Development of Biometric-Based Design Criteria for Nature-like Fishways

Alex Haro, Research Ecologist
Leetown Science Center - S.O. Conte Anadromous
Fish Research Laboratory
U.S. Geological Survey
Turners Falls, Massachusetts
aharo@usgs.gov

James Turek, Restoration Ecologist
NOAA Restoration Center
Narragansett, Rhode Island
james.g.turek@noaa.gov

River Herring Technical Expert Working Group (TEWG)
Habitat Committee Conference Call and Webinar
September 1, 2016

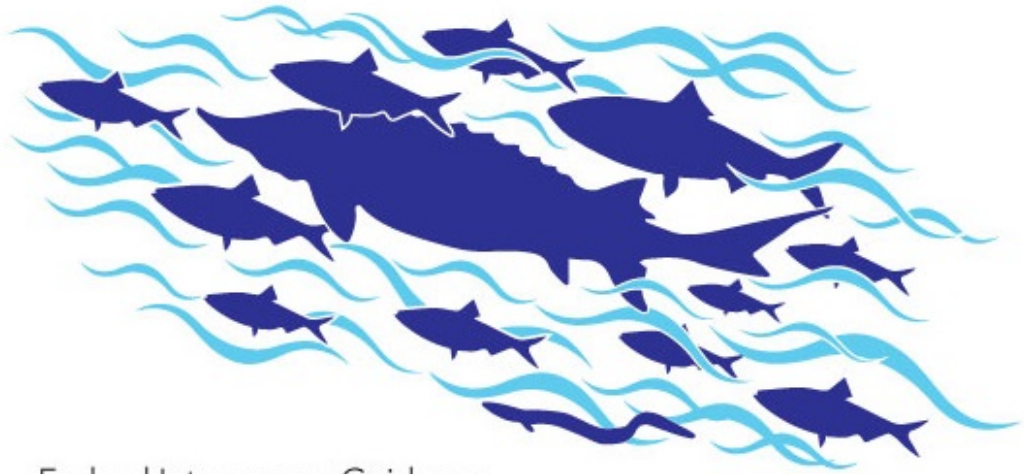
Disclaimer/Caveats:

- “Criteria” vs. Guidelines
- Design guidelines - NOT agency required or mandated design criteria
- Subject to change as more information becomes available

Interagency Guidelines Document:

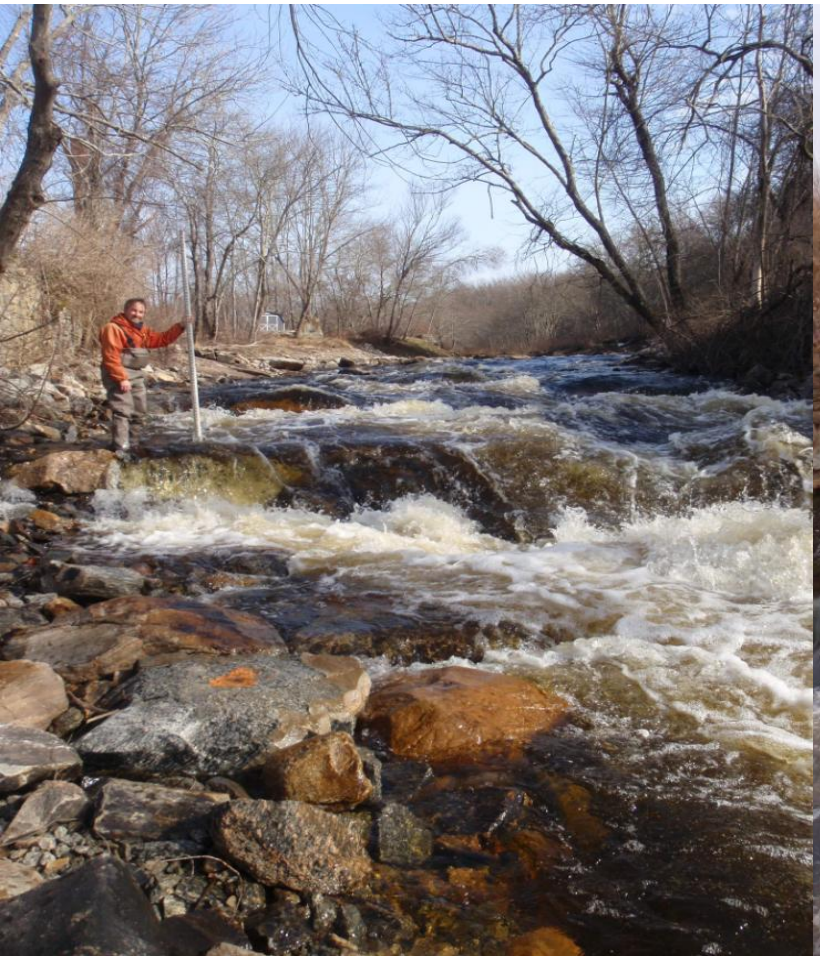
http://www.habitat.noaa.gov/pdf/Final_Federal_Interagency_Technical_Memorandum_Fish_Passage_Guidelines.pdf

Technical Memorandum
Federal Interagency
Nature-like Fishway Passage Design Guidelines
for Atlantic Coast Diadromous Fishes



Federal Interagency Guidance:
Atlantic Coast Diadromous Fishes

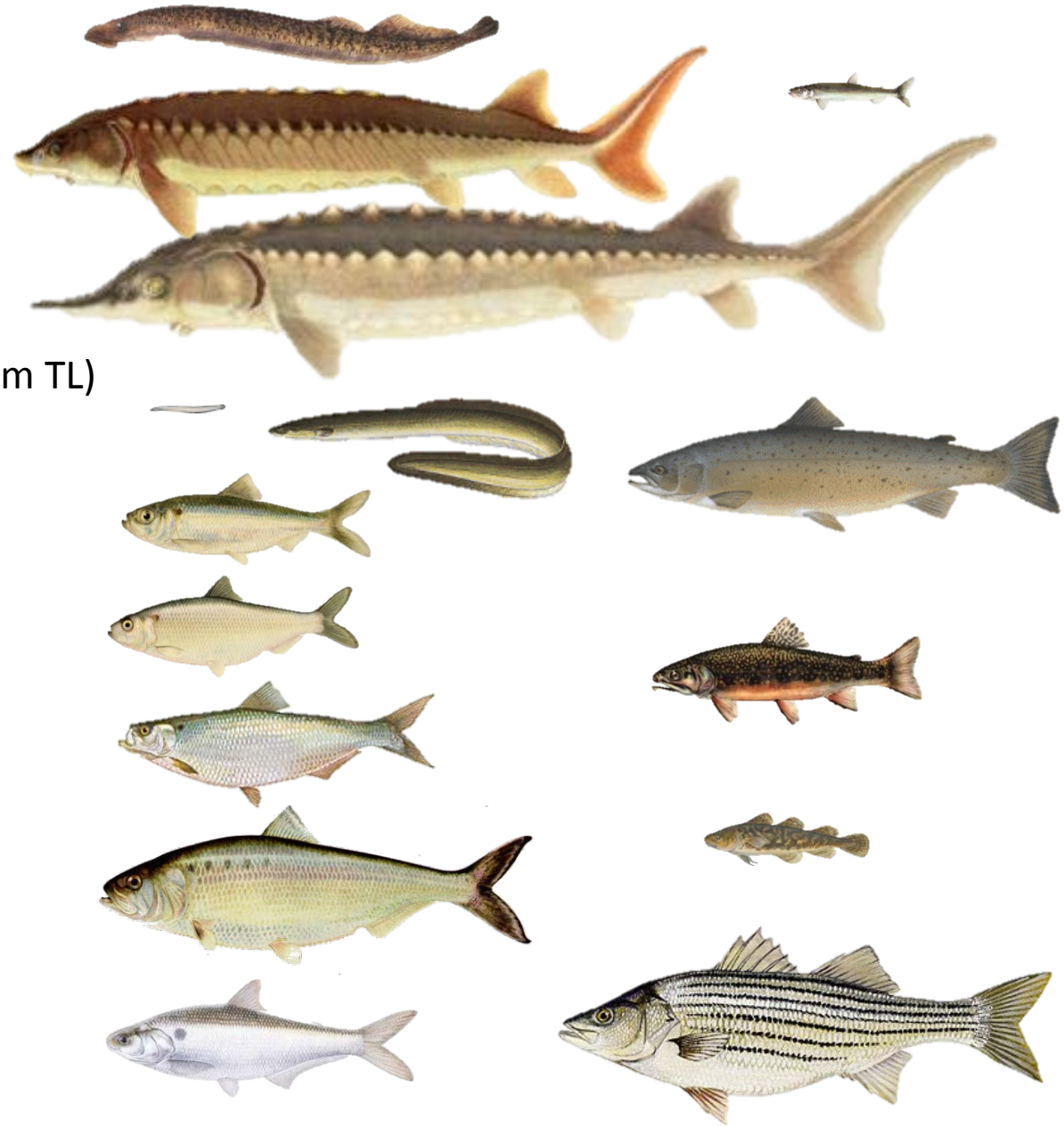
NLF designs – variable, complex hydraulics



Other existing guidelines and criteria

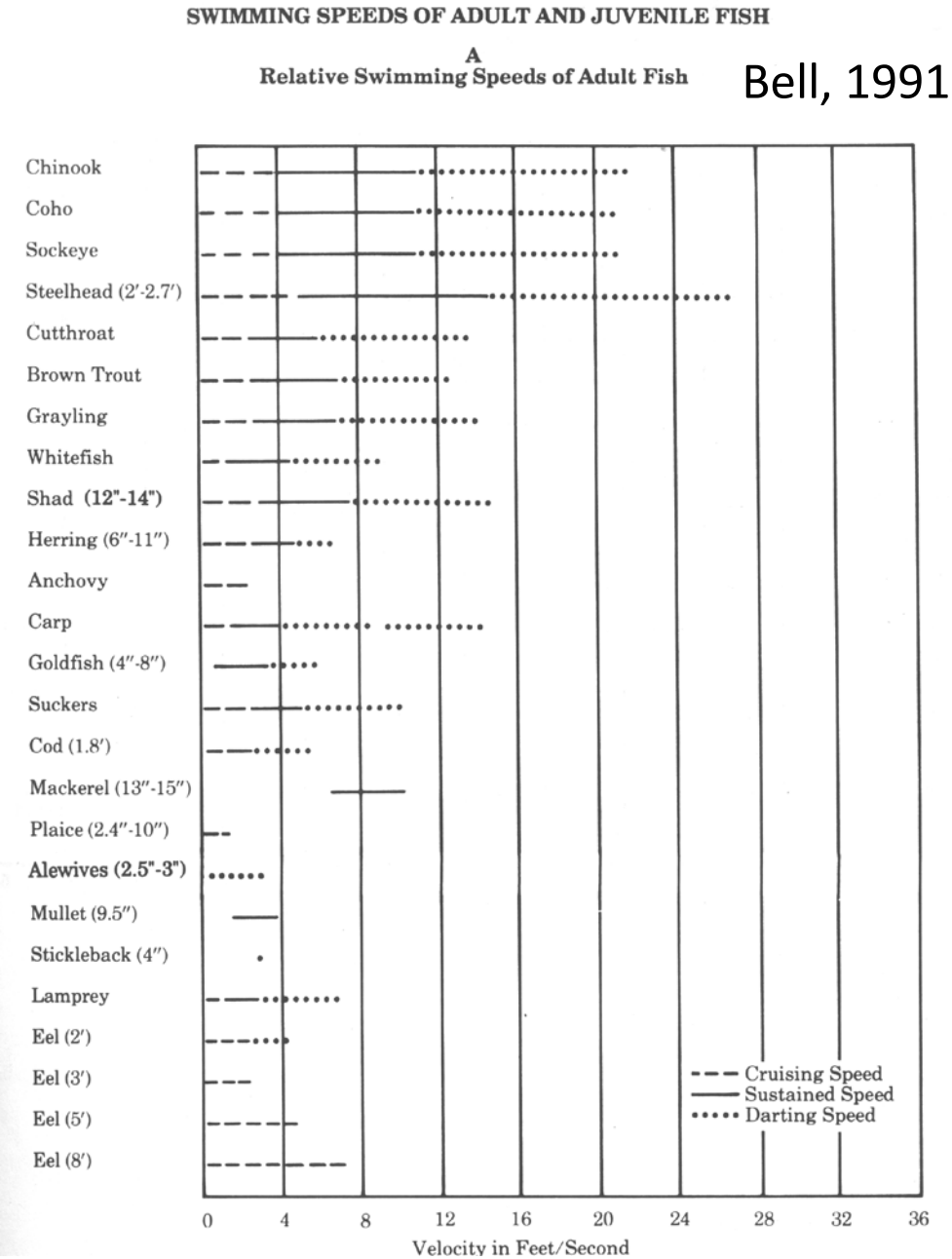
Target Species

Sea Lamprey
Shortnose Sturgeon
Atlantic Sturgeon
American Eel (< 15 cm and >15 cm TL)
Blueback Herring
Alewife
Hickory Shad
American Shad
Gizzard Shad
Rainbow Smelt
Atlantic Salmon
Sea Run Brook Trout
Juvenile Salmonid < 20 cm TL
Atlantic Tomcod
Striped Bass



Incomplete swimming speed data

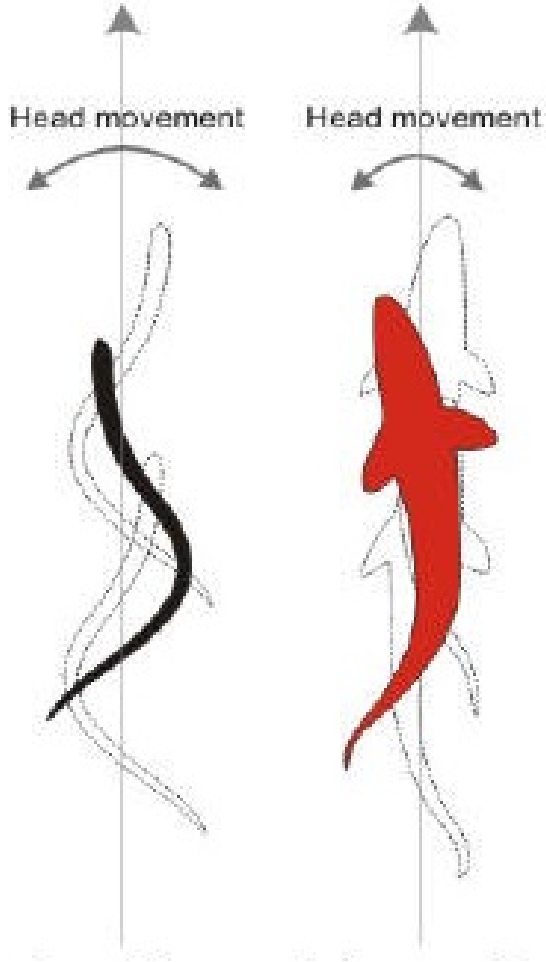
- Anecdotal observations
- Forced swimming in confined lab apparati
- No data for many species
- Swim *duration* data lacking



Not all fish swim the same…

Anguilliform swimming
(eels, sturgeons)

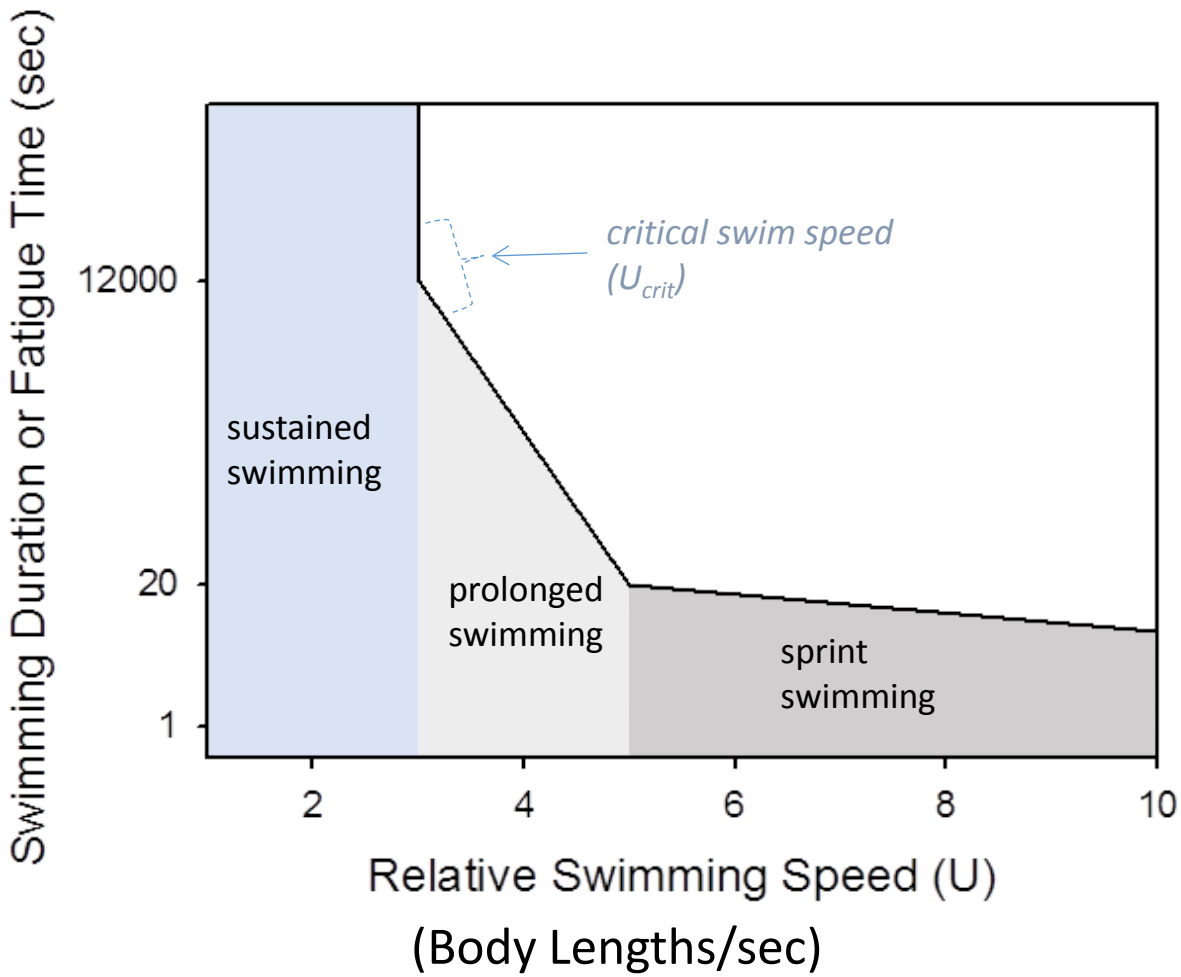
- *slower*
- *more energy efficient*



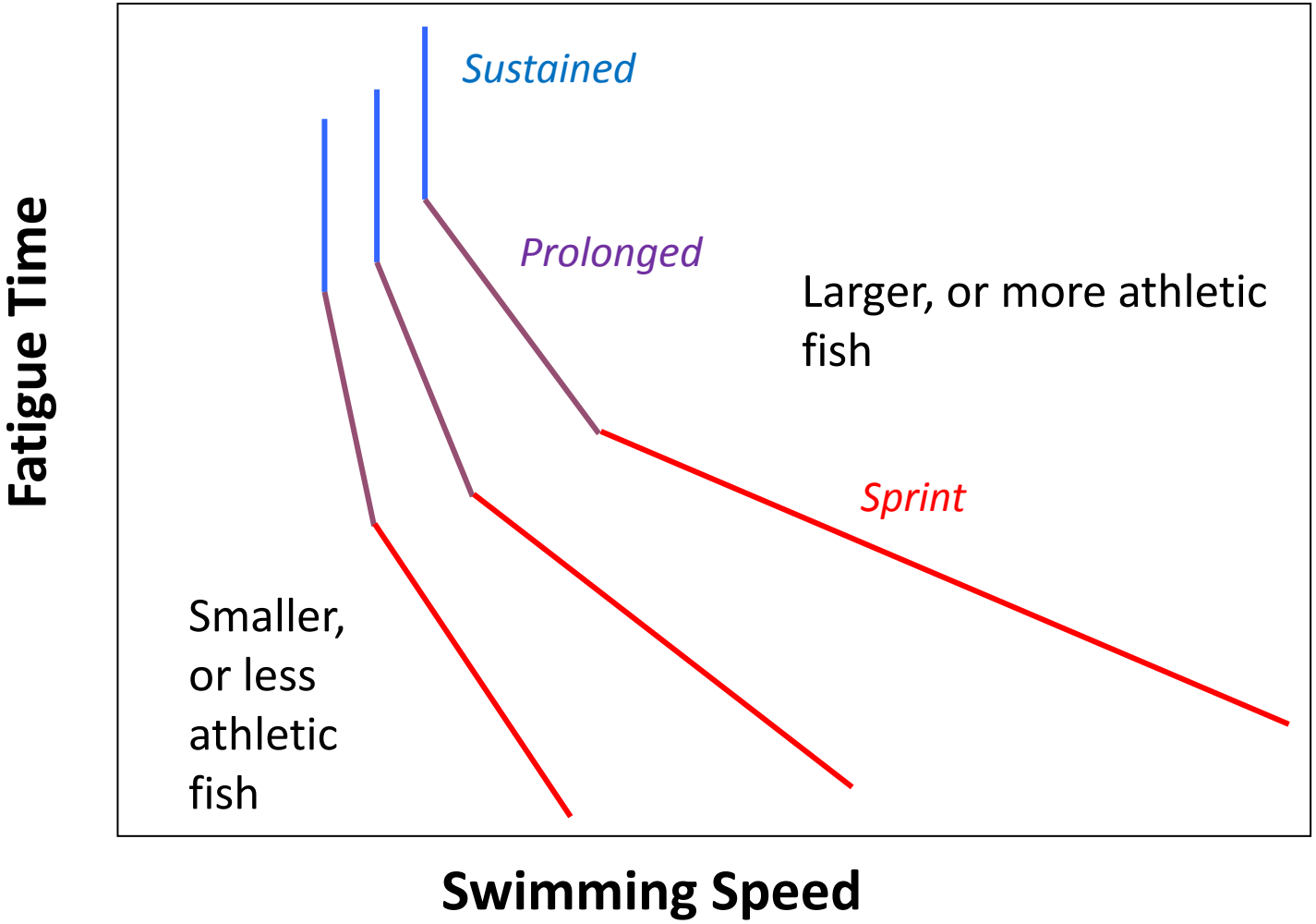
Subcarangiform swimming
(alosines, salmonids)

- *faster*
- *less energy efficient*

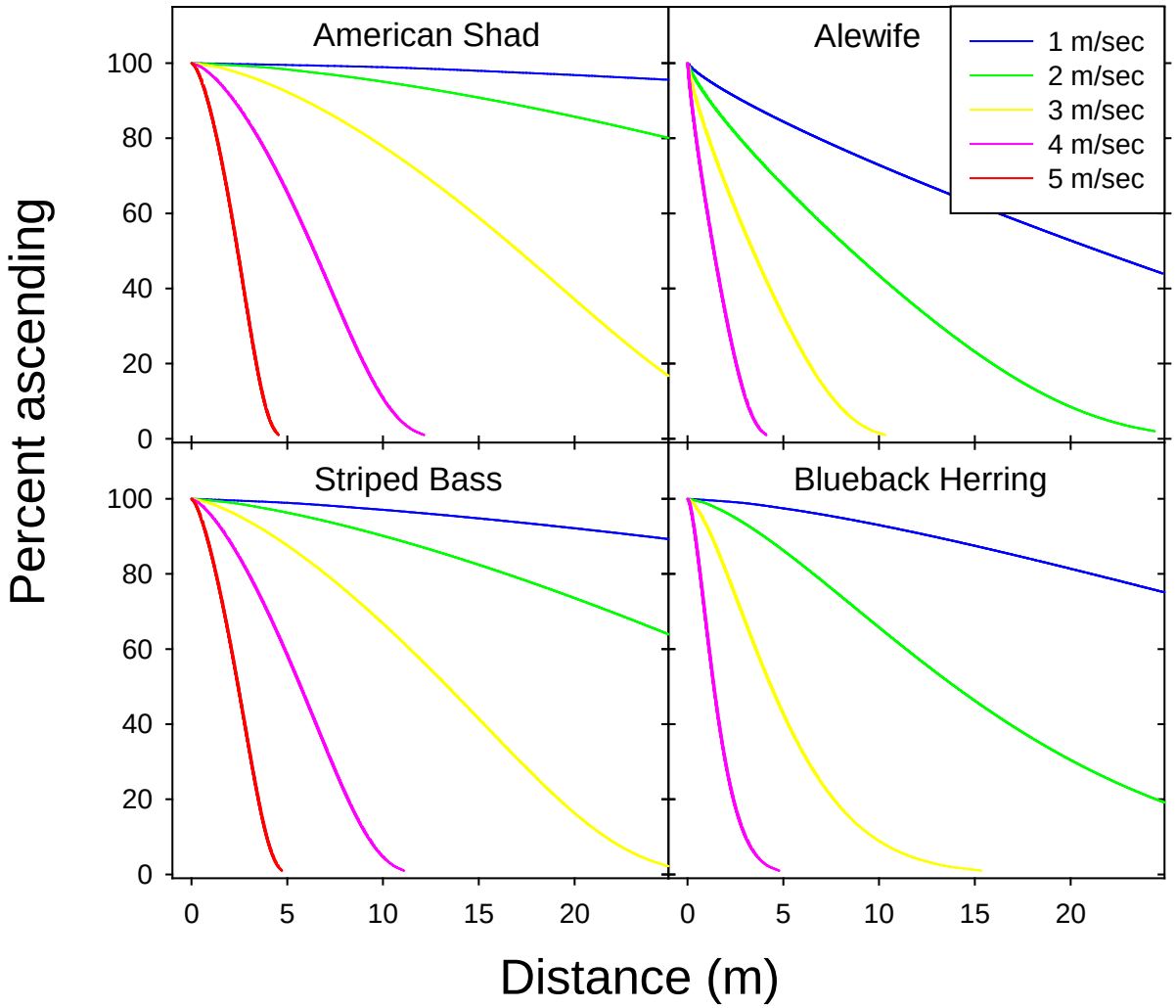
Swim speed – duration curve



Swim speed curves vary between species and fish body size



Sprint swimming studies: direct measurement of speed-distance relationships



Compilation of fish swimming

SPECIES	Life History Stage	Min. Length (cm)	Max. Length (cm)	Mean Length (cm)	Water Temp. (°C)	Type of test	Swimming Performance	Reference
Sea Lamprey	subadult	14.5	39.0		5.0	respirometer	10 min swimming duration at 0.17-0.34 m/s	Beamish 1974
	subadult	14.5	39.0		10.0	respirometer	10 min swimming duration at 0.17-0.35 m/s	Beamish 1974
	subadult	14.5	39.0		15.0	respirometer	10 min swimming duration at 0.24-0.41 m/s	Beamish 1974
	adult			38.0	2.0	respirometer	1 min swimming duration at 0.23 m/s	Skidmore & McCauley 1958
	adult			38.0	15.0	respirometer	1 min swimming duration at 0.23 m/s	Skidmore & McCauley 1958
	adult			51	10.0-16.8	open flume	1 m/sec swim speed maintained for 60 sec duration; 2 m/sec for 10 sec duration; 3 m/sec for 3 sec duration	McAuley 1996
Shortnose Sturgeon	juvenile	16.5	26		17.0-21.7	respirometer	U_{crit}=0.48 m/s	Dadswell, unpub. data
Atlantic Sturgeon	juvenile	17.2	19.5		17.2-19.5	respirometer	U_{crit}=0.42 m/s	Dadswell, unpub. data
American Eel	elver	6.9	7.5	7.2	12.0	open flume	3 min swimming duration at 7.2 BL/s; 0.7 min at 5 BL/s; 0.27 min at 7.5 BL/s; no upstream progress at > 0.5 m/s water velocity	McCleave 1980 (*A. anguilla*)
	elver			56	17-23	open flume	sustained swimming at 0.15 m/sec; prolonged swimming at 0.25 m/sec; burst swimming at 0.4 m/sec	Barbin and Krueger 1994
	elver	5.0	8.0		11.1	open flume	20 sec duration at 0.36 to 0.5 m/sec	Clough and Turnpenny 2001 (*A. anguilla*)
	elver -				12.0-		"burst" swimming at 0.5 to 1.5 m/sec	Sörensen 1951 (*A. anguilla*)
	adult	32.5	52.0	41.7	13.3-21.6	open flume	See Fig. 2B-2; SPRINTSWIM program	Haro et al. 2004
Gizzard Shad	no data							
Rainbow Smelt	adult			7.0	10.0	respirometer	U_{crit}=0.30 m/s	Griffiths 1979
	adult			10.0	10.0	respirometer	U_{crit}=0.36 m/s	Griffiths 1979
	adult			13.0	10.0	respirometer	U_{crit}=0.41 m/s	Griffiths 1979
	adult			16.0	10.0	respirometer	U_{crit}=0.46 m/s	Griffiths 1979
	adult					field obs.	Velocity barrier for adults at water velocities > 1.2 m/sec	B. Chase, Massachusetts Div. Marine Fisheries, pers. comm.
Atlantic Salmon	juvenile	15.0	20.0			respirometer	20 min swimming duration at 0.70-1.00 m/s	Byrne et al. 1972
	adult			35.9	10.2	respirometer	U_{crit}=0.93 m/sec	Wagner et al. 2003
	adult			45.0	12.0	respirometer	U_{crit}=1.55 m/sec	Beddow & McKinley 1999
	adult			47.0	10.4	respirometer	U_{crit}=1.20 m/sec	Ytrestoyl et al. 2001
	adult			57.5	12.0	respirometer	U_{crit}=1.70 m/sec	Booth et al. 1997
	adult			57.5	18.0	respirometer	U_{crit}=1.98 m/sec	Booth et al. 1997
				52.0	4.0	respirometer		Thorstad et al. (2000)
				52.0	4.0	respirometer		Thorstad et al. (2000)
				52.0	4.0	respirometer		Thorstad et al. (2000)
				52.0	4.0	respirometer		Thorstad et al. (2000)
				52.0	4.0	respirometer		Thorstad et al. (2000)
				52.0	4.0	respirometer		Thorstad et al. (2000)
				59.0	5.0	respirometer		Thorstad et al. (1997)
				59.0	5.0	respirometer		Thorstad et al. (1997)
				59.0	5.0	respirometer		Thorstad et al. (1997)
				59.0	5.0	respirometer		Thorstad et al. (1997)
	kelt	46.0	62.0		5.0	respirometer	U_{crit}=0.93-1.22 m/sec	Booth et al. 1997
	smolt			16.5	5.0	respirometer	U_{crit}=0.64 m/sec	Booth et al. 1997
	smolt			16.5	7.0	respirometer	U_{crit}=0.71m/sec	Booth et al. 1997
	smolt			16.5	9.0	respirometer	U_{crit}=0.77 m/sec	Booth et al. 1997
	smolt			16.5	11.0	respirometer	U_{crit}=0.83 m/sec	Booth et al. 1997

SPECIES	Life History Stage	Min. Length (cm)	Max. Length (cm)	Mean Length (cm)	Water Temp. (°C)	Type of test	Swimming Performance	Reference
Sea Lamprey	subadult	14.5	39.0		5.0	respirometer	10 min swimming duration at 0.17-0.34 m/s	Beamish 1974
	subadult	14.5	39.0		10.0	respirometer	10 min swimming duration at 0.17-0.35 m/s	Beamish 1974
	subadult	14.5	39.0		15.0	respirometer	10 min swimming duration at 0.24-0.41 m/s	Beamish 1974
	adult			38.0	2.0	respirometer	1 min swimming duration at 0.23 m/s	Skidmore & McCauley 1958
	adult			38.0	15.0	respirometer	1 min swimming duration at 0.23 m/s	Skidmore & McCauley 1958
	adult			51	10.0-16.8	open flume	1 m/sec swim speed maintained for 60 sec duration; 2 m/sec for 10 sec duration; 3 m/sec for 3 sec duration	McAuley 1996

Rationale for selection of swimming speed criteria

Sprint swimming data?

Yes → U_{max}= **U (sprinting speed) of maximum 60 sec duration**, for fish of minimum size (TL_{min})

No ↓

U_{crit} known?

Yes → U_{max}= **2 times U_{crit}**, for fish of minimum size (TL_{min})

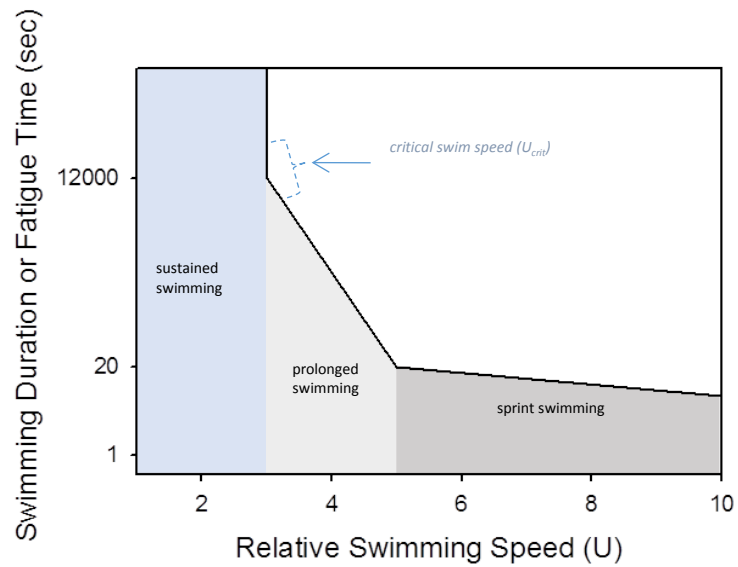
No ↓

Body Morphology/ Swimming Mode

Anguilliform → U_{max} = **3 BL/sec**, for fish of minimum size (TL_{min})

Subcarangiform → U_{max} = **5 BL/sec**, for fish of minimum size (TL_{min})

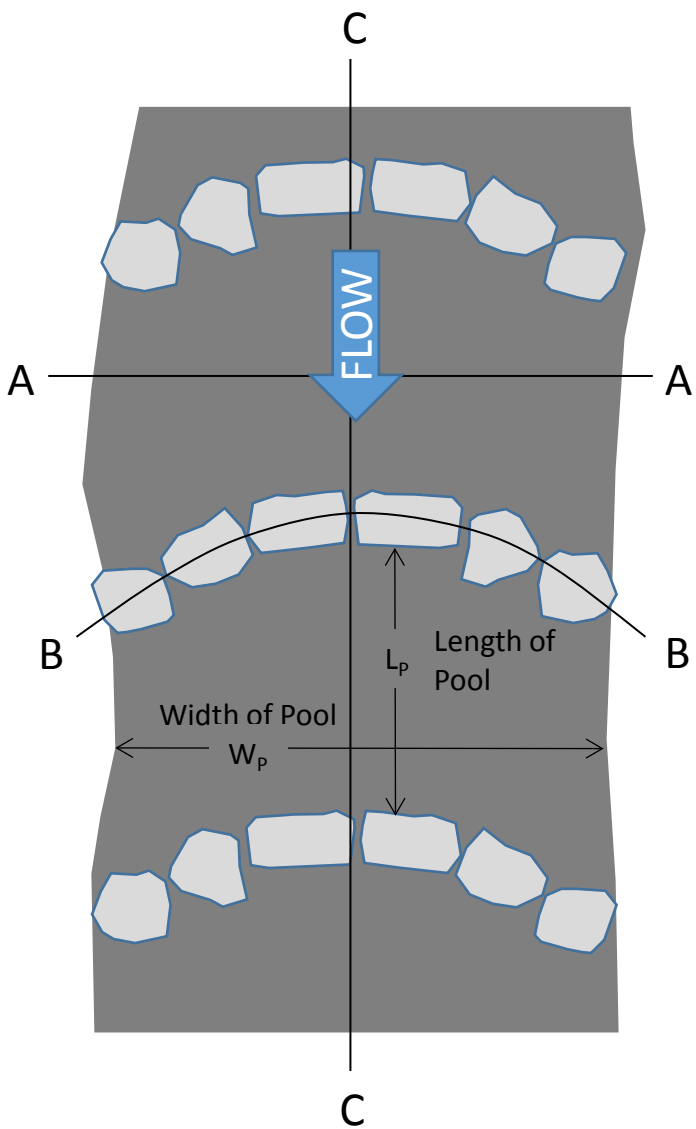
Observational data? → Adjust U_{max} if necessary; set $\mathbf{V_{max} = U_{max}}$



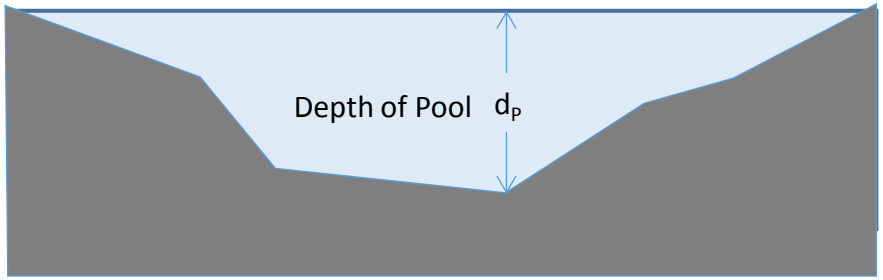
Selected values for V_{max}

Species	Minimum Total Length TL_{min} (cm)	Basis for Swim Speed	Nominal Swim Speed Limit U (BL/sec)	Calculated Maximum Weir Opening Water Velocity U_{max} (ft/sec)	Maximum Weir Opening Water Velocity V_{max} (ft/sec)		"6 BL/sec" (ft/sec)
Sea Lamprey	60	Sprint data +Obs	2.00	3.94	6.00*	<	11.8
Shortnose Sturgeon	52	3 BL/sec	3.00	5.12	5.00	<	10.2
Atlantic Sturgeon	88	3 BL/sec	3.00	8.66	8.50	<	17.3
American Eel ≤ 15 cm TL	5	Sprint data	4.60	0.75	0.75	<	1.0
American Eel >15 cm TL	15	U_{crit}	0.97	0.95	1.00	<	3.0
Blueback Herring	20	Sprint data +Obs	6.00	3.94	6.00*	>	3.9
Alewife	22	Sprint data +Obs	5.50	3.97	6.00*	>	4.3
Hickory Shad	28	5 BL/sec	5.00	4.59	4.50	<	5.5
American Shad	36	Sprint data	7.00	5.74	8.25*	>	7.1
Gizzard Shad	25	5 BL/sec	5.00	4.10	4.00	<	4.9
Rainbow Smelt	12	U_{crit}	3.15	2.48	3.25	>	2.4
Atlantic Salmon	70	U_{crit}	3.00	13.78	13.75	=	13.8
Sea Run Brook Trout	10	Sprint data	10.00	9.84	3.25	>	2.0
Juvenile Salmonid ≤ 20 cm TL	5	U_{crit}	7.30	2.40	2.25	>	1.0
Atlantic Tomcod	15	Obs.	unknown	0.98	0.75*	<	3.0
Striped Bass	40	Sprint data	4.00	5.2	5.25	<	7.9

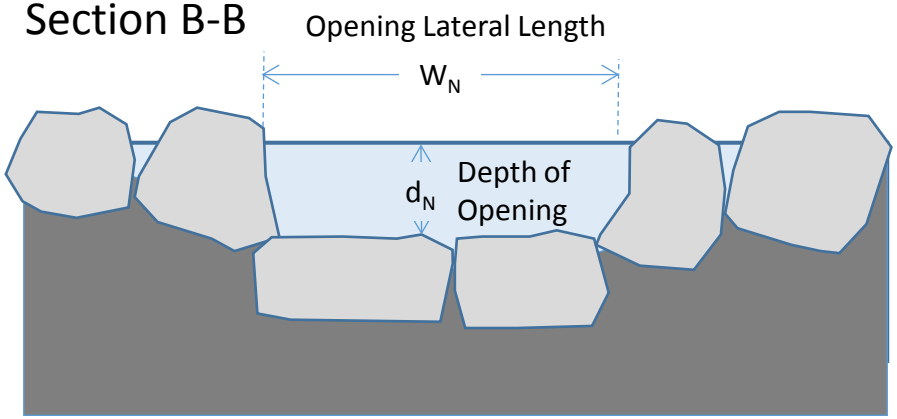
Pool and Weir Dimensions



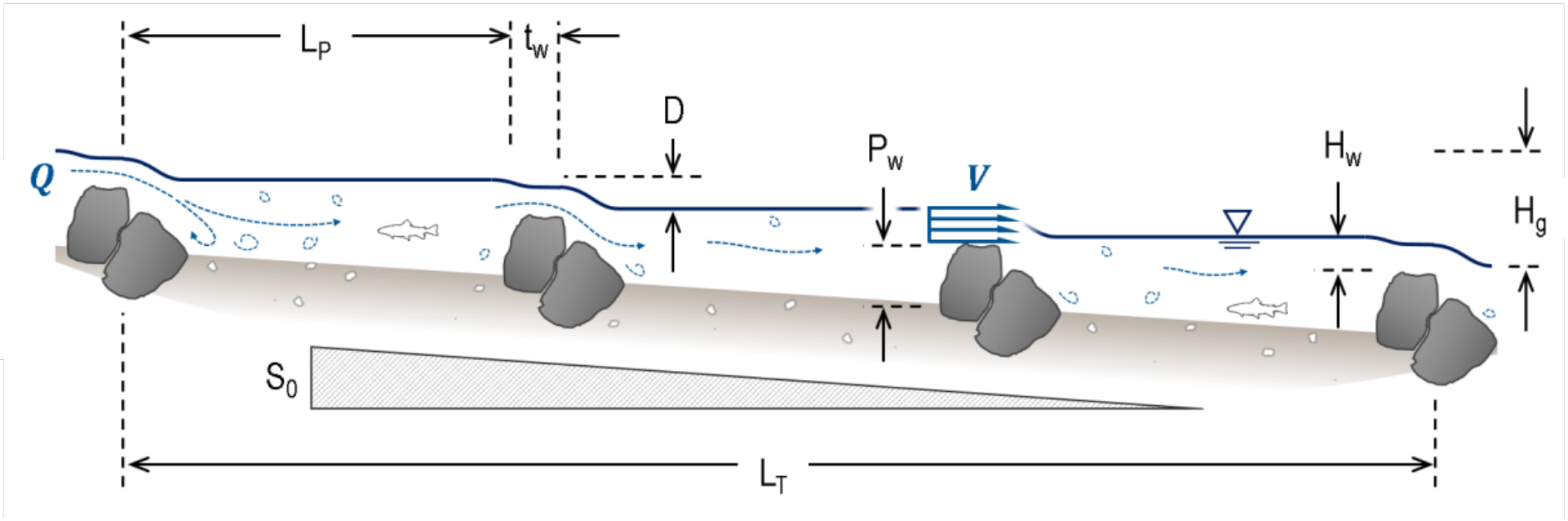
Section A-A



Section B-B



Pool and Weir Dimensions (section C-C)



Pool Width, Depth, and Length

Pools large enough to provide protection from terrestrial predators and accommodate body size, run size, and resting behavior, as well as meeting other criteria:

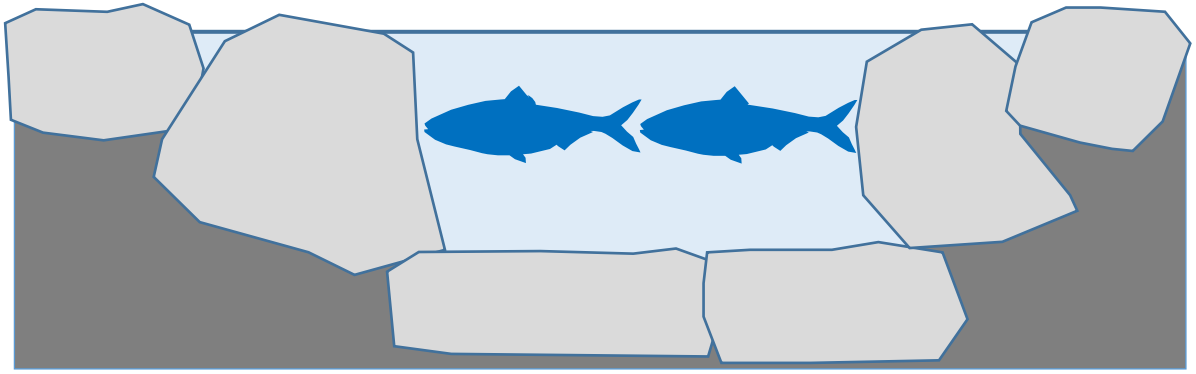
- in-pool flow characteristics
- energy dissipation
- slope

Difficult to derive criteria for in-pool velocities due to flow/depth/jet complexity

Weir Opening Width (W_N):

Provide a primary passage opening wide enough to accommodate fish body size and swimming mode and schools of upstream migrating target species adults

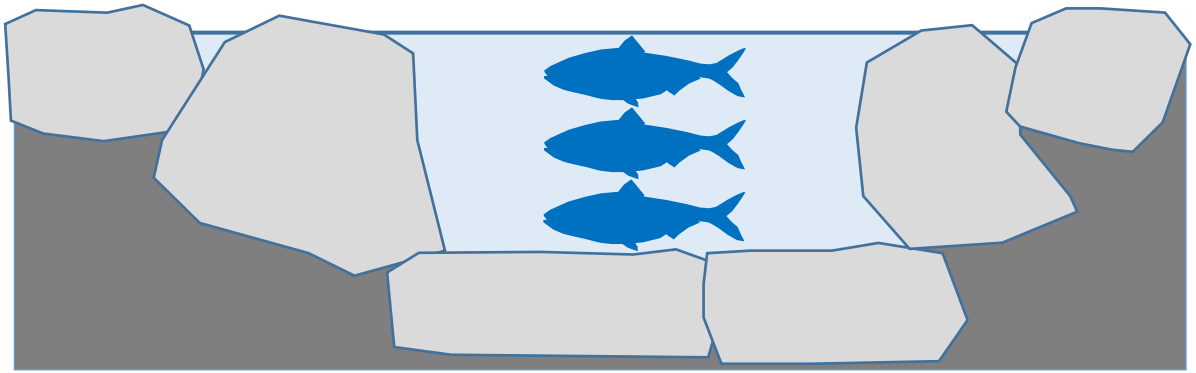
- Sea lamprey and American eel: W_N = 2 times tailbeat amplitude (~8-10% total body length)
- Sturgeons: W_N = 2 times the body width, including maximum pectoral fin spread (~27% total body length)
- All other species: W_N = 2 times maximum total body length



Weir Opening Depth (d_N):

Provide enough depth to accommodate the full depth (vertical depth of body when swimming horizontally) of the body, including extended dorsal and ventral fins to minimize potential for injury.

- All species: d_N = 3 times total body depth
- Greater passage opening water depth is preferred at locations where schooling fish, like American shad, are passing simultaneously or passing fish are at high risk to predation.
- Sufficient water depths are also needed to create a low-velocity bottom zone to facilitate ascent by bottom-dwelling or smaller, weaker-swimming species.



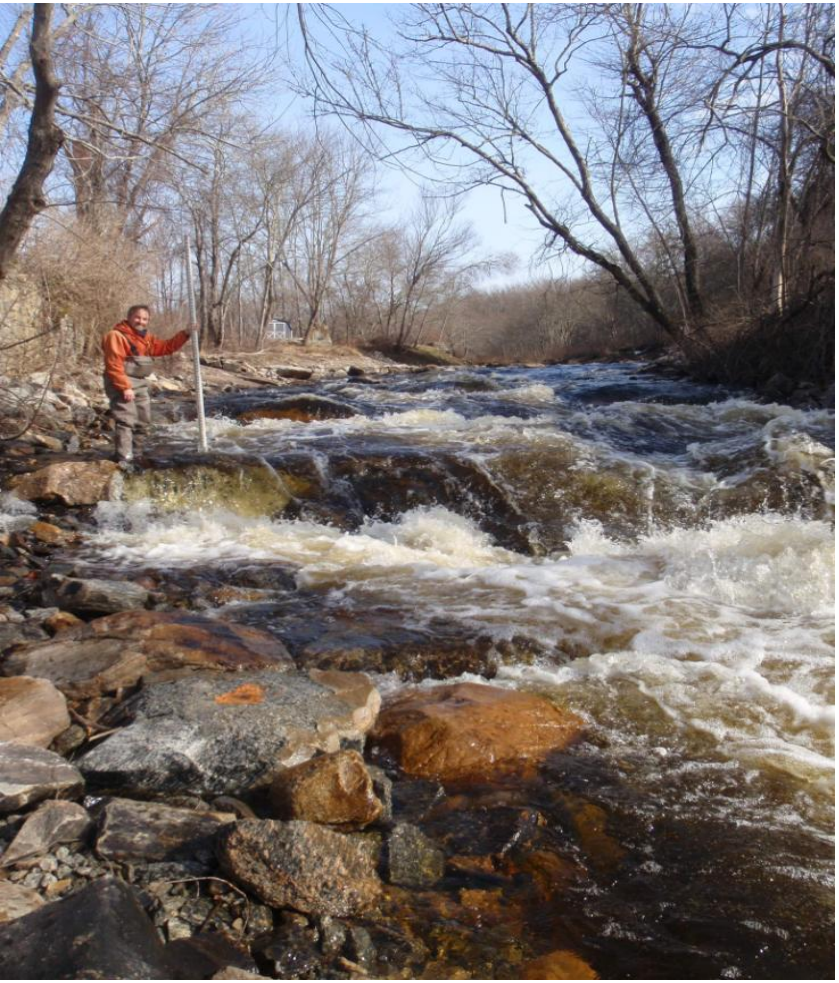
For small streams, calculated weir opening widths/depths may be challenging in maintaining flow depth/stability under low flow conditions.

For some species, weir opening depths may be increased and width decreased to ensure flow stability. Notches and other passageway features must *always* be designed to accommodate minimum fish-run flows and low-flow depths.

Selected values for weir width and depth

Species	Maximum TL TL_{max} (cm)	Maximum Body Depth BD_{max} (cm)	Minimum Weir Opening Width W_N (ft)	Minimum Weir Opening Depth d_N (ft)
Sea Lamprey	86	6.2	0.75	0.75
Shortnose Sturgeon	143	21.2	2.75	2.25
Atlantic Sturgeon	300	45.0	5.50	4.50
American Eel $\leq$ 15 cm TL	15	1.0	0.25	0.25
American Eel >15 cm TL	116	7.9	0.75	1.00
Blueback Herring	31	7.8	2.25	1.00
Alewife	38	8.9	2.50	1.00
Hickory Shad	60	13.3	4.00	1.50
American Shad	76	22.2	5.00	2.25
Gizzard Shad	50	16.2	3.50	1.75
Rainbow Smelt	28	3.6	1.00	0.50
Atlantic Salmon	95	20.4	6.25	2.25
Sea Run Brook Trout	45	11.5	1.50	1.25
Juvenile Salmonid $\leq$ 20 cm TL	20	5.0	1.25	0.50
Atlantic Tomcod	30	6.1	2.00	0.75
Striped Bass	140	31.5	9.25	3.25

Other Criteria:



Slope:

- Established primarily by site constraints and passageway design
- Range of 1:20 (salmonids) to 1:50 (sturgeons, small species)
- Slope usually needs to be reduced to limit velocity

Energy Dissipation Factor:

- Generally given for resting pools in technical fishways as between 1 and 5 ft-lbf/s/ft^3 - “3” for alosids, “5” for salmonids
- Anecdotal – not supported by controlled studies
- Lacking for many species
- Are EDF values meaningful?

Conclusions/Summary:

- Design guidelines are derived from best available scientific knowledge
- Need for refinement of baseline data, filling in of data gaps
- Additional species?
- Guidelines will change as time goes on – dynamic document

SMath Design Tool (courtesy of USFWS, Brett Towler)

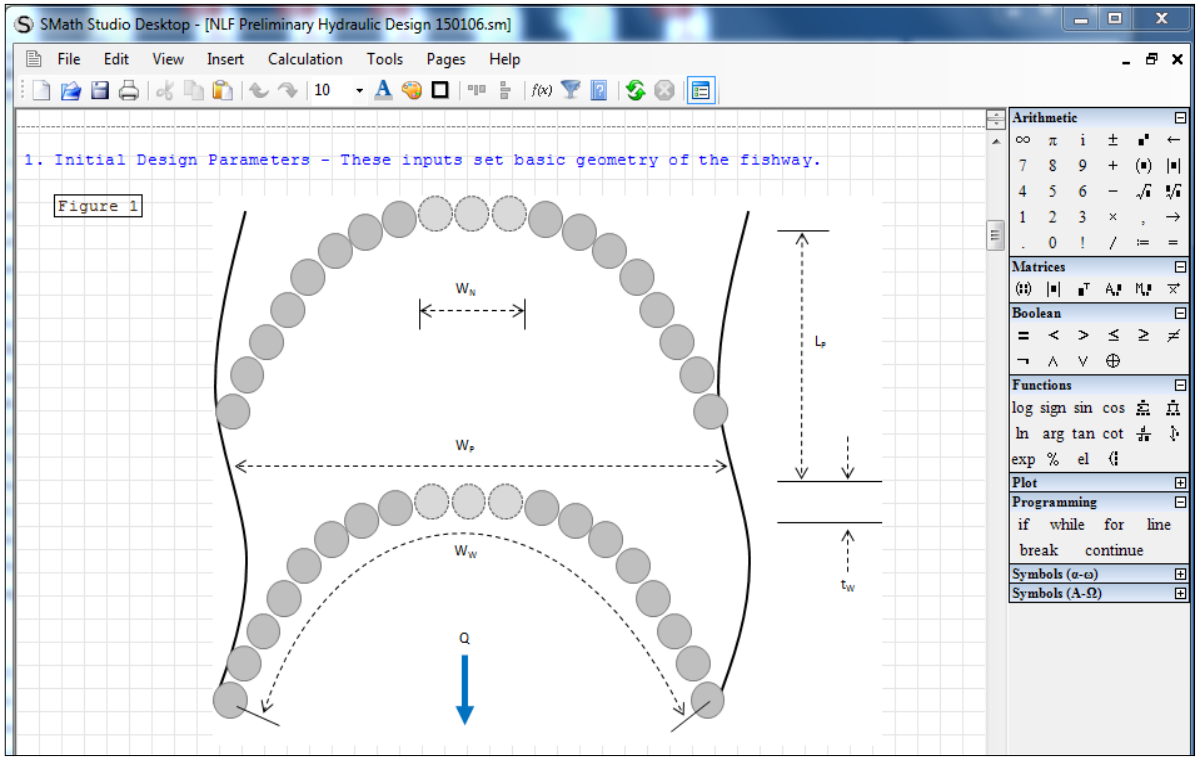
http://scholarworks.umass.edu/fishpassage_technical_reports/3/

Main Inputs:

- Gross head, flow range
- Number of pools
- Pool width, depth
- Slope
- Drop per pool
- Weircrest height
- Thickness of weir
- Notch width, height above bottom

Outputs:

- Head on weir
- Weir opening depth
- Weir opening velocity
- EDF

Compare with biological criteria

For low, medium, and high design flows