Hydraulic modeling of the Maple River aqueduct

2024 Fargo-Moorhead Area Diversion Conference

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Project Sponsors

US Army Corps of Engineers® St. Paul District

Metro Flood Diversion Authority

City of Fargo

Moorhead Minnesota

Modeling Partners

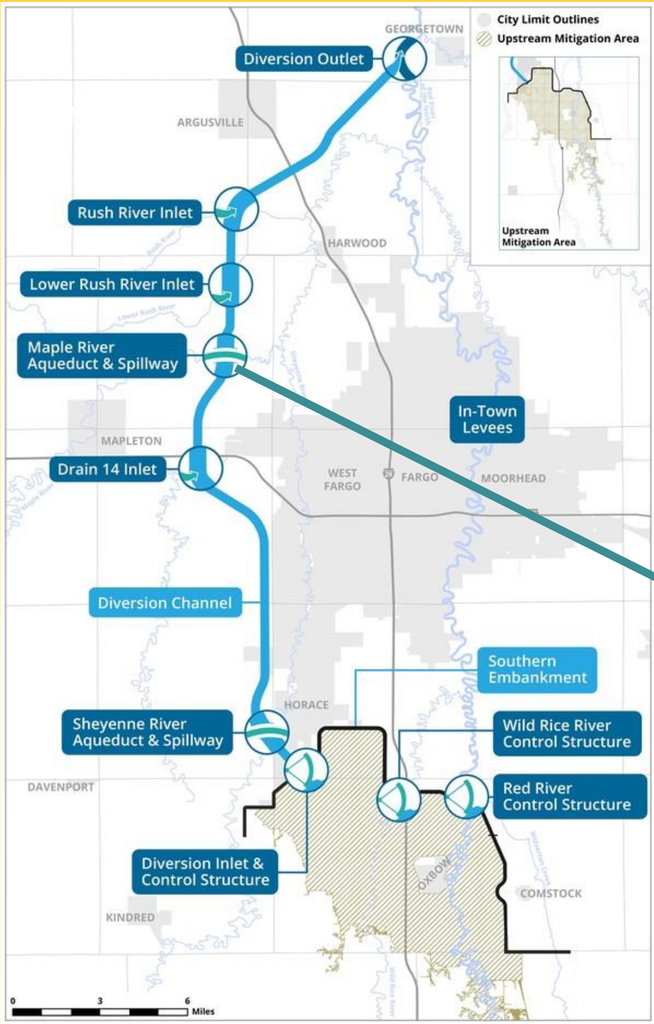
Hanson

HDR

Bergmann associates — architects // engineers // planners

CRREL Cold Regions Research and Engineering Laboratory — ERDC

Overview - Maple River aqueduct & spillway system



Credit: Metro Flood Diversion Authority

Diversion channel crosses the Sheyenne and Maple Rivers

- Aqueduct carries **entire** Maple River flow over diversion **at low discharges (less than 2-year events)**
- Spillway inlet diverts **excess** flows from Maple River into diversion for **higher discharges**
- Diversion passes under aqueduct while **maintaining** respective **inverts** and minimizing diversion **head loss**

Unique features (even for aqueducts)

- Sub freezing winter temperatures in Fargo- Moorhead area
- Maple And Sheyenne aqueducts carry natural rivers over man-made structure.

Test: L7

Tributary Inflow: 7000cfs
Diversion Inflow: 23500cfs

Date: January 13, 2015

Project team

- Bergman, Hanson, HDR Joint Venture under USACE – St . Paul District focusing on numerical modeling
- St. Anthony Falls Laboratory physical modelers
- Specialized ice modeling by Cold Regions Research and Engineering Laboratory – USACE
- <u>Work from 2012 to 2015</u>

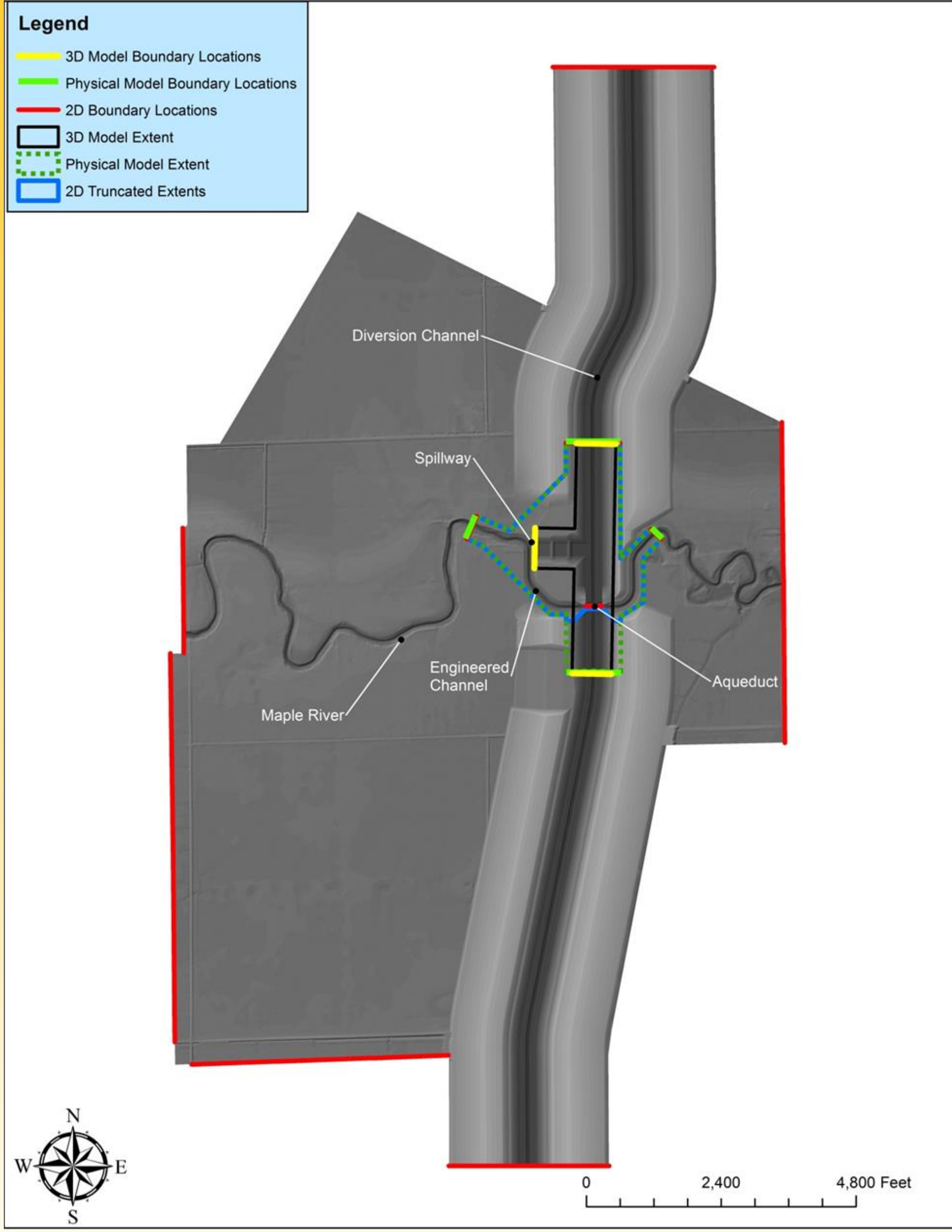
Modeling goals

- Optimize geometry of aqueduct, spillway and engineered channels.
- Determine areas of ice buildup
- Determine effects of debris blockage in diversion conduits under aqueduct
- Measure velocities in the channels and spillway to determine extent and material for erosion mitigation
- Optimize hydraulic connectivity/fish passage along the Maple River across the aqueduct.
- Optimize passage of Maple River excess flows into the diversion channel while maintaining natural flow in the for normal conditions.
- Determine if only numerical modeling can be used to design the Sheyenne River Aqueduct of other modifications. Build confidence in models.

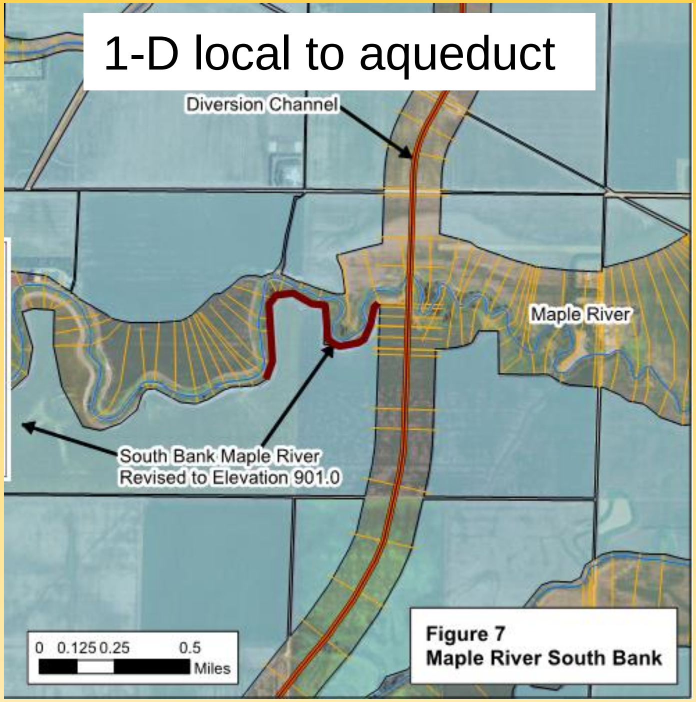
Optimization effort using multiple models and design meetings

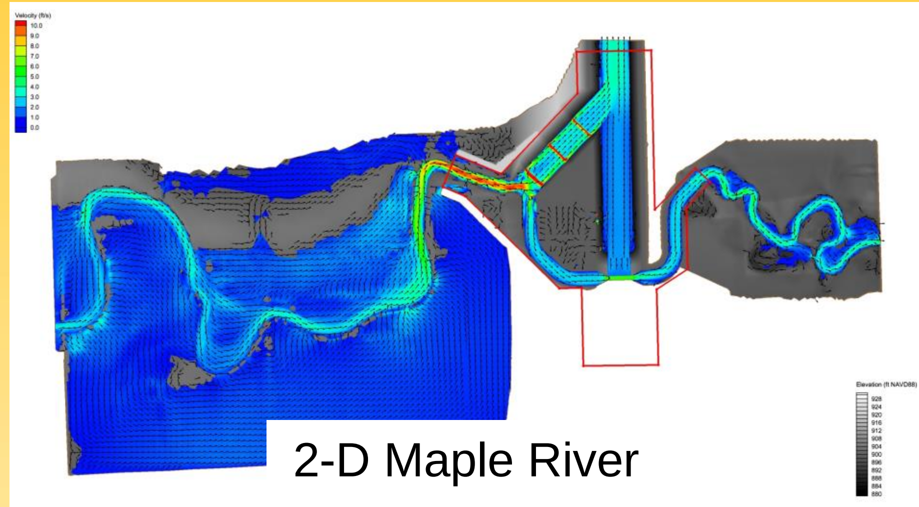
- 1-D model (HEC-RAS) – large scale model of
- 2-D model (AdH) - identifies Maple River flow split and erosive flows
- 3-D model (Flow 3D®)- assesses flow through conduits and turbulence in the diversion channel
- Physical model used for numerical model validation and detailed measurements

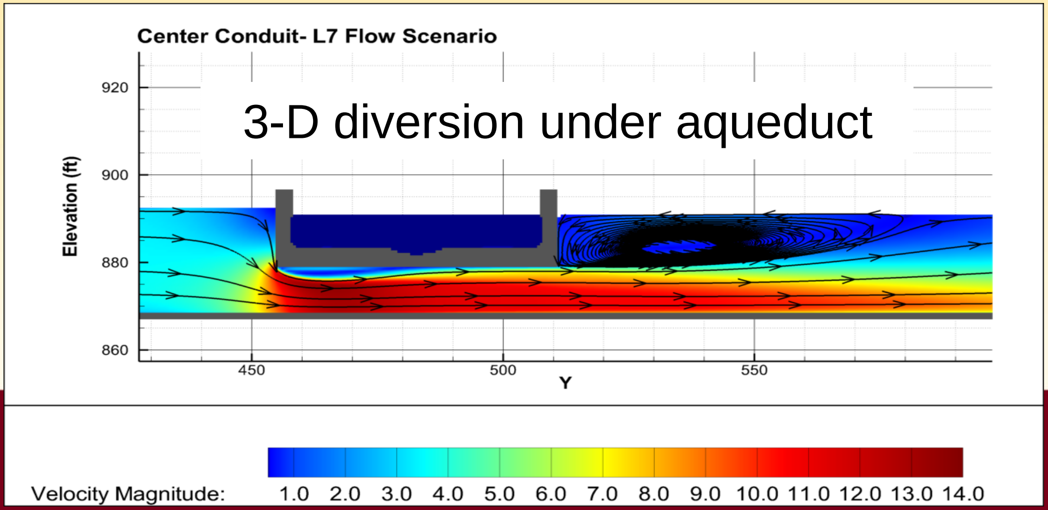
- Initial design meeting
- Initial testing
- Iterative design optimization process using appropriate models
- Intermediate Results Workshop
- Remodel with optimizations and detailed testing for four flow scenarios
- Reporting

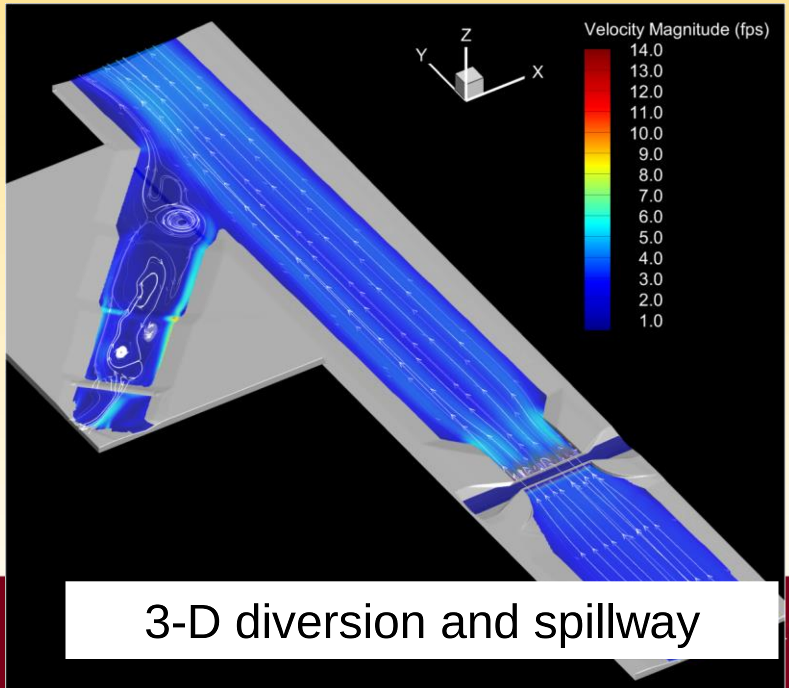


Numerical models







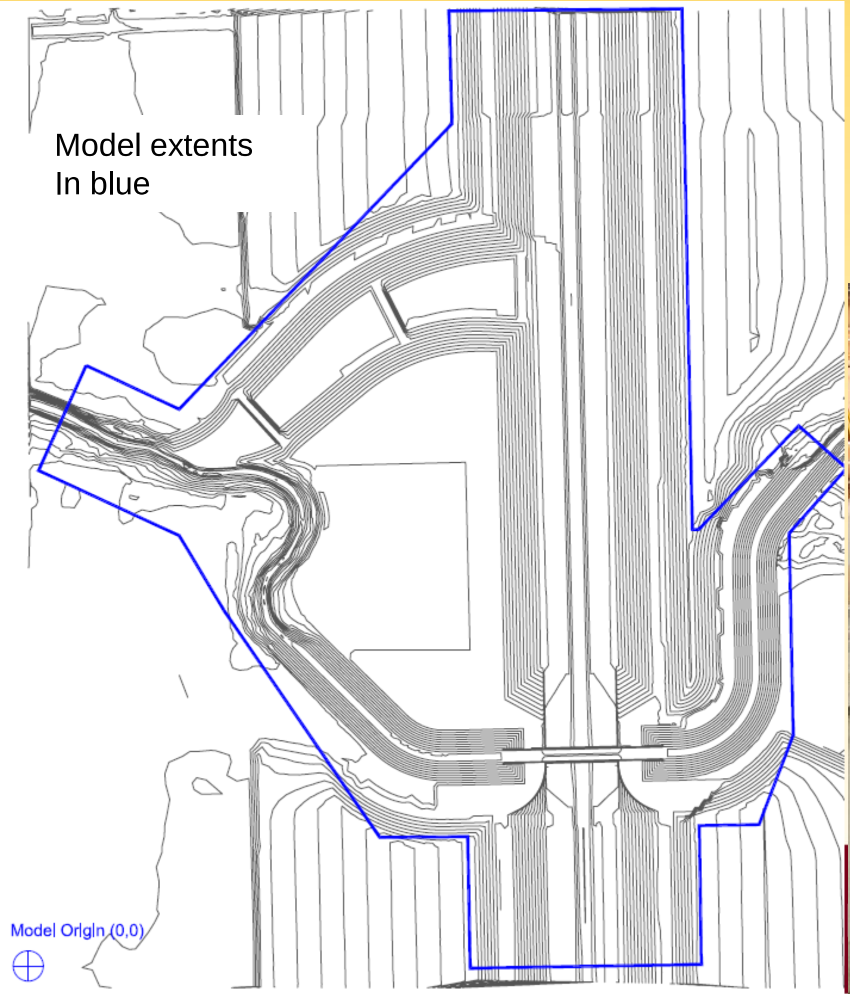


Physical model specs

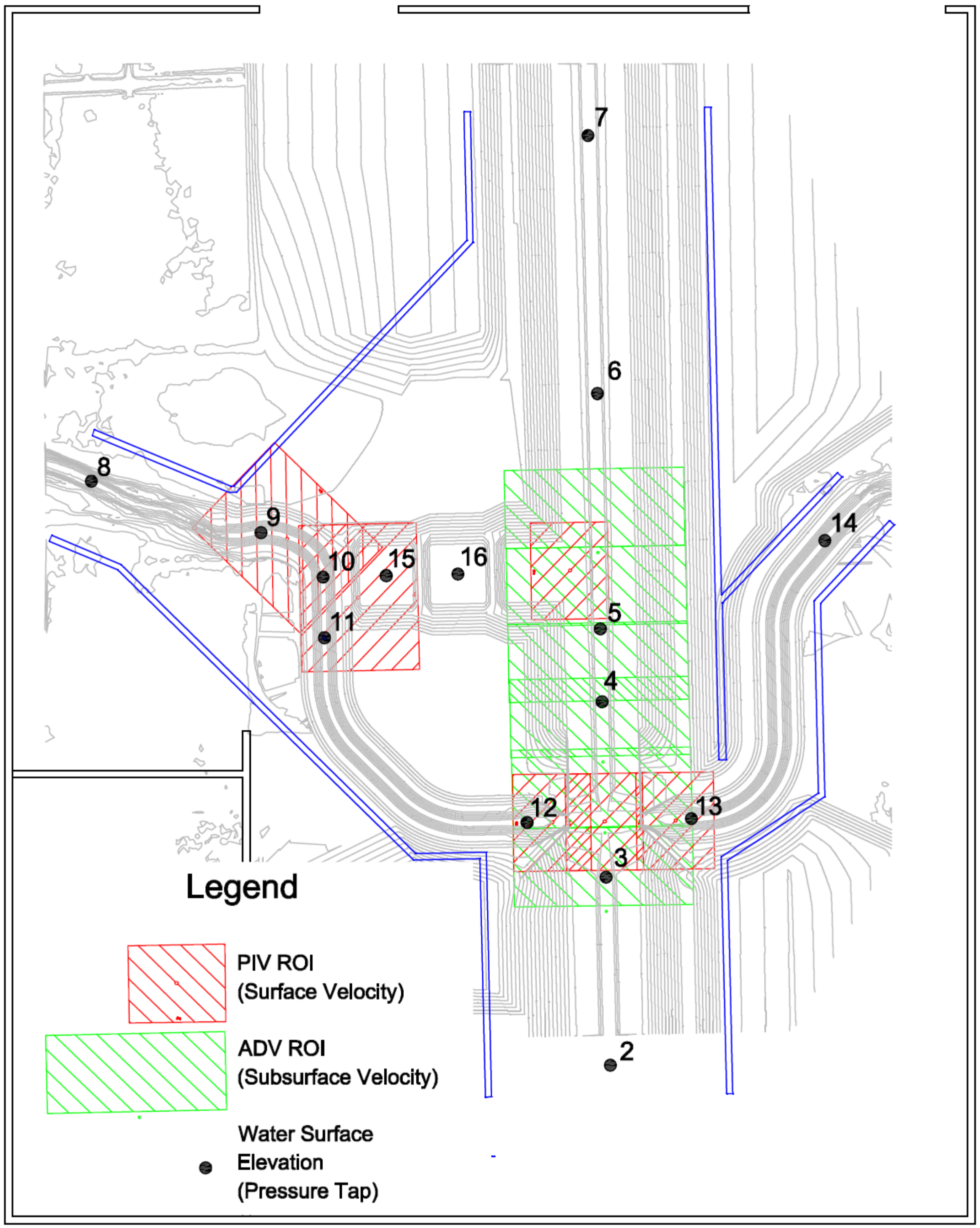
- Froude scaled, 1:50 undistorted length scale
- Model size ~80 feet by 60 feet
- Prototype ~4000 feet by 3000 feet
- Stage-discharge curve for tailwater control

Froude scaled parameters

Parameter	Relationship	Scale
Length	L_r	1:50
Velocity	$L_r^{1/2}$	1:7.07
Flowrate	$L_r^{5/2}$	1:17,678
Time	$L_r^{1/2}$	1:7.07
Pressure	L_r	1:50
Manning's *n*	$L_r^{1/6}$	1:1.92
Reynolds Number	$L_r^{3/2}$	1:354
Bed Shear Stress	L_r	1:50



Physical model instrumentation



- Water surface elevations
- Surface velocities (tributary)
- Subsurface velocities (diversion channel in vicinity of aqueduct and at spillway/diversion confluence as depth allows)
- Discharge (upstream tributary and diversion channel, downstream tributary)
- Simulated local ice transport and effects (tributary)
- Dynamic pressures (diversion channel under aqueduct)

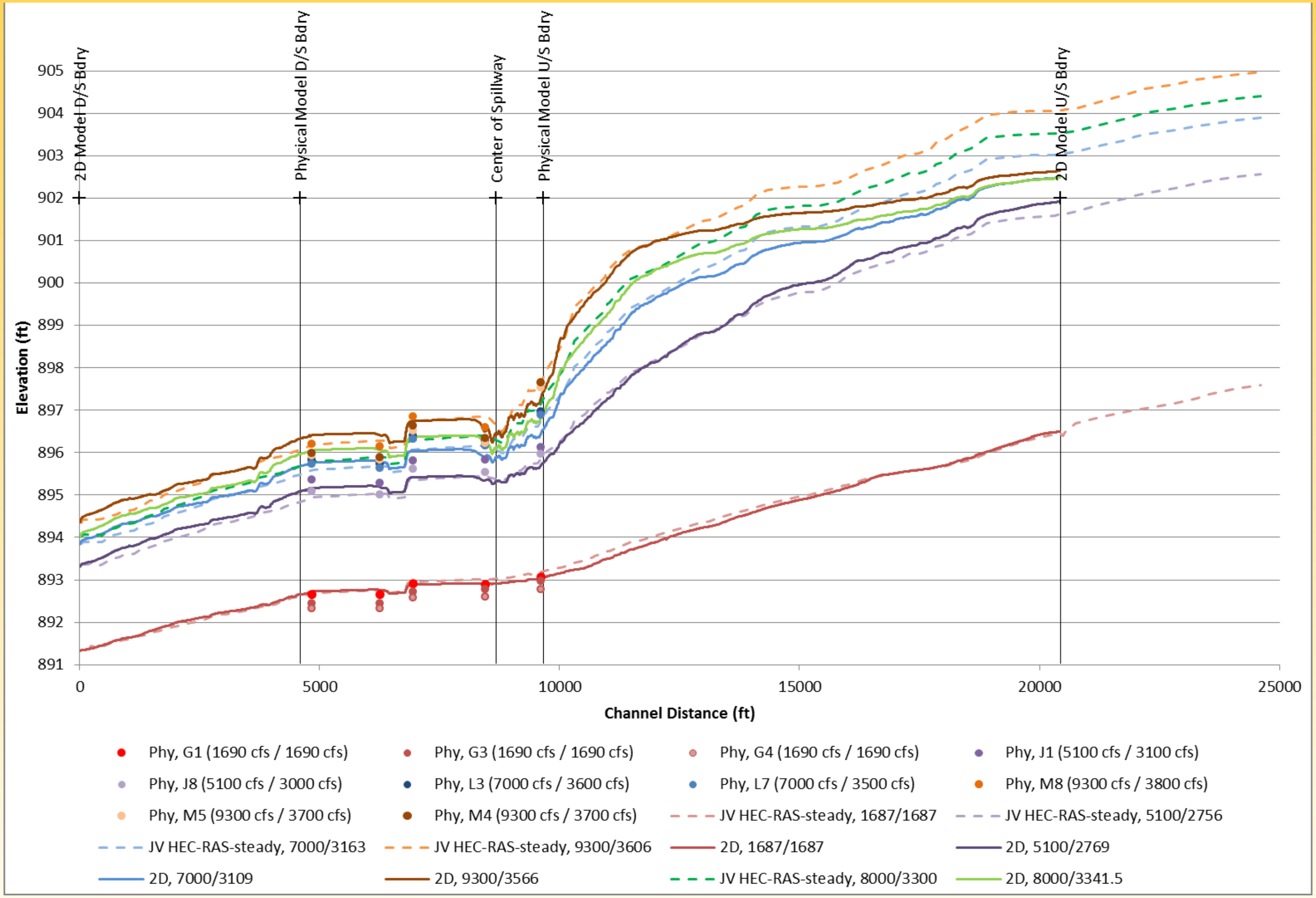
Physical model construction

Open house held July 24, 2014

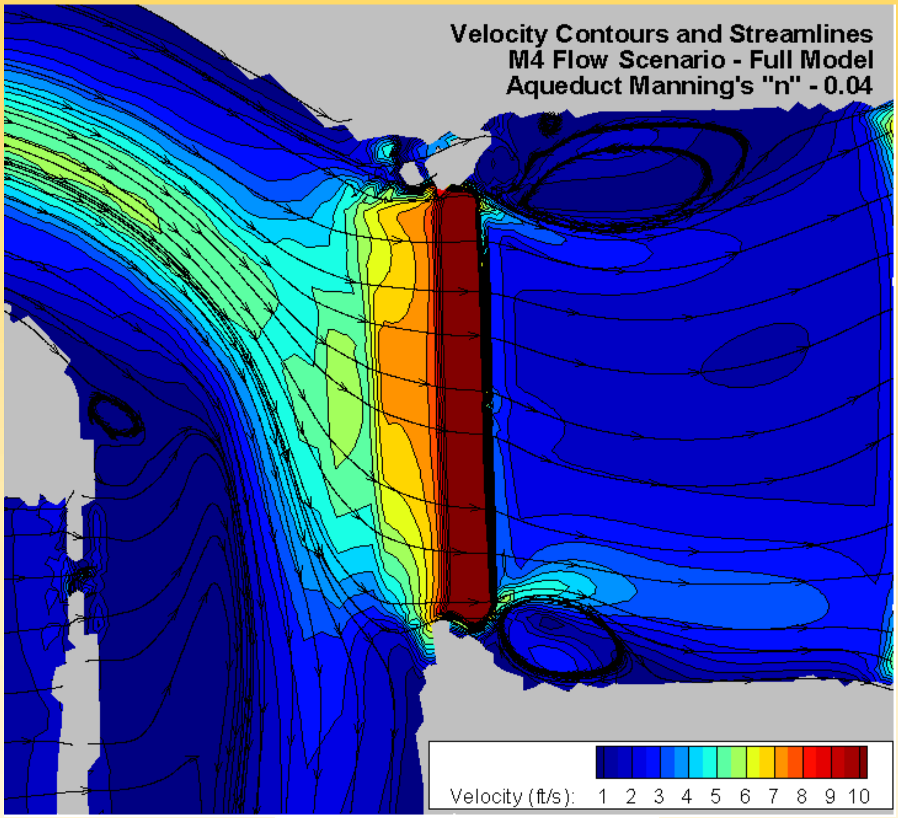
Hosted by USACE – St. Paul District

- For stakeholders, media, etc.
- Display aqueduct /spillway numerical and physical modeling as well as overall diversion project
- https://www.youtube.com/@usacemvppao or search for "Maple River aqueduct model"

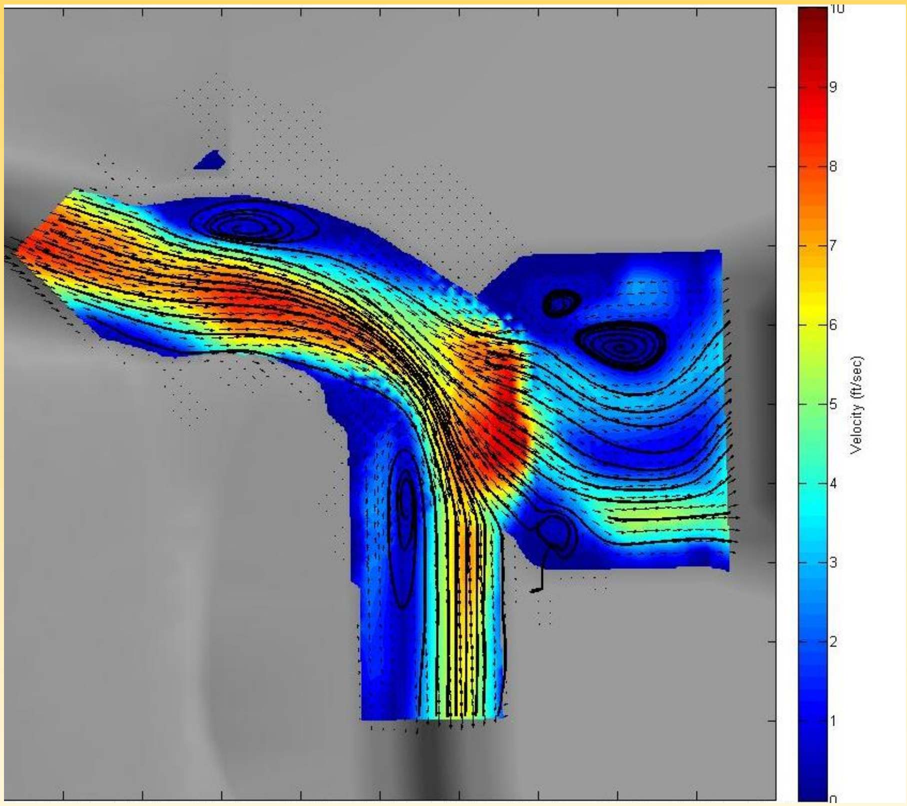
Model comparison
Water surface elevation
1-D, 2-D, physical on Maple River



Model comparison
Flow split at control weir
2-D, physical on Maple River

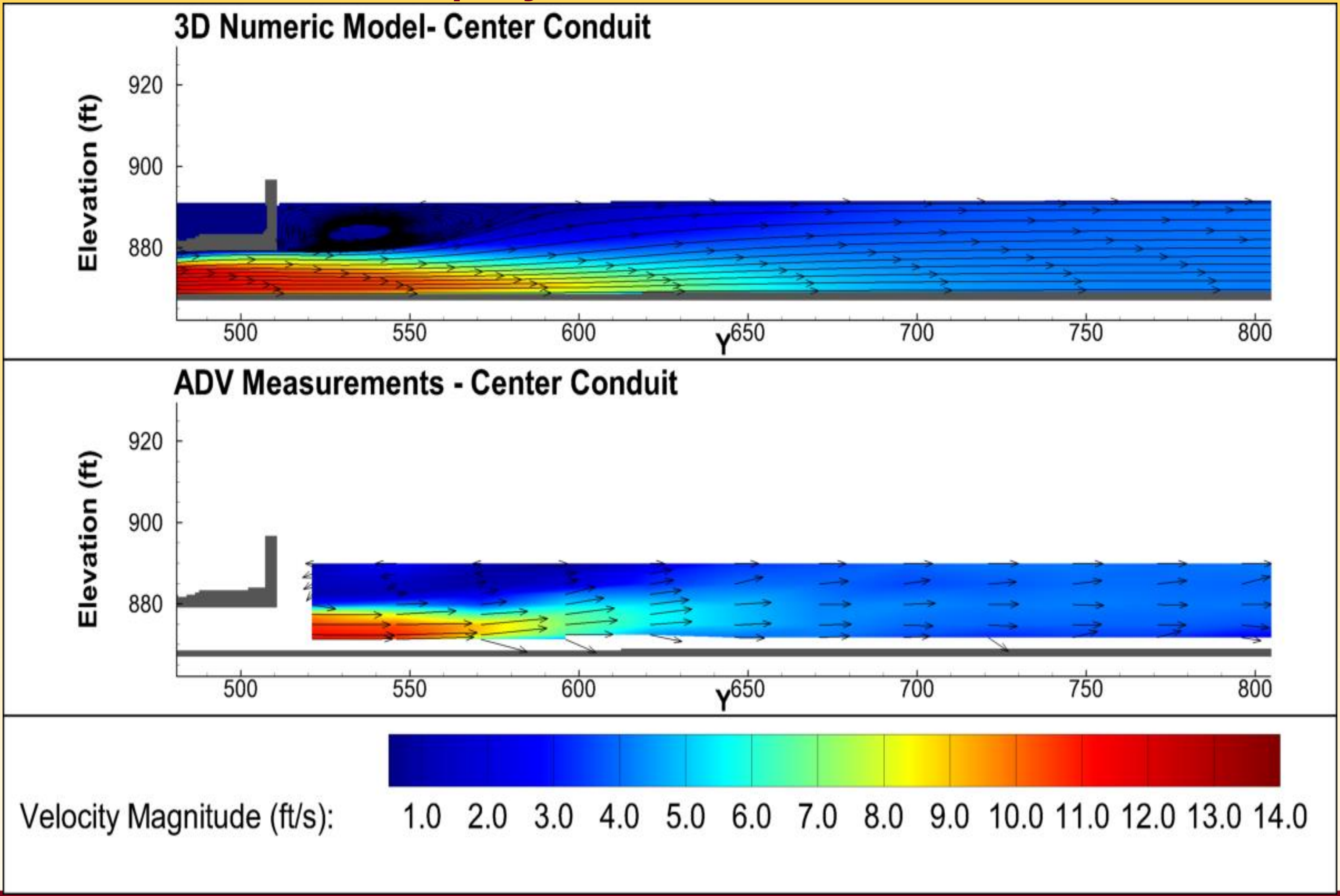


2-D Numerical



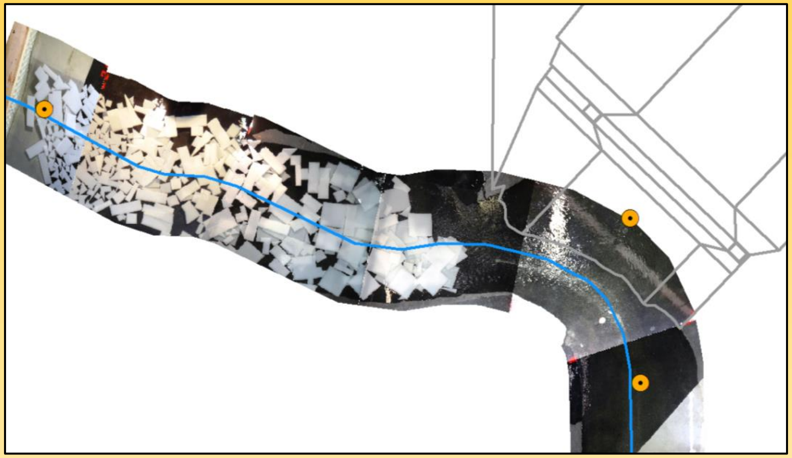
Physical

Model comparison
Conduit exit
3-D, physical in diversion



Ice modeling

Performed by Cold Regions Research and Engineering Laboratory (CRREL)

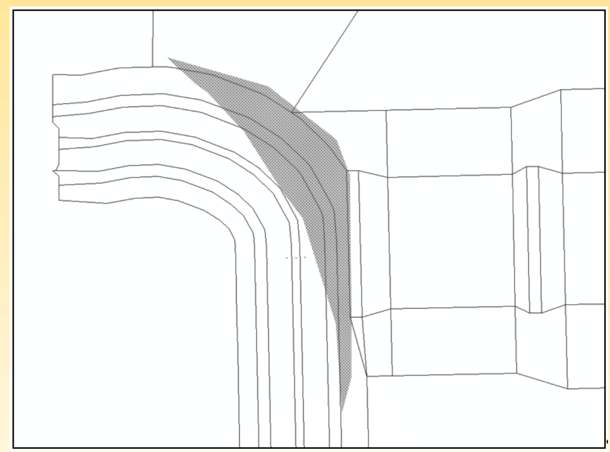


Goals

- Determine if ice stays locked in place
- If mobile, determine potential ice blockage issues
- Ice effects on flow split and spillway activation flow

Recommendations

- More natural engineered channel to prevent jams at transition
- Modifications of approach to spillway control weir
- Reduce circulation zones as much as possible
- Ice generally cannot pass aqueduct entrance. Recommend ice retention system upstream of spillway.
- Erosion and scour protection around control weir should take into account ice thicknesses and extent.



Location of additional bed protection needed related to single or multi layer ice floes

Reported optimizations and recommendations

Diversion conduits

- Triangular pier noses
- 3" radius on conduit entrance crown
- Radial and 45 degree offer same diversion head loss

Activation weir and spillway

- Spillway control weir oriented north/south and immediately adjacent to Maple River
- Spillway alignment closer to aqueduct and 90 degrees from diversion channel
- Spillway control weir modifications to created desired flow split and reduce edge jets along spillway
- Lowered final pool elevation to diversion low flow channel shoulder to mitigate critical flow in this area

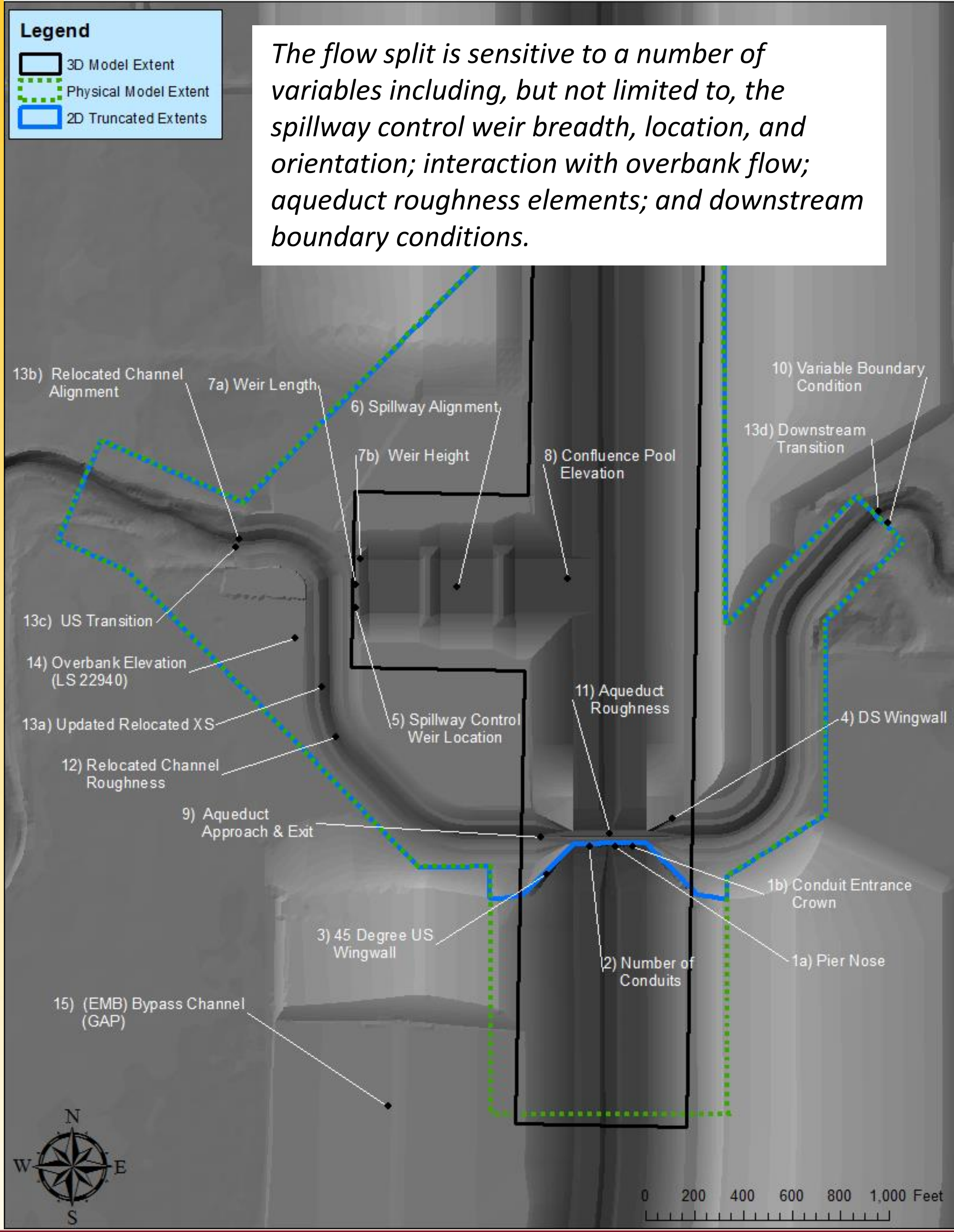
Flow split sensitivity

- Maple River tailwater. 100- year event tailwater depths **+/- 10%** varied Maple River protected flow from **3,000 to 4,600 cfs**.
- Aqueduct roughness. **Manning's "n" from 0.015 to 0.08** varied 100-year Maple River protected flow from **3,800 to 1,600 cfs**

Maple River relocated channel

- Updated channel cross section to better match natural channel.
- Smoother transitions into and out of natural channel.
- Transition into engineered channel moved further upstream away from control weir.

The flow split is sensitive to a number of variables including, but not limited to, the spillway control weir breadth, location, and orientation; interaction with overbank flow; aqueduct roughness elements; and downstream boundary conditions.



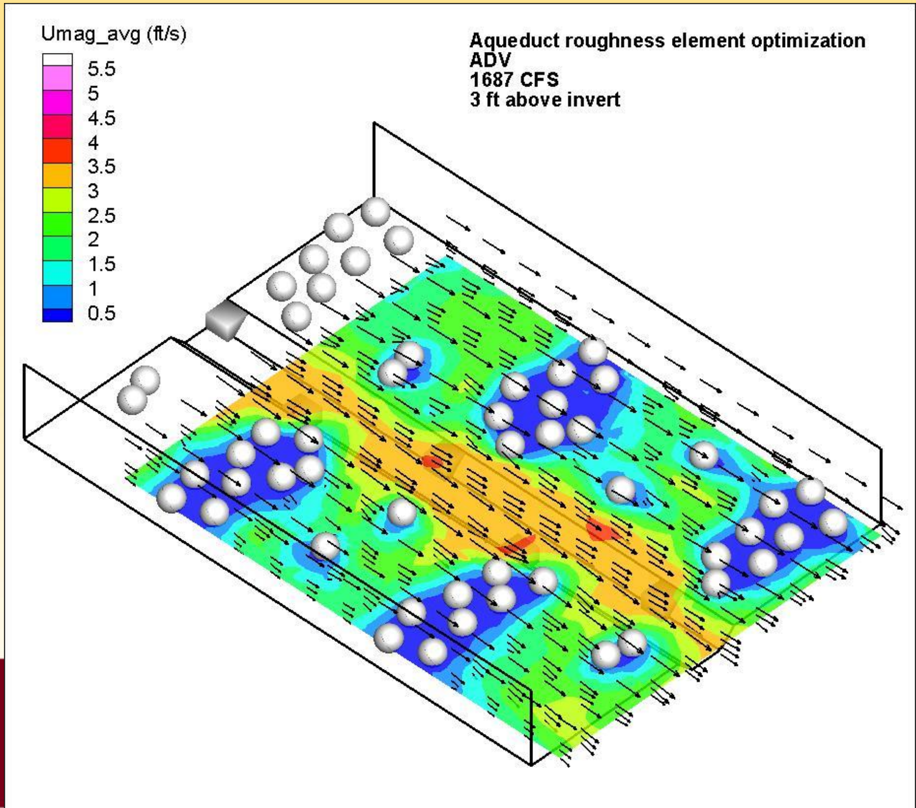
Follow up project
1:15 scale model of aqueduct flume

Goals

- Create a more “fish friendly” flow path through the aqueduct
  - Near zero velocity resting zones
  - increased flow complexity
- Increase head loss through the aqueduct
- Preserve constructability and maintainability

Tested configuration

- A pseudo-randomized variation of the Alternating Rows boulders (~2.5” rocks)
- Sensitivity of low flows to varying tailwater
- 3 ft baffle blocks located in the low flow channel at alternating 15 ft spacing



Screenshot from Construction verview video
www.youtube.com/@FMDiversion