Leveraging Existing Data to Improve Fish Movement & Passage Analysis

The "ELAM" Approach

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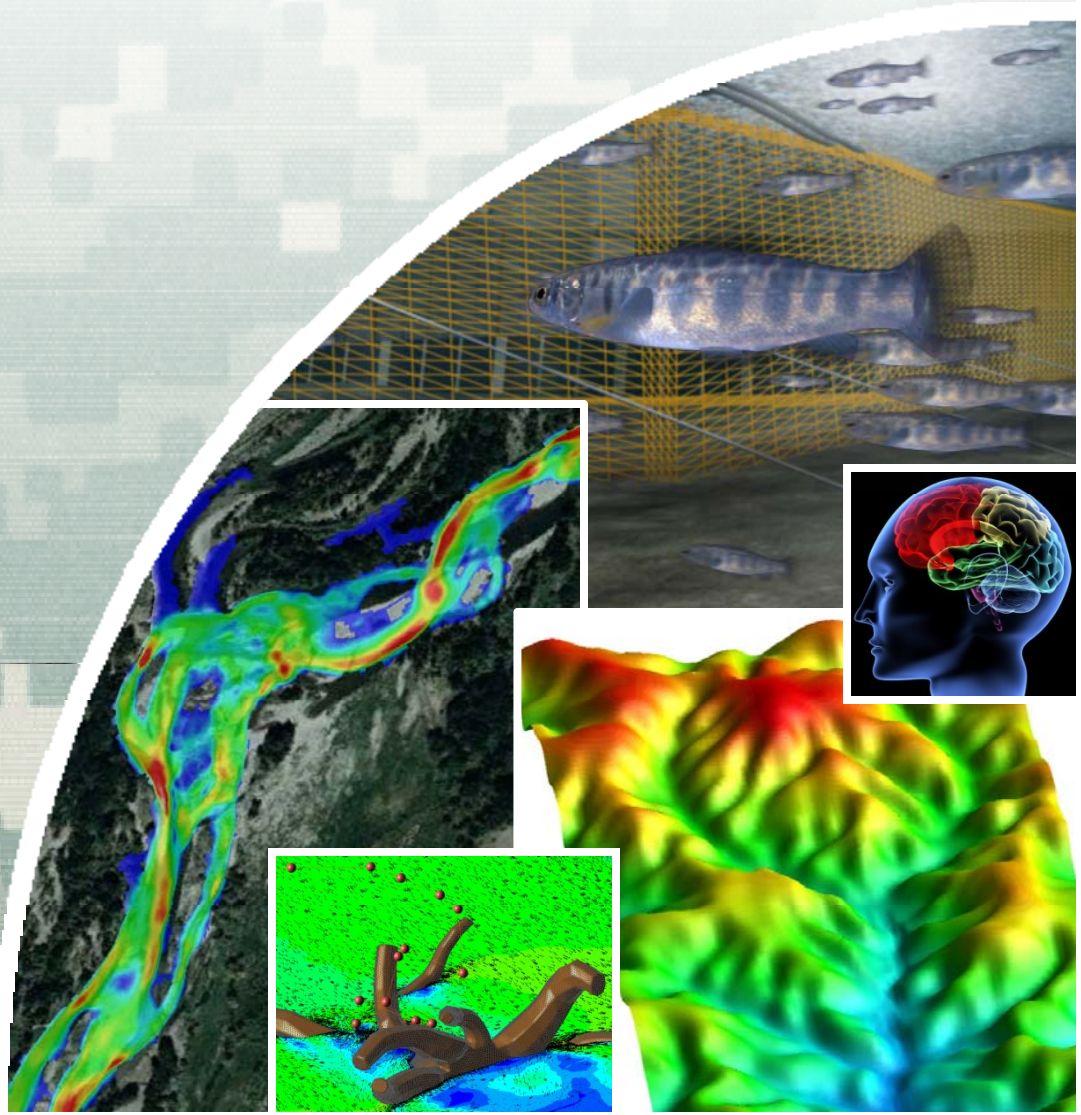
US Army Corps of Engineers

BUILDING STRONG®



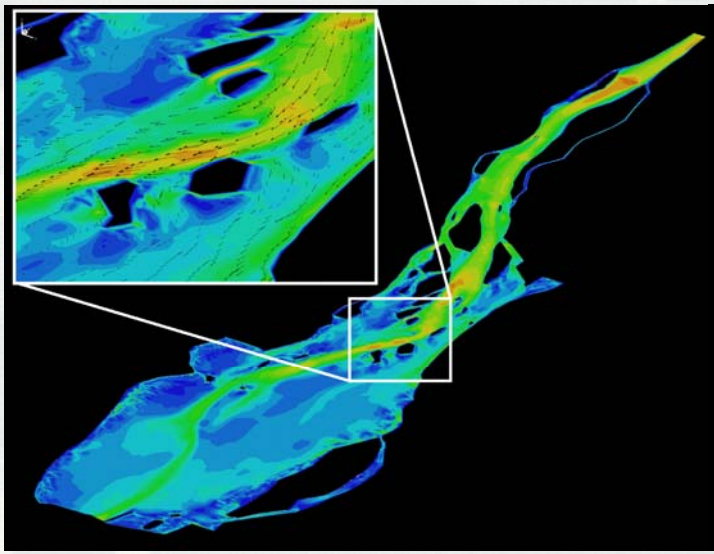
The Problem Issue

(Why bother with yet another tool ?)

Fish Movement & Habitat Analysis/Forecasting

(e.g., some suite of hydraulic and water quality variables)

(e.g., some description where to find fish or what fish are responding to)



Tractable ?

Generally, assumptions include:

- individual has perfect knowledge of the global environment,
- does not experience a change in internal state, and
- exhibits an all-or-nothing choice.

Mounting Evidence

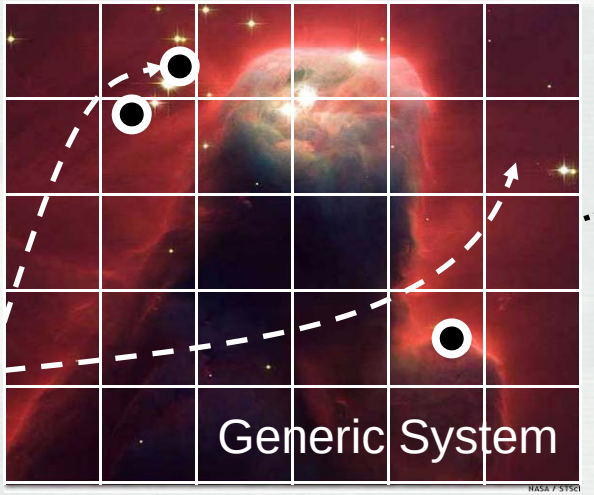
More flexible approach acknowledging:

- information limited due to varying sensory acuity and past experience,
- changes in internal state (e.g., physiology, learning) are important,
- decisions sometimes show irregularity and partial preferences, and
- continuous behavior adjustment in response to these factors.

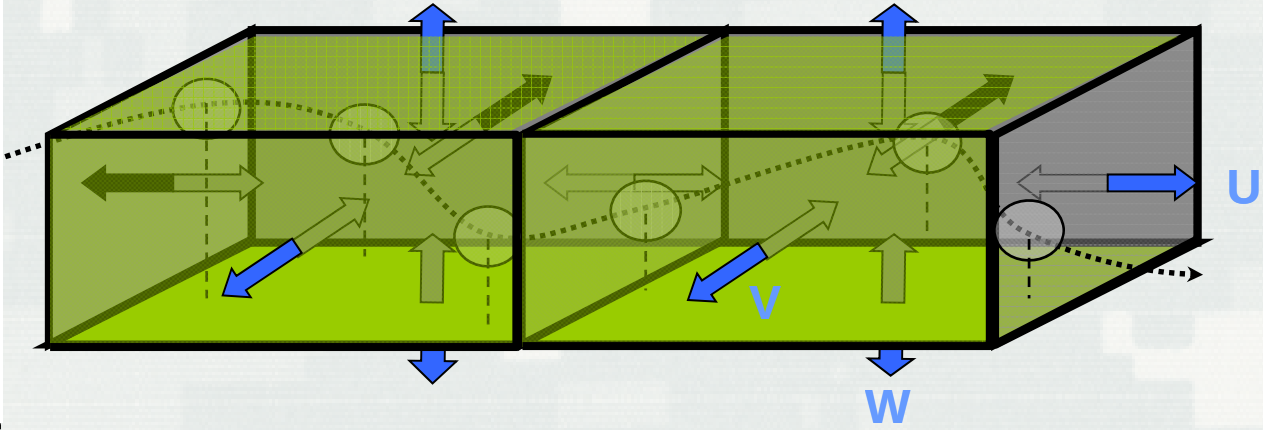
Our Solution Approach

(Integrate available data resources for a higher-fidelity approach)

The *Eulerian-Lagrangian-Agent Method* (*ELAM*)



Aquatic System



Discretize it (Eulerian)
- Interstellar Dust
- Hydraulics / Water Quality
- Vegetation / Land Use

Capturing Phenomena - small in time and space scale
- large/rare in time or space scale
- internal state important

1) Eulerian framework: governs physical, hydraulic, water quality, terrestrial, & avian (atmospheric) domains,

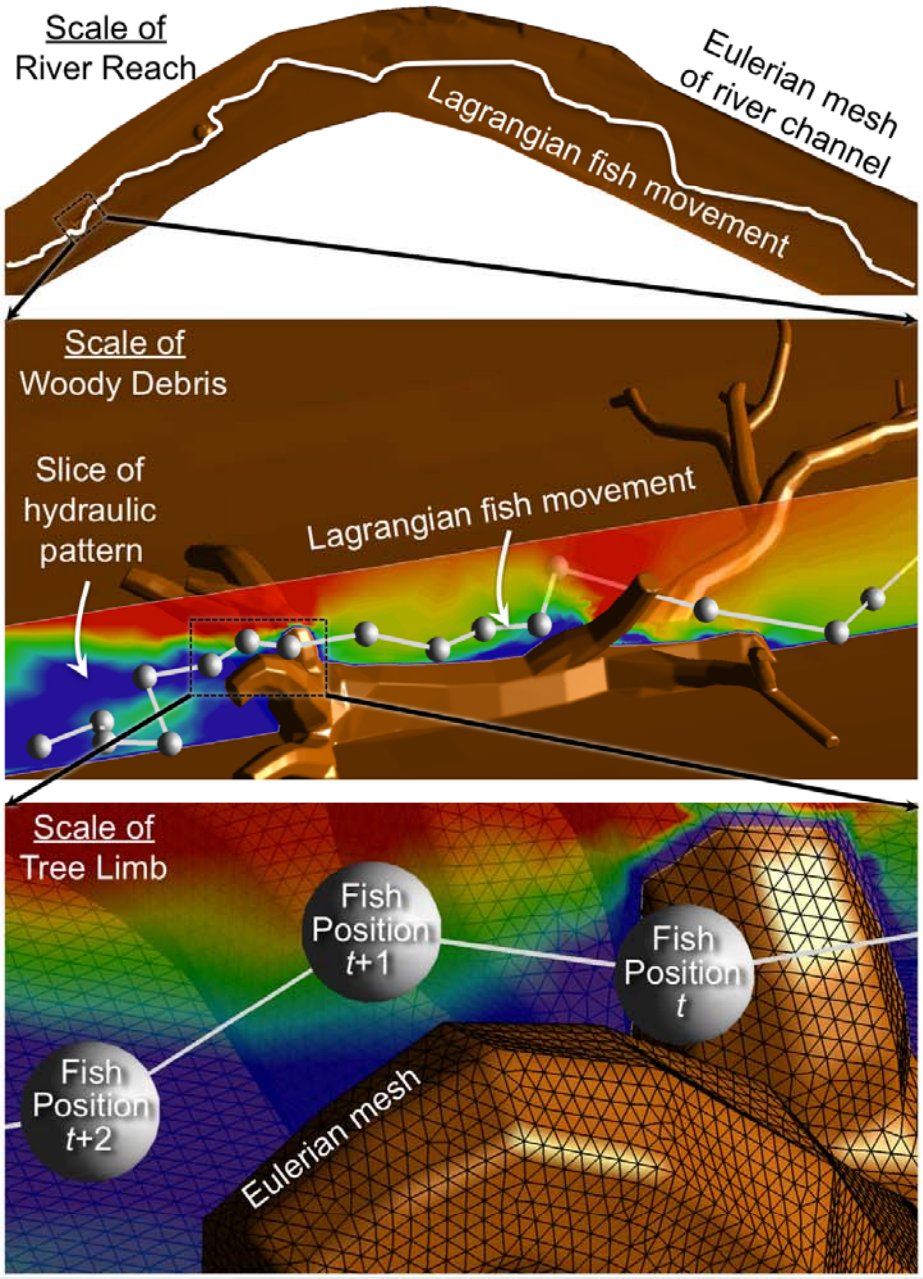
   mesh composed of nodes. Used by GIS and virtually all hydraulic and water quality models.

2) Lagrangian framework: governs sensory perception and movement trajectories of individuals (fish, geese),

   continuous directional trajectory composed of discrete locations.

3) agent framework: governs cognitive and memory domains responsible for behavior decisions of individuals.

   mathematics of animal perception for handling stimuli sensory processing, internal state, memory, response behavior, passage of time, and psychology.



Engineered Structure (Habitat)

Framework	Ecological Principle
Eulerian	Mesh composed of nodes used to describe pattern in landscape, hydraulics, and water quality.
Lagrangian	Continuous directional trajectory composed of discrete locations used to describe movement trajectories of individuals and perceptive range.
Agent	Biological mechanisms (internal state, cognition, physiology, bioenergetics) used to describe behavior response.

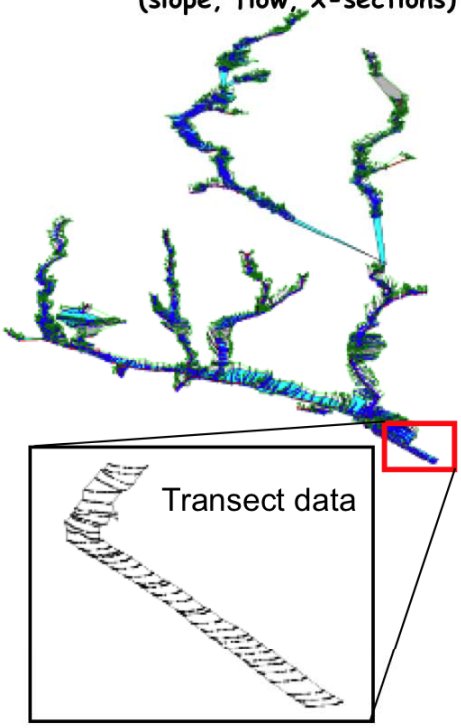
Engineered Structure (Dam)

Hydro Modeling is Readily Doable

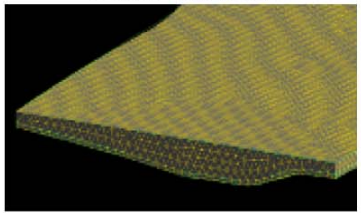
(Needed basic data exists for most all systems)

SHAPE – Stream Habitat Analyses Package → MultiD high-fidelity ecological simulations from readily available data

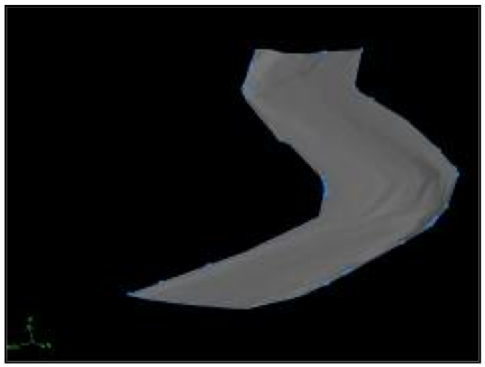
(1) Start with existing, low-resolution model (e.g., HEC-RAS)
(slope, flow, x-sections)



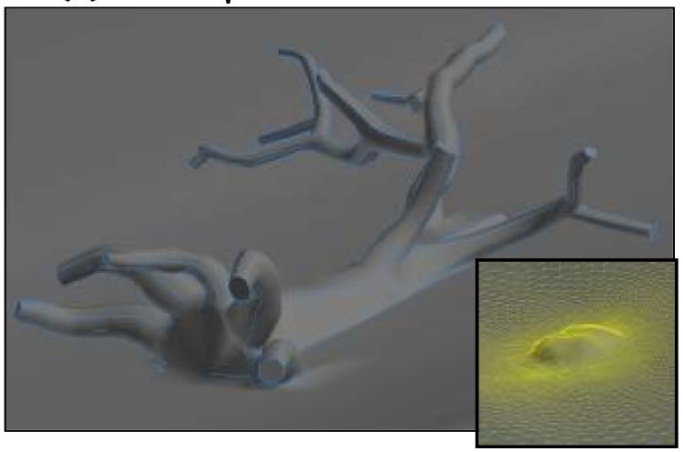
(3) Develop multiD environment



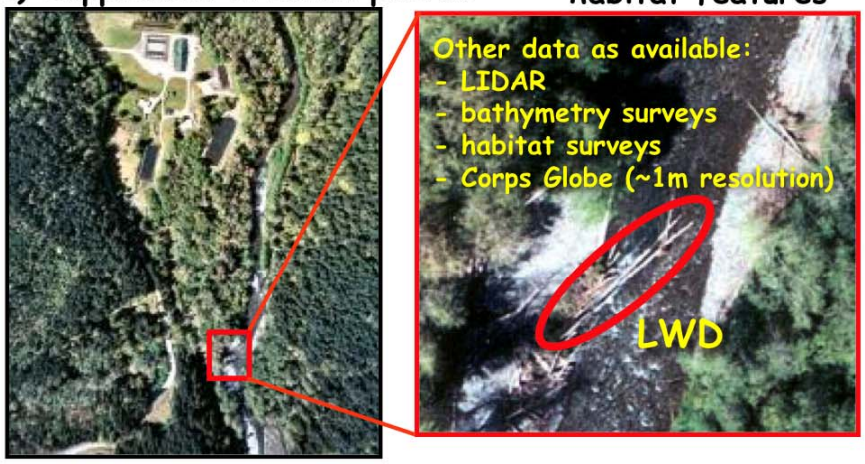
(4) Develop bathymetry between transects



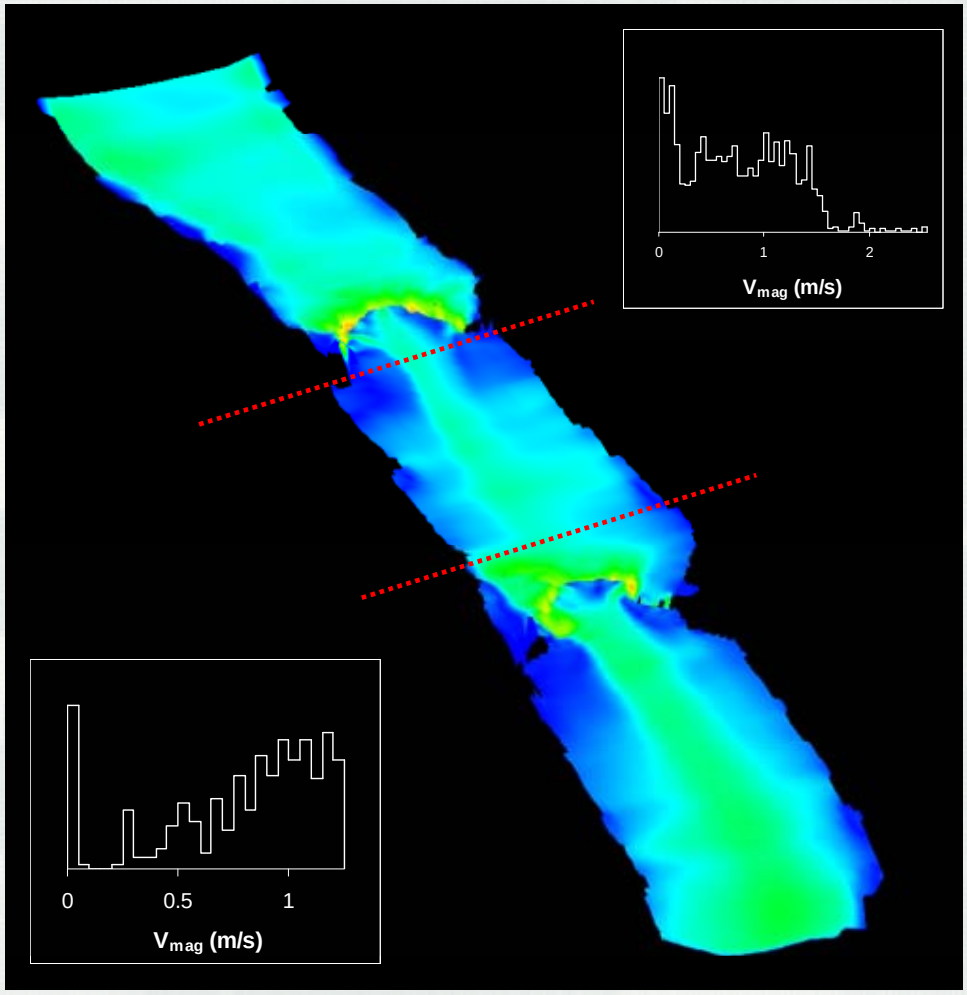
(5) Add important habitat features



(2) Supplement w/aerial photos → Highlight important habitat features



Information in a Hydraulic Model

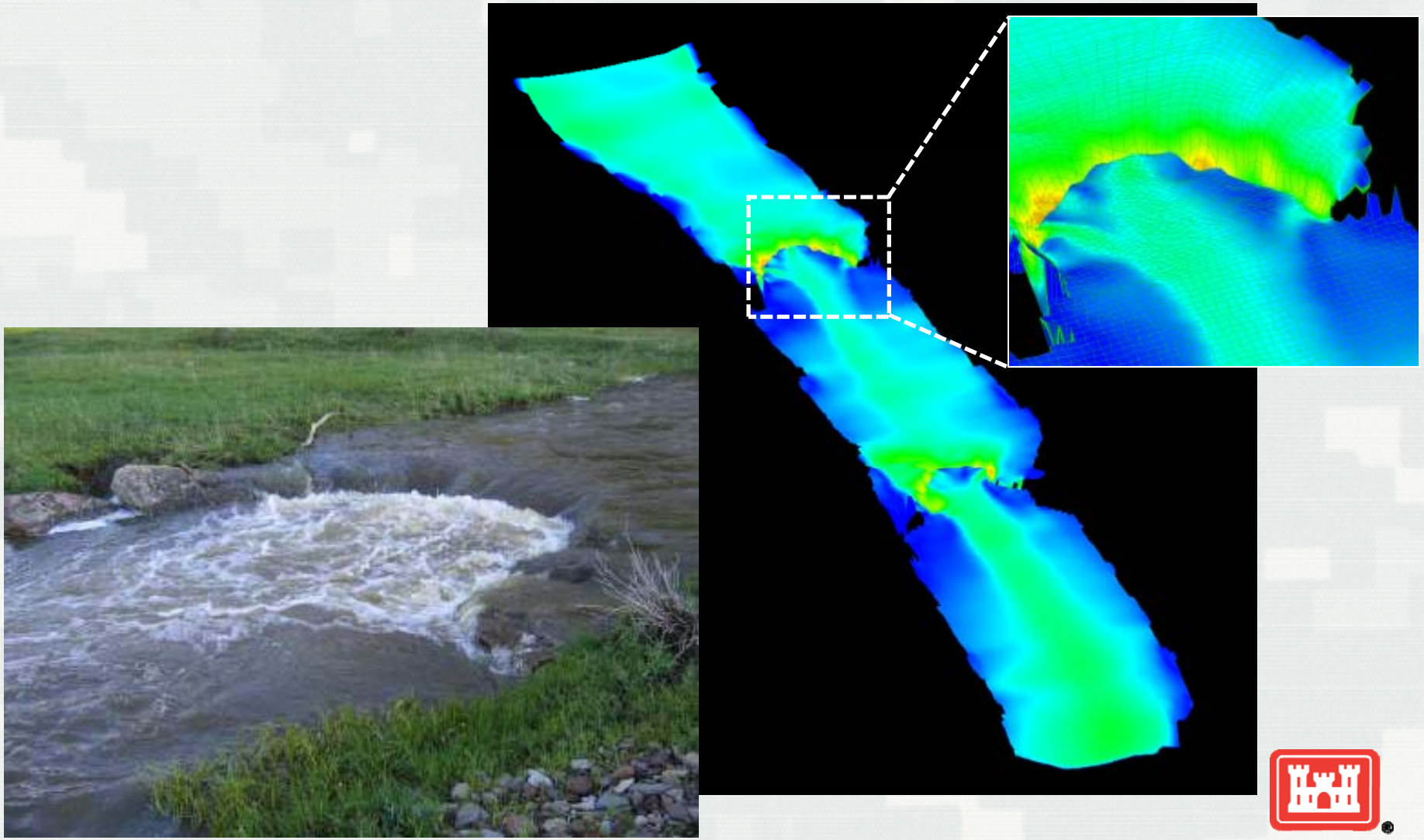


Velocity Magnitude

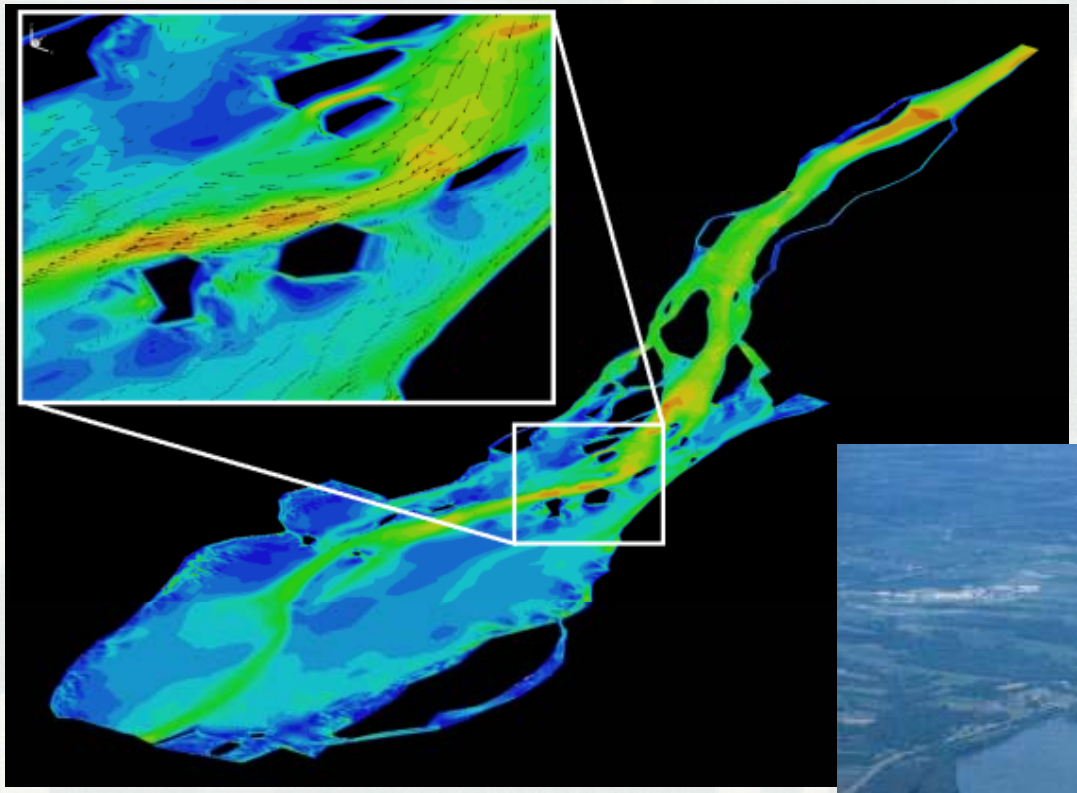
N = 1257
Mean = 0.749 m/s
S.D. = 0.514 m/s
Min = 0 m/s
Max = 2.542 m/s

N = 414
Mean = 0.793 m/s
S.D. = 0.363 m/s
Min = 0 m/s
Max = 1.238 m/s

Small Rivers



Large Rivers



Mississippi River

Hydraulic model courtesy of Dr. Larry Weber
Photo courtesy of USGS

Animal Decision-Making Behavior

(Fish on par with non-human primates in some cognitive tasks)

Robust Phenomena

- Most biological systems adapt to different conditions & environments.
- Nervous system has mechanisms that use prior experience to predict future events.
- **These mechanisms can potentially support behavioral prediction.**
- Little known about which specific mechanisms are used.

SYSTEMS NEUROSCIENCE

NATURE|Vol 448|9 August 2007

Timing is everything

Phillip Larimer and Ben W. Strowbridge

Interactions among neurons in brain circuits underlie sensory perception and information storage. Work in locusts shows how the timing of different neuronal signals is synchronized to ensure effective communication.

ANIMAL BEHAVIOUR

Vol 445|22 February 2007

nature

Planning for breakfast

Sara J. Shettleworth

It is commonly believed that planning for the future is a skill unique to humans. Could other animals, even those as evolutionarily distant as western scrub-jays, share this skill with us?

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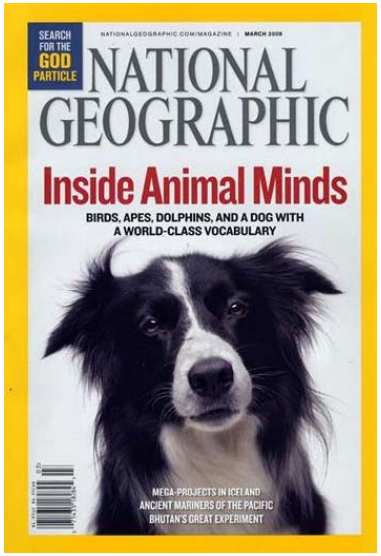
March 2008

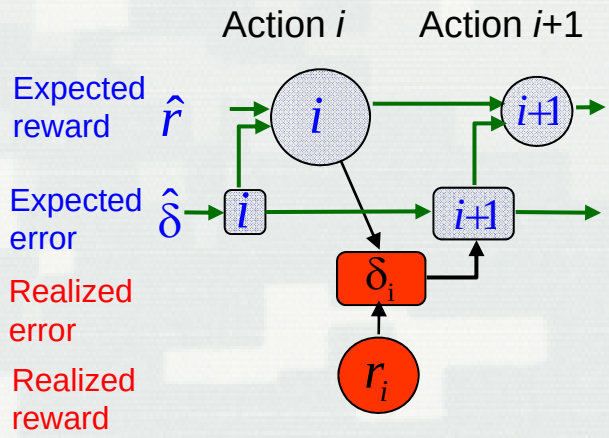
Inside Animal Minds

Brainy fellow creatures show that humans are not alone in their ability to invent, plan, or contemplate.



Our Approach to

Modeling Individual & Group Behavior in Complex Environments



Purpose:

- Identify/capture robust phenomena regarding how individuals detect/respond to environmental changes.

Product/Results:

- Concise, neurologically- and physiologically-realistic algorithm replicating fundamental & pervasive behavioral phenomena.

Payoff:

- A common "ELAM" model applicable to many fish species & contexts (passage, movement, habitat restoration).

1

Track Acclimatization to Stimulus

$$I_{a_i}(t) = \left(1 - m_{a_i}\right) \cdot I_i(t) + m_{a_i} \cdot I_{a_i}(t-1)$$

2

Environmental Stimulus Intensity

$$E_i(t) = I_i(t) - I_{a_i}(t)$$

Perceived Present Acclimated

3

Determine Perceived Stimulus Events

$$e_i(t) = 0 \quad \text{if} \quad E_i(t) < k_i$$
$$= 1 \quad \text{if} \quad E_i(t) \geq k_i$$

4

Probability of Response

$$P_i(t) = (1 - m_i) \cdot e_i(t) + m_i \cdot P_i(t-1)$$

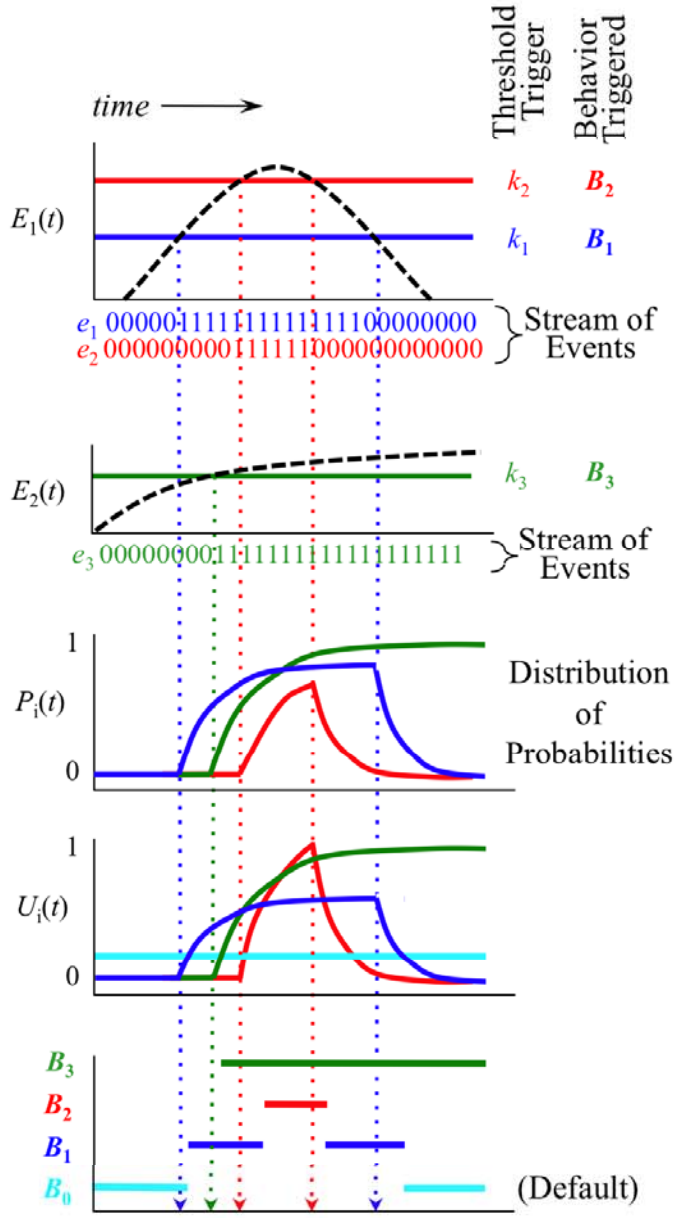
5

Utility (Weighted Probability) of Response

$$U_i(t) = P_i(t) \cdot u_i - C_i(t)$$

6

Behavior Repertoire



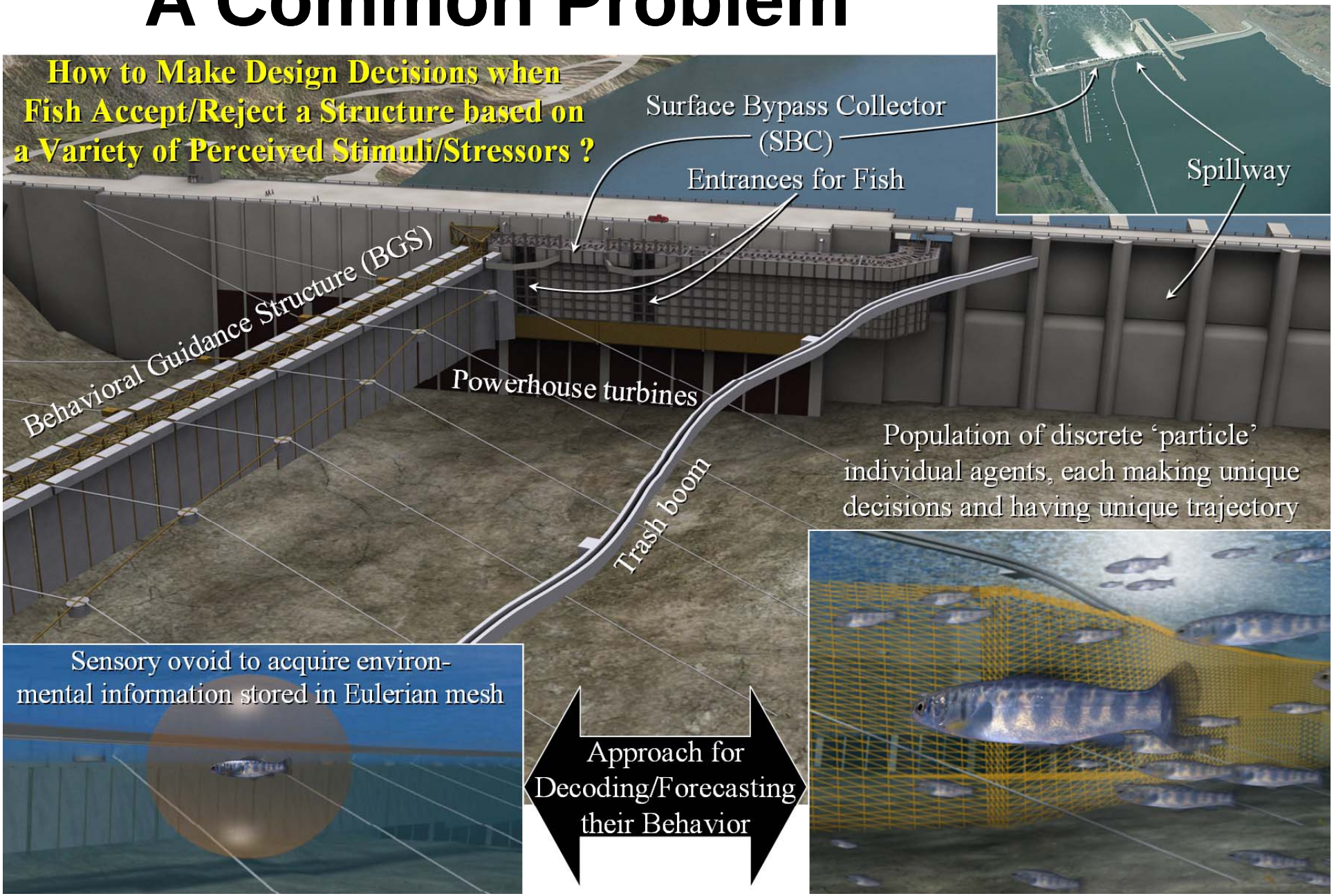
Testing the Approach

(At detailed and broad scales)

Why a PacNW Fish Passage Test ?

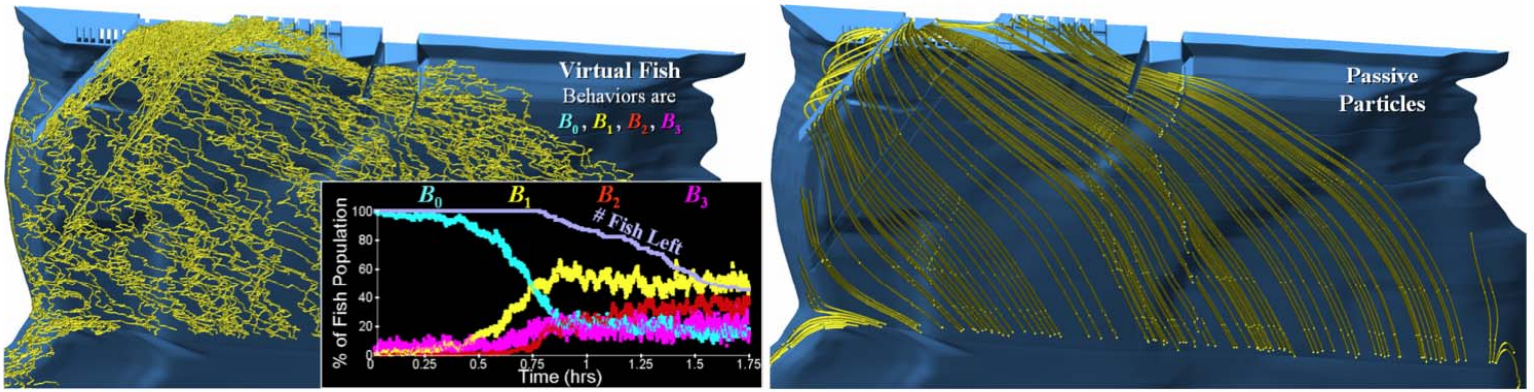
- Approach *not specific* to fish passage
  - …but test data must come from somewhere
- PacNW data affords the *toughest* test:
  - Can modeled fish released a km upstream pass into meter-size openings at dam in correct proportions
  - Amount of fish data available in PacNW probably exceeds rest of world *combined*
- **USACE's opportunity**: sharpen knowledge of approach for apps where data is scant.

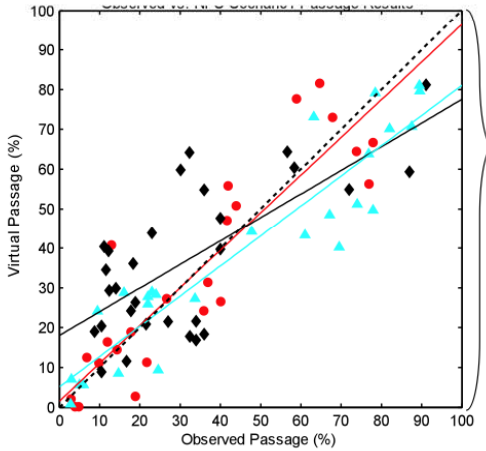
A Common Problem



How Well Does it Work ?

How Well Does it Work ?



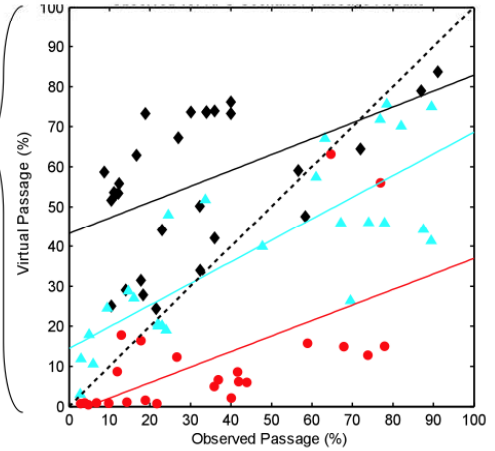


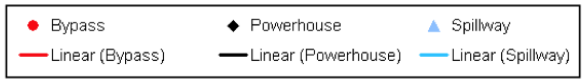
NFS Version 11 (*Best_1*)

Analysis Including: ALL					
Linear Model					Custom
Slope	r^2	RMSE	Intercept	RMSE	Metric
Optimum	Optimum	Optimum	Optimum	Optimum	Optimum
1.0	1.0	0	0	0.0000	1.000
0.9484	0.8058	11.9105	1.5763		
0.5946	0.49	13.8216	18.0503	11.7837	0.777
0.759	0.8668	9.6191	5.1462		

Passive Particles

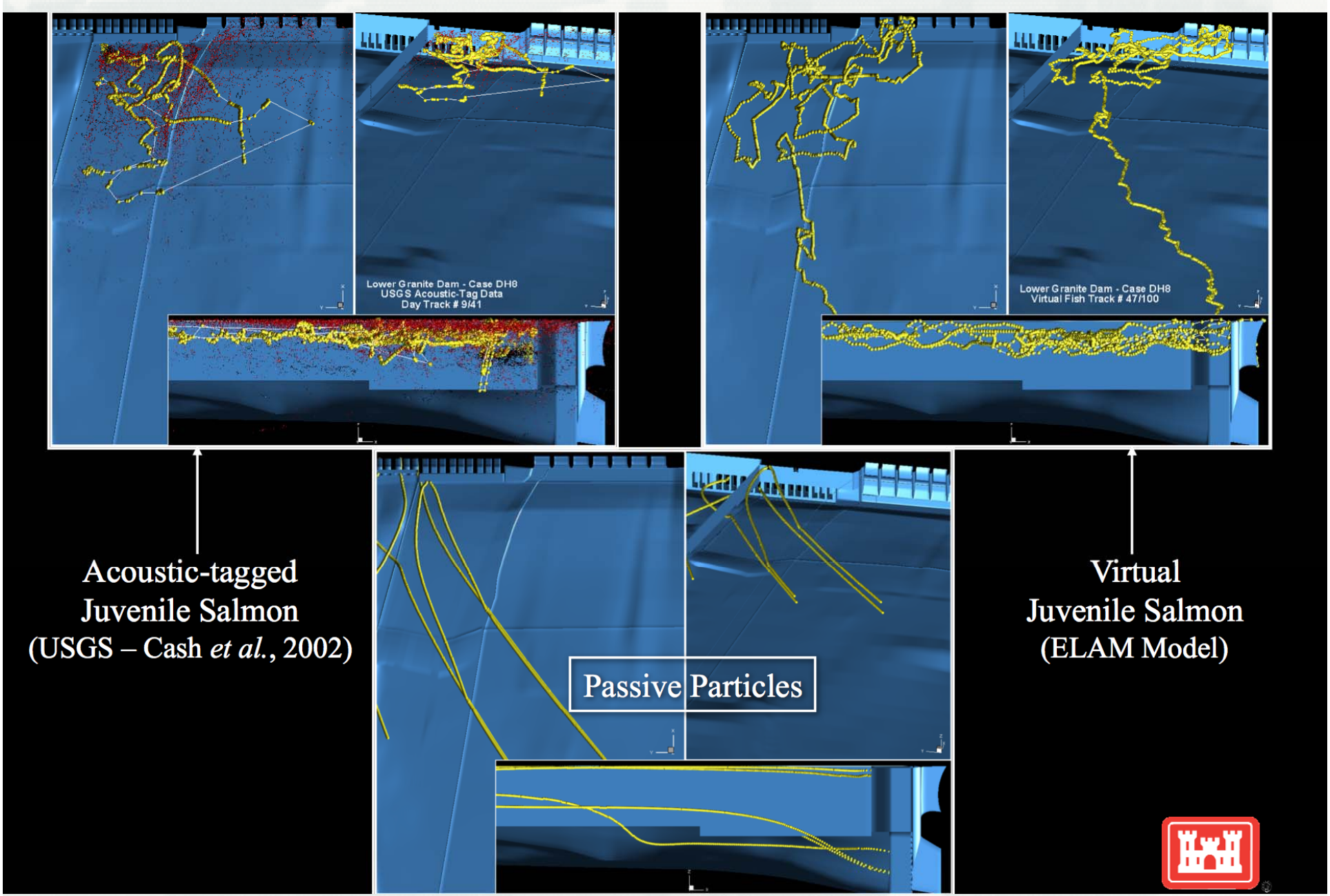
Analysis Including: ALL					
Linear Model					Custom
Slope	r^2	RMSE	Intercept	RMSE	Metric
Optimum	Optimum	Optimum	Optimum	Optimum	Optimum
1.0	1.0	0	0	0	1.0
0.3875	0.3667	13.0279	-1.8218		
0.3965	0.2485	15.7099	43.2033	14.00903	0.416
0.5417	0.6346	13.2893	14.4342		



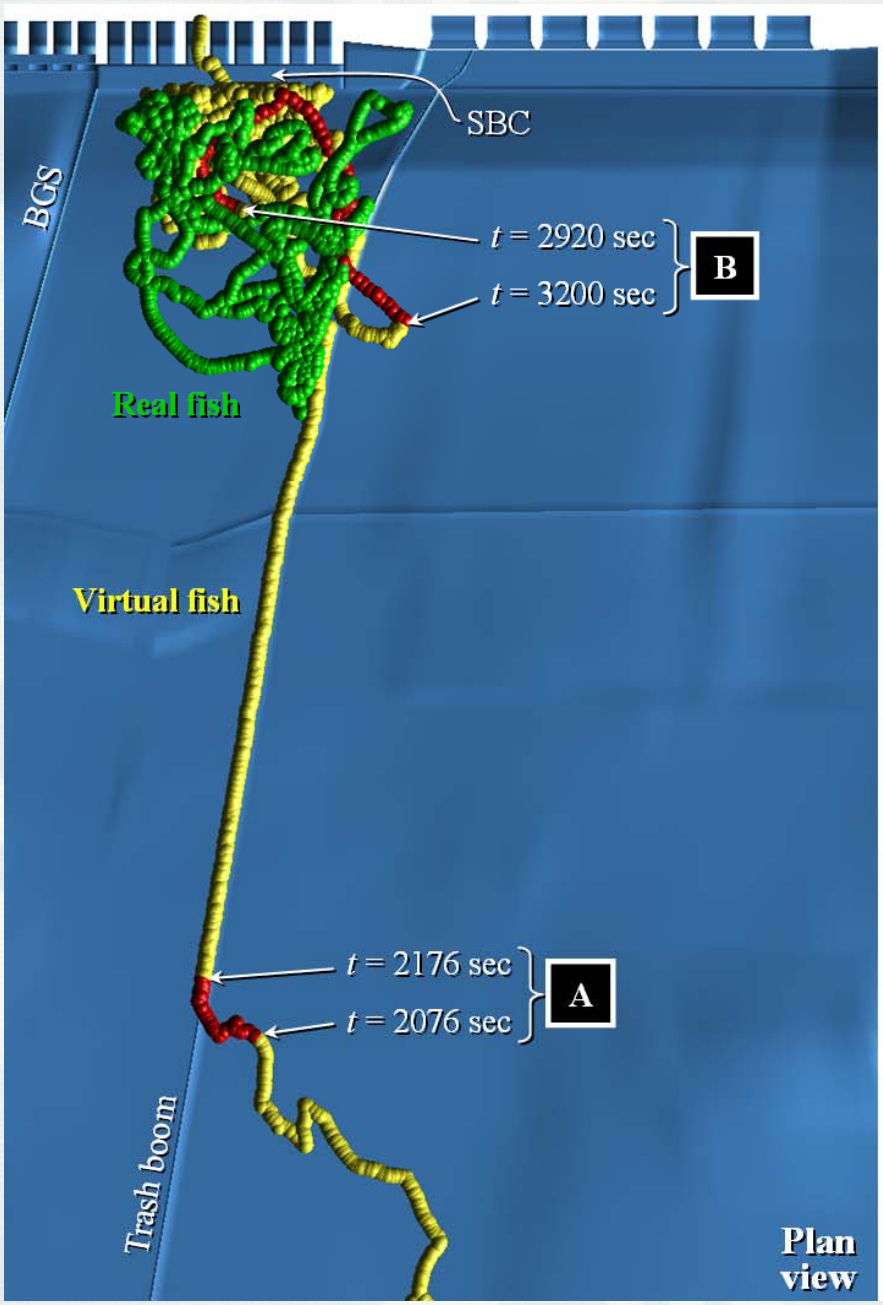


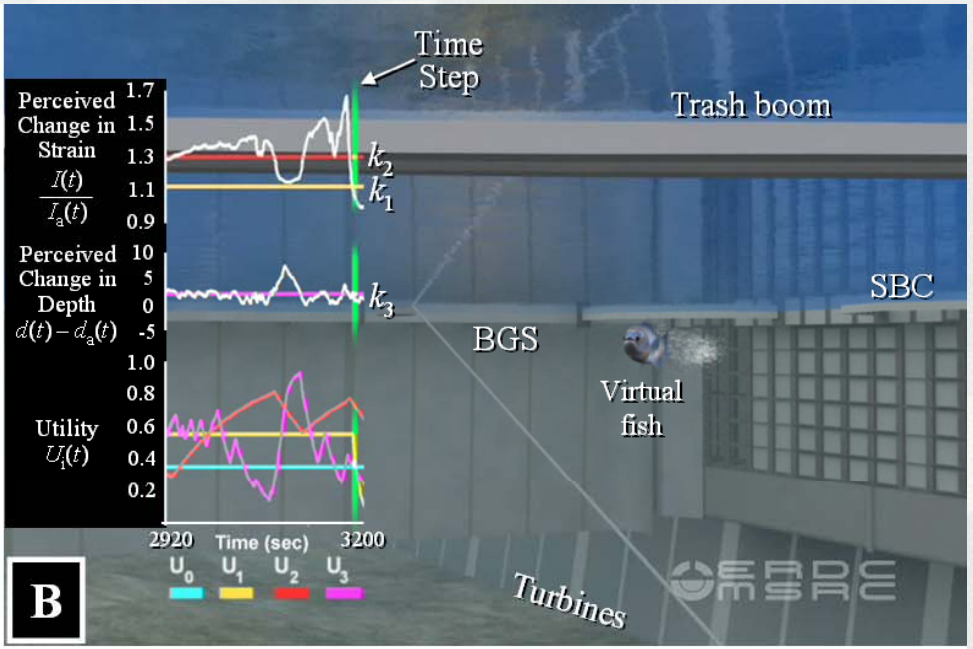
All Dams

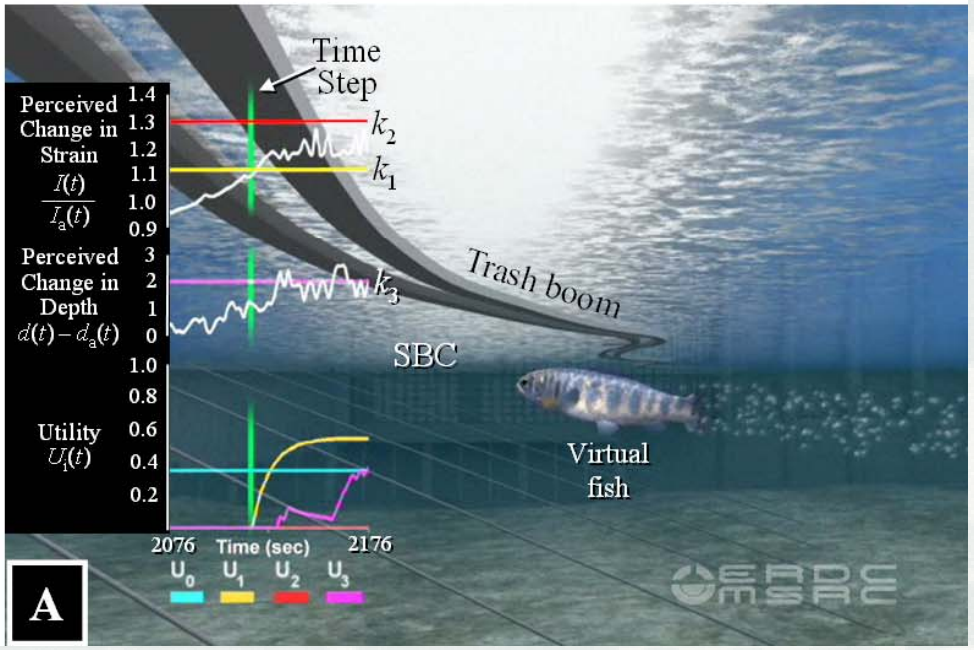
(LGR, IHD, TDA, WAN, PRD)


Lower Granite Dam - Case DH8
USGS Acoustic-Tag Data
Day Track # 9/41
Lower Granite Dam - Case DH8
Virtual Fish Track # 47/100
Acoustic-tagged
Juvenile Salmon
(USGS – Cash *et al.*, 2002)
Passive Particles
Virtual
Juvenile Salmon
(ELAM Model)

Fish ‘Agent’ as it Moves thru Flow Field







Fish Swim Path Comparisons (3-D): Real *vs.* Model

http://EL.erdc.usace.army.mil/emrrp/nfs/individualfish.html

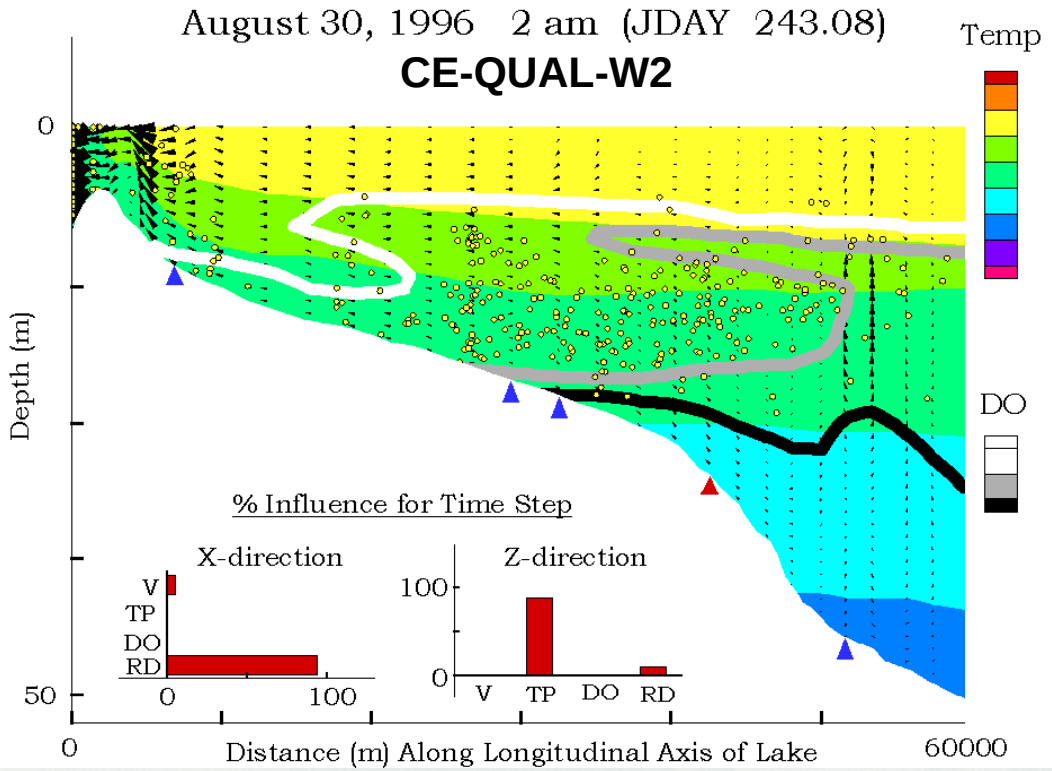
Is *hindcast* accuracy sufficient to *forecast* 'what if' future alternative scenarios ?

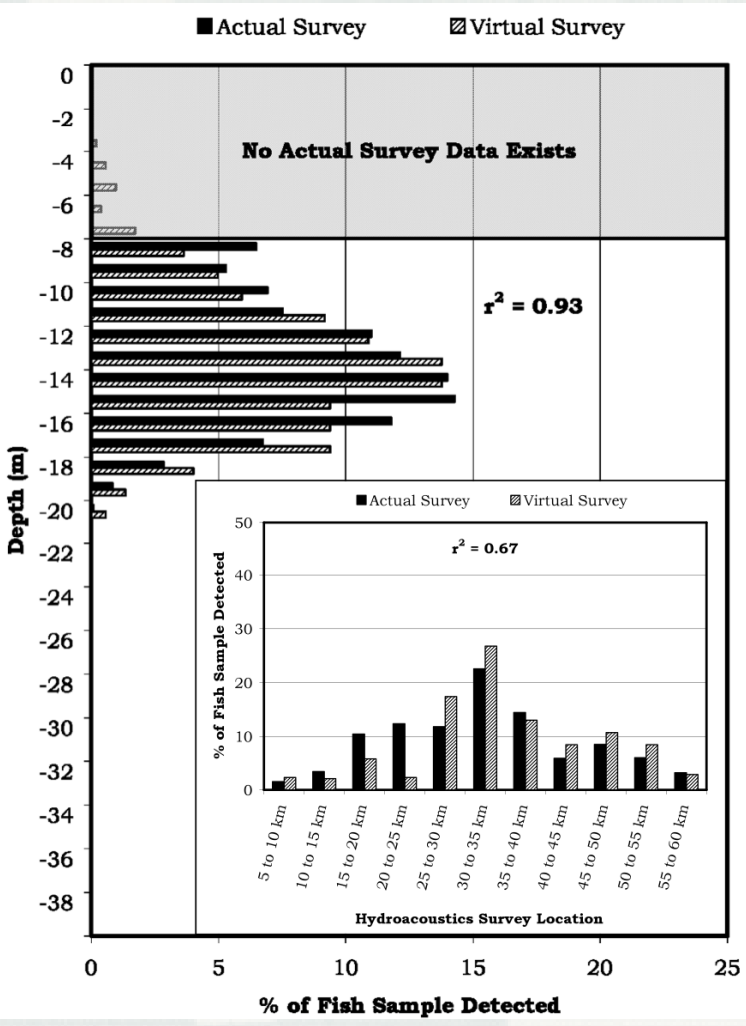
A Test from the Southeastern U.S.

- Advance system knowledge with simple data
  - Fish data from netting
  - Hydro/WQ patterns only at broad scales
- Operational impact on fish over many miles & months:
  - Can modeled fish released near beginning of year resemble distributions measured many months later
- Data may not need to be greater than that used to initially identify/observe problem in first place

Fish Movement over 60 km

- Temperature
- Dissolved oxygen
- Flow





Movement Comparisons (2-D): Modeled Fish *vs.* Particles

http://EL.erdc.usace.army.mil/emrrp/nfs/fishhabitat.html

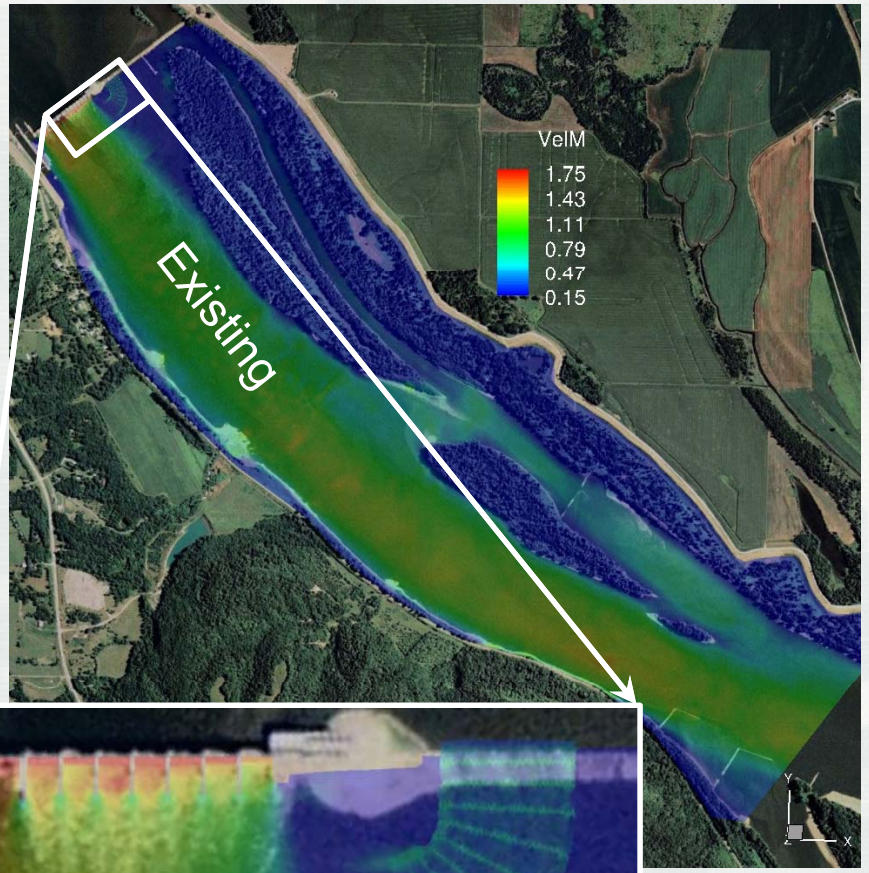
Is *hindcast* accuracy sufficient to *forecast* 'what if' future alternative scenarios ?

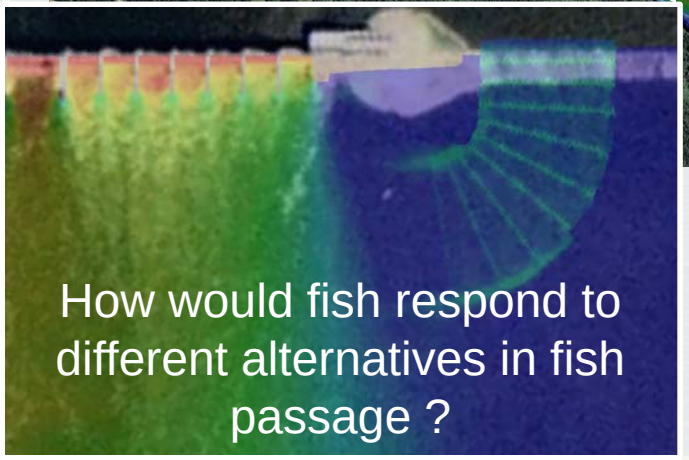
Observations of the Approach

- Can begin tackling behavior analysis within 5 hrs of hydraulic data arrival
- Performed well when model results developed prior to biological data being available
- Works for tested east- and west-coast species
- Works across years of observation
- Works at many different sites & scales

Emerging Capability

Mississippi River - Sturgeon

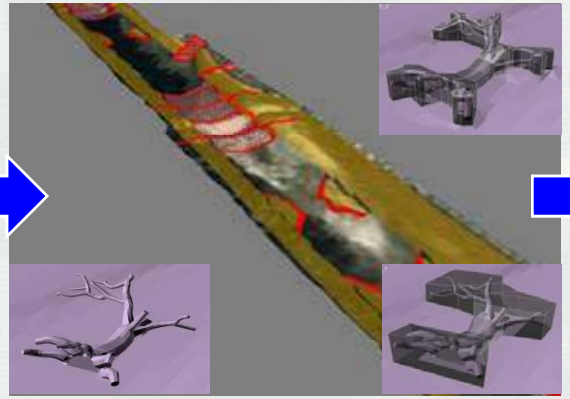




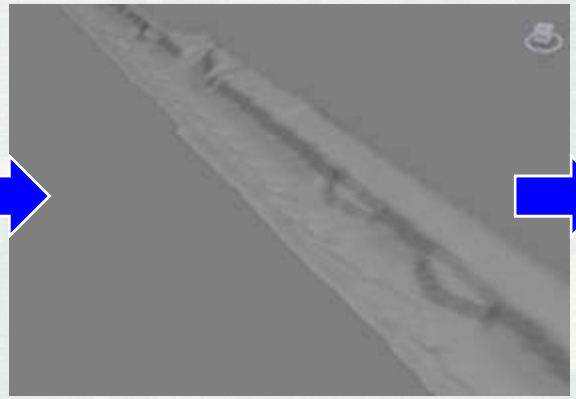
Stream Restoration – Dozens of Species

Project Site

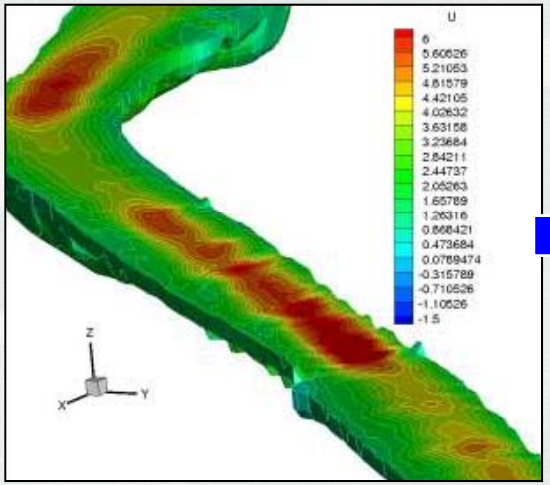
Conceptual Designs (Alternatives)



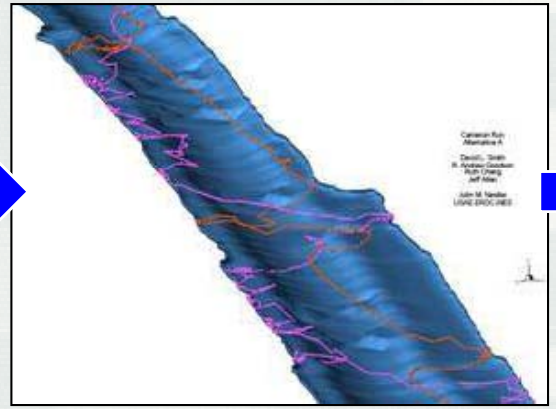
Models w/Features from Conceptual Designs



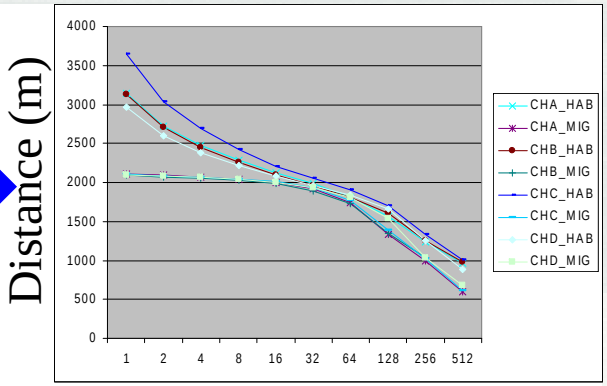
Hydraulic Output



ELAM Fish Movement



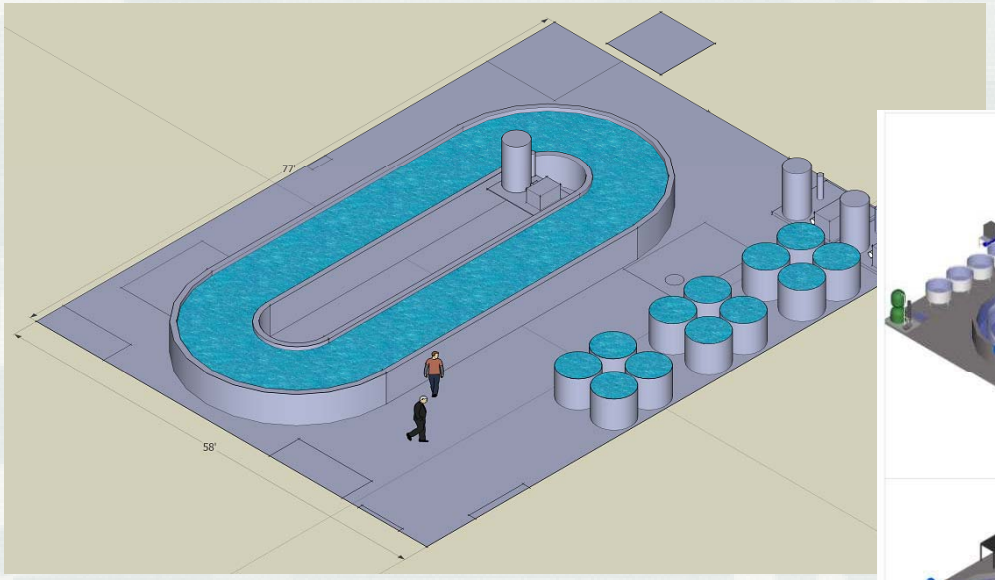
Assimilate into USACE Planning Model of Alternatives (e.g., HSI curves)

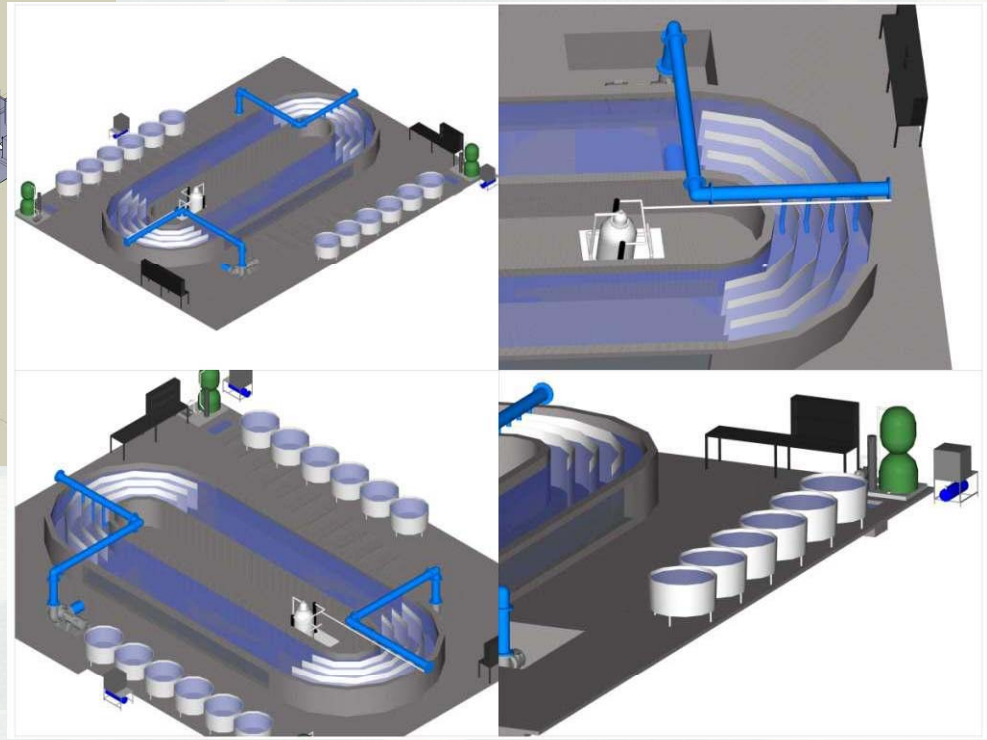


Rapidly-deployable Behavior Analysis

Cognitive Ecology Research Flume

- $1.3M facility w/movement tracking
- Probe multi-modal sensory stimuli response
- Response to different flow/WQ fields





The *Eulerian-Lagrangian-Agent Method* (*ELAM*)

When is the use of an *ELAM* important ?

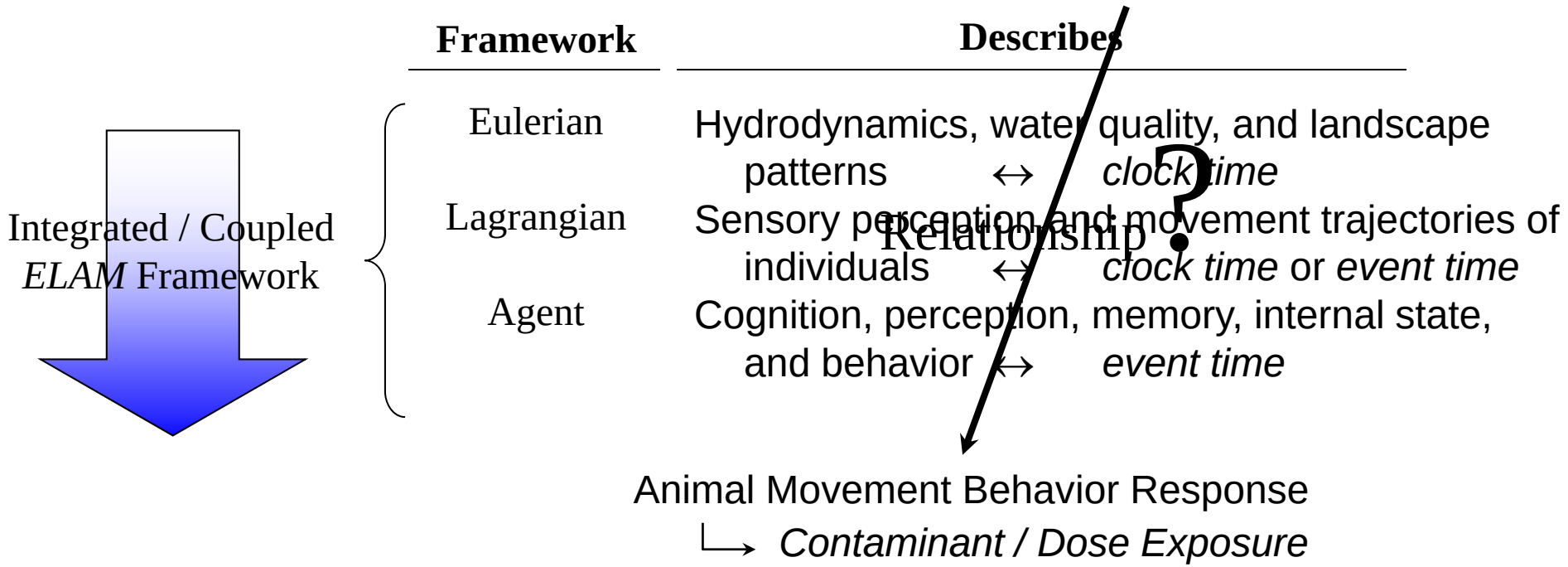
When movement behavior of highly mobile individuals influences 'success'

What is an *ELAM* ?

Integration of all 3 reference frameworks such that:

- temporal and spatial scaling of each process is optimally simulated,
- information is transformed as needed to meet requirements of linked processes,
- maximum fidelity to "real world" using "first principles" is achieved.

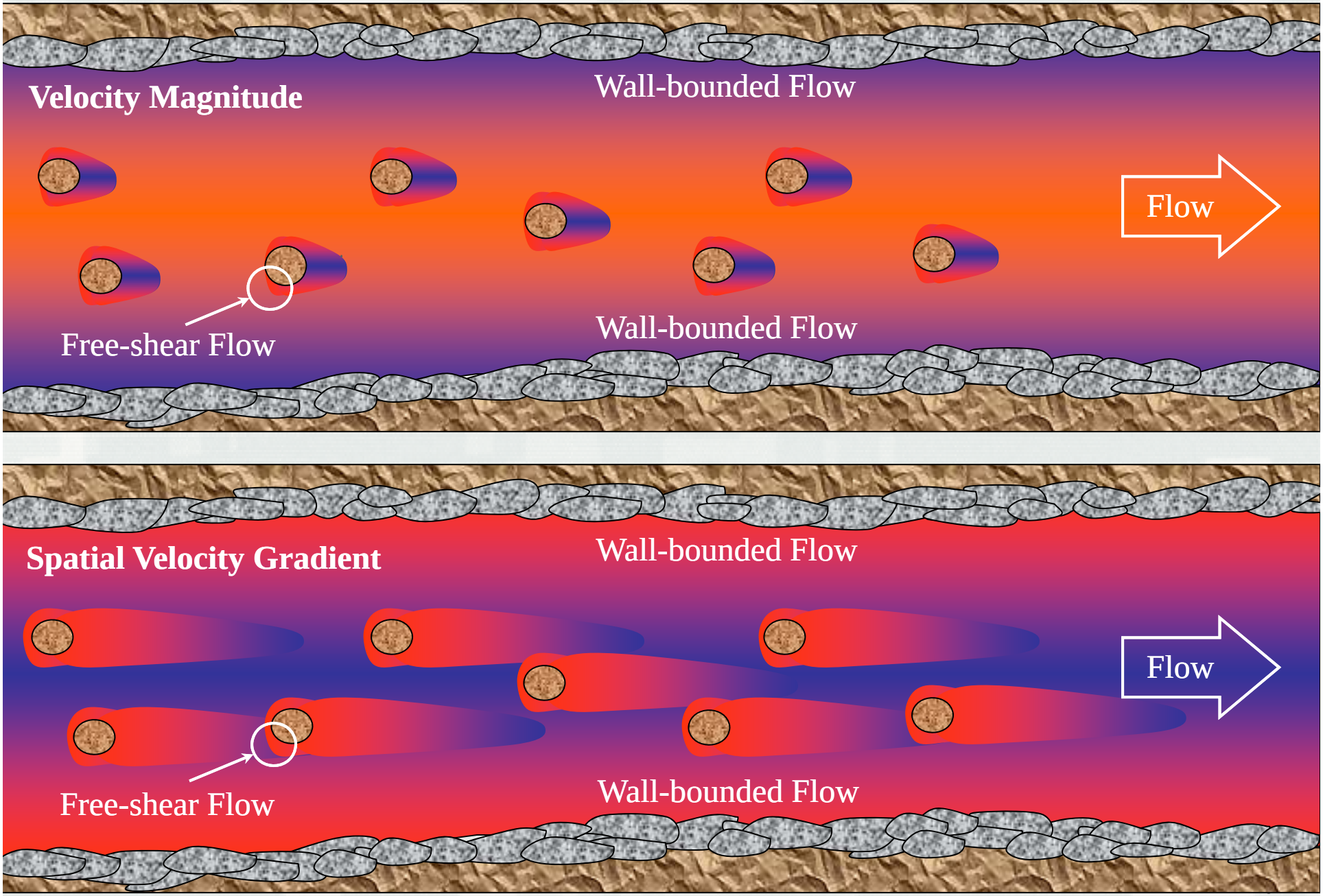
How to Assess Alternative Perturbations to Environmental Pattern

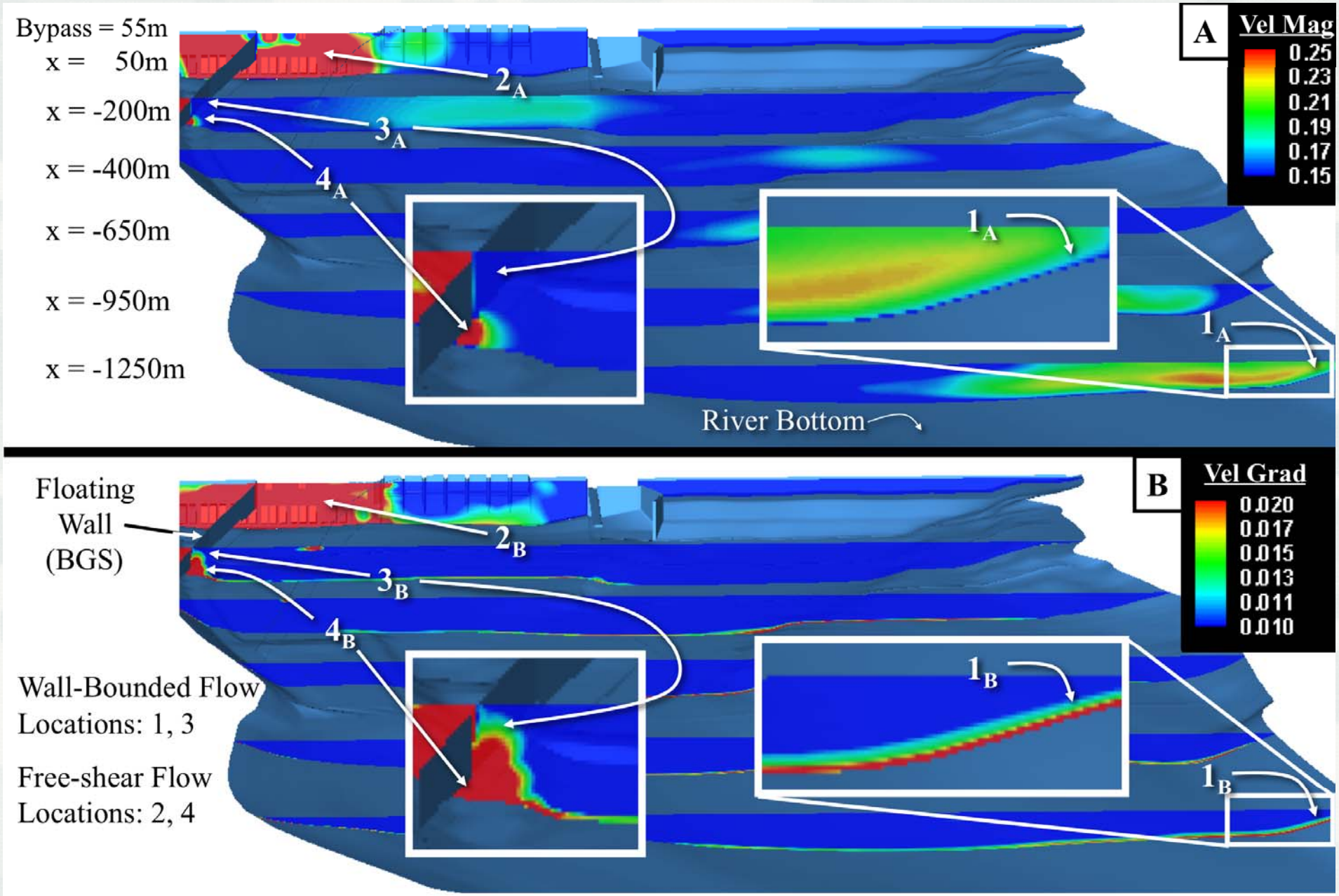


Model Accuracy & Quality of Engineering Guidance → Hypothesis Limited

- As mechanistic biological hypothesis develops/improves:
  → so does simulated behavior
  → so does decision-support

Questions / Comments / Criticisms ???


Velocity Magnitude
Wall-bounded Flow
Flow
Free-shear Flow
Wall-bounded Flow
Spatial Velocity Gradient
Wall-bounded Flow
Flow
Free-shear Flow
Wall-bounded Flow


Bypass = 55m
x = 50m
x = -200m
x = -400m
x = -650m
x = -950m
x = -1250m
A
Vel Mag
0.25
0.23
0.21
0.19
0.17
0.15
2A
3A
4A
1A
1A
River Bottom
B
Vel Grad
0.020
0.017
0.015
0.013
0.011
0.010
Floating Wall (BGS)
2B
3B
4B
1B
1B
Wall-Bounded Flow
Locations: 1, 3
Free-shear Flow
Locations: 2, 4