

Reading the River: How Fish Find a Way Through Fast Flows

A note on lateral-line sensing and the limits of average-velocity criteria in fish passage design

Standard fish-passage design commonly typically asks a single question of a culvert or channel: is the average water velocity below the regulatory ceiling (commonly around 0.3 m/s (1.0 ft/s)) for small indigenous species, or several times that for strong-swimming salmonids? It is a fair first approximation, and it has served the profession reasonably well. A growing body of physiology and hydraulics shows it captures only part of what determines whether a fish gets through and, worked through carefully, the missing part cuts both ways: some “compliant” structures can fail fish, and some “non-compliant” ones should pass fish.

Sensing the flow, not just enduring it

Fish possess a dedicated flow-sensing organ that vision and intuition easily miss: the lateral line, a row of sensors called neuromasts running along the head and flank. Each neuromast is a cluster of hair cells topped by a jelly-like cupula; water motion bends the cupula, deflecting the hair cells and firing a directional nerve signal. Neuromasts embedded in fluid-filled canals (opening to the water through a row of pores) sense pressure differences between adjacent pores. This is precisely the signature of a vortex and the neuromasts exposed on the skin sense local flow velocity and direction directly. Together they let a fish detect the rotational structure of turbulent flow well enough to ride it. This is the physiological basis for a well-documented observation being: fish can ascend reaches whose bulk-average velocity exceeds their steady swimming speed, not because they are stronger than the average implies, but because they are reading structure the average discards.

Why the “average” itself is a problem

Pass-ability depends on how far a fish must swim continuously before reaching a refuge, set against how long it can sustain the required speed before fatiguing — not on velocity alone. Castro-Santos (2005) frames barrier passage explicitly as this kind of distance problem, and the principle is already reflected in engineering practice: NOAA Fisheries’ salmonid passage guidance scales its maximum allowable velocity with culvert length — 1.8 m/s (6 ft/s) permitted under 18 m (60 ft), stepping down to 0.6 m/s (2 ft/s) beyond 90 m (300 ft). New Zealand’s culvert-passage review (Boubée et al. 1999) makes the same point from the fish’s side, deriving swimming distance directly from velocity and body length.

A worked comparison

Applying the New Zealand review’s own equations to a 70 mm (2.8 in) inanga (*Galaxias maculatus*) gives a stark illustration. In a straight, smooth culvert running at exactly the recommended ceiling of 0.3 m/s (1.0 ft/s) being fully compliant, sustained swimming carries the fish only about 33 m (108 ft) before its own fatigue curve drops its speed back to the current: nearly ten minutes of maximal effort for a modest distance, and no further. The same fish, in a nominally non-compliant culvert with local velocities of 0.6 m/s (2.0 ft/s) but refuges (baffle wakes, boundary-layer pockets etc) spaced every 2 m (6.5 ft) or so, can burst from refuge to refuge in 4.5-second hops, almost indefinitely, regardless of length. One structure satisfies the number and fails the fish; the other fails the number and passes fish.

Refuges are more than rest stops

The same low-velocity pockets that arrest fatigue also deliver food. Classic drift-foraging theory holds that fish position themselves in slack water immediately beside a faster current that carries sustenance, and is a pattern confirmed directly in a New Zealand galaxiid, banded kōkopu, whose holding position tracks exactly this structure. A refuge-rich structure lets a migrating juvenile feed as it rests whereas a smooth, featureless one offers neither.

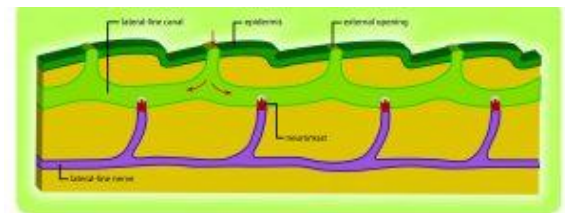
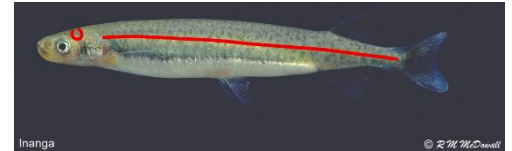
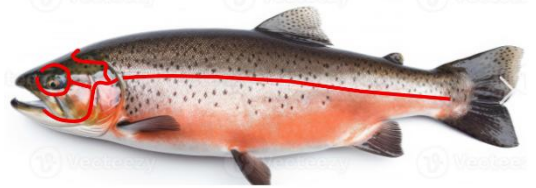
Fish sense only what is nearby

The lateral line’s sensing is inherently short-range. The canal neuromasts detect pressure differences between adjacent pores, a gradient measured over a fraction of a body length, and the pressure signal decays steeply with distance in water. A fish can sense the current immediately around it well enough to swim the distance-maximising pace above, but it has no way to sense in advance whether a culvert is 20 m or 200 m long. Fish do not rely primarily on vision for navigation as they often move at night and also when the water is turbid, therefore a fish cannot judge beforehand whether an attempt is survivable. It commits to its best local strategy and discovers the outcome only after the energy is already spent. A refuge-spacing criterion matches this reality in a way a bare velocity number cannot. It offers the fish a sequence of short, locally-sensible decisions rather than one long, blind commitment.

Toward a better criterion

None of this argues for abandoning velocity limits however adds more nuance. A criterion built around refuge spacing and maximum continuous un-refuged distance, alongside velocity, would extend rather than contradict the length-graduated logic NOAA already applies, and would let a complex, “non-compliant” structure and a smooth, “compliant” one be judged by what a fish actually experiences passing through them.

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