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Modeling: Effects of Hydraulic Structures on Fish Passage: An Evaluation of 2D vs 3D Hydraulic Analysis Methods

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EFFECTS OF HYDRAULIC STRUCTURES ON FISH PASSAGE: AN EVALUATION OF 2D VS 3D HYDRAULIC ANALYSIS METHODS

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- U.S. Fish and Wildlife Service
  - Bozeman Fish Technology Center
  - Fish Passage Program

Outline

- **Study Objectives**
- Lyons Whitewater Park
- Methods
- Results
- Conclusions
- Questions
- References

Study Objectives

- Compare 2D and 3D CFD based fish passage analysis methods for Lyons, Colorado field site
- Assess whether 2D CFD modeling can adequately capture complex flow
- Identify key hydraulic variables for predicting the effects of a structure on upstream fish passage

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Lyons Whitewater Park

- North Fork St. Vrain River at Lyons, Colorado
- Prior to September 2013 flooding event

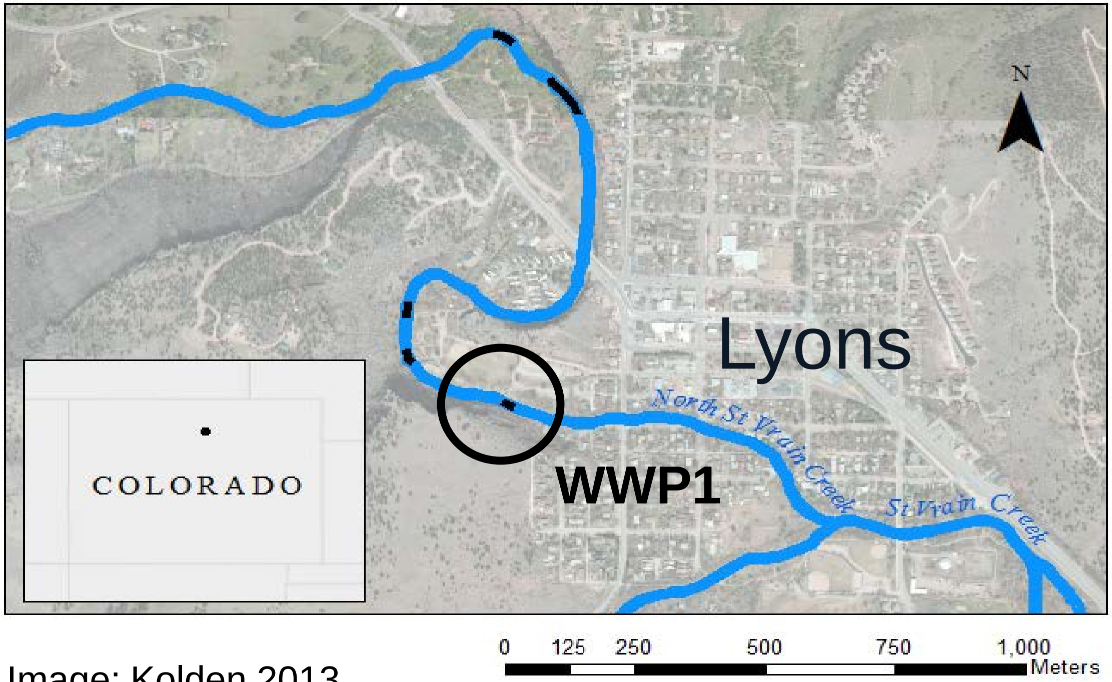


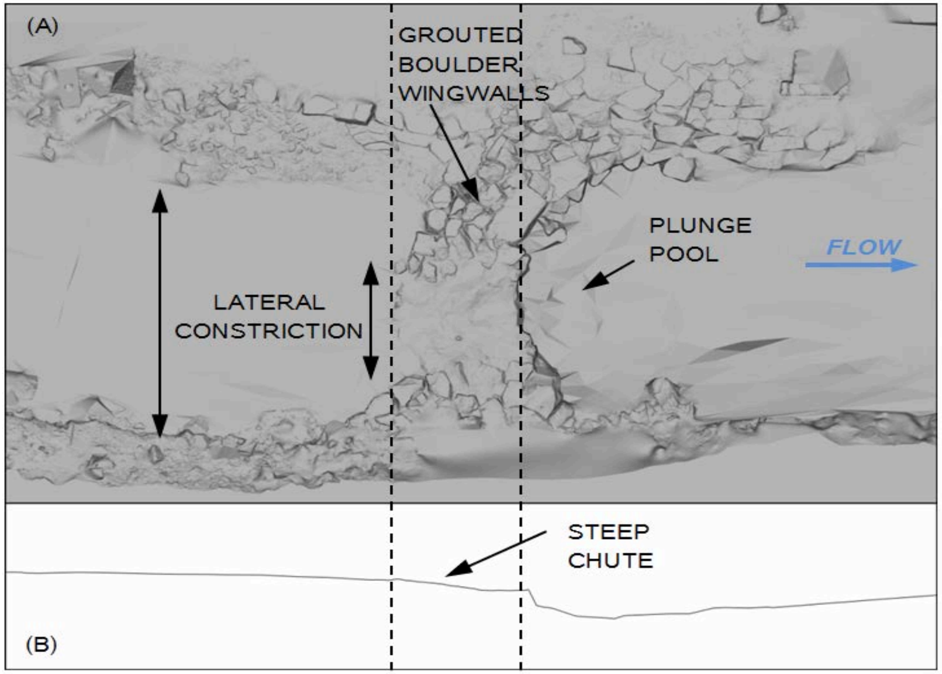
Image: Kolden 2013

Salmo trutta

Oncorhynchus mykiss

Images: fwp.mt.gov

Lyons Whitewater Park



$$Fr = \frac{V}{\sqrt{gd}}$$

Images: Fox 2013

Outline

- Study Objectives
- Lyons Whitewater Park
- **Methods**
- Results
- Implications
- Conclusions
- References

Methods – Overview

Develop potential swim paths → Hydraulic description → Apply physical criteria → Statistical analysis

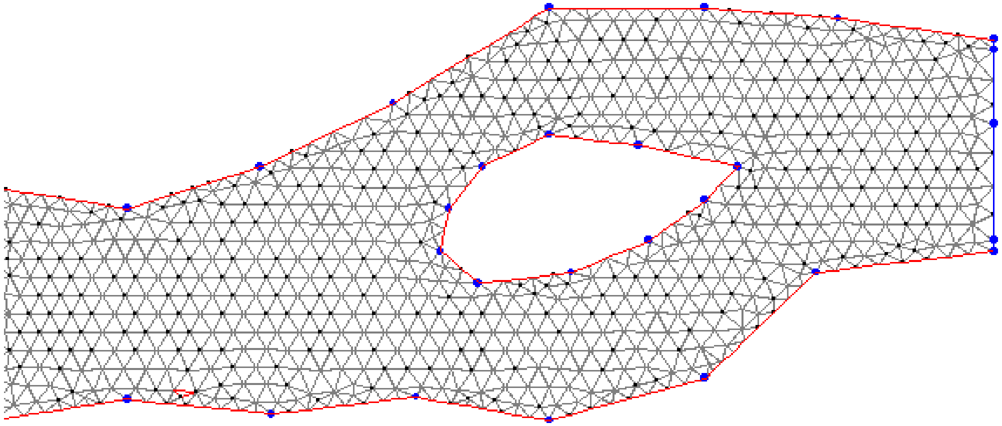


Image: www.river2d.ualberta.ca

Methods – Path Hydraulics

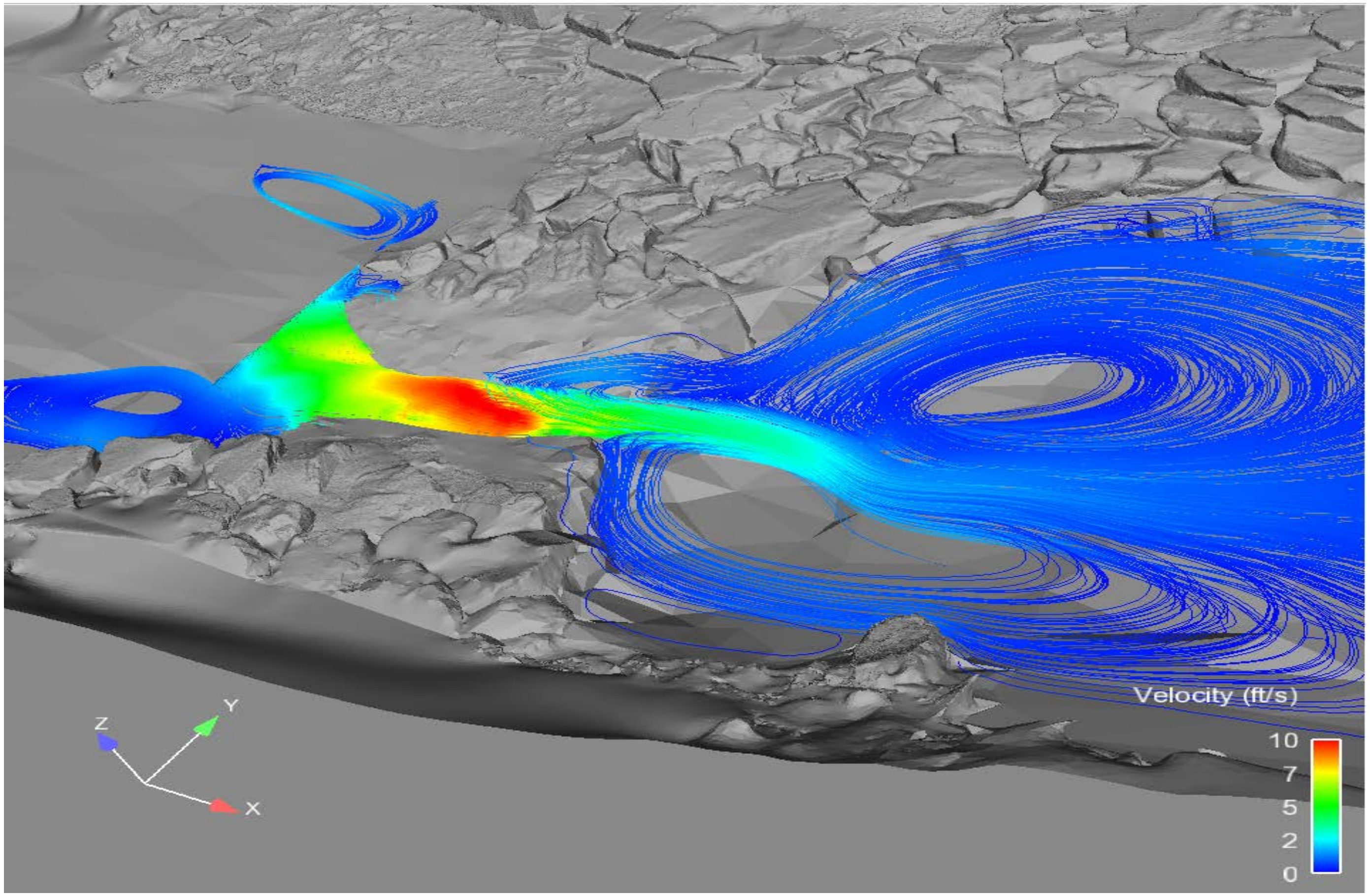
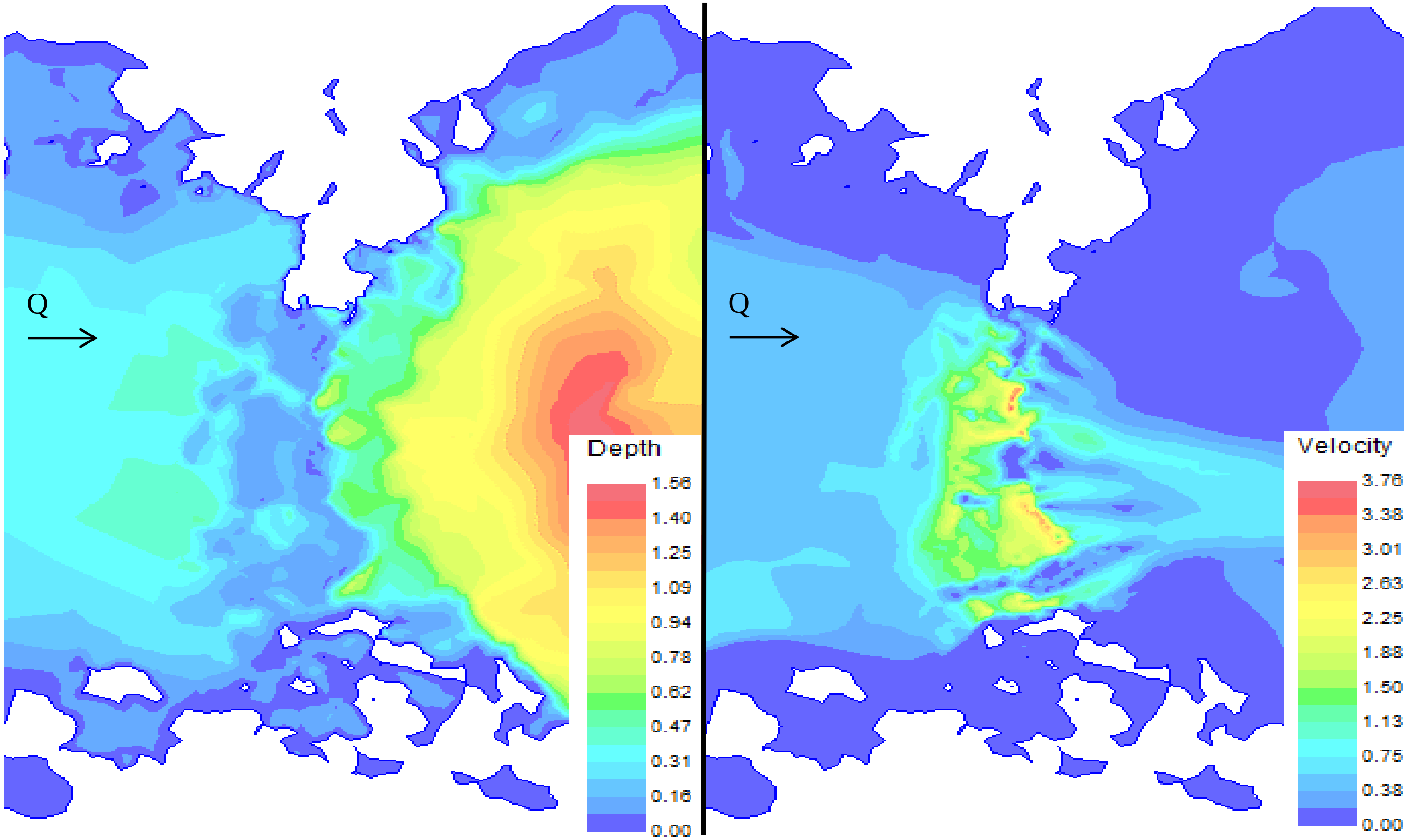


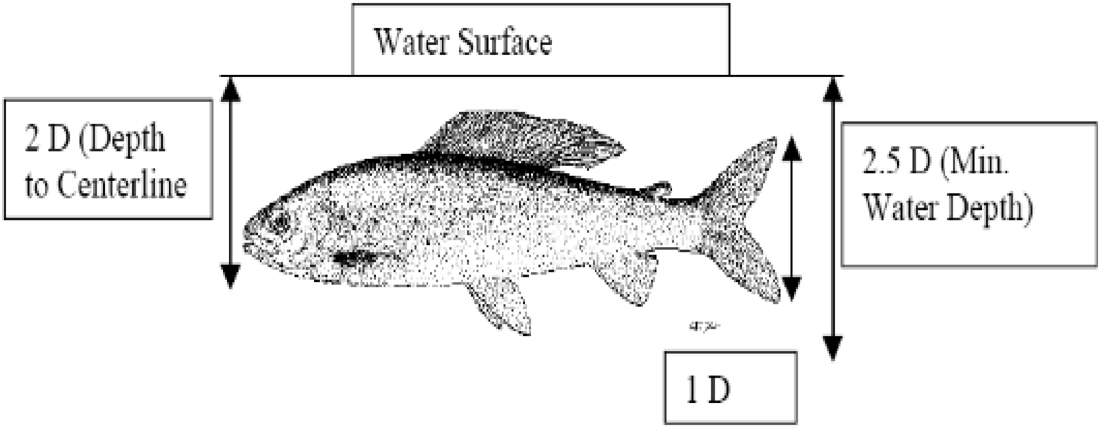
Image: Stephens, 2014

Methods – Path Hydraulics



Methods – Physical Criteria

- MDC – Minimum Depth Criterion
  - 0.18 m
  - 0.11 m



- MVR – Maximum Velocity Ratio
  - 10 BL/s
  - 25 BL/s

$$\text{velocity ratio} = \frac{v_{rms}}{v_{burst}}$$

Methods – Statistical Analysis

Movement Data

- 204 total observations, Boolean
- Species and body length

Variable Selection

- Bivariate fits
- Stepwise regression

Logistic Regression

- Various variable combination
- Prediction accuracy

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Results – Portion "Impassable"

	Discharge (cms)	Fish body length 100 mm	125 mm	150 mm	175 mm	200 mm	225 mm	250 mm	275 mm	300 mm	325 mm	350 mm	375 mm	400 mm
2D	0.42	0.13	0	0	0	0	0	0	0	0	0	0	0	0
	0.85	0.21	0.05	0	0	0	0	0	0	0	0	0	0	0
	1.70	0.34	0.15	0.03	0	0	0	0	0	0	0	0	0	0
	2.83	0.27	0.21	0.10	0.01	0	0	0	0	0	0	0	0	0
3D	0.42	0.89	0.20	0.12	0.07	0.02	0.02	0	0	0	0	0	0	0
	0.85	1	0.44	0.12	0.08	0.01	0	0	0	0	0	0	0	0
	1.70	1	0.25	0.13	0.06	0.05	0	0	0	0	0	0	0	0
	2.83	1	0.95	0.21	0.07	0	0	0	0	0	0	0	0	0

Ranges:	1	0.99 - 0.80	0.79 - 0.60	0.59 - 0.40	0.39 - 0.20	0.19 - 0.01	0

Results – Portion "Impassable"

	Discharge (cms)	Fish body length 100 mm	125 mm	150 mm	175 mm	200 mm	225 mm	250 mm	275 mm	300 mm	325 mm	350 mm	375 mm	400 mm
2D	0.42	0.95	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
	0.85	0.88	0.83	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
	1.70	0.92	0.82	0.75	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
	2.83	0.85	0.82	0.73	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
3D	0.42	0.98	0.72	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
	0.85	1	0.83	0.62	0.60	0.56	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
	1.70	1	0.98	0.88	0.87	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
	2.83	1	0.96	0.45	0.34	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29

Ranges:	1	0.99 - 0.80	0.79 - 0.60	0.59 - 0.40	0.39 - 0.20	0.19 - 0.01	0

Results – Prediction Accuracy

		2D Analysis					3D Analysis		
		Predicted					Predicted		
	Observed	Pass	No Pass	% Correct		Observed	Pass	No Pass	% Correct
$MDC_{0.11}$	Pass	46	8	85.2%	$MDC_{0.11}$	Pass	44	10	81.5%
	No Pass	8	142	94.7%		No Pass	8	142	94.7%
	Overall % Correct			92.2%		Overall % Correct			91.2%
$MDC_{0.11}$ & MVR_{10}	Pass	4	50	7.4%	$MDC_{0.11}$ & MVR_{10}	Pass	0	54	0.0%
	No Pass	8	142	94.7%		No Pass	0	150	100.0%
	Overall % Correct			71.6%		Overall % Correct			73.5%
$MDC_{0.11}$ & MVR_{25}	Pass	45	9	83.3%	$MDC_{0.11}$ & MVR_{25}	Pass	40	14	74.1%
	No Pass	8	142	94.7%		No Pass	8	142	94.7%
	Overall % Correct			91.7%		Overall % Correct			89.2%

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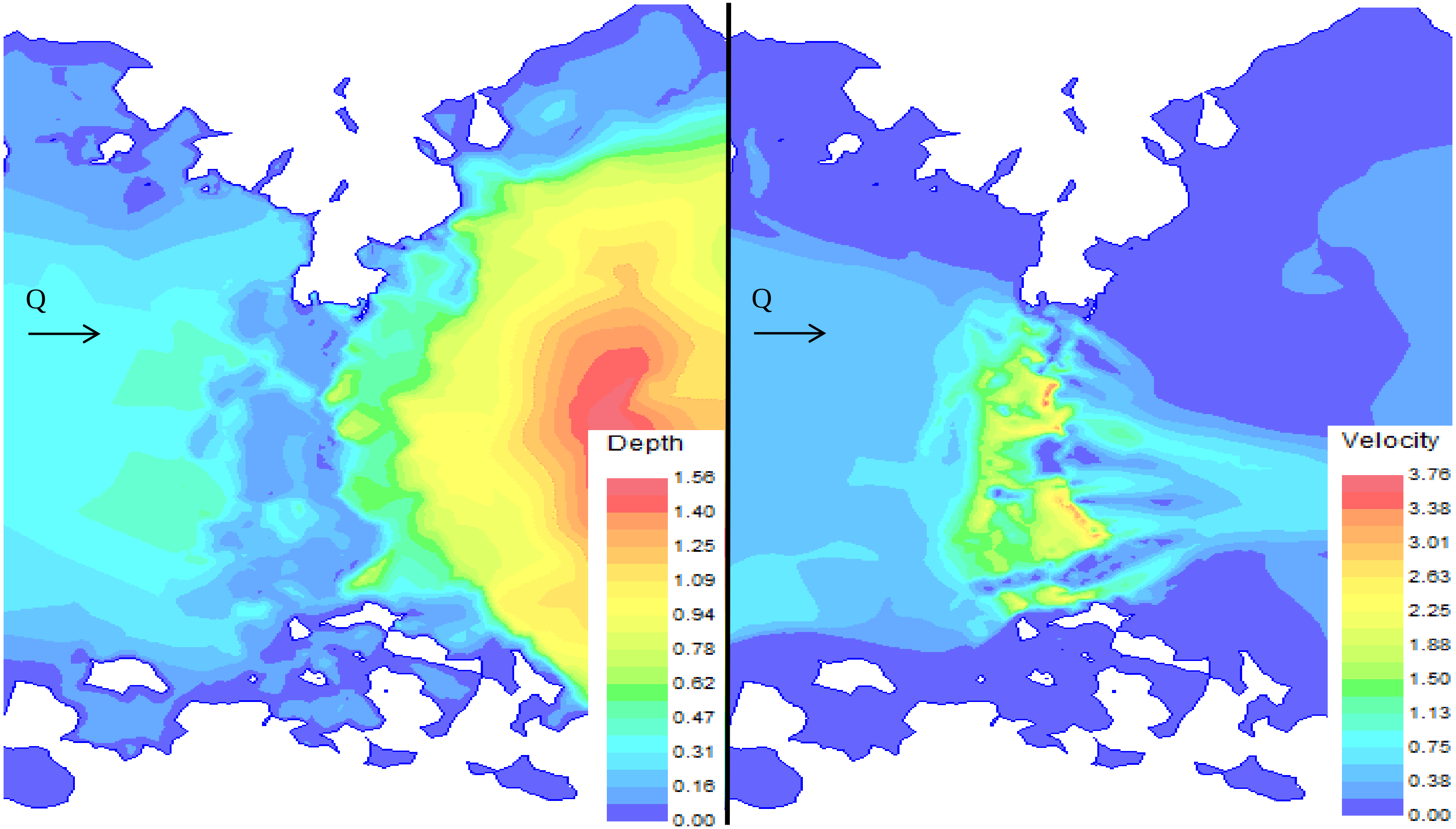
Conclusions

- Novel upstream passage assessment methods

- Comparing 2D and 3D Analysis Methods
  - Comparable prediction accuracy at *this* structure for *these* species

- Key Hydraulic Variables
  - Depth: > 0.11 m
    Velocity: < 25 BL/s

Questions?


Q
Depth
1.56
1.40
1.25
1.09
0.94
0.78
0.62
0.47
0.31
0.16
0.00
Q
Velocity
3.76
3.38
3.01
2.63
2.25
1.88
1.50
1.13
0.75
0.38
0.00

References

- Fox, B., 2013. Eco-Hydraulic Evaluation of Whitewater Parks as Fish Passage Barriers. Masters Thesis, Colorado State University, Department of Civil and Environmental Engineering, Fort Collins, CO.
- Kolden, E., 2013. Modeling in a Three-dimensional World: Whitewater Park Hydraulics and Their Impact on Aquatic Habitat in Colorado. Masters Thesis, Colorado State University, Department of Civil and Environmental Engineering, Fort Collins, CO.
- Ryan, E., 2015. Effects of Hydraulic Structures on Fish Passage: An Evaluation of 2D vs 3D Hydraulic Analysis Methods. Masters Thesis. Colorado State University, Department of Civil and Environmental Engineering, Fort Collins, CO.
- Stephens, T., 2014. Effects of Whitewater Parks on Fish Passage: A Spatially Explicit Hydraulic Analysis. Masters Thesis. Colorado State University, Department of Civil and Environmental Engineering, Fort Collins, CO.

Results – Prediction Models

	Predicted logit of (passage success) =	Likelihood ratio test (*p* -value)	Goodness-of-fit test (*p* -value)	Parameter Estimate (*p* -value)	Odds ratio (e^{β})		Observations accurately predicted (overall %)
2D Analysis	(-48.57) + 58.99*$MDC_{0.11}$	< 0.0001	< 0.0001	< 0.0001	$MDC_{0.11}$	4.17E+25	92.2
	(-29.61) + 32.11*$MDC_{0.11}$&MVR_{10}	< 0.0001	< 0.0001	< 0.0001	$MDC_{0.11}$ & MVR_{10}	8.78E+13	71.6
	(-48.57) + 58.97*$MDC_{0.11}$&MVR_{25}	< 0.0001	0.899	< 0.0001	$MDC_{0.11}$ & MVR_{25}	4.07E+25	91.7
3D Analysis	16.61 + (-27.75)*$MDC_{0.11}$	< 0.0001	< 0.0001	< 0.0001	$MDC_{0.11}$	8.91E-13	91.2
	(-4.33) + 3.34*$MDC_{0.11}$&MVR_{10}	0.3483	0.0828	0.3982	$MDC_{0.11}$ & MVR_{10}	28.35003	73.5
	20.92 + (-33.22)*$MDC_{0.11}$&MVR_{25}	< 0.0001	< 0.0001	< 0.0001	$MDC_{0.11}$ & MVR_{25}	3.73E-15	89.2