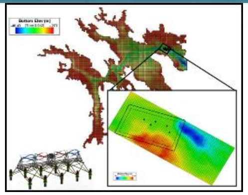
SAND2022-12024C

Sandia National Laboratories

MISSISSIPPI RIVER CHARACTERIZATION FOR CURRENT ENERGY CONVERTER (CEC) SYSTEMS



PRESENTED BY

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Portland, Oregon

September 13-15, 2022

umerc University Marine Energy Research Community + METS MARINE ENERGY TECHNOLOGY SYMPOSIUM

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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Research Motivation and Objectives

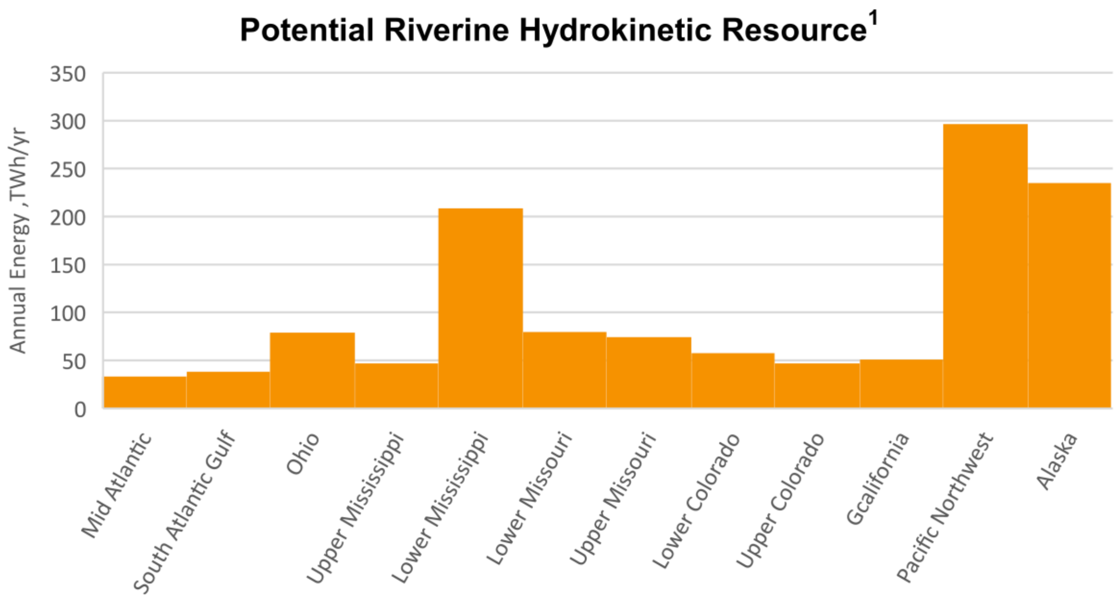

Photo credit: ORPC

Next Gen | **Modular**

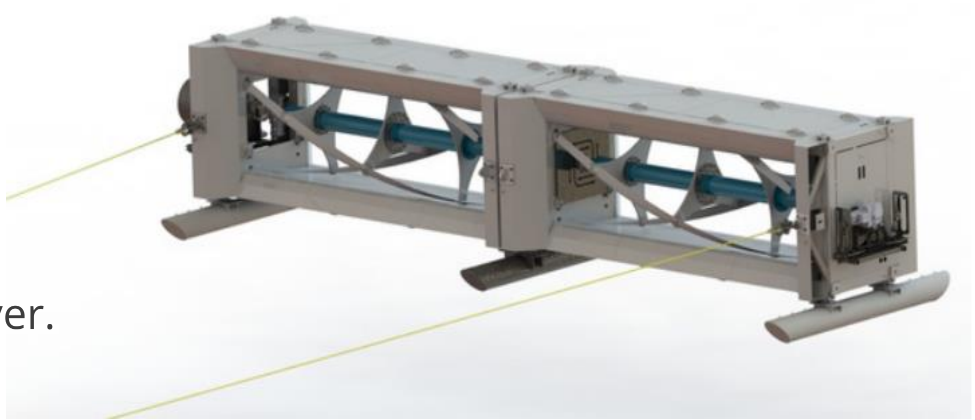

Photo credit: ORPC

ORPC RivGen Development

- **2014** – Deployed and operated in Kvichak River (Village of Igiugig, Alaska).
- **2015** – Reinstalled and demonstrated operations for 2 months.
- **2018** – License to install and operate a RivGen® Power System.
- **2021** – RivGen 2.1 Power System deployed long term in Kvichak River.
- **2022** – Addition of a second RivGen is deployed in the River.

(1) Ravens, T., Cunningham, K. and Scott, G., 2012. Assessment and mapping of the riverine hydrokinetic energy resource in the continental United States. *Electric Power Research Institute, Palo Alto, CA, Retrieved: http://water. energy. gov/pdfs/riverine hydrokinetic resource assessment and mapping. pdf*.

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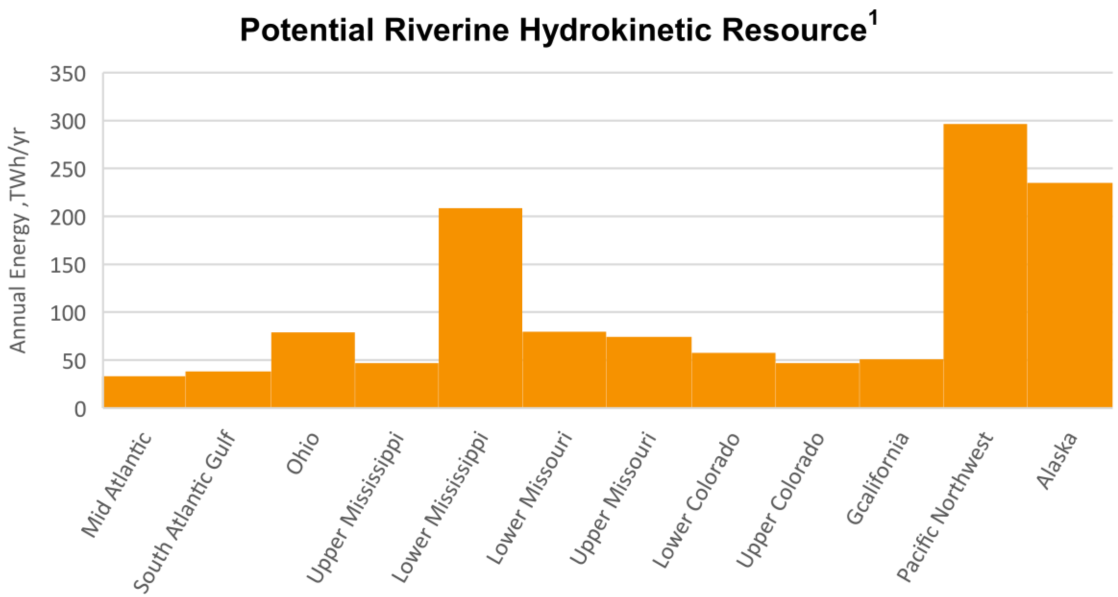

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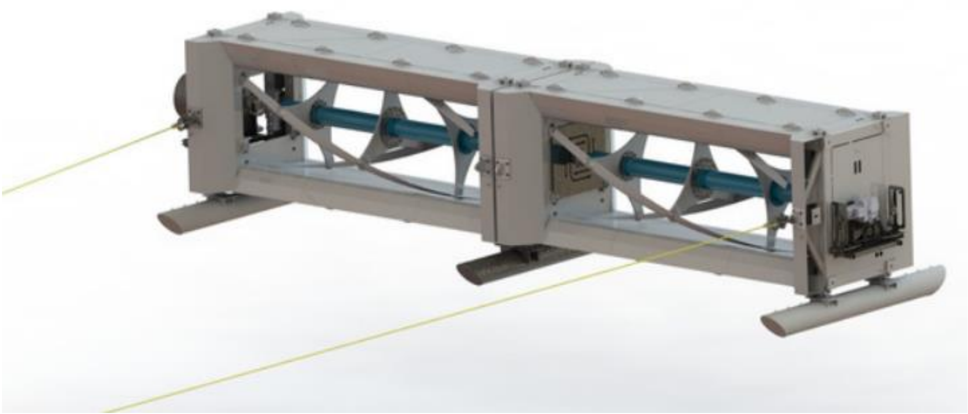


Photo credit: ORPC

Study Approach

- International Electrotechnical Commission (IEC) TC 114 PT 62600-301 Marine Energy - Wave, tidal and other water current converters - Part 301: River energy resource assessment and characterization.
- Annual energy production calculated using modeling and long term historical data (>=10 years).

(1) Ravens, T., Cunningham, K. and Scott, G., 2012. Assessment and mapping of the riverine hydrokinetic energy resource in the continental United States. *Electric Power Research Institute, Palo Alto, CA, Retrieved: http://water. energy. gov/pdfs/riverine hydrokinetic resource assessment and mapping. pdf*.

Site Selection

Data Sources:

- NHDPlus V2: Modeled discharge and velocity across entire National Hydrography Dataset
- USGS National Water Information System (NWIS): Measured discharge and flow speed and select stream gages

Process:

- Screened NHDPlus river segments for minimum velocities
- Developed Visual Basic Code to generate NWIS stream gage statistics
- Screened stream gage statistics for minimum depth, velocity, field measurements and other river characteristics
- Selected areas with favorable NWIS and NHDPlus values
- Outreach to USGS and Army Corps staff for further site validation

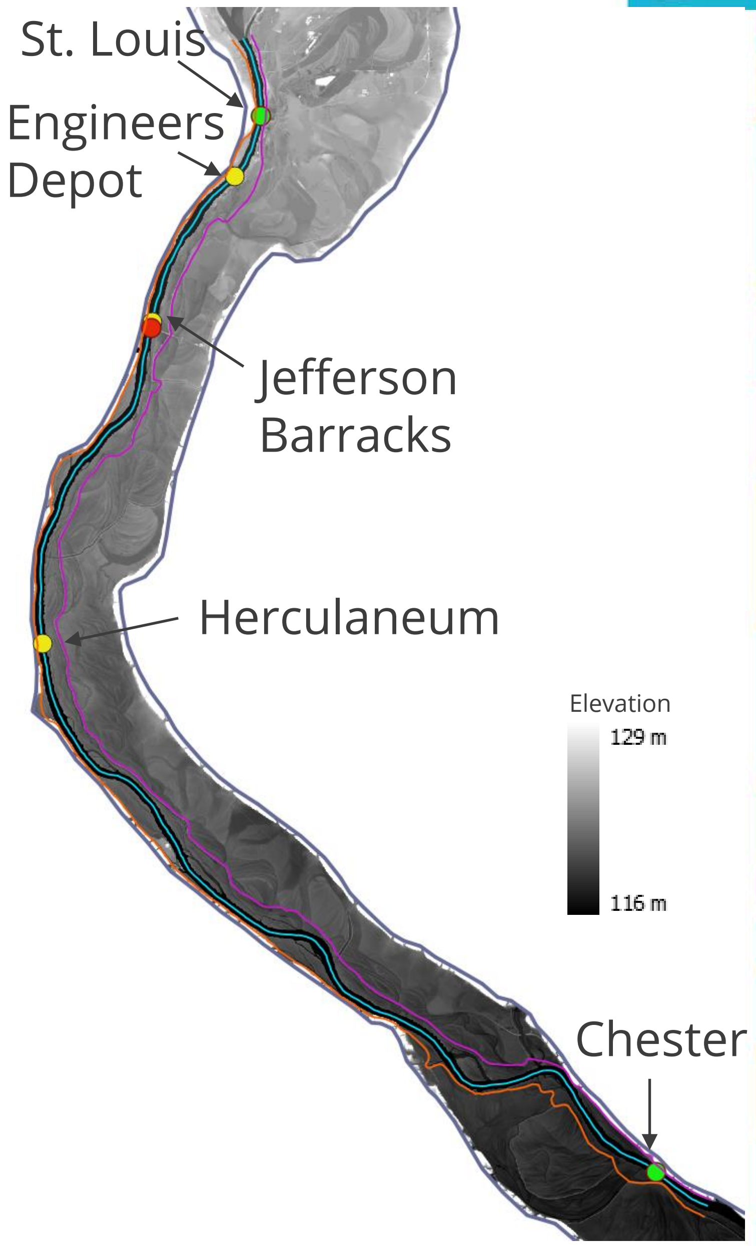
Field Data Available for Modeling

Geometric component for hydrodynamic model

- Land model component
  - Bathymetry
    - GIS layers from USACE of bathymetry in 2019 for navigable portions of main channel
    - Longitudinal profiles from USACE of 2014 Low Water Reference Plane
  - River bank and floodplain topography
    - GIS layers from USGS of National Elevation Dataset for floodplain topography
  - River waters edge, centerline, and banks
    - Delineated using USDA National Agricultural Imagery Program (NAIP) imagery from 2018

Hydrologic boundary conditions for model

- Inlet: Discharge
  - USGS discharge and water level gaging station at St. Louis, MO
- Outlet: Water Level
  - USGS discharge and water level gaging station at Chester, IL
- Calibration stations
  - USACE water level gaging stations at Engineers Dept, Jefferson Barracks, and Herculaneum



Numerical Modeling

Delft3D Flexible Mesh

SNL-Delft3D

SNL-Delft3D – Turbine Integration Modeling

Delft3D Flexible Mesh Suites

- 2D/3D modeling
- Finite Volume method
- Both z and σ layers are supported.
- RANS Navier Stokes:
  - Shallow water equation

$$\frac{D\omega}{Dt} \ll g$$

SNL-Delft3D model

Momentum loss $$S_Q = -\frac{1}{2} C_T A U^2$$

Turbulence source $$S_k = \frac{1}{2} C_{\mathrm{T}} A \left(\beta_{\mathrm{p}} U^3 - \beta_{\mathrm{d}} U k \right),$$

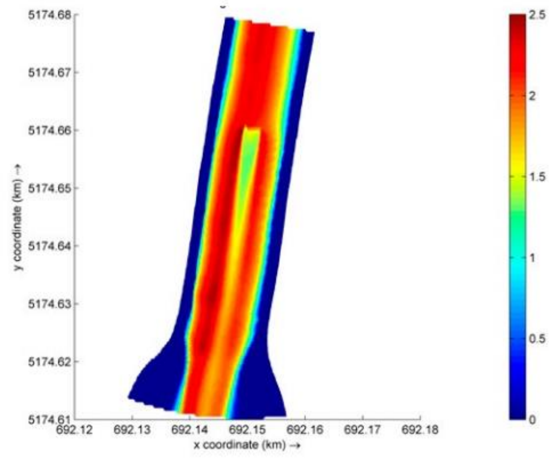
Turbulence dissipation $$S_\varepsilon = C_{\varepsilon 4} \frac{\varepsilon}{k} S_k,$$

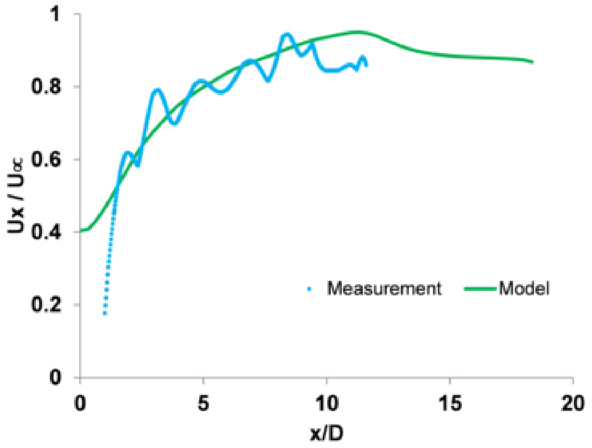
U: flow velocity
A: turbine frontal area

C_T: thrust coefficient
β_p, β_d, $C_{\varepsilon 4}$: optional canopy coefficients

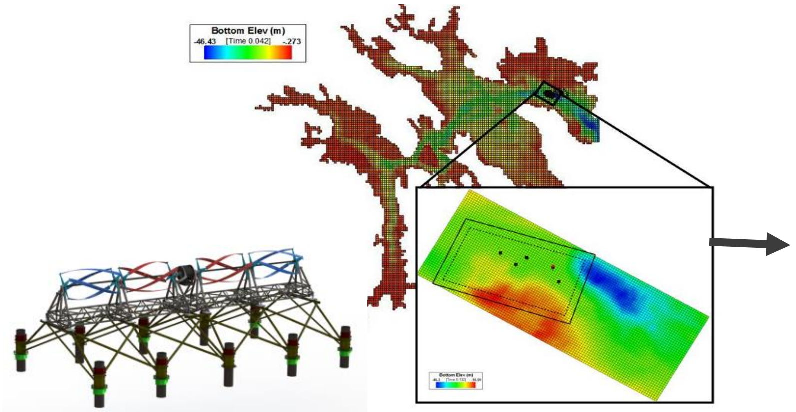
Program @ https://github.com/SNL-WaterPower/SNL-Delft3D-FM-CEC

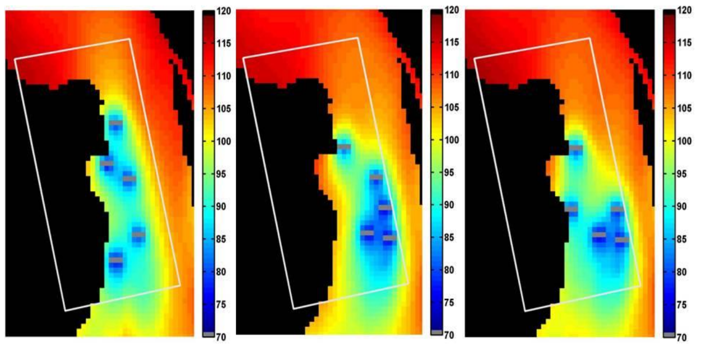
Roza Main Canal Field Measurement [2]





ORPC TidGen in Cobscook Bay, ME [3]





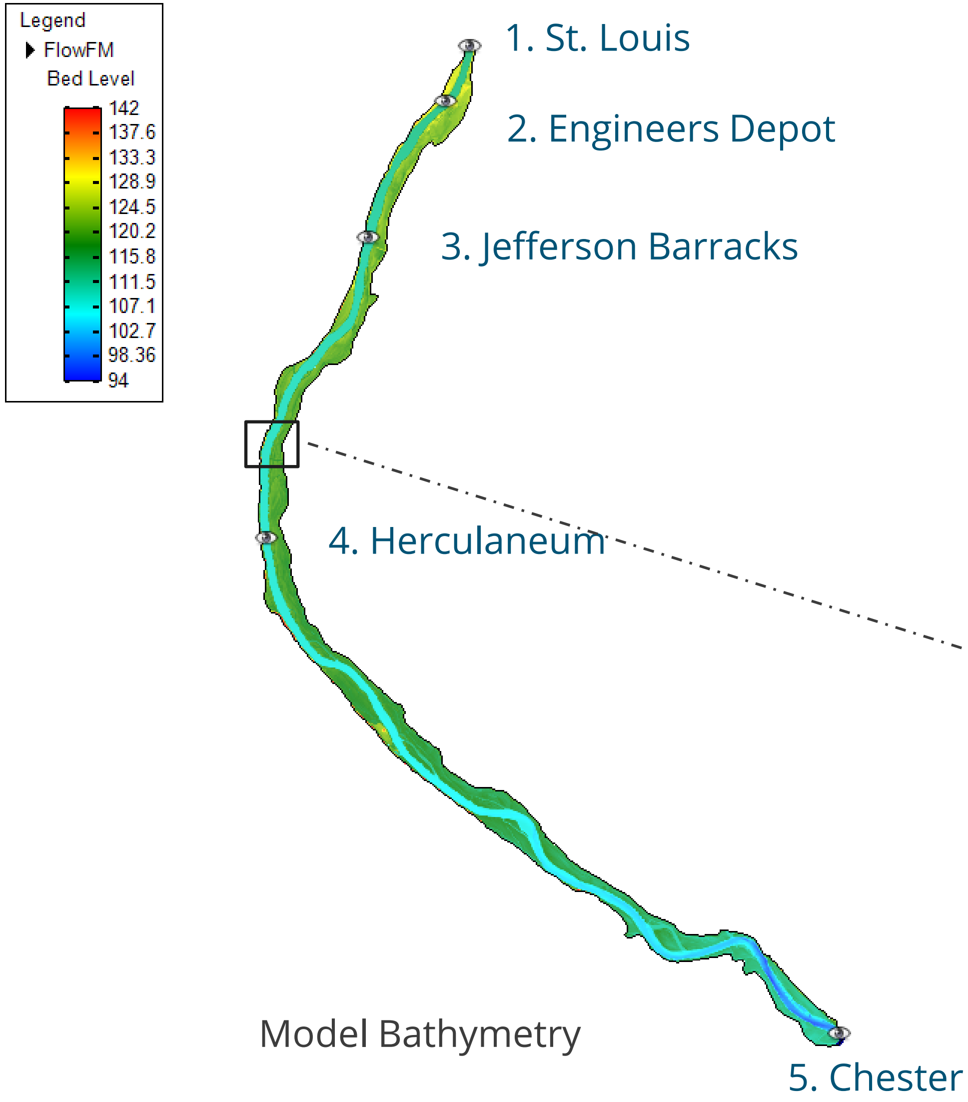
Power Outputs from Different Array Configurations

(2) Gunawan, B., Neary, V.S., Mortensen, J. and Roberts, J.D., 2017. *Assessing and Testing Hydrokinetic Turbine Performance and Effects on Open Channel Hydrodynamics: An Irrigation Canal Case Study* (No. SAND-2017-4925R). Sandia National Lab.(SNL-NM), Albuquerque, NM (United States).

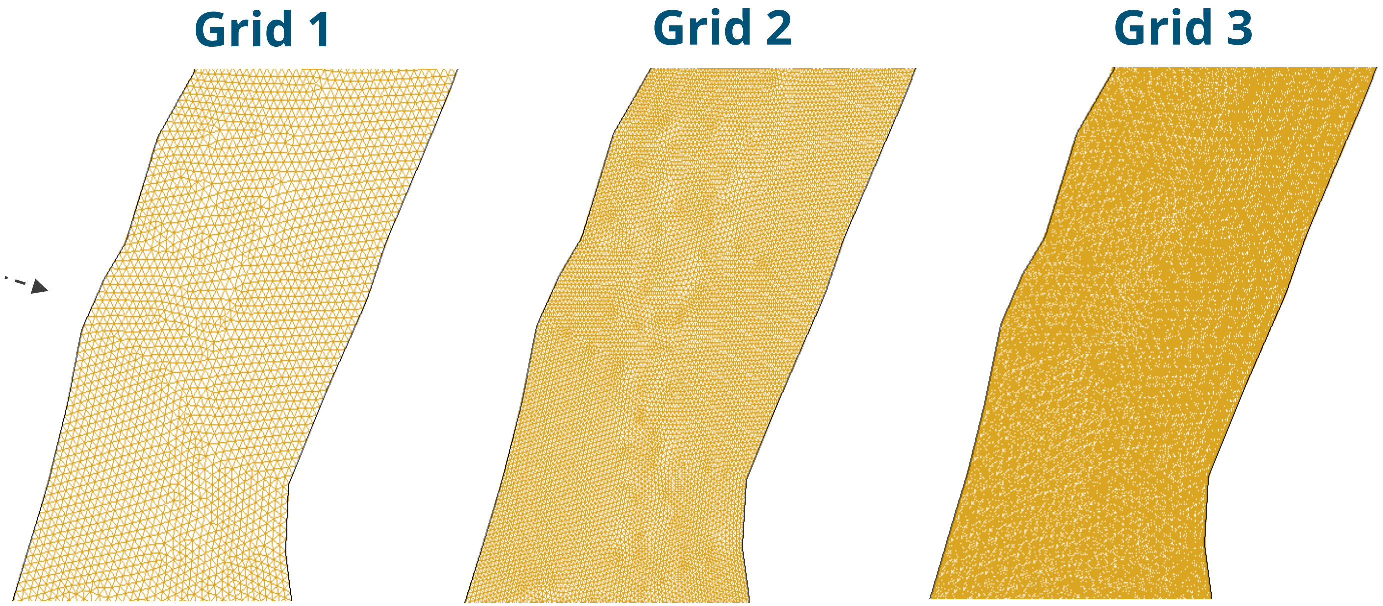
(3) Roberts, J., Nelson, K., Jones, C. and James, S.C., 2014. A framework for optimizing the placement of current energy converters.

Grid construction

	Grid 1	Grid 2	Grid 3
No. Elements (~)	210,000	850,000	3,300,000
Edge Length (m)	27-82	13-42	6-22
Max Orthogonality	0.052	0.001	0.001

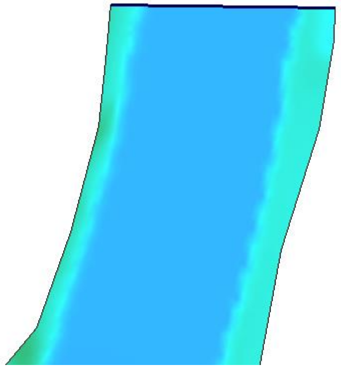


Model Bathymetry



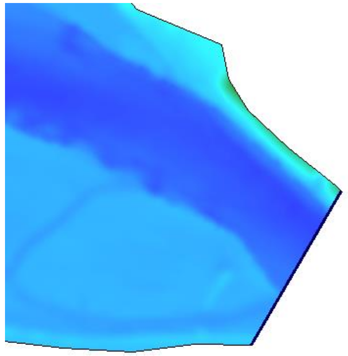
Boundary Conditions and Simulation Matrix

Inlet Conditions



	Discharge $(m^3 s^{-1})$
15th	2888.3
25th	3539.6
50th	5663.4
75th	9231.3
90th	12969.1

Outlet Conditions



	Water Level (m)
15th	105.4
25th	106.0
50th	108.1
75th	110.8
90th	112.8

Simulation Matrix

	Grid 1	Grid 2	Grid 3
15th	x	x	x
25th	x	x	x
50th	x	x	x
75th	x	x	x
90th	x	x	x

$$CFL = \frac{u\Delta t}{\Delta x}$$

Courant Numbers		
0.35	0.7	1.4

Bed Roughness

Model: Manning

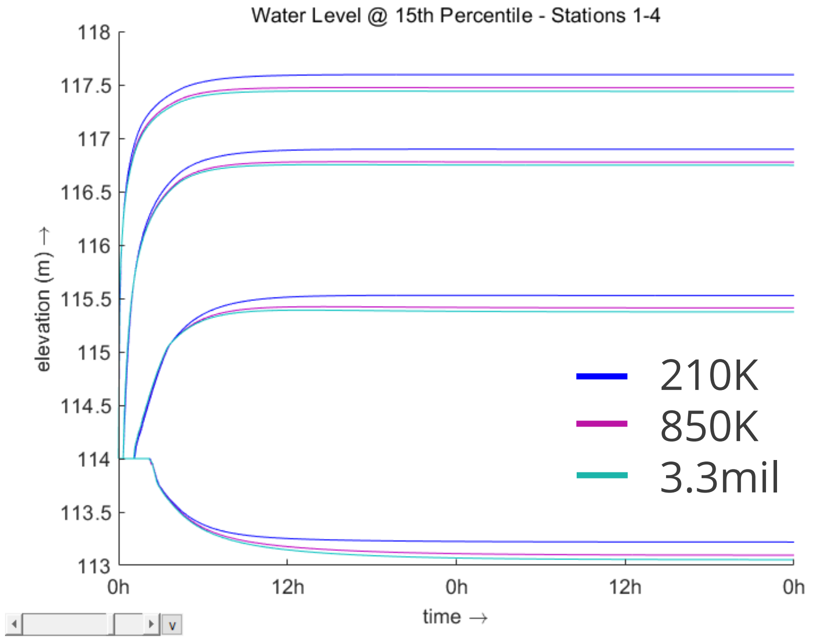
Values (n): 0.01-0.029 (Glass to Earth weedy channel)

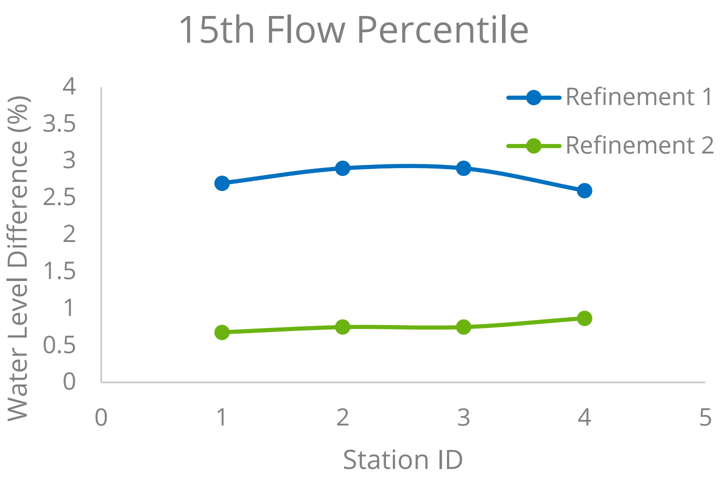
Results

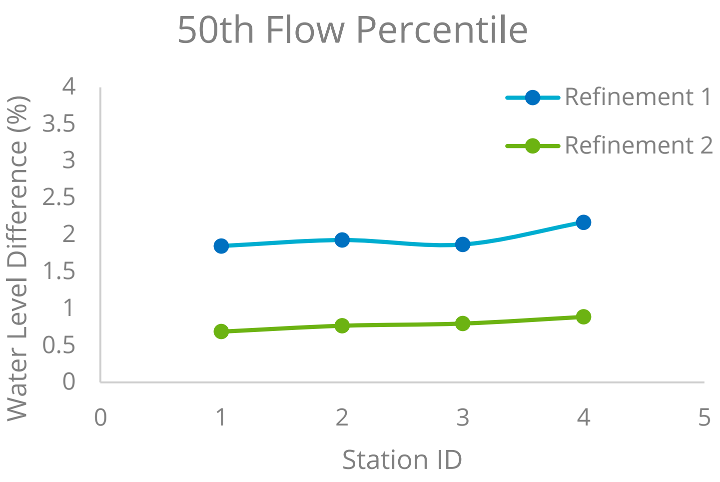
Delft3D Flexible Mesh

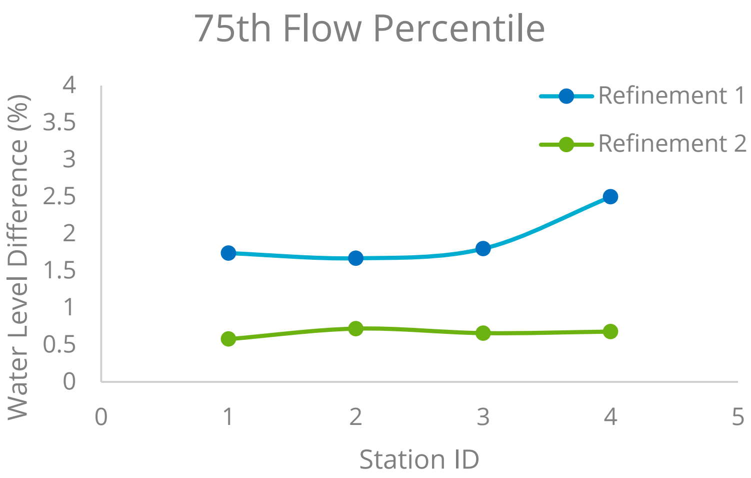
SNL-Delft3D

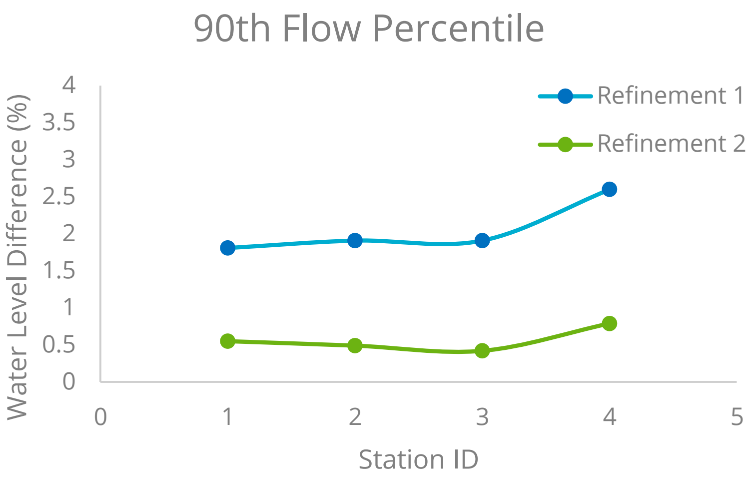
Mesh Convergence Study





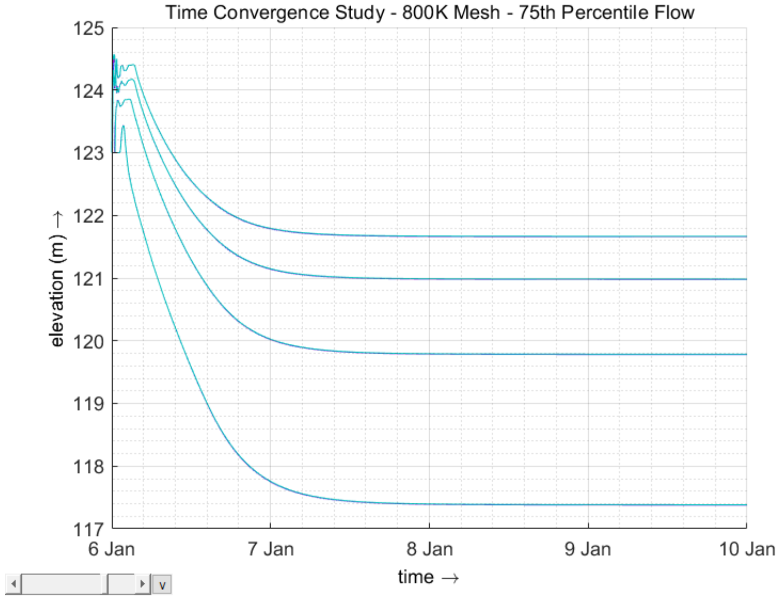


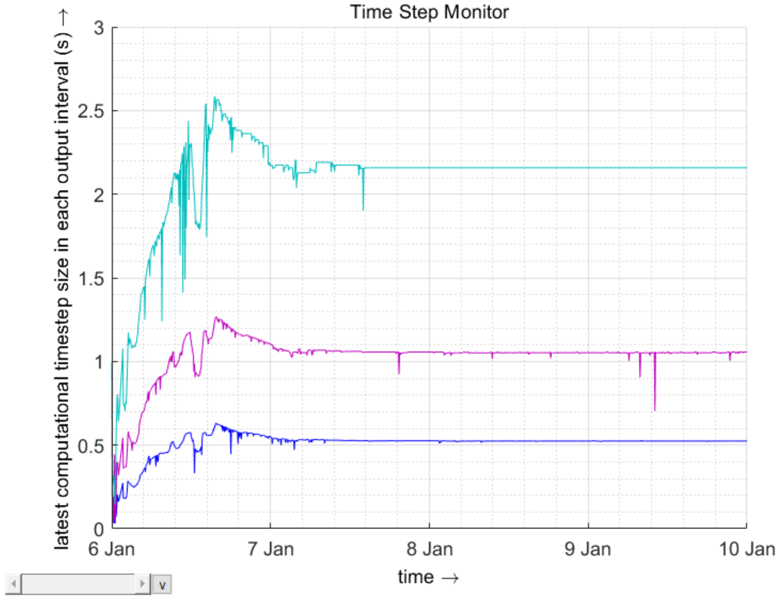




Time Convergence Check

0.35 (~53hrs) 0.70 (~29hrs) 1.40 (~15hrs)



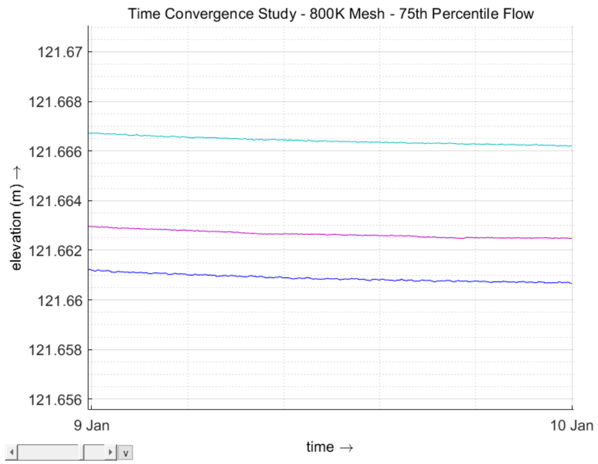


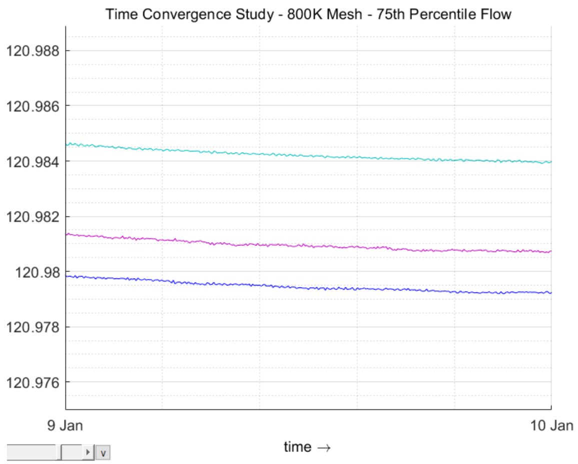
Time Settings:

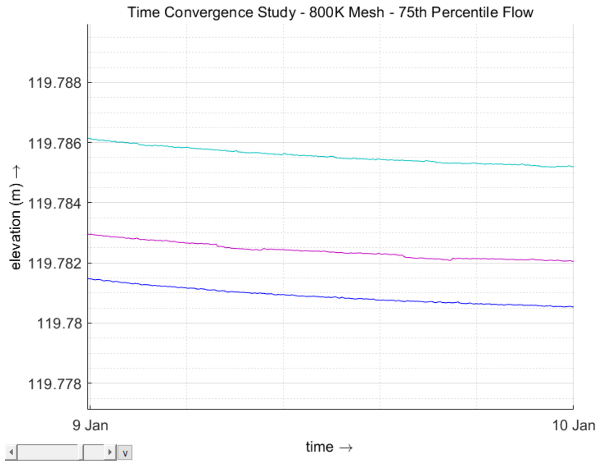
- Dt Initial: 1s
- Dt Max: 30s
- CFL: **0.35, 0.7, and 1.4**

- **Note:* D3D recommend CFL $\leq$ 0.7

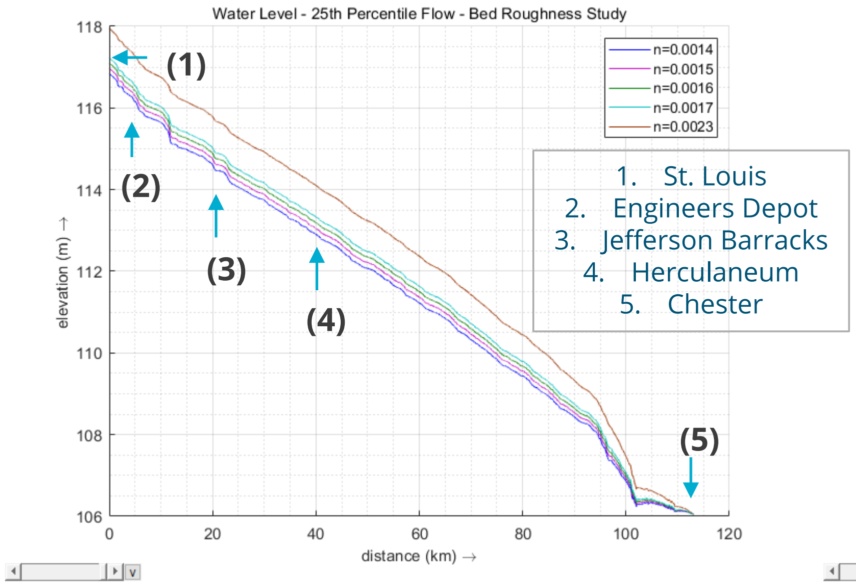
- **Results: converged to within 0.06% of WD.**

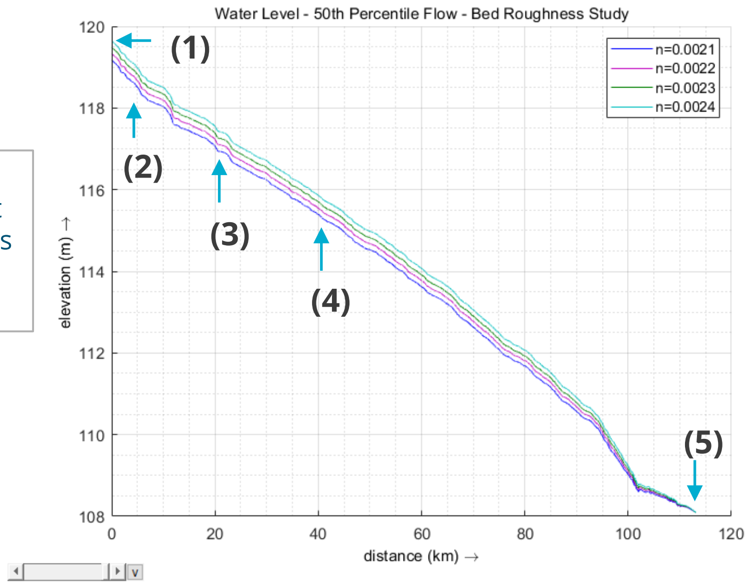


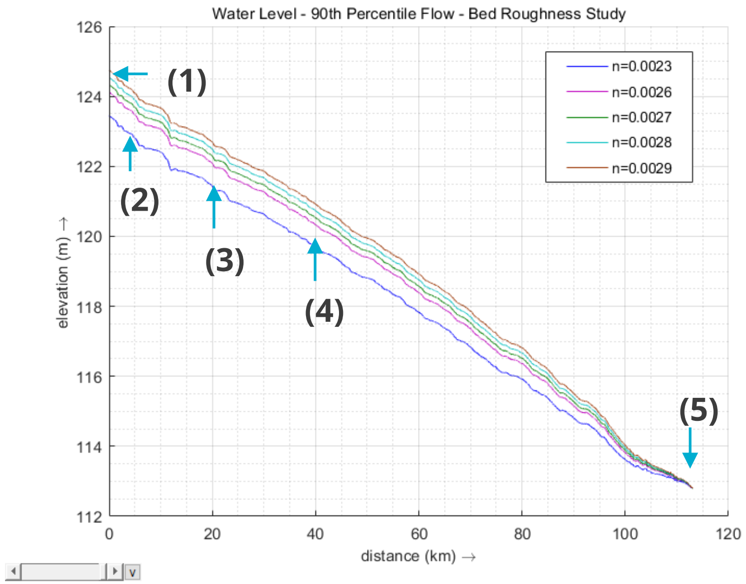


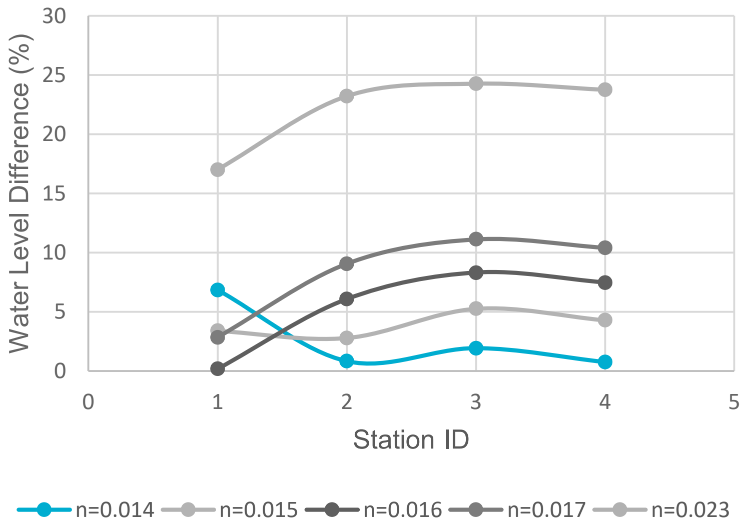


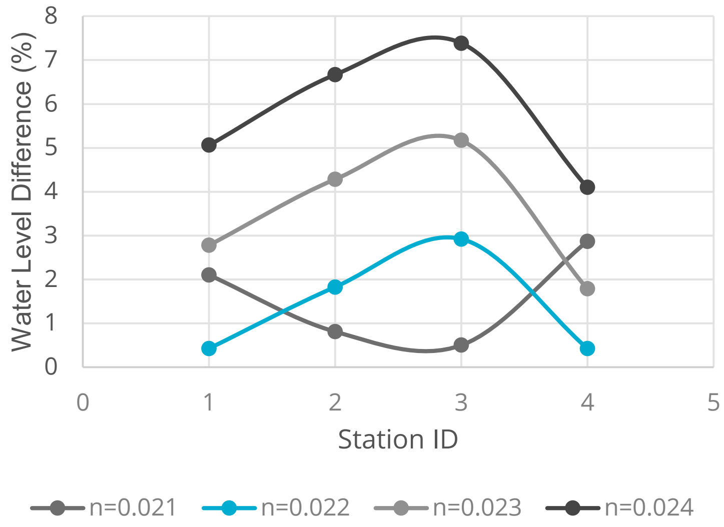
25^{th} , 50^{th} , and 90^{th} Percentile Flow Water Level

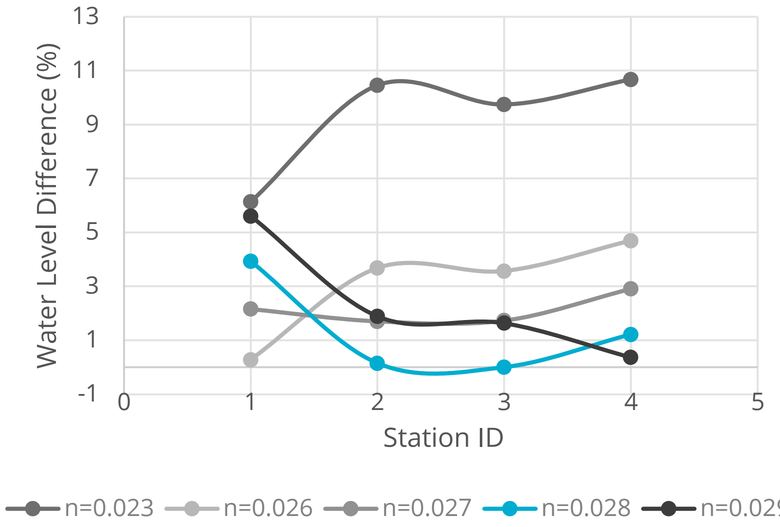




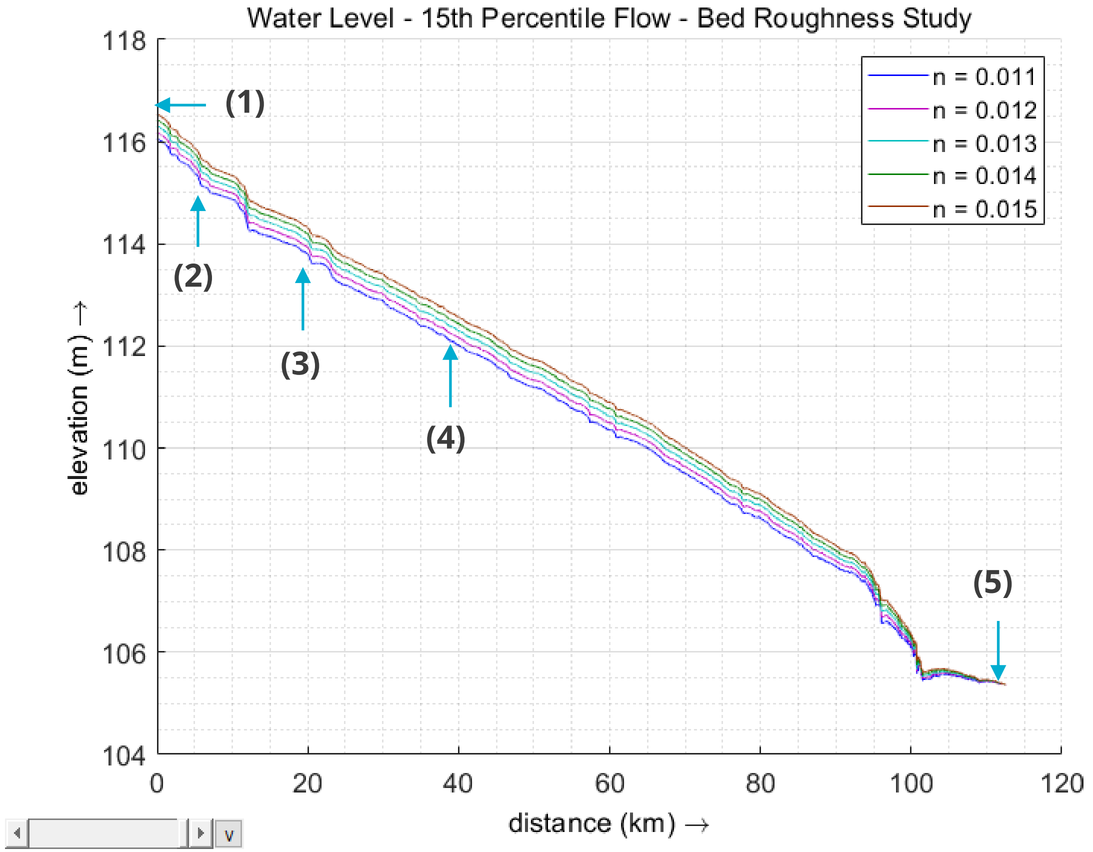


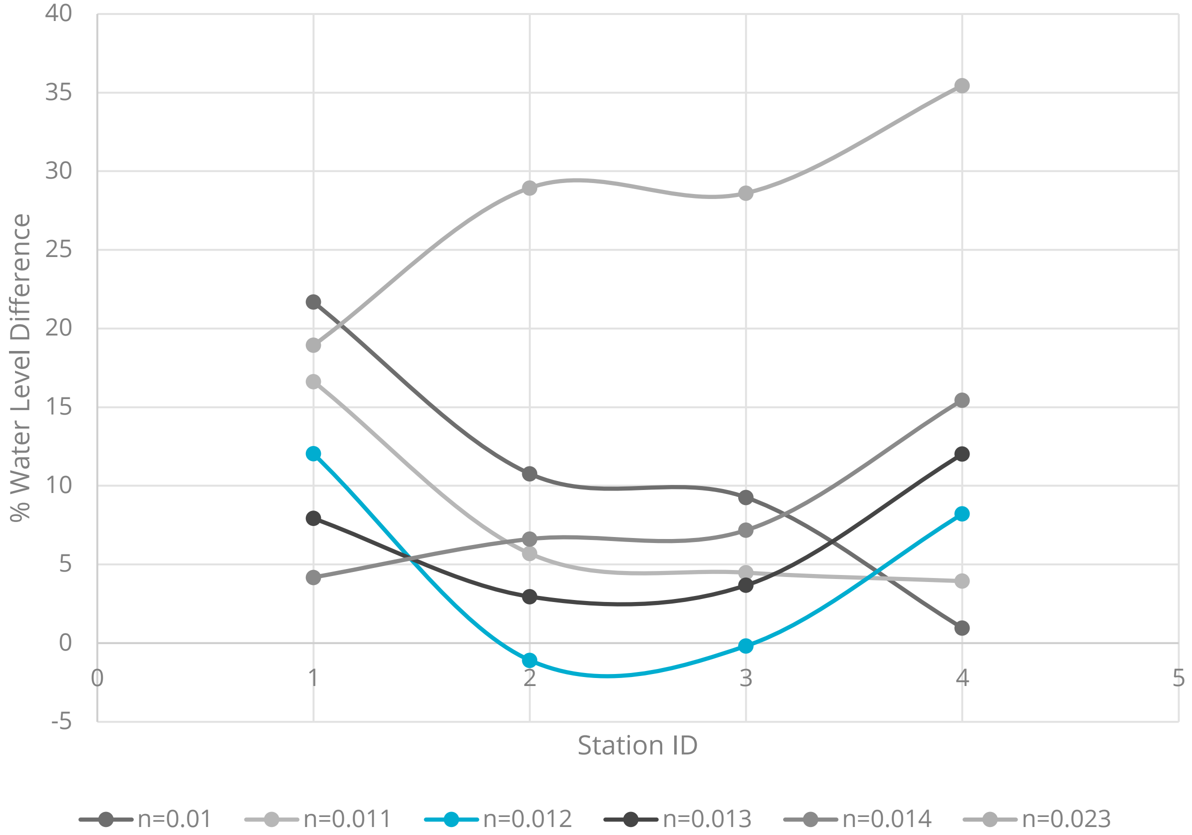




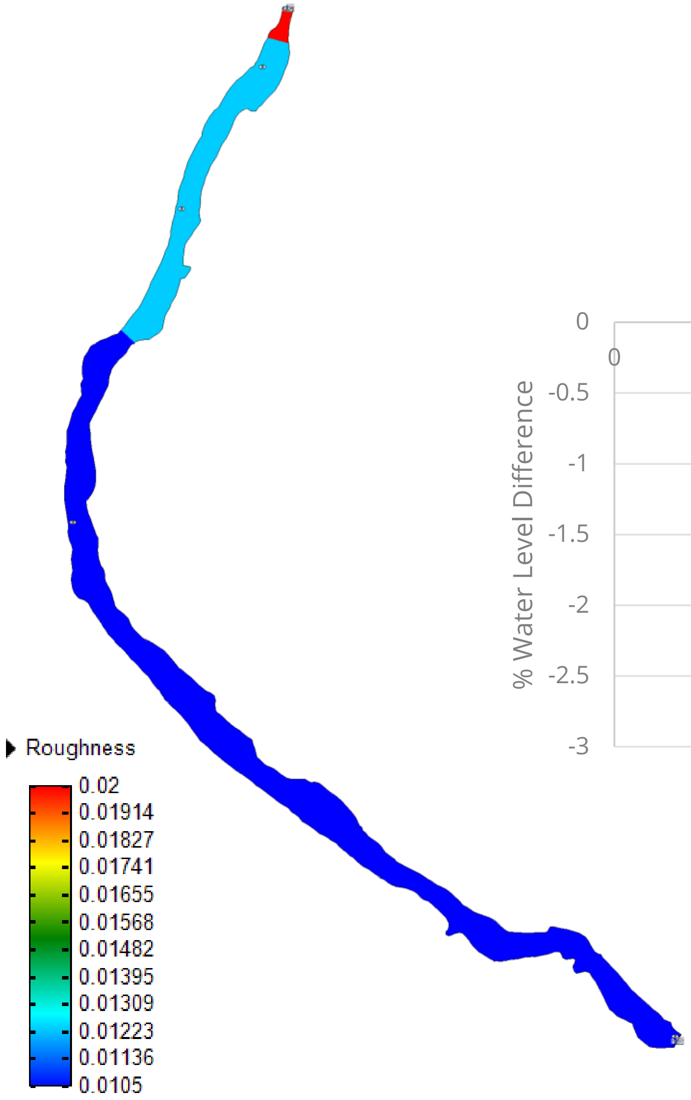


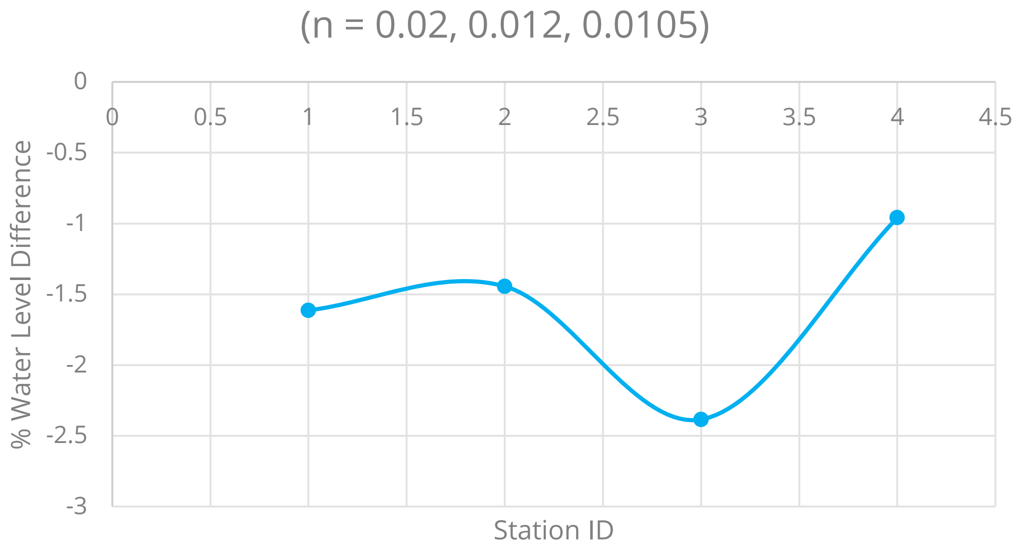
15th Percentile Flow – Water Level

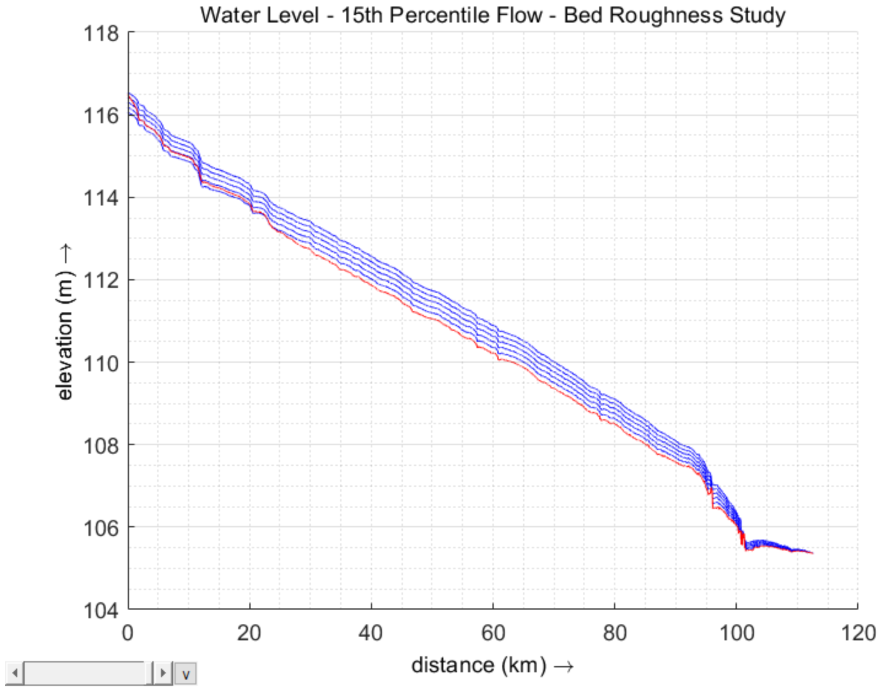




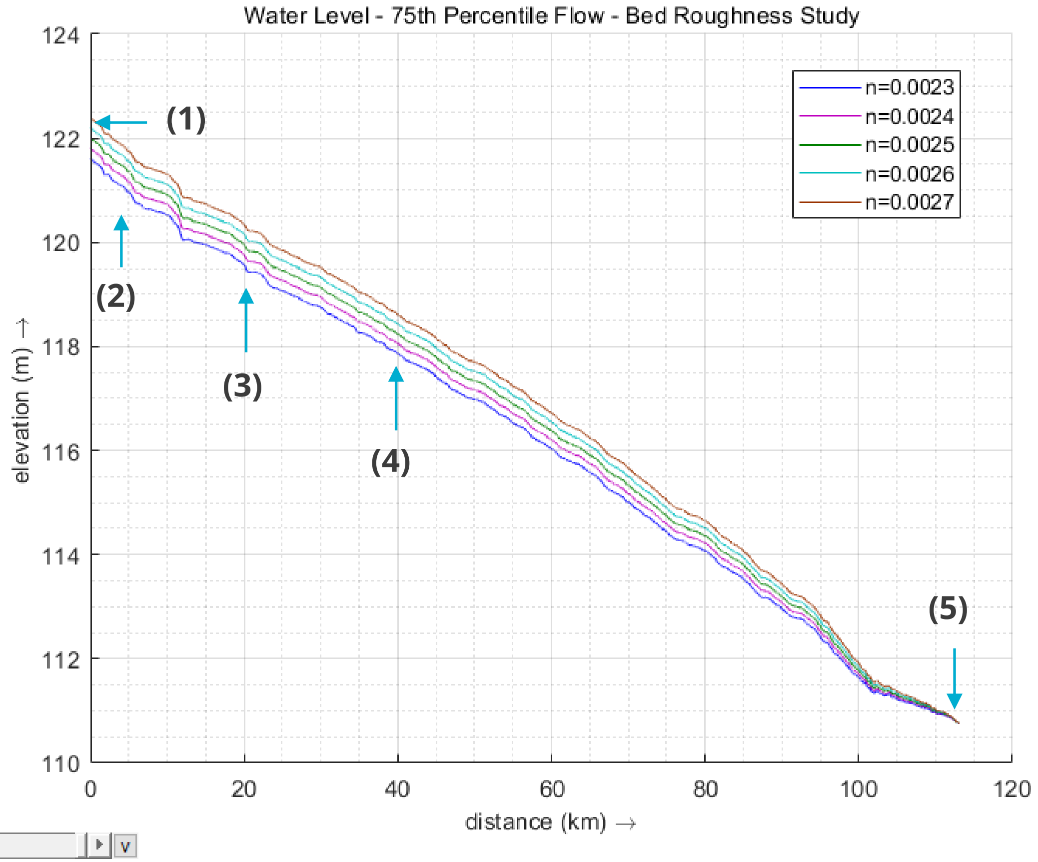
15th Percentile Flow – Bed Roughness Calibration

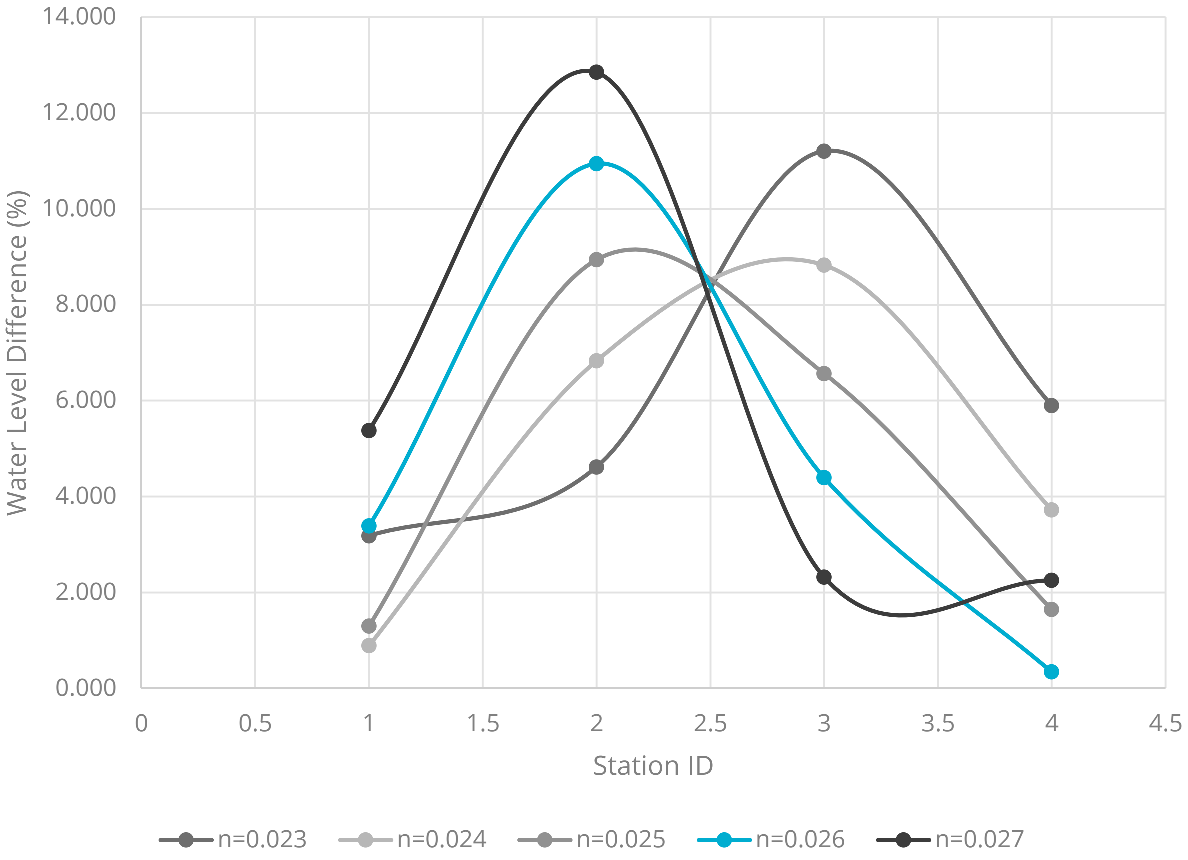




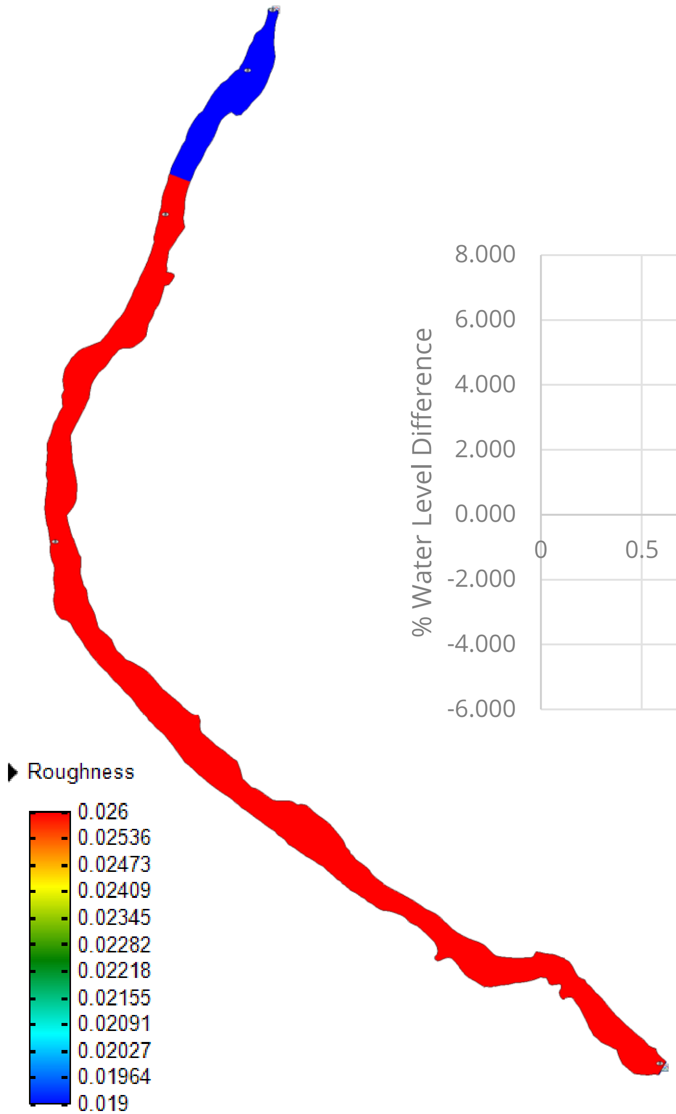


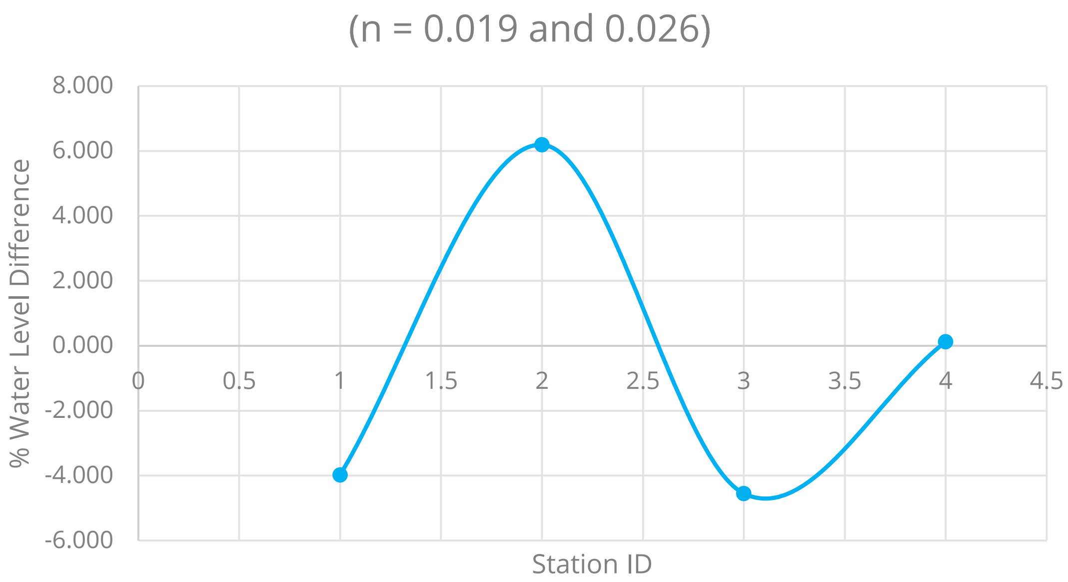
75th Percentile Flow – Water Level

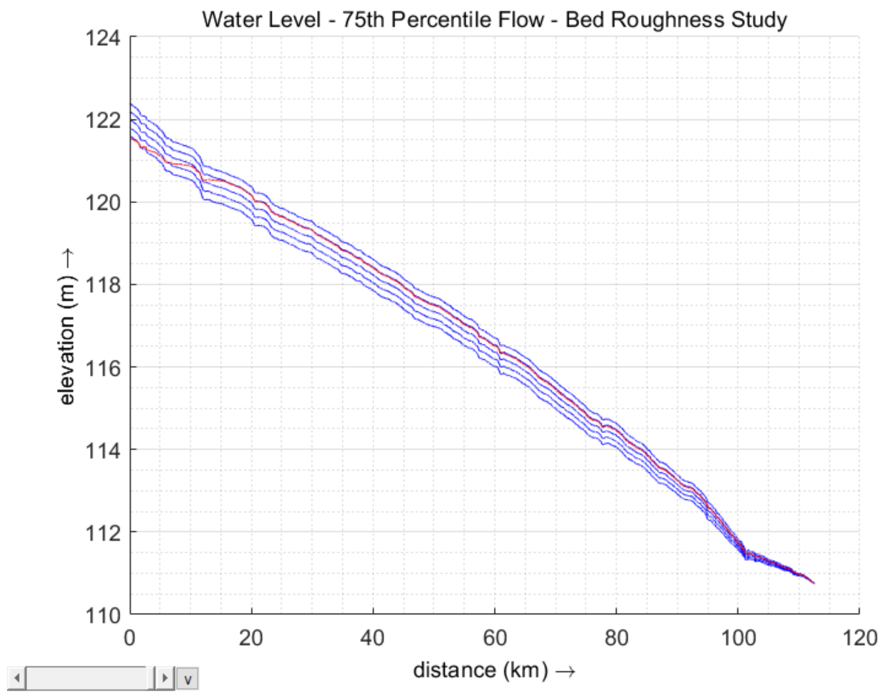




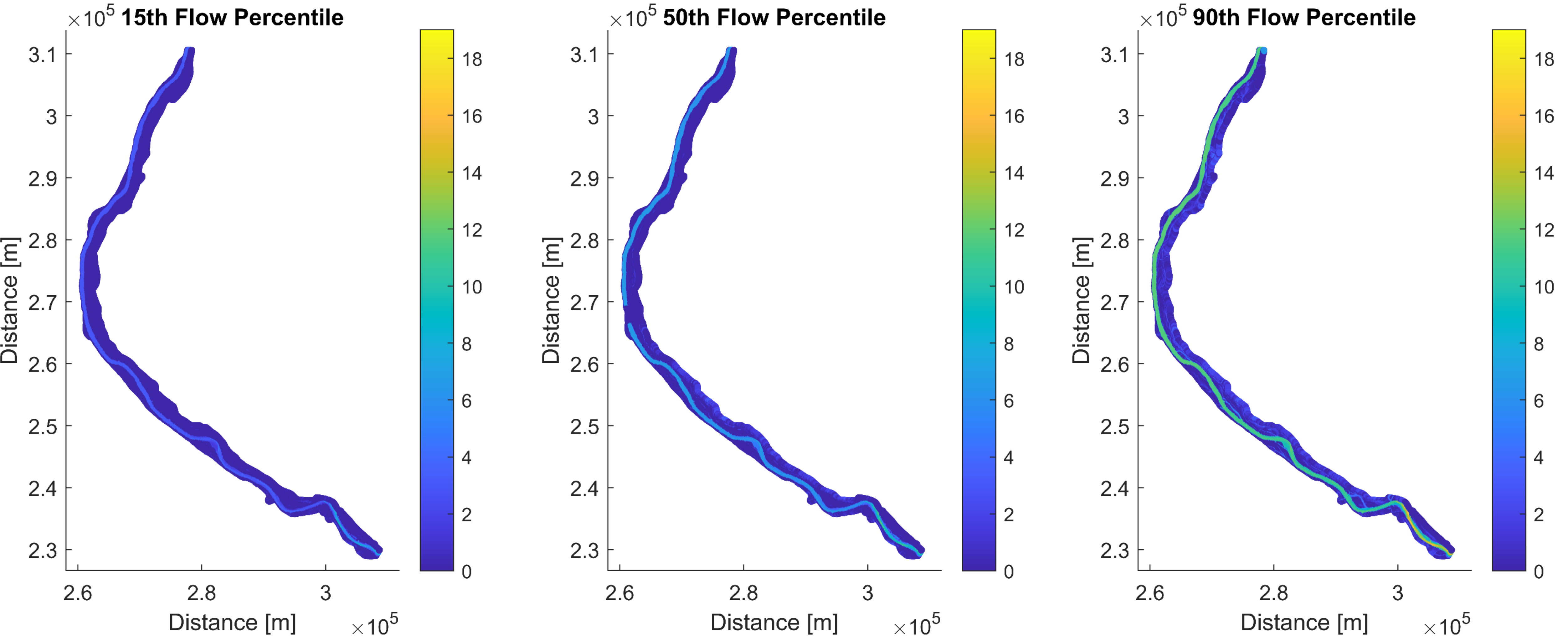
75th Percentile Flow – Bed Roughness Calibration



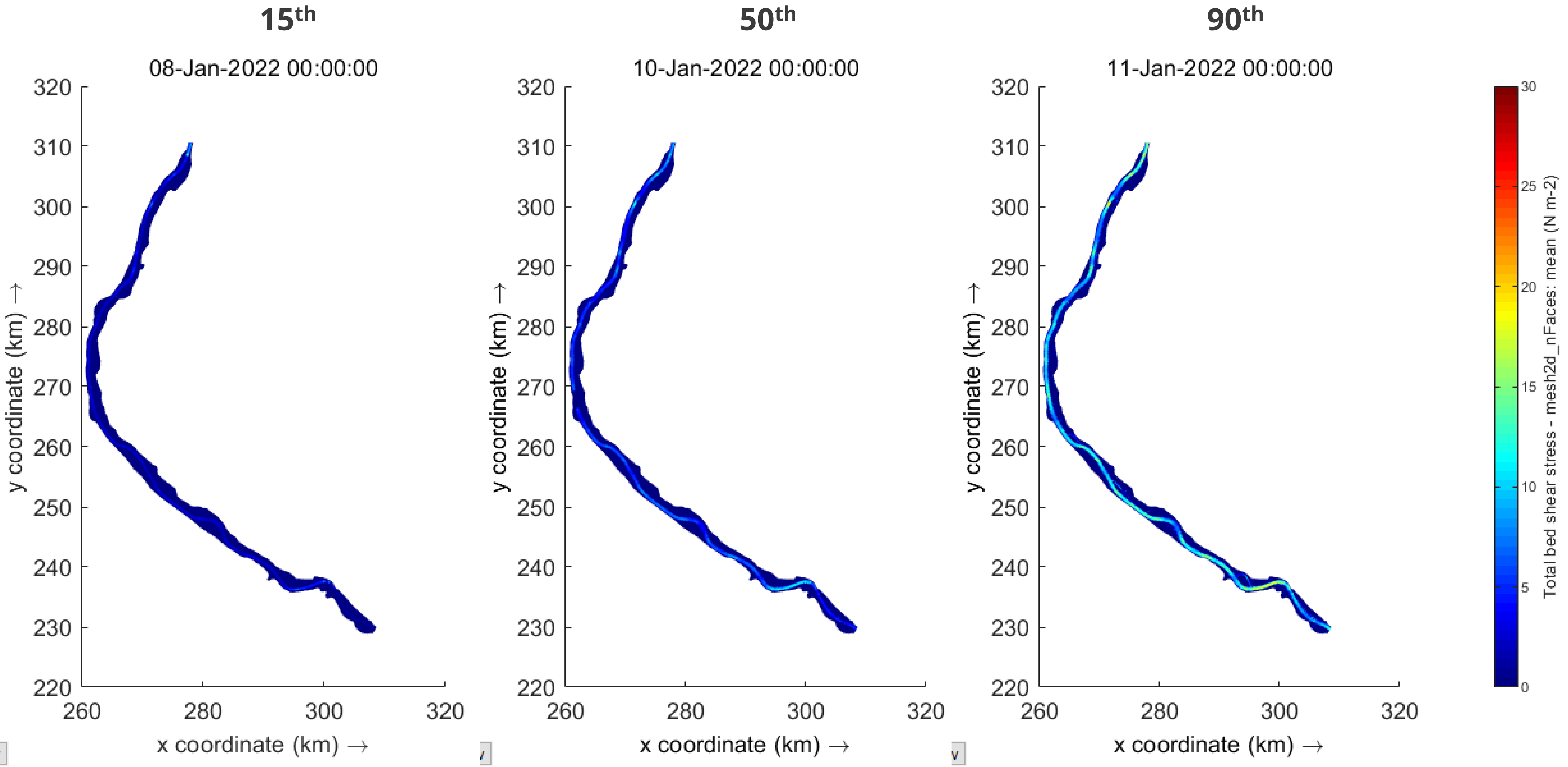




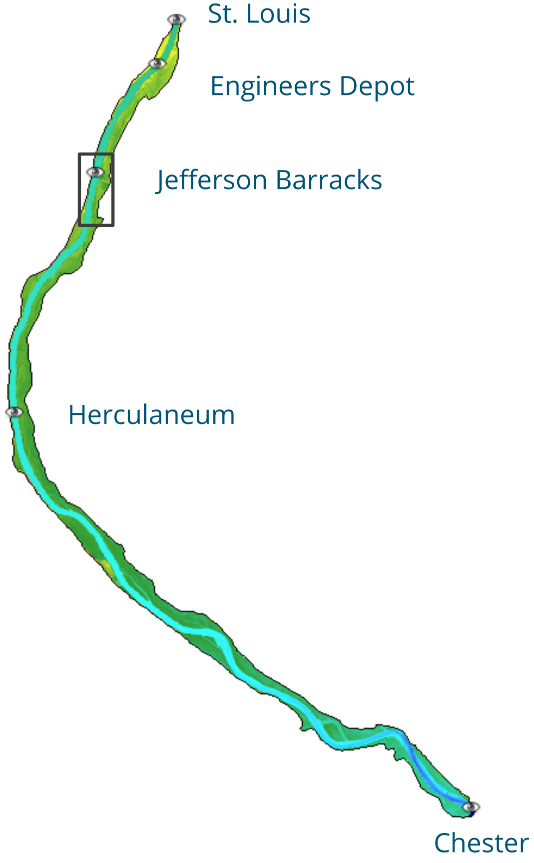
Water Level Across Flow Percentiles

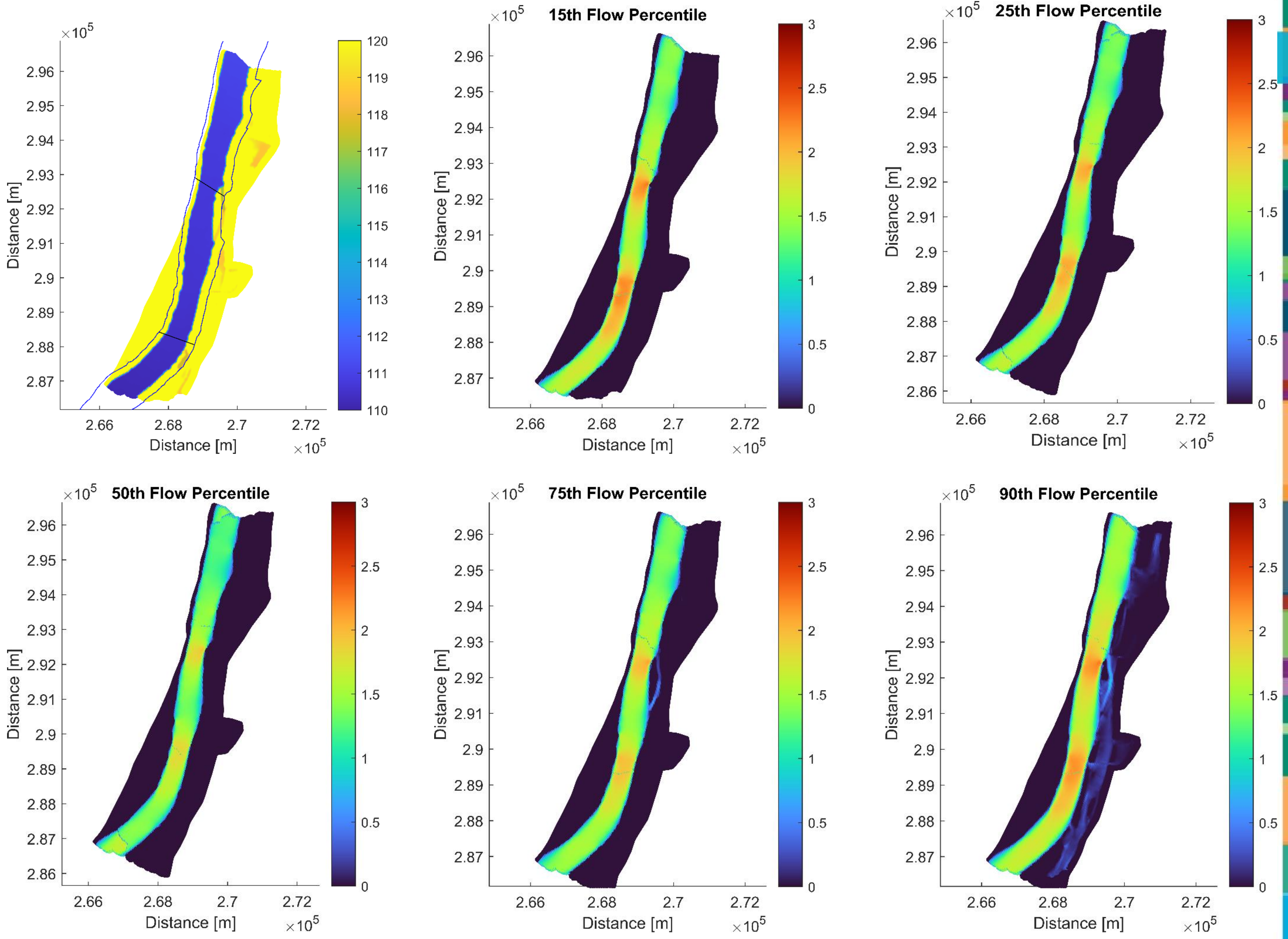


Bed Shear Stress Across Flow Percentiles

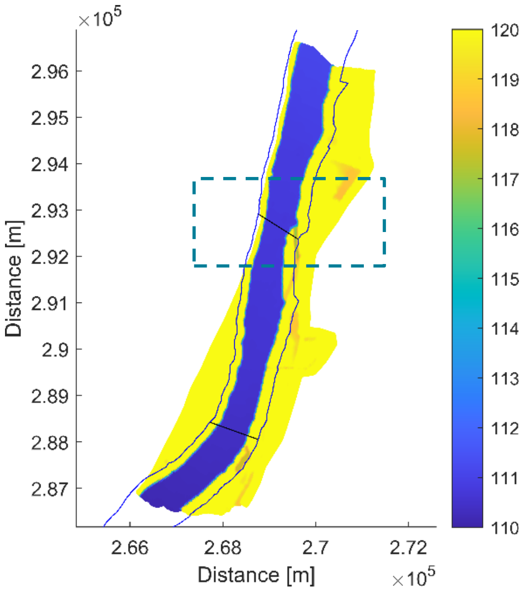


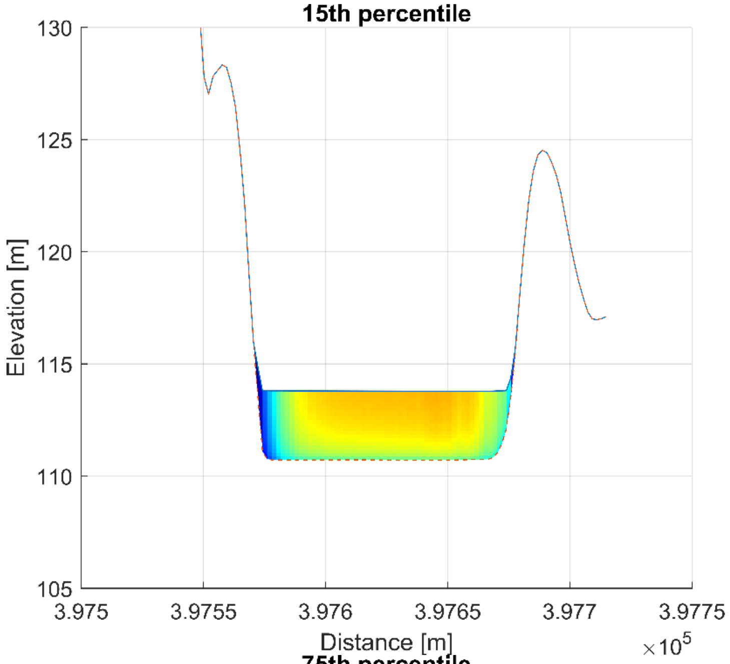
Depth Averaged Velocity around Jefferson Barracks

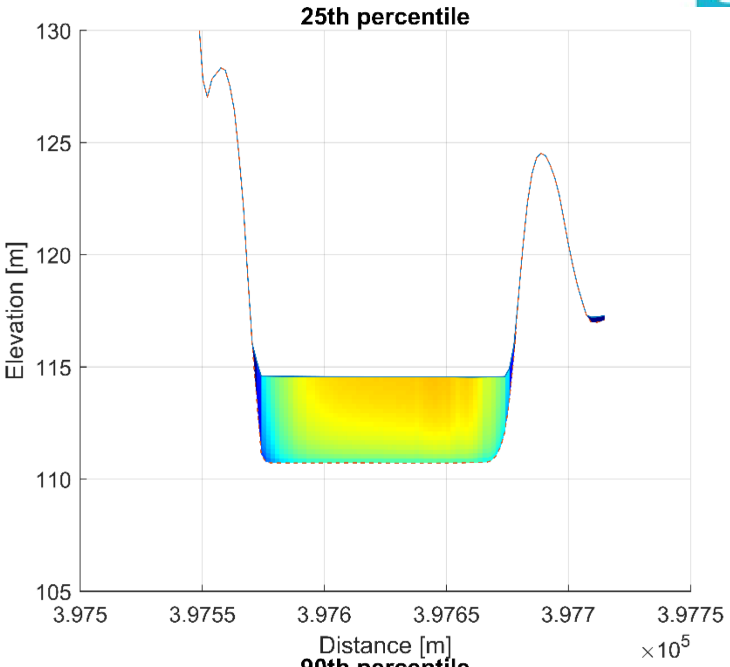


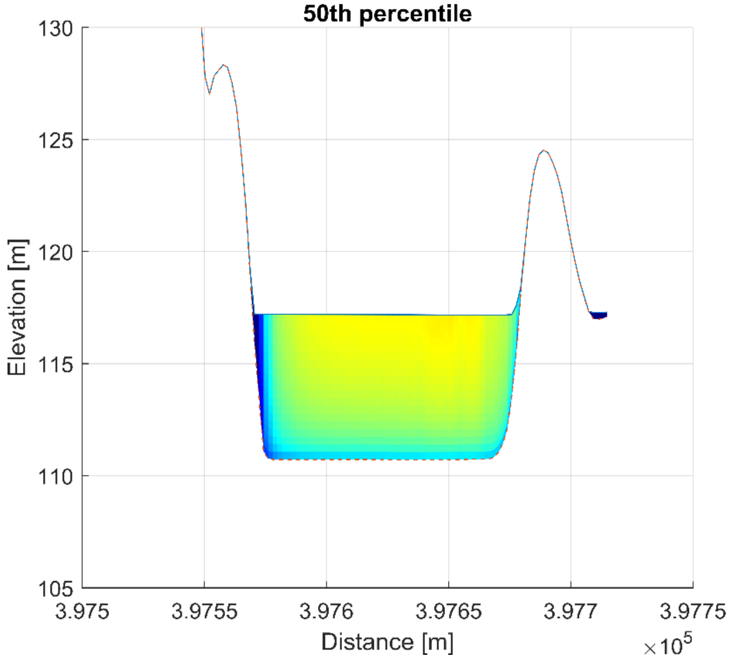


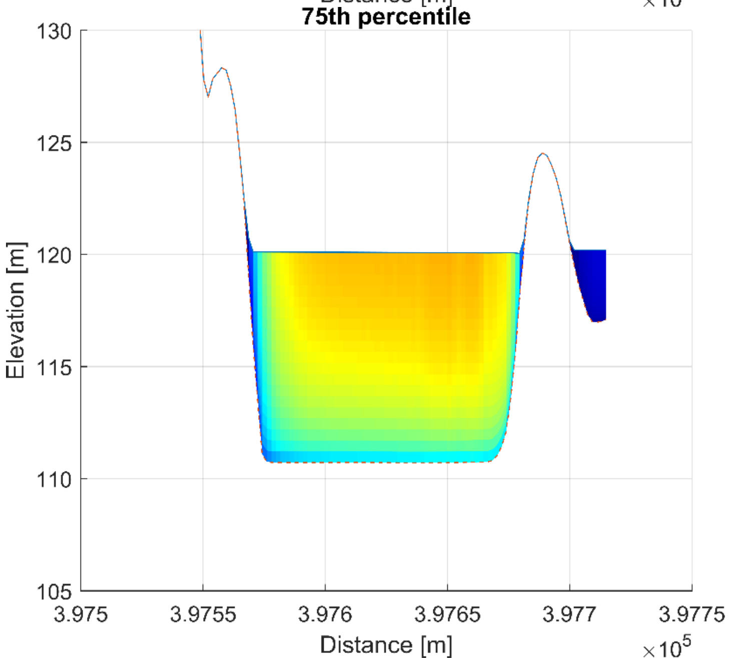
Cross-sectional velocity (m/s) - Line 1:

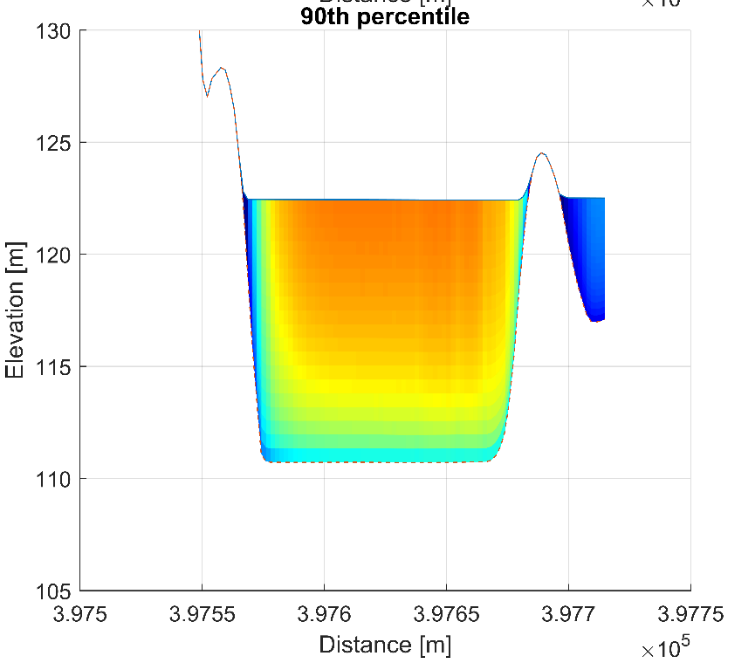




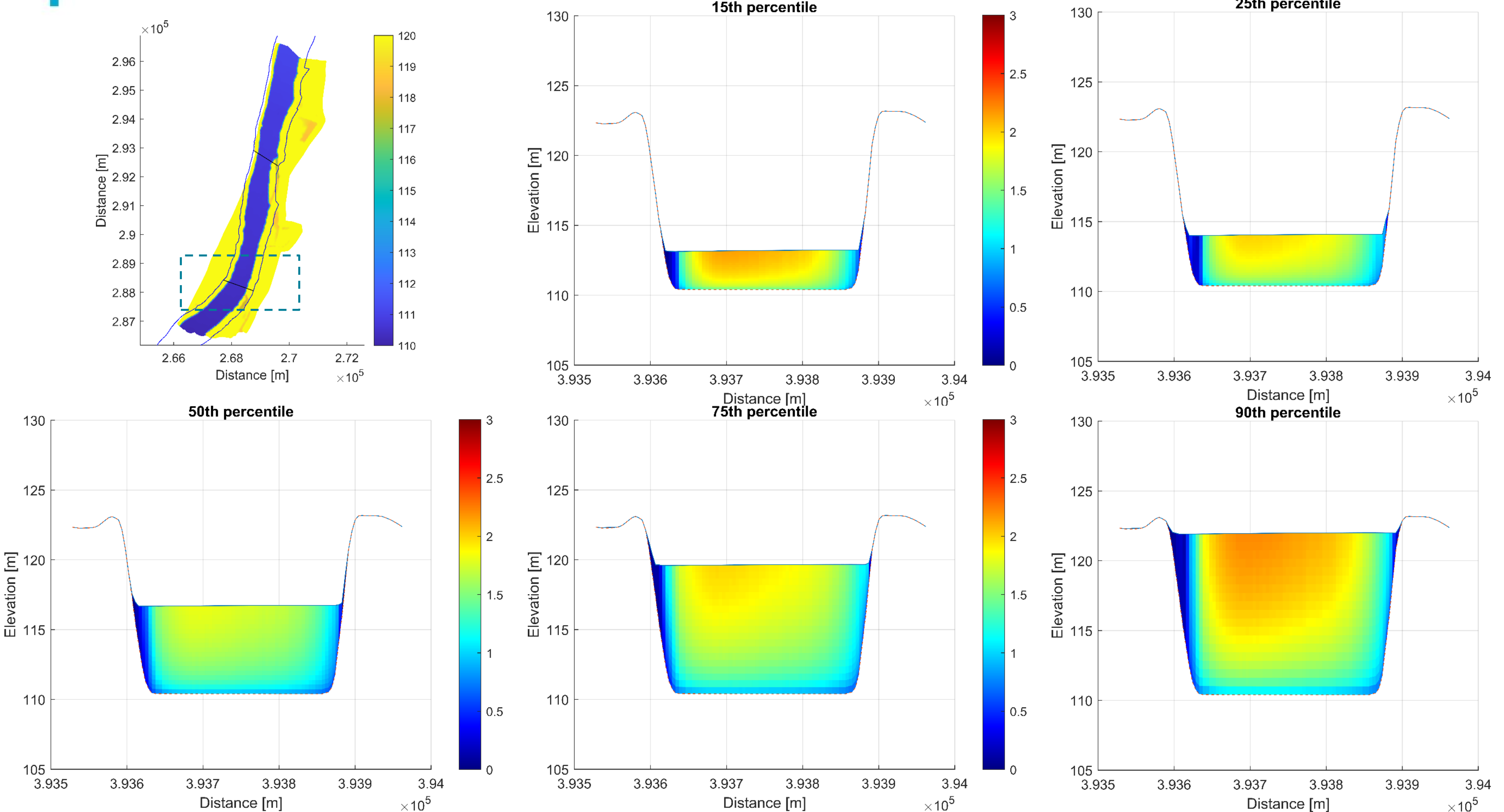




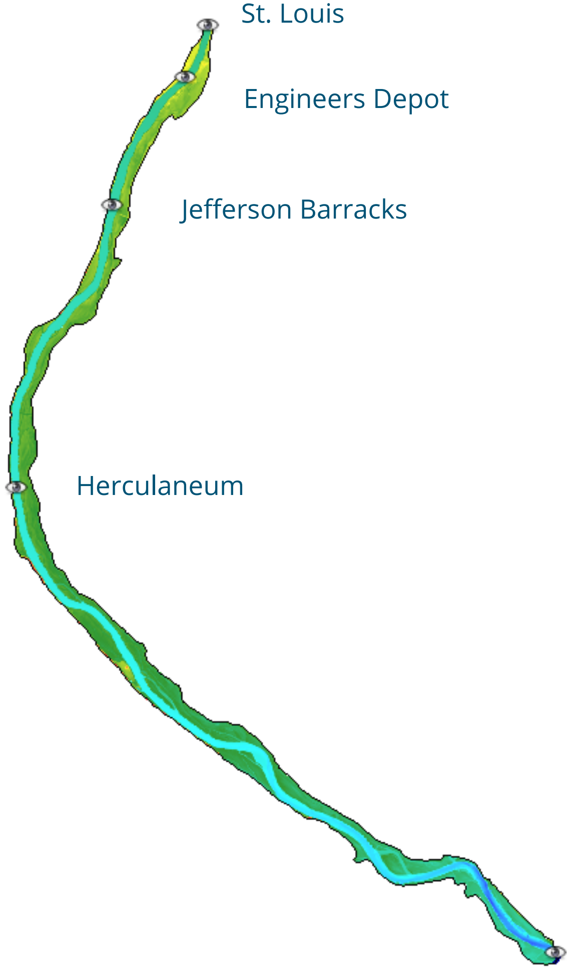




Cross-sectional velocity (m/s) - Line 2:



Conclusion and Future work



- Numerical simulations of **70 mile of Mississippi River.**
- Five conditions were studied: **15th, 25th, 50th, 75th, and 90th.**
- **Bed Roughness** study was conducted to **calibrate** the model at five stations: **St. Louis, Engineers Depot, Jefferson Barracks, Herculaneum, and Chester**.
- **Water level** outputs from the model achieve maximum difference of **6 percent** compared with published **field data.**
- **Cross-sectional velocities, bed shear stress, and water level** information will help identify potential deployment sites.
- ***Future work:***
  - Re-simulating the River model including the Rivgen turbines.
  - Optimizes the turbine array configuration for power outputs and minimal bottom shear stress increases.

THANK YOU