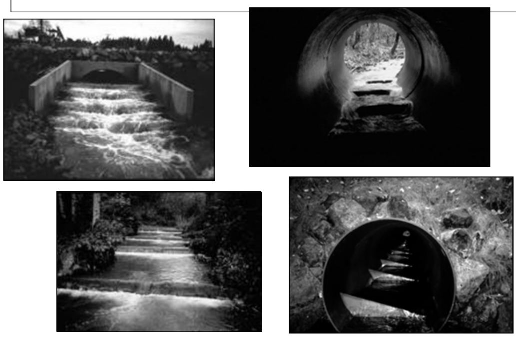
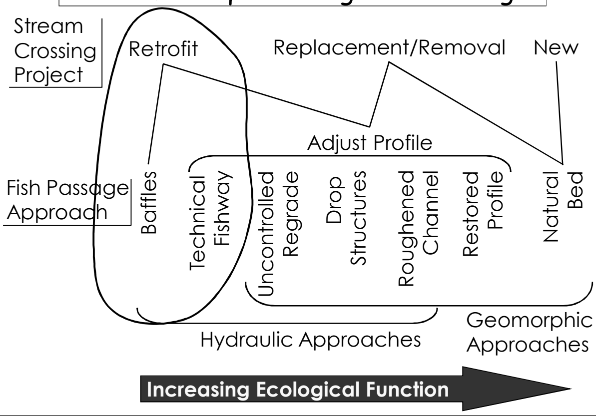
1.5

Retrofits of Existing Culverts



1

Tools for Aquatic Organism Passage

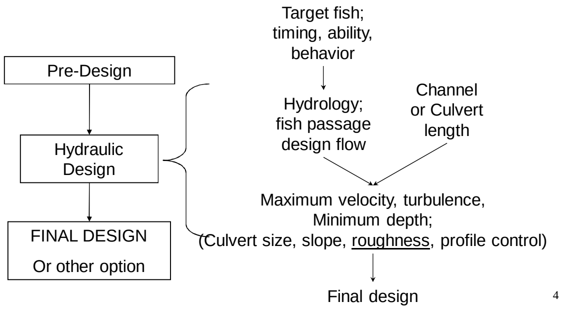


Three design options - Premises

- Low-slope: The design of an oversized culvert in a low risk site can be simplified and built with little risk
- Hydraulic: A structure with appropriate hydraulic conditions will allow target species to swim through it.
- Stream Simulation: A channel that simulates characteristics of the adjacent natural channel will present no more of a challenge to movement of organisms than the natural channel.

3

Hydraulic Design Option



4

Hydraulic Method Design Flows

NOAA Fisheries SW Region and CDFG fish passage design flows

High Design Flow for Fish Passage

Species/Life Stage	Percent Annual Exceedance Flow	Percentage of 2-yr Recurrence Interval Flow
Adult Anadromous Salmonids	1%	50%
Adult Non-Anadromous Salmonids	5%	30%
Juvenile Salmonids	10%	10%
Native Non-Salmonids	5%	30%
Non-Native Species	10%	10%

Low Design Flow for Fish Passage

Species/Lifestage	Percent Annual Exceedance Flow	Alternate Minimum Flow (cfs)
Adult Anadromous Salmonids	50%	3
Adult Non-Anadromous Salmonids	90%	2
Juvenile Salmonids	95%	1
Native Non-Salmonids	90%	1
Non-Native Species	90%	1

5

Hydraulic Method Allowable Velocities

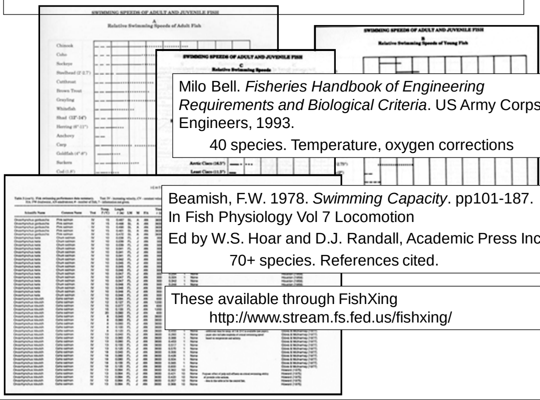
NOAA Fisheries SW Region and CDFG allowable velocities

Culvert Length vs Maximum Average Water Velocity for Adult Salmonids

Culvert Length (ft)	Adult Non-Anadromous Salmonids (fps)	Adult Anadromous Salmonids (fps)
<60	4	6
60-100	4	5
100-200	3	4
200-300	2	3
>300	2	2
Juvenile salmonids		1

6

Fish Swimming Speed Summaries



Milo Bell. *Fisheries Handbook of Engineering Requirements and Biological Criteria*. US Army Corps of Engineers, 1993.

40 species. Temperature, oxygen corrections

Beamish, F.W. 1978. *Swimming Capacity*. pp101-187. In Fish Physiology Vol 7 Locomotion

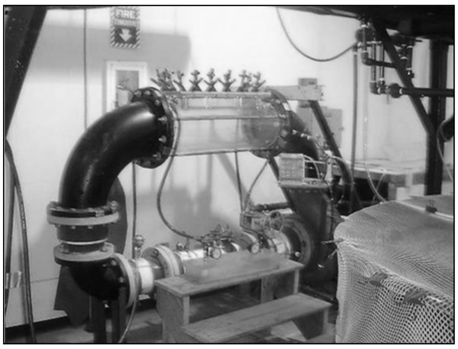
Ed by W.S. Hoar and D.J. Randall, Academic Press Inc.

70+ species. References cited.

These available through FishXing

http://www.stream.fs.fed.us/fishxing/

7



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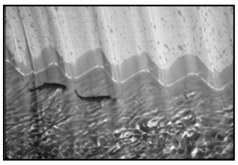
Hydraulic method
Roughness and slope control velocity

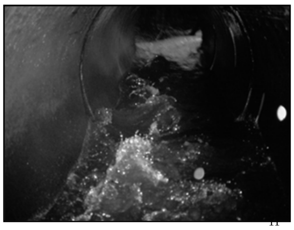


- Culvert walls
- Bed material
- Baffles
  - Limitations of turbulence, debris, maintenance
- Roughened channel
  - Bed stability
  - Variety of migration pathways
  - Turbulence limitation though higher EDF than baffles

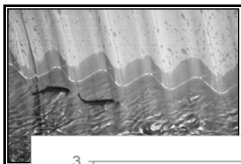
10

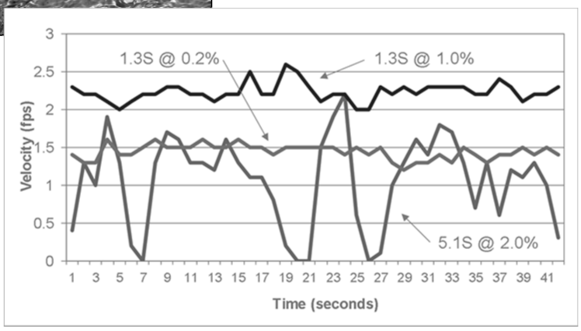
Turbulence

- Measured by Energy Dissipation Factor (EDF)
- Limits fish passage

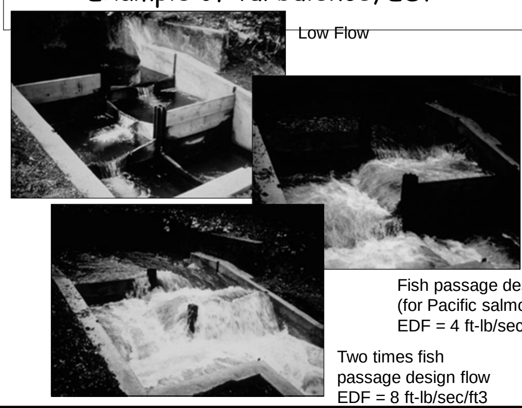


Turbulence in Vocc





Example of turbulence, EDF



Low Flow

Fish passage design flow
(for Pacific salmon)
EDF = 4 ft-lb/sec/ft3

Two times fish
passage design flow
EDF = 8 ft-lb/sec/ft3

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Energy Dissipation Factor (EDF)

- Energy dissipation factor
  - A measure of turbulence
  - Energy dissipated per unit volume of water
  - Culvert $EDF = \frac{\gamma Q S}{A}$
- Recommended maximum EDF for adult salmon
  - Fishways and weirs: 4.0 ft-lb/sec/ft^3
  - Baffled culverts: min: 3.0, max: 5.0 ft-lb/sec/ft^3 (estimated)
  - Roughened channels: 7.0 ft-lb/sec/ft^3 (estimated)

Example: Find EDF in a 3.0% channel with Q=54cfs, A=20 sq ft

62.4 lb/ ft^3 x 54 cfs / 20 sq ft x 0.03 = 5 ft-lb/sec/ft^3

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Baffles for Fish Passage

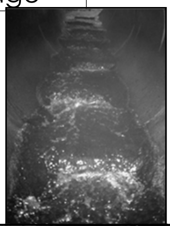
Culvert Retrofit Improves Fish Passage

- Increase Hydraulic Roughness
  - Reduces Velocity
  - Increases Depth

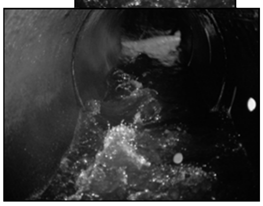
Two Hydraulic Regimes

- Plunging Weir Flow (Low Flow)
  - sharp crested weirs
  - turbulence dissipated in pool below baffle
- Streaming Flow (High Flow)
  - hydraulic roughness
  - uniform turbulence

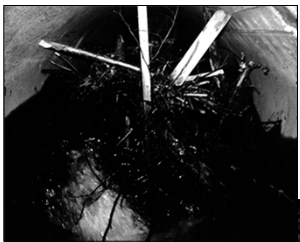
Weirs?



Baffles?

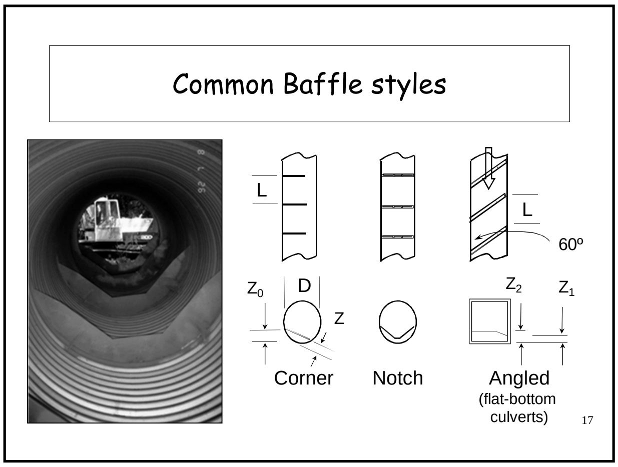


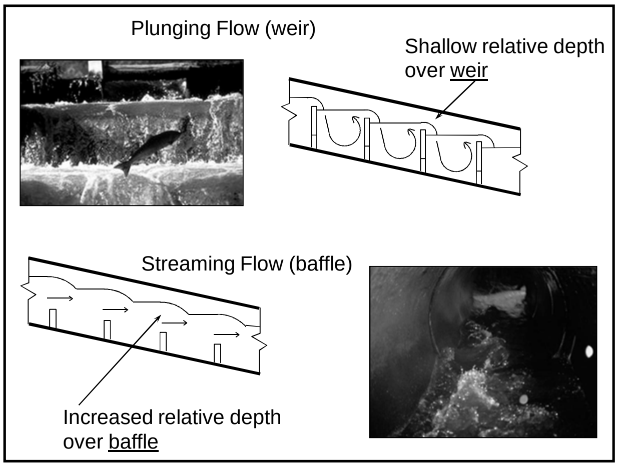
Some Typical Baffles

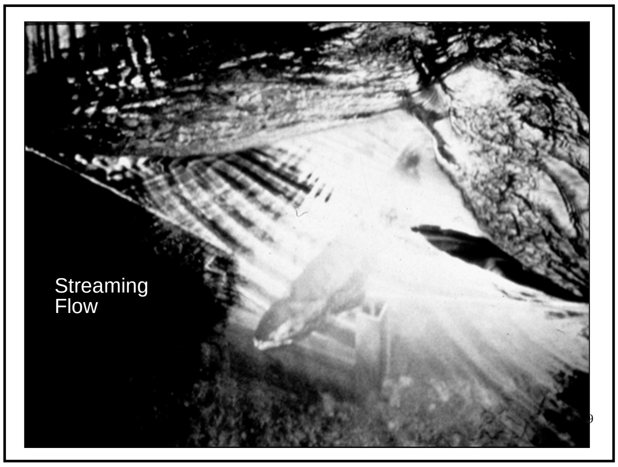


Debris trap

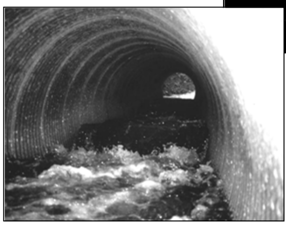
Baffle failure


Common Baffle styles
L
L
60º
Z0
D
Z
Z2
Z1
Corner
Notch
Angled
(flat-bottom
culverts)
17


Plunging Flow (weir)
Shallow relative depth
over weir
Streaming Flow (baffle)
Increased relative depth
over baffle


Streaming
Flow

Low Flow – Weirs

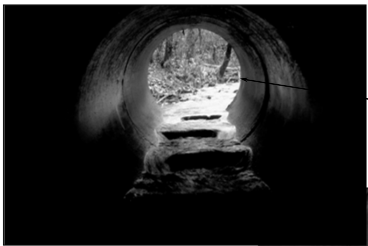


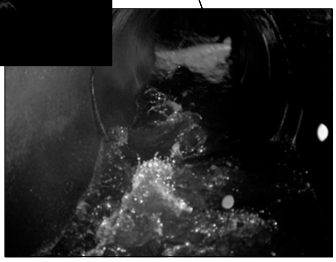
Moderate Flow – Transition from weir to roughness

20

Low Flow
Baffles as weirs

Note change in stream flow



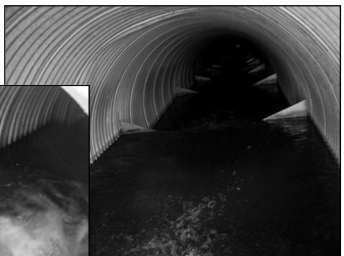


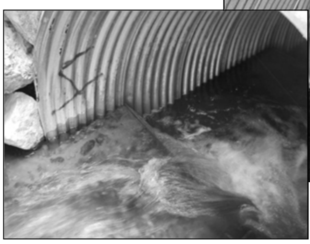
Countyline Cr

Moderate Flow
Baffles as roughness

Fishways in culverts
These are not baffles

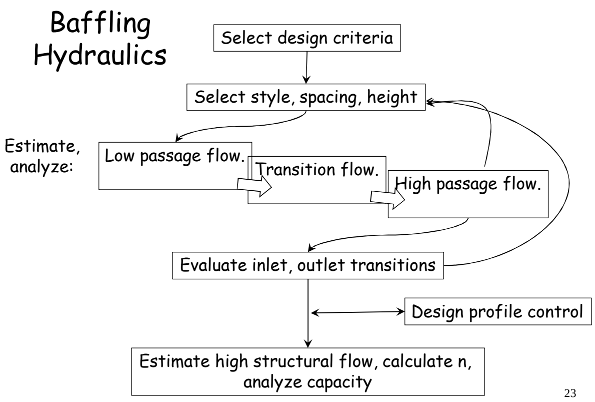
Designed as fishway, not baffle criteria. Usually not feasible.





22

Baffling Hydraulics



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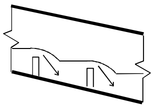
Low passage flow. → Transition flow. → High passage flow.

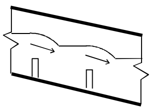
Low passage flow.

- Plunging Flow
- Weir, or partial submerged
- Find depth



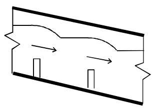
Transition flow.

- Find Pool EDF
- Rule of thumb: streaming @ 50% submergence



High passage flow.

- Streaming Flow (baffle). R&K 1990, Lang 2008
- Find Z_0, Vel, EDF



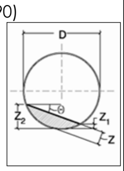
24

Empirical Equations for Baffle Hydraulics at Streaming Flow

Corner Baffles (from Rajaratnam and Katopodis, 1990)

$$Y_o = D\left[\frac{Q}{C\sqrt{gS_oD^5}}\right]^{\frac{1}{a}}$$

Y_o = Normal Flow Depth (ft)
D = Culvert Diameter (ft)
S_0 = Culvert Slope (ft/ft)
L = Spacing between baffles (ft)
Z = Baffle height, as shown



Empirical Coefficients

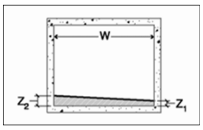
Baffle Arrangement	Z	L	C	a	Limits of Application
Weir Baffle D1	0.15D	0.6D	5.39	2.43	$0.25 \le Y_o/D \le 0.8$
Weir Baffle D2	0.15D	1.2D	6.6	2.62	$0.35 \le Y_o/D \le 0.8$
Weir Baffle D2e	0.15D	2.4D	8.5	3.00	$0.35 \le Y_o/D \le 0.8$
Corner Baffle	0.10D	0.5D	7.81	2.63	$0.20 \le Y_o/D \le 0.8$
Weir Baffle D3	0.10D	0.6D	8.62	2.53	$0.20 \le Y_o/D \le 0.8$
Weir Baffle D4	0.10D	1.2D	9.0	2.36	$0.20 \le Y_o/D \le 0.8$
Weir Baffle D4e	0.10D	2.4D	9.6	2.50	$0.20 \le Y_o/D \le 0.8$

26

Empirical Equations for Baffle Hydraulics at Streaming Flow

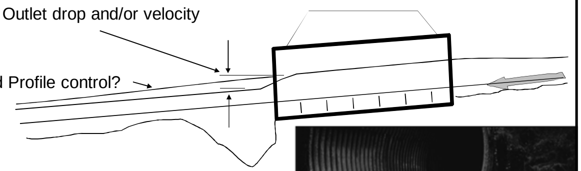
Angled Baffles (from Lang, 2008)

$$Y_o = W\left[\frac{Q}{C\sqrt{gS_oW^5}}\right]^{\frac{1}{a}}$$

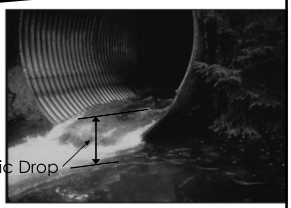


Angled Baffle Arrangement	L	Z_1	Z_2	C	A
Close-Spacing Tall Baffle Height	0.50W	0.132W	0.202W	0.122	1.85
Close-Spacing Medium Baffle Height	0.50W	0.092W	0.158W	0.123	1.70
Close-Spacing Low Baffle Height	0.50W	0.050W	0.112W	0.113	1.64
Intermediate-Spacing Tall Baffle Height	0.75W	0.132W	0.202W	0.139	1.82
Intermediate-Spacing Medium Baffle Height	0.75W	0.092W	0.158W	0.125	1.82
Intermediate-Spacing Low Baffle Height	0.75W	0.050W	0.112W	0.119	1.68
Far-Spacing Tall Baffle Height	1.00W	0.132W	0.202W	0.169	1.79
Far-Spacing Medium Baffle Height	1.00W	0.092W	0.158W	0.166	1.73
Far-Spacing Low Baffle Height	1.00W	0.050W	0.112W	0.180	1.64

Hydraulic profile – outlet drop



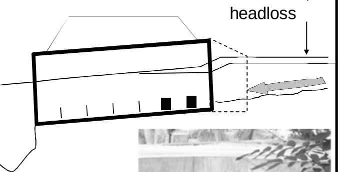
- Avoid Excessive Hydraulic Drop
- Evaluate with FishXing
- Match Normal Depth to Tailwater



Hydraulic profile – inlet control

Inlet Backwater
- Raises flood w.s.
- Causes deposition
- High velocity contraction
- Turbulence of jump

Inlet headloss targets
- 0.2' for juveniles
- 0.5' for adults



Solutions:
- Compromise hydraulic design
- Space inlet baffles
- Improve inlet
- Modify channel

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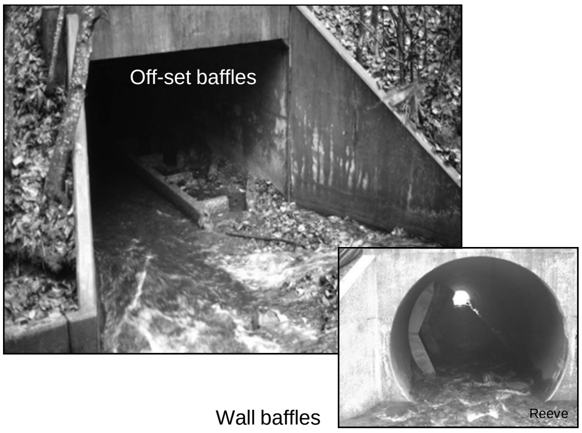
Dickerson Creek
Jacked pipe with baffles
as weirs at low and
moderate flows

30



Wall baffles

Baffling Summary Thoughts

- Retrofit only
- Debris snag
- Reduce capacity
- Turbulence blocks fish
  - Allowable EDF varies; higher with diversity
- Turbulence needed to scour, maintain roughness
  - 0.2’ drop per baffle
- Match normal depth to tailwater

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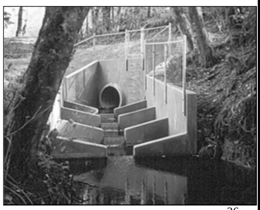
Fishways

- Rigid permanent bed control
- Passage typically optimized for target species, not diverse
- Narrow flow range
- Minimum footprint
- Often high construction, operation, maintenance cost

Fishways

- Entrance (attraction) is critical …. NFI = NFO
- Pool and weir styles typically used downstream of culverts.
- Passage behavior by species; leaping, swimming
- Criteria
  - Step height, step shape, depth
  - energy dissipation limits flow range
- Debris, sediment maintenance concerns



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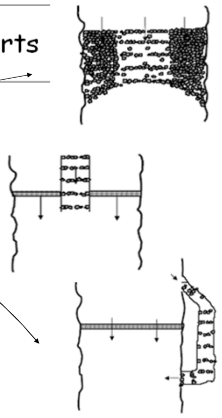
Fishway Styles at Culverts

- Full width
  - Attraction optimized
  - Space for diversity
- Partial width
  - Blend
- Bypass
  - Steepest; "Vertical" slope
  - Greatest flood capacity
  - Flow control necessary
  - Limited diversity



Bypass Fishways

Full Width

Partial Width

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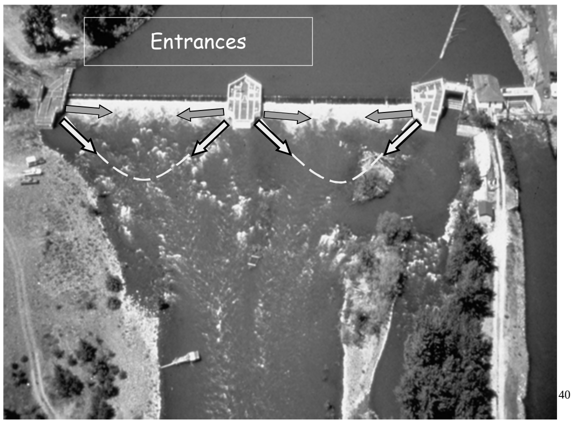
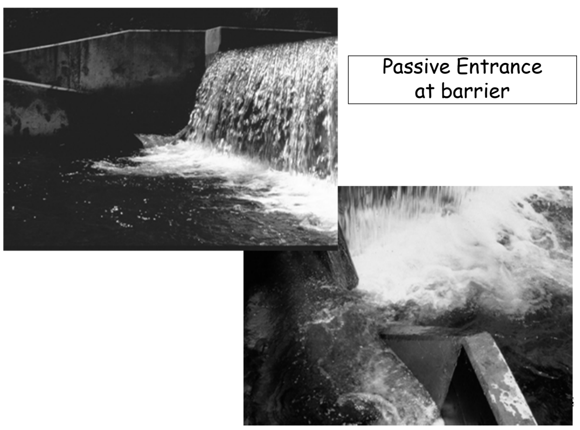

Entrances
40


Passive Entrance
at barrier

Fishways as grade control

Little Park Cr

Flow Control

Sediment, Debris

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Example of EDF in pool and weir fishway

Adult salmon design flow
EDF = 4 ft-lb/sec/ft3

Calculate EDF in a fishway pool

Q = 7.5 cfs
H = 1.0 ft
Pool; L=6', w=5', d=4'

$$EDF = \frac{62.4\ lb/ft^3 \times 7.5\ ft^3/s \times 1.0\ ft}{6\ ft \times 5\ ft \times 4\ ft}$$

$= 3.9$ ft-lb/sec/ft^3
< 4.0 ft-lb/sec/ft^3

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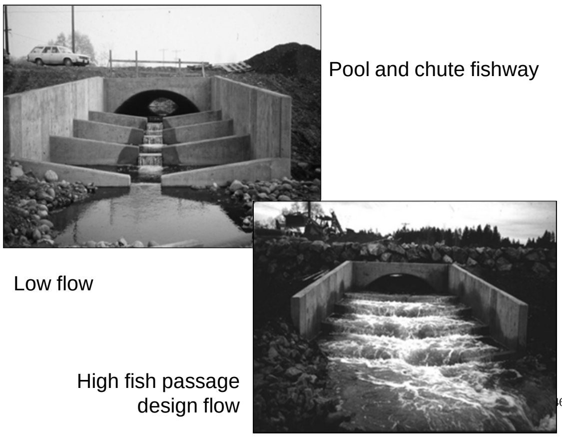
Pool and chute fishway



Low flow

High fish passage design flow

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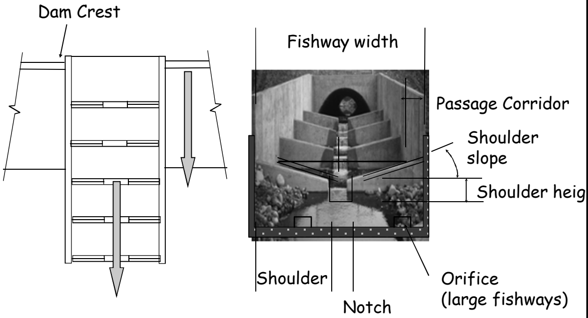
Pool and chute layout



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Kozmo Ken Bates
Kozmo@AquaKoz.com