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

Lower Columbia Estuary Partnership

inter·fluve inc.

Background

- Year 3 of an ongoing, EPA-funded study of cold water inputs to the lower Columbia River
- Year 1: Lower Gorge tributary assessment (15 streams) (water temperature, plume formation, flow)
- Year 2: Main-stem and downstream tributary assessment

Lower Columbia River Thermal Refuge Study, 2015–2018

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Report of research by

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for

United States Environmental Protection Agency

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Rationale for study

- Warming main-stem temperatures associated with climate change
- Few existing, suitable thermal refuge areas in lower Columbia R.
- Extensive salmon use of man-made, cold water embayments at mid-Columbia tributary confluences:

Eagle Creek

✚ Bonneville Dam

Question

Can we alter the hydrodynamics around lower Gorge tributary confluences to create suitable refuges for summer migrating salmon, similar to those found upstream?

Future aspects:

cost,

geomorphic analysis,

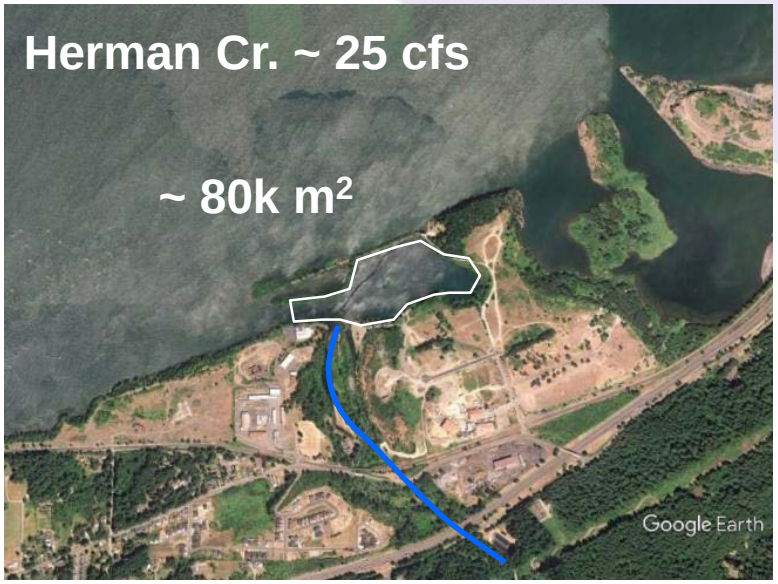
social considerations

Challenges

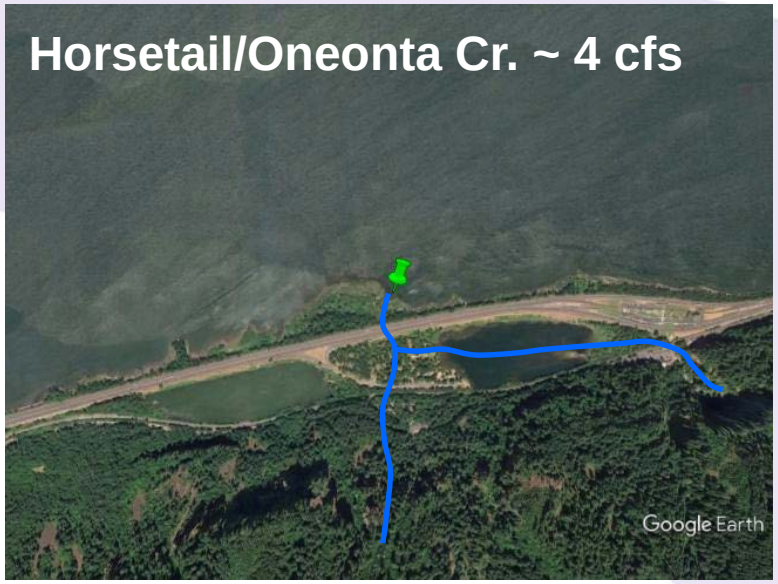
Gorge streams have lower flows relative to mid-Columbia refuge tributaries

Lack of natural or manmade enclosures surrounding Gorge stream confluences

Mid Columbia Tribs.



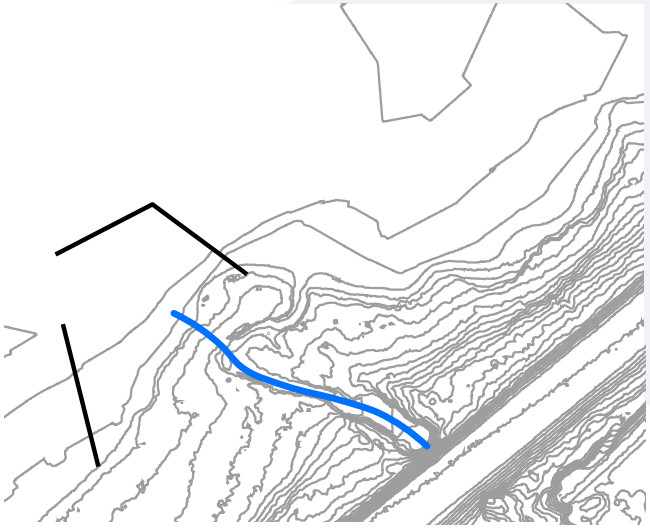
Lower Gorge Tribs.

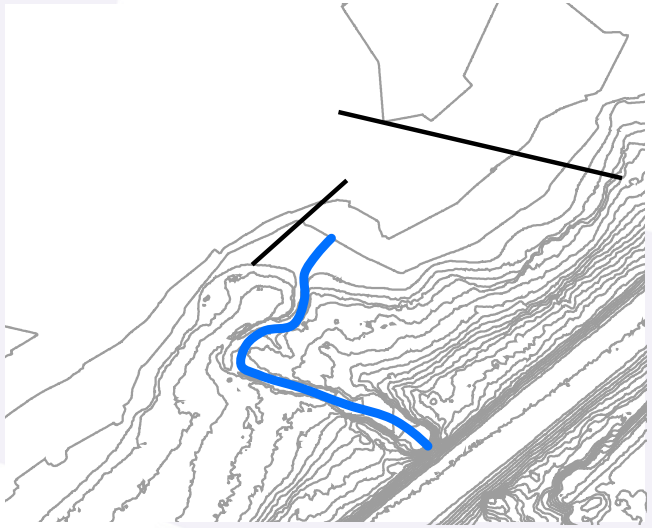


Approach

Use 3D hydrodynamic model with water temperature module to model:

- existing conditions
- multiple stream outlet/flow diversion structure orientations



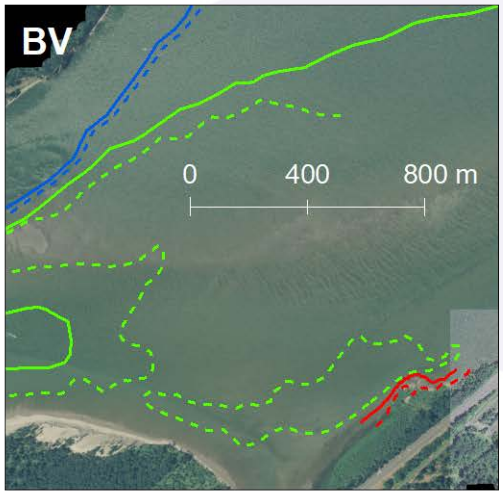


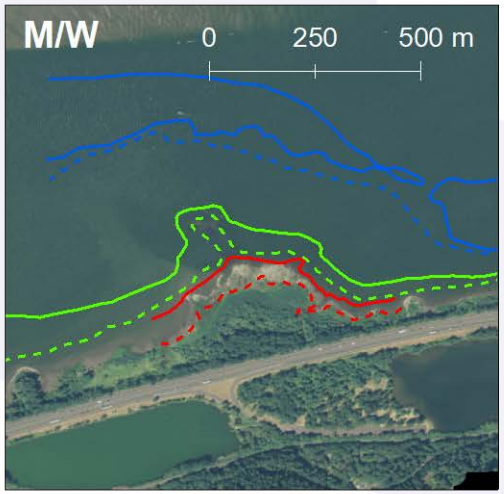
- include atmospheric effects (radiation, air temperature, clouds, precipitation, wind)

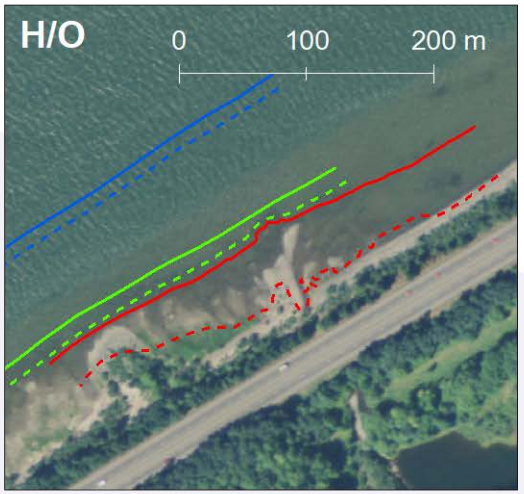
Tributary Selection

cold, adequate discharge, accessible to adult/juvenile salmonids

	Bridal Veil Cr.	Multnomah/Wahkeena Cr.	Horsetail Oneonta Cr.
flow (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







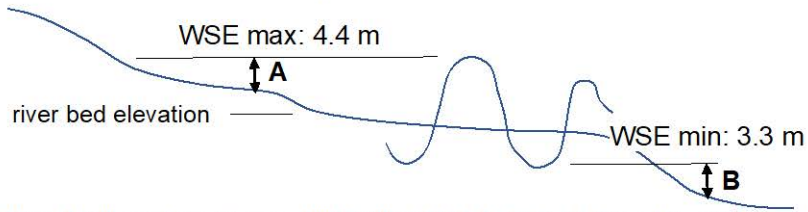
Relevant depth contours for salmon migration:

0.5 m (juvenile) **2m depth (adult)** **10m depth (adult)**

WSEmax WSEmax WSEmax

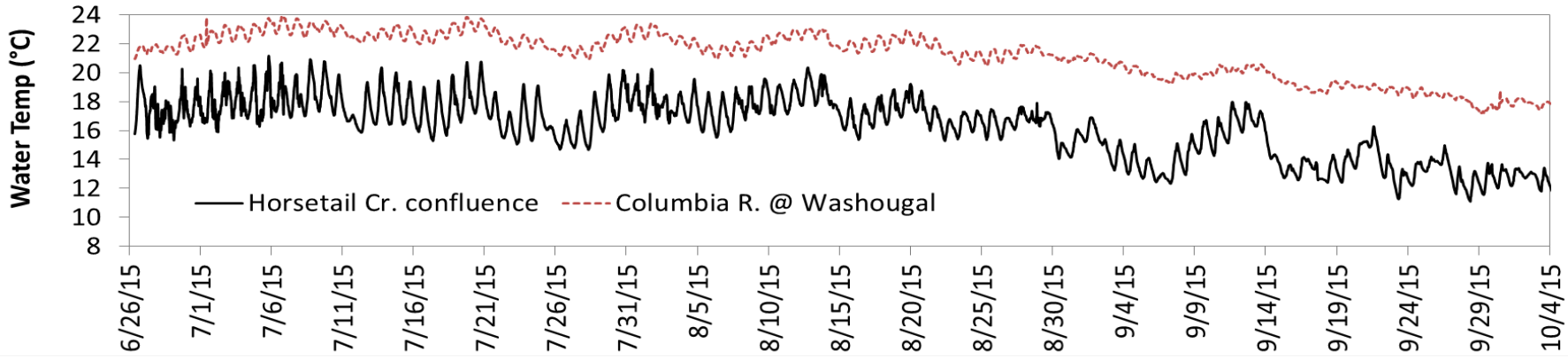
WSEmin WSEmin WSEmin

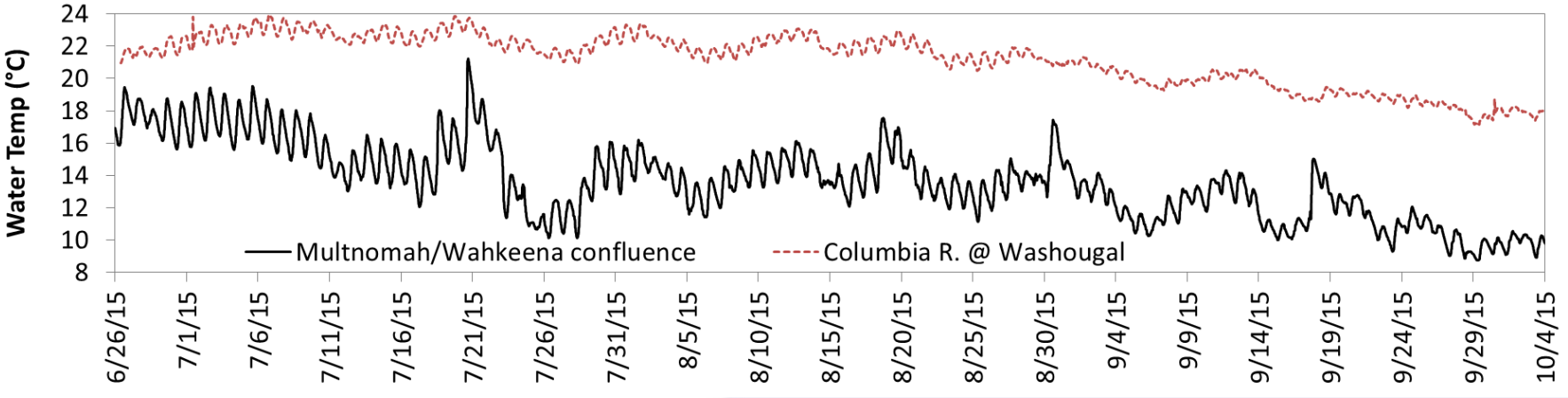
Derivation of 0.5 m depth contours for Bridal Veil Creek

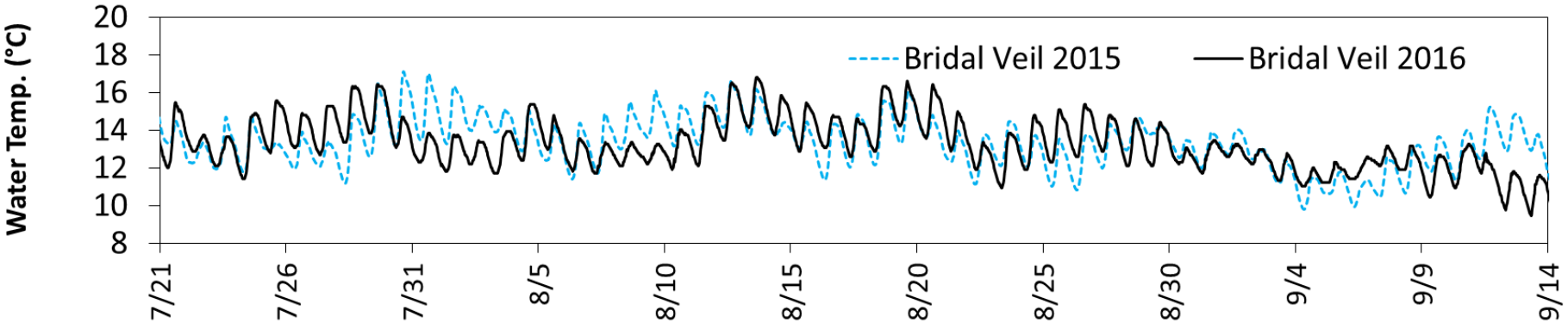


0.5m depth contour @ max. WSE (dim A): 4.4 - 0.5 = 3.9 m elev. contour
0.5m depth contour @ min. WSE (dim B): 3.3 - 0.5 = 2.8 m elev. contour

Water temperatures, selected tributaries







Physical Model

Atmospheric inputs applied globally:
- solar radiation
- air temperature, relative humidity
- cloud cover
- precipitation
- wind

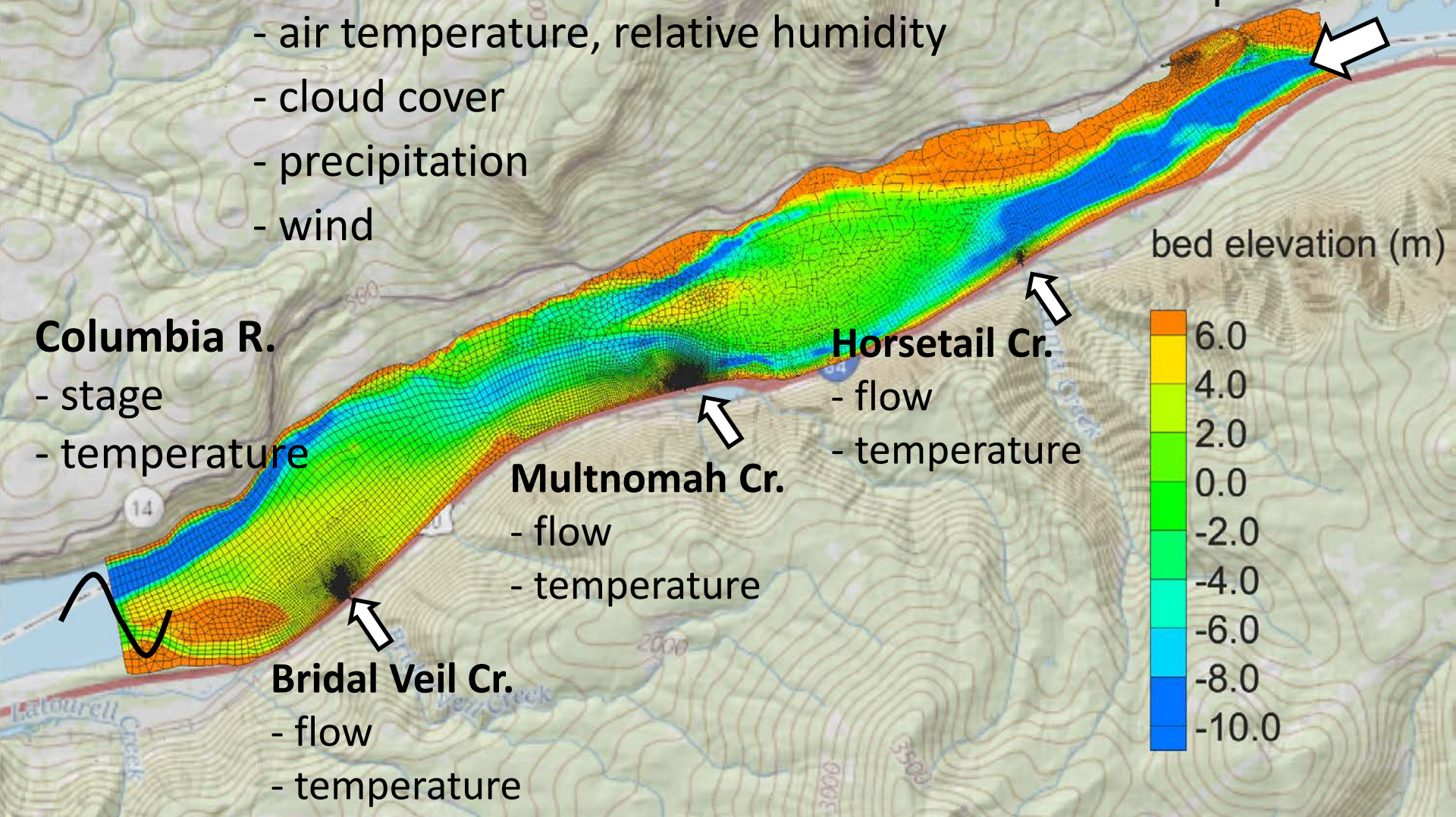
Columbia R.
- flow
- temperature

Columbia R.
- stage
- temperature

Horsetail Cr.
- flow
- temperature

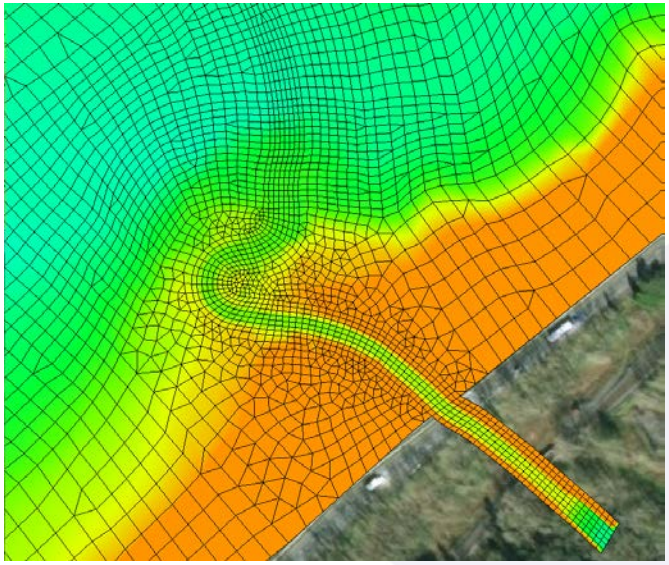
Multnomah Cr.
- flow
- temperature

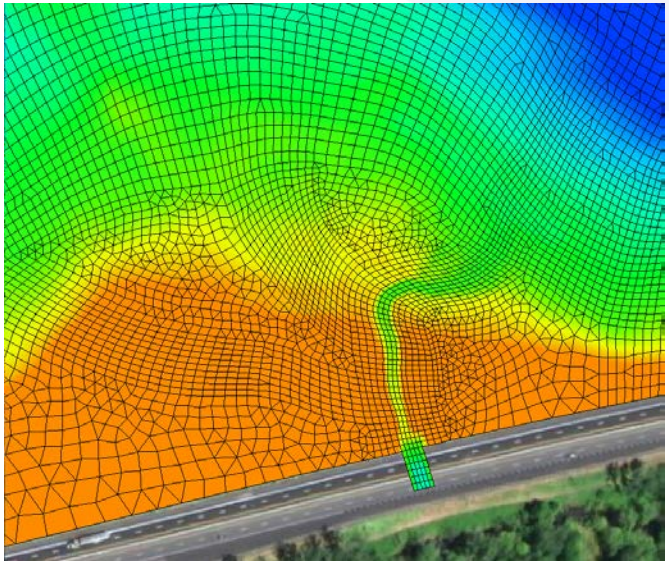
Bridal Veil Cr.
- flow
- temperature



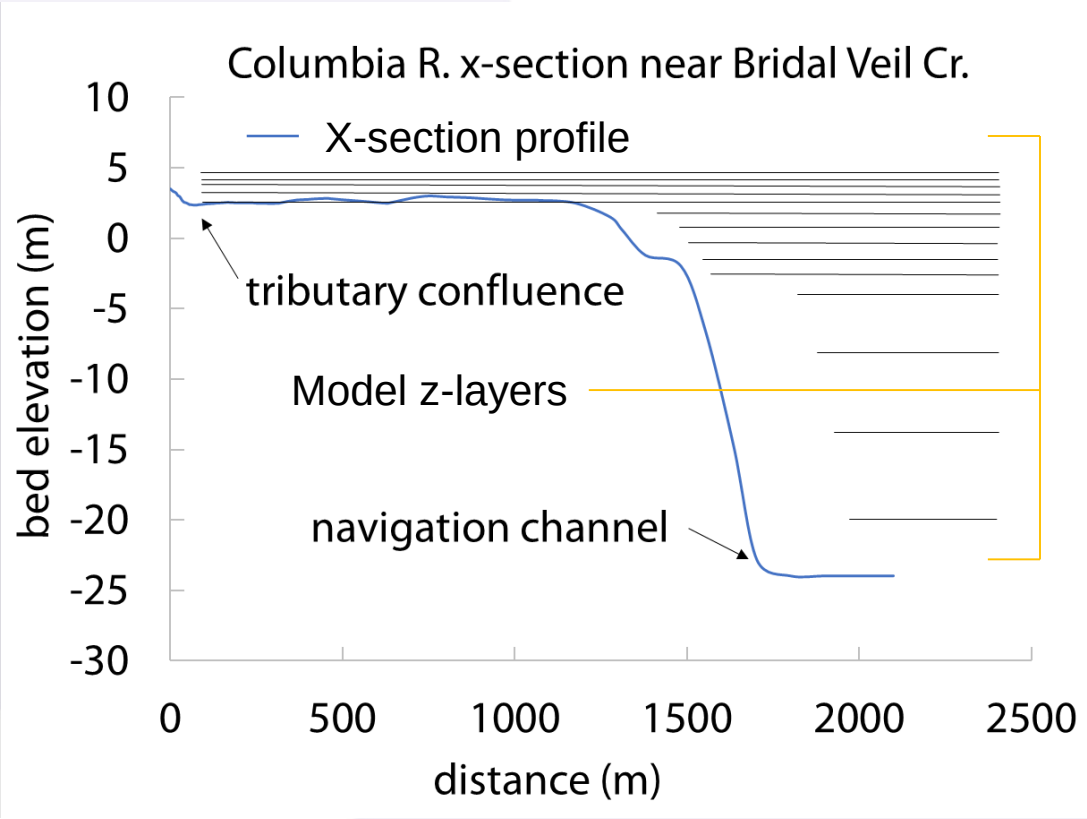
Model Resolution

Horizontal





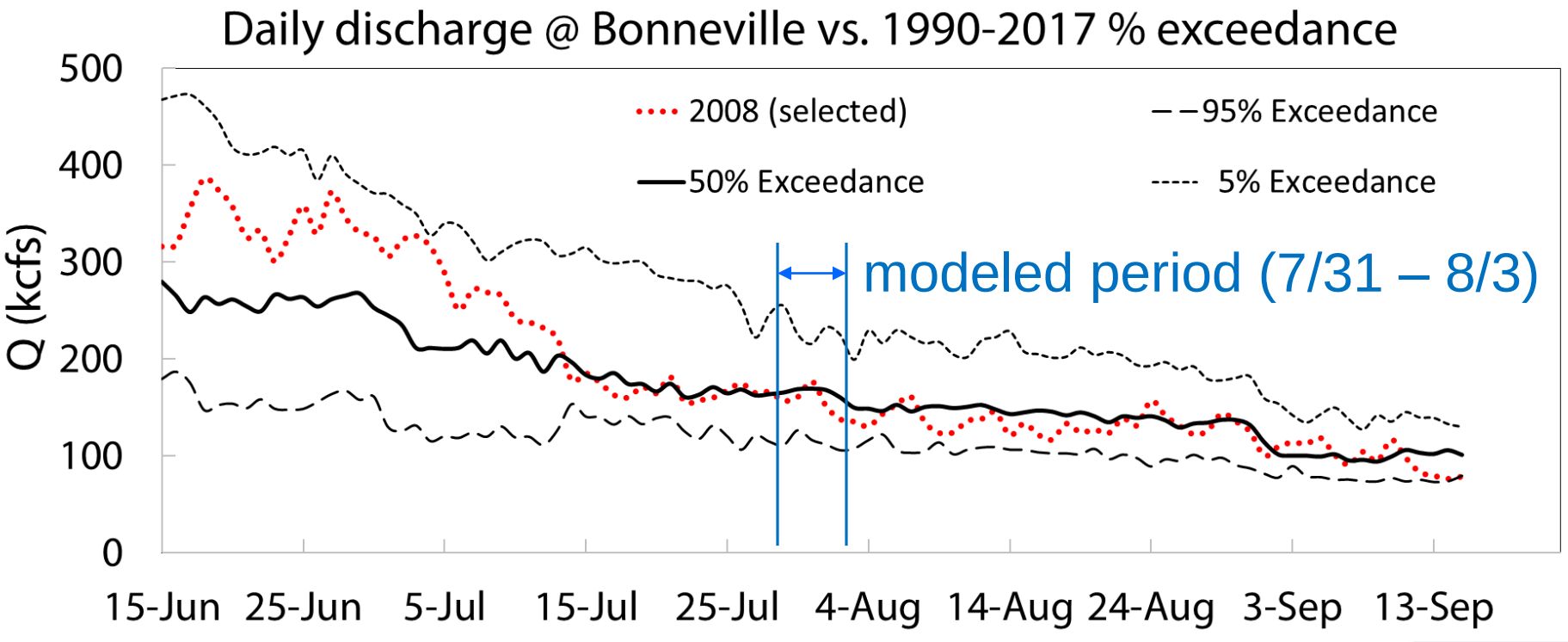
Vertical



3D model: outputs results at each vertical z-layer

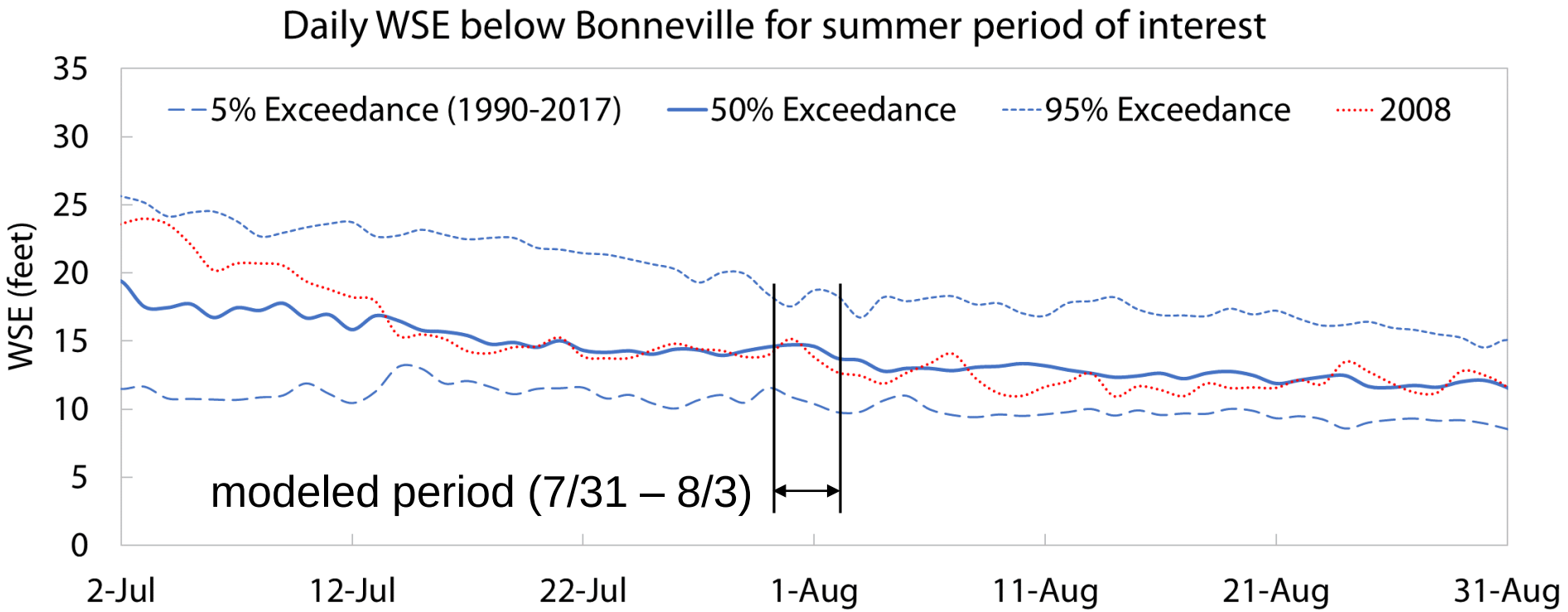
Model Boundary Data Selection

- Period of interest for salmonids: July – August
- Available forcing data:
  - **2008** water surface elev. data at Sand Island (downstream boundary)
  - 2008 is a good representation of average conditions:



Model Boundary Data Selection

- WSE comparison, 2008 vs. average:



Model Boundary Inputs

Sample time period:

	Columbia R.		Tributary Q			Water 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

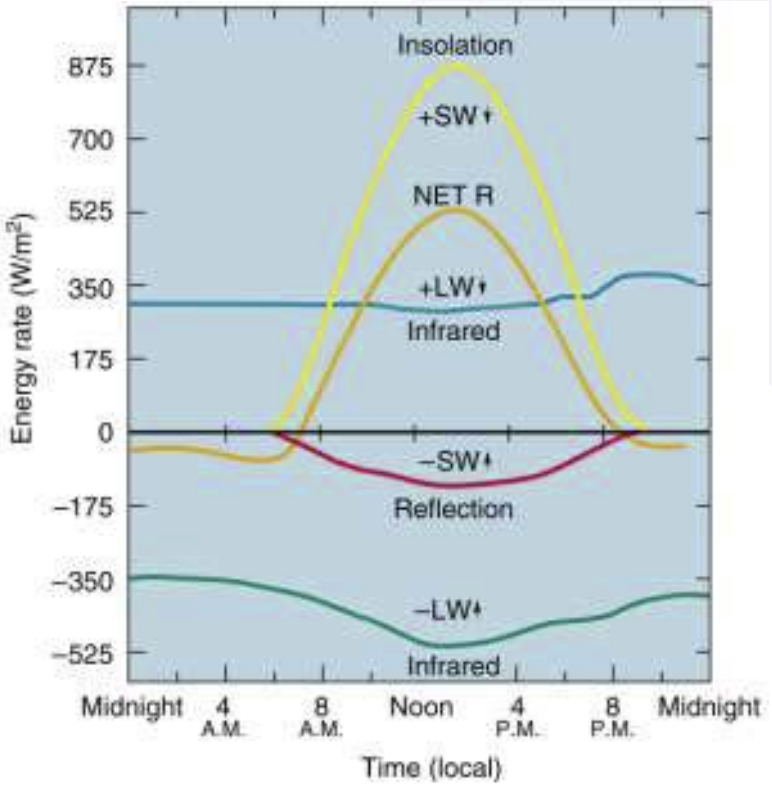
Sources:

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

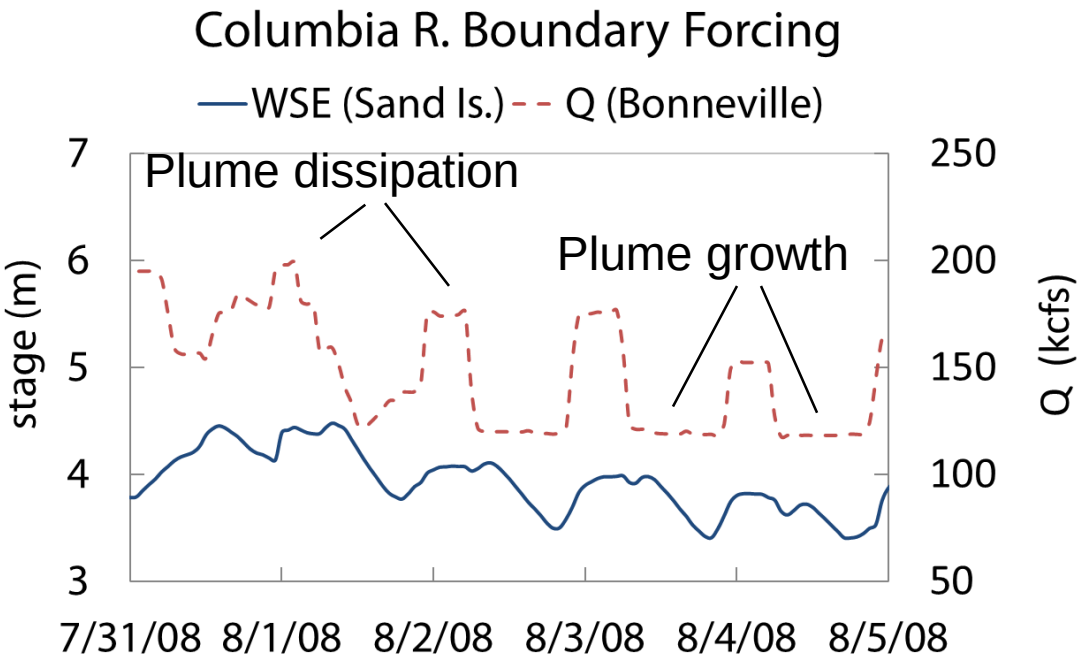
Boundary Forcing Variability

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

Atmospheric inputs



Discharge



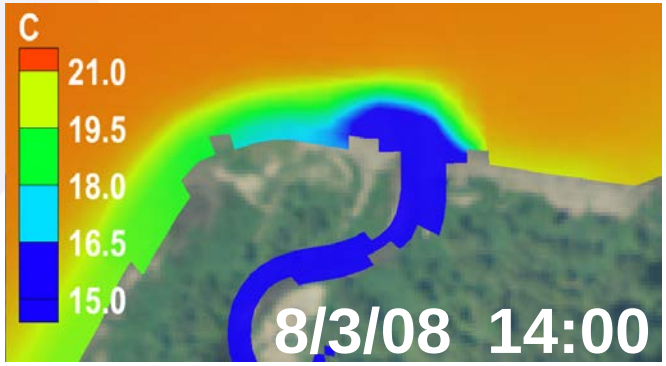
Model Validation

Stream confluence

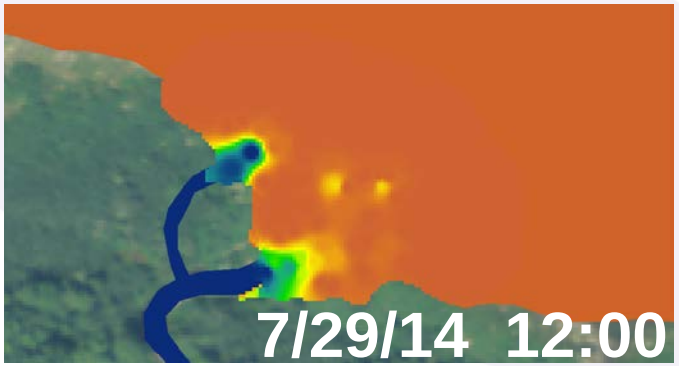
observed temperature

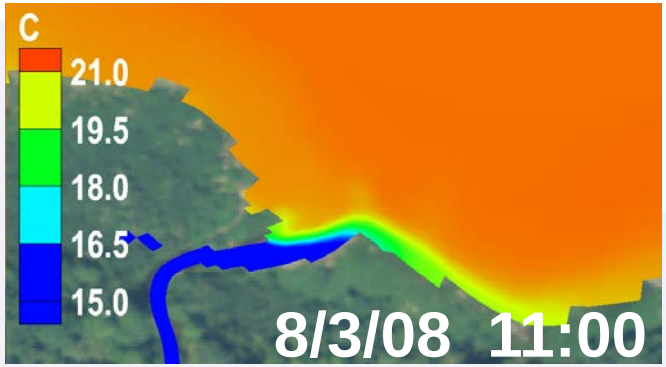
model temperature

Bridal Veil
(@ surface)

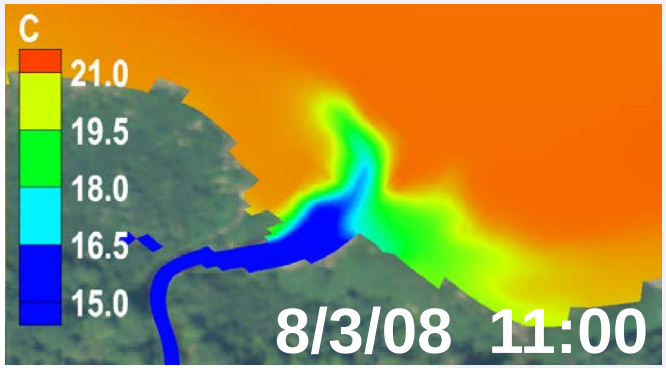


Multnomah
(@ surface)



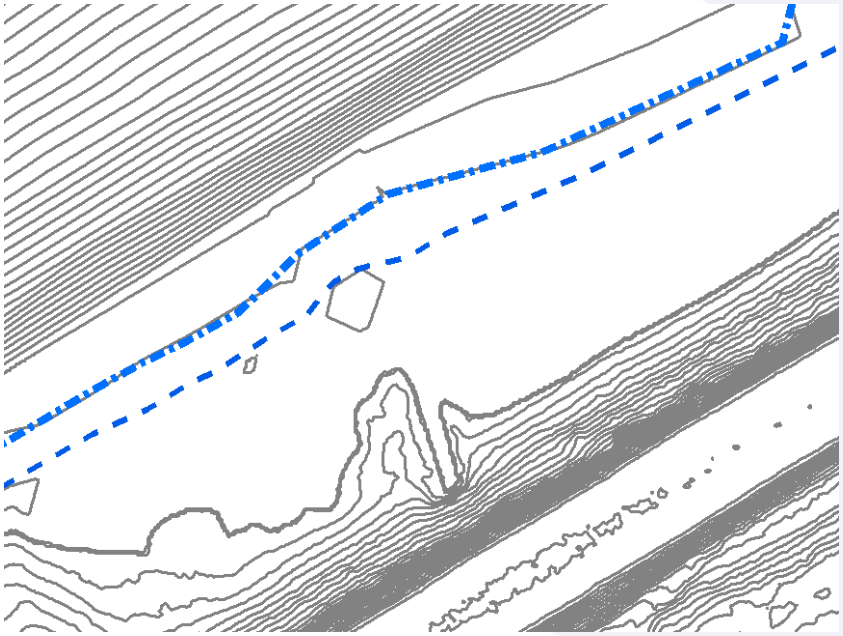


Multnomah
(@ max. depth)



Horsetail Creek – structure placement

Existing condition

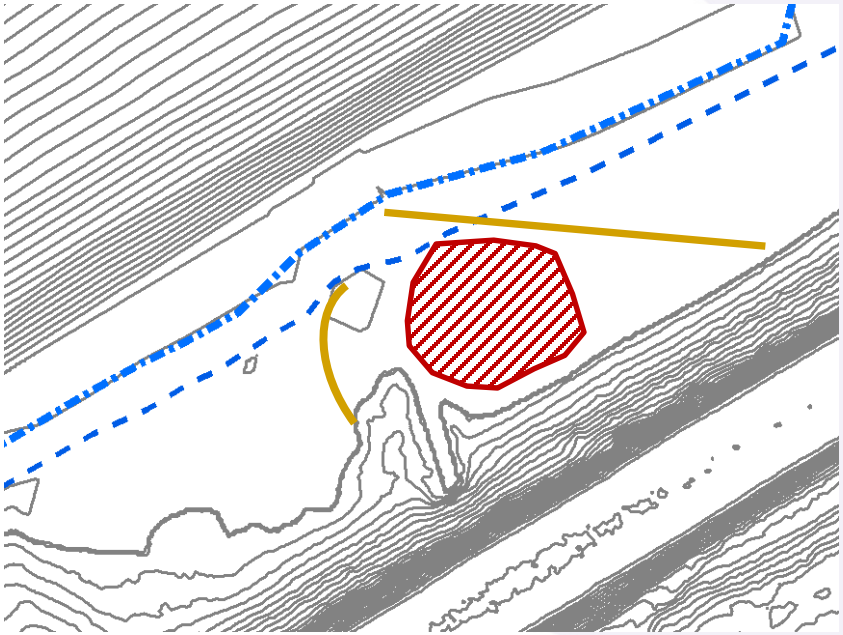


2 m depth contour range

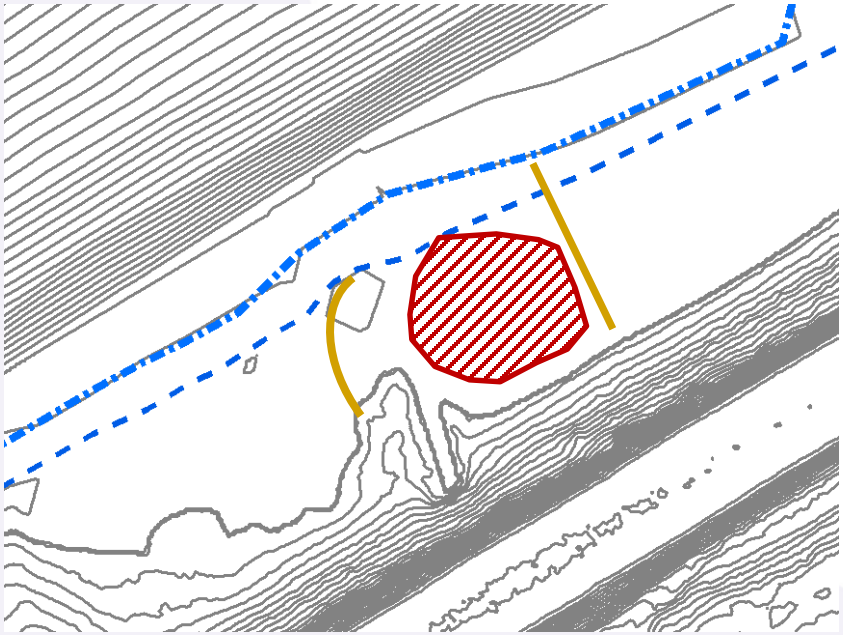
Flow trace

Horsetail Creek – structure placement

full structures



full structures, perpendicular



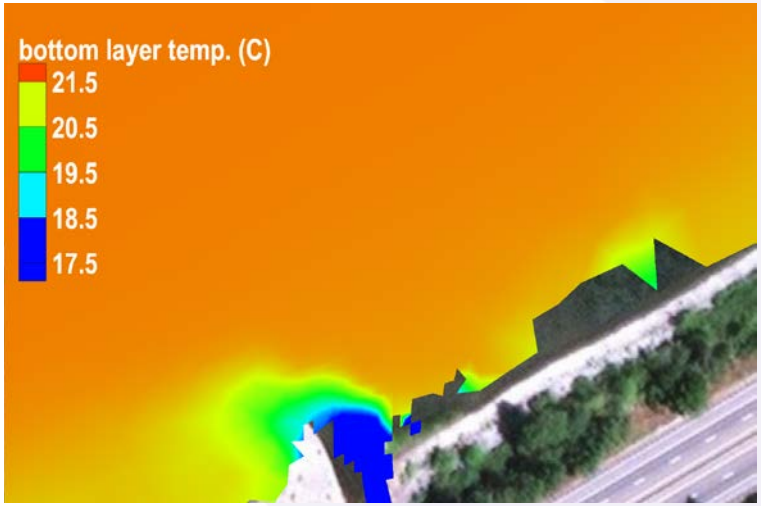
2 m depth contour range

structure placement

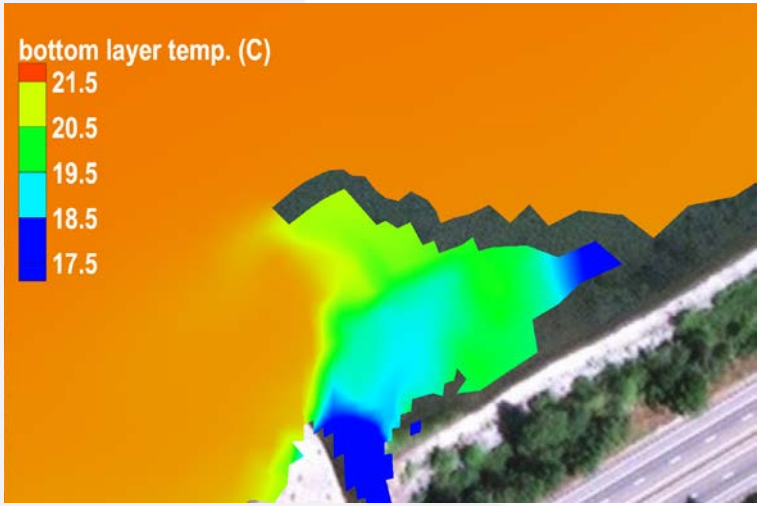
excavate to 2m depth min.

Results - **Horsetail Creek**

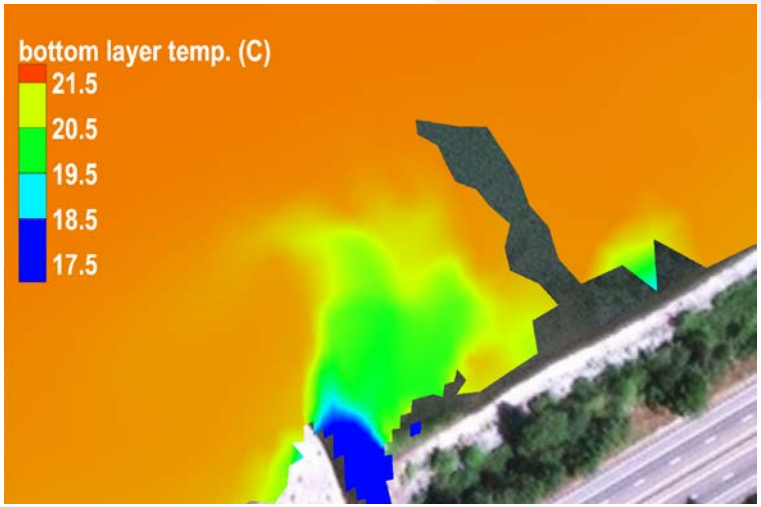
existing



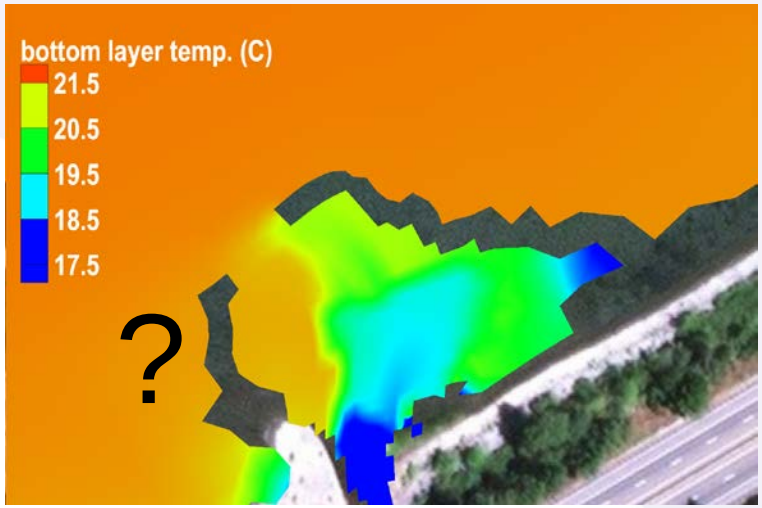
US structure



US perpendicular



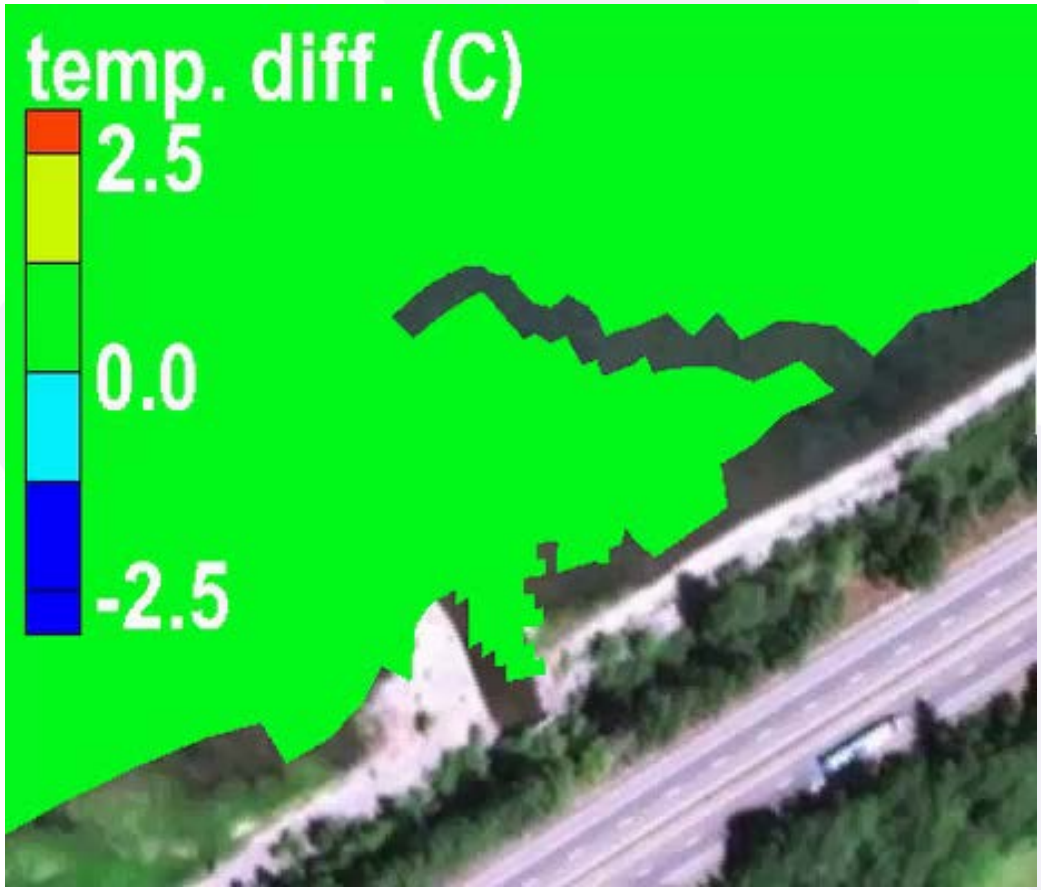
full structures



Results - **Horsetail Creek**

spatial temperature differences over time between scenarios

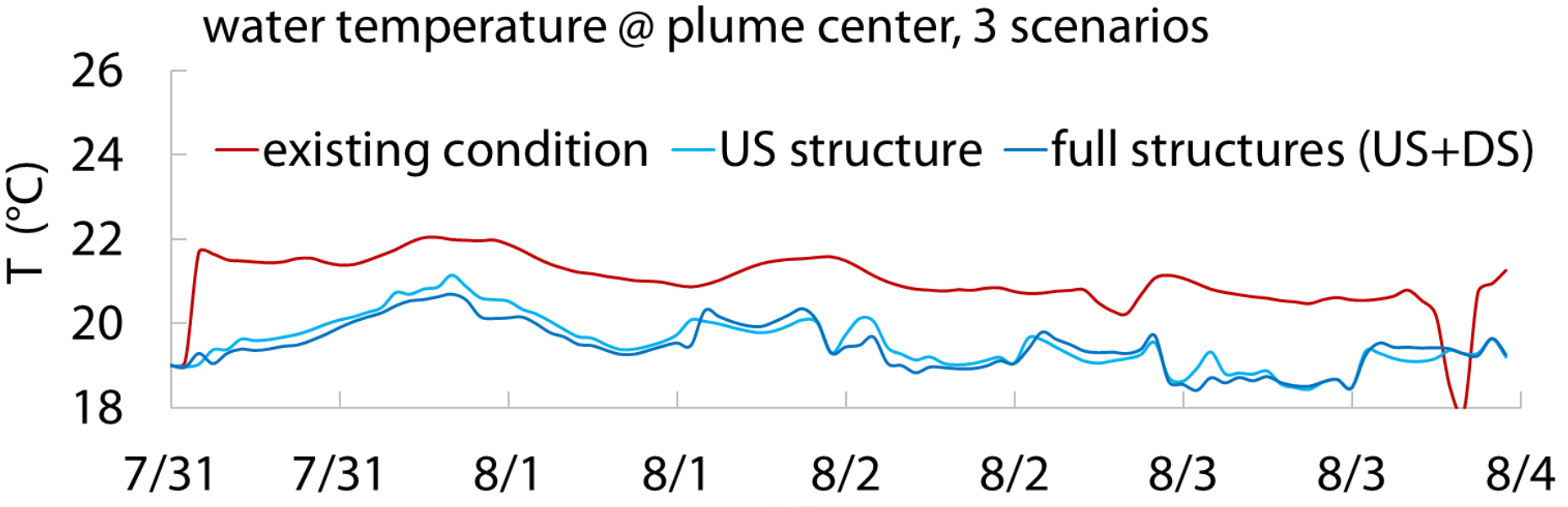
US structure – existing condition (at max. depth):



blue shades: areas of cold water enhancement

Results - **Horsetail Creek**

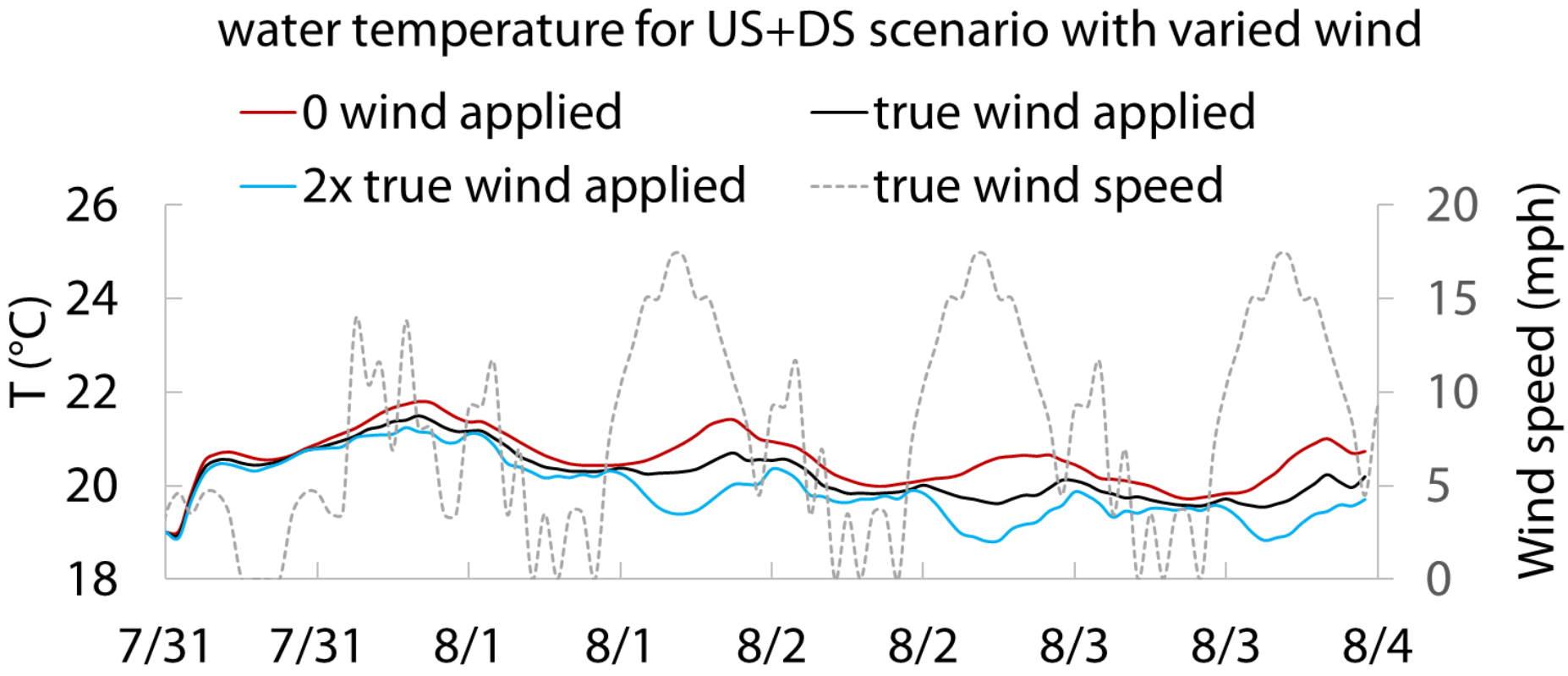
- Plume characteristics are dynamic



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

Results - **Horsetail Creek**

Does DS structure enhance plume? Maybe, if wind is factored in:

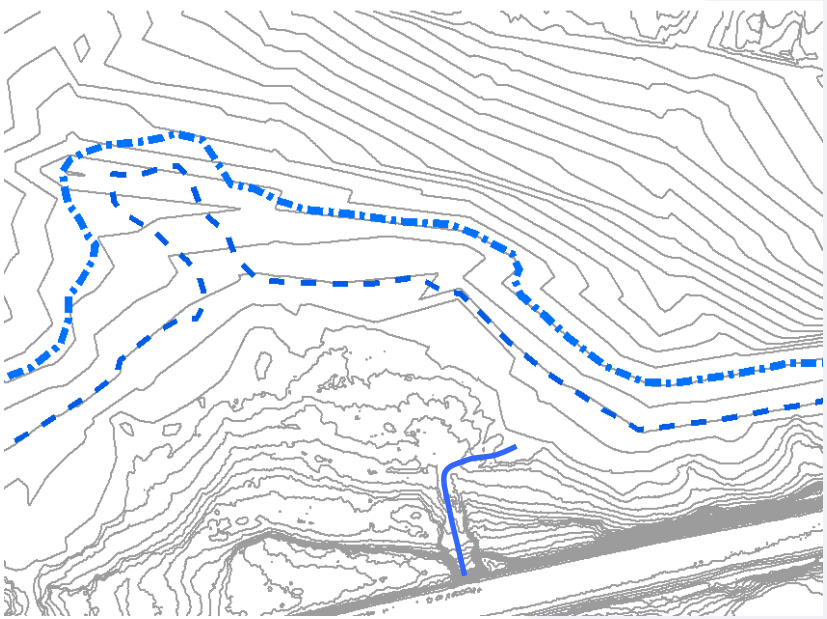


Largest differences during late day (maximum wind velocities)

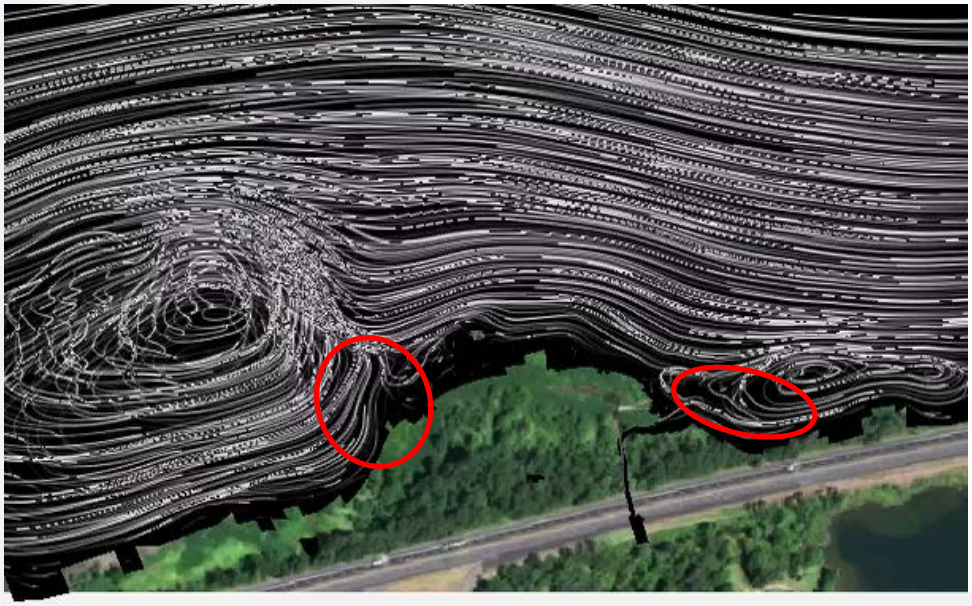
Stronger west winds enhance plume? Needs more analysis..

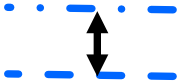
Multnomah Creek – structure placement

Existing condition



Flow trace

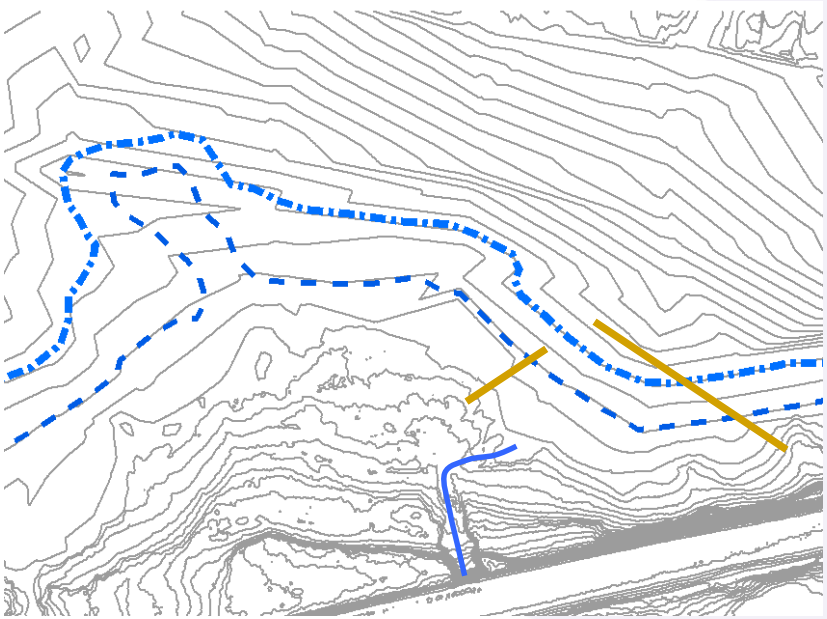




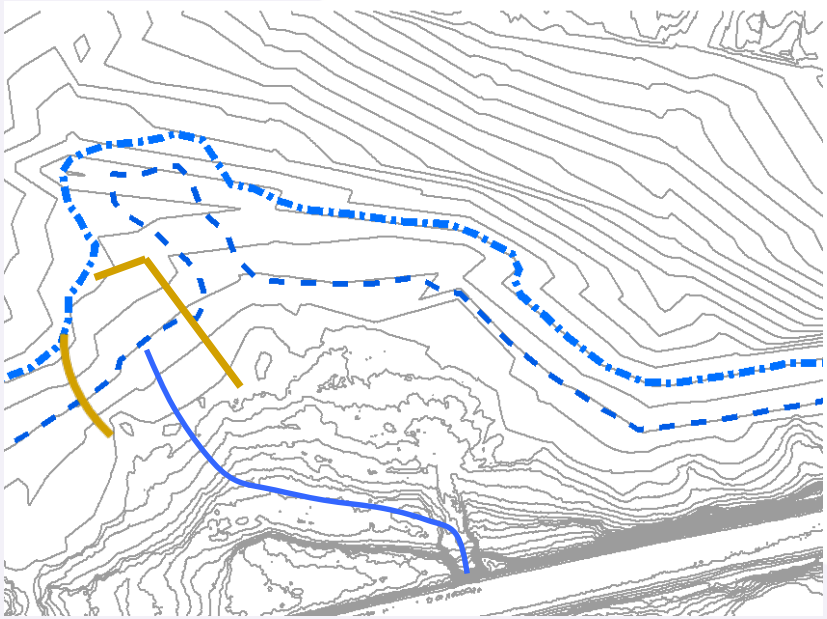
2 m depth contour range

Multnomah Creek – structure placement

Full structures



West channel: full structures

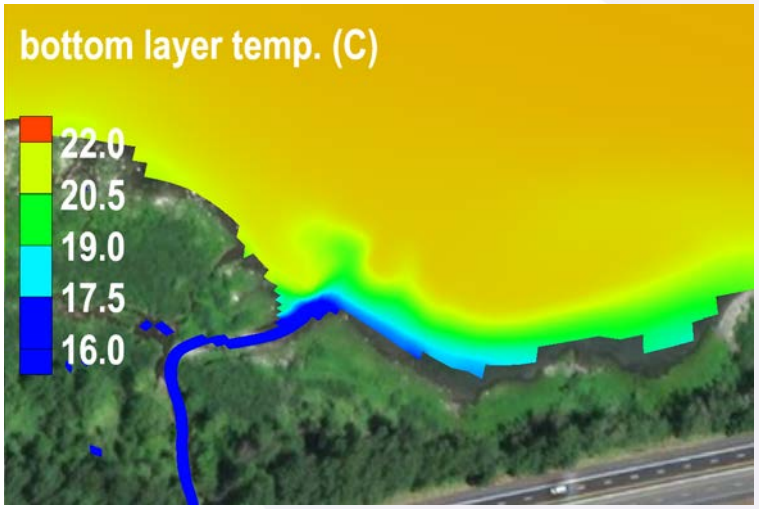


2 m depth contour range

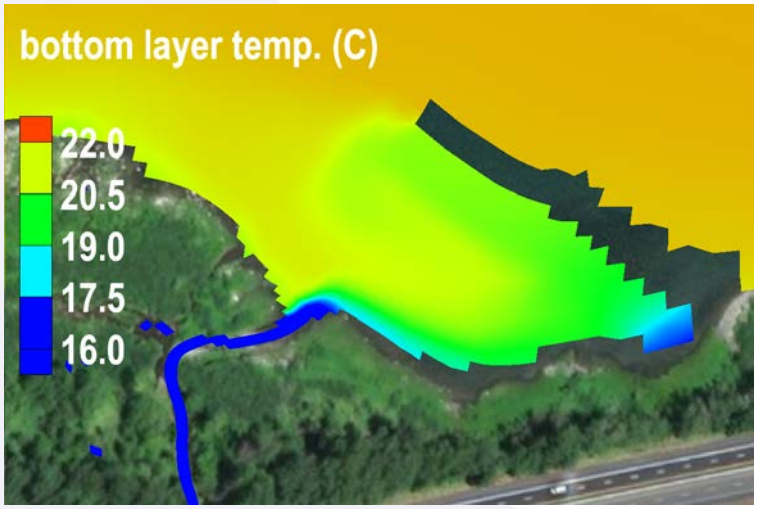
structure placement

Results - **Multnomah Creek, east outlet**

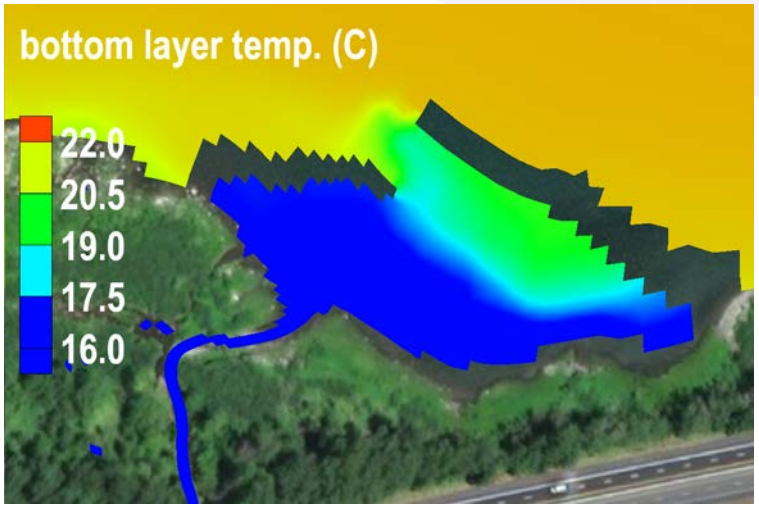
a: existing



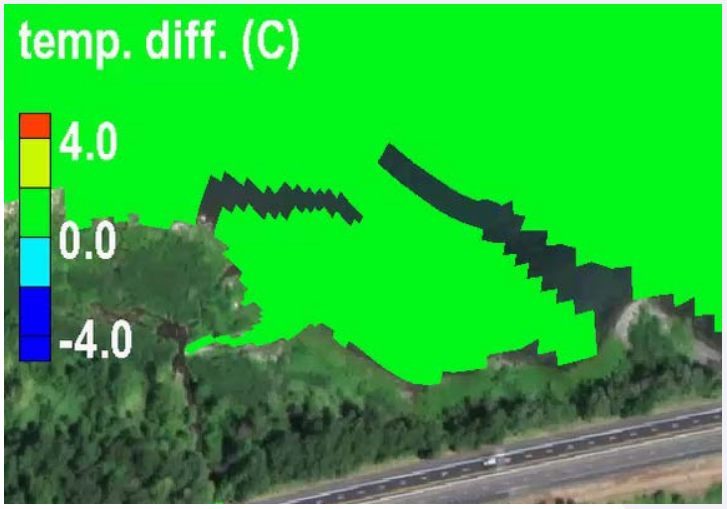
b: US



c: full (US+DS)

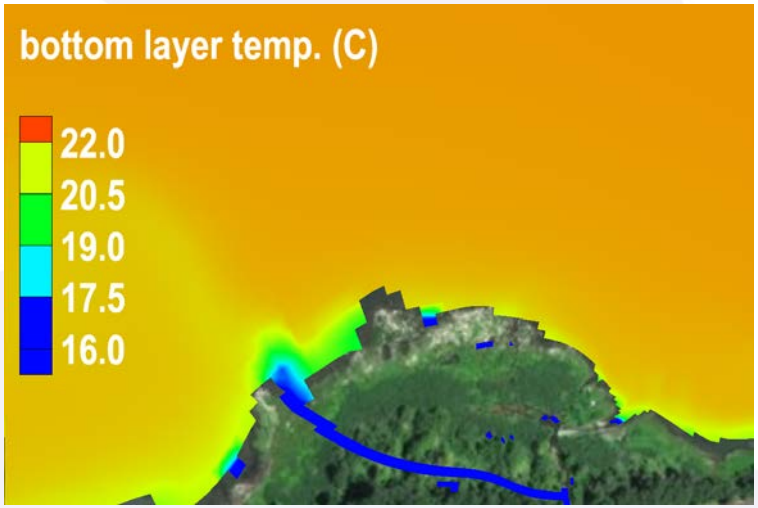


difference: c - a

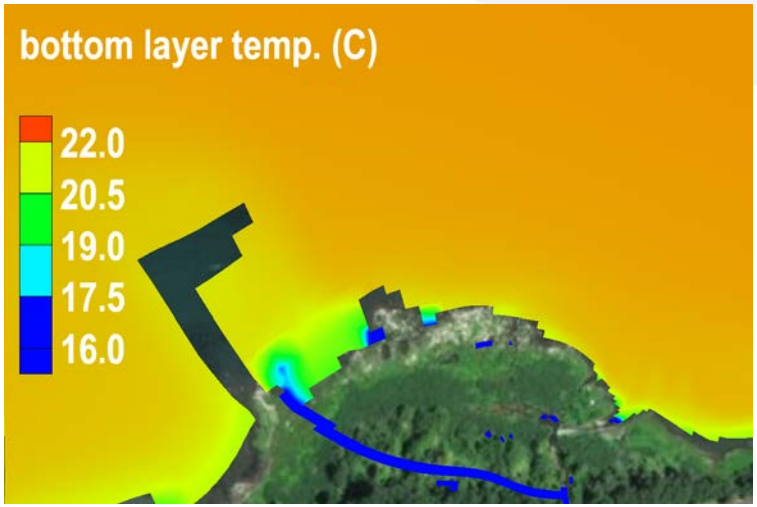


Results - **Multnomah Creek, west outlet**

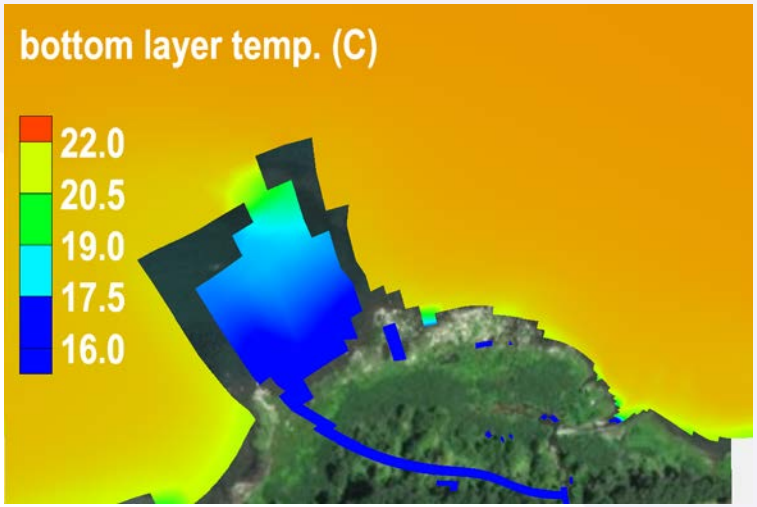
a: no structures



b: DS

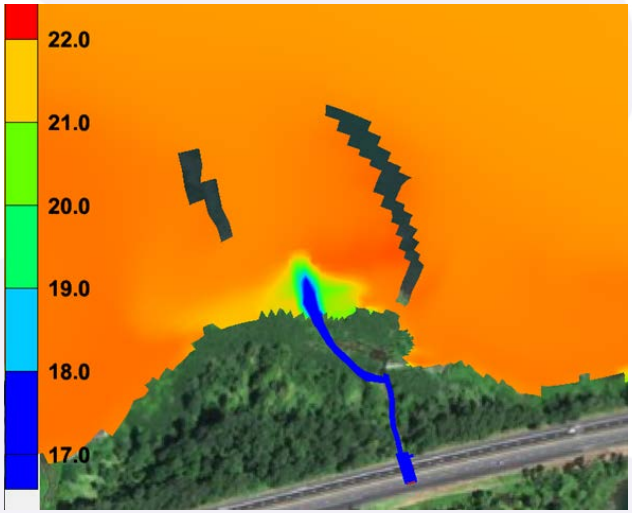


c: US+DS

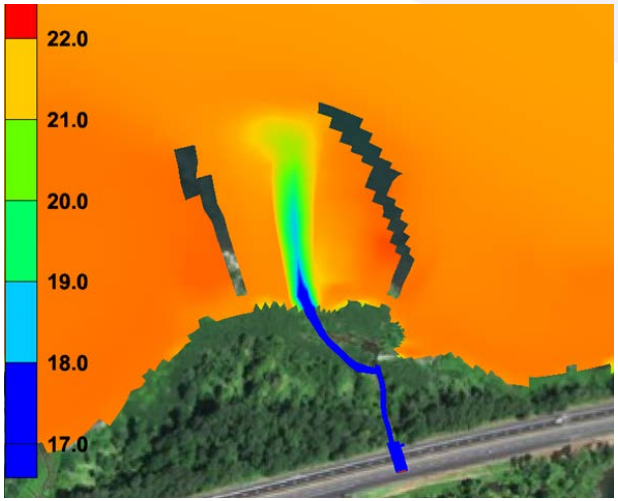


Results - **Multnomah Creek, north outlet**

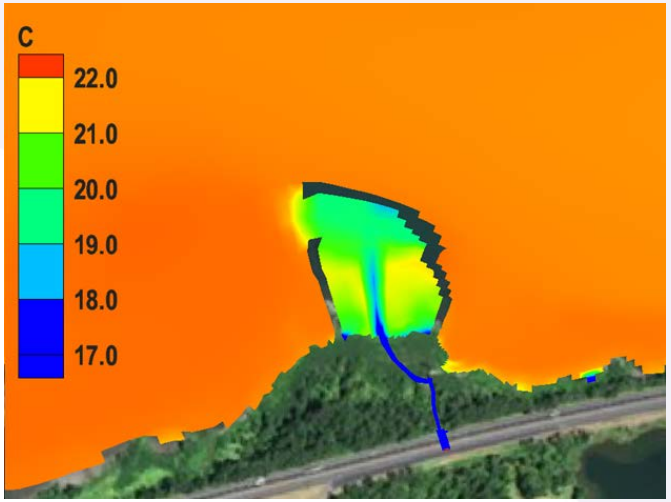
a: partial structures



b: extended DS structure

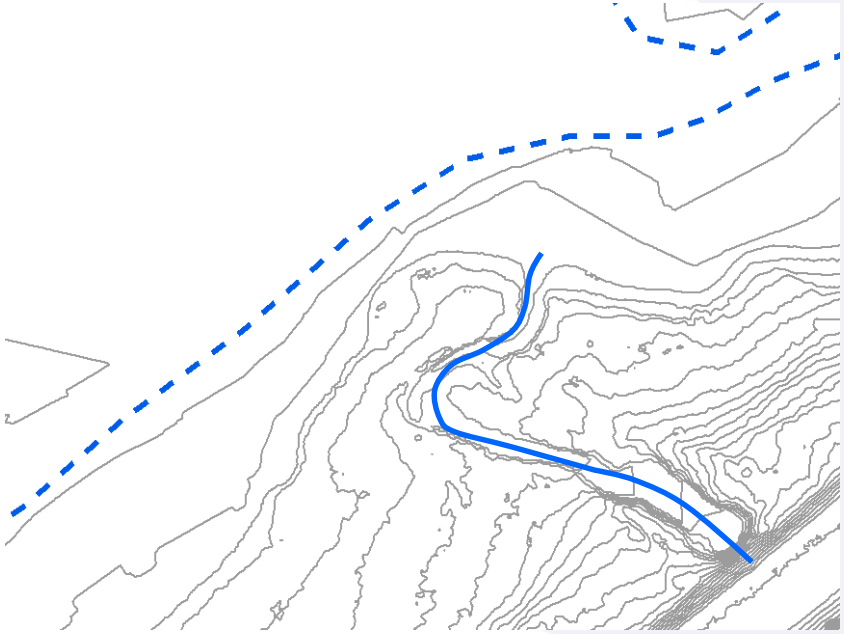


c: full structures



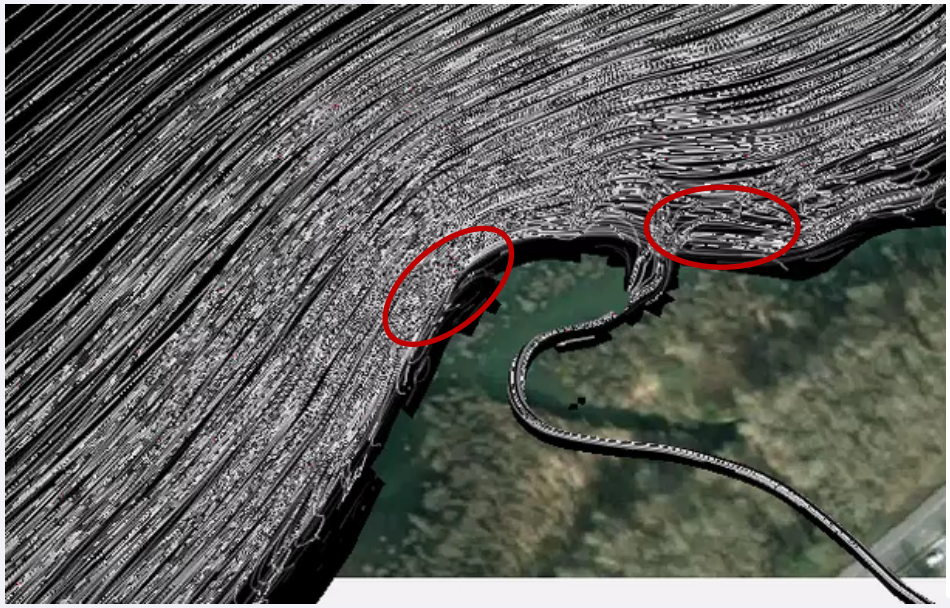
Bridal Veil Creek - structure placement

Existing condition



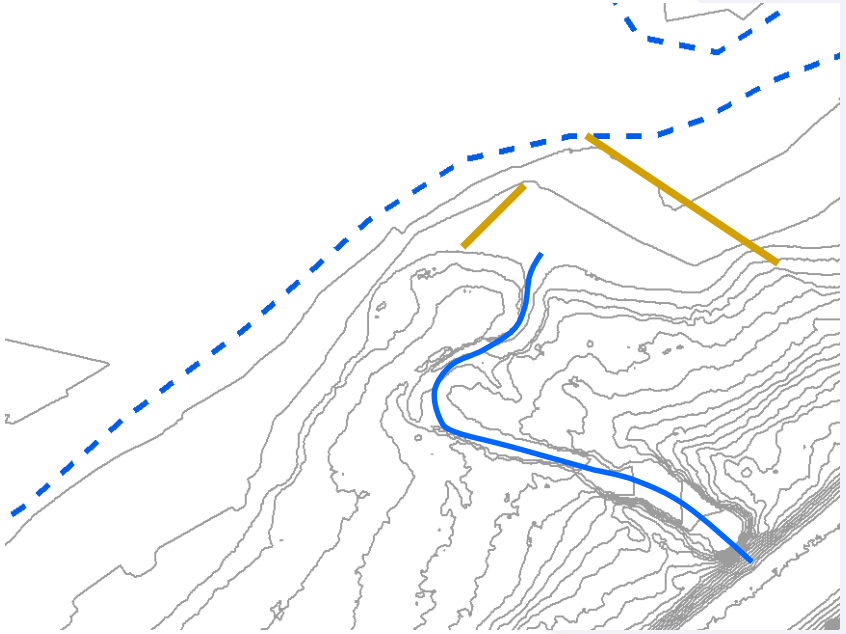
2 m depth contour @ maximum WSE for analysis period

Flow trace

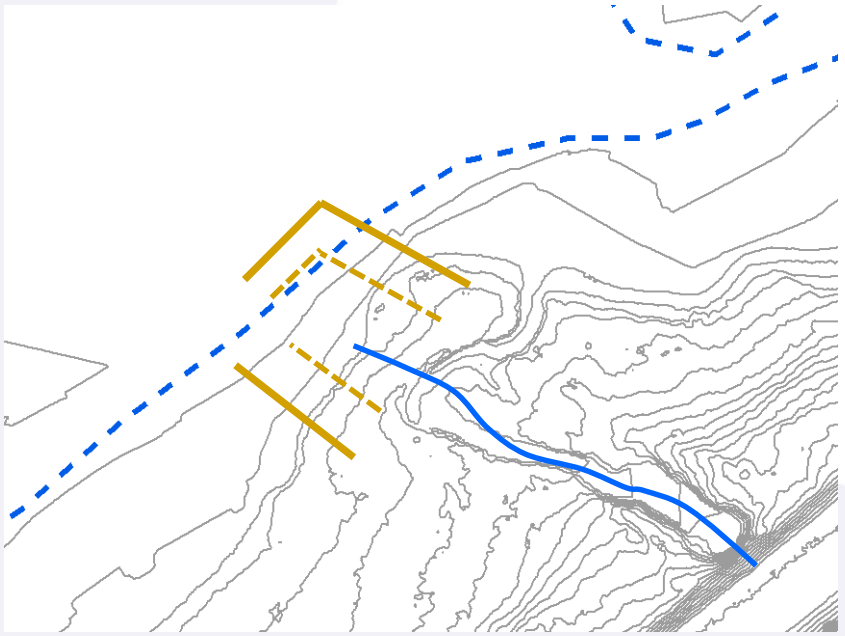


Bridal Veil Creek - structure placement

Full structures



North channel: full structures, increase area

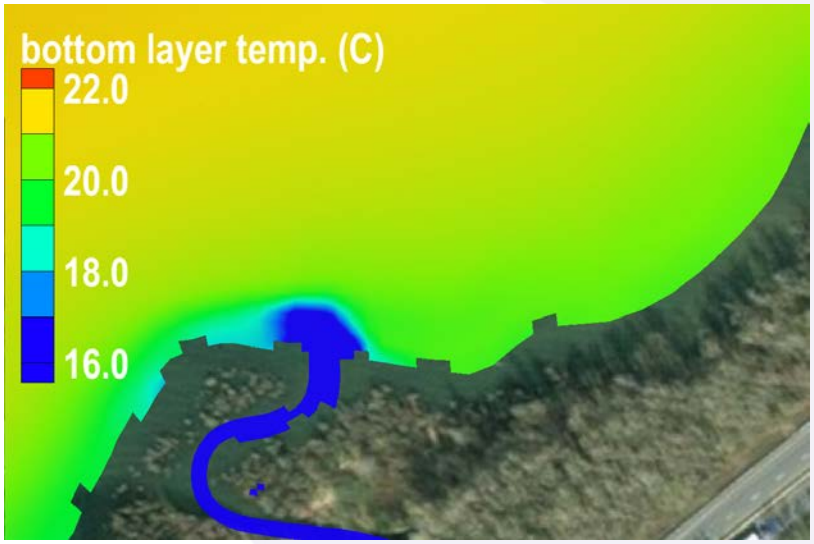


2 m depth contour @ maximum WSE for analysis period

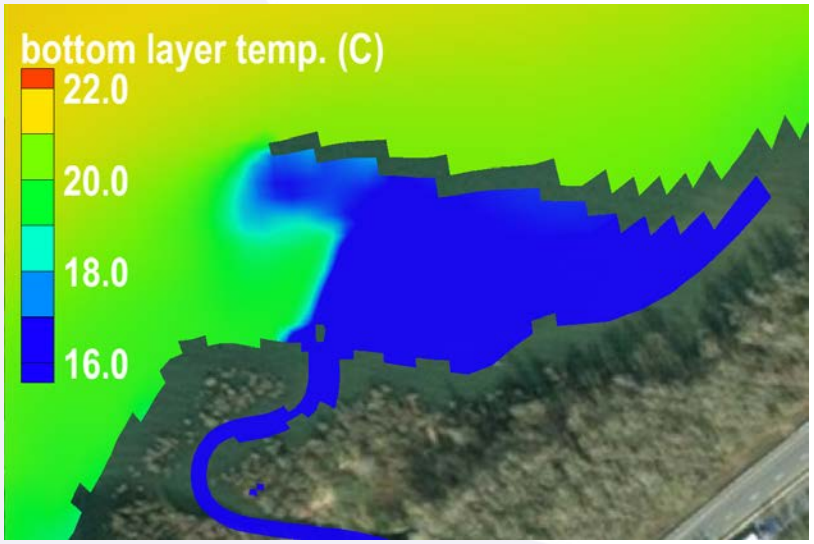
structure placement

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

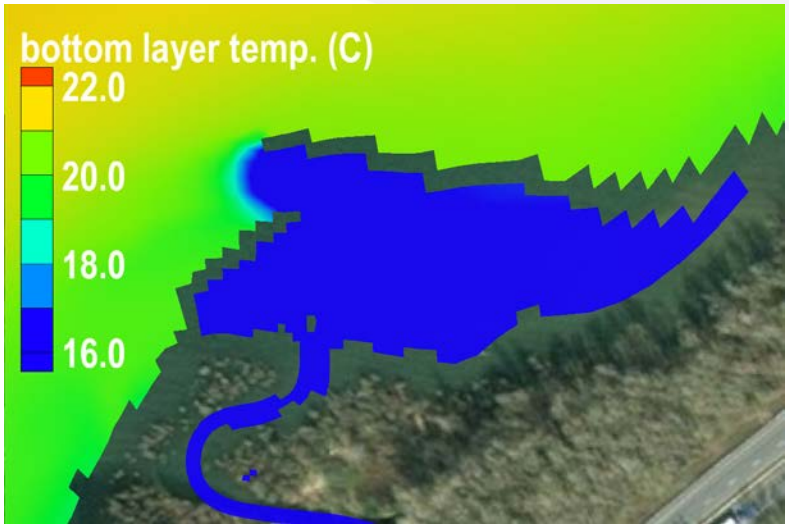
a: existing



b: US



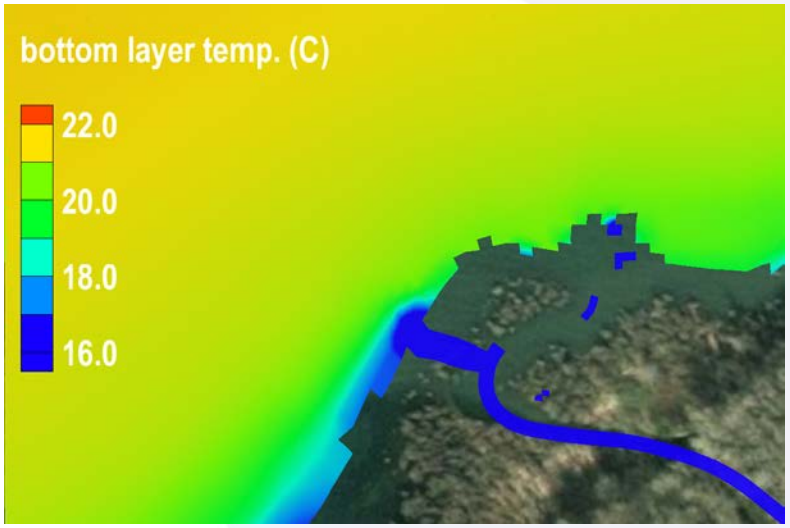
c: full (US+DS)



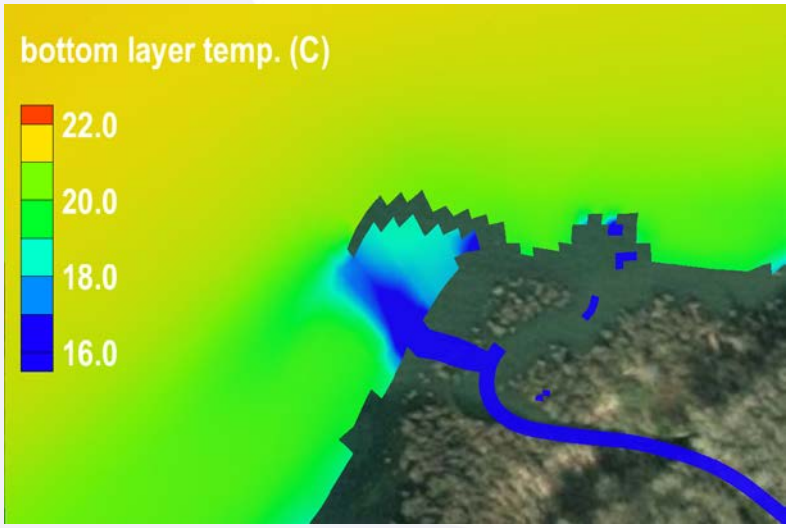
difference: c - a

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

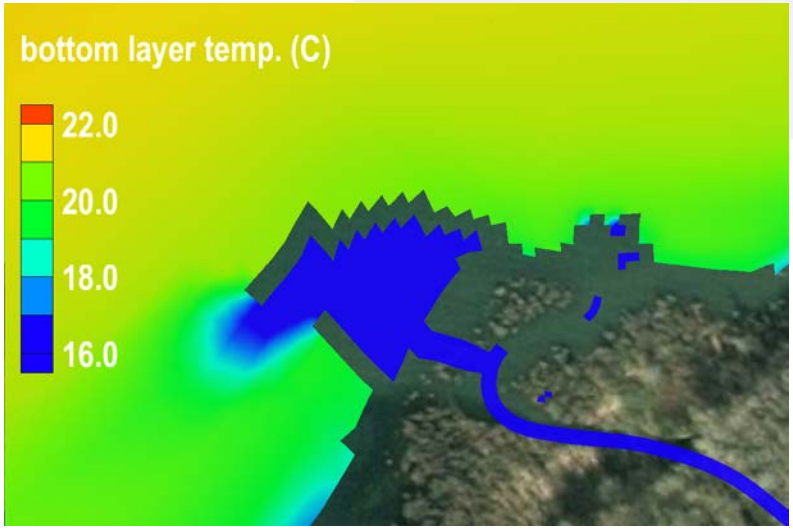
a: no structures



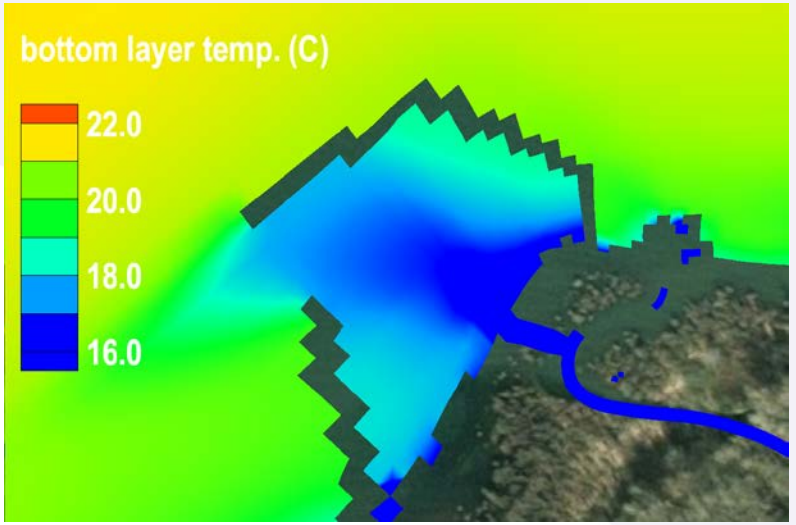
b: US



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

Conclusions

- Based on model results, 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 (flows, water temperatures, atmospheric effects)

Next steps

- Simulate different structure types for selected alternatives. Full vs. partial, material types, etc.
- Geomorphic analysis (structure, plume, tributary stability).
- Closer assessment of secondary forcing factors (wind, air temperature, etc.).
- Test model sensitivity (friction, eddy viscosity)