Enhancement of Cold Water Sources for Salmon Refuge in the lower Columbia River Gorge:
A 3D Hydrodynamic Modeling Assessment

[1]*Keith Marcoe*, Chris Collins, Catherine Corbett
[2]Mike Burke

1 Lower Columbia Estuary Partnership
2 inter·fluve

Background

- Year 3 of an ongoing, EPA-funded study of cold water inputs to the lower Columbia River

2017 - 2018

- Plume enhancement feasibility study for lower Gorge tributaries

  Rationale:
  - Extensive salmon use of man-made, cold water embayments at mid-Columbia tributary confluences:

Question

Can we alter the hydrodynamics around existing cold water sources in the lower Columbia River Gorge to create suitable refuges for summer migrating salmon, similar to those found upstream?

Future aspects:
sea level rise, cost, geomorphic analysis, social considerations

Photo courtesy of Tony Meyer, LCFEG

Challenges

Typical mid-Columbia tributary summer discharges:

- Little White Salmon River (Drano Lake): ~ [1]**90 cfs**
- Herman Creek: [2]**20 – 30 cfs**

Typical lower Gorge tributary summer discharges:

- [3]**1 – 15 cfs**

At these low discharges, can lower Gorge tributaries form cold water plumes of adequate size to be used as refuge by migrating salmon?

Data sources:

1. *Volume of Cold Water Refuge Associated with 26 tributaries providing CWR in the lower Columbia River*. US EPA draft technical memorandum. Dec. 2017

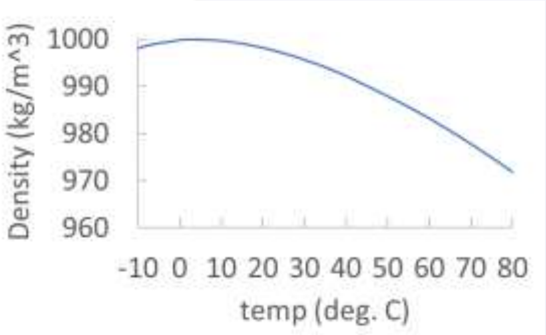
2. *Temperature Characteristics of Herman Creek Cove and its Function as a Cool-Water Refuge for Adult Salmon and Steelhead in the Columbia R*. Cramer Fish Sciences, 2007.

3. LCEP 2015 Cold Water Refuge monitoring study.

Plume Assessment Method

Considerations:

- small tributary discharges ➡ small plume outlines
- capture vertical temperature profile over water column due to temperature/density relationship
- assess multiple stream outlet/structure orientations



- include atmospheric effects (radiation, air temperature, clouds, precipitation, wind)

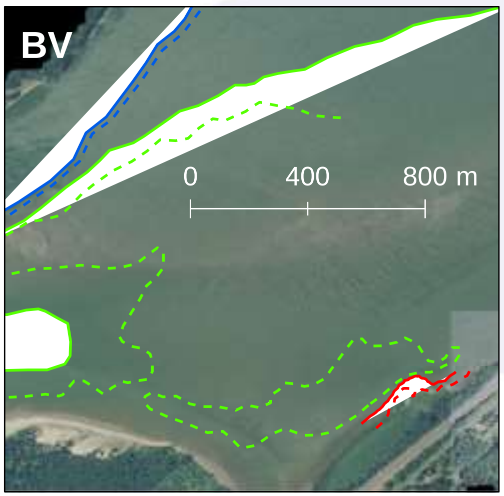
Approach:

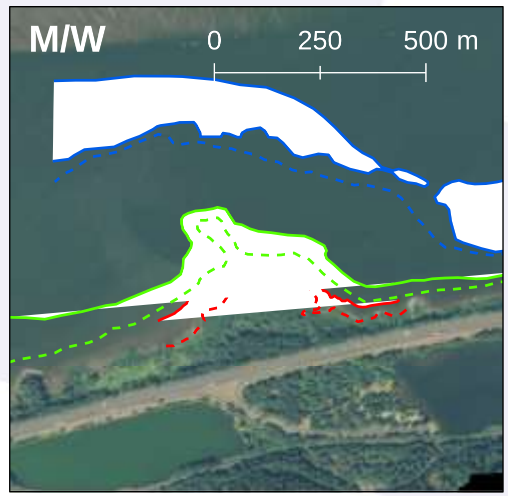
3D hydrodynamic model with advection/dispersion module + atmospheric inputs

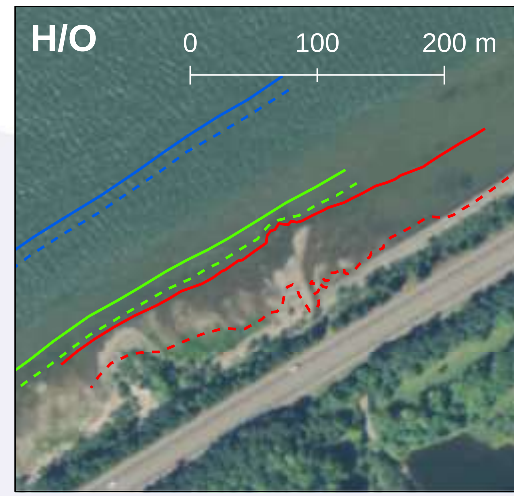
Tributary Selection

cold, adequate discharge, accessible to adult/juvenile salmonids

	Bridal Veil Cr.	Multnomah/Wahkeena Cr.	Horsetail Oneonta Cr.
discharge (cfs)	14 – 10	11 – 7	7 – 3
temperature (°C)	13.5 (mean)	13.3 (mean)	17.2 (mean)
juvenile access	Yes	Yes	Yes
Adult access	??	Yes	Yes



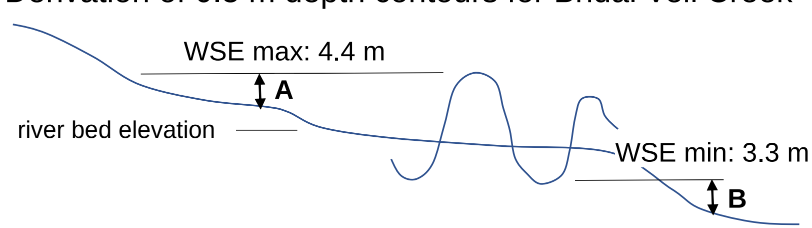




Relevant depth contours for salmon migration:

0.5 m (juvenile)	2m depth (adult)	10m depth (adult)
WSEmax	WSEmax	WSEmax
WSEmin	WSEmin	WSEmin

Derivation of 0.5 m depth contours for Bridal Veil Creek



0.5m depth contour @ max. WSE (dim A): 4.4 - 0.5 = 3.9 m elev. contour
0.5m depth contour @ min. WSE (dim B): 3.3 - 0.5 = 2.8 m elev. contour

Model Engine

Tuflow FV: finite volume, 3D numerical model (hydrodynamics)

Tuflow AD: advection/dispersion module for FV (water temperature)

TUFLOW FV

Overview | Background | Features

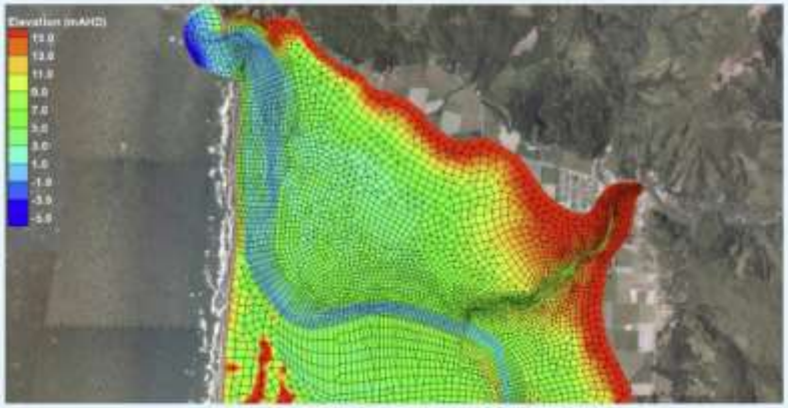
A flexible mesh finite volume numerical model that simulates hydrodynamic, sediment transport and water quality processes in oceans, coastal waters, estuaries and rivers.

Applicability

- **Coastal and nearshore environments**
- **Beaches and coastlines**
- **Offshore**
- **Estuaries, river entrances and deltas**
- **Floodplains**

Modules available include:

- 2D HD: the standard hydrodynamic engine
- AD: an advection dispersion module
- ST/MOR: a mud and sand sediment transport and morphology module (beta development version)
- Advanced structures for floodplain application
- WQ: water quality processes
- 3D: all of the above in 3D, with option for automatic 3D/2D transition for floodplain applications



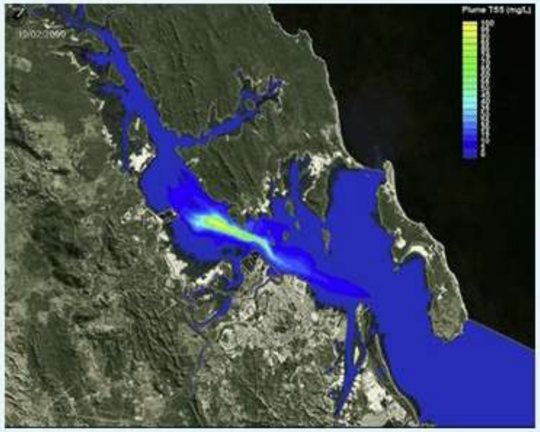
TUFLOW FV Modules

AD Module | ST Module | 3D Module | WQ Module

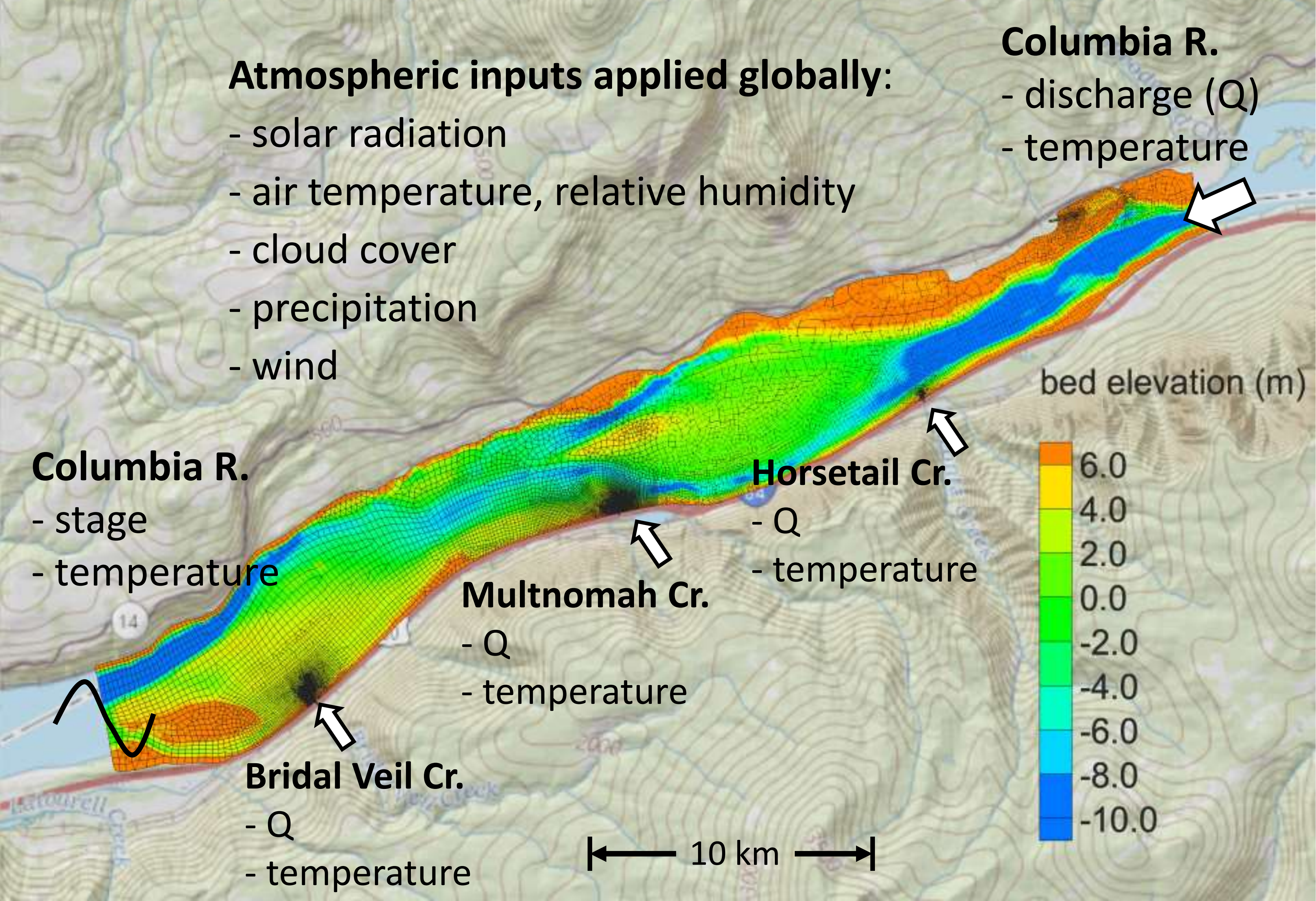
AD Module

The AD module simulates the advection and dispersion of conservative constituents in the water column. It has the following features:

- Drivers are the TUFLOW FV hydrodynamic field (2D or 3D)
- 1st and 2nd order AD schemes
- Essentially unlimited number of AD parameters / constituents
- Option to apply decay rates
- Inclusion of heat budget and atmospheric exchange routines for detailed temperature modelling
- For the 3D module, inclusion of baroclinic effects due to variations in salinity, temperature and suspended sediment concentrations

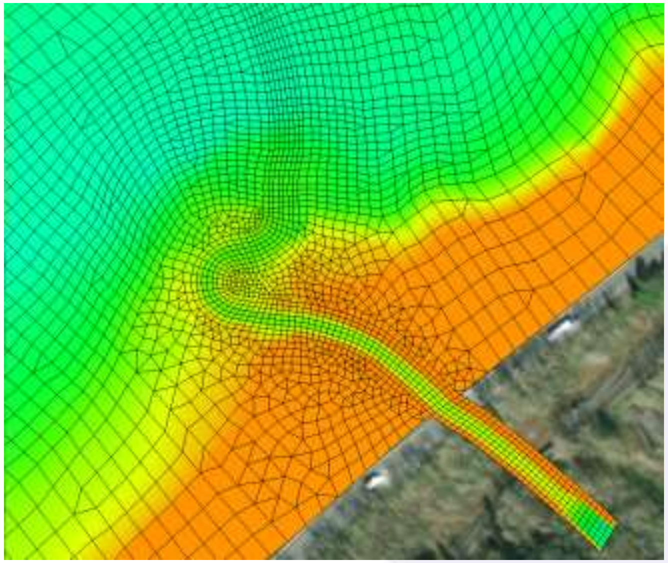


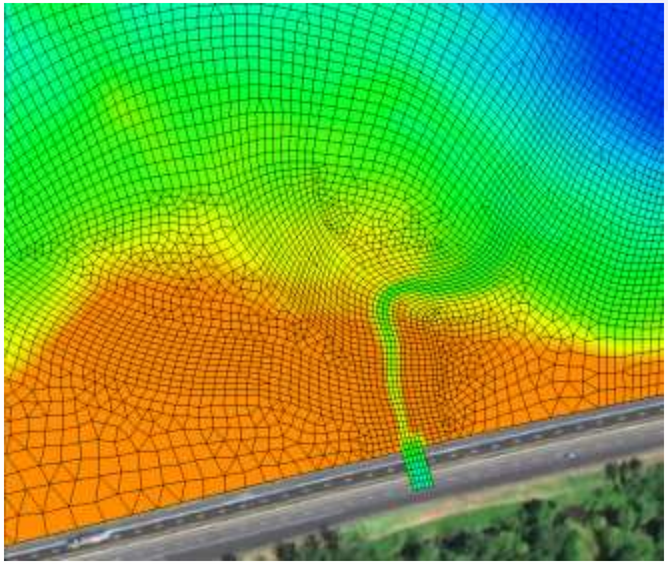
Physical Model



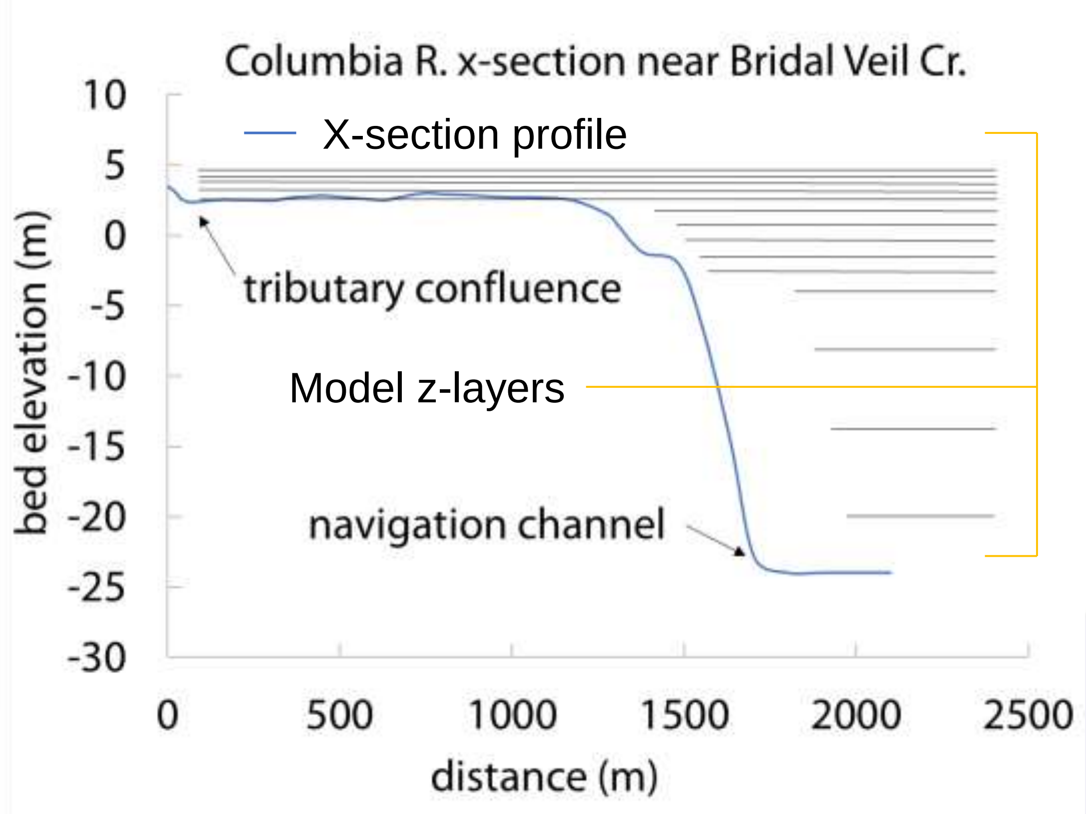
Model Resolution

Horizontal (~ 3m)





Vertical (< 1m)

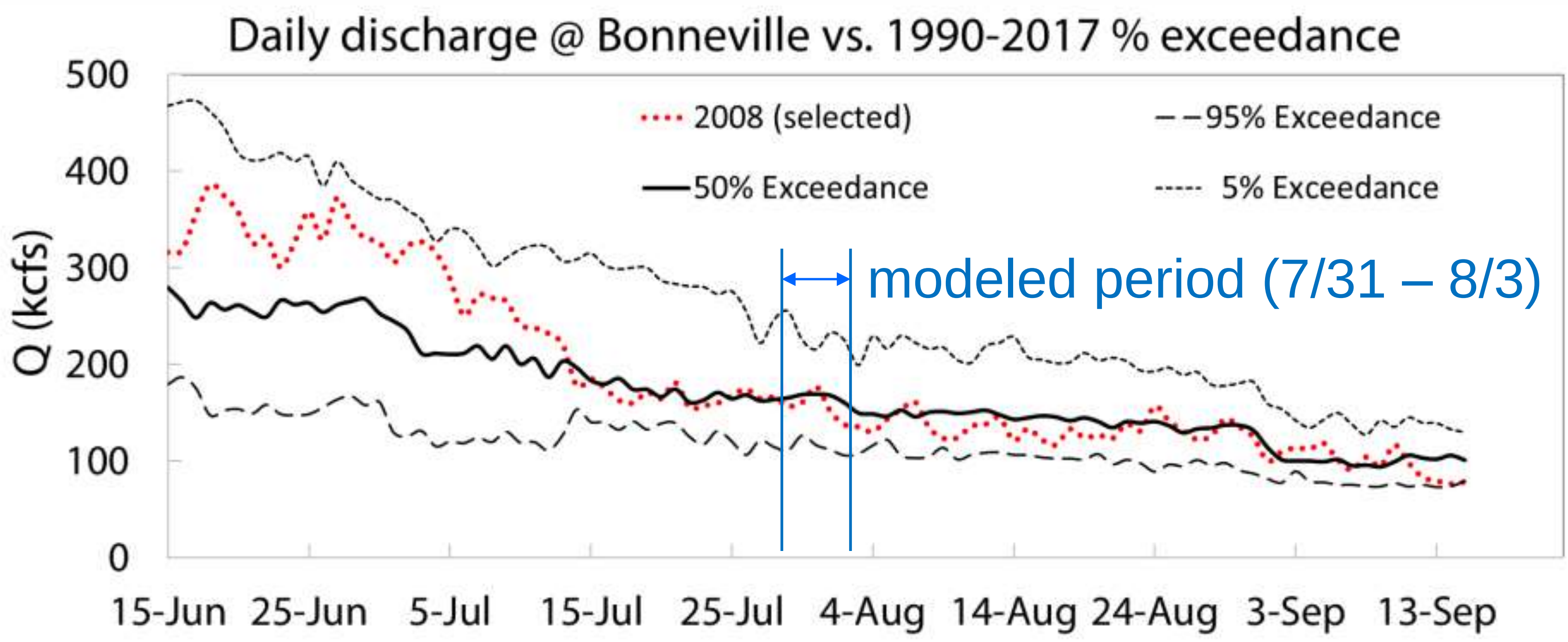


3D model: results for each z-layer

2D model: single, depth averaged result

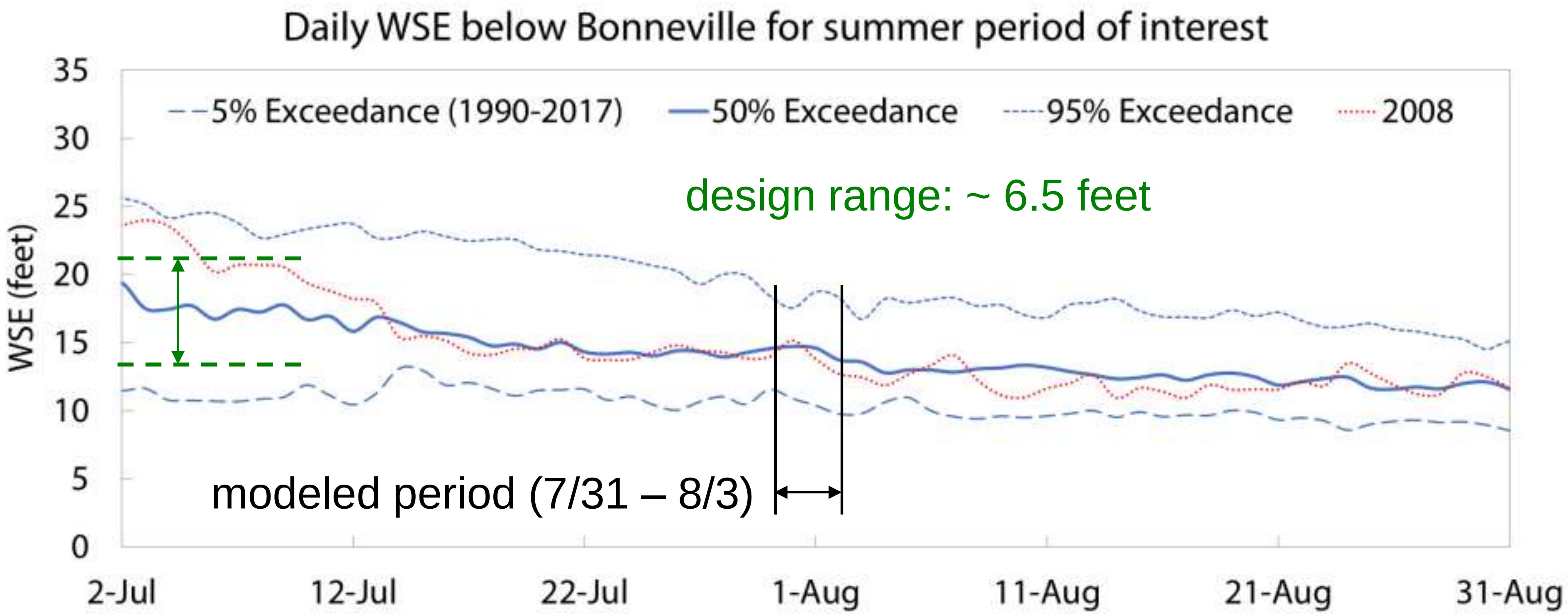
Model Boundary Data Selection

- Period of interest for salmonids: July – August
- Selected year: **2008**
  - Available water surface elevation data at Sand Island (downstream boundary)
  - Good representation of average conditions:



Model Boundary Data Selection

- Water surface elevation (WSE) during summer period of interest (July – August)



- Informs design elevation range for structures

Model Boundary Inputs

Sample time period:

	Columbia R.		Tributary Q			Tributary temp.				Atmospheric Inputs							
time	WL (m)	Q (kcfs)	Qbv (cfs)	Qm (cfs)	Qht (cfs)	Tcol	Tbv	Tm	Tht	AIR_TEMP	CLOUD	LW_RAD	PRECIP	REL_HUM	SW_RAD	Wx	Wy
8/3/08 4:00	4.0	175.4	11.7	8.7	4.7	20.7	12.0	14.2	17.3	11.1	0.8	300	0.00	0.89	300	3.1	0
8/3/08 5:00	4.0	176.5	11.7	8.7	4.7	20.6	11.8	14.1	17.3	11.7	0.8	310	0.00	0.89	350	0.0	0
8/3/08 6:00	4.0	157.5	11.7	8.7	4.7	20.5	11.7	14.0	17.2	12.2	0.8	320	0.00	0.86	400	1.6	0
8/3/08 7:00	3.9	123.1	11.7	8.7	4.7	20.4	11.7	14.0	17.2	12.2	0.8	330	0.00	0.86	450	0.0	0
8/3/08 8:00	3.9	120.9	11.7	8.7	4.7	20.5	11.7	13.8	17.2	12.2	0.8	340	0.00	0.86	500	1.6	0
8/3/08 9:00	4.0	120.9	11.7	8.7	4.7	20.5	11.7	13.8	17.0	12.8	0.8	350	0.00	0.83	550	1.6	0
8/3/08 10:00	4.0	120.9	11.6	8.6	4.6	20.6	11.8	13.8	17.0	13.3	0.8	360	0.00	0.8	600	0.0	0
8/3/08 11:00	3.9	119.2	11.6	8.6	4.6	20.6	12.0	13.8	17.2	13.9	0.8	370	0.00	0.77	650	3.1	0
8/3/08 12:00	3.9	118.8	11.6	8.6	4.6	20.8	12.2	13.8	17.0	15.0	0.8	370	0.00	0.69	658	4.6	0
8/3/08 13:00	3.8	118.7	11.6	8.6	4.6	20.9	12.7	14.2	17.3	16.7	0.8	380	0.00	0.65	658	5.6	0
8/3/08 14:00	3.7	118.7	11.6	8.6	4.6	21.2	13.3	14.3	17.6	18.9	0.3	382	0.00	0.56	658	6.7	0
8/3/08 15:00	3.7	118.6	11.6	8.6	4.6	21.3	13.7	14.5	17.9	20.0	0	382	0.00	0.52	658	6.7	0
8/3/08 16:00	3.6	120.0	11.6	8.6	4.6	21.4	13.8	14.7	18.2	21.7	0	360	0.00	0.49	650	7.7	0

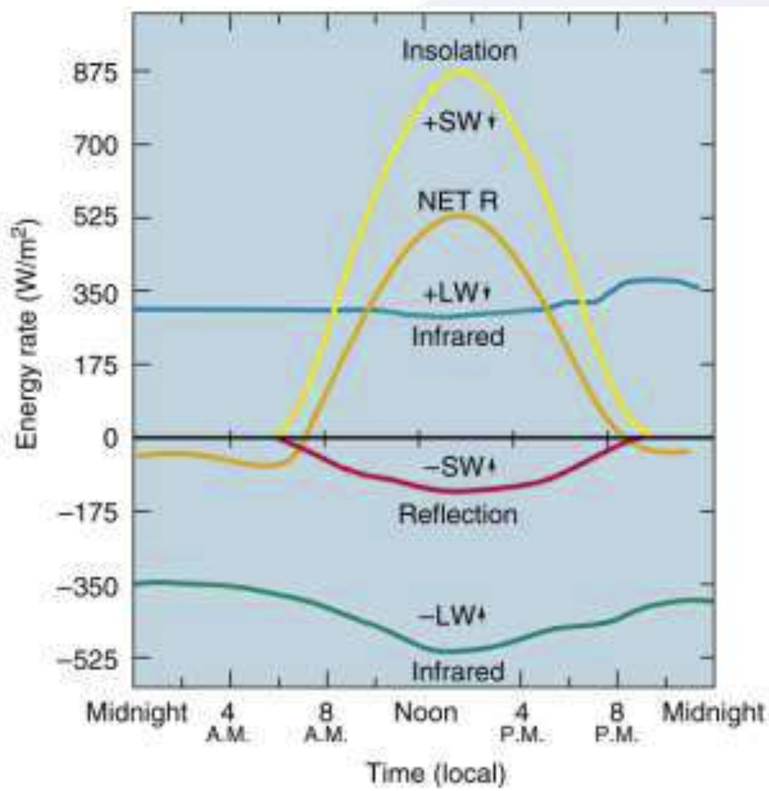
Sources:

WL: LCEP/PNL Q: Fish Passage Center	LCEP estimated	LCEP measured	radiation: standard curves weather: Troutdale, OR station

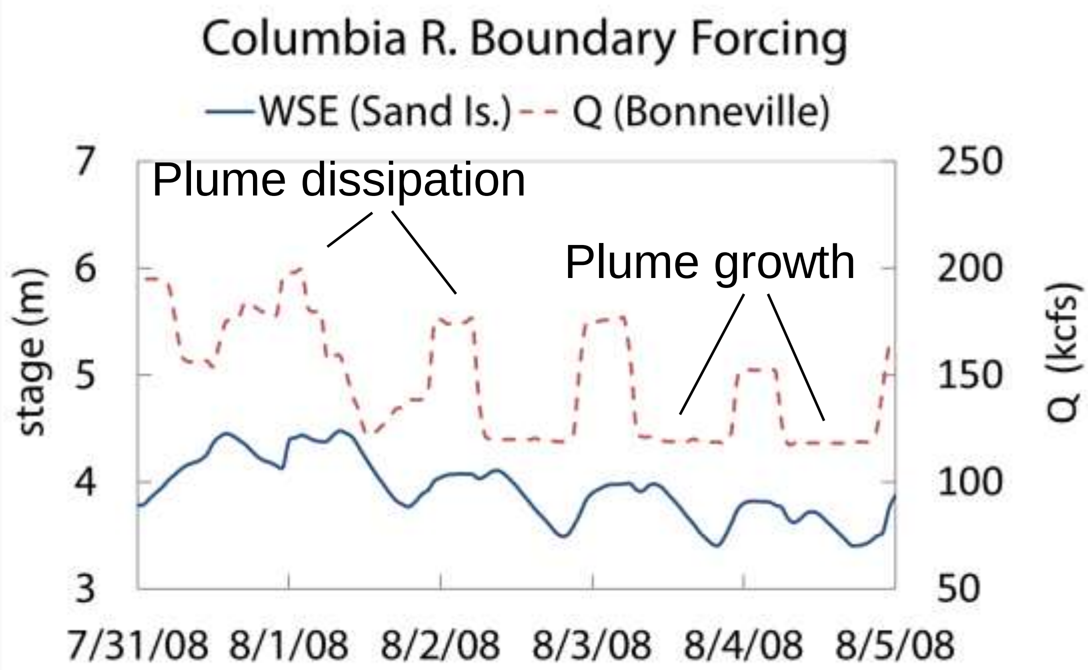
Boundary Forcing Variability

Daily variations in boundary forcing elements can have significant effects on plume characteristics

Atmospheric inputs



Discharge



Model Validation

- Rough comparison of observed vs. simulated plume extents

- Dates (and therefore temperature ranges) differ for observed versus simulated results, but we found generally good agreement for plume extents.

- Model time steps selected for comparison were chosen based on best combination of parameters at time of observations (time of day, river stage, atmospheric conditions).

Model Validation

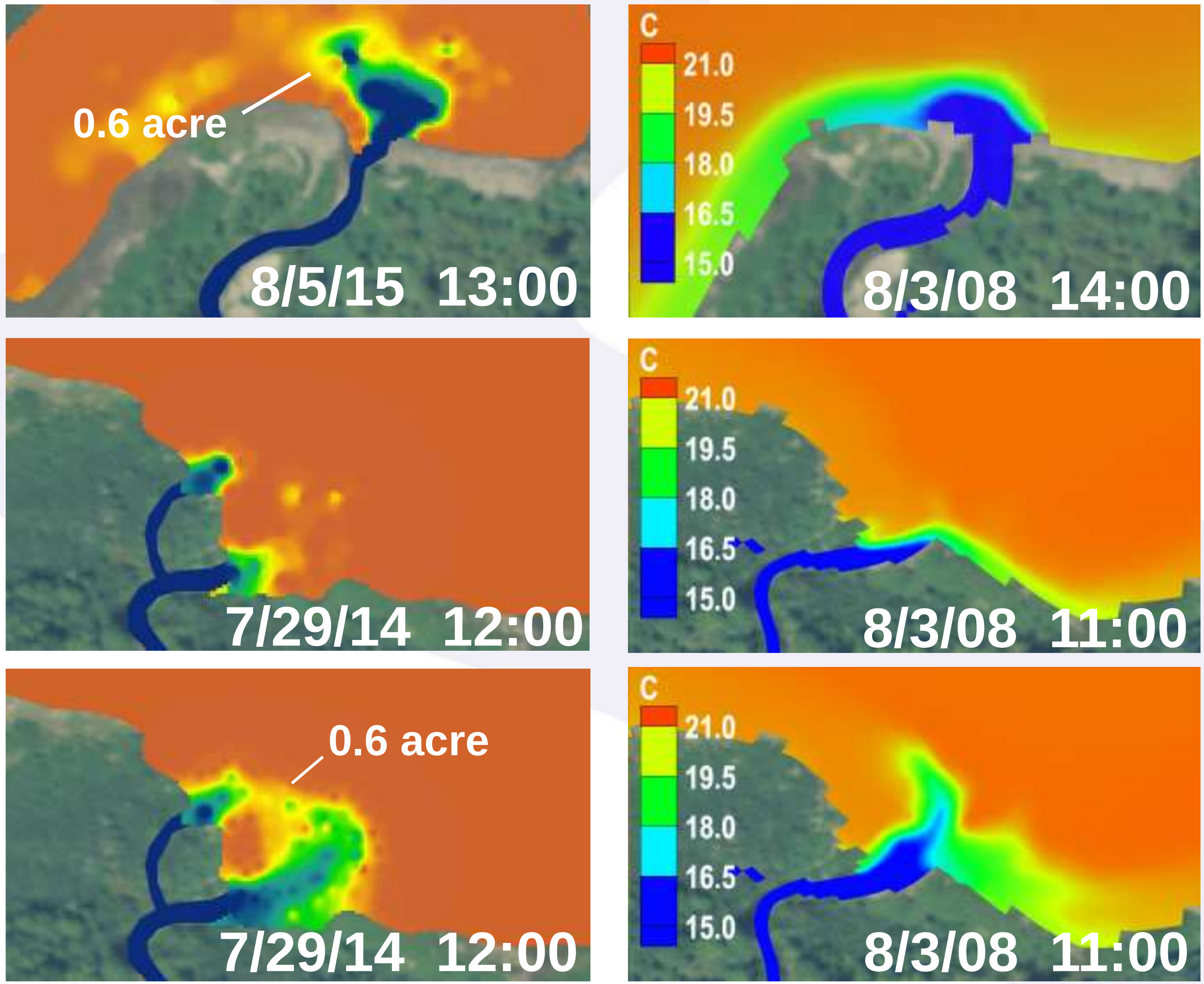
Stream confluence

observed temperature | model temperature

Bridal Veil
(@ surface)

Multnomah
(@ surface)

Multnomah
(@ max. depth)



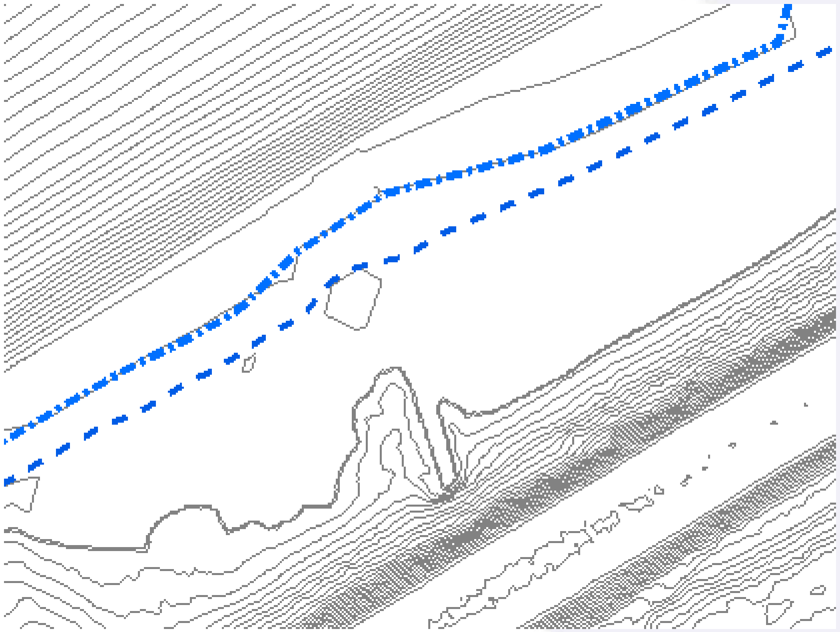
Results

- Current analysis assumes solid (non-permeable) diversion structures. Actual structure types TBD based on future analysis.

- Use existing landforms to inform structure placement and help minimize constructed lengths.
- Focus on water temperatures at depth. More likely to be used by adult salmonids.

Results - **Horsetail Creek**

Existing condition

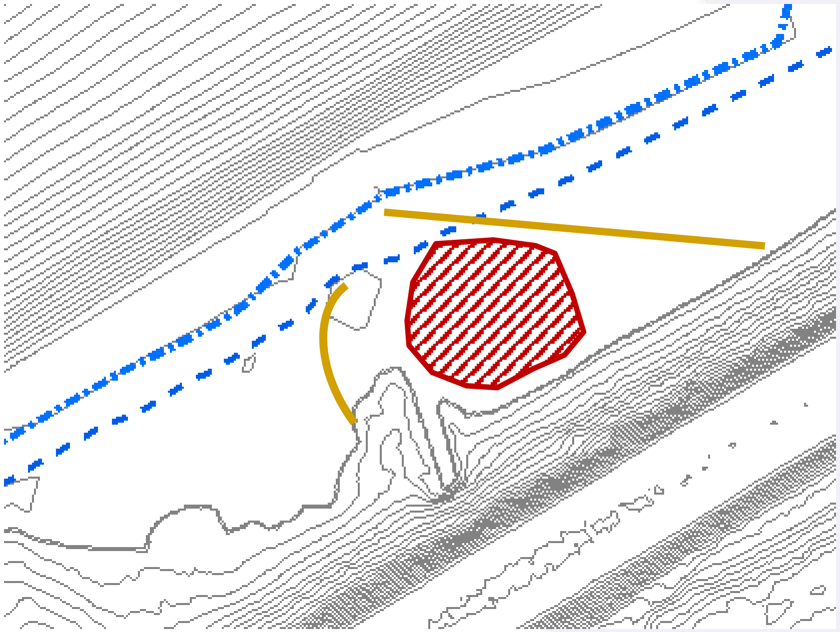


2 m depth contour range

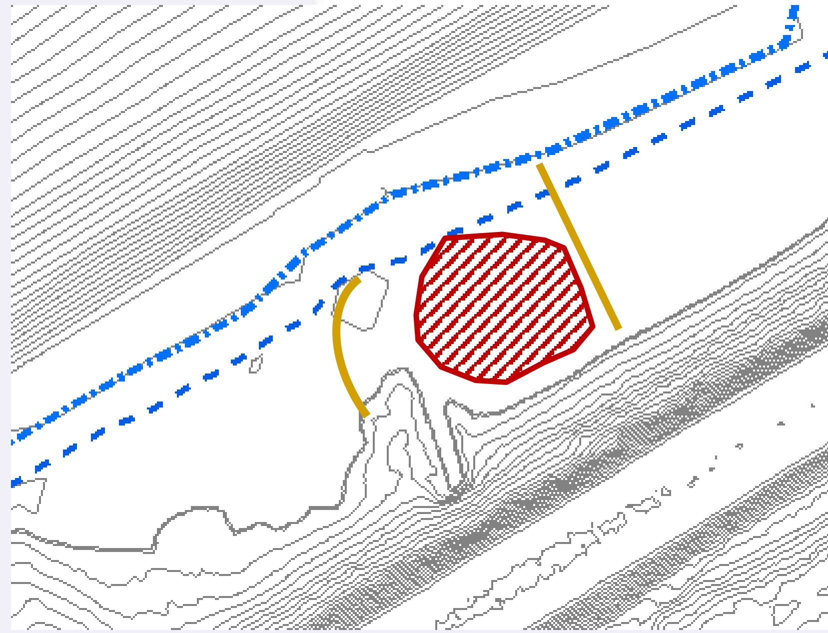
Flow trace

Results - **Horsetail Creek**

full structures



full structures, perpendicular



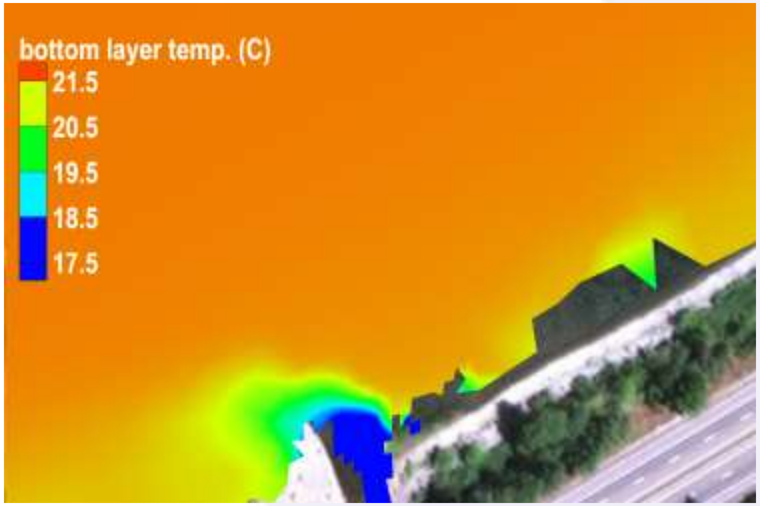
2 m depth contour range

structure placement

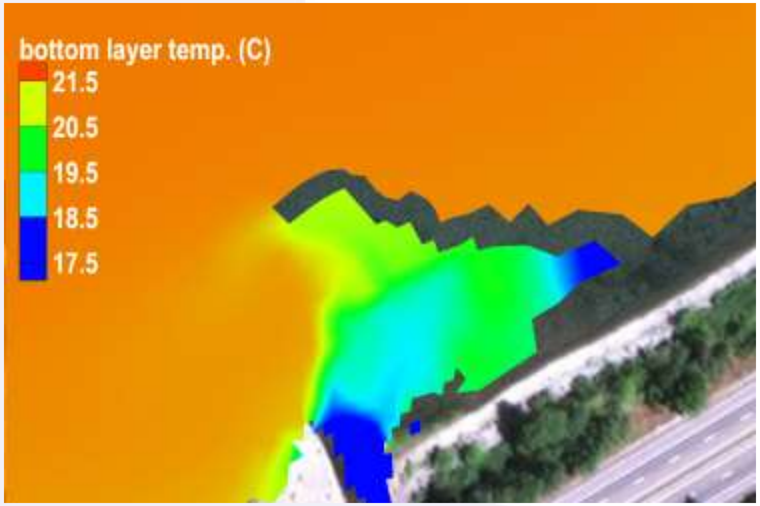
excavate to 2m depth min.

Results - **Horsetail Creek**

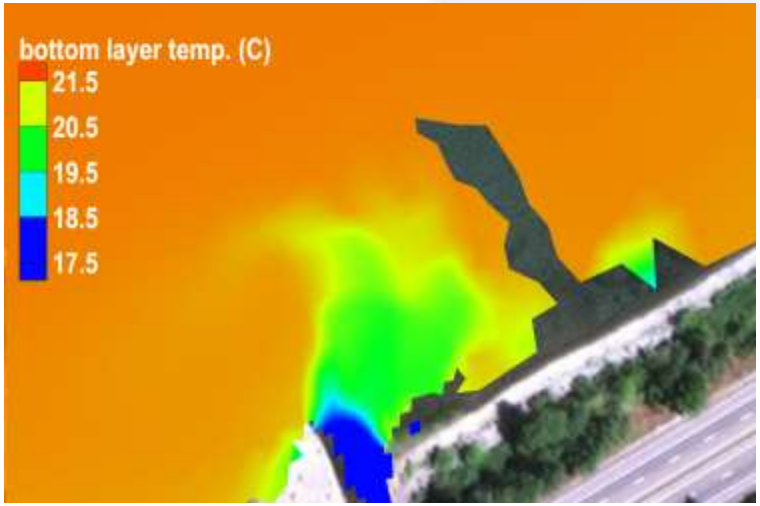
existing



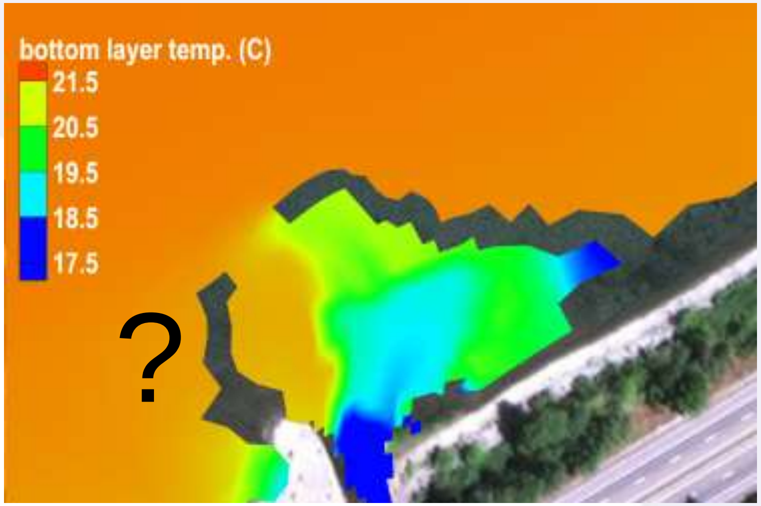
US structure



US perpendicular

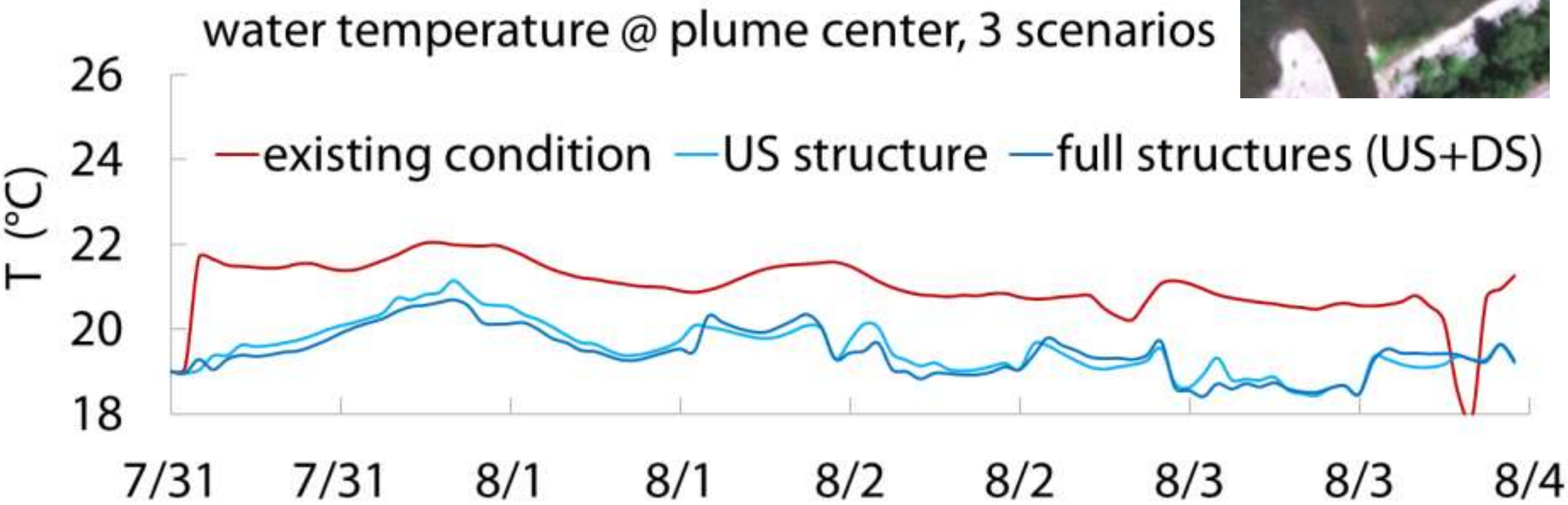


full structures



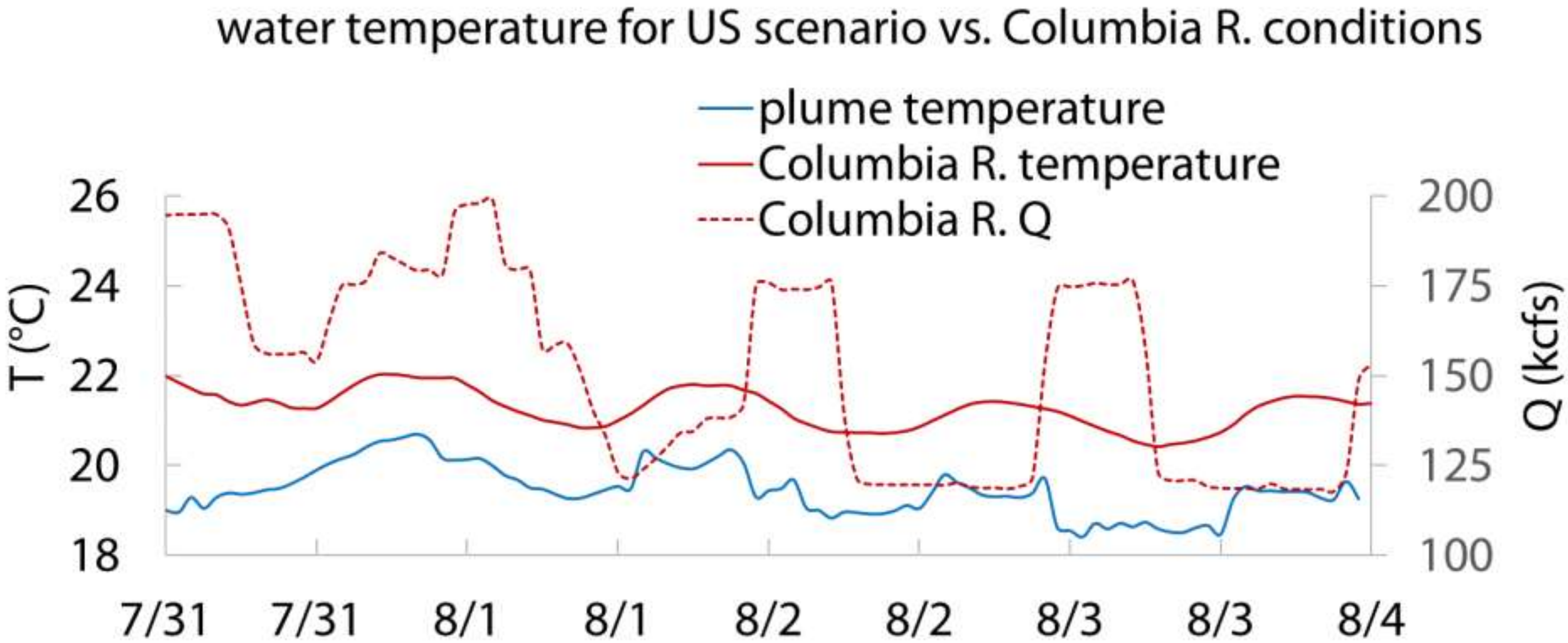
Results - **Horsetail Creek**

- Plume characteristics are dynamic



- Relative contributions from:
  - Columbia River forcing (discharge and temperature)
  - atmospheric forcing (temperature, clouds, rain, wind)

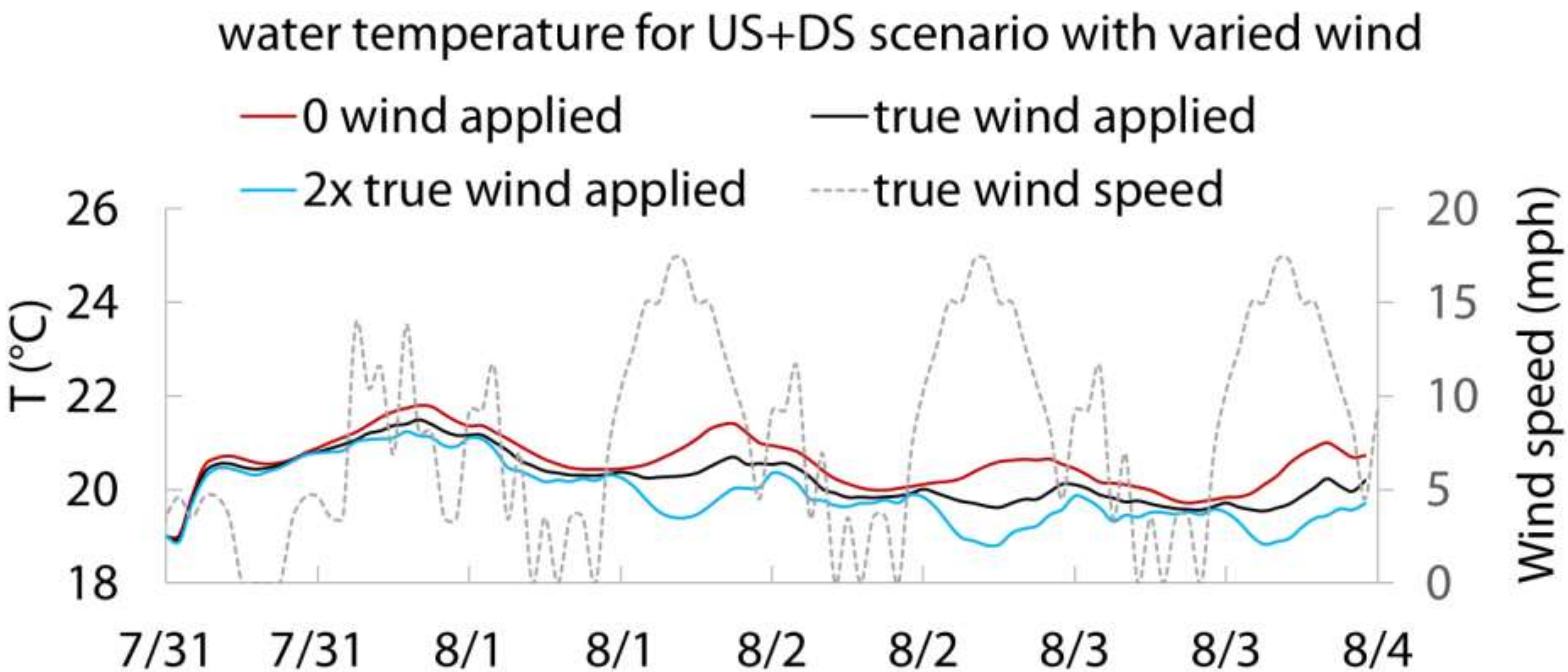
Results - **Horsetail Creek**



- Not a direct correlation to Columbia R. discharge at Horsetail plume. Other factors contributing.

Results - **Horsetail Creek**

Does DS structure enhance plume? <u>Maybe</u>, if wind is factored in:

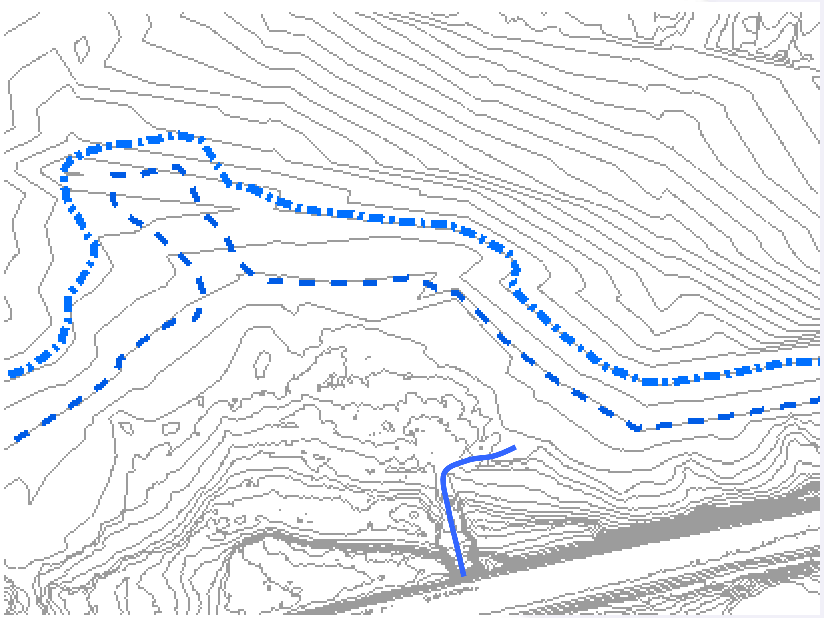


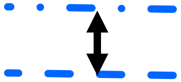
Largest differences during late day (maximum wind velocities)

Stronger west winds enhance plume? Needs more analysis..

Results - **Multnomah Creek**

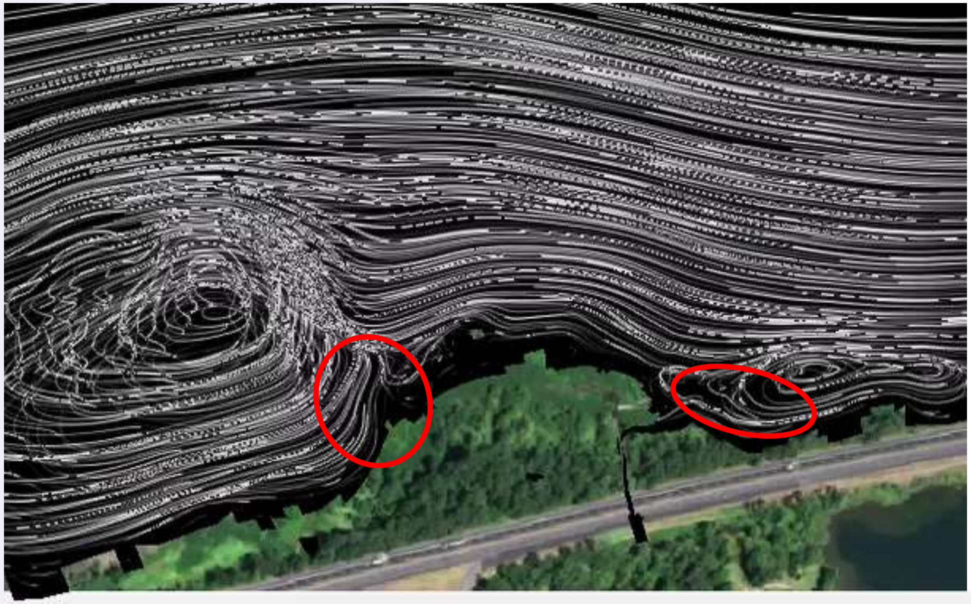
Existing condition





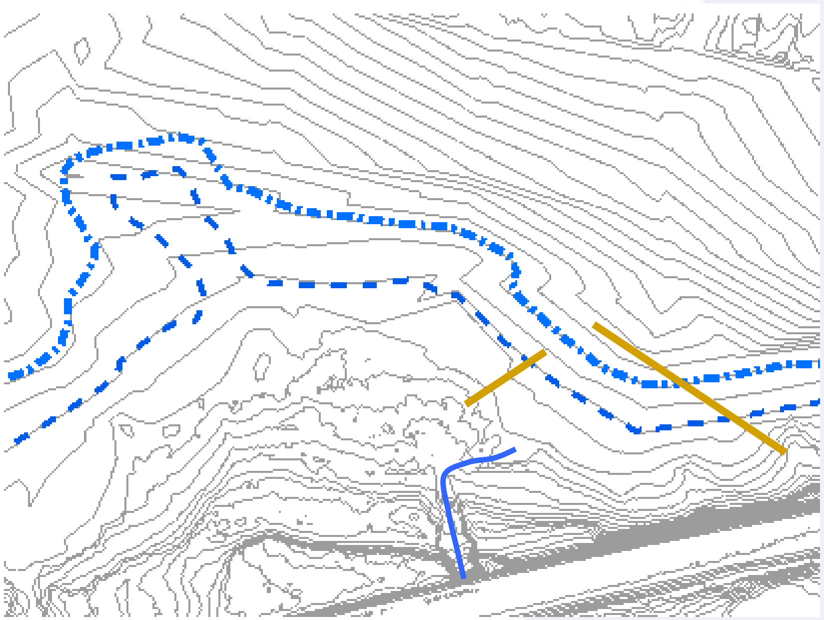
2 m depth contour range

Flow trace

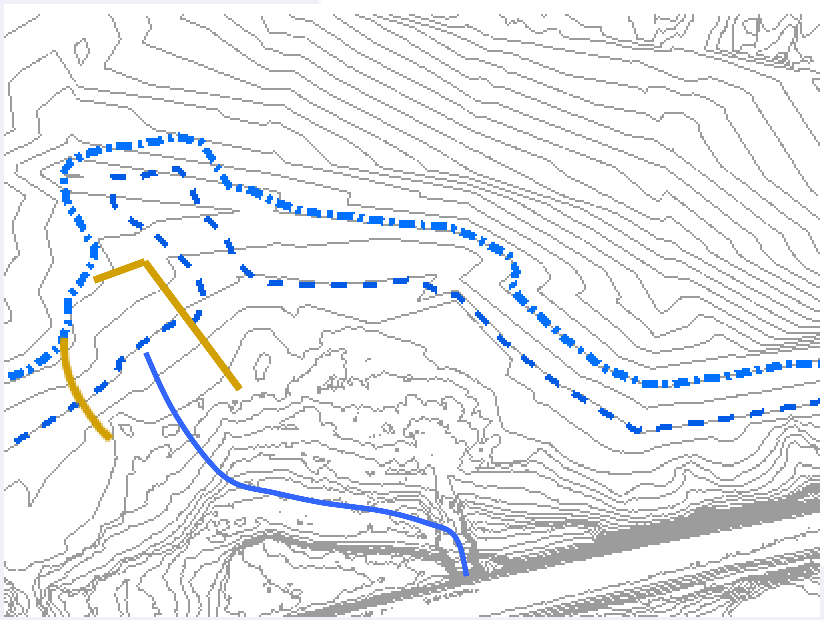


Results - **Multnomah Creek**

Full structures



West channel: full structures

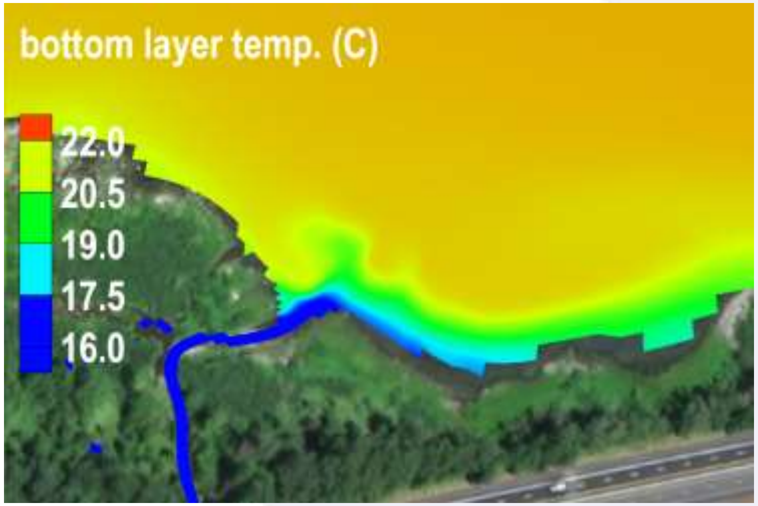


2 m depth contour range

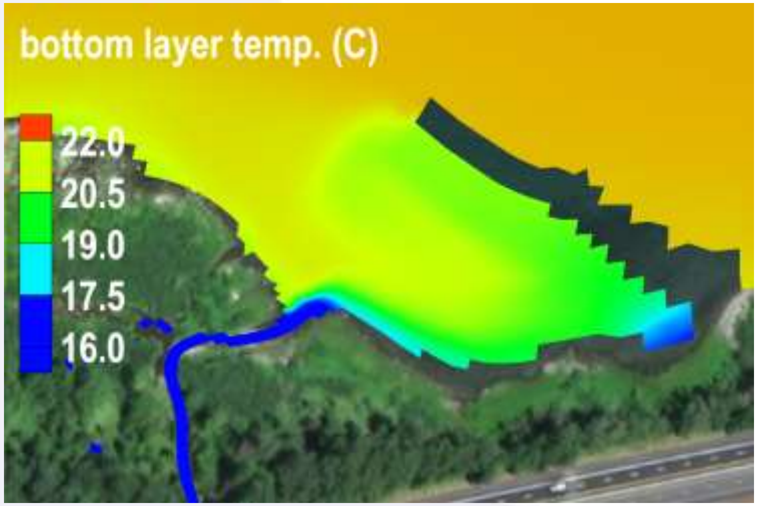
structure placement

Results - **Multnomah Creek, east outlet**

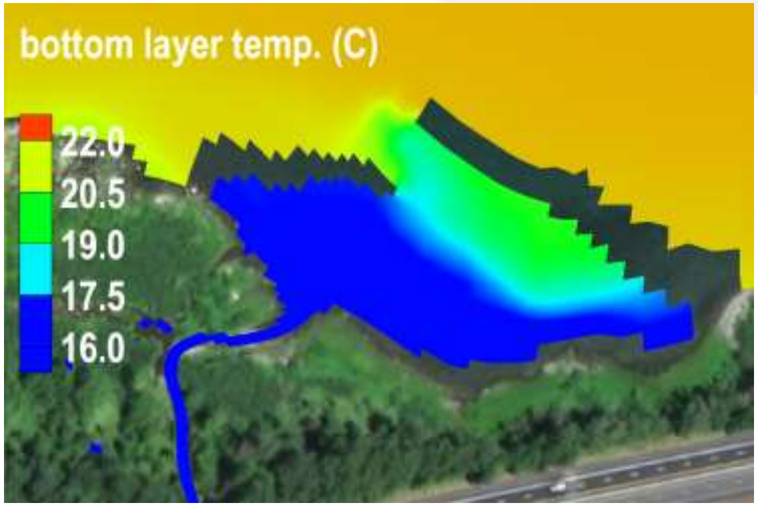
a: existing



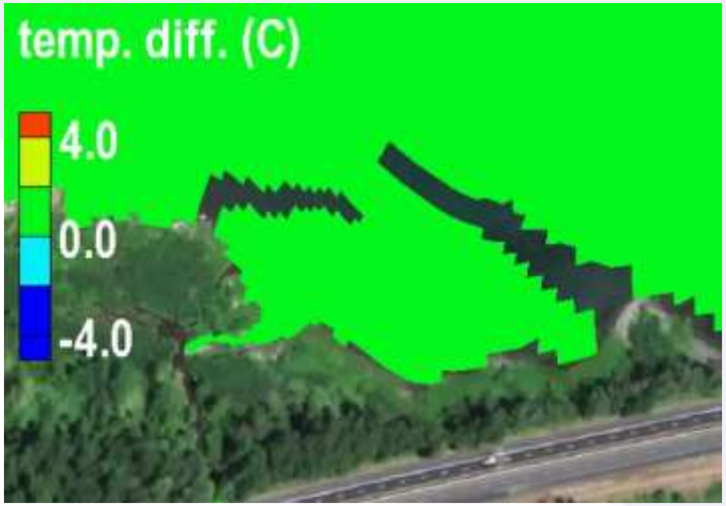
b: US



c: full (US+DS)

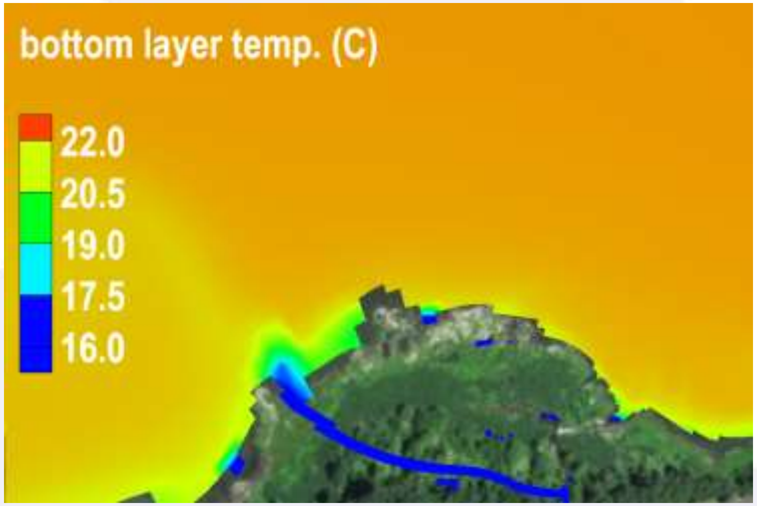


difference: c - a

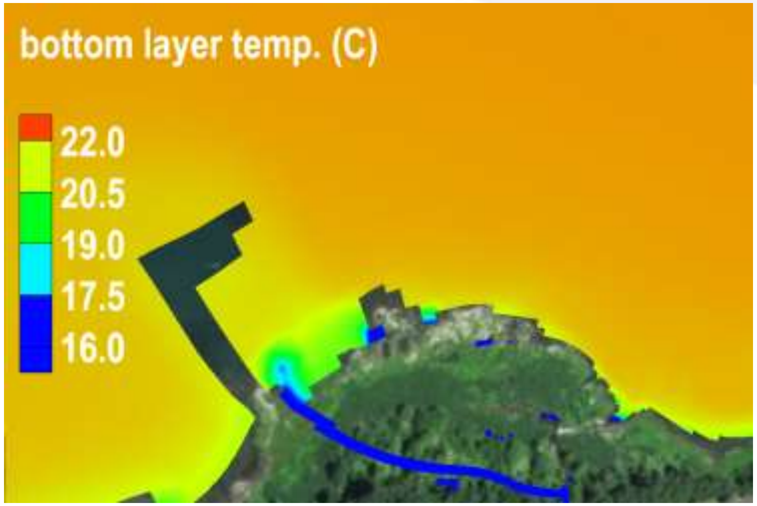


Results - **Multnomah Creek, west outlet**

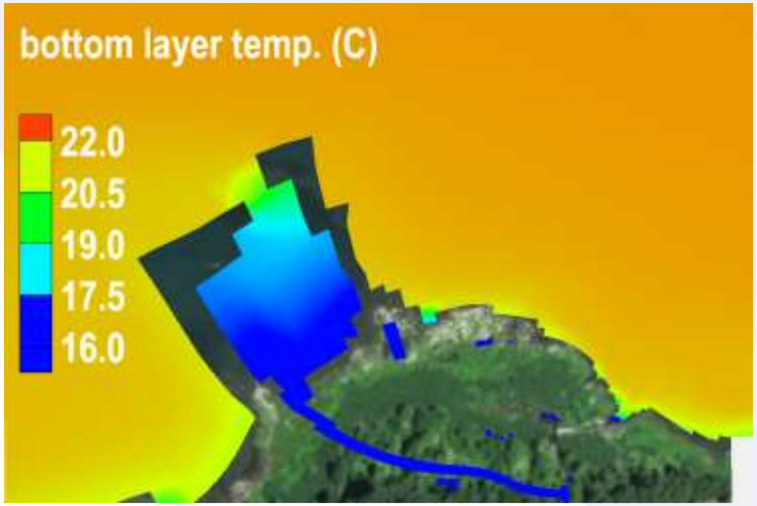
a: no structures



b: DS

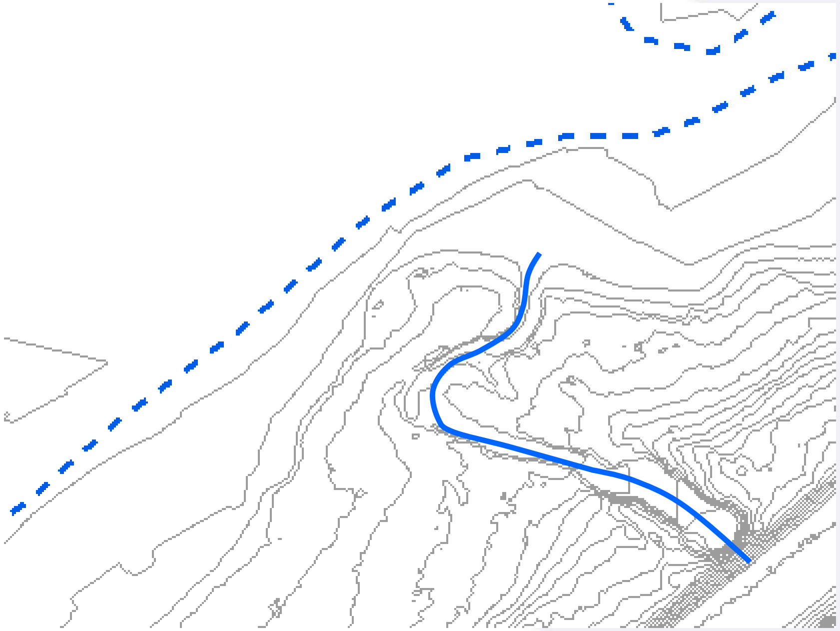


c: US+DS



Results – **Bridal Veil Creek**

Existing condition

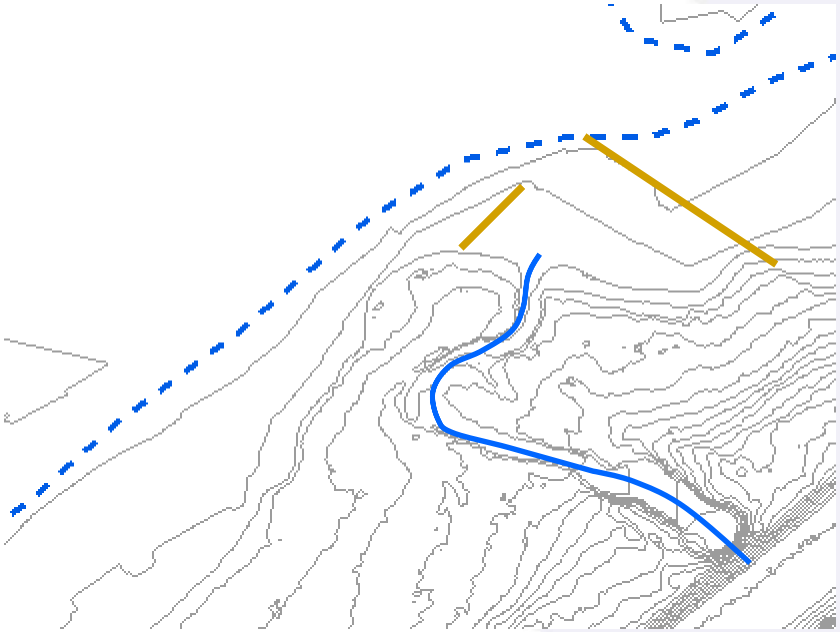


Flow trace

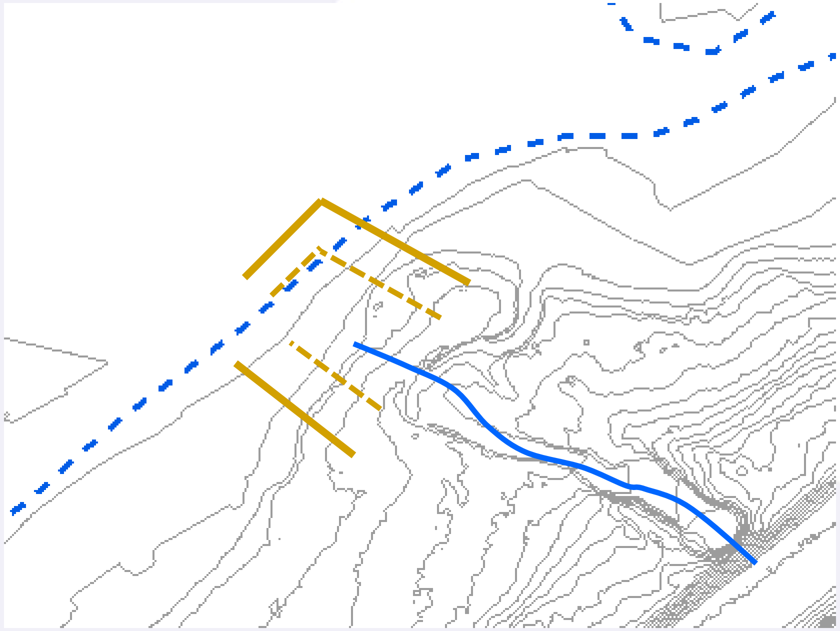
2 m depth contour @ maximum WSE for analysis period

Results – **Bridal Veil Creek**

Full structures



North channel: full structures, increase area

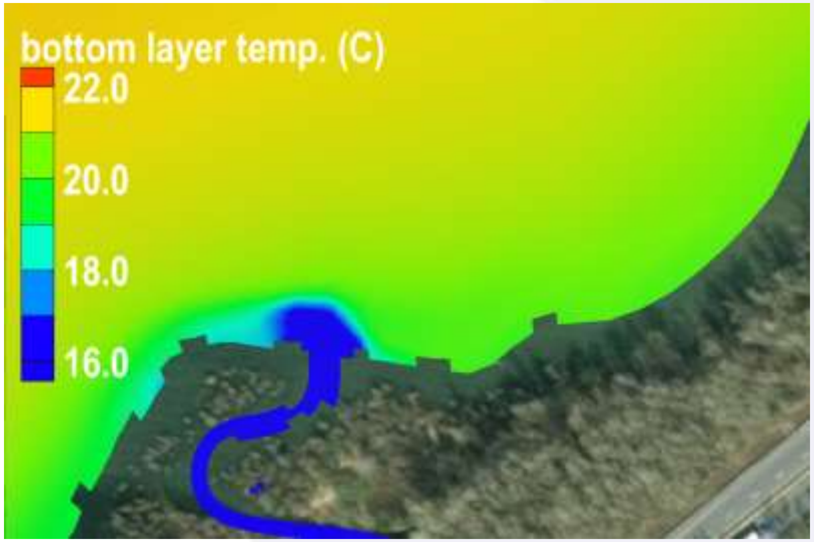


2 m depth contour @ maximum WSE for analysis period

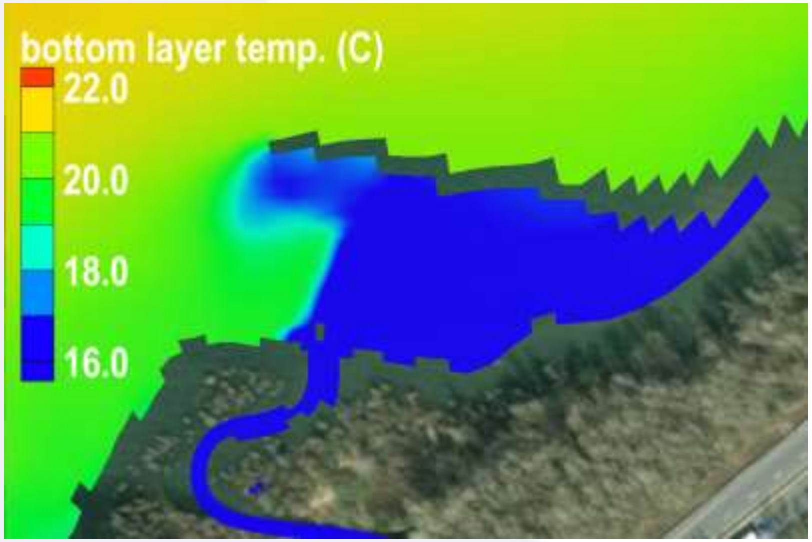
structure placement

Results – **Bridal Veil Creek, east outlet**

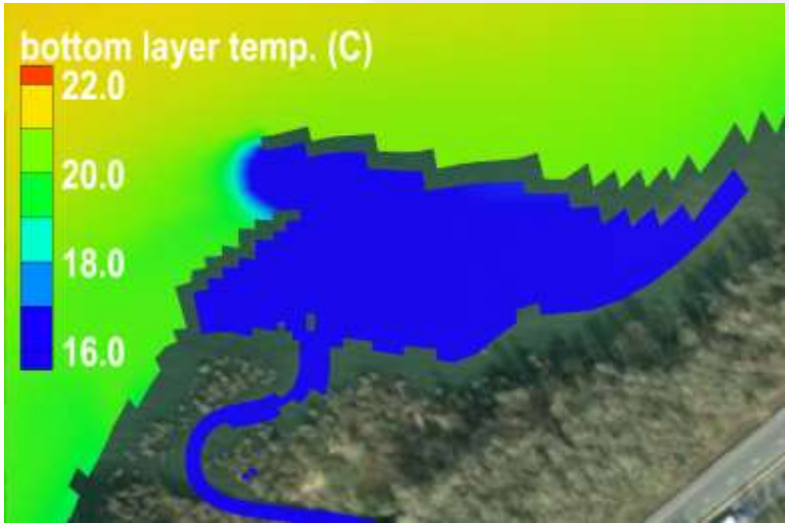
a: existing



b: US



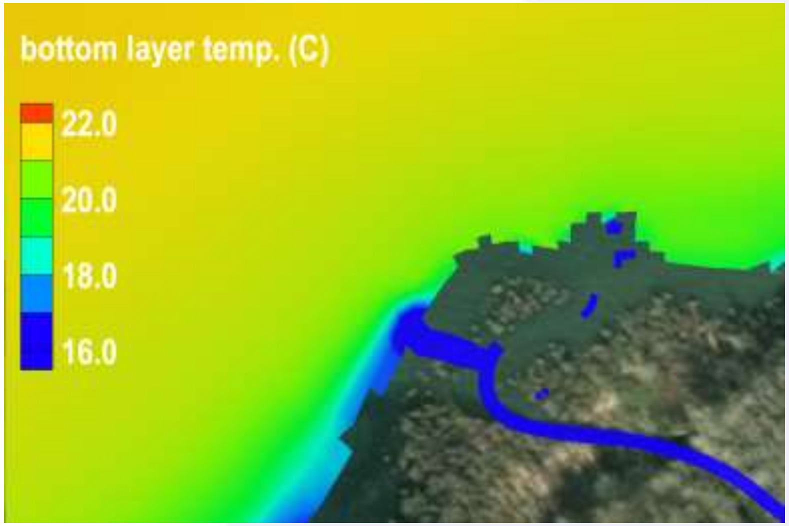
c: full (US+DS)



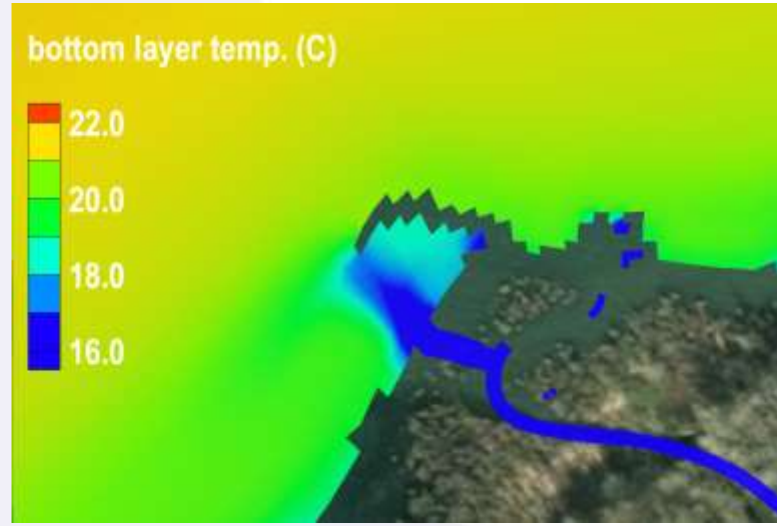
difference: c - a

Results – **Bridal Veil Creek, north outlet**

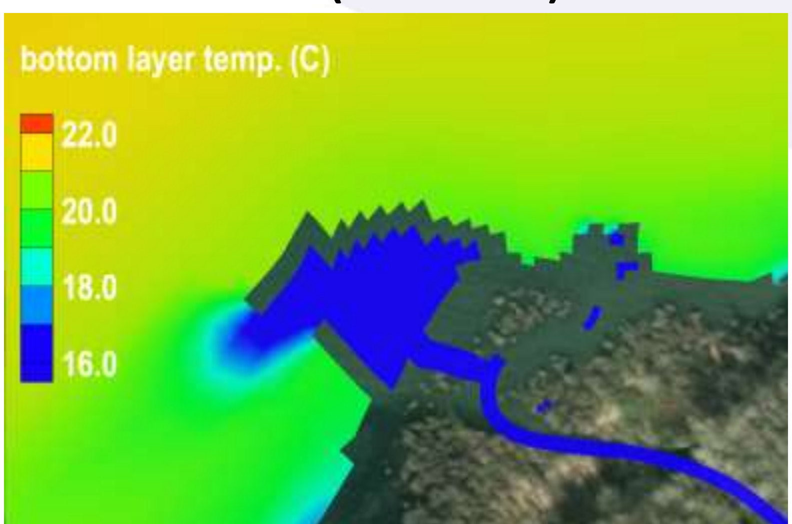
a: no structures



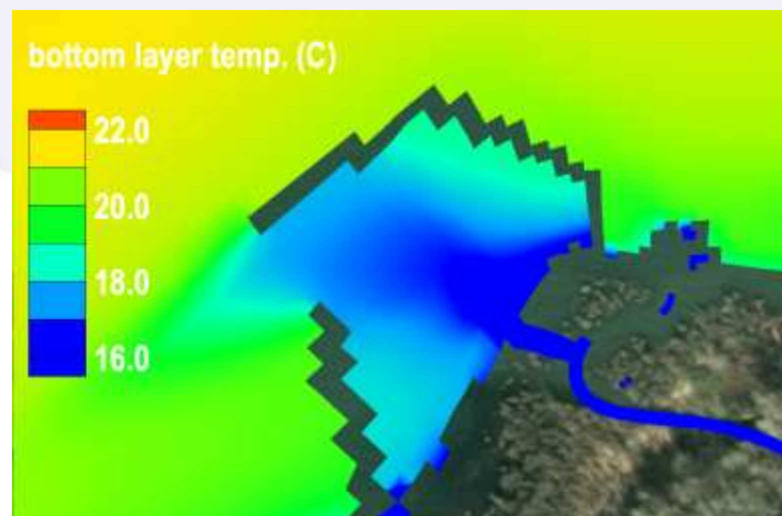
b: US



c: full (US+DS)



d: full, increased area



Relative Plume Size Comparison

- mid - Columbia refuges:

  Eagle Creek: ~ 5,000 m^2

  Herman Creek: ~ 80,000 m^2

- lower Columbia modeled *initial plume estimates:

  Horsetail Creek: ~ 5,000 m^2

  Multnomah Creek: ~ 25,000 m^2

  Bridal Veil Creek: ~ 20,000 – 30,000 m^2

  total: **~ 50,000 - 60,000 m^2**

*plumes can likely be made larger, but cost must be considered

Plume optimization

- Using length as a proxy for cost, can do a rough optimization of plume sizes based on model results:

	simulation	total structure length (m)	maximum plume area (m^2)	length/area
Horsetail/ Oneonta	US	120	4,100	0.029
	US perp.	70	2,090	0.033
	US full	170	4,100	0.041
Multnomah/W ahkeena				
	east channel: US	150	5,100	0.029
	east channel: full	230	12,350	0.019
	north channel: full	280	11,600	0.024
	north channel full extended	400	24,200	0.017
	west channel: DS	180	3,670	0.049
	west channel: full	320	18,800	0.017
Bridal Veil	east channel: US	215	11,300	0.019
	east channel: full	290	13,000	0.022
	west channel: DS	80	1,300	0.062
	west channel: full	160	7,000	0.023
	west channel: full extended	300	23,400	0.013

Conclusions

- Based on model analysis, existing lower Columbia Gorge tributary confluences could provide effective summer refuge for migrating salmonids, with enhancement.
- Sizes of created refuges in the lower Gorge would be comparable to those of existing mid-Columbia refuges with documented salmonid use.
- Structures are needed to divert mainstem flows. Existing landforms are not enough by themselves
- Plume characteristics (size and temperature) are highly dynamic due to multiple forcing factors (discharges, water temperatures, atmospheric effects)

Questions…

Keith Marcoe
Lower Columbia Estuary Partnership
(503) 226-1565, Ext.230
kmarcoe@estuarypartnership.org