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WASHINGTON, D.C. • MARCH 13-15, 2024
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Downstream Eel Passage at Hydro Dams: Technologies for Safe Passage

Steve Amaral

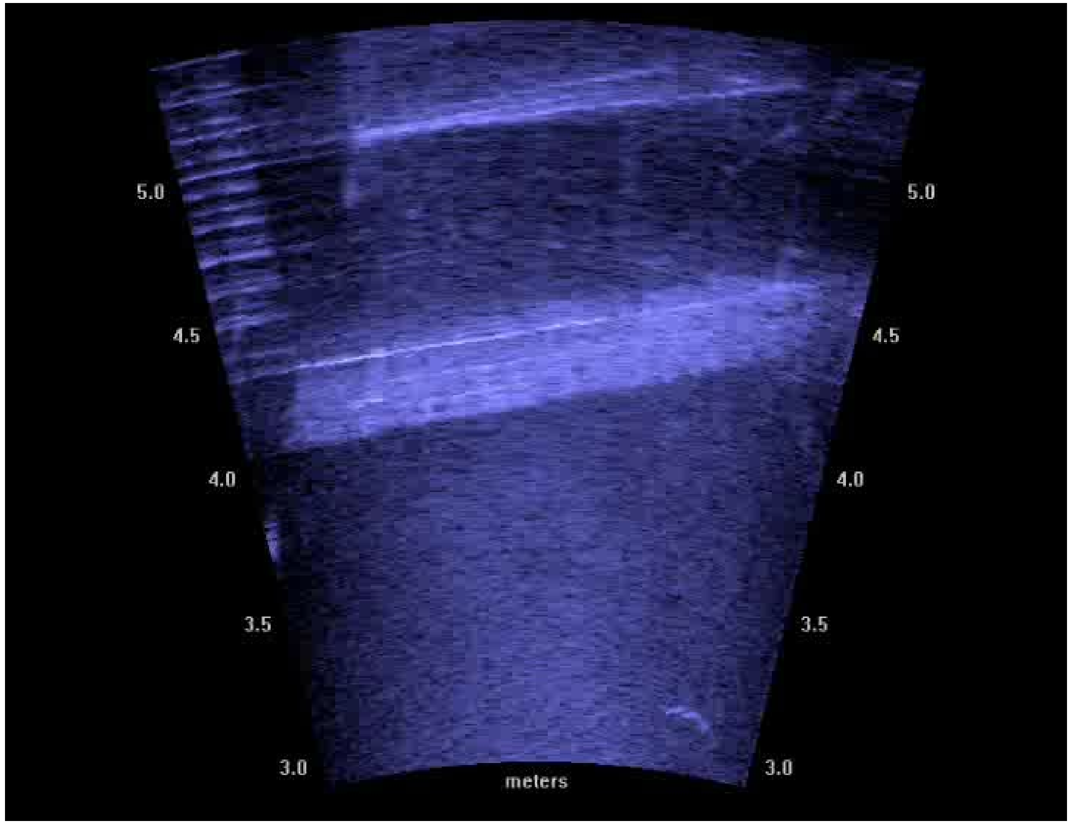
ALDEN a verdantas company

Downstream Eel Passage at Hydro Dams

- Bypassing Turbines
  - Exclusion and Guidance Technologies
  - Downstream Bypasses
- Turbine Designs for Safer Passage
- Total Project Survival Modeling

Physical Exclusion and Guidance

Narrow-spaced Bar Racks and Angled Screens/Louvers



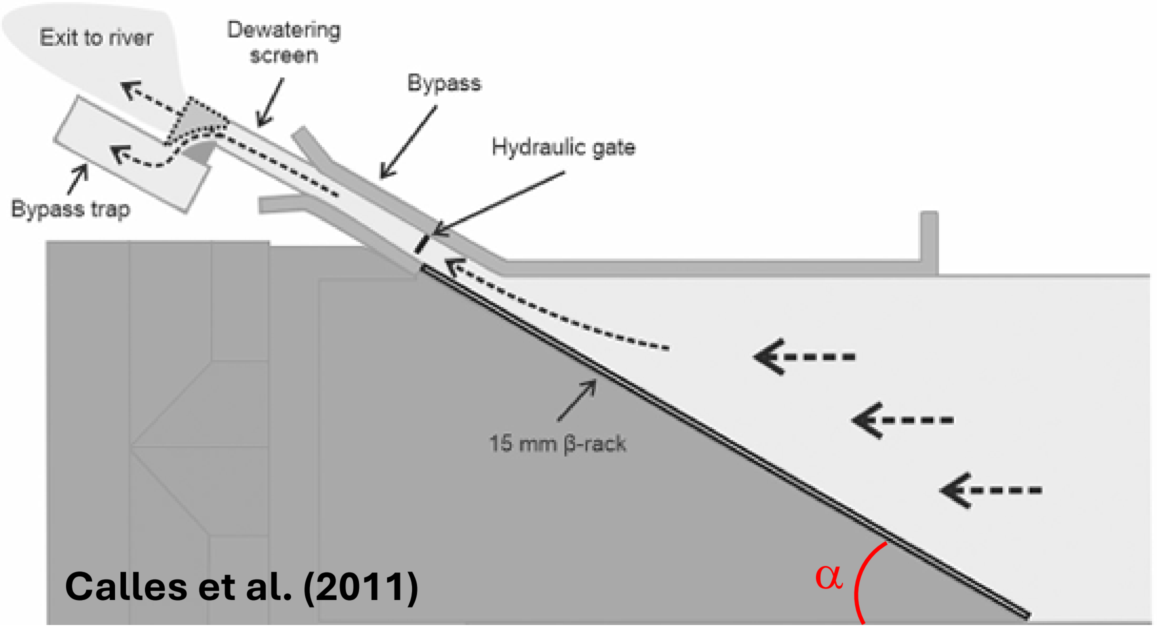
Physical Exclusion and Guidance

Narrow-spaced Bar Racks and Angled Screens/Louvers

- USFWS design criteria for bar racks:
  - 0.75-inch clear bar spacing
  - 2 ft/s max approach velocity
  - Angled no greater than 45° to flow

Holyoke Canal Louver Array

- Inclined rack/screen design (Europe):
  - 10 – 20 mm clear spacing (0.4 to 0.8 inches)
  - ≤ 1.5 ft/s max approach velocity
  - ≤ 35° angle (α)

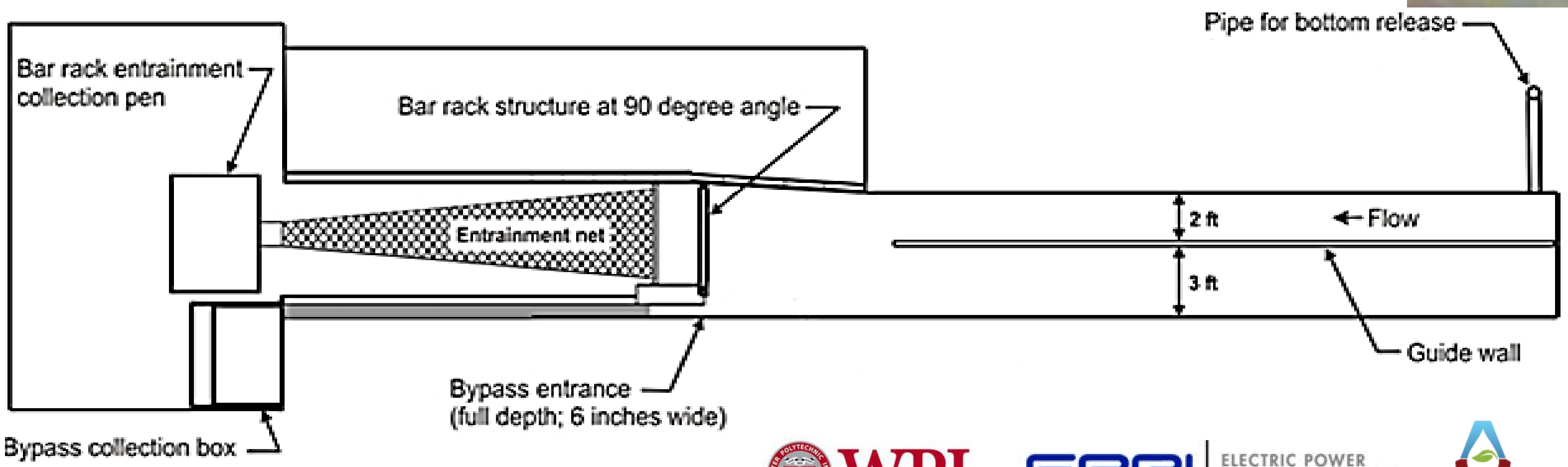


Calles et al. (2011)

Physical Exclusion and Guidance

Narrow-spaced Bar Racks – Laboratory Evaluation

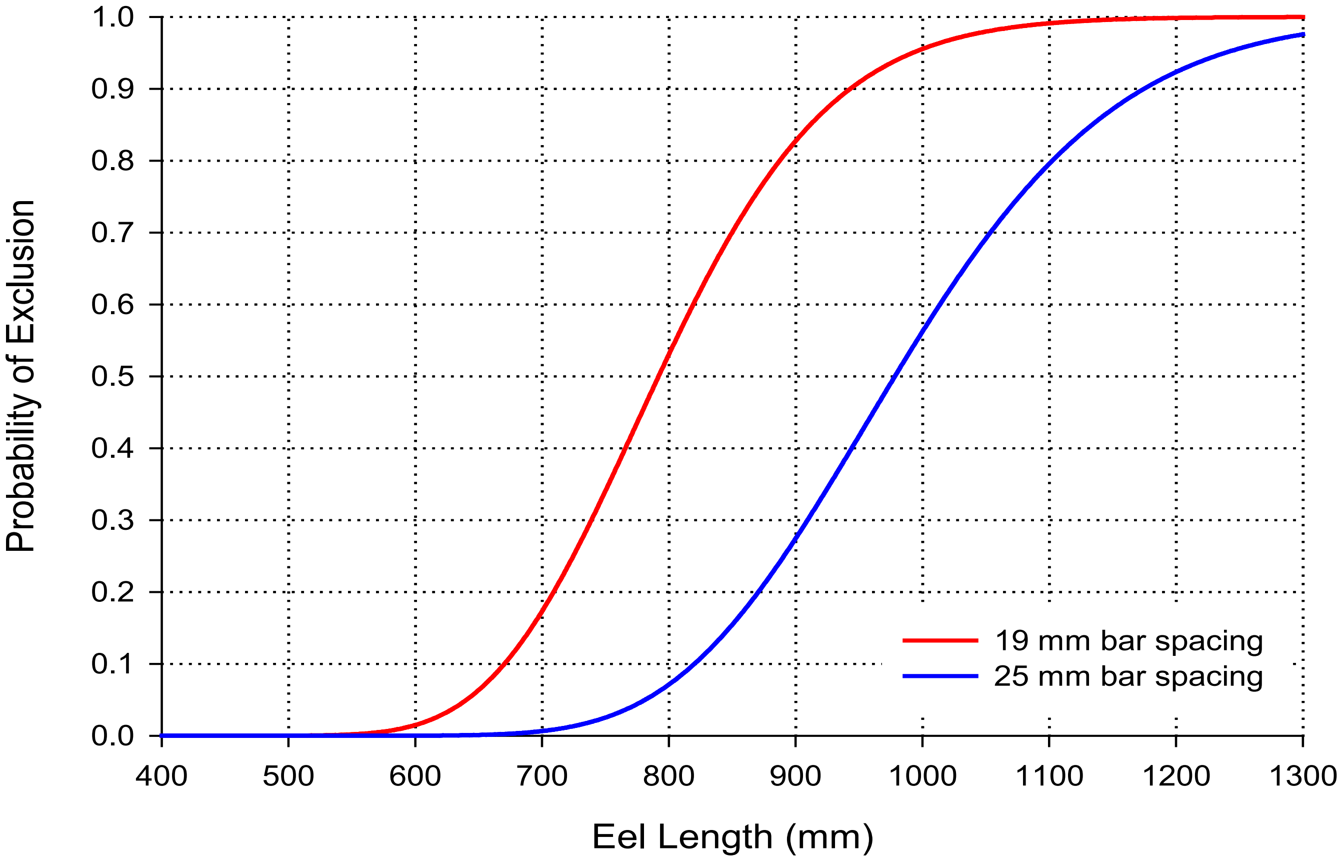
Bar Spacing (inches)	Approach Velocity (ft/s)	Mean Length (mm)	Mean Bypass Efficiency (%) (±95% CI)
0.75	1.5	751	96.2 (7.5)
	2.0	736	88.8 (9.0)
1.00	1.5	742	72.1 (0.1)
	2.0	763	69.9 (16.9)



Physical Exclusion and Guidance

Narrow-spaced Bar Racks – Laboratory Evaluation

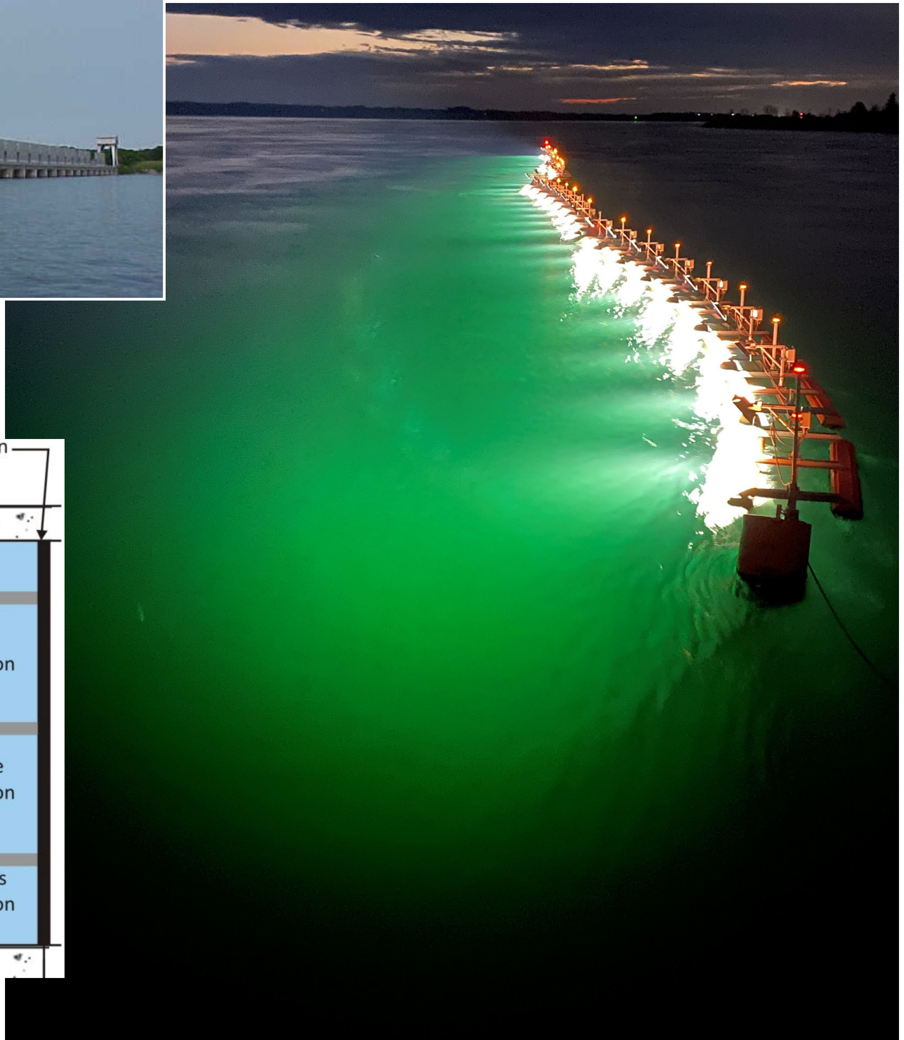
Head Width > 1.3 x bar spacing =
100% physical exclusion



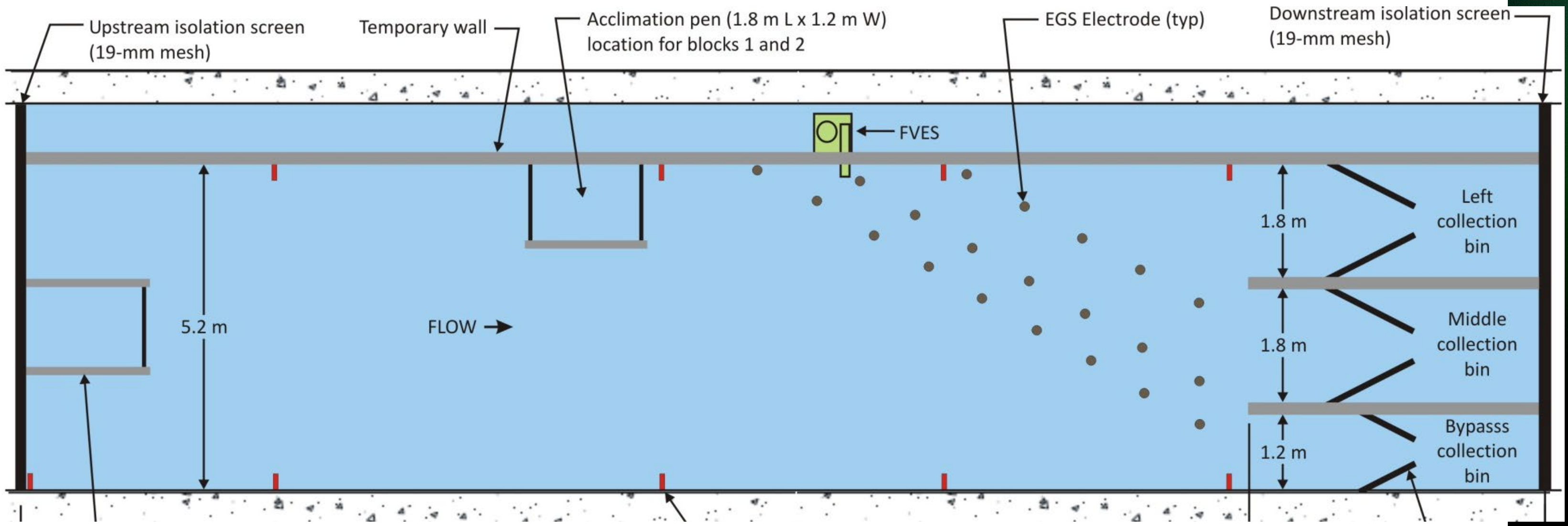
Bar Spacing (in)	Approach Velocity (ft/s)	Length Range (mm)	Bypass Efficiency (%)	Physically Excluded (%)
0.75	1.5	≤ 700	94.7	4.2
		701-800	95.3	10.6
		801-900	100.0	64.7
		901-1000	100.0	100.0
	2.0	≤ 700	90.0	0.0
		701-800	82.1	9.7
		801-900	100.0	58.8
		901-1000	100.0	100.0
1.00	1.5	≤ 700	63.6	0.0
		701-800	71.1	2.1
		801-900	100.0	23.5
	2.0	≤ 700	47.1	0.0
		701-800	73.5	0.0
		801-900	87.5	8.7

Behavioral Deterrents and Guidance Technologies

- Light
- Sonic and infrasonic sound; vibration
- Electric fields
- Turbulent and accelerated flow paths
- EMF



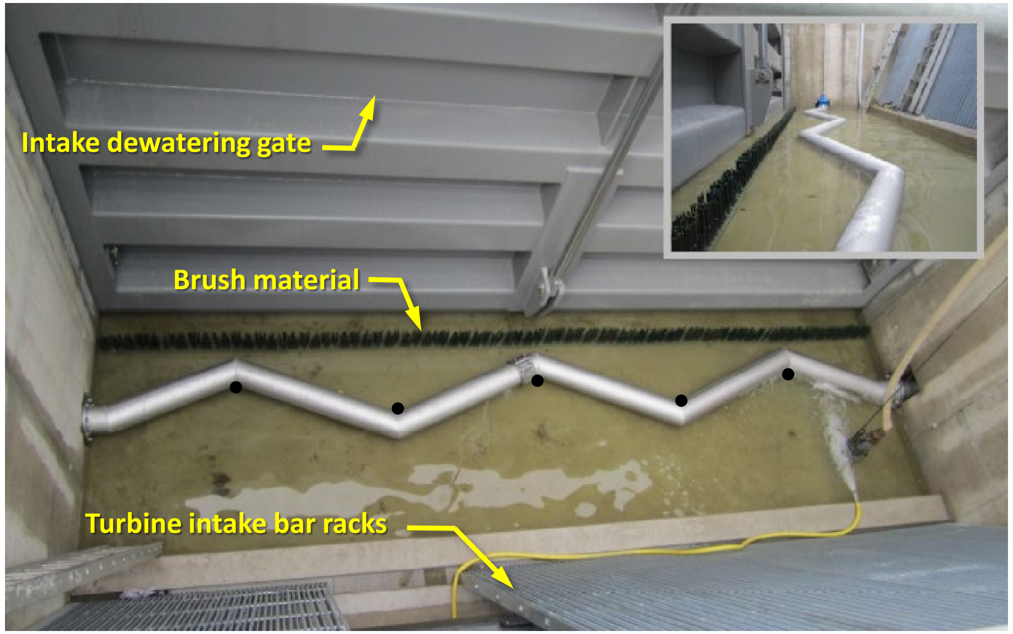
Iroquois Dam, St. Lawrence River

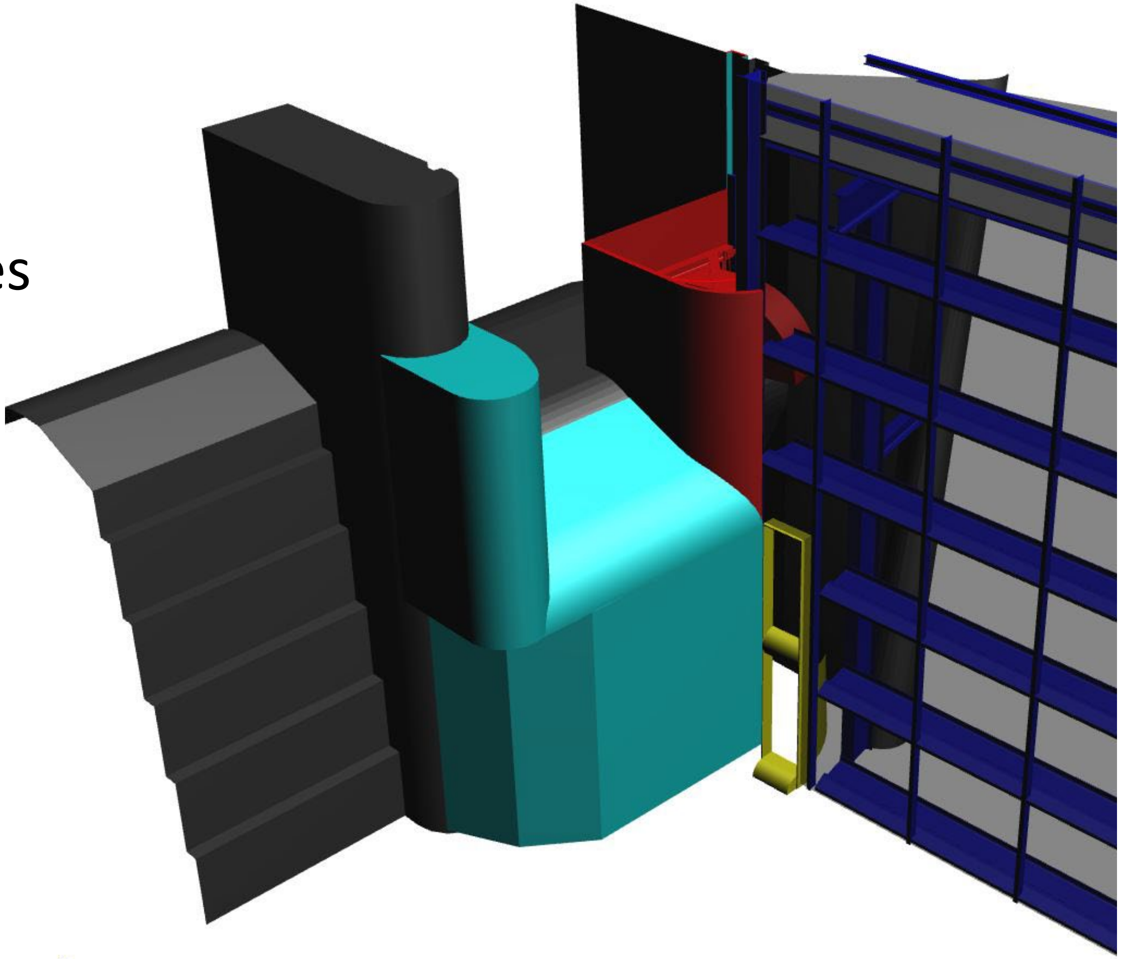


EPRC Lab Evaluation of Behavioral Cues at Alden
(Electric Field, FVES, Vibration, EMF)

Bypass Systems

- Surface weirs
- Submerged entrances (mid depth or near bottom)
- KLAWA horizontal zig-zag conduit with orifices
- Conte airlift system

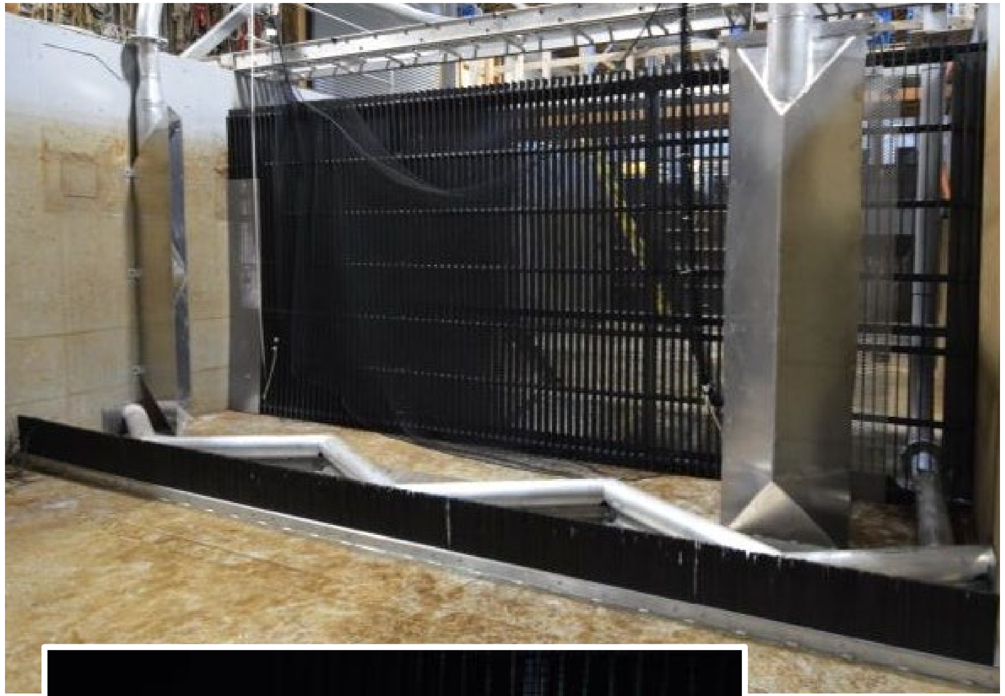




Bypass Systems

Vertical and KLAWA Zig-Zag Conduit Laboratory Evaluation

Bar Spacing (in)	Test Condition	16-inch Perf-Plate Overlay on Lower Rack	Entrained (%)	Bypass Efficiency (%)
1	Both bypass systems	Yes	7.8	91.0
	Vertical bypasses only	Yes	23.3	67.7
2	Both bypass systems	No	39.1	40.4
	Zig-zag bypass only	Yes	17.8	75.0
	Vertical bypasses only	Yes	60.7	14.3



ALDEN
Solving Flow Problems Since 1894

Lakeside Engineering, Inc.
Mirror Lake, New Hampshire

Blue Leaf Environmental

U.S. Department of Energy
Energy Efficiency & Renewable Energy

Bypass Systems

Vertical and KLAWA Zig-Zag Conduit Field Evaluation

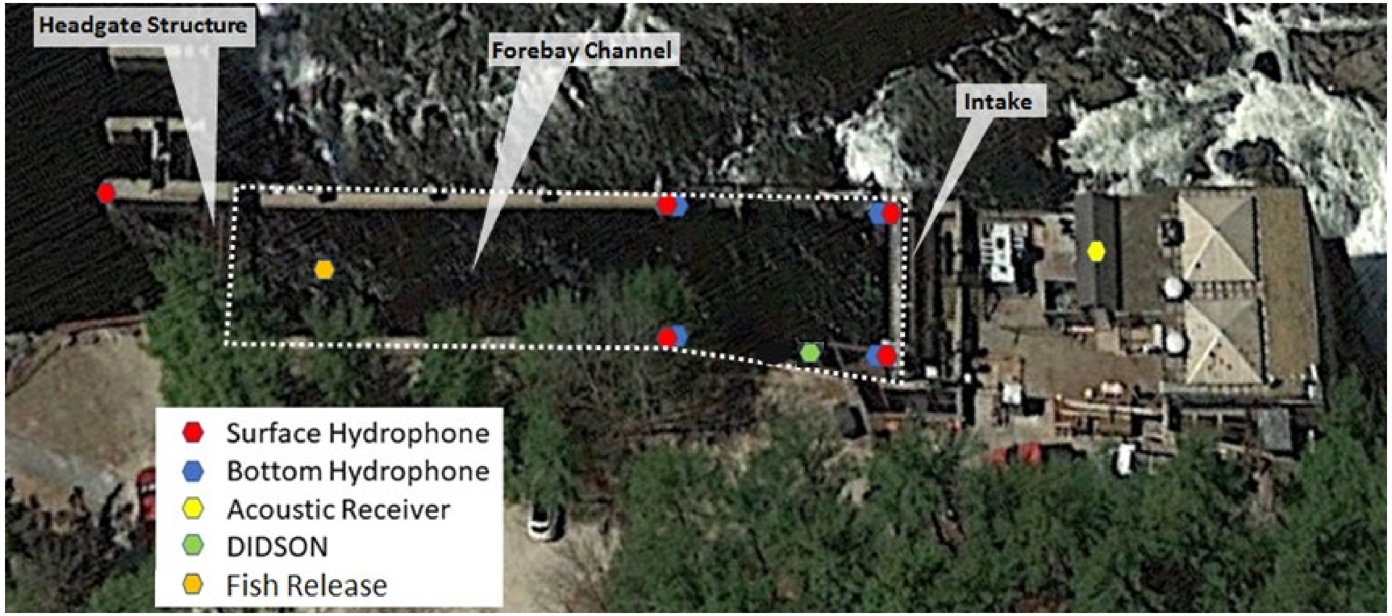
Mine Falls Hydroelectric Project, Nashua River, NH

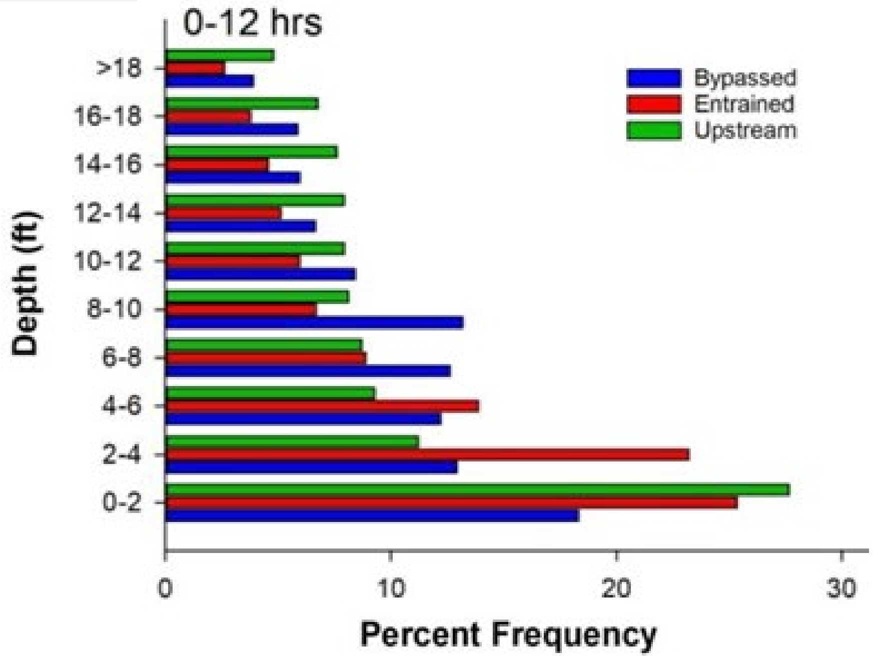
Nashua
NEW HAMPSHIRE'S GATE CITY

Bypass Systems

Vertical and KLAWA Zig-Zag Conduit Field Evaluation

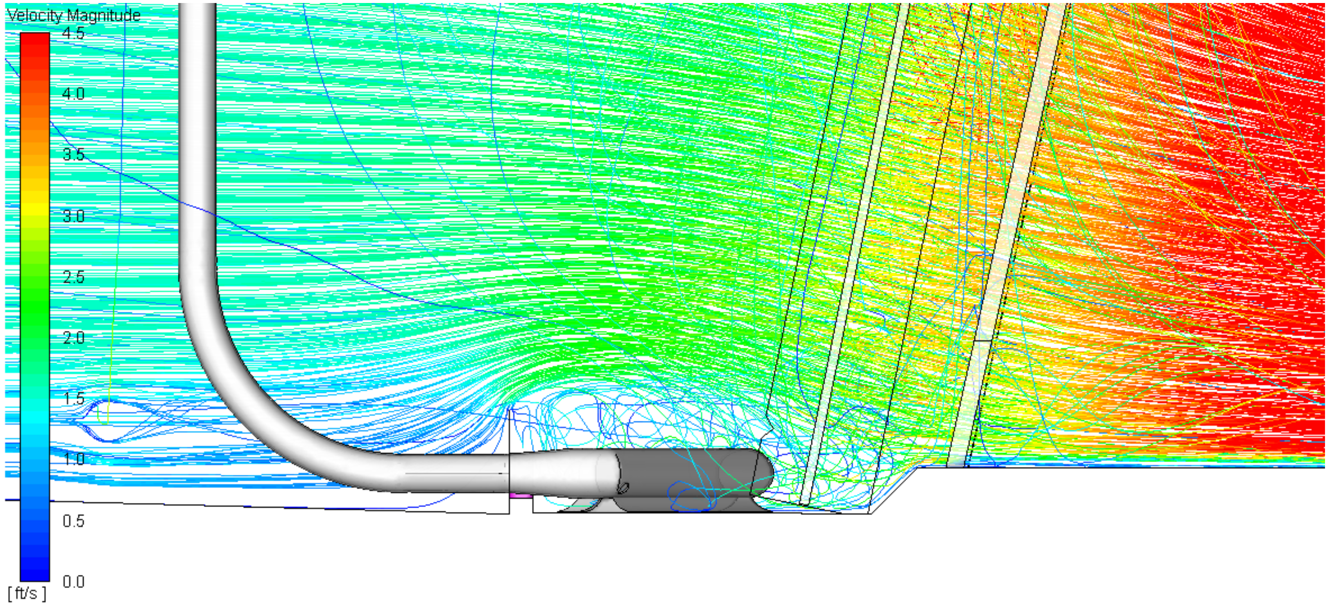
Release	Bar Spacing (inches)	Gate Opening (%)	Number Released	No Detection	Percent Entrained	Percent Upstream	Bypass Efficiency (%)
1	1.13	50	45	1	35.6	42.2	33.3
2	1.13	75	45	2	82.2	13.3	0.0
3	1.13	40	45	0	31.1	60.0	12.5
4	3.00	50	64	0	44.0	56.0	0.0

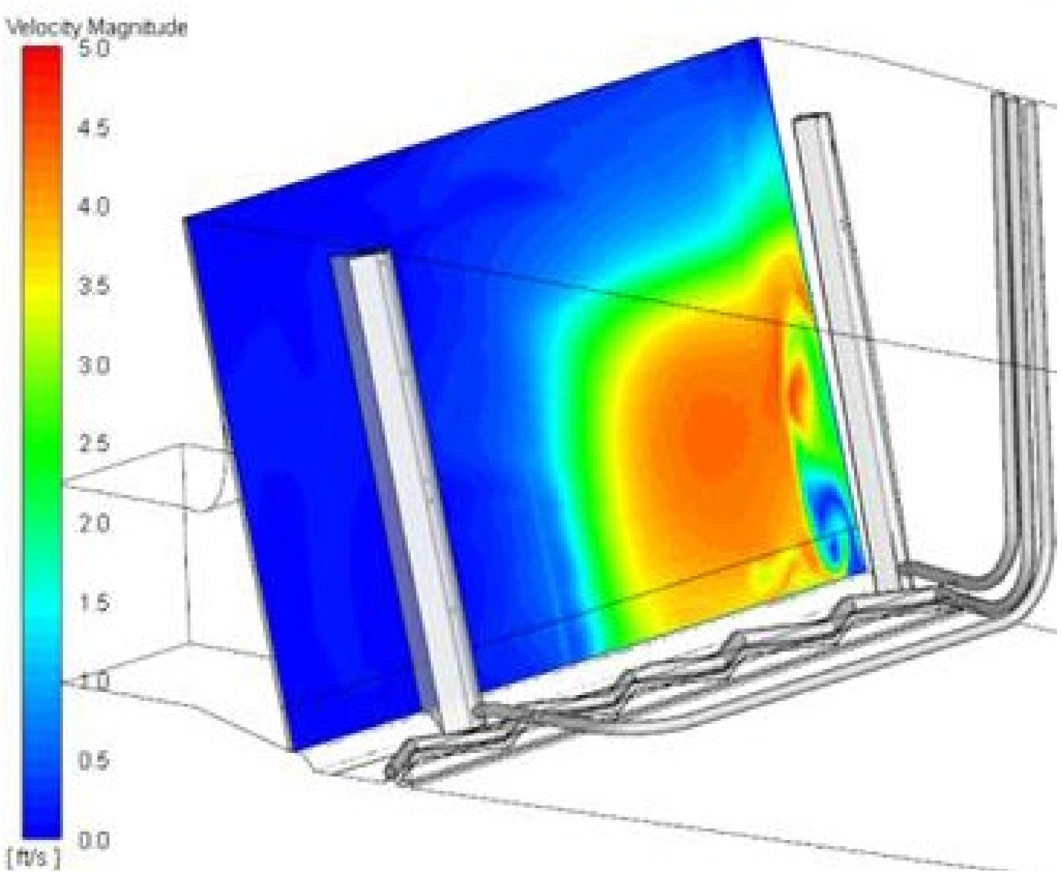




Bypass Systems

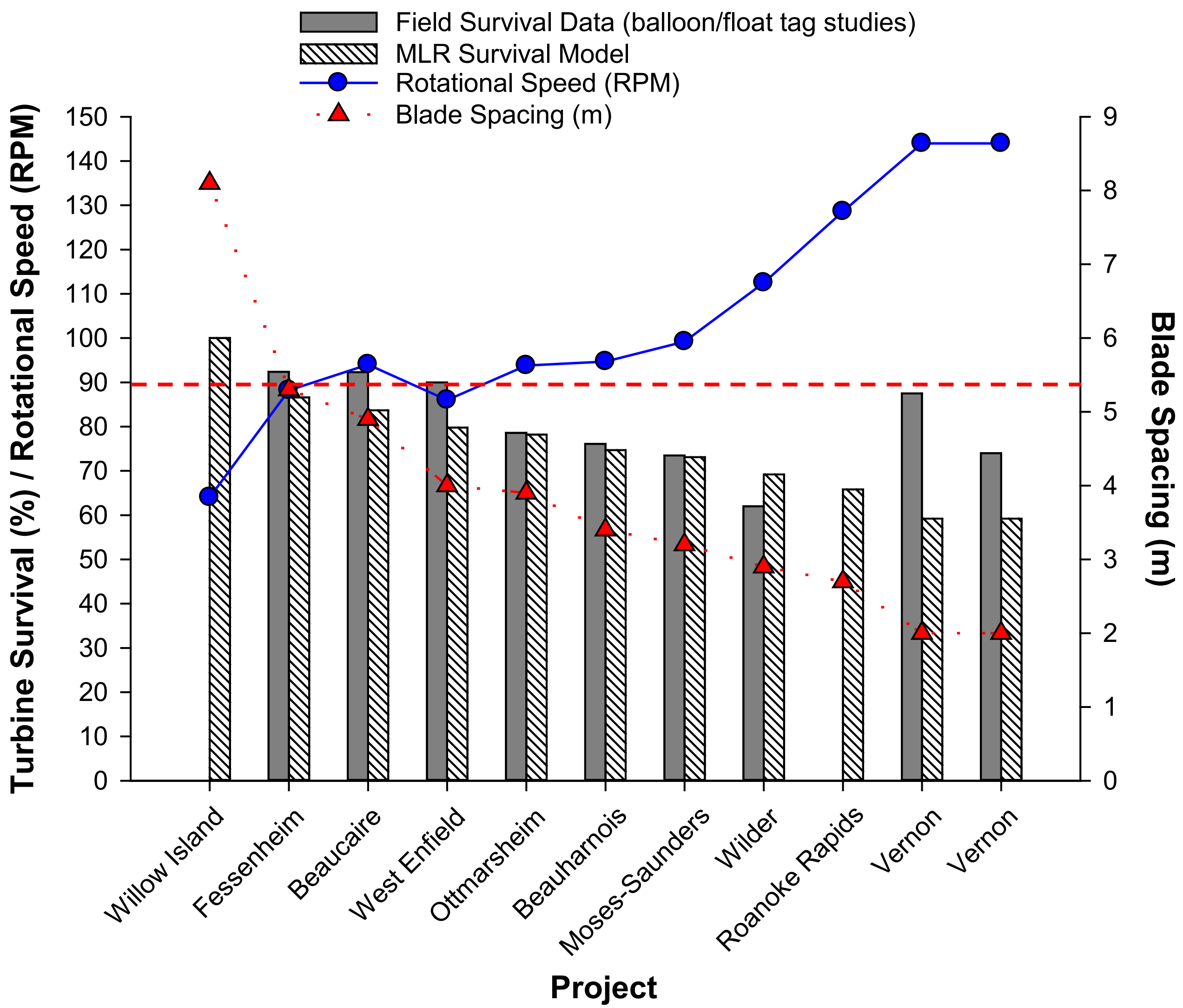
Vertical and KLAWA Zig-Zag Conduit Field Evaluation





Turbine Passage

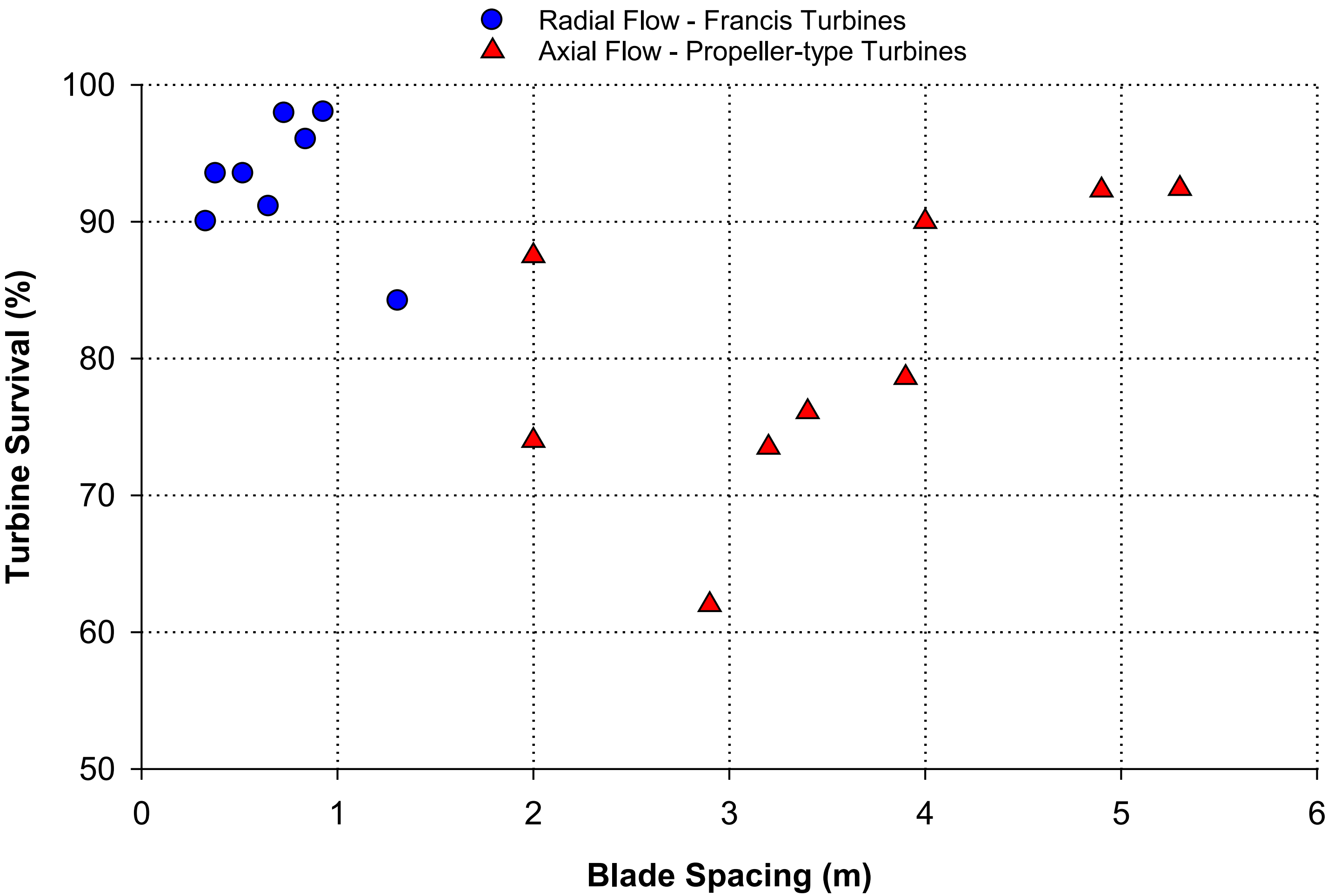
Axial-Flow Designs (Fixed-Blade Propeller and Kaplan Units)

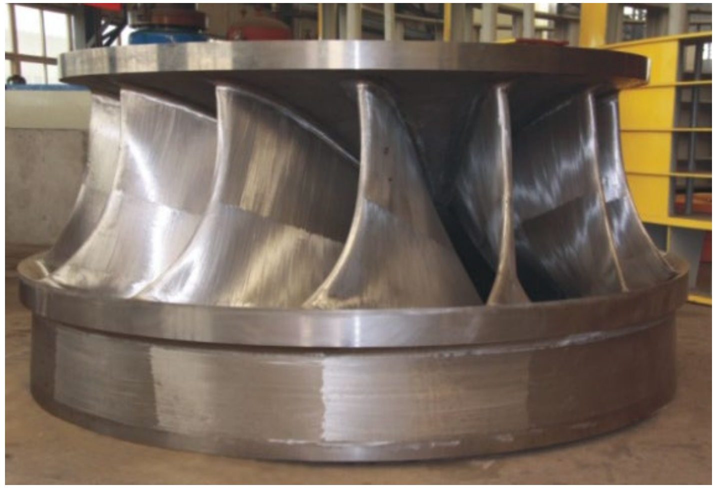


Turbine Passage

Francis (radial flow) vs. Kaplan/Propeller (axial flow) Turbines

Field Survival Data – Balloon/Float Tag Studies



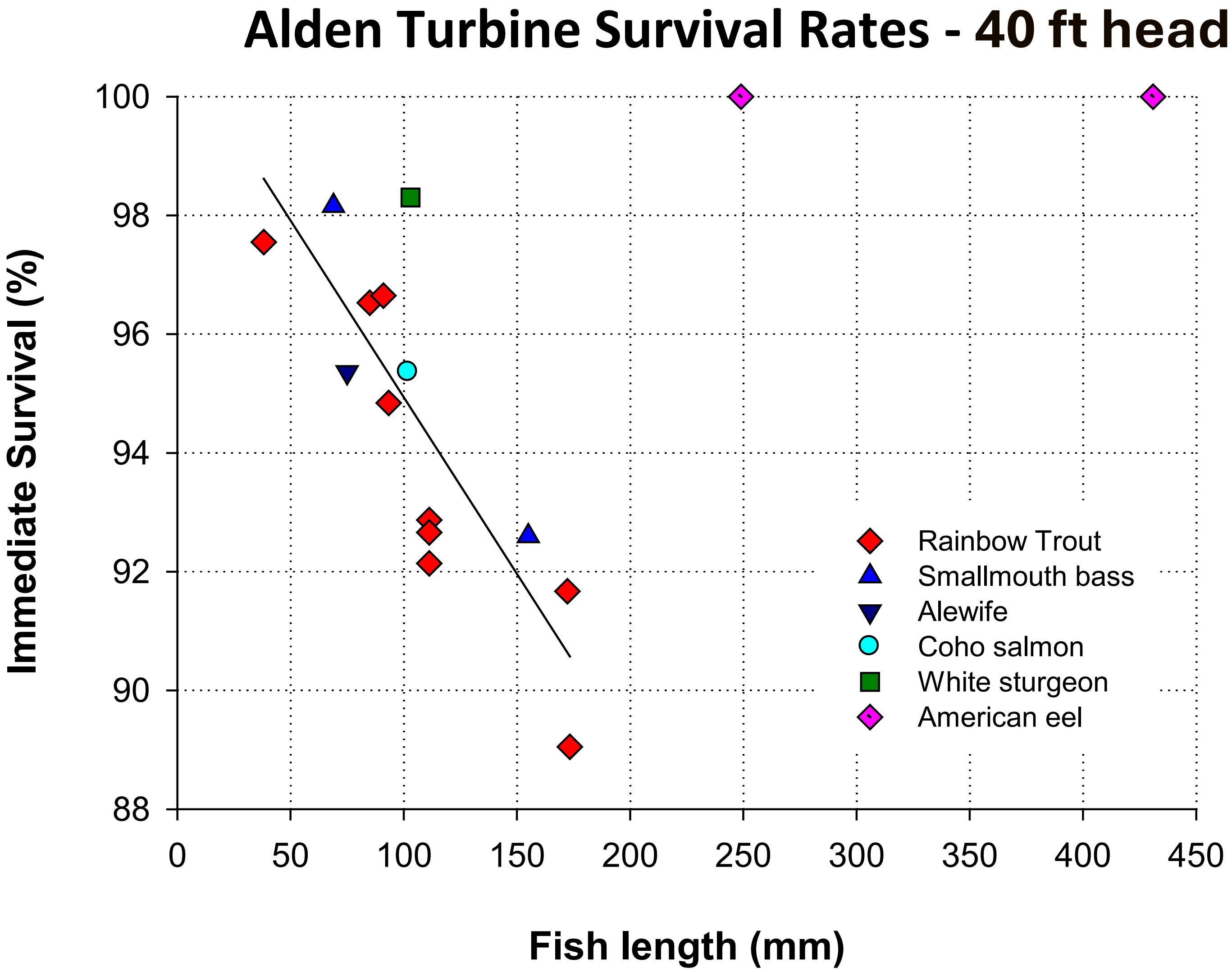


Francis Turbine

Kaplan Turbine

Fish-Safe Turbine Designs

Alden Turbine



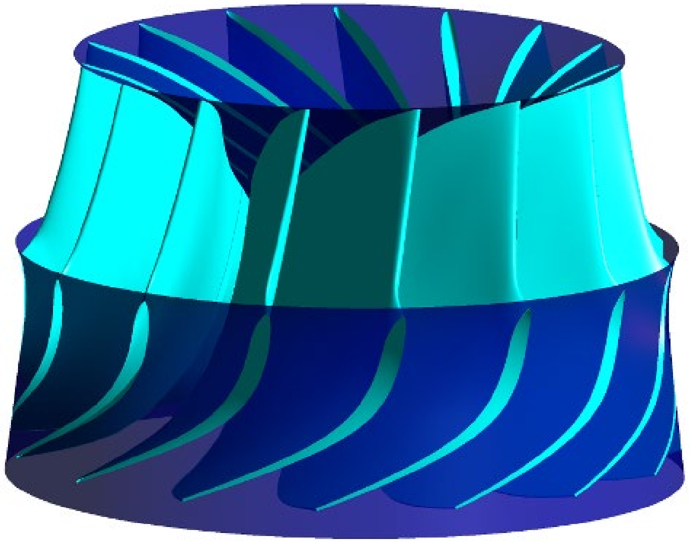
American eel - 305 and 432 mm mean lengths

100% immediate survival

99.6/98.3 total survival

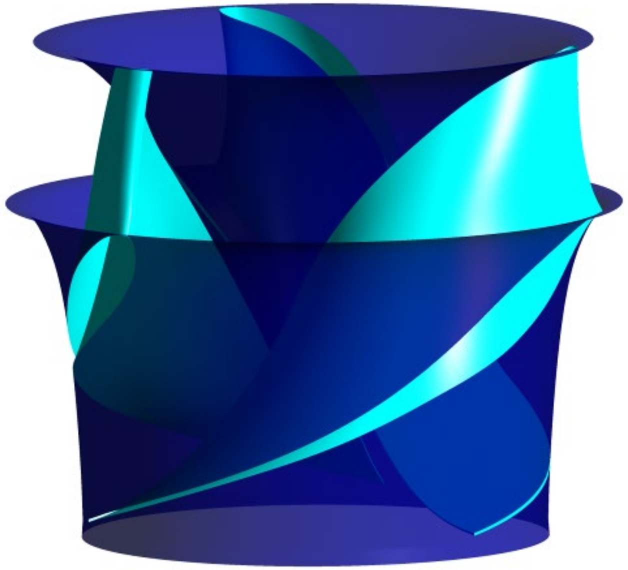
Fish-Safe Turbine Designs

Alden Turbine



Conventional Francis Turbine

VOITH



Alden Turbine

What makes it fish-safe?: larger diameter, slow rotation speed, small number of blades (3), thick blade leading edges, and no damaging pressure changes or shear forces.

Fish-Safe Turbine Designs

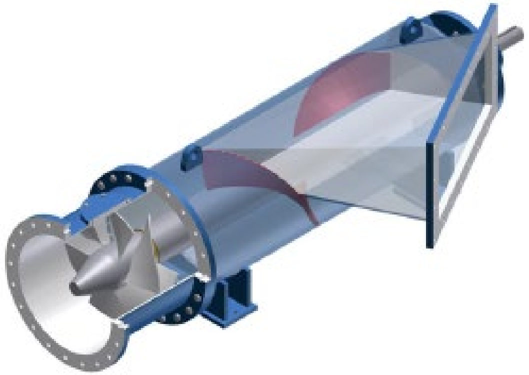
Low Head Turbine Designs

Archimedes Screw Turbines
< 30 ft head

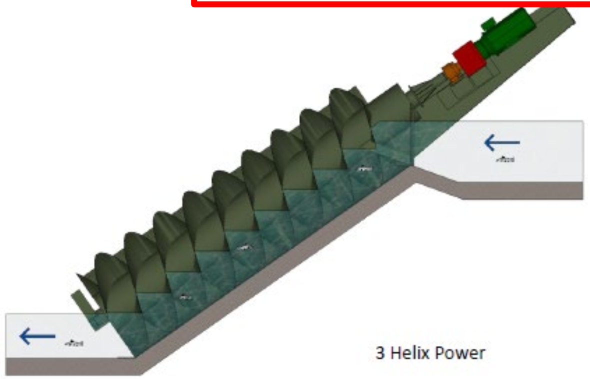
MJ2 Technologies
Very Low Head turbine (VLH)
< 12 ft head

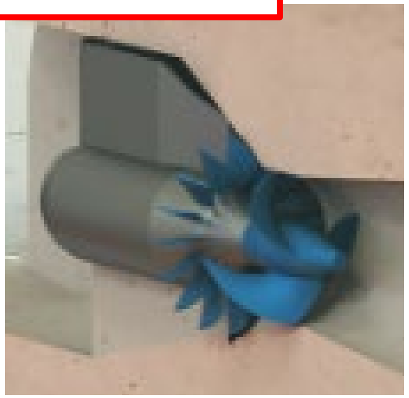
Pentair Fairbanks
Nijhuis Turbine
< 12 ft head

Gault Green Energy
Vaneless Turbine
< 12 ft head



Eel Turbine Survival: 98 to 100%

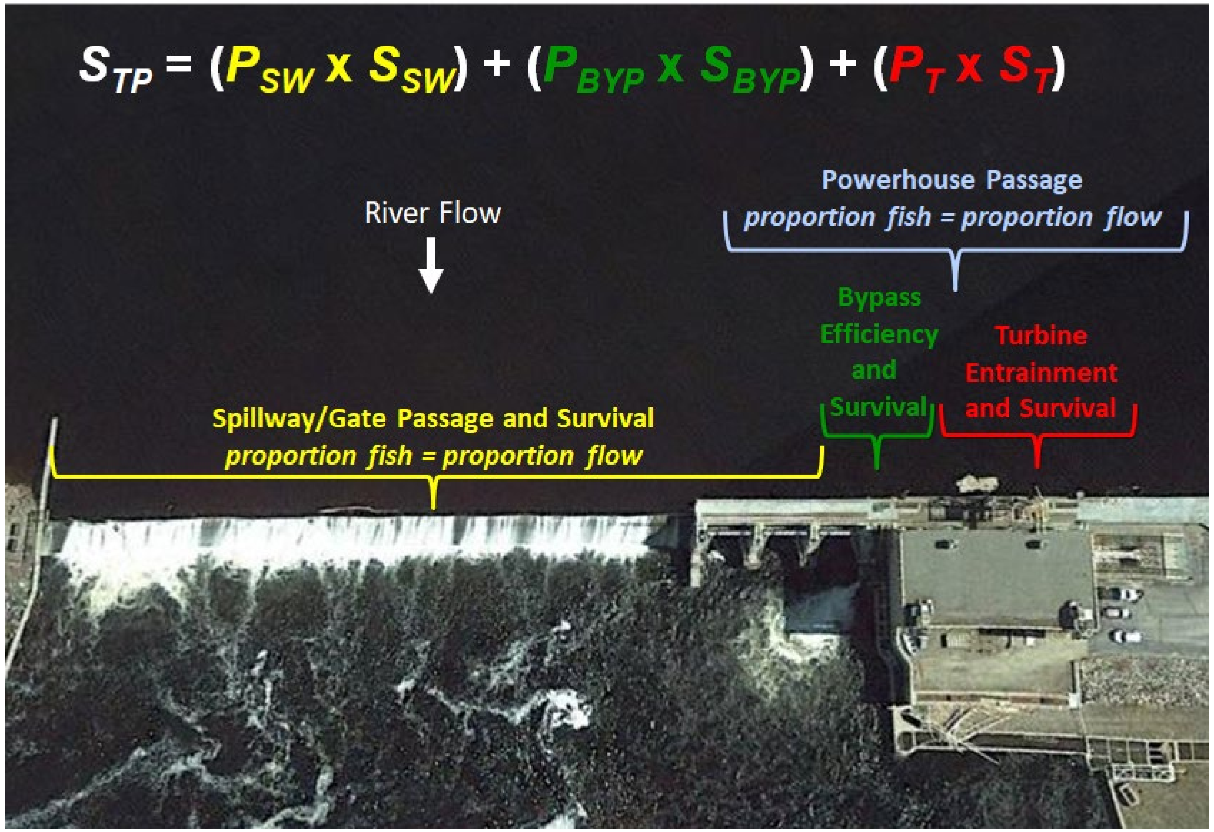




Total Project Survival Modeling

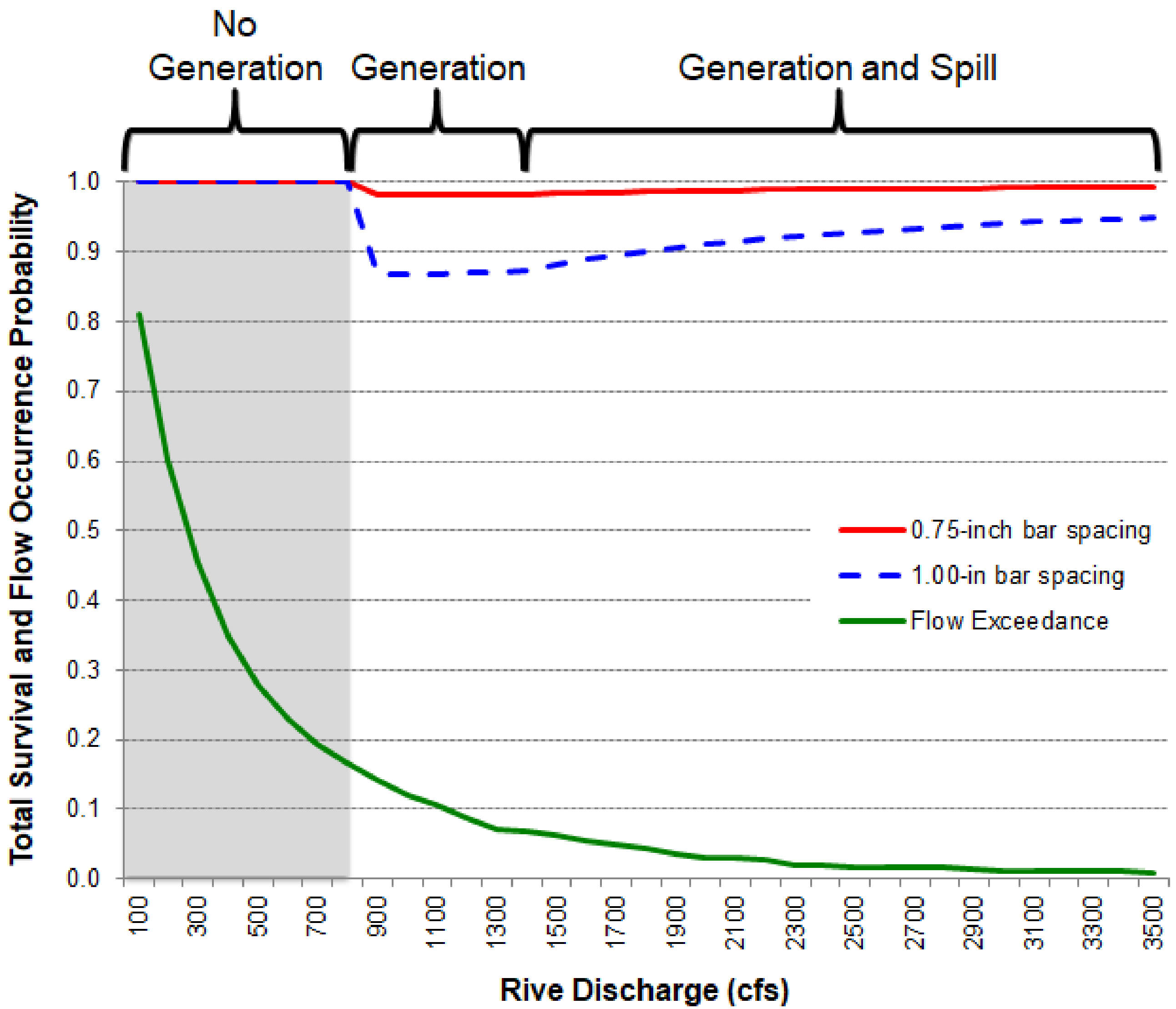
Study Approach

- Calculate river flow occurrence probabilities for migration season.
- Determine flow allocations to each potential passage route (spillway, gates, turbines, fish bypasses) by river discharge.
- Estimate entrainment rates based on bar spacing and approach velocities.
- The proportion of eels approaching spillway/gates and powerhouse is assumed to be equal to proportion of flow.
- Spillway, gate, and bypass survival rates typically based on available literature; turbine survival is estimated with blade strike models (e.g., TBSA) or a regression model developed from field study data.
- At specified river flow intervals, multiply route-specific survival rates by proportion of fish passing through each route. Sum proportional survival rates for an estimate of total survival for a specified migration season.



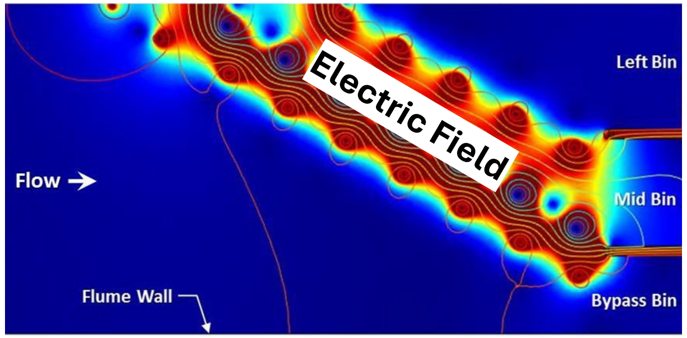
Total Project Survival Modeling

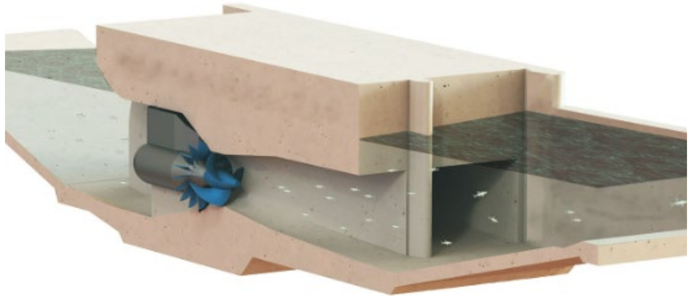
Study Approach



Takeaways

- Bar spacings on racks and screens should be selected based on the level of exclusion required to meet total project survival goals (but ≤ 1 inch probably needed).
- Max approach velocities to an exclusion rack or screen should be about 2 ft/s.
- There is considerable evidence that light can be used to repel or guide eels. Effectiveness will vary depending on site-specific conditions, including project configuration and presence of other behavioral cues that may influence eel behavior.
- For each turbine type, survival increases with decreasing rotational speed and increasing blade spacing; eel length has a lesser effect.
- Eel survival is higher for Francis turbines than propeller-type units (conventional designs), possibly due to how eels enter Francis runners and interact with blade leading edges (i.e., better deflection or avoidance, less damaging impact).
- Fish-safe turbine designs are available for a wide range of project heads and flow rates.
- Desktop modeling can be used to estimate total passage survival for existing conditions and for assessment of protective technologies to determine acceptable alternatives.





Join us for a Fish Entrainment Study Workshop (virtual)

March 19, 12-4 pm EDT

Pacific Northwest NATIONAL LABORATORY

ALDEN a verdantas company

Presentations will include:

Silver Eel Turbine Survival

Total Passage Survival Case Studies

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