DESIGN OF UPSTREAM FISH PASSAGE SYSTEMS

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Section 1.3 - Fish Passage Design Flows

- In the Northwest Region, NMFS requires that fishways for upstream passage of anadromous salmonids function at least **90% of the time** during the fish passage season, or **between the 5% and 95% exceedence flows** that occur during the fish passage season

Example: Fish Passage Design Flows

- There are runs of winter steelhead and spring Chinook in the Easycatchum river. Historically in the Easycatchum, per the local biologist, steelhead are known to migrate from December 1 to April 1, and Chinook migrate from May 15 to September 1. A fishway has been identified as the most suitable option and is currently being designed to provide fish upstream passage past the Slowemdown Power Dam.

Example: Fish Passage Design Flows

- The **USGS gage data** for the site contains 24 years of daily flow data. This daily flow data is **downloaded into a two column** spreadsheet in sequential format, i.e. from earliest date of record to latest date of record, with the corresponding daily average flows in the adjacent column. The entire data set contains about **8,766 (24 years times 365 days) flow records**, in theory (some records may be missing or unusable).

Example: Fish Passage Design Flows

- From the **passage seasons** identified above, the **45 dates** between April 1 and May 15 and the 90 dates between September 1 and December 1 are **deleted from the data set**. When the original data set is reduced by the 3,240 (45 days times 24 years plus 90 days times 24 years) daily records, the resulting data is about 5,526 daily average flow records long.

Example: Fish Passage Design Flows

- This data set is then **sorted by flow amount** from high flow to low flow.
- After the sort, the flow corresponding to the **276th record** (calculated by **5%** of 5,526, or 276 when rounded) represents the **Fish Passage Design High Flow**, or the 5% exceedence flow during passage season.
- Similarly, the flow corresponding to the **5,250th** record (**95%** of 5526) represents the **Fish Passage Design Low Flow**, or the 95% exceedence flow during passage season.

Example: Fish Passage Design Flows

- The fish passage design flow range must always be **checked against operational conditions** at the impediment.
- If in this example, 70% of the river flow is diverted into the powerhouse leaving only 30% of the **flow in the bypass reach**, the flow in this reach **must also be assessed** for fish passage as well as other habitat conditions.

Example: Fish Passage Design Flows

- If the Slowemdown powerhouse always operates during fish passage season, it can be justified that the passage facility attraction flows at the powerhouse can be reduced by 70%, since this flow is not included in the tailrace.
- This must be **carefully considered** before this decision is made. Could the spillway, powerhouse or individual turbines ever be shut down for periods that overlap into fish passage season, putting a different percentage of flow in the bypass reach? Do spillway flows combine with powerhouse flows such that no attraction flow reduction is warranted?

Section 1.4 - Basic Fish Passage Hydraulics

- Continuity **(equation 1) Q = VA**
- Q equals flow in cubic feet per second (cfs), V equals velocity in feet per second (fps) and A equals cross sectional flow area perpendicular to the average velocity vector, measured in square feet.

Example: Continuity Equation

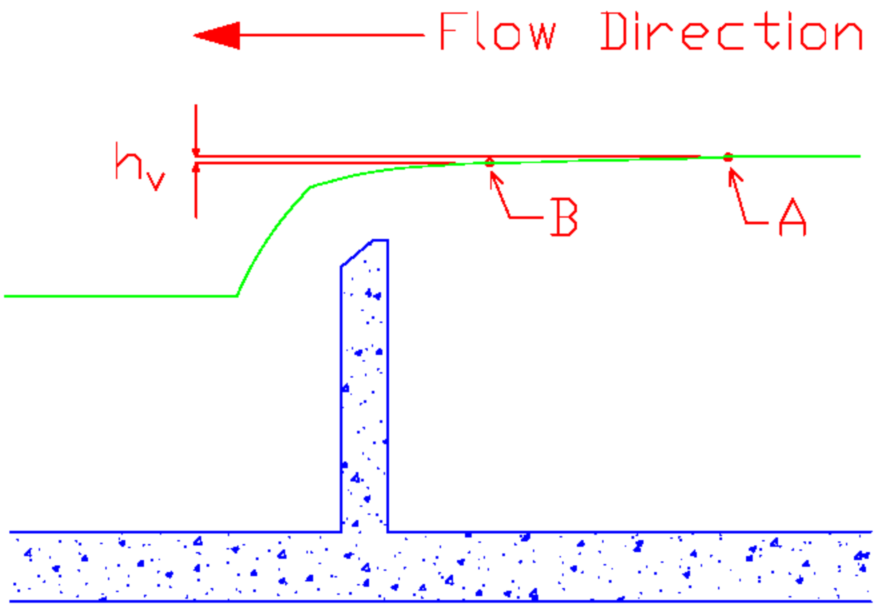
- If water flows 1 foot deep at an average velocity of 4 fps in a circular pipe 2 feet in diameter, what is the flow rate?
- The flow area is half of the area of the 2 foot diameter pipe's area, or 1/2 times pi times the radius squared.
- $A = 0.5 \times 3.14 \times 1^2$
- $A = 1.57\ ft^2$.
- Since V is 4 fps, $Q = 4 \times 1.57$, or 6.28 cfs.

Velocity Head Calculation

- When water moves, potential energy is converted to kinetic energy termed velocity head, and is calculated by the relationship: **(equation 2) $h_v = V^2 / 2g$**, where
- h_v is velocity head
- V is water velocity
- g is the gravitational constant 32.2 feet per second squared.

Example: calculation of velocity head as flow approaches a weir

- If water velocity at point B is 4 fps, then velocity head at point B is calculated as:
- $h_v = V^2 / 2g$
- $= (4\ fps)^2 / (2 \times 32.2\ ft/s^2)$
- $= 16/64.4$
- $= 0.25$ feet
- A velocity head of 0.25 feet means that the water surface will drop 0.25 feet from A to B.

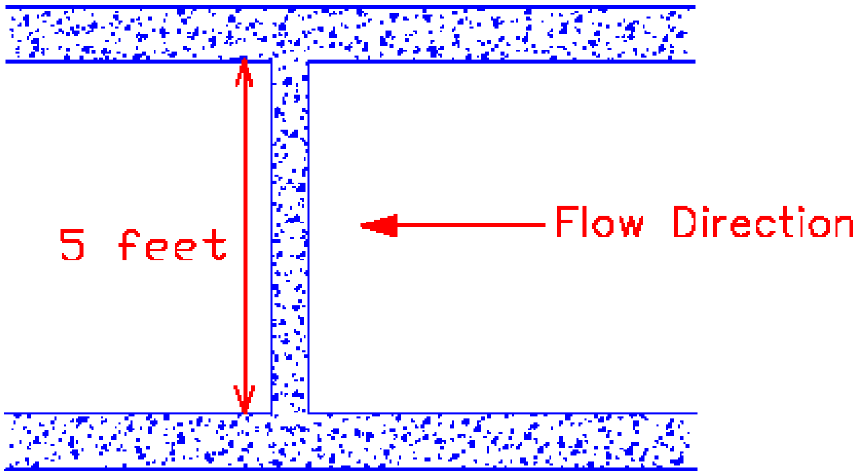


Weir Flow Calculation

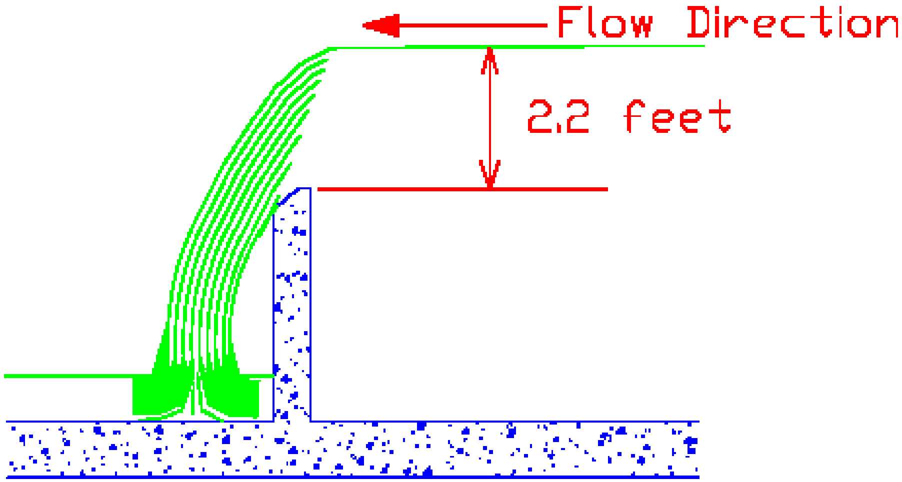
- When water flows over a sharp-crested weir, the flow rate can be estimated by equation 3:
- **(equation 3) $Q = 3.33 \times L \times H^{1.5}$**, where
- L is the length of the weir in feet, and
- H is the head on the weir in feet, and
- Q is in cfs.

Example: Calculation of flow over a sharp-crested weir

A sharp crested weir crest extends across a 5 foot wide rectangular channel, where flow drops into a pool well below the weir crest.
The flow depth over the weir crest is 2.2 feet.



Plan View



Cross-Section

Example: calculation of flow over a sharp-crested weir

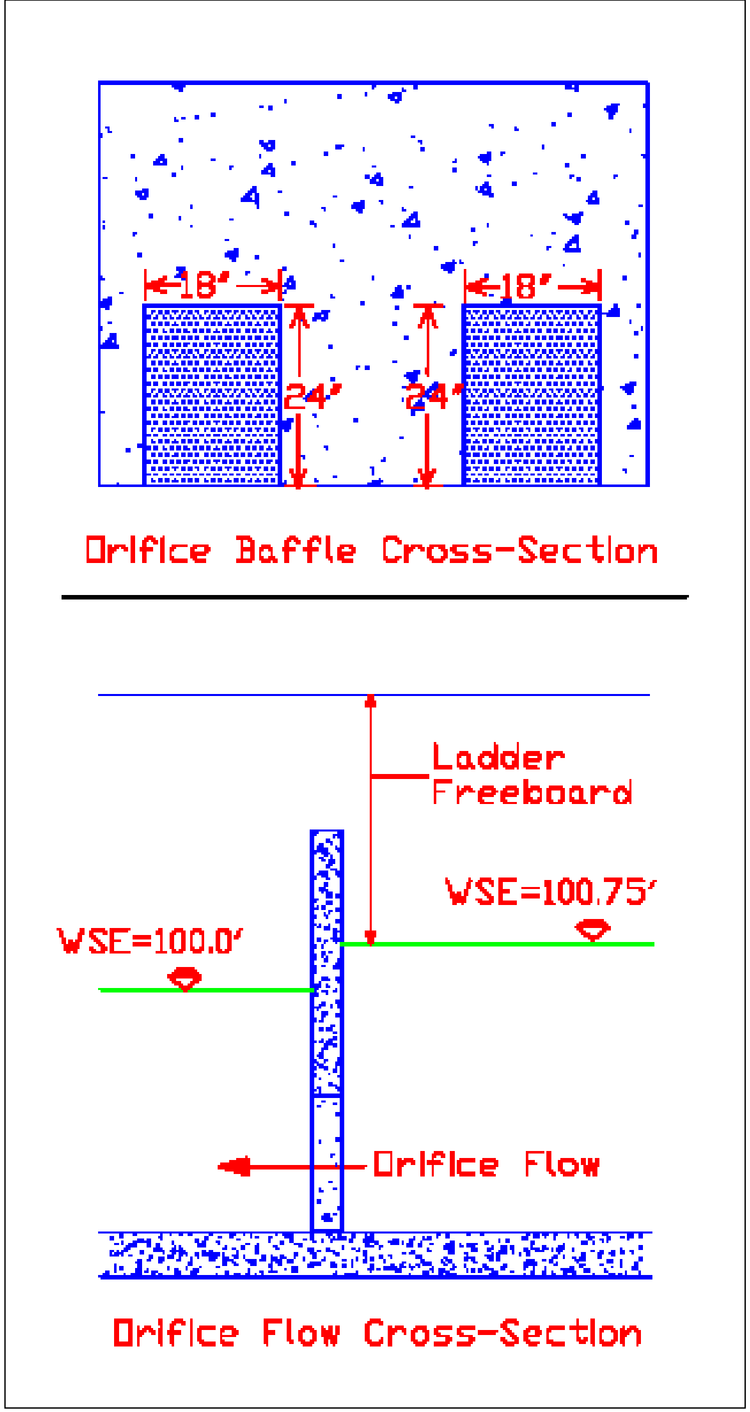
- The flow rate is calculated by equation 3:
- $Q = 3.33 \times 5 \text{ feet} \times 2.2^{1.5} = 54.3 \text{ cfs}$
- Note that the coefficient of 3.33 is **<u>only</u>** for a **sharp-crested weir**.
- For further guidance including calculation of weir coefficients for a variety of weir configurations, see “Water Measurement Manual”, U.S. Bureau of Reclamation, Denver, Colorado, 1981.

Orifice Flow Calculation

- When water flows through a submerged rectangular orifice flow can be calculated by equation 4.
- **(equation 4) $Q = 0.61 \times A \times [2g(H + h_v)]^{1/2}$,** where
- Q is in cfs
- A is the area of the orifice in square feet
- H is the difference in water surface elevation from upstream to downstream of the orifice
- h_v is the velocity head upstream of the orifice, as described by equation 2
- g is the gravitational constant of 32.2 ft/s^2.

Example: Orifice Flow Equation

The entire fishway flow passes through two 18” x 24” orifices with a 0.75 foot difference in water surface elevation. The forebay velocity is 0.1 ft/s. Calculate the orifice flow rate.



Priest Rapids FB Control Orifices

Example: calculation of orifice flow

- First, calculate the velocity head (equation 2):
- h_v = 0.1^2 / (2 x 32.2) = .00016 ft
- Using equation 4: Q = 0.61 x A x $[2g(H+ h_v)]^{½}$
- Q = 0.61 x 18/12 ft x 24/12 ft x $[2 \times 32.2 \times (9/12 + 0.00016)\ ft]^{½}$
- = 0.61 x 1.5 x 2 x 6.95 = 12.7 cfs,
- Or, Q = 25.4 cfs for both orifices
- Note that the calculated velocity head is negligible (slow forebay velocity)
- Note that the coefficient of 0.61 is <u>**only**</u> for a **rectangular orifice**.
- For further guidance on various orifice coefficients for a variety of shapes, see "Water Measurement Manual", U.S. Bureau of Reclamation, Denver, Colorado, 1981.

Section 1.5 - Fish Passage Math

- **<u>Handy Conversions</u>**
- 1 cubic feet per second = 448.8 gallons per minute
- 1 gallon per minute = 1440 gallons per day
- 1 cubic meter per second = 35.31 cubic feet per second
- 1 acre-foot per day = 0.504 cubic feet per second
- 1 cubic feet = 7.48 gallons
- 1 cubic feet of water weighs 62.4 pounds
- 1 gallon of water weighs 8.34 pounds
- 1 foot per second = 0.3048 meters per second
- (degrees Fahrenheit minus 32) times 5/9 = degrees Celsius
- 1 kilogram = 2.2 pounds
- 1 foot per second = 1.097 kilometers per hour = 0.682 miles per hour = 16.4 miles per day.
- Email me at Bryan.Nordlund@noaa.gov for a handy conversions freeware

Section 1.6 - Fish Passage Physics and Biomechanical Ability

- **Some species** of fish have been **studied** fairly **extensively** in regard to their swimming ability - **many have not.**
- If the swimming capability of a species of fish to be passed at a project is unknown, biological investigation is warranted either by conducting swim stamina tests, or potentially by literature research.
- There are probably a number of ways that swimming performance studies can by conducted, but most involve placing fish in a flow conveyance that has the ability to vary water velocity. Fish are generally tested to fatigue at various velocities, and the time is recorded.

Section 1.6 - Fish Passage Physics and Biomechanical Ability

- One helpful resource is “Fisheries Handbook of Engineering Requirements and Biological Criteria” Milo C. Bell, U.S. Army Corps of Engineers, North Pacific Division, 1990.
- Also see the Suggested References at the end of this chapter.

Cruising Speed

- **Cruising speed** is the speed normally utilized by a fish in **migration mode**.
- **Migration speed** is determined by the **cruising speed** capability of a fish and the **water velocity that they swim through.**
- For example, if a fish can sustain a swimming speed of 4 fps, and is swimming into a flow velocity of 1 fps, the migration speed is 3 fps, or about 49 miles a day, if this swimming velocity is constantly maintained.
- However, **migration rates vary** over the course of the day, depending on factors predator activity, time of day, amount of daylight, passage conditions and others.

Example: Cruising speed

- In 2007, PIT tag data for adult Chinook salmon showed that they **averaged 8.65 days** to travel from the Priest Rapids Dam to Wells Dam, **passing 118 miles** of river and **4 dams.**
- Using a **rule of thumb of 24 hours** for passage past a single dam, these Chinook **traveled about 25 miles** a day through reservoirs where velocities range from near zero up to around 3 or 4 fps.
- 118 miles/(8.65 days – 4 days passing dams) = 25.4 miles/day or 1.5 ft/s
- This calculation of daily travel distance **matches reasonably well with the known range of cruising speed** for Chinook , (1 to 4 fps), and the assumption that migration slows or stops during non-daylight hours.

Sustained Speed

- **Sustained speed** is the swimming mode that a fish utilizes when **challenged** by an impediment for a **few minutes**.
- As examples, sustained speed is used by a fish when they swim through a lengthy glide in a river, or ascend a few pools in a fishway prior to resting.

Example: Sustained speed – adult salmon passage criterion

- The average sustained speed for all species of adult Pacific salmon is something on the order of 8 fps.
- This means that most or all adult Pacific salmon can jump a height of about 1 foot, at a jump angle of 45° (example jump height calculation is coming shortly), and many salmon can repeat this jump numerous times before requiring rest.

Example: Sustained speed – adult salmon passage criterion

- **Sustained speed forms the basis for design criteria** for upstream passage designs. For Pacific salmon, the jump height per fishway pool is one foot, with further provisions that fishway pools contain sufficient volume and pool hydraulics such that each pool contains holding volume, where a fish can recover and continue its migration.
- **Word of caution** regarding this example – some species of salmon will not jump to pass a barrier, and most species of salmon show a preference for a passage route that does not require them to jump.

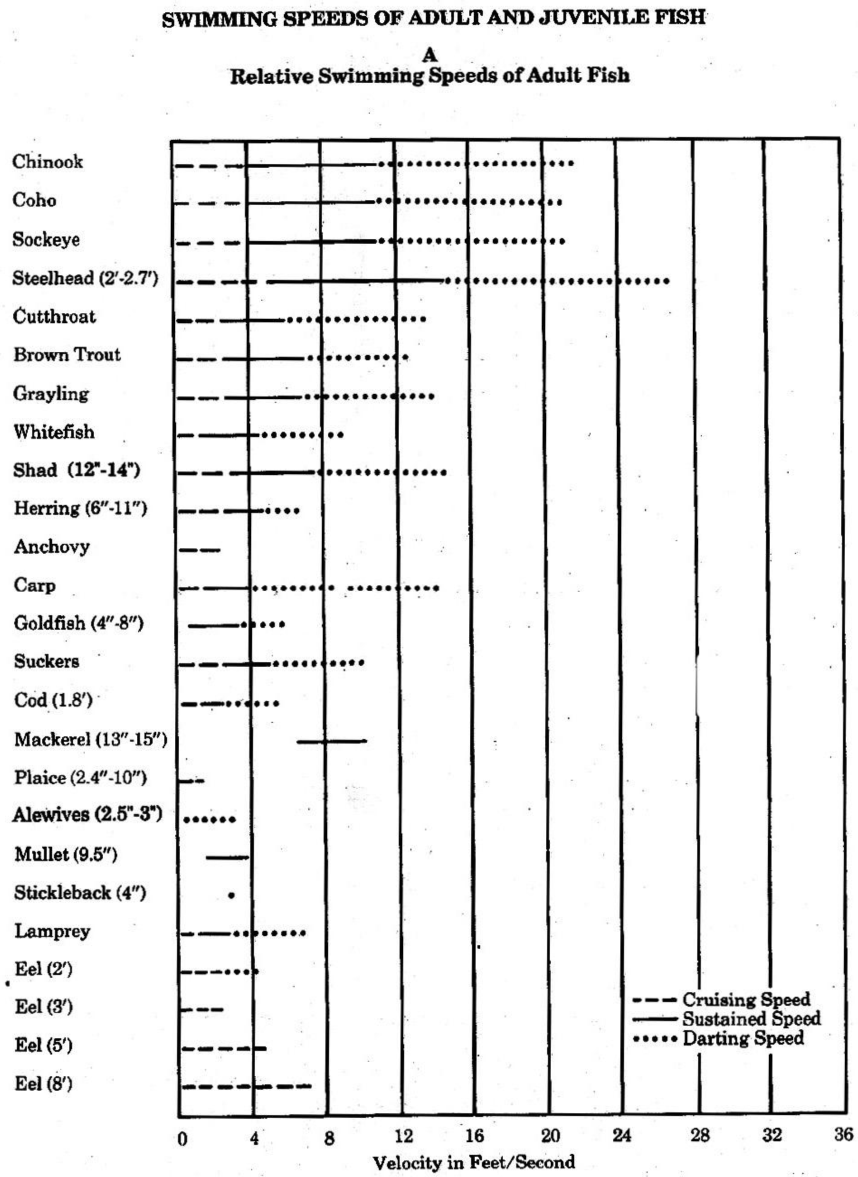
Example: Sustained speed – adult salmon passage criterion

- Most fishways for salmon include a submerged passage route, such as a deep vertical slot, a roughened chute, an orifice, or a combination of overflow weir and orifice.
- The take home message – for the species of fish that require passage at a passage impediment, it is of **paramount importance** to not only understand the **range of sustained speed** for the species, but understand the **behavioral aspects** as well.

Burst Speed

- **Burst speed, also called darting speed**, is used by a fish to overcome a swimming challenge that lasts only a **few seconds**, usually to **avoid being entrained** into passage route that the fish wishes to avoid.
- Burst speed is also used by fish to **jump a vertical barrier** of limited height and length to pass upstream.
- Burst speed can be also be used as the **initial attempt to escape predation**, with a conversion to sustained speed after the initial escape. Whether the predator goes hungry for the moment or the prey escapes is determined by both of these swim speeds and the capability for the prey to find refuge before the predator catches up.
- Generally speaking, burst speed is 3 to 5 times the maximum cruising speed for salmonid species.

Swim Speed table from Milo Bell, 1991

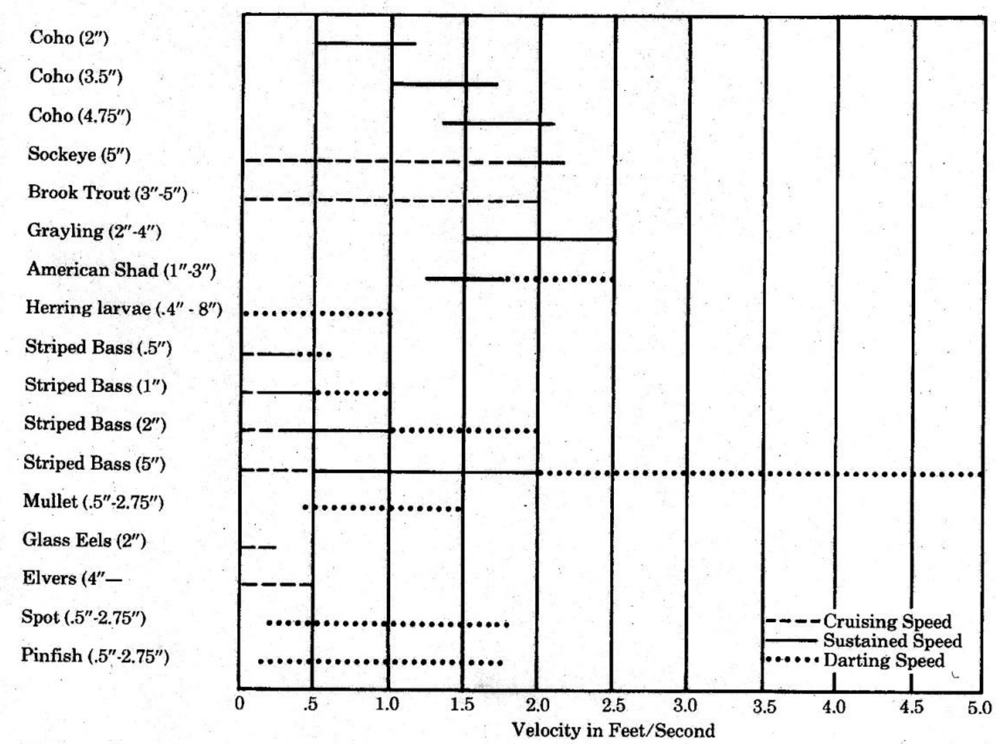


Swim Speed table from Milo Bell, 1991

SWIMMING SPEEDS OF ADULT AND JUVENILE FISH

B

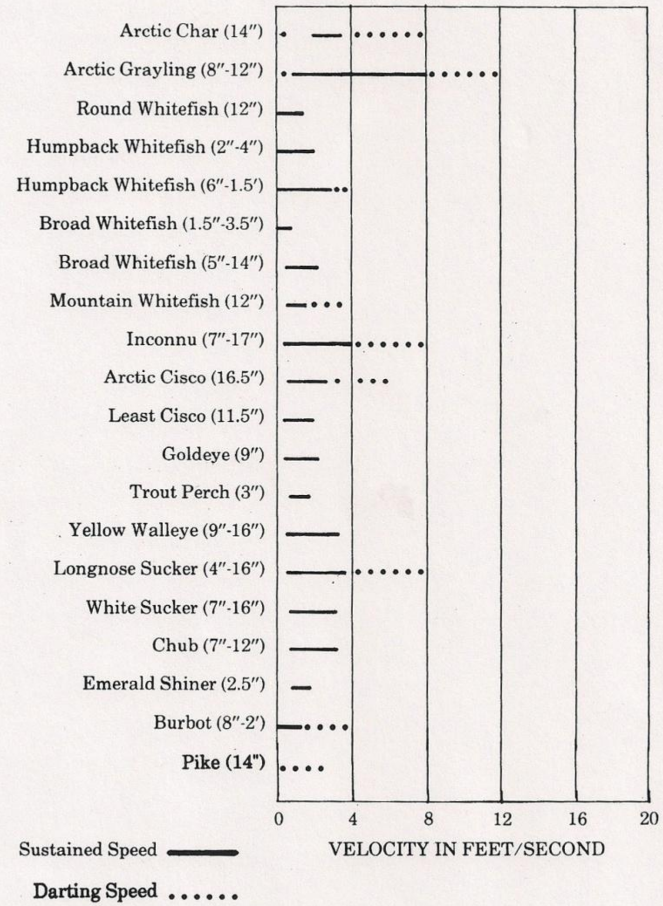
Relative Swimming Speeds of Young Fish



Swim Speed table from Milo Bell, 1991

SWIMMING SPEEDS OF ADULT AND JUVENILE FISH

C
Relative Swimming Speeds



MacKenzie River data used for sustained speed.

Ala[illegible] data used to extend swimming speed to darting level.

Example: Cruising, sustained and burst speed – juvenile upstream passage

- A stream simulation channel is being designed to pass rearing juvenile salmon upstream, into habitat with superior water quality.
- The proposed channel is 450 feet long, has a diversity of channel roughness and the average channel velocity based on Manning's equation (consult with an engineer or hydrologist to verify this calculation) is 3.5 fps.
- If the juvenile salmon have a sustained speed of about 2 fps, is this channel passable?

Original Impediment - Fulton Dam (Chewuch River, Washington)

(Photo courtesy of Tom Kahler, Douglas PUD)

Example: Juvenile upstream passage (continued)

- At 2 fps sustained swim speed, in one minute a fish can swim 120 feet.
- At the minimum 0.4 fps cruising speed, in five minutes a fish can travel 120 feet.
- A two second burst at the darting (burst) speed of 4 feet per second allows a fish to travel only 8 feet.

Example: Juvenile upstream passage (continued)

- Considering that a natural stream channel at a slope of 3% or so is considered to be fairly optimal for coho salmon spawning and rearing, and the average velocity at this stream slope is on the order of 4 to 5 fps, **what makes this natural channel work** for fish passage?
- The answer is **channel complexity**. So long as the channel contains sufficient variety of streambed material, including boulders, cobbles, gravels, sands and silts and each bed material is properly located in the simulated stream channel design, this still has a chance to work for juvenile upstream passage.

Example: Juvenile upstream passage (continued)

- The design reviewer should consider how a fish could navigate upstream in the proposed channel assuming that the path of migration (migration corridor) begins at either side of the channel.
- Generally, the stream velocity is maximum in the center of the channel, is reduced on the fringes of the channel, and is near zero behind obstructions such as protruding boulders in the channel.
- So, if boulders are placed such that they are 8 feet apart, a juvenile fish could dart from boulder to boulder. If longer stretches of lower velocity can verified in the design, a juvenile fish can use these glides to ascend up to about 120 feet, so long as no intermittent turbulence or zones of higher velocity occur in the glide.

Example: Juvenile upstream passage (continued)

- As previously discussed, fish passage criteria are developed such that they are intentionally conservative.
- For a stream simulation channel, this includes consideration of **stream velocities and depths** at the **high and low design flows**.

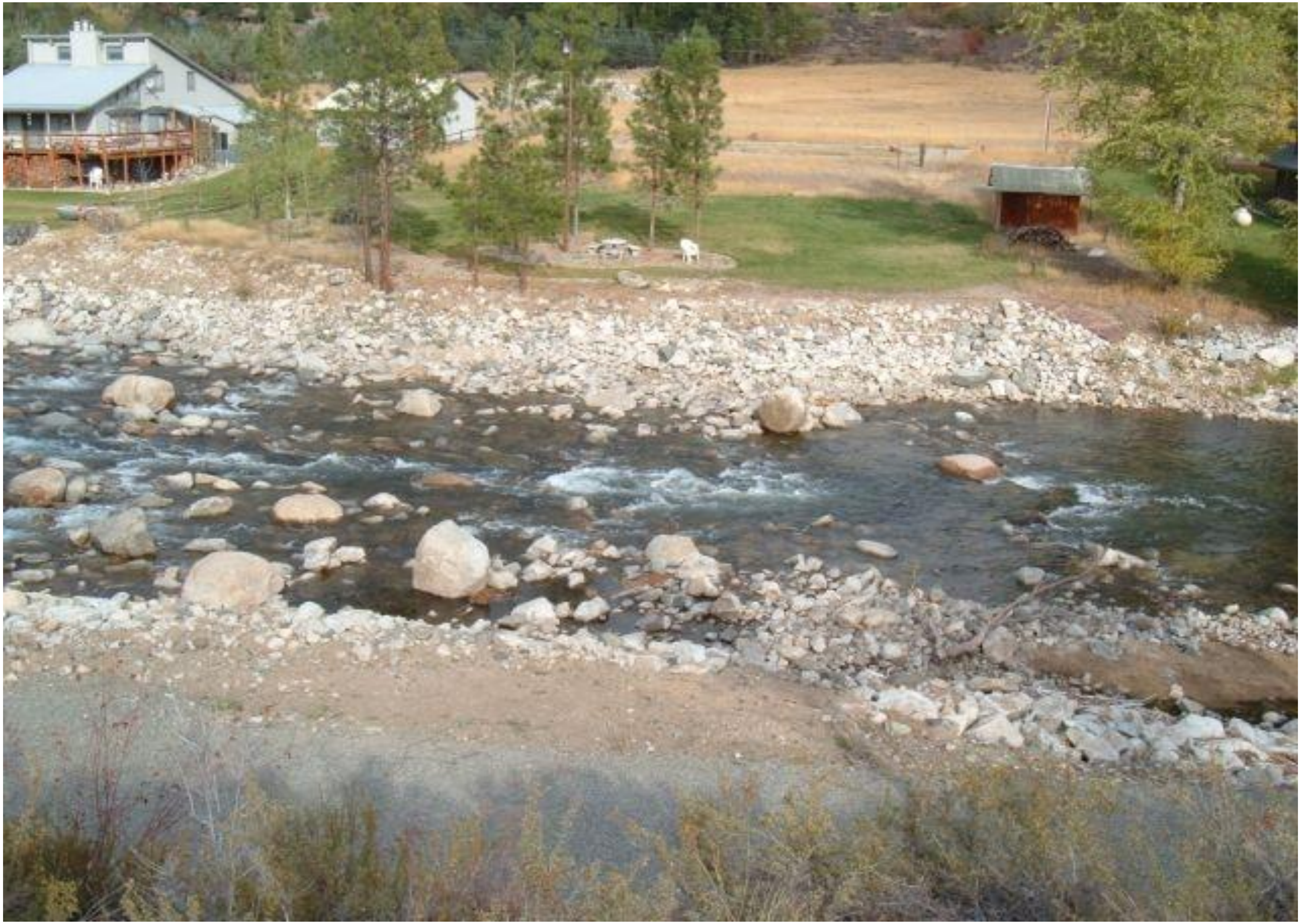
Example: Juvenile upstream passage (continued)

- Never be so arrogant such that you decide that you can replicate a stream over the course of a construction season that nature takes eons to perfect.
- Any questionable stream simulation design that is approved should **include a monitoring and maintenance program**, to verify the design works as intended, and to insure that the design is maintained over time.

Example: Juvenile upstream passage (continued)

- In particular, flood flows move large debris that can dislodge boulders, move cobble and gravels, and remove sands and silts.
- If the **flood aftermath** leaves the simulated channel in non-design conditions, **passage corridors need to be re-assessed** using the rationale described above.
- If a stream **does not carry bedload** of sufficient quantity and size **to reseal** the simulated bed, the stream flow could **go sub-surface** rendering passage impossible.

Fulton Roughened Channel (Chewuch River, Washington)



(Photo courtesy of Tom Kahler, Biologist, Douglas PUD)

Integrating Biomechanical Ability into Fishway Designs

- **Not all species of fish** will not **jump** to clear a barrier
- **Not all species** will **pass through an orifice** opening.
- Most fishway designs provide a **combination** of swim-through passage and jump-over passage.
- Anadromous salmonid passage is usually provided by a designing a **fishway** with a combination of **sufficiently low fishway velocities** and easily **passable hydraulic drops such** that swimming through the passage corridor utilizing **combinations of cruising speed and burst speed** is possible.
- The **upper end of the range of sustained speed or lower end of burst speed** is used in fishway design to allow fish to jump weirs or to swim through submerged orifices.

Biomechanical Ability and Physical Constraints

Conditions for a fish to successfully **jump a single barrier**:

1. Sufficient jump **pool volume** to attain burst velocity
2. A fish's **burst speed** must be sufficient to generate the required trajectory to obtain the required jump height and jump length.
3. A fish must land above the barrier in sufficient flow depth and velocity such that it can **continue swimming when it lands**.
4. Conditions upon landing from a jump must allow a fish to continue upstream and **not fall back** over the barrier.

Jump Pool Depth and Volume

- **Pool depths** that allow burst velocity to be attained are at least **1.25 times the vertical drop** and at least **1.25 times the maximum fish body length**, **assuming** that a species can nearly instantaneously attain burst speed with a stroke or two of the tail fin.
- Adequate pool depth must allow a fish to **exit the lower pool** at burst speed at the **appropriate location** to clear the barrier.
- To accomplish this, the fishway designer must have a **basic understanding of the hydraulics** in the pool, especially where flow from the weir plunges into the lower pool.

Jump Pool Depth and Volume (continued)

- **Aerated flow reduces the burst speed** of a species because the water's density is reduced. If the flow contains 50% air, the force of a fish's fin pushing on the water to propel itself is reduced by 50%, which reduces burst speed by the same factor.
- **Turbulence** at the point of jump exit can also cause a fish to miss its target (think microbursts in air flight).

Fish Projectile Physics

- When a fish leaves the water, **burst speed and jump angle translate into a projectile velocity** (recall velocity is speed with a direction).
- Projectile velocity must be sufficient to generate the required jump height and length.

Fish Projectile Physics

- (**equation 5**)

  Jump height = $(\sin \alpha \times V_b)^2/2g$ (vertically)
- (**equation 6**)

  Jump length = $(\sin \alpha \times \cos \alpha \times V_b^2)/2g$, (horizontally at maximum jump height), where:
- α is the angle relative to the water surface that a fish exits the water
- V_b is the fish's burst velocity
- g is the gravitational constant of 32.2 ft/s^2.

Remember, some fish can't ….

- **Can you** run and jump as high as when you were in your prime?
- To be conservative, assume that **burst speed is diminished** by as much as one-half as the **condition** of the fish **deteriorates** prior to spawning.
- Some humans can high jump around 8 feet and broad jump nearly 30 feet, but I can't, so
- To be conservative, one-half the burst speed might be used for to get a <u>sense</u> of the passibility of a barrier for the **entire population** that requires passage.

Example: Assessing a barrier dam

A steelhead approaches a dam that drops flow 8 feet into a 12 foot deep pool. The crest of the dam is located 3 feet horizontally from the outside edge of the plunging flow. Water velocity at the crest of the dam is 7 fps, and is 4 inches deep for a distance of a few feet, then deepens and slows to less than 4 fps prior to the flowing over the dam. If the steelhead has a burst velocity of 26 fps and is 30 inches long, assess whether passage is possible.

Example: Assessing a barrier dam

Step 1: Check for sufficient jump pool depth to attain burst velocity

- calculate the minimum required pool depth
- Minimum pool depth = D
- D = 1.25 times the vertical drop
- D = 1.25 x 8’
- D = 10’ (pool is 12’ deep, so this is ok)

Example: Assessing a barrier dam

Step 1 (continued): Check for sufficient jump pool depth to attain burst velocity

- Need to verify that pool hydraulics and turbulence allow a fish to stage at the correct location to initiate the jump.
- Need to check air entrainment, and reduce assumed burst velocity if entrained air is present.

Example: Assessing a barrier dam

Step 2: A fish's burst speed must be sufficient to generate the required trajectory to obtain the required jump height and jump length.

- The jump angle **α is not provided**, but a **range of possible jump angles** can be gleaned from the data.
- If a fish leaps 90° to the water surface it will achieve the maximum jump height, but it will come straight down and re-enter the pool at the exact point of exit, obviously not clearing the barrier. This is how the occasional unwise shooter manages to shoot themselves in the head when shooting a gun in the air. Note that this result comes from equation 6 if the angle α is set to 90° – the cosine of 90° is 0, and the calculated jump length (independent of burst velocity) is zero.

Example: Assessing a barrier dam

- Step 2 (continued):
- Since we know the fish must jump 3 feet horizontally and 8 feet vertically, the optimal angle α can be calculated from trigonometry. Dividing 8 by 3 and taking the arctangent shows that this optimal α is 69.4°. Using this value for α in equation 5 gives:
- Vertical Jump Height = $(\sin \alpha \times Vb)^2/2g = (\sin 69.4° \times 26)^2/(2 \times 32.2) = 9.2' > 8'$ (ok)

Example: Assessing a barrier dam

- Step 3: A fish must land above the barrier in sufficient flow depth and velocity such that it can continue swimming when it lands Calculate horizontal jump distance
- Calculate horizontal jump length L (equation 6)
- $L = (\sin \alpha \times \cos \alpha \times Vb^2)/g$
- $L = (\sin 69.4° \times \cos 69.4° \times 26^2)/64.4$
- L = 3.5’
- Meaning, a fish must jump from 3.5 feet from base of dam to land in the 4-inch deep water at the top of the dam.

Example: Assessing a barrier dam

- Step 3: (continued)
- It’s important to note that this calculated horizontal distance is only to the high point or apex of the jump. If a fish winds up at the same elevation that it started from, the jump length would be twice this result. If a fish clears the barrier by some distance vertically, it will also continue on its parabolic trajectory to attain a greater distance horizontally.

Example: Assessing a barrier dam

Step 4: Conditions upon landing from a jump must allow a fish to continue upstream and not fall back over the barrier.

- A 30-inch long steelhead has a tail that is greater in height than the 4 inch depth at the crest of the dam.
- In other words, the tail is not entirely submerged so top burst speed can not be assumed upon landing.
- Since the water velocity at the top of the dam is less than one-half the maximum burst velocity, and only a few feet of travel are required after the jump, this <u>particular</u> fish could probably make it past the dam if it can achieve the jump.

Example: Assessing a barrier dam

Conclusion: These calculations show that this particular fish could very likely make this jump successfully, **but:**

- Other factors need to be considered before this dam could be deemed passable for the steelhead run at large, or for other species that may need to pass.
- For example, if a fish is in poor condition (eg. gravid, far from salt water, injured) or is a less than prime physical specimen (eg. small fish or weak swimmer), the maximum burst speed of 26 fps can not be assumed.

Example: Assessing a barrier dam

Conclusion (continued):

- If the above calculations are re-done using one half the burst velocity, as is suggested by the literature for fish in poor condition, the jump will not be successful.
- In addition, if the jump angle is not optimal, the fish will not be able to make the jump. A steelhead is a relentless migrator, so it may make many attempts at the jump, each jump taking a toll on available energy reserves, and each jump potentially causing injury, depending on where it lands.

Example: Assessing a Barrier Dam Passage – Final Conclusion

- In conclusion, this dam is **likely** not passable to the steelhead run at large, even if it may be passable to the athletic steelhead in the example.
- So, the biologist needs to think about an **appropriate fish ladder design**, maybe taking part in the **next session** of the upstream fish passage design course to see how to do this.

Section 1.7 – Upstream Fish Passage Facility Design Phases

Conceptual designs are:

- also called functional design, initial design, feasibility design, preliminary design.
- considered to be the initial level of design development for fishway design approval.
- if acceptable, ideal for inclusion as a component of a Section 18 fishway prescription, on the condition that fishway approval is also part of the Section 18.

Section 1.7 – Upstream Fish Passage Facility Design Phases

Subsequent design phases of 30%, 60% and 90% are generally also reviewed, but review of a 100% design may or may not be necessary to approve the final design of the fishway.

Section 1.7 – Conceptual Design

A conceptual upstream fish passage facility design should minimally identify:

- the **general construction footprint** of the passage facility relative to the existing project features
- **flow distribution** into all project components
- how **project operations** affect operation of fish passage facilities
- **fish species present** and their **run timing**
- where design **uncertainty** needs to be resolved by model studies (physical, hydraulic, and mathematical), or behavioral studies (acoustic tag, radio tag).

Merwin Dam Hydraulic Model

(Photo courtesy of PacifiCorp Energy; model at NHC Seatac)

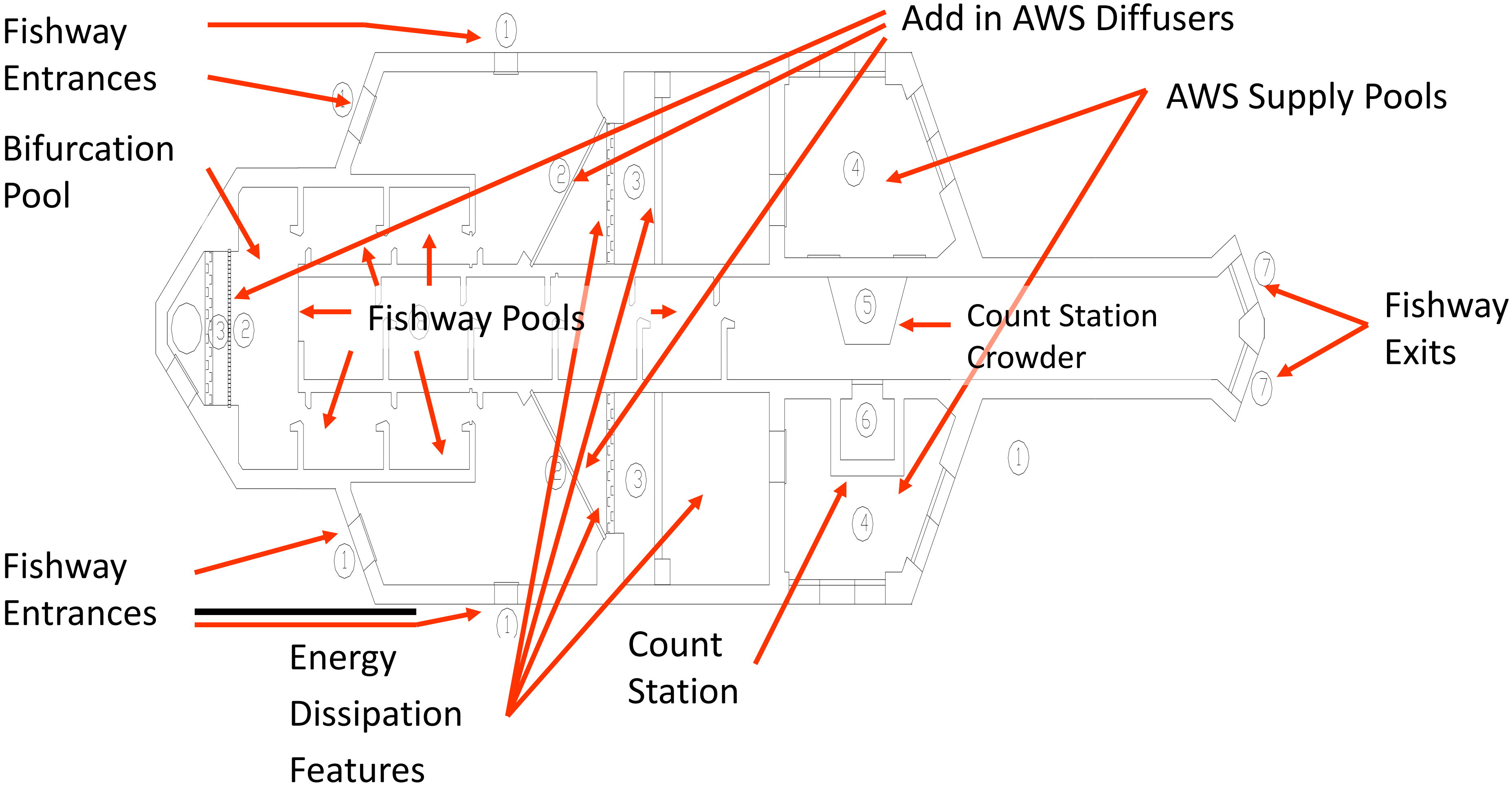
Section 1.7 – Conceptual Design (continued)

A conceptual upstream fish passage facility design should minimally identify or reflect:

- **major flow features** including the range of fishway flow amounts
- how **flow will be distributed** throughout the fishway
- the forebay and tailwater **rating curves**
- high and low **fish passage design flows** (see Section 1.3)
- project **ramping rates**
- method of **controlling forebay and tailwater changes**
- **style of fish ladder**

Section 1.7 – 30%, 60%, 90% Design Features

- **30% design** is a refinement of the conceptual design, generally defining such design features as fishway weirs, fishway entrances, diffusers, auxiliary water systems, and confirming the migration corridor through the fishway
- **60% design** continues to refine these features, but may also reflect fairly significant design changes if certain feature reflected in the 30% design are not feasible, or can be designed more cost effectively.
- **90% design** is should be pretty close to the final design and adds design features such as control systems and detailed mechanical features. There should be no functional changes in passage features after the 60% design, unless specifically approved by the reviewing fisheries agencies.
- **100% design** is rarely reviewed by NMFS because it generally involves the addition of finishing details – paint, handrails, landscaping.



Section 1.8 - Features of an Upstream Fish Passage Facility

Section 1.18 - Selected References and Additional Reading

- See selected references in Section 1.18 (around page 52) of the course text.

I’m done!!!!!!!!!

Going fishing……

(Photo Courtesy of Mike Delarm – retired NMFS biologist)