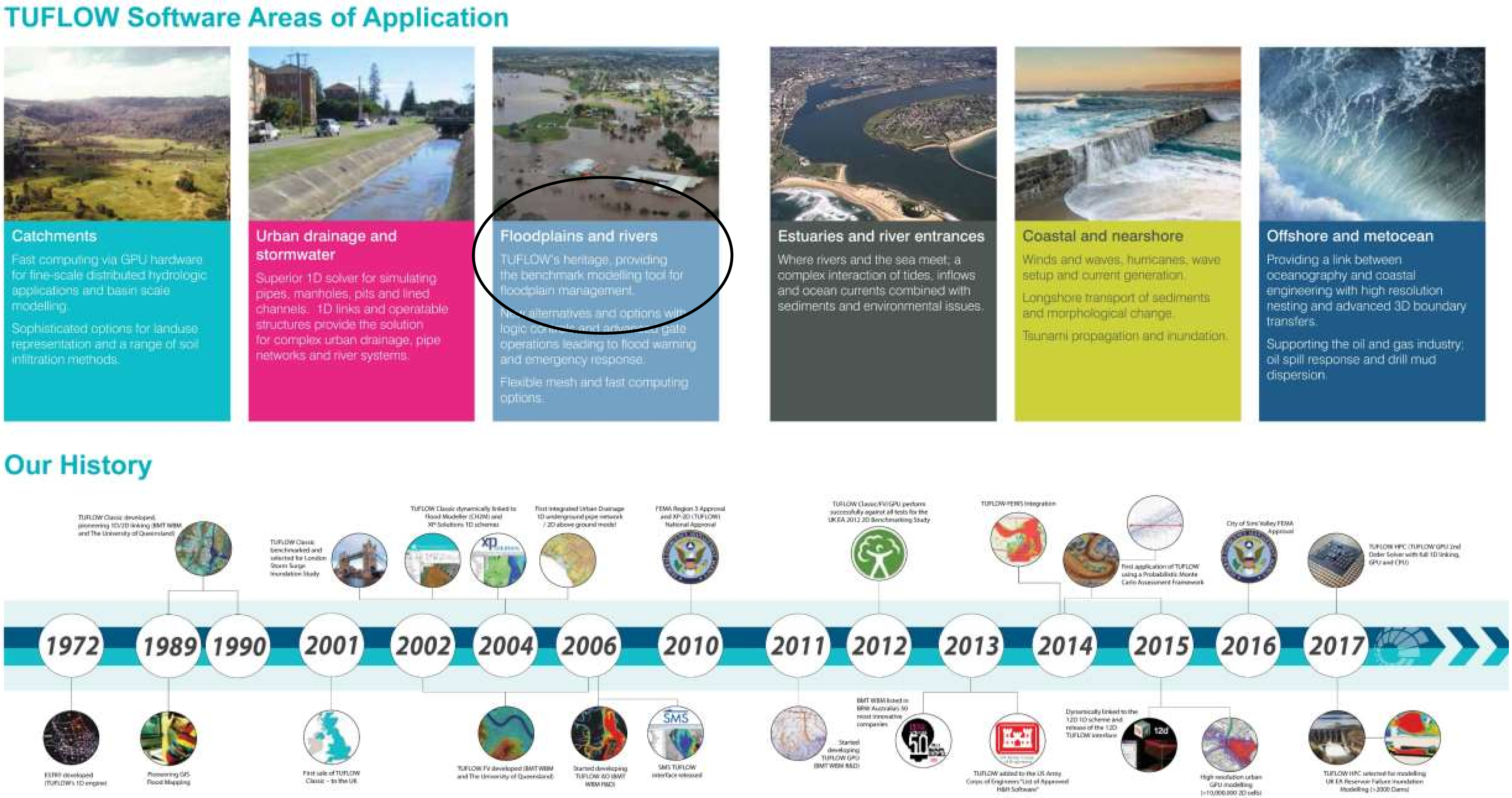
Ridgefield Pits Restoration Design: Physical Model Overview

Model Package: Tuflow (University of Queensland / British Maritime Technology)



Tuflow FV Flexible Mesh (www.tuflow.com)

Flexible Mesh Modelling

A 1D / 2D / 3D flexible mesh finite volume numerical model that simulates hydrodynamic, sediment transport and water quality processes in oceans, coastal waters, estuaries and rivers. A powerful engine proven at all scales.

FV Solution Scheme

The finite volume numerical scheme solves the conservative integral form of the non linear shallow water equations (NLSWE).

The equations can be solved in 1D, 2D (vertically averaged) and 3D.

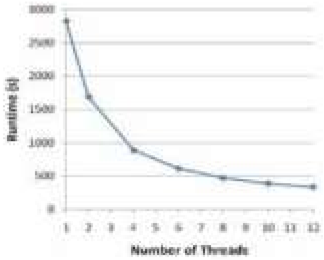
Engines

Key FV Scheme Features

- Intrinsically handles shocks
- Subcritical, supercritical and transitional flows
- Locally (and globally) conservative to numerical precision
- Robust wetting/drying
- Parallelised explicit scheme (varying Courant dependent timestep)
- 2D and 3D with 1st and 2nd order schemes

Speed

TUFLOW FV code is optimised and parallelised for multi-processor machines, using the OpenMP implementation of shared memory parallelism.



Features

Flexible controls / interfacing

TUFLOW FV inputs are controlled via a macro style text-file interface. This allows the user to flexibly and efficiently control model configuration, boundary condition specification and output requirements.

Open boundaries

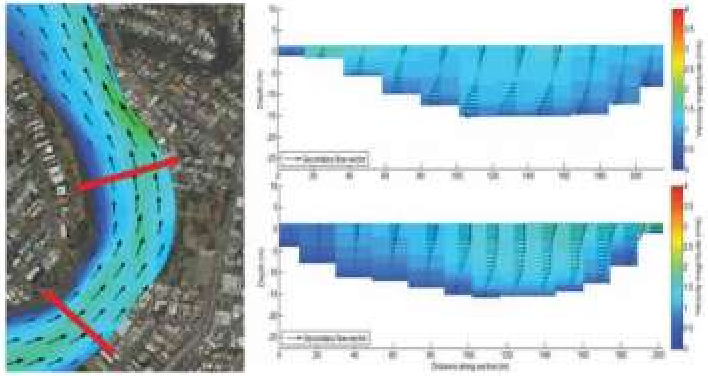
- Fully open (non-reflective)
- Specified water level
- Specified discharge
- 3D linkages to ocean circulation models

Additional forcings

- Global cell inflows and outflows (e.g. rainfall, evaporation)
- Cell inflows/outflows (e.g. pollutant source/sinks)
- Wind and wave stresses, atmospheric pressure
- Holland parametric cyclone wind and pressure model

Structures

- Weirs, culverts
- Adjustable beds, levee failure, etc
- hQh matrix specification at selected cells
- Logical controls
- Auto weir function



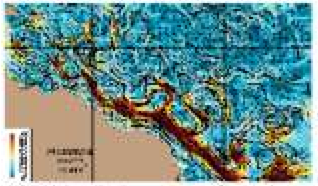
A combined 2D/3D flood model

TUFLOW FV has an option to insert 3D within a 2D model. This feature, which allows simulation of overland inundation plus complex 3D flow patterns in the main river channel, was successfully applied to the design of riverbank infrastructure.

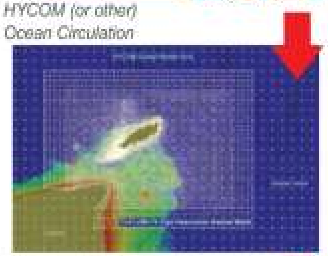
Complex problems require clever solutions

A nested modelling approach around Trinidad and Tobago to establish design parameters for infrastructure:

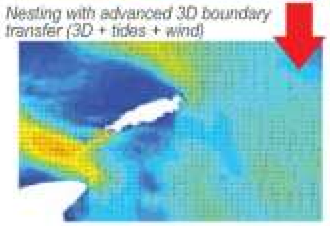
- 3D currents and vortex shedding from the HYCOM global model
- Hurricane activity, generating high currents on local and regional scales
- Rapidly shallowing bathymetry, with tidal and wind driven currents becoming influential close to the coastline



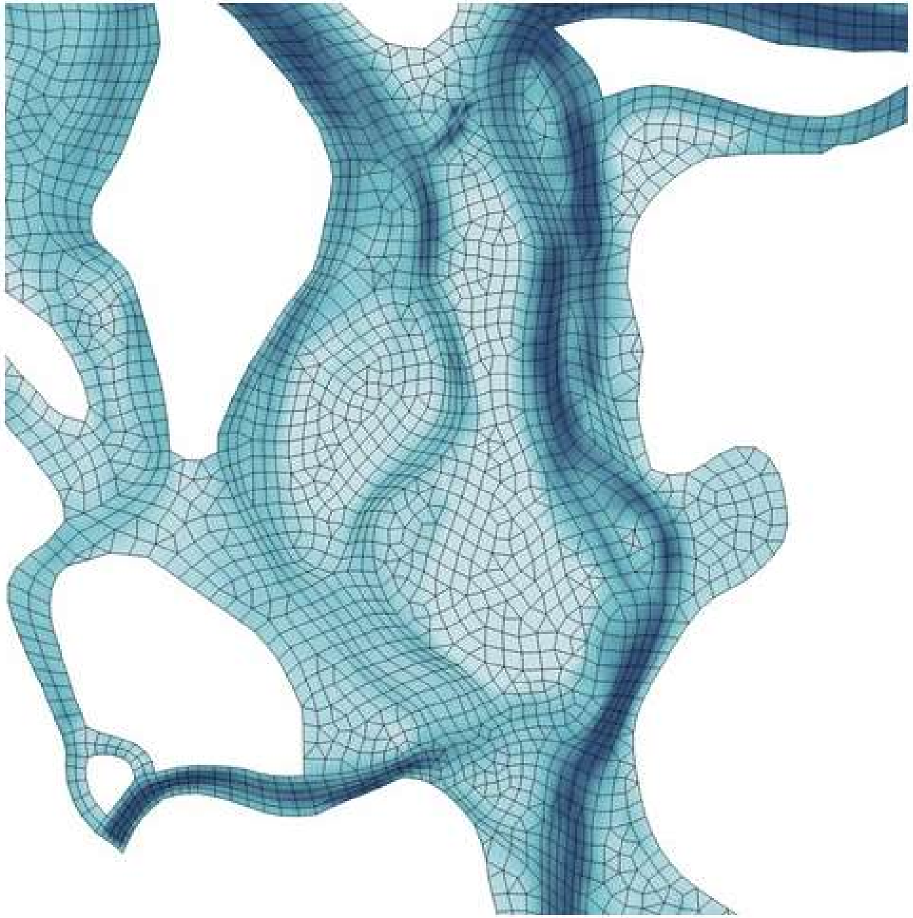
HYCOM (or other) Ocean Circulation



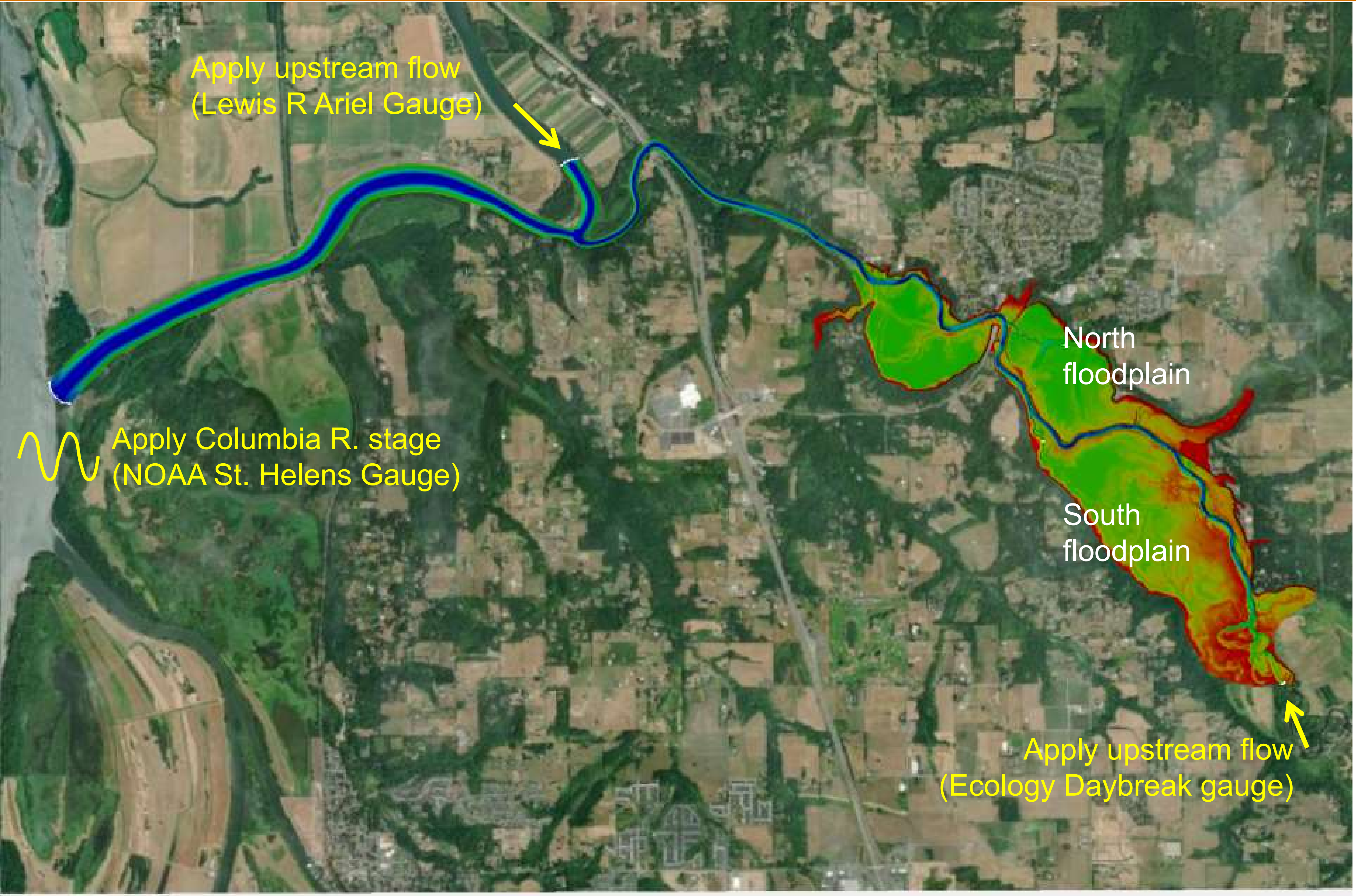
Nesting with advanced 3D boundary transfer (3D + tides + wind)



TUFLOW FV Ocean + winds + local effects



East Fork Downstream Hydro Model – La Center Floodplain Projects (2012-205)



Modeled levee breach scenarios at northern and southern floodplain wetland segments upstream of La Center.

Estimated relationship between Daybreak and Heisson gauge data, to allow application of a wider range of flows.

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East Fork Downstream Hydro Model – La Center Floodplain Projects (2012-2015)

Began long term collection of East Fork Lewis River stage data from La Center to above Mason Creek confluence

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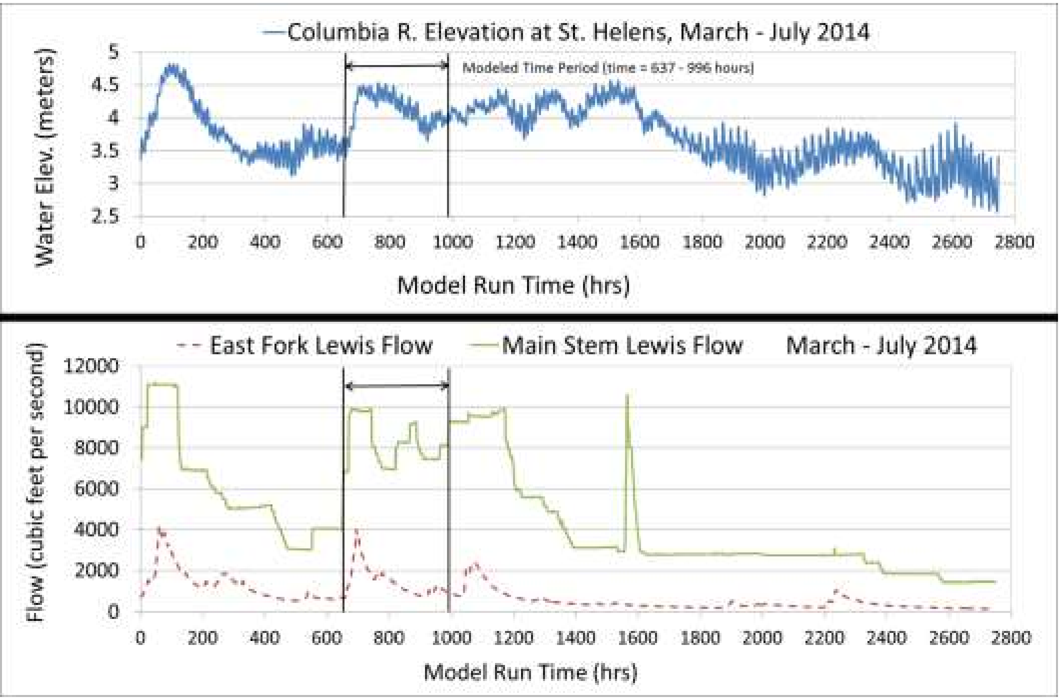
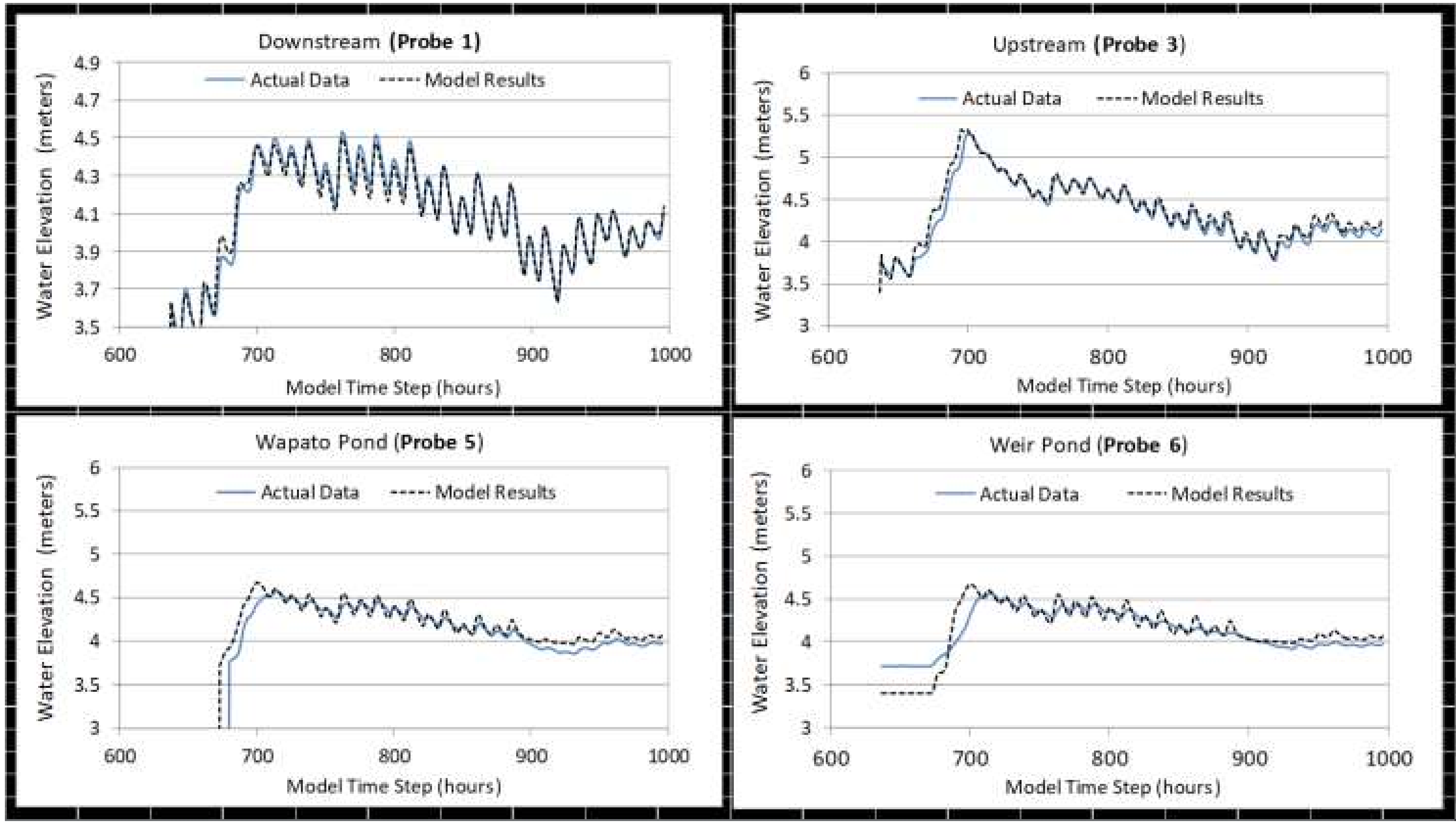
East Fork Downstream Hydro Model – La Center Floodplain Projects (2012-2015)

- Initial model validation at 1-year flood return interval and low-flow

boundary condition inputs:

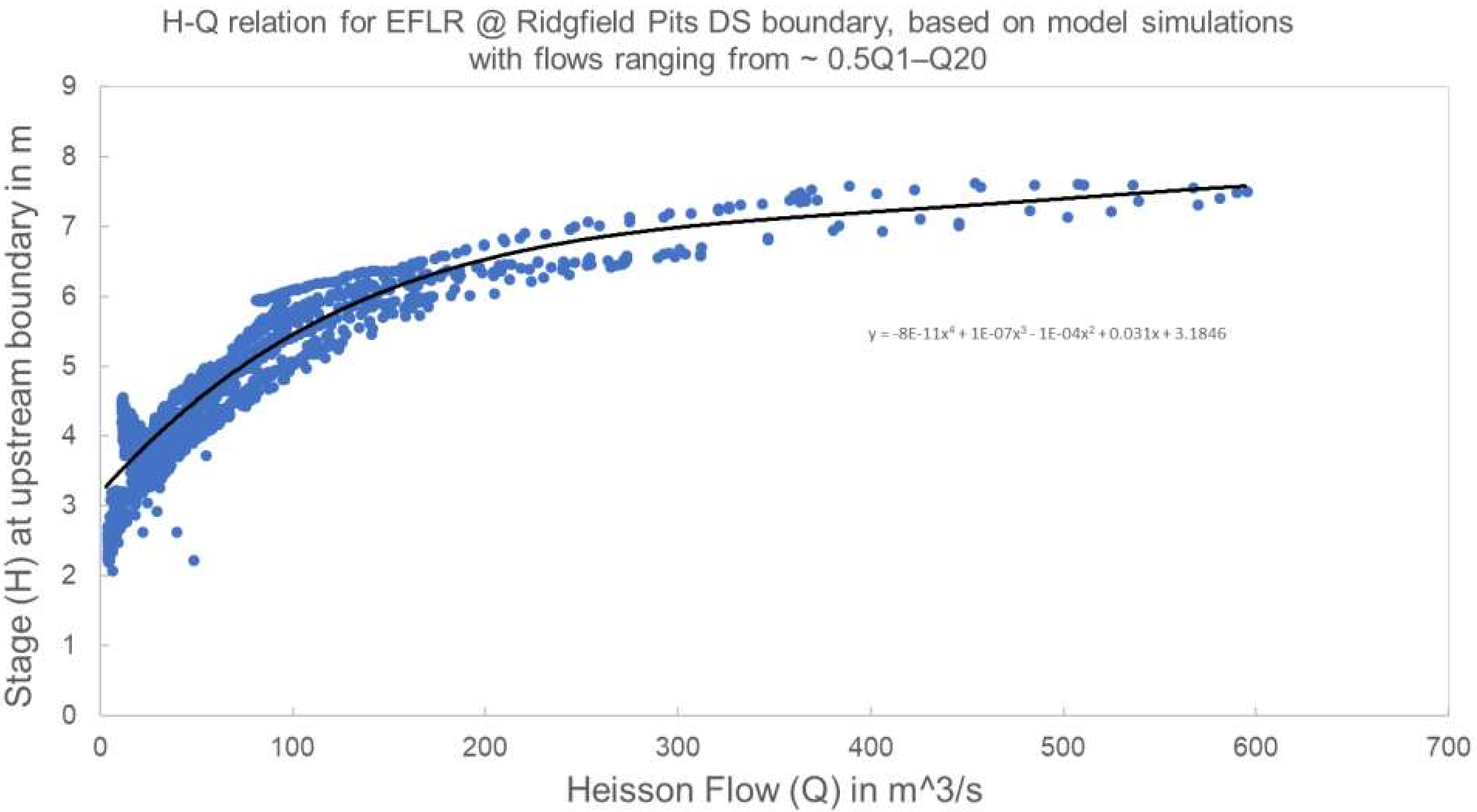


results, simulated vs. observed:



- Later calibrations were performed for 2-year and 80-year (Dec. 2015) flood return intervals

East Fork Hydro Model Phase 2 – Add Ridgefield Pits/Daybreak Upstream (2018)



Used Downstream model to establish stage-discharge (H-Q) relationship that can be applied to run the Ridgefield Pits/Daybreak model

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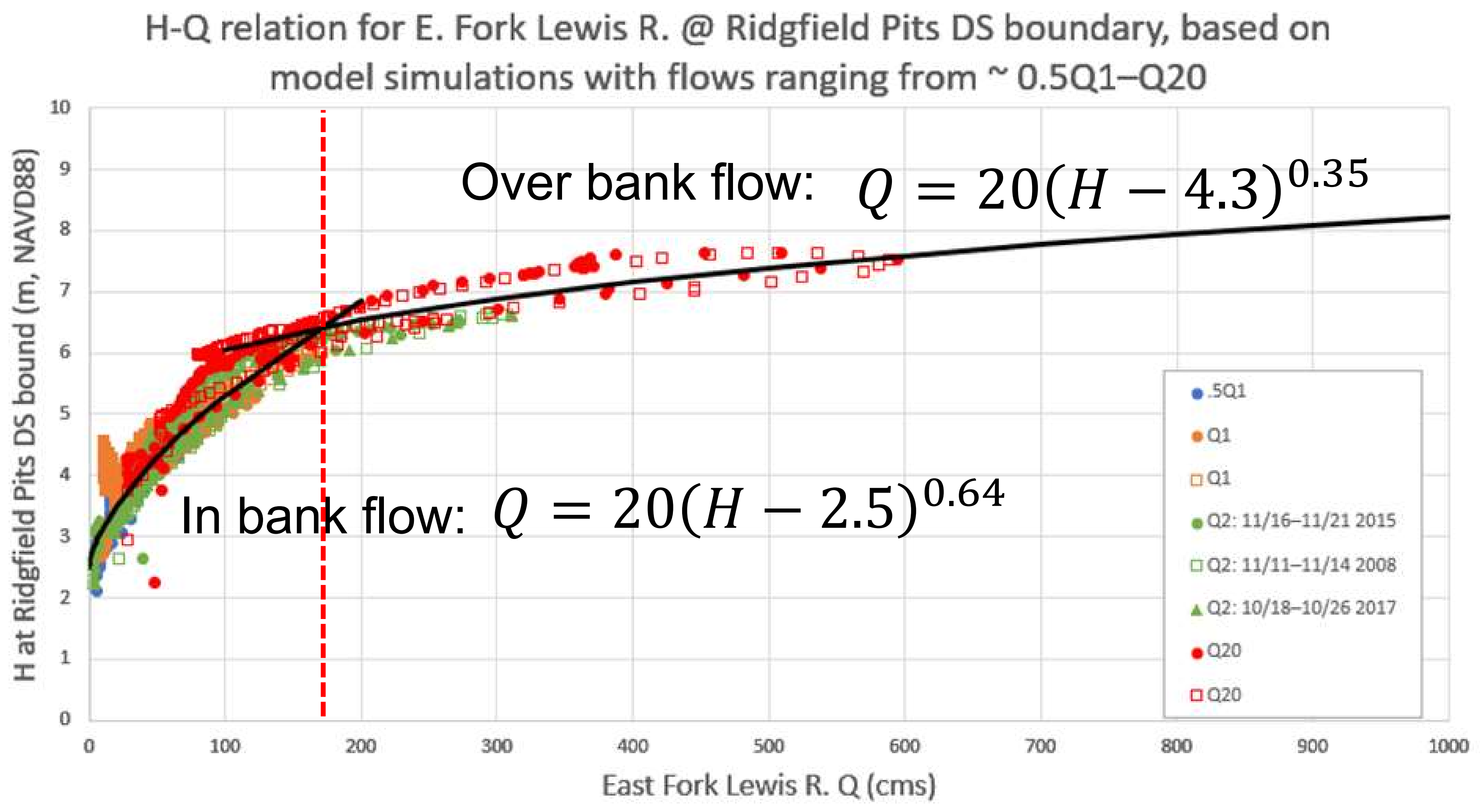
Model hydraulic inputs: H-Q rating curve

Established relationship between upstream flow (Q) and downstream water level based on available data:

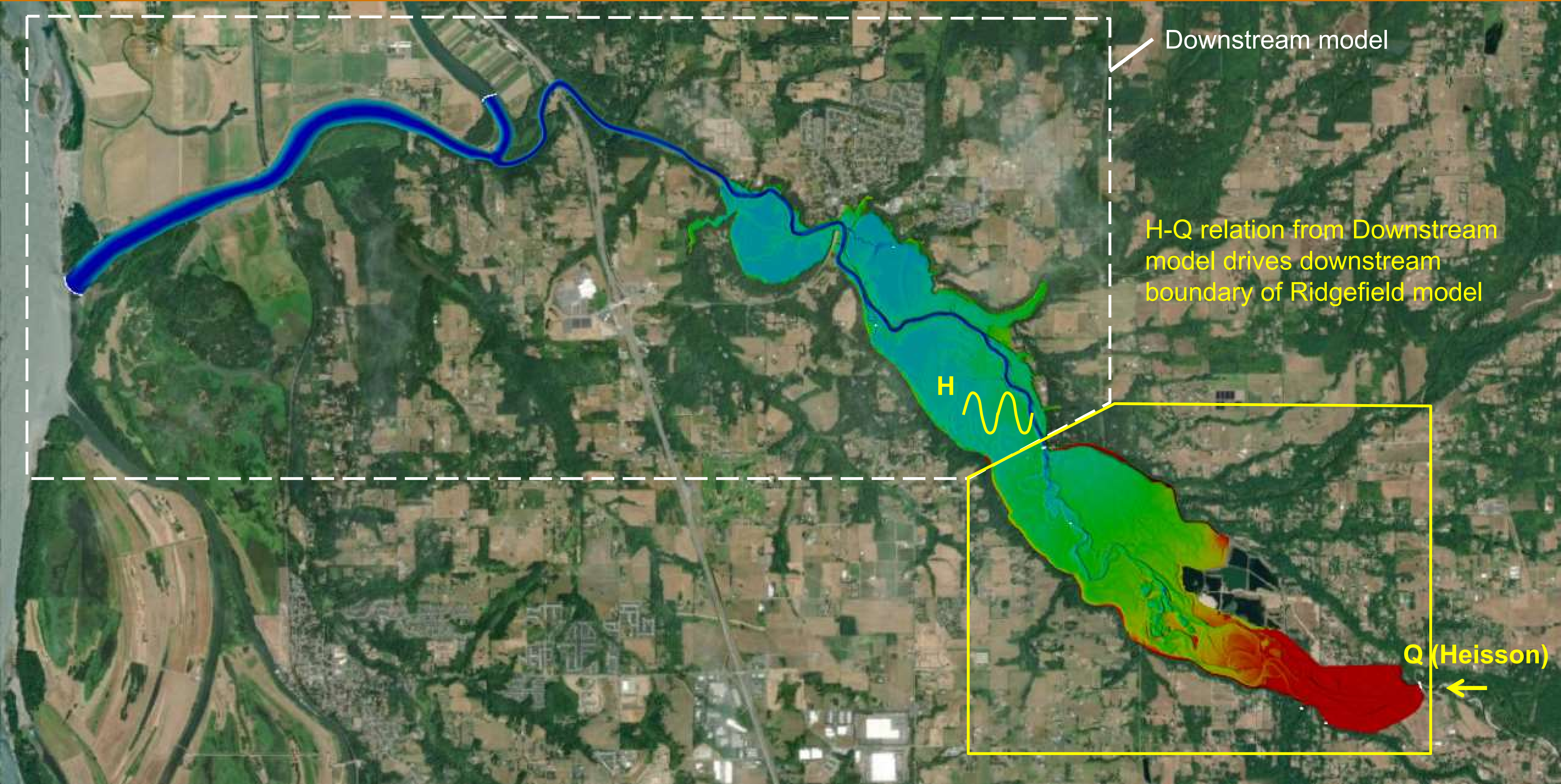
$$Q = C_r(H - a)^{\beta}$$

C_r, β: rating curve constants

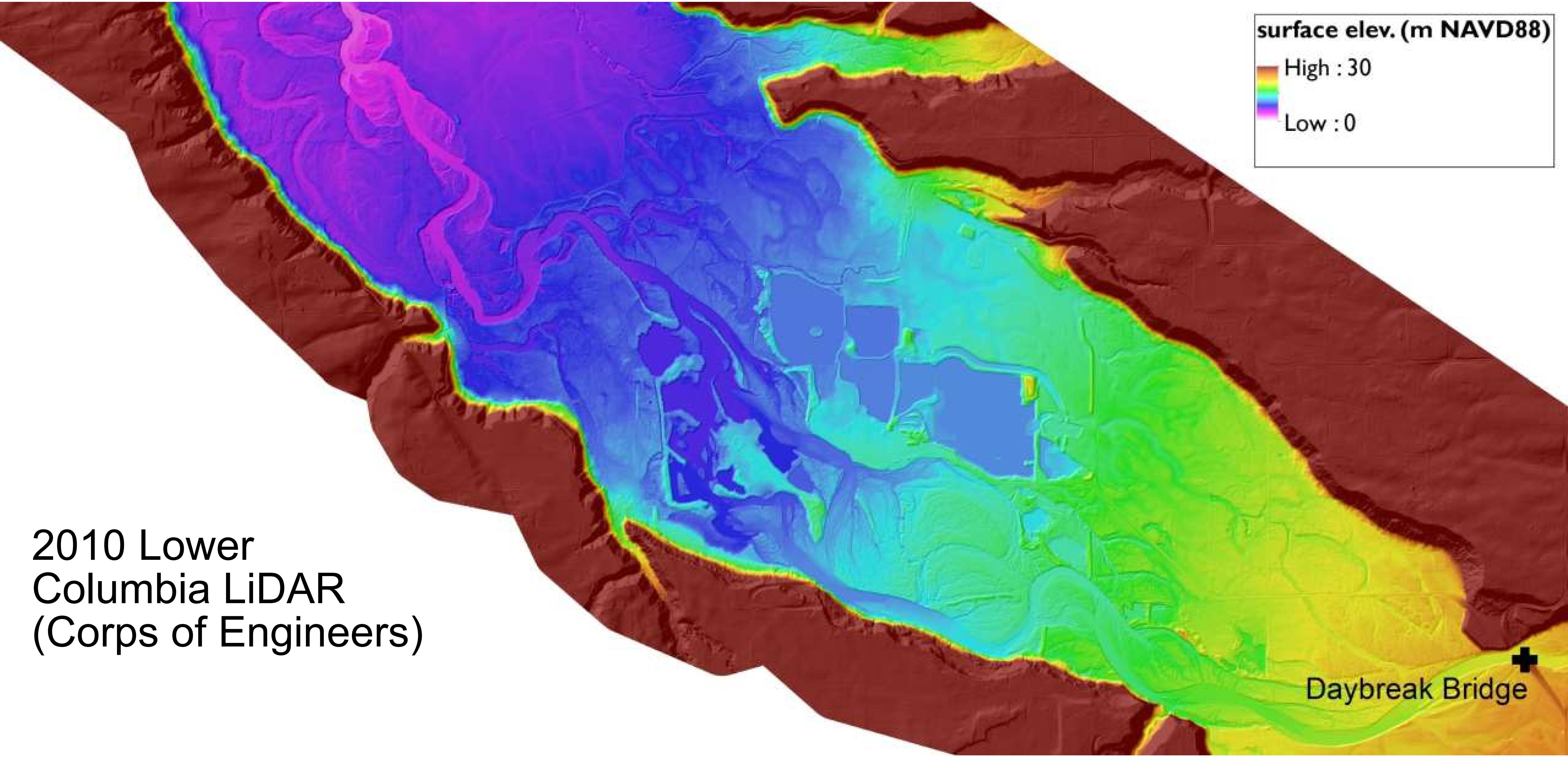
a: constant which represents the gauge reading corresponding to zero discharge.



East Fork Hydro Model Phase 2 – Add Ridgefield Pits/Daybreak Upstream (2018)

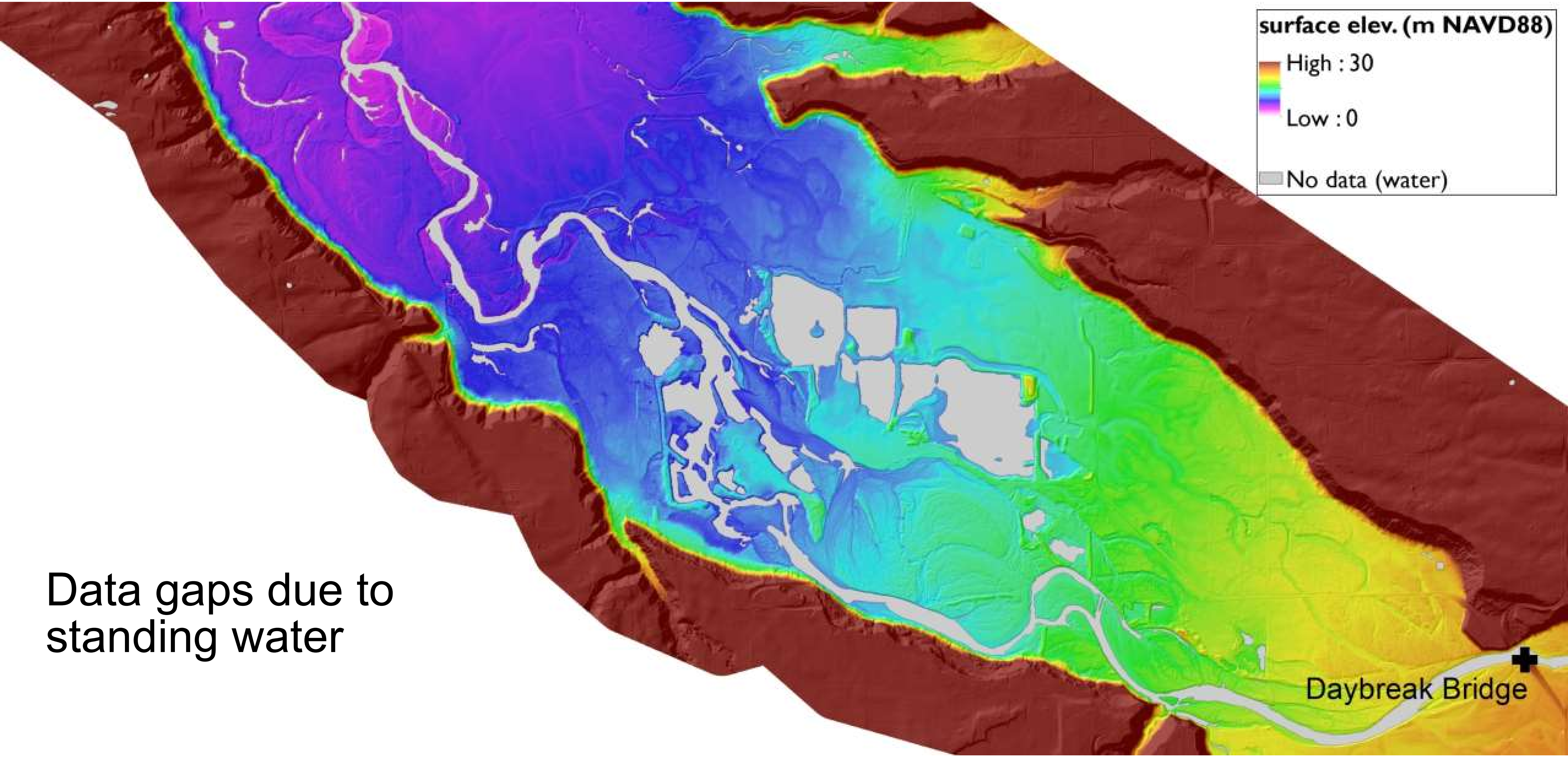


Ridgefield Model Topographic Inputs: 2010 LiDAR



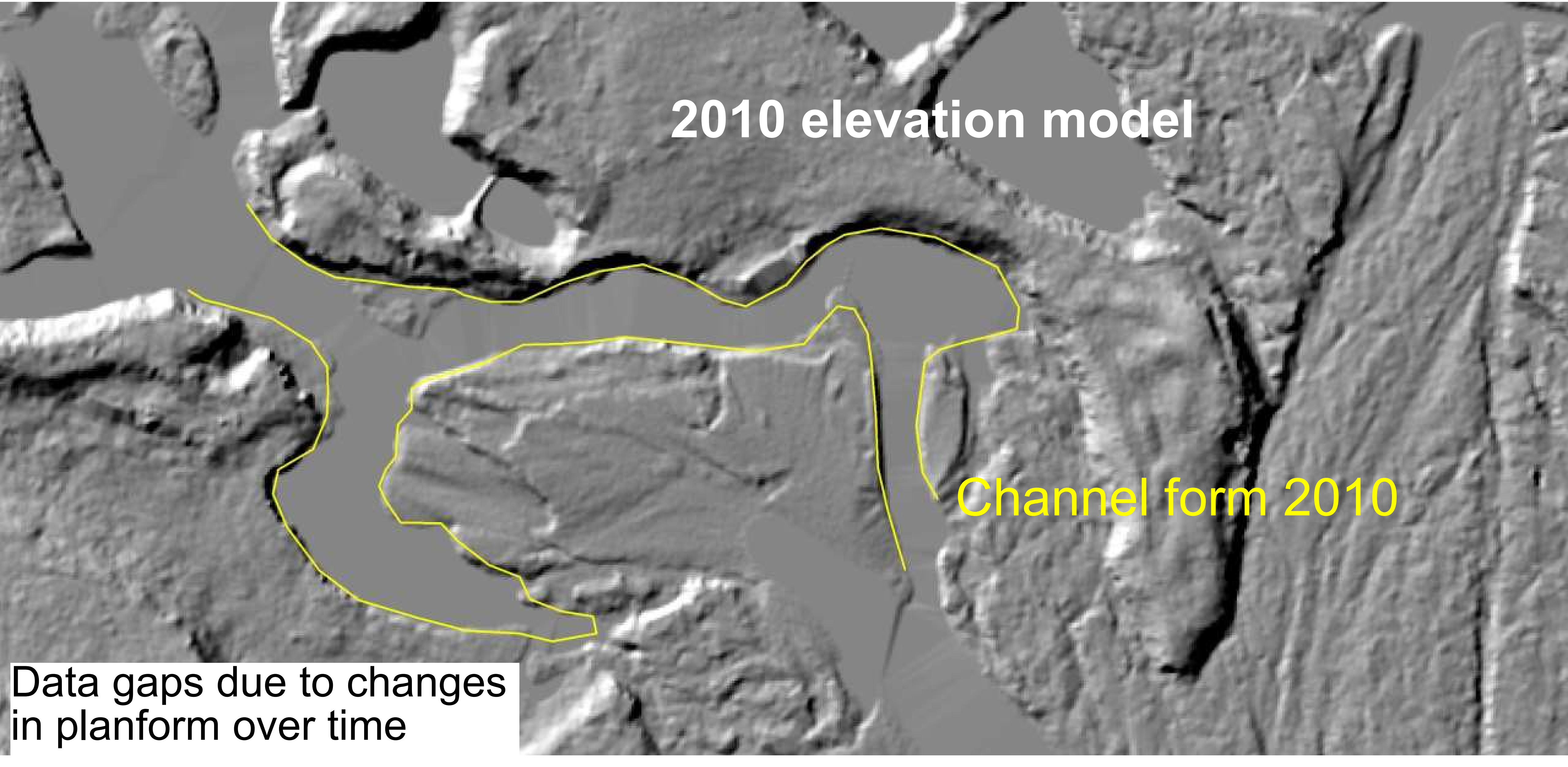
2010 Lower Columbia LiDAR (Corps of Engineers)

Ridgefield Model Topographic Inputs: 2010 LiDAR



Data gaps due to standing water

Ridgefield Model Topographic Inputs: 2010 LiDAR



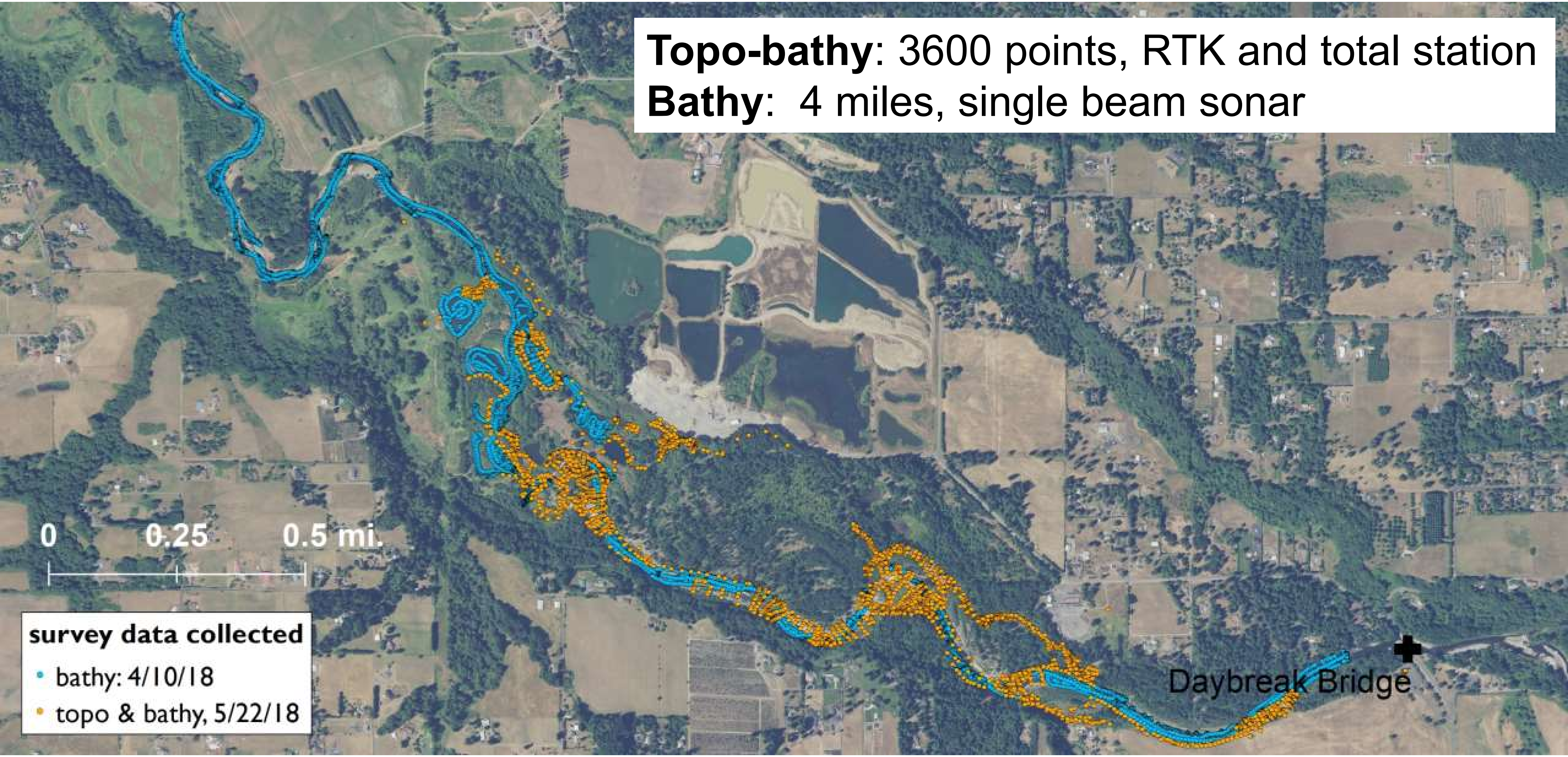
Data gaps due to changes
in planform over time

Ridgefield Model Topographic Inputs: 2010 LiDAR

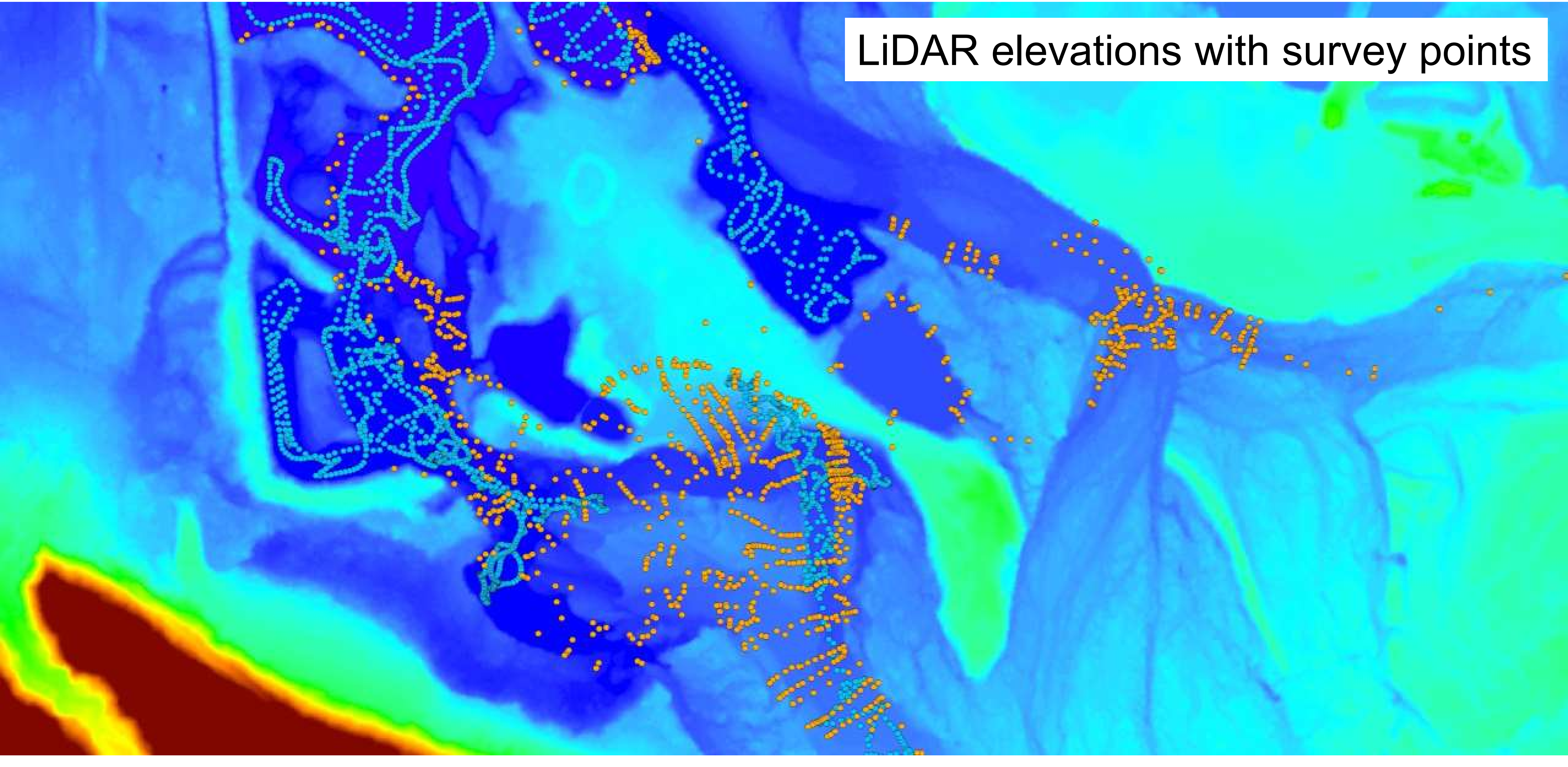
Data gaps due to changes in planform over time

Ridgefield Model Topographic Inputs: Topo-bathy data collected in 2018 (I-fluve/LCEP)

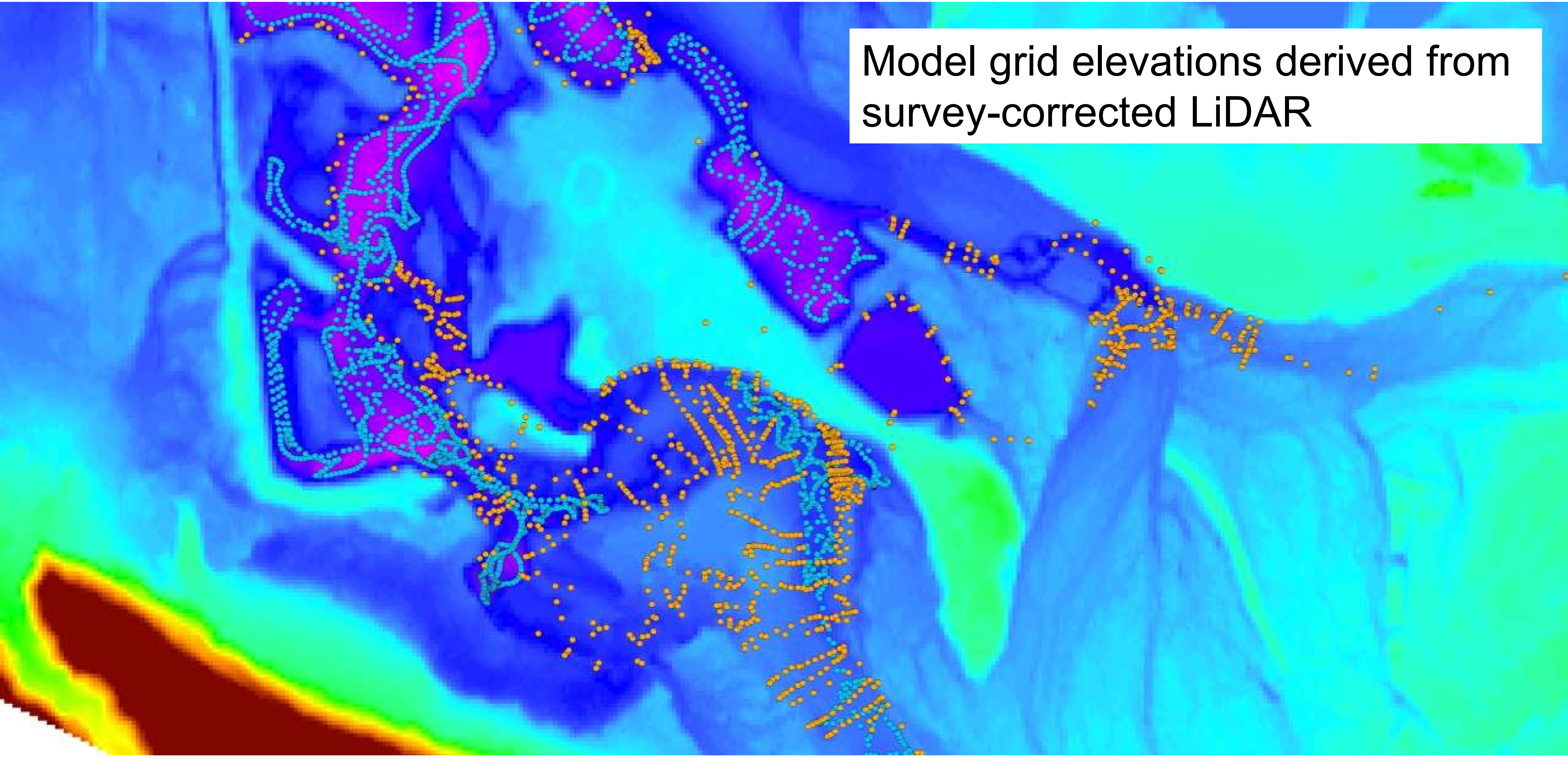
Topo-bathy: 3600 points, RTK and total station
Bathy: 4 miles, single beam sonar



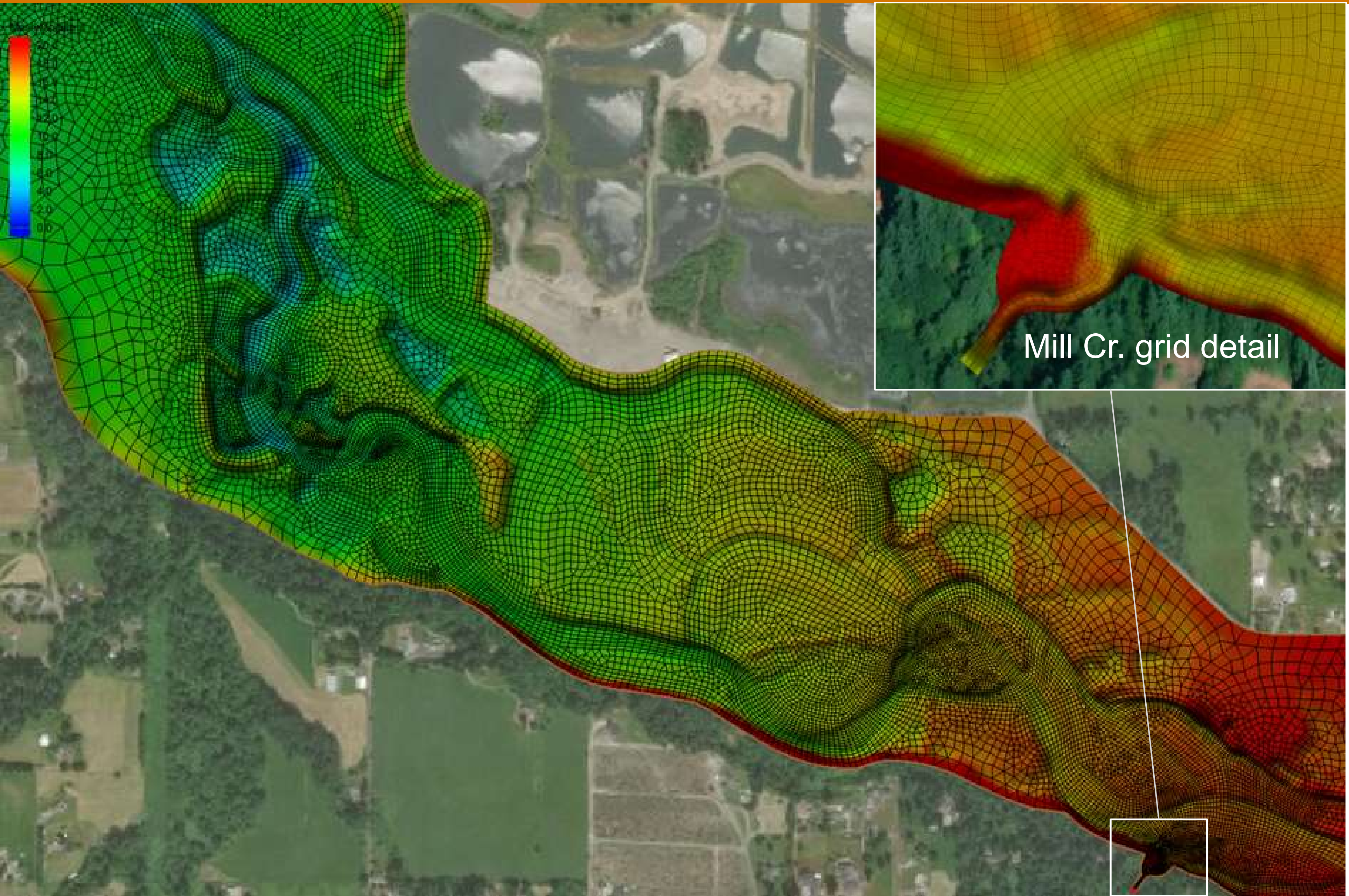
Ridgefield Model Topographic Inputs: Topo-bathy data collected in 2018 (I-fluve/LCEP)



Ridgefield Model Topographic Inputs: Topo-bathy data collected in 2018 (I-fluve/LCEP)



Ridgefield Model Grid Development



Initial model grid

- Cells conform to channel geometries (flexible mesh)
- High cell resolution (2m) where needed to effectively represent existing topography.
- Lower cell resolution elsewhere to minimize model run times

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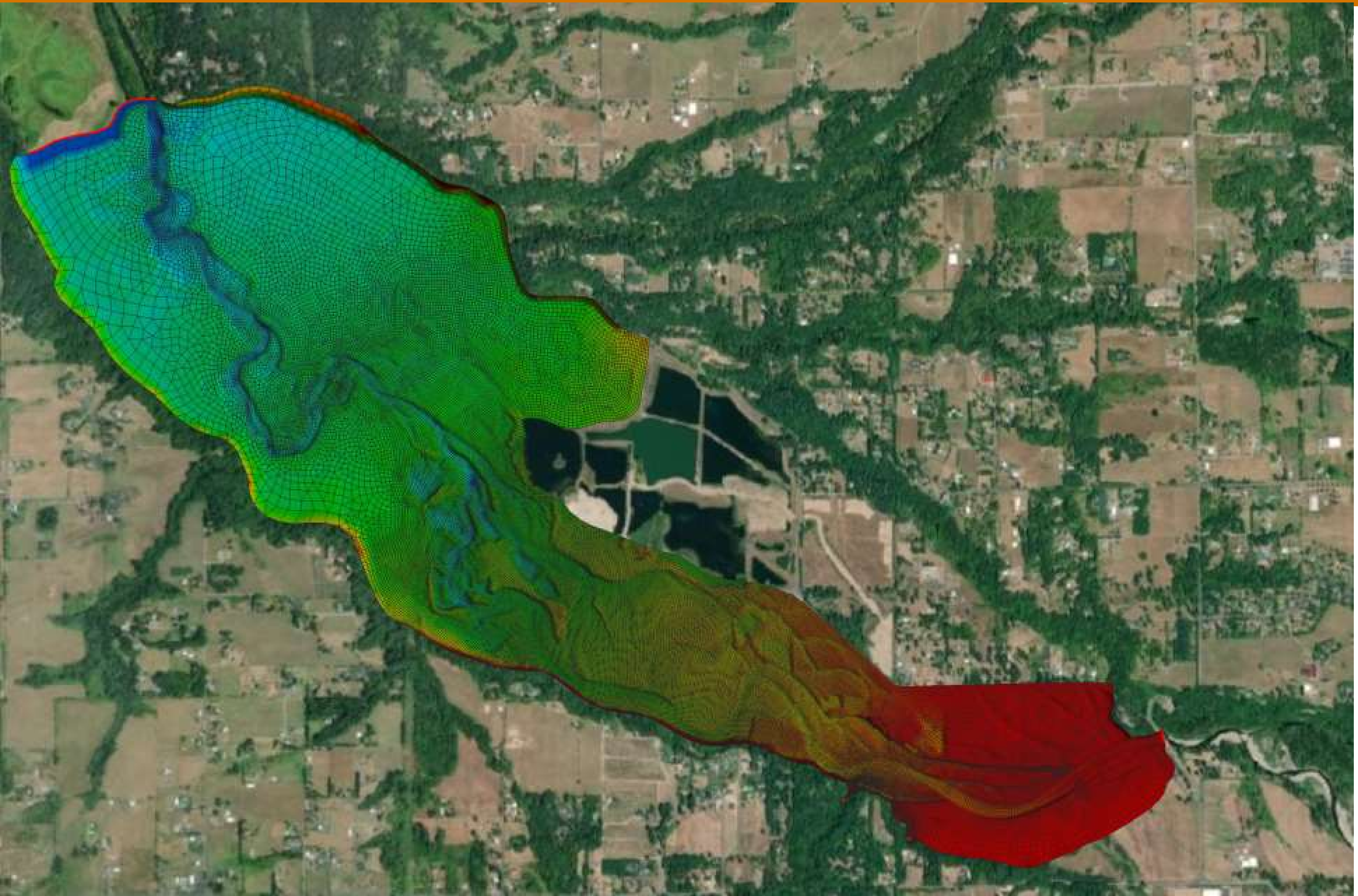
Ridgefield Model Grid Development



Revised model grid

- Expanded coverage through DS floodplain
- Switched to semi-fixed grid in project area to:
  - improve performance of sediment/morpho-dynamic module
  - eliminate grid biases when comparing design alternatives

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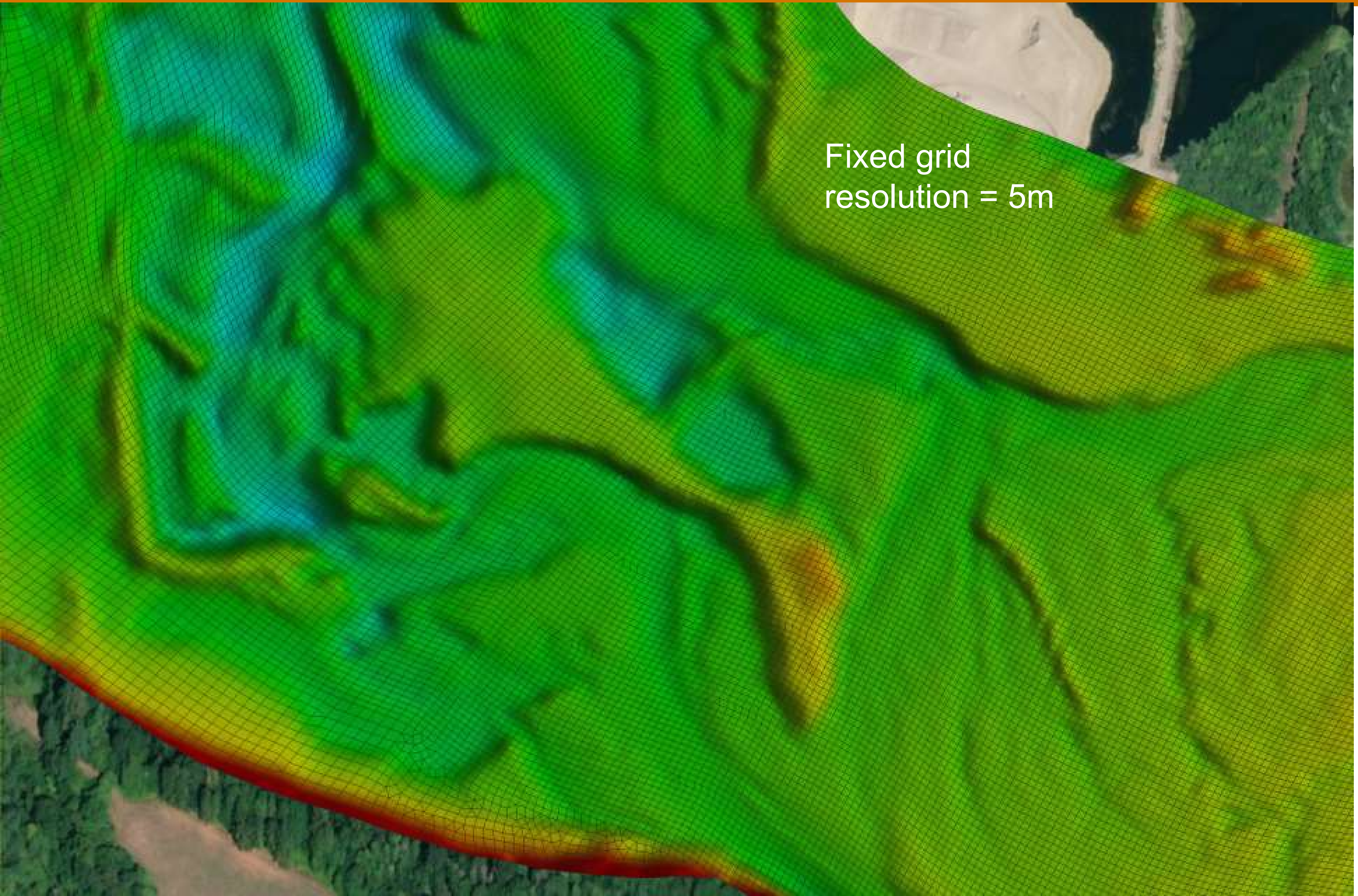
Ridgefield Model Grid Development



Revised model grid

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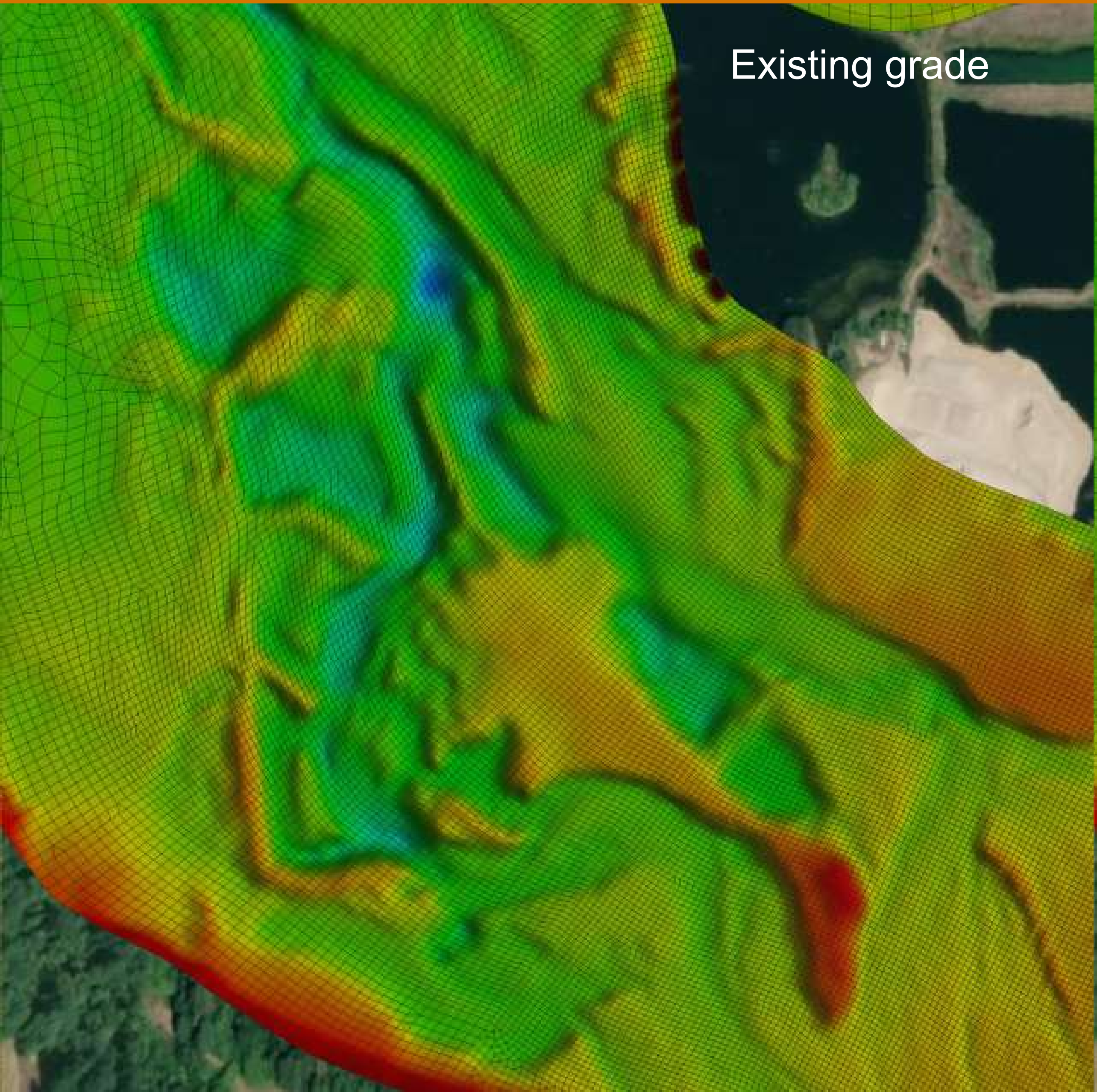
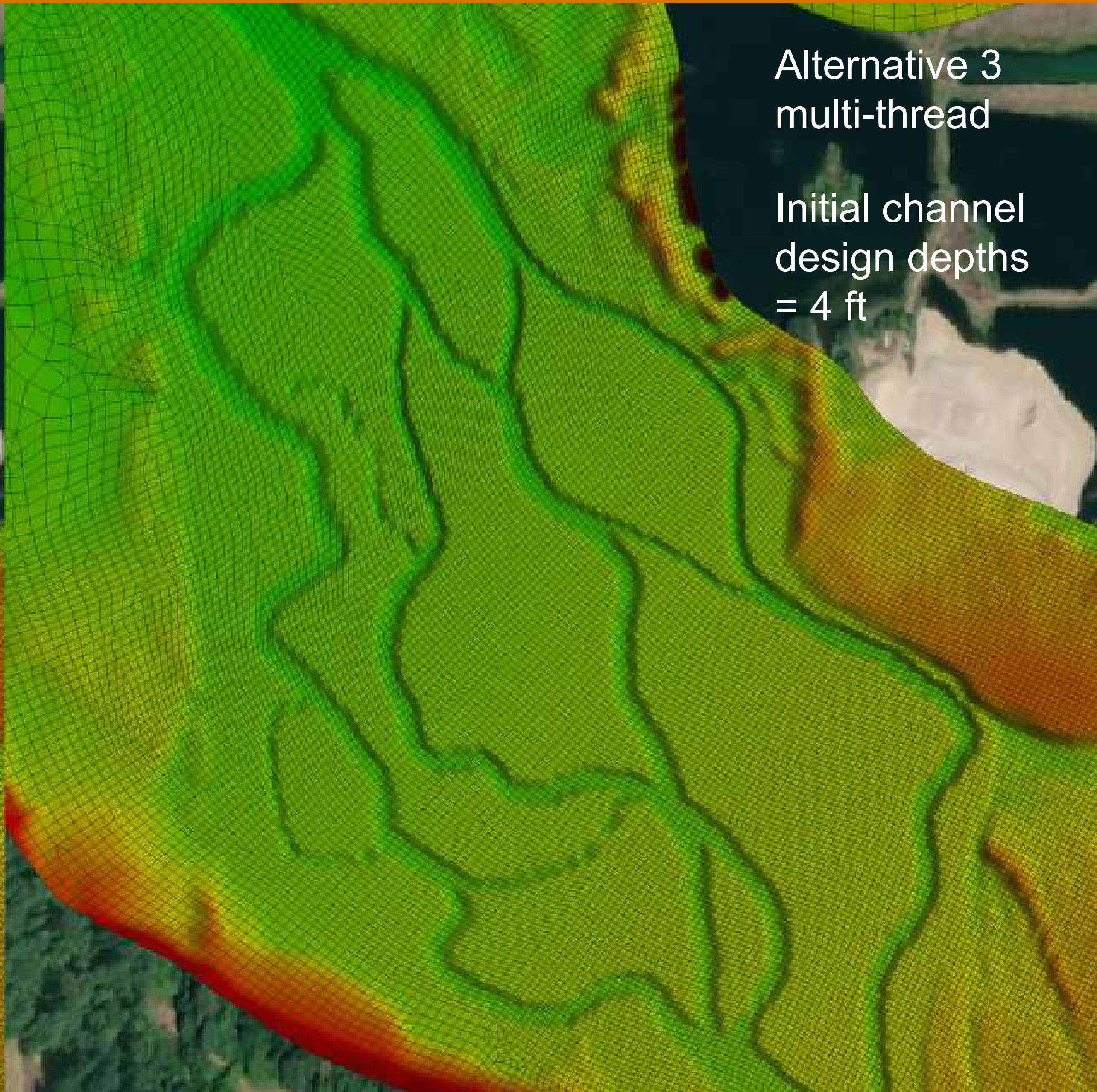
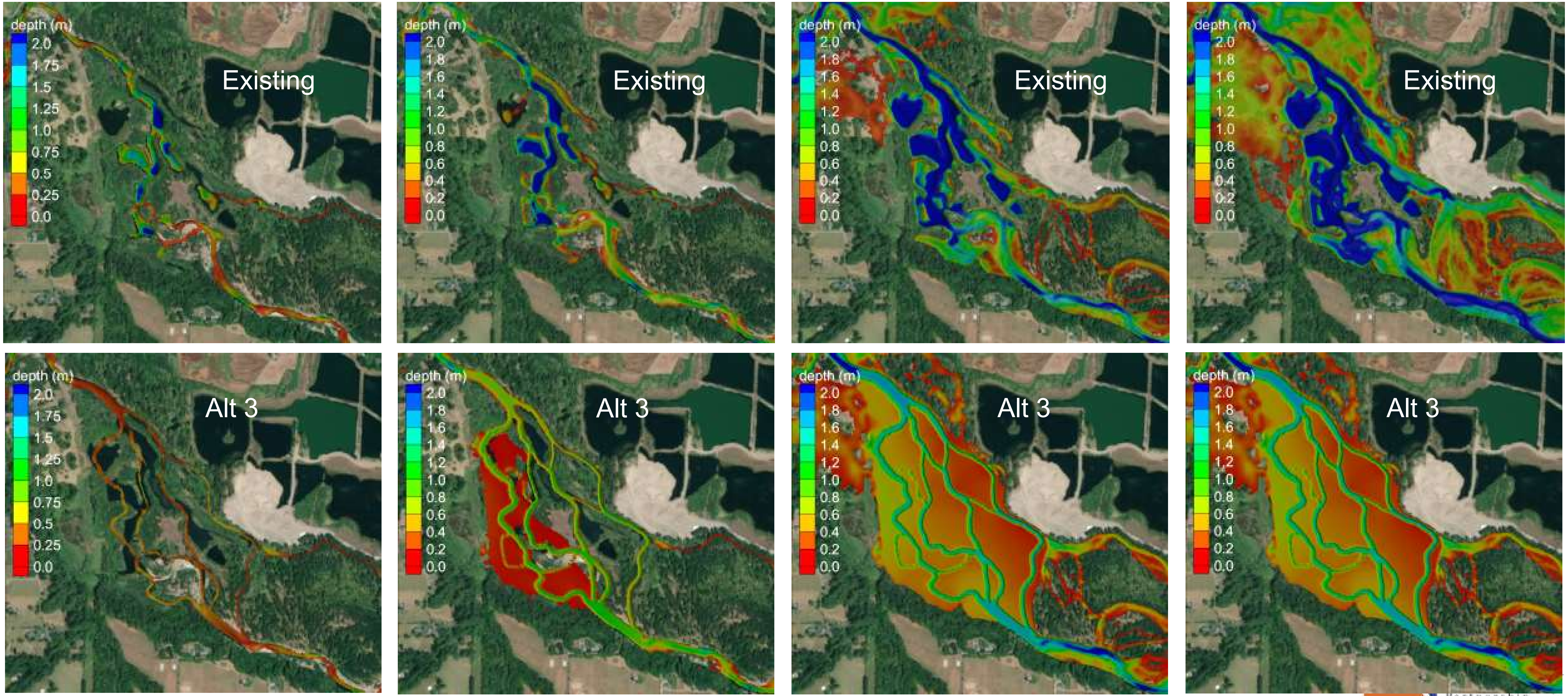
Ridgefield Model Grid Development – Alternative 3, multi-thread



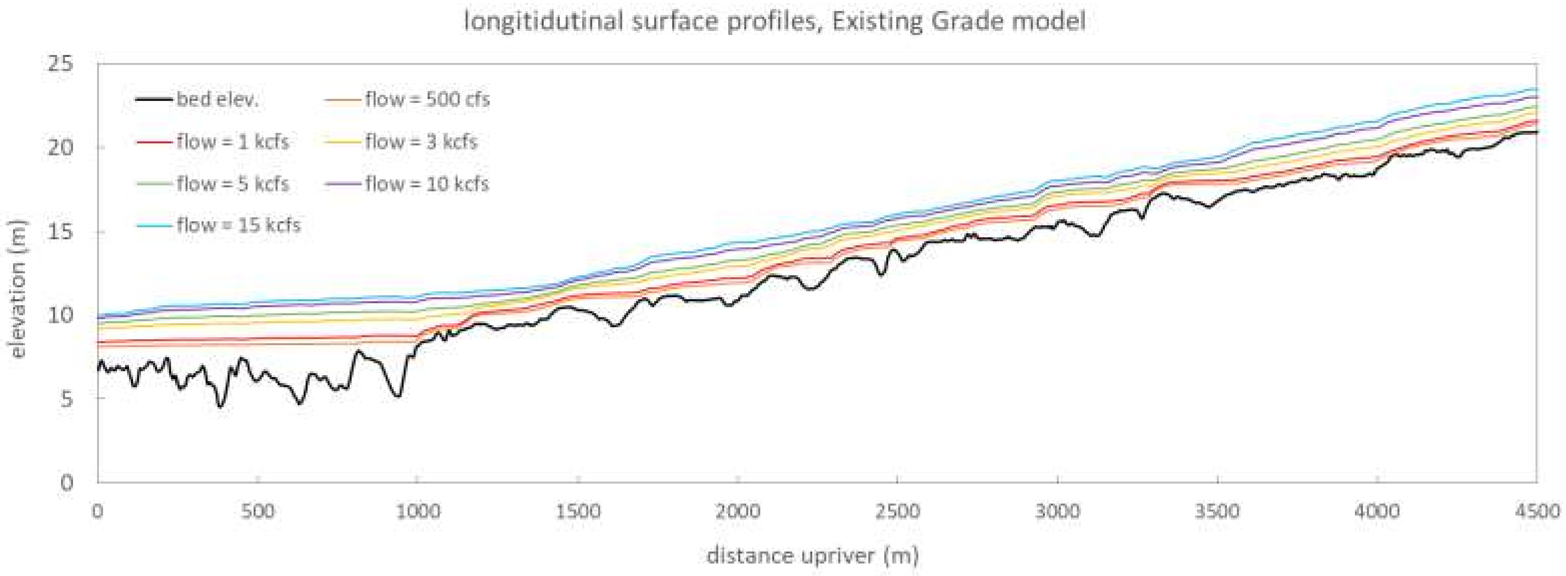


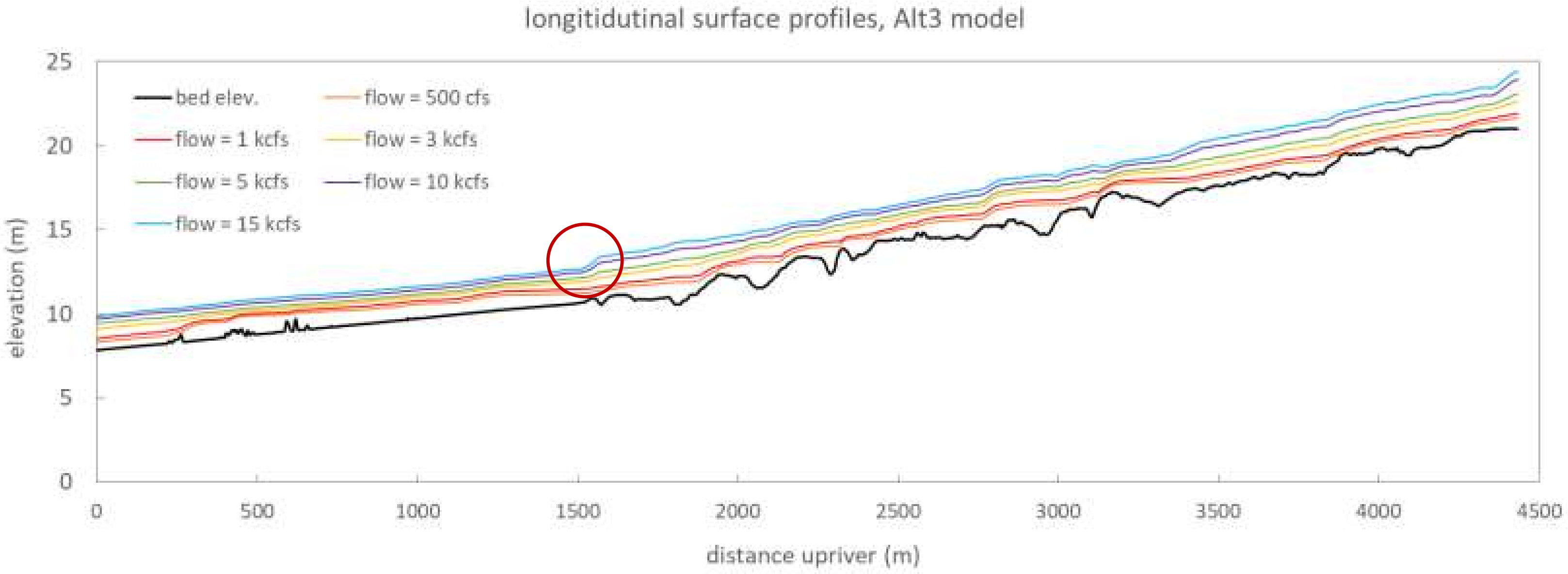
Ridgefield Model Hydro Results Comparison – Simulated Water Depths

Low flow (60 cfs) | Base flow (1kcfs) | 1-year (5k cfs) | 5-year (15k cfs)



Ridgefield Model Hydro Results Comparison – Longitudinal Profiles





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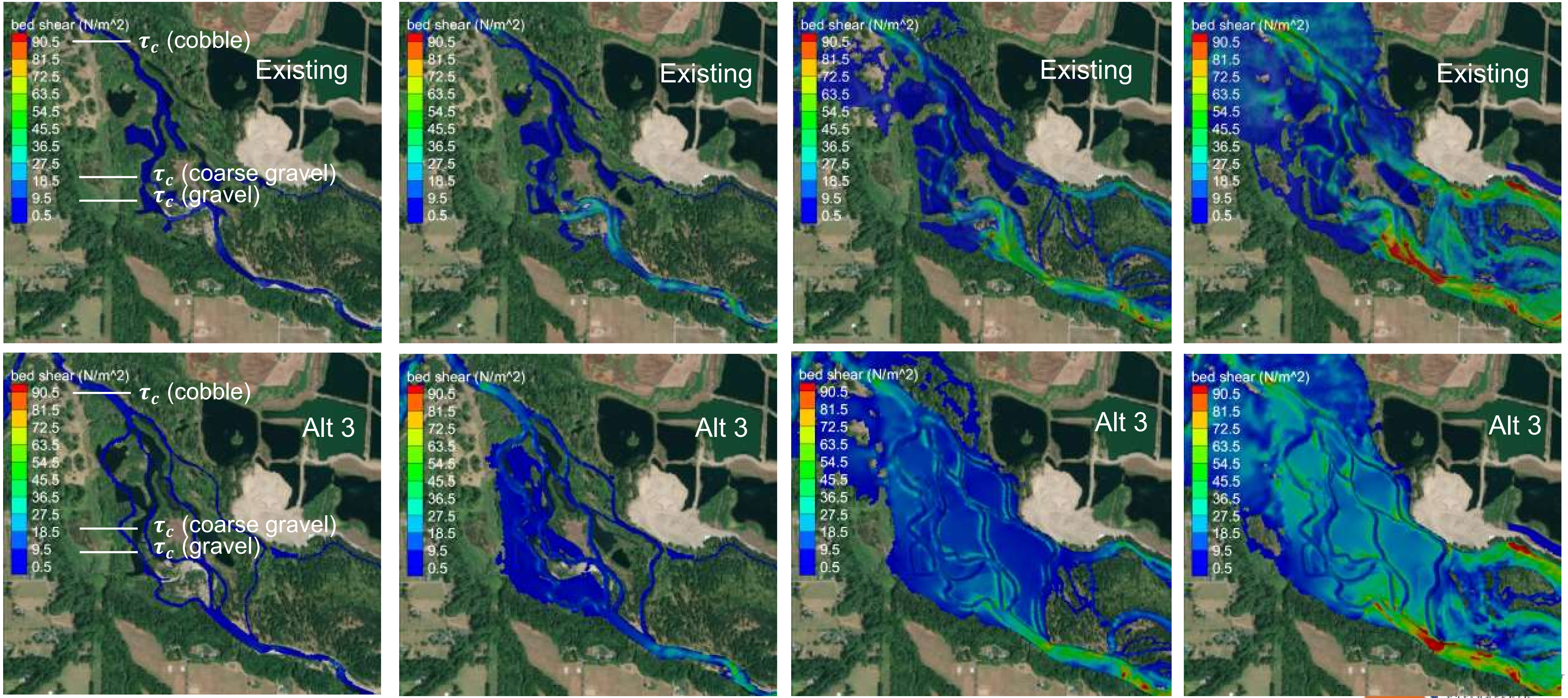
Ridgefield Model Hydro Results Comparison – Simulated Bed Shear Stress

Low flow (60 cfs)	Base flow (1kcfs)	1-year (5k cfs)	5-year (15k cfs)



Grain Size and Critical Shear Stress

Critical Shear Stress

$$\theta_{cr} = Y_{cr} = \frac{0.24}{D_*} + 0.055[1 - \exp(-0.020D_*)] \qquad (23)$$

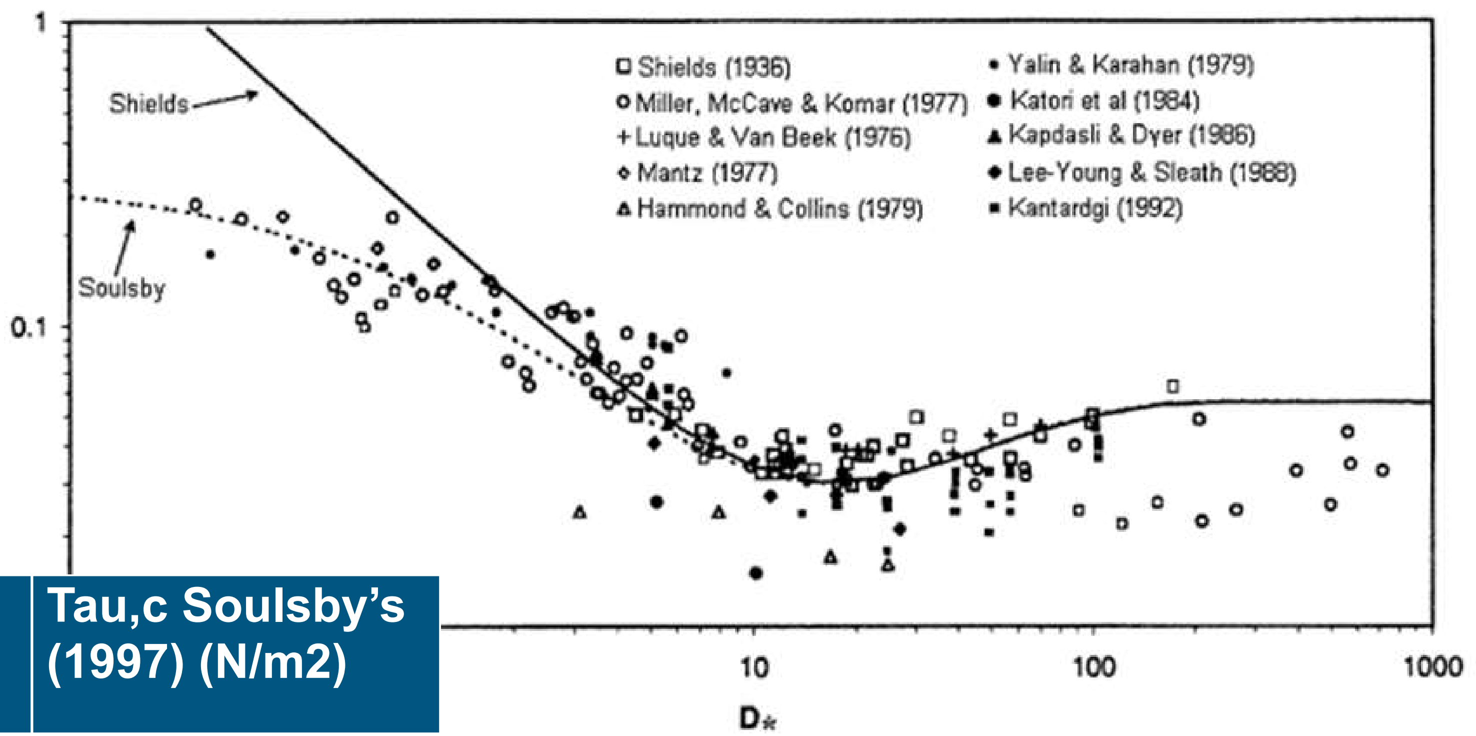
$$\theta_{cr} = Y_{cr} = \frac{0.30}{1 + 1.2D_*} + 0.055[1 - \exp(-0.020D_*)] \qquad (24)$$

Eq. (23) is fitted to the original Shields curve, and (24) contains the modification for small D_*. The discussers have

with:

D_* = d_{50} $[(s-1)\,g/\nu^2]^{1/3}$ = dimensionless sediment size (m),

θ = $\tau_{b,c}/[(\rho_s-\rho_w)gd_{50}]$ = Shields parameter (-),

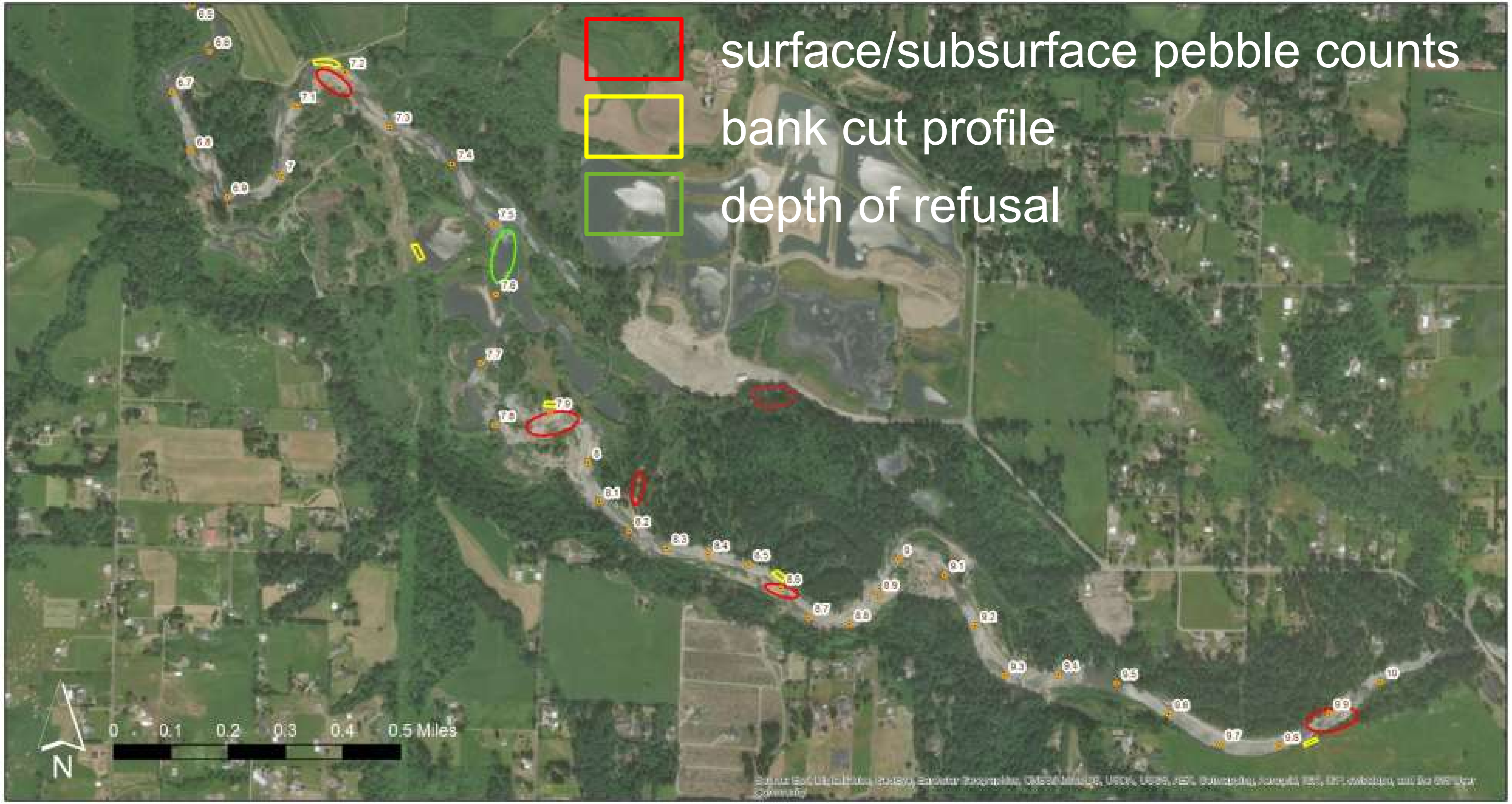


Horizontal Bed: Graph of $\theta_{cr} = Y_{cr}$ and D_* as Given by Eq. (22) [from Soulsby and White-

Description	Grain Size (mm)	Tau,c Shields' (1936) (N/m2)	Tau,c Soulsby's (1997) (N/m2)
Fine Sand	1	0.50	0.50
Gravel	10	9.0	9.0
Coarse Gravel	25	22.4	22.4
Cobble	100	89.1	89.1

Slide source: BWT-WBM (Tuflow FV)

Sediment Sampling Plan (2018)



EF Lewis Ridgefield Pits
Sediment Sampling Plan
Created Oct 2018

Type

- Surface and subsurface pebble counts
- Bank cut profile (descriptive)
- Surface characterization and depth of refusal

Surface samples to be collected using pebble counts on transects across the active channel. Subsurface counts to be done by removing the surface layer at a representative sampling location and performing pebble counts on the subsurface material as described in Buffington (1996) as cited and described in Bunte and Abt (2001).

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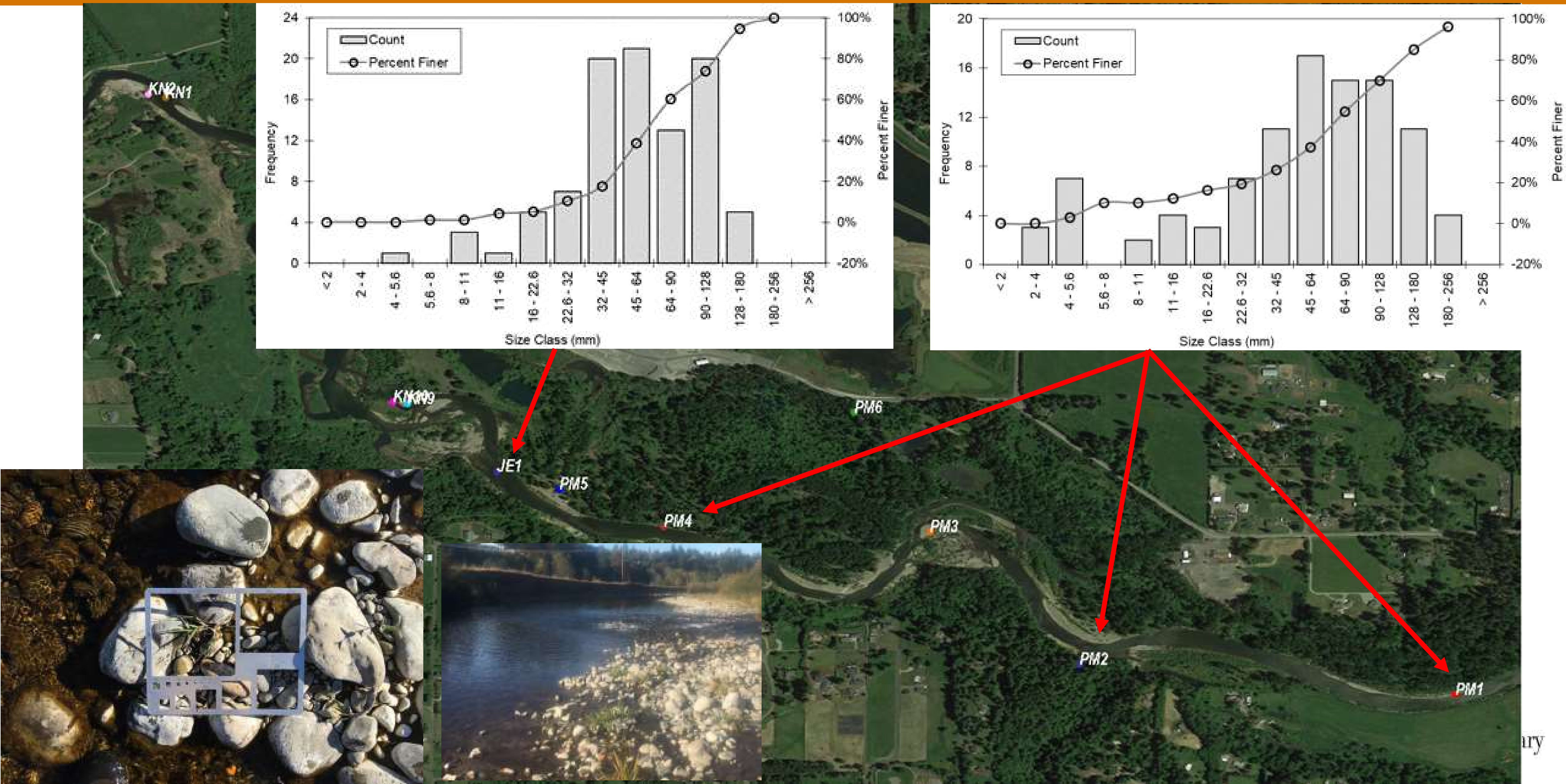
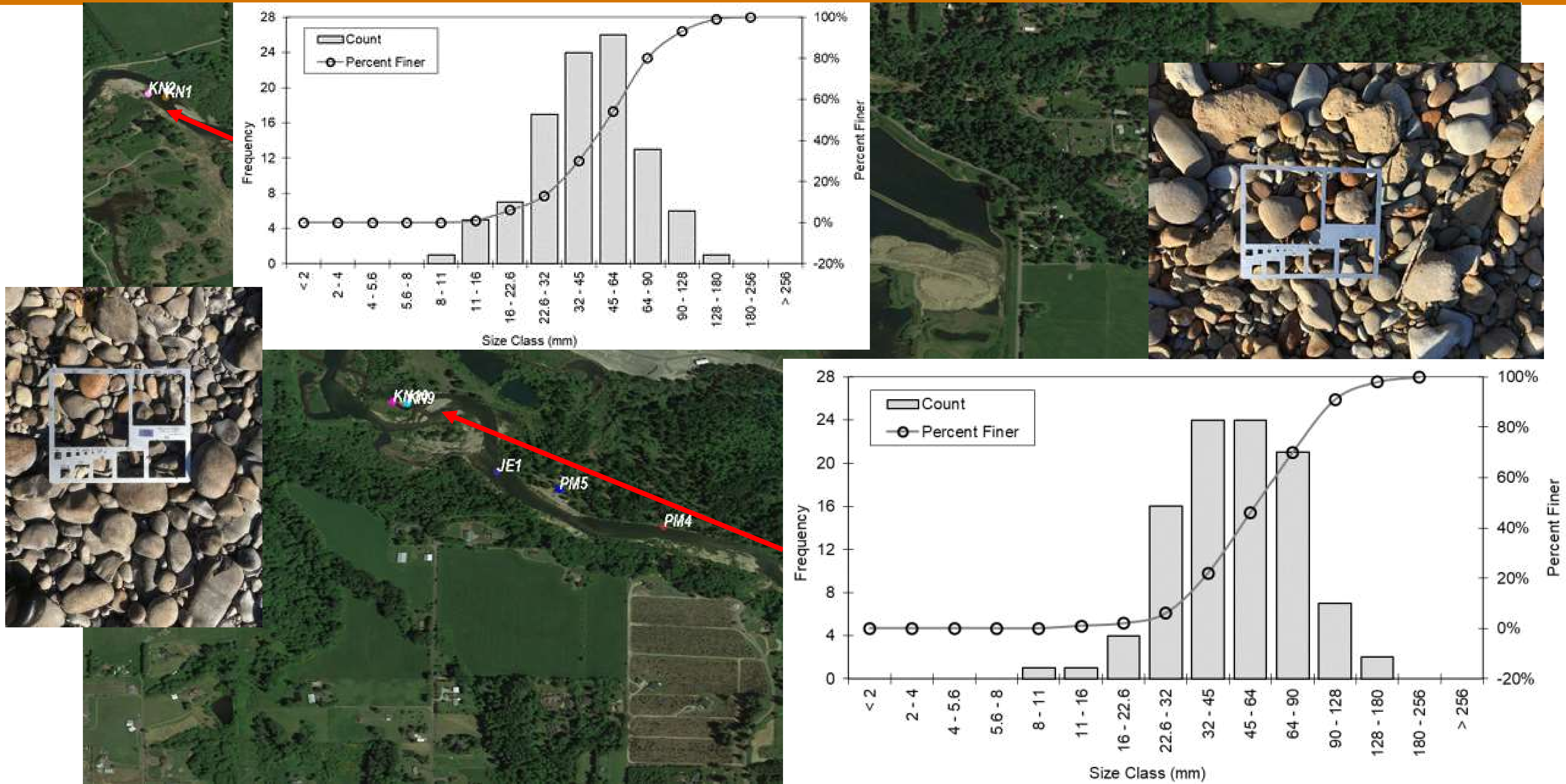
Sediment Sampling – Bed Material (Surface/Armoring)



Sediment Sampling – Bed Material (Surface/Armoring)



Sediment Sampling – Bed Material (Surface/Armoring)

- **Relatively consistent size distribution throughout the study area**
- D10 ≈ 20mm Coarse Gravel
- D50 ≈ 50mm Very Coarse Gravel
- D84 ≈ 100mm Cobble

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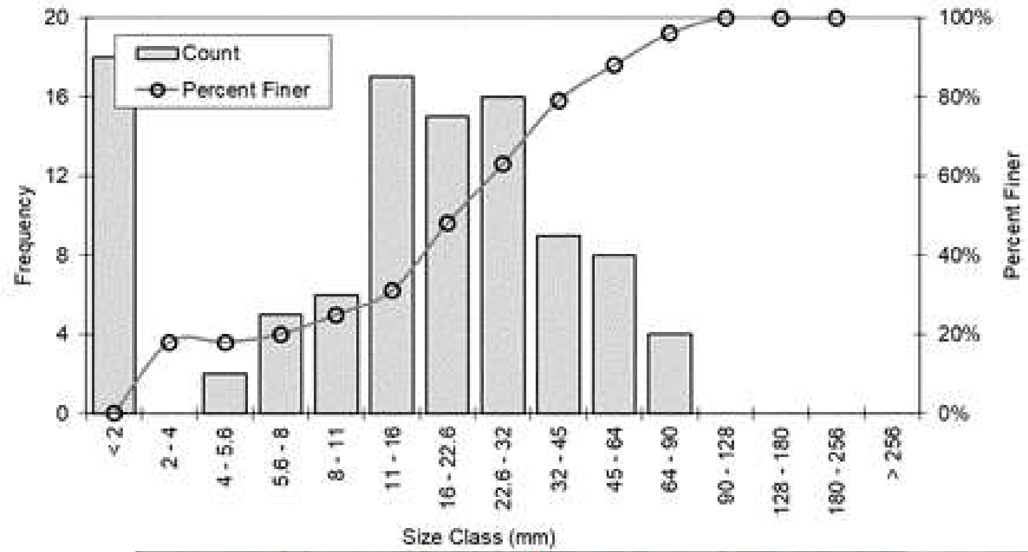
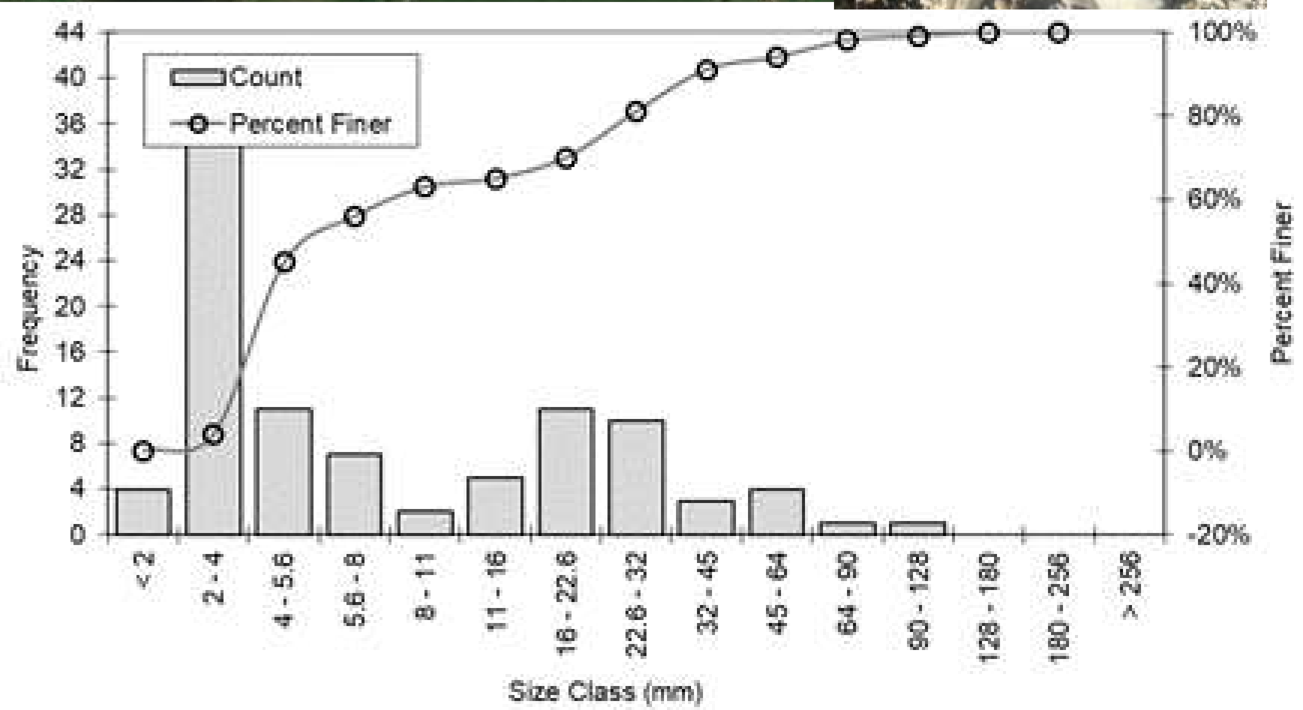
Sediment Sampling – Bed Material (Subsurface)

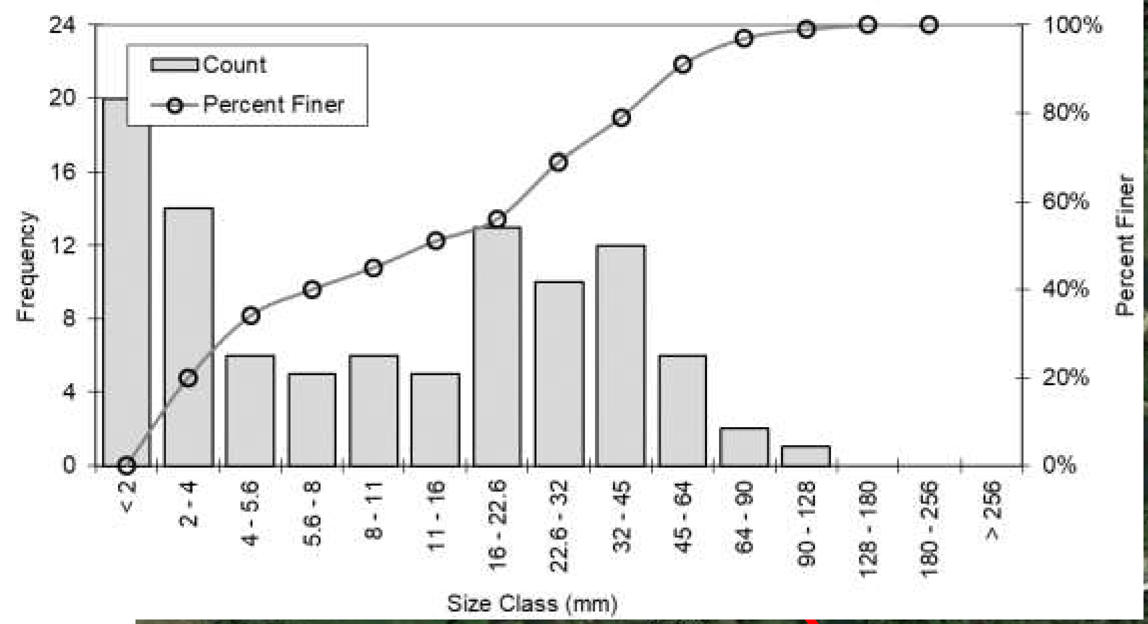


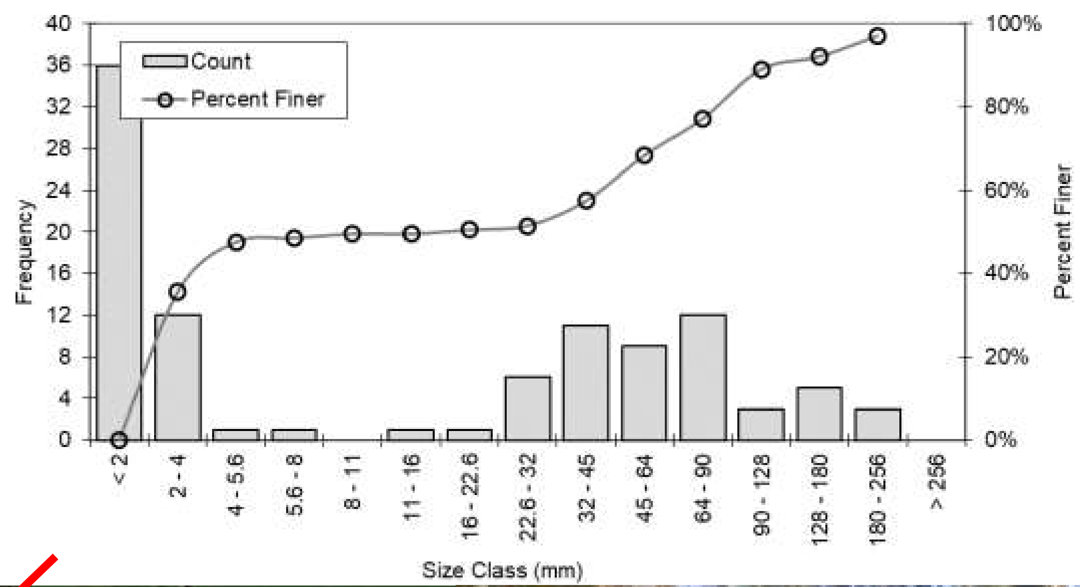


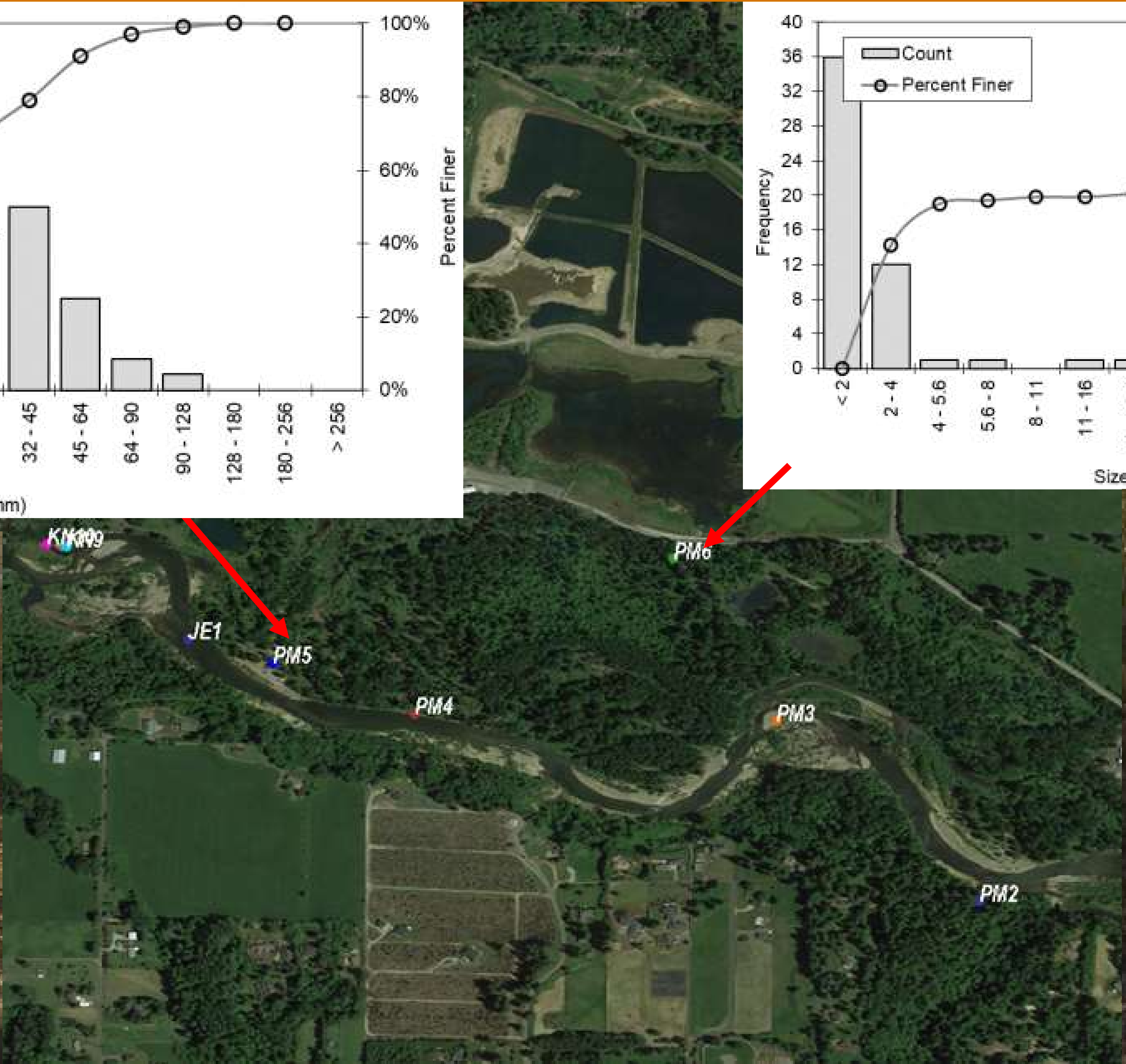
Sediment Sampling – Bed Material (Subsurface)

- **Two peaks in grain size, i.e. mixture of:**
  1. Coarse components: Gravel/Cobble, ~ same as river bed
  2. Fine components: Sands, even silts (2mm and less)

Sediment Sampling – Floodplain Material





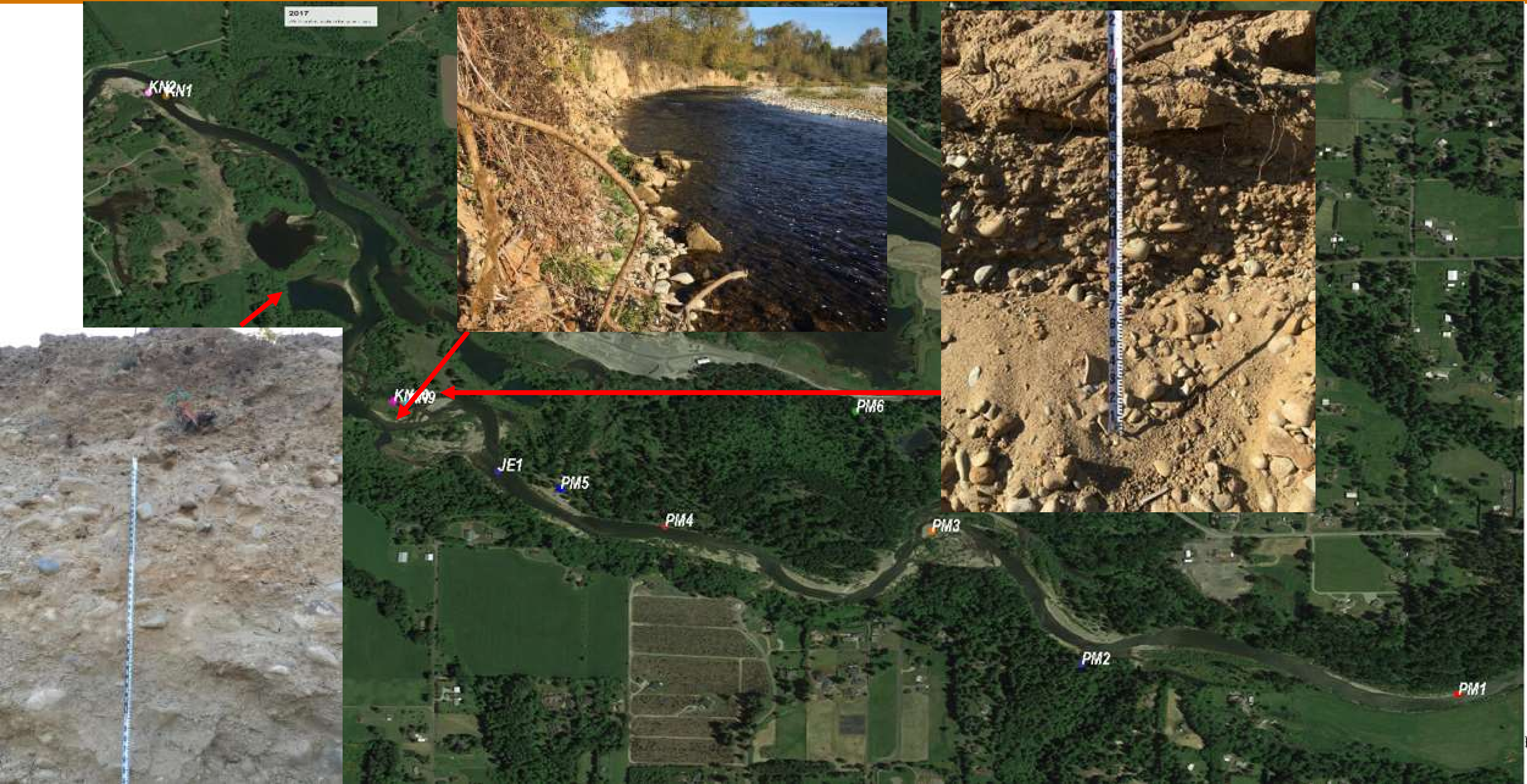


Sediment Sampling – Floodplain Material

- **Also has two peaks in grain size. Similar profiles to riverbed subsurface.**

Sediment Sampling – Vertical Bank Profile

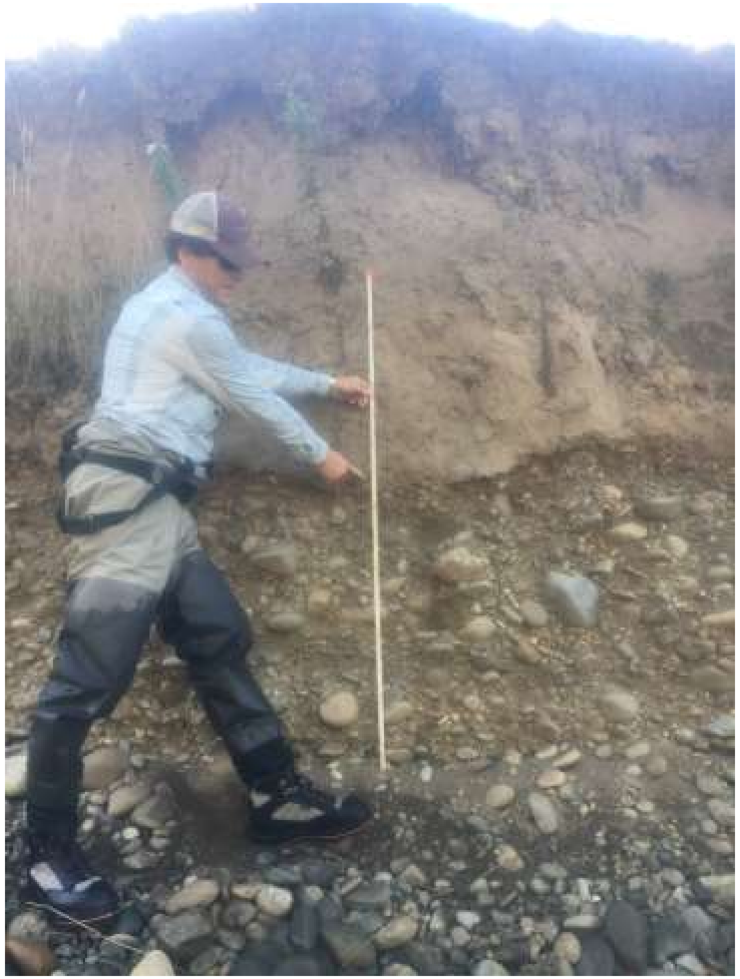
Sediment Sampling – Vertical Bank Profile



Sediment Sampling – Vertical Bank Profile

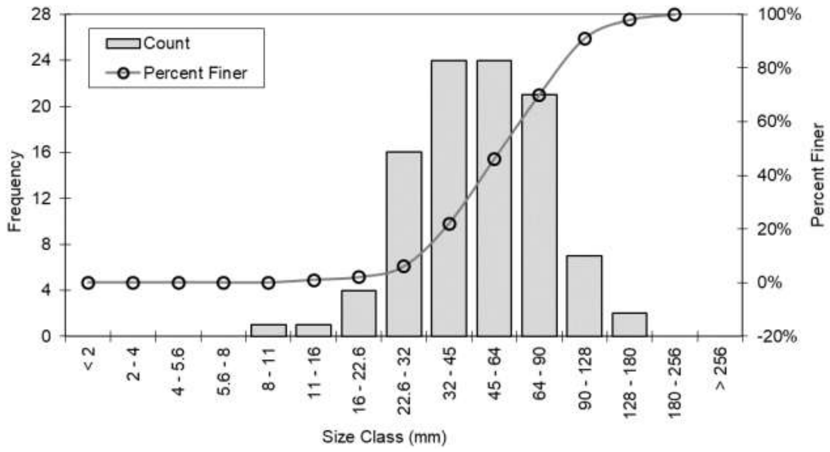
Type 1: Single layer of mixed sand, gravel, cobble. Forested floodplains.

Type 2: Two layer structure with thick sand/silt layer over the Type 1 layer. More dominant.

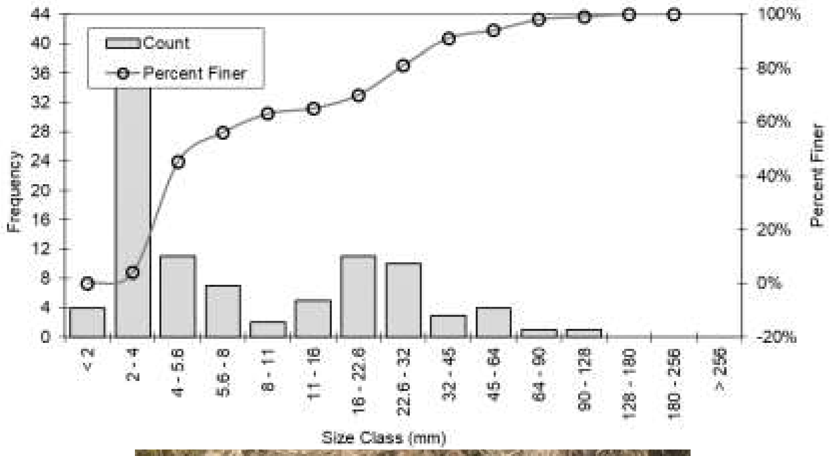


Proposed Sediment Parameters for Modeling

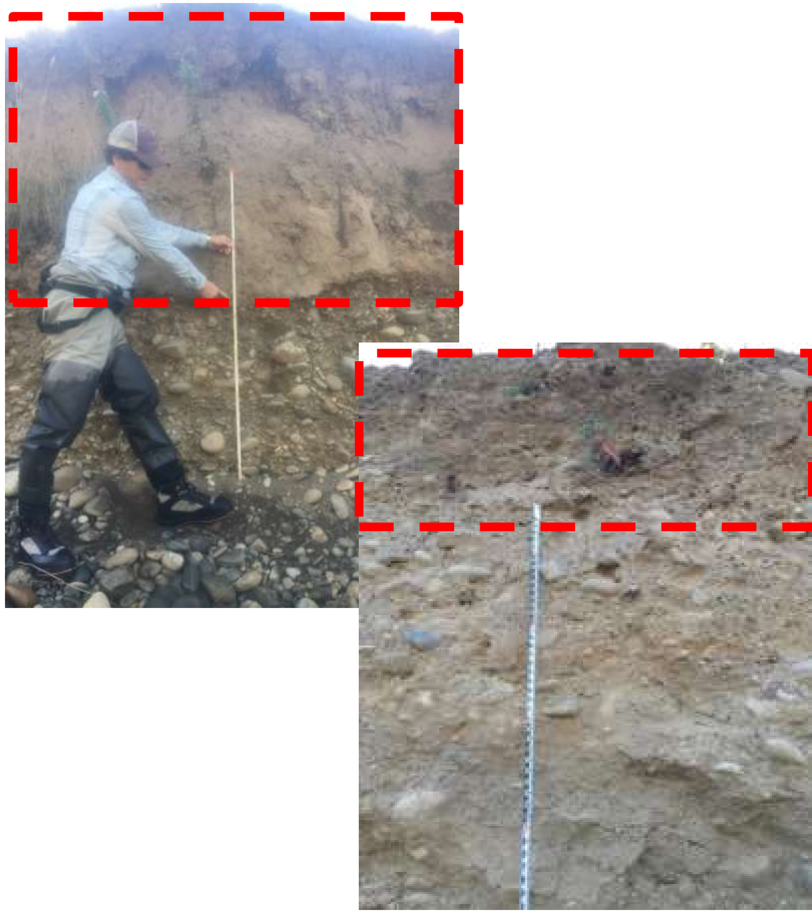
Sediment Type A:
bed surface layer



Sediment Type B:
bed sublayer, forested floodplain



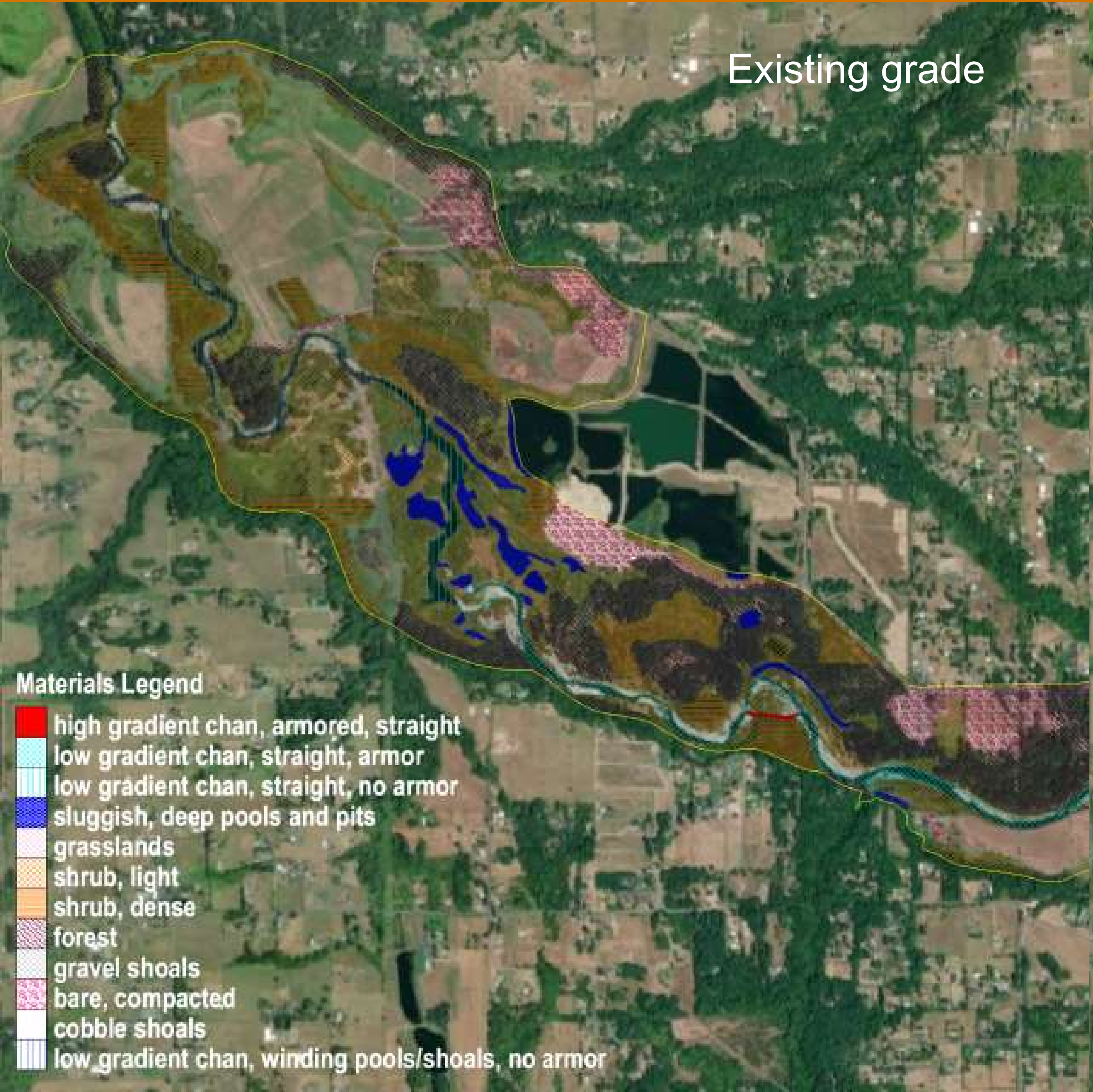
Sediment Type C:
Bank top layer,
uniform size of
1 or 2 mm

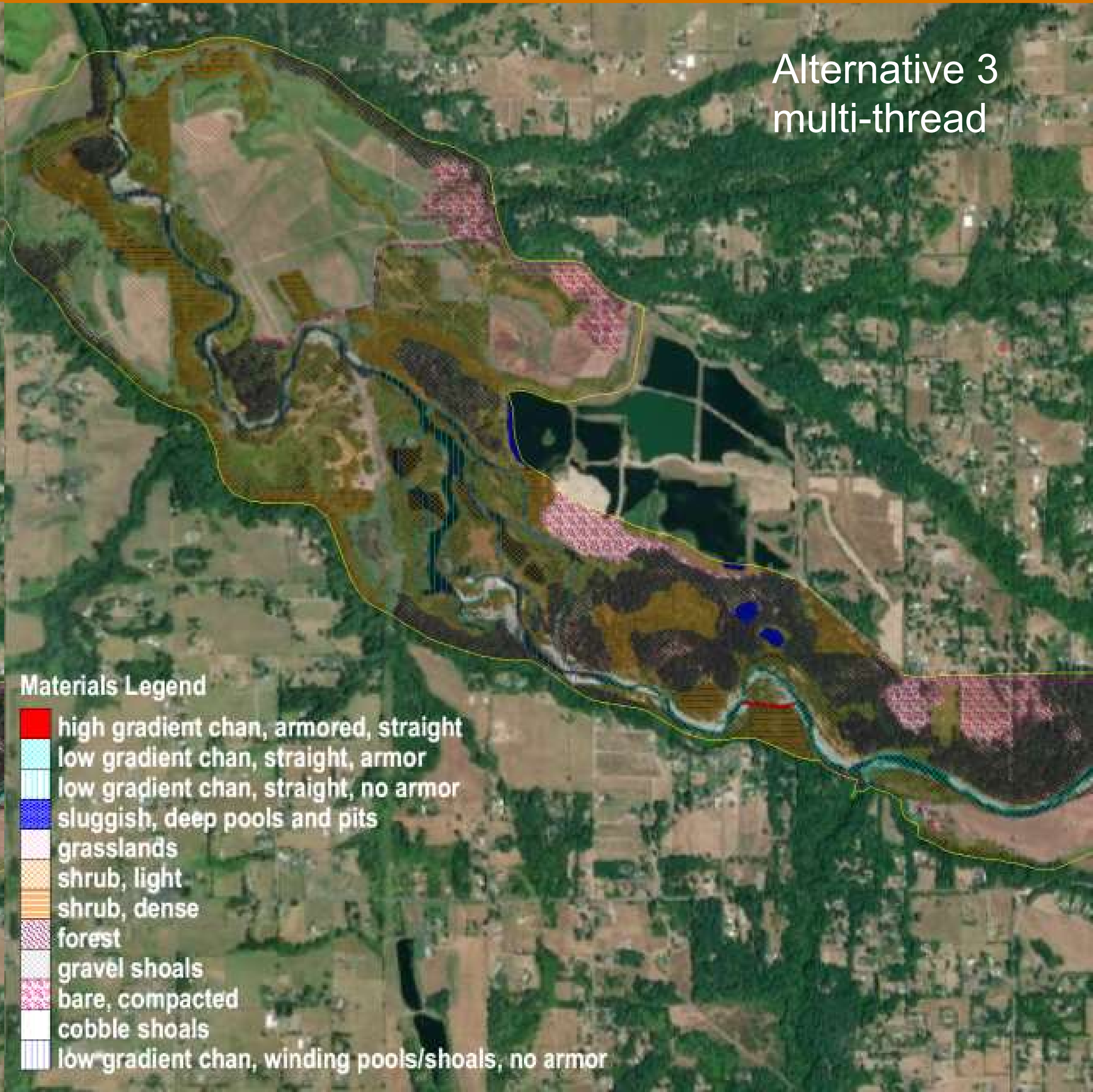


Proposed Sediment Parameters for Modeling

Area	Layer	Sediment Type*	Grain Size			
			2mm Sand	20mm Gravel**	50mm Gravel	100mm Cobble
River Bed	1	A		√	√	√
	2	B	√	√	√	√
River Bank	1	C	√			
	2	B	√	√	√	√
Forestry Floodplain	1	B	√	√	√	√

Ridgefield Model Grid – Friction and Sediment Parameter Assignment

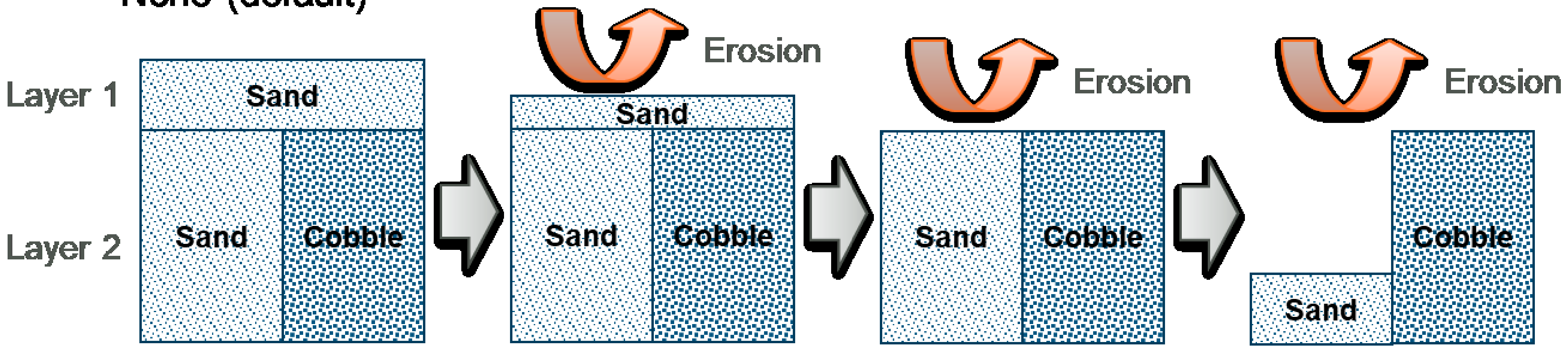




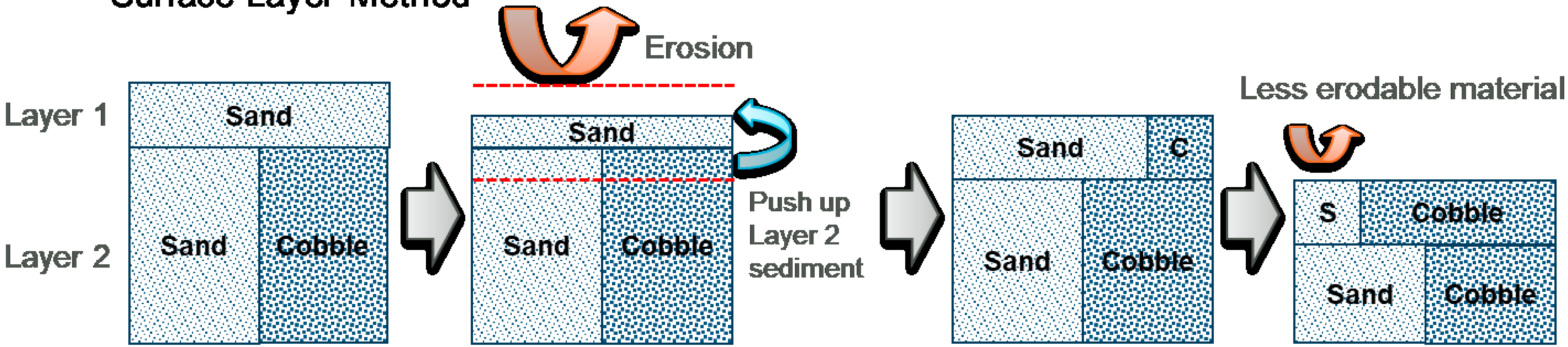
Tuflow FV Sediment Module: Armouring Feature

Bed Armouring Model == Surface-Layer-Method

- None (default)



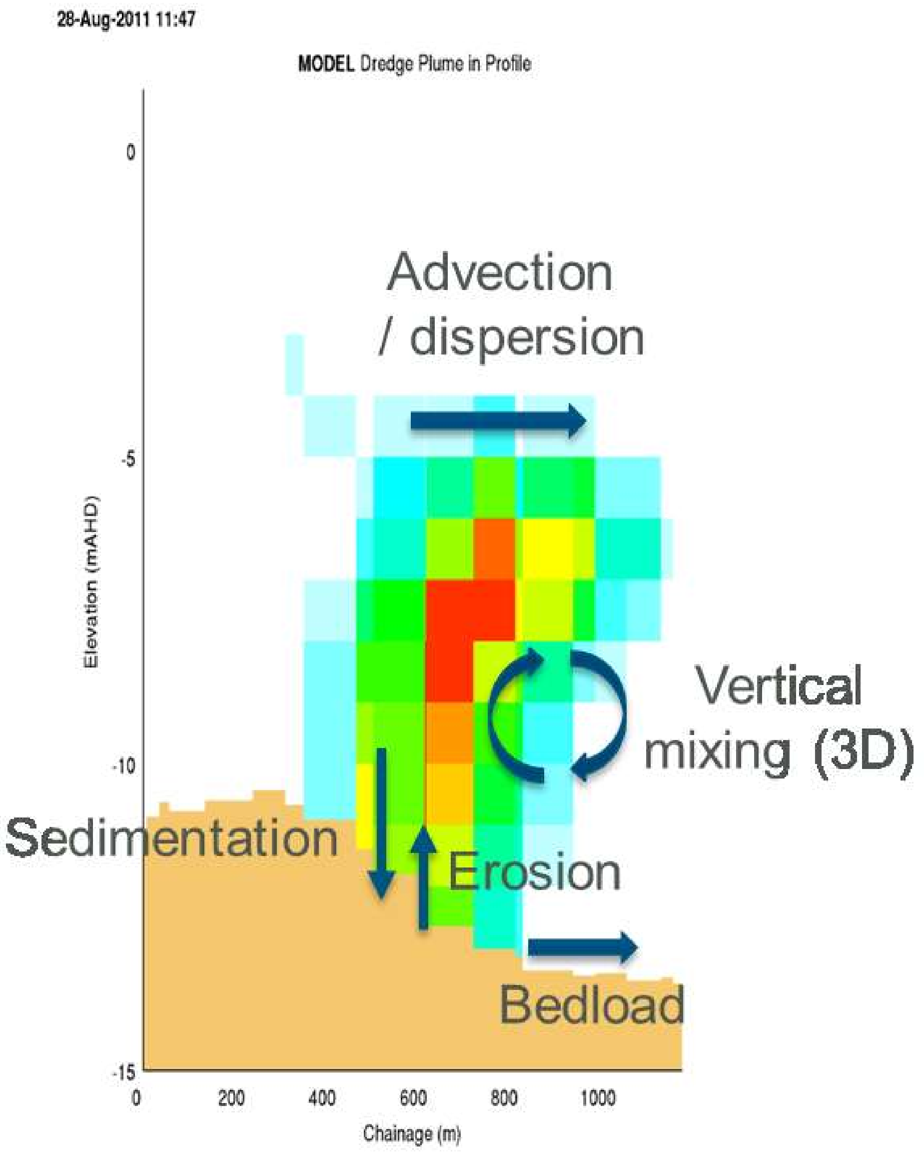
- Surface-Layer-Method



Slide source: BWT-WBM (Tuflow FV)

Tuflow FV Sediment/Morpho-dynamic Model Key Features

- **Suspended load**
  - Hydraulic module
    → advection / dispersion
  - Sedimentation / Erosion (Mehta Model)
- **Bedload** (Meyer-Peter Mueller Model, Wilcock Crowe just added)
- **Morphology** (adjusts bed elevation in response to sediment transport)
- **Multiple sediment fraction**
- **Multiple bed layer**
- **Armouring**
- **2D/3D**



Slide source: BWT-WBM (Tuflow FV)

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Transport Mode Governing Equations

Suspended Load Erosion Model == Mehta

Mehta's erosion model

$$E = E_r\left(\tau_b/\tau_{b,c} - 1\right)^{\alpha}$$

Bedload Model == MPM

Meyer-Peter Müller's equation

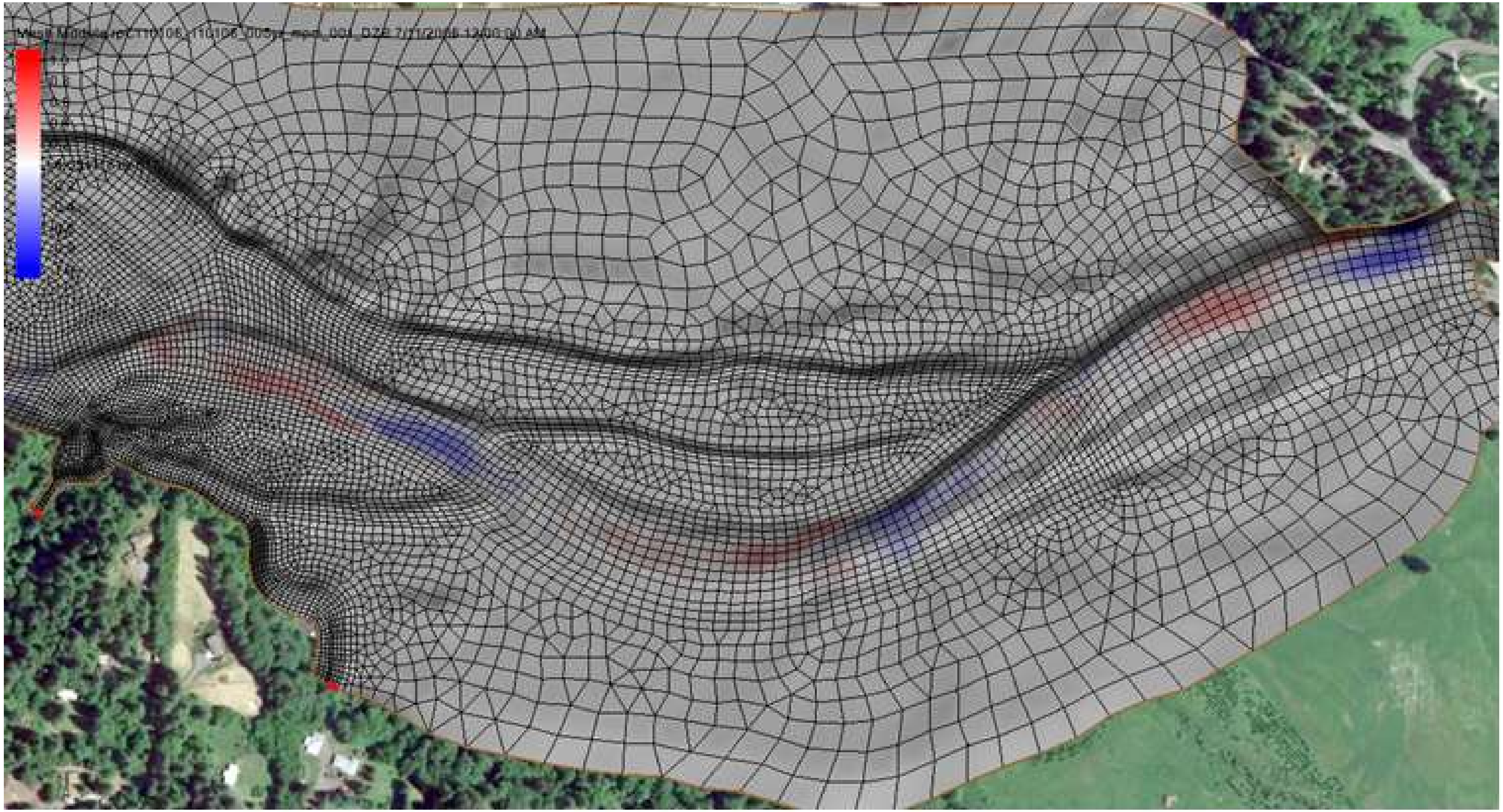
$$\frac{q_{bv}}{\sqrt{(G-1)gd_{50}^3}} = 8(\tau_{b*} - 0.047)^{3/2}$$

- Condition for sediment transport: Bed shear stress (τ_b) > critical shear stress (τ_c)

- Look at τ_b values output by hydrodynamic (or sediment) model to get a sense of where sediment is predicted to move under different flow conditions.

- Compare to known sources (imagery) to see if model is making sense

Morpho-dynamic Module Results: Bed Elevation Change, post 5-yr event



Bed elevation change (m)

1.0

0

-1.0

**morpho-dynamic simulations take a long time, so we are waiting to have the restoration alternatives more developed before running additional scenarios

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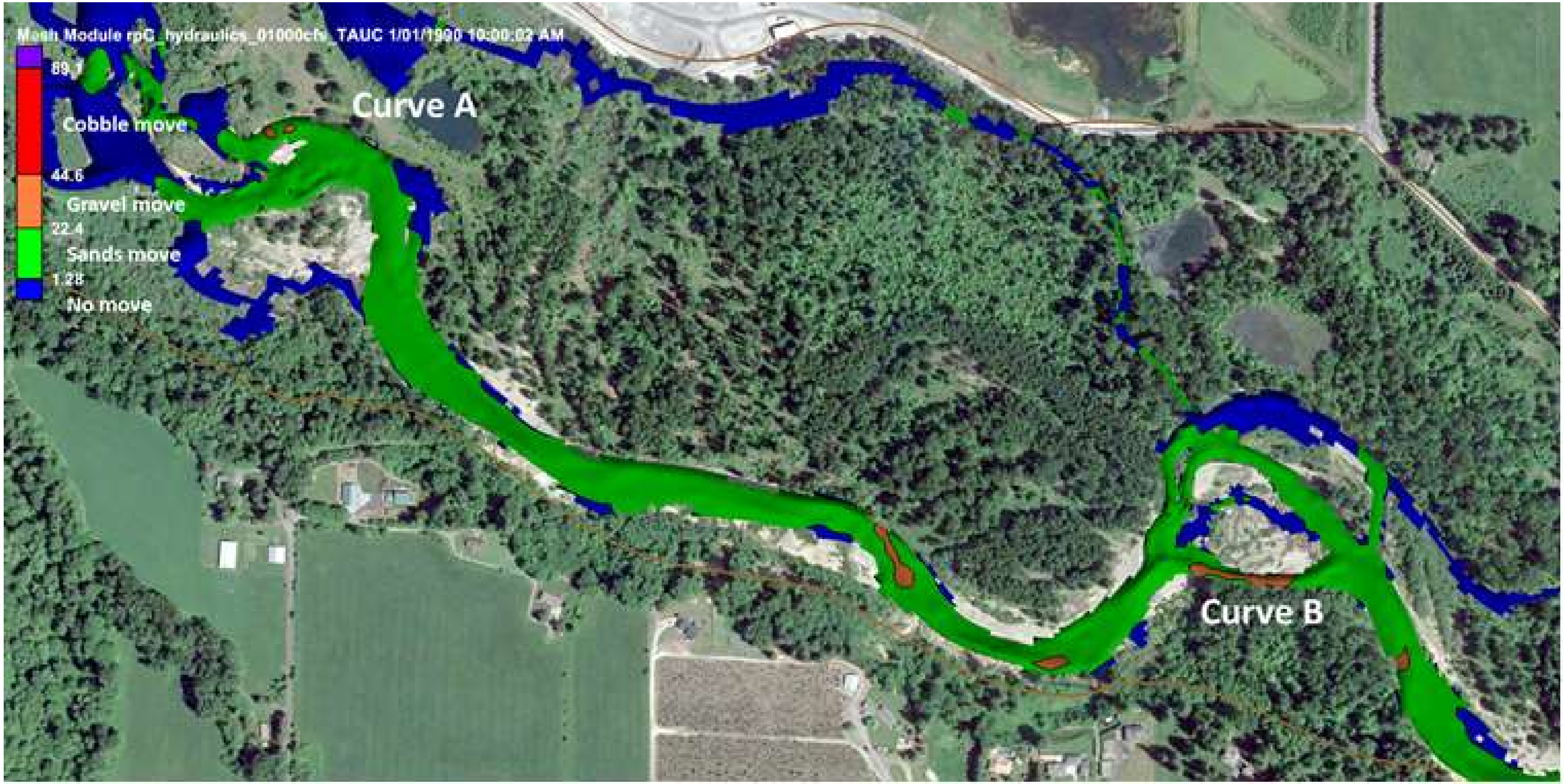
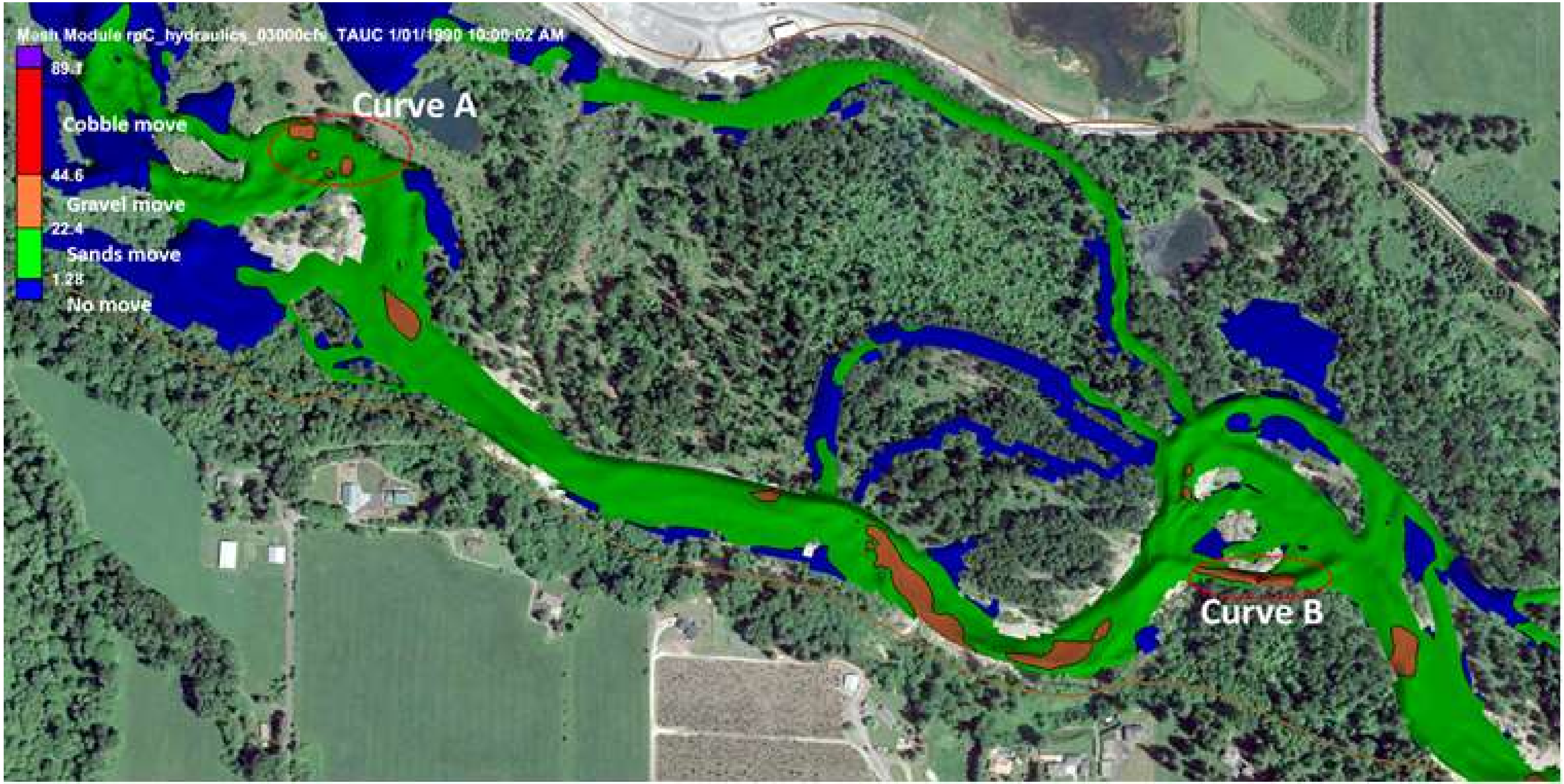
Model Results: Bed Shear Stress, Q = 1000 cfs (base flow)



$\tau_b > \tau_c$ for:

- cobble
- gravel
- sand
- none

Model Results: Bed Shear Stress, Q = 3000 cfs (~Q1)



$\tau_b > \tau_c$ for:

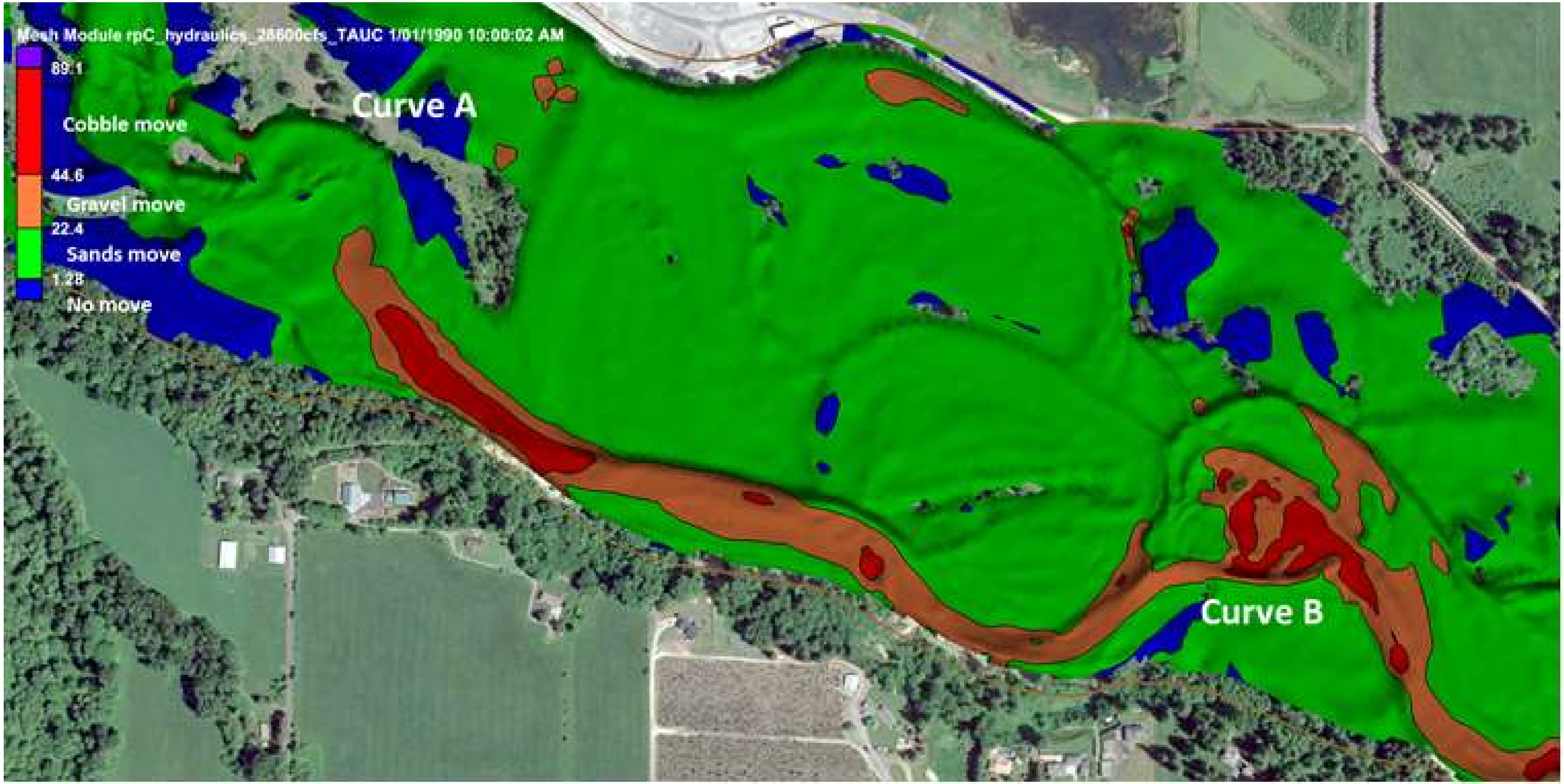
- cobble
- gravel
- sand
- none

Model Results: Bed Shear Stress, Q = 15,000 cfs (~Q20)

$\tau_b > \tau_c$ for:

- cobble
- gravel
- sand
- none

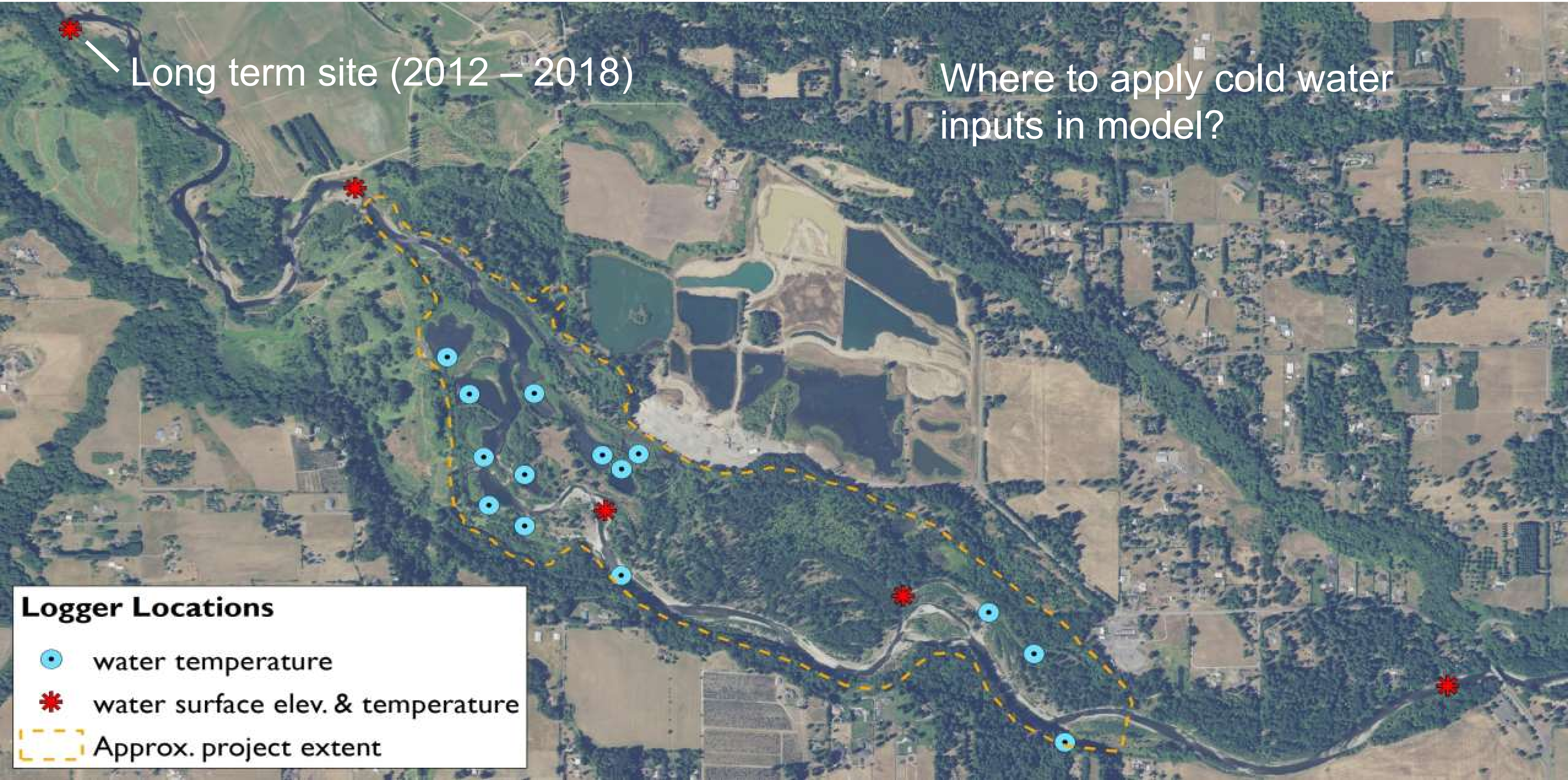
Model Results: Bed Shear Stress, Q = 28,600 cfs (~Q100)



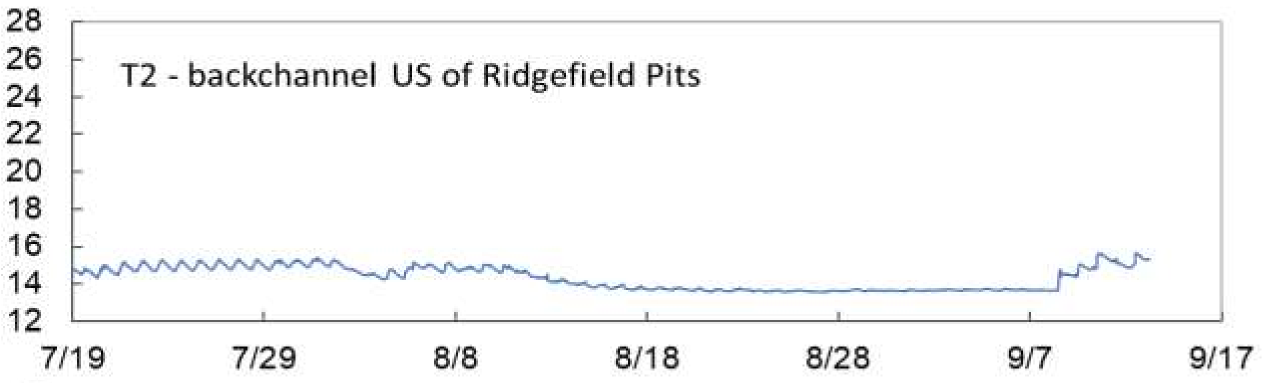
$\tau_b > \tau_c$ for:

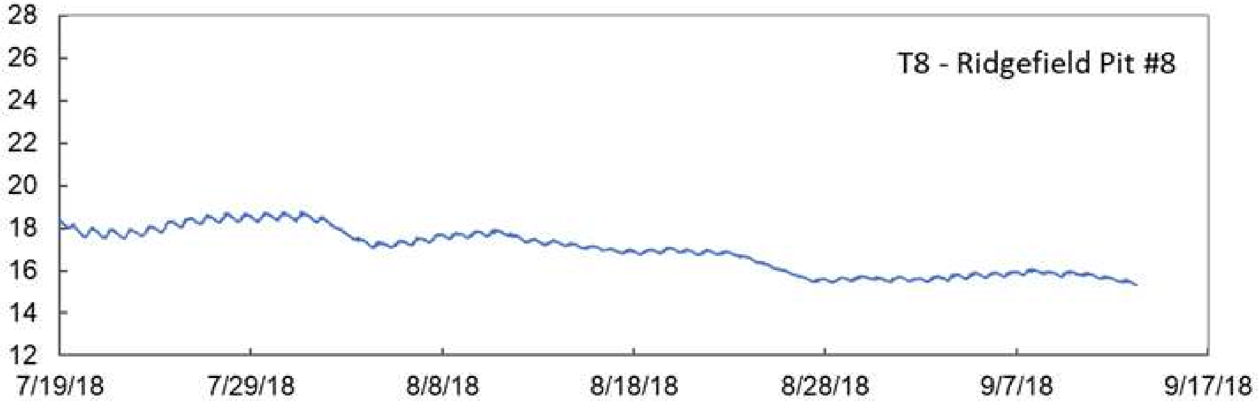
- cobble
- gravel
- sand
- none

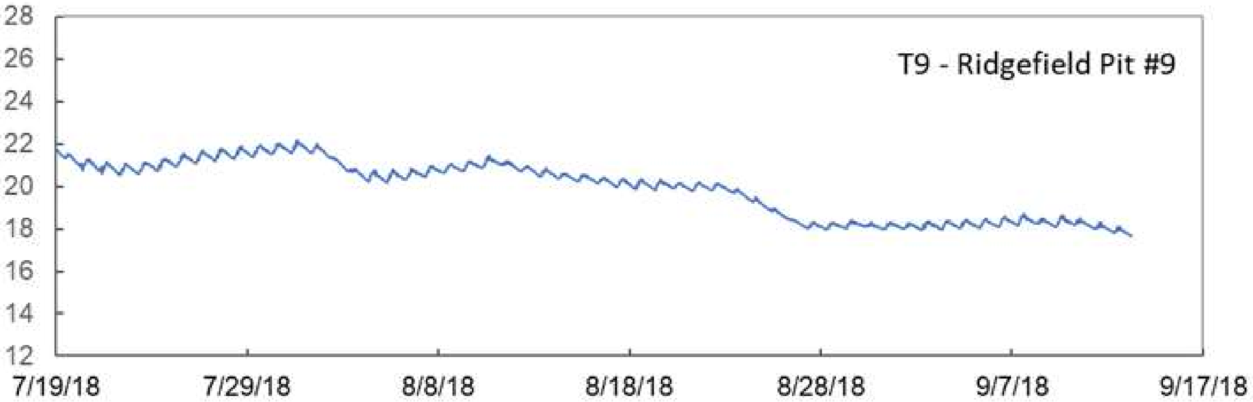
Water Temperature Modeling – Field Data Plan For Model Input

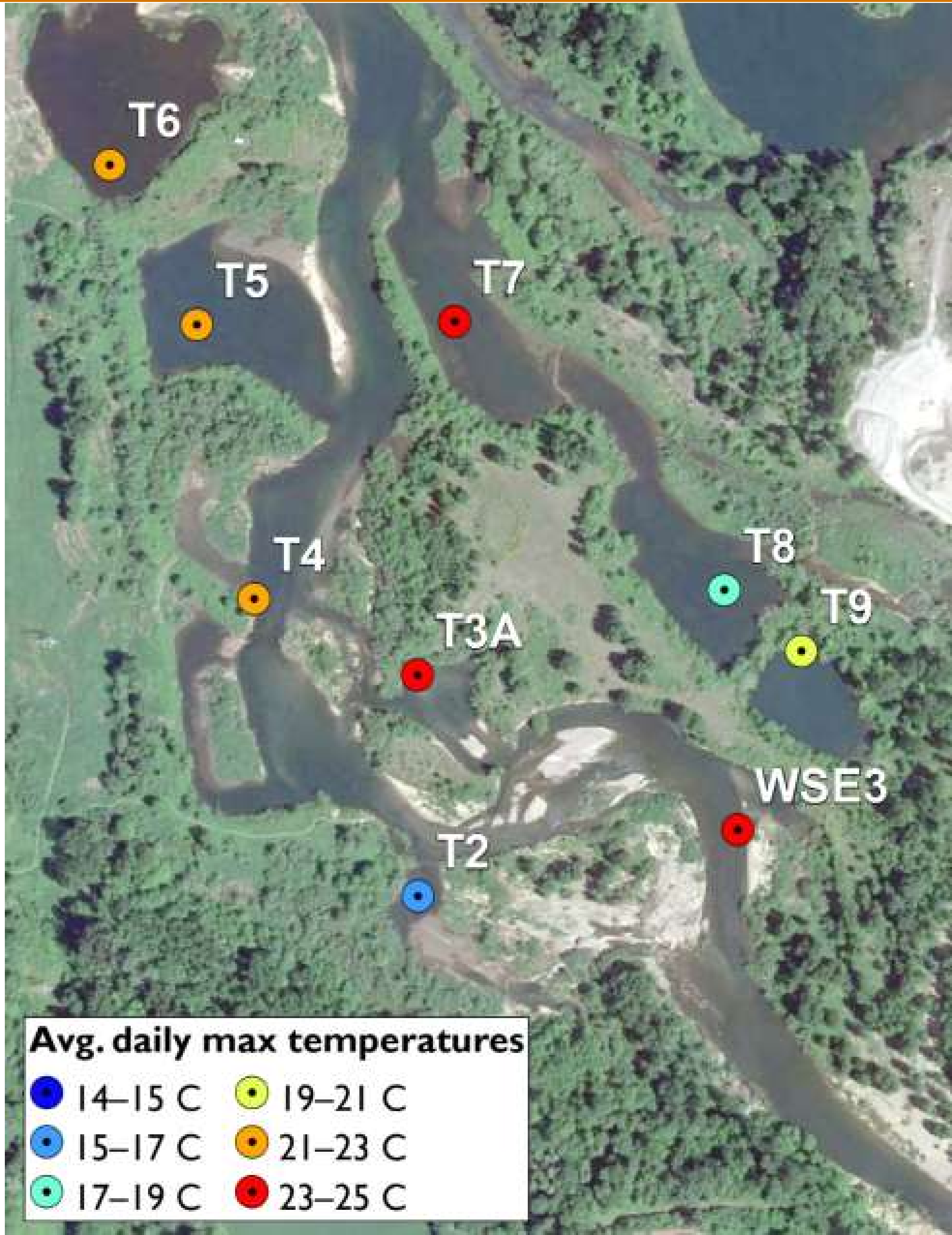


Water Temperature Modeling - In-situ Temperature Monitoring Results

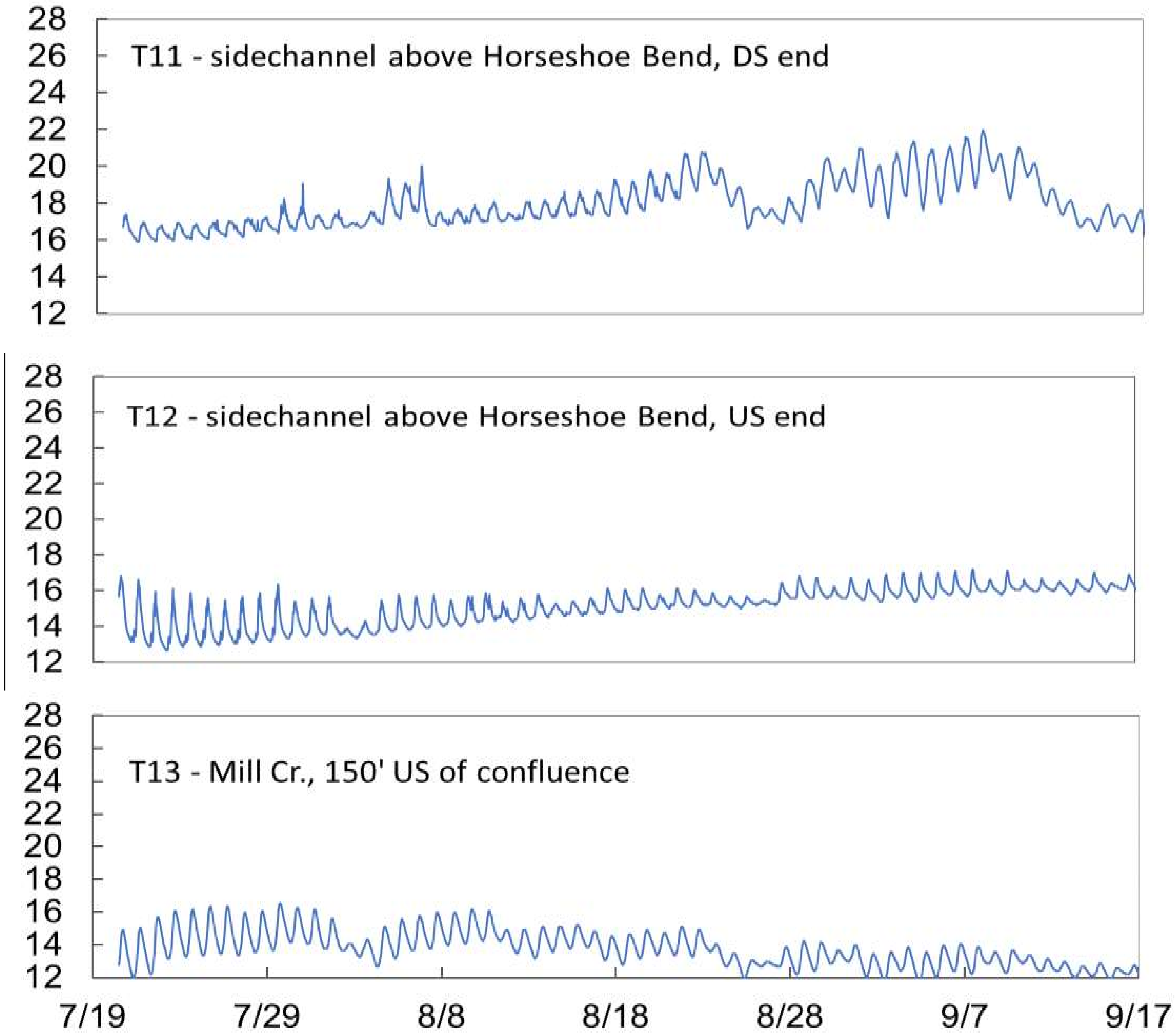


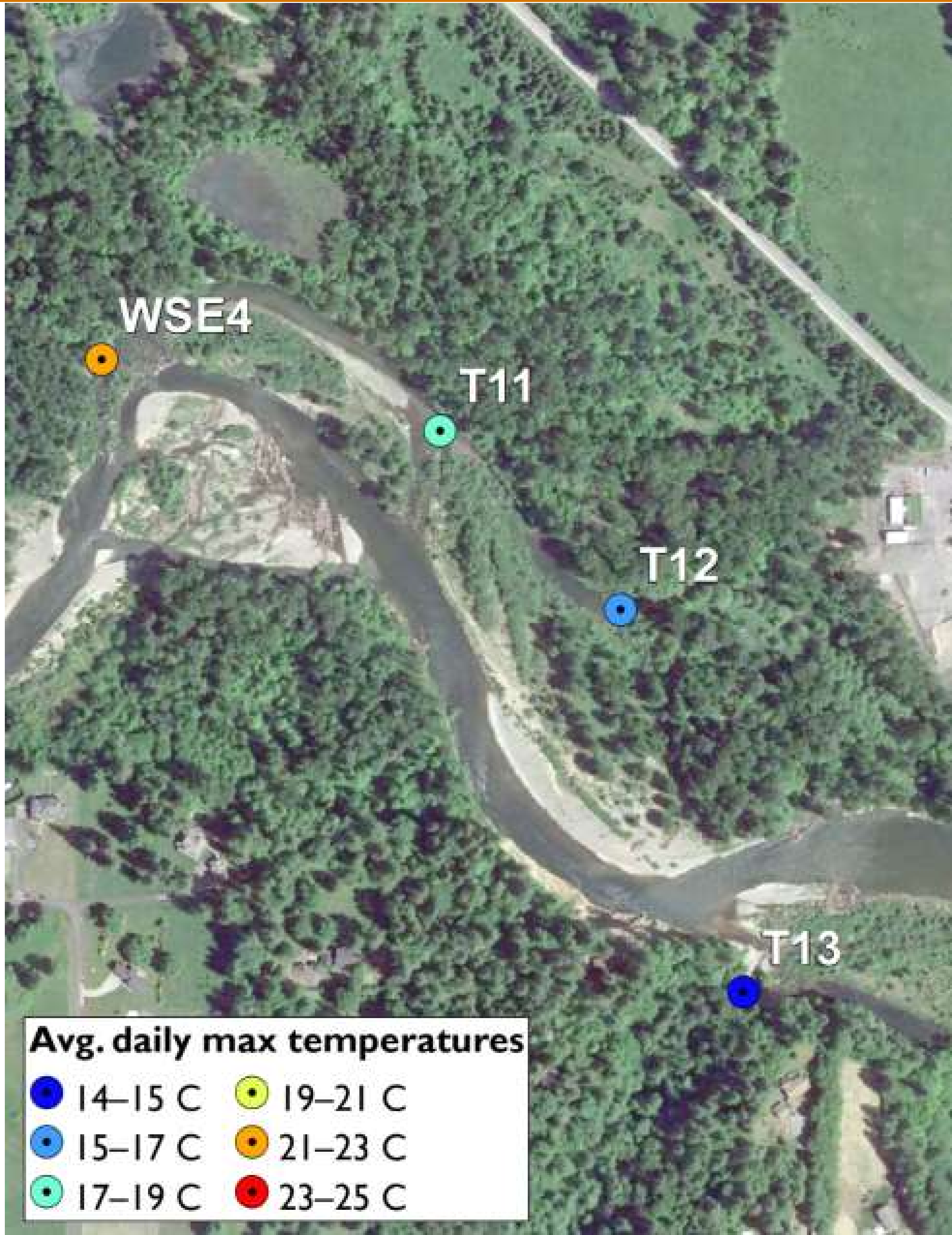




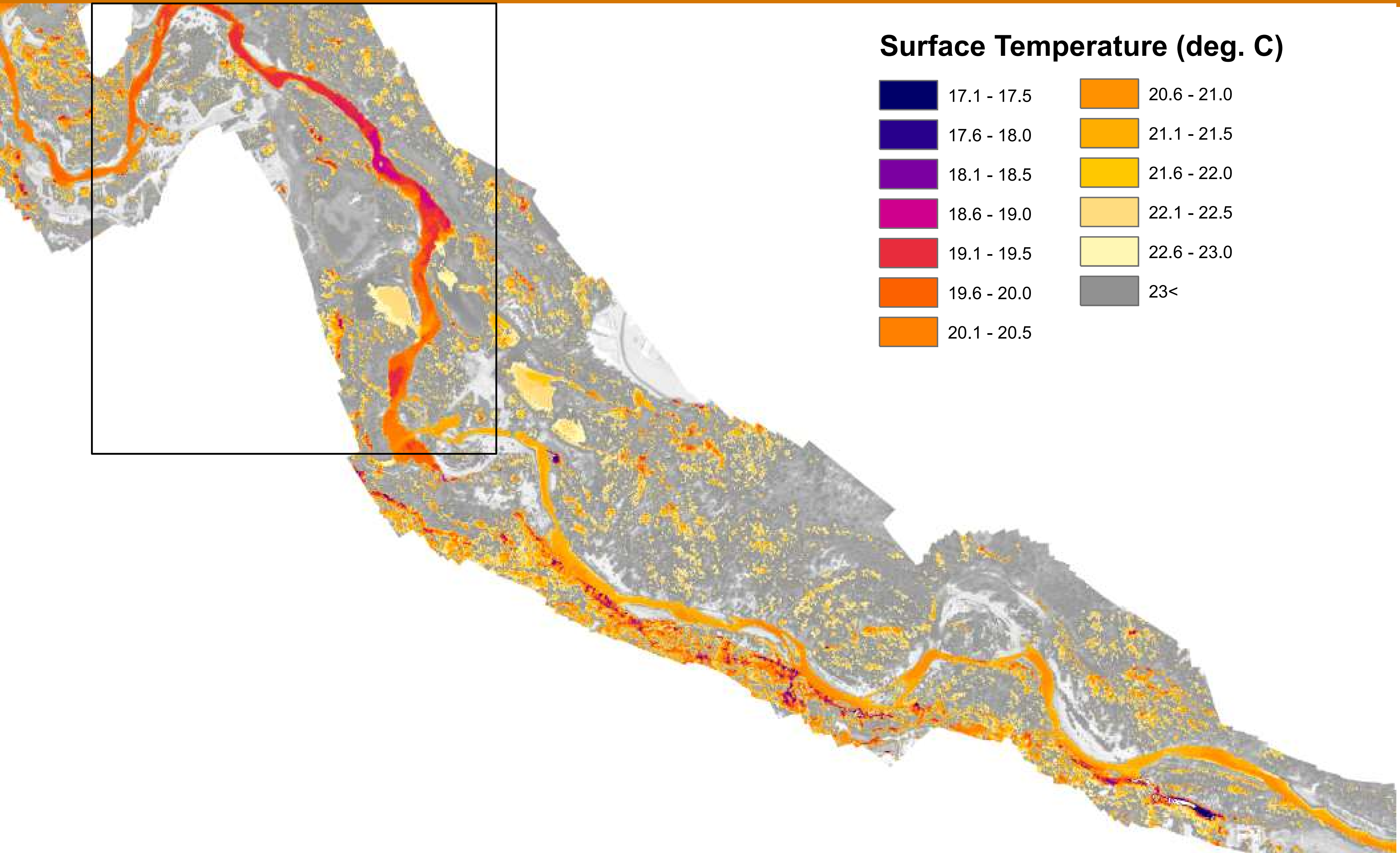


Water Temperature Modeling - In-situ Temperature Monitoring Results





Water Temperature Modeling - High Resolution FLIR Temperature Survey (2020)



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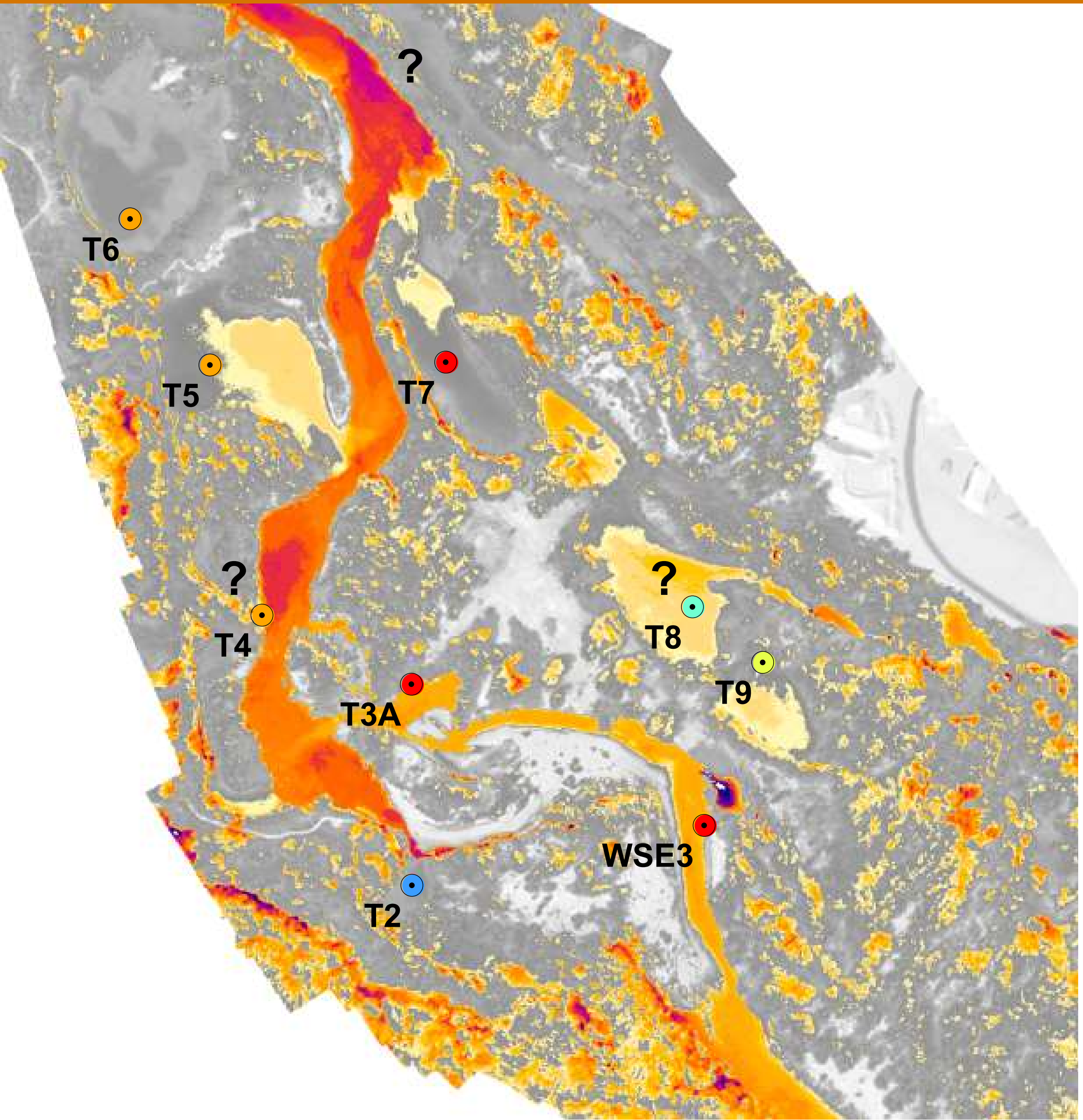
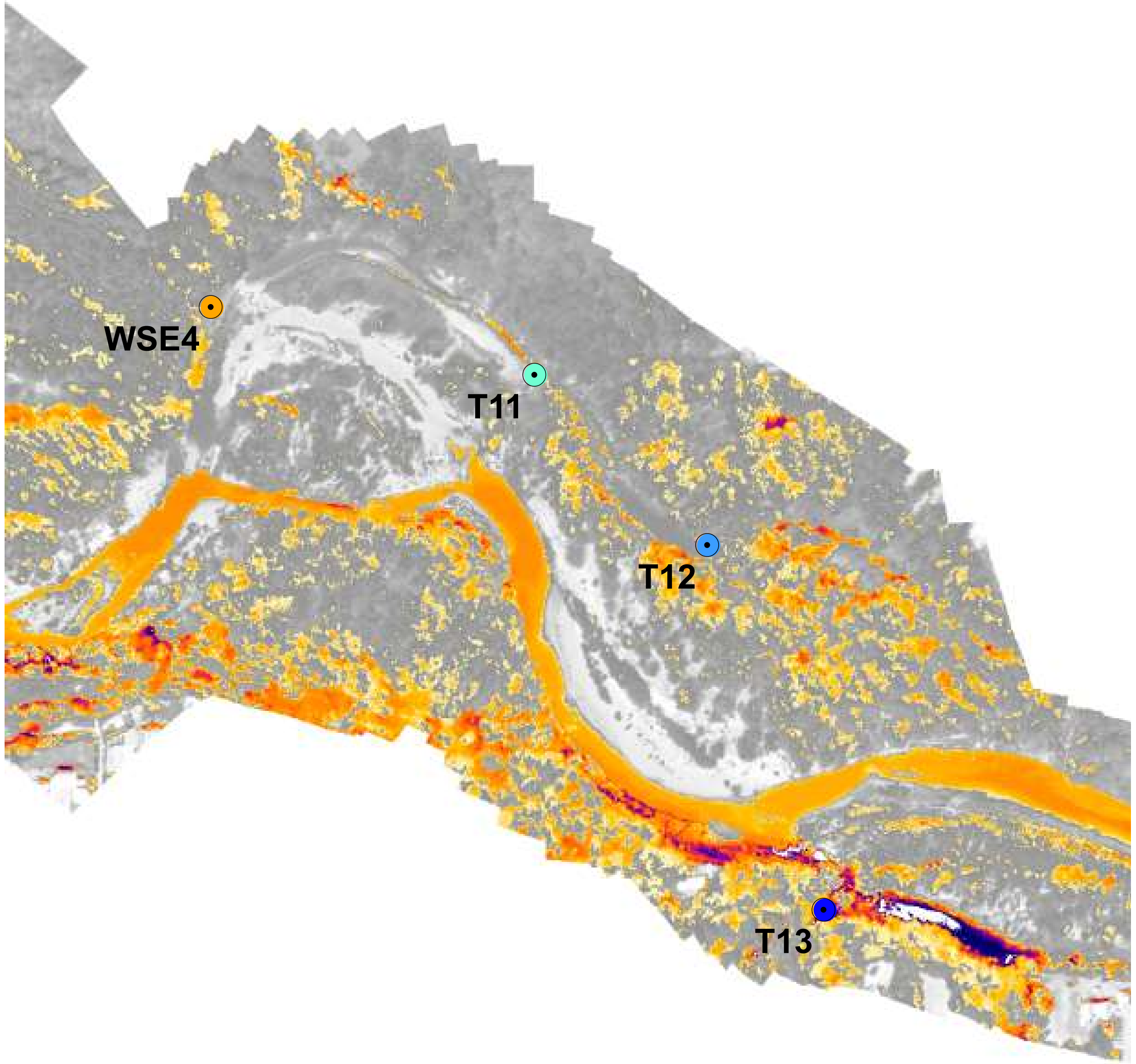
Water Temperature Modeling – FLIR/In-Situ Comparison

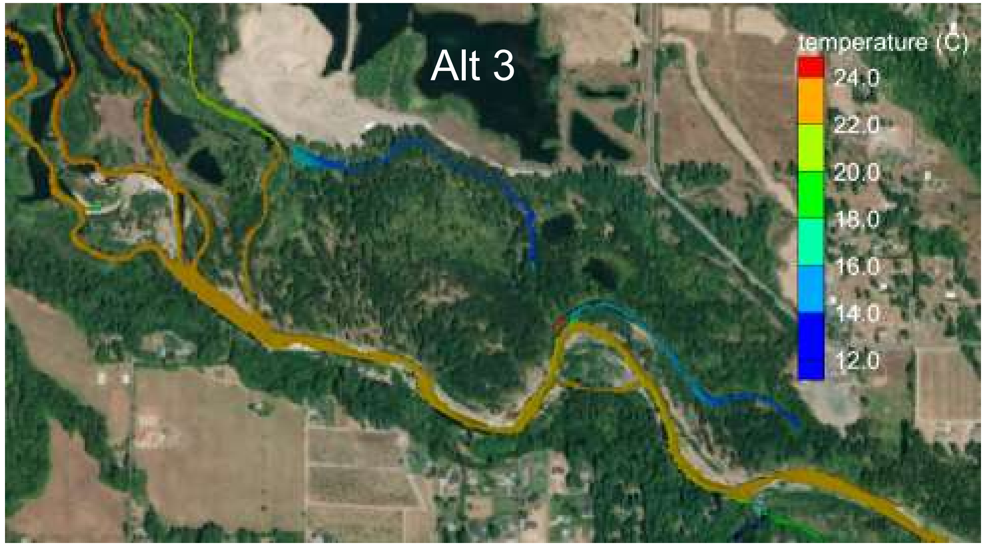


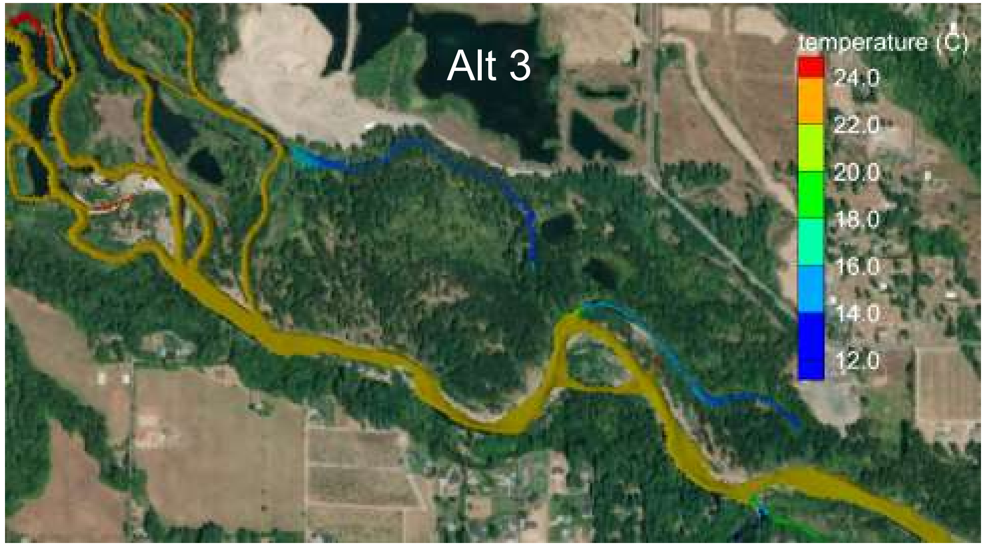


Water Temperature Modeling – Sample Results

Low flow (60 cfs)

Base flow (500 cfs)





Source inputs based on in-situ data

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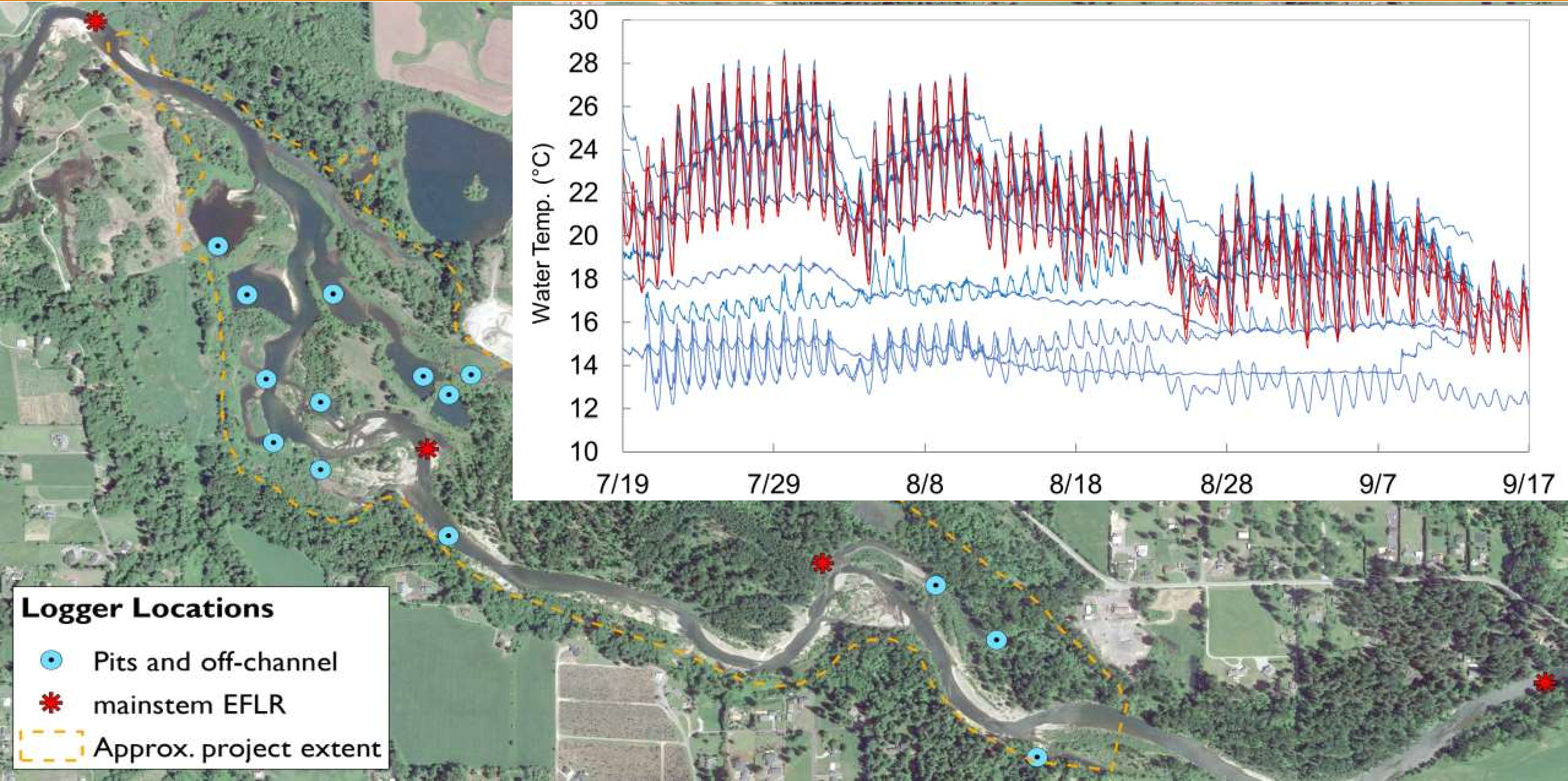
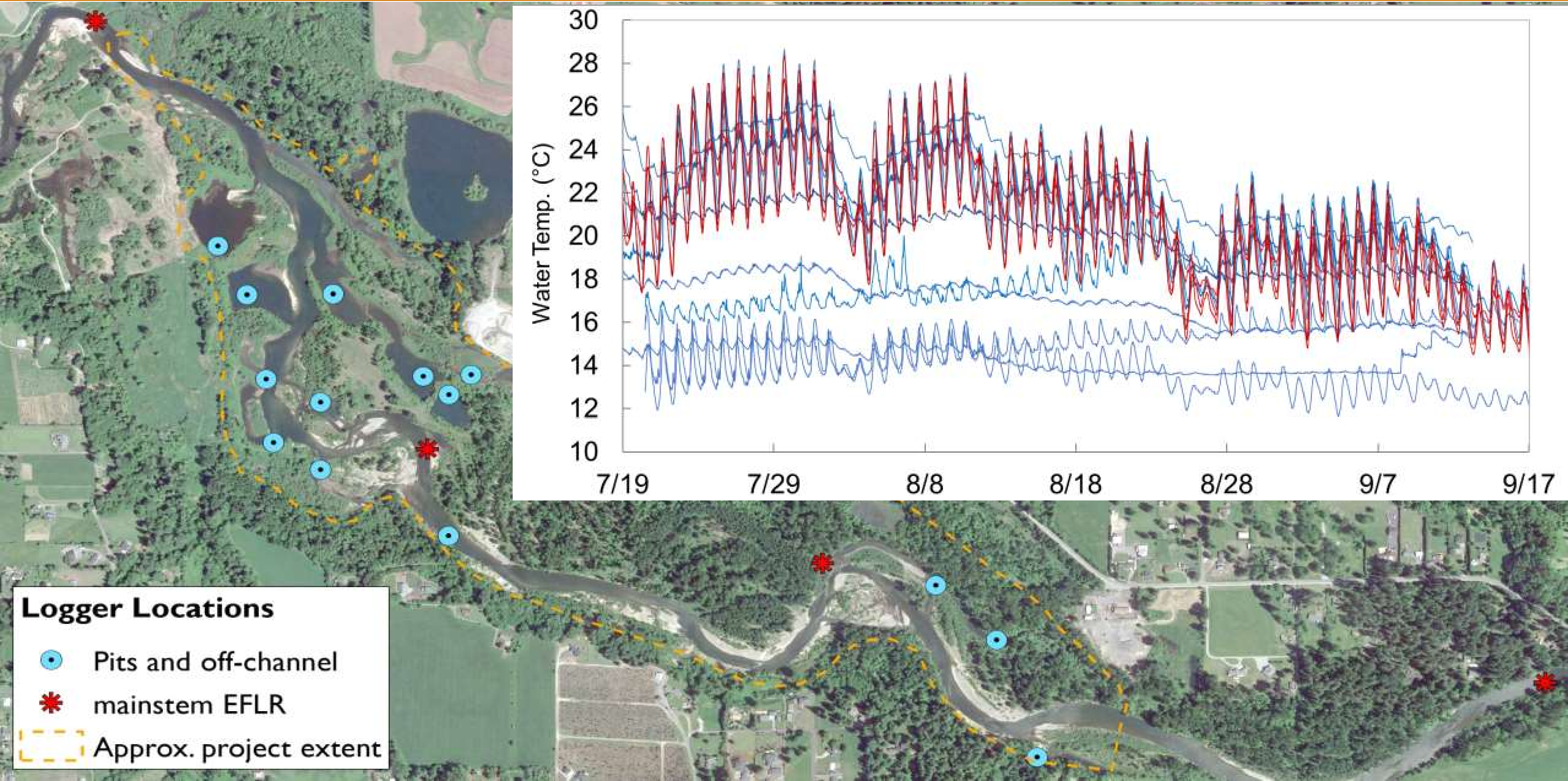
Water Temperature (2018)



Water Temperature (2018)



Water Temperature (2018)

Model Next Steps:

1. Hydro/Temperature Model Updates

- refine Alternative 3
  - improve cut/fill balance (currently 400,000 yd^3 deficit)
  - remove cross-floodplain slope

- create Alternative 2/3 hybrid (2-3 channel option)
  - 2-3 thread system through Pits area

- refine water temperature inputs based on new FLIR data

- begin evaluating Mill Creek and Side Channel alternatives

2. Run morpho-dynamic simulations

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• Questions?
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