Science, Service, Stewardship

Fish Ladder Types

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Ladder Types

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- Pool and Weir
- Weir and Orifice
- Vertical Slot
- Pool & Chute
- Baffled Chute
- Full Width Sills
- Roughened Chute

Photo courtesy of Douglas PUD

Pool & Weir Fish Ladders

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Pool and Weir Fishways

- Series of pools at one-foot elevation increments.
- Energy of flow entering pool is dissipated almost completely before exiting pool.
- Very scalable…Works for low flow or high flow projects. But not both in the same project.
- Works for wide range of total project head
  - 1 foot to ???
  - As long as energy fully dissipated in each pool.

Pool & Weir Fish Ladders

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- Hydraulics of pool and weir fishways
  - Flow Regime
    - Plunging flow is appropriate for pool and weir ladders.
    - Plunging flow is necessary to ensure full energy dissipation.
    - Care must be taken to ensure flow does not enter plunging-streaming transition as excess turbulence can occur. A symptom of flows in the transition range is oscillations within the ladder.
    - There are procedures to calculate the transition flow, but they are beyond the scope of this training.

Pool & Weir Fish Ladders

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- Hydraulics of pool and weir fishways, Cont.
  - Turbulence
    - Turbulence is required in order to dissipate energy in the ladder pools (conservation of energy).
    - Turbulence must be limited. The rate at which energy is dissipated through turbulence is called the energy dissipation factor (EDF).
    - $EDF=[(\gamma)(Q)(H)]/[V]$
    - NMFS criteria for ladder pools allows for a maximum EDF of 4.
      - EDF is one of the primary drivers of pool size, once ladder flow is known.
    - If the EDF is too low, the ladder may have sedimentation issues. (Turbulence helps to keep sediment suspended as it passes down the ladder.)
    - In particularly large or deep pools, turbulence may not occur in all areas of the pool. Therefore care must be taken to not include these areas in EDF calculation.
      - These calculations are beyond the scope of this training.

Pool & Weir Fish Ladders

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- Head differential in pool and weir ladders:
  - In ladders that are intended to pass adult salmonids, the maximum head differential between pools is 1 foot.
  - If juvenile salmon passage is identified as a priority by a NMFS biologist, there may be different requirements that will be determined for the site.
    - Again, important to note that adult passage is NMFS first priority and must not be compromised in order to facilitate juvenile passage.

Pool & Weir Fish Ladders

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- Appropriate applications for pool and weir ladders:
  - High or low head projects
    - Primarily constant head projects unless fishway equipped with forebay and tailwater control systems
  - High or low ladders flows
- Inappropriate applications and limitations:
  - Variable ladder flow rates may render a site unsuitable.
    - Eg. Full stream width ladders, particularly in flashy systems.
    - Some flow variability can be accomodated with a properly designed weir crest that maintains head relatively constant.
  - Ladders where the target species cannot or will not use a weir.

Weir and Orifice Fish Ladders

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- Weir and Orifice Fishways

Photo courtesy of Douglas PUD

Weir and Orifice Fish Ladders

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- Background
  - Subset of pool and weir ladders.
  - Same basic criteria but with a few added elements.
  - Used extensively in mainstem Columbia and Snake River ladders.
  - Includes Ice Harbor and Half Ice Harbor style ladders.

Weir and Orifice Fish Ladders

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- Appropriate applications for weir and orifice ladders:
  - Generally the same as for pool and weir ladders, but due to minimum size of orifice (12”w x 15”h), weir and orifice ladders will not work for particularly low flow projects.
  - Orifice aids in sediment removal.
  - Allows for passage of species that prefer not to leap.
- Limited application in projects with excessive forebay or tailwater elevation fluctuation.
  - Would require extensive flow controls in exit control section.

Weir and Orifice Fish Ladders

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- Ice Harbor Ladders
  - Originally used on Ice Harbor Dam on the Snake River.
  - Very specific form of weir and orifice fish ladder.
  - Built on 1’v to 10’h slope.
  - Has flow stabilizing baffle facing upstream and located next to overflow weir.
  - Frequently modified (cut in half) to create Half Ice Harbor Ladder that functions similarly, but with lower flows.

Weir and Orifice Fish Ladders

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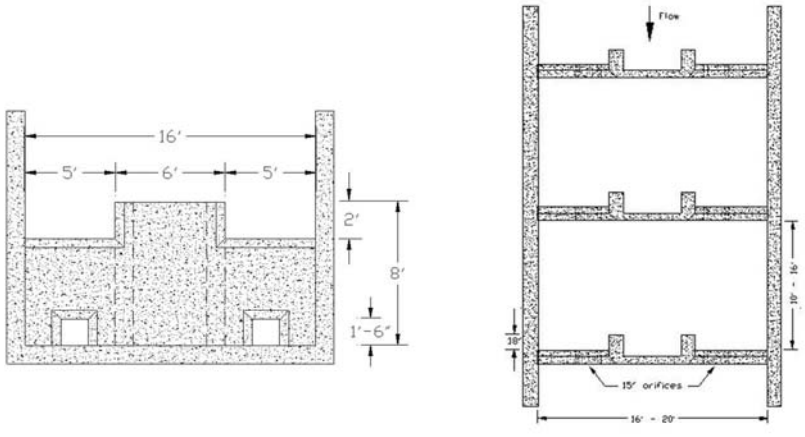

Ice Harbor Design

Weir and Orifice Fish Ladders

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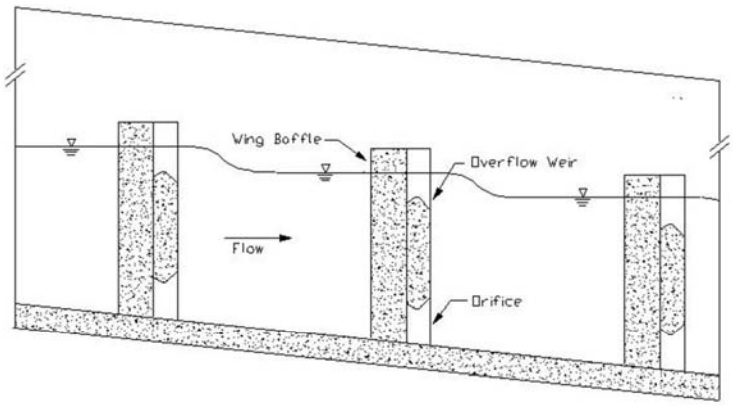

Ice Harbor fishway flow profile

Weir and Orifice Fish Ladders

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Ice Harbor Ladder Dewatered
Photo courtesy of Grant PUD

Half Ice Harbor ladder
(Photo courtesy of Peter Christensen, Design Engineer, R2 Resource Consultants)

Vertical Slot Fish Ladders

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- Vertical Slot Fishways

Photo courtesy of Thad Mosey, Biologist, Chelan PUD

Vertical Slot Fish Ladders

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- Background and advantages of vertical slot fishways
  - Very common and flexible fishway that is widely used in passage of salmon and steelhead
  - Self regulates throughout range of fishway flows.
  - Also self-regulating with respect to <u>some</u> fluctuation in forebay and tailwater conditions.
    - Usually on the order of 10% of total project hydraulic drop.
  - The principle allowing for this self regulation is that as flows increase, the water surface elevation in the ladder is also increasing, thereby increasing the depth in the pools, which increases the volume for energy dissipation. Hence, energy dissipation remains basically constant throughout the operational flow range.
    - Higher tailwaters that backwater the lower pools makes energy dissipation non-constant, but ladder can still be effective as long a tailwater fluctuations don't exceed ladder's design.
  - Similarly to orifices, full depth slots assist in sediment transport.

Vertical Slot Fish Ladders

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- Limitations of vertical slot fishways
  - Sites with forebay or tailwater fluctuations beyond the range of the vertical slot (eg. slot depth) need forebay and/or tailwater control sections designed into the fishway.
  - Vertical slot ladders must use proven geometric dimensional ratios in pool and slot geometry in order to maintain proper hydraulic operation.
  - Due to minimum slot widths and flow depths, vertical slot ladders will not work for particularly low flows.

Vertical Slot Fish Ladders

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- Hydraulics of vertical slot fishways
  - As in pool and weir ladders, energy is dissipated from pool to pool as long as sufficient volume is provided.
  - Turbulence is generated (and energy dissipated) by the jet cushioning and mixing with water between the larger baffles.
    - Critical to ensure pool volume sufficient to fully dissipate energy.
  - Geometry is critical to ensure the proper formation of the eddies that shape the flow and dissipate energy, allowing effective use of the entire pool volume.
  - As shown by Rajaratnam (1986), the flow through the slot has constant velocity throughout the water column. This is the principle that allows for effective passage at largely variable flow.

Vertical Slot Fish Ladders

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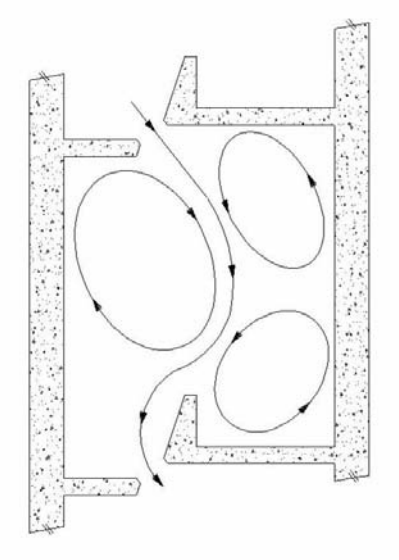

Photo courtesy of Peter Christensen, R2 Resources Engineering

Vertical Slot Fish Ladders

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- Hydraulics, cont.
  - The flow through the slot can be calculated by the formula:
    - $Q = W \times D \times C_d \times V$
  - Energy dissipation should be calculated for each pool for all flows within the fish passage flow range.
  - Like other fishway designs, hydraulic drop between pools is 1-foot.

Vertical Slot Fish Ladders

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- Hydraulics, cont.
  - Coefficient of discharge, or C_d, as mentioned before depends on the size and geometry of the slot.
  - Typical Discharge coefficients range from .7 to .8
  - Coefficients outside this range are possible.
  - Selection of this value is very important.
    - If too low a coefficient is selected, flows may be higher than expected, leading to additional turbulence as well as higher slot velocities.
    - If too high a coefficient is used, meaning that the slot is less efficient than anticipated, the ladder may not pass the full range of anticipated flows.
  - Uncertainty in discharge coefficient can be limited by using proven pool and slot geometries, and ensuring proper construction.

Vertical Slot Fish Ladders

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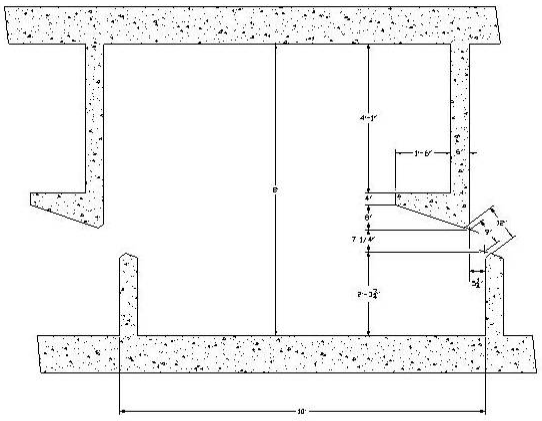

Typical dimensions in vertical slot ladder

Pool and Chute Fish Ladders

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Pool and Chute Fish Ladders

Pool and Chute Fish Ladders

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- Background and advantages of pool and chute fishways:
  - Developed by Ken Bates in the early nineties
  - Hybrid fishway that operates in both plunging and streaming flow regimes.
  - Acts as Pool and Weir fishway at low flows with most or all flow passing through notch at center of weirs.
  - At higher flows, jet forms in center, passing large flows, but plunging flow remains in “passage corridor” at edges of weirs due to angled configuration.

Pool and Chute Fish Ladders

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Silver Creek Pool & Chute ladder at low flow

Same ladder at high flow

Photos taken from Love and Bates, 2009

Pool and Chute Fish Ladders

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- Advantages of pool and chute fishways, Cont.
  - Due to hybrid design, passes large range of flows. Often used for full stream flows.
    - Full stream ladders have advantage of all attraction water leading fish to ladder.
  - Flood flows tend to scour out sediment buildup, reducing maintenance.
  - Diverse passage routes for species that may have differing passage preferences.
  - Allows for smaller pools than would be required in pool and weir ladder for same high design flow.

Pool and Chute Fish Ladders

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- Limitations of pool and chute fishways
  - Due to jet formation and streaming flow that cause energy carryover, a ladder with more than 5 or 6 weirs may fail at high flows.
  - Again, due to jet formation, ladder must be straight with no bends. This may eliminate some sites from consideration for this ladder type.
  - Flow direction must be parallel to river flow.
  - Design process is complex.

Pool and Chute Fish Ladders

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- Hydraulics of pool and chute fishways:
  - At low flow, height of weir notches controls pool depth.
  - Transition from plunging to streaming flow in notch area should not occur until there is plunging flow over a portion of the slanted shoulders.
    - Minimum depth over lowest point of slanted shoulder should be six inches at transition point
  - Drop per weir based on pool and weir criteria.
    - Generally 1-foot, with exception of upper most weir.

Pool and Chute Fish Ladders

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- Hydraulics of pool and chute fishways, Cont.
  - Unlike traditional pool and weir ladder, pool and chute ladders have a velocity head component.
    - Since upstream-most weir has no velocity head, it should be 20% lower relative to profile of other weirs.
  - Maximum slope is about 10%.
    - At higher slopes, weirs have to be very close together to allow streaming flow.
    - This precludes proper energy dissipation for plunging flow at shoulders of ladder.

Pool and Chute Fish Ladders

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- Hydraulics of pool and chute fishways, (last one, I promise)
  - Shoulder weir slope should be 25% or less though a range of 10% to 20% is preferred.
  - Length of shoulder weirs, when combined with weir slope should leave 2 foot passage corridor that does not have any overflow at each side wall.
    - This provides resting areas.
  - Spreadsheet developed by Pat Powers is very helpful in working through the necessary hydraulic calculations.

Full Stream Sills

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Full Stream Width Sills

Full Stream Sills

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- Background and Advantages of full width sills
  - In use in many sizes of streams for decades.
  - Can pass large range of stream flows.
  - Tend to handle debris and sediment well.
    - While pools will tend to fill with sediment, higher flows concentrated by sloping weir tend to scour out pools below weirs.
  - Each weir is gently sloped from thalweg to stream edge, which consolidates flow during low flow periods.

Full Stream Sills

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- Construction & Materials:
  - Materials:
    - Concrete
    - Logs
    - Boulders
  - Weirs must be protected against undermining.
    - Anchor to bedrock
    - Reinforce with boulders
    - Pool lining with concrete
      - Must provide minimum 4 foot depth downstream of weirs
  - Minimum depth criteria must be met in low flow notch at minimum stream flow.

Roughened Chutes

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Roughened Chute Fishways

River Mill Temporary Denil Ladder
(Photos courtesy of Peter Christenson, R2 Engineering)

Roughened Chutes

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- Background and Advantages of Roughened Channels
  - Includes Baffled Chutes.
    - Denil
    - Alaska Steeppass
  - Roughened chutes.
    - Covered in depth in another presentation.
  - Can provide excellent attraction characteristics with relatively low flow if sited correctly.
  - Can work at relatively steep slopes.

Roughened Chutes

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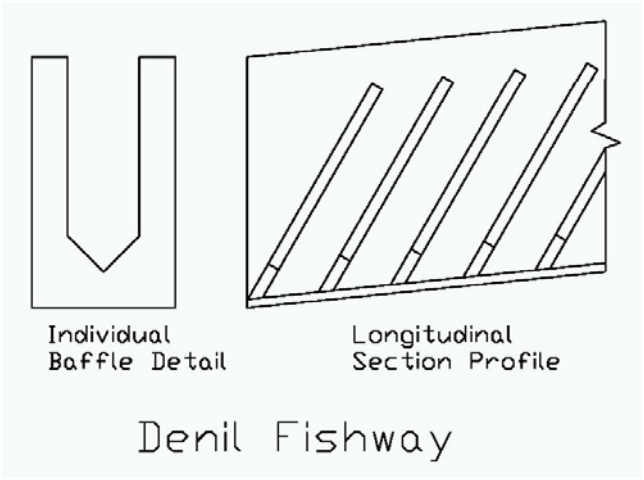

Roughened Chutes

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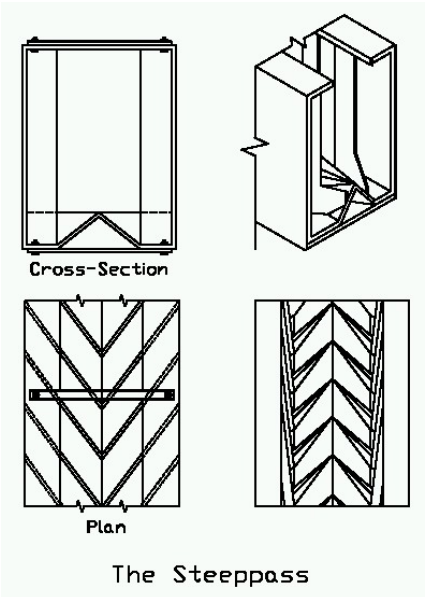

Roughened Chutes

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- Limitations
  - Baffled chutes are very susceptible to debris and sediment.
  - Must be closely monitored.
  - May not be used where downstream passage occurs.
  - No resting locations within ladder itself.
    - Resting pools between ladder sections often provided.
      - Energy must be fully dissipated in these pools.

Roughened Chutes

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- Hydraulics
  - Slope
    - Denil ladders have been used up to slopes of 20%.
    - Steeppass ladders have been used up to 28%.
  - Discharge is constant for a given normal depth.
  - Energy dissipated constantly throughout length of fishway.
  - Velocity should be less than 5 fps in both ladders.

Roughened Chutes

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- Hydraulics, Cont.
  - Minimum Flow depth:
    - 2.0 feet in Denil ladder.
    - 1.5 feet in Steeppass ladder.
  - Resting pools:
    - Should be provided every 25 horizontal feet.
    - Resting pools must have sufficient volume to dissipate all energy as calculated using EDF formula and values discussed previously.

Credits and Bibliography

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