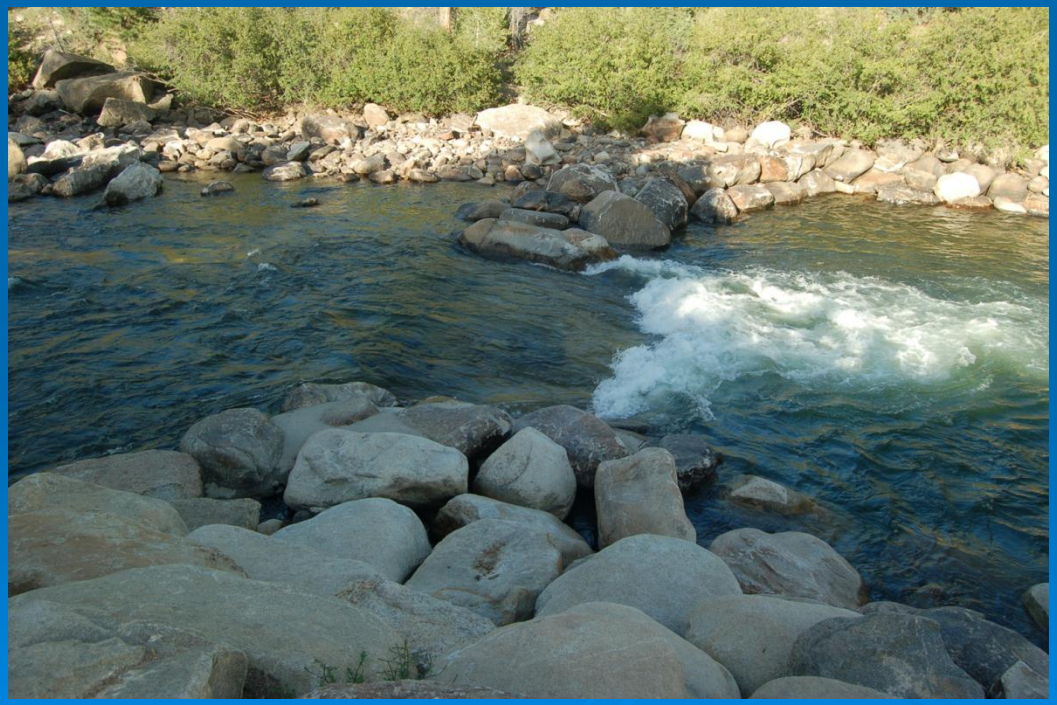
Jun 10th, 2:10 PM - 2:30 PM

Spatially explicit hydraulic analysis of the effects of whitewater parks on fish passage

T. Stephens
University of Wisconsin - Madison

SPATIALLY EXPLICIT HYDRAULIC ANALYSIS OF THE EFFECTS OF WHITEWATER PARKS ON FISH PASSAGE



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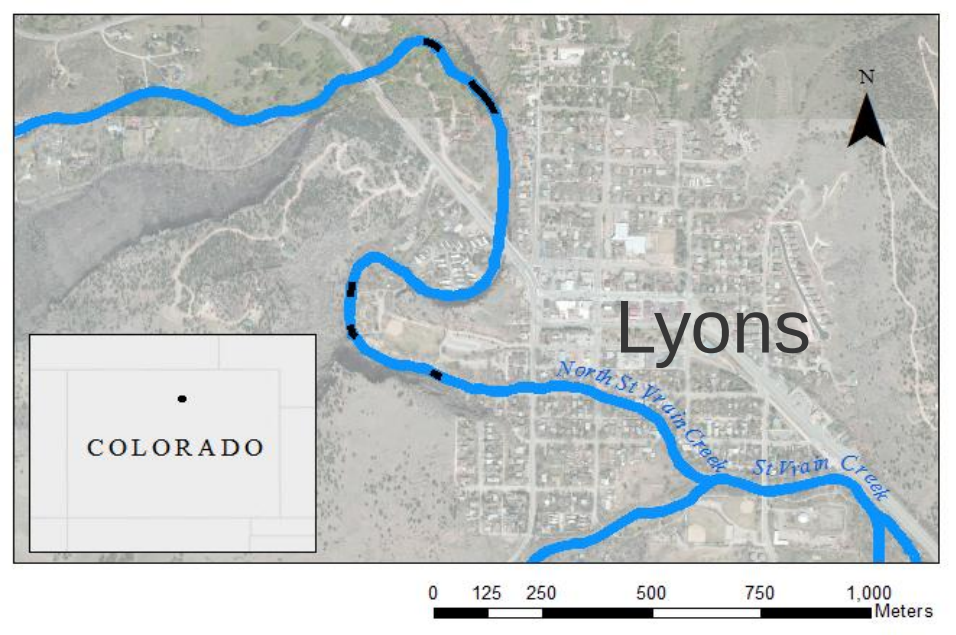
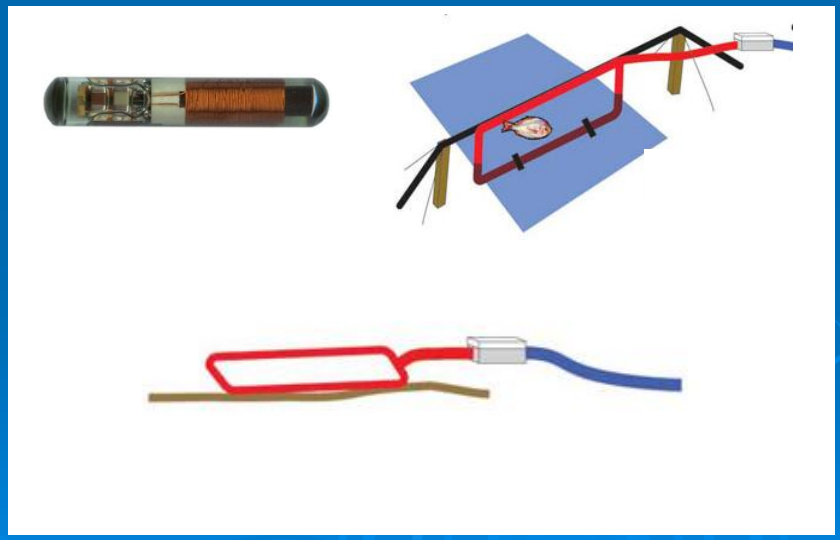
Outline

- Site Description
- Suppression of Movement
- Current Knowledge Base
- Objectives
- Qualitative Hydraulic Assessment
- Quantitatively Describing the Flow Field
- Results
- Conclusions

Fish Tracking Data



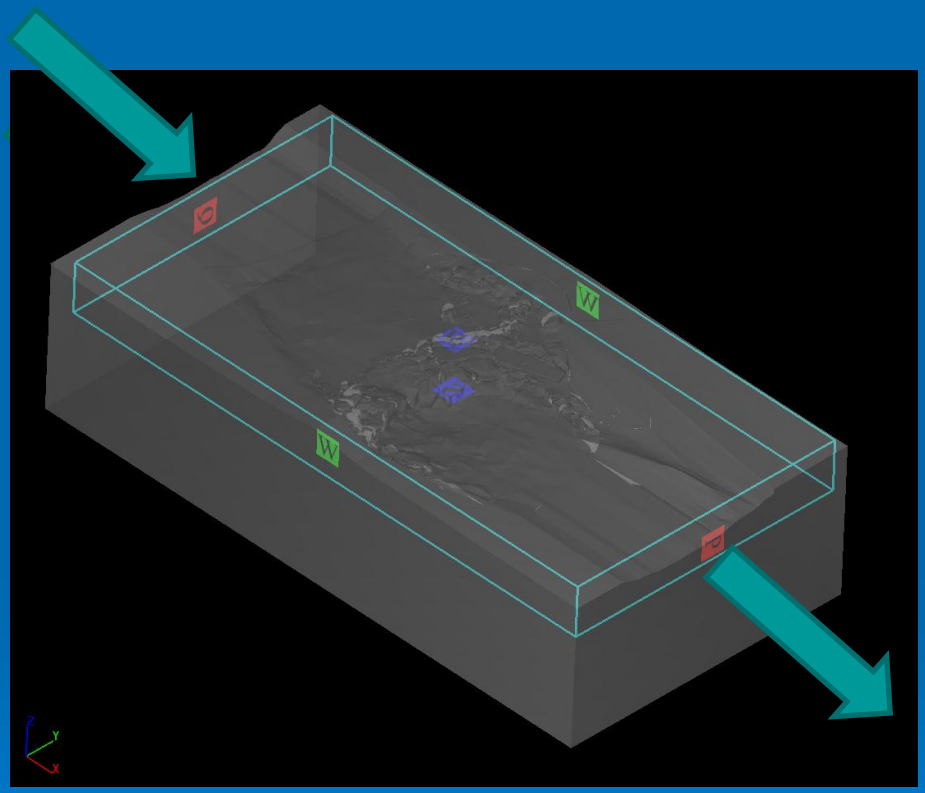
- North St. Vrain River, Lyons, CO
- 14 months of fish tracking data
- 3 WWP structures and 3 natural reaches



(Fox, 2013; Kolden, 2013)

Hydraulic Modeling

Numerical Modeling Results
(Software: FlOW-3D)



(Fox, 2013; Kolden, 2013)

- North St. Vrain River, Lyons, CO
- 3 WWP structures and 3 natural reaches
- Modeled 7 discharges
- Model Resolution: approximately 3 inch mesh size
- Post processing using EnSight 10.03

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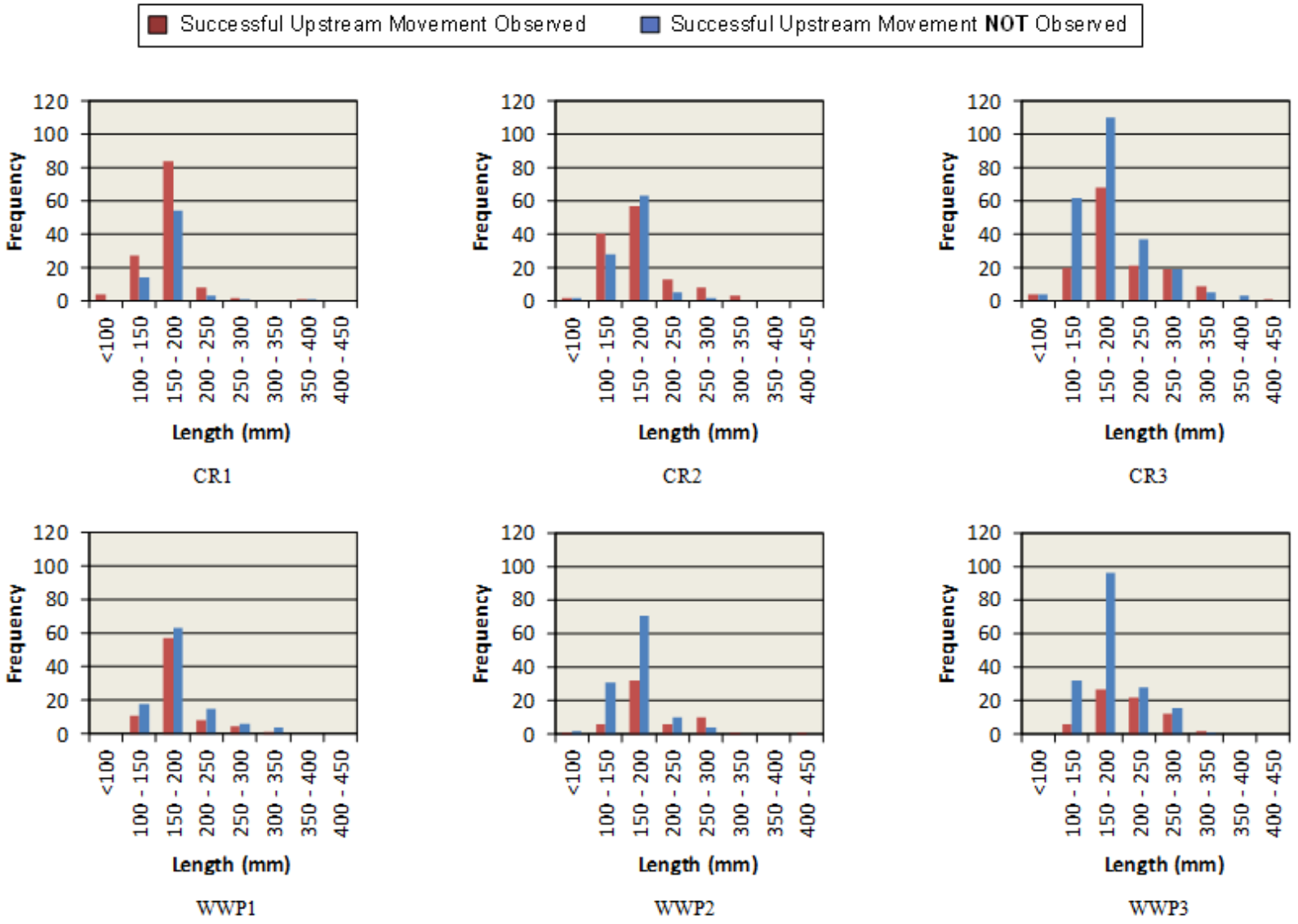
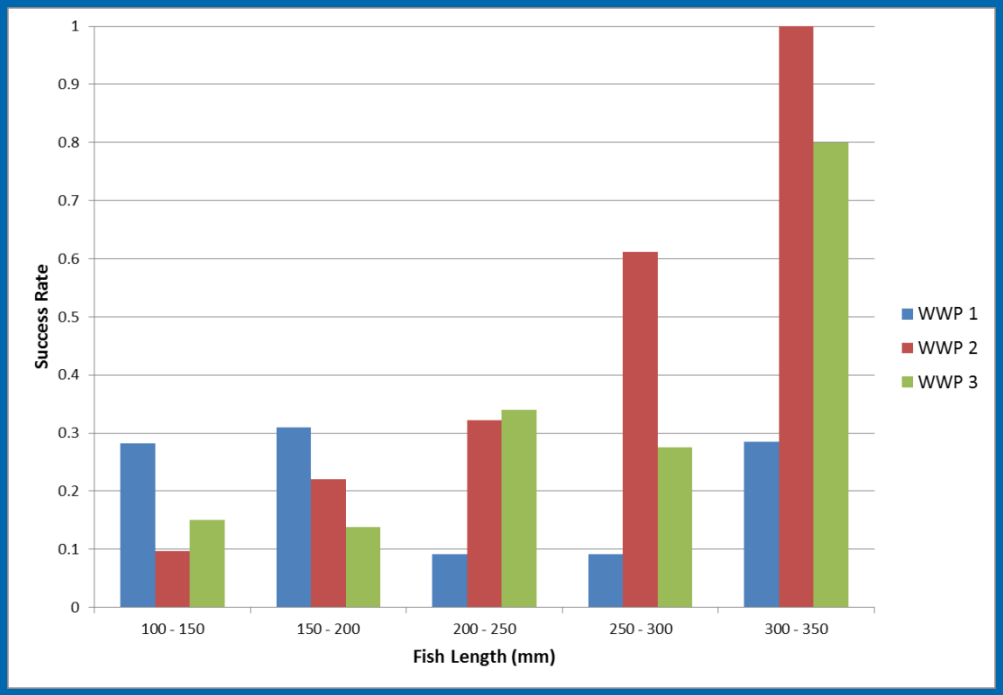
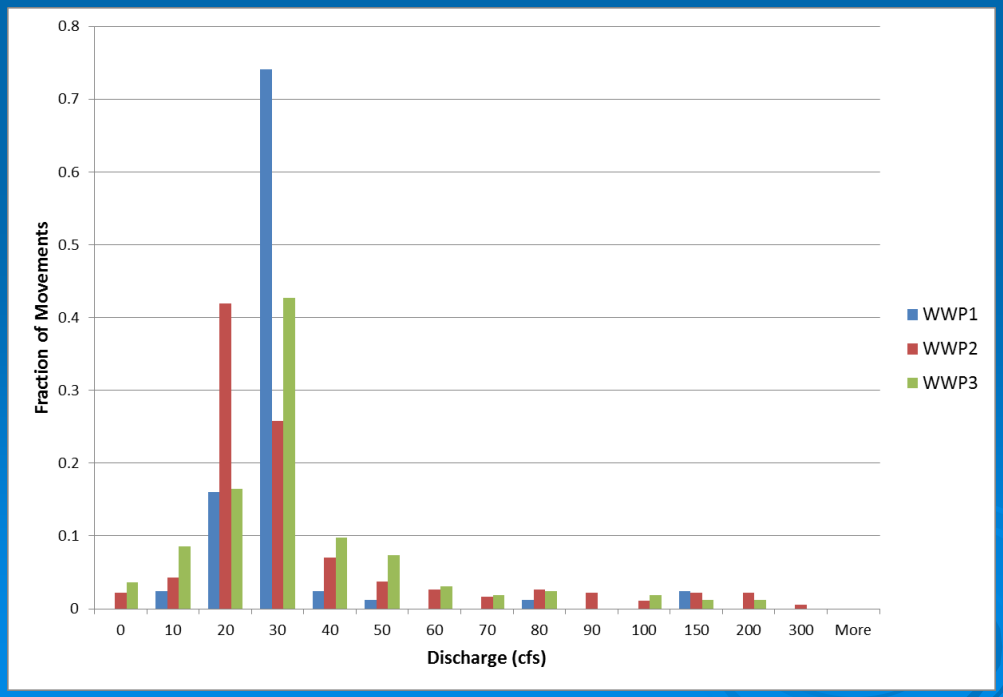
Suppression of Movement (Fox, 2013)



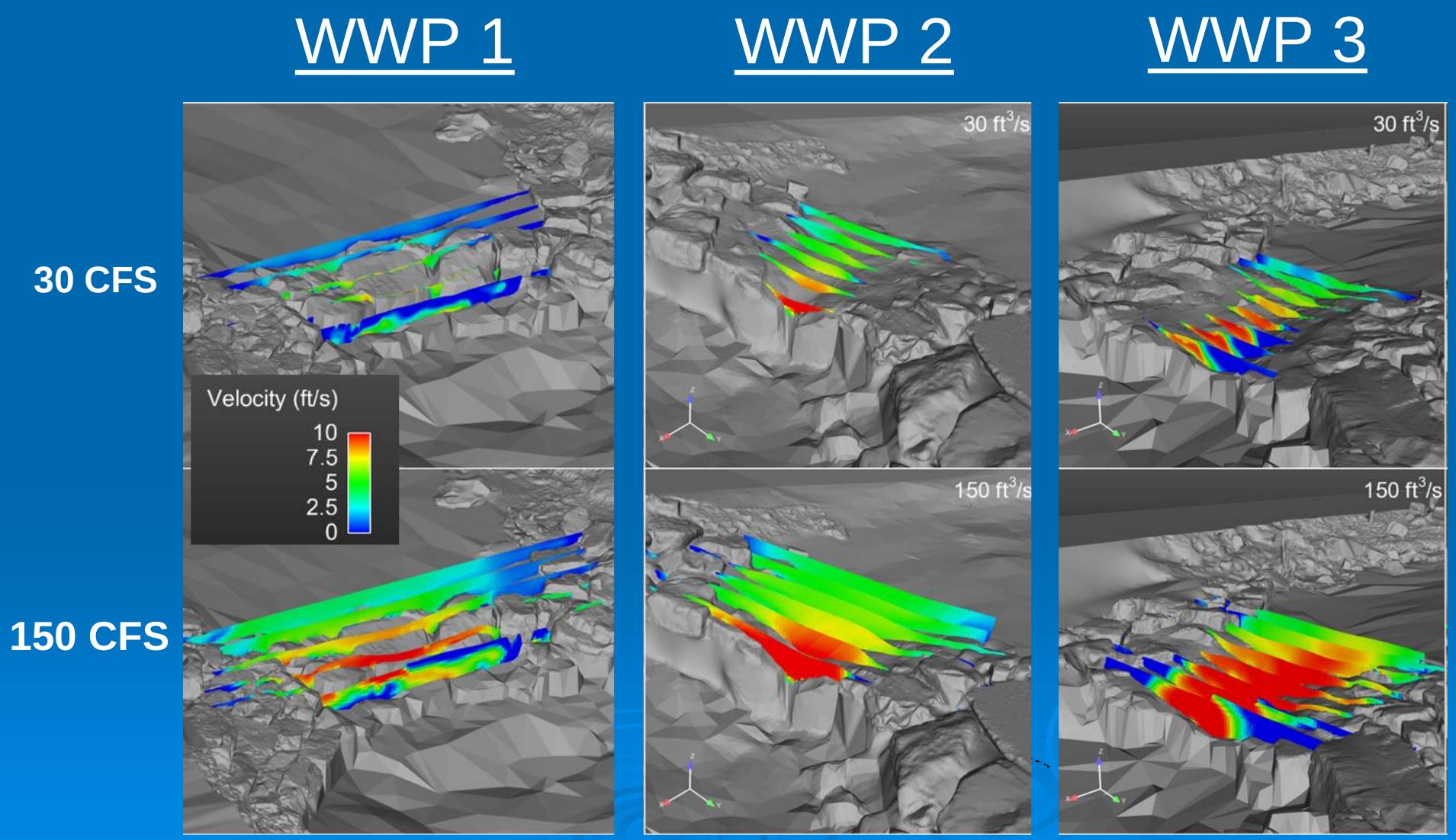




Passage Success

- Varies among the three WWP structures
- Varies among size classes of fish at each individual structure
- The fraction of observed movements among the 3 WWP structures varies with discharge

Spatial and Temporal Hydraulic Heterogeneity



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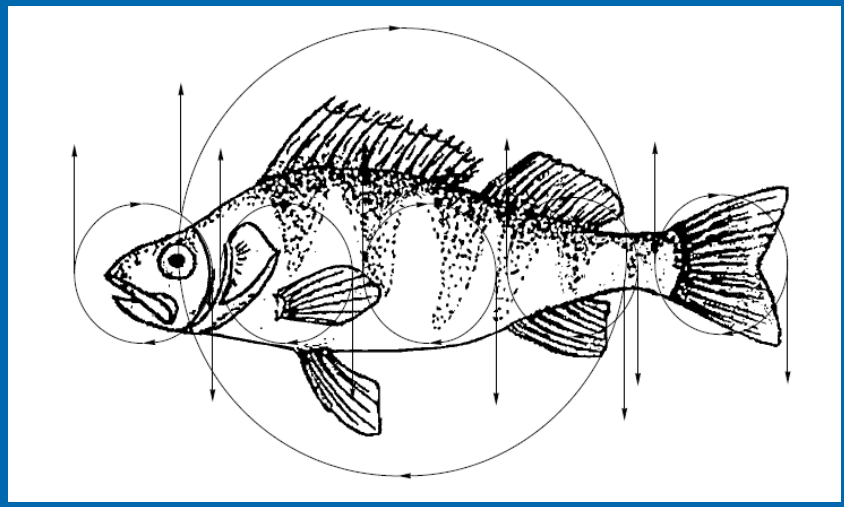
Fish Swimming Abilities

- Fish body length is correlated with swimming ability (Castro-Santos et al., 2012).
- High levels of turbulence pose a stability challenge for fish (Tritico and Cotel, 2010).
- At high current speeds, turbulence can reduce a fish's swimming ability (Lupadin, 2005; Pavlov et al., 2000).



(Lupandin, 2005)

Quantifying Hydraulics

- 3-D field studies are limited to point measurements that are not spatially continuous.
- Additional field studies are limited by a 2-D analysis and averaging over larger spatial scales.
- Laboratory studies that continuously quantify hydraulics in 3-D are limited in transferability (Lacey et al, 2012).

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Objectives

- Provide a continuous and spatially explicit description of velocity, vorticity, and TKE along the flow field at a scale meaningful to a fish.
- Compare the magnitude and structure of velocity, vorticity, and TKE among the Lyons WWP structures.
- Determine the influence of velocity, vorticity, TKE, and depth on the suppression of movement of upstream migrating trout.

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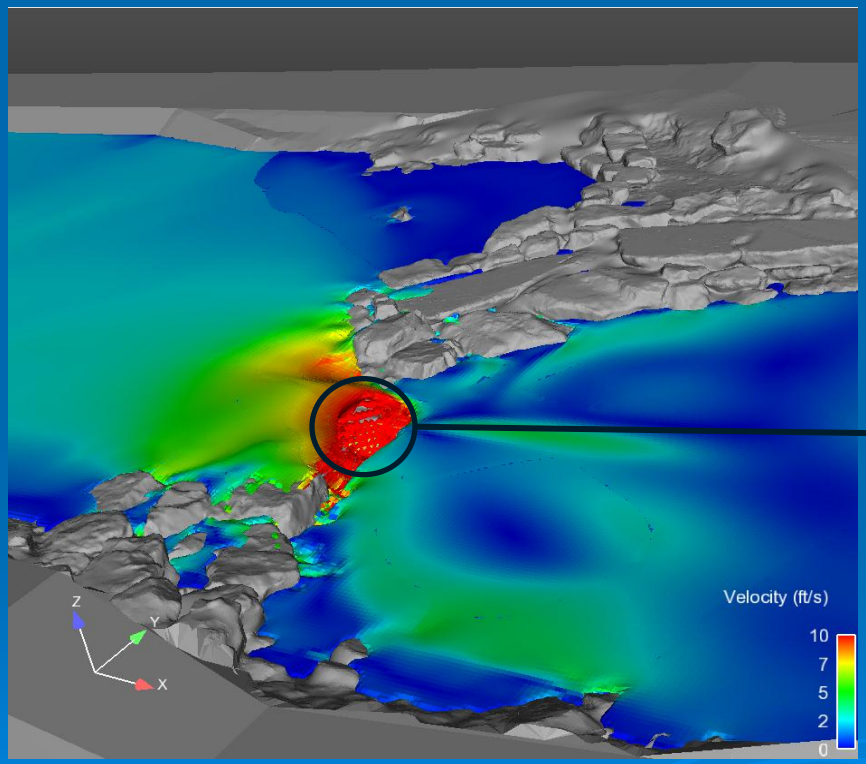
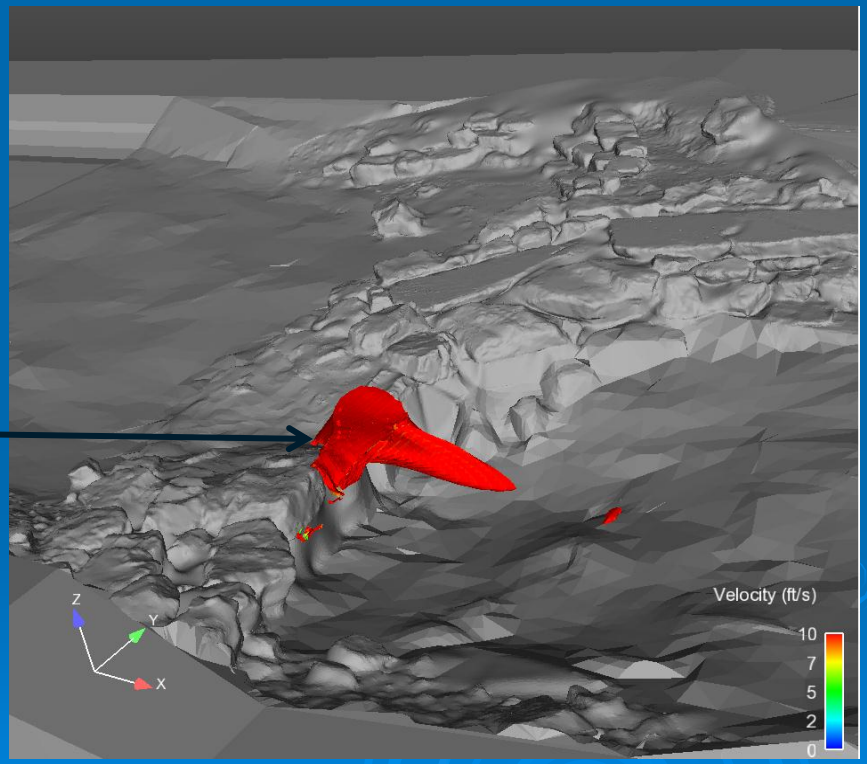
Velocity Barrier

All velocities below 10 ft/s

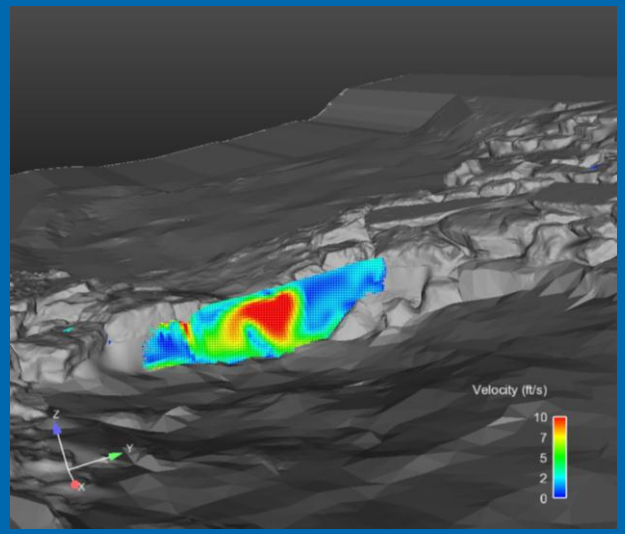


All velocities above 10 ft/s

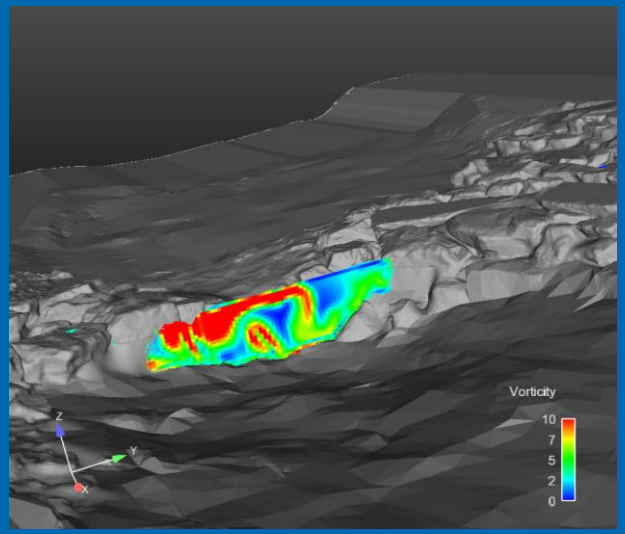


Hydraulic Interaction

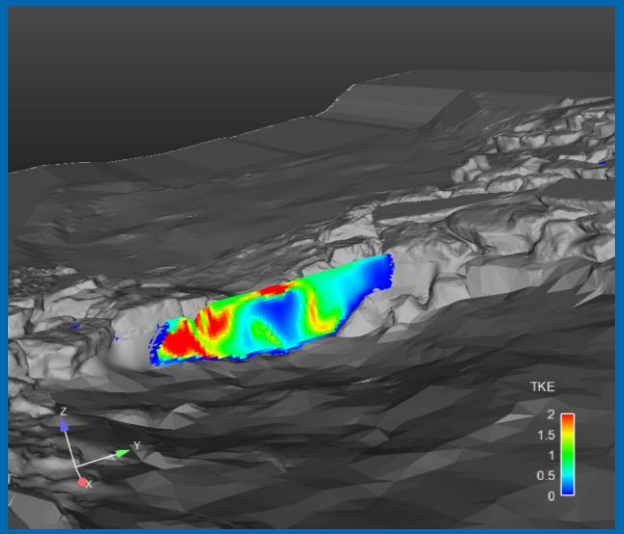
Velocity



Vorticity



TKE



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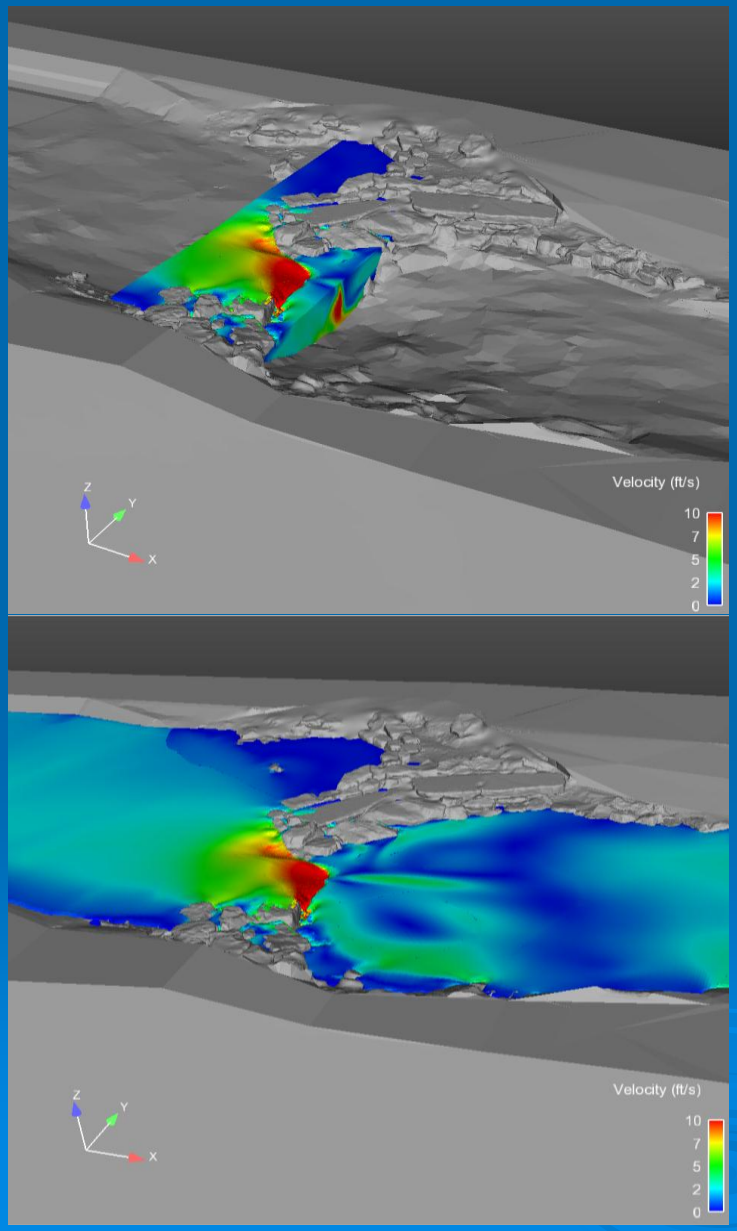
Defining the Flow Field Dimensions

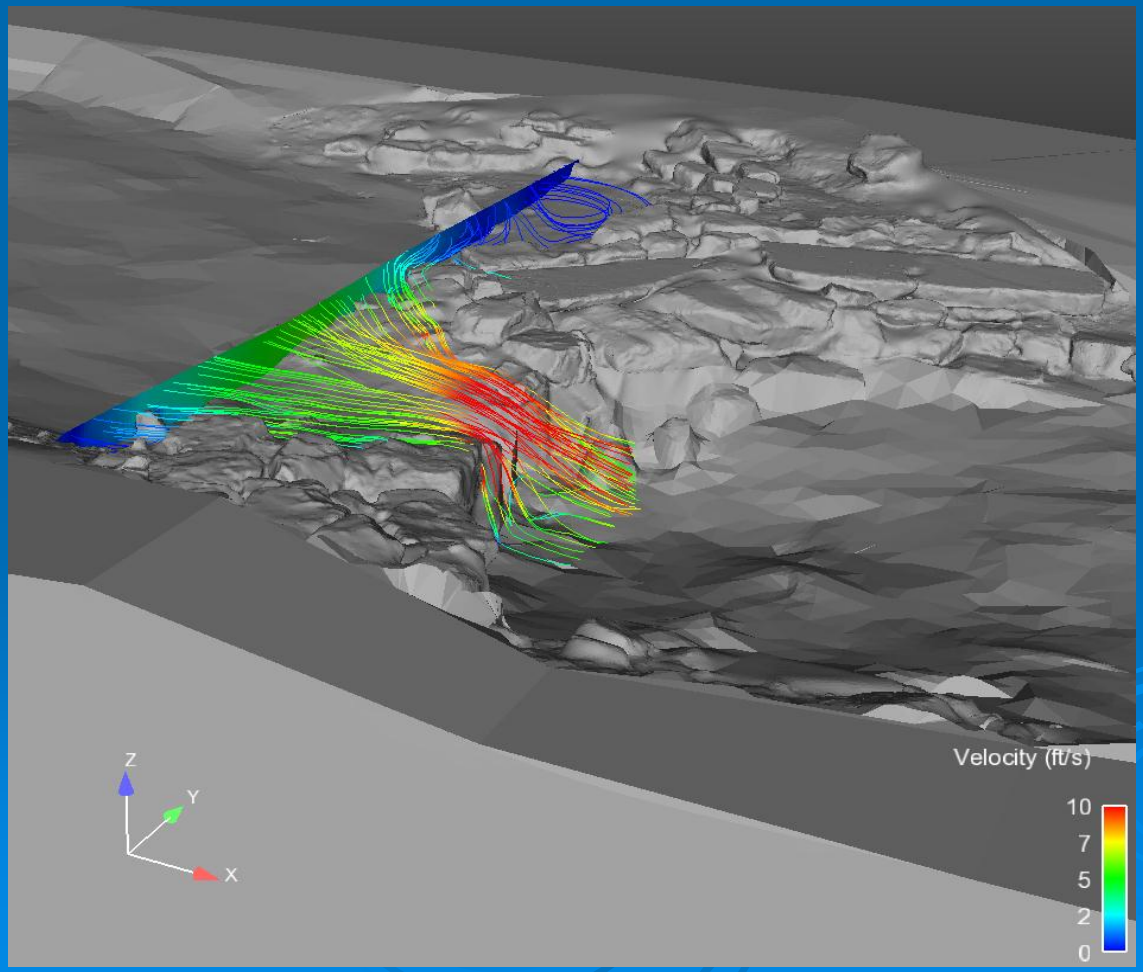


- Establish a physical criteria for the upstream and downstream boundary
- Must be equally comparable across flows at each structure
- Must be equally comparable across all structures
- Incorporate the full length of potential hydraulic barriers

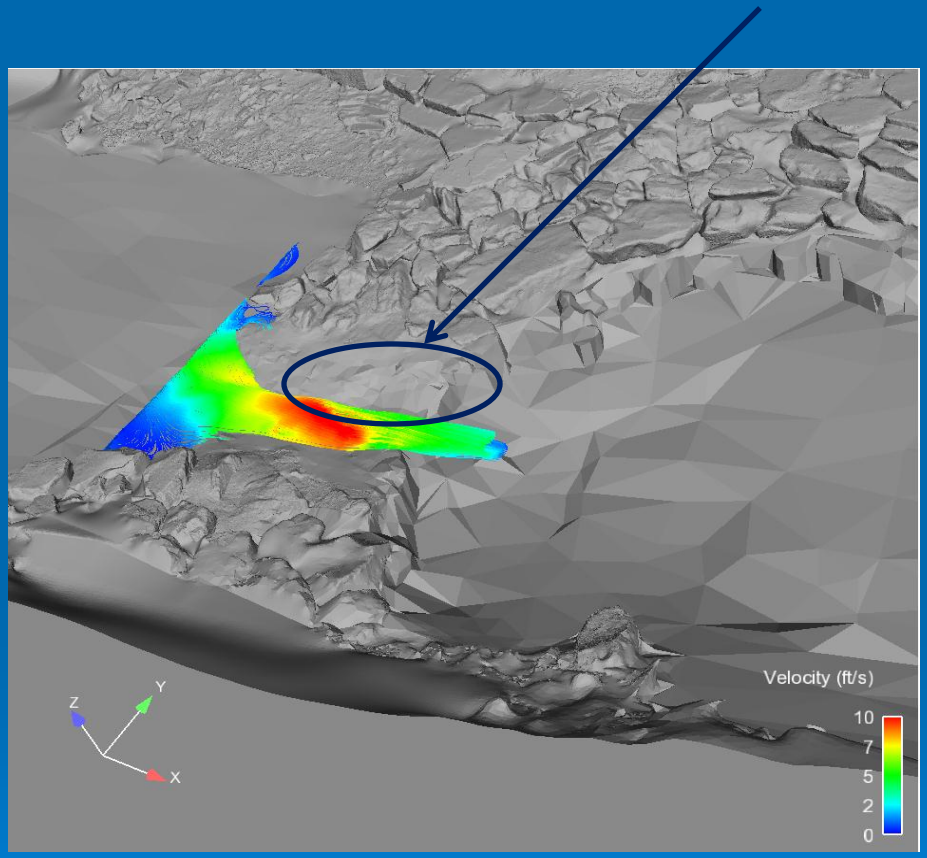
Continuous and Spatially Explicit Description

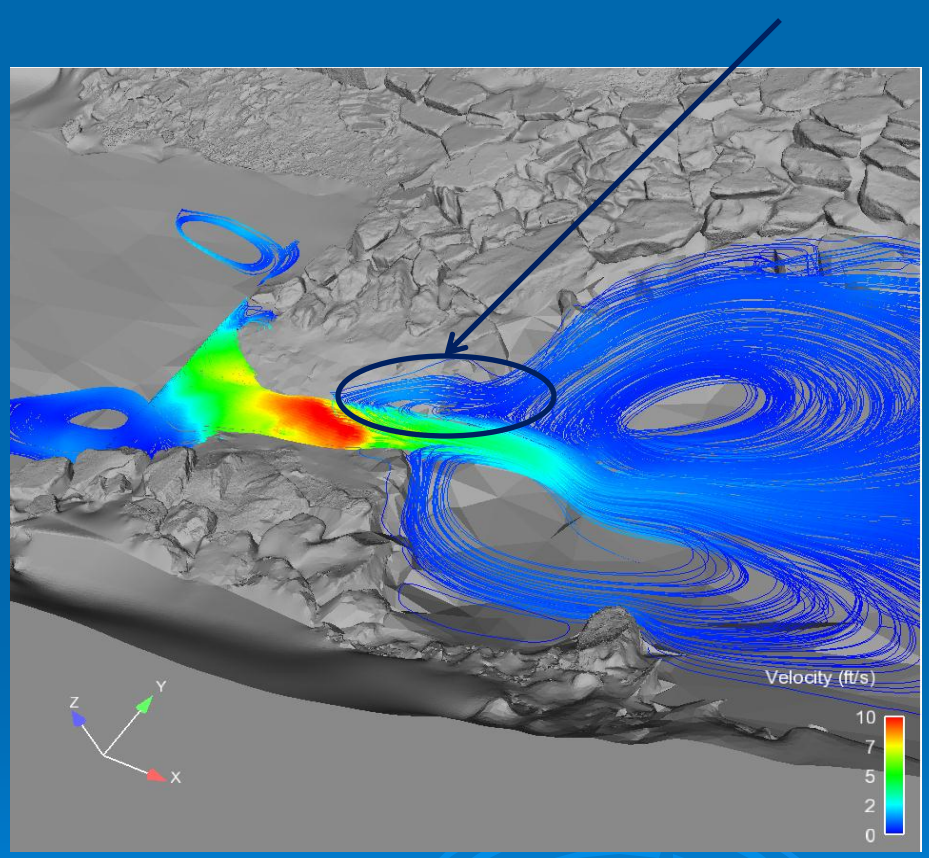
Emit "*n*" particle traces through the flow field

n ≈ 10,000 – 20,000 (encompass all features of the flow field)



Encompassing the Entire Flow Field





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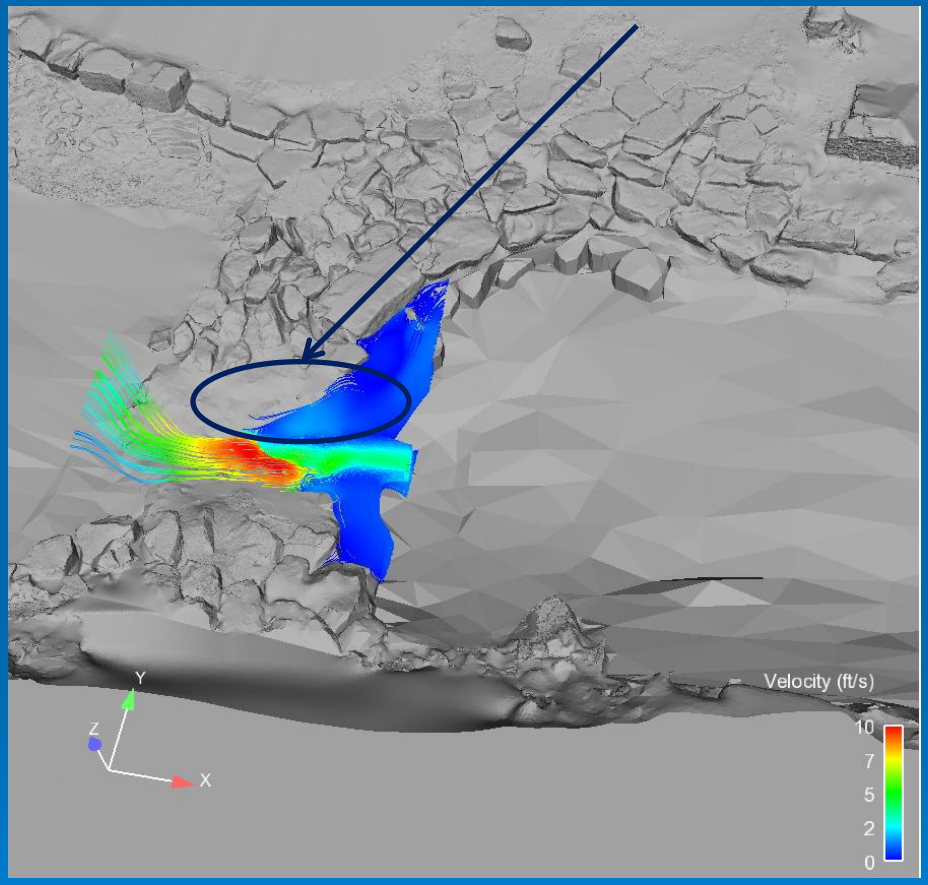
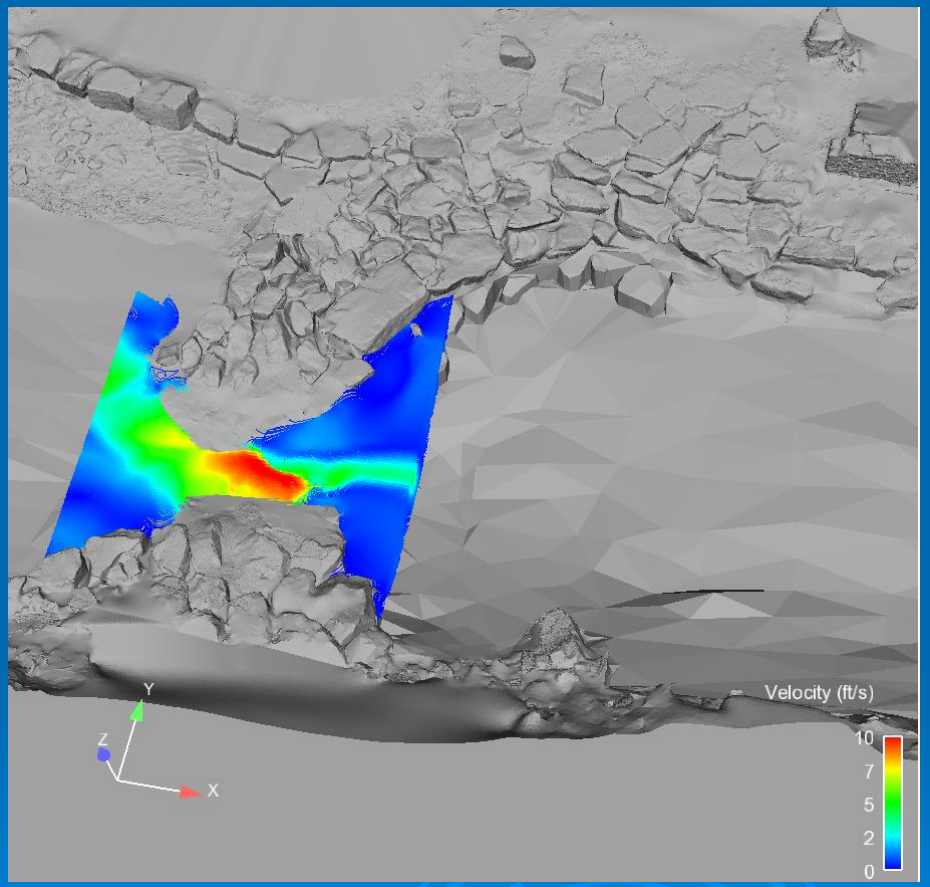
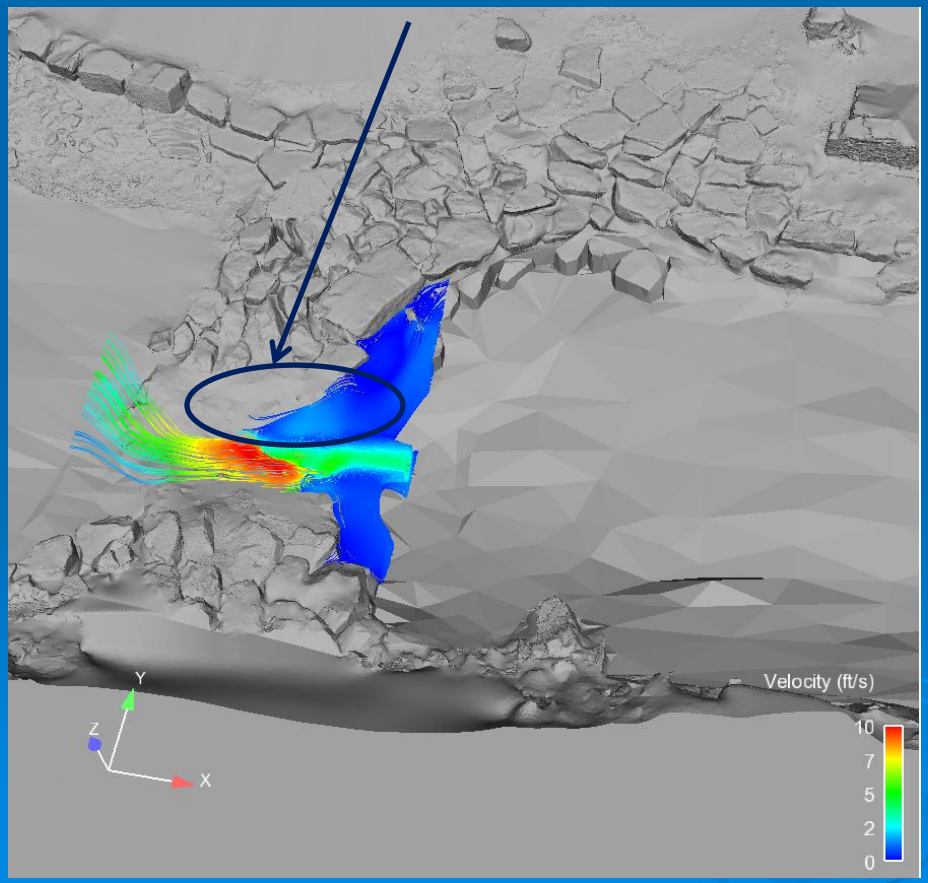




Hydraulic Descriptors

- Incorporate a directional component of velocity based on the upstream direction



- Cost along a trace

$$Cost = \sum v_{rms}^2 \times d$$

- Ratio of water velocity to burst swimming speed

$$\frac{v_{water}}{v_{burst}}$$

- Fraction of usable cross-sectional area based on a usable minimum flow depth
- Sum of vorticity along a trace
- Sum of TKE along a trace

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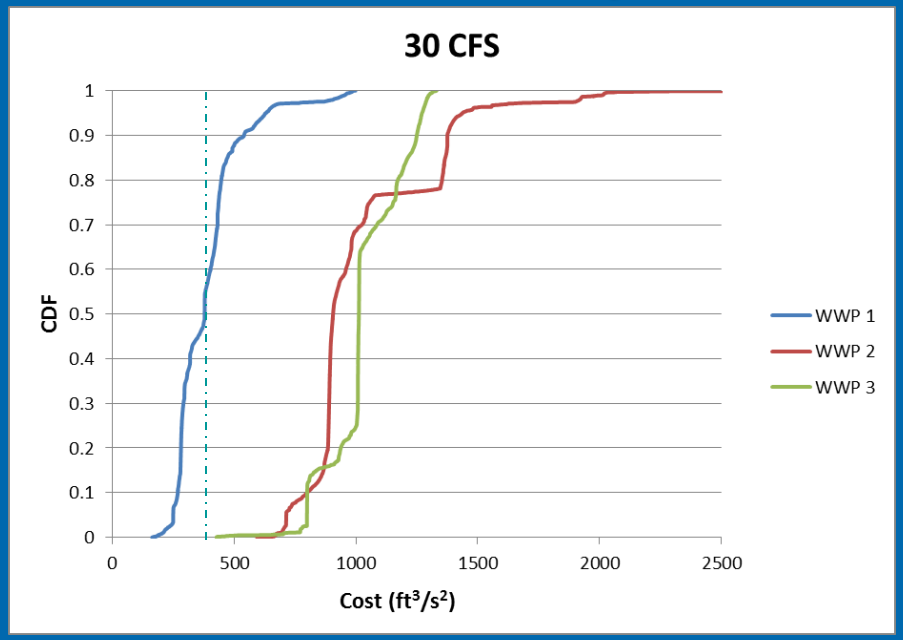
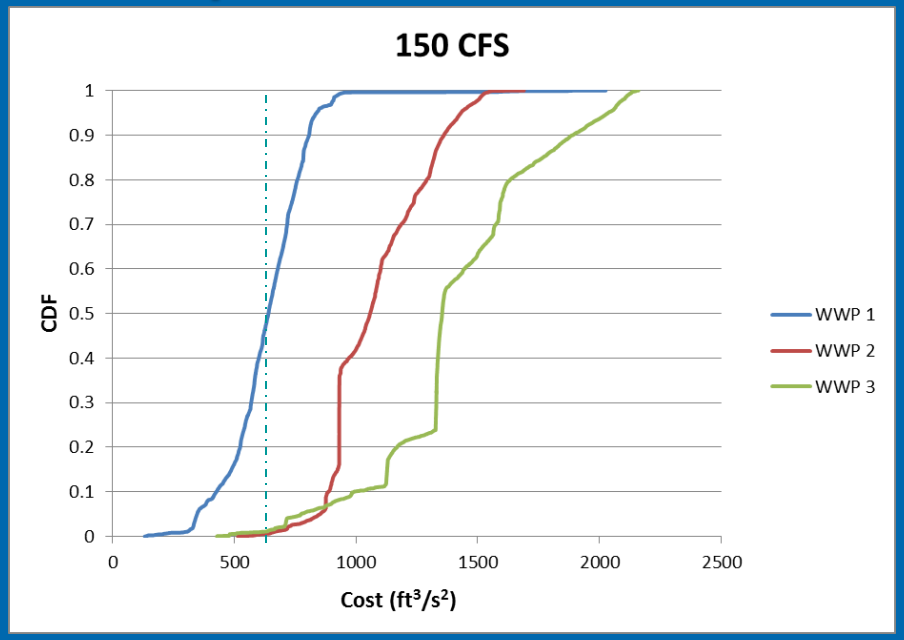
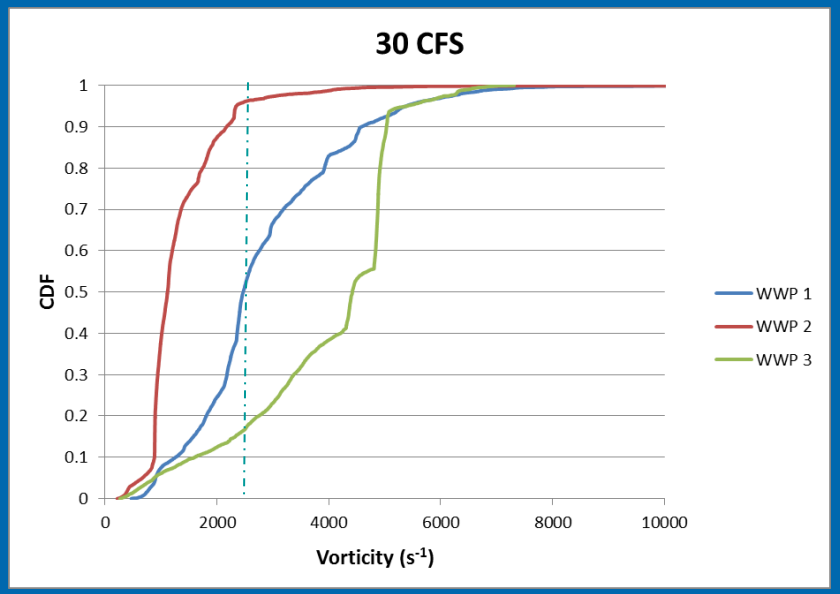
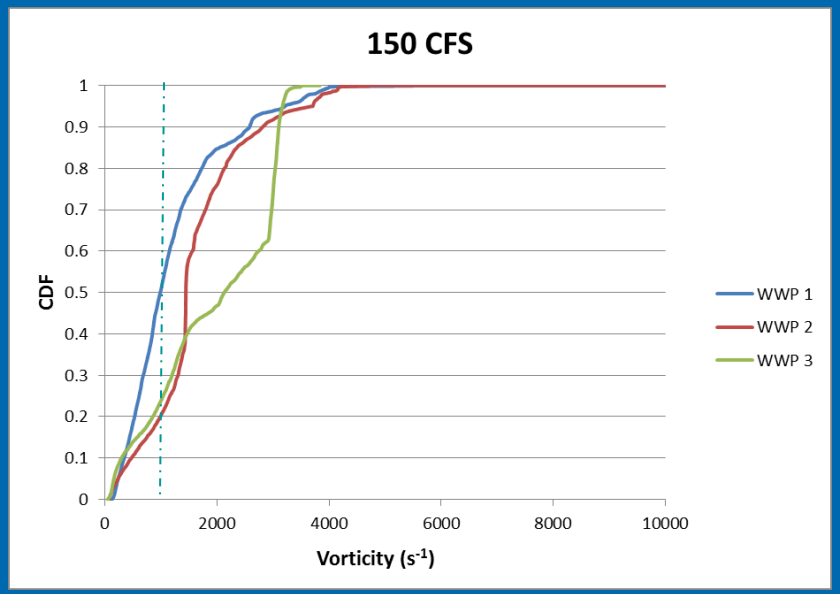


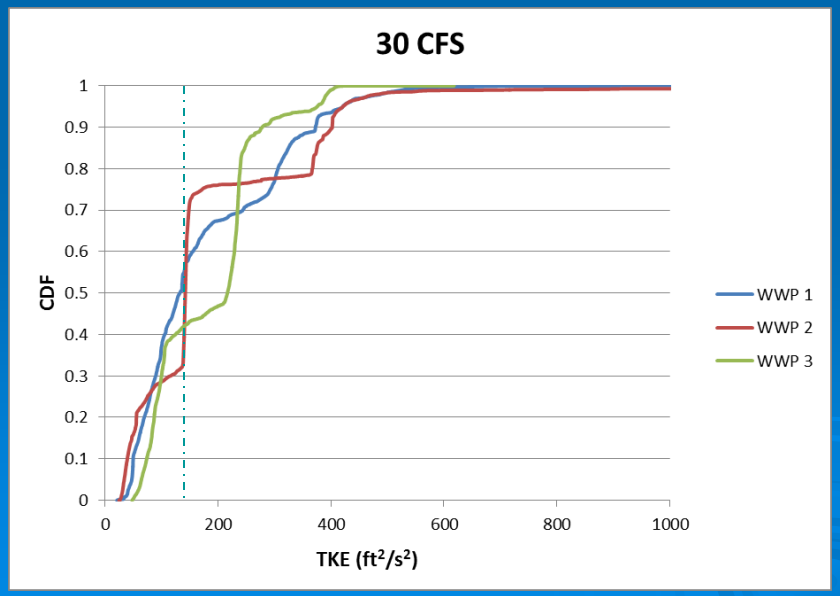


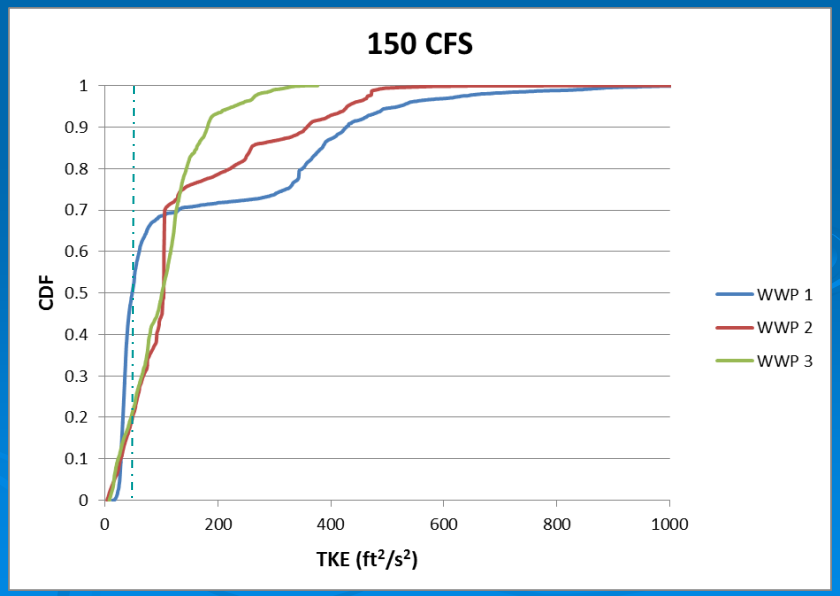
		Fraction of Traces Where V_{water}/V_{burst} >= 1												
Fish Size Class (mm)		100	125	150	175	200	225	250	275	300	325	350	375	400
15 cfs	WWP1	0.88762	0.20284	0.11712	0.071758	0.01794	0.01794	0	0	0	0	0	0	0
	WWP2	0.84914	0.11123	0	0	0	0	0	0	0	0	0	0	0
	WWP3	1	0.072575	0	0	0	0	0	0	0	0	0	0	0
150 cfs	WWP1	0.98927	0.89847	0.099289	0.033678	0.030186	0.004241	0.003118	0.003118	0.003118	0.003118	0.003118	0.003118	0.003118
	WWP2	1	0.75988	0.61974	0.15062	0.002828	0	0	0	0	0	0	0	0
	WWP3	1	0.90052	0.50491	0.003821	0	0	0	0	0	0	0	0	0
300 cfs	WWP1	0.96295	0.54333	0.046467	0.005163	0.003746	0.003746	0.003746	0.003746	0.003746	0.003746	0.003746	0.003746	0.003746
	WWP2	1	0.97627	0.22859	0.028296	0.00184	0	0	0	0	0	0	0	0
	WWP3	0.99987	0.75633	0.34351	0.009666	0	0	0	0	0	0	0	0	0

Hydraulic Descriptors









Stepwise Regression

- Fraction of traces where $v_{water}/v_{burst} > 1$ for 25-BLS and 10-BLS for each individual fish
- 5^{th}, 16^{th}, 50^{th}, 84^{th}, & 95^{th} percentiles of cost
- 50^{th} percentile of the sum and Maximum Vorticity along each trace
- 50^{th} percentile of the sum and Maximum TKE along each trace
- Fraction of usable cross-sectional area based on minimum depth criteria

Significant

- $v_{water}/v_{burst} > 1$ for 25-BLS
- $v_{water}/v_{burst} > 1$ for 10-BLS
- 16^{th} percentile of cost
- 50^{th} percentile of the sum of vorticity
- 50^{th} percentile of the maximum vorticity
- 50^{th} percentile of the sum of TKE
- Depth criteria

Logistic Regression

Inclusion

- $v_{water}/v_{burst} > 1$ for 25-BLS
- Depth criteria

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	127.64228	2	255.2846	<.0001*
Full	235.09806			
Reduced	362.74035			

RSquare (U)	0.3519
AICc	476.233
BIC	489.645
Observations (or Sum Wgts)	654

Measure	Training	Definition
Entropy RSquare	0.3519	1-Loglike(model)/Loglike(0)
Generalized RSquare	0.4822	(1-(L(0)/L(model))^(2/n))/(1-L(0)^(2/n))
Mean -Log p	0.3595	∑ -Log(ρ[j])/n
RMSE	0.3215	√ ∑(y[j]-ρ[j])²/n
Mean Abs Dev	0.2107	∑ |y[j]-ρ[j]|/n
Misclassification Rate	0.1177	∑ (ρ[j]≠ρMax)/n
N	654	n

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	24.1854197	1.9927563	147.30	<.0001*
25BLS	-2.6987911	0.9286701	8.45	0.0037*
Depth	-26.788947	2.1017976	162.45	<.0001*

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Conclusions

- A continuous and spatially explicit description of the flow field highlights the difference in the magnitude and distribution of velocity, vorticity, and TKE among the WWP structures and across a range of discharges.
- The variation in the magnitude and distribution of the water velocity relative to the burst swimming ability of a fish is reflective of relative passage success at each structure.
- Logistic regression shows a statistically significant influence of velocity and depth on passage success.
- These results might be transferable to other WWPs and can help inform future projects; however, additional WWPs of various sizes and hydrologic regimes must be investigated.
- These results have implications for native fishes with lesser swimming abilities.

Questions?