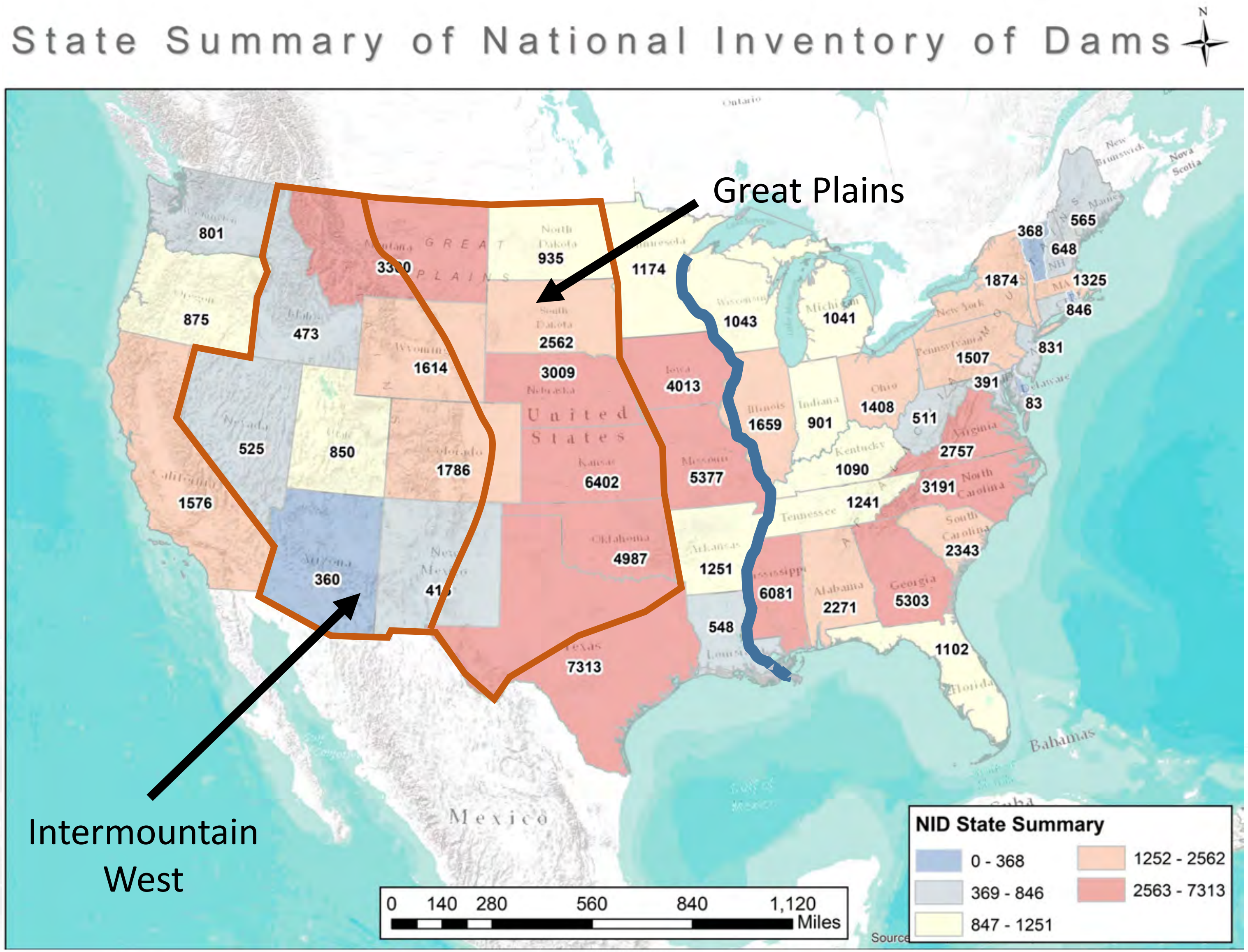
Fish Ramps in the Inter-Mountain West and Great Plains

National Fish Passage Program

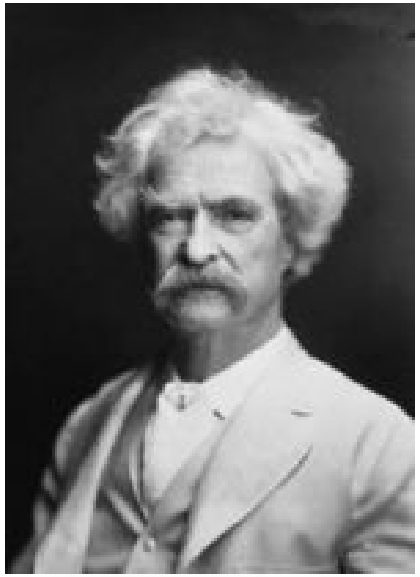
William Rice, PE
Fish Passage Engineer
U.S. Fish and Wildlife Service

Fisheries and Aquatic Conservation

How Many Dams Are There?

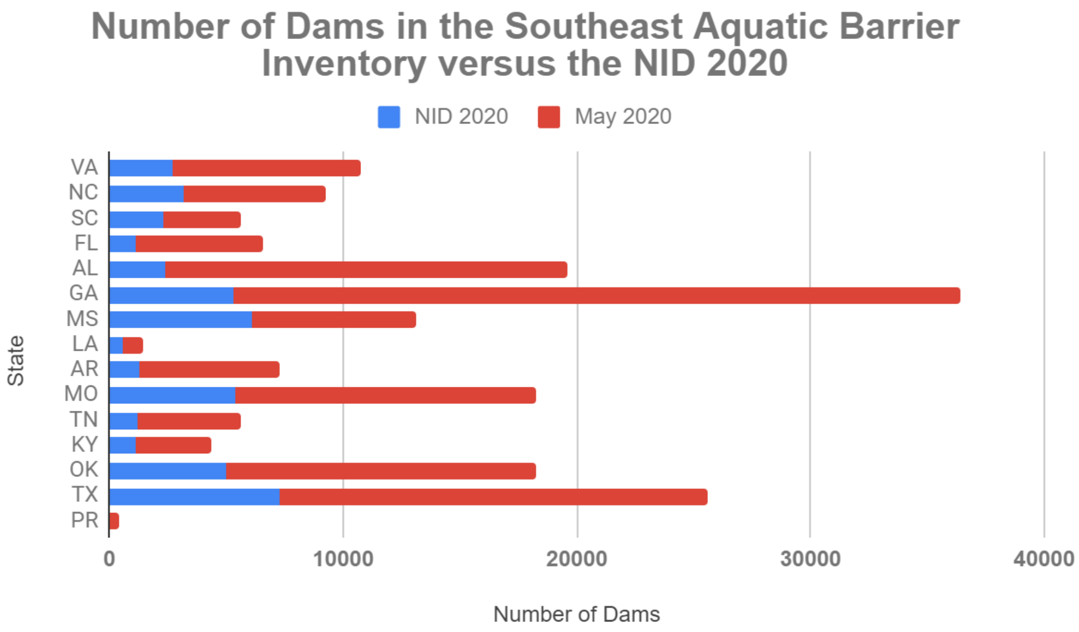


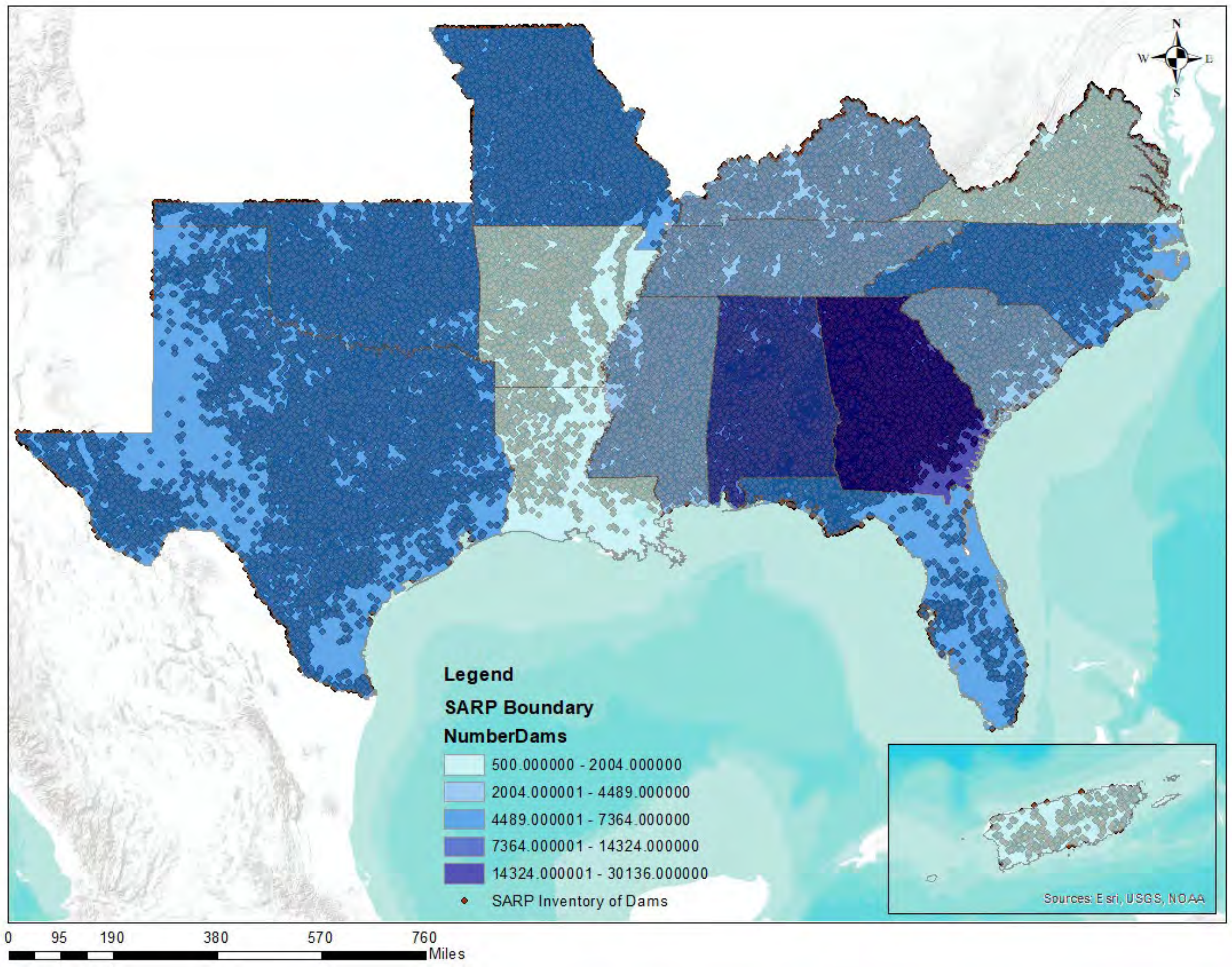
"Whiskey is for drinking, water is for fighting over" – Mark Twain



<u>55% of NID Dams are west of the Mississippi</u>

Water Supply and Irrigation Diversions





Water Supply and Irrigation Diversions

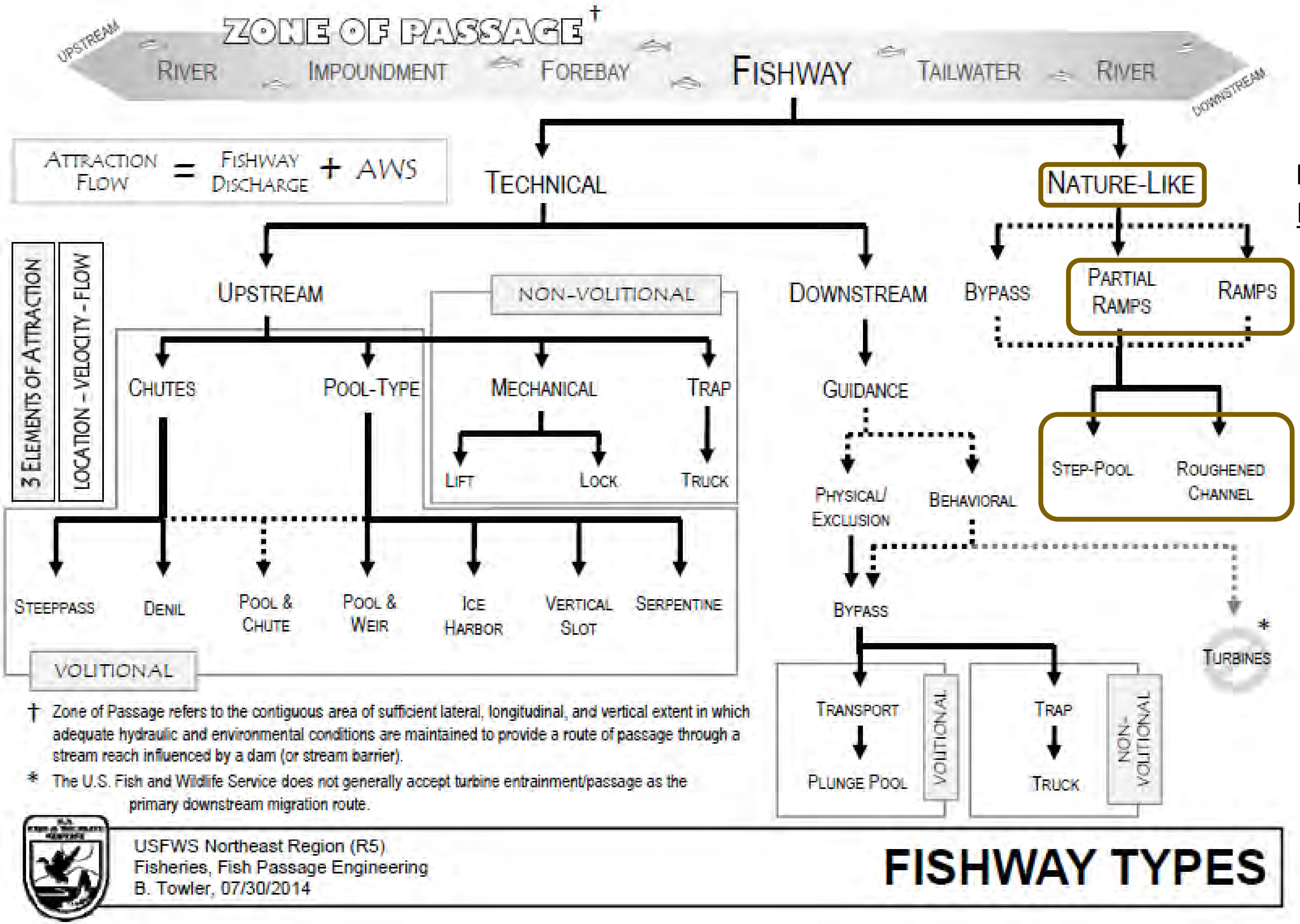
Wood and Metal Private Irrigation Dam
Big Hole Valley, Montana
Photo by: Matt Blank

Figure 1 – Flint Creek, Allendale Intake Structure & Diversion

From: Preliminary Engineering Report, Allendale Canal Intake and Fish Screen, Montana

- Typically <3 meters in height
- Many are undocumented

Engineered,
Not Natural



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

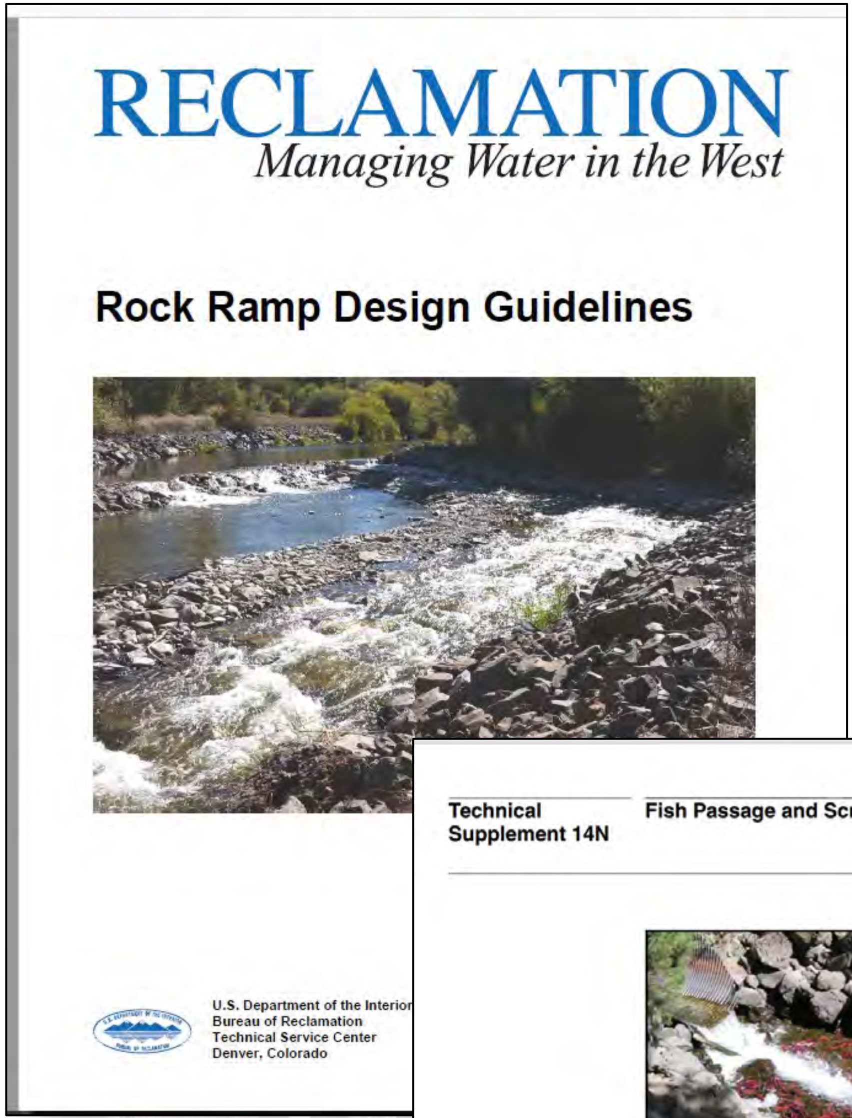
Un-Grouted Nature-Like Ramps


Step-Pool Ramp, Minnesota

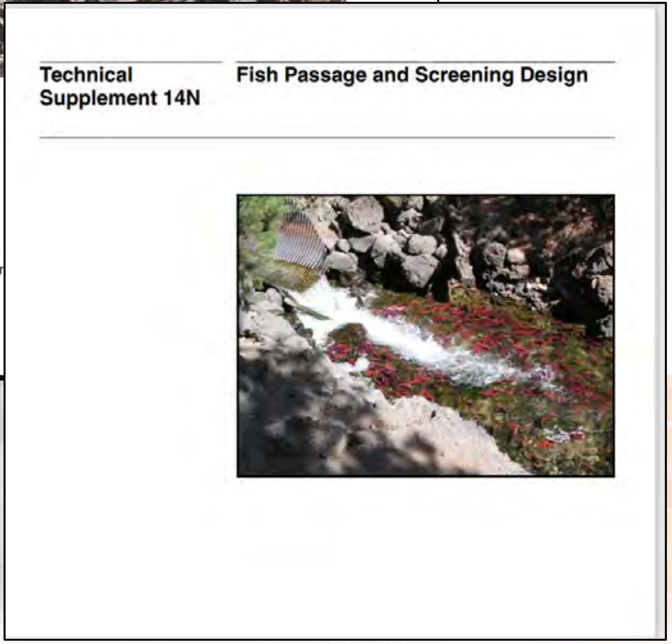

Step-Pool Ramp, Kansas


Riffle Ramp. Granby, Colorado

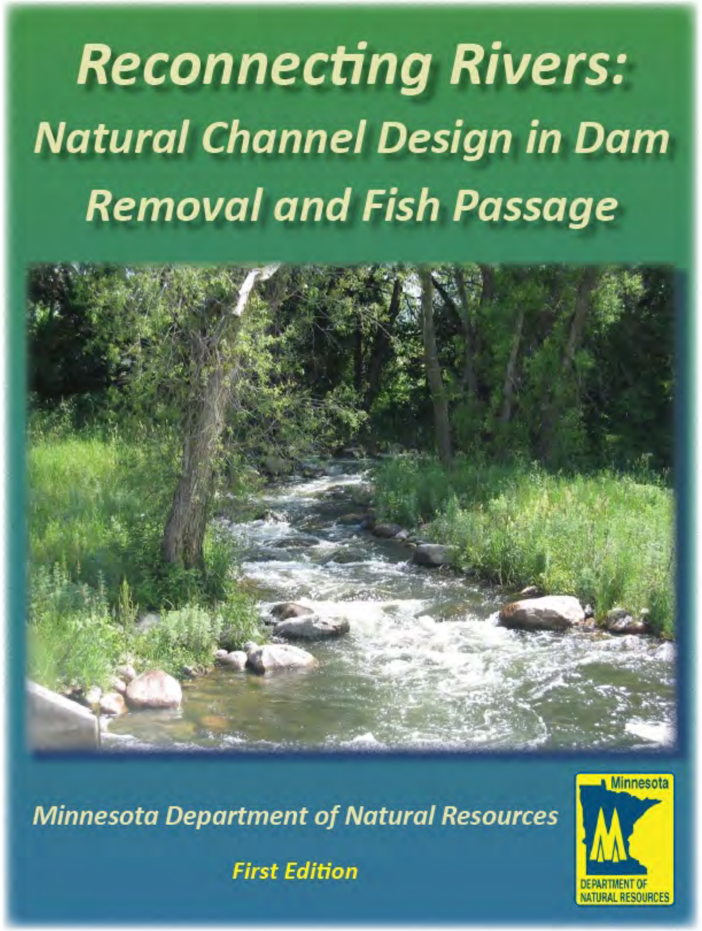
Design



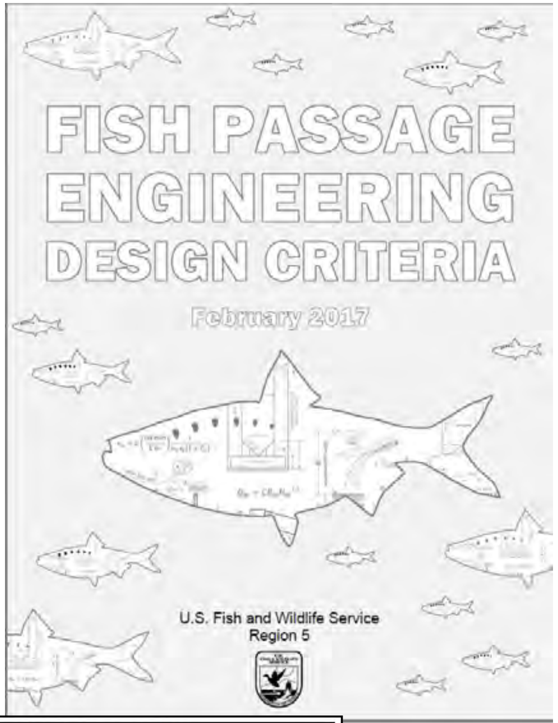
RECLAMATION
Managing Water in the West
Rock Ramp Design Guidelines
U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado



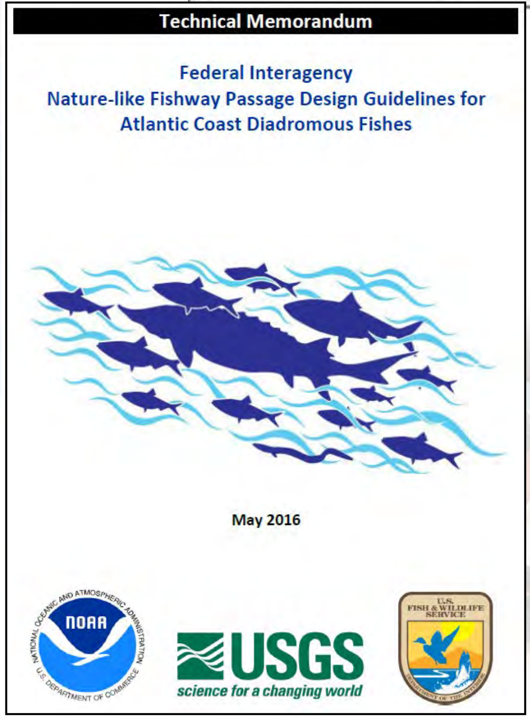
Technical Supplement 14N
Fish Passage and Screening Design



Reconnecting Rivers:
Natural Channel Design in Dam Removal and Fish Passage
Minnesota Department of Natural Resources
First Edition



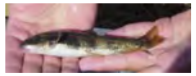
FISH PASSAGE ENGINEERING DESIGN CRITERIA
February 2017
U.S. Fish and Wildlife Service
Region 5



Technical Memorandum
Federal Interagency
Nature-like Fishway Passage Design Guidelines for Atlantic Coast Diadromous Fishes
May 2016
USGS
science for a changing world

Biology

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



Smallest

Largest

Biomass

Biology

Smallest → Need low water velocity and turbulence

Largest → Need depth and space

Biomass → Need space

Example of Some Fish Across the Region and Performance

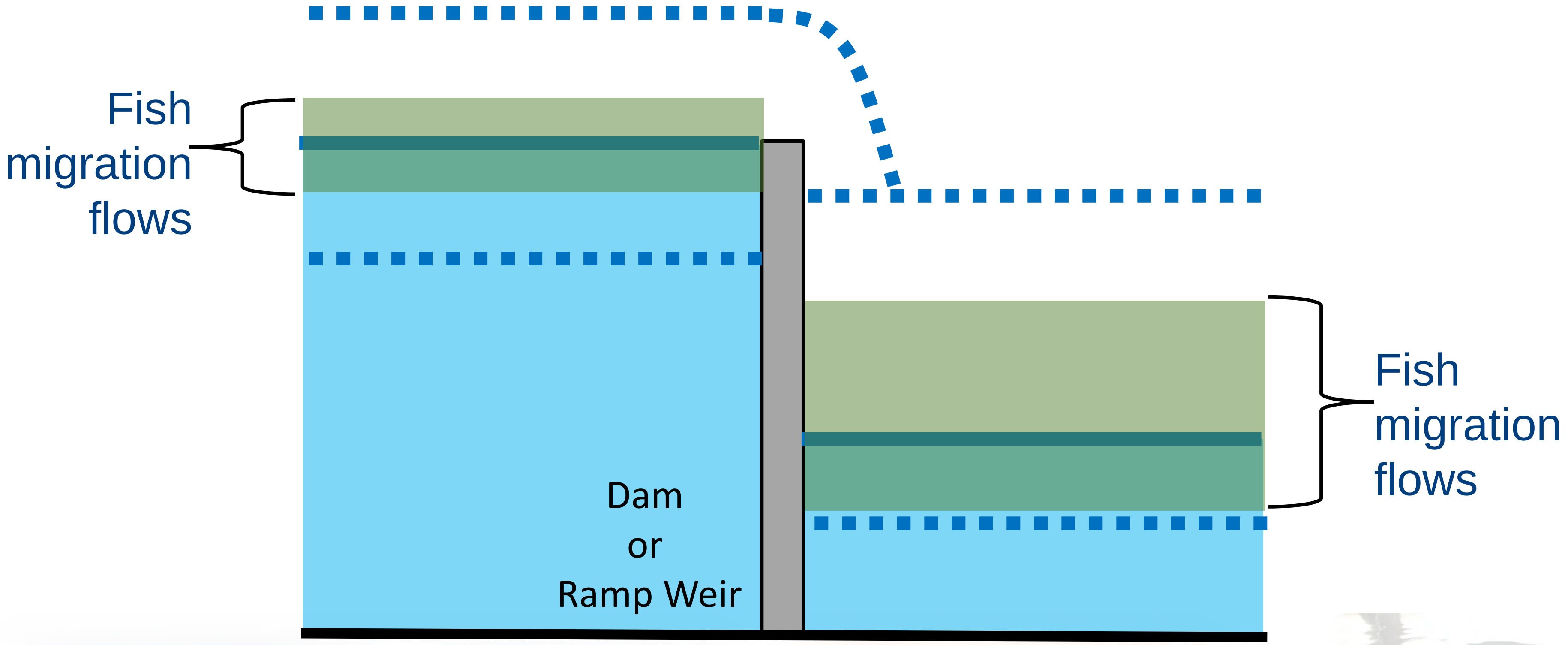
Design Criteria for Fish Passage Structures Colorado

Species Assemblage	Velocity (ft/s)	Minimum Depth (ft)	Vertical Drop (ft)
Native minnows and darters	1-2	0.50	0.00
Native dace and suckers	2-3	0.50	0.00
Trout	3-6	0.5-1.0	0.5-1.0

Colorado Parks and Wildlife, 2015.

m/s	meter	meter
0.3-0.6	0.1	0.0
0.6-0.9	0.1	0.0
0.9-1.8	0.1-0.3	0.1-0.3

Hydrology



Design Flows

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

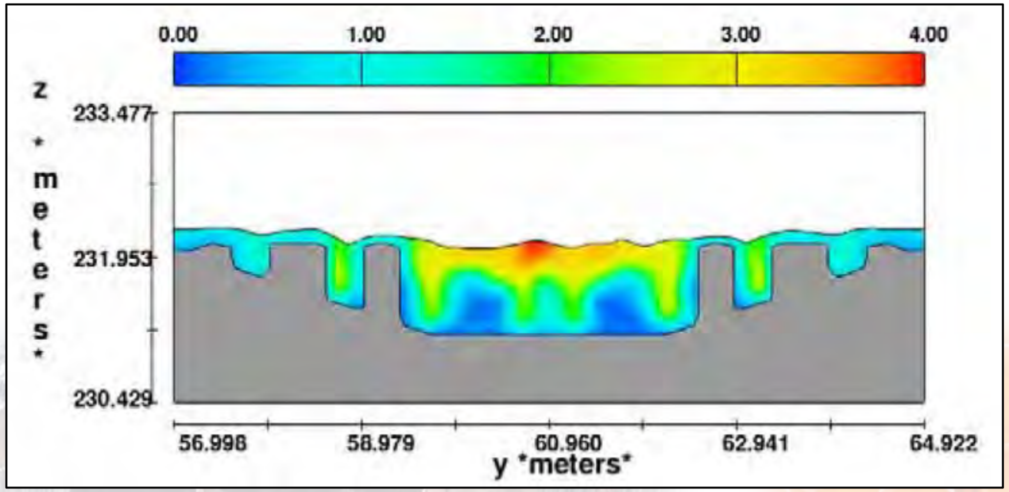
High and Low Fish Passage Flows Options:

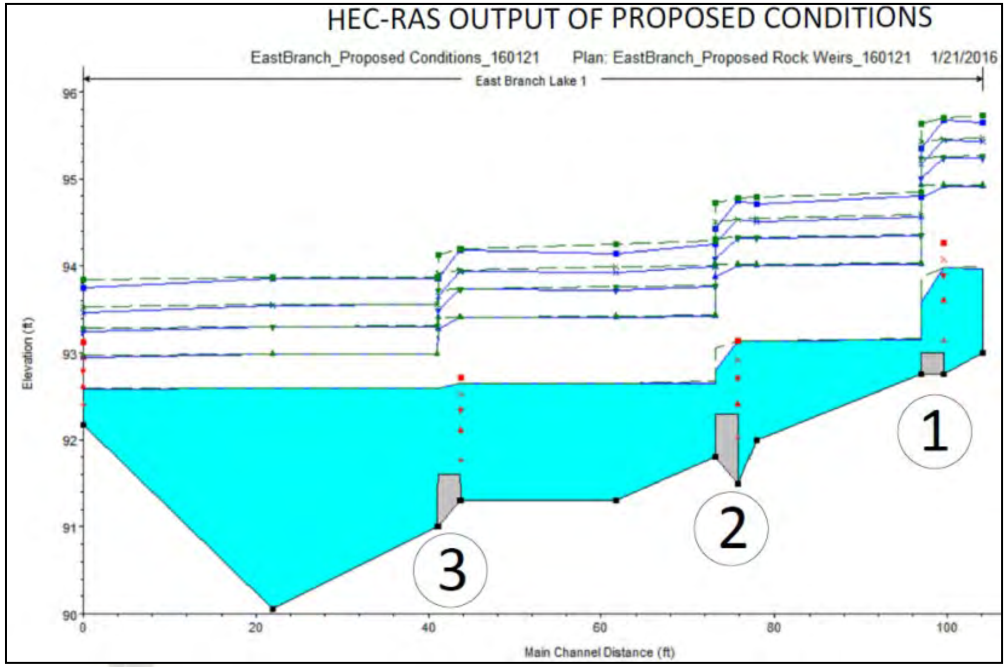
- 5% and 95% Annual Flow Duration Curve
- Seasonal
- Other

Modeling

<u>Modelling:</u>

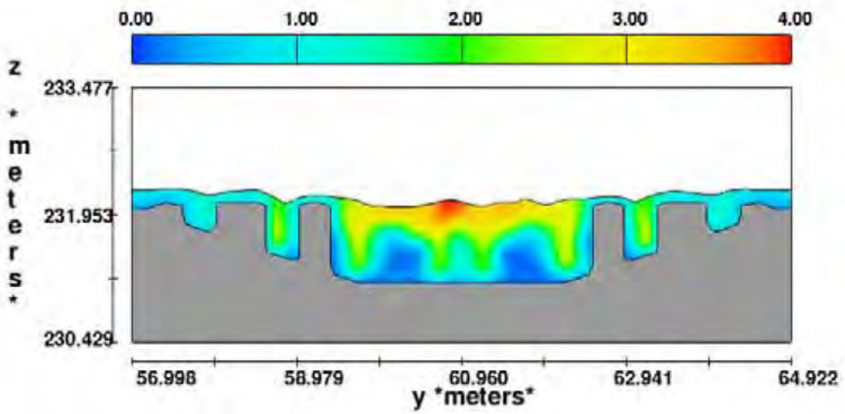
- 1D – Most times is just fine
- 2D – More important for braided, sinuous channels, outside bends, complicated hydraulics
- 3D – Used on more large-scale, expensive or research-oriented applications





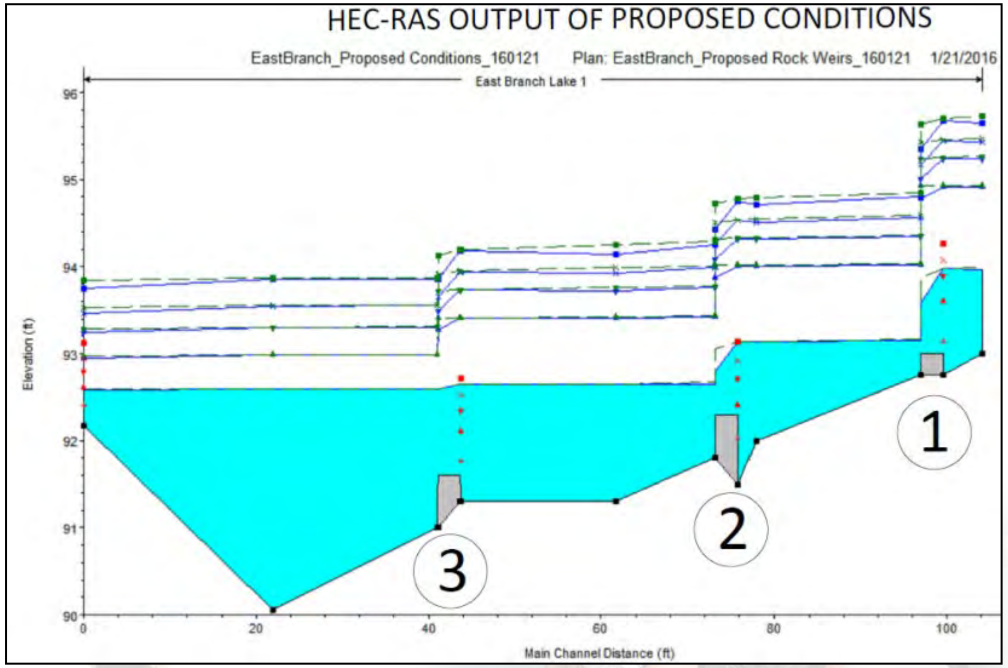
Manning's n

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



<u>Be conservative – pick a value we see in rivers.</u>

- River channels generally in the 0.025 to 0.045 range 🙂



<u>Watch modeling vs reality</u>…..

- Manning's n higher than 0.04 <u>*might*</u> be problematic for fish if slope is in the > 1% range – be sure the run turbulence calculations

Nature-Like Fishway Design

Roughened Channel Rock Ramp

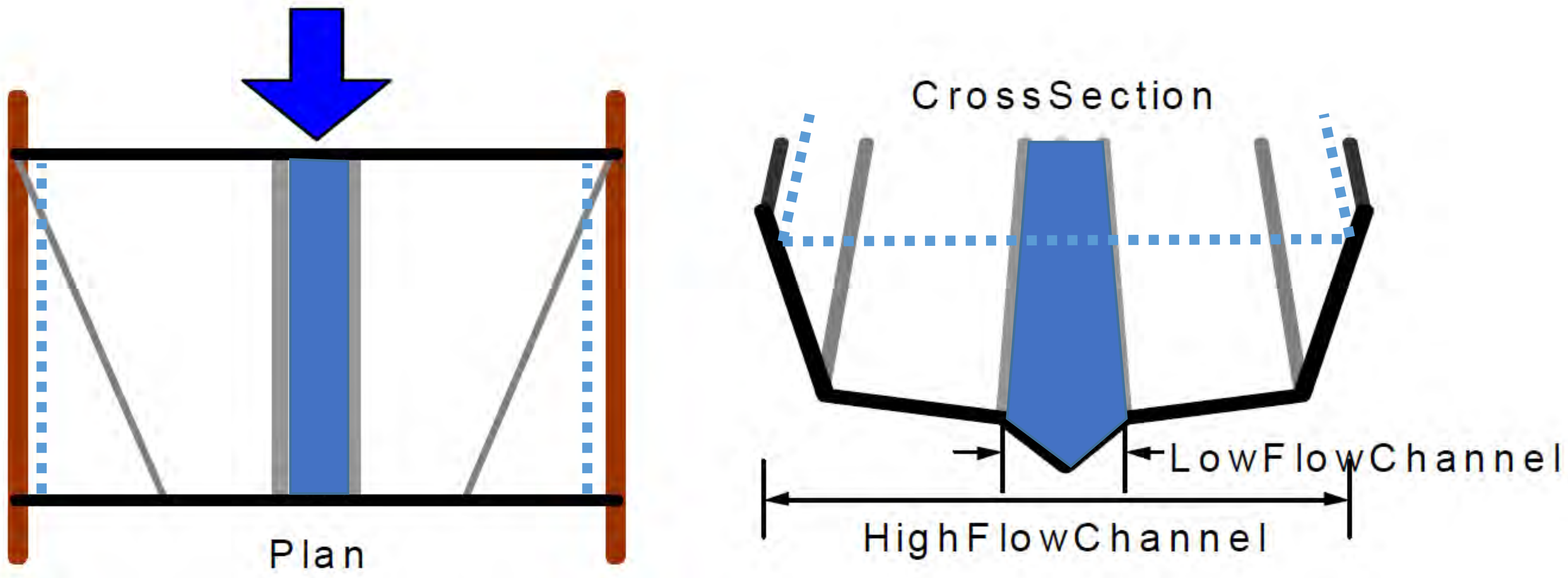
- Hydraulic control (and velocities) influenced by channel roughness or friction: *Manning's n*
- USFWS recommends that roughened channels are designed at slopes equal or less than 3%
- Resilient design that is not as susceptible to significant impact by unexpected high flows and/or material shifting

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
- <u>Iterate</u>
- Calculate High flow Hydraulics
- <u>Iterate</u>



Rock Ramp Design Guidelines, USBR, 2007.

Design Procedure

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

Rock Ramp Design Guidelines, USBR, 2007.

RIP RAP DESIGN METHODS

Abt and Johnson (1991)

USACE (1991)

Ullmann (2000)

Ferro (1999)

Whittaker and Jaggi (1986)

Robinson et al. (1998)

NRCS Technical Supplement 14N

Rosgen (2002/2006)

- 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

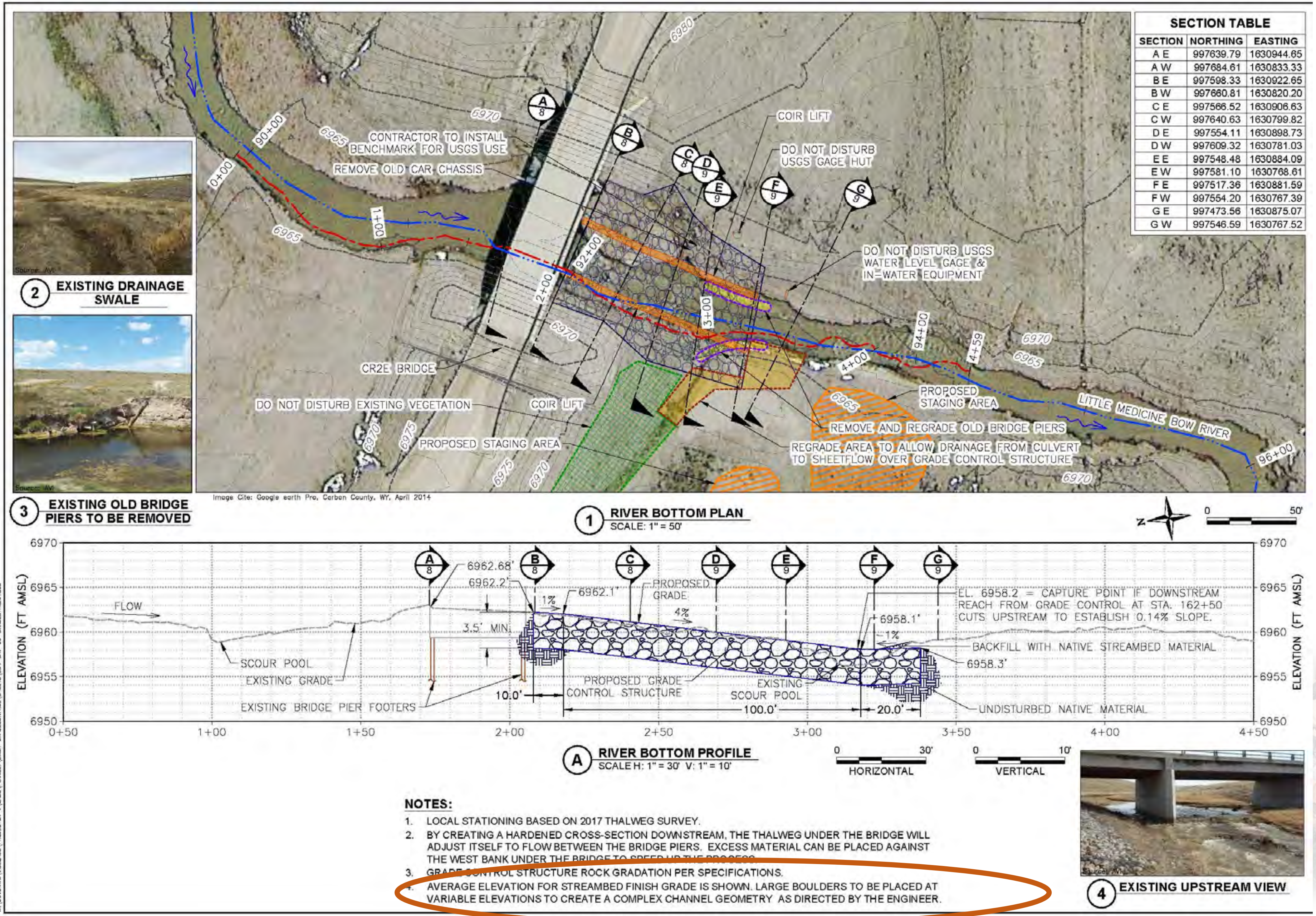
Roughened Riffle Ramp

Riffle-Ramp with Steps

Step-Pool Ramp

Roughened Channel
“**Roughened Riffle Ramp**”

Little Medicine Bow River Grade Control Fish Ramps, Wyoming



SECTION TABLE

SECTION	NORTHING	EASTING
A E	997639.79	1630944.65
A W	997684.61	1630833.33
B E	997598.33	1630922.65
B W	997660.81	1630820.20
C E	997566.52	1630906.63
C W	997640.63	1630799.82
D E	997554.11	1630898.73
D W	997609.32	1630781.03
E E	997548.48	1630884.09
E W	997581.10	1630768.61
F E	997517.36	1630881.59
F W	997554.20	1630767.39
G E	997473.56	1630875.07
G W	997546.59	1630767.52

NOTES:

1. LOCAL STATIONING BASED ON 2017 THALWEG SURVEY.
2. BY CREATING A HARDENED CROSS-SECTION DOWNSTREAM, THE THALWEG UNDER THE BRIDGE WILL ADJUST ITSELF TO FLOW BETWEEN THE BRIDGE PIERS. EXCESS MATERIAL CAN BE PLACED AGAINST THE WEST BANK UNDER THE BRIDGE TO SPEED UP THE PROCESS.
3. GRADE CONTROL STRUCTURE ROCK GRADATION PER SPECIFICATIONS.
4. AVERAGE ELEVATION FOR STREAMBED FINISH GRADE IS SHOWN. LARGE BOULDERS TO BE PLACED AT VARIABLE ELEVATIONS TO CREATE A COMPLEX CHANNEL GEOMETRY AS DIRECTED BY THE ENGINEER.

Courtesy of: Wyoming Game and Fish

Roughened Channel
“**Roughened <u>Riffle Ramp</u>**”

Little Medicine Bow River Grade Control Fish Ramps, Wyoming

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.

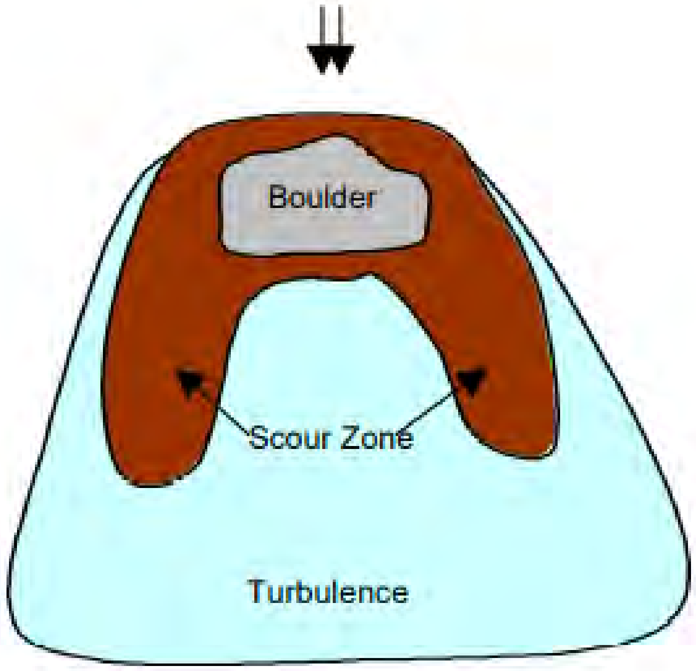
Photo 6. Post-construction Grade Control 1, Station 92+50 at the CR-2E Bridge – Looking N across the Grade Control 1 area toward the CR-2E Bridge. Captured September 25, 2020.

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

Fish Passage: Wake length for spacing



*State of Oregon, 2010
*Fischenich, C., and Seal, R. (1999)
*Rosgen, 2002/2006

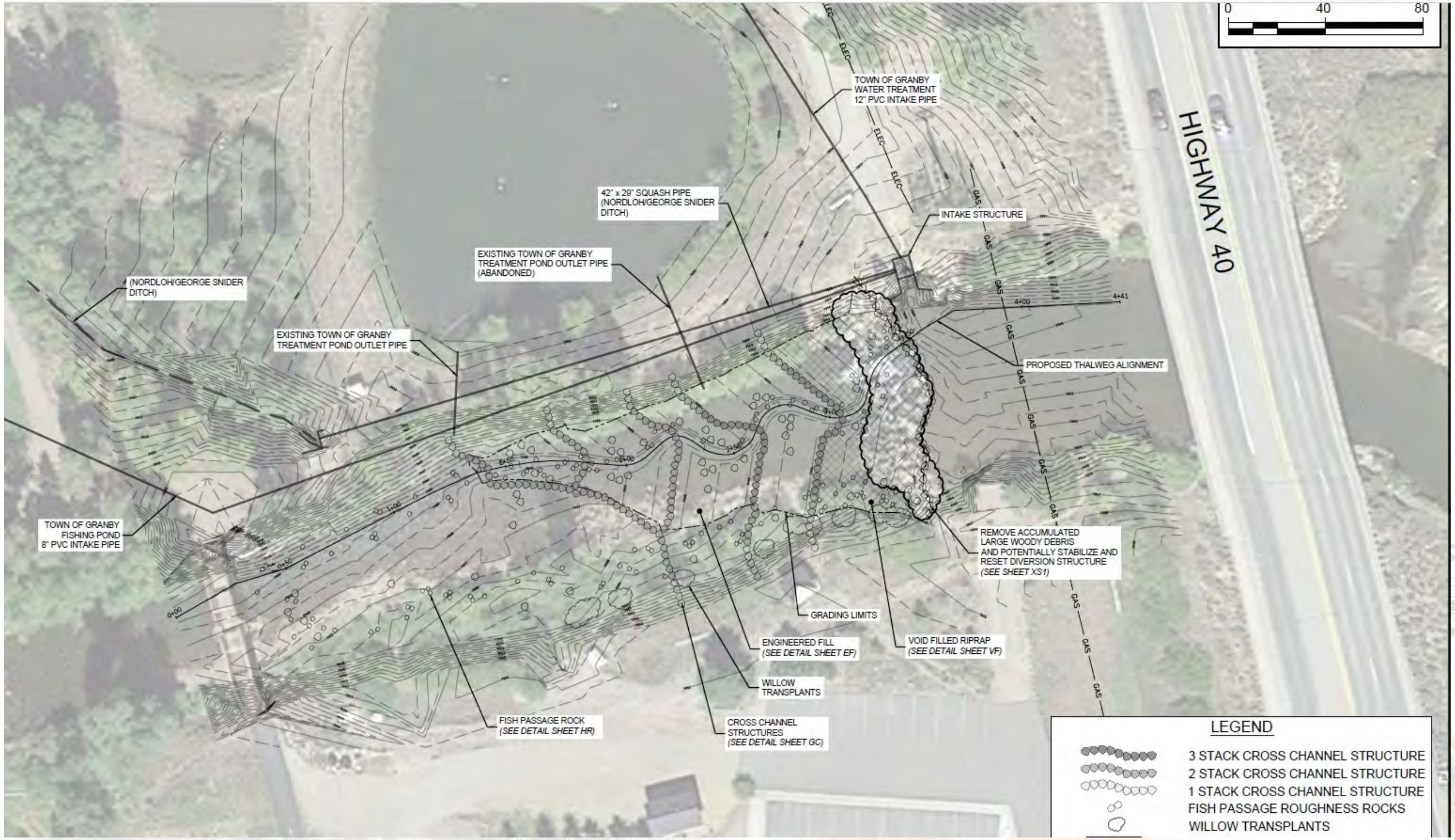
Granby Roughened Riffle Ramp

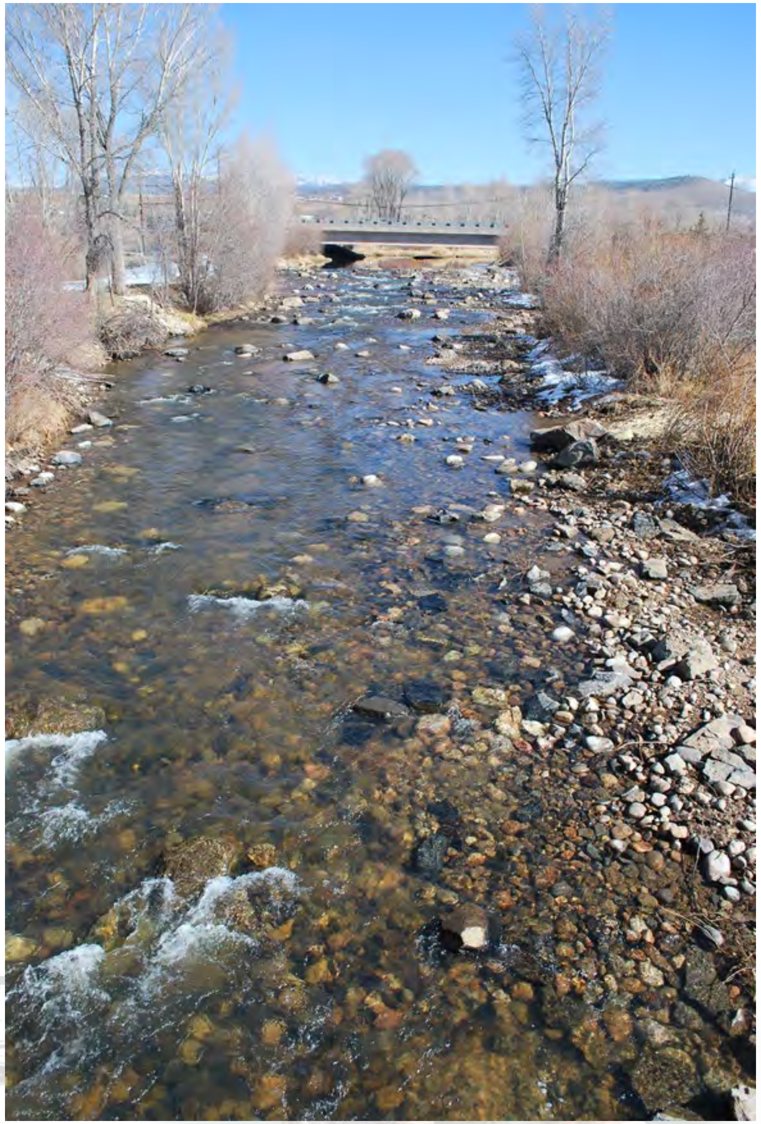
Location: Granby, Colorado USA
River: Frasier
100-Yr Discharge Event: 3,010 cfs (85 cubic m/s)

Dam Height: 7.0 ft. (2 m)
River Width: 40 ft. (12 m)
Rock Ramp Slope: 3.7 %

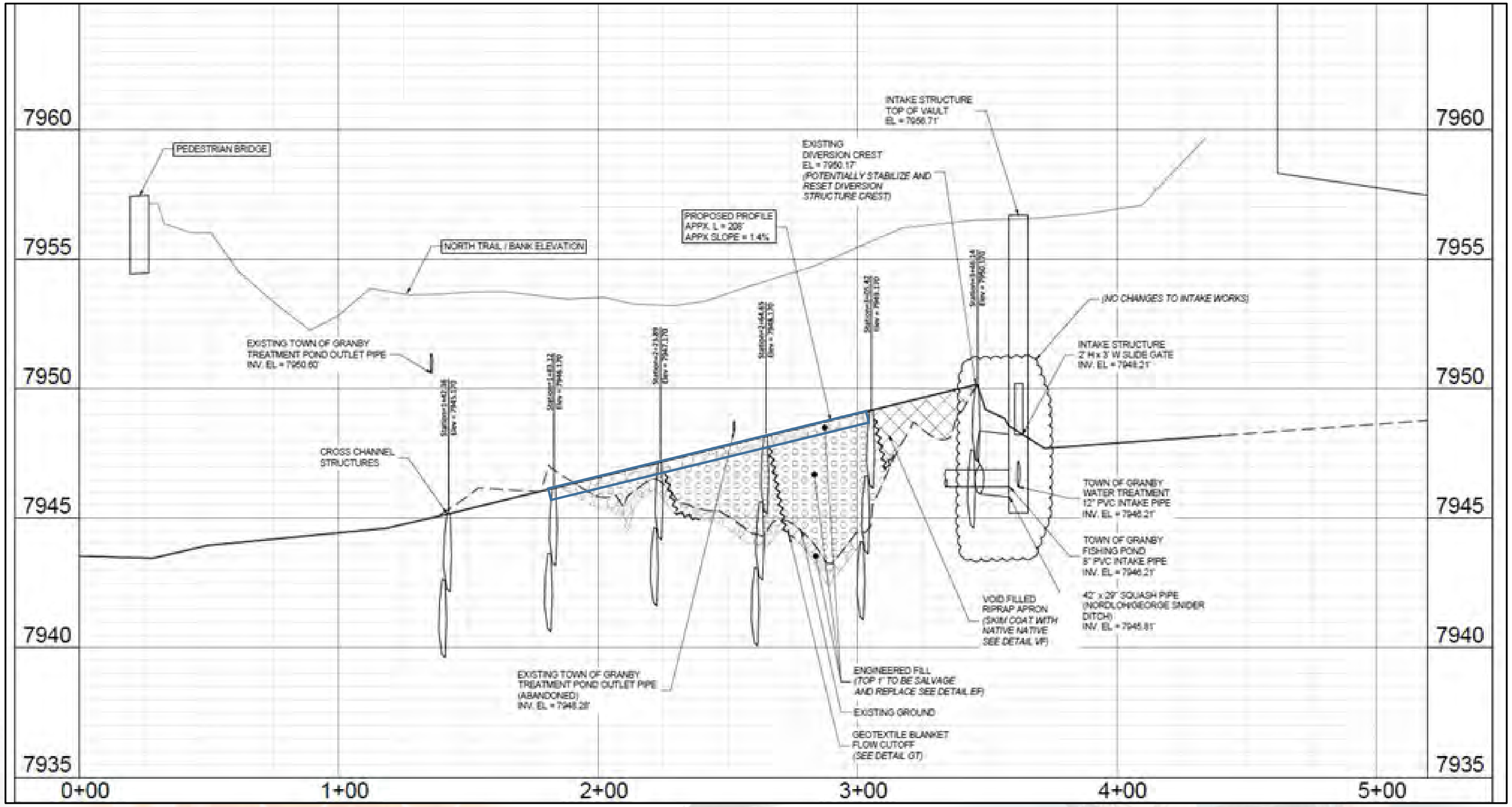
Roughened Riffle Ramp, Granby, Colorado

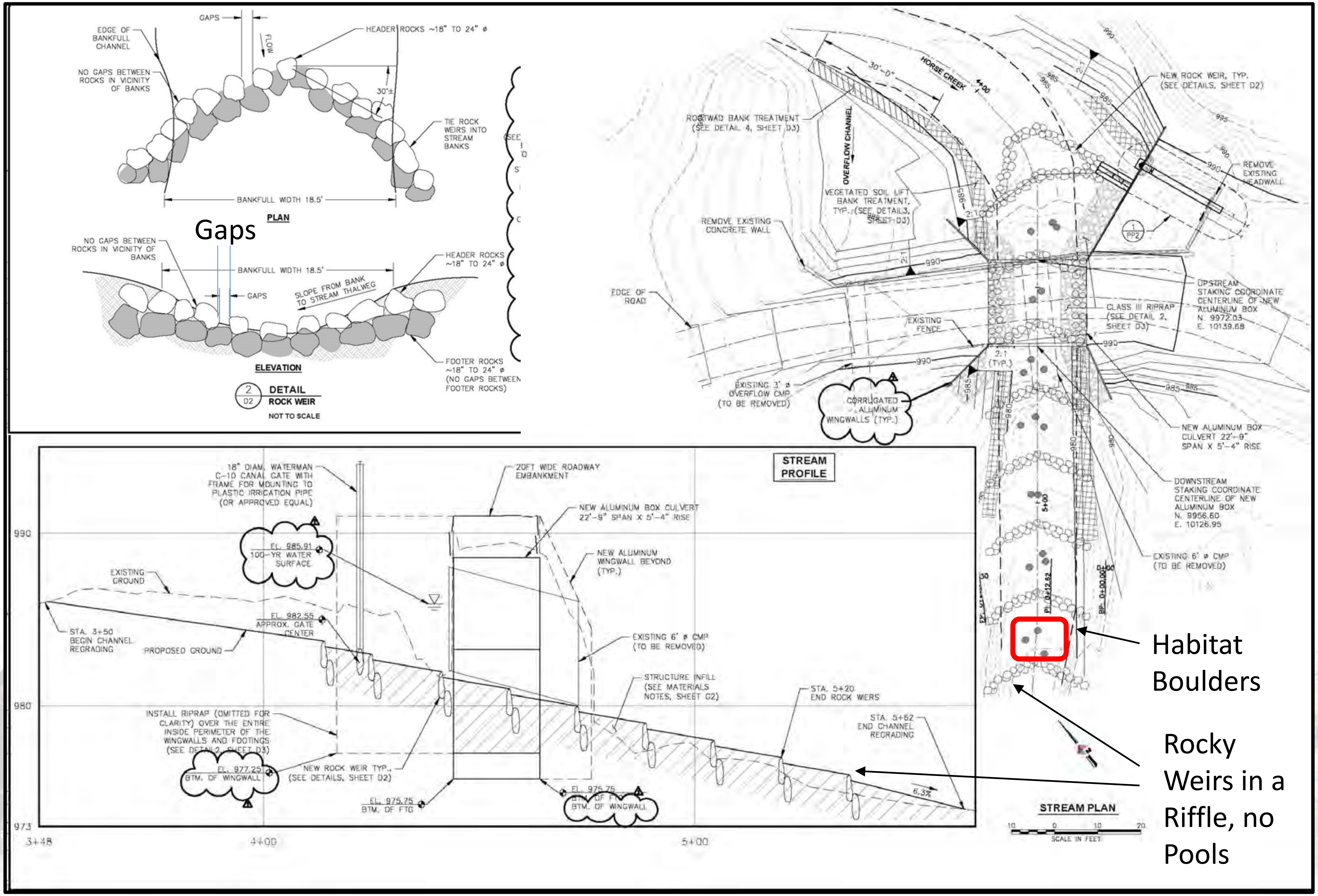
Ramp Slope: 3.7%
Length: 180 feet (55 m)





Roughened Riffle Ramp, Granby, Colorado





Roughened Channel "**Riffle Ramp with Steps**"

Horse Creek Culvert and Ramp Project, Wyoming

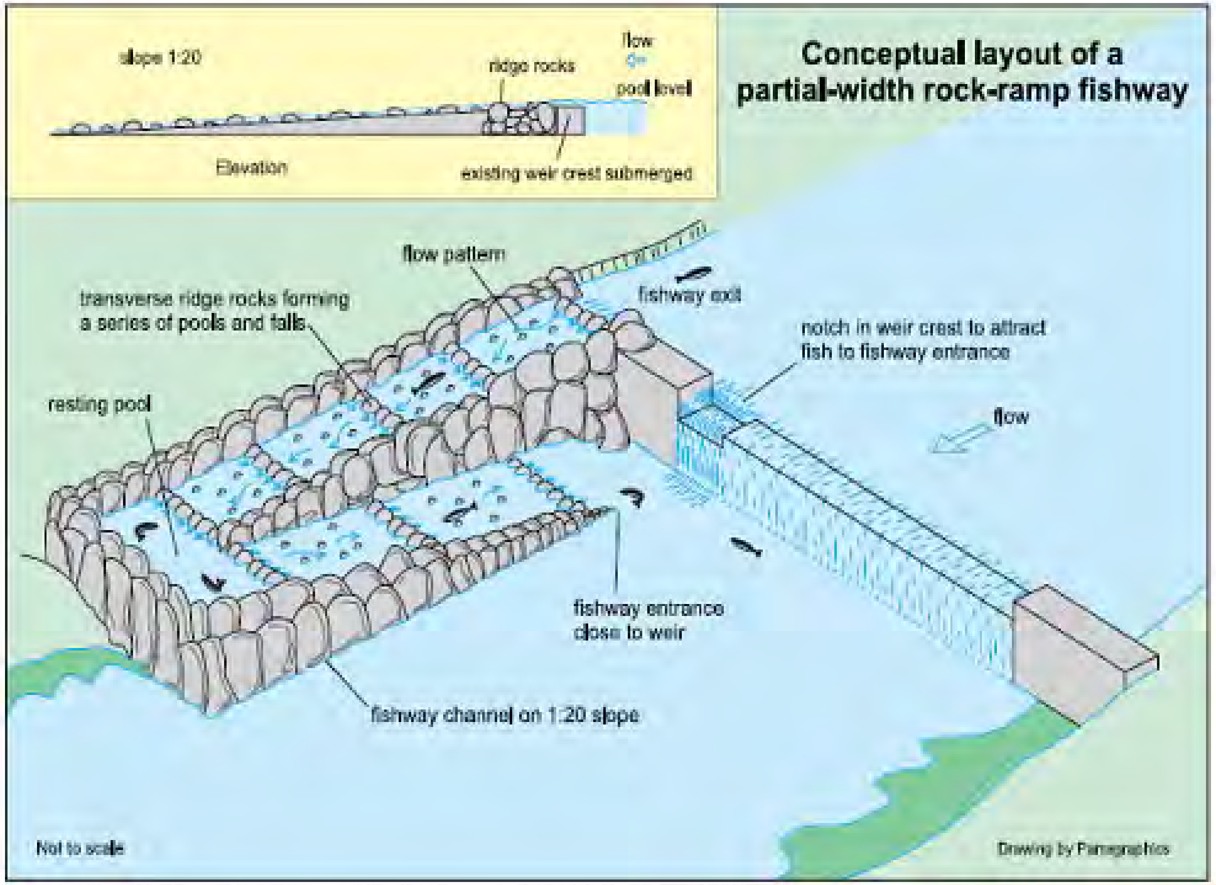
Courtesy of: Wyoming Game and Fish

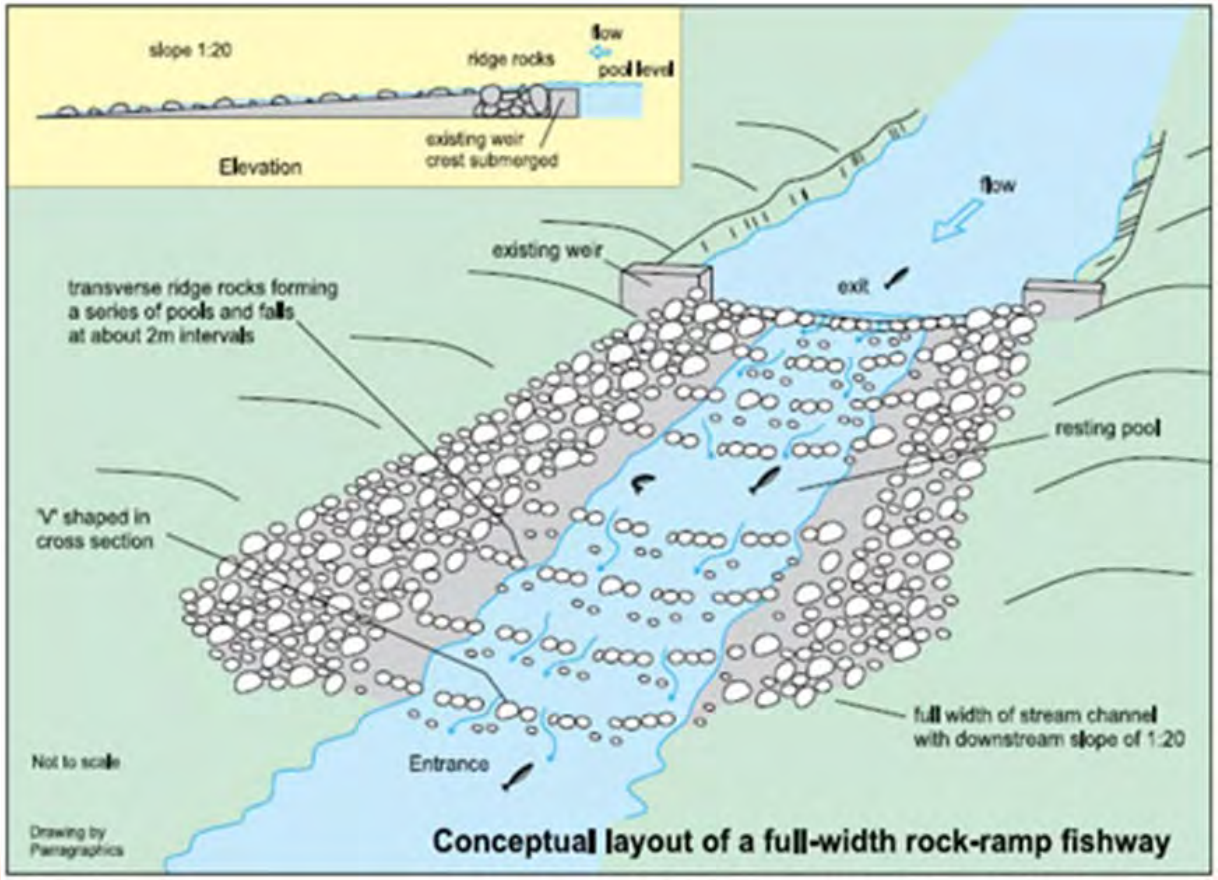
Riffle Ramp with Steps

*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





Cross-Vane Step-Pool Approach

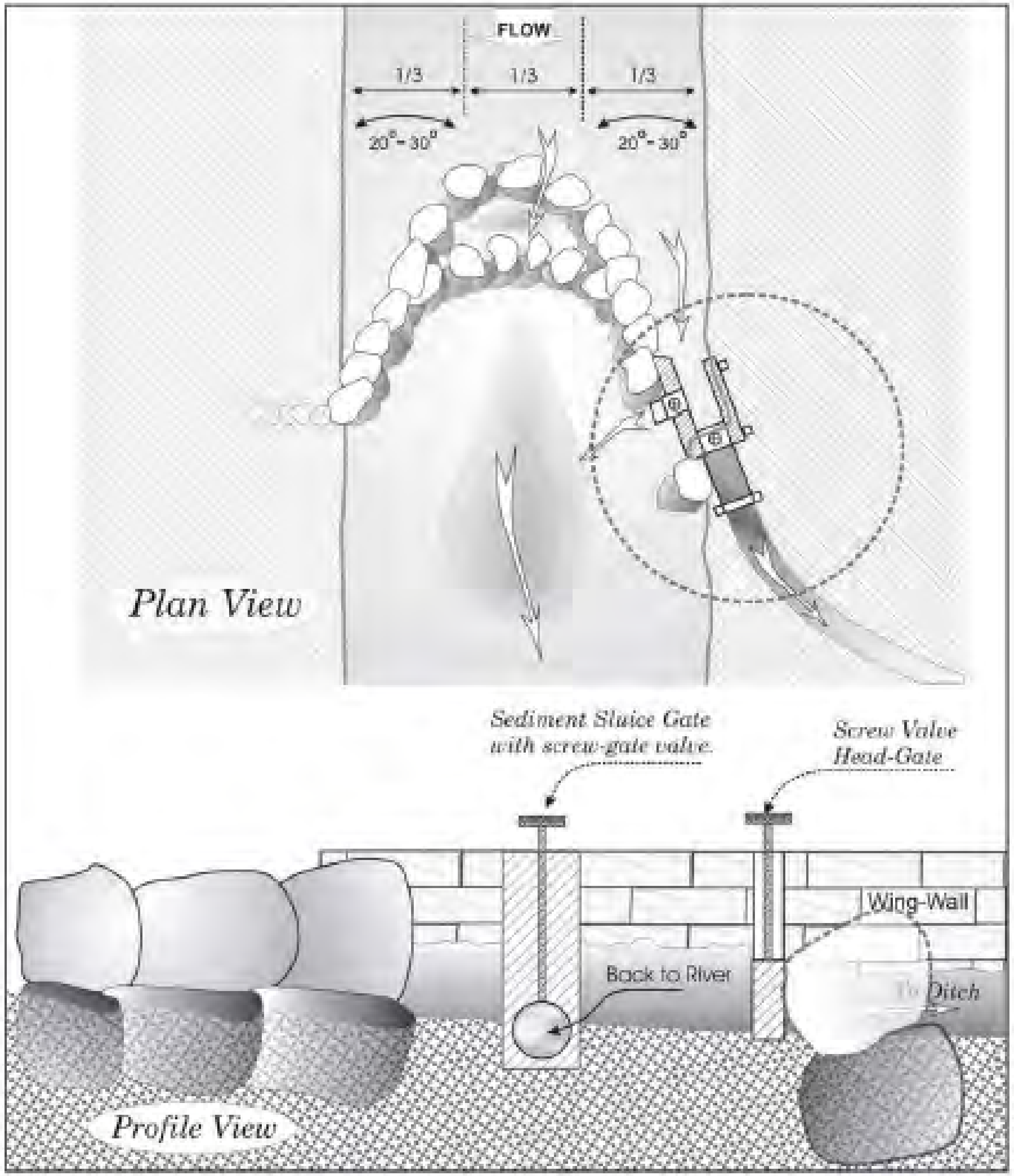
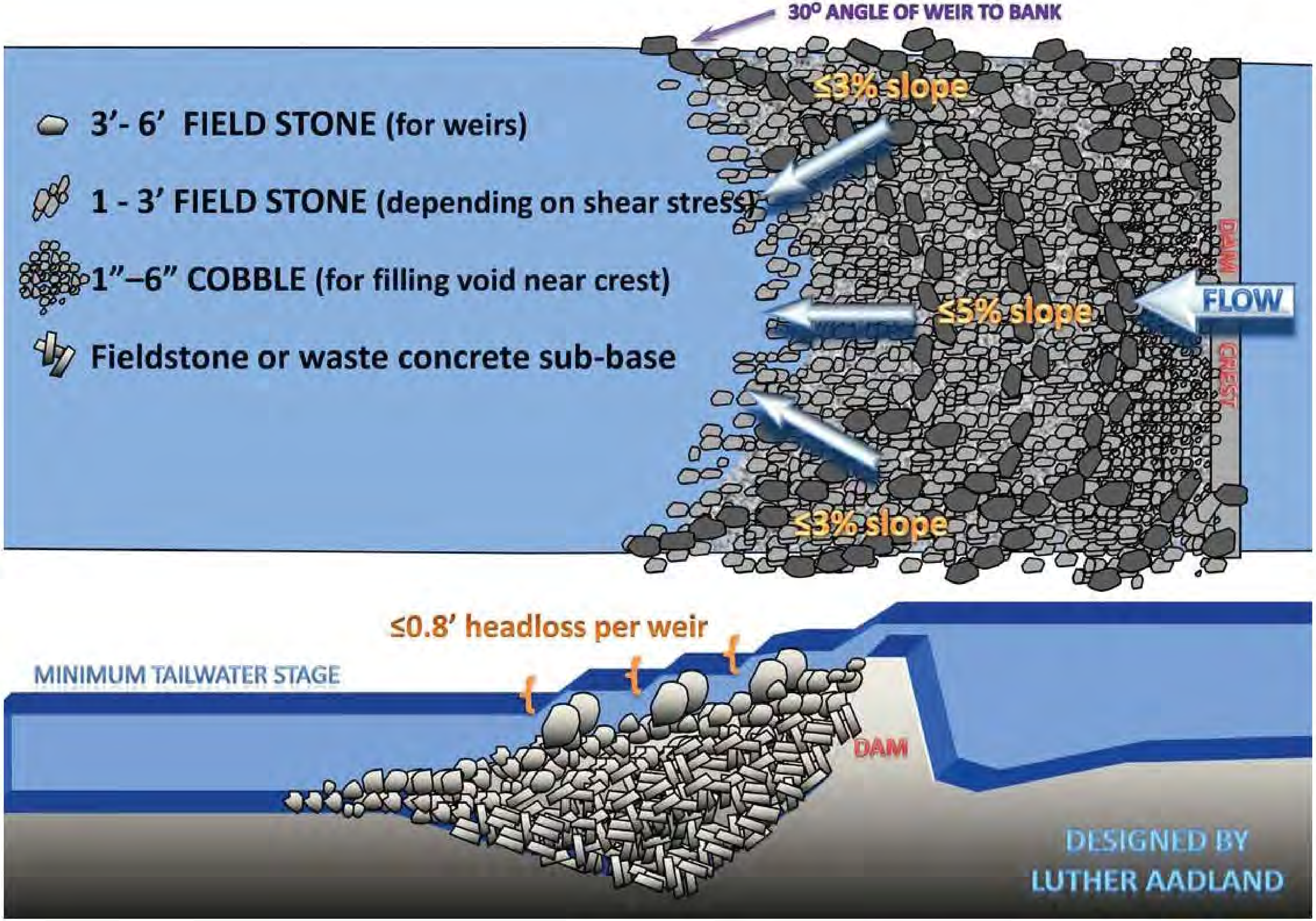


Figure 5. Conceptual example of a cross-vane diversion structure with irrigation head gate and sediment sluice (Rosgen, 2006).

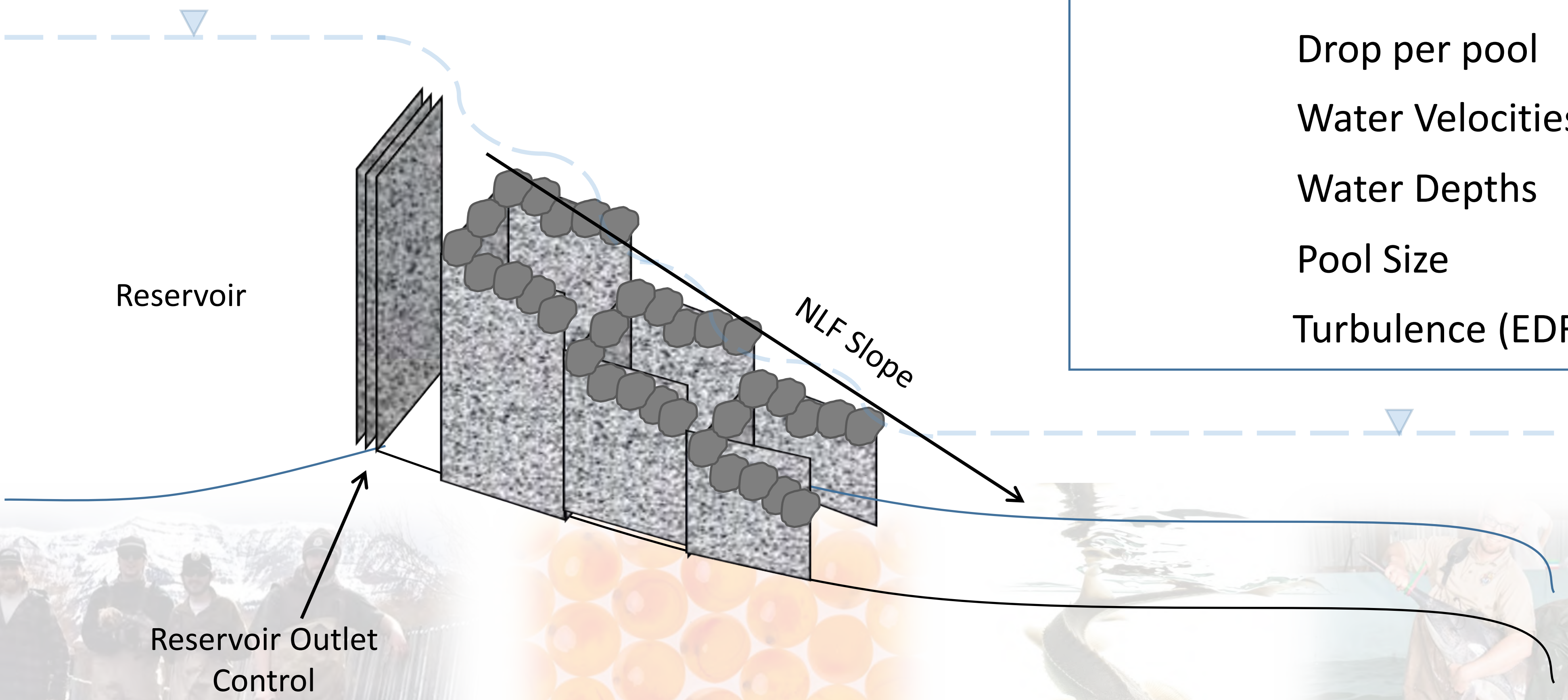
Cross-Vane Diversion, near the Blue River in Colorado

Rosgen, 2006

Another Step-Pool Approach



General Step Pool Rock Ramps



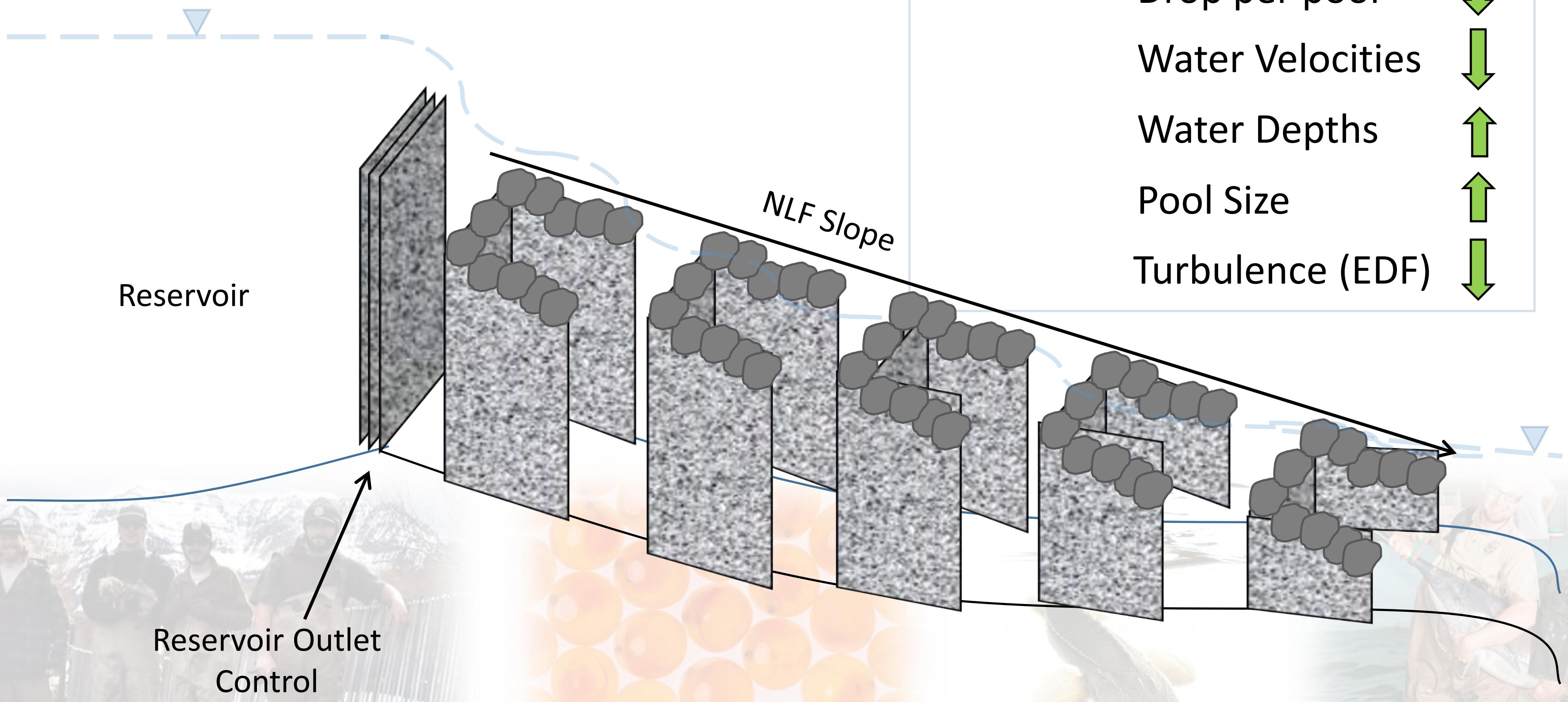
Steeper slopes result in a zone of passage with:

- Drop per pool ↑
- Water Velocities ↑
- Water Depths ↓
- Pool Size ↓
- Turbulence (EDF) ↑

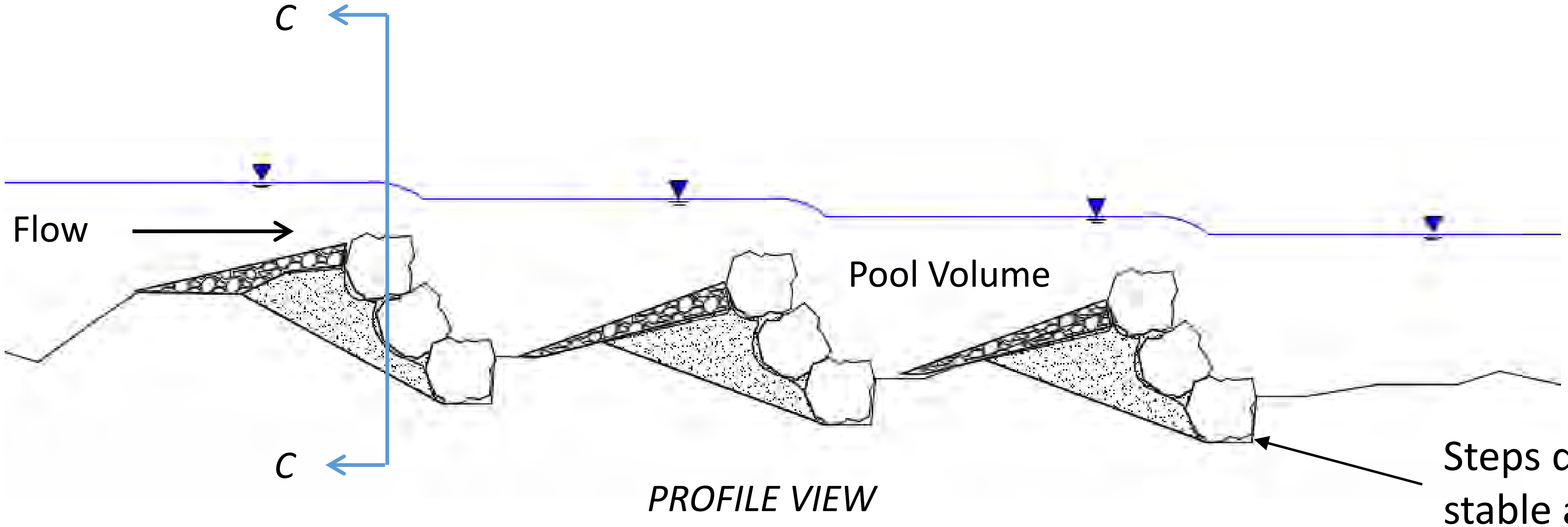
General Step Pool Rock Ramps

Milder slopes result in a zone of passage with:

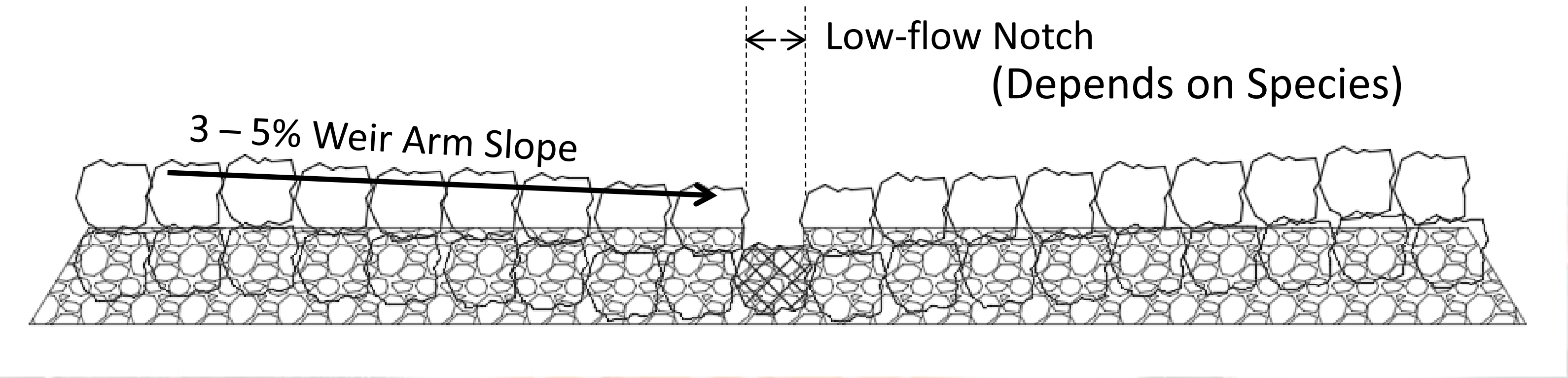
- Drop per pool ↓
- Water Velocities ↓
- Water Depths ↑
- Pool Size ↑
- Turbulence (EDF) ↓



General Step-Pool Ramp Design



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



PROFILE VIEW
C-C

Turbulence

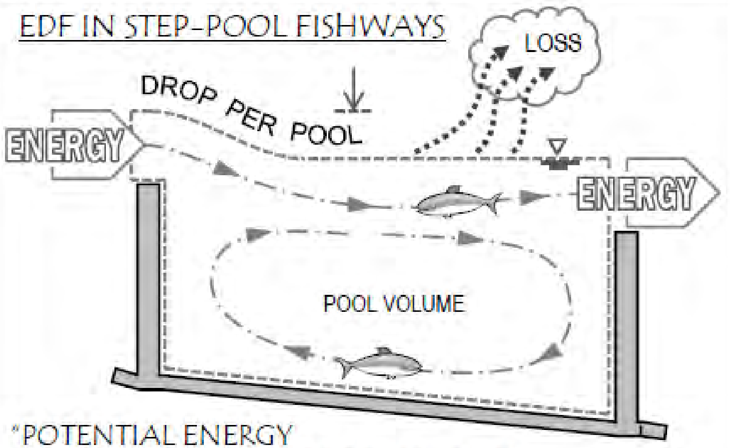
FT-LB/S/FT³ RECOMMENDATIONS & REQUIREMENTS

ENERGY DISSIPATION FACTOR (EDF)

- 16 — AWS dissipation, max. (31.33 ft-lb/s/ft³); EA UK (2010)
- AWS dissipation, min. (20.89 ft-lb/s/ft³); EA UK (2010)
- **AWS POOLS (16.0 ft-lb/s/ft³) †**
- check weirs, salmon (10.44 ft-lb/s/ft³); Larinier et al. (1999)
- 7 — roughened culverts (7.0 ft-lb/s/ft³); WA DFW (2003)
- baffled culverts, max. (5.0 ft-lb/s/ft³); CalTrans (2013)
- salmonids (5.0 ft-lb/s/ft³); Maine DOT (2008)
- vertical slot pools (4.18 ft-lb/s/ft³); FAO and DWVK (2002)
- 5
- **ATLANTIC SALMON (4.0 ft-lb/s/ft³) †**
- 4 — salmonids, adult (3.13 ft-lb/s/ft³); NOAA (2011)
- **AMERICAN SHAD (3.15 ft-lb/s/ft³) †**
- 3 — trout (3.13 ft-lb/s/ft³); EA UK (2010)
- non-salmonids (2.09 ft-lb/s/ft³); EA UK (2010)
- 2 — step-pools at turns (2.09 ft-lb/s/ft³); EA UK (2010)
- salmonids, juvenile (2.0 ft-lb/s/ft³); NOAA (2011)
- 1 — resting pools (1.04 ft-lb/s/ft³); FAO and DWVK (2002)
- 0 — Denil resting pools (0.52 ft-lb/s/ft³); FAO and DWVK (2002)

† U.S. Fish and Wildlife Service criteria

EDF IN STEP-POOL FISHWAYS



"POTENTIAL ENERGY DISSIPATION RATE PER UNIT VOLUME"

DESIGN: $$V = \frac{\gamma Q D}{EDF}$$

EVALUATE: $$EDF = \frac{\gamma Q D}{V}$$

where:
EDF is the volumetric power dissipation rate in ft-lb/s/ft³
V is the water volume in the fishway step pool in ft³
D is the hydraulic drop from one pool to the next in ft
Q is the flow over the weir crests, through the fishway, in cfs
γ is the unit weight of water (62.4 lbs/ft³)

- Larinier et al. (1999) "Passes a Poissons"
- WA DFW (2003) "Design of Road Culverts for Fish Passage"
- FAO and DWVK (2002) "Fish Passes"
- EA UK (2010) "Fish Pass Manual"
- NOAA (2011) "Anadromous Salmonid Passage Facility Design"
- CalTrans (2013) "Fish Passage Design for Road Crossings"
- Maine DOT (2008) "Waterway & Wildlife Crossing Policy & Design Guide"

USFWS Northeast Region (R5), FAC
Fish Passage Engineering, B. Towler

Issued 1/6/2017; replaces "Power Dissipation Rates" 7/26/2014

POWER DISSIPATION RATES
REFERENCE PLATE 5-2

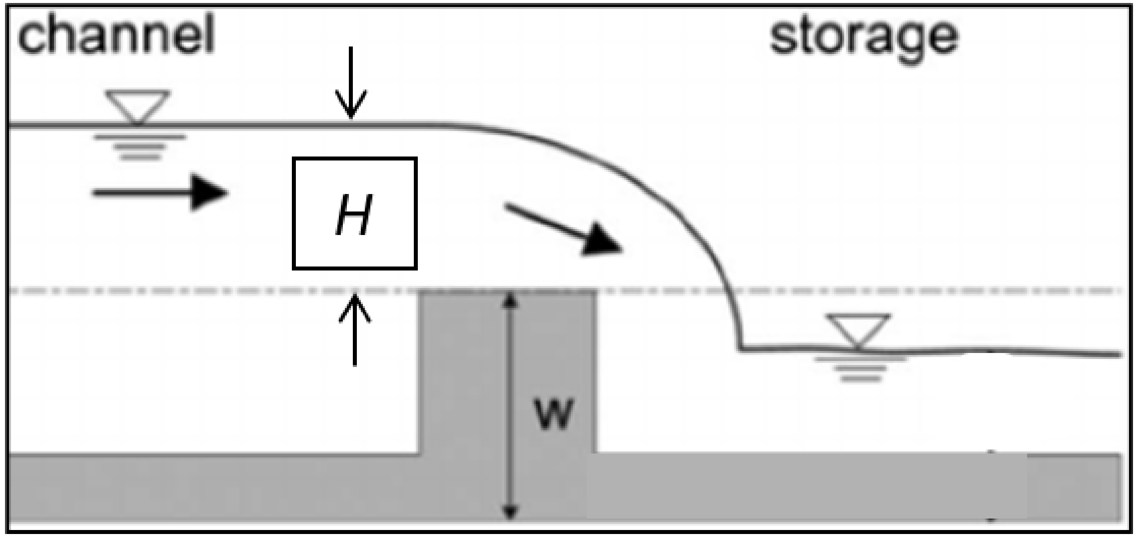
$$\text{Turbulence (EDF)} = \frac{\text{Energy entering the pool}}{\text{Pool volume}} \quad (W/m^3)$$

<u>USFWS Recommends:</u>

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

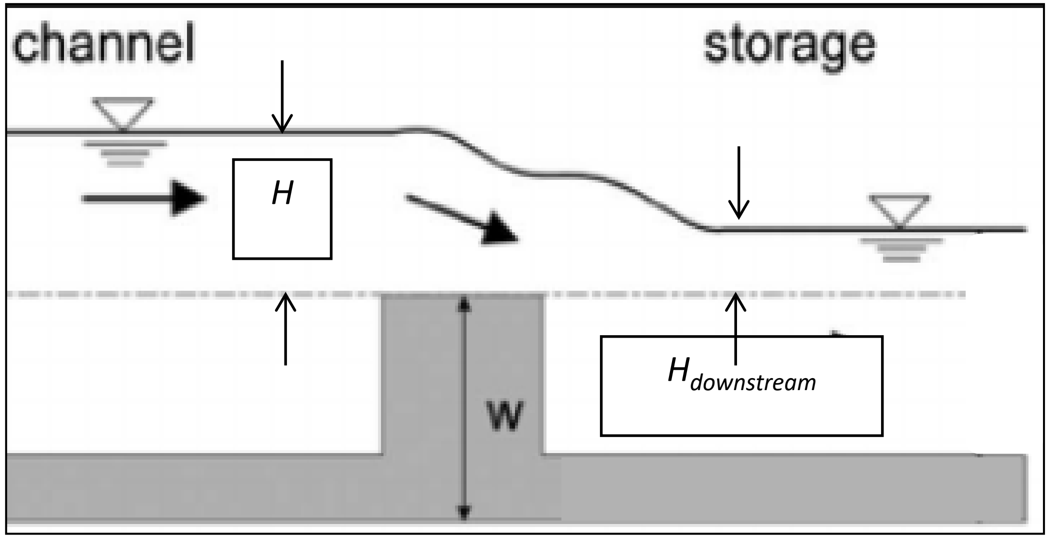
Free Weir vs. Nature-Like Fishway Weir

Typical Free Weir Flow



Design method more for jumpers

Typical NLF Submerged Flow

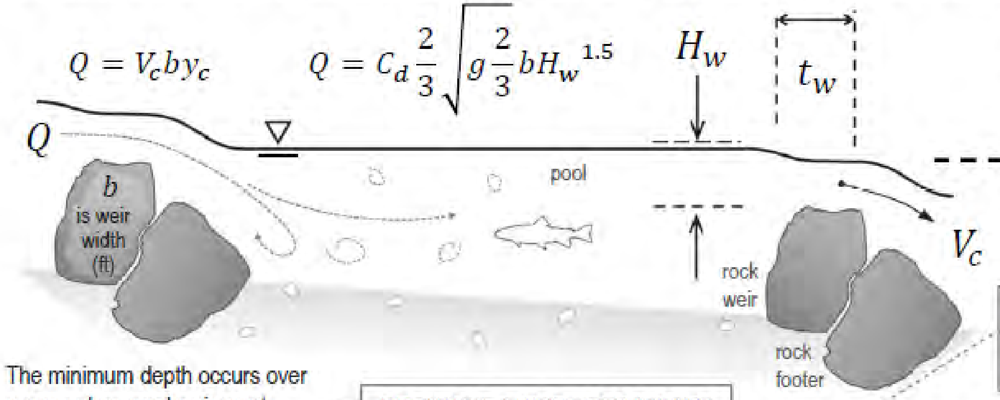


Design method more in line with non-salmonids non-jumpers

Design - Hydraulics

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

$Q = V_c b y_c$ $\qquad$ $Q = C_d \frac{2}{3}\sqrt{g\frac{2}{3}}\, b H_w^{1.5}$



note: V_c may not occur when weir is submerged

The minimum depth occurs over a non-submerged weir crest:

$$y_c = \sqrt[3]{Q^2 / g b^2}$$

The maximum velocity occurs at this minimum depth:

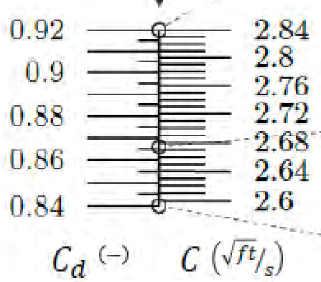
$$V_c = \sqrt{g y_c}$$

Expressed in terms of the discharge coefficient and head:

$$V_c = \sqrt[3]{C_d}\sqrt{\tfrac{2}{3} g H_w}$$

DISCHARGE & WEIR COEFFICIENTS

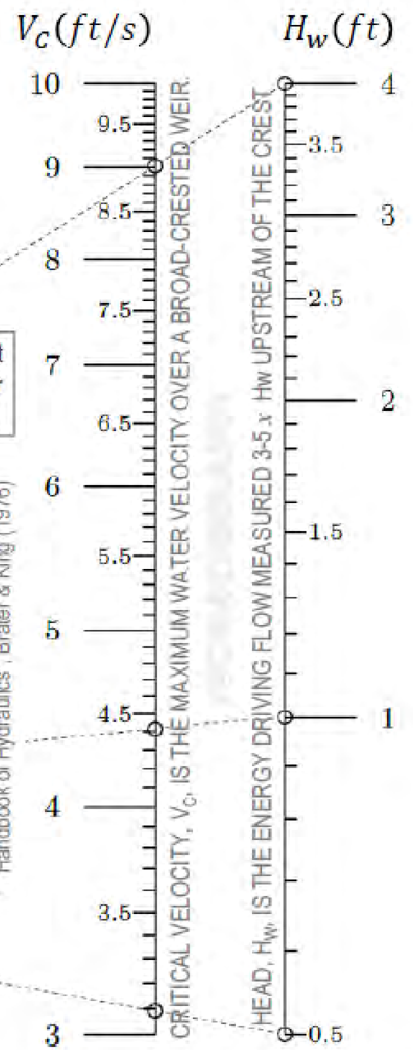
$$C_d \frac{2}{3}\sqrt{g\frac{2}{3}} = C$$



Weir Thickness, t_w (ft); Head Over Weir Crest, H_w (ft); C ($\sqrt{ft}/s$)

Head Over Weir Crest, H_w (ft)	5	4	3	2.5	2
0.6	2.7	2.69	2.68	2.6	2.61
0.8	2.68	2.68	2.67	2.6	2.6
1	2.68	2.67	2.65	2.64	2.66
1.2	2.66	2.67	2.64	2.65	2.7
1.4	2.65	2.65	2.64	2.68	2.77
1.6	2.65	2.66	2.68	2.75	2.89
1.8	2.65	2.66	2.68	2.74	2.88
2	2.65	2.68	2.72	2.76	2.85
2.5	2.67	2.72	2.81	2.89	
3	2.66	2.73	2.92		
3.5	2.68	2.76			
4	2.7	2.79			

* "Handbook of Hydraulics", Brater & King (1976)



NOMOGRAPH EXAMPLE

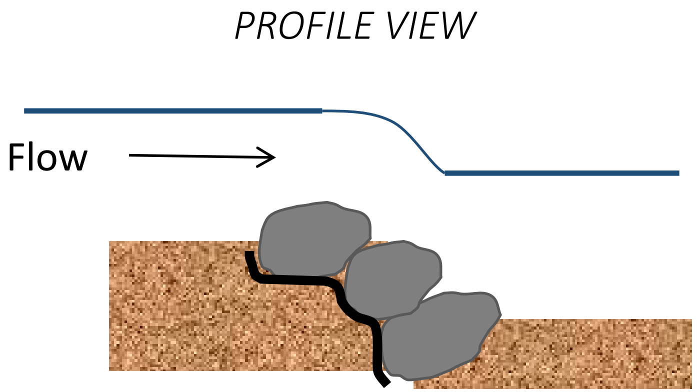
With the aid of this nomograph, table, and a straight edge, one can quickly estimate the maximum velocity over a rock weir. Given a weir thickness of 4 feet and a head of 1 foot, the table indicates C = 2.67. Aligning the straight edge from C = 2.67 on the left scale to H_w = 1 foot on the right scale indicates V_c = 4.4 feet per second on the center scale (values shown on dotted line).

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

Constructon

- 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

Full-Scale Roughened Channel Test Facility

<u>Research and Case Study Results for nonsalmonids:</u>

- 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.

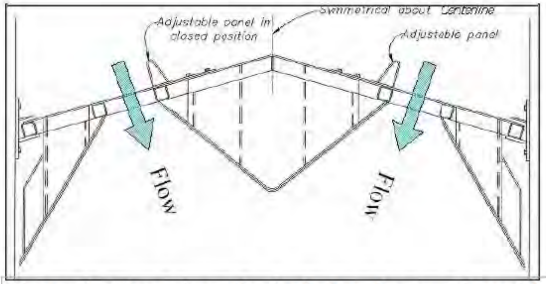


Figure 3 – Plan view of a dual-slot chevron shaped baffle with downstream guide walls.

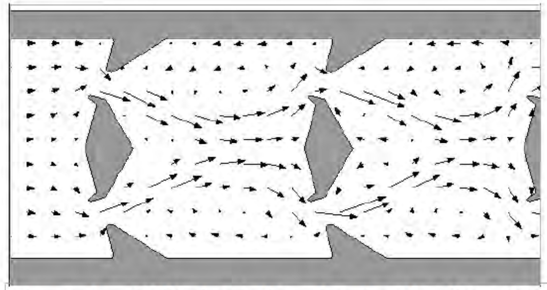


Figure 4 – CFD simulation showing the flow vector field in a fishway with dual-slot chevron baffles.

Mefford, 2009.

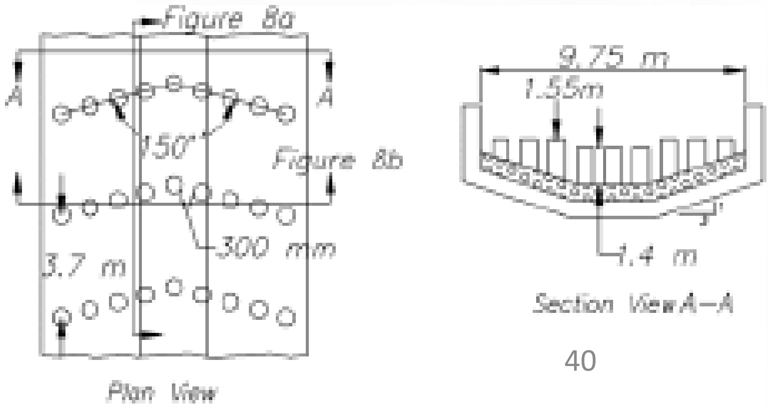
Rocky Ramp Analogs in Technical Fishways

USA - US Bureau of Reclamation

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

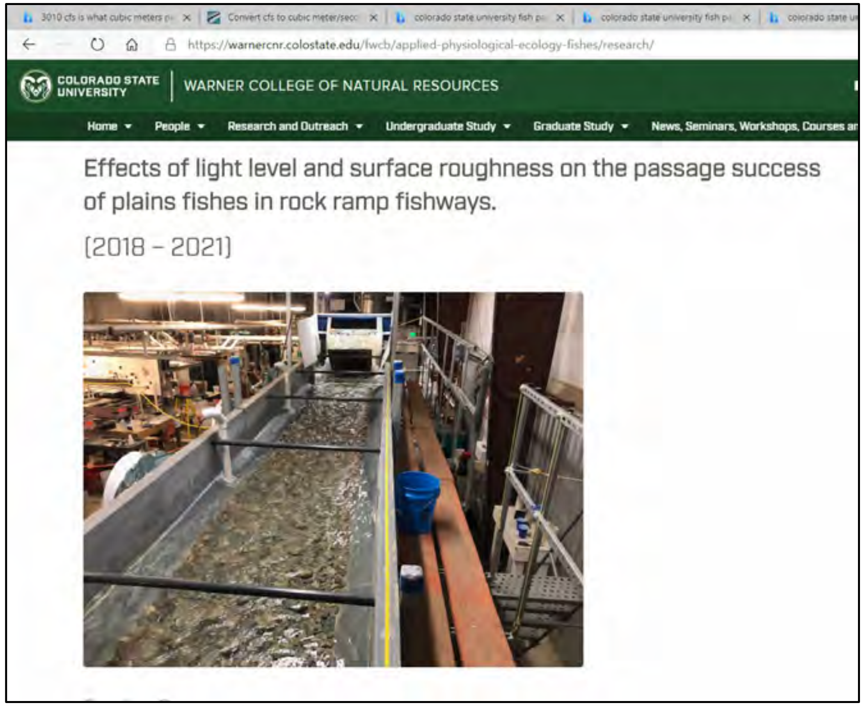
Australian Designs – Cone Fishways

USA - US Bureau of Reclamation
Cylinder Fishway
Price-Stubb Dam, Colorado River



Research

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/ecohydraulics/

Monitoring

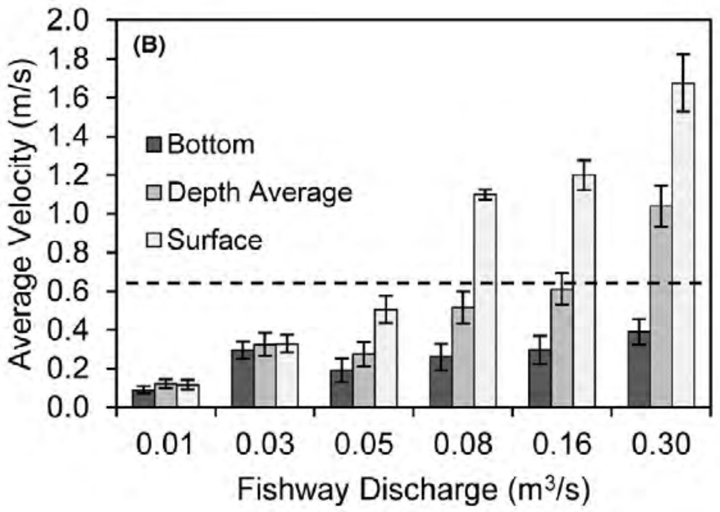
North American Journal of Fisheries Management

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1002/nafm.10516

MANAGEMENT BRIEF

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

Eric E. Richer,* Eric R. Fetherman, Elizabeth A. Krone, F. Boyd Wright III, and Matt C. Kondratieff
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

Hilliard Canal Step-Pool Ramp, Utah

Questions?
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