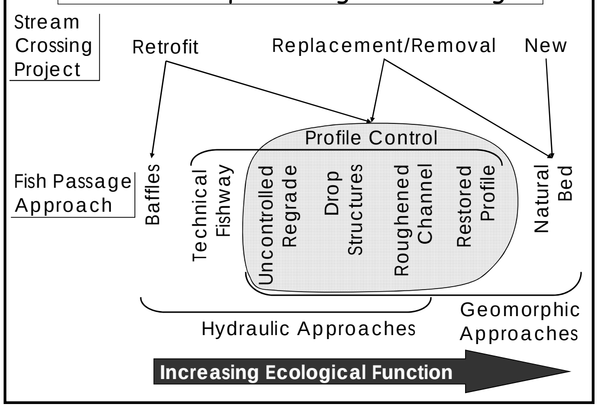
Profile Control

Michael Love, P.E.
mlove@h2odesigns.com

Tools for Aquatic Organism Passage



Profile Control Options

	Slope	Pros / Cons
Restored Profile	Limited by channel type	+ Passage diversity, Habitat - Scale/cost
Roughened Channel	Durability, bedload limit	+ Passage diversity - Species, failure risk
Boulder Weirs	≤5%	+ Passage diversity, Habitat - Failure risk
Rigid Weirs (log, concrete)	≤5%	+ Rigid, durable - Species, habitat
Technical Fishway	10% or "vertical"	+ Small footprint - Species specific, flow, sediment, debris

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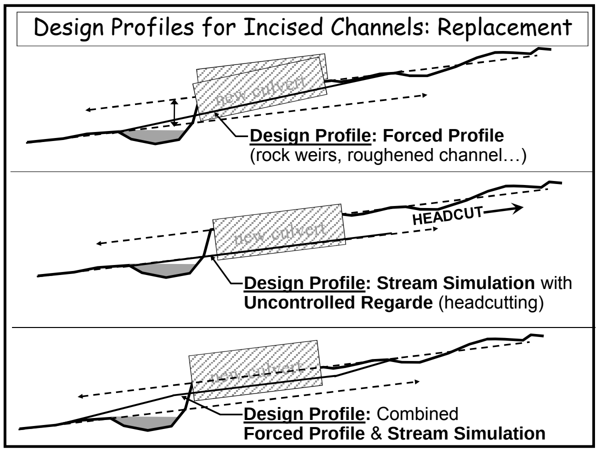
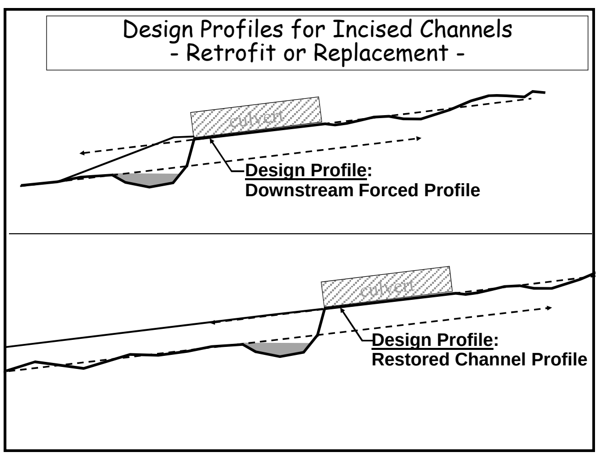
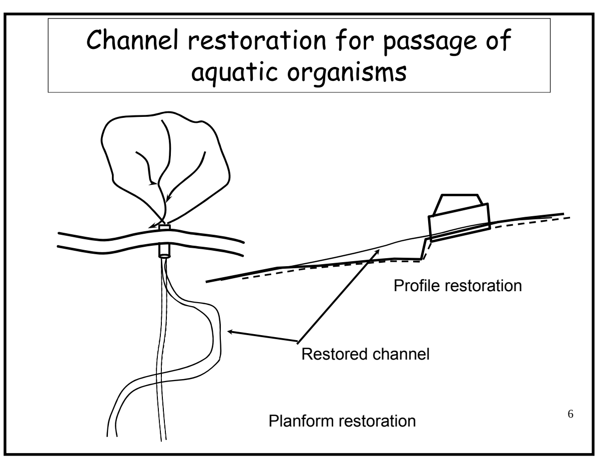

Design Profiles for Incised Channels: Replacement
new culvert
Design Profile: Forced Profile
(rock weirs, roughened channel…)
new culvert
HEADCUT
Design Profile: Stream Simulation with
Uncontrolled Regarde (headcutting)
new culvert
Design Profile: Combined
Forced Profile & Stream Simulation


Design Profiles for Incised Channels
- Retrofit or Replacement -
culvert
Design Profile:
Downstream Forced Profile
culvert
Design Profile:
Restored Channel Profile


Channel restoration for passage of
aquatic organisms
Profile restoration
Restored channel
Planform restoration
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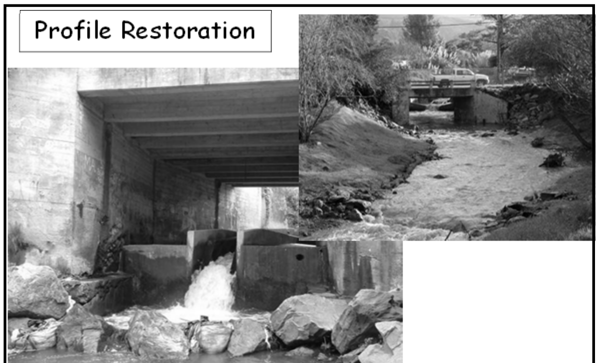
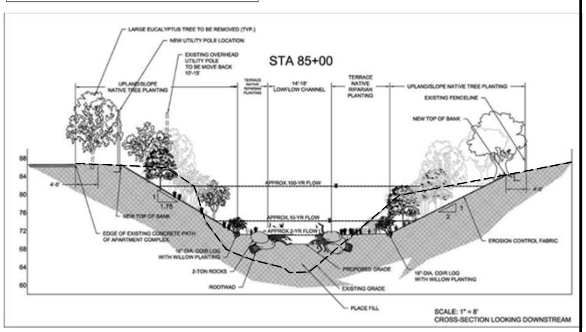
Profile Restoration



From Christine Chann,
San Pedro Creek
Watershed Coalition

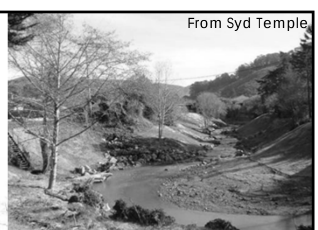
Restored 1,300 feet of incised channel:
- **Stabilized Banks**
- **Created Instream and Riparian Habitat**
- **Eliminated a Culvert Barrier**

Profile Restoration

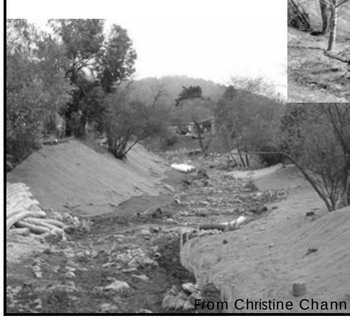


From Christine Chann,
San Pedro Creek
Watershed Coalition

Profile Restoration



From Syd Temple



From Christine Chann

- Sloped-back banks to reduced entrenchment
- Raised channel bed as much as 8 feet using native and imported fill
- Increase bankfull width by 20% and built floodplains
- Installed profile control to force riffles and pool

Profile Restoration
Outlet Creek

Channel restoration
for fish passage correction

Constructed 2000
Photos from 2005

Photos from Kozmo Bates

Profile Restoration
Outlet Creek

Upstream of Culvert
No Incision Experienced

Downstream of Project
Channel Remains Incised

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Photos from Kozmo Bates

Site 10 was constructed as a spanner racked additional wood.
Looking downstream and aggradation is along right bank.

Wood Count: 93 total wood fractions (Volume: 60.9 cubic meters)
17 large trees with rootwads,
69 large logs,
3 medium logs,
4 bunches of “small wood debris” (aka slash)

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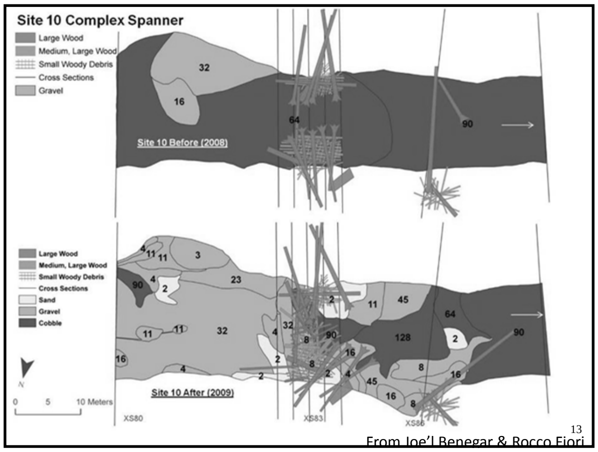
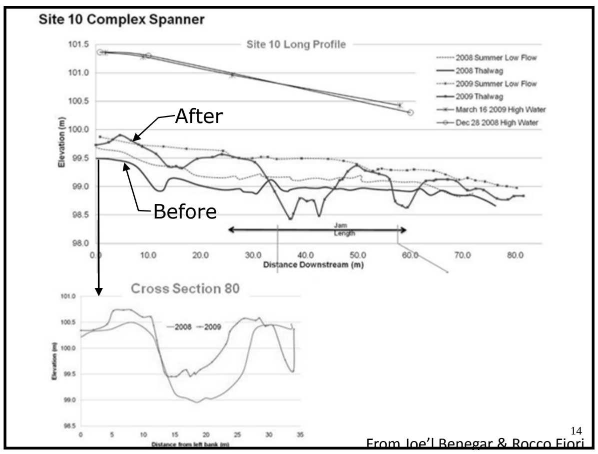
From Joe’l Benegar & Rocco Fiori

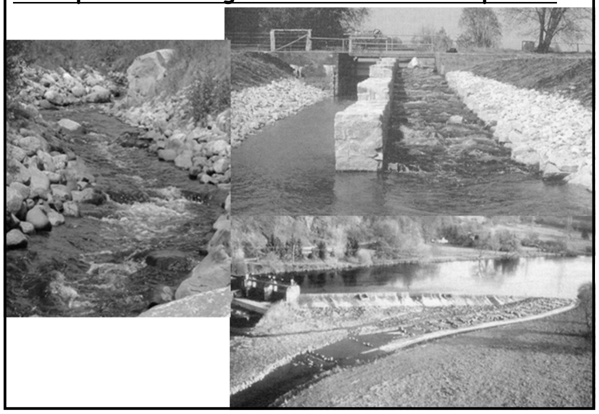




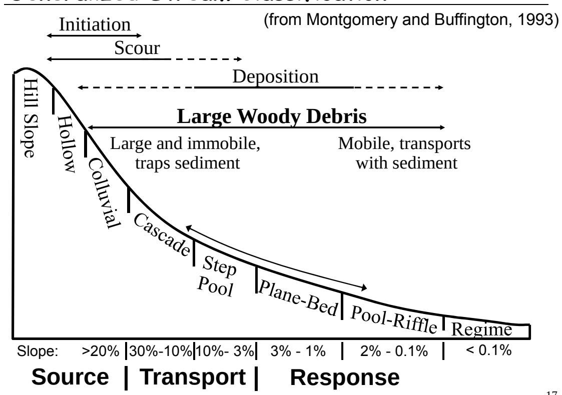
Geomorphically-Based Roughened Channels

- Channel constructed **steeper** than the adjacent channel (profile control)
- Based on morphology of steeper stream channel
- Stable *engineered streambed material (ESM)* forms channel bed & banks
- Quazi-hydraulic design for target species/lifestages (velocity, depth, drop, EDF)

Examples of a Roughened Channel in Europe



Generalized Stream Classification



Natural Steep Stream Morphology

Steep Boulder-Cobble Stream Channels

Natural Step Pool Stream Morphology

Geomorphically-Based Roughened Channel Concept

Common Channel Types

Increasing Slope ↓

- ❖ Roughened Riffles
- ❖ Plane Bed Channel (rock ramps)
- ❖ Rapids or Chutes & Pools
- ❖ Step-Pools
- ❖ Cascades & Pool

Caution:

- ➢ Only use channel types & slopes that the target species/lifestage are known to ascend
- ➢ Risk increases further the roughened channel characteristics deviates from the natural channel (i.e. slope, bed material, entrenchment)

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Plane-Bed (Rock Ramp) Roughened Channels

Slope & Length Thresholds:

- ➢ Slope Range: $\leq$ 4%
- ➢ Max Head Diff.: 5 feet
- ➢ Use chutes and Pools for Larger Head Differentials

Bed Morphology:

- ➢ Random placement of rock
- ➢ D100 < Channel Depth

Grub Creek "Rock Ramp"

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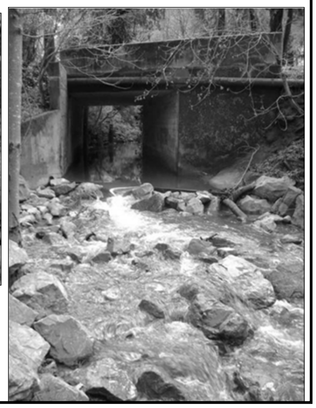
Woodacre Creek at San Geronimo Valley Road

2 Years After



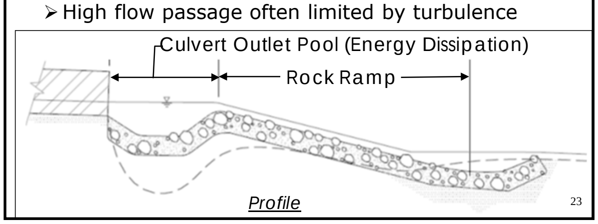
Plane-Bed (Rock Ramp) Roughened Channels

Fish Passage Pros:

- Doesn't rely on leaping abilities
- Large amount of hydraulic diversity at all flows

Cons:

- Shallow depths at low flows
- High flow passage often limited by turbulence



Profile

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Chutes & Pools Roughened Channels

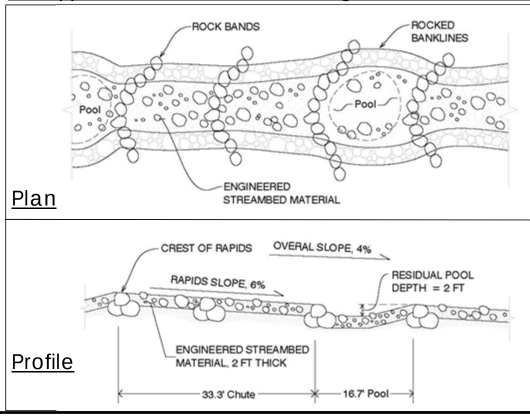
Slope & Length Thresholds (for armored pools):

- Slope Range: ≤ 8% across a chute
  ≤ 4% overall
- Max Head Diff.: 2 feet per chute

Bed Morphology:

- Chutes (Rapids) with Random Rock Placement
- D100 < Channel Depth
- Pools Armored with Coarse Bed Material

Typical Chutes & Pools Roughened Channel



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Chutes & Pools Roughened Channels

Fish Passage Pros:

- No leaping required
- Large amount of hydraulic diversity
- Pools provide resting/ holding habitat and dissipate energy

Cons:

- Shallow depths at low flows, especially on steep chutes
- High flow passage often limited by turbulence

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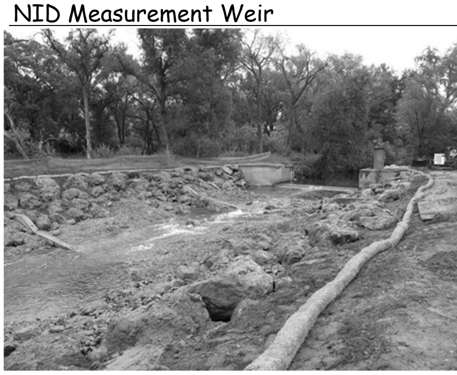
NID Measurement Weir



Concrete sills provide added stability & control subsurface flow

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NID Measurement Weir

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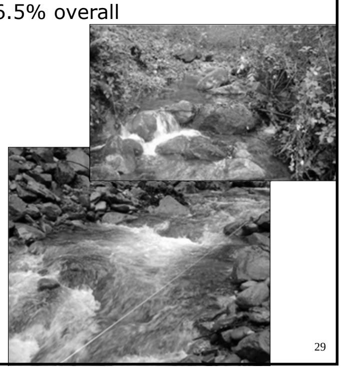
Step-Pool Roughened Channels

Slope & Length Thresholds:

- Slope Range: 3% to 6.5% overall

Bed Morphology:

- Rhythmic Pattern of Boulder Steps/Weirs
- Larger Rocks in Step 0.5 to 1.0 Bankfull Depth
- Oversized Pool every 3 to 5 feet of drop
- Pools Armored with Coarse Bed Material



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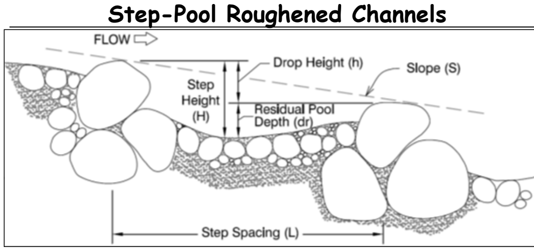
Step-Pool Roughened Channels



Morphology of Steps (general guidance):

- Step-pool channel slopes $\leq$4%:
  $2 \leq H / L / S \leq 5$ (Chin 1998)
- D50 of Rocks forming Step ≈ Step Height (H) (Chin 1999; Chartrand & Whiting, 2000)
- Drop Height (h) & Pool Depth (dr) should satisfy fish passage criteria

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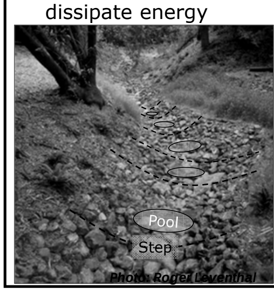
Step-Pool Roughened Channels

Fish Passage Pros:

- Good low-flow passage
- Pools provide resting/ holding habitat and dissipate energy



Cons:

- May require fish to leap
- Challenging to construct complex steps
- Not suited for large, wide or unconfined streams
- Steeper slopes with small drops (i.e. 6 inch) result in small pools
  - Less holding/energy dissipation
  - Channel instability (streaming flows)

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Gulch 7 Step Pool
Roughened Channel-Stream Simulation Hybrid

2006

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Gulch 7 Step Pool
Roughened Channel-Stream Simulation Hybrid

2013

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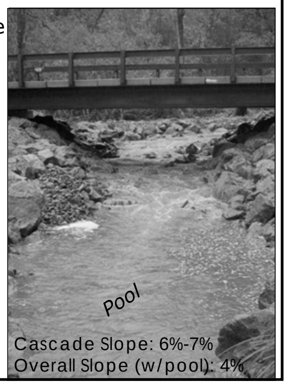
Cascade & Pool Roughened Channels

Slope & Length Thresholds:

- Slope Range: > 5% cascade
  $\geq$ 4% overall

Bed Morphology:

- Complex series of small drops and pools
- Largest keystone boulders $\geq$ bankfull depth
- Drops and constructions form jet & wake hydraulics
- Armored pool every 3 to 5 feet of drop to dissipate energy



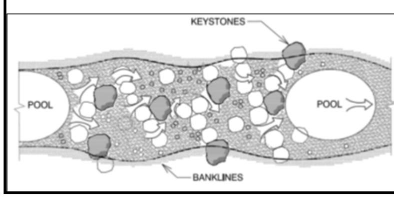
Cascade & Pool Roughened Channels

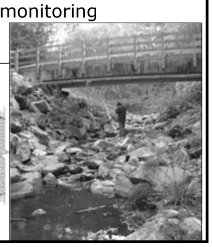
Fish Passage Pros:

- Passage of non-leaping fish
- Diverse high-flow hydraulics for passage
- Pools provide resting/ holding habitat and dissipate energy

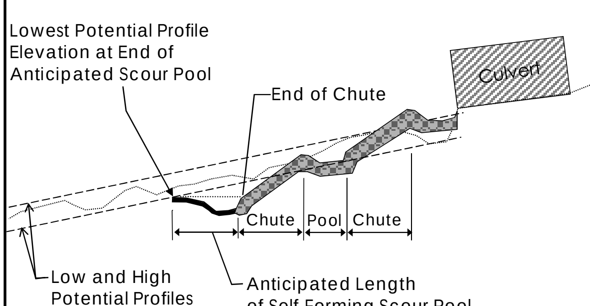
Cons:

- Poor low-flow passage
- Requires straight & entrenched channel reach
- Considered experimental for juvenile passage, May require monitoring





Profile Control Transitions
Chutes & Pools Roughened Channel



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The Roughened Channel Design Concept

Limitation - Lack of Sediment Continuity

Engineered Bed Material is:

- Larger than bedload transported into roughened channel
- No replacement by natural bedload material
- Sized to be stable to a *bed design flow* (Q100yr)

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Developing the Channel Design and Bed Mixture

The **Iterative** Design Process

1. Calculate Qbed & Qfish
2. Develop initial channel shape & slope to fit site
3. Calculate Stable D84 rock size at Qbed:
   - Initial guess for D84
   - Use hydraulic roughness relationships dependent on flow & substrate size
   - Calculate Unit Discharge for channel
   - Calculate a stable D84

   Iterate
5. Evaluate fish passage conditions

If unsuitable, change channel shape/slope and repeat no. 2-5

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Estimating Hydraulic Roughness

Flow resistance for steep mountain streams:

$$n = \frac{0.0926R^{1/6}}{1.16+2\log(R/D_{84})}$$ (Limerinos, 1970)

n – Manning's roughness; R – Hydraulic Radius

$$\sqrt{\frac{8}{f}} = 5.62 \bullet \log_{10}\left(\frac{h}{D_{84}}\right) + 4$$ (Bathurst, 1985)

f – Darcy Friction Factor; h – Water Depth; D_{84} – 84% of bed material finer than D_{84}

Numerous relationships developed with varying limitations.
See Appendix B in CDFG Part XII for more relationships.

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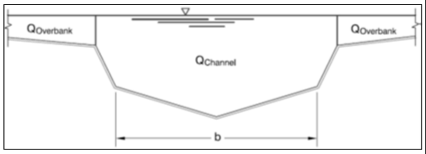
Designing a Stable Bed Using Unit Discharge Method

Unit Discharge:

$$q = \frac{Q_{channel}}{b}$$



Water surface slope

Unit discharge (cfs/ft) at *stable bed design flow* (100 year flow)

$$D_{30-ACOE} = \frac{1.95 S^{0.555} 1.25 q^{\frac{2}{3}}}{g^{\frac{1}{3}}}$$

Gravitational acceleration (ft/s²)

from ACOE EM 1110-2-1601 based on Abt et al, 1988

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Developing Gradation of Bed Material

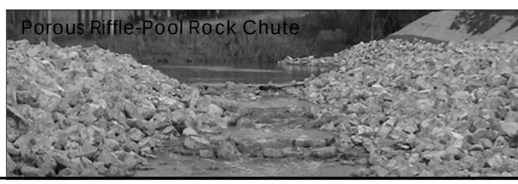
ACOE (1994) produces **porous uniform gradation** for bed material:

D84/D15 = 1.7 to 2.7

Natural channel streambed material has wide gradation:

D84/D15 = 8 to 14 (typical in steeper streams)

- Larger Material (>D50) is framework for stability
- Smaller material (<D50) fills voids to control porosity



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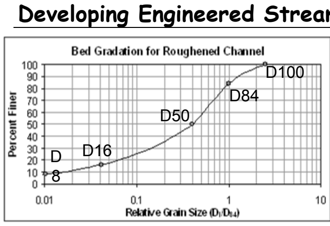
Developing Engineered Streambed Material (ESM)



Gradation Shift for ESM:

$D84_{ESM} = 1.5\ (D30_{ACOE})$

(from WDFW, 2003)

For $D_i \geq D50_{ESM}$ use Ratios Relative to D84:

$D100_{ESM} = 2.5(D84_{ESM})$

$D50_{ESM} = 0.4(D84_{ESM})$

(from WDFW, 2003)

Sometimes produces oversized rock

For $D_i < D50_{ESM}$ use Fuller-Thompson Equation:

$$D_i = (2 \cdot i)^{1/n} D_{50}$$

n ranged from 0.45 to 0.70

Set n to achieve D8 ≃ 2mm

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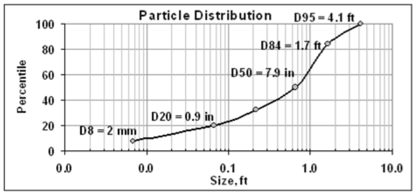
Sizing and Specifying Material Gradations



Example Specifications for Gradation of ESM

Percent of Mix	Range of Size (Intermediate Axis)	
16	20 in	48 in
34	8 in	20 in
18	3 in	8.0 in
12	¼ in	1.0 in
8	Passes Sieve #10 **(2 mm)**	

Use largest size class to form structures (steps, keystones)

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Evaluating Fish Passage Conditions
Rock Ramps/Chutes & Pools/Cascades

In Ramps, Chutes & Cascades

- Ave. Cross Section Water Velocity (U)
- Max Water Depth
- Turbulence ($EDF = gUS$)

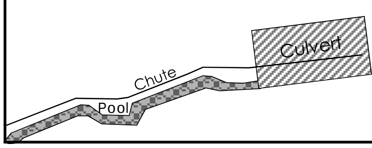
In Armored Pools

- Pool Depth
- Turbulence (EDF) from change in Velocity Head

$$EDF = \frac{\gamma Q h}{2gV}$$

where,

$$h = \frac{U_{chute}^2 - U_{pool}^2}{2g}$$



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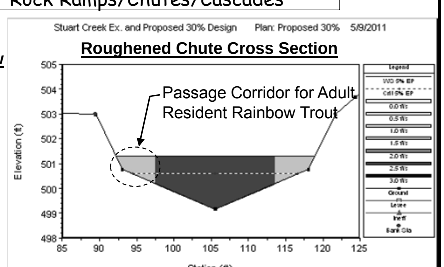
Dividing Channel into Subsections
Rock Ramps/Chutes/Cascades

High Passage Flow
Adult Resident Rainbow Trout



Passage Conditions in Subsection

Mean Width = 4.5 ft (DFG min = 4 ft)
Ave. Depth = 0.76 ft
Ave. Velocity =1.45 ft/s

Flow in Section = 5.0 cfs
Water Surface Slope = 0.03 ft/ft
EDF = 2.7 ft-lb/s/ft^3

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Construction Sequencing and Methods

1. Grading and Compact

2. Placing Rock Structures

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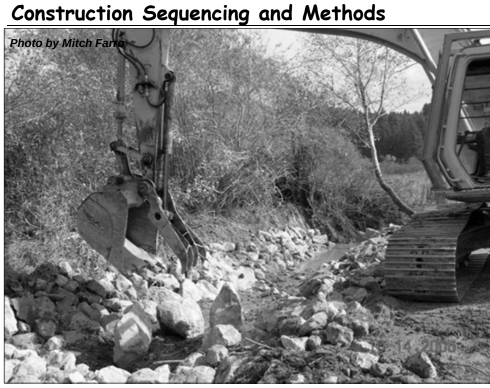
Construction Sequencing and Methods



3. Keystones and Bankline Rock

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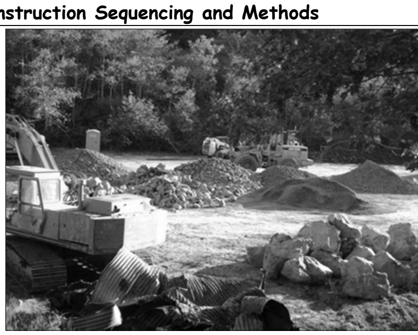
Construction Sequencing and Methods



4. Stockpile Engineered Streambed Material onsite. Within a small section of channel, place material in correct proportions and mix with excavator bucket ...

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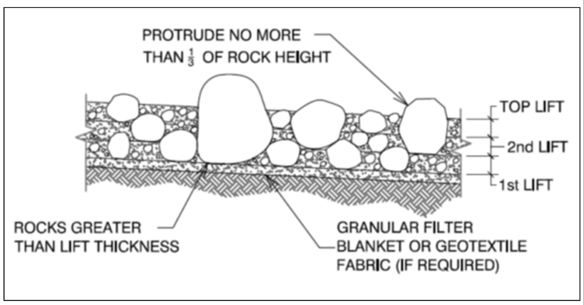
Construction Sequencing and Methods

4. ...If delivered premixed to site, must be remixed in channel due to settling in truck.

5. Install Engineered Streambed Material (ESM)…

Construction Sequencing and Methods



5. ..Construct channel bed in lifts. Compact each lift.

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Construction Sequencing and Methods

6. Fill voids in bed and banks with finer material (typically river run).

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Construction Sequencing and Methods

For best results: Flood each lift and then use a plate compactor

7. Flood channel bed and banklines to fill voids, compact bed, and wash fines off surface. Collect and remove fines from bottom of reach.

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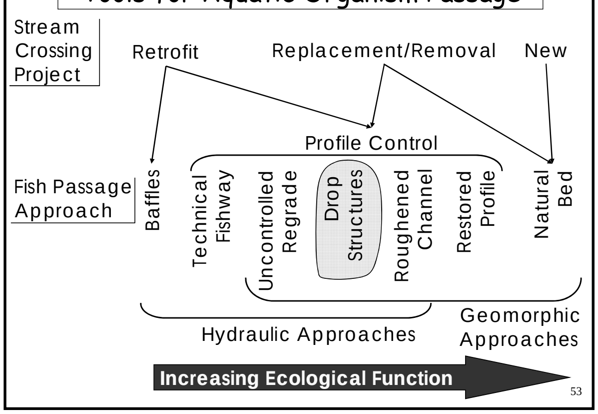
Tools for Aquatic Organism Passage



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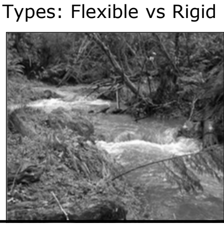
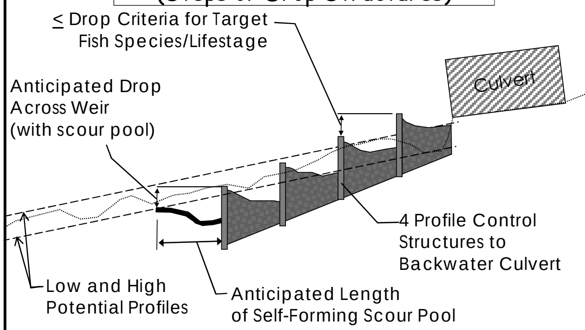
Forced Profiles with Drop Structures

Drop Structures (weirs, sills, chutes):

- Discrete structures
- Distinct drops in the channel
- Native streambed material between
- Types: Flexible vs Rigid



Profile Control Transitions (Steps or Drop Structures)



❖ Place End of Profile Control based on Low Potential Profile with Anticipated Scour Pool

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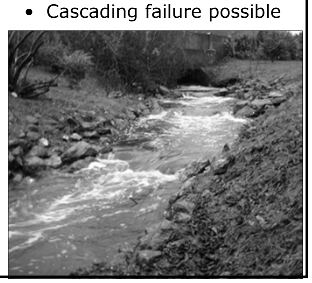
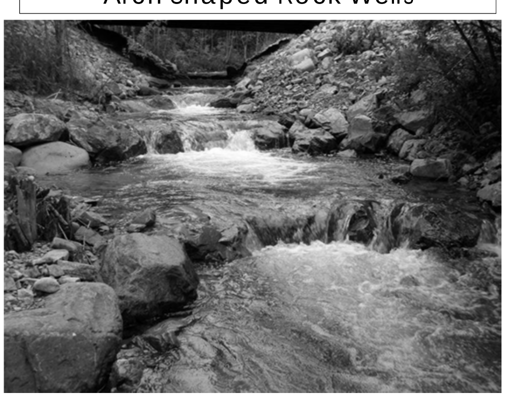
Rock Weirs & Chutes

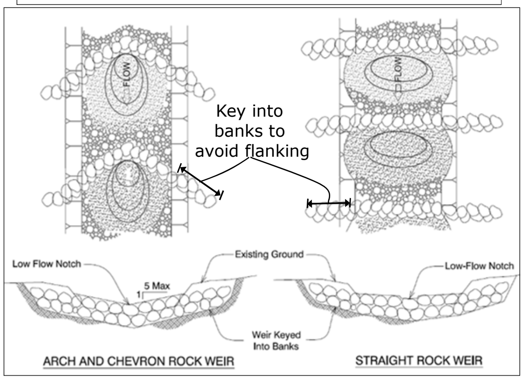
- Irregular surface provide hydraulic diversity
- Withstands small shifts, and easy to field adjust
- Maintains channel shape
- Lower cost than roughened channel
- Requires skilled operator
- Larger Vertical Tolerance
- Built at lower slopes than rigid weirs (max 4 to 5%)
- Cascading failure possible



Arch Shaped Rock Weirs

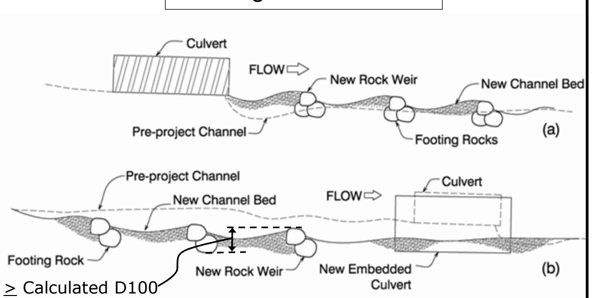


Shape of Rock Weirs

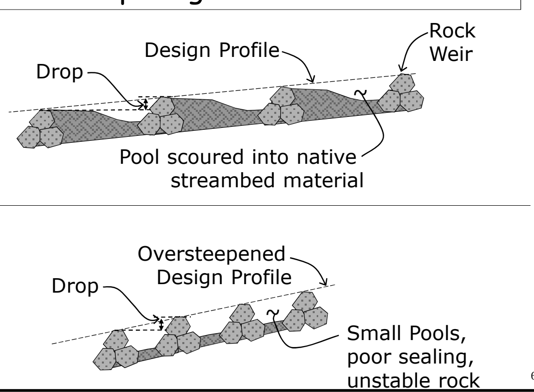


From CA DFG Restoration Manual, Part XII (2009)

Footing of Rock Weirs



Spacing of Rock Weirs



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Rock Sizing for Weirs

From Design of Rock Weirs (NRCS, 2000)

$$D_{50-riprap} = \frac{2.9wDS}{CK}$$

Far West States (FWS) Lane Method riprap sizing method (NRCS, 1996)

w = channel top width at the design flow (feet)

D = maximum depth of flow in channel (feet)

S = channel slope (feet/feet)

C = coefficient for channel curvature (1 for straight channels)

K = side slope coefficient. 0.53 for 1.5H:1V, 0.87 for 3H:1V,

Rock Weir Gradation

Dmin-Weir = 0.75 (D50-Riprap)
D50-Weir = 2 (D50-Riprap)
D100-Weir = 4(D50-Riprap)

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Rock Riffles and Chutes as Drop Structures

Individual Chutes:
- Energy dissipation
- Diversity
- Slope from crest to crest typically ≤ 3%

Shape of Chute:
- Top width
- Head differential (typ. 2 ft max)
- Plan vee
- Cross section vee
- Low flow channel

Riffles and Chutes

Spring Prairie Cr
Cobble riffle

From Luther Aadland

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Rock Riffles and Chutes

Rigid Weirs: Concrete, sheet pile, …

- Objectives:
  - Steepen grade (self sealing)
  - Rigid permanent bed control to maintain steep grade
- Max 5% grade in small streams
- Prefabricated; installation easy but demands care
- Deeper keys into bed and banks than rock weirs
- Shape to fit channel and control thalweg (v-shape)
- Can add hydraulic complexity along crest to improve passage

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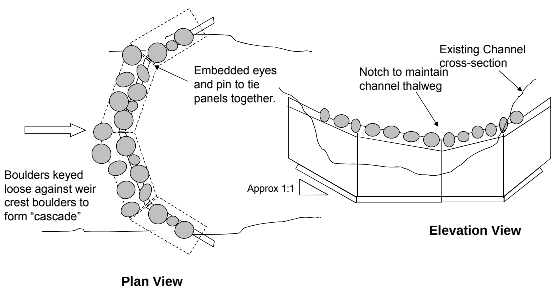

Modular Arch Drop Structure

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Horizontal Double Log Sills

- Keeps log wetted to increases longevity
- Easy to construct
- Spreads out flow
  - Forms wide pools, rather than long
  - Anticipate bank erosion when keying
- Wide smooth surface/ low hydraulic complexity
  - May not be good for juvenile passage

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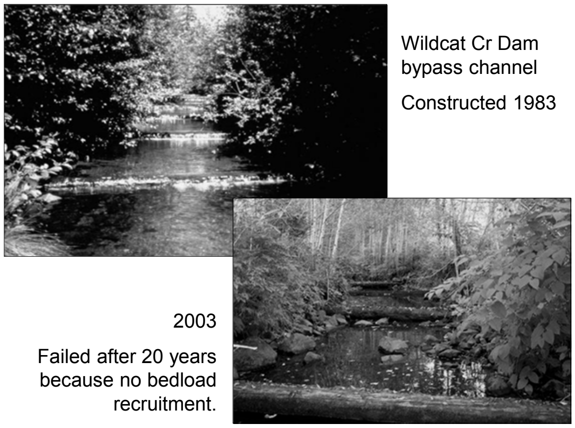
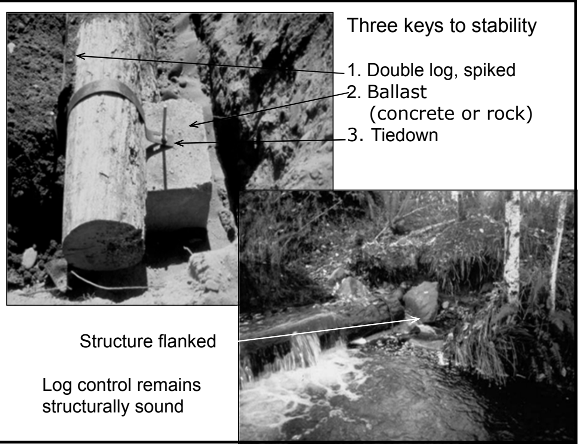


Wildcat Cr Dam bypass channel

Constructed 1983

2003

Failed after 20 years because no bedload recruitment.

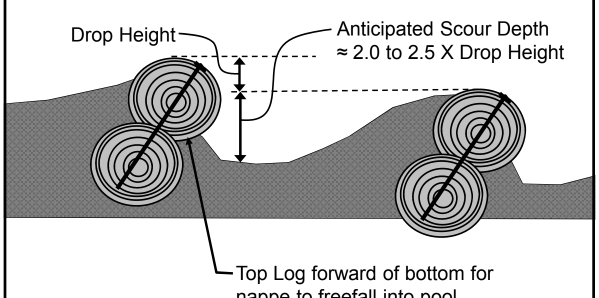


Three keys to stability

1. Double log, spiked
2. Ballast (concrete or rock)
3. Tiedown

Structure flanked

Log control remains structurally sound



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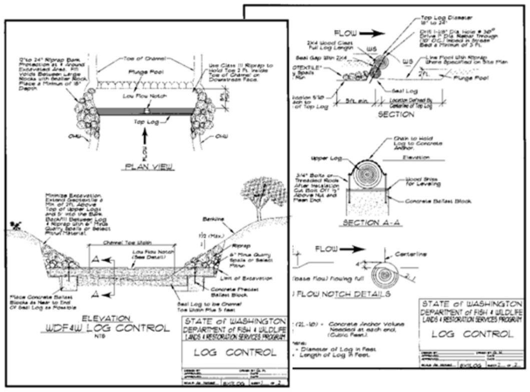

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http://www.wa.gov/wdfw/hab/engineer/cm/culvert_manual_final.pdf

Complex Log Steps

Index Creek
Vee log weirs

74

Complex Log Steps

Physt R. trib

"X-weirs"

75

Natural Log Steps

Complex Log Steps

Complex Log Steps

Log controls

- **Straight**
  - Objective: Steepen grade, optimize select passage, minimize cost and length, secure elevation control
  - 5% grade max as bed retention
  - Uniform channel
  - Secure designs available
- **V- Shape**
  - Objective: Steepen grade, deepen thalweg, narrow channel, provide select passage
  - More diverse channel
- **Can be made complex**
- **Durable**

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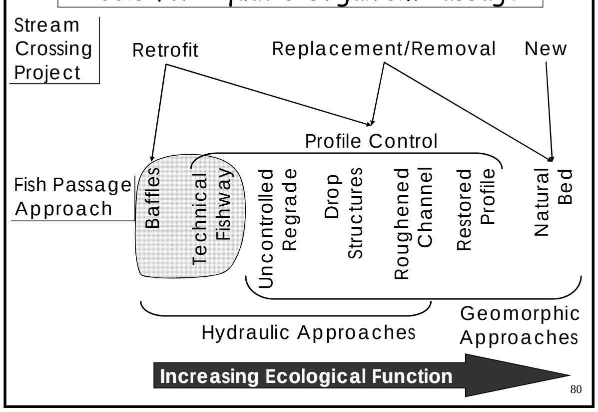
Tools for Aquatic Organism Passage



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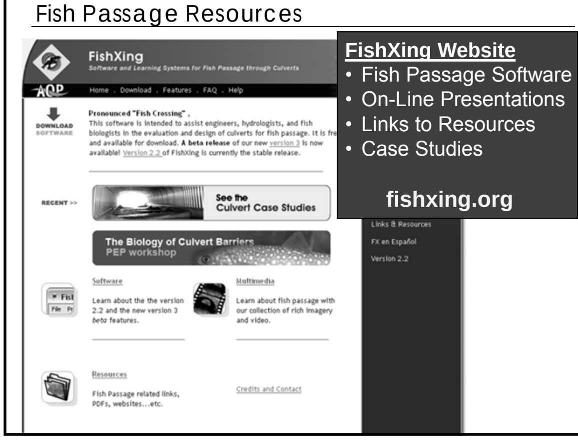
Fish Passage Resources



Fish Passage Case Studies

fishxing.org