The Numerical Fish Surrogate – An Integration of Ecology, Hydro-geomorphology, and Information Technology

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ERDC Collaborators

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University Collaborators

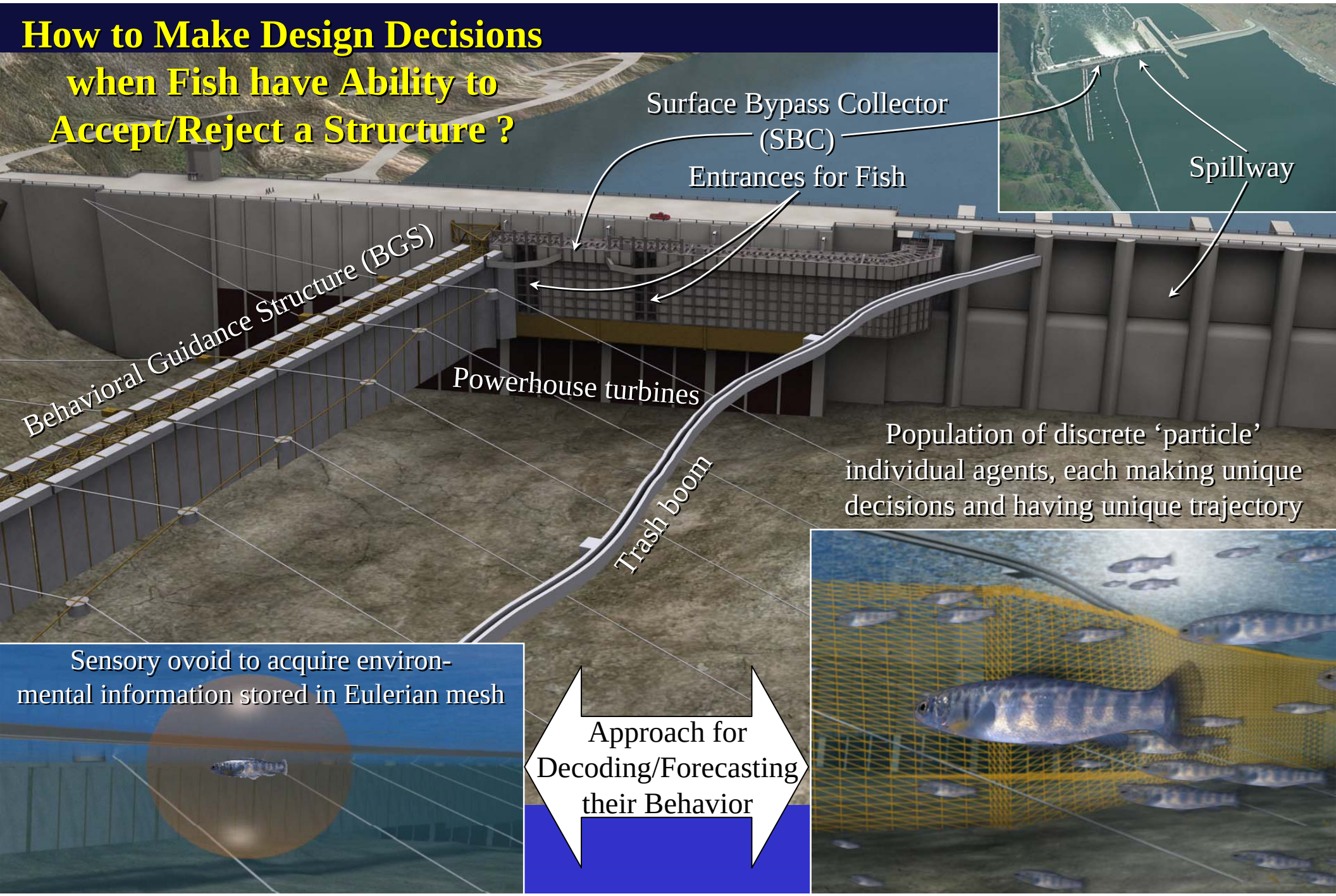
Cornell University, Universities of: Iowa, Washington; Florida; Birmingham (UK), Guelph (Canada); del Littoral (Argentina)

Introductory Video

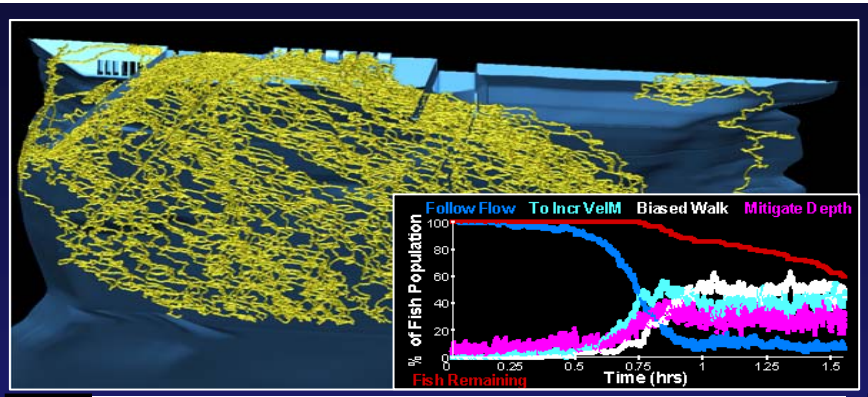
3-D: Juvenile Salmon in the Columbia & Snake River Basin.
"Technical Audience AVI Video"

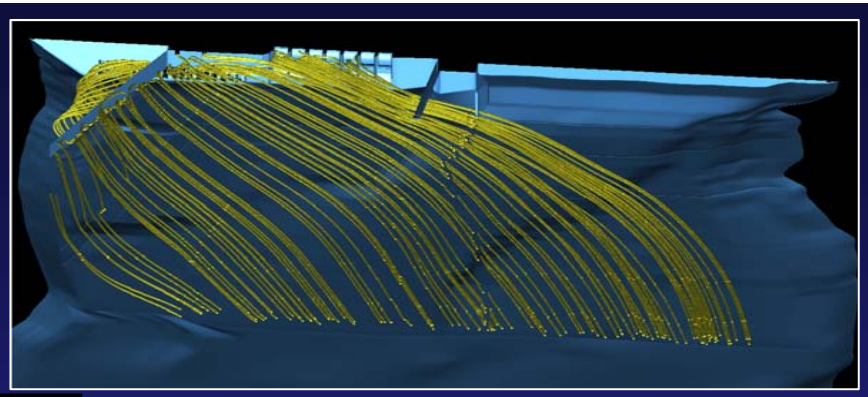
(Click here to download video.)

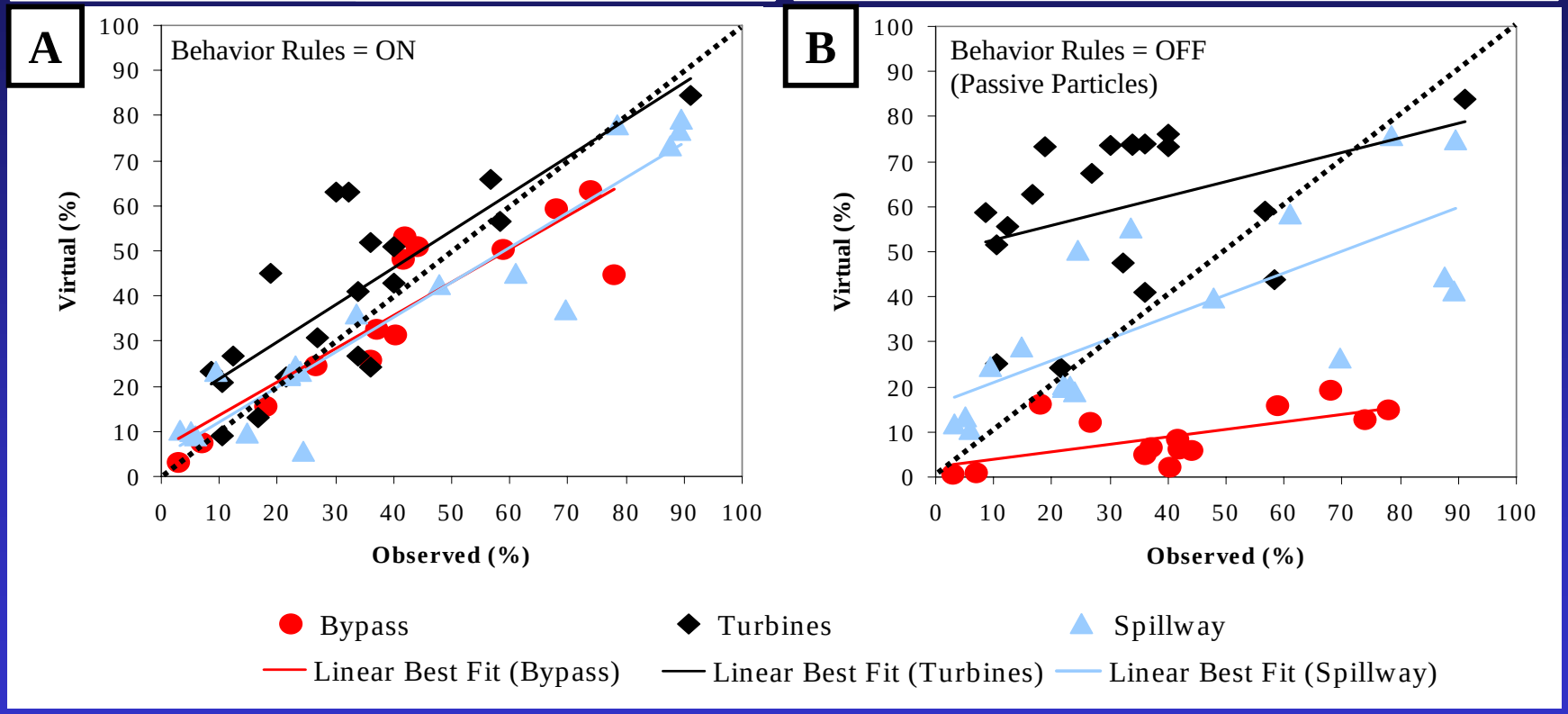
How to Make Design Decisions when Fish have Ability to Accept/Reject a Structure ?



Does it Work?

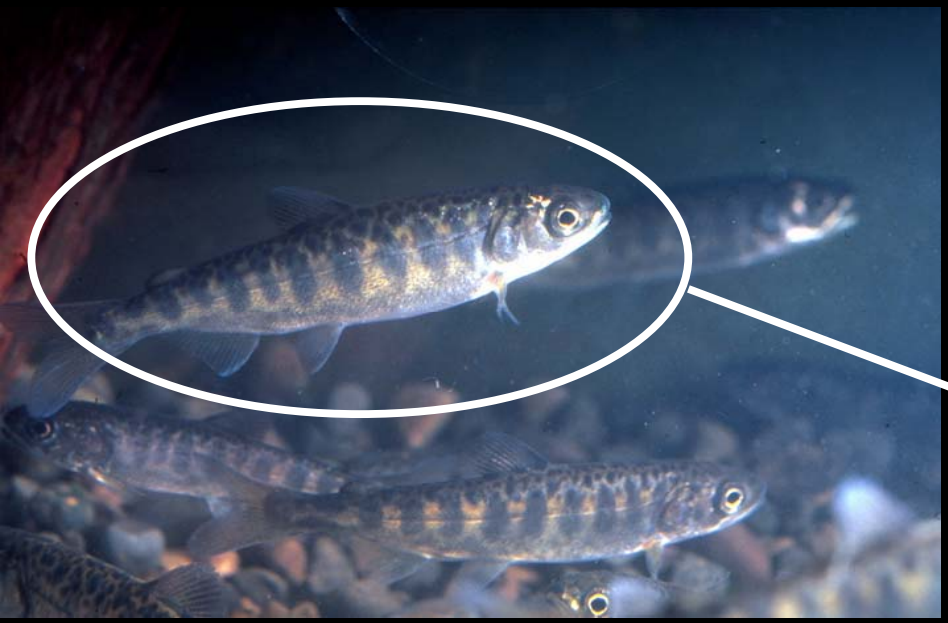






	Slope / RSQ	Slope / RSQ
Bypass	1.07 / 0.80	0.10 / 0.10
Spillway	0.95 / 0.85	0.49 / 0.50
Turbine	1.15 / 0.61	0.24 / 0.08

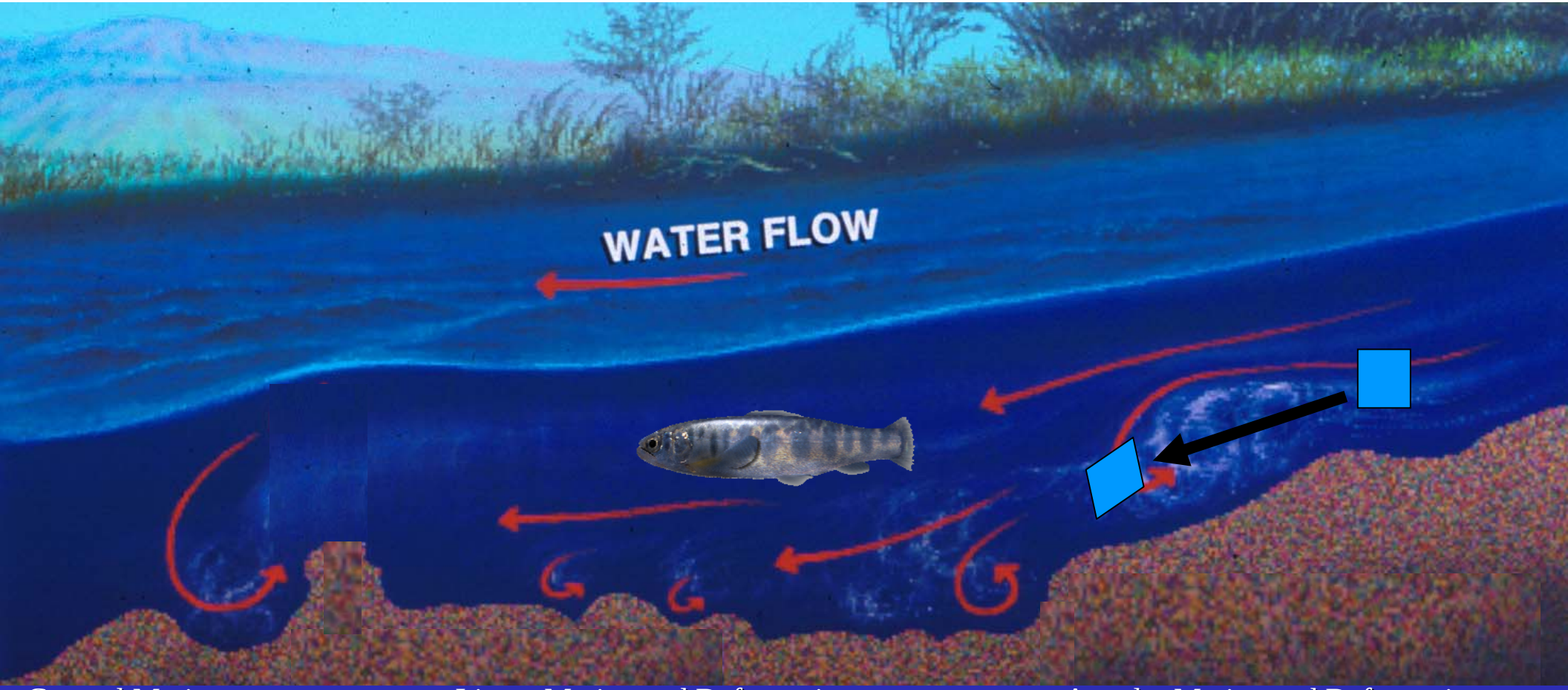
How Does a Fish Find its Way at Night in Muddy Water?



- **What Causes Flow Pattern in Streams?**
  - **Flow Resistance - without it there is nothing to change a unit volume of water once it is set into motion by gravity.**

- **Are There Different Types of Flow Resistance?**
  - **Friction resistance (skin resistance)**
  - **Form friction (internal distortion resistance)**

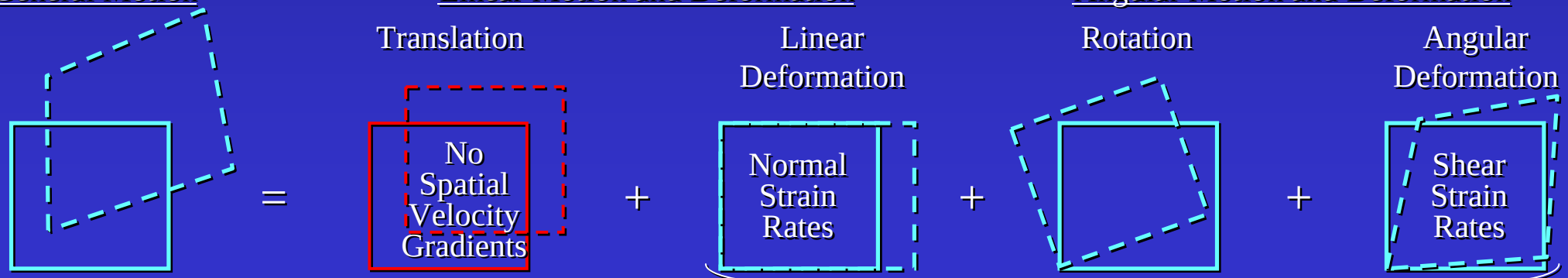
- **Minimum Hydraulic Information Separating Q Resistance?**



General Motion

Linear Motion and Deformation

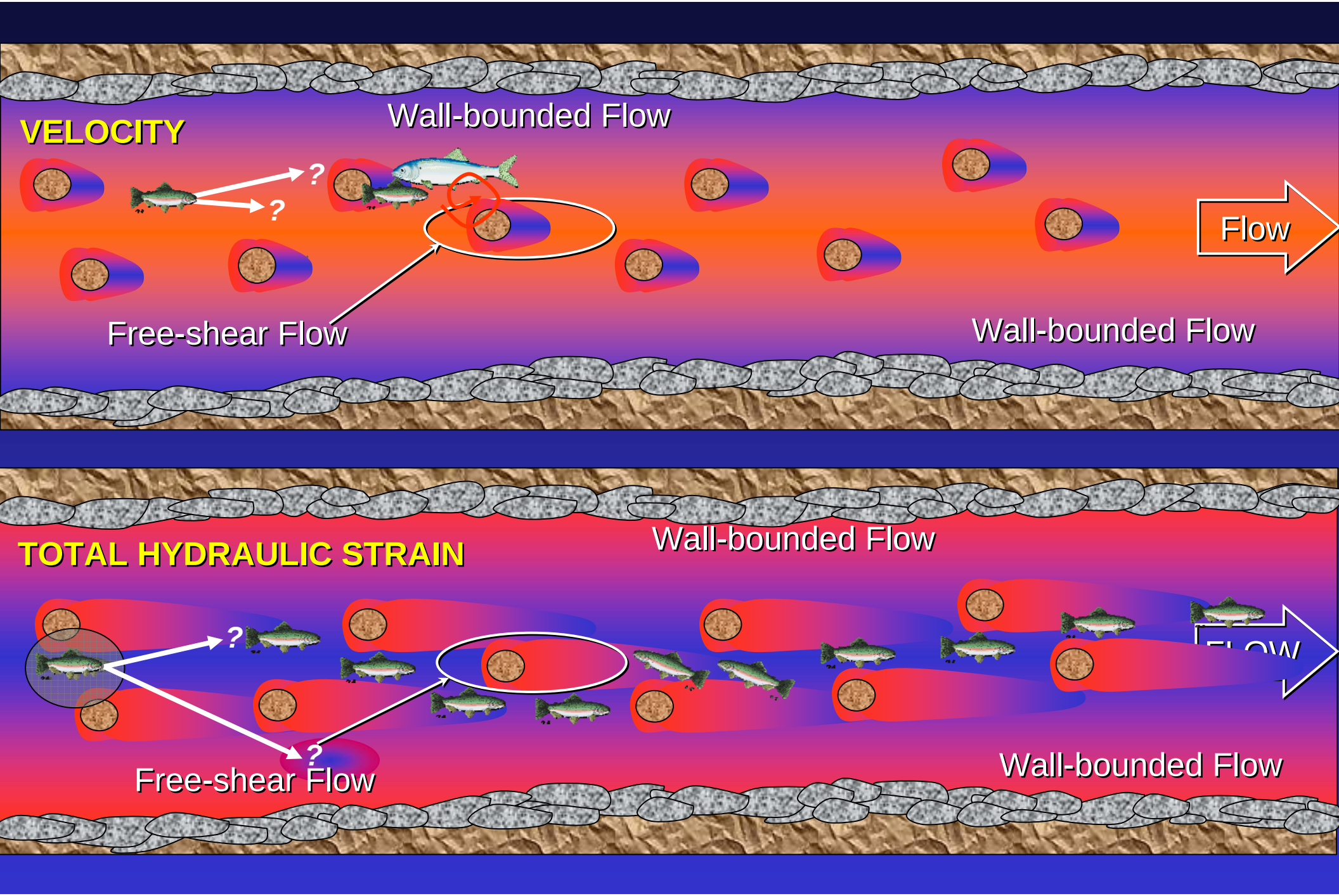
Angular Motion and Deformation

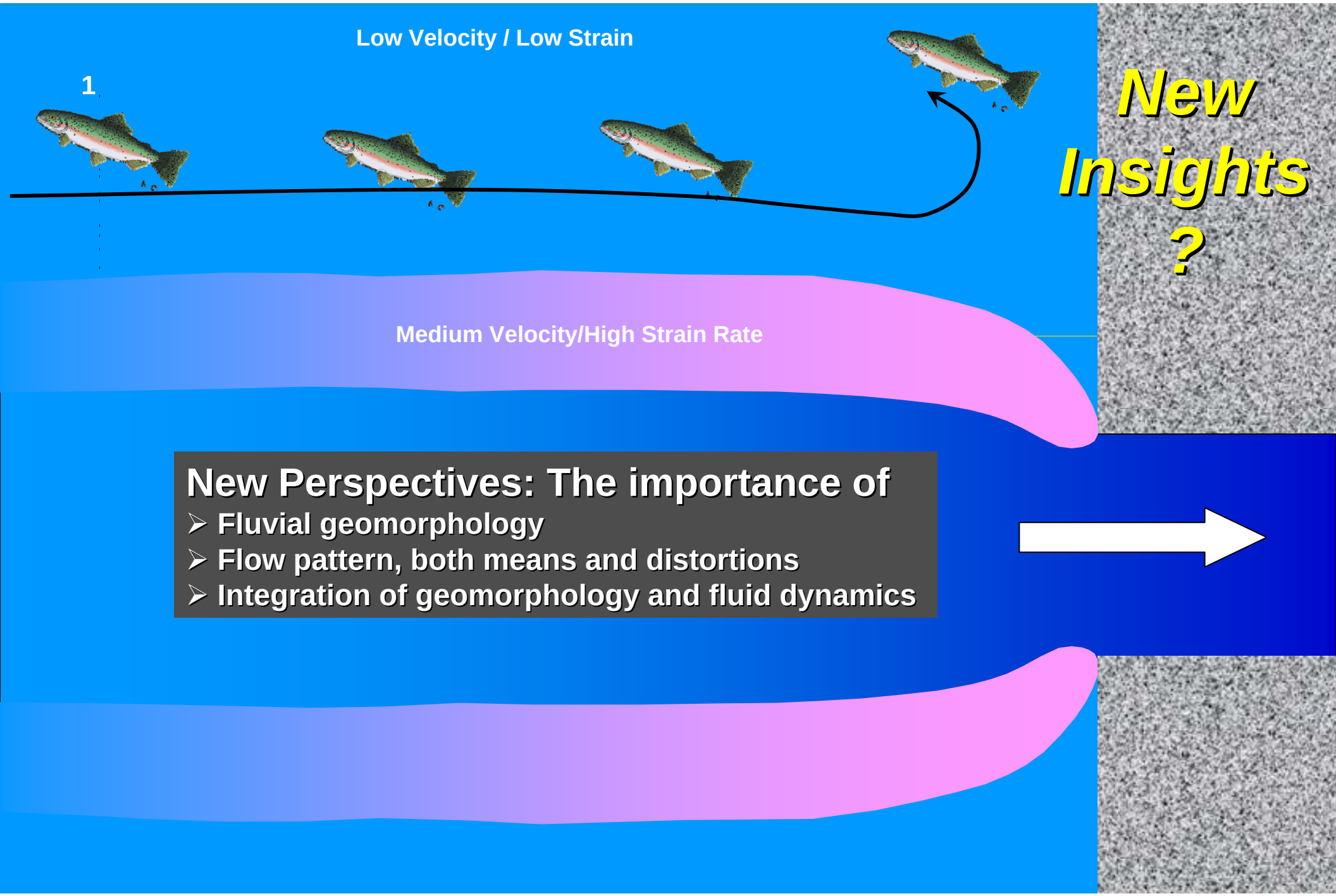


Control Volume at t_0

Control Volume at $t_0 + \Delta t$

Distortion Mechanisms caused by Velocity Gradients


VELOCITY
Wall-bounded Flow
?
?
Flow
Free-shear Flow
Wall-bounded Flow
TOTAL HYDRAULIC STRAIN
Wall-bounded Flow
?
?
Free-shear Flow
Wall-bounded Flow



New Perspectives: The importance of

- Fluvial geomorphology
- Flow pattern, both means and distortions
- Integration of geomorphology and fluid dynamics

Assess Fish Response to CE Activities?

Place-Specific Activity

- Feeding at a feeding station
- Spawning at nesting site

Place Searching Activity

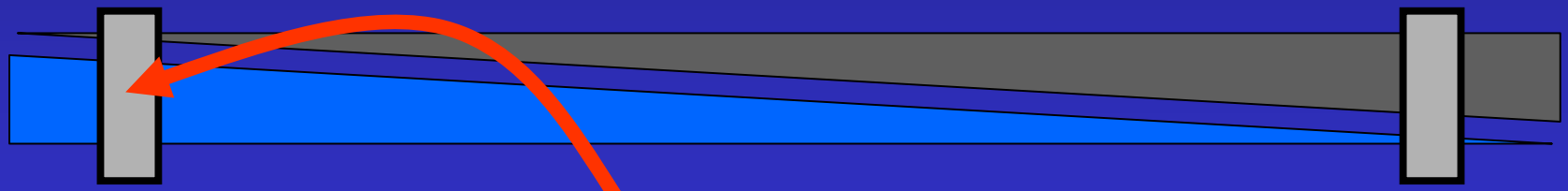
- Locating a new feeding station
- Finding a spawning site

Roadmap Hydraulic Variables

- Absolute values critical
- Background less important

Roadmap Hydraulic Variables

- Absolute values less important
- Background very important



Small resident fishes in small, baseflow streams: e.g, darters, sculpins, trout

Conventional Hydraulic Habitat Tools

Large mobile fishes in large, flood pulse rivers: e.g, sturgeon, paddlefish, salmon

Integrating Concept 2

Integrated Reference Frameworks Concept

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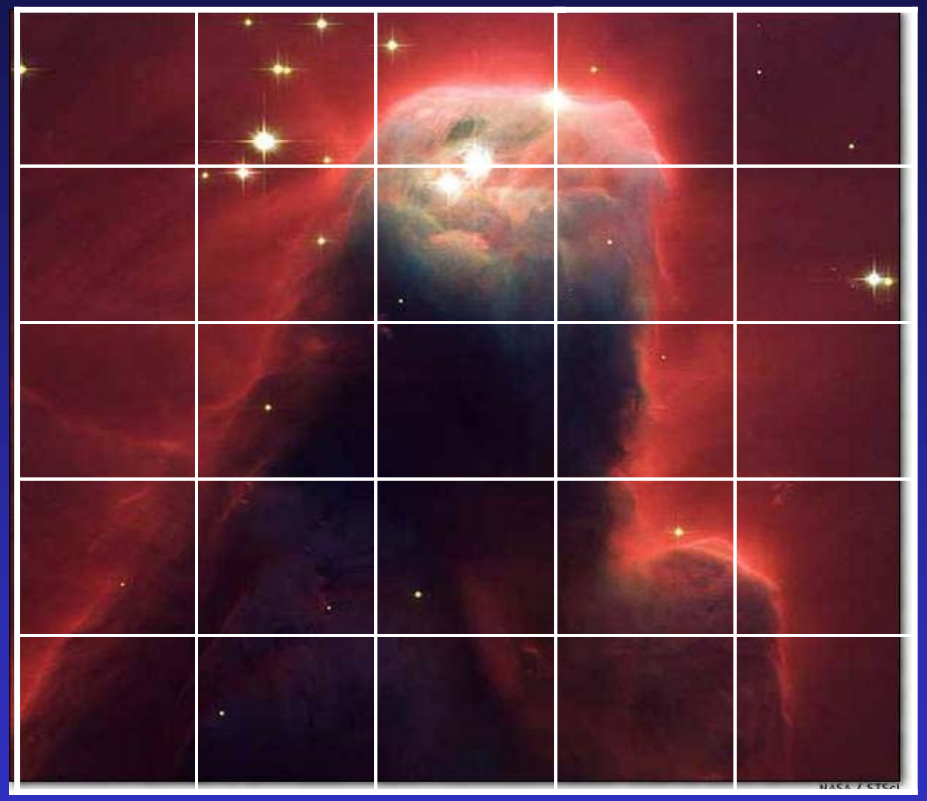
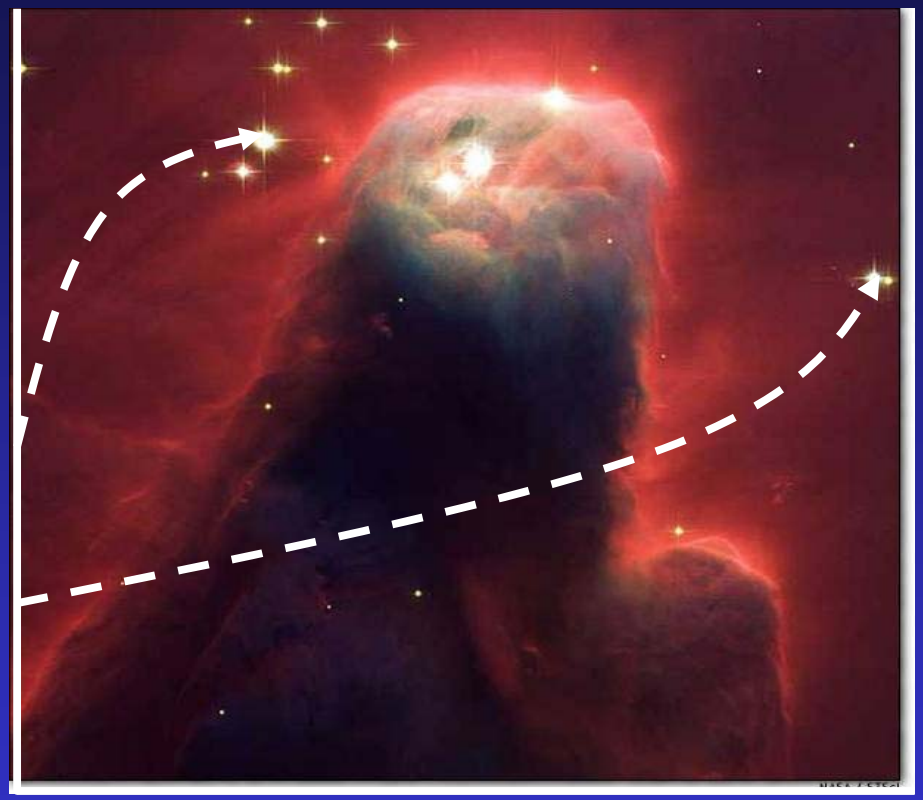


- **Discretize it (Eulerian)**
  - **Interstellar dust**
  - **Hydraulic routing**
  - **Water Quality**

Integrating Concept 2

Integrated Reference Frameworks Concept



- **Track it (Lagrangian)**
  - **Stars**
  - **Gravel**
  - **Fish eggs**

Integrating Concept 2

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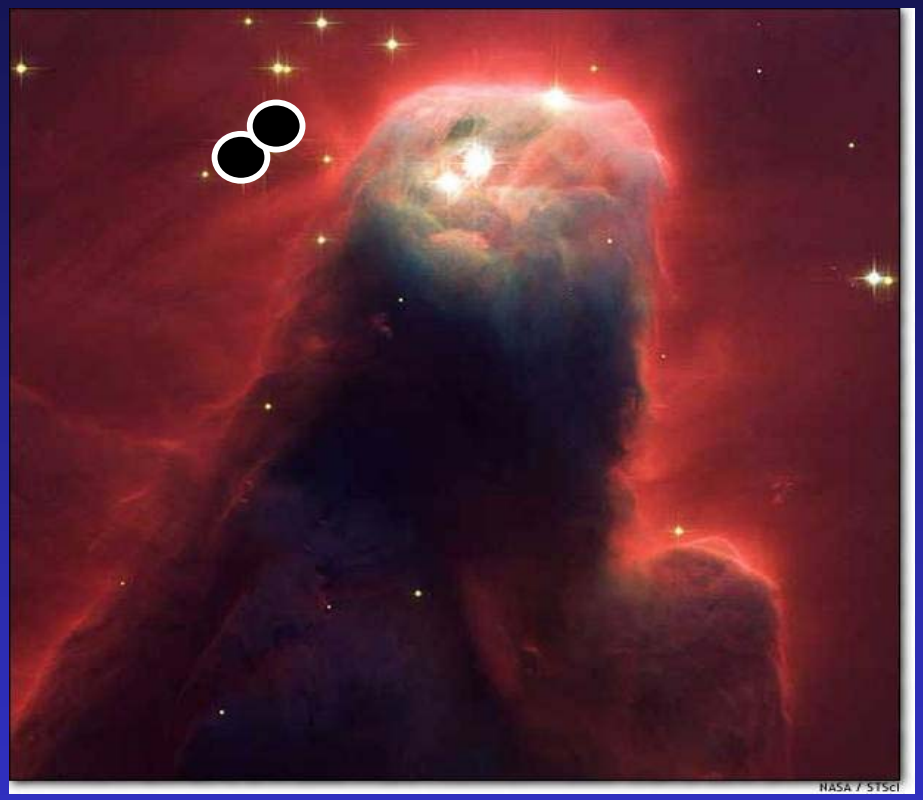

- **Center it (Agent)**
  - **Black holes (event horizons)**
  - **Fish**
  - **Grizzly bears**

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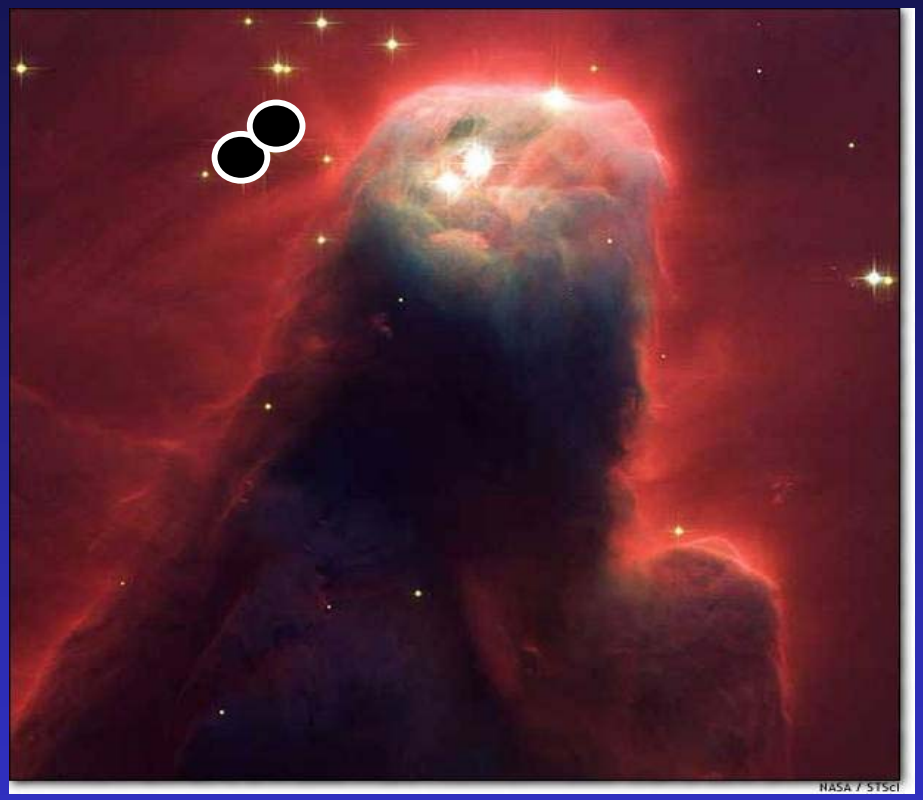
Integrated Reference Frameworks Concept



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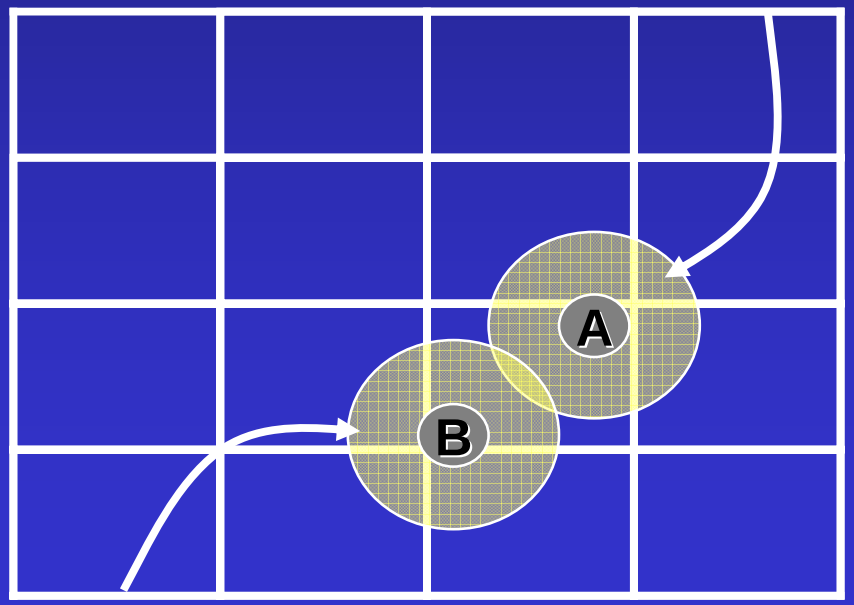
Complete system description requires all three frameworks. Hence: Eulerian-Lagrangian-Agent Method



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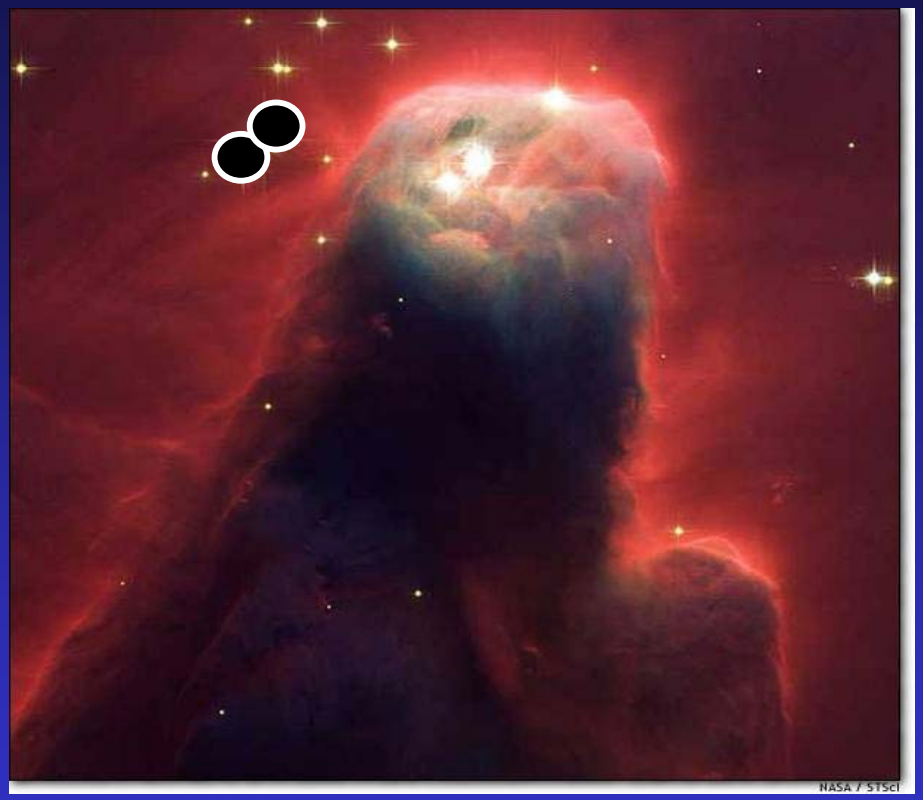

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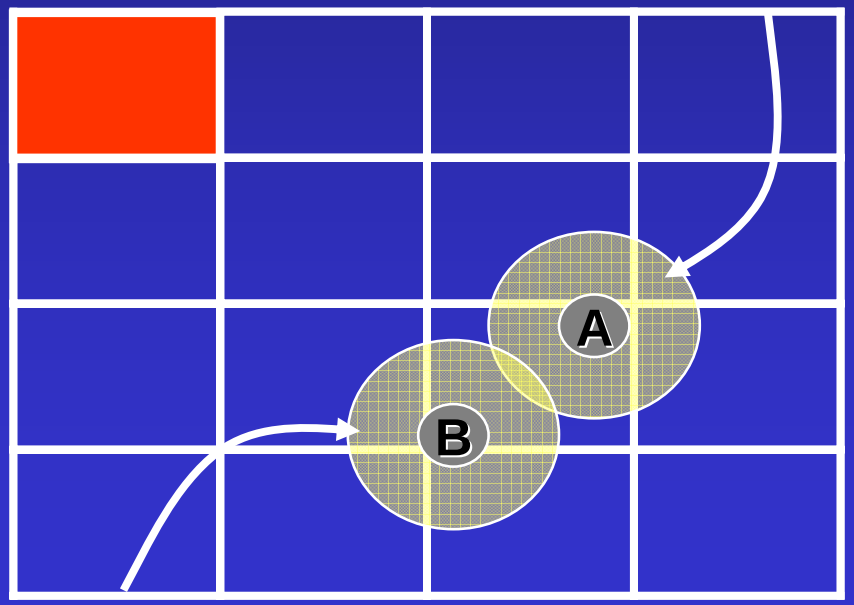
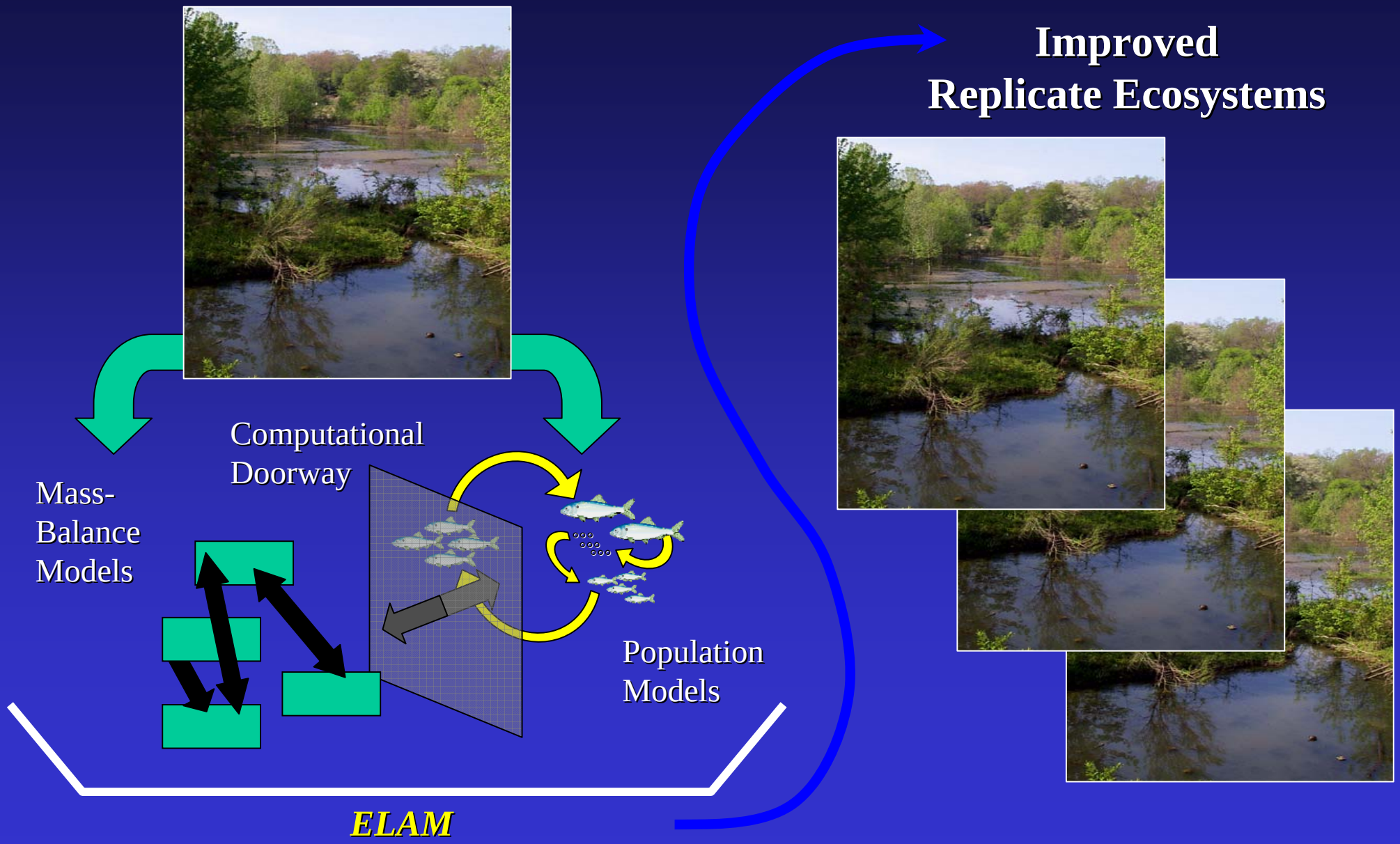


How *ELAM*s Fit In



Peer-Review Manuscripts

Simulating fish movement in hydropower reservoirs & tailwaters. 2001. *HydroReview*

Simulating mobile populations in aquatic ecosystems. 2001. *ASCE Journal of Water Resources Planning and Management*

Simulating movement patterns of blueback herring in a stratified southern impoundment. 2002. *Transactions of the American Fisheries Society* 131:55-69.

Evolving approaches and technologies to enhance the role of ecological modeling in decision-making. 2003. *Ecological Modeling for Resource Management*, Springer Verlag

Coupling of biological & engineering models for ecosystem analysis. 2005. *ASCE Journal of Water Resources Planning and Management*

Forecasting 3-D Fish movement behavior using a Eulerian-Lagrangian-agent method (ELAM). 2006. *Ecological Modeling*

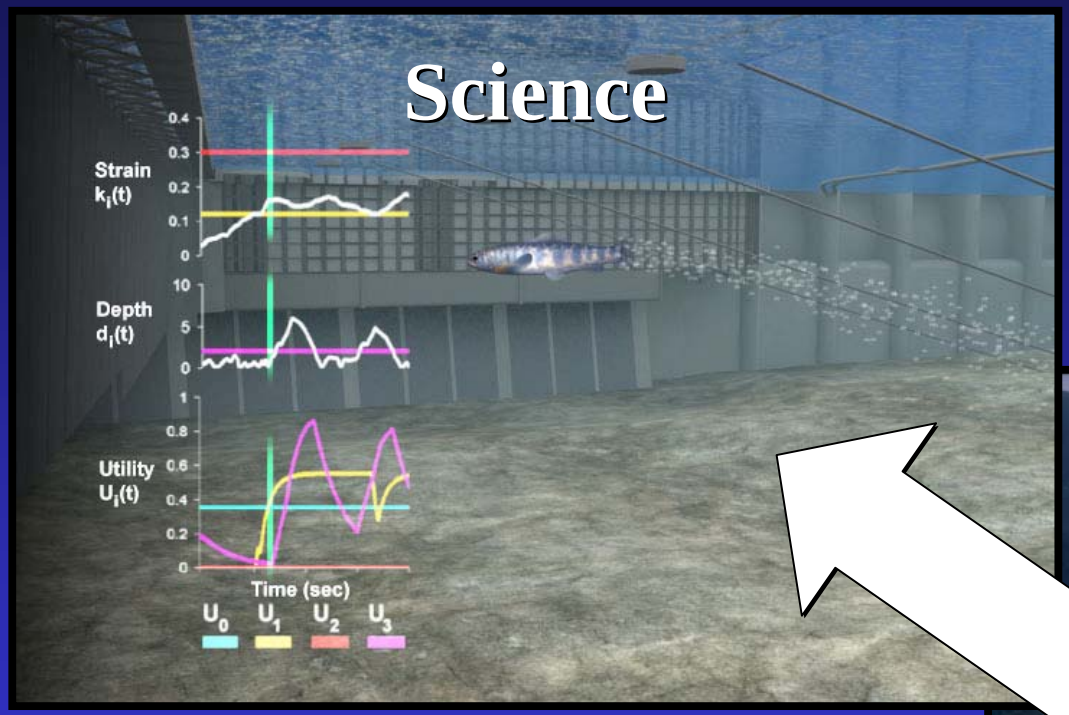
Advancing science for water resources management. 2006. *Hydrobiologia*

CFD model considerations and application of an Eularian-Lagrangian-agent-method (ELAM) to rank alternative designs of a juvenile fish passage facility during project planning. 2006. *Journal of Hydroinformatics*.

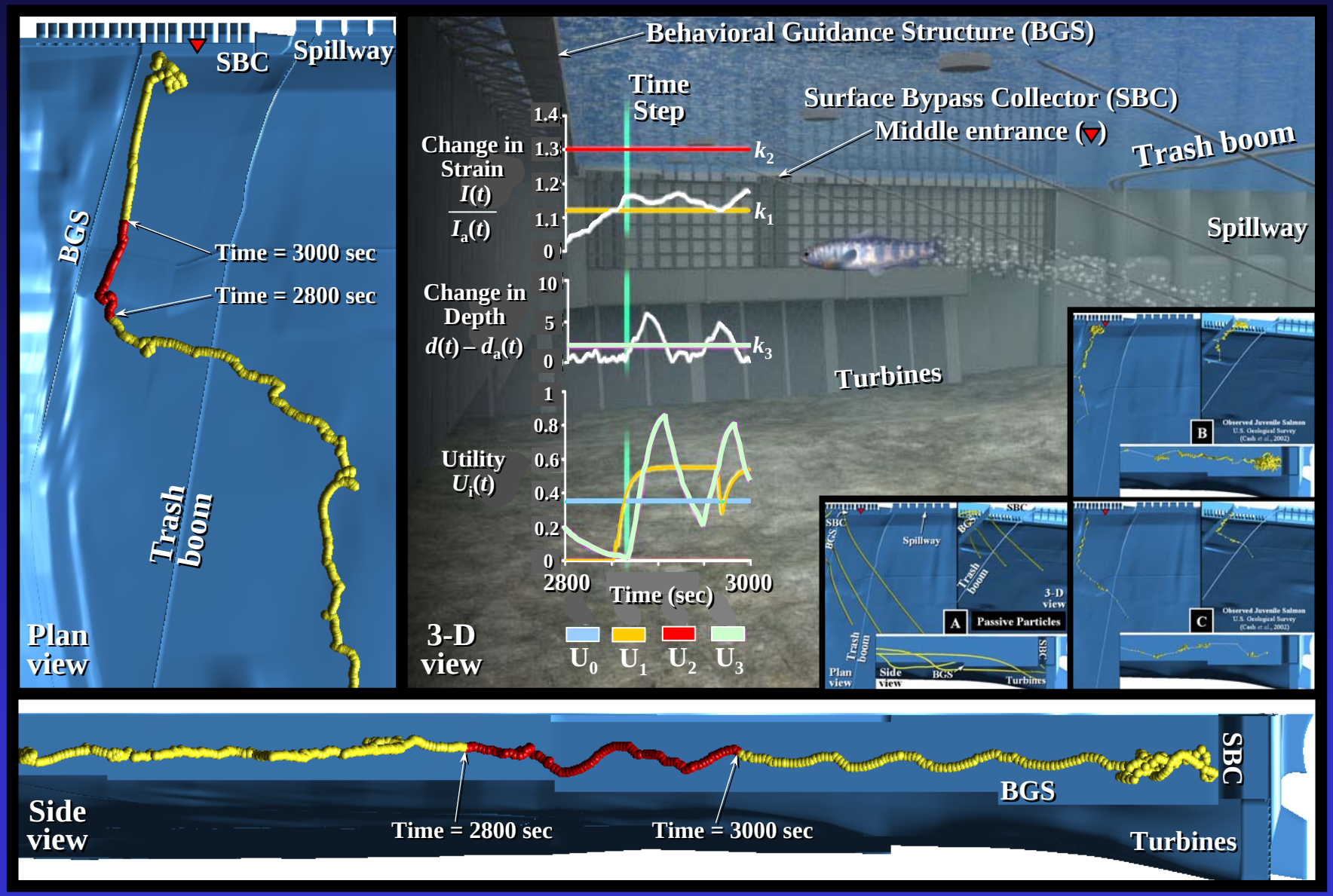
A Mathematical and Conceptual Framework for Ecohydraulics. In press. *Hydroecology and Ecohydrology: Past, Present, and Future,* John Wiley & Sons, Ltd.

What Does All This Mean?

We Can Do Better!

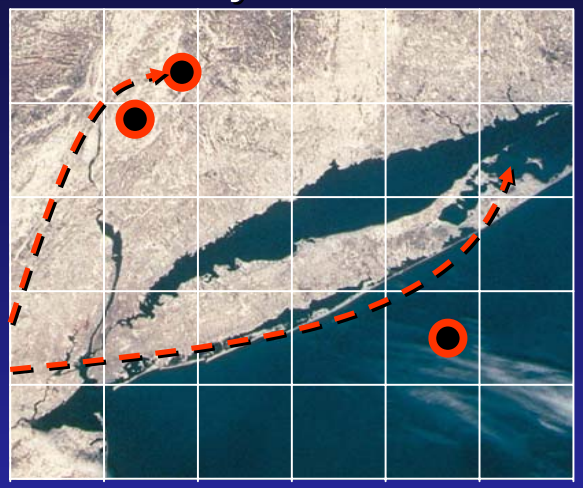


How Does an Agent Make Decisions ?

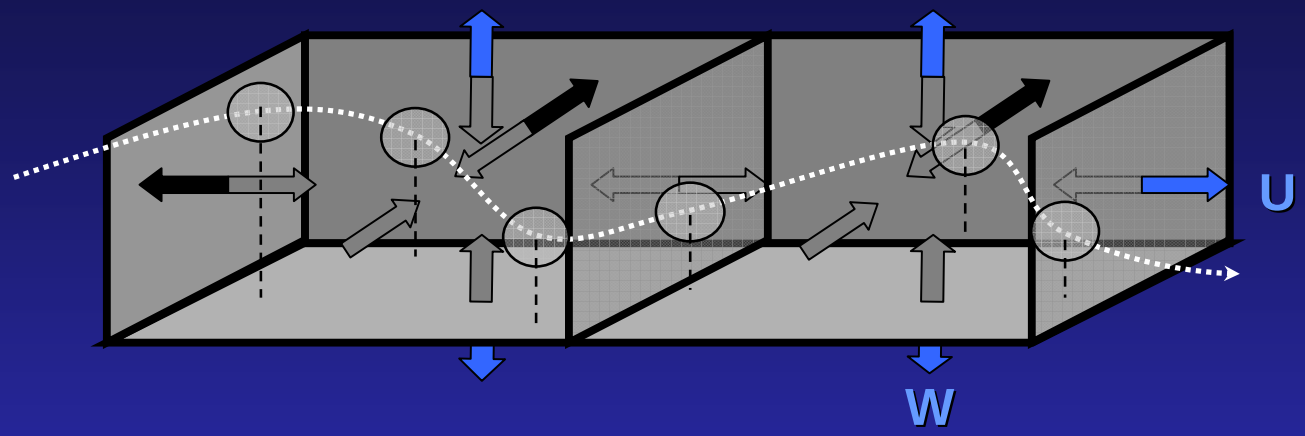


The *Eulerian-Lagrangian-Agent Method* (*ELAM*)

Systems



Aquatic Systems



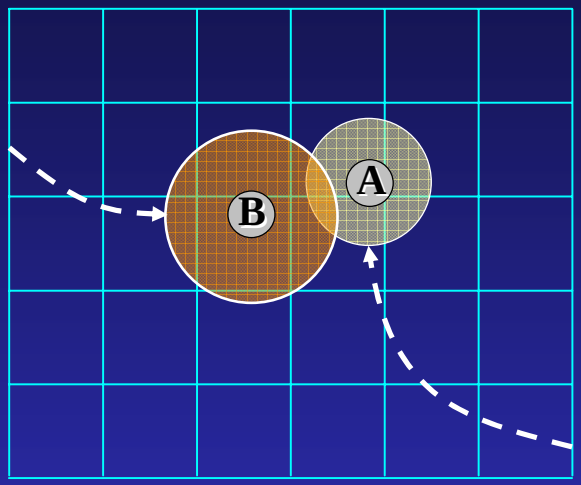
Capturing Phenomena - small in time and space scale
- large/rare in time or space scale
- cognition and internal state important

1) Eulerian framework: governs physical, hydraulic, water quality, atmospheric, landscape, & cultural 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,
   → *continuous directional trajectory composed of discrete locations (fish, geese, deer, insurgents).*

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 (avoidance, panic, escape, IED placement).*

Summary



Physical Systems

- Coastal / Estuarine / Rivers
- Terrestrial Landscapes
- Battlespace

When is the use of an *ELAM* important ?

- When movement behavior of highly mobile individuals is important

Agent Dynamics

- Populations change because ‘events’ experienced by individuals affect future condition and, therefore, response
- Events are inherently complex and affected by features of the environment and interactions with other individuals
- Individual cognition and memory important to movement/behavior
- ‘Vitality’ can represent an individual animal’s condition integrating effects of diverse stressors (e.g., *contaminant dose exposure*)

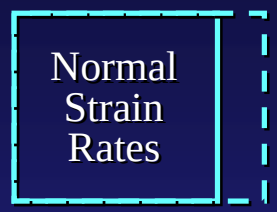
Integrated Frameworks

- Information transformed as needed to meet requirements of linked processes
- Very large storage/processor requirements for ‘real’ systems

$$\begin{pmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} & \frac{\partial u}{\partial z} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} & \frac{\partial v}{\partial z} \\ \frac{\partial w}{\partial x} & \frac{\partial w}{\partial y} & \frac{\partial w}{\partial z} \end{pmatrix} =$$

Spatial Velocity Gradient Tensor

Linear Deformation

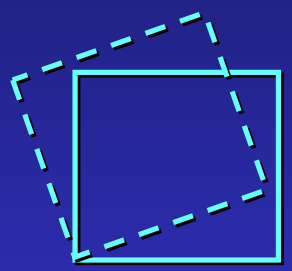


Pure Strain Tensor (components are normal strain rates)

$$\begin{pmatrix} \varepsilon_{xx} & 0 & 0 \\ 0 & \varepsilon_{yy} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{pmatrix} \equiv \begin{pmatrix} \frac{\partial u}{\partial x} & 0 & 0 \\ 0 & \frac{\partial v}{\partial y} & 0 \\ 0 & 0 & \frac{\partial w}{\partial z} \end{pmatrix}$$

+

Rotation



Rotation or Angular Velocity Tensor (components are angular velocities)

$$\begin{pmatrix} 0 & \omega_{xy} & \omega_{xz} \\ \omega_{yx} & 0 & \omega_{yz} \\ \omega_{zx} & \omega_{zy} & 0 \end{pmatrix} \equiv \begin{pmatrix} 0 & \frac{1}{2}\left[\frac{\partial u}{\partial y} - \frac{\partial v}{\partial x}\right] & \frac{1}{2}\left[\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\right] \\ \frac{1}{2}\left[\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right] & 0 & \frac{1}{2}\left[\frac{\partial v}{\partial z} - \frac{\partial w}{\partial y}\right] \\ \frac{1}{2}\left[\frac{\partial w}{\partial x} - \frac{\partial u}{\partial z}\right] & \frac{1}{2}\left[\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\right] & 0 \end{pmatrix}$$

+

Angular Deformation

Shear Strain Tensor (components are shearing strain rates)

$$\begin{pmatrix} 0 & \varepsilon_{xy} & \varepsilon_{xz} \\ \varepsilon_{yx} & 0 & \varepsilon_{yz} \\ \varepsilon_{zx} & \varepsilon_{zy} & 0 \end{pmatrix} \equiv \begin{pmatrix} 0 & \frac{1}{2}\left[\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right] & \frac{1}{2}\left[\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right] \\ \frac{1}{2}\left[\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right] & 0 & \frac{1}{2}\left[\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right] \\ \frac{1}{2}\left[\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right] & \frac{1}{2}\left[\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right] & 0 \end{pmatrix}$$