Fish Ramps in the Inter-Mountain West and Great Plains

National Fish Passage Program

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“Whiskey is for drinking, water is for fighting over” – Mark Twain

55% of NID Dams are west of the Mississippi
Water Supply and Irrigation Diversions

Number of Dams in the Southeast Aquatic Barrier Inventory versus the NID 2020

Legend
SARP Boundary
Number Dams
- 500.000000 - 2004.000000
- 2004.000001 - 4489.000000
- 4489.000001 - 7364.000000
- 7364.000001 - 14324.000000
- 14324.000001 - 30136.000000
- SARP Inventory of Dams
Water Supply and Irrigation Diversions

- Typically <3 meters in height
- Many are undocumented

Wood and Metal Private Irrigation Dam
Big Hole Valley, Montana
Photo by: Matt Blank

From: Preliminary Engineering Report, Allendale Canal Intake and Fish Screen, Montana
Zone of Passage refers to the contiguous area of sufficient lateral, longitudinal, and vertical extent in which adequate hydraulic and environmental conditions are maintained to provide a route of passage through a stream reach influenced by a dam (or stream barrier).

* The U.S. Fish and Wildlife Service does not generally accept turbine entrainment/passage as the primary downstream migration route.

Engineered, Not Natural

Fishery and Aquatic Conservation

Engineered, Not Natural

Fishway

Attraction Flow = Fishway Discharge + AWS

Technical

Nature-Like

Partial Ramps

Ramps

Guidance

Physical/Exclusion

Behavioral

Bypass

Step-Pool

Roughened Channel

Volitional

Voluntary

Volutional

Transport

Plunge Pool

Voluntary

Trap

Truck

USFWS Northeast Region (R5)
Fisheries, Fish Passage Engineering
B. Towler, 07/30/2014

FISHWAY TYPES
Fish Ramps in This Region

Concrete Grouted

Un-Grouted

Roughened Riffle Ramp  
Riffle-Ramp with Steps  
Step-Pool Ramp
Grouted Nature-Like Ramps

Big Creek, Wyoming. Photo courtesy of Wyoming Game and Fish

Harland Dam Fish Passage, Colorado

Fisheries and Aquatic Conservation
Un-Grouted Nature-Like Ramps

Step-Pool Ramp, Minnesota

Step-Pool Ramp, Kansas

Riffle Ramp, Granby, Colorado
Biology

- >250 different fish species in Great Plains and Intermountain West

Smallest

Largest

Biomass

Fisheries and Aquatic Conservation
Biology

- Smallest: Need low water velocity and turbulence
- Largest: Need depth and space
- Biomass: Need space
### Design Criteria for Fish Passage Structures Colorado

<table>
<thead>
<tr>
<th>Species Assemblage</th>
<th>Velocity (ft/s)</th>
<th>Minimum Depth (ft)</th>
<th>Vertical Drop (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native minnows and darters</td>
<td>1-2</td>
<td>0.50</td>
<td>0.00</td>
</tr>
<tr>
<td>Native dace and suckers</td>
<td>2-3</td>
<td>0.50</td>
<td>0.00</td>
</tr>
<tr>
<td>Trout</td>
<td>3-6</td>
<td>0.5-1.0</td>
<td>0.5-1.0</td>
</tr>
</tbody>
</table>

Note: EDF = Energy Dissipation Factor ($\gamma QS/A$)

<table>
<thead>
<tr>
<th>m/s</th>
<th>meter</th>
<th>meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3-0.6</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>0.6-0.9</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>0.9-1.8</td>
<td>0.1-0.3</td>
<td>0.1-0.3</td>
</tr>
</tbody>
</table>

Hydrology

Fish migration flows

Dam or Ramp Weir

Fish migration flows

Design Flows
- 25, 50, 100-Year Events
- Low Flow

High and Low Fish Passage Flows Options:
- 5% and 95% Annual Flow Duration Curve
- Seasonal
- Other
Modeling

Modelling:
• 1D – Most times is just fine
• 2D – More important for braided, sinuous channels, outside bends, complicated hydraulics
• 3D – Used on more large-scale, expensive or research-oriented applications
Manning’s n

- Manning’s n (i.e., channel roughness): velocities goes down, but turbulence goes up as Manning’s n increases.

Be conservative – pick a value we see in rivers.
- River channels generally in the 0.025 to 0.045 range.

Watch modeling vs reality.....
- Manning’s n higher than 0.04 might be problematic for fish if slope is in the > 1% range – be sure the run turbulence calculations are accurate.
Nature-Like Fishway Design

- Hydraulic control (and velocities) influenced by channel roughness or friction: *Manning’s n*

- USFWS recommends that roughened channels are designed at slopes equal or less than 3%

- Resilient design that is not as susceptible to significant impact by unexpected high flows and/or material shifting

**Roughened Channel**

**Rock Ramp**

**Step-Pool**

**Rock Ramp**

- Hydraulic control (and velocities) influenced by a transition from sub to supercritical flow over the weir: *Weir Flow Coefficient C*

- Suitable fish passage conditions can often be created in step-pools with slopes of 5% or less. Note: Salmonids in steep areas (up to 15%)!

- Adequate hydraulic conditions are vulnerable to small alterations to the original design. Some level of monitoring and maintenance will always be necessary.
Design Procedure

- Select Initial Ramp Diameter, Slope, Manning’s n
- Calculate Low flow Hydraulics
- Iterate
- Calculate High flow Hydraulics
- Iterate

Design Procedure

- Conduct Riprap Design
- Iterate
- Entrance/Exit Transitions
- Biological Review
- Add Special Features
  - Boulders, clusters
  - Step Pools


RIP RAP DESIGN METHODS
- Abt and Johnson (1991)
- Ullmann (2000)
- Ferro (1999)
- Whittaker and Jaggi (1986)
- Robinson et al. (1998)

- Well-Graded Mixture: Maximize Density (Fuller-Thompson Eq.)
- Ensure enough fines (for Example ~10% (sand size and below))
Fish Ramps in This Region

Concrete Grouted

Un-Grouted

Roughened Riffle Ramp
Riffle-Ramp with Steps
Step-Pool Ramp
Roughened Channel
“Roughened Riffle Ramp”

Little Medicine
Bow River
Grade Control
Fish Ramps,
Wyoming

Courtesy of:
Wyoming Game and Fish
Photo 5. Post-construction Grade Control 1, Station 92+50 at the CR-2E Bridge – Looking SE across the Grade Control 1 area. Captured November 5, 2020.


Courtesy of: Wyoming Game and Fish
Guidelines for placing habitat boulders or clusters?

• Not much for rocky ramp design – Needs Study!
• What are some thoughts.....
  – Look towards natural alluvial rivers of similar slope, geomorphic setting
  – Various rules of thumb from river restoration literature*
    • Boulders should occupy <10% of flow area at bankfull flow
    • Boulder clusters should not exceed 1/3 of the active channel width and not direct flow to cause excessive erosion
    • No more than 25% of low flow channel cross-sectional area blocked
    • Avoid clustering at upper end of riffle
    • Place on periphery of upstream wakes of other boulders
    • Keep at least 1-2x diameter from banks or bank armoring may be needed
    • Size of boulders based on stability at design flow

*State of Oregon, 2010
*Rosgen, 2002/2006
Granby Roughened Riffle Ramp

Location: Granby, Colorado USA
River: Frasier
100-Yr Discharge Event: 3,010 cfs (85 cubic m/s)

Dam Height: 7.0 ft. (2 m)
River Width: 40 ft. (12 m)
Rock Ramp Slope: 3.7 %
Roughened Riffle Ramp, Granby, Colorado

Ramp Slope: 3.7%
Length: 180 feet (55 m)
Roughened Riffle Ramp, Granby, Colorado
Roughened Channel
“Riffle Ramp with Steps”

Horse Creek Culvert and Ramp Project, Wyoming

Habitat Boulders
Rocky Weirs in a Riffle, no Pools

Courtesy of: Wyoming Game and Fish
Riffle Ramp with Steps

*Location: United States – Nebraska
*River: Middle Loup
*100 Yr Discharge Event: 150 m3/s

*Dam Height: 7.5m
*River & Ramp Width: 35m
*Rock Ramp Slope: 20H:1V
Step Pool Rock Ramps

Conceptual layout of a partial-width rock-ramp fishway

Conceptual layout of a full-width rock-ramp fishway

Fisheries and Aquatic Conservation
Cross-Vane Step-Pool Approach

Cross-Vane Diversion, near the Blue River in Colorado

Rosgen, 2006
Another Step-Pool Approach

- 3’-6’ FIELD STONE (for weirs)
- 1’-3’ FIELD STONE (depending on shear stress)
- 1”-6” COBBLE (for filling void near crest)
- Fieldstone or waste concrete sub-base
- ≤3% slope
- ≤5% slope
- ≤0.8’ headloss per weir
- Designed by Luther Aadland
Steeper slopes result in a zone of passage with:

- Drop per pool
- Water Velocities
- Water Depths
- Pool Size
- Turbulence (EDF)
General Step Pool Rock Ramps

Milder slopes result in a zone of passage with:

- Drop per pool
- Water Velocities
- Water Depths
- Pool Size
- Turbulence (EDF)
General Step-Pool Ramp Design

Steps designed to stay stable at 100-year flow (USACE, 1991) Bed Eqn.

3 – 5% Weir Arm Slope

Profile View

C-C

Low-flow Notch
(Depends on Species)
Turbulence

USFWS Recommends:
- EDF > 1 can facilitate fine sediment movement
- Estimate 2.0-2.5 for nonsalmonids though it’s very little studied.

Energy entering the pool

\[
\text{Turbulence} = \frac{\text{EDF}}{\text{Pool volume (W/m}^3\text{)}}
\]
Free Weir vs. Nature-Like Fishway Weir

Typical Free Weir Flow

Typical NLF Submerged Flow

Design method more for jumpers

Design method more in line with non-salmonids non-jumpers
Design - Hydraulics

HYDRAULICS OF STEP-POOL TYPE. NATURE-LIKE FISHWAYS CAN BE APPROXIMATED AS BROAD-CRESTED WEIRS.

\[ Q = V_c b y_c \]
\[ Q = C_d \frac{2}{3} \sqrt{\frac{g}{3}} \frac{2}{3} b H_w^{1.5} \]

\[ V_c = \sqrt{g y_c} \]

The maximum velocity occurs at this minimum depth:

\[ V_c = \sqrt{g y_c} \]

Expressed in terms of the discharge coefficient and head:

\[ V_c = \frac{1}{2} C_d \frac{2}{3} g H_w \]

DISCHARGE & WEIR COEFFICIENTS

Note: \( V_c \) may not occur when weir is submerged.

Critical Velocity, \( V_c \); is the maximum water velocity over a broad-crested weir.

Head Over Weir Crest, \( H_w \); is the energy driving flow measured 3.5 ft upstream of the crest.

Critical Depth, \( y_c \), is the depth that allows flow to occur with the maximum velocity.

Rock Weir Hydraulics

USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler
 Issued 1/6/2017; replaces “Rock Weir Hydraulics” 2/17/2017

Rock Weir Hydraulics

Reference Plate 10-1
• It’s a tricky puzzle to put together!
• Footer rocks should be positioned such that sliding cannot occur
• Footer rocks create slope into pool
• Fill alternatives around steps include: Geotextile, sand/clay, mixes
Roughened Riffle Ramp
- Engineered fill
- Habitat rocks/clusters
- Most natural-looking

Riffle-Ramp with Steps
- Engineered fill
- Weir “Steps” of larger boulders
- No pools
- Weir rocks spaced out

Step-Pool Ramp
- Engineered fill
- Weir “Steps” of larger boulders
- Formal step/pool morphology
US Bureau of Reclamation Research

Research and Case Study Results for nonsalmonids:
• Boulder steps should be placed in an upstream pointing chevron
• Chevron angle 120-150 degrees have good success
• Typical boulder gaps are 300-400 mm, can be more
• Spacing depends on flow and drop across weir
• Center boulder largest “tuning boulder” and for large rivers 1 m – 1.25 m minimum size.

Full-Scale Roughened Channel Test Facility

Mefford, 2009.
Rocky Ramp Analogs in Technical Fishways

Chevron Dual Vertical Slot Fishway
Government Highline Diversion Dam Fishway, Colorado River, CO.

Australian Designs – Cone Fishways

USA - US Bureau of Reclamation
Cylinder Fishway
Price-Stubb Dam, Colorado River
Colorado State University
Fort Collins, Colorado

Rocky Ramp Flume Experiments, Ongoing. Dr. Chris Myrick
https://warnercnr.colostate.edu/fwcb/applied-physiological-ecology-fishes/research/

Bozeman Fish Technology Center and Montana State University
Bozeman, Montana

Fish Performance Studies, Ongoing.
https://www.montana.edu/eco hydraulics/
Monitoring

Multispecies Fish Passage Evaluation at a Rock-Ramp Fishway in a Colorado Transition Zone Stream

Colorado Parks and Wildlife, 317 West Prospect Road, Fort Collins, Colorado 80526, USA

- Velocities near the bed allowed small fish passage even when velocities overall were higher than criteria though this diminished with higher and higher flows.

- Attraction and eliminating jumps greatly improved small fish passage
Close Out

• **Nature-like is not natural!**
  - Constructed from rock and natural materials
  - High gradient, engineered channels
  - Range from Riffle-Like to Step-Pools

• **Advantages**
  - Aesthetics
  - Enhances passage for multiple species
  - Upstream and downstream passage

• **Disadvantages**
  - Size, cost, and need for more performance studies

Questions?
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