Modeling Fish Passage through Nature-Like Rapids using Civil3D and HEC-RAS in the Context of Dam Removal

GEI Consultants

Presented by:

Samuel Prentice, P.E.

Marquette, Michigan

A Case for Nature-Like Rapids

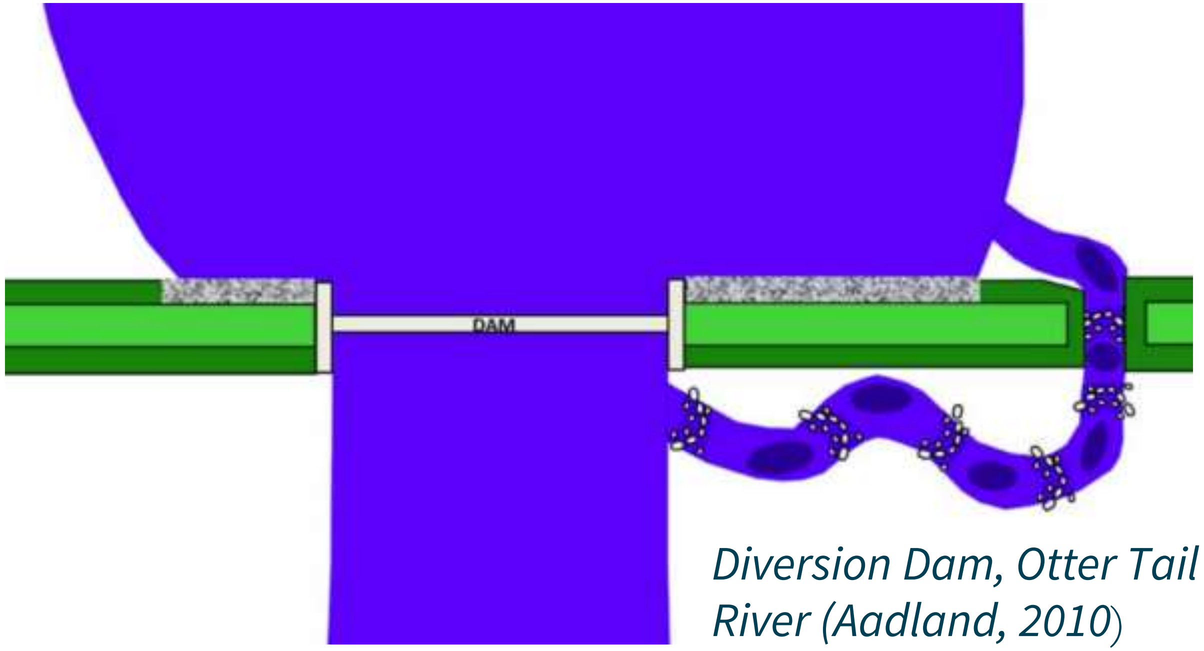
Reconnecting Rivers following Dam Removal

- Rock Rapids
  - In-line with main channel flow
  - Revised design from a continuous rock ramp
  - Series of boulder weirs that control drop of river from desired headwater to tailwater over a wide flow range
  - Resting pools in between grade controlling weirs
  - Can be built up to existing dam crest or in-place after dam removal

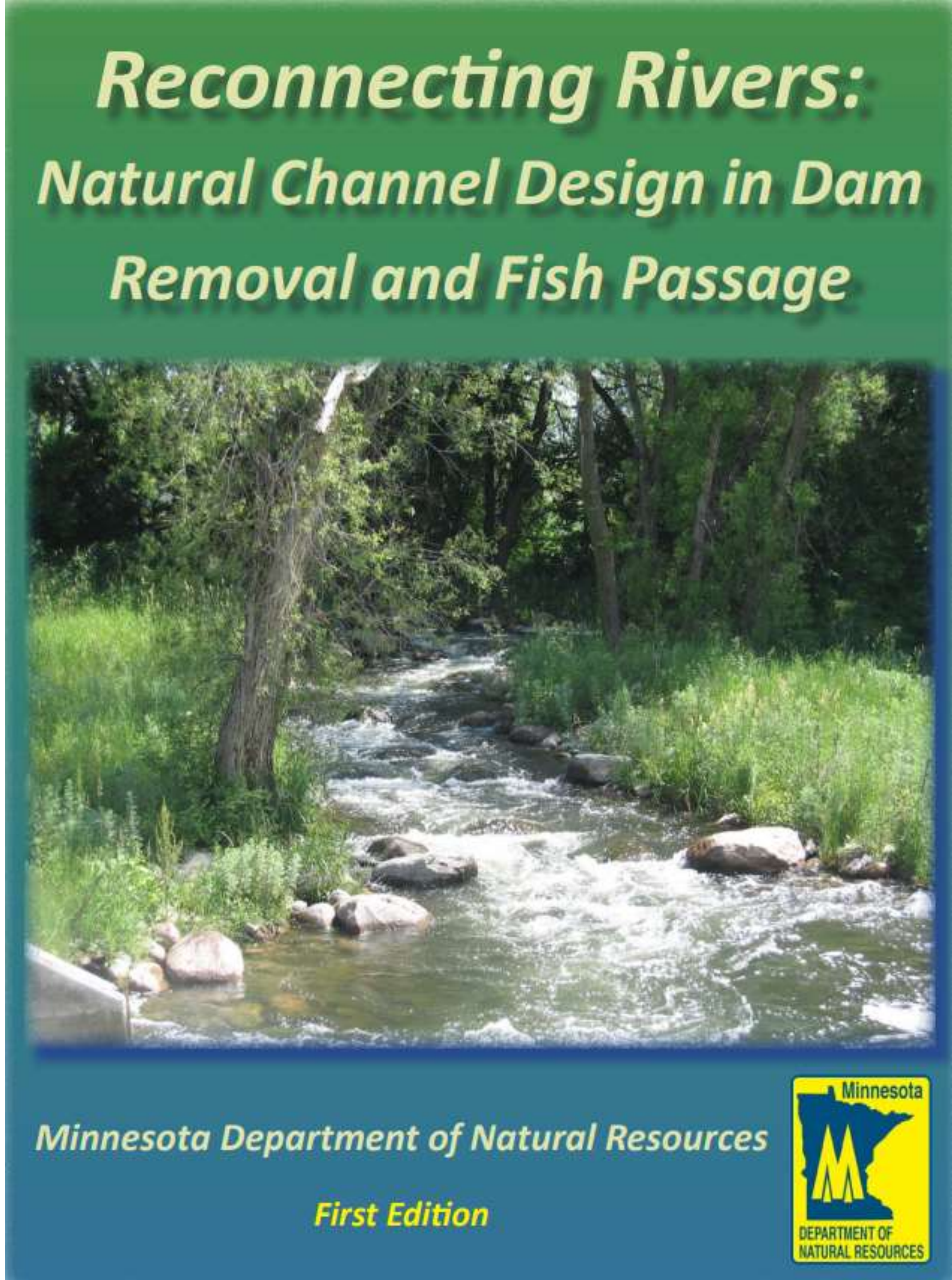
Willow River Rapids (Aadland, 2023)

Reconnecting Rivers following Dam Removal

- By-pass Fishway
  - Built off to the side of the main channel
  - Dam can remain in place and notched
  - Natural channel design criteria typically used



Diversion Dam, Otter Tail River (Aadland, 2010)



What Do the Fish Think?

- Nature-Like Rapids have greater hydraulic complexity than traditional chute and baffle structures and rock ramps
- Greater hydraulic complexity leads to passing more species and age classes of fish, especially warmwater fish that are not strong swimmers
- Deep pools in between rapids allow for resting habitat and burst speeds through weir gaps
- Maximizes fish passage for different species, sizes, and age classes

Adult walleye in nature-like rapids (provided by Dr. Luther Aadland)

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Small-bodied minnows and darters swimming through nature-like rapids (provided by Dr. Luther Aadland)

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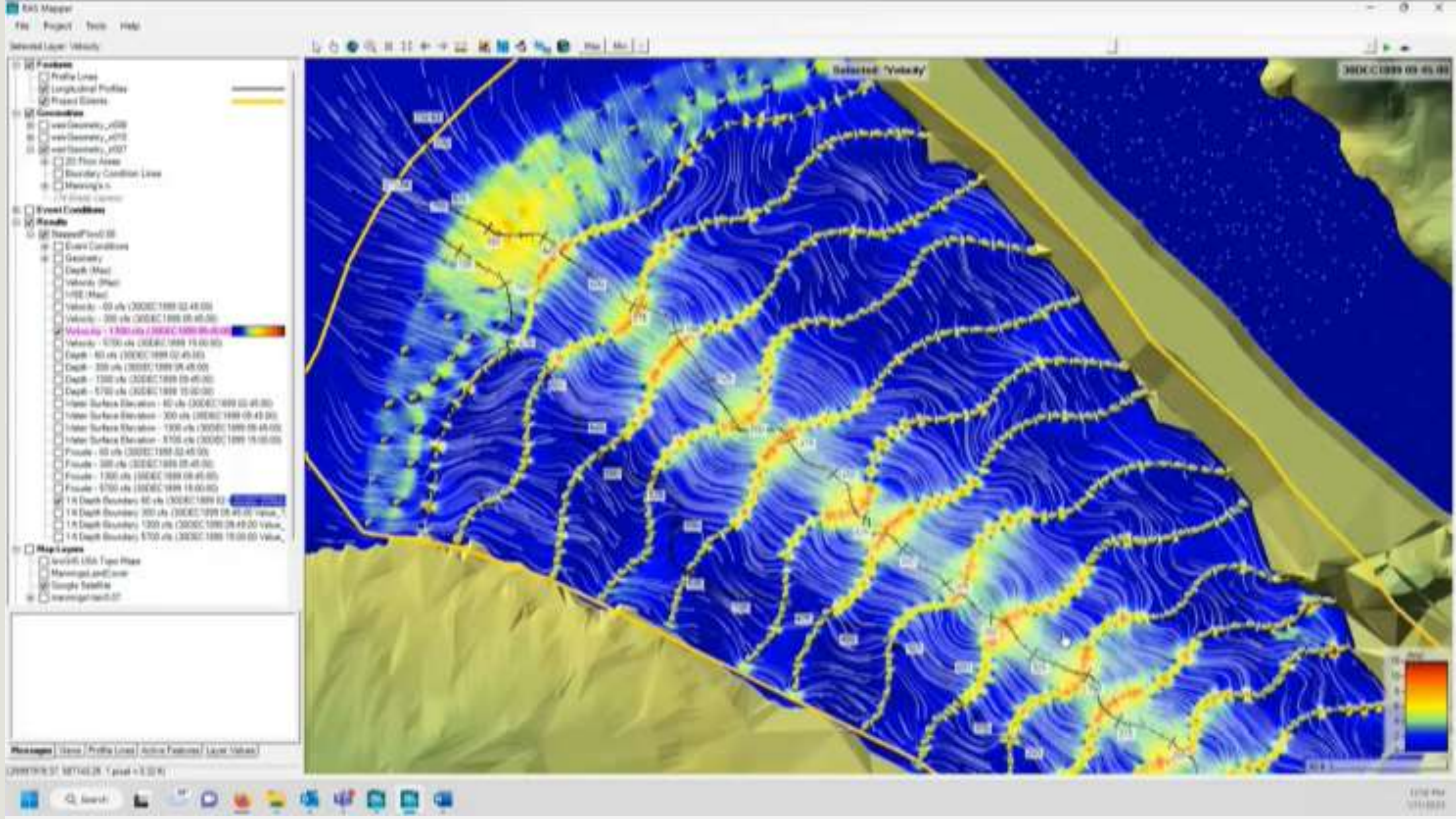
Muskie captured during survey of nature-like rapids (provided by Dr. Luther Aadland)

Modeling Fish Passage

Why Is Modeling Important?

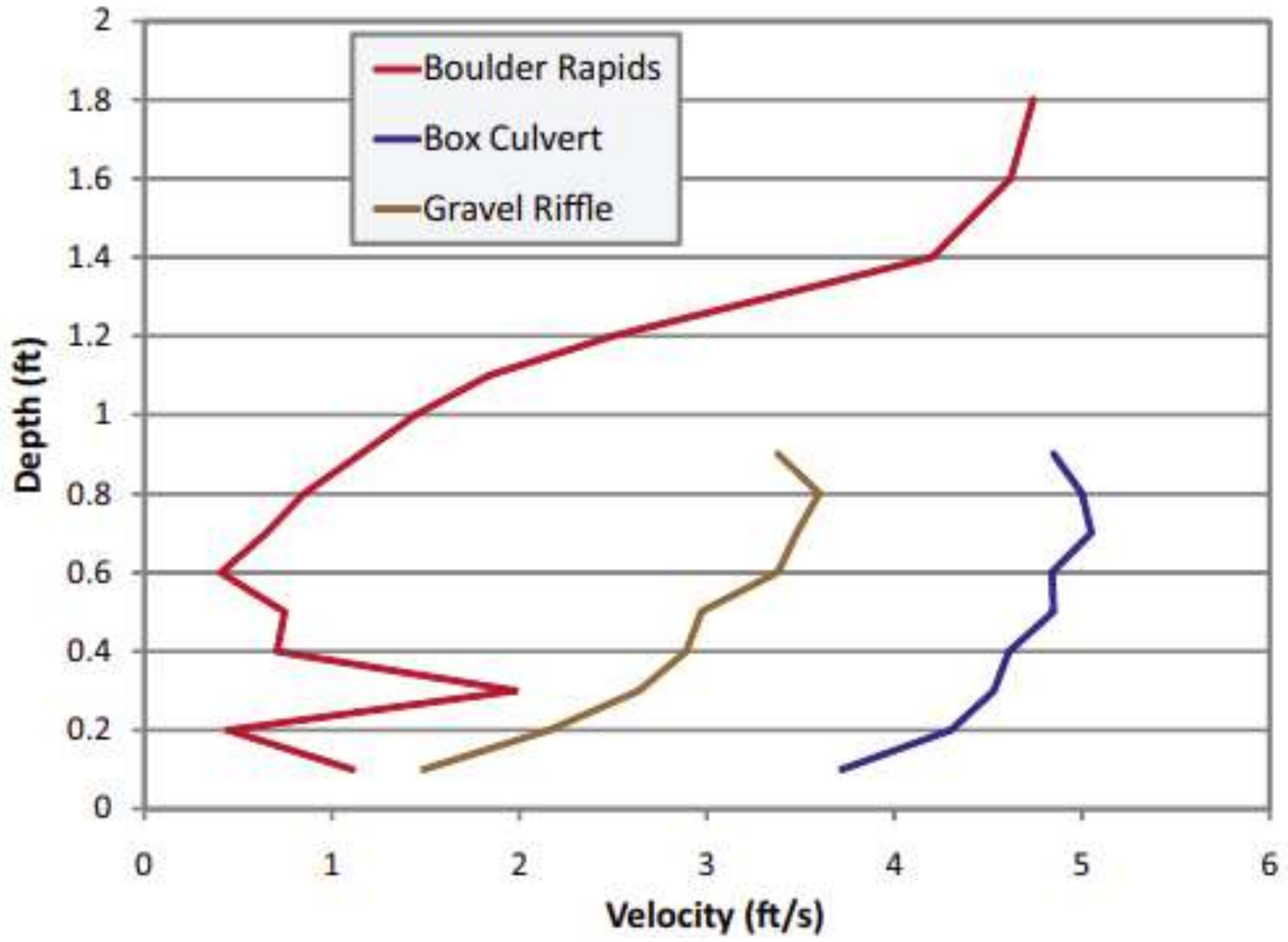
- River systems and fish passage are innately complex, natural phenomenon
- Building volumetric surface gives designer and contractor volumes for different materials
- Creating hydraulic models allows for output of required regulatory thresholds for project
- Gives regulatory staff and designers greater confidence project will maximize fish passage
- Detailed results in two-dimensions (results are depth averaged) for velocity, water depth, Froude number, and shear stress



Nature-like rapids two-dimensional hydraulic model output

What Models Were Used?

- Most common design and grading software
  - AutoCAD Civil3D
- Most common hydraulic modeling software
  - Hydrologic Engineering Center's (CEIWR-HEC) River Analysis System (HEC-RAS)
- Limitations
  - Models are only as good as their inputs and assumptions
  - Civil3D tools are much better at building roads and other linear plans. Makes modeling rivers and rapids challenging.
  - HEC-RAS can model rivers in one- and two-dimensions
  - Third dimension (depth) is averaged



Velocity profiles over three different substrate types in the Otter Tail River. The rock rapids profile was from a constructed fishway (Aadland, 2010)

What Are the Design Criteria?

- Collaborate with fish passage expert and local biologist
- Species
- Passage vs. time of year vs. flow
- Water depth (multiple flows – pick summer low flow to model minimum depth)
- Velocity (think about velocity in the depth column, fish burst speed, prolonged speed)
- Fish swimming performance (Voluntary swim performance vs. flumes or respirometers)
- Turbulence (subcritical vs. supercritical flow)
- Gap width between boulders and head differential between weirs
- Roughness, Slope, Substrate, Shear stress
- Vertical drops

Sturgeon swimming during low-flow conditions (provided by Dr. Luther Aadland)

Fish Velocity - River Velocity = Ground speed

Distance ÷ Ground Speed = Travel Time

River Velocity →

← Fish Swim Velocity

If Time to Exhaustion is < Required Travel Time, The Fish Will Not Pass

Schematic provided by Dr. Luther Aadland

Peak Swimming Speeds of Fish

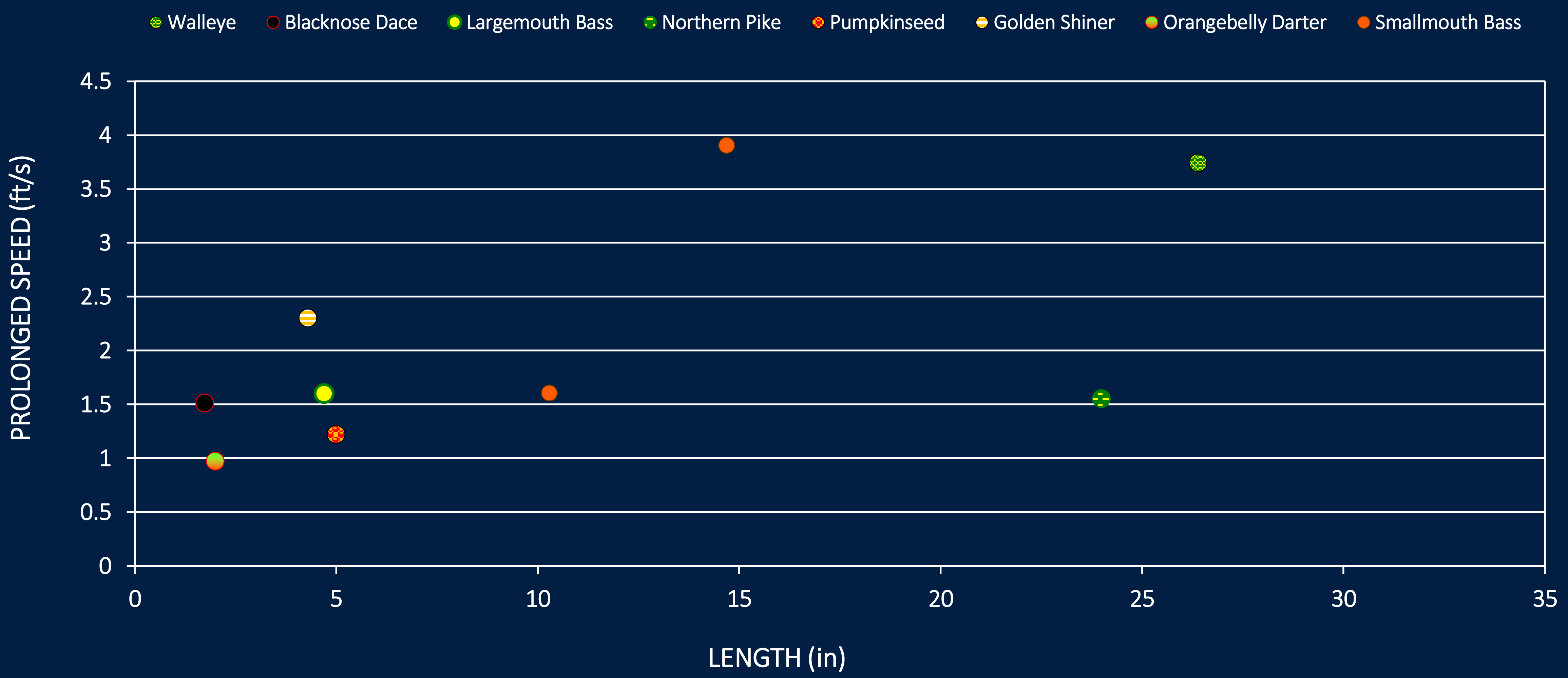
(Typically 8 to 10 lengths per second)

* Back-calculated from maximum jump heights
Burst speeds can be maintained for a few seconds or less
Sustainable swimming speeds are typically 30% of burst or less

Information provided by Dr. Luther Aadland

Prolonged Swimming Speeds of Freshwater Fish

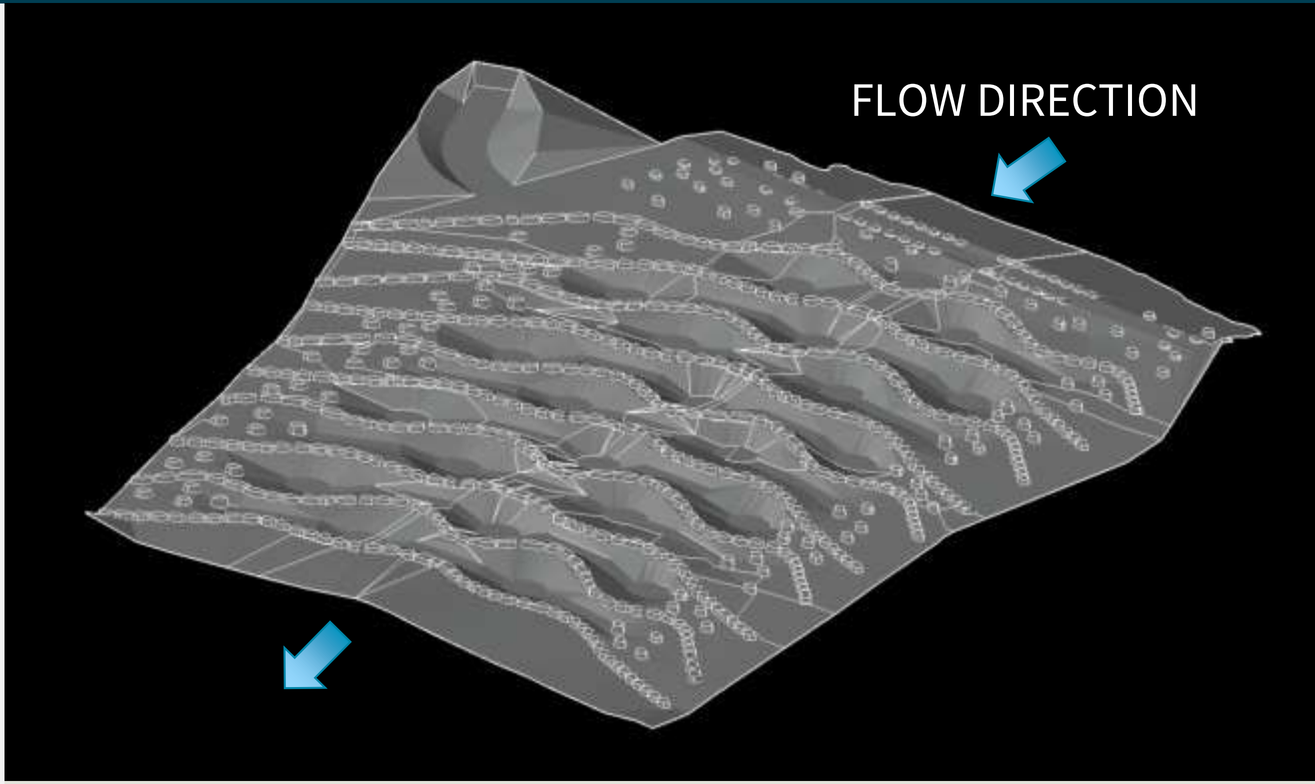
(typically 1 to 4 body lengths per second)



Information provided by Dr. Luther Aadland

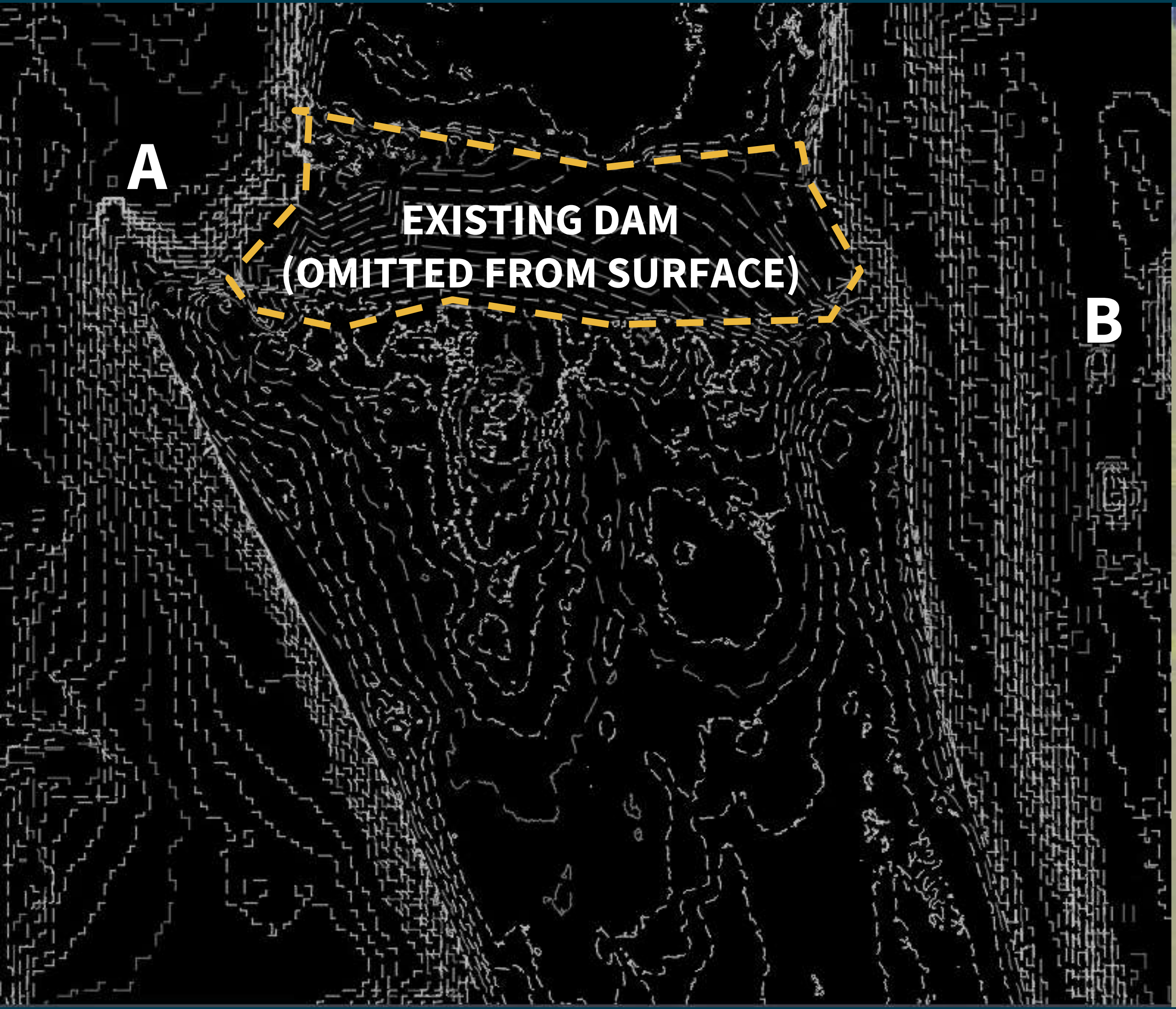
Design and Grading Model – AutoCAD Civil3D

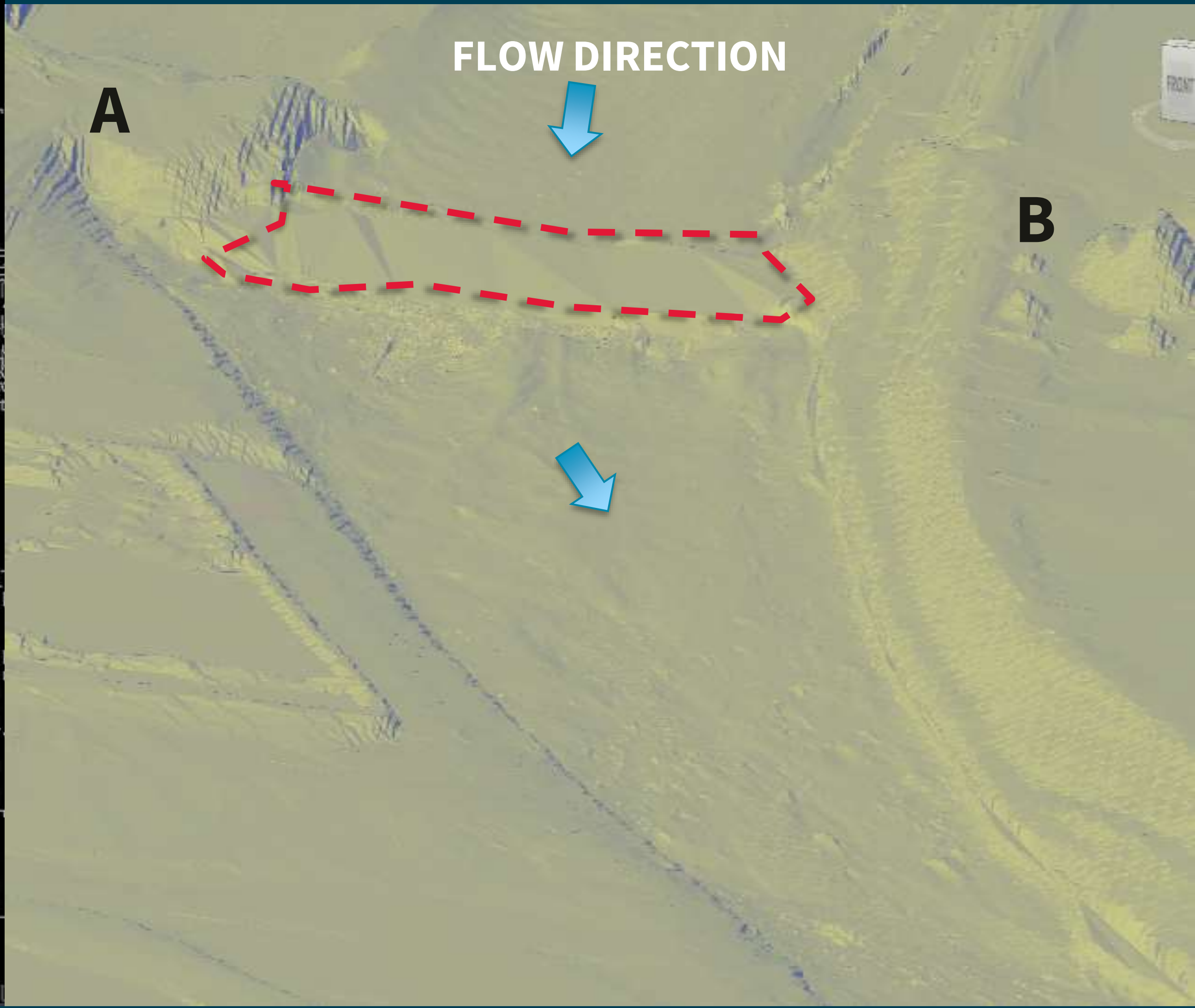
1. Import Existing Topographic and Bathymetric Data – Typically combination of public data and ground survey
2. Set tie-in points for rapids upstream and downstream and along both banks
3. Create feature lines for tie-in points in river between bottom of pool and bottom of boulders
4. Create feature lines for bottom of resting pools between each weir
5. Create feature lines for shallow excavation connecting resting pools
6. Create feature lines for bottom and top of boulders, copy/paste or use array to place boulders along weir footprint
7. Volume comparison surface



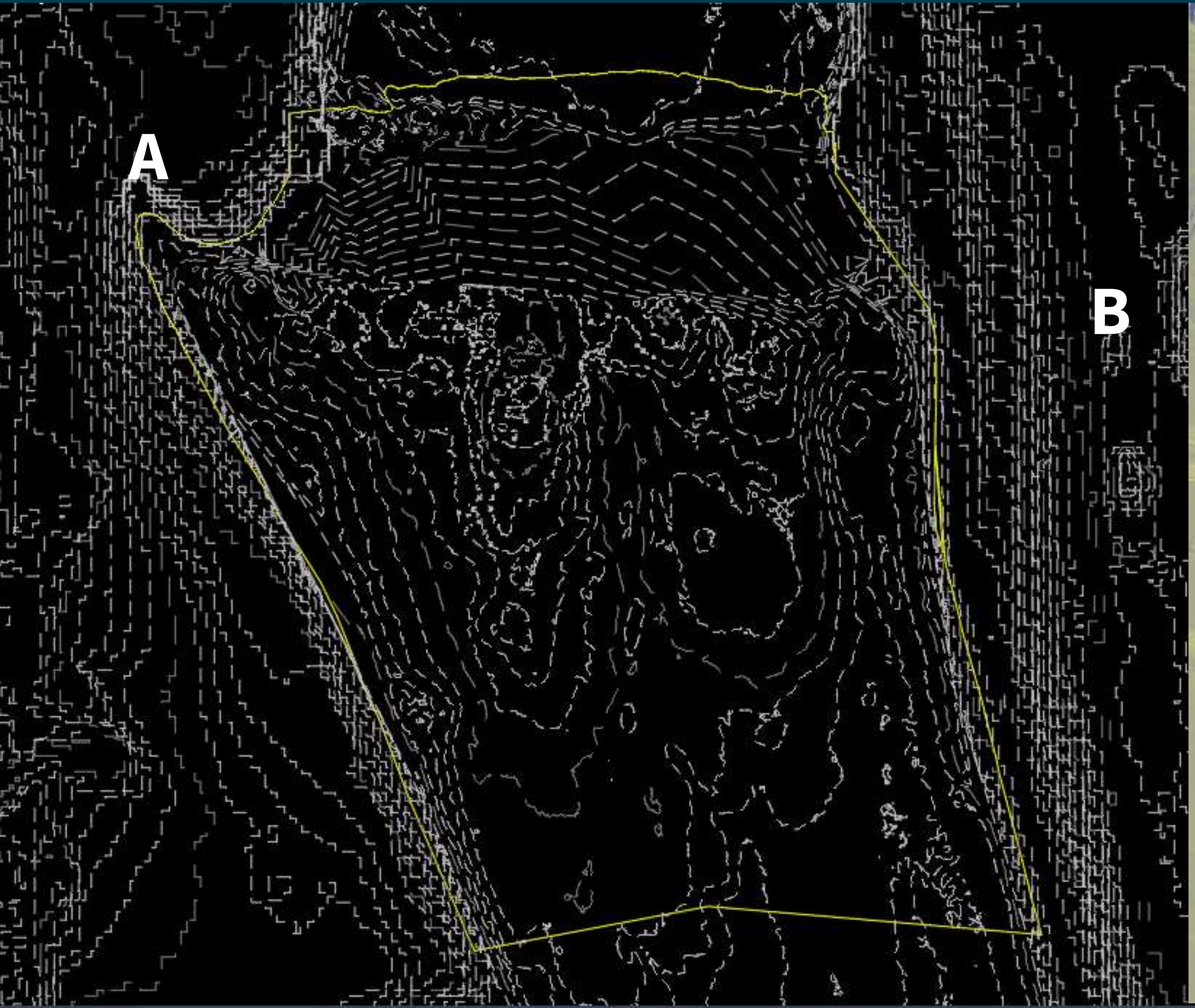
Rendering of nature-like rapids from AutoCAD Civil3D

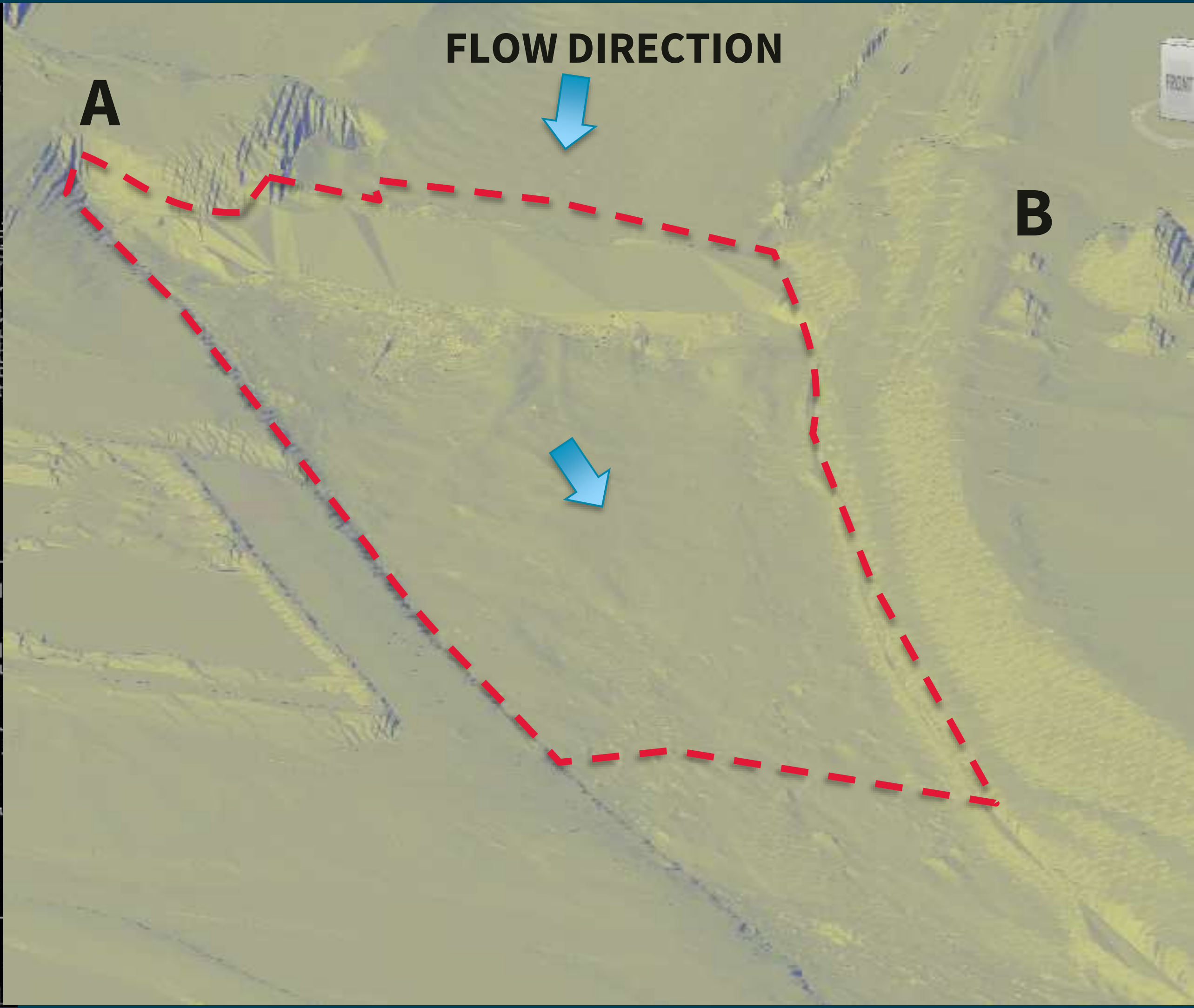
1. Import Existing Topographic and Bathymetric Data



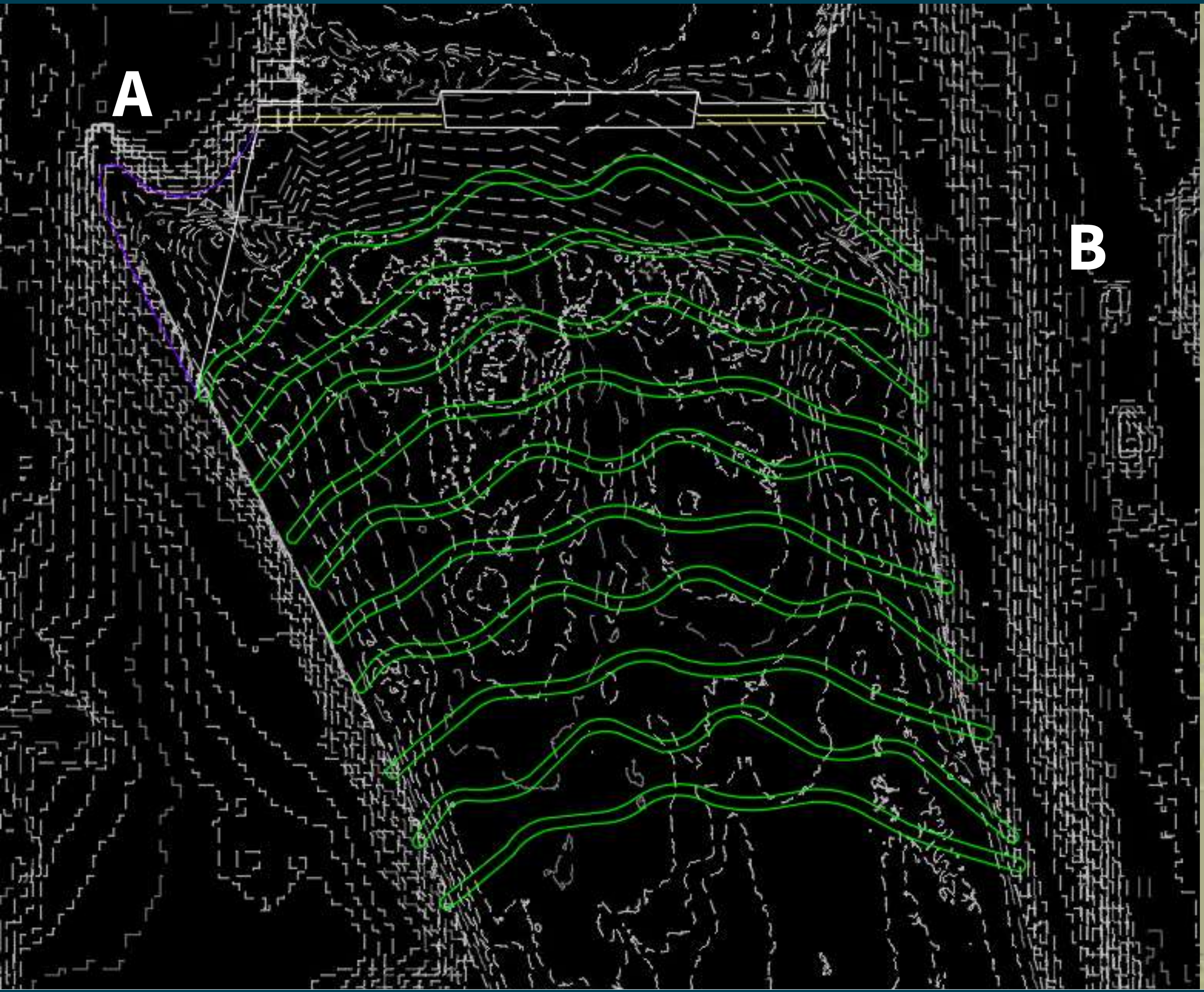


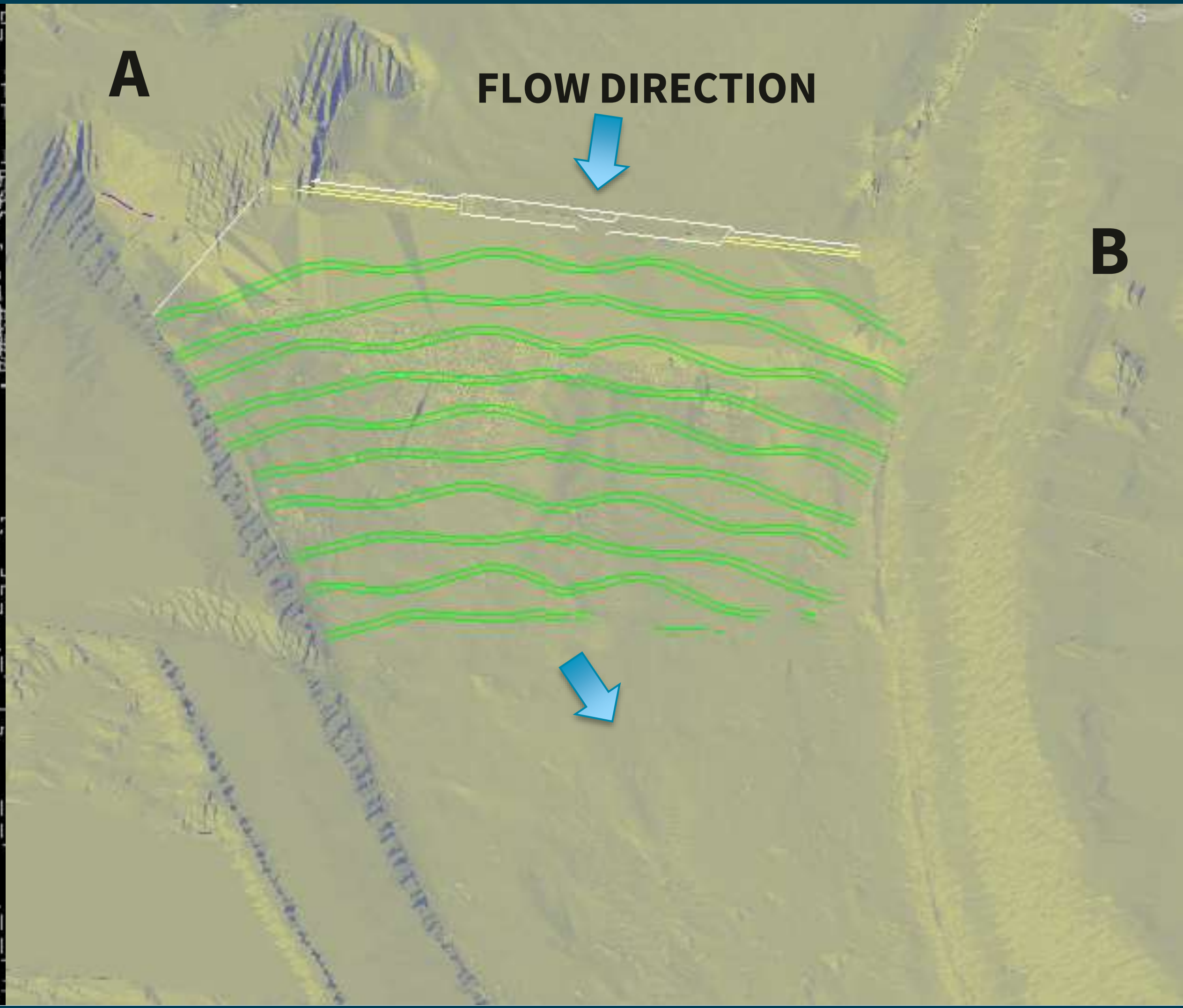
2. Set Tie-in Points for Rapids



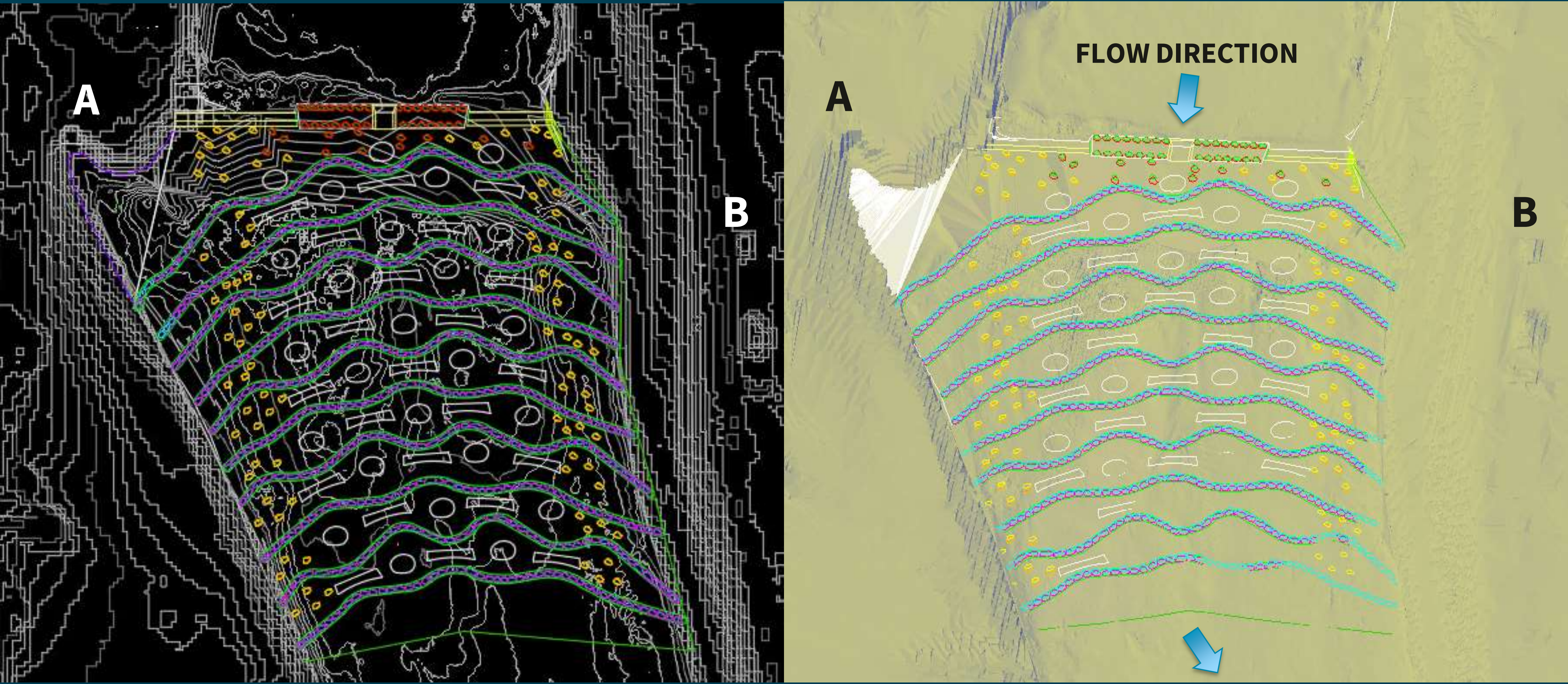


3. Create Feature Lines between Bottom of Pool and Bottom of Boulders

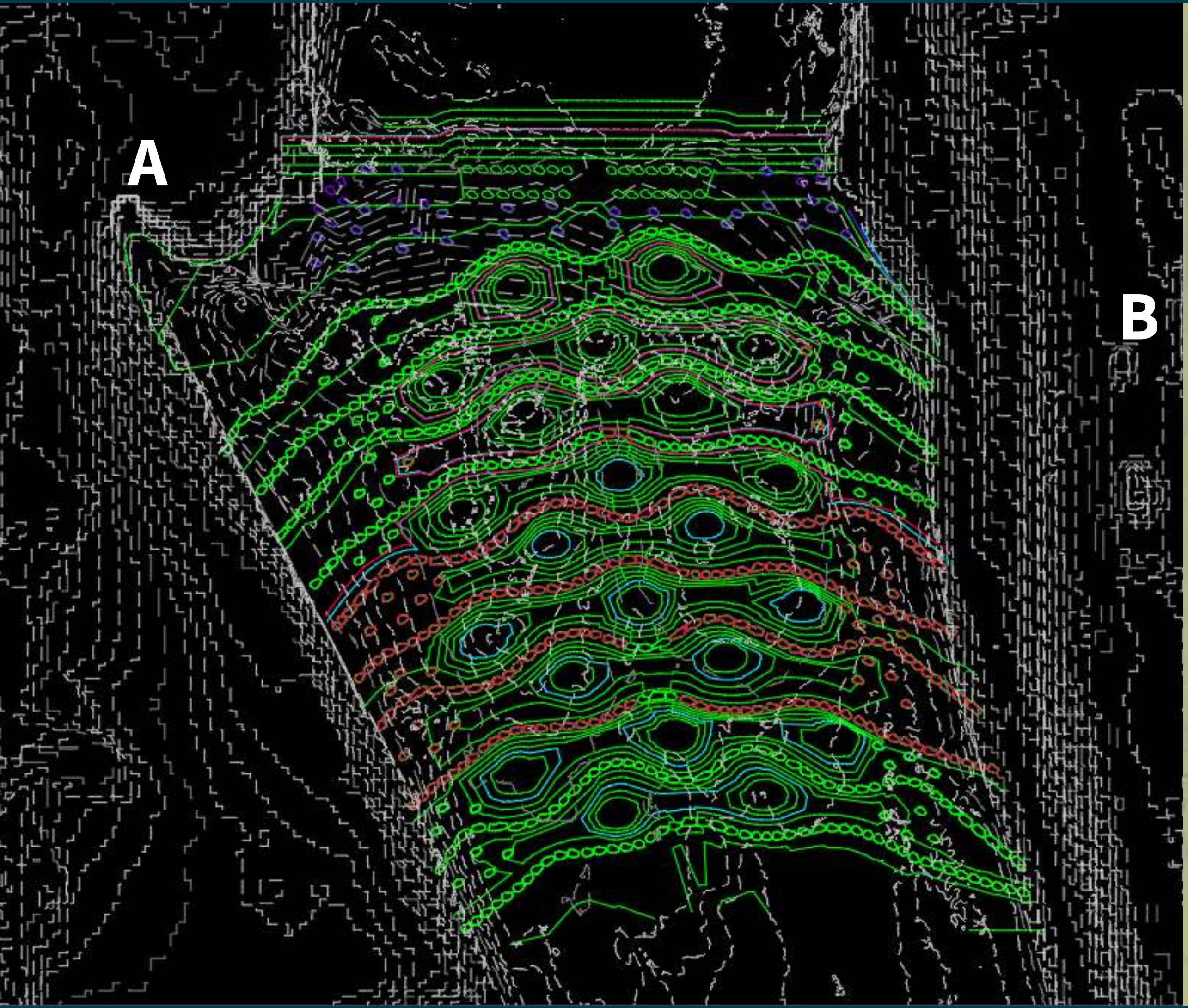


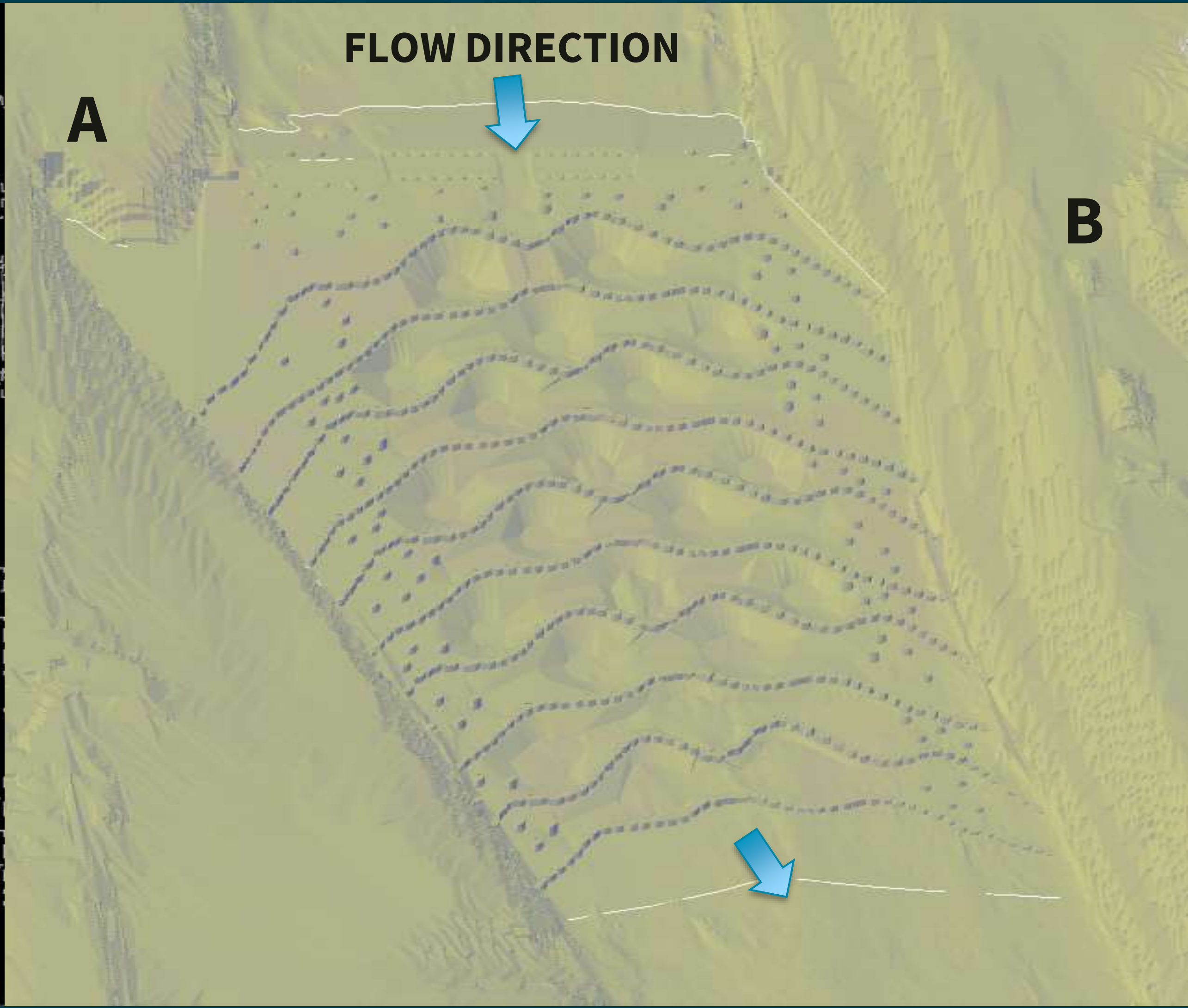


4-6. Feature Lines for Boulders (Bottom/Top), Pools, and Connections



7. Volume Comparison Surface





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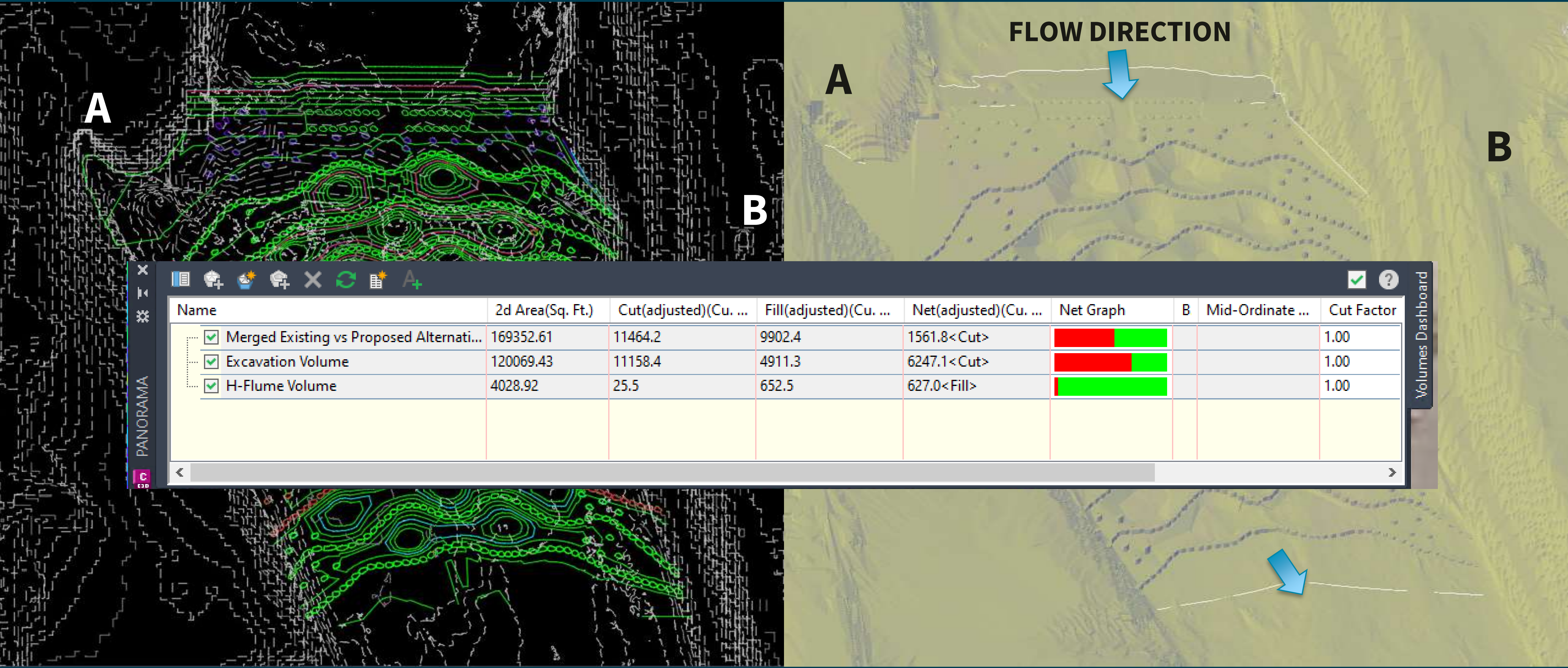

Name	2d Area(Sq. Ft.)	Cut(adjusted)(Cu. ...	Fill(adjusted)(Cu. ...	Net(adjusted)(Cu. ...	Net Graph	B	Mid-Ordinate ...	Cut Factor
Merged Existing vs Proposed Alternati...	169352.61	11464.2	9902.4	1561.8<Cut>				1.00
Excavation Volume	120069.43	11158.4	4911.3	6247.1<Cut>				1.00
H-Flume Volume	4028.92	25.5	652.5	627.0<Fill>				1.00

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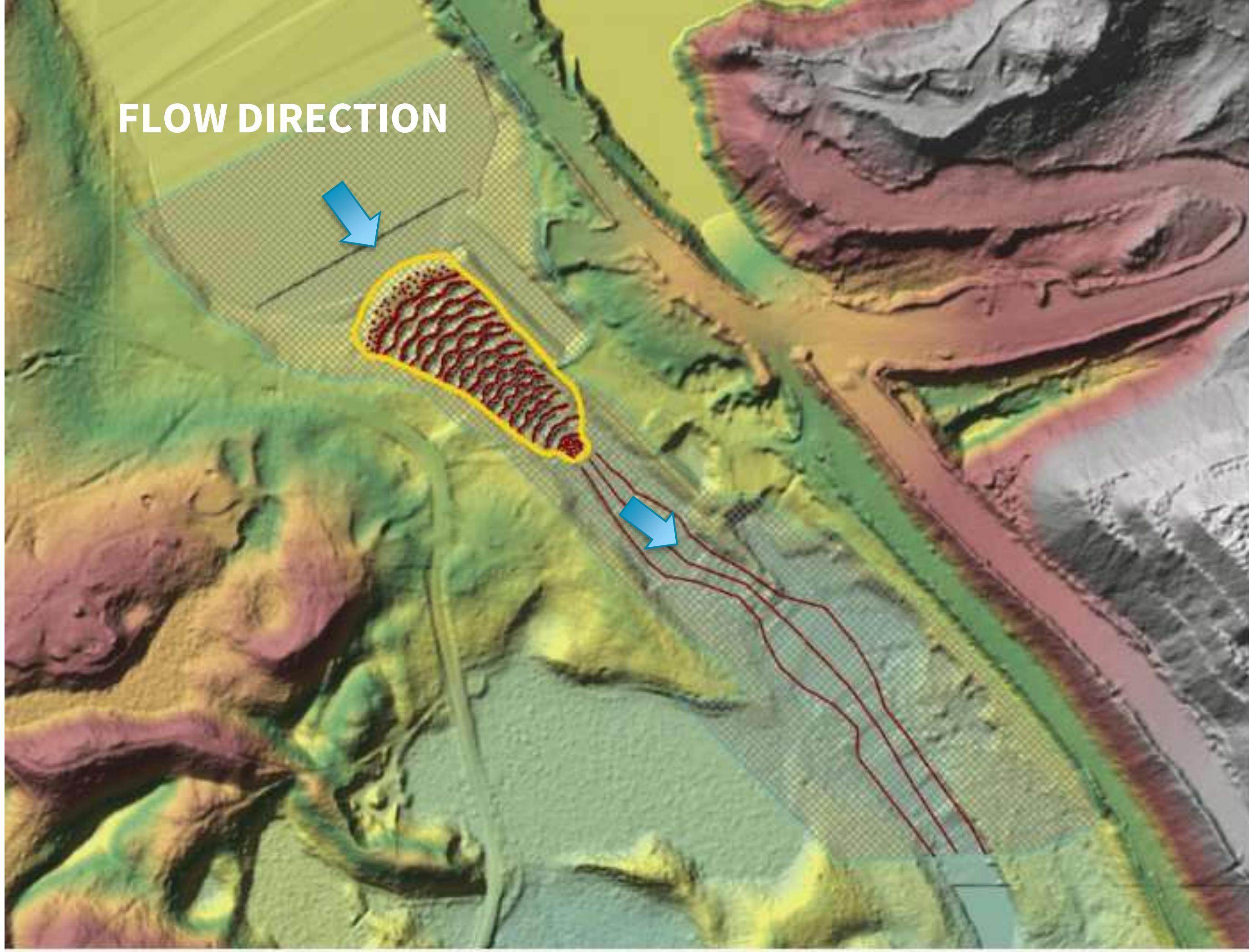
Hydraulic Model – HEC-RAS 2D

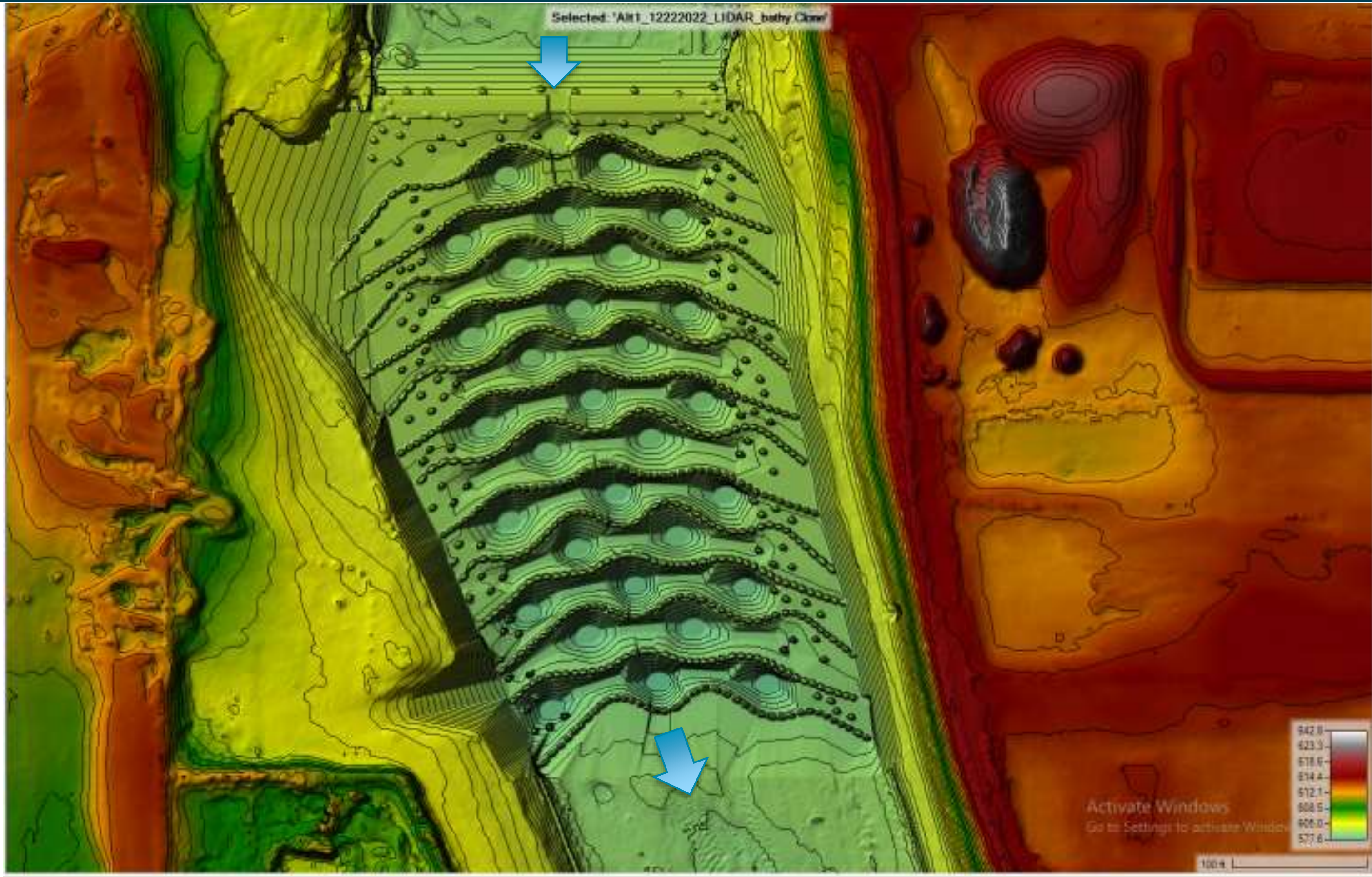
1. 1D Model, steady state can be used to run more efficient models
2. Run full momentum unsteady equation for detailed velocity evaluation
3. Import rapids terrain and merge with existing terrain.
4. Develop 2D mesh for model run
5. Input hydrograph for different flow events
6. Increase Manning's n to represent boulder roughness (0.048 – 0.08)
7. Geometry pre-processor (quick error check)
8. Set model to run overnight (multiple hours of run time)



Combined rock rapids and surrounding topography terrain

Import Rapids Terrain and Merge with Existing Terrain

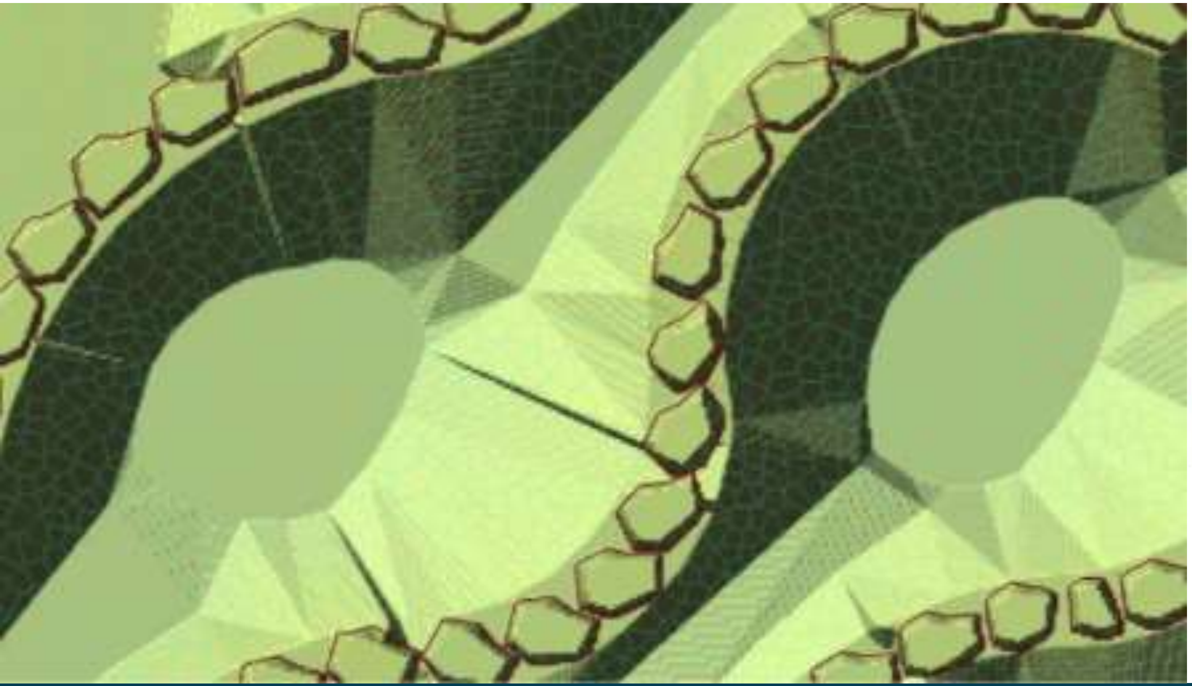
1. Set cell size
2. Layer multiple TIFF files
3. Check edges of proposed surface

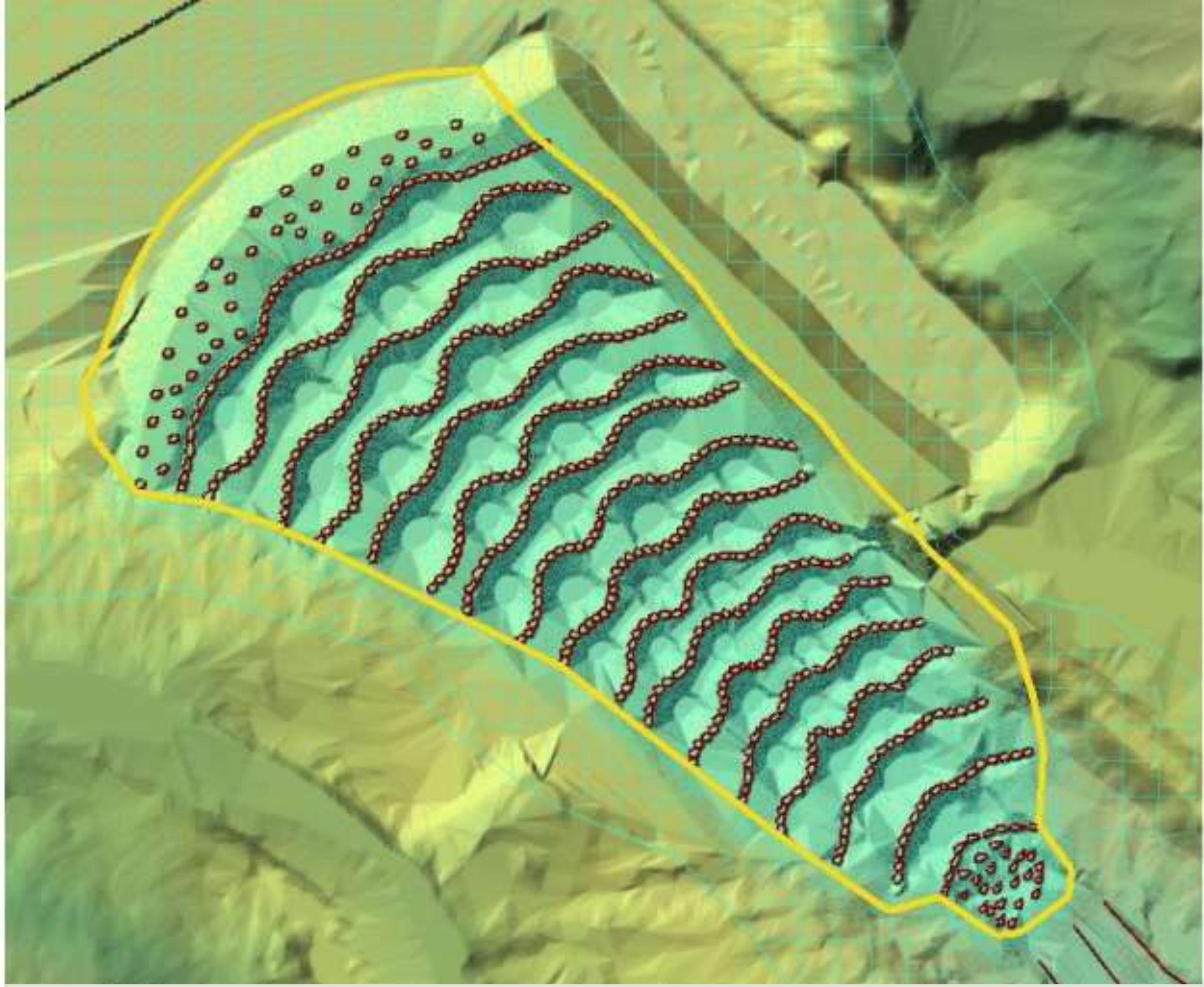


Merged Proposed and Existing Terrain

Develop 2D Mesh

1. 1-foot mesh spacing at rapids crest
2. 2-foot mesh elsewhere in rapids
3. Align mesh with weirs
4. Mesh size is inversely proportional to run time



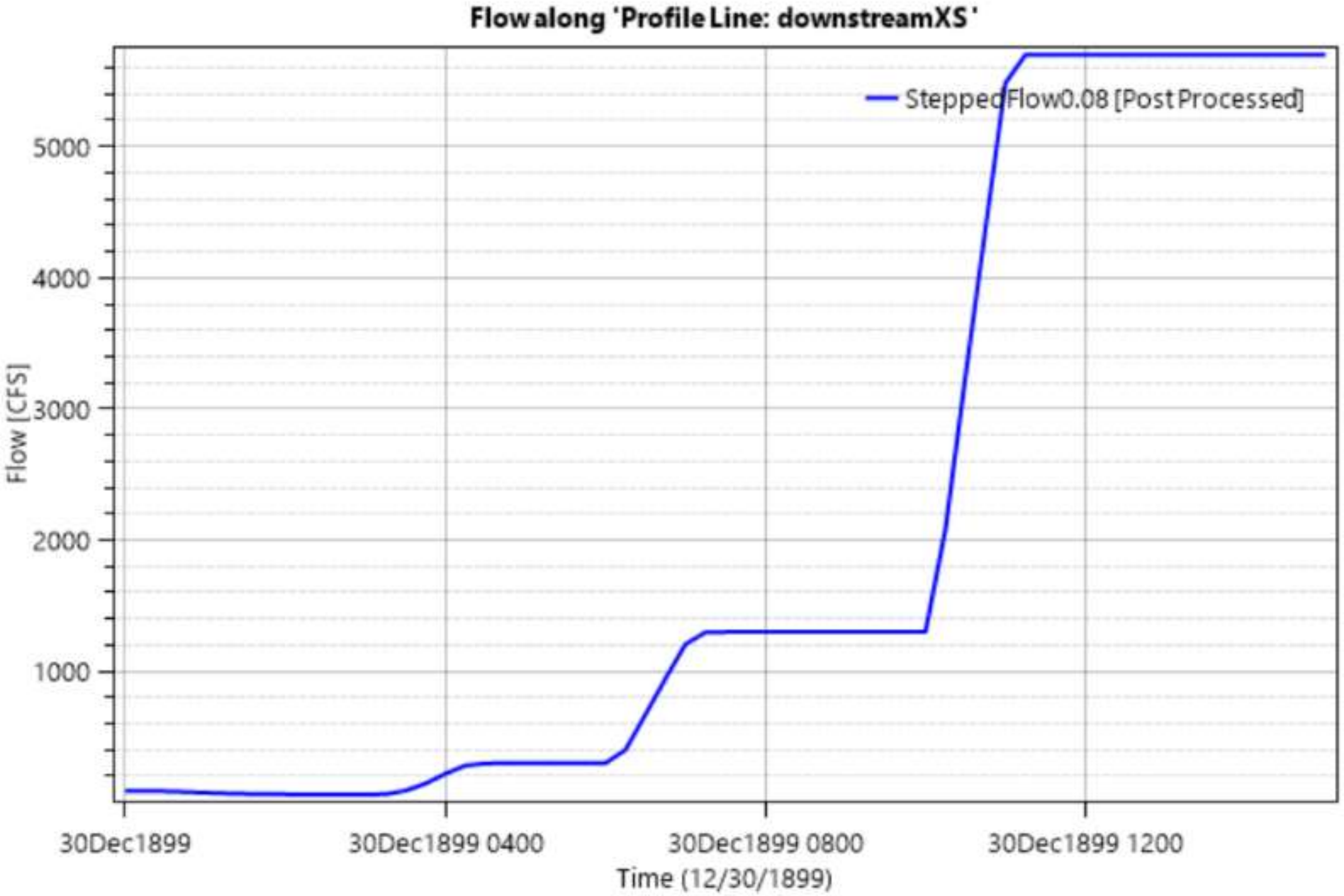


Rendering of nature-like rapids from HEC-RAS

Build Hydrograph for Multiple Flow Events

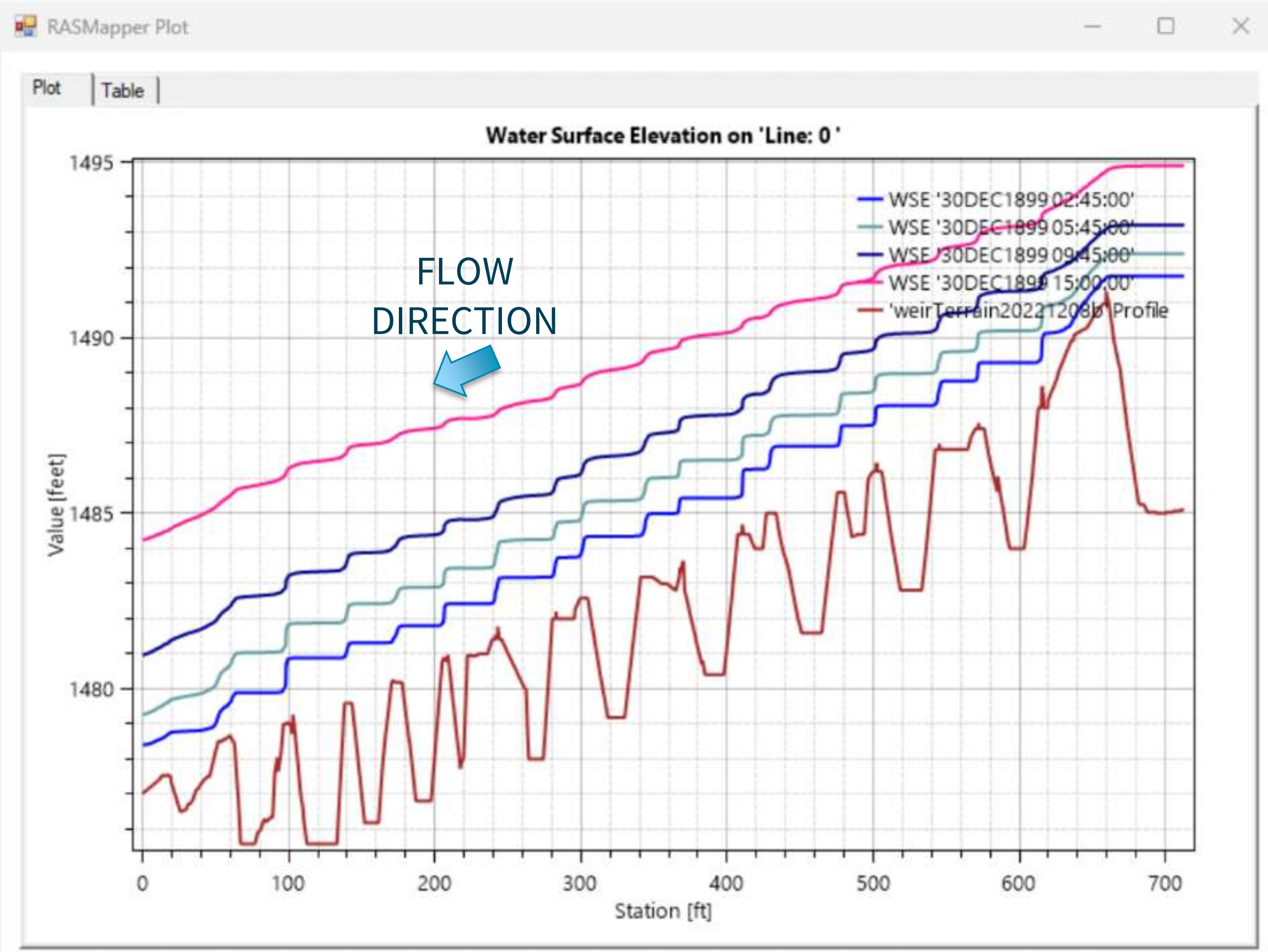
1. Select low, medium, and high flows
2. Allow for long enough time step for model to stabilize
3. Avoids multiple flow files

	Flow	Time
Summer Low Flow	60 cfs	02:45
Average Daily	300 cfs	05:45
Bankfull	1300 cfs	09:45
100-Year	5700 cfs	15:00



One hydrograph representing multiple flows in HEC-RAS

Interpreting Results – Water Surface Elevation



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Summer Low Flow	60 cfs	02:45
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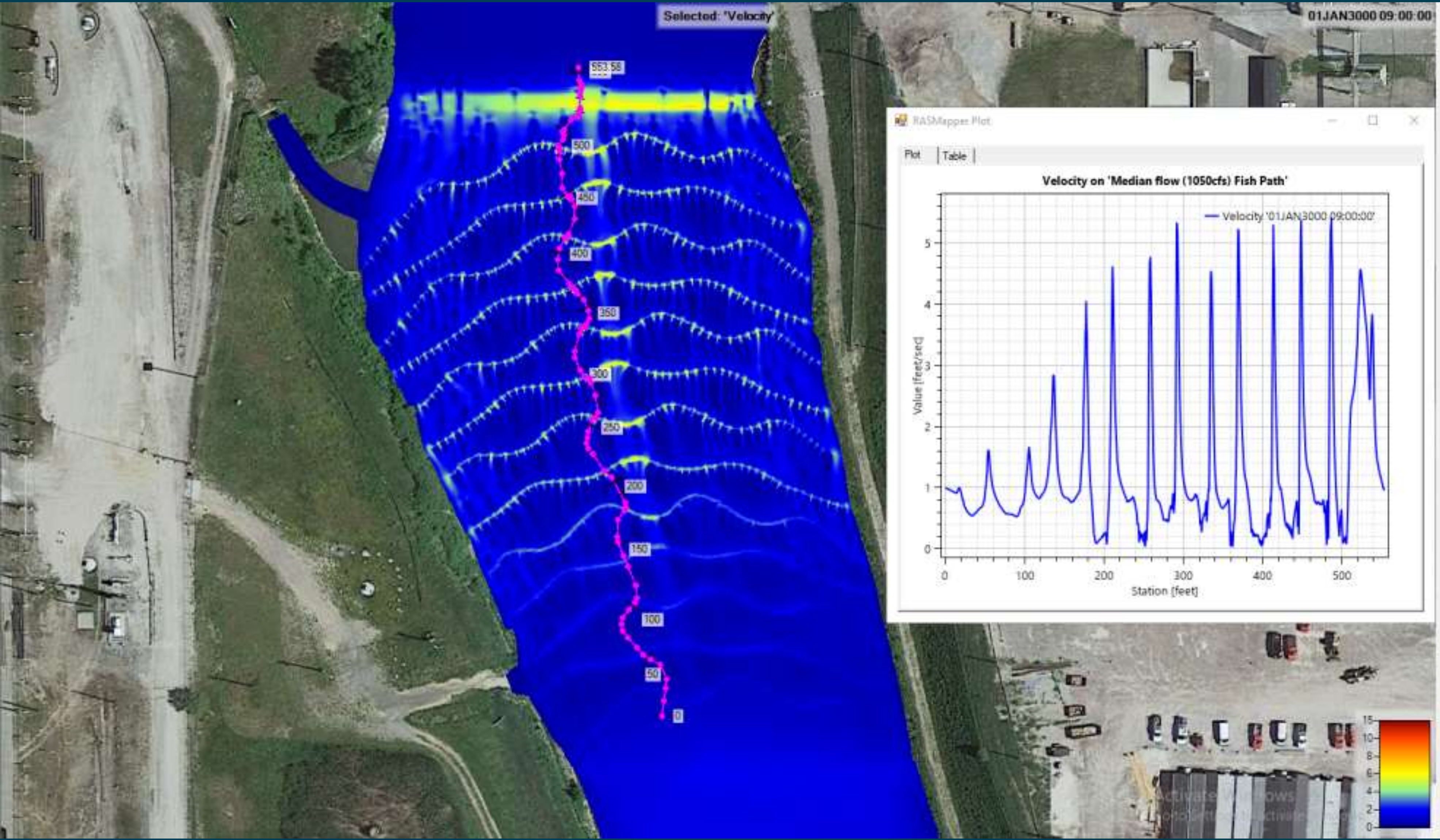
Bankfull	1300 cfs	09:45
100-Year	5700 cfs	15:00

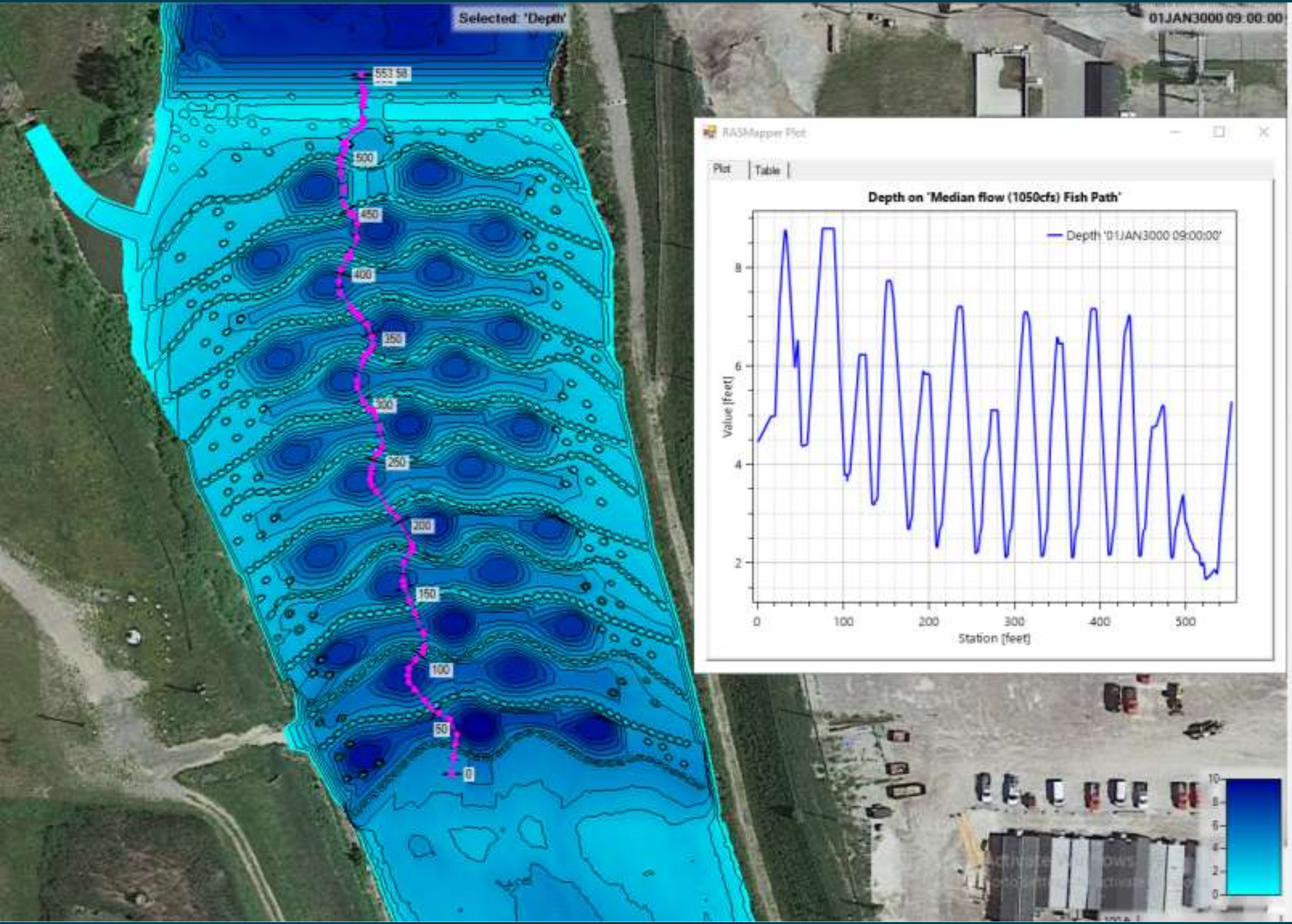
Results mapper showing rapids and water surface elevation for multiple flow events.

Interpreting Results – Velocity



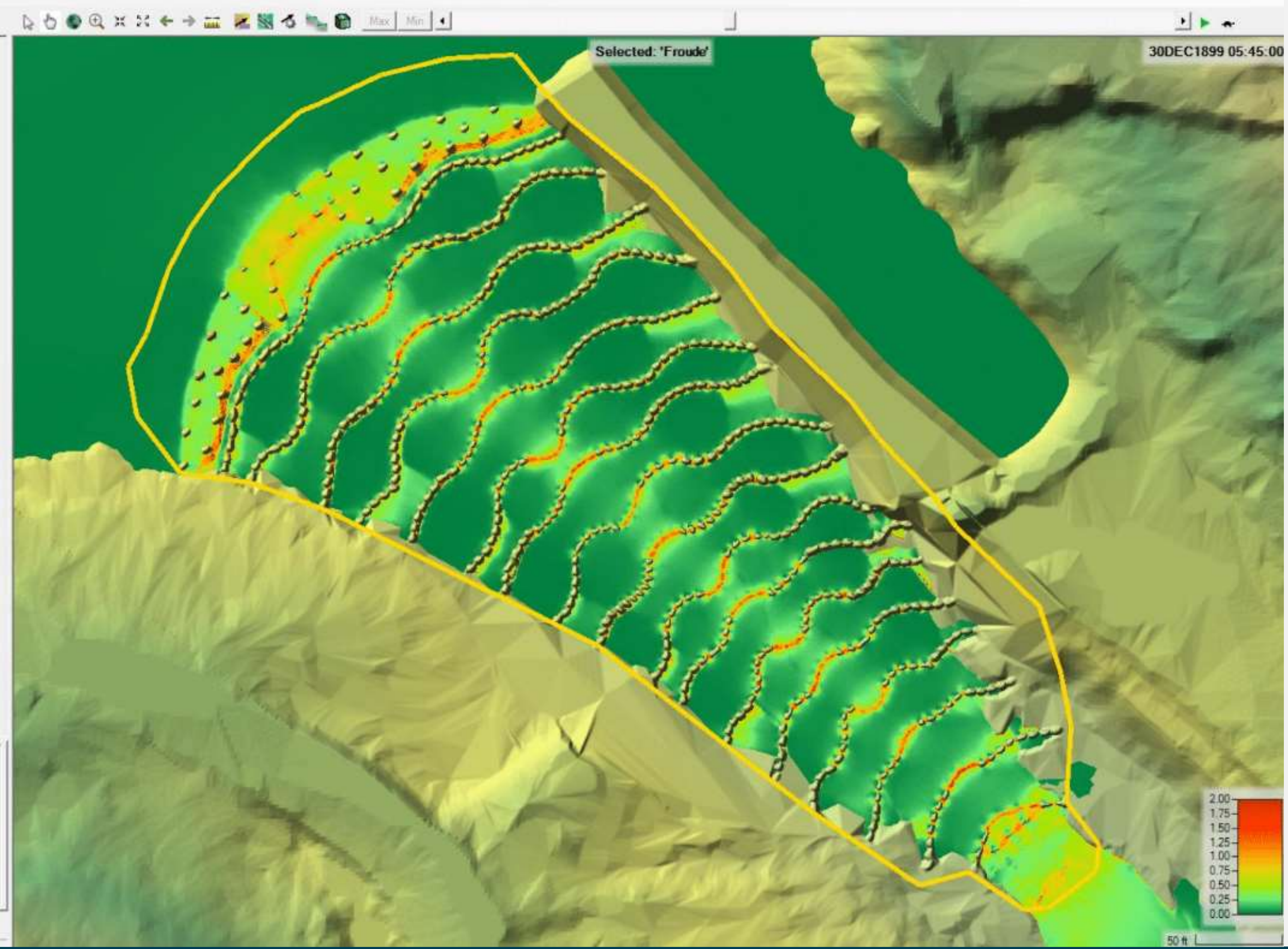
Results mapper showing velocities along selected flow path during April median flow.

Interpreting Results – Water Depth



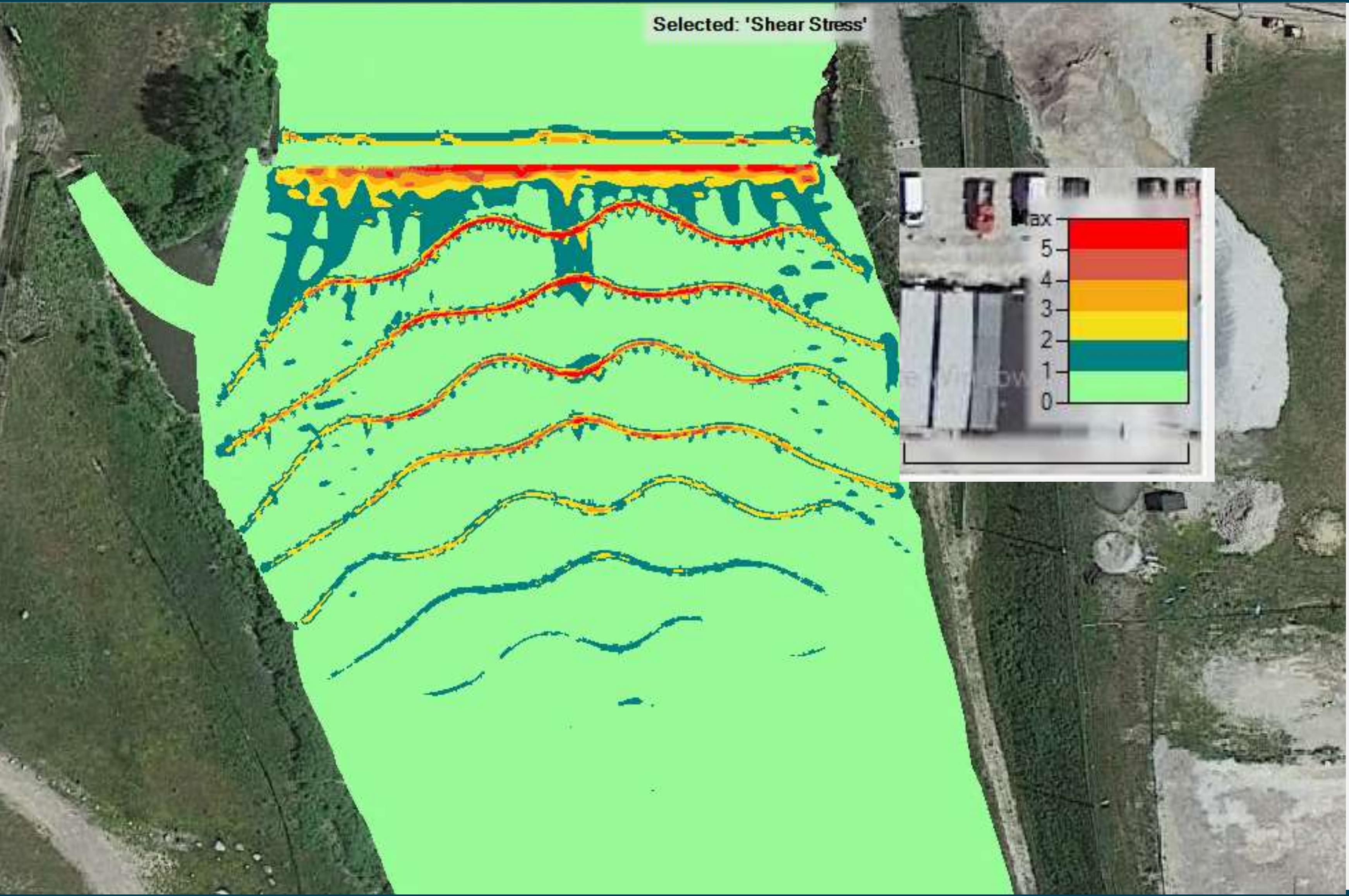
Results mapper showing water depth along flow path for Average Daily Flow.

Interpreting Results – Froude Number



Results mapper showing sub- and supercritical flow for Average Daily Flow.

Interpreting Results – Shear Stress



Results mapper showing shear stress values for April median flow.



GEI Consultants

Thank you for all you do to keep our rivers flowing, floodplains wide, and resources protected!

Samuel Prentice, P.E.
Marquette, Michigan
sprentice@geiconsultants.com
517-897-2843