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An approach to model swimming behavior of smolts in the forebay of hydro dams

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AN APPROACH TO MODEL SWIMMING BEHAVIOR OF SMOLTS IN THE FOREBAY OF HYDRO DAMS

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Introduction and Research Questions

Understanding juvenile salmon swimming patterns can assist in:

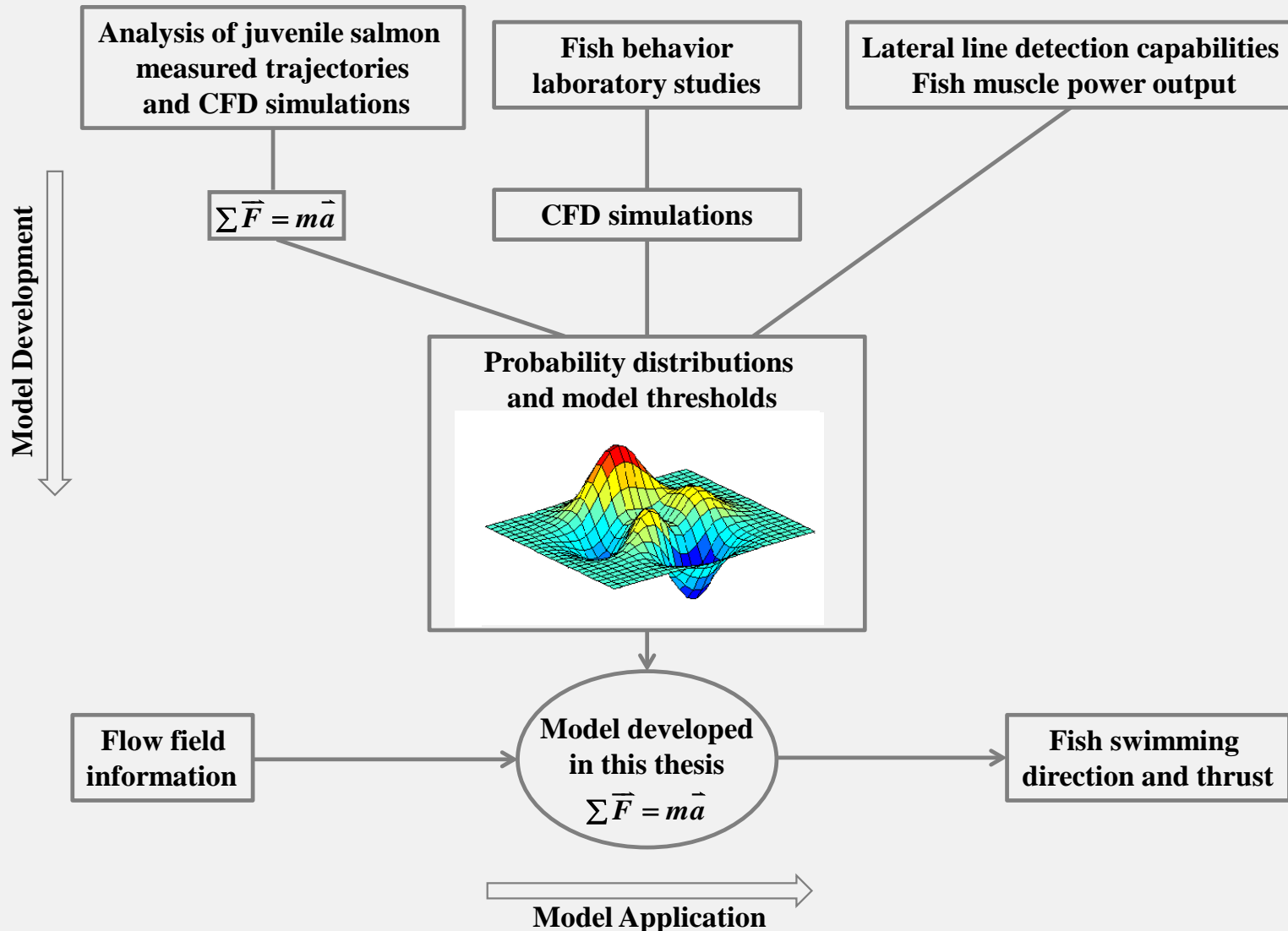
- Conducting fish survival studies
- Assessing fish bypass efficiency
- Designing diversion structures
- Defining spillway and powerhouse operating conditions
- Estimating Total Dissolved Gas (TDG) exposure
- Meeting regulations

Currently, acoustic tags are commonly used to monitor fish behavior as they approach hydropower dams.

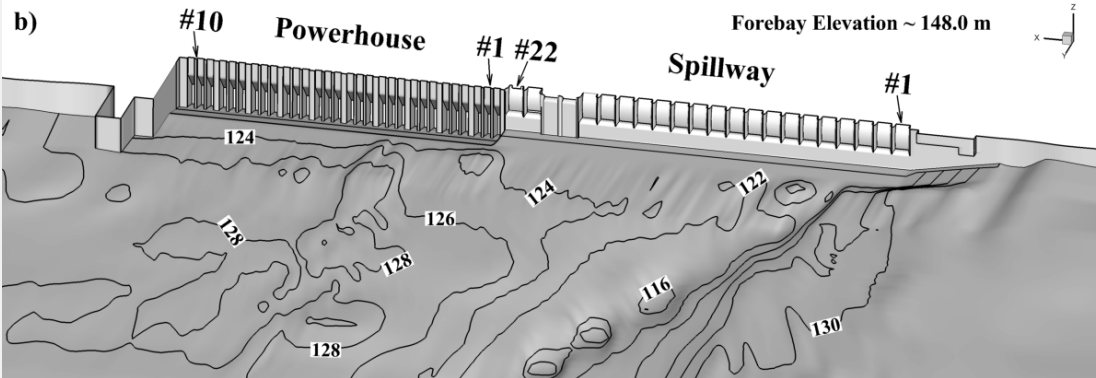
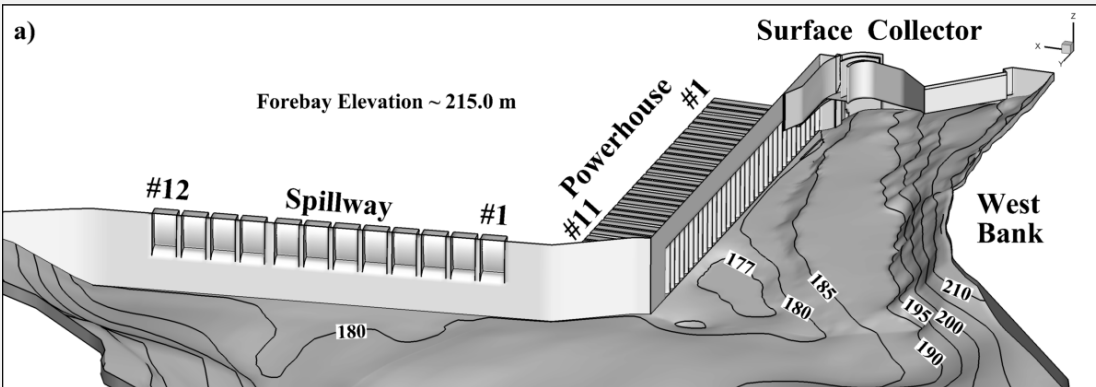
Is there a way to use measured fish behavior to make fish behavior predictions under flow conditions different from those present when fish behavior was measured?

Is there a way to use measured fish behavior to make fish behavior predictions at locations different from the site where fish behavior was studied?

Conceptual Model



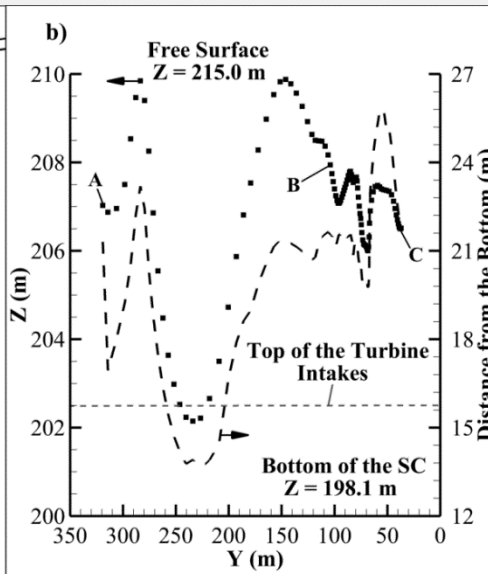
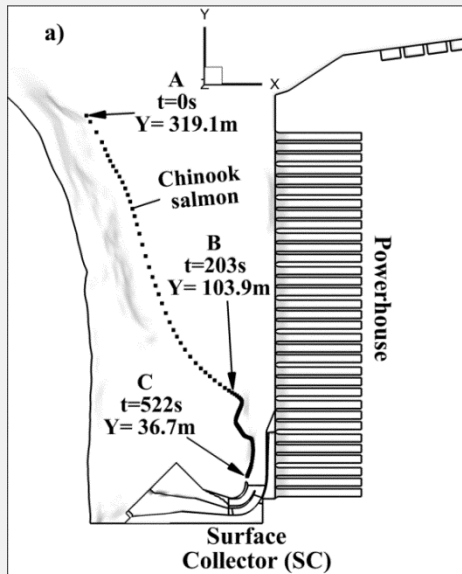
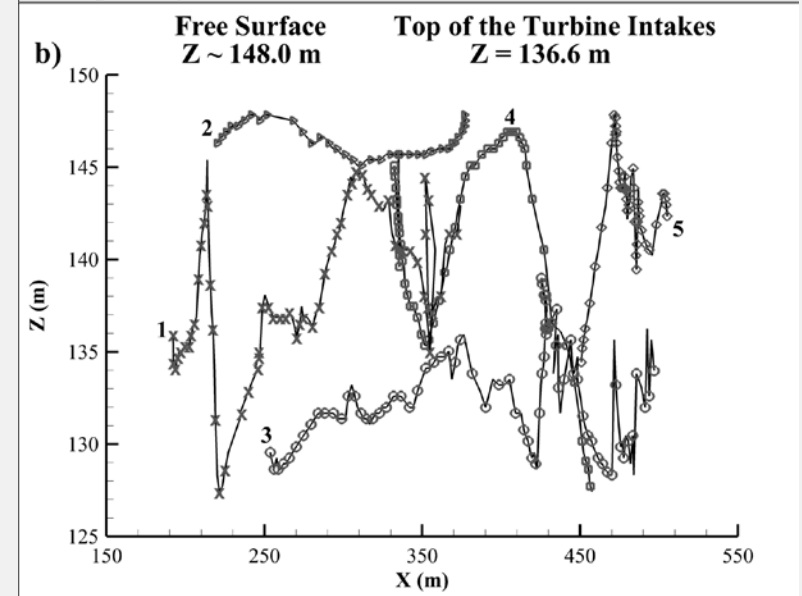
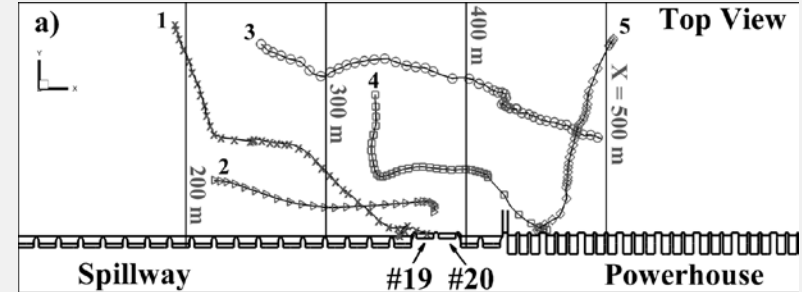
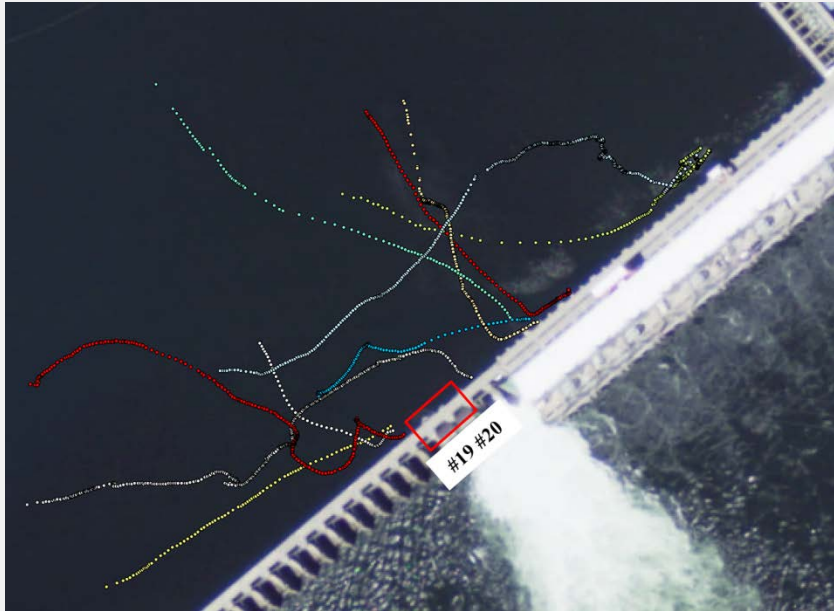
Study Area and Flow Conditions



	PRD	2007	2008
FB Level (m)			
		148.1	148.0
Powerhouse	#1	473.5	345.1
	#2	437.6	389.2
	#3	450.3	398.1
	#4	457.6	390.6
	#5	448.6	424.9
	#6	434.9	376.3
	#7	430.6	383.7
	#8	432.2	384.3
	#9	430.0	368.6
	#10	453.7	385.5
	Total	4449.2	3846.4
Spillway	#1	0.0	0.0
	#2	0.0	0.0
	#3	0.0	0.0
	#4	0.0	0.0
	#5	0.0	0.0
	#6	0.0	0.0
	#7	0.0	0.0
	#8	0.0	0.0
	#9	0.0	0.0
	#10	0.0	0.0
	#11	0.0	0.0
	#12	0.0	0.0
	#13	0.0	0.0
	#14	0.0	0.0
	#15	0.0	0.0
	#16	0.0	0.0
	#17	0.0	0.0
	#18	0.0	0.0
	#19	182.1	181.9
	#20	182.1	181.9
	#21	0.0	209.6
	#22	0.0	20.8
Total	364.2	594.1	
River	4813.4	4440.5	

RRD		2005
FB Level (m)		214.6
Powerhouse	#1	340.5
	#2	337.7
	#3	293.9
	#4	277.7
	#5	276.4
	#6	207.9
	#7	197.3
	#8	217.3
	#9	182.8
	#10	146.3
	#11	80.7
Total	2558.5	
Spillway	#1	0.0
	#2	102.8
	#3	0.0
	#4	101.9
	#5	136.7
	#6	168.3
	#7	135.6
	#8	0.0
	#9	0.0
	#10	0.0
	#11	0.0
	#12	0.0
Total	645.3	
SC	In	161.6
	Return	155.2
River	3210.2	

Measured Swim Paths



Number of swim paths

Ch: 401

Sk: 243

St: 616

Fish positions

Ch: 63,465

Sk: 27,752

St: 450,374

Balance of Forces

outcome

$$\begin{aligned}
 1) \quad m_f \frac{d\vec{u}_f}{dt} &= \vec{F}_D + \vec{F}_T \\
 2) \quad \text{Re}_f &= \rho |\vec{u}_{rf}| L / \mu \quad 4) \quad C_{df} = \begin{cases} \text{If swimming} & \begin{cases} \frac{493.9}{\text{Re}_f^{0.922}} & \text{if } \text{Re}_f > 2000 \\ \frac{24}{\text{Re}_s} (1 + b_1 \text{Re}_s^{b_2}) + \frac{b_3 \text{Re}_s}{b_4 + \text{Re}_s} & \text{if } \text{Re}_f \leq 2000 \end{cases} \\ \text{If gliding} & \begin{cases} \frac{0.072}{\text{Re}_f^{0.2}} \end{cases} \end{cases}
 \end{aligned}$$

m_f = Fish mass

\vec{u}_f = Fish velocity

\vec{u}_{rf} = Fish relative velocity

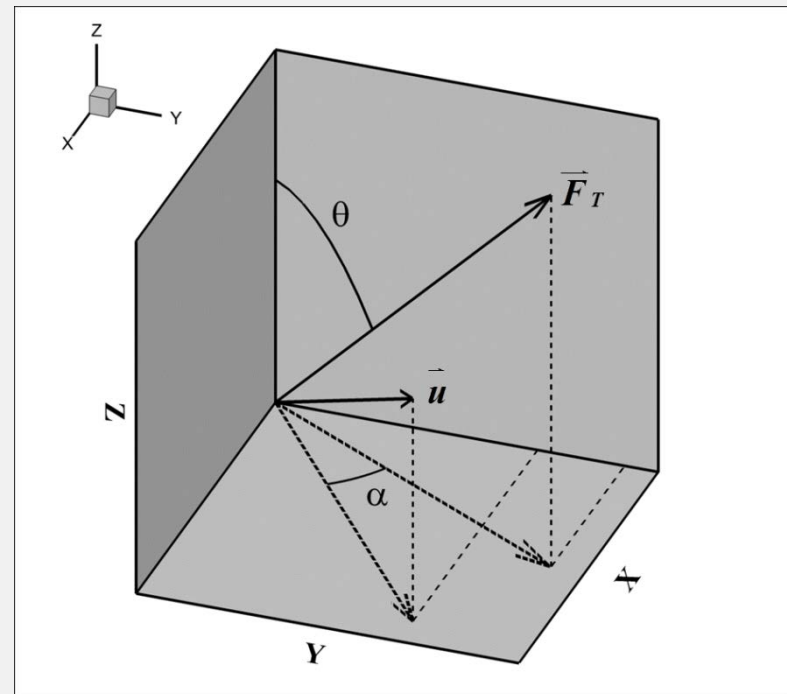
\vec{F}_D = Drag force

\vec{F}_T = Fish Thrust

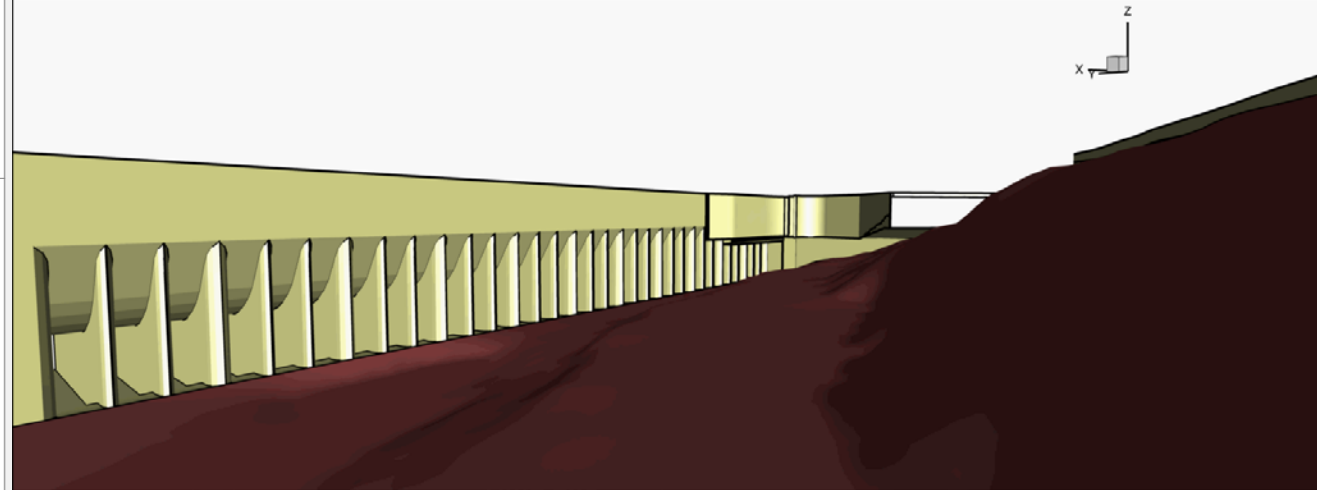
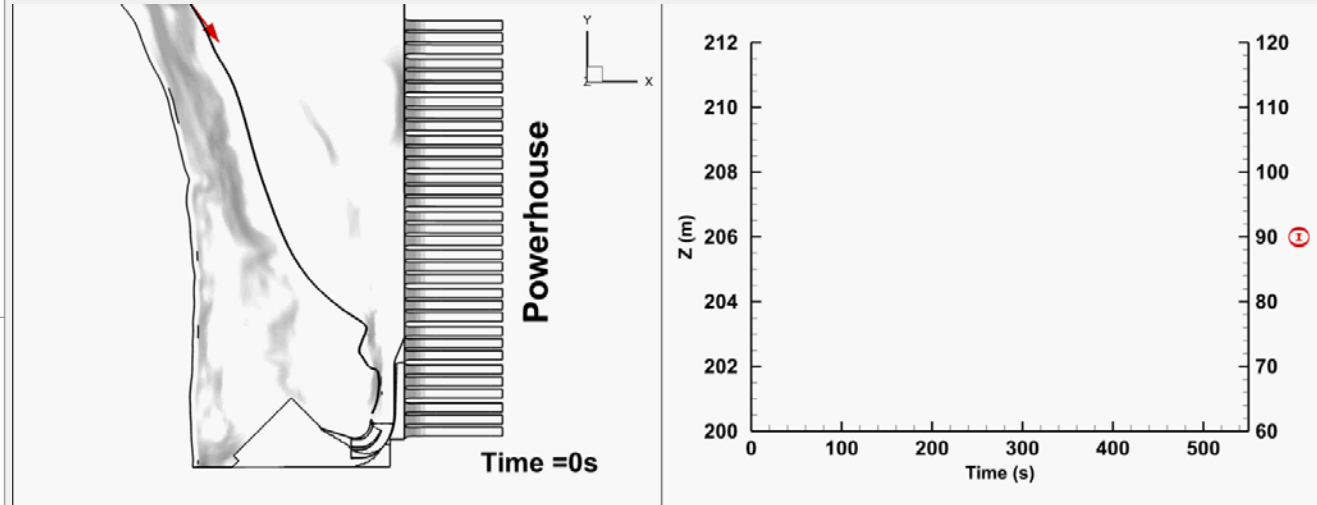
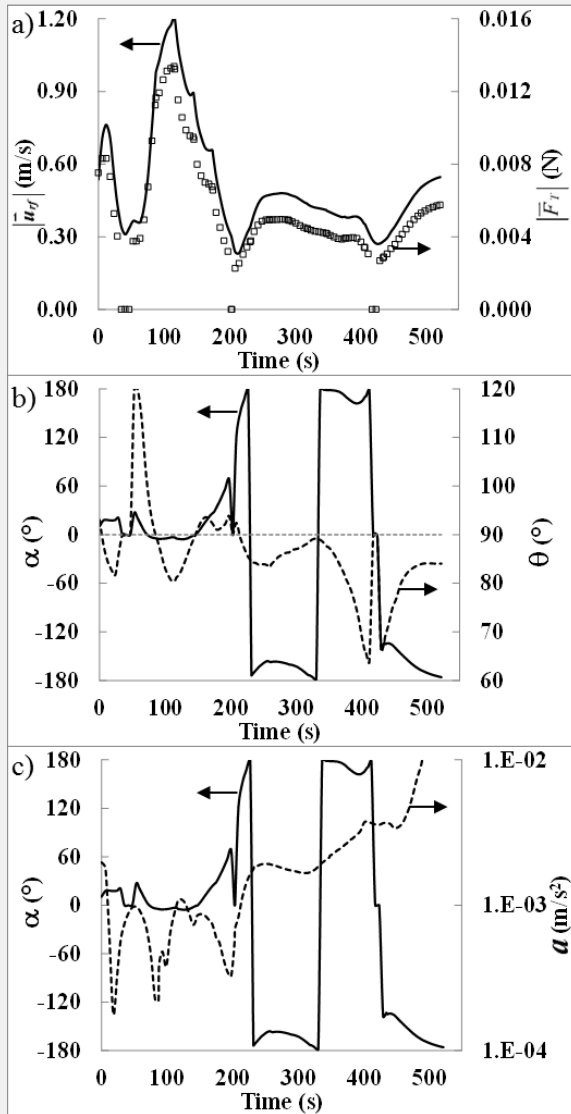
C_{df} = Drag coefficient

Re_f = Reynolds number

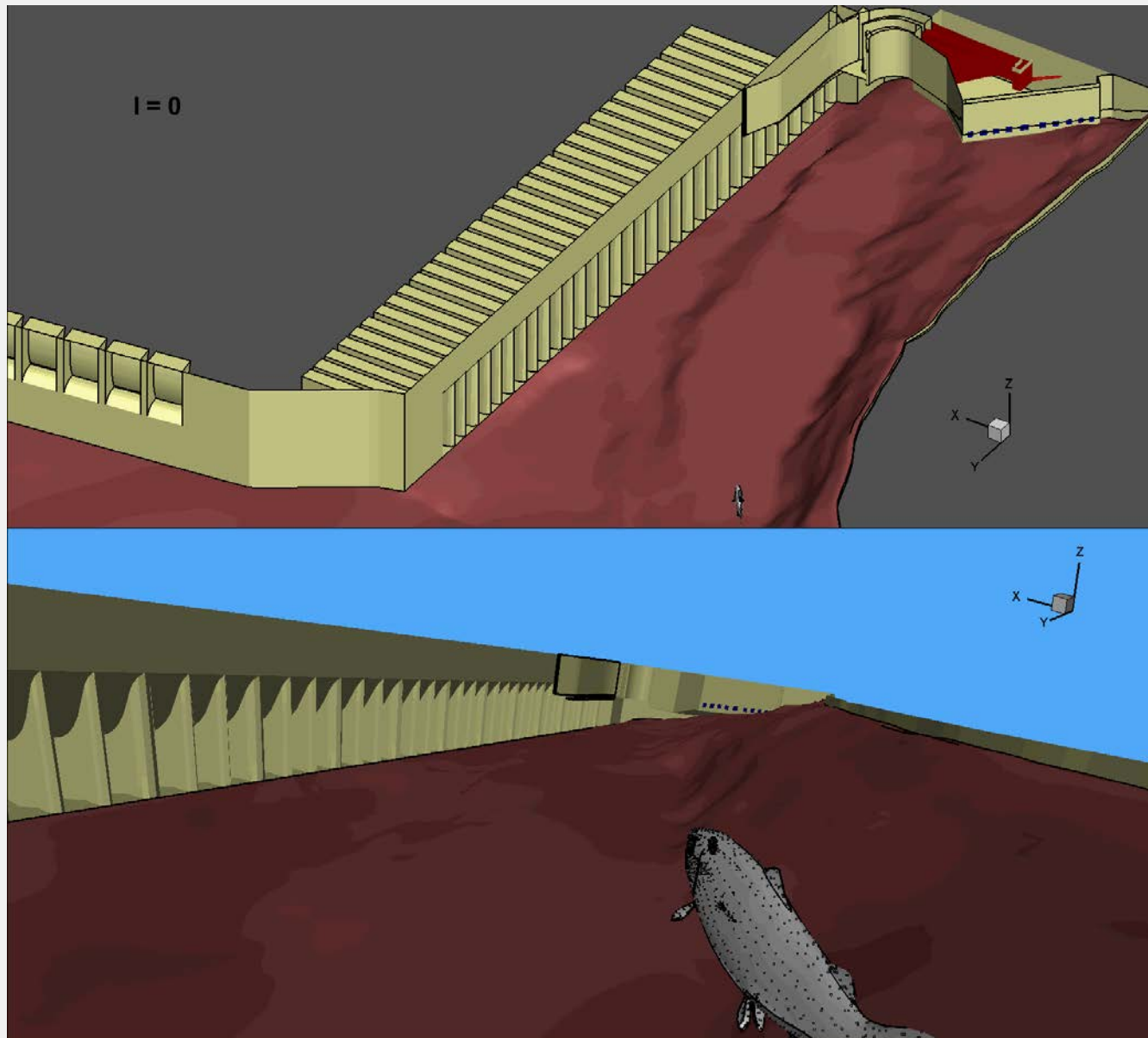
L = Fish length



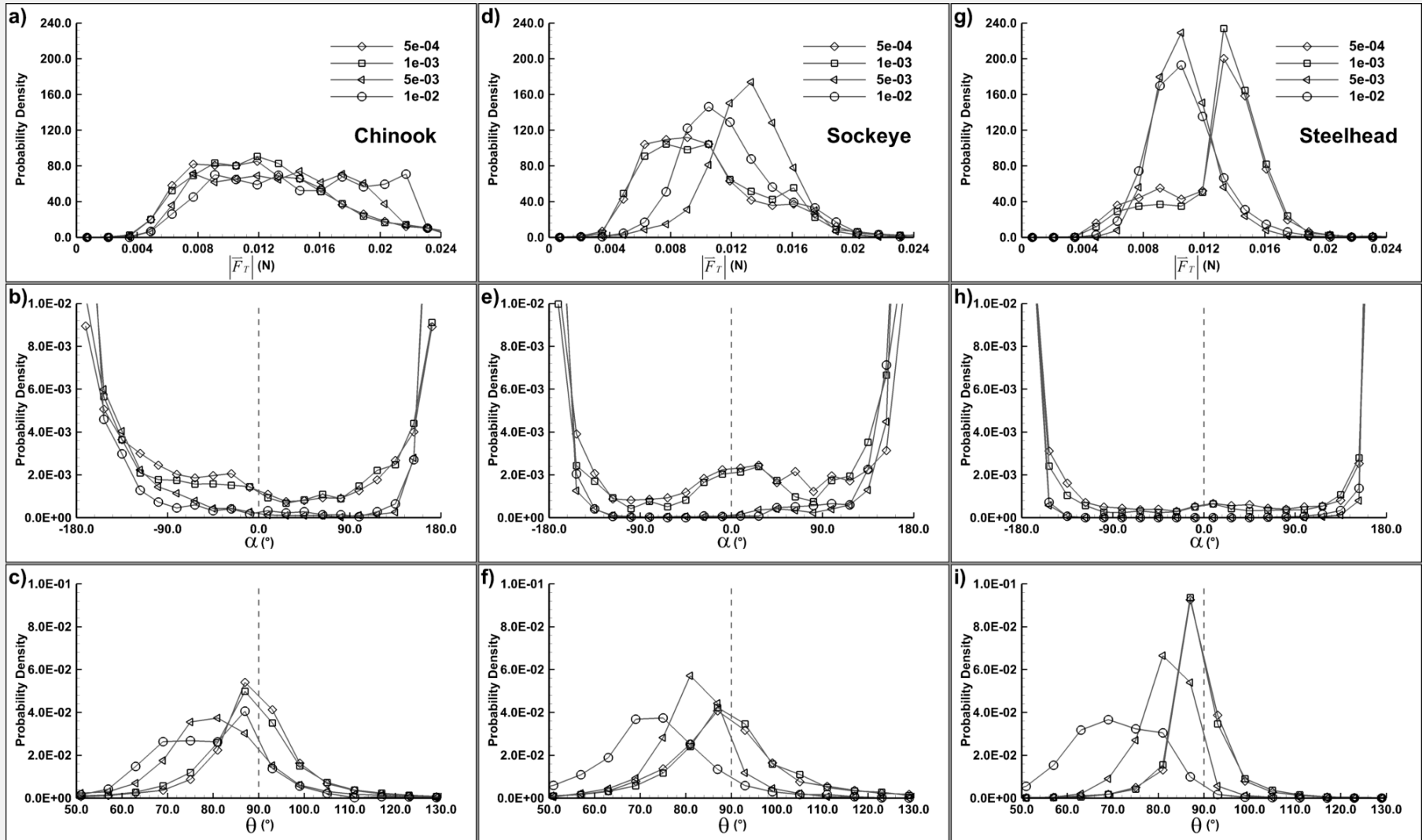
Results



Results



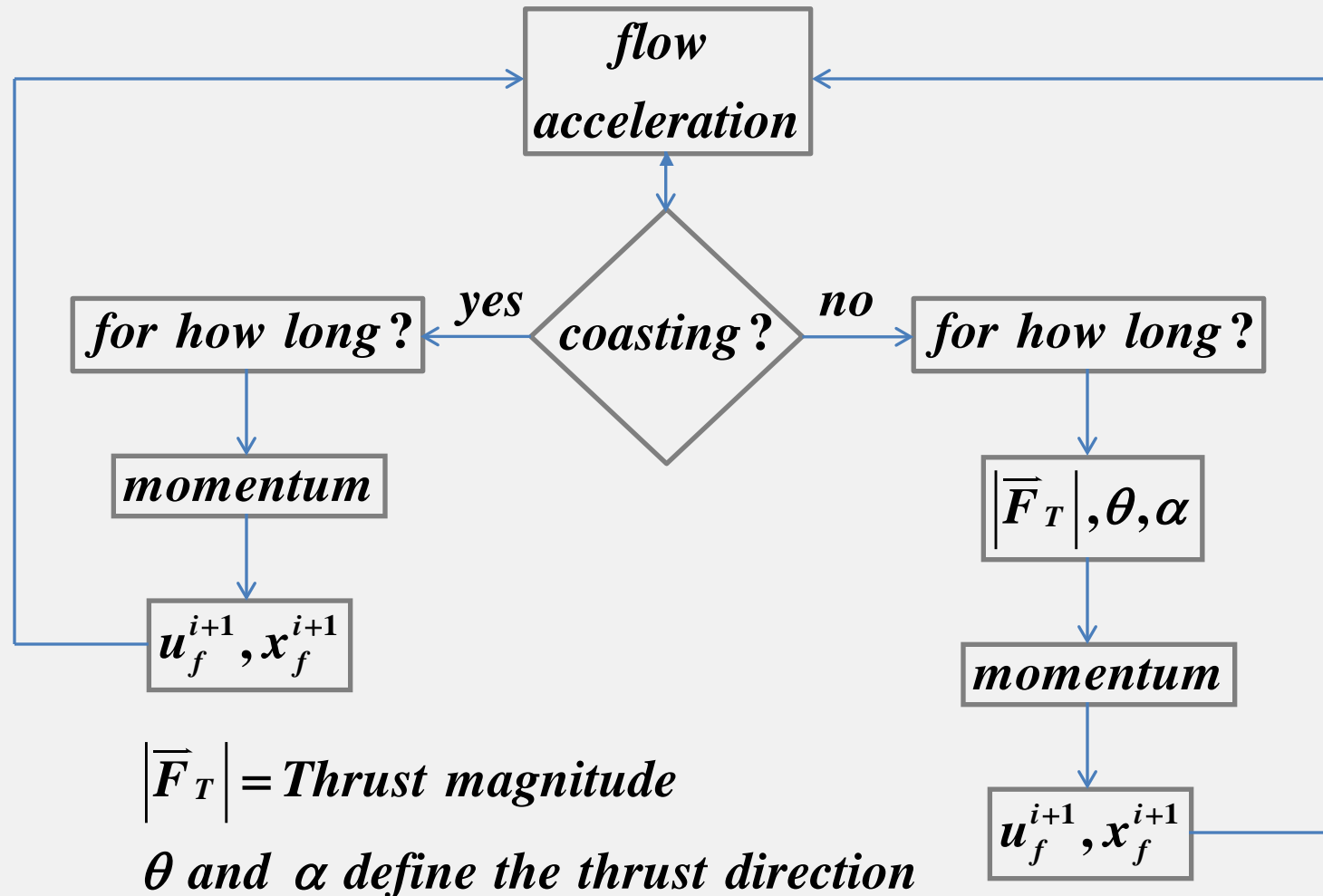
Distributions



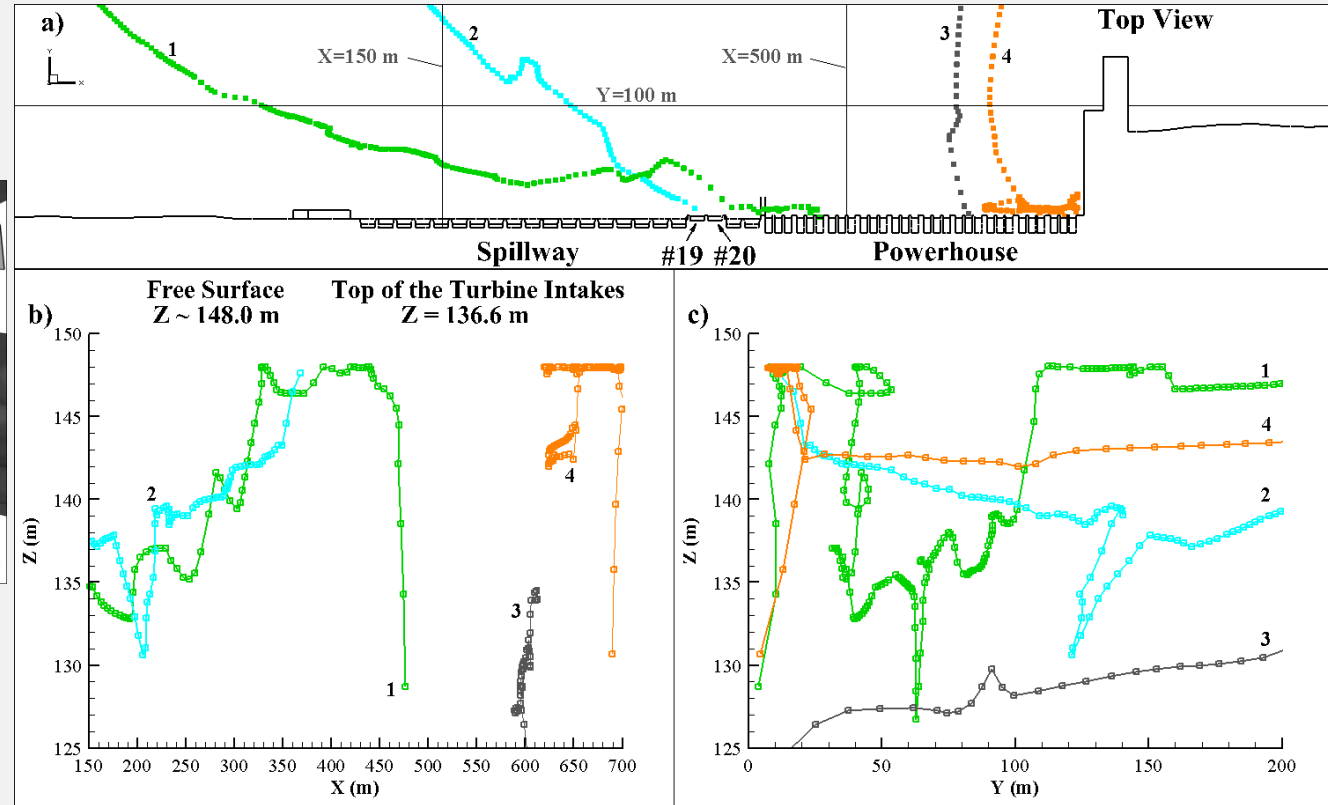
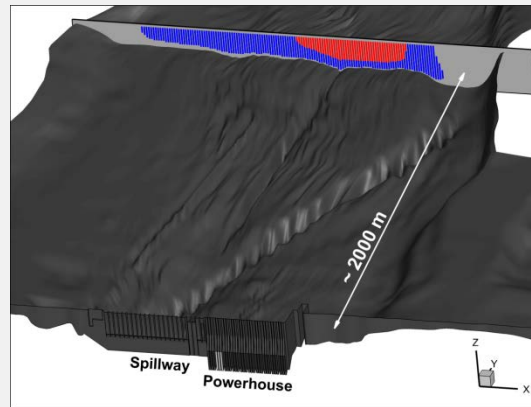
FMM Formulation Overview

- The fish movement model (FMM) proposed is tailored to simulate downstream migrating juvenile salmon swim paths
- Parameters are based on observed and measured juvenile salmon behavior
- Parameters are represented by probability distributions
- FMM focuses on the resultant thrust exerted by fish
- Coasting activity is included in the model
- Away from obstacles, simulated fish select a swimming direction referenced to the water velocity vector
- FMM is based on flow acceleration values
- High flow accelerations trigger avoidance behavior
- Obstacle avoidance is accomplished using the detection distance concept

FMM Simplified Flow Chart

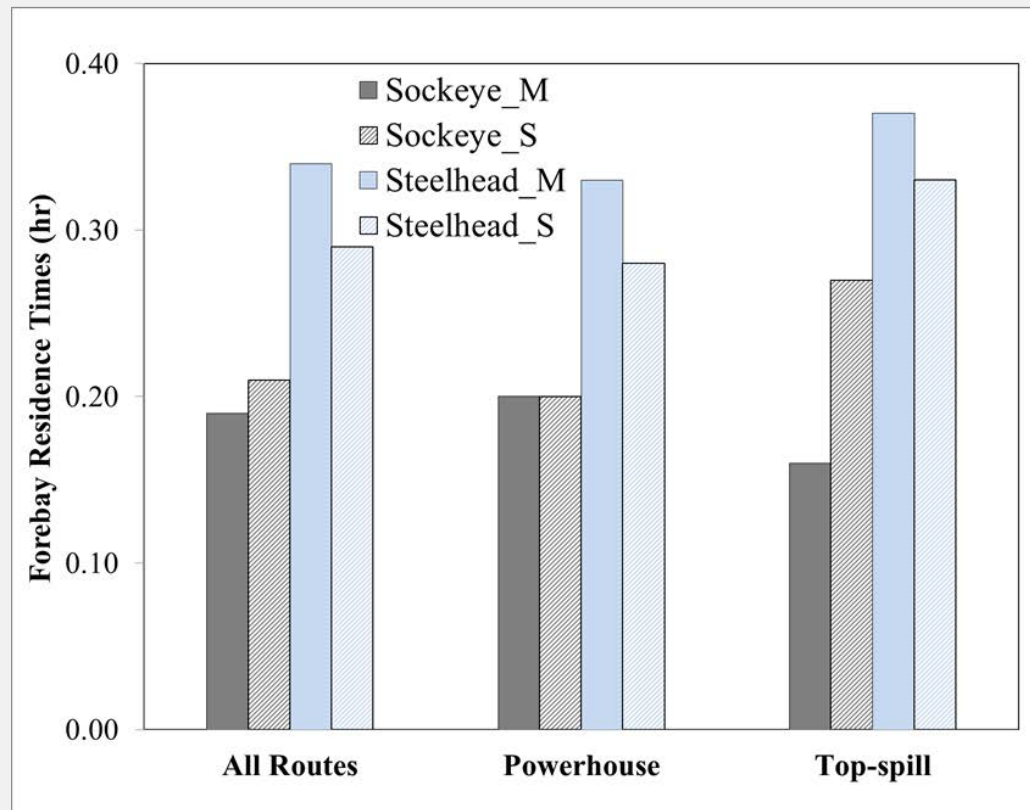
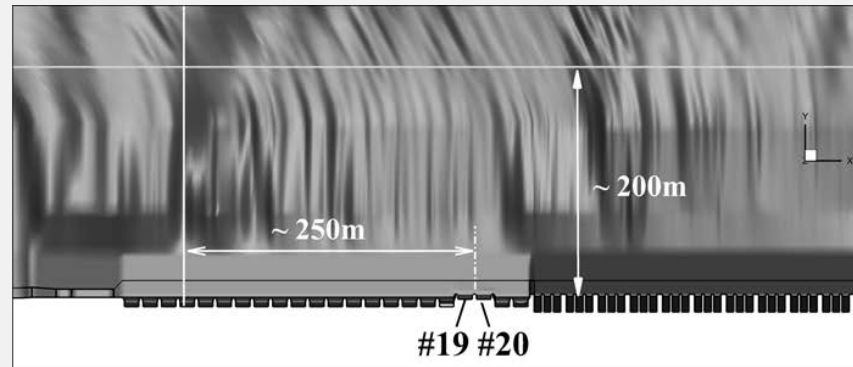


Simulated Swim Paths



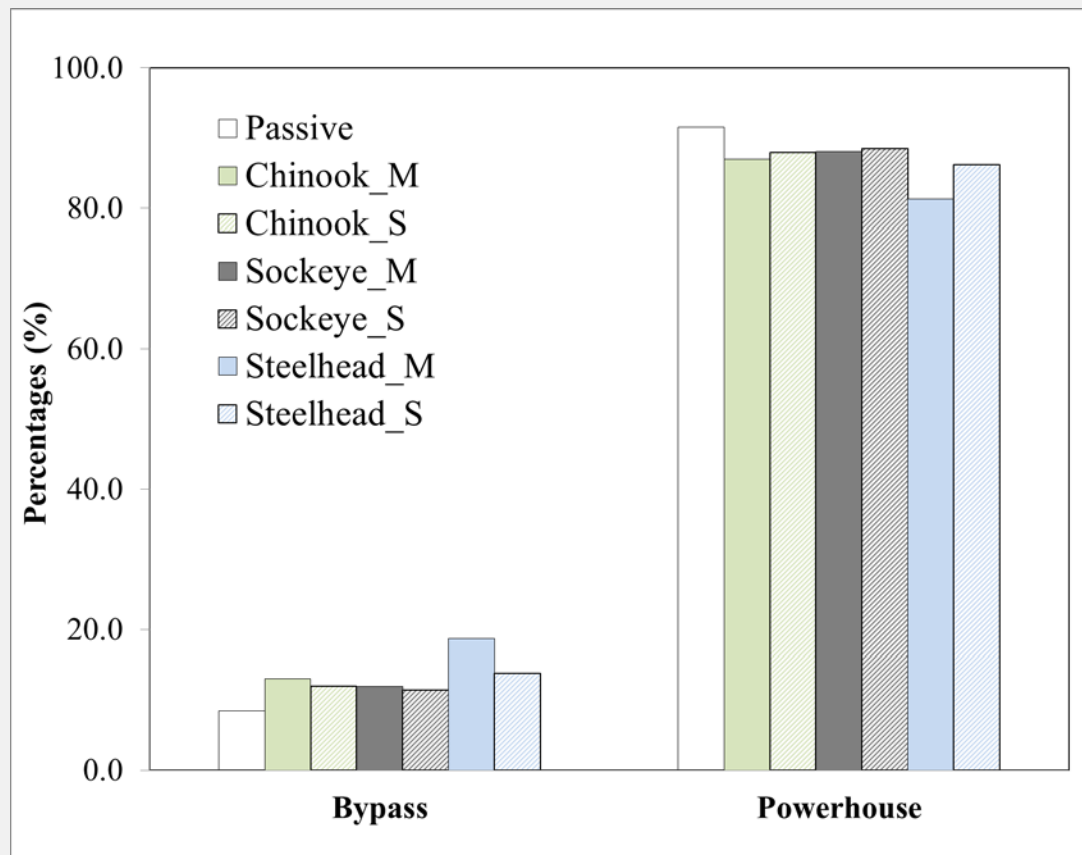
Four selected Sockeye simulated swim paths. Flow conditions in PRD in 2007

Residence Time



Final Exit

	Passive Particles	Chinook		Sockeye		Steelhead	
		M	S	M	S	M	S
Bypass	8.5	13.0	12.0	11.9	11.5	18.7	13.8
Powerhouse	91.5	87.0	88.0	88.1	88.5	81.3	86.2



Conclusions and Final Remarks

- Good agreement between measured and predicted final exits for Chinook could be an indication that the model is a useful tool to “transfer” measured fish behavior from one dam to another. It also suggests the existence of universal relations between fish behavior and hydrodynamics
- Model predictions capture fish final exit and residence time general trends
- The proposed methodology could also be used to simulate fish reactions to other stimuli like temperature, total dissolved gas, light, and sound
- Other variables can be included in the formulation of the model, such as temperature, time of the day, food availability, and predator abundance
- In the current model formulation simulated fish behavior is not influenced by antecedent flow conditions. Distributions given current and past flow conditions can be developed
- By averaging flow conditions over several days, local flow conditions that can trigger fish reactions can be overlooked

Acknowledgments

Chelan County PUD and Grant County PUD provided the measured swim paths

Dr. Eva Enders shared data on smolt avoidance behavior

QUESTIONS & COMMENTS