Predicting Permeability

Probability, Parsimony, and Polemics

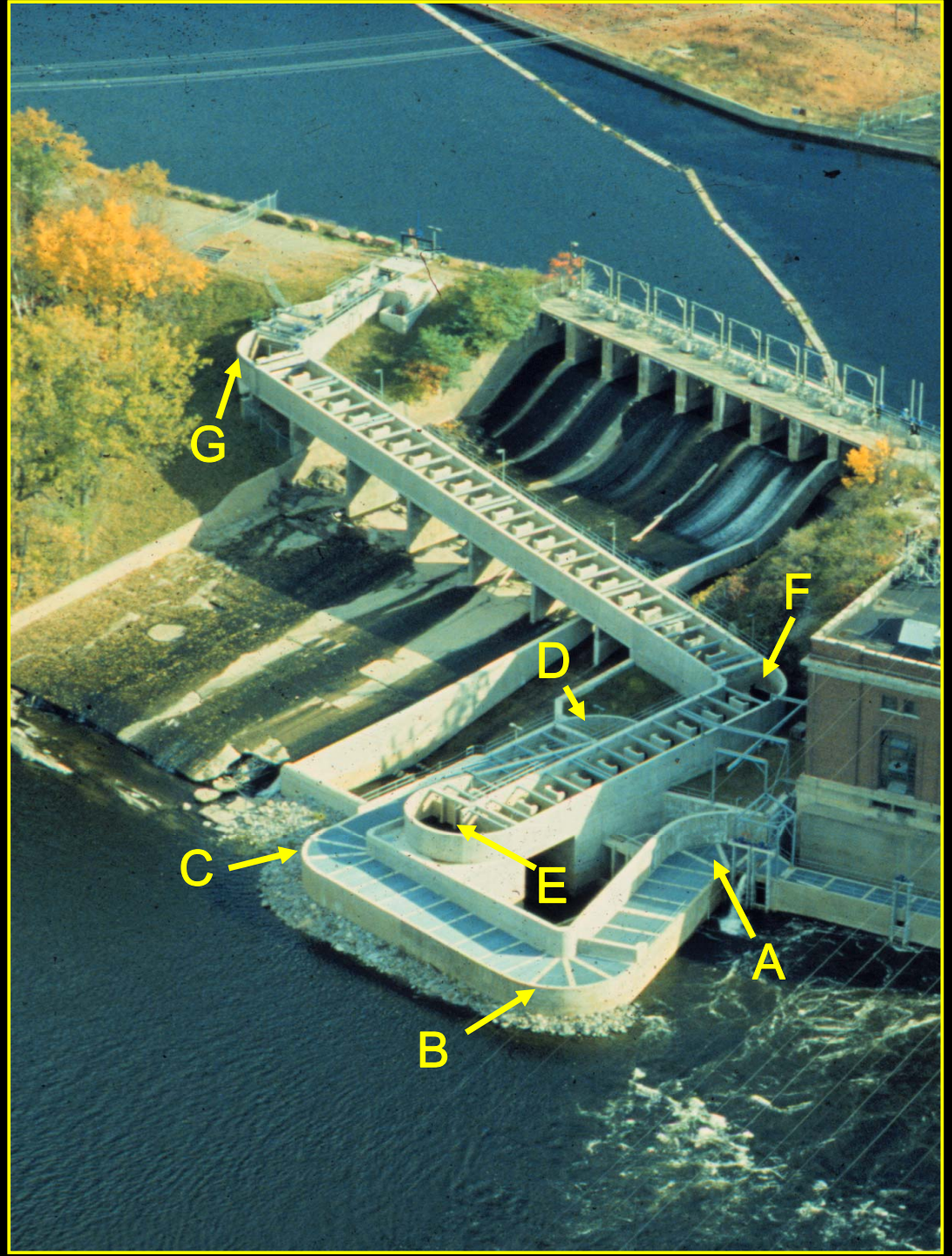
(What do we really need to know to predict passage, and how much so?)

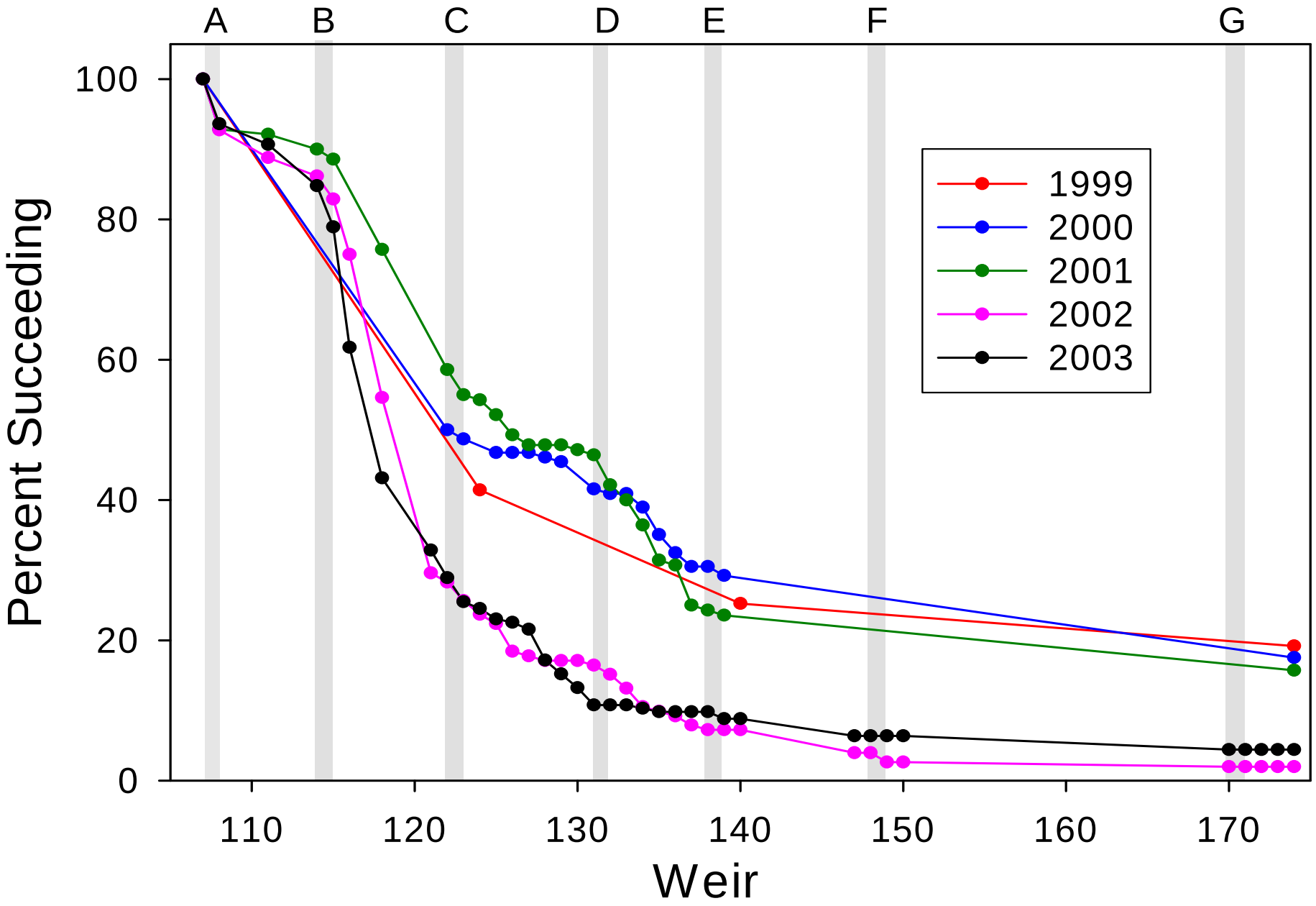
Theodore Castro-Santos

S.O. Conte Anadromous Fish Research Center

USGS

What Barrier?


G
F
D
C
E
A
B

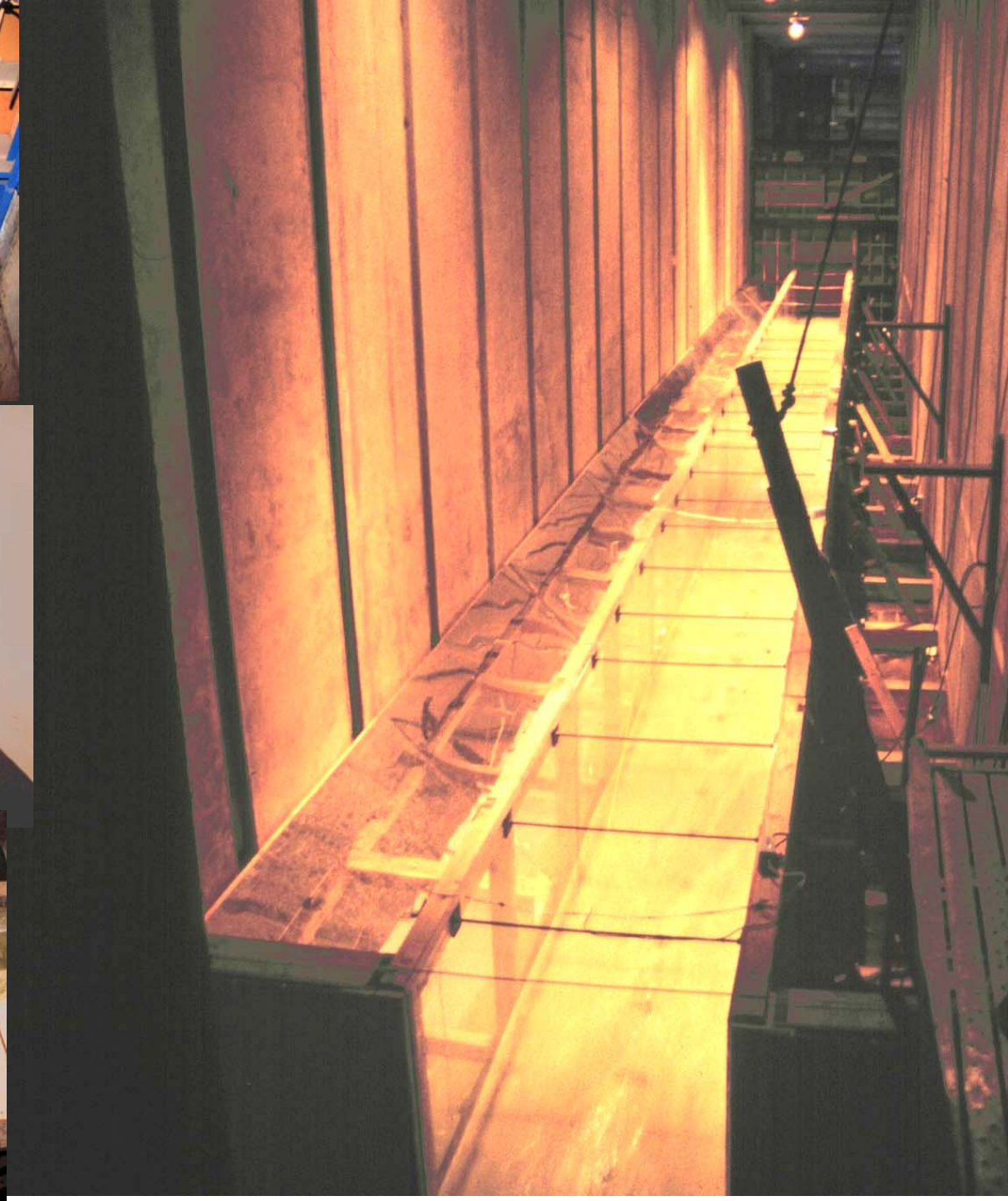

A
B
C
D
E
F
G
100
80
60
40
20
0
Percent Succeeding
110
120
130
140
150
160
170
Weir
1999
2000
2001
2002
2003

Passage success is a discrete measure of a continuous process

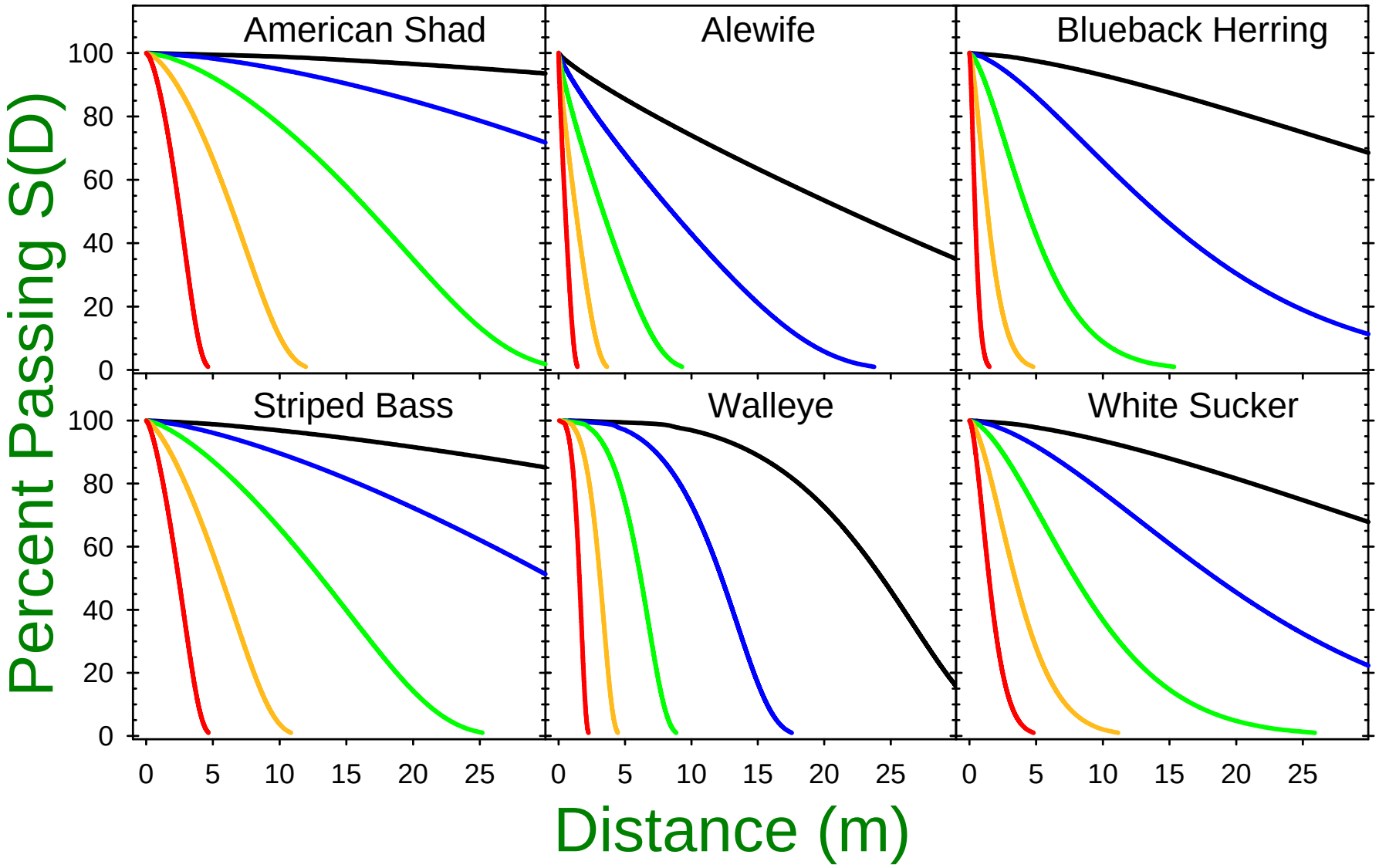
Permeability =

Proportion Passing=

Probability



Predictive Models S(D): 1 – 5 m s^{-1}



Pros and Cons of the Empirical Approach

- Maximum parsimony
- Engineering-friendly

- Species, populations differ
- Complex, site-specific hydraulics
- Insufficient resources for general application
- Ignores key behaviors

Fish Passage Polemics

- Dam/Barrier removal
- Stream simulation
- Nature-like fishways
- Technical fishways
- Improved culvert/channel design
- Parsimony vs. Cost Efficiency

The Problem:

- Hydraulic and other site characteristics define boundaries on designs for culverts, fishways, and other barriers
- Need to integrate physiology, biomechanics, and behavior into predictions of fish passage
- **Need to reconcile *feasibility* and *reliability***

Current (historic) practices

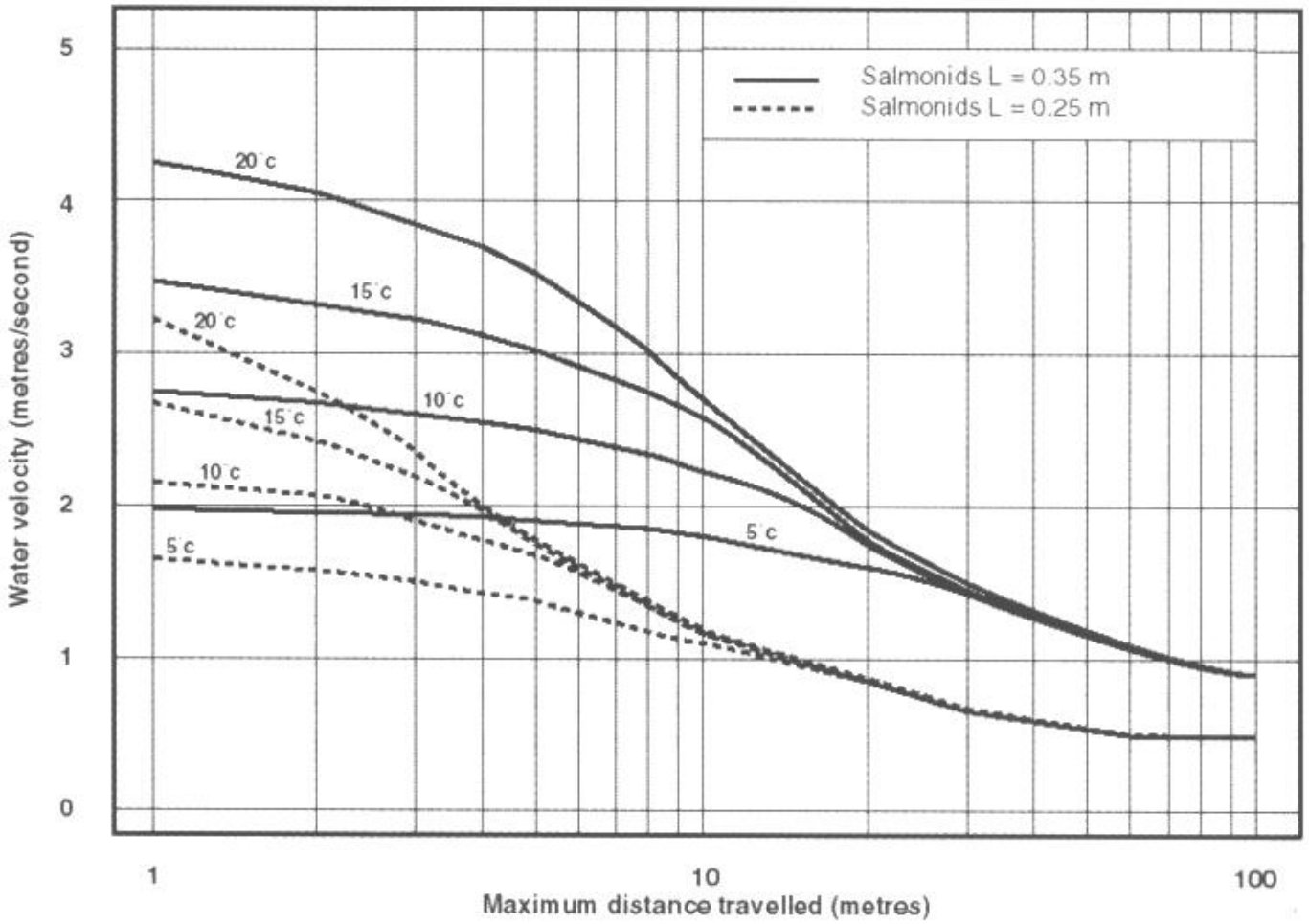


Figure 4: Maximum swimming distance vs. water velocity and temperature for 2 lengths of salmonid.

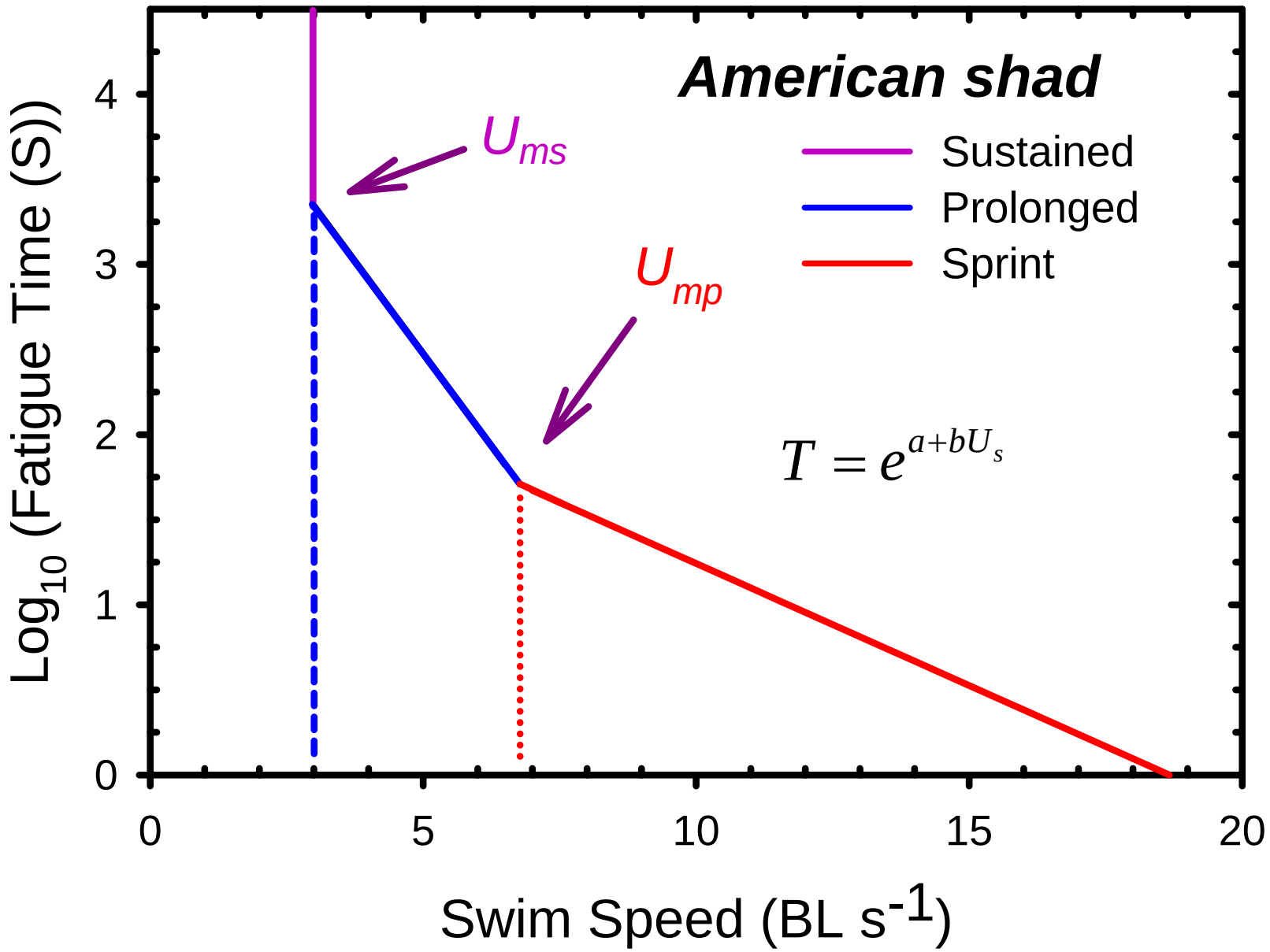
What’s wrong with Beach (1984)?

- Flawed biological basis
  - Assumes broad similarities within and across taxa
  - Ignores 30 years of research
- Variables:
  - Hydraulics
  - Swim speeds
  - Condition and swimming performance

The next generation:

- User-control of swimming performance parameters
- Extensive literature base for finding best approximation of a given site
- Differential mode selection and swim speeds

Modes of steady swimming



Crossing Input

Site Info

Stream Name:

Fish Information

Custom Settings

Literature Swim Speeds | User-defined Swim Speeds | Hydraulic Criteria

Fish Length 40 cm

Select Data

Prolonged | Use Both | Burst

Prolonged Speed 0.46 m/s

Time to Exhaustion 3.00 min

Alosa sapidissima
American shad
Temp: NR Deg C
Speed Range: 0.4 - 0.52 m/s
Fish Body Depth: 0.1 m

Burst Speed 3.28 m/s

Time to Exhaustion 20.00 s

Alosa sapidissima
American shad
Temp: NR Deg C
Speed Range: 2.44 - 4.12 m/s
Fish Body Depth: 0.1 m

Min Depth 0.15 m

Outlet Criteria

Max Outlet Drop 0.00 m

Culvert Information

Culvert 1 of 1

Shape Box Details

Height 300 Width 300 cm

Material Concrete

Installation

Not Embedded

Depth 0 m

Percent 0 %

Culvert Roughness (n) 0.013 ...

Bottom Roughness (n) ...

Culvert Length 30 m

Inlet Bottom Elevation 100.30 m

Culvert Slope 1.00 %

Outlet Bottom Elevation 100 m

Entrance Loss (Ke) 0.5 ...

Velocity Reduction Factors

Inlet 1 Barrel 1 Outlet 1

Fish Passage Flows

Low 4 cms High 5 cms

Tailwater Constant Tailwater

Save < Back Calculate

Crossing Input

Site Info

Stream Name:

Fish Information

Custom Settings

Literature Swim Speeds | User-defined Swim Speeds | Hydraulic Criteria

Fish Length 40 cm

Prolonged | Use Both | Burst

Prolonged Speed 2 m/s

Time to Exhaustion 3.00 min

Burst Speed 4 m/s

Time to Exhaustion 20 s

Min Depth 0.15 m

Outlet Criteria

Max Outlet Drop 0.00 m

Culvert Information

Culvert 1 of 1

Shape Box Details

Height 300 Width 300 cm

Material Concrete

Installation

Not Embedded

Depth 0 m

Percent 0 %

Culvert Roughness (n) 0.013 ...

Bottom Roughness (n) ...

Culvert Length 30 m

Inlet Bottom Elevation 100.30 m

Culvert Slope 1.00 %

Outlet Bottom Elevation 100 m

Entrance Loss (Ke) 0.5 ...

Velocity Reduction Factors

Inlet 1 Barrel 1 Outlet 1

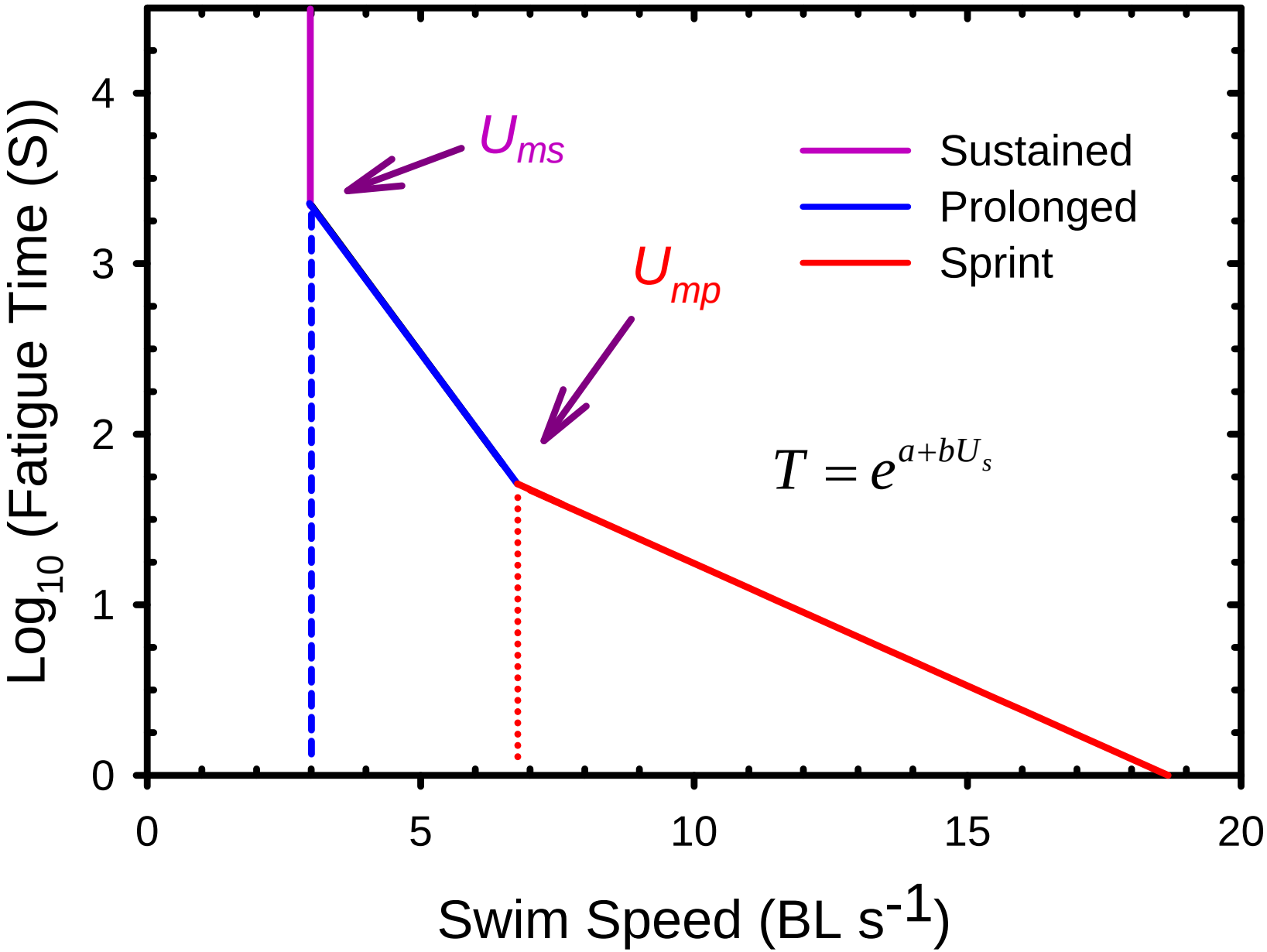
Fish Passage Flows

Low 4 cms High 5 cms

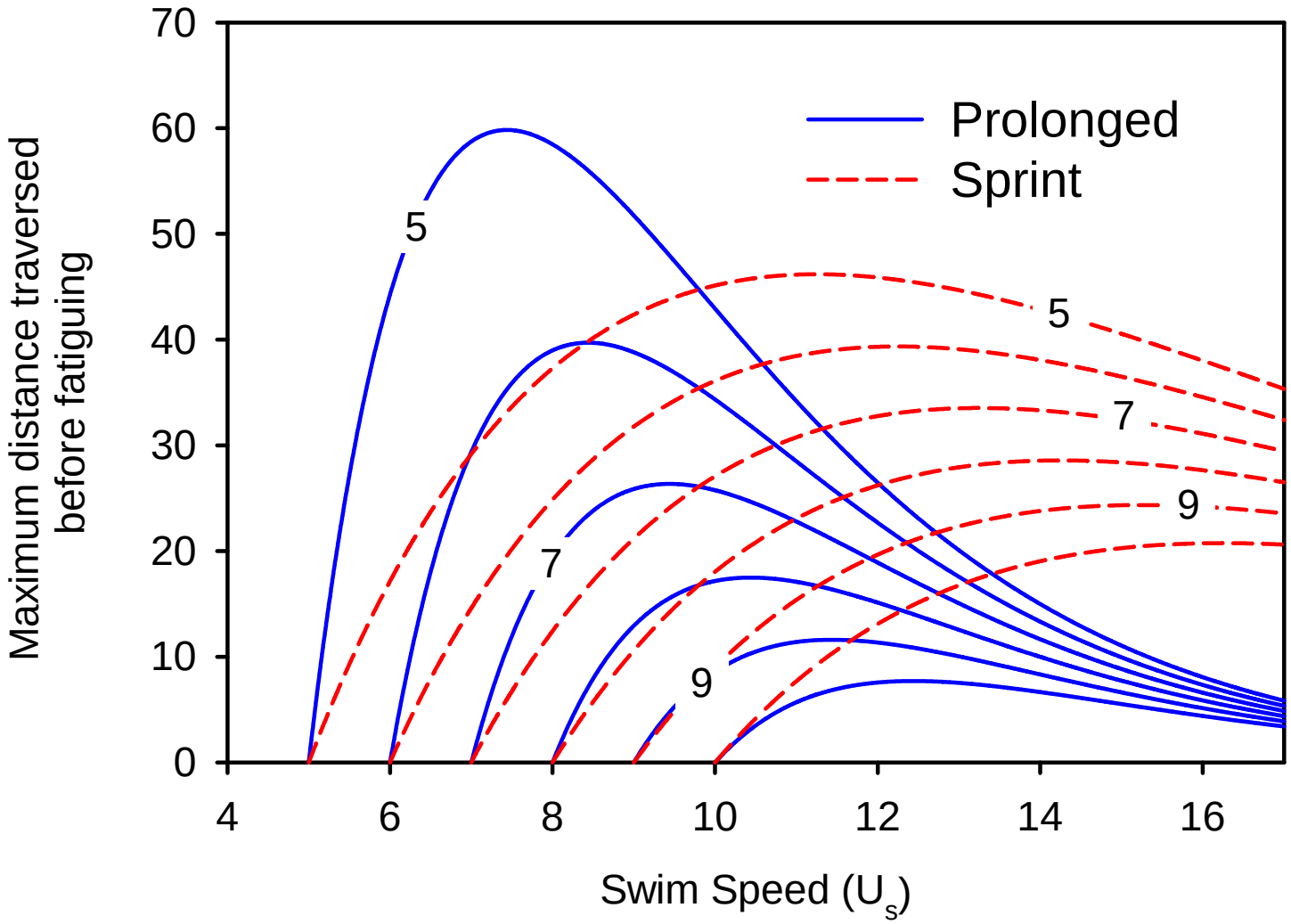
Tailwater Constant Tailwater

Save < Back Calculate

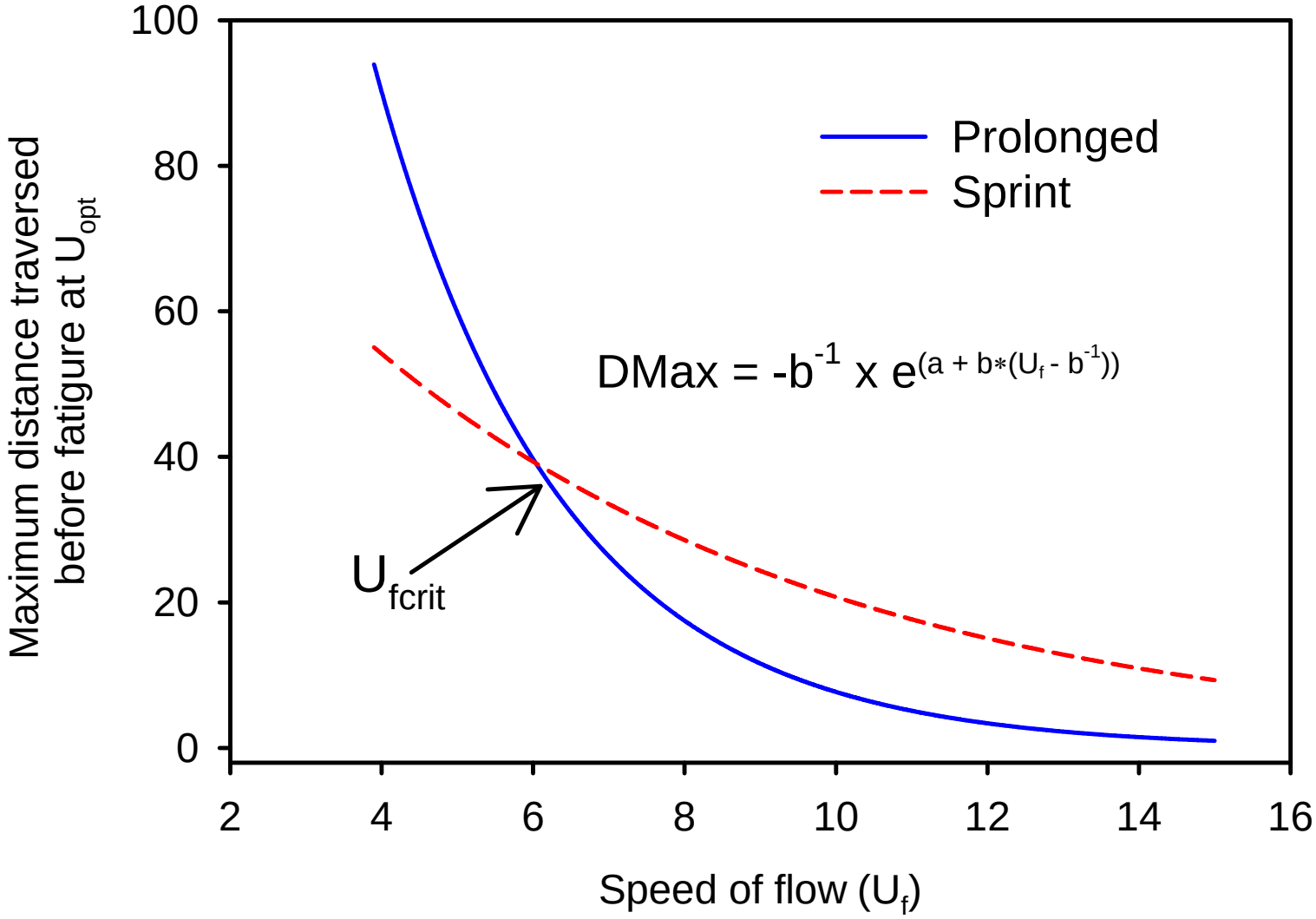
Modes of steady swimming



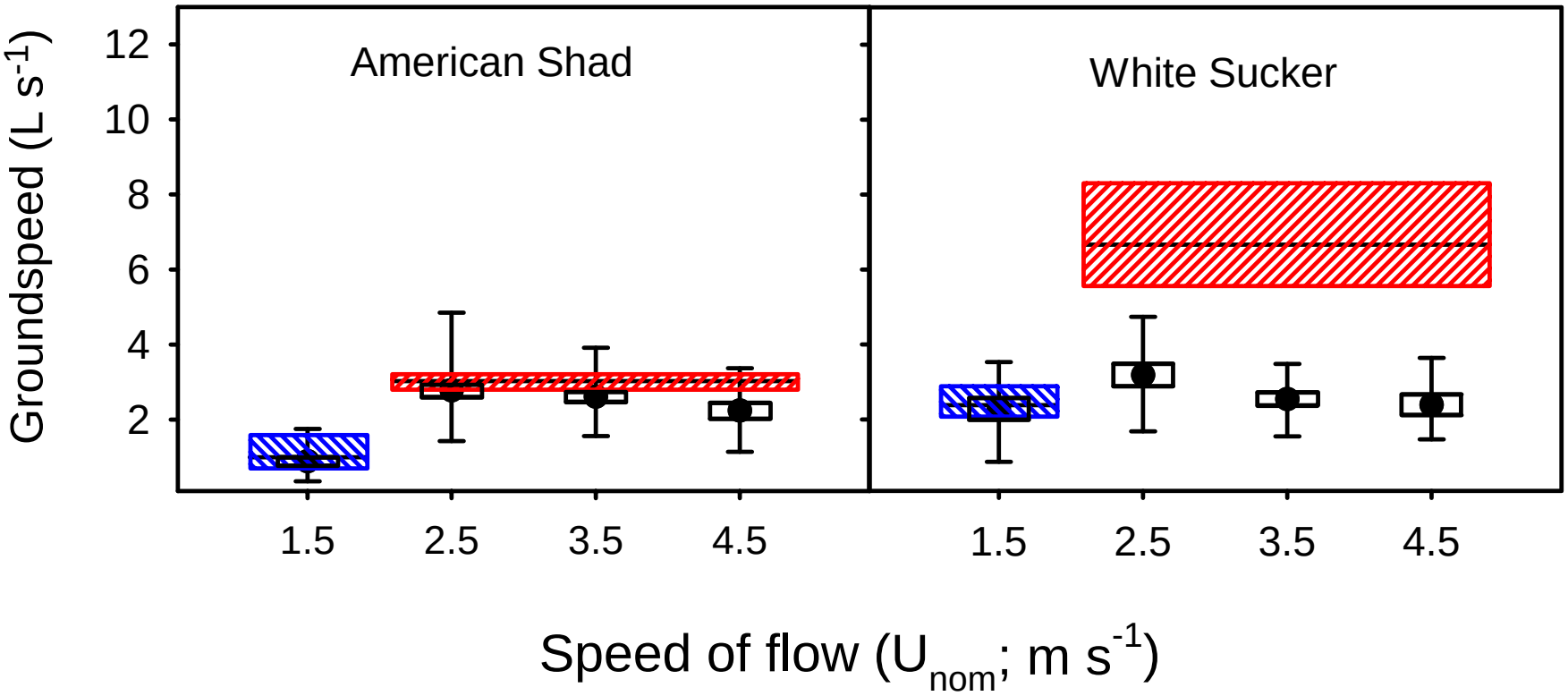
Swim speed and distance maximization



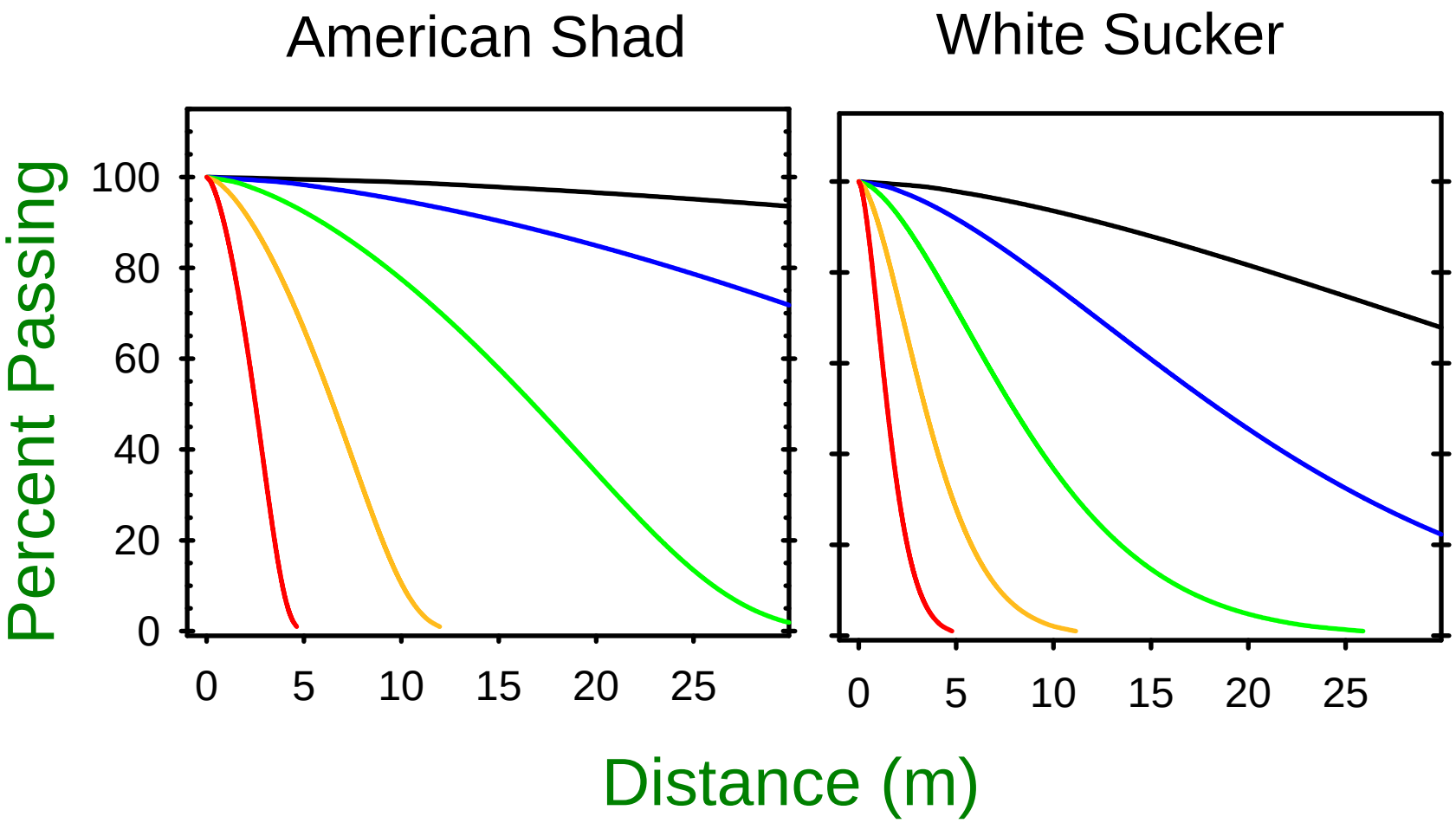
Swim speed and distance maximization



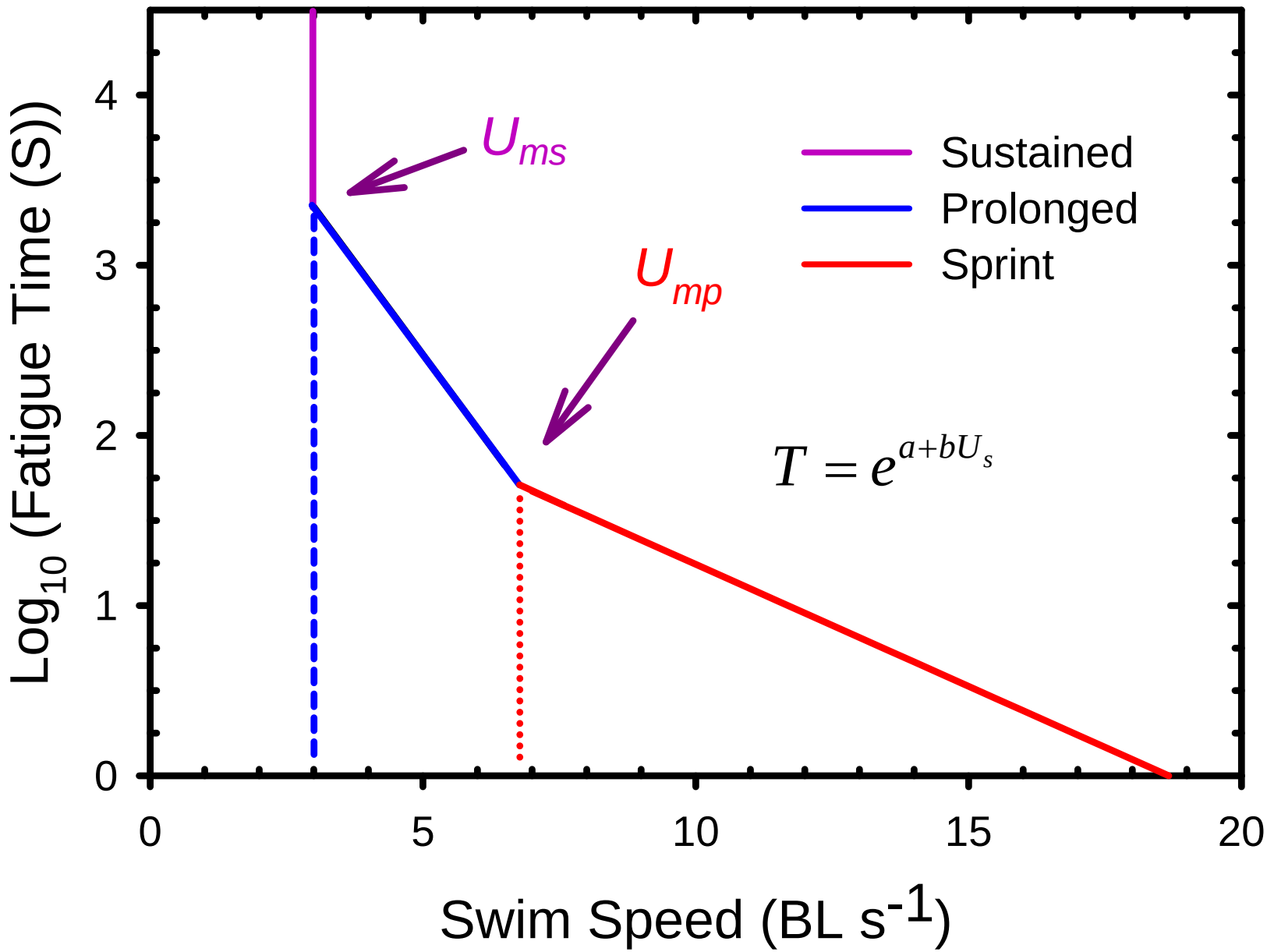
Swim speeds are neither constant nor optimal! Which means…



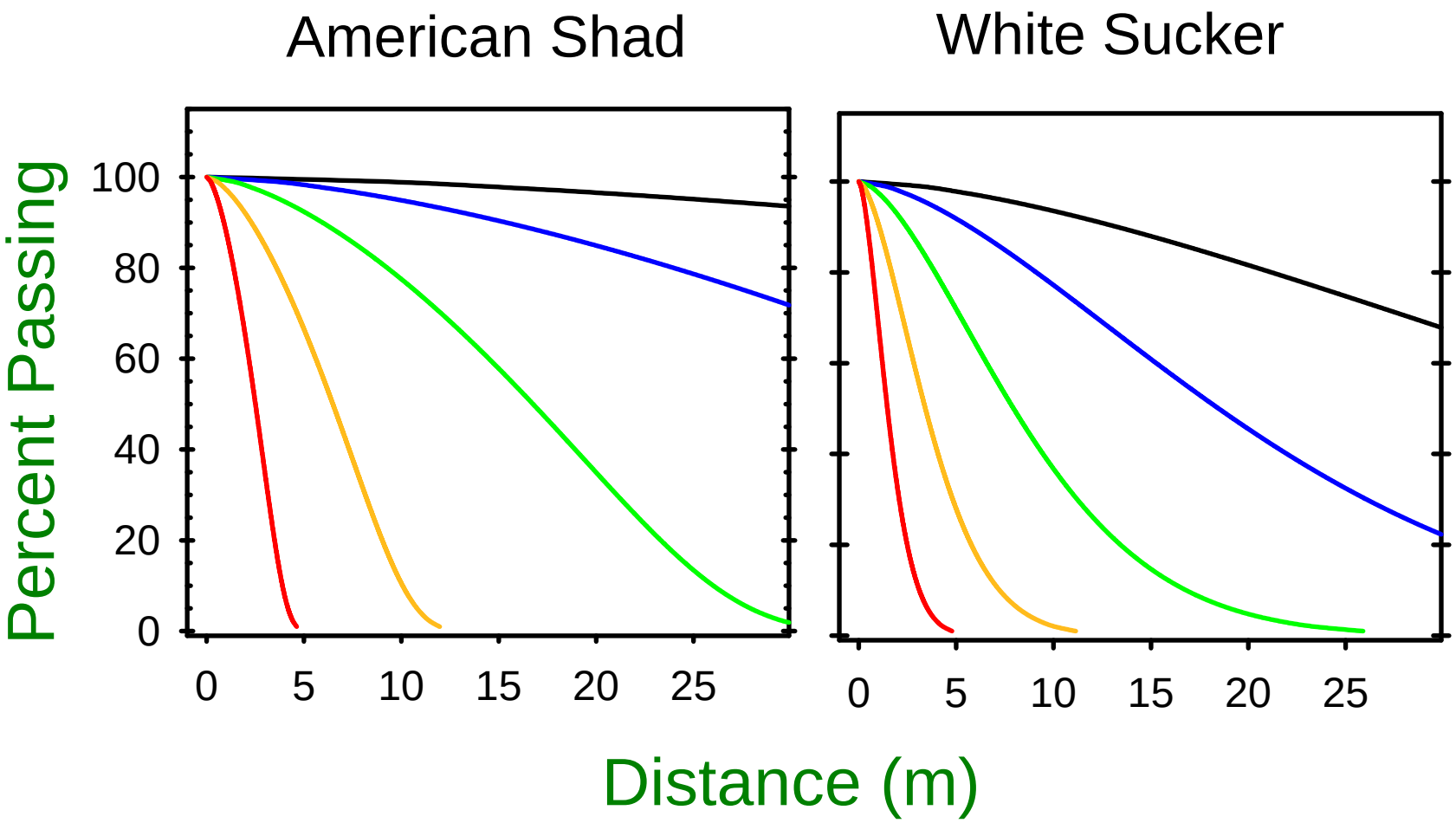
Passage success is not determinsitic



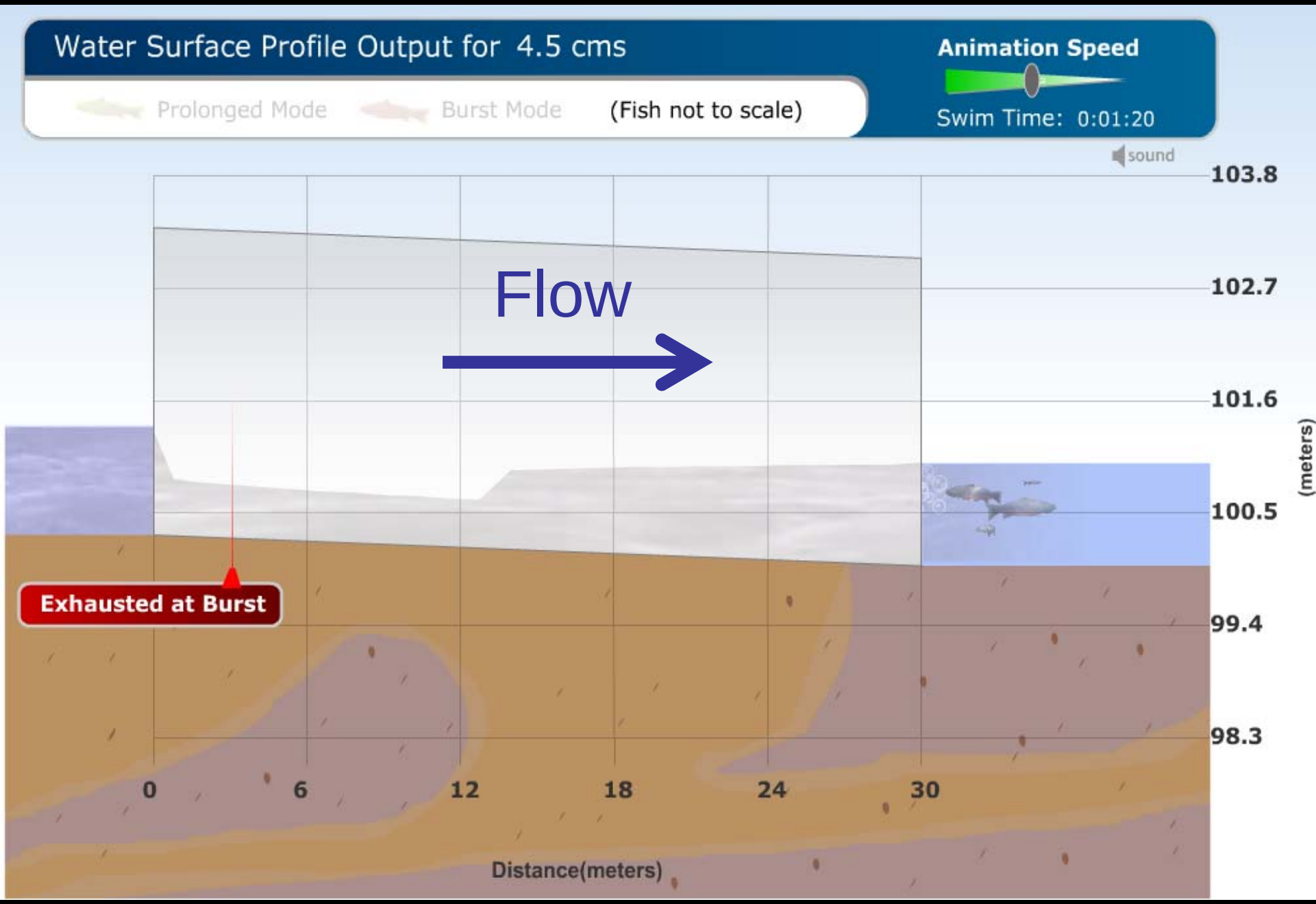
So how do we get from here…



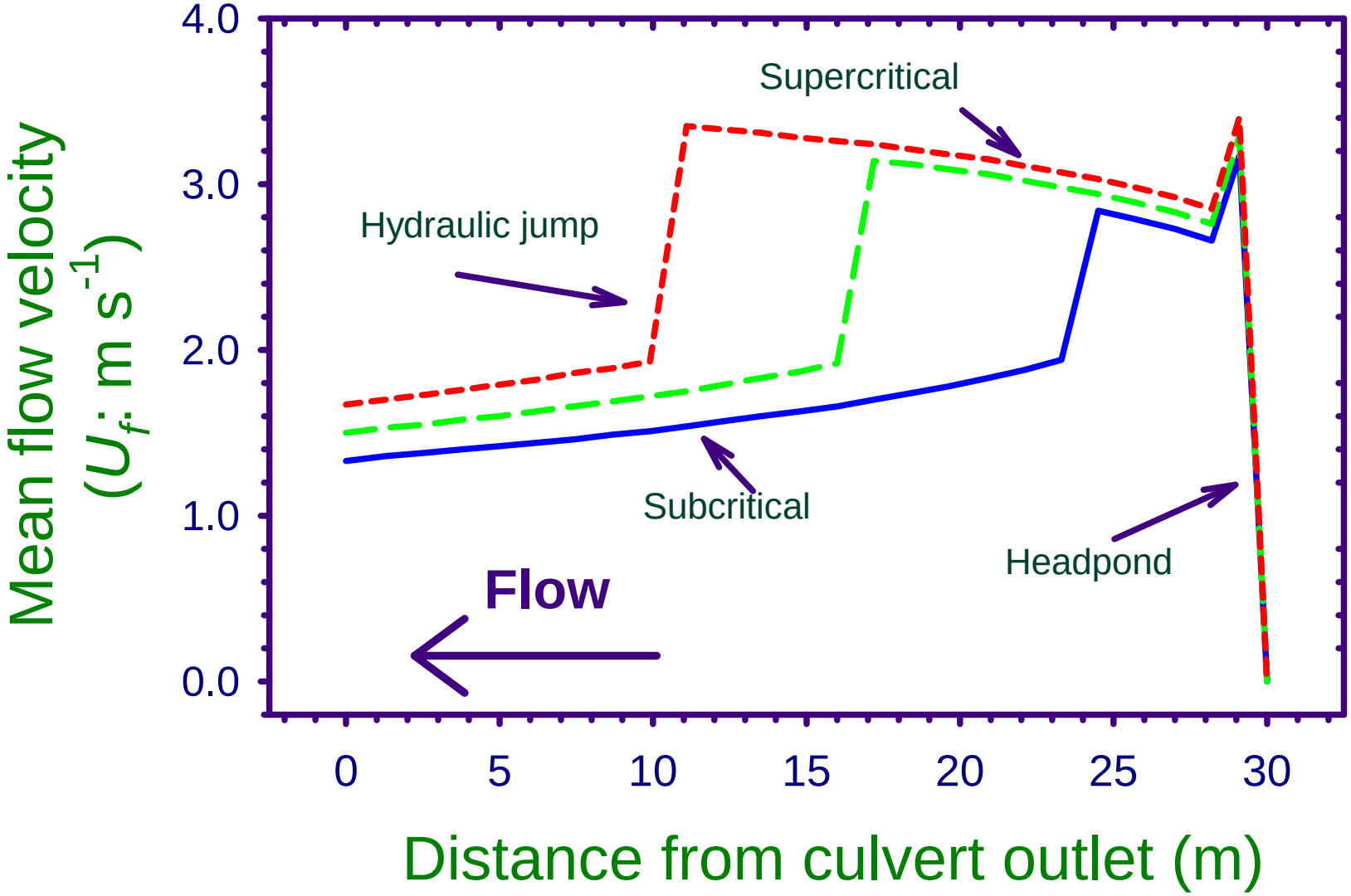
…to here?


American Shad
White Sucker
Percent Passing
100
80
60
40
20
0
0
5
10
15
20
25
0
5
10
15
20
25
Distance (m)

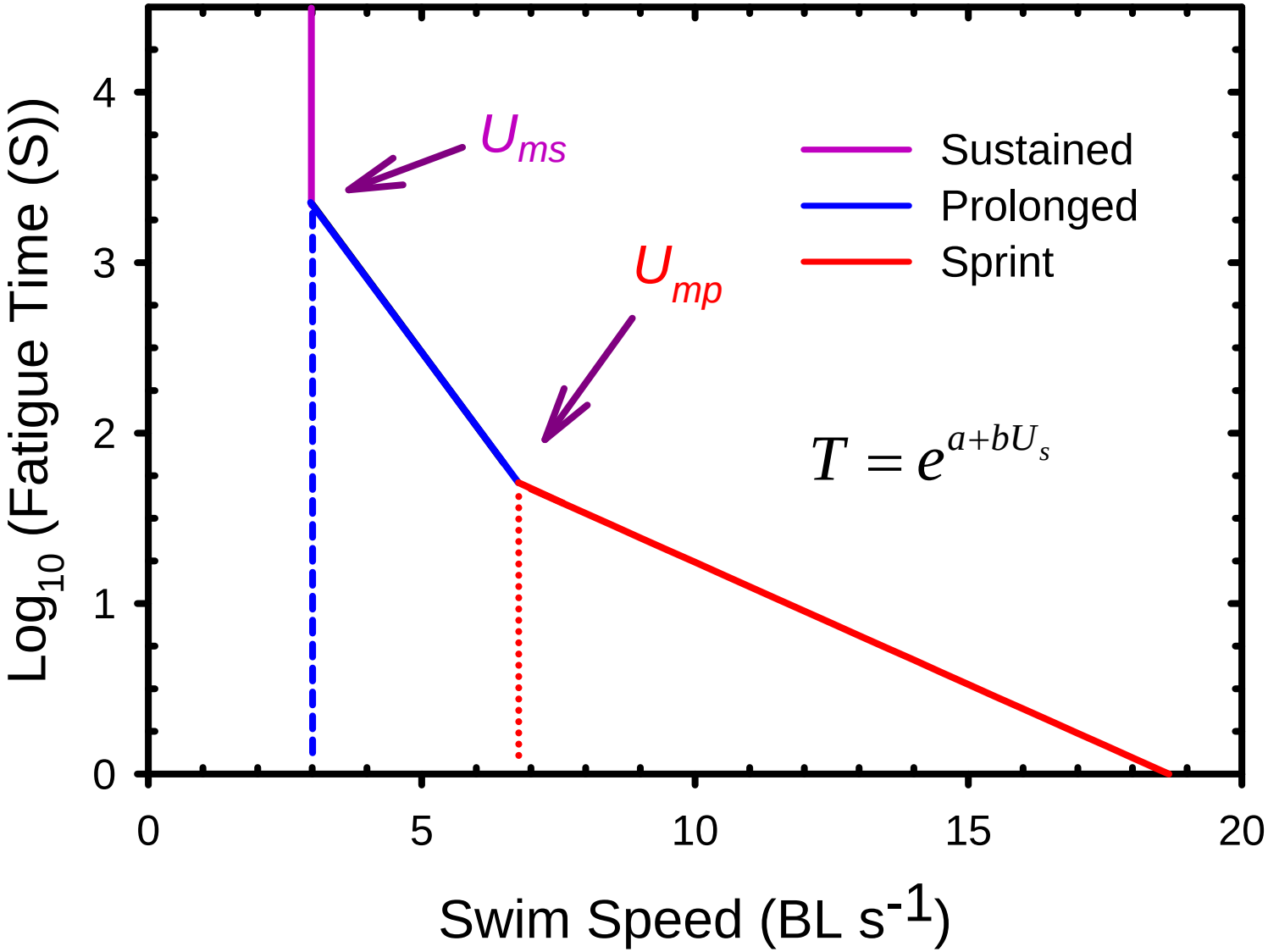
First, ‘account’ for hydraulic complexity

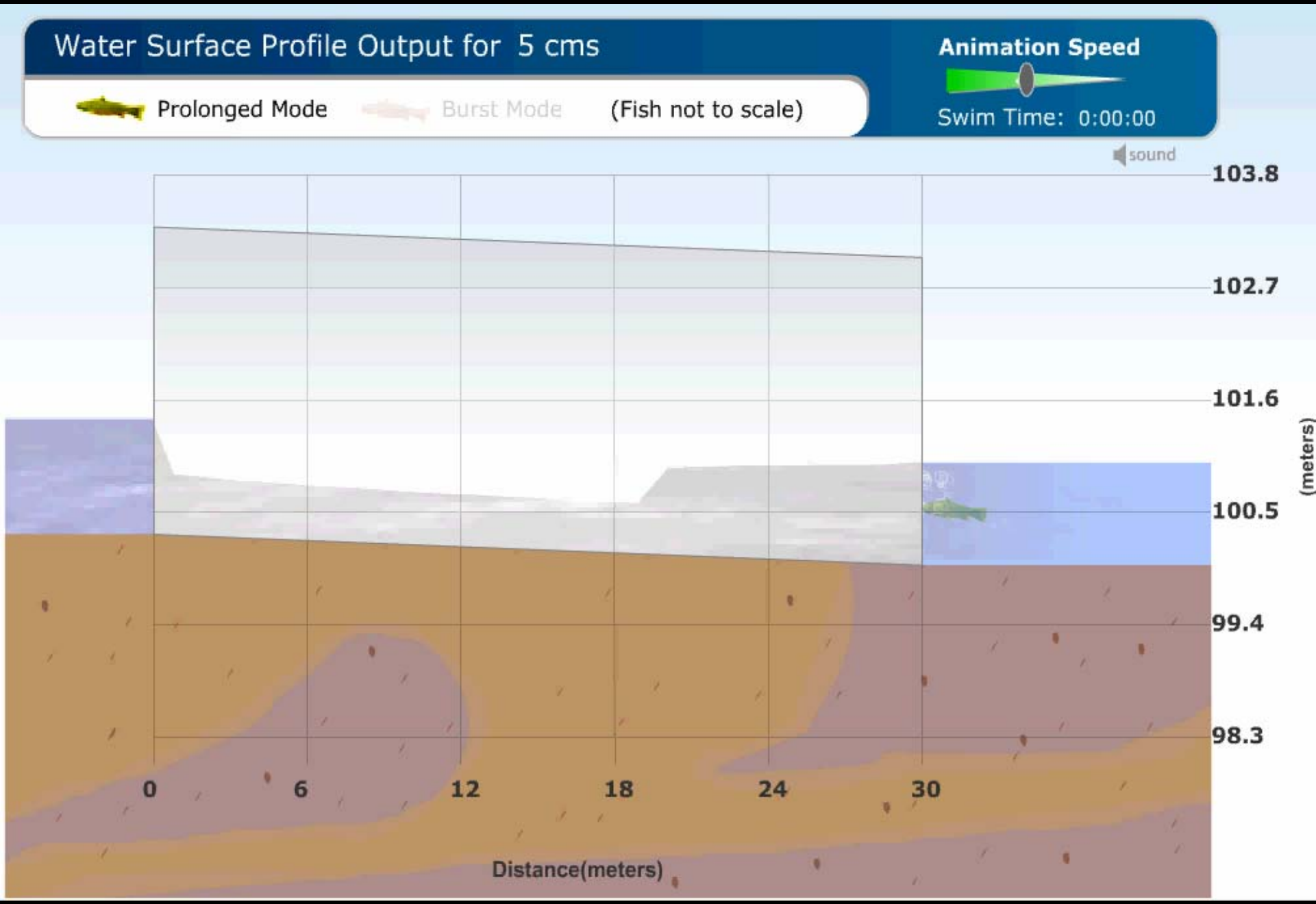

Water Surface Profile Output for 4.5 cms
Prolonged Mode
Burst Mode
(Fish not to scale)
Animation Speed
Swim Time: 0:01:20
sound
Flow
Exhausted at Burst
103.8
102.7
101.6
100.5
99.4
98.3
(meters)
0
6
12
18
24
30
Distance(meters)

Culvert hydraulics at 4.0, 4.5, and 5.0 m^3s^{-1}



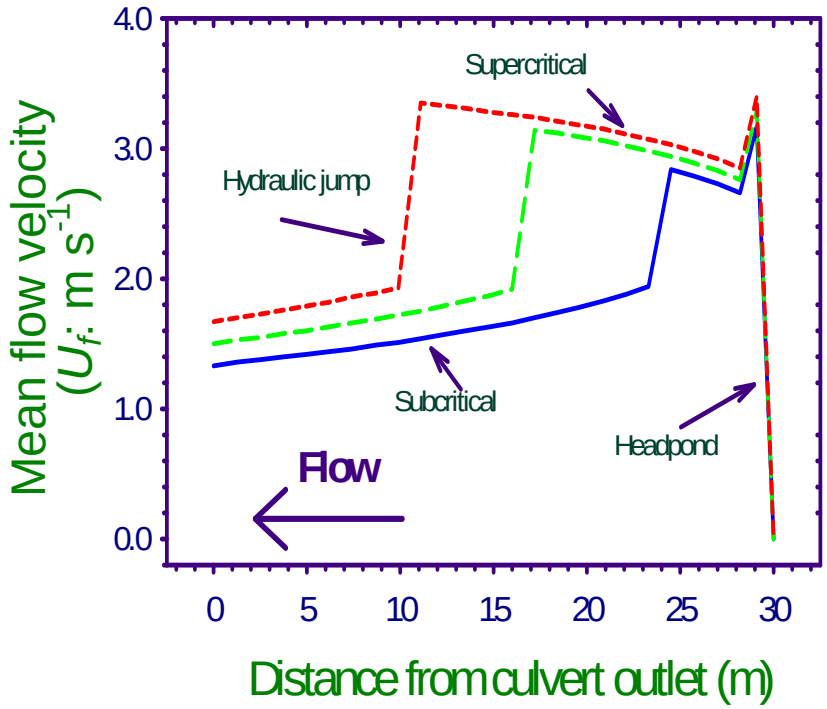
Swim Speed and Fatigue Time determine distance

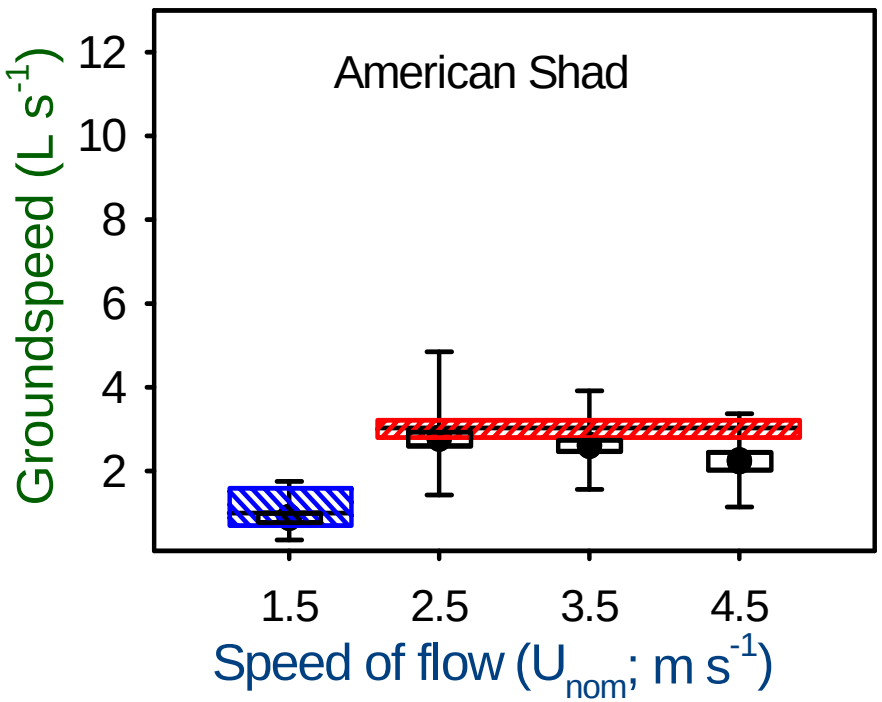



Water Surface Profile Output for 5 cms
Prolonged Mode
Burst Mode
(Fish not to scale)
Animation Speed
Swim Time: 0:00:00
sound
103.8
102.7
101.6
100.5
99.4
98.3
(meters)
0
6
12
18
24
30
Distance(meters)

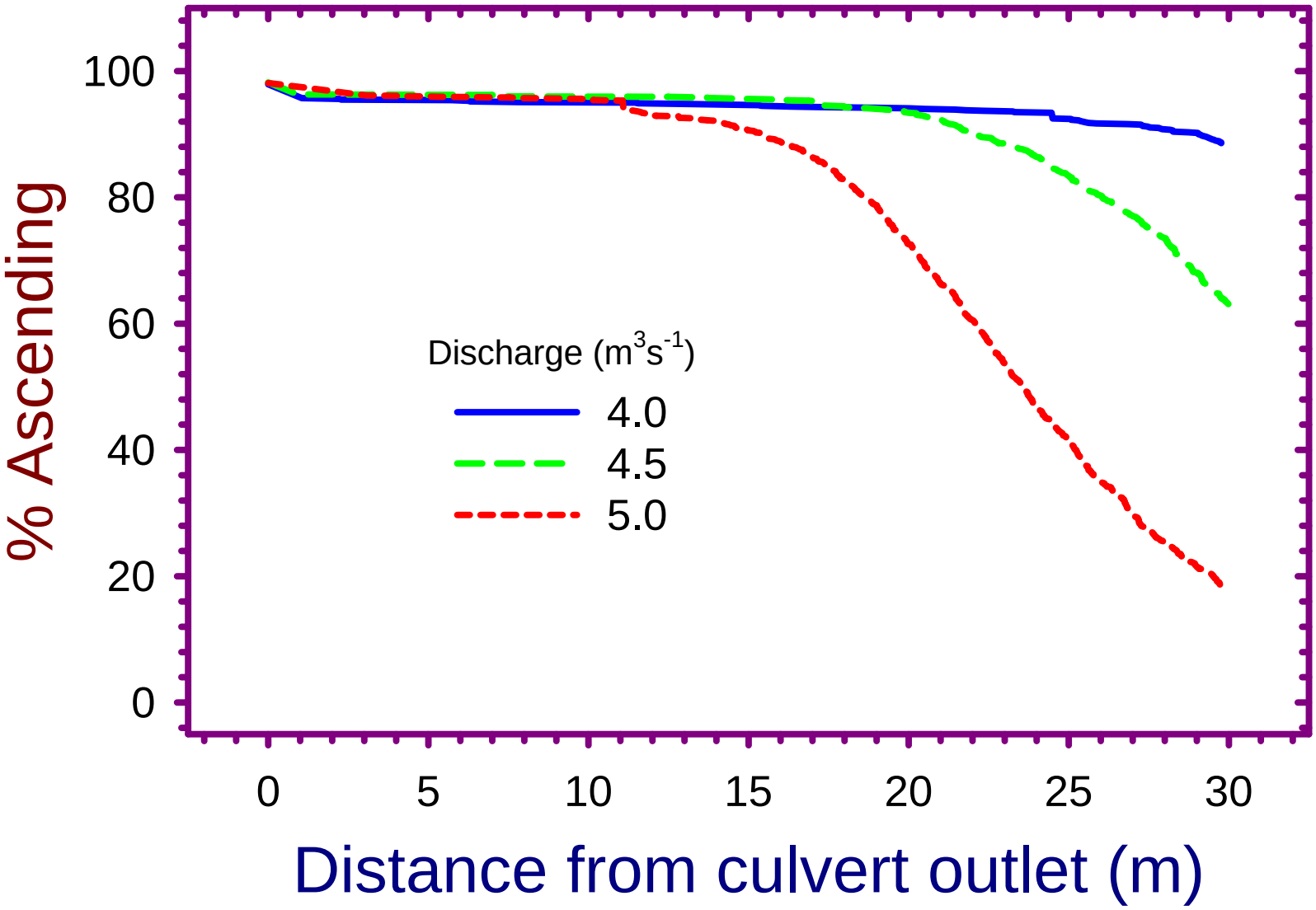
The next challenge:

Varying swim speeds and cumulative fatigue





Stochastic Models



Necessary Data

- Swim speed-fatigue time
  - Variability
- Behavioral optimization and variability

- Attempt rate/attraction

Conclusions

- Fish passage is stochastic, not deterministic
- Models are getting better, but…
- They're only as good as the data they're fed
- It's possible to be right for the wrong reasons

Recommendations

- Significant cost savings can be realized with better data
- Existing models of swimming performance underestimate actual performance in the field
- Lots of unanswered questions:

  - Turbulence
  - Water depth
  - Perched outlets
  - Attempt rate

Dogma