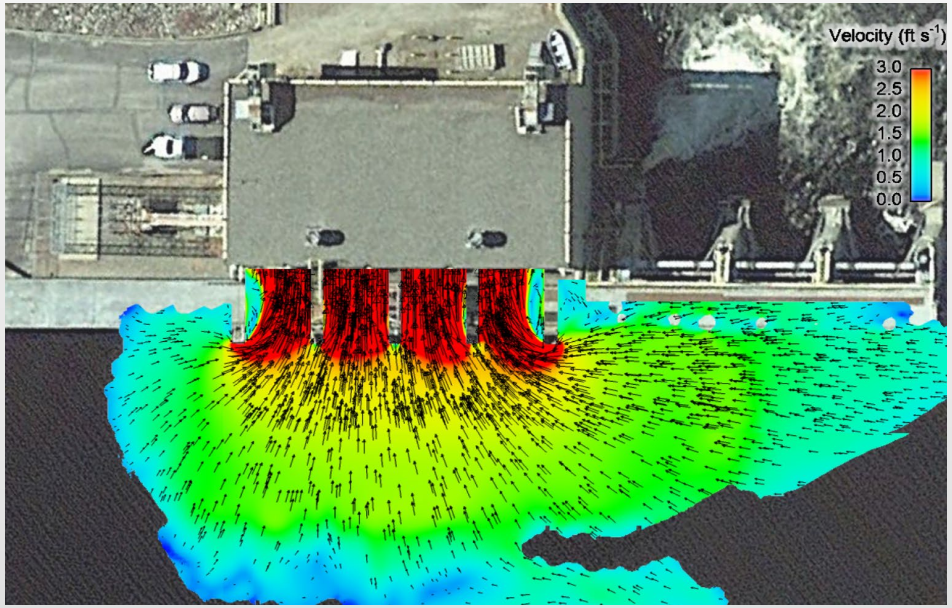
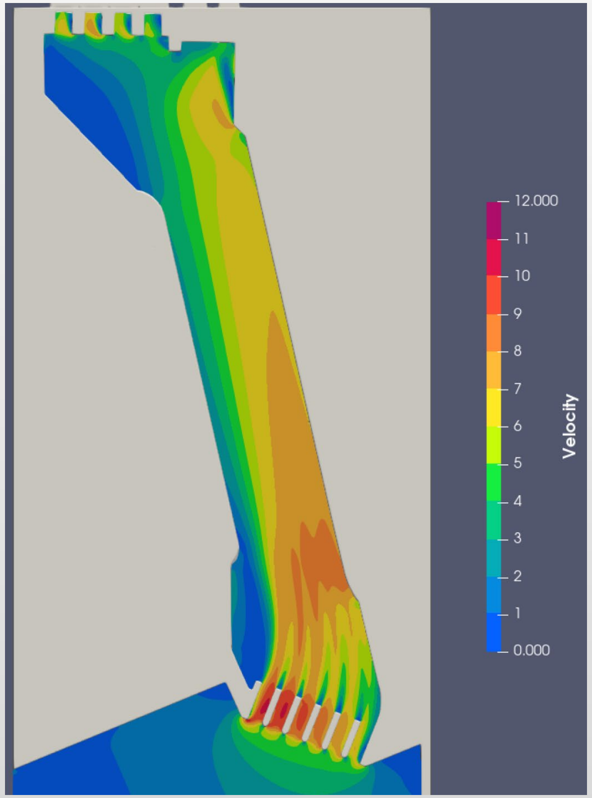
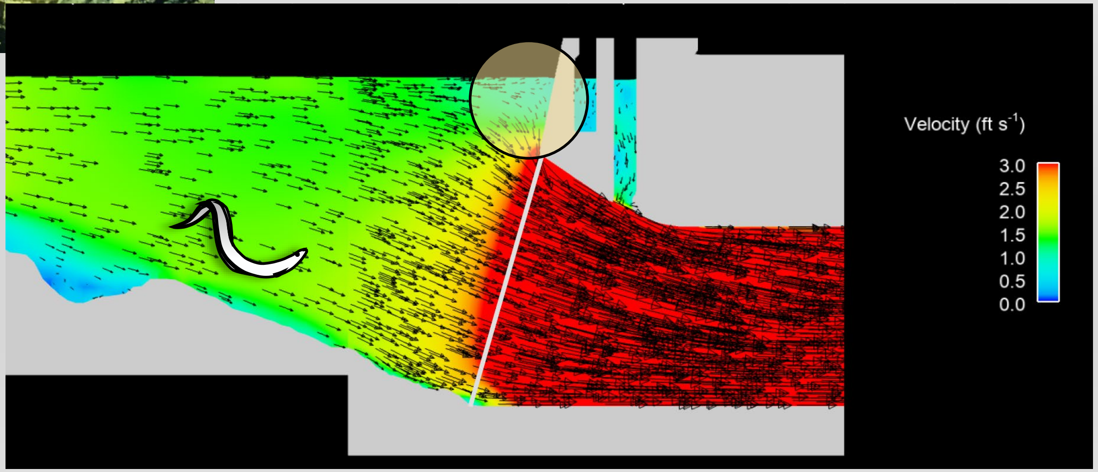
# Variability of Hydraulics



# Key USFWS Fish Passage Engineering Design Guidelines for Downstream Passage of American eel

❖ In the absence of better information (i.e., site-specific studies), the FWS does not recognize passage through the turbine/s as an acceptable downstream route for fish.

- **¾" or less** spacing of **full-depth** intake racks to prevent entrainment of most American eel
- Normal velocity (perpendicular to rack) of **2 ft/s or less** to prevent impingement
- Sweeping velocity greater than or equal to normal velocity to provide guidance to a bypass
- Minimum bypass flow of **5% of station capacity**
- **Low-level** bypass openings preferred

# Guidelines based on Best Available Science

**A SUMMARY OF AMERICAL EEL LITERATURE ASSOCIATED WITH DOWNSTREAM PASSAGE AND RACK SPACING**

| Reference | Location | Study Type | Eel Lengths (mm) | Rack Spacing (in) | Angle of racks Investigated: Angled, deg | Angle of racks Investigated: Inclined, deg | Entrainment, % | Impingement, % | Velocity US of Rack, ft/s | Key Findings/Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| Russon, 2010 | International Centre of Ecohydraulics | Lab | 583 to 806 | 0.5 | 15, 30, 45 | 30, 90 | 0 for angled, 2.8 for inclined | 0 | 1 to 1.6 | 98% of eels utilized bypass for angled racks; no bypass for inclined racks (just looked at impingement/entrainment) "Bar racks spaced at angles <45 deg on the vertical or horizontal planes will likely prove most effective at diverting downstream migrating eels to bypass channels." |
| Okland, 2019 | Germany | Field | 600 to 1,080 | 0.4 | | 27 | 0 | 0 | did not state (however must be low given the 27 deg orientation) | 100% survival; bypasses incorporated on the face of the racks; investigated drift and found that dead eels drifted up to 21 km downstream; project had 10 migration routes other than the units (e.g., side bypasses, bypasses on face of racks, bottom sill trap); eels moved 9 months out of the year! |
| Travade, 2010 | France | Field | 610 to 840 | 0.75 and 1.1 | 30 | | 54 to 60 | 0 | 1.4 | 47% of eels passed during constant river flow, 22% of eels passed during the day, and 25% of eels passed through the units without exploring any other routes; "The 30 cm (1.1") bars were practically impassable to eels longer than 800mm but easily passable for eels shorter than 600mm." |
| Travade, 2010b | France | Lab | | | | | | | | Studied the max length of eels that could pass through intake and found the following relationship: Bar Spacing (BS) = 0.028 x TL; for BS = 18mm, max TL = 643mm |
| Amaral, 2003 | US - Alden | Lab | avg 558 & 569 | 1.0 and 2.0 | 15, 45 | | 12 to 45 | 0 | 1 to 3 | Guidance efficiencies varied from 54.5 for the 2" rack at 45 deg, (56.8-65.9) for the 1" rack at 45 deg, 61.9 for the 45 deg louver with 2" spacing, and the highest of 88% for the louver at 15 deg and 2" spacing; The bypass received 10-12% of total flow. "The estimated guidance efficiencies indicate that angled bar racks and louvers have potential for diverting American eels away from hydro intakes, particulary if a shallow angle is employed." |
| Calles, 2010 | Sweden | Field | 500 to 1,000 | 0.75 | | 63 | 46 | 54 | 3 to 4 | 240 untagged eels were impinged and removed during the study period; All eels that were entrained were 680mm or less |
| Calles, 2013 | Sweden | Field | 500 to 1,000 | 0.7 | | 35 | 10 | 0 | max of 1.7 | 90% overall passage success; mortality went from >70% to less than 10%; each of the 3 intake screens were outfitted with 2 bypass openings near the surface |
| Alden, 2021 | US - NH | Field | 625 to 1,043 | 1.1 and 3.0 | 90 | 90 | 31 to 82 for 1.1" racks | 0 for 3", impingement of tagged and untagged eels observed for 1.1" racks | 2.5 to 4 | This is the DOE funded study at Mine Falls on the Nashua River in NH to test the efficiency of the KLAWA zig-zag system, and Lakeside Engineering vertical bypass. Bypass efficiencies ranged from 0-33% for all runs. |
| Gosset, 2005 | France | Field | did not state | 1.1 | | 25 | 28 to 36 | 0 | max of 1.6 | 42-53% utilized bottom sluice, 8-14% used surface sluice; bypass flow was 2-5% of station capacity; "Efficiency could be improved by reducing the bar spacing to 2cm (0.75")" |
| UKEA, 2016 | UK | Field | 335 to 555 | 0.4 and 0.5 | 18 | | 0 | 0 | max of 1.4 | The UK Environmental Agency (UKEA) currently recommends 0.5" screening for eel and smolts; This study included trials with smolts with very little entrainment or impingment; UKEA also recommends a max approach velocity of 1.6 ft/s |
| Pederson, 2011 | Denmark | Field | 560 to 860 | 0.4 | 60 | | did not state | did not state | max 3.2 | 42% of eels were not detected downstream of the hydropower station. Impingement has been witnessed at this site but not defined within the study. Eels struggled to find the bypass, taking 2h to 11 days to pass the site. Danish legislation requires physical screens with 10mm (0.4") spacing to be installed in front of hydroelectric turbines |
| Melong, 2014 | US - Alden | Lab | 609 to 914 | 0.75 and 1.0 | 90 | | 3.2 to 22 | 0 | 1.5 to 2.0 | 70-72% guidance efficiency for 1" spaced racks, and 89-96% guidance efficiency for 0.75" rack; The 96% value is associated with 0.75" spacing with an approach velocity of 1.5 ft/s. The highest level of entrainment of 22% was associated with 1" spacing and a 2 ft/s velocity |
| Calles, 2021 | Sweden | Field | 586 to 1,040 | 0.6 | 30 | | 0 | 0 | did not state | 95% of eels bypassed the units via the downstream bypass and nature-like fishway; downstream bypass was full depth |
| EPRI, 2016 | US | Criteria | All three references make the same recommendations for optimal guidance of downstream migrating eel: 1. Bar spacing less than or equal to 1.0" for smolts, 0.5 - 0.75" for eels longer than 500mm | | | | | | | |
| Baran, 2012 | Paris | Criteria | 2. Normal velocity (perpendicular to intake rack) < 0.5 m/s (1.6 ft/s) | | | | | | | |
| Courret, 2015 | International FP Conference | Criteria | 3. Incline angle (measured off floor) less than or equal to 26 deg, and angled screen (relative to flow) less than or equal to 45 deg | | | | | | | |

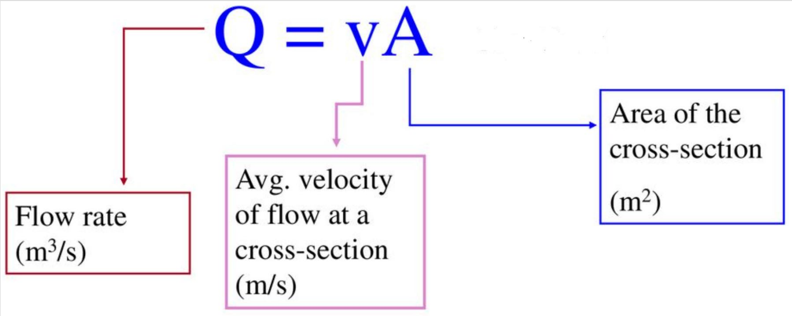
- ❖ All studies showed least amount of entrainment for rack spacing ≤ ¾”
- ❖ Rack spacing and angle/incline have been studied since 2003
- ❖ EPRI 2016 described state of the Science supporting ½ - ¾” racks for eels

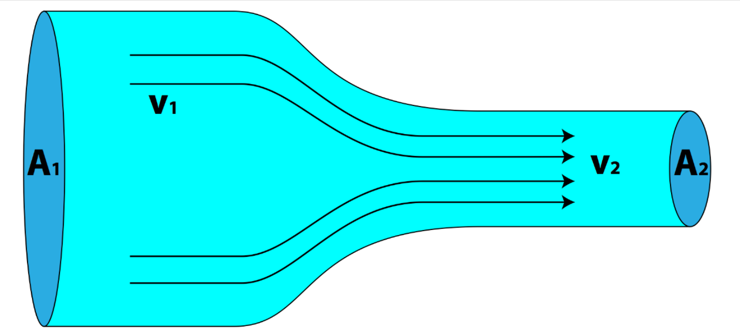
# Application of Key USFWS Fish Passage Engineering Design Guidelines

- **INTENT**: Protect downstream migrating American eel AND allow hydro facility to operate at full capacity
- **SOLUTION**: Prevent eels from entrainment & impingement at full station capacity

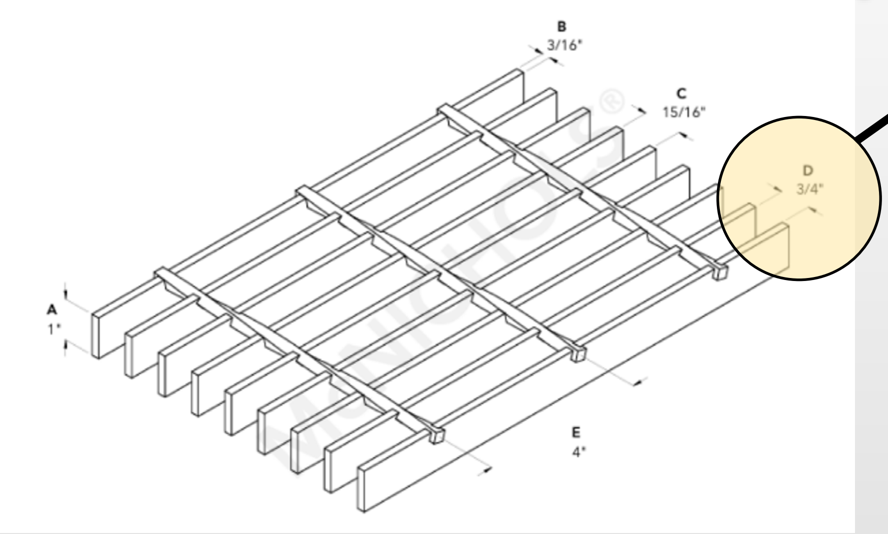
1. Physical exclusion
2. Guidance to Bypass

1. Velocities ≤ 2 ft/s
2. Guidance to Bypass



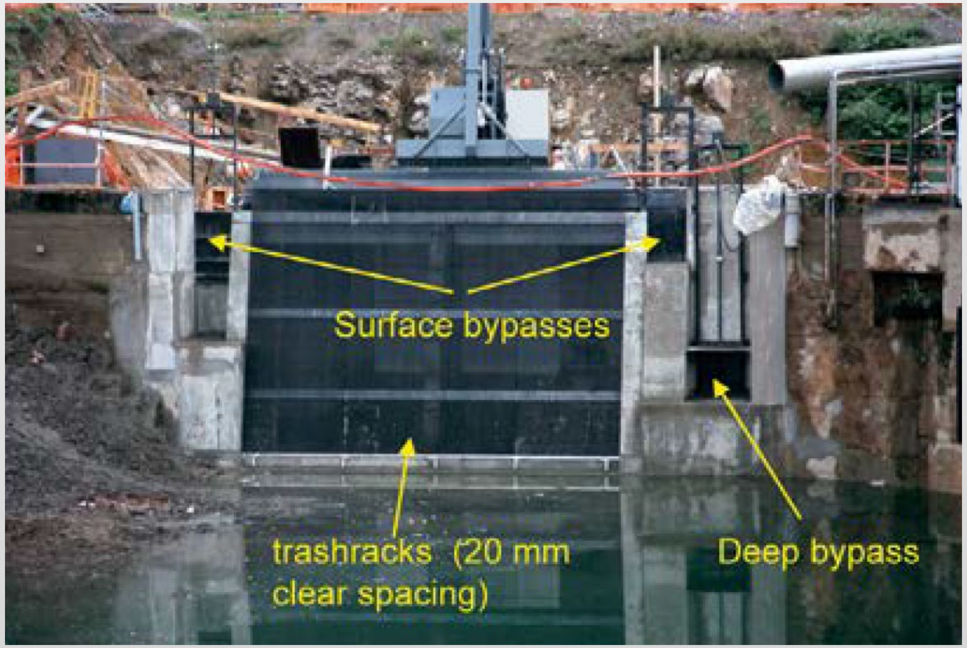



# Solution 1: In-kind Replacement of Intake Racks




Bar Spacing (BS),mm = 0.028 * Total Length (TL)[1]

25.4 mm (1”) protects eels ≥ 907 mm
19.0 mm (3/4”) protects eels ≥ 678 mm
12.7 mm (1/2”) protects eels ≥ 454 mm




- ONLY applies to sites that provide normal velocities ≤ 2 ft/s AND provides bypass flows ≥ 5% of station capacity

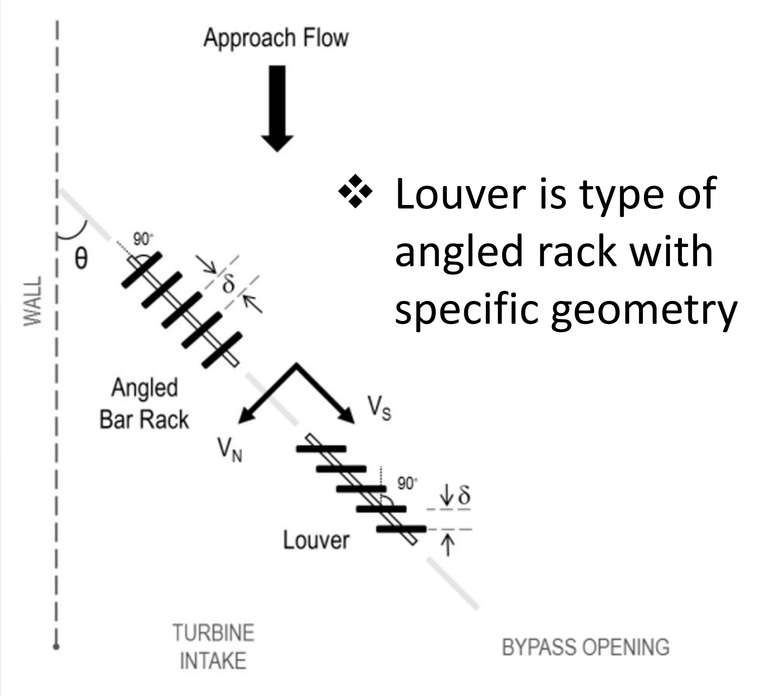
AND validates safe, timely, and effective passage via biological testing

[1] Travade F., Larinier M., Subra S., Gomes P., and De-Oliveria E. 2010. Behaviour and passage of European silver eels (Anguilla Anguilla) at a small hydropower plant during their downstream migration. *Knowledge and Management of Aquatic Ecosystems (2010) 398,01*

# Solution 2: Angled Intake Racks

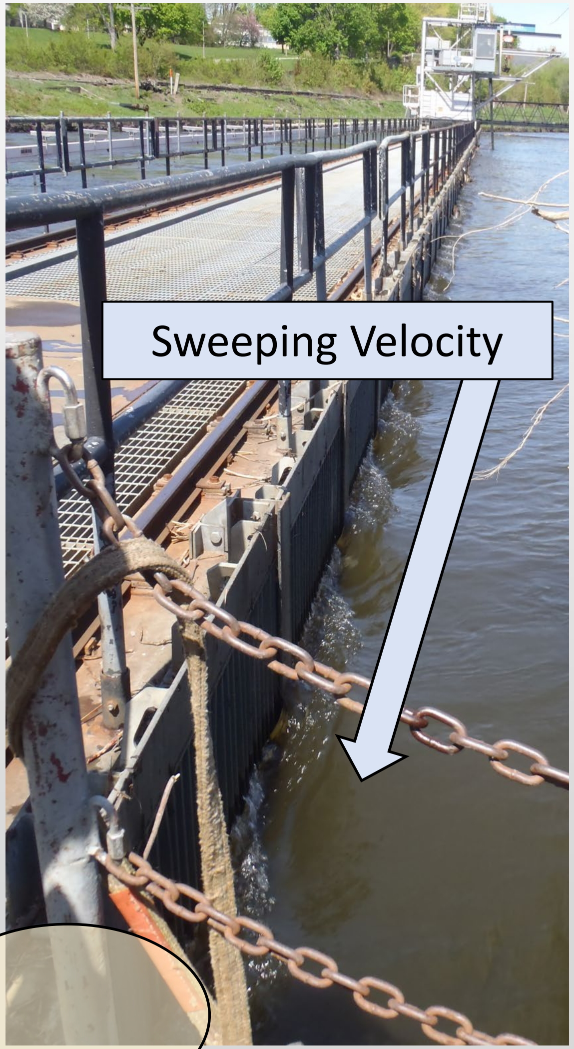
**Benefits:**

- Increased rack area; decreased normal velocity
- Provides physical guidance to bypass via rack itself and **sweeping velocity**
- May allow flows less than 5% of station capacity




❖ Louver is type of angled rack with specific geometry

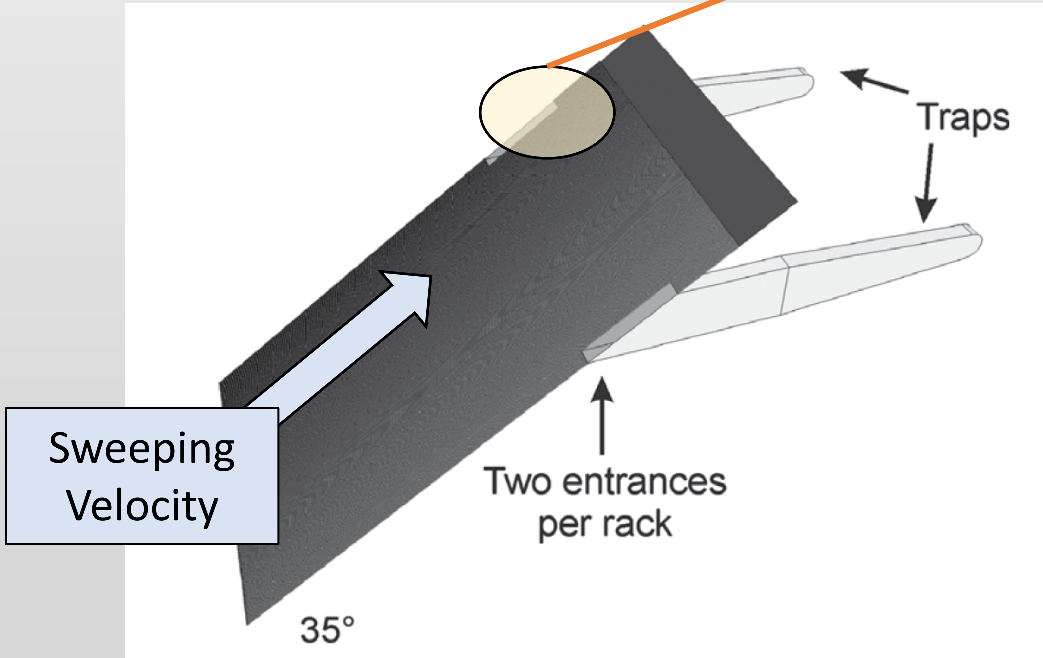
Bypass opening

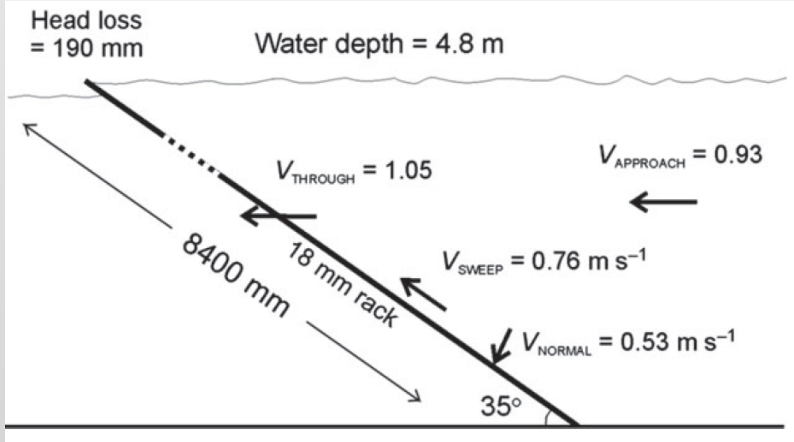


# Solution 3: Inclined Intake Racks

❖ **Same benefits as angled racks**

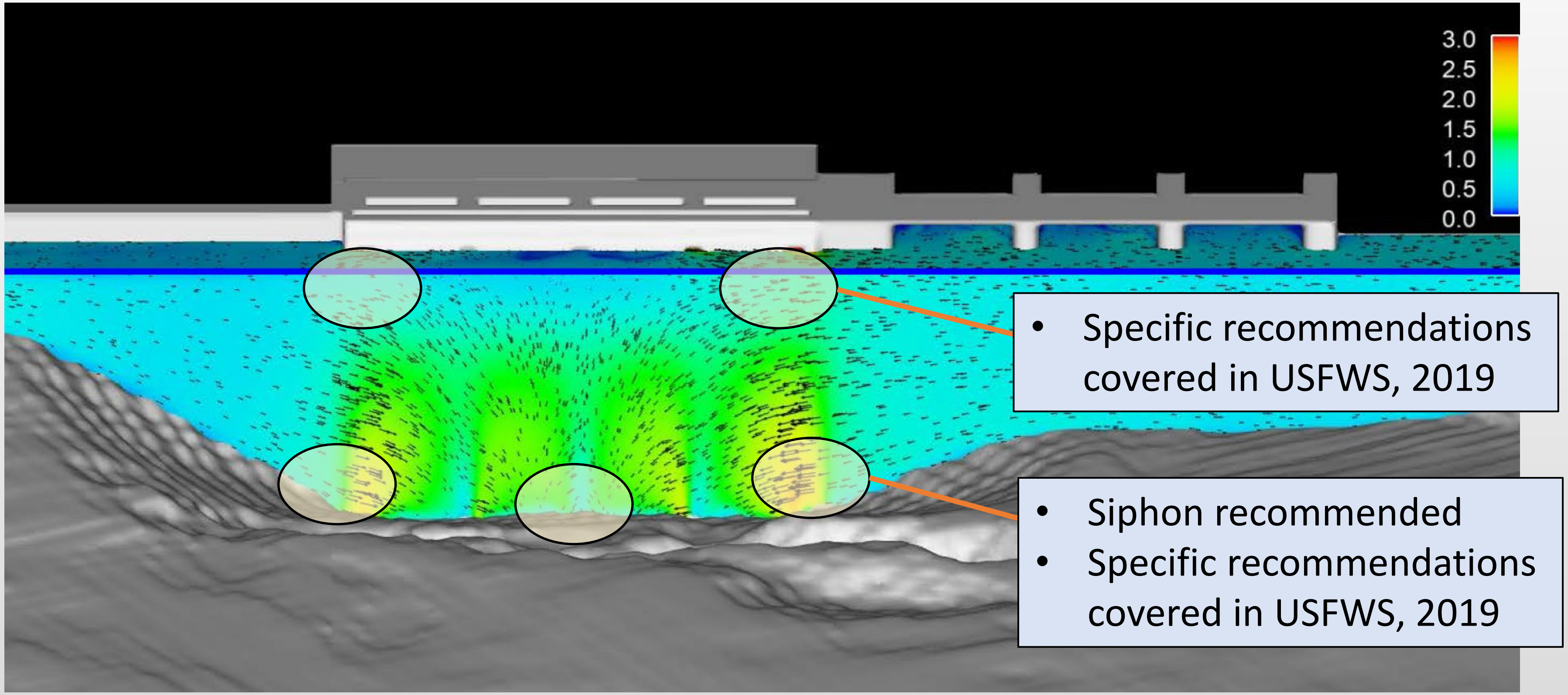
Bypass openings




[1] Calles O., Karisson S., Vezza P., Comoglio C., and Tielman J. 2013. Success of a low-sloping rack for improving downstream passage of silver eels at a hydroelectric plant. *Freshwater Biology (2013)*

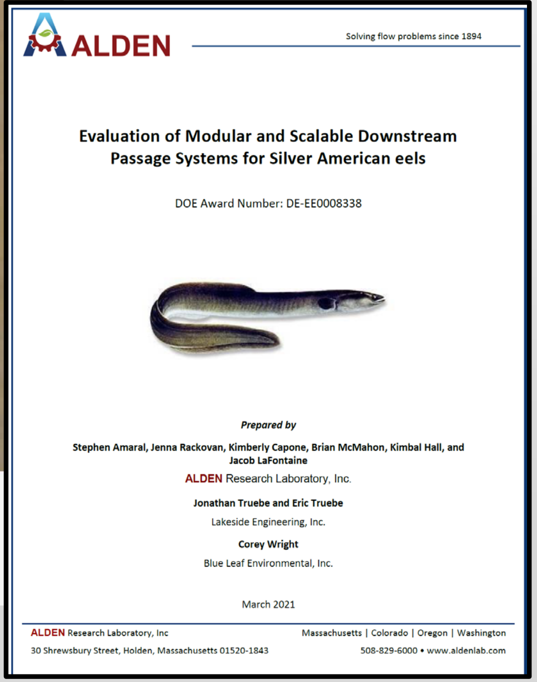
# All Solutions MUST Consider Bypass Location & Flow




- Minimum bypass flow of **5% of station capacity**
  - Bypass flow must be discernible amongst hydraulics at intake racks
  - Increased bypass flow may be necessary for intake racks that do not create a sweeping velocity
  - **Low-level bypasses** must be considered for deep headponds

# The research continues!

The laboratory evaluation was conducted in a large re-circulating flume using the Klawa horizontal zig-zag eel bypass system and a vertical eel bypass system developed by Lakeside Engineering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Solving flow problems since 1894

**Evaluation of Modular and Scalable Downstream Passage Systems for Silver American eels**

DOE Award Number: DE-EE0008338

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# Consideration of Interim Solutions

- Full depth angled/inclined screens can be costly and require significant civil work which requires time (2-3+ years) to complete the design/bid/construction process
- Resource agencies may recommend interim solutions during the time period prior to installation of permanent mitigation measures

1. **Turbine Shutdowns**
    - Shutdowns deemed an interim measure due to the unknown time periods of when eels move throughout the year[1] and changes to those patterns over the license period caused by factors such as climate change.
    - Shutdowns typically occur during nighttime hours when most eels are actively migrating, however blanket shutdowns have been integrated
2. **Unit Turndowns**
    - ONLY if ¾" racks are already integrated, but waiting to install angled/inclined screen
    - Reduction of flow through the turbine such that the velocity standard of ≤ 2 ft/s is met during entirety of migratory season

[1] Eyler S, Welsh S, Smith D, Rockey M. 2016. Downstream Passage and Impact of Turbine Shutdowns on Survival of Silver American Eels at Five Hydroelectric Dams on the Shenandoah River

# Staff Guidance on Performance Standards for American eel

- Taking "Safe, Timely, and Effective" one step further; What's safe enough?
- Performance standards aid in clearly defining the level of impact that is acceptable at each hydro development
- Some performance standards are based on biological modeling efforts[1]
- Performance standards can also be based on Policy decisions
- Helps in clarifying the goal, and interpreting results of biological studies
- Performance standards have been applied for various species (e.g., American shad, river herring, Atlantic salmon, American eel) throughout the Northeast

[1] Stich, D.S., Sheehan, T.F., and Zydlewski, J.D. 2019. A dam passage performance standard model for American shad. Canadian Journal of Fisheries and Aquatic Sciences **76**(5): 762-779.

# QUESTIONS?