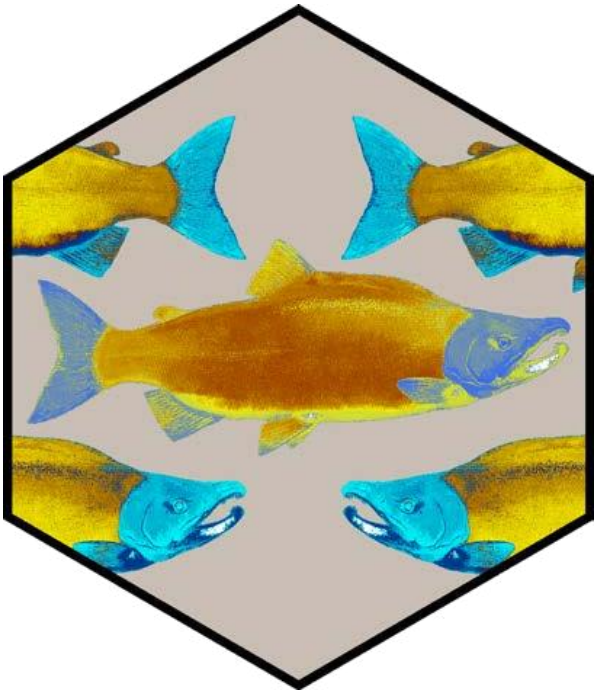


Individual-based modeling of cold water refuge use in the Columbia River

November 8, 2017

Marcía Snyder, Joseph Ebersole, Nathan Schumaker,
Randy Comeleo, Jason Dunham, Matthew Keefer,
Allen Brookes, Scott Heppell, Dru Keenan, and John Palmer

Introduction

Warm water in the Columbia River is impacting salmon and steelhead migration.

Fish cope by using cool water refuges along the migration corridor.

We are using a simulation model to ask:

What are the population level consequences of cold water refuge use?

Consequences of refuge use?

Refuge use has many benefits, but also presents some risks.

Studies of radio tagged fish suggest that survival rates sometimes decline with refuge use.

Quantifying trade-offs associated with refuges is difficult. Evaluating impacts on population-scale dynamics is harder.

Simulation models can provide insights into these processes.

Project Overview

Salmon and steelhead management benefit from models that account for dynamic migration corridor conditions, disturbance regimes, fish behaviors, and physiology.

We are constructing a mechanistic model in order to conduct virtual experiments that rank proposed management actions.

Our model is extensible and will be augmented as more data become available, or new research questions arise.

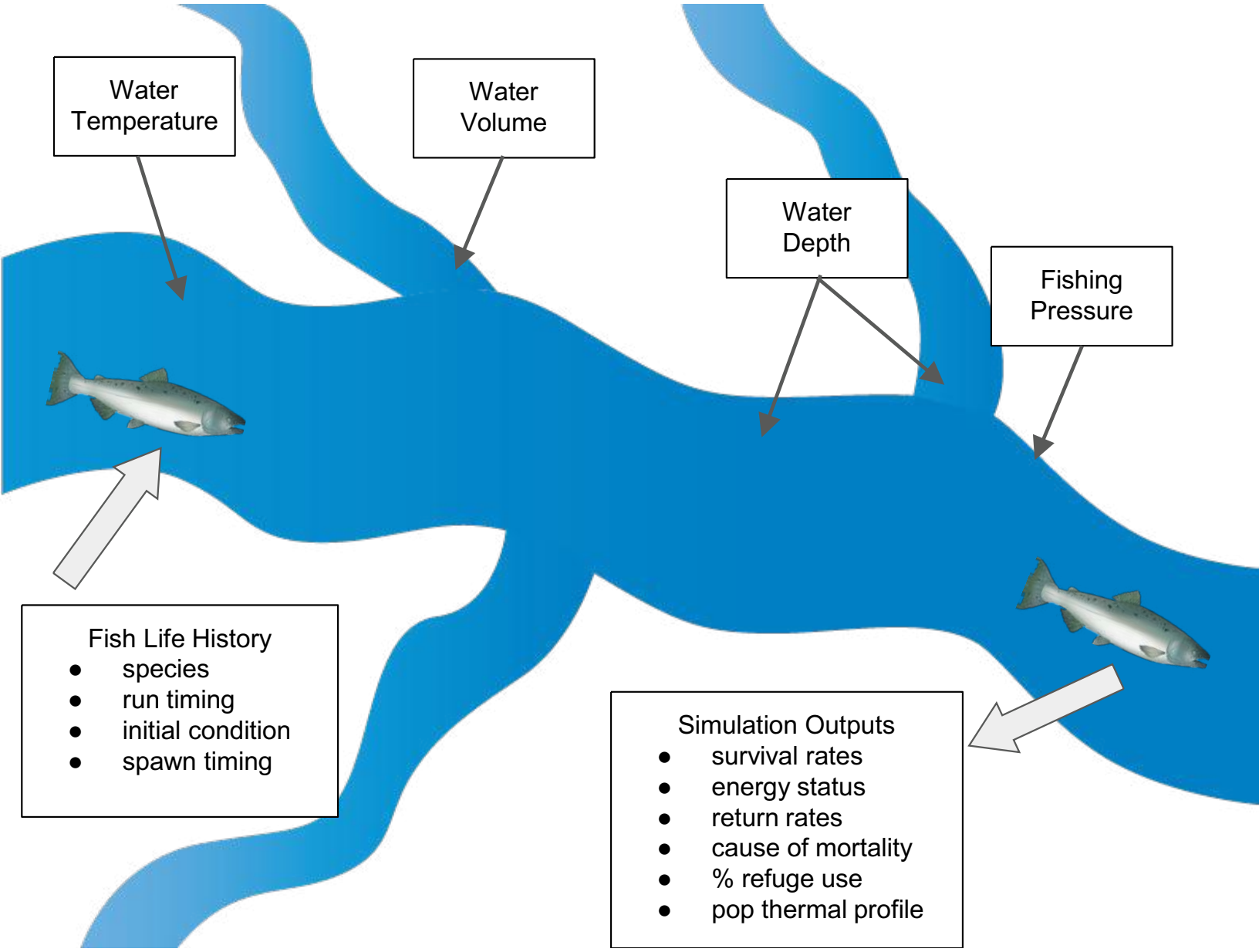
Our goal of sharing this technology with other research groups is an important factor driving model selection and design.

Project Overview

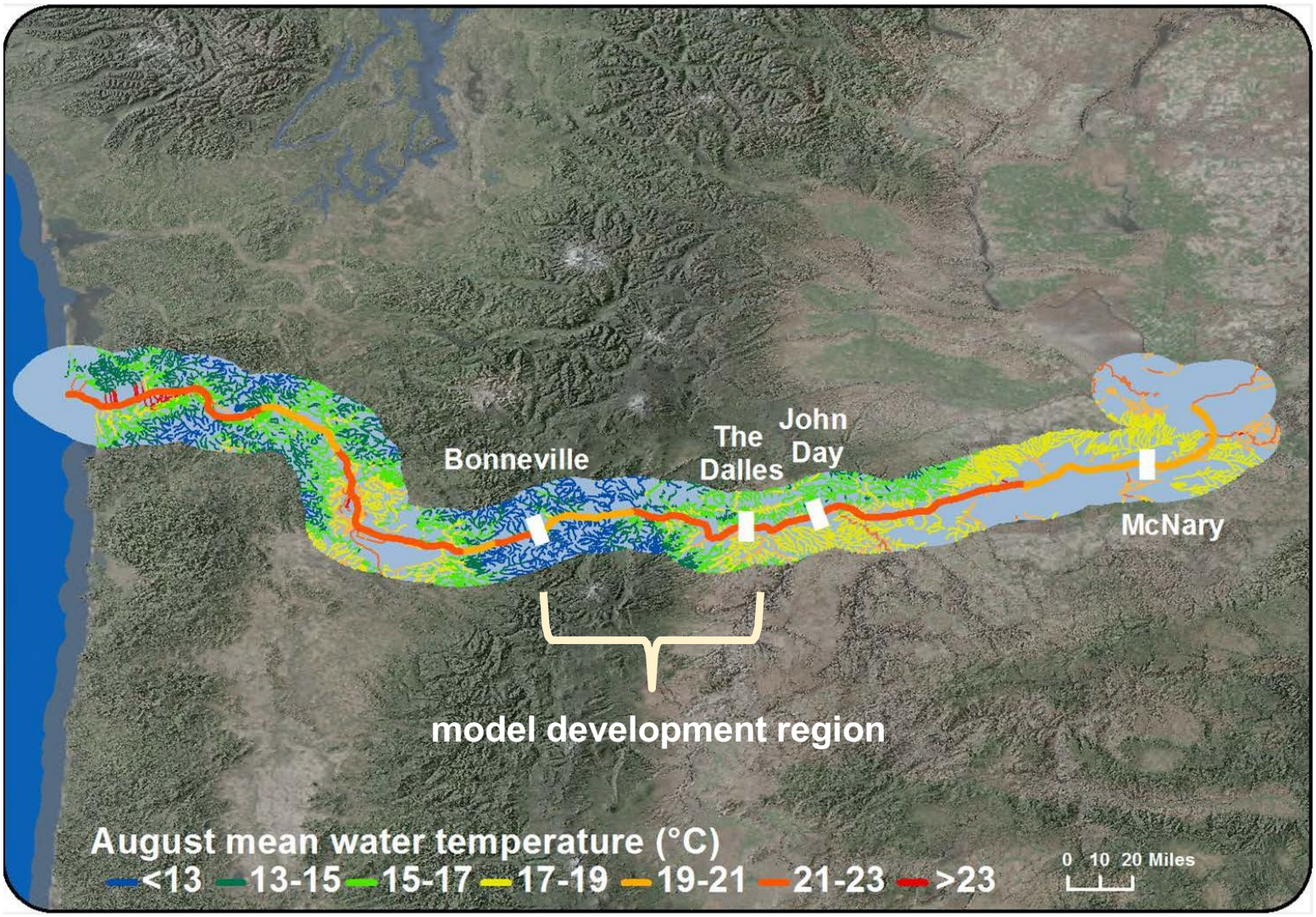
Existing mechanistic aquatic simulation models do not address both fine scale spatial detail and large scale network structure, and scale up from individuals to the population.

- Fine scale landscape features include cold water refuge shape and size, river depth, population density, fishing pressure.
- Large scale landscape features include longitudinal connectivity, distribution of cold water refuges, hydropower dams, and others.

The HexSim model overcomes these limitations found in other available models.

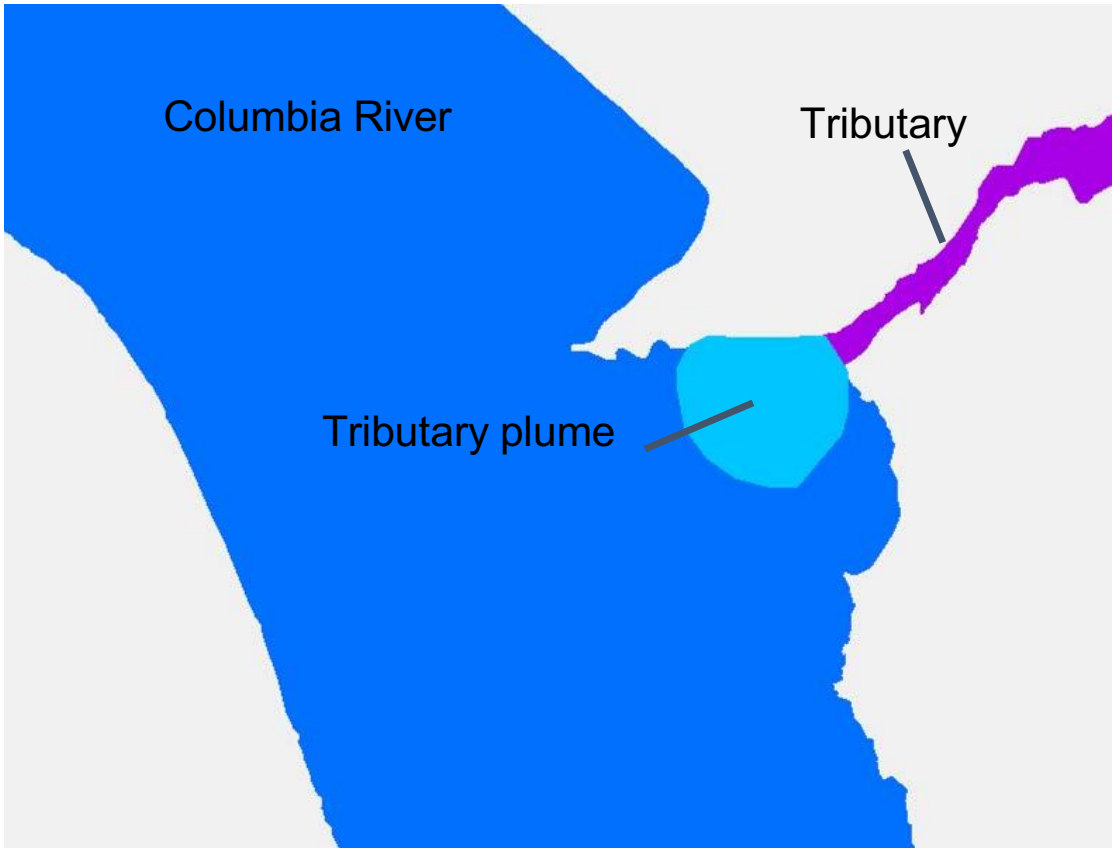

Water Temperature
Water Volume
Water Depth
Fishing Pressure
Fish Life History
species
run timing
initial condition
spawn timing
Simulation Outputs
survival rates
energy status
return rates
cause of mortality
% refuge use
pop thermal profile

Study area


Bonneville
The Dalles
John Day
McNary
model development region
August mean water temperature (°C)
<13
13-15
15-17
17-19
19-21
21-23
>23
0 10 20 Miles

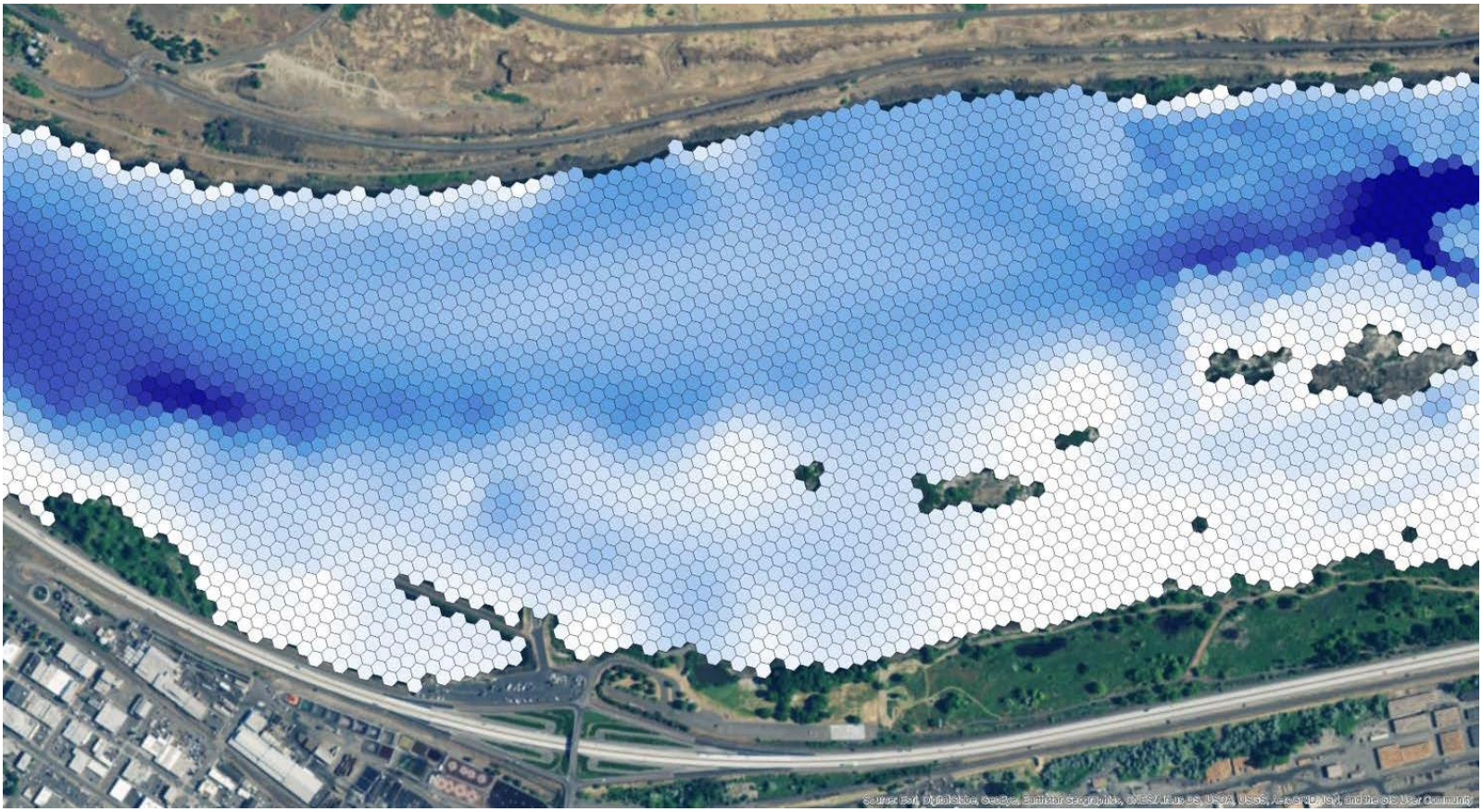
Riverscape: temperature

Thermal regimes (and other simulation model inputs) can be characterized by tributaries, their plumes, and the Columbia River.



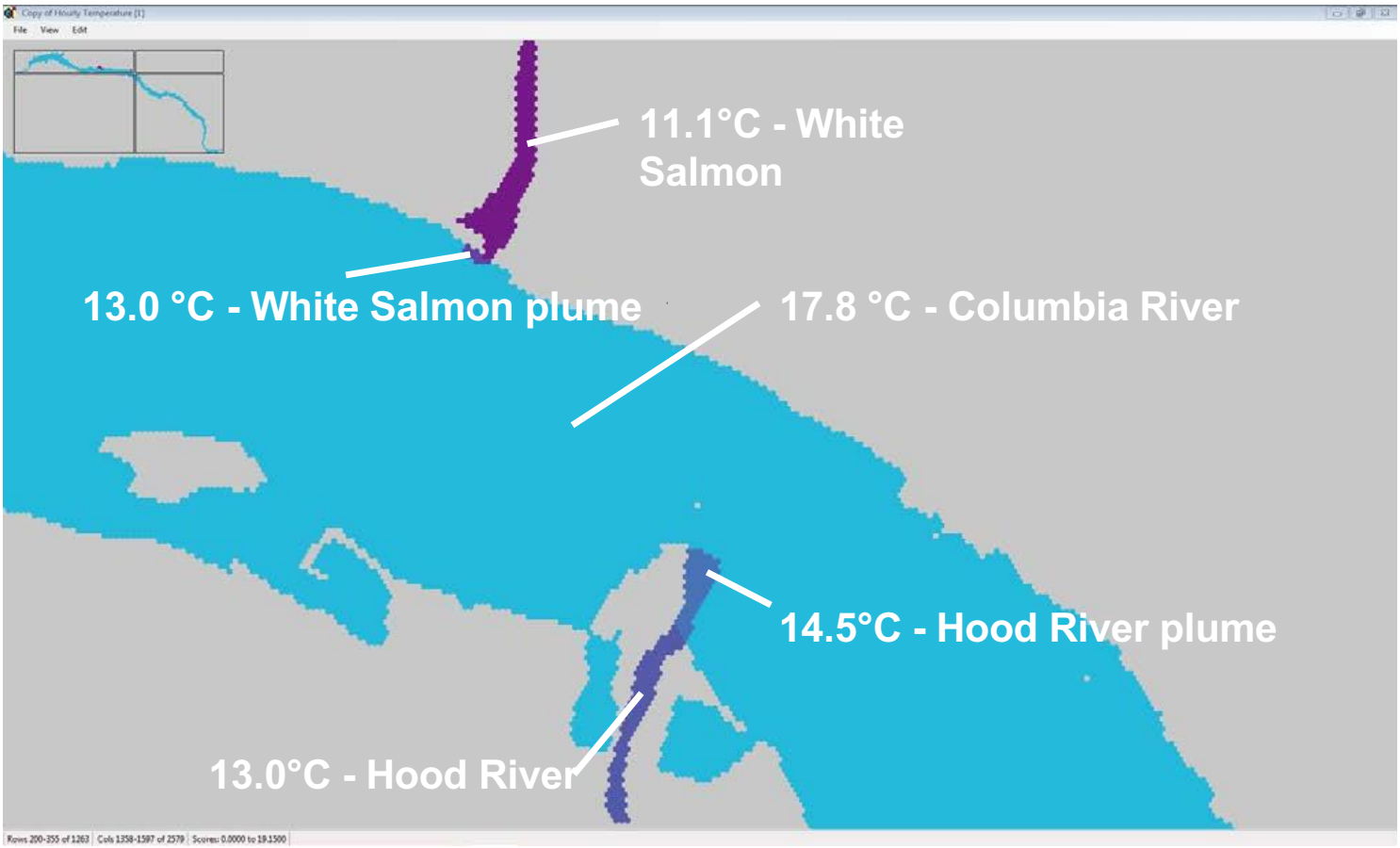
Riverscape: depth

Simulated fish will use fine scale depth information in a behavioral decision tree used to evaluate movement options.



Riverscape: temperature

Hourly water temperatures in our model change independently in the river, plumes, and tributaries.



Riverscape: cold water refuges

Cold water refuge volumes are represented by coupling dynamic 2-D maps of tributaries and plumes, with depth.

The simulation model will track changes in the size, extent, and temperature of refuges, and use this information to influence fish behavior and physiology.

Fish life history

Individual salmon and steelhead enter the model with associated characteristics.

Species –Summer Steelhead
Population - Salmon River
Weight – (2.2-6.8 kg)
Bonneville passage date – (July 20 –Sept. 27)
Spawning date – (Mar.1 - May 30)
Distance to spawning site – (728- 969 km)

Species –Fall Chinook
Population - Upper Columbia
Weight – (4.5-20 kg)
Bonneville passage date – (Aug. 24 – Oct. 6)
Spawning date – (Sept. 29 – Nov. 22)
Distance to spawning site – (533 – 877 km)

Fish life history

Life history characteristics vary by species and population.

During migration, behavioral characteristics that influence fish responses to stress include:

- depth
- density dependence
- spawning motivation
- propensity to hold in cold water

The simulated fish utilize a behavioral decision tree to capture species specific behavioral responses to environmental gradients.

Simulation Outcomes

Track individual exposure through space and time

- Measure cumulative exposure and impacts to multiple stresses
- Aggregate individual outcomes to the population scale

How do the costs and benefits of cold water refuges manifest at population and landscape scales?

Simulation Outcomes

How does the availability and use of cold water affect salmon and steelhead populations?

Population consequences will be evaluated using:

- survival rates
- energy status
- return rates
- cause of mortality
- percent using refuges
- population thermal profile

Simulation Outcomes

Test the sensitivity of emergent model properties (passage time, survival, energy remaining) to:

- Warmer Columbia River temperatures
- Higher or lower volumes of cold water
- Changes in migration timing
- Location of harvesting

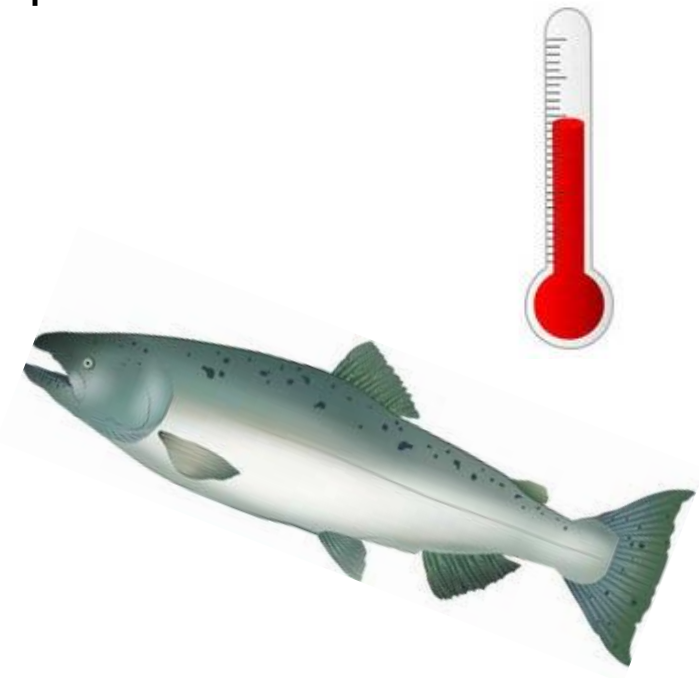
Fish behavioral decision tree determines how fish move.

How fish move determines their exposure to environmental conditions.

Behavioral decision incorporates exposure and life history information.

Fish can move:

- Upstream
- Downstream
- Toward cold water
- Randomly



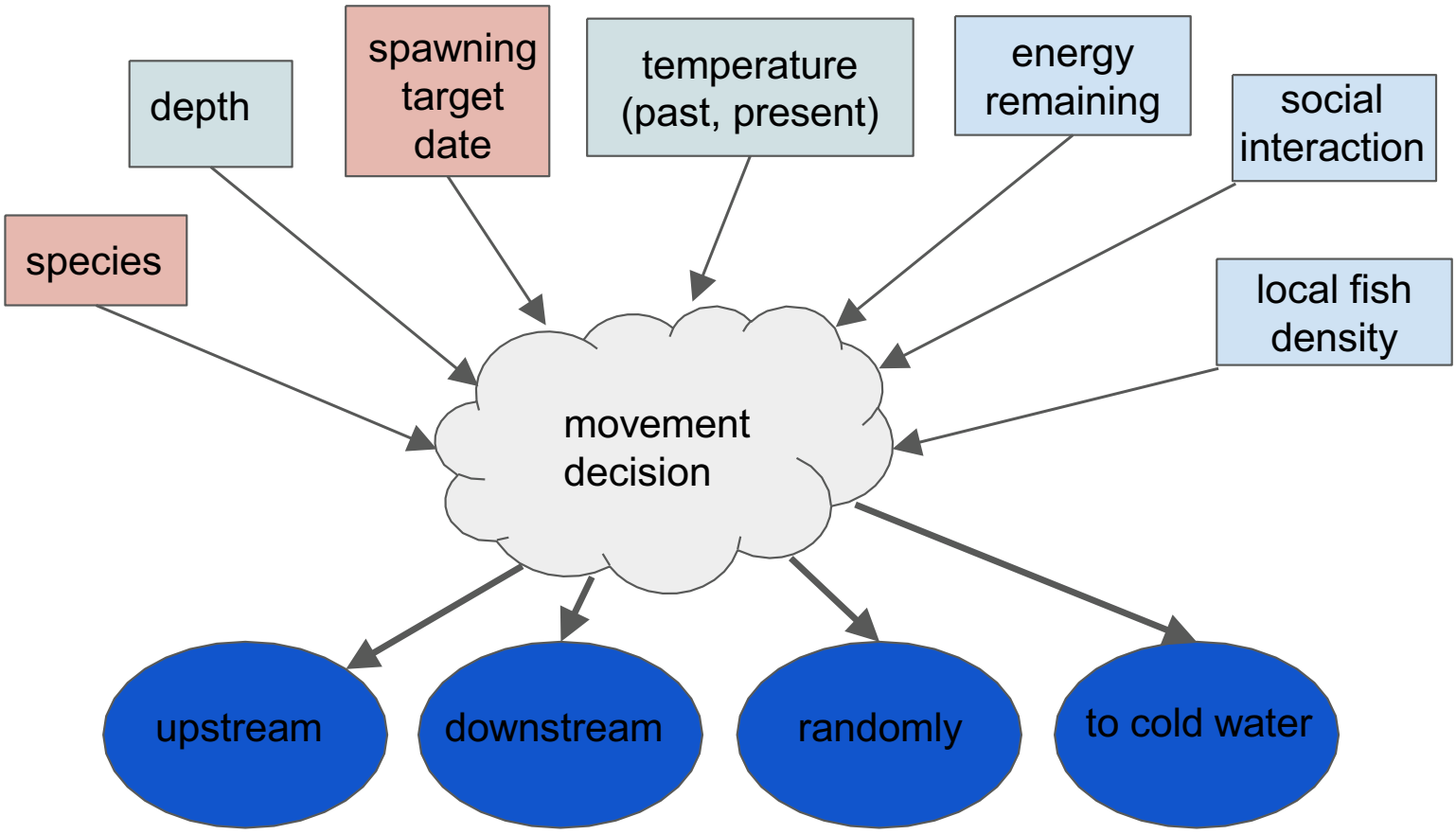
Fish behavioral decision tree

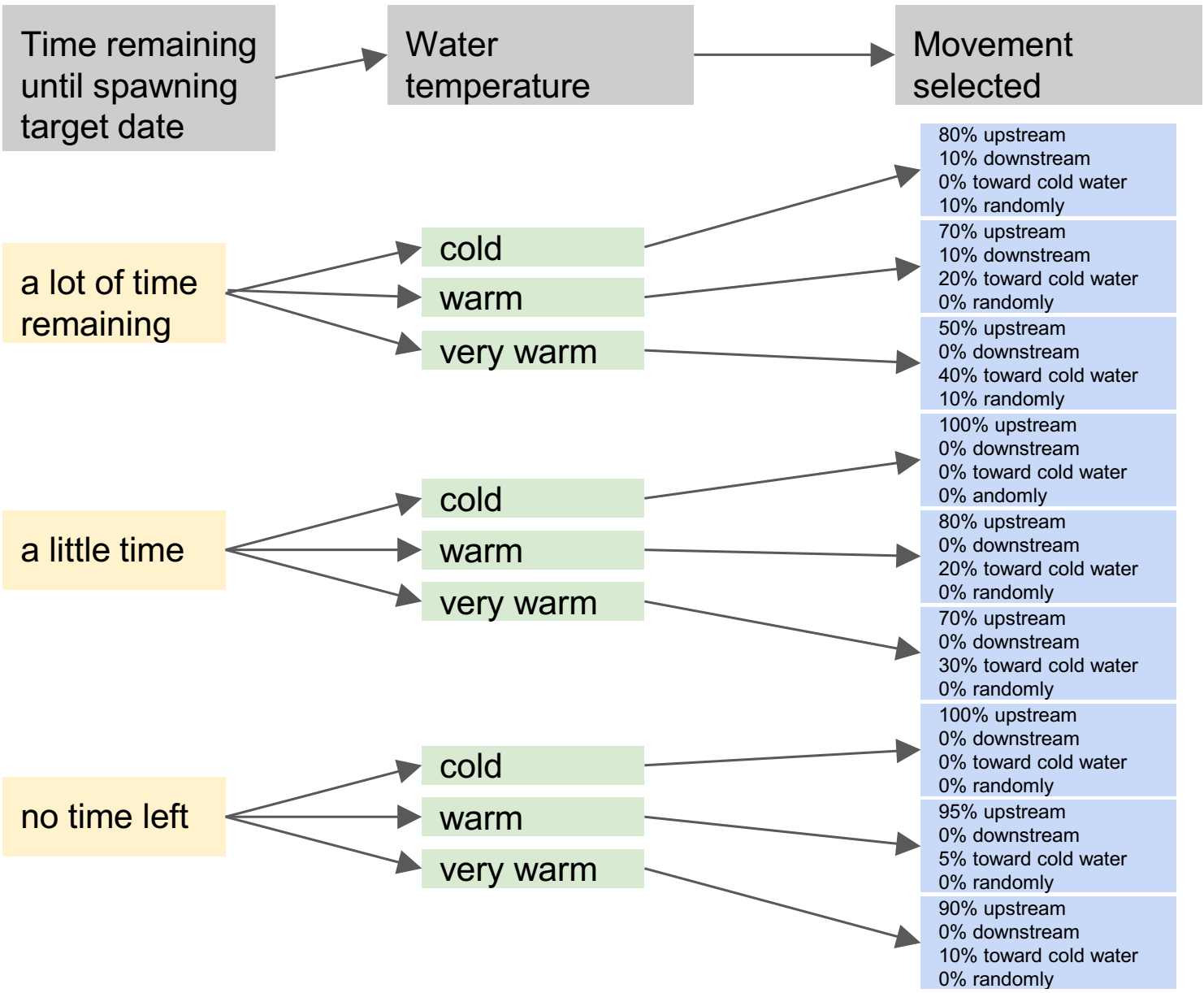
The behavioral decision tree reflects our current understanding of fish behavior.

We intend to use the decision tree sub-module to test hypothesis about factors motivating fish to seek cold water.

These experiments will help us identify gaps in our understanding of fish behavioral responses to stress.

Behavioral decision tree - Design



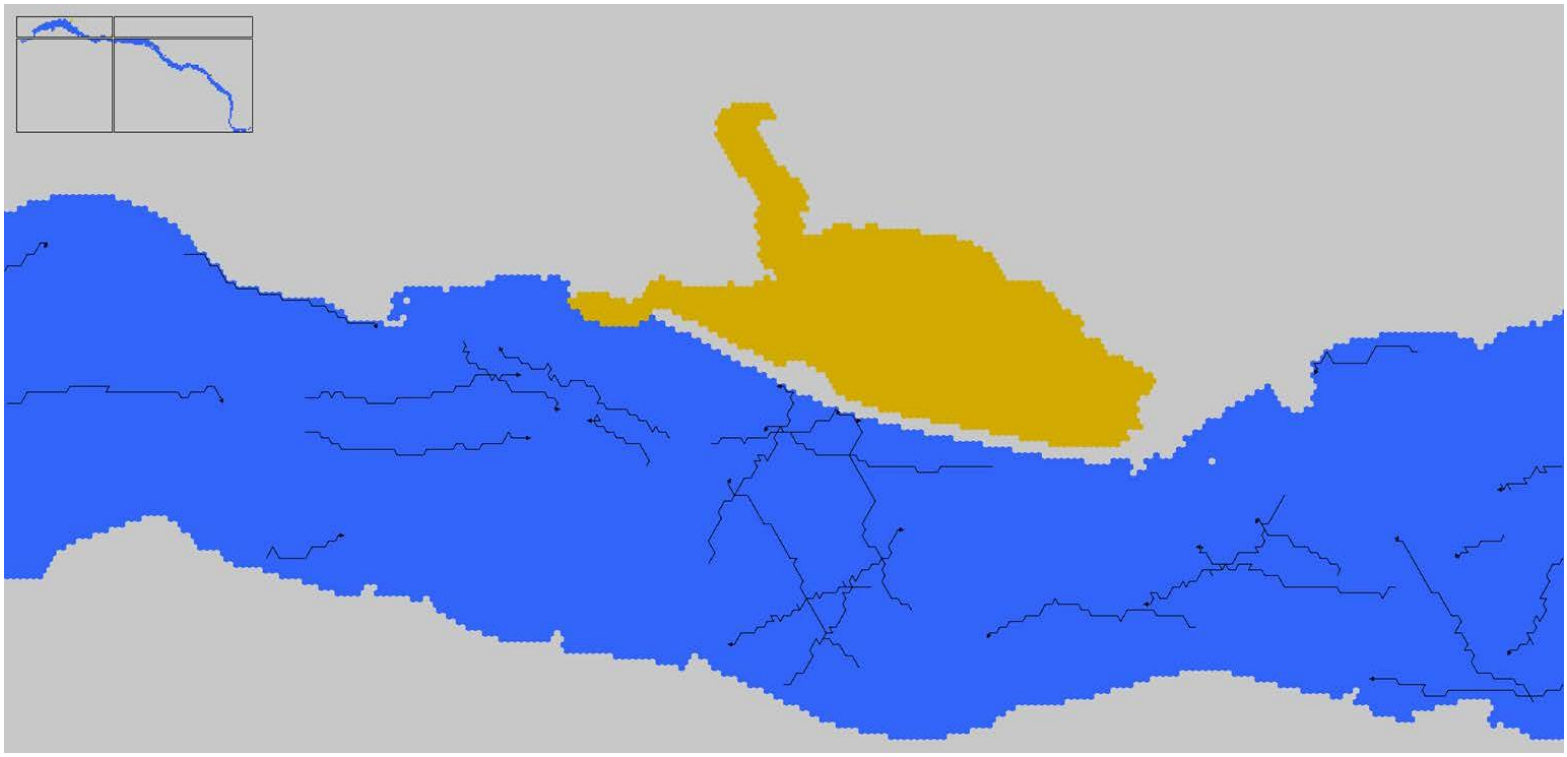

Time remaining until spawning target date
Water temperature
Movement selected
a lot of time remaining
cold
warm
very warm
80% upstream
10% downstream
0% toward cold water
10% randomly
70% upstream
10% downstream
20% toward cold water
0% randomly
50% upstream
0% downstream
40% toward cold water
10% randomly
a little time
cold
warm
very warm
100% upstream
0% downstream
0% toward cold water
0% andomly
80% upstream
0% downstream
20% toward cold water
0% randomly
70% upstream
0% downstream
30% toward cold water
0% randomly
no time left
cold
warm
very warm
100% upstream
0% downstream
0% toward cold water
0% randomly
95% upstream
0% downstream
5% toward cold water
0% randomly
90% upstream
0% downstream
10% toward cold water
0% randomly

Behavioral decision tree -- Validation

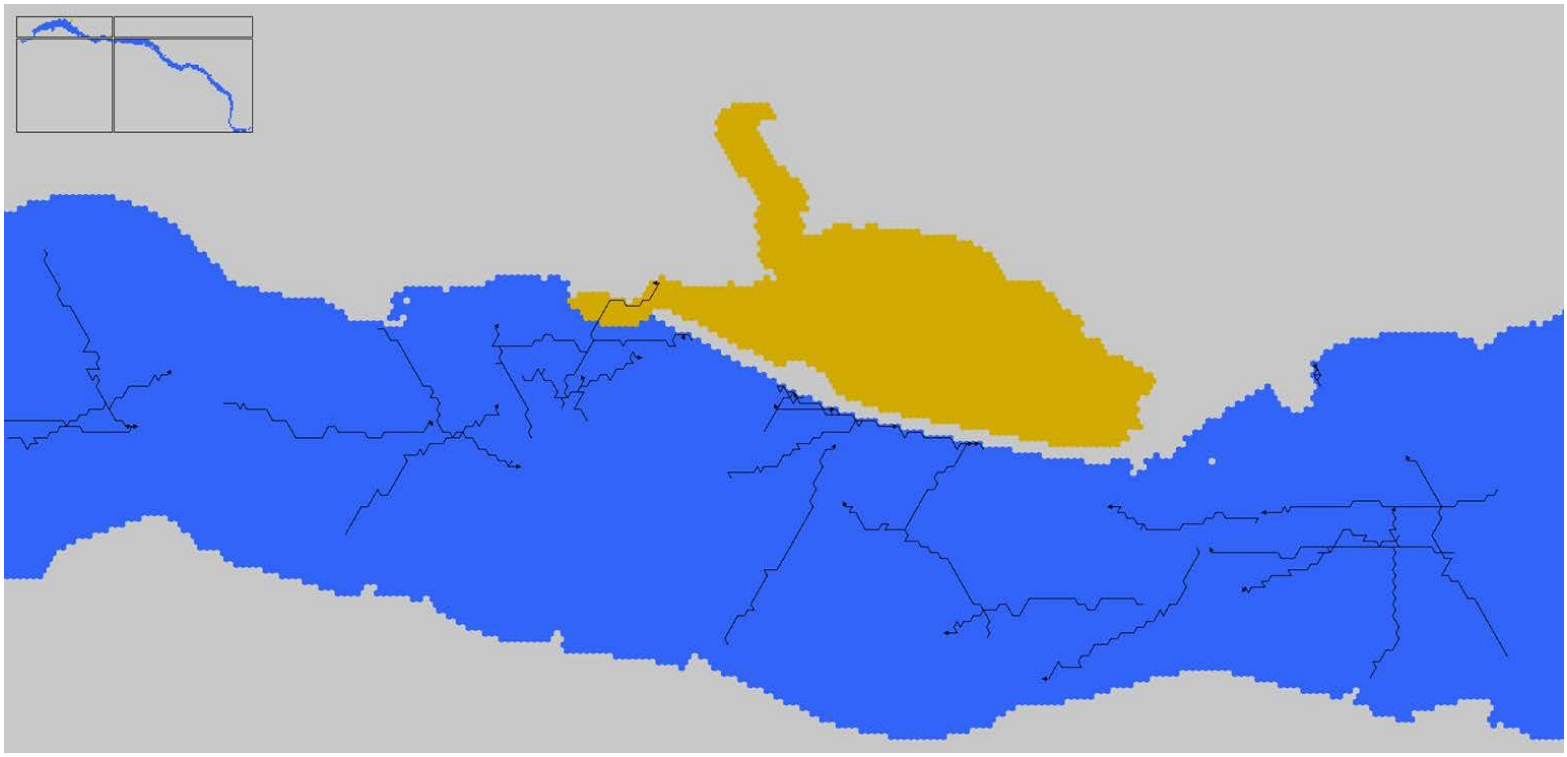
Fish decision tree validation will be assessed through examination of emergent properties aggregated at the population scale:

- percentage of fish utilizing cold water refuges
- time spent in cold water refuges
- passage time distributions
- CWR relative usage statistics
- etc...

Movement



Movement



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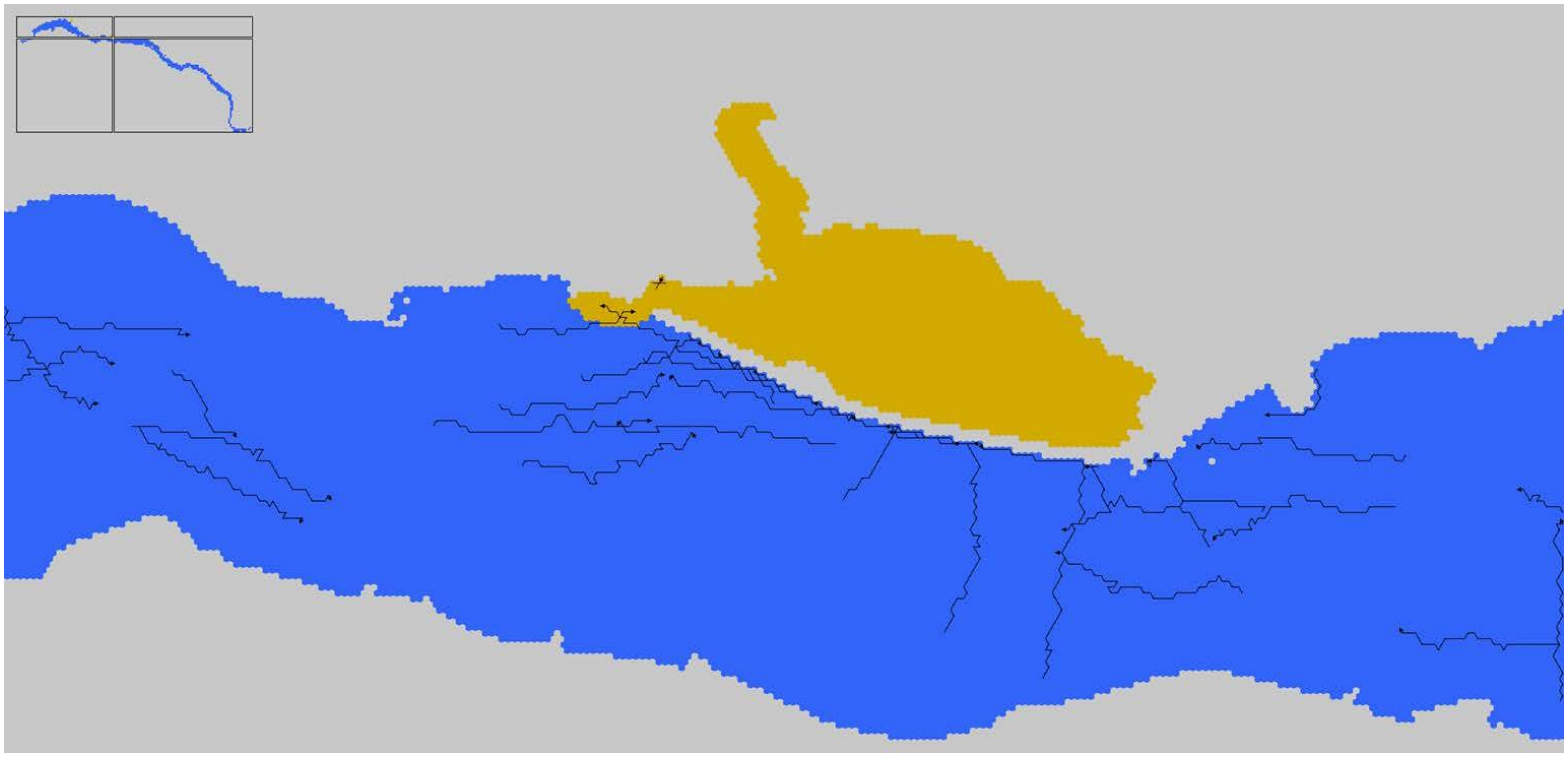
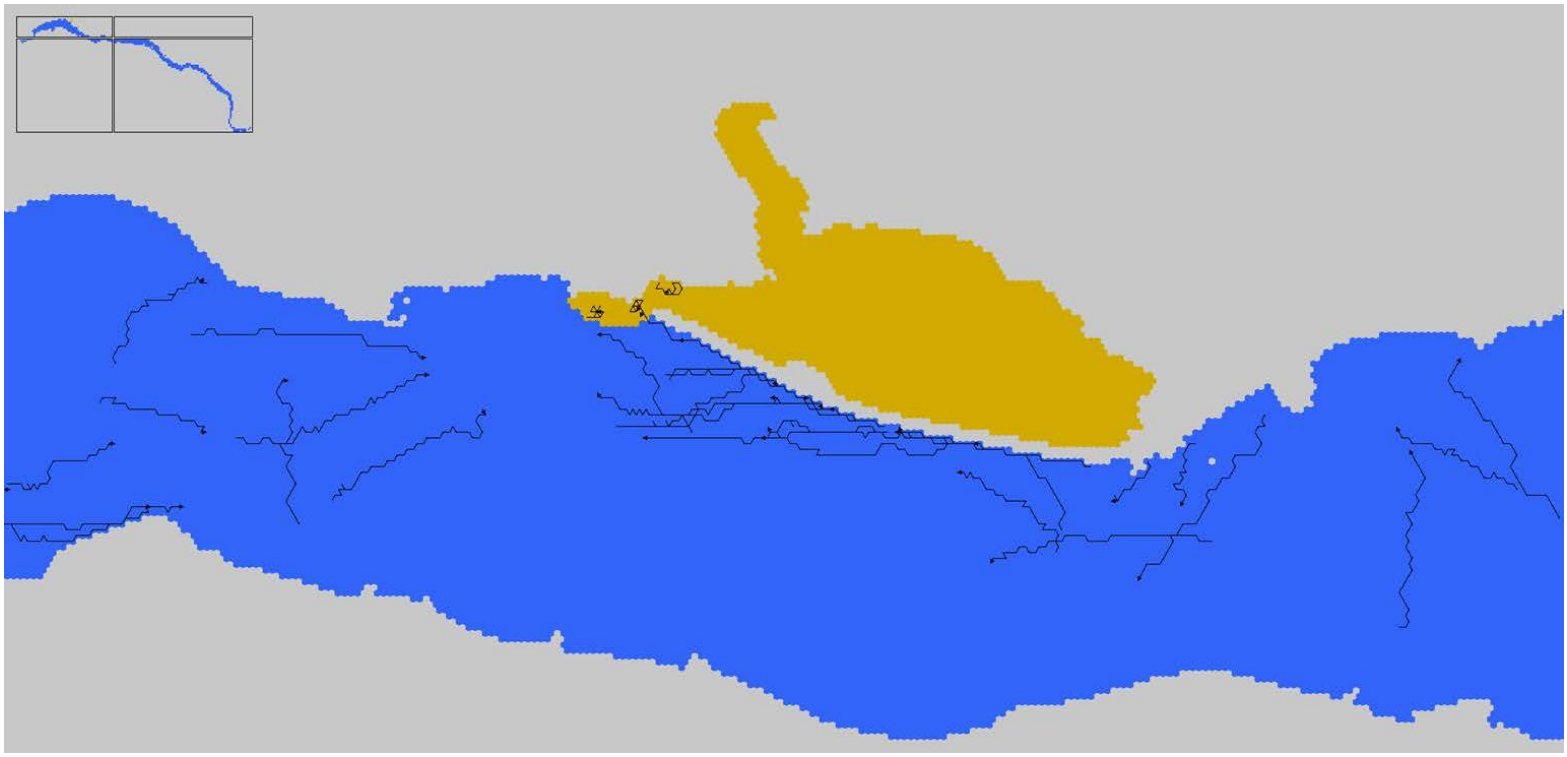
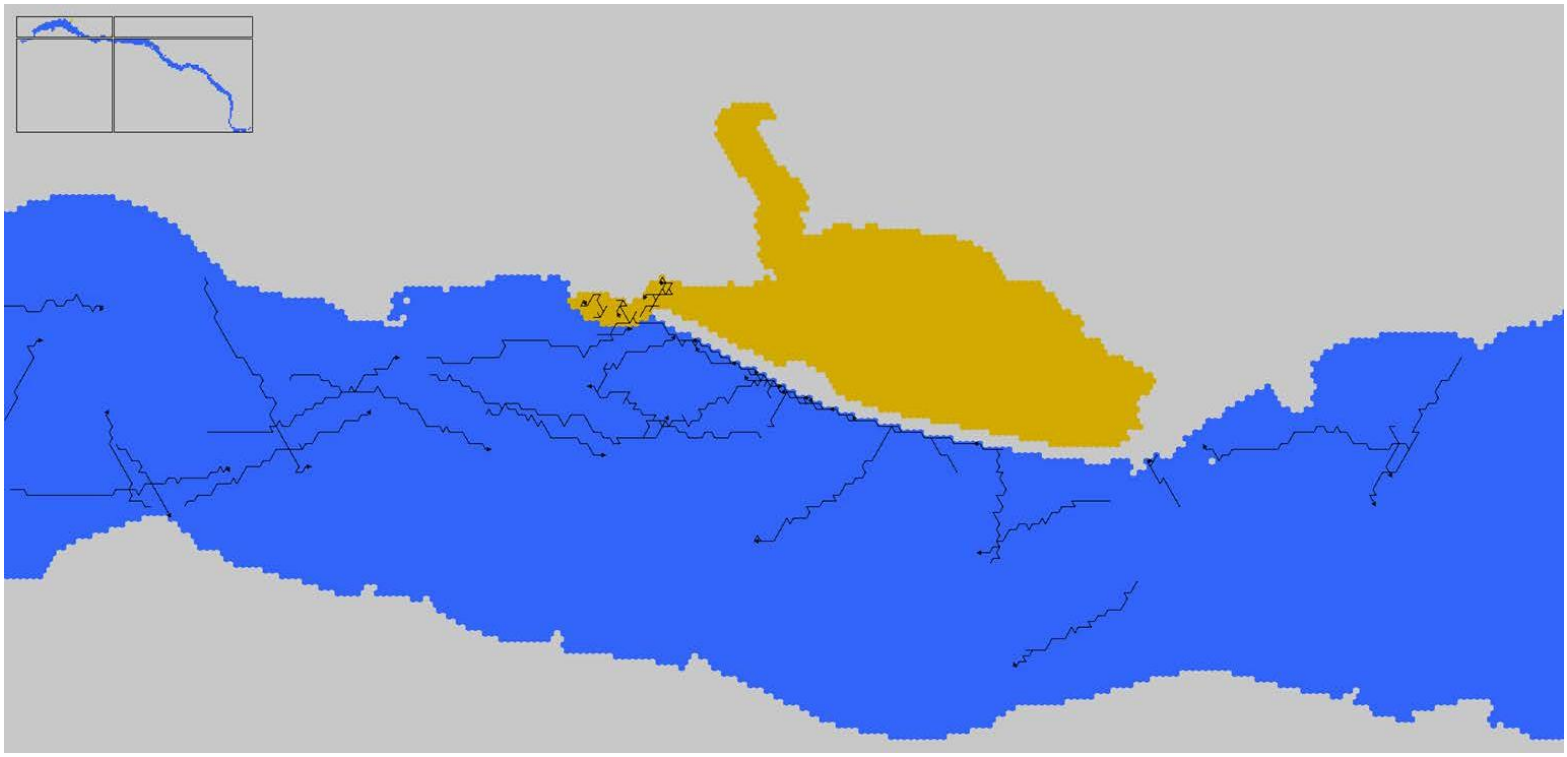


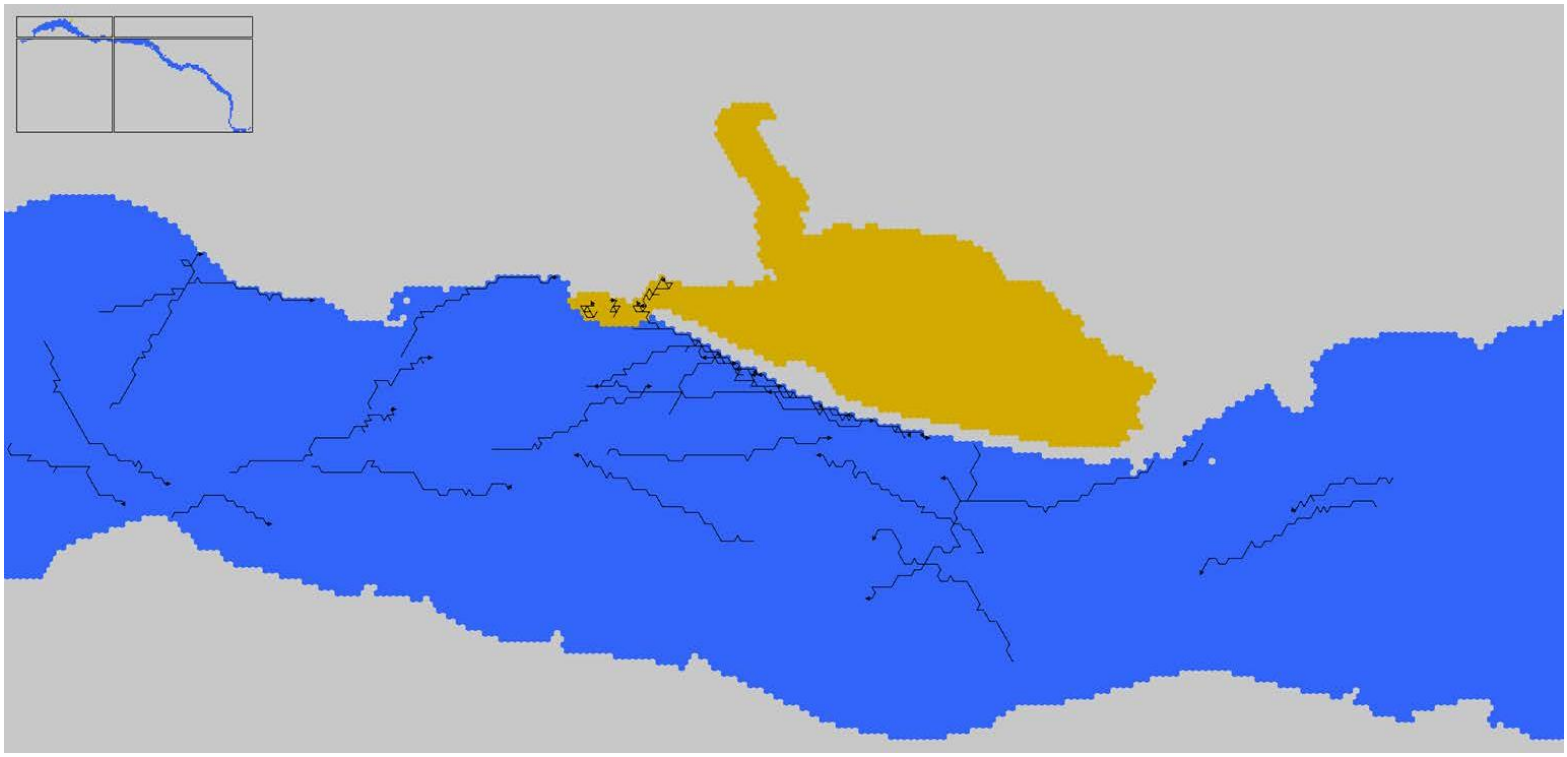
Movement



Movement



Movement



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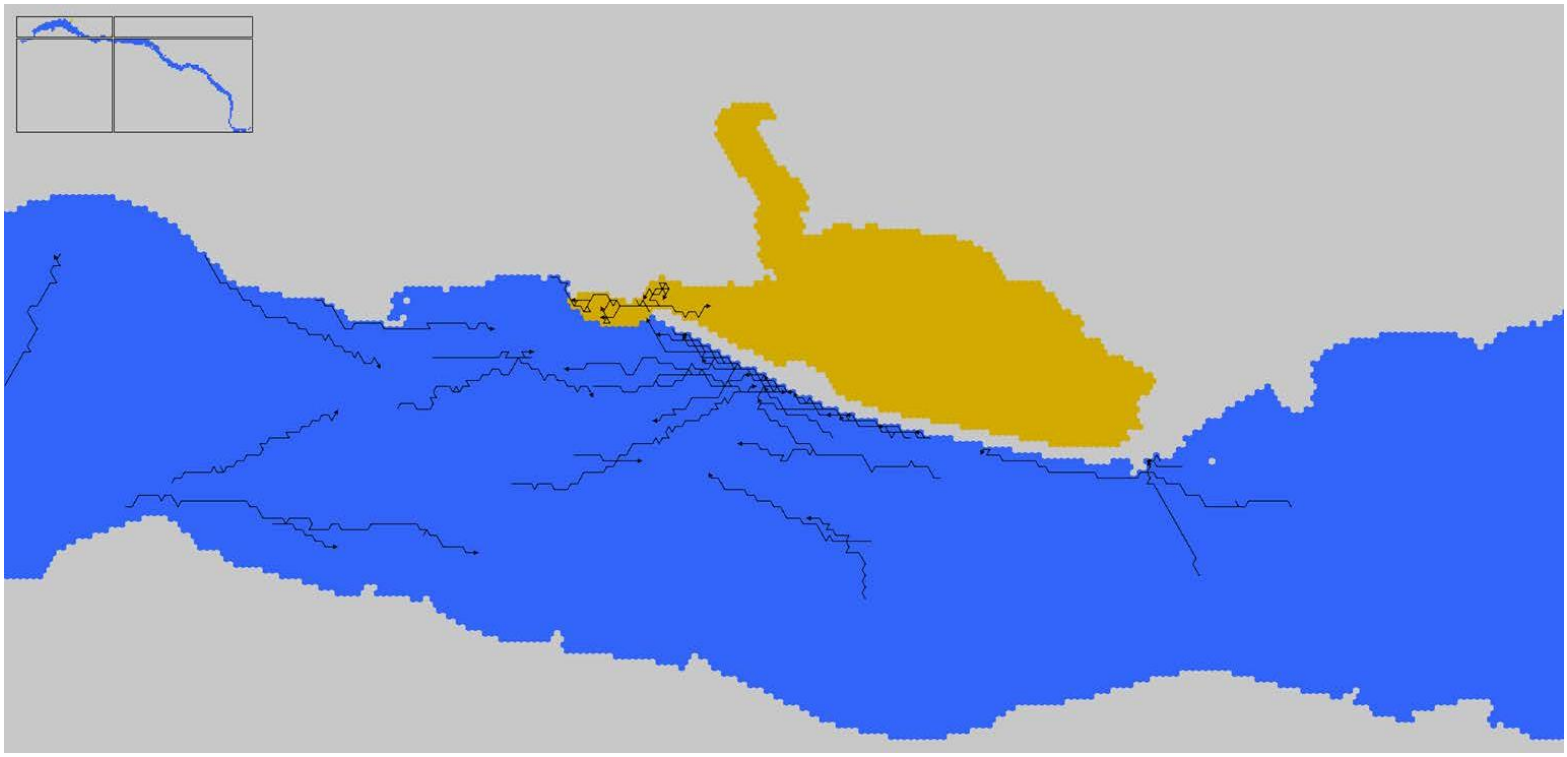

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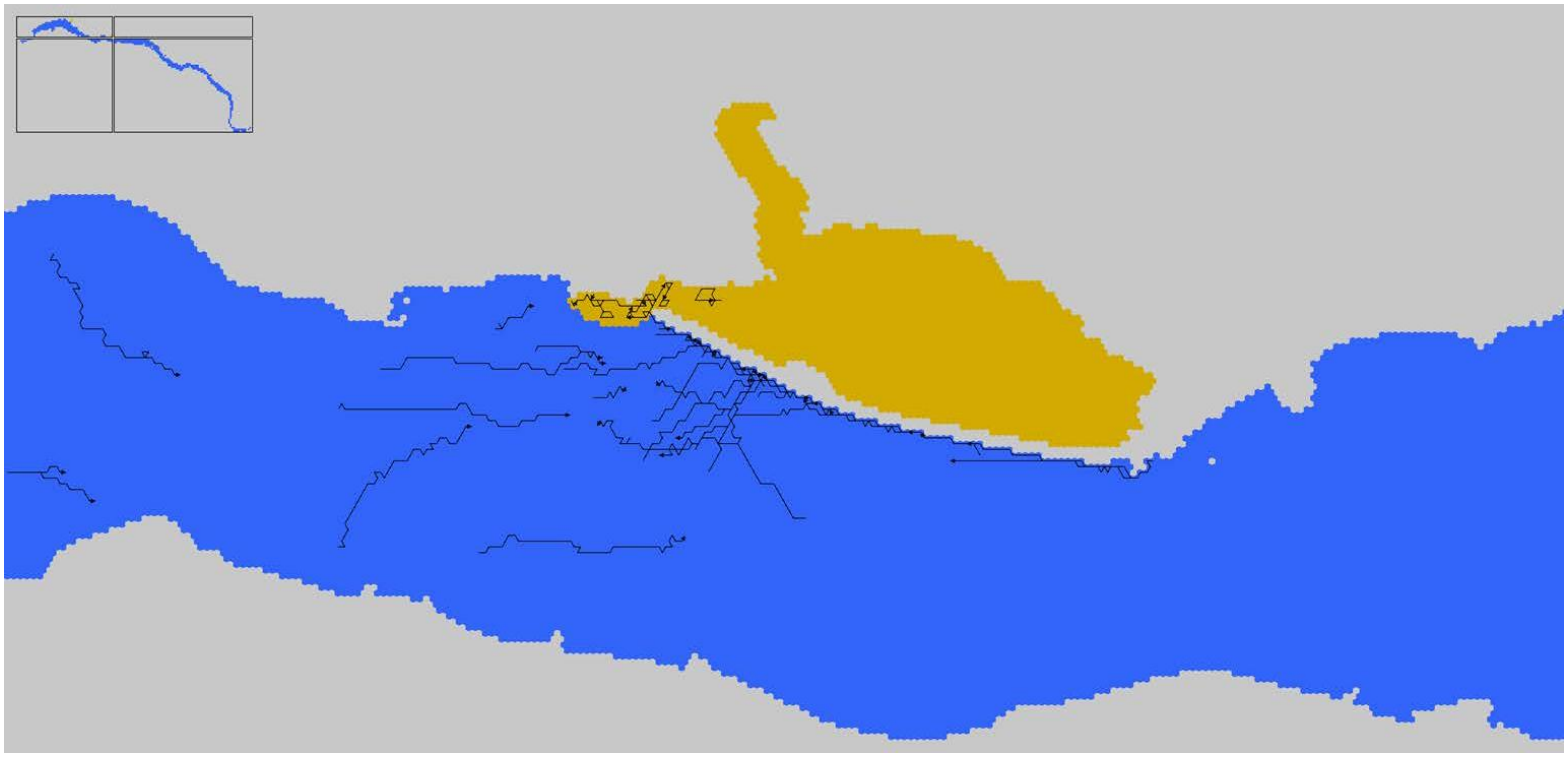

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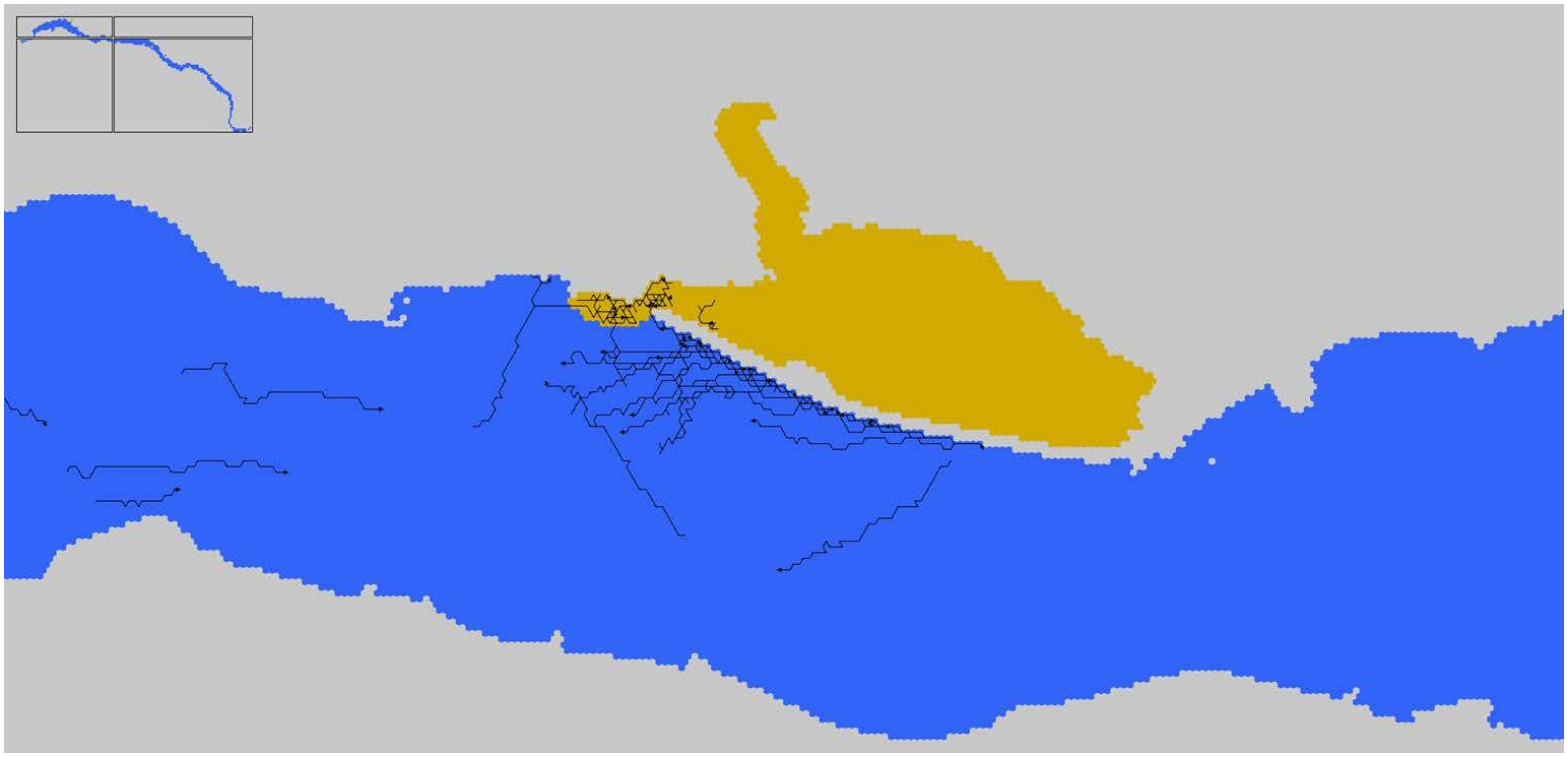

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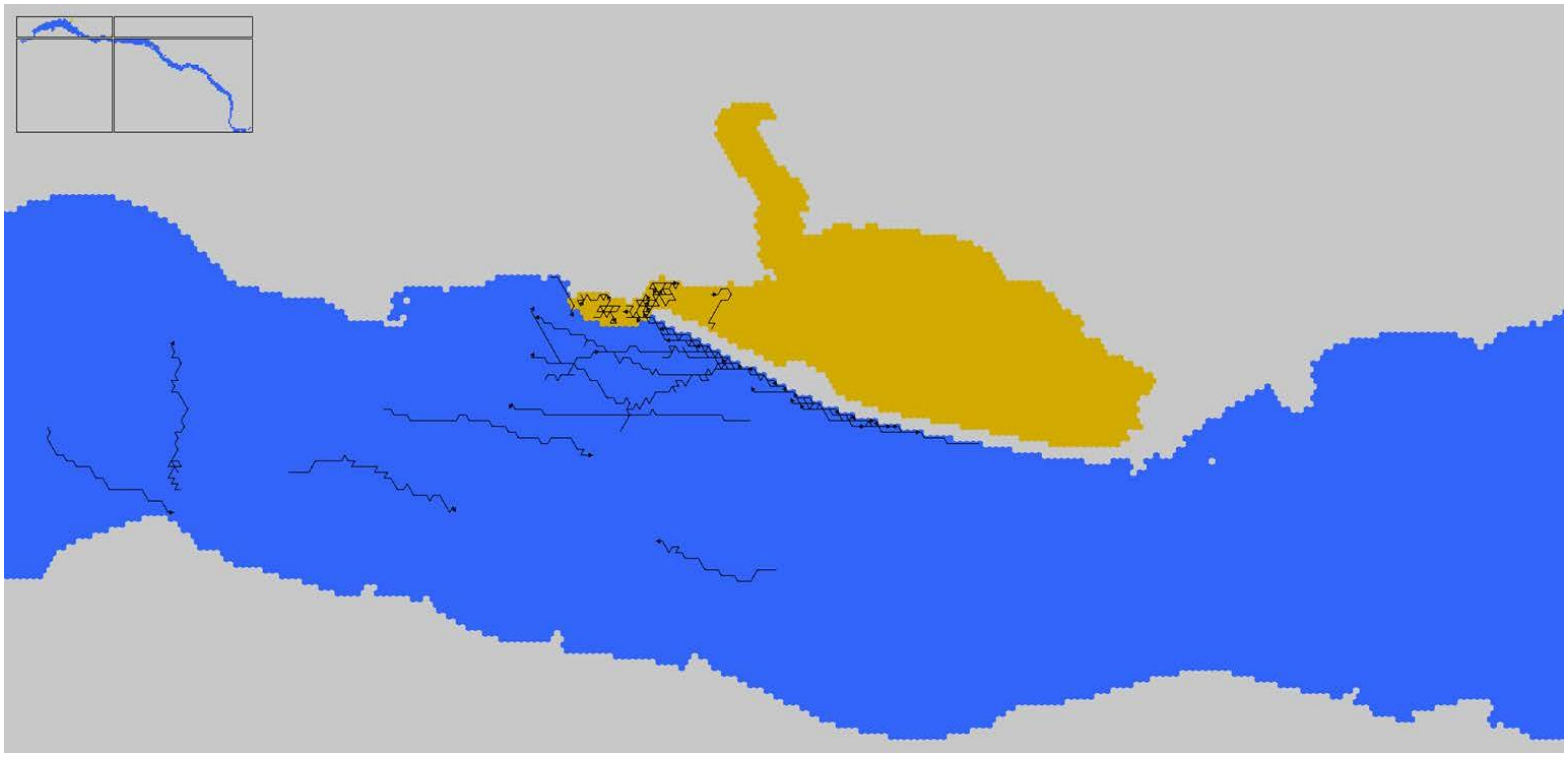

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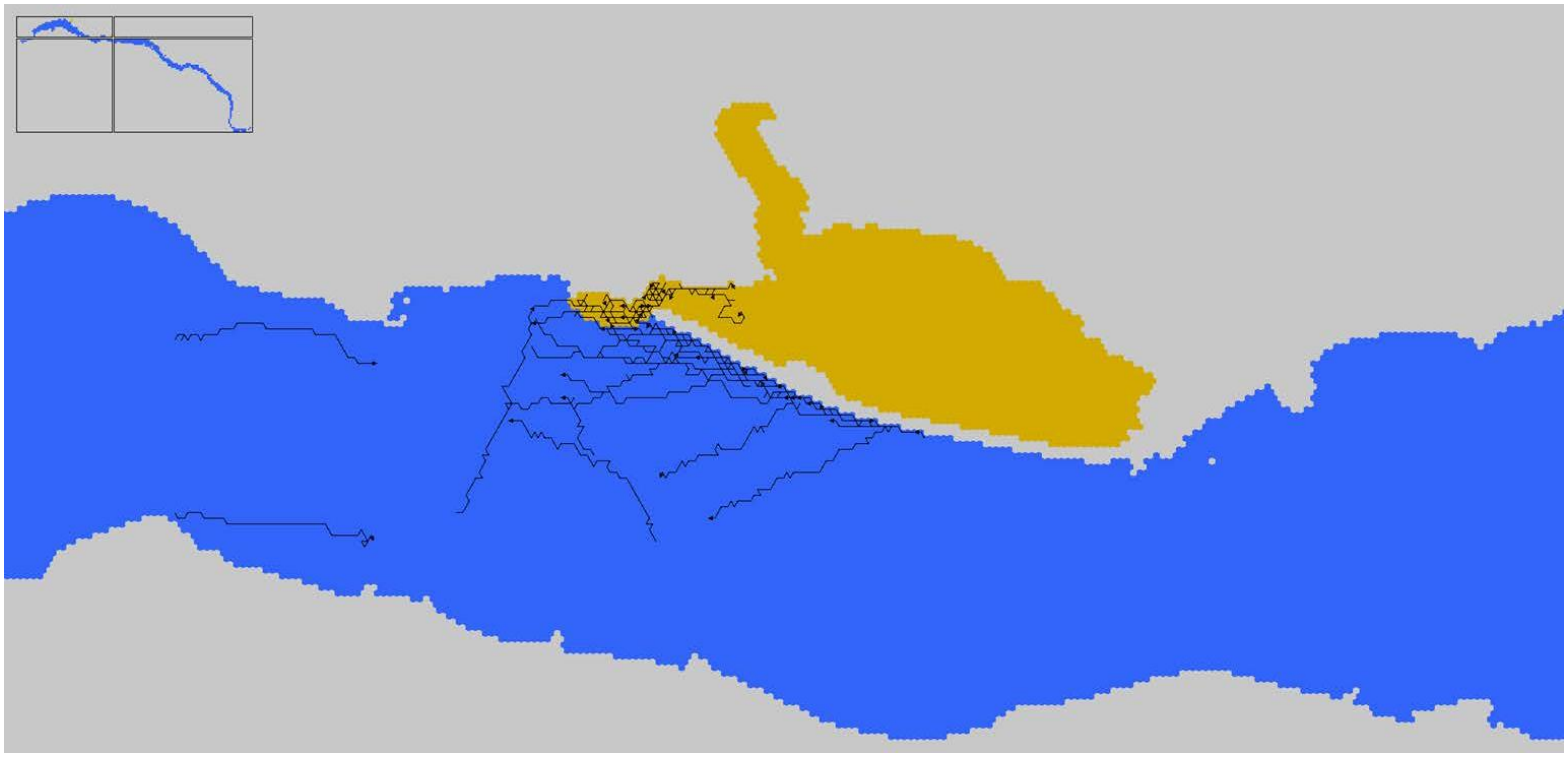

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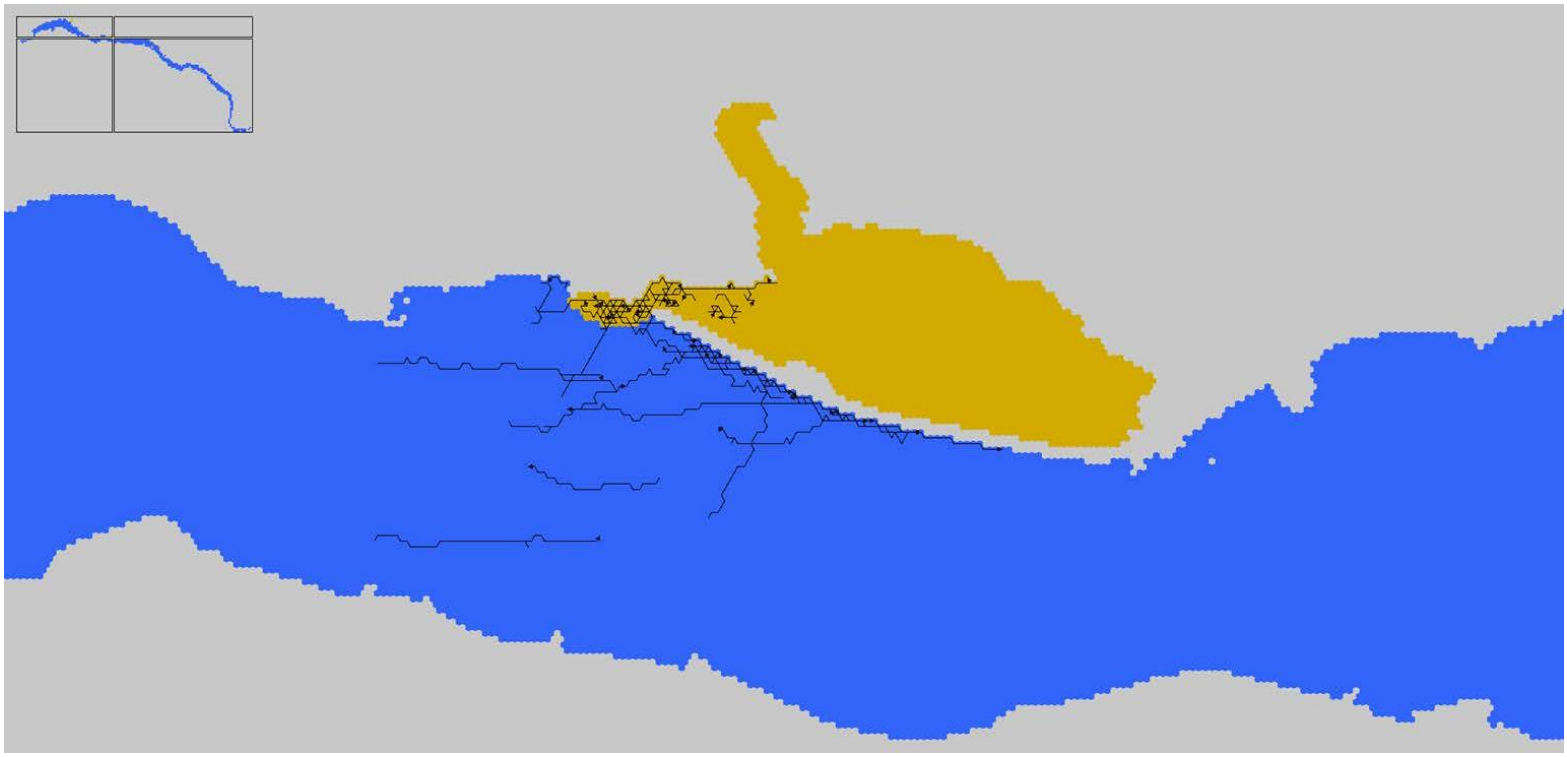

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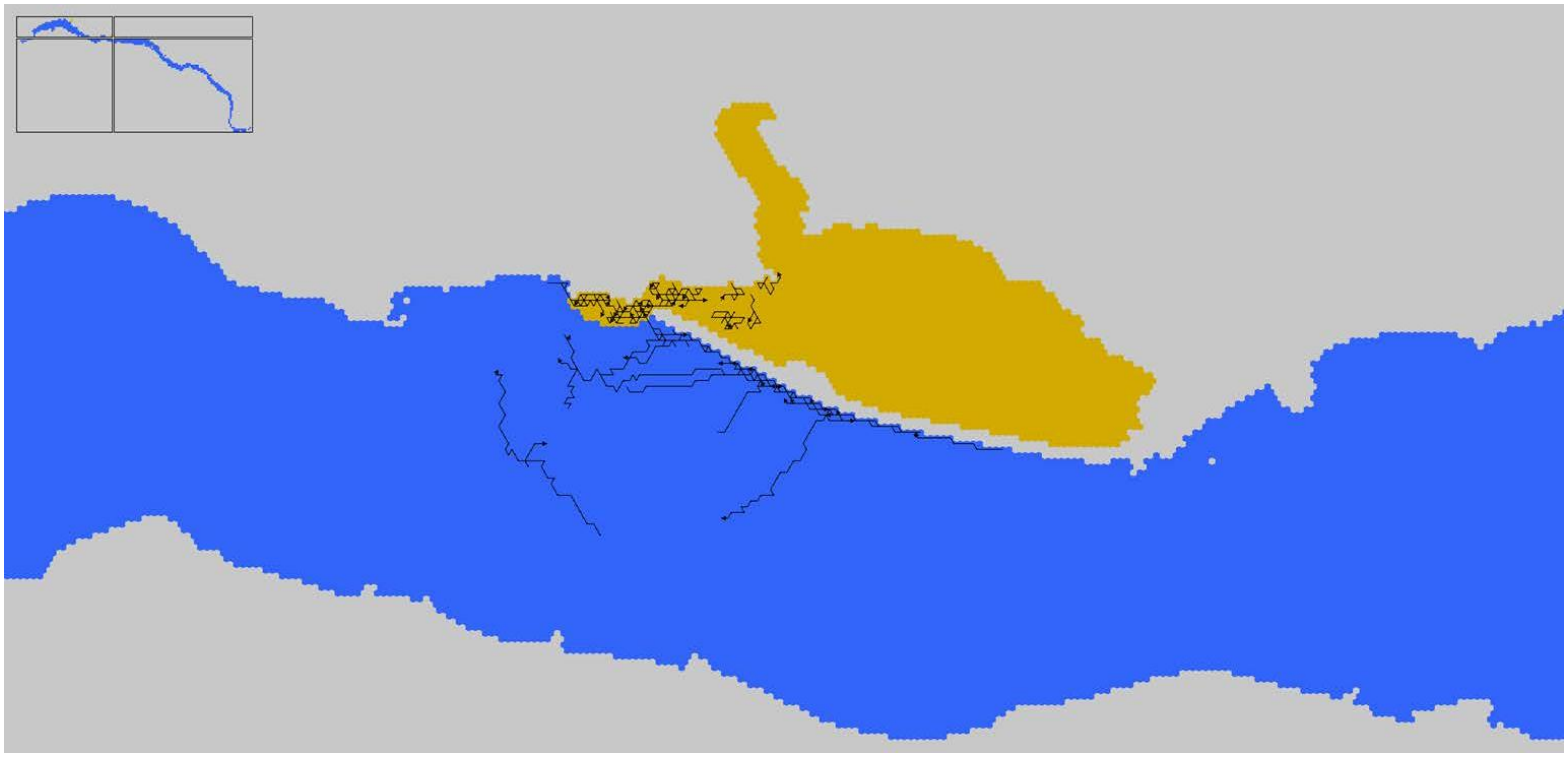

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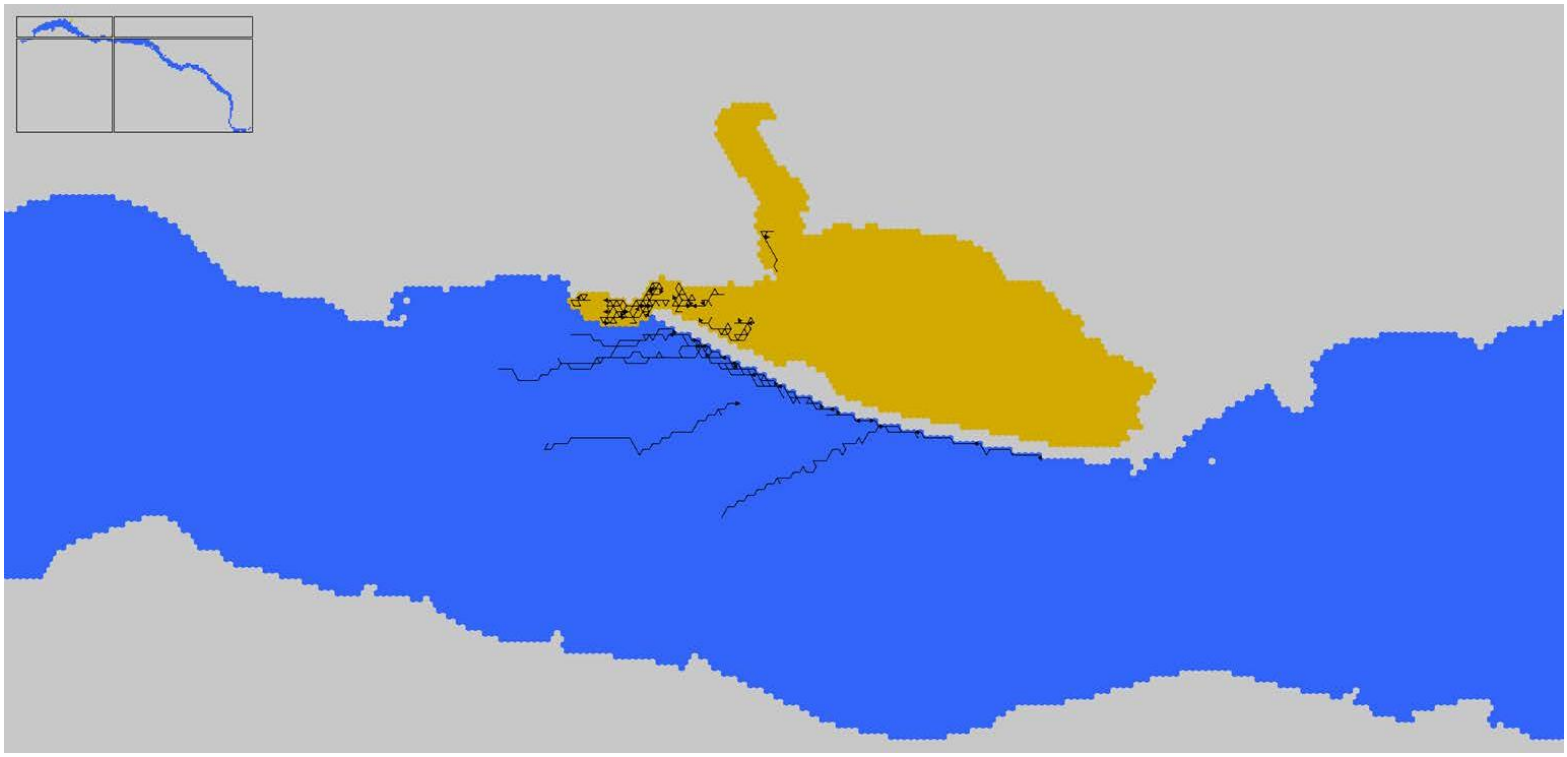

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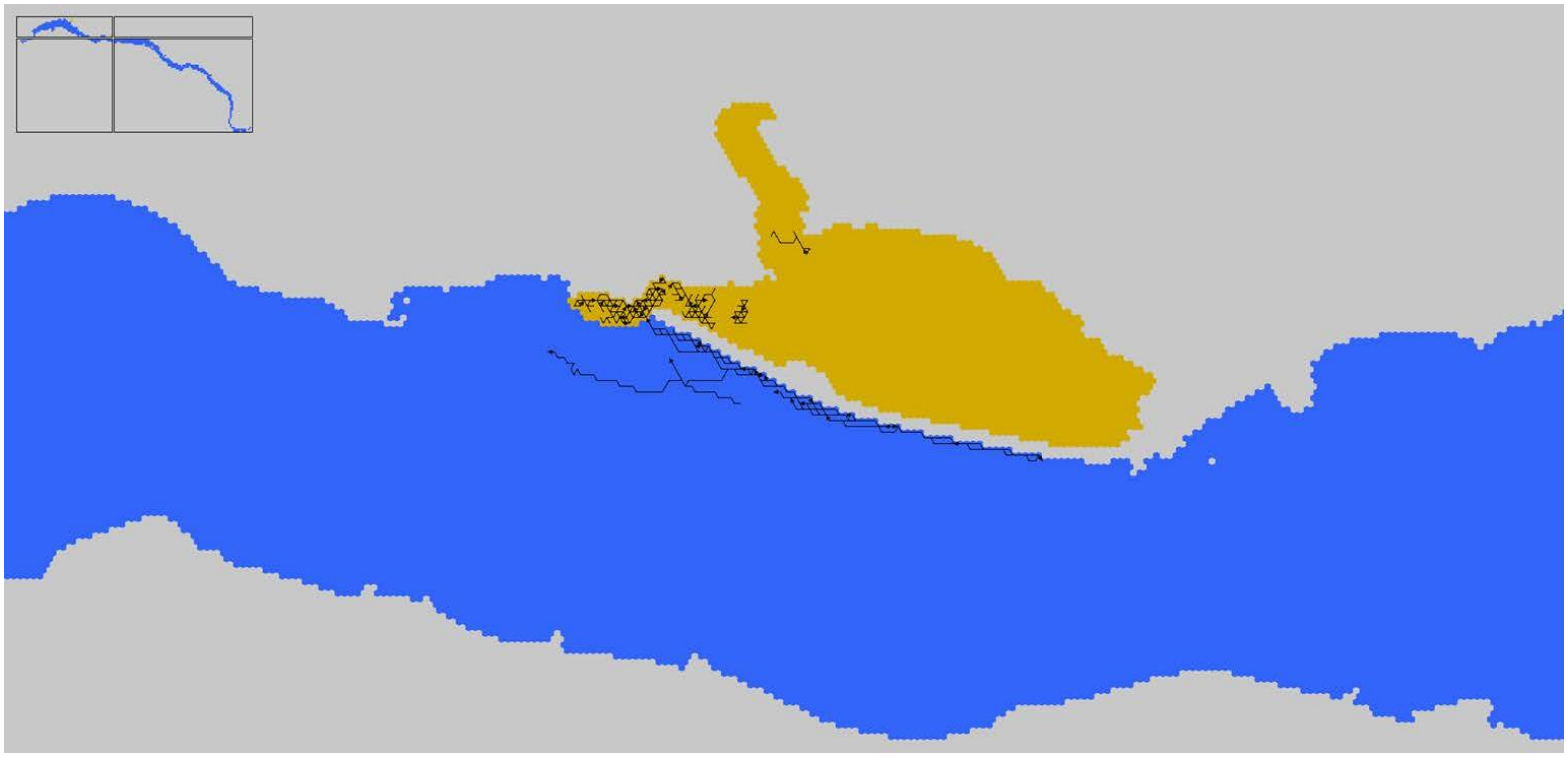

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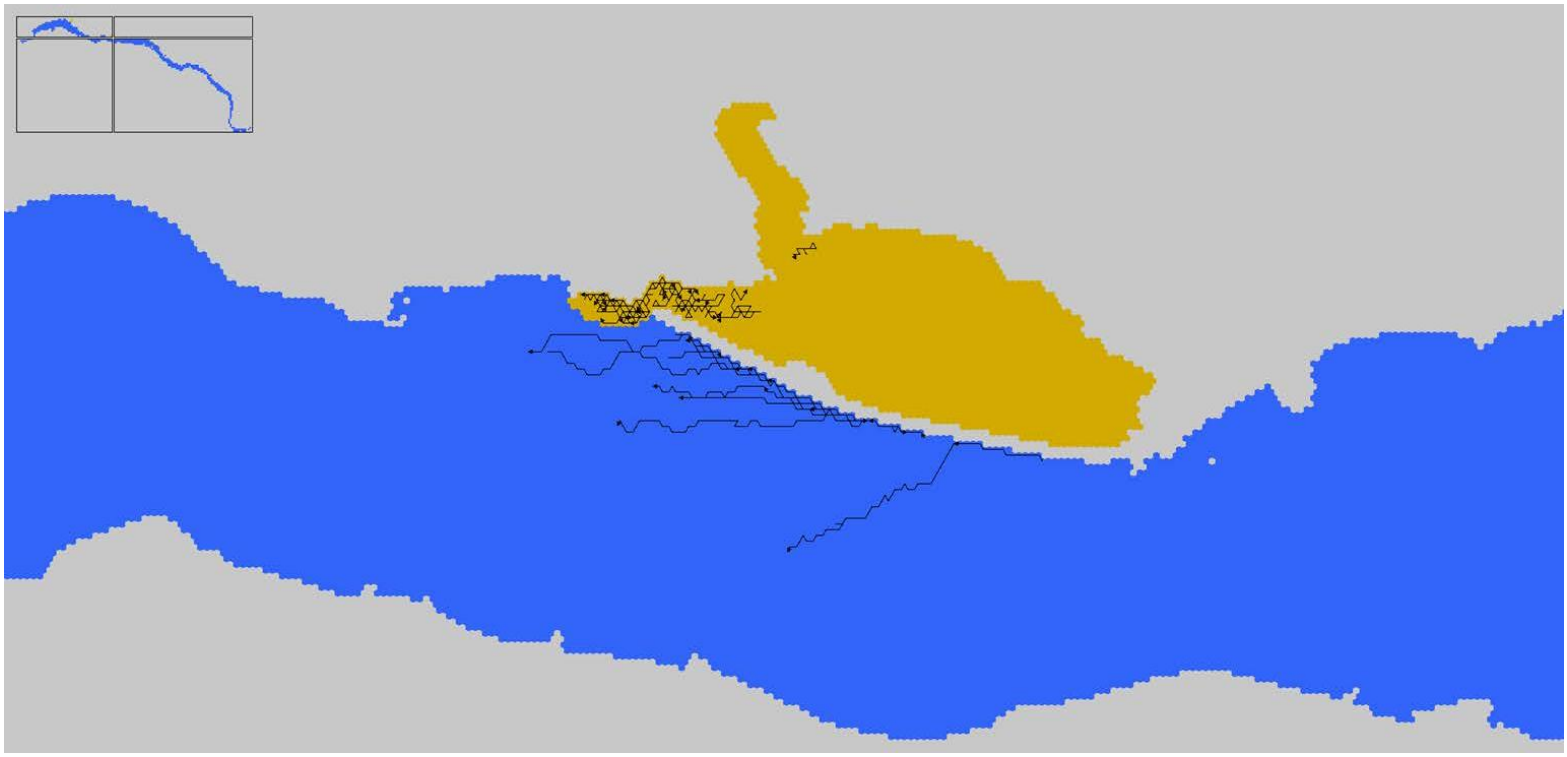
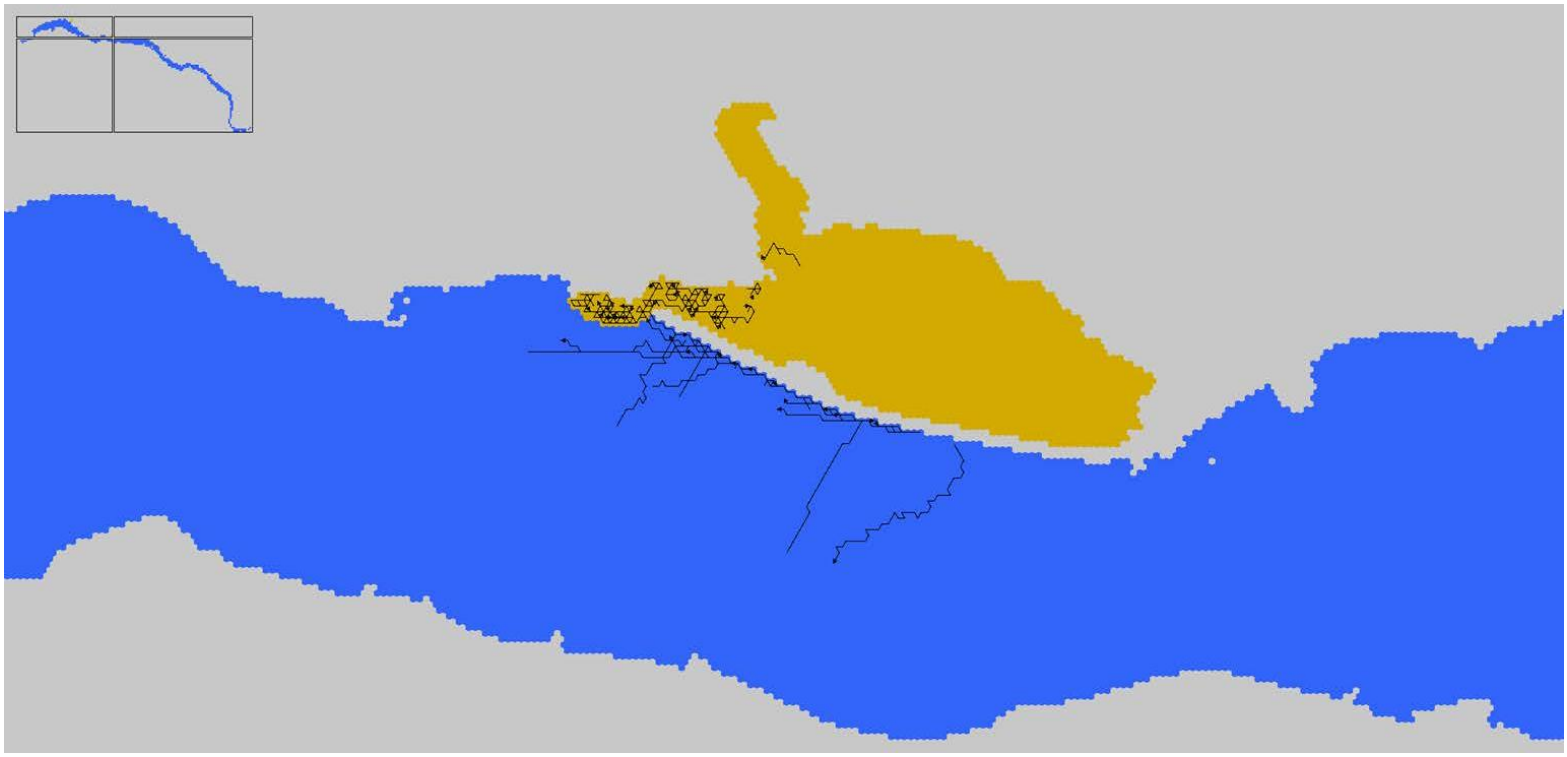
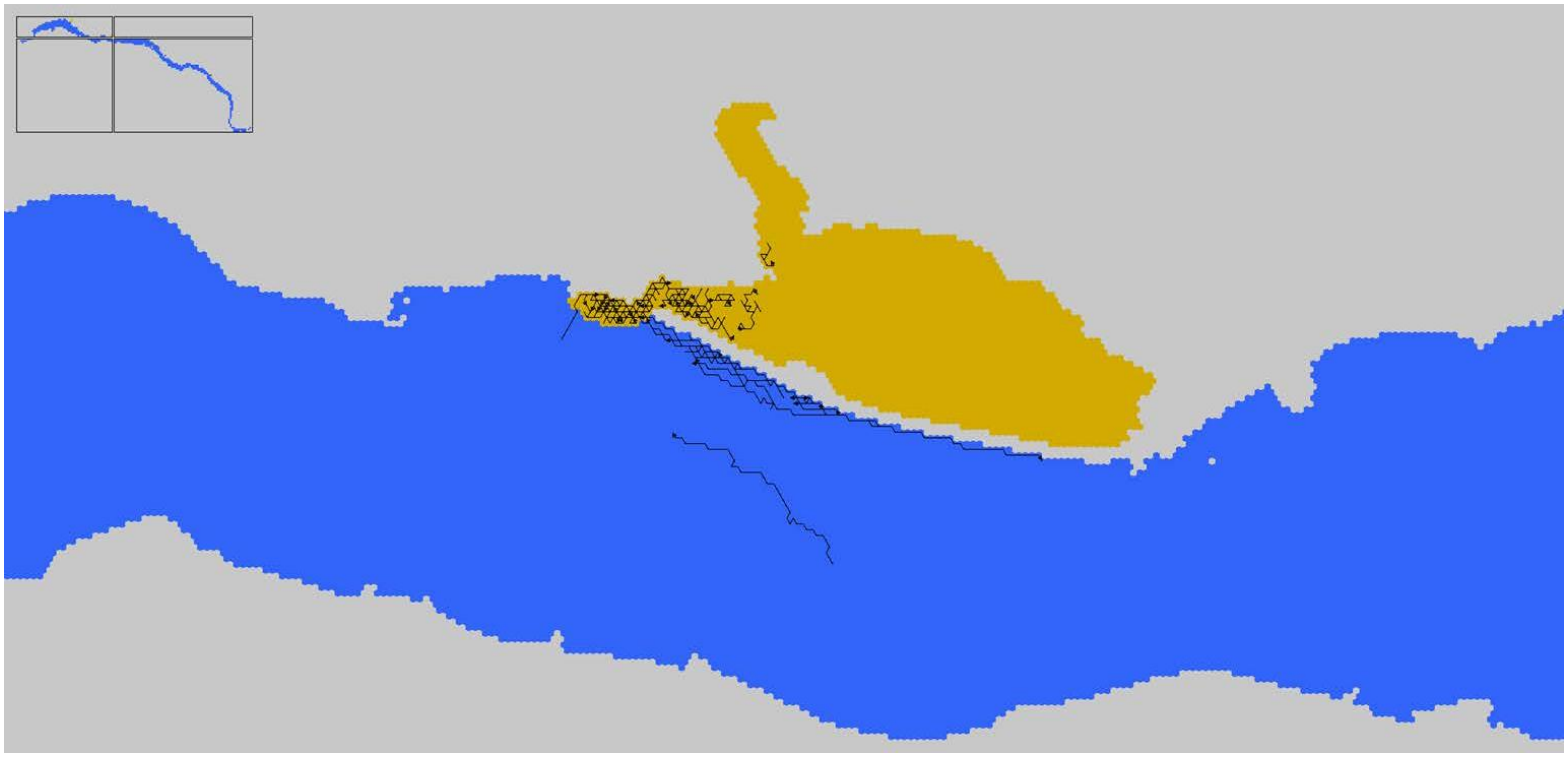


Movement



Movement



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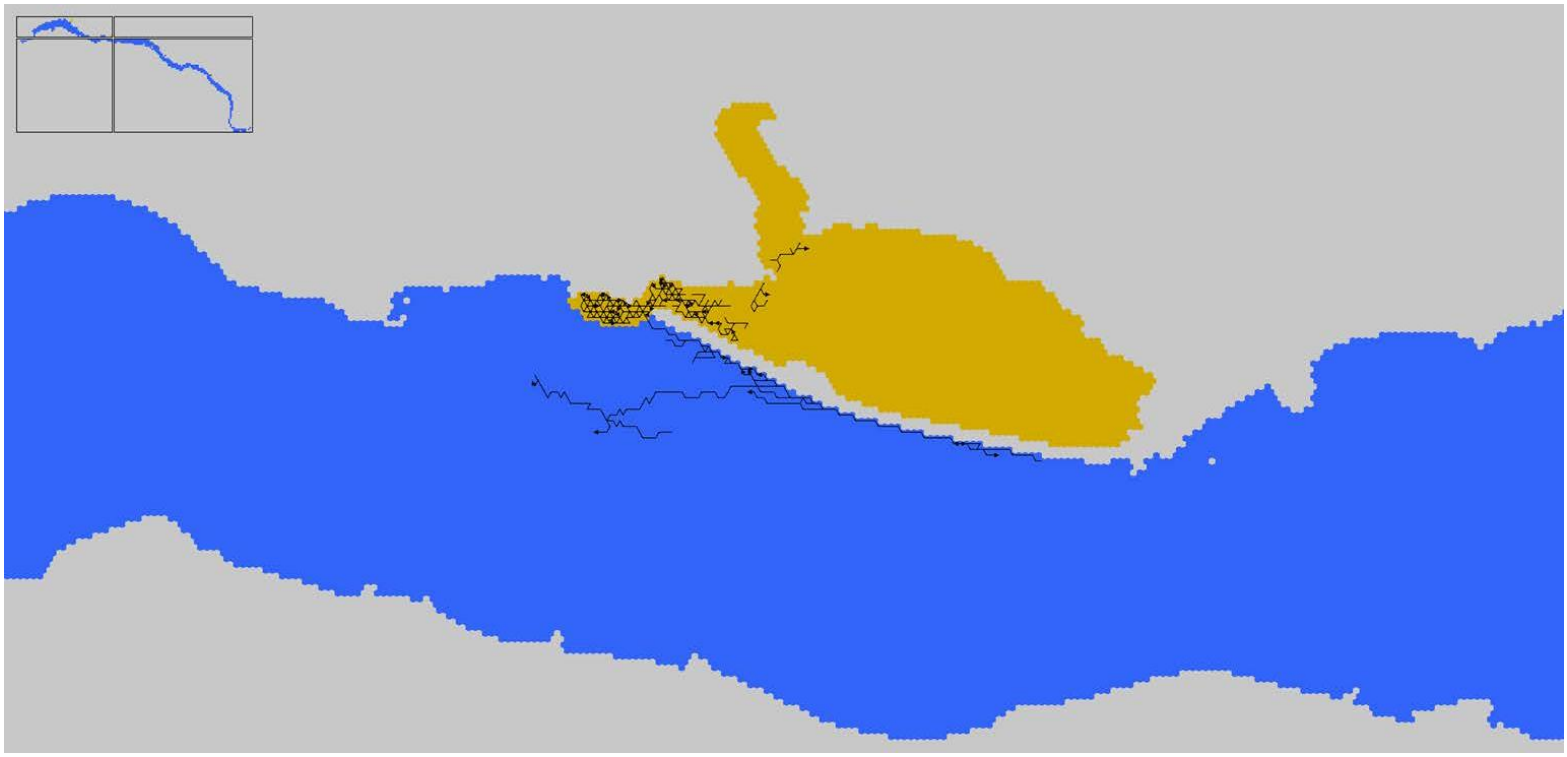

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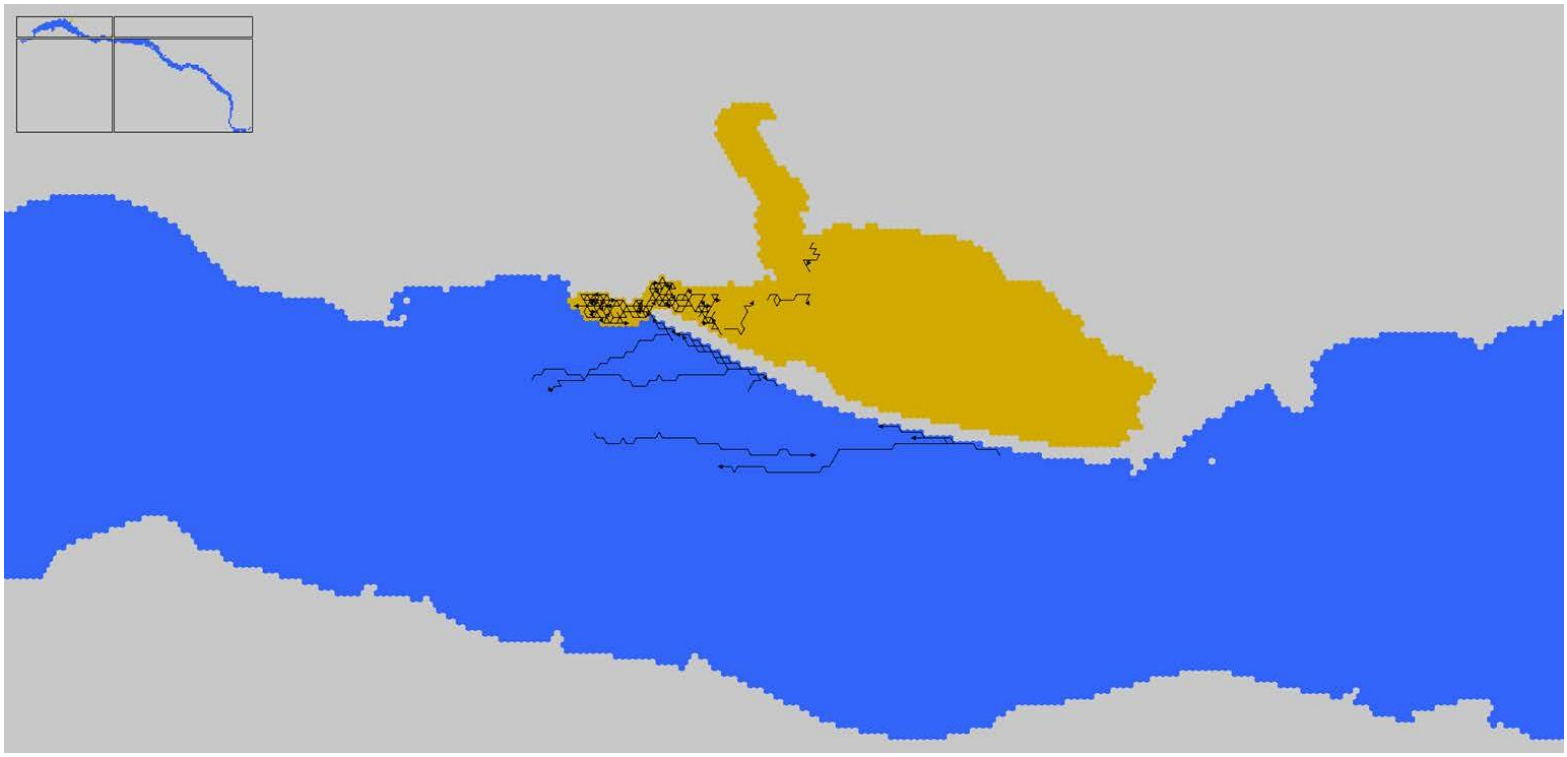
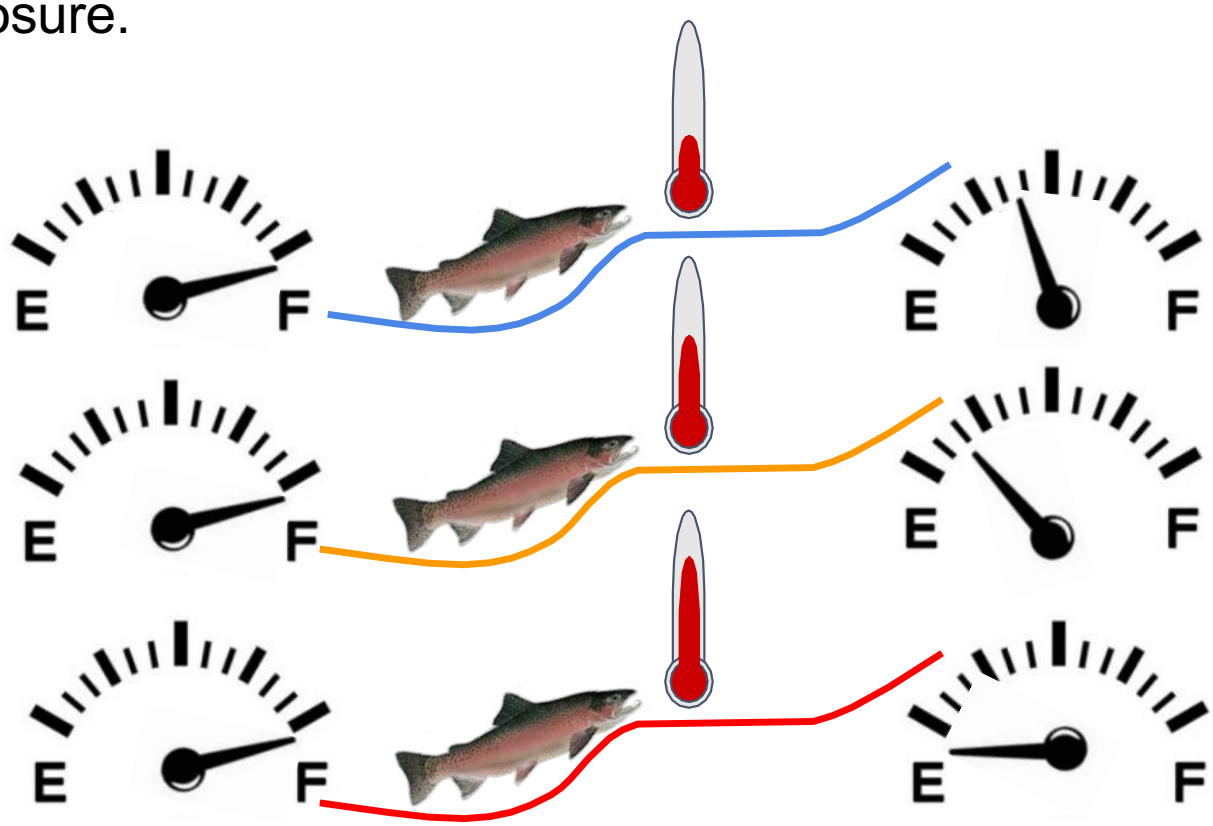


Bioenergetics and sufficiency

We are using bioenergetics equations to keep track of the available energy for a fish.

The equations take into account the fish weight and thermal exposure.



Summary

Relevant Applications: The primary goal of this effort is to evaluate the net effects of thermal refuge use for salmon and steelhead migration survival and reproductive success in order to prioritize management activities.

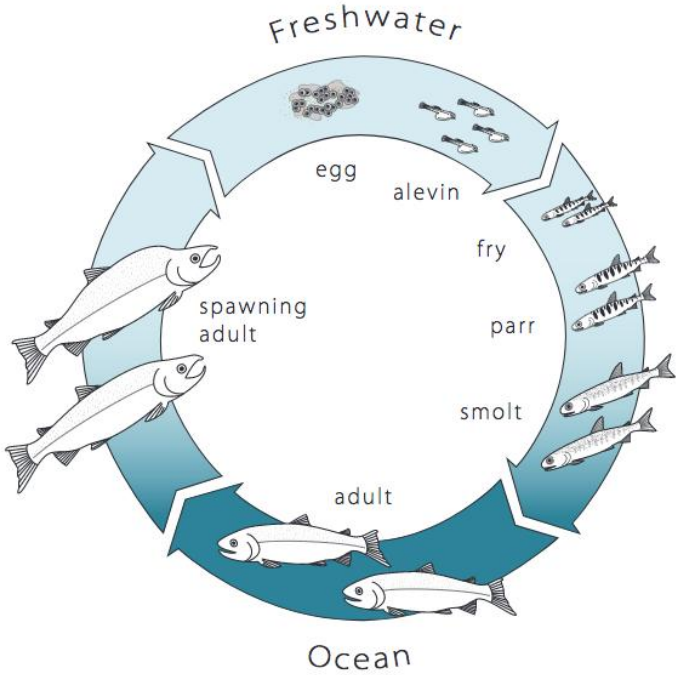
Novel Research: We are constructing a mechanistic spatial IBM that couples fish physiology and behavior in a dynamic environment including multiple stresses.

Tools and Methods: Our model emphasises extensibility and transferability in order to facilitate adoption by other researchers and application to different study systems.

Thank you!

This presentation has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for presentation. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Life cycle



We are only modelling the migration corridor.
The model framework is extendable to include more of the life cycle.

Image from NOAA-NWFSC