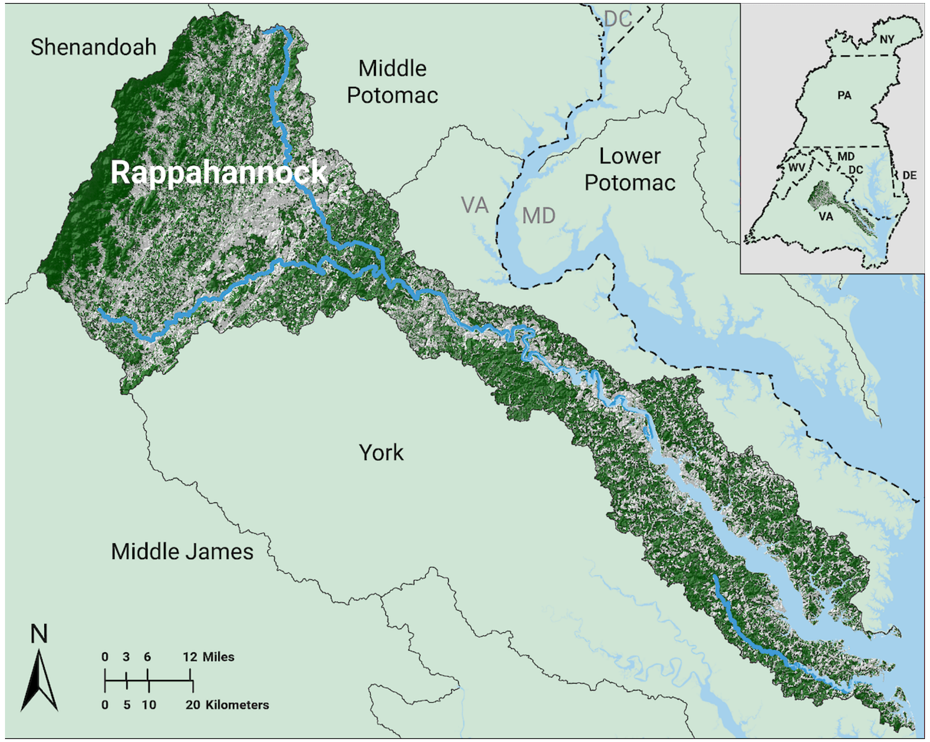
Introduction

- The Rappahannock River is the longest free-flowing river in Virginia
- Few studies on the water quality
  - Kuo and Neilson (1987):

    hypoxia in the lower portion, which is affect by the exchange between the river and the bay
  - Llansó (1992): hypoxia impacts the benthic community
  - Moore et al. (2001): SAV has been degrading
  - Devereux et al. (2021) – EPA CBP study:

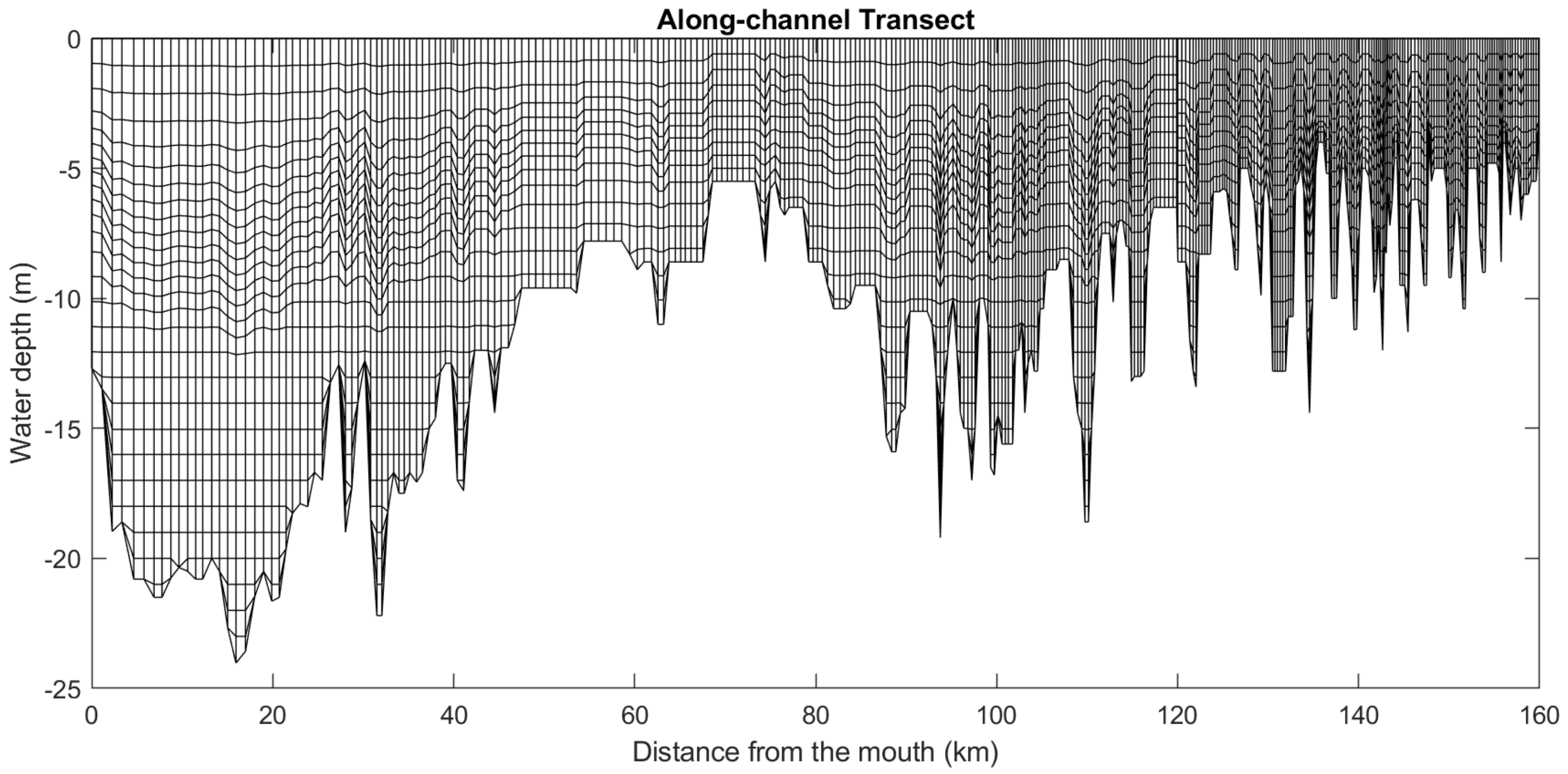
    summer bottom oxygen have degraded in the lower river over 1985-2018;

    long-term trends of other water quality state variables

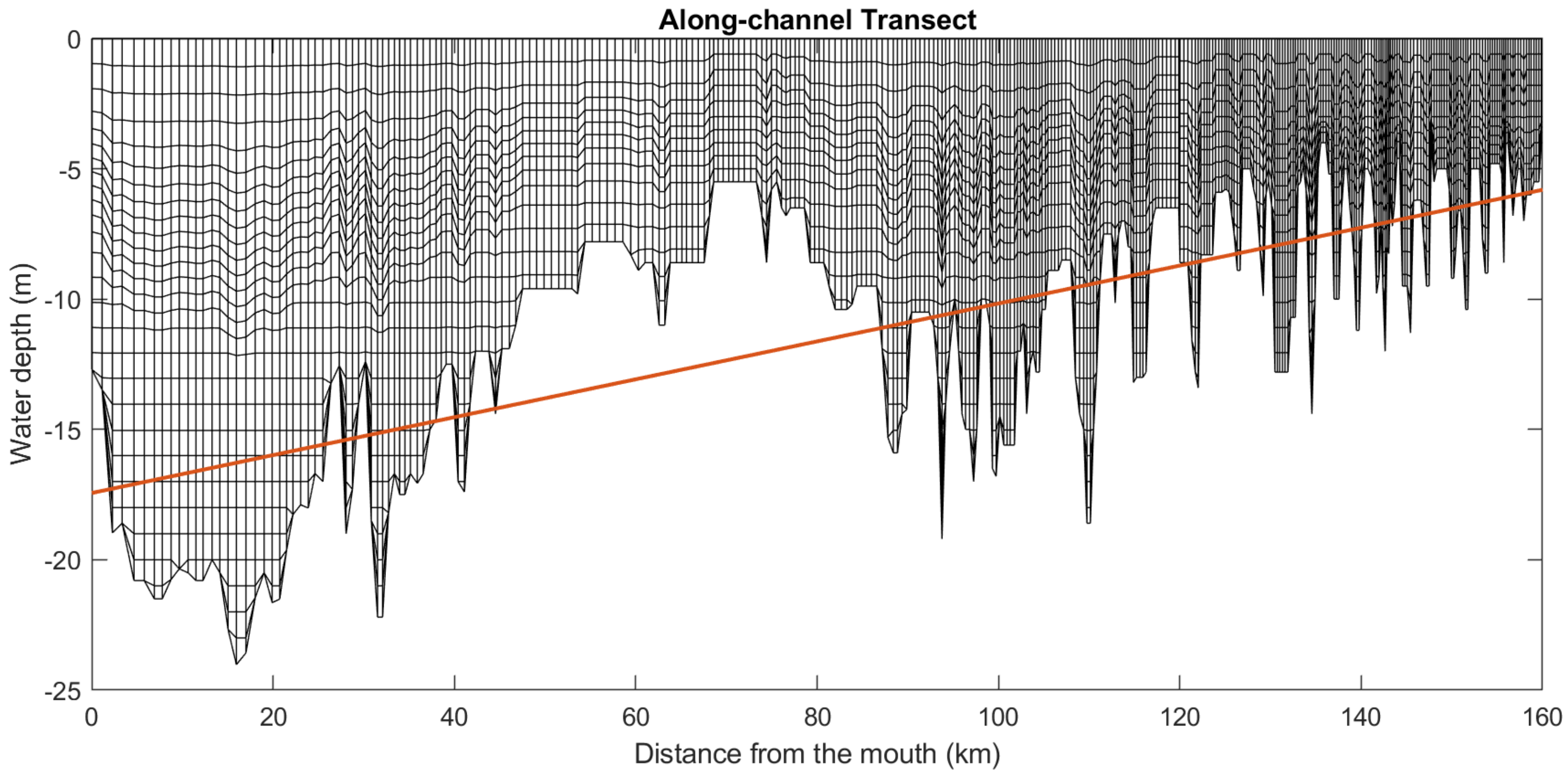


https://ecoreportcard.org/report-cards/chesapeake-bay/watershed-regions/rappahannock/

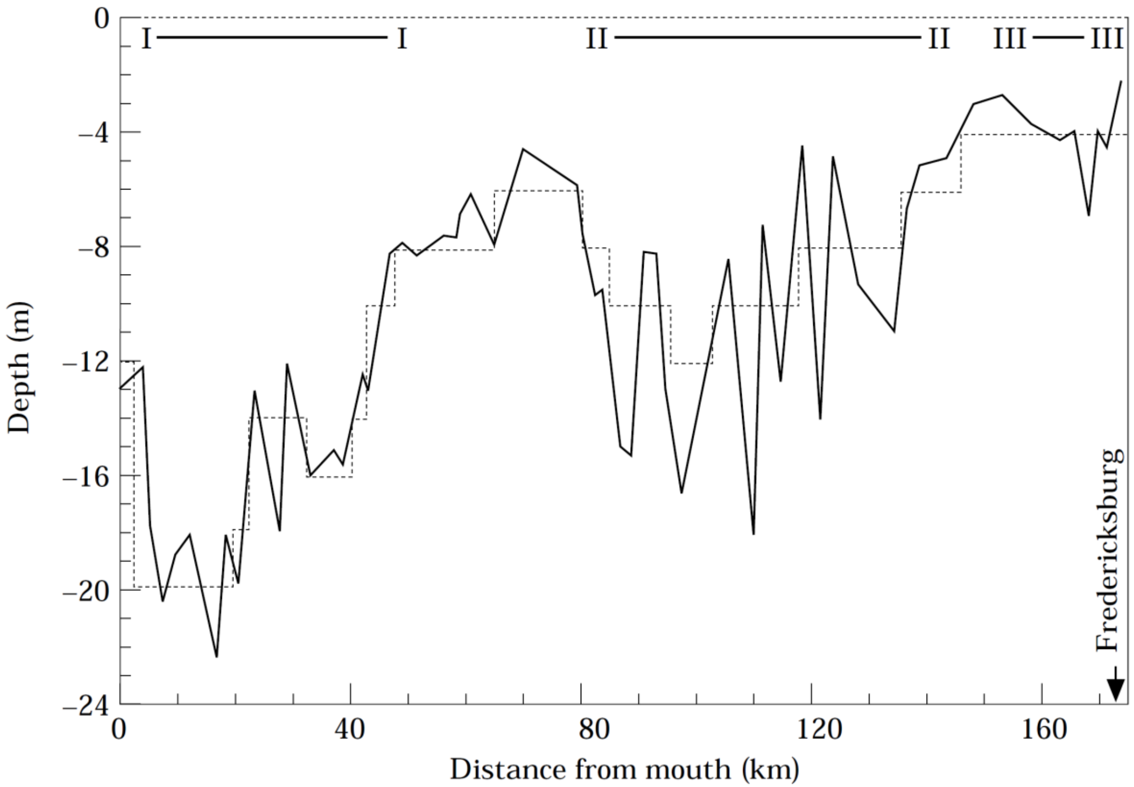
The shallow region in the middle-lower Estuary



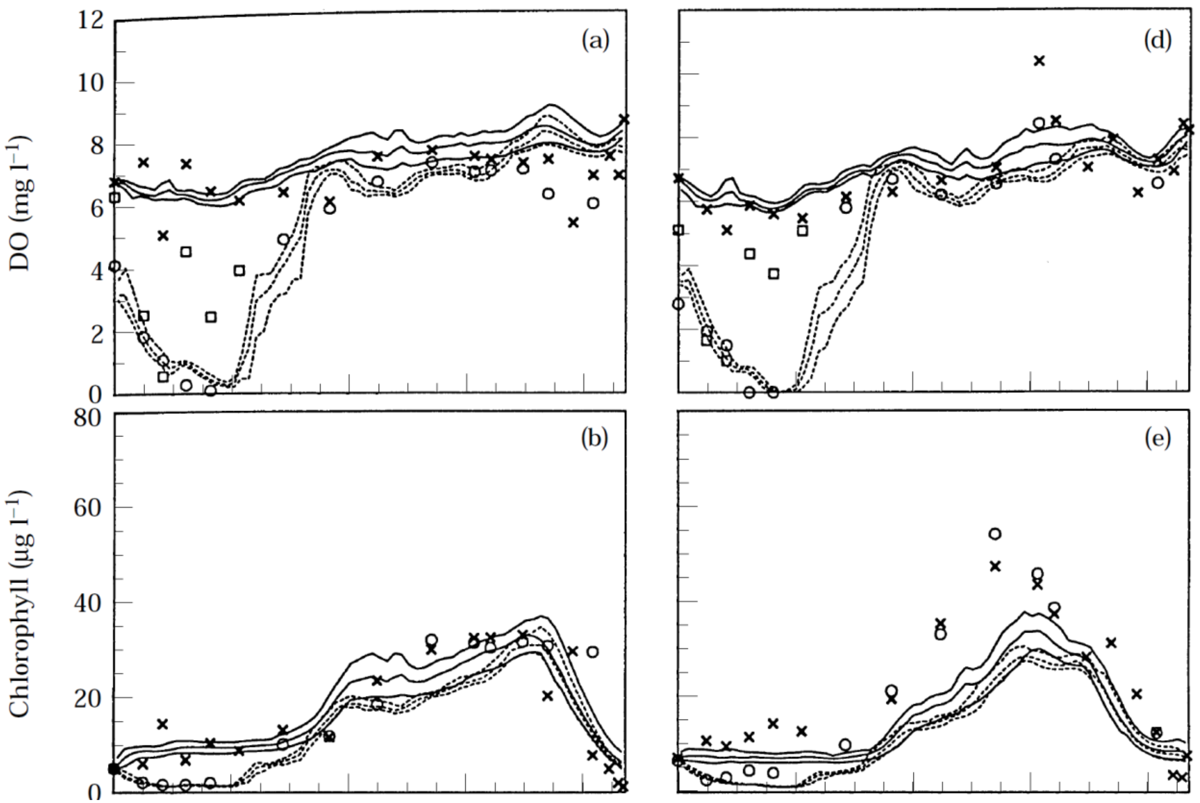
The shallow region in the middle-lower Estuary



The shallow region has been suggested to impact water quality



I–I, hypoxic region;
II–II, high chlorophyll region;
III–III, sewage treatment plant dominant region.



Park et al. (1996)

Objective

- Understand the retention and transport conditions due to the presence of a shallow region in the middle river

Methods

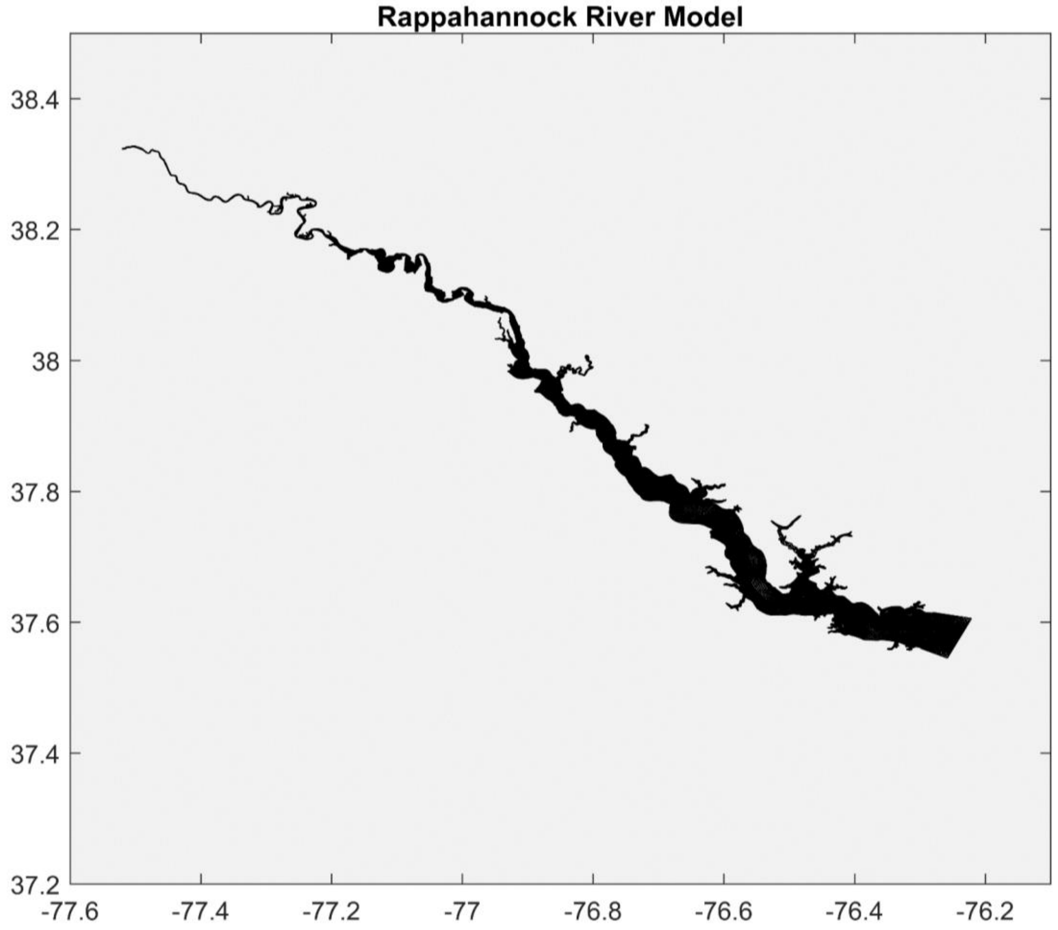
Hydrodynamics scenarios: Baseline vs Dredging – removal of the shallow region

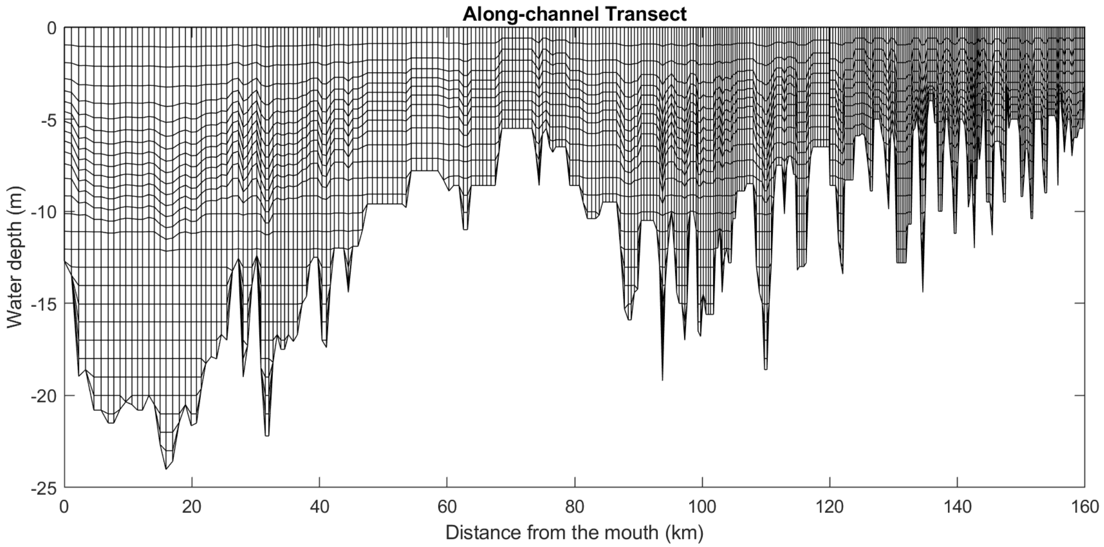
Examine salinity distribution – material enters the river from the mouth

Particle tracking modeling – material enters the river from the head

- Passive particles
- Sinking particles with different velocities.

The Rappahannock River Model

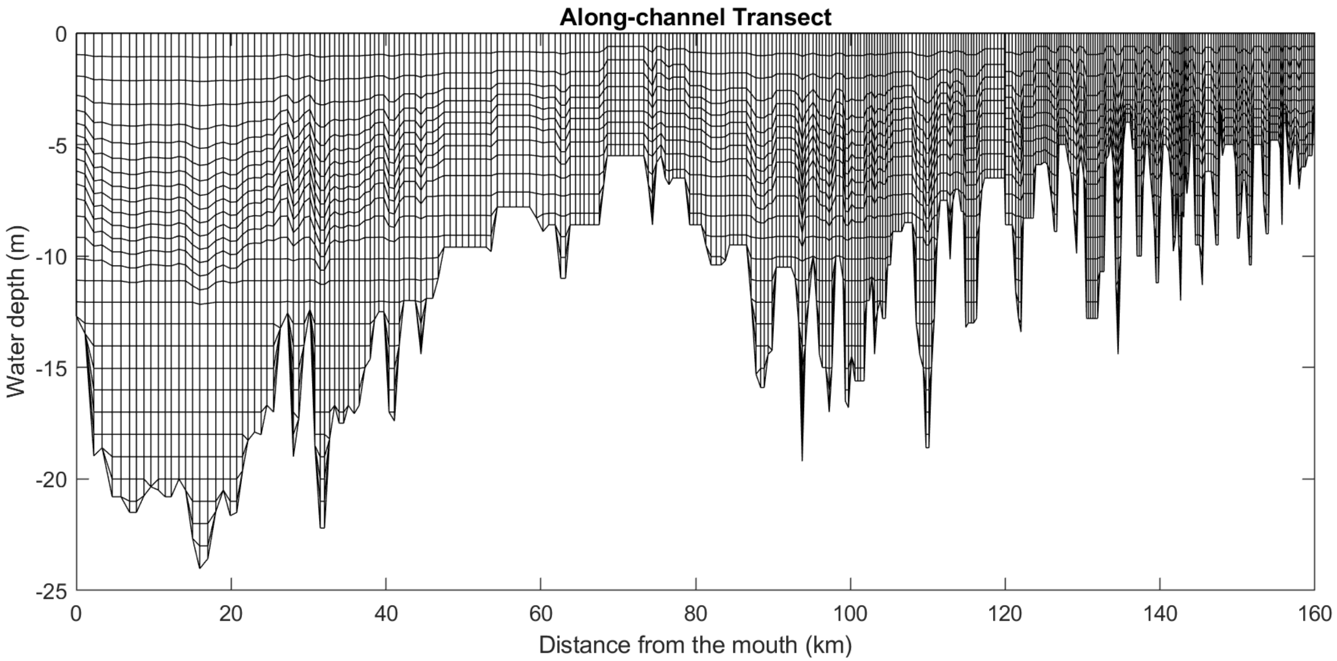


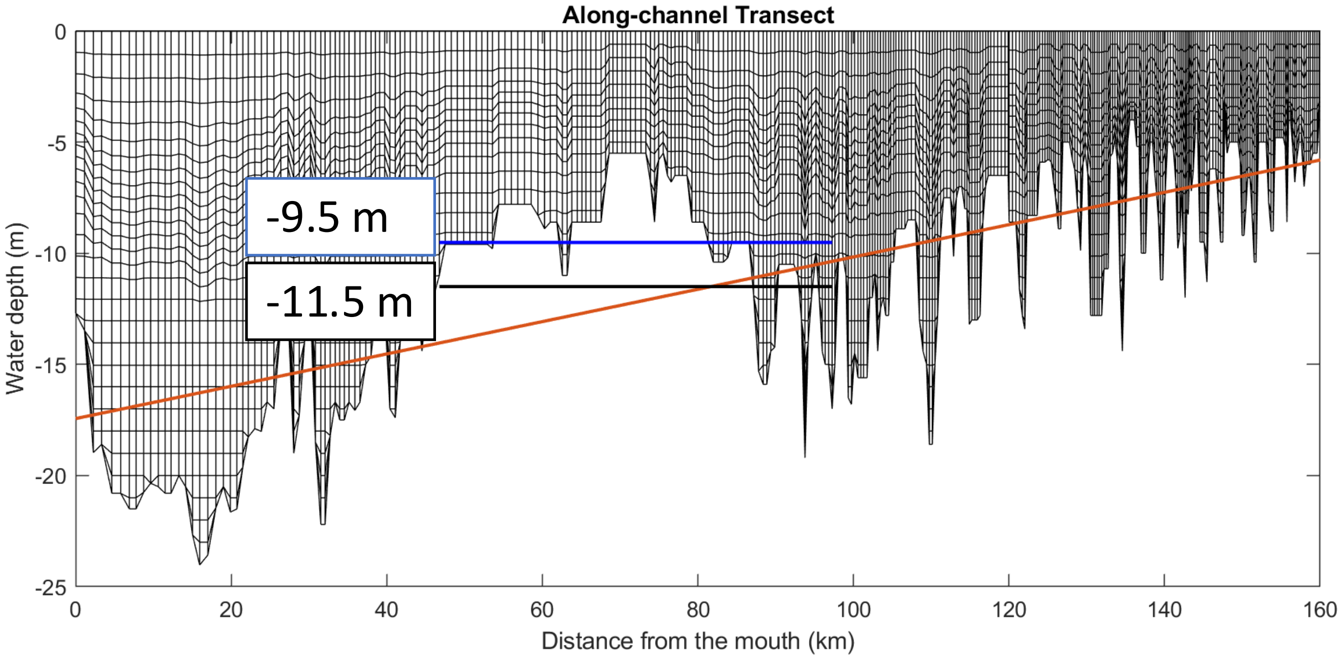


Mouth

Head

Methods: Dredging

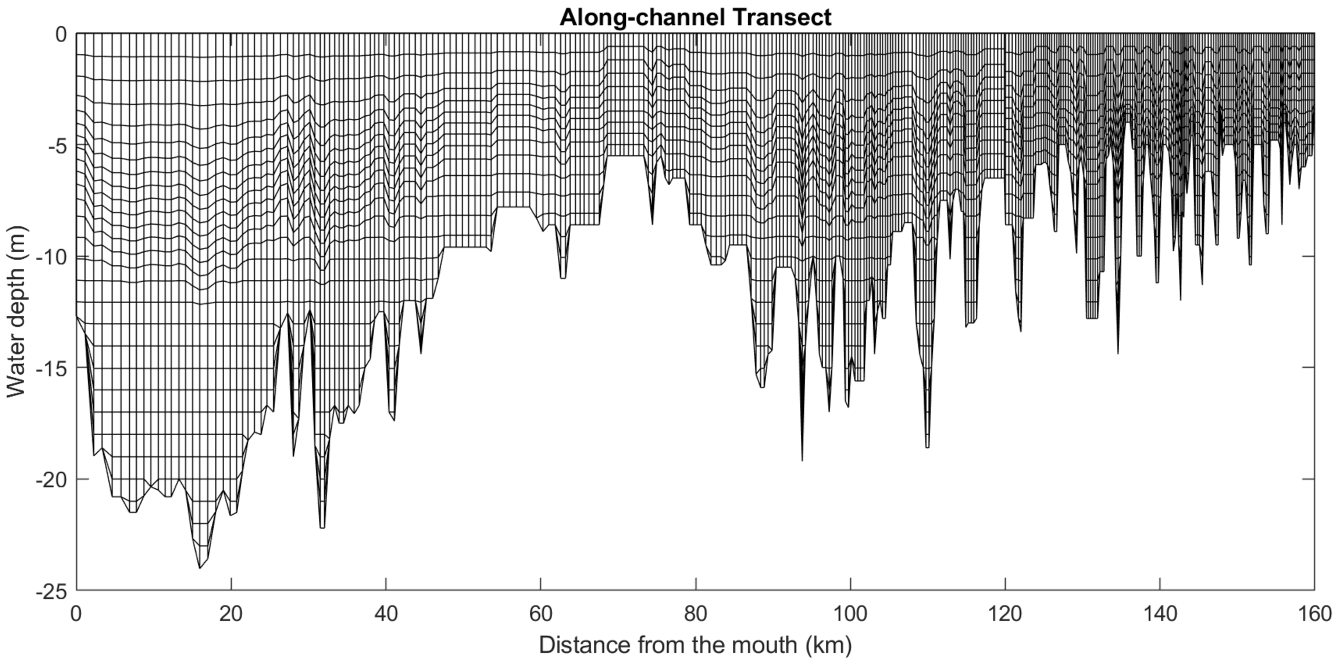


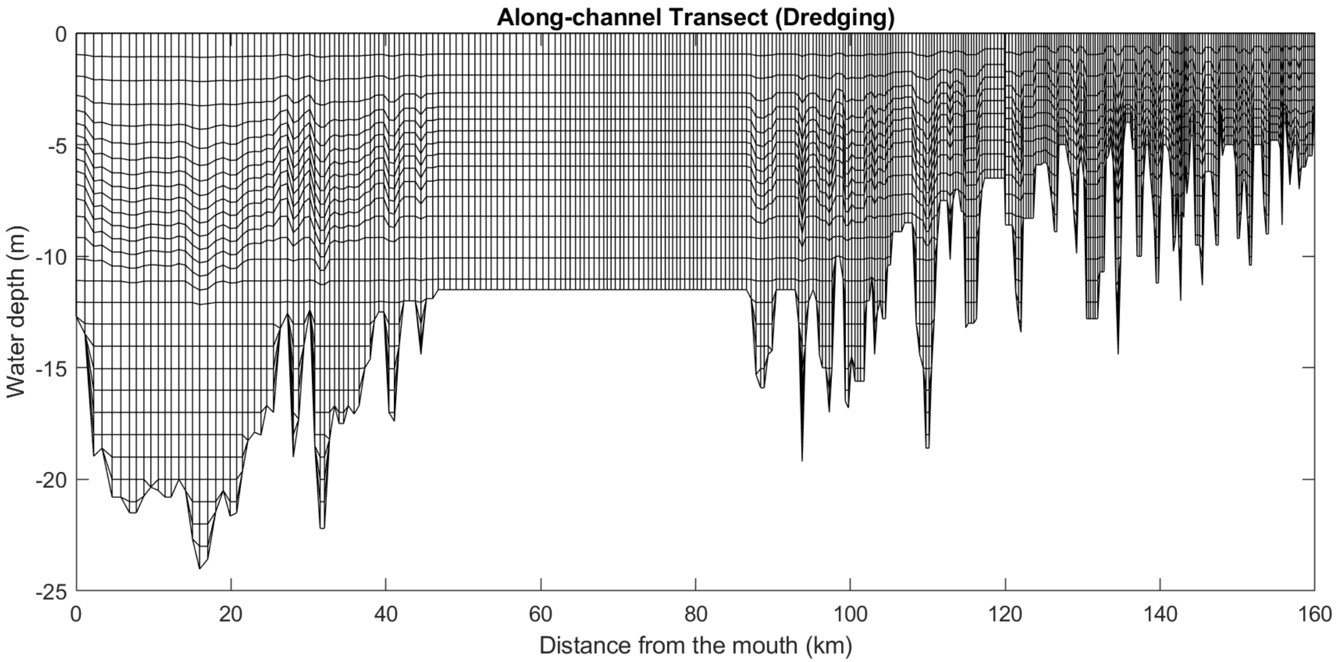


Methods: Dredging

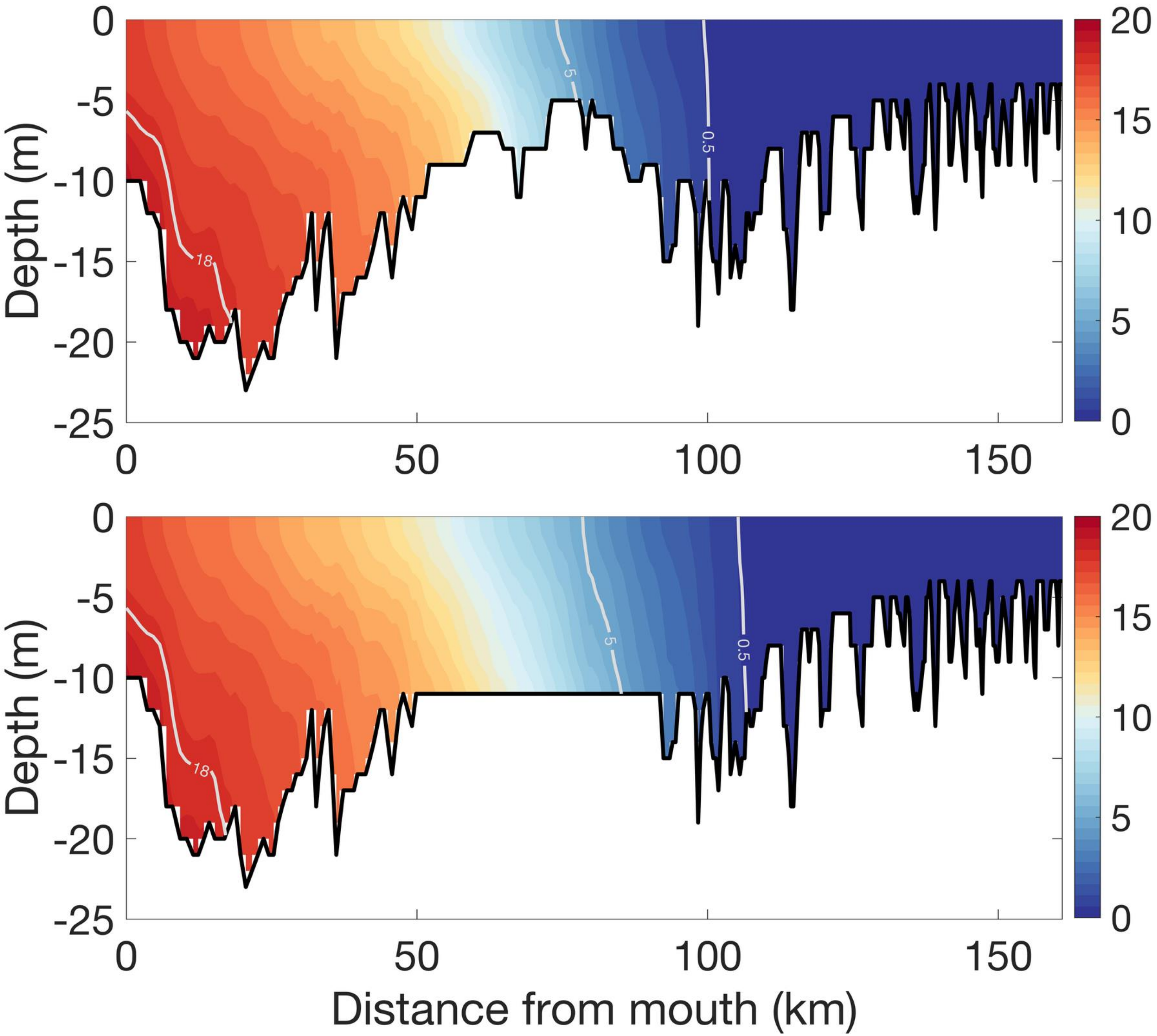
Run hydrodynamics models for Year 2010

Examine salinity distribution

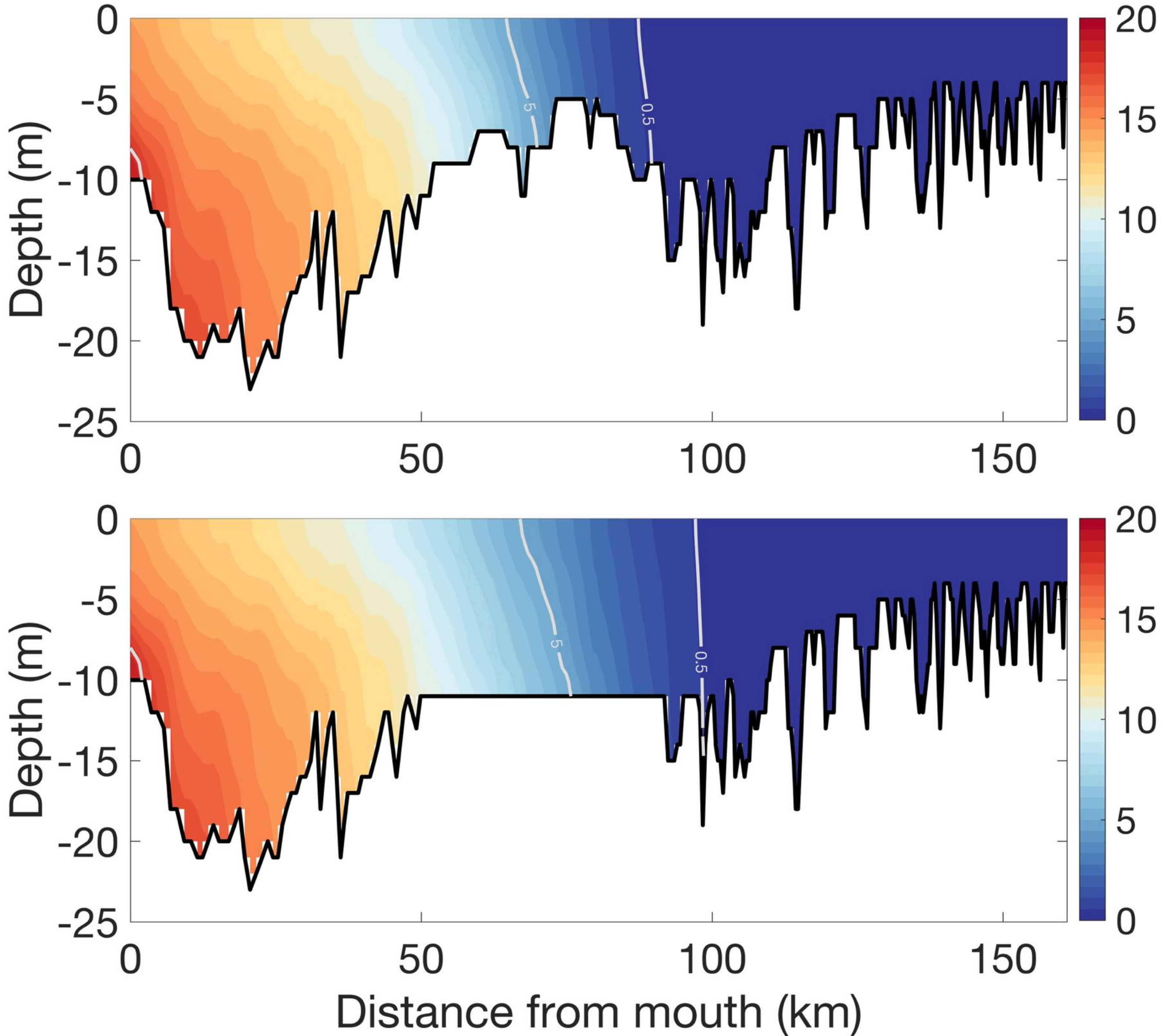




Salinity
Jan-Mar Average

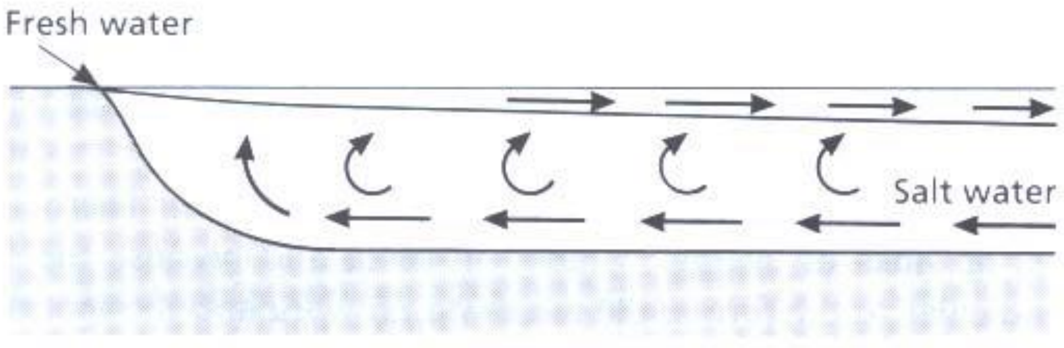


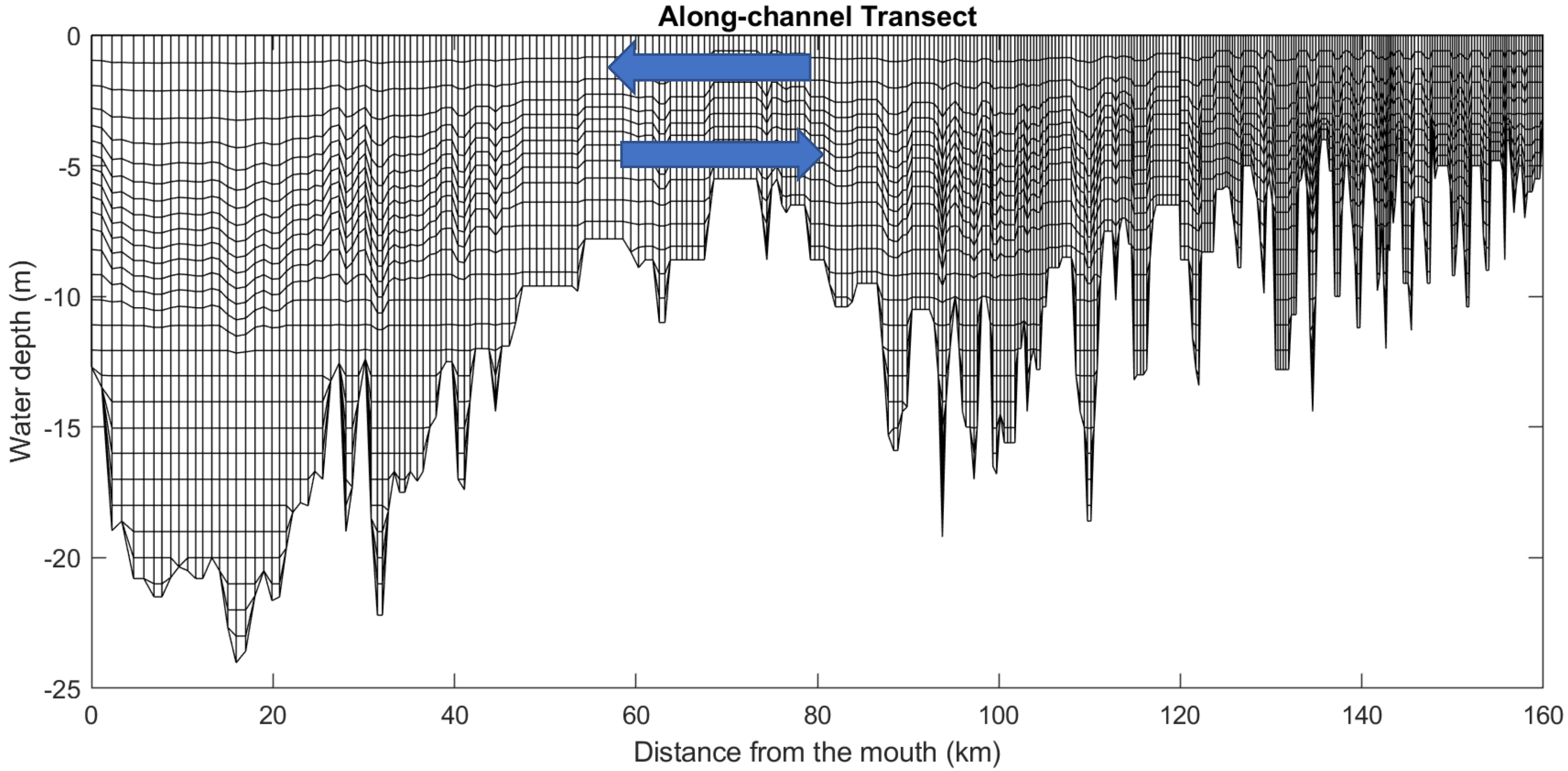
Salinity
Jun-Aug Average



Gravitational Circulation

$U \sim h^3$





Mann & Lazier (1991)

Gravitational Circulation

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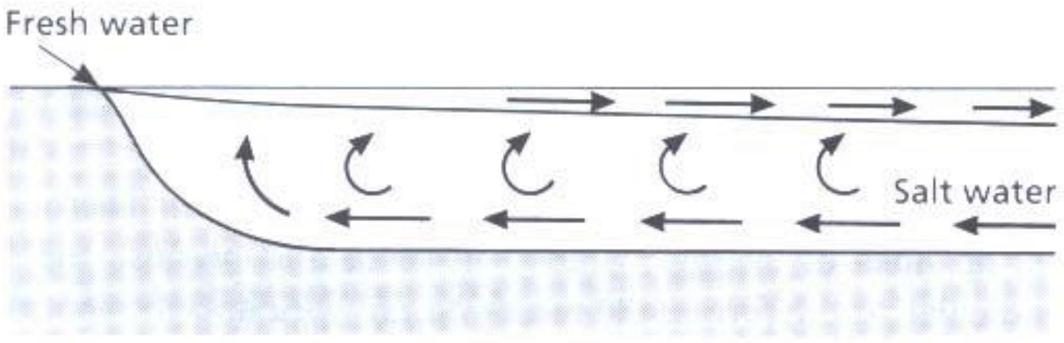
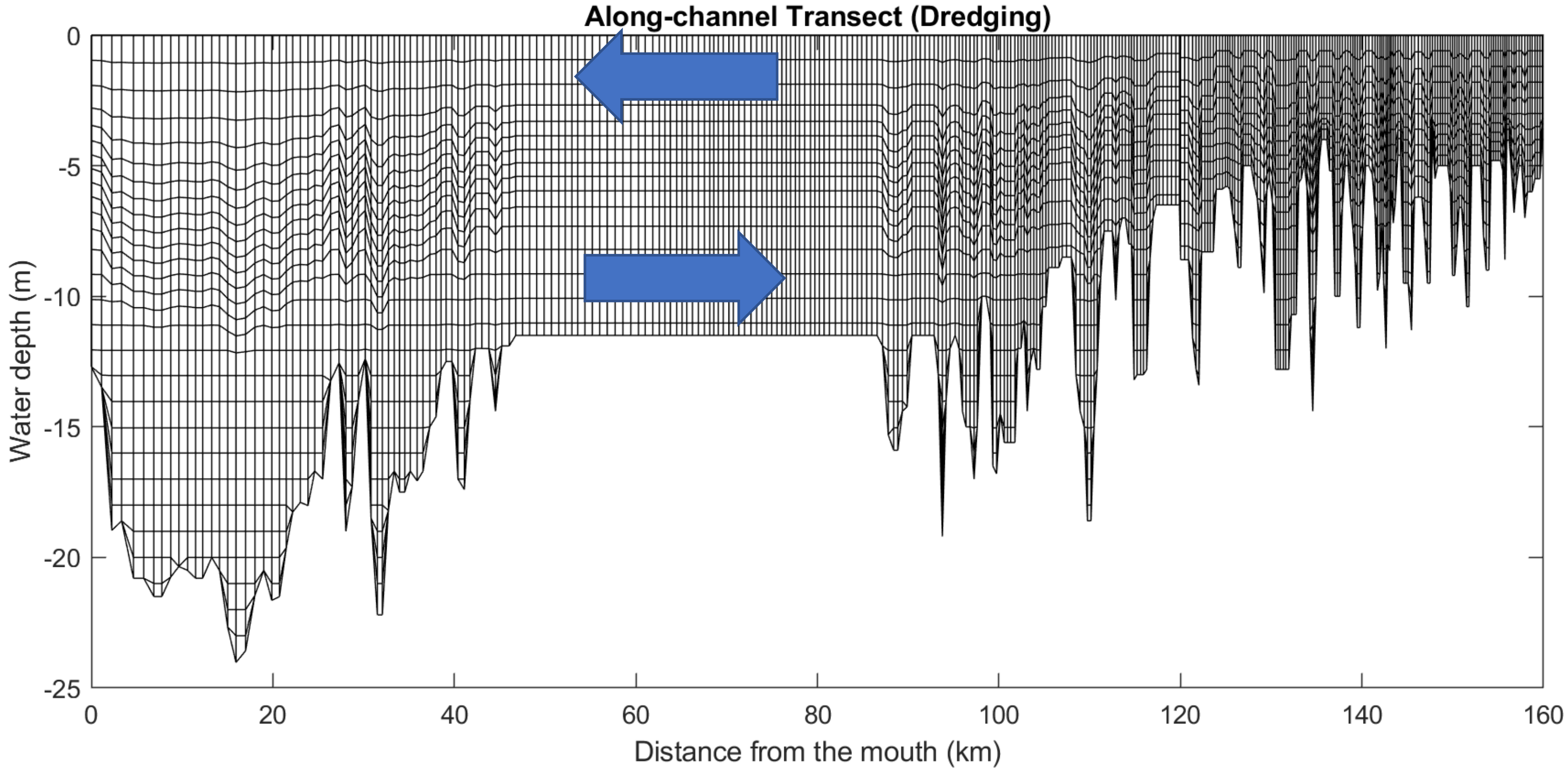
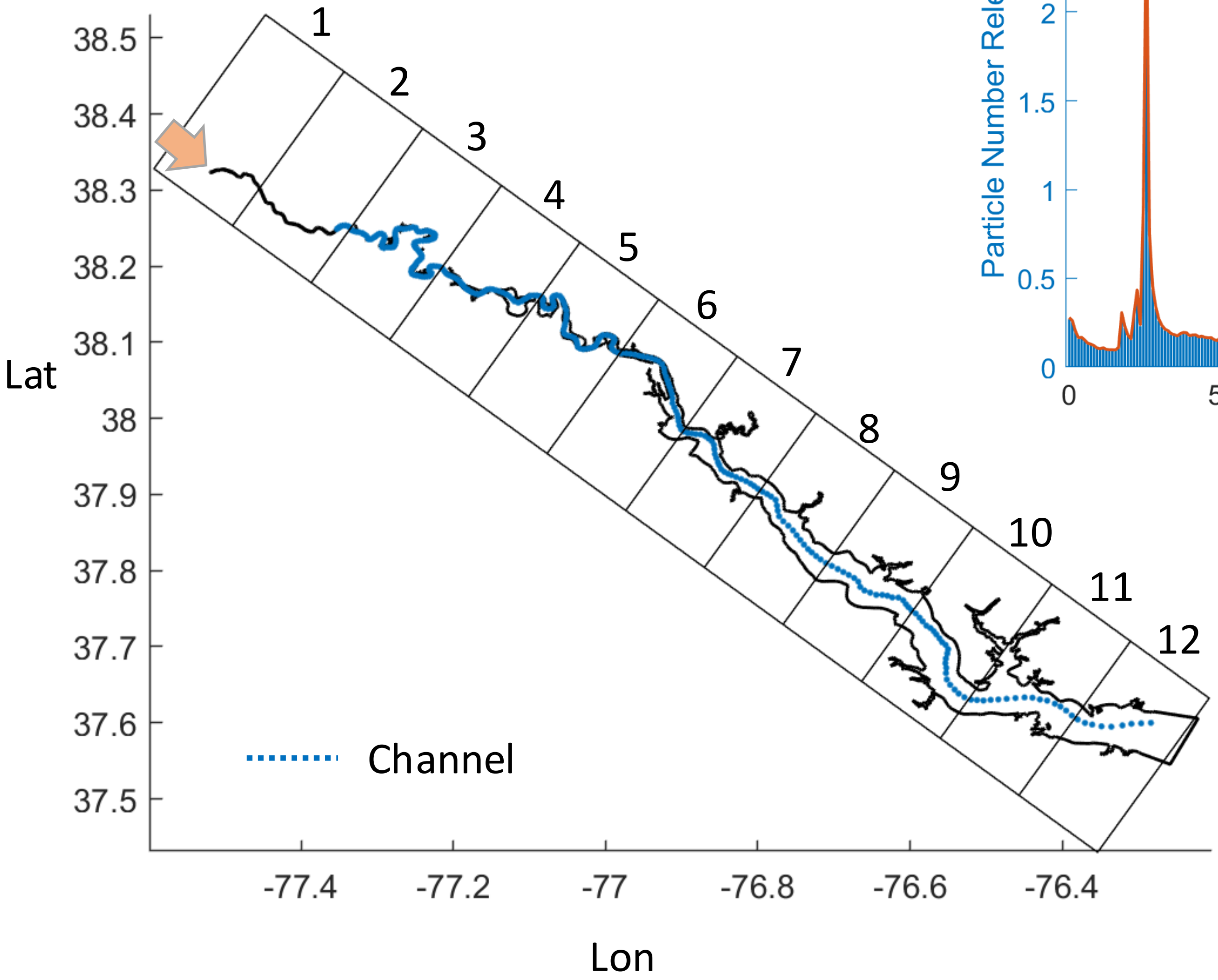
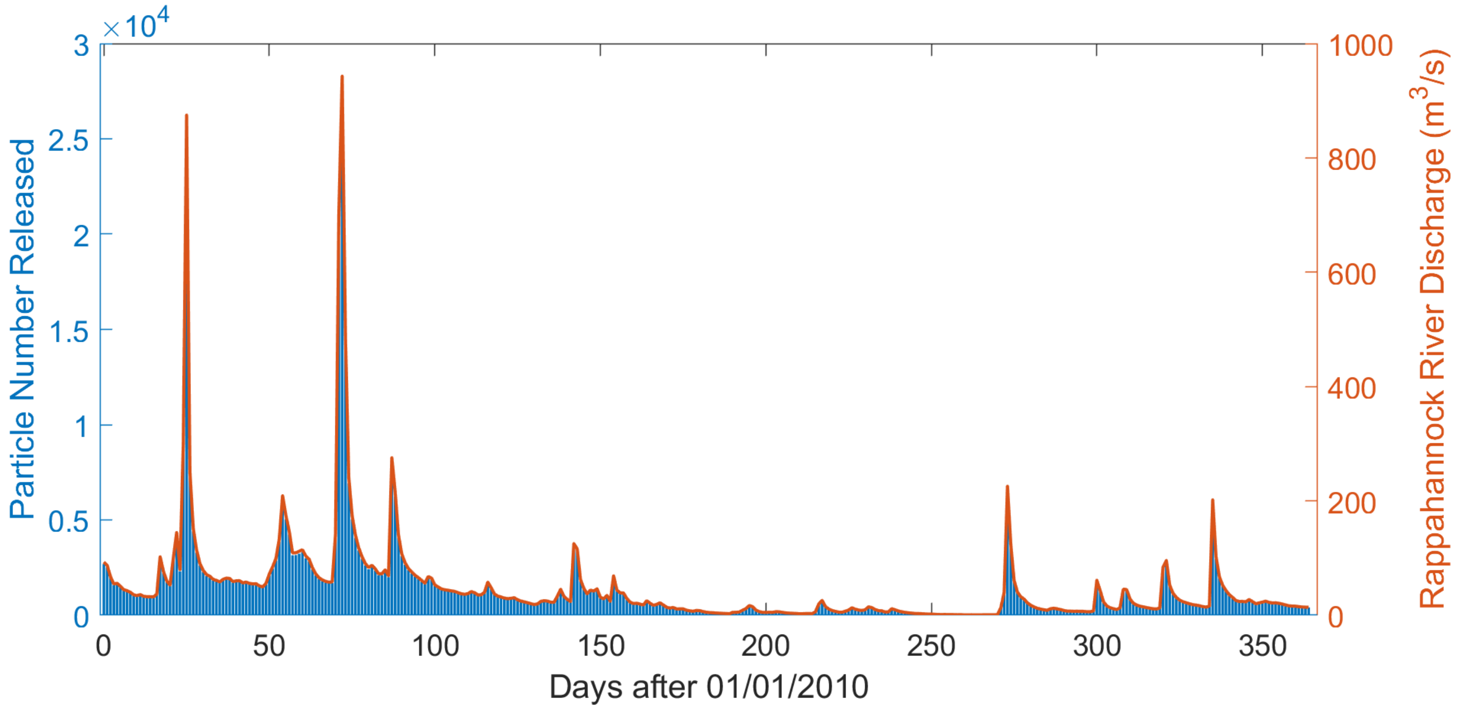


Mann & Lazier (1991)



Methods: Particle Tracking





- Release about 500,000 particles continuously for 365 days from the head of the river, proportional to river discharge (representing watershed derived materials);

- Divide the Rappahannock River into 12 segments along the direction of the channel; and

- Calculate mean particle age for each segment.

Methods: Particle Tracking

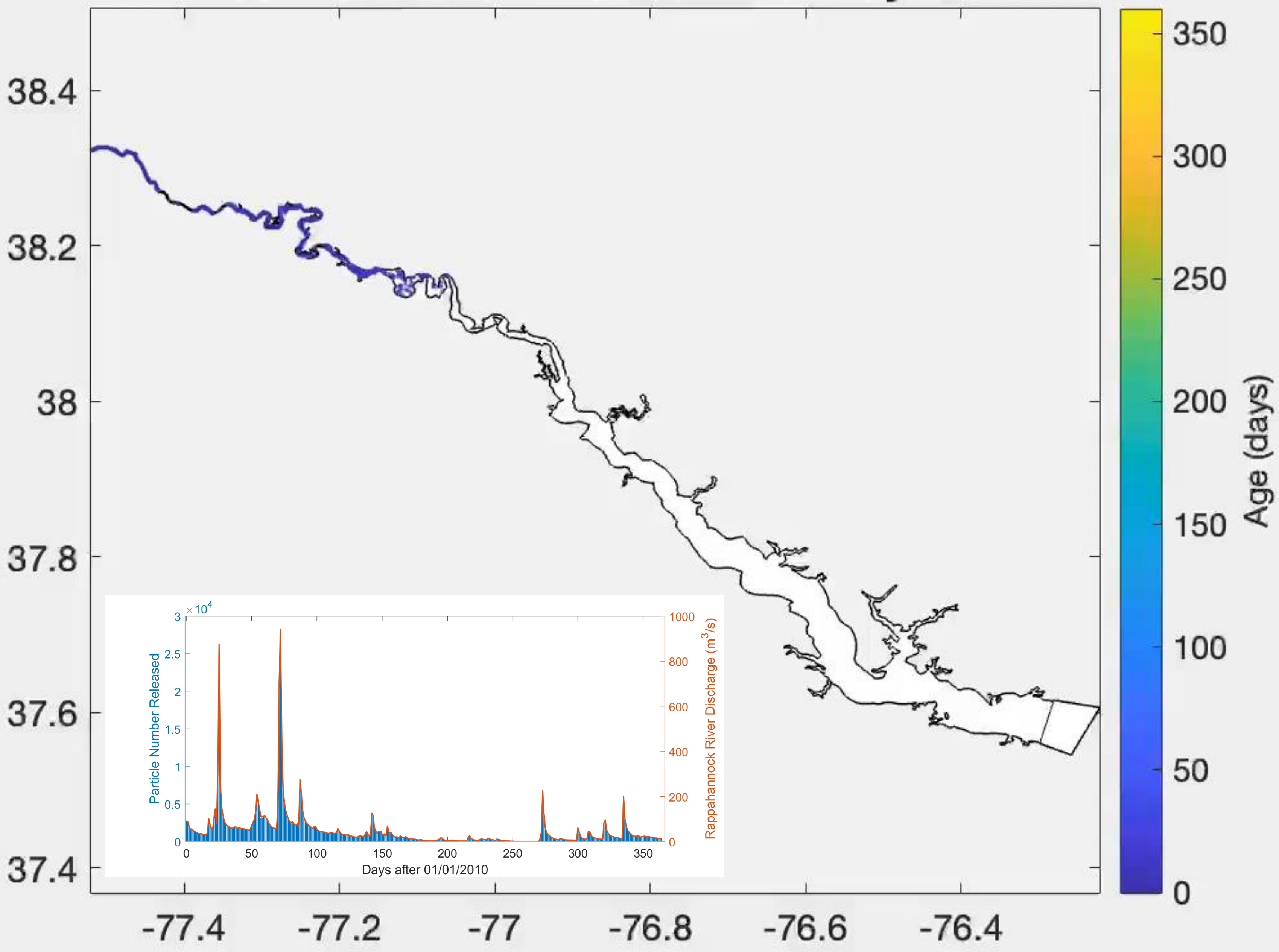
Particle Tracking Model Scenarios

Table. Particles and vertical velocity. Upward (+); downward (-).

Particle	Vertical velocity (cm/s)	
Passive	0	
Active	-0.00001	= -0.0086 m/d
Active	-0.0001	= -0.086 m/d
Active	-0.001	= -0.86 m/d

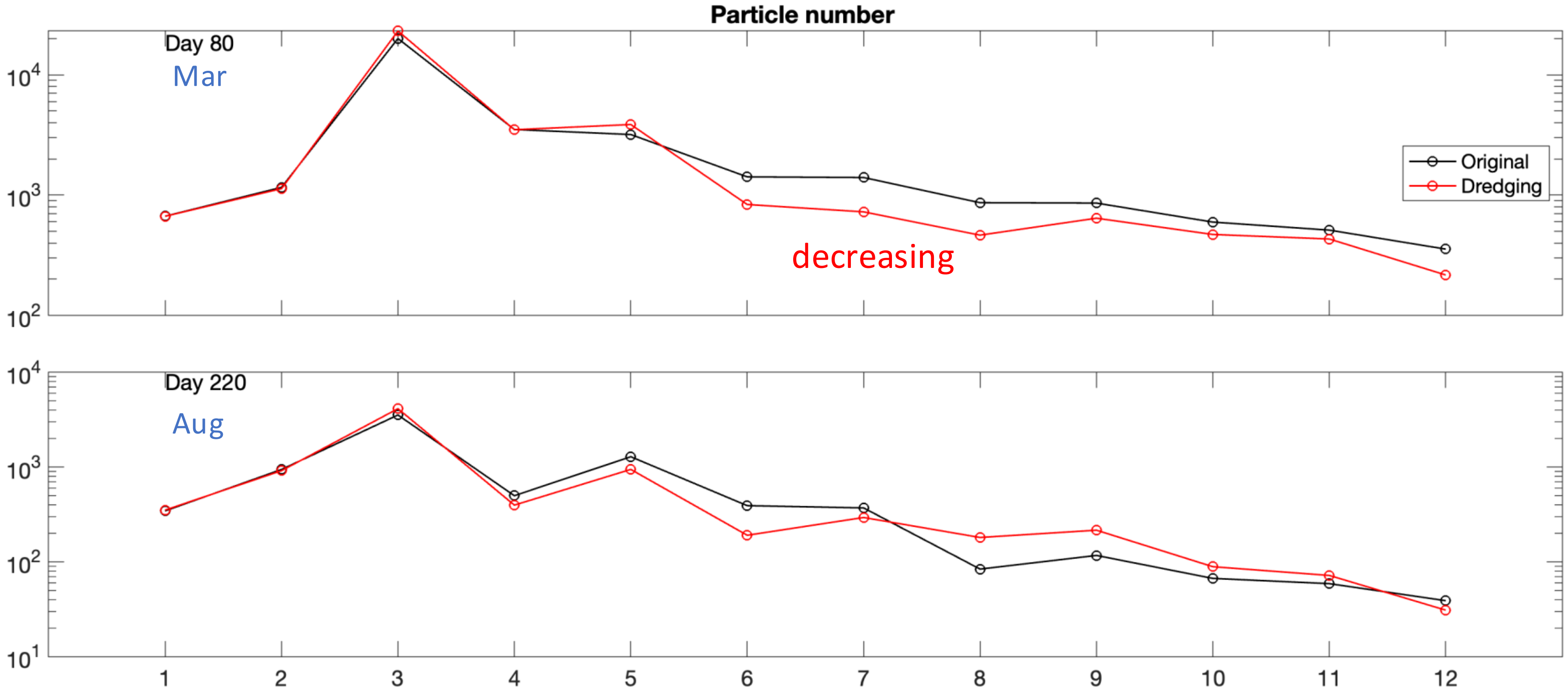
Original Bathymetry Scenarios
Dredging Scenarios

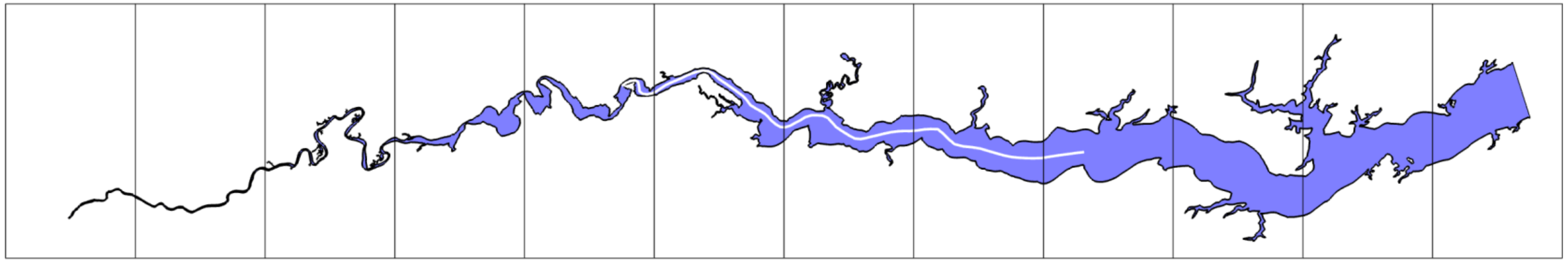
Surface Particle Distribution on Day 10



Surface (< 1 m)

Passive particles

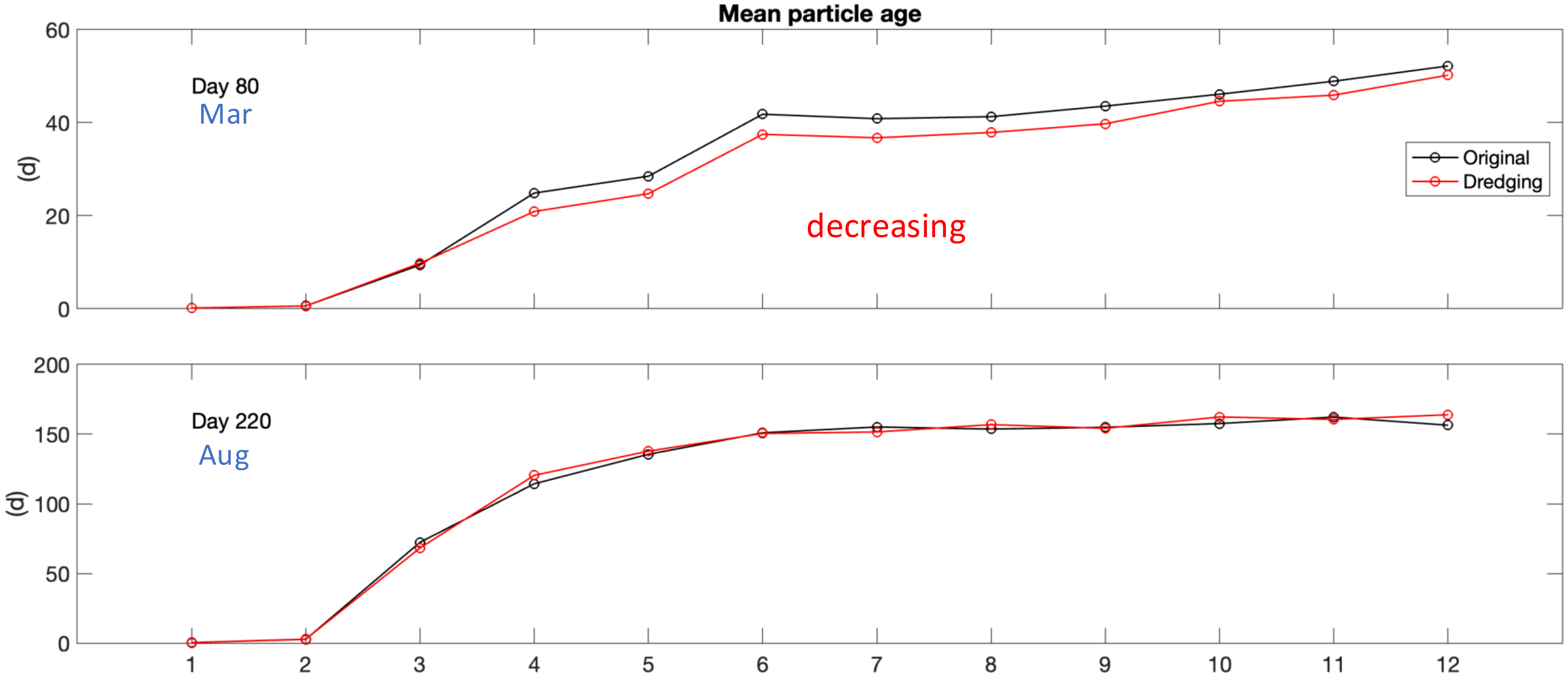


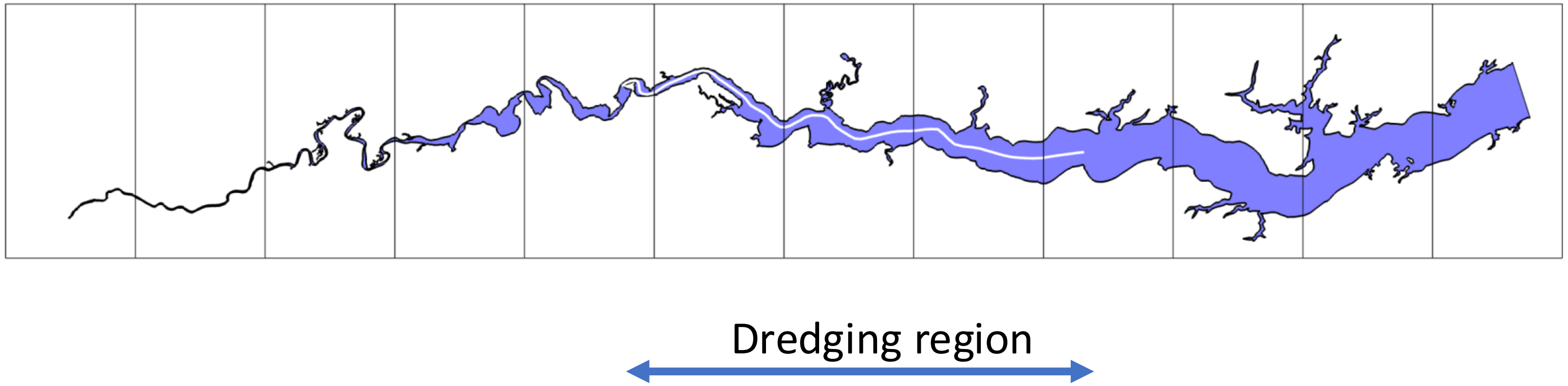


Dredging region

Surface (< 1 m)

Passive particles





Gravitational Circulation

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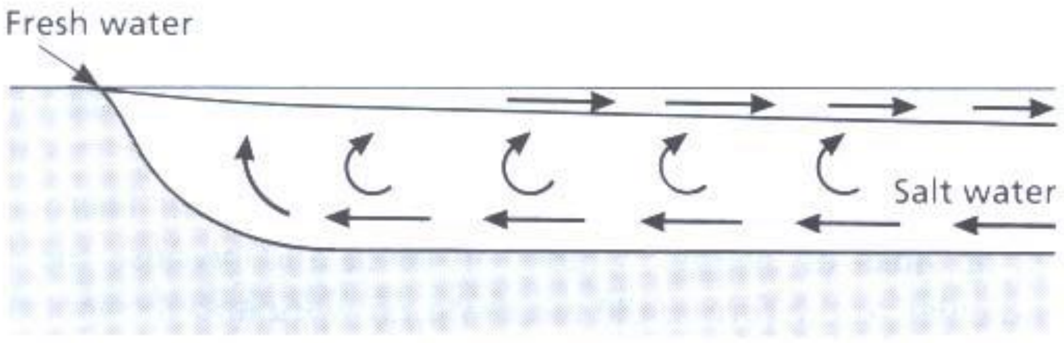
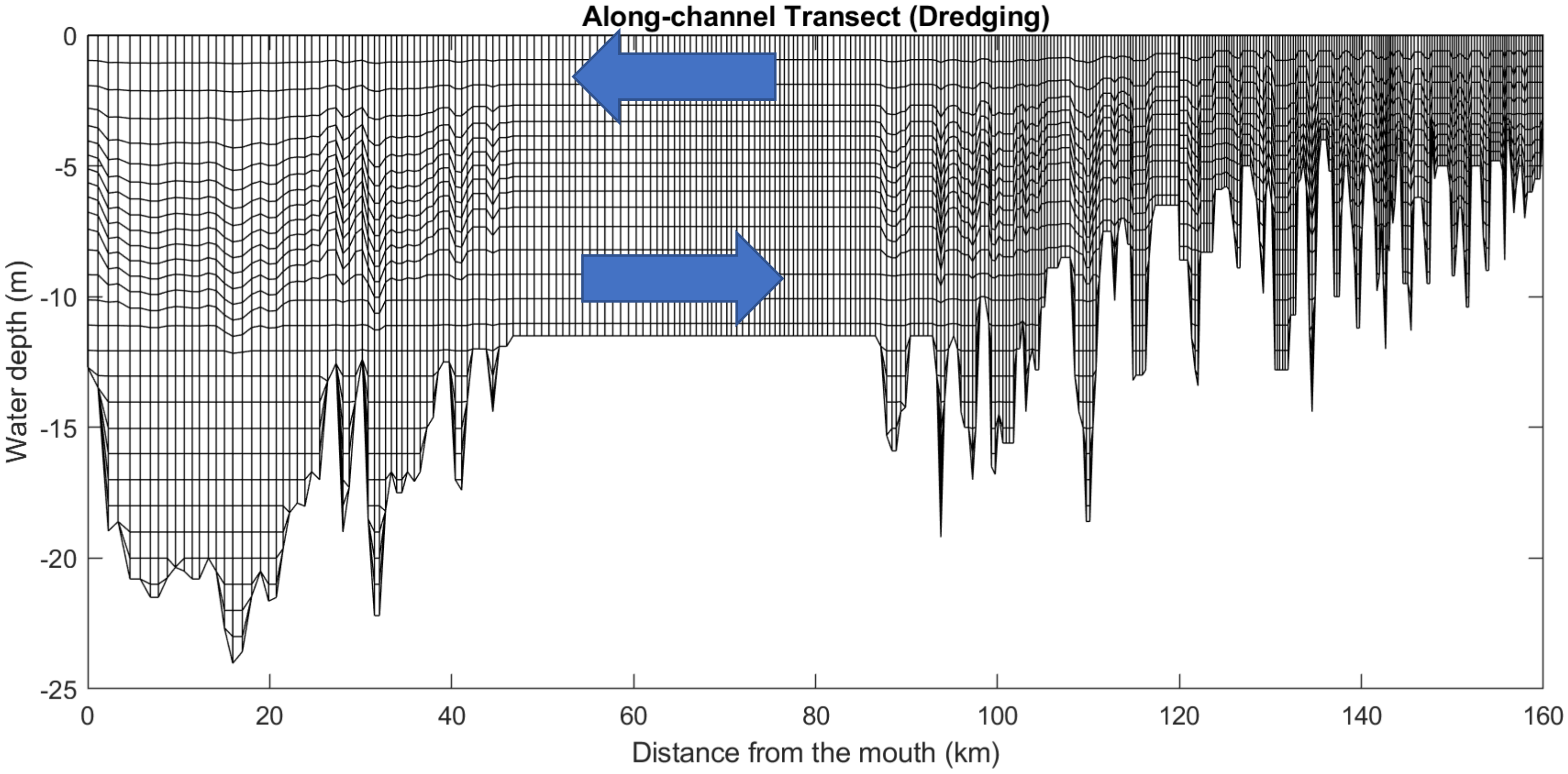
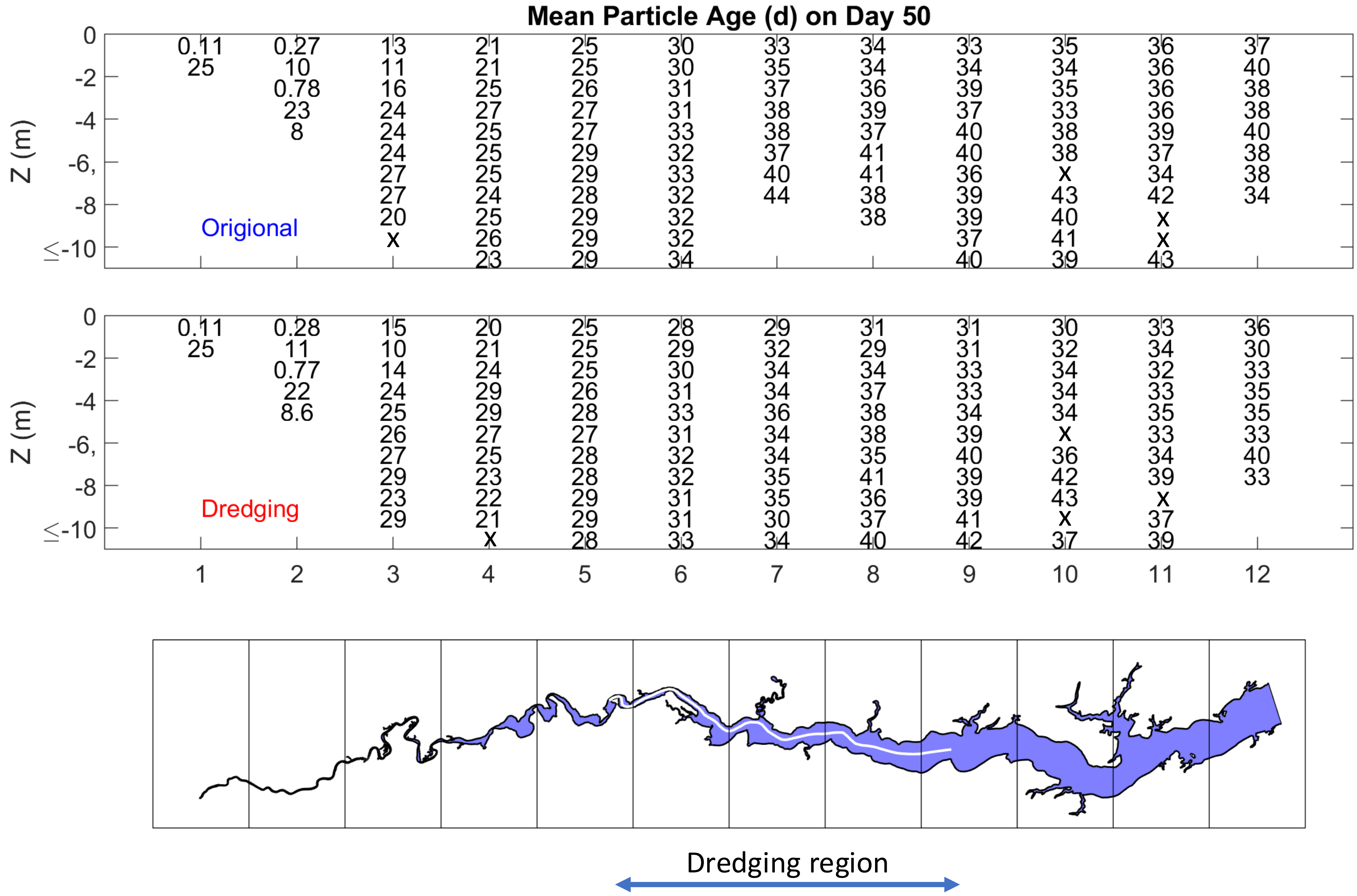


Mann & Lazier (1991)



All depths

Passive particles

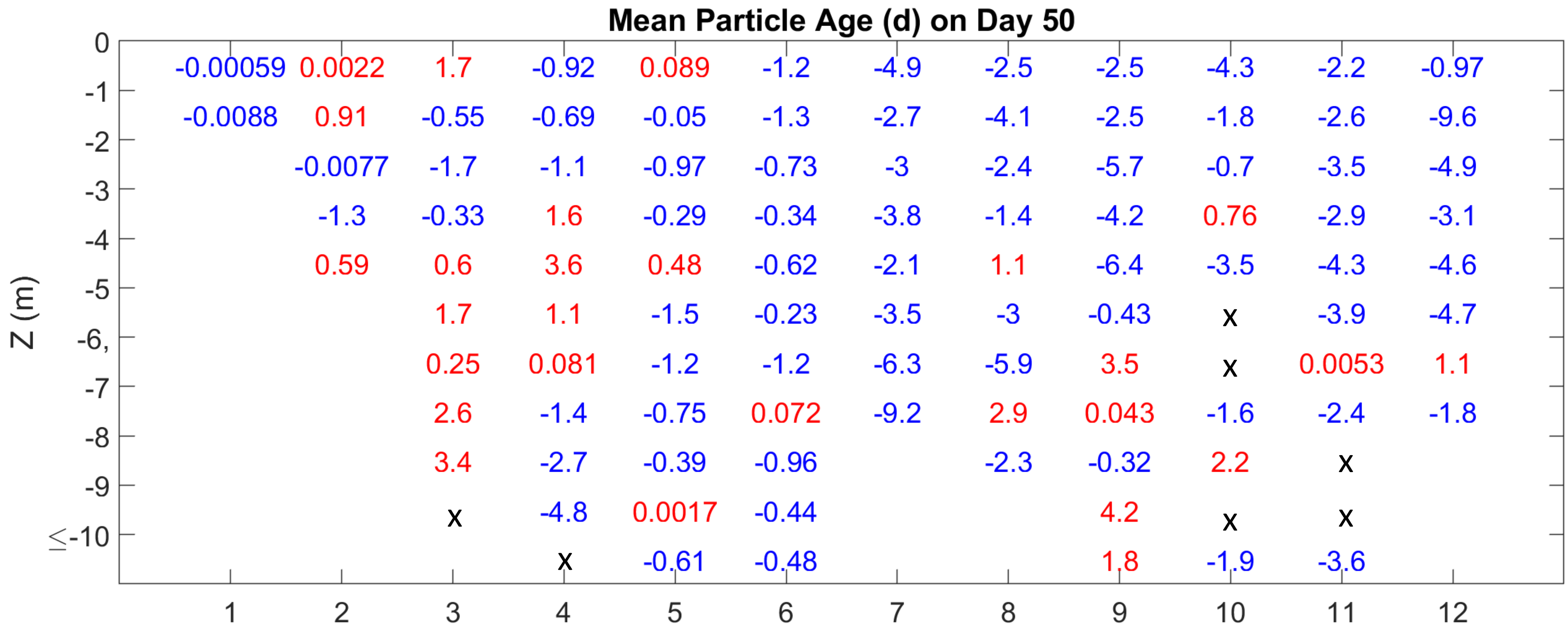


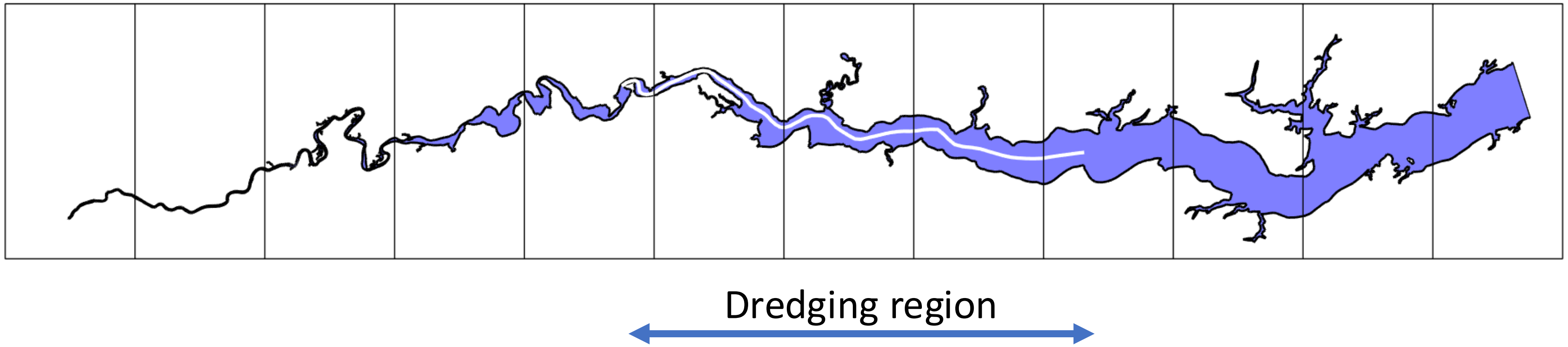
All depths

Passive particles

Age difference

Blue: move faster
Red: slower





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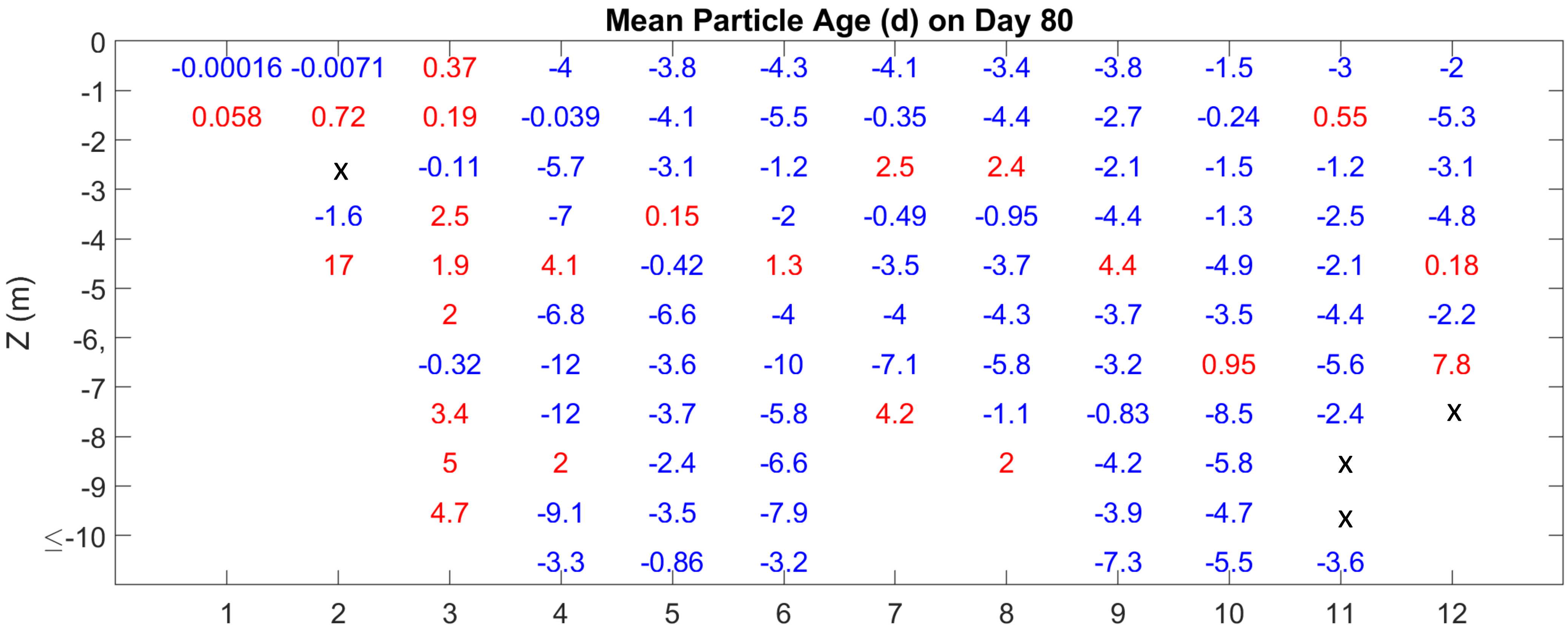
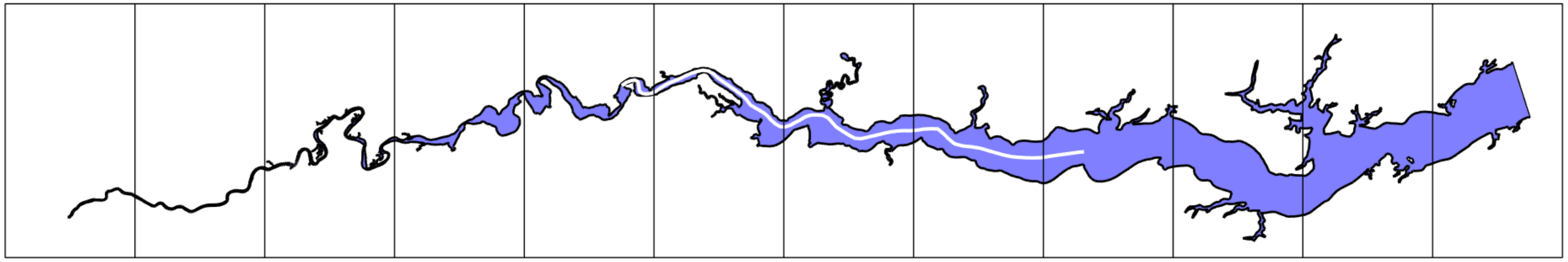
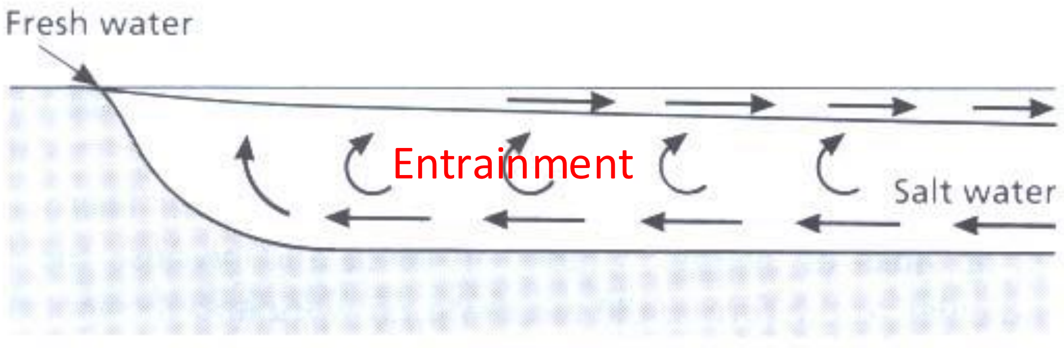


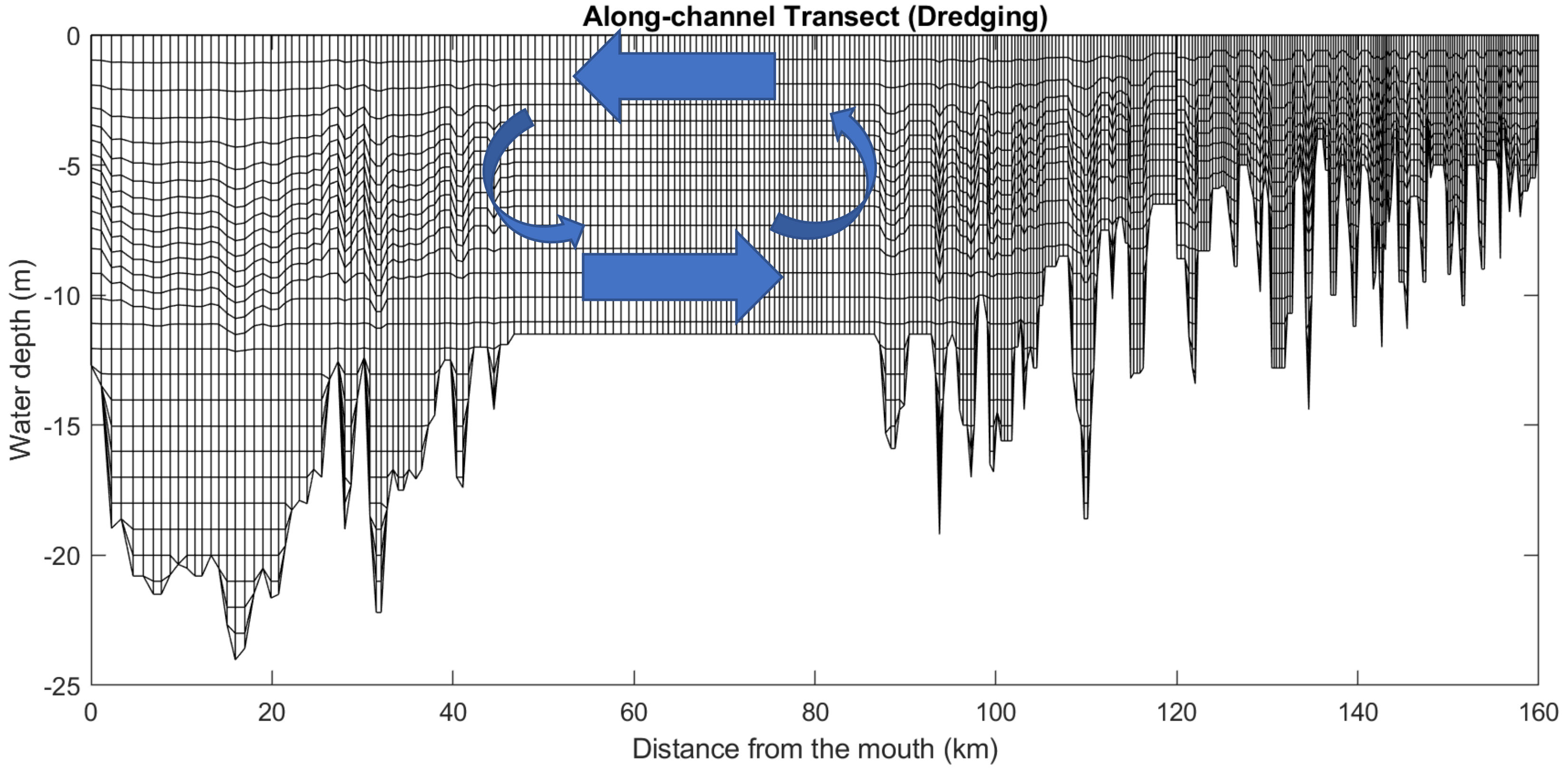


Dredging region

Gravitational Circulation

$U \sim h^3$





Mann & Lazier (1991)

Entrainment reduces the difference between the particle ages in the upper and lower layers of the water column

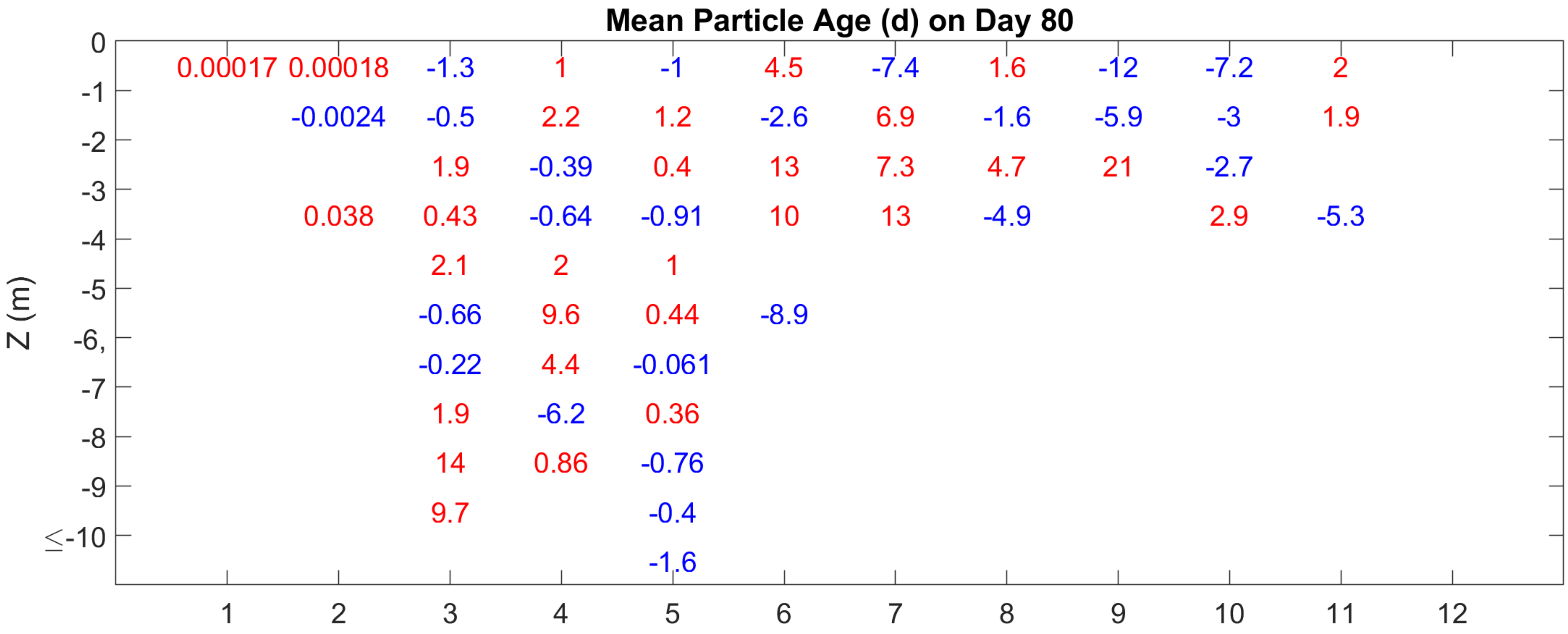
All depths

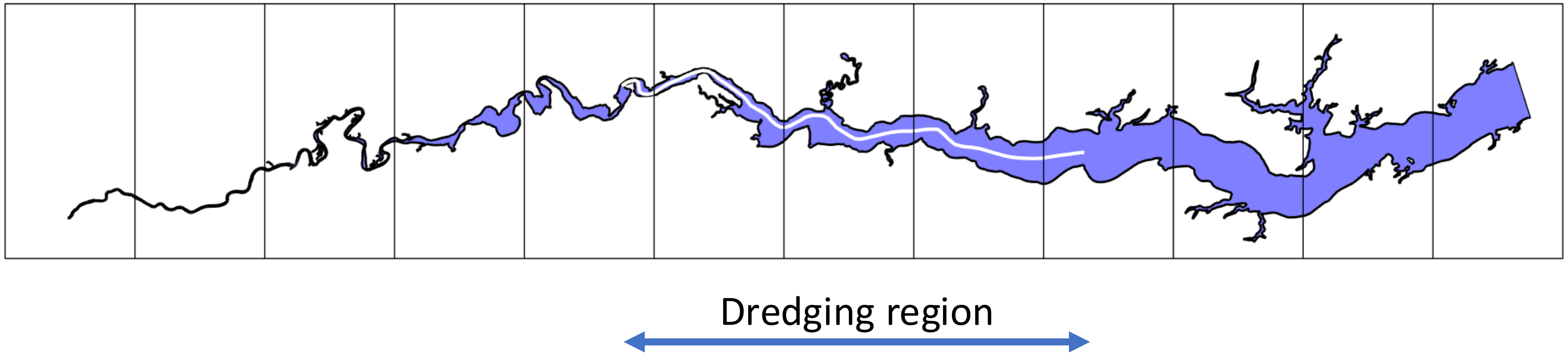
Sinking particles

= -0.0086 m/d

Age difference

Blue: move faster
Red: slower





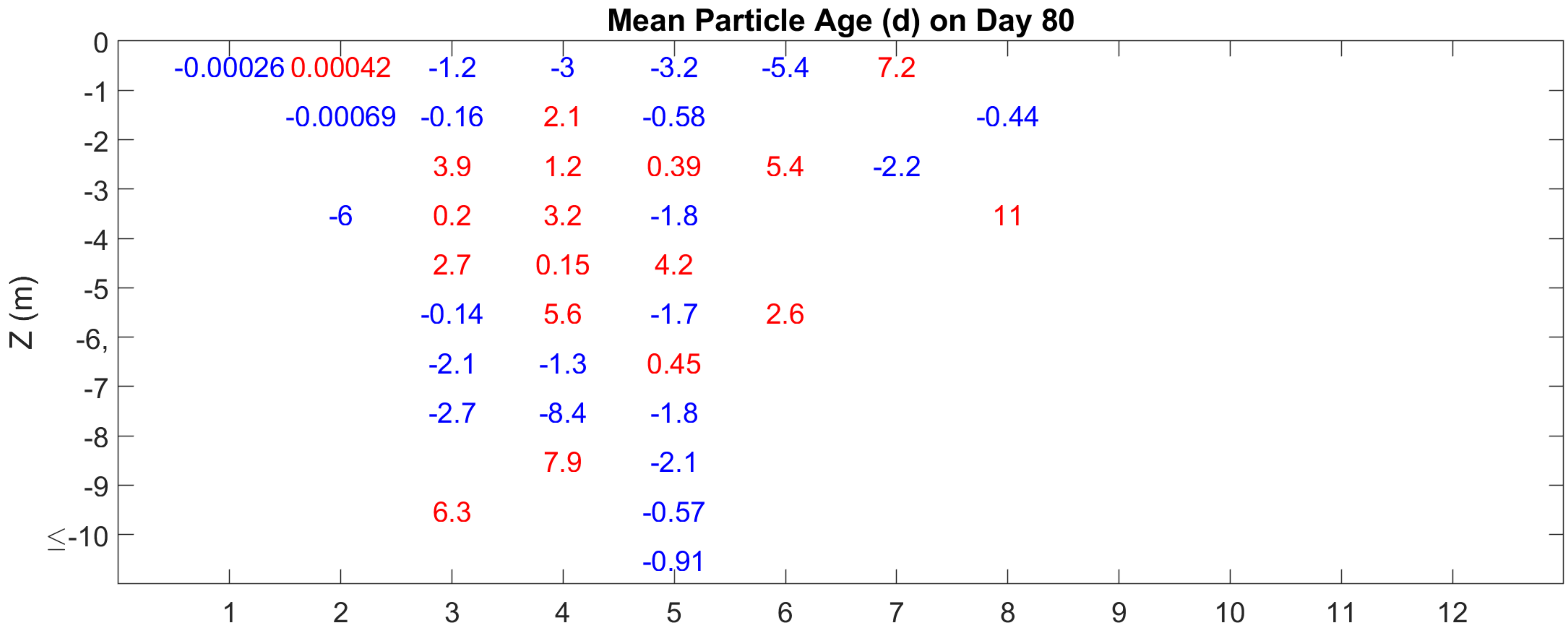
All depths

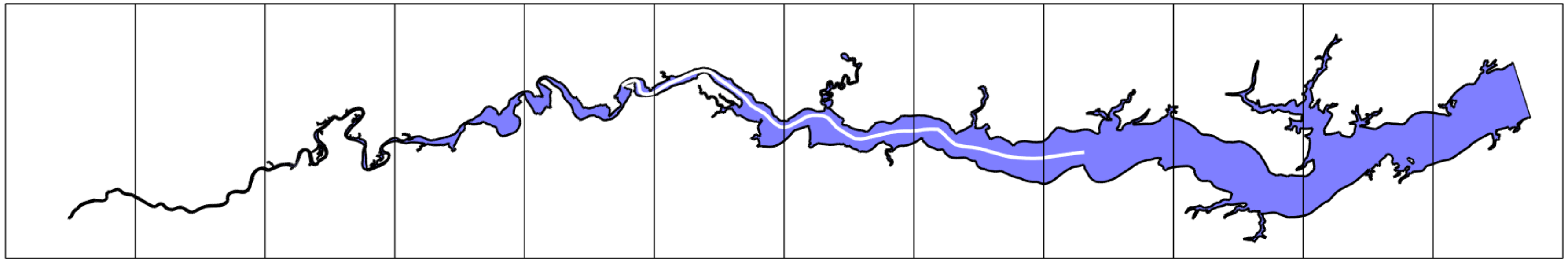
Sinking particles

= -0.086 m/d

Age difference

Blue: move faster
Red: slower





Dredging region

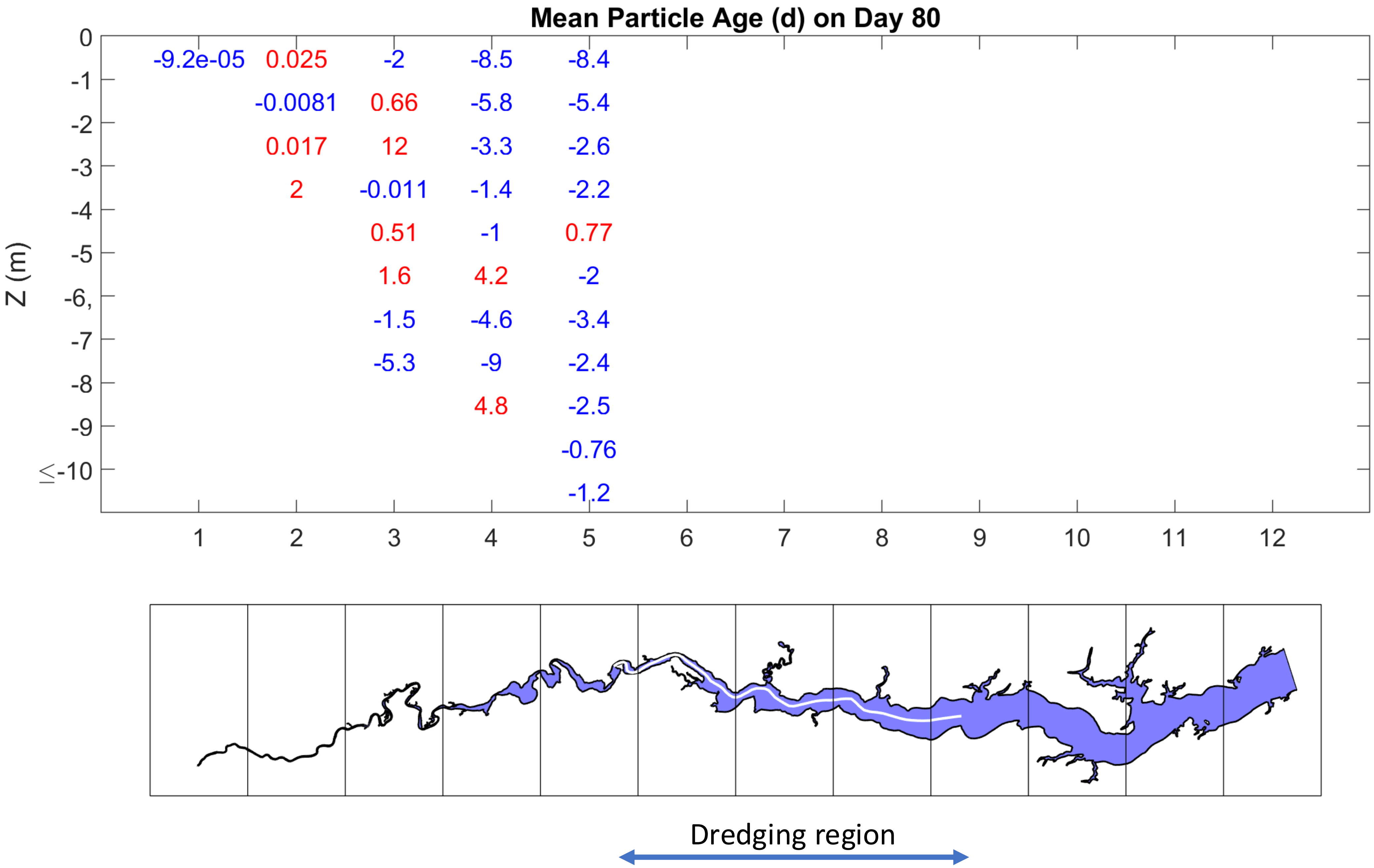
All depths

Sinking particles

= -0.86 m/d

Age difference

Blue: move faster
Red: slower



Summary

With dredging in the middle-lower Rappahannock River, changes in hydrodynamic and transport conditions are small but significant throughout the river.

Saltwater will extend further upstream without the shallow region.

For passive particles, removing the shallow region may generally decrease their age during high flow conditions, indicating faster downstream transport.

With varying sinking velocities of particles, the interactions become more complex.

Water quality indications (salinity, turbidity, nutrients, dissolved oxygen, …)

Questions?
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