Profile Control

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

Tools for Aquatic Organism Passage

Stream Crossing Project

Fish Passage Approach

Profile Control

Retrofit
Replacement/Removal
New

Technical Fishway
Uncontrolled Regrade
Drop Structures
Roughened Channel
Restored Profile
Natural Bed

Hydraulic Approaches

Geomorphic Approaches

Increasing Ecological Function
Profile Control Options

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<tr>
<th>Profile</th>
<th>Slope</th>
<th>Pros / Cons</th>
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<tr>
<td>Restored Profile</td>
<td>Limited by channel type</td>
<td>+ Passage diversity, Habitat - Scale/cost</td>
</tr>
<tr>
<td>Roughened Channel</td>
<td>Durability, bedload limit</td>
<td>+ Passage diversity - Species, failure risk</td>
</tr>
<tr>
<td>Boulder Weirs</td>
<td>≤5%</td>
<td>+ Passage diversity, Habitat - Failure risk</td>
</tr>
<tr>
<td>Rigid Weirs</td>
<td>≤5%</td>
<td>+ Rigid, durable - Species, habitat</td>
</tr>
<tr>
<td>Technical Fishway</td>
<td>10% or “vertical”</td>
<td>+ Small footprint - Species specific, flow, sediment, debris</td>
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</tbody>
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Design Profiles for Incised Channels: Replacement

- **Design Profile:** Forced Profile (rock weirs, roughened channel…)
- **Design Profile:** Stream Simulation with Uncontrolled Regarde (headcutting)
- **Design Profile:** Combined Forced Profile & Stream Simulation
Design Profiles for Incised Channels - Retrofit or Replacement -

Design Profile: Downstream Forced Profile

Design Profile: Restored Channel Profile

Channel restoration for passage of aquatic organisms

Profile restoration

Restored channel

Planform restoration
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
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

From Syd Temple

Profile Restoration

Channel restoration for fish passage correction

Constructed 2000
Photos from 2005

Outlet Creek

Photos from Kozmo Bates
Profile Restoration
Outlet Creek

Upstream of Culvert
No Incision Experienced

Downstream of Project
Channel Remains Incised

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)

From Joe’l Benegar & Rocco Fiori
Before

After

Site 10 Complex Spanner

Site 10 Before (2008)

Site 10 After (2009)

Site 10 Long Profile

Cross Section 80

Elevation (m)

Distance Downstream (m)

Before

After

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**

(from Montgomery and Buffington, 1993)

- **Source**
  - Hill Slope
  - Hollow
  - Colluvial
- **Transport**
  - Cascade
  - Step
  - Pool
  - Plane-Bed
  - Pool-Riffle
- **Response**
  - Regime

**Large Woody Debris**
- Large and immobile, traps sediment
- Mobile, transports with sediment

**Natural Steep Stream Morphology**

Steep Boulder-Cobble Stream Channels

- Plane-bed
- Step-Pool
- Cascade
Natural Step Pool Stream Morphology

Geomorphically-Based Roughened Channel Concept

Common Channel Types

- 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)
**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
- \( D_{100} < \text{Channel Depth} \)

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**Woodacre Creek at San Geronimo Valley Road**

*Before*  
*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

**Chutes & Pools Roughened Channels**

**Slope & Length Thresholds (for armored pools):**
- Slope Range: \( \leq 8\% \) across a chute
  \( \leq 4\% \) 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

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
Concrete sills provide added stability & control subsurface flow
**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

**Morphology of Steps (general guidance):**
- Step-pool channel slopes \( \leq 4\% \):
  \[ 2 \leq \frac{H}{L/S} \leq 5 \]  
  (Chin 1998)
- D50 of Rocks forming Step \( \approx \) Step Height (H)  
  (Chin 1999; Chartrand & Whiting, 2000)
- Drop Height (h) & Pool Depth (dr) should satisfy fish passage criteria
**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

Photo: Roger Leventhal
Gulch 7 Step Pool
Roughened Channel-Stream Simulation Hybrid

Slope & Length Thresholds:
- Slope Range: > 5% cascade
  > 4% overall

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

Cascade Slope: 6%-7%
Overall Slope (w/pool): 4%
**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

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**Profile Control Transitions**

**Chutes & Pools Roughened Channel**

- Lowest Potential Profile
- Elevation at End of Anticipated Scour Pool
- End of Chute
- Chute Pool Chute
- Anticipated Length of Self-Forming Scour Pool
- Culvert

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Low and High Potential Profiles
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
4. Evaluate fish passage conditions
   - If unsuitable, change channel shape/slope and repeat no. 2-5
5. Iterate
**Estimating Hydraulic Roughness**

Flow resistance for steep mountain streams:
\[
n = \frac{0.0926 R^{1/6}}{1.16 + 2 \log (R/D_{84})} \quad \text{(Limerinos, 1970)}
\]

Manning’s roughness

\[
\frac{8}{\sqrt{f}} = 5.62 \cdot \log_{10} \left( \frac{h}{D_{84}} \right) + 4 \quad \text{(Bathurst, 1985)}
\]

Water Depth

\[
\frac{8}{\sqrt{f}} \text{ Darcy Friction Factor}
\]

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:
\[
q = \frac{Q_{\text{channel}}}{b}
\]

Gravitational acceleration (ft/s²)

\[
D_{30-ACOE} = 1.95S^{0.55} \cdot 1.25q^{2/3}
\]

Water surface slope

\[
D_{30-ACOE} = \frac{1}{g^{3/2}}
\]

Unit discharge (cfs/ft) at stable bed design flow (100 year flow) from ACOE EM 1110-2-1601 based on Abt et al, 1988
Developing Gradation of Bed Material

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

- \( \frac{D_{84}}{D_{15}} = 1.7 \) to 2.7

Natural channel streambed material has wide gradation:

- \( \frac{D_{84}}{D_{15}} = 8 \) to 14 \text{ (typical in steeper streams)}

  - Larger Material (>\( D_{50} \)) is framework for stability
  - Smaller material (<\( D_{50} \)) fills voids to control porosity

![Porous Riffle-Pool Rock Chute](image)

Developing Engineered Streambed Material (ESM)

**Gradation Shift for ESM:**

- \( D_{84_{ESM}} = 1.5 \left( D_{30_{ACOE}} \right) \)
  
  (from WDFW, 2003)

**For** \( D_i \geq D_{50_{ESM}} \) **use**

- Ratios Relative to \( D_{84} \):

  - \( D_{100_{ESM}} = 2.5(D_{84_{ESM}}) \)
  - \( D_{50_{ESM}} = 0.4(D_{84_{ESM}}) \)

  (from WDFW, 2003)

**For** \( D_i < D_{50_{ESM}} \) **use**

- **Fuller-Thompson Equation:**

  \[
  D_i = (2 \cdot i)^{\frac{1}{n}} D_{50}
  \]

  \( n \) ranged from 0.45 to 0.70
  Set \( n \) to achieve \( D_8 \approx 2\text{mm} \)

Sometimes produces oversized rock
Sizing and Specifying Material Gradations

Example Specifications for Gradation of ESM

<table>
<thead>
<tr>
<th>Percent of Mix</th>
<th>Range of Size ( Intermediate Axis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>20 in 48 in</td>
</tr>
<tr>
<td>34</td>
<td>8 in 20 in</td>
</tr>
<tr>
<td>18</td>
<td>3 in 8 in</td>
</tr>
<tr>
<td>12</td>
<td>¼ in 1.0 in</td>
</tr>
<tr>
<td>8</td>
<td>Passes Sieve #10 (2 mm)</td>
</tr>
</tbody>
</table>

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

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

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

where,
$$h = \frac{U_{chute}^2 - U_{pool}^2}{2g}$$
Dividing Channel into Subsections
Rock Ramps/Chutes/Cascades

High Passage Flow
Adult Resident
Rainbow Trout

Roughened Chute Cross Section

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/ft³

Construction Sequencing and Methods

1. Grading and Compact
2. Placing Rock Structures
3. Keystones and Bankline Rock

4. Stockpile Engineered Streambed Material onsite. Within a small section of channel, place material in correct proportions and mix with excavator bucket ...
4. ...If delivered premixed to site, must be remixed in channel due to settling in truck.

5. Install Engineered Streambed Material (ESM)...

5. ...Construct channel bed in lifts. Compact each lift.
6. Fill voids in bed and banks with finer material (typically river run).

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

*For best results:* Flood each lift and then use a plate compactor.
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- Drop Structures
- Roughened Channel
- Restored Profile
- Natural Bed

Hydraulic Approaches

- Geomorphic Approaches

Increasing Ecological Function

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

Low and High Potential Profiles

Anticipated Drop Across Weir (with scour pool)

4 Profile Control Structures to Backwater Culvert

< Drop Criteria for Target Fish Species/Lifestage

Anticipated Length of Self-Forming Scour Pool

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

Key into banks to avoid flanking

From CA DFG Restoration Manual, Part XII (2009)
Footing of Rock Weirs

> Calculated D100

Spacing of Rock Weirs

Pool scoured into native streambed material

Oversteepened Design Profile

Small Pools, poor sealing, unstable rock
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

- \( D_{min-Weir} = 0.75 \times (D_{50-Riprap}) \)
- \( D_{50-Weir} = 2 \times (D_{50-Riprap}) \)
- \( D_{100-Weir} = 4 \times (D_{50-Riprap}) \)

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

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
3 pre-cast panels for channels up to 12 ft

Vary arch orientation at channel bends

Boulders keyed loose against weir crest boulders to form "cascade"

Embedded eyes and pin to tie panels together.

Approx 1:1

Elevation View

Existing Channel cross-section

Notch to maintain channel thalweg

Plan View

Modular Arch Drop Structure

Log Controls
Used to raise incised channel

Passage optimized, Habitat not
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

Log controls

Wildcat Cr Dam bypass channel
Constructed 1983

2003
Failed after 20 years because no bedload recruitment.
Structure flanked
Log control remains structurally sound

Three keys to stability
1. Double log, spiked
2. Ballast (concrete or rock)
3. Tiedown

Log controls: Rule of Thumb for Scour

Drop Height
Anticipated Scour Depth ≈ 2.0 to 2.5 X Drop Height

Top Log forward of bottom for nappe to freefall into pool
Complex Log Steps

Index Creek
Vee log weirs
Complex Log Steps

Physt R. trib
"X-weirs"

Barnard

Natural Log Steps

Training logs along bank confine flow

Dunn Creek
Complex Log Steps

No Rock Used
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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Fish Passage Resources

FishXing
Software and Learning Systems for Fish Passage through Culverts

Fish Passage Case Studies

FishXing Website
- Fish Passage Software
- On-Line Presentations
- Links to Resources
- Case Studies

FishXing.org