Removing Powerdale and Middle Fork Nooksack River Dams:

Designing Riverbeds For Fish Passage in High Energy Environments

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R2 Resource Consultants, Inc.

Acknowledgments

- **Project Owners/Sponsors:**
  - Powerdale Dam – PacifiCorp
  - Middle Fork Nooksack Dam – City of Bellingham/American Rivers/ Paul Allen Foundation
- **Project Prime/Technical Collaborators:**
  - Powerdale Dam – Black and Veatch (Larry Magura)
  - Middle Fork Nooksack Dam – HDR (Ed Zapel, Matt Prociv), American Rivers (April McEwen), NHC (Peter Brooks, Andrew Nelson)

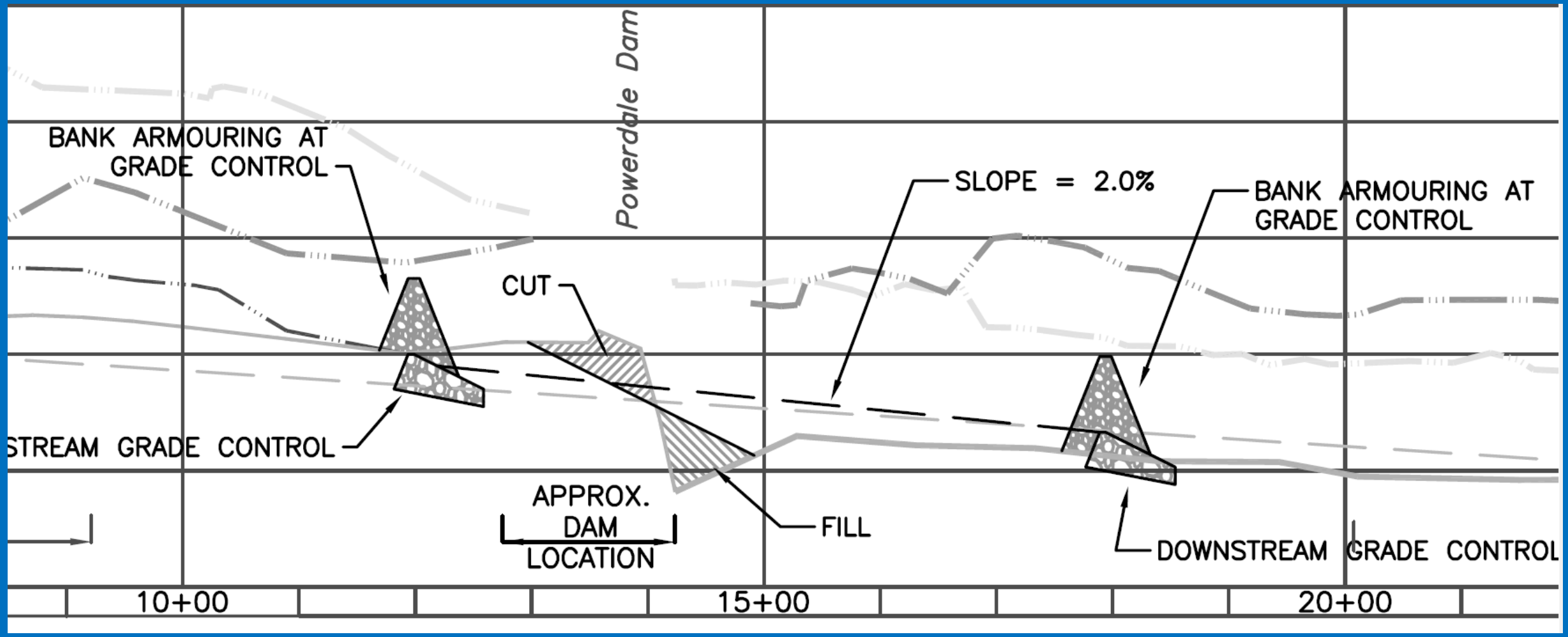
Case Studies

- **Common Goals:**
  - **Design a riverbed for long term upstream passage that can adjust naturally without unraveling significantly, in high energy rivers**
- **Differences in Design Approach:**
  - **Powerdale: Reference-based**
  - **Middle Fork Nooksack: Mechanistic-based**
- **Common Design Philosophy:**
  - **Adjustment Shouldn't (Can't) be Avoided**

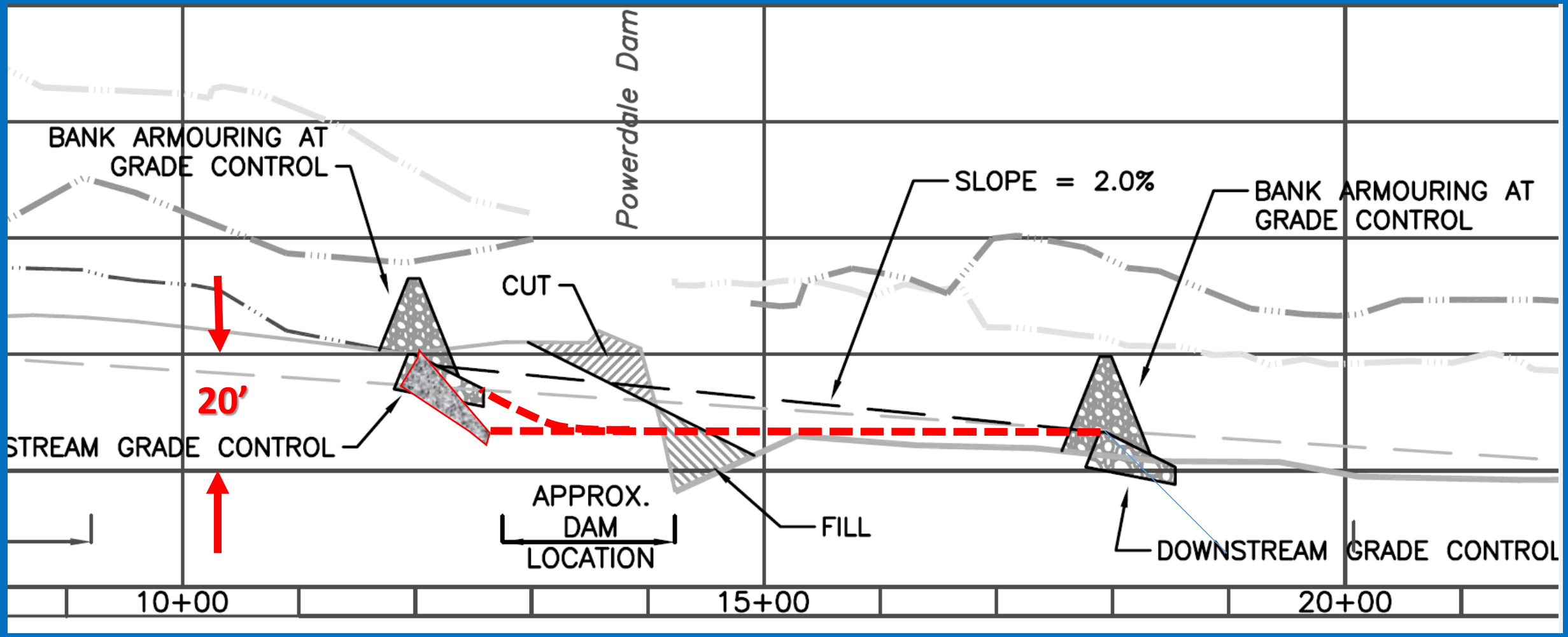
Powerdale Dam Goals

- Remove All Dam Facilities
- Unfettered Upstream Fish Passage
- No Future Headcut
  - Neal Creek Upstream

Fixed Grade Control?



Fixed Grade Control?… Well, not really…

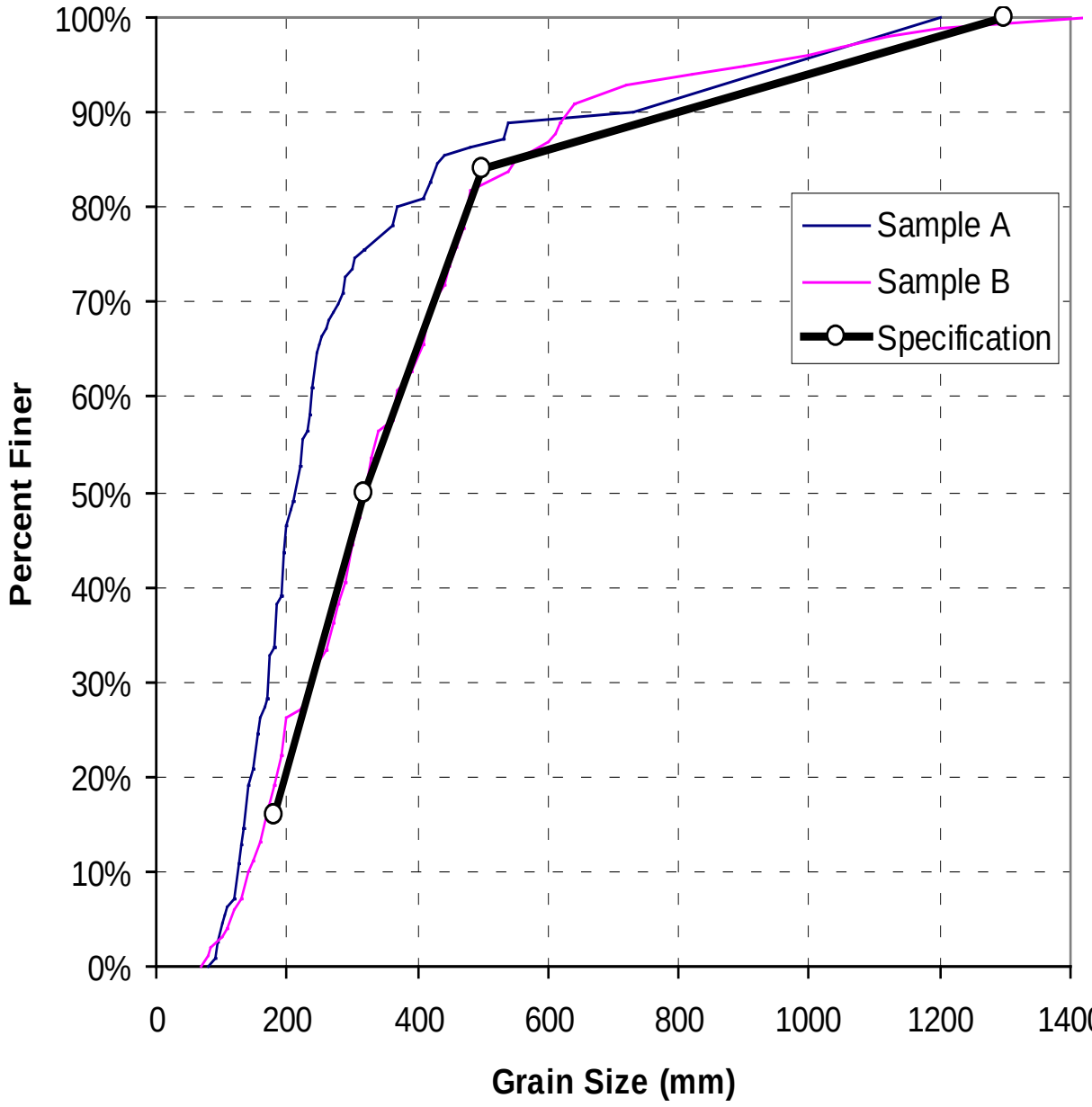


JUST SAY NO
... TO HARD GRADE CONTROL !!!

River Has Characteristic Grade & Substrate…

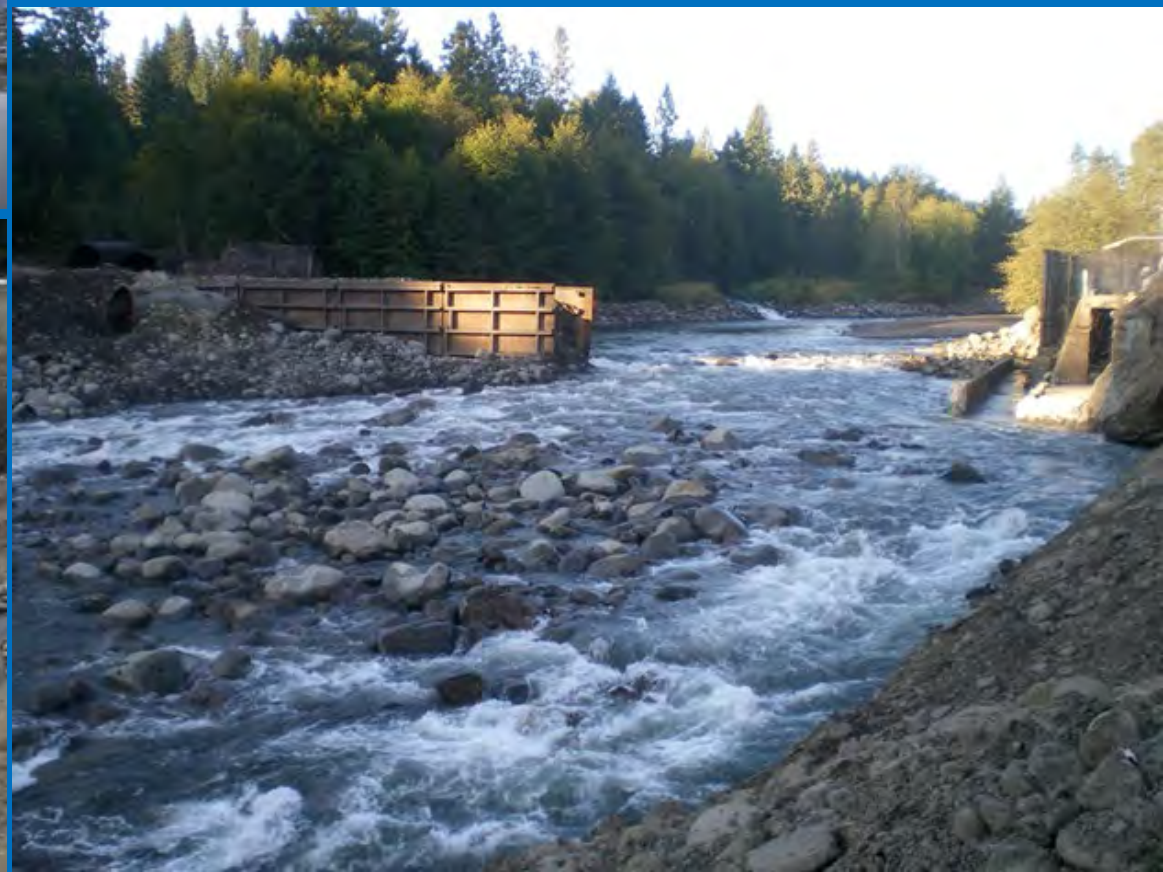
Upstream/Downstream Riffles = Reference Condition

Design Specification:



High Gradient Riffle
Location of Former Hydraulic Control Riffle
Area Filled With Boulder Mix
Cofferdam
Image © 2018 DigitalGlobe

First Water…



One Year Later…

2004
Hydraulic Control
"Riffle"
Flow
"Riffle"

2010

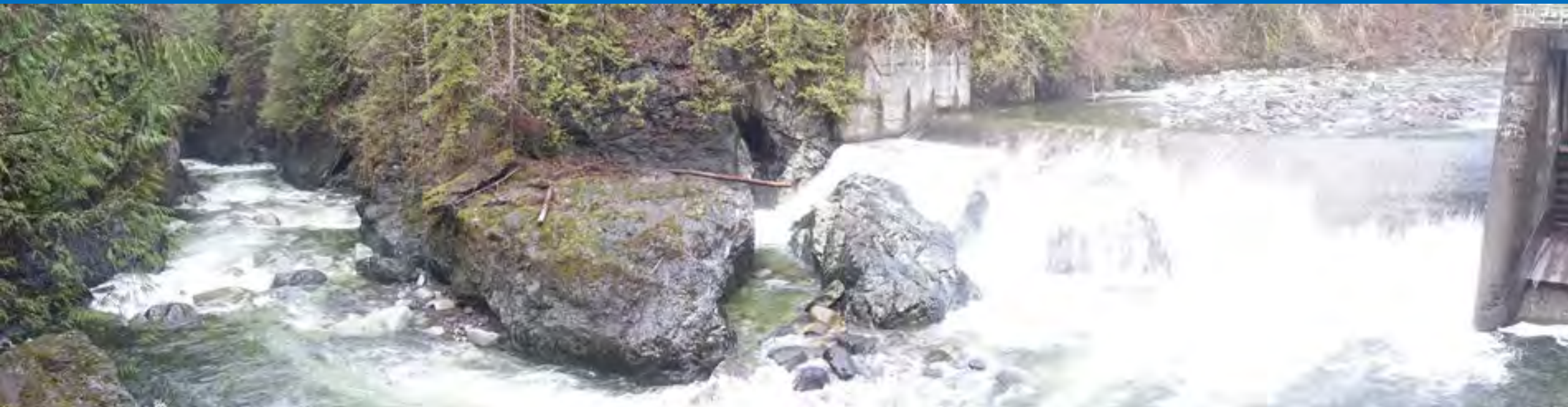
2011

Aug
2016

2018

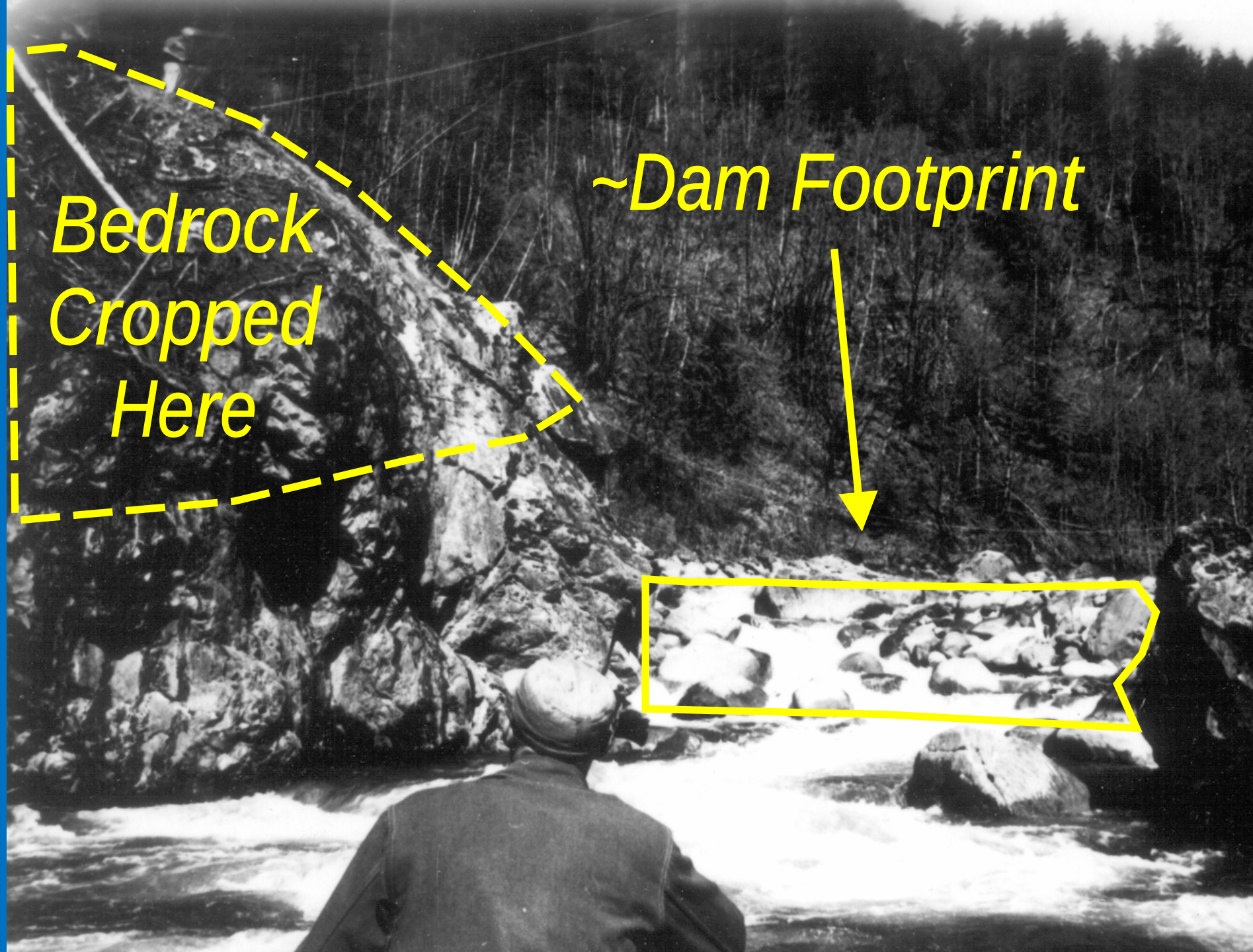
Middle Fork Nooksack

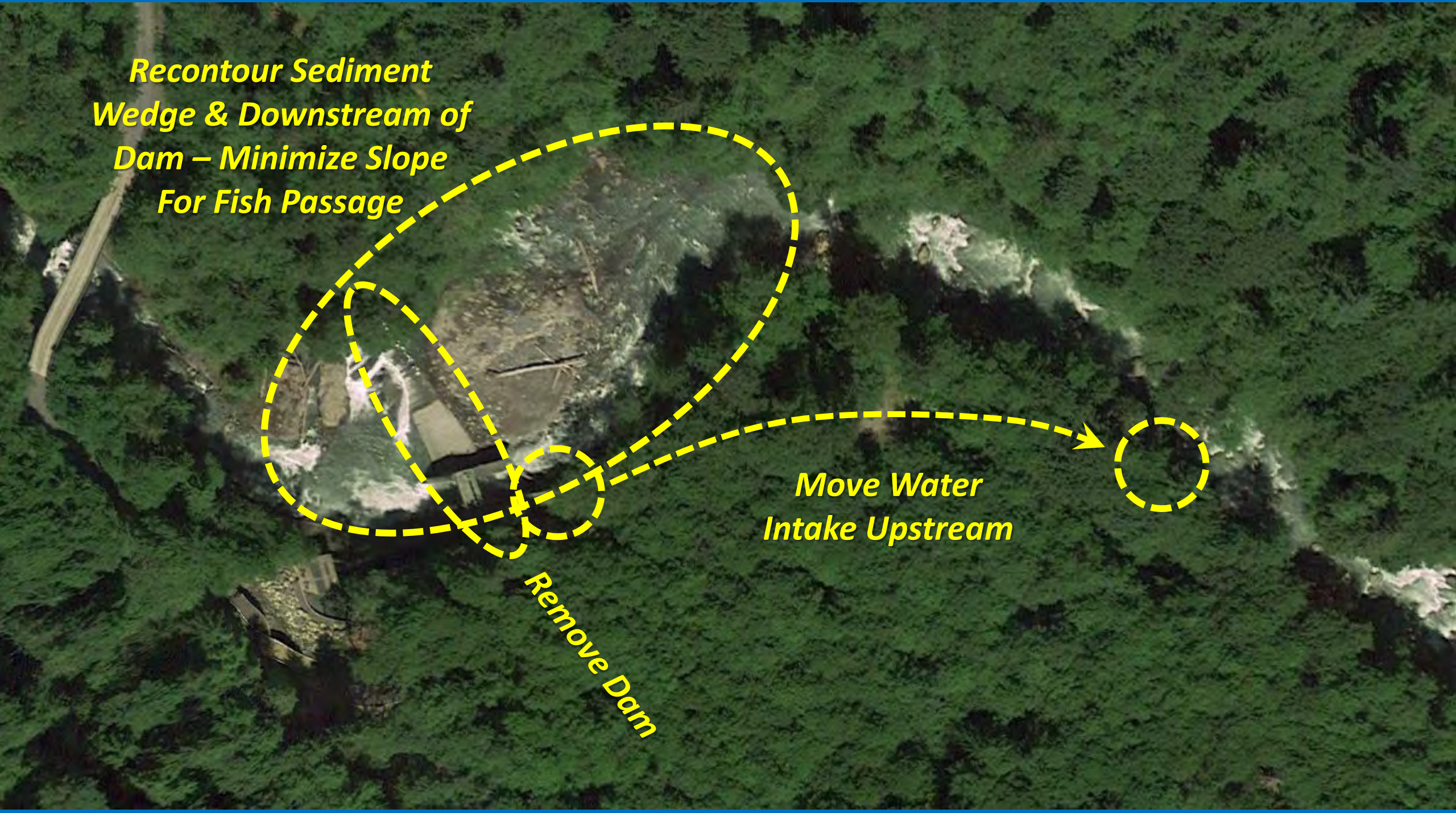
- **Provide Upstream Fish Passage to Historic Habitat**
- **Restore Graded Riverbed**
  - ***Similar Passage Conditions to Historic, or Better***



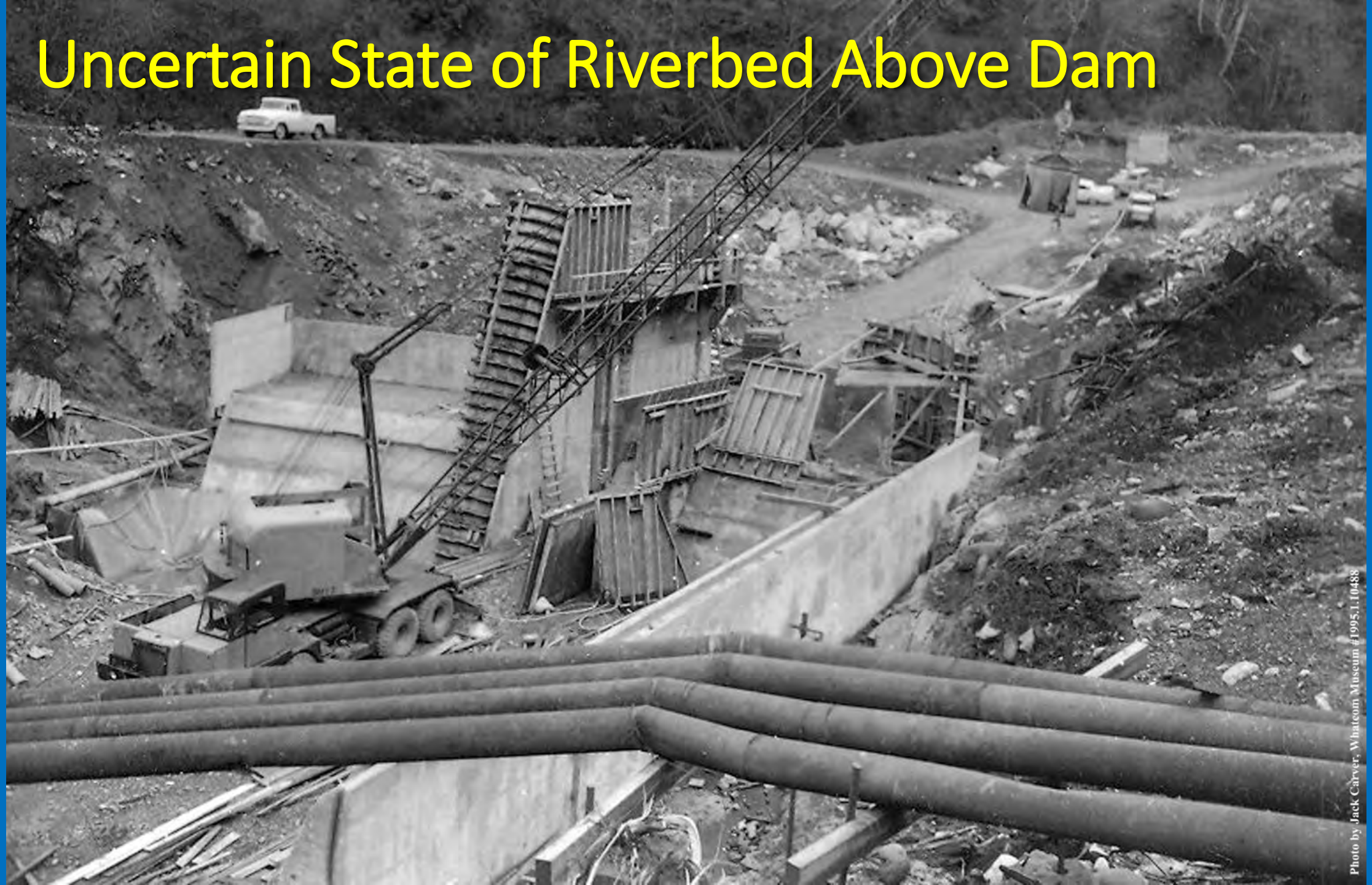
Historic Conditions

- Difficult Upstream Passage in Downstream Canyon & at Site
- Dam Built on top of Cascade




Recontour Sediment Wedge & Downstream of Dam – Minimize Slope For Fish Passage
Move Water Intake Upstream
Remove Dam

Uncertain State of Riverbed Above Dam



Idealized Design – Remove Dam, Let ‘R Rip….

- **High Risk of Fish Passage Restrictions, Headcut in Recontoured Reach:**
  - **Uncertainty of Material Size Behind Dam**
  - **Re-Scouring of Filled Scour Hole Below Dam**
  - **High Energy Environment**
  - **Uncertainty re. Sediment Supply vs. Transport Balance**

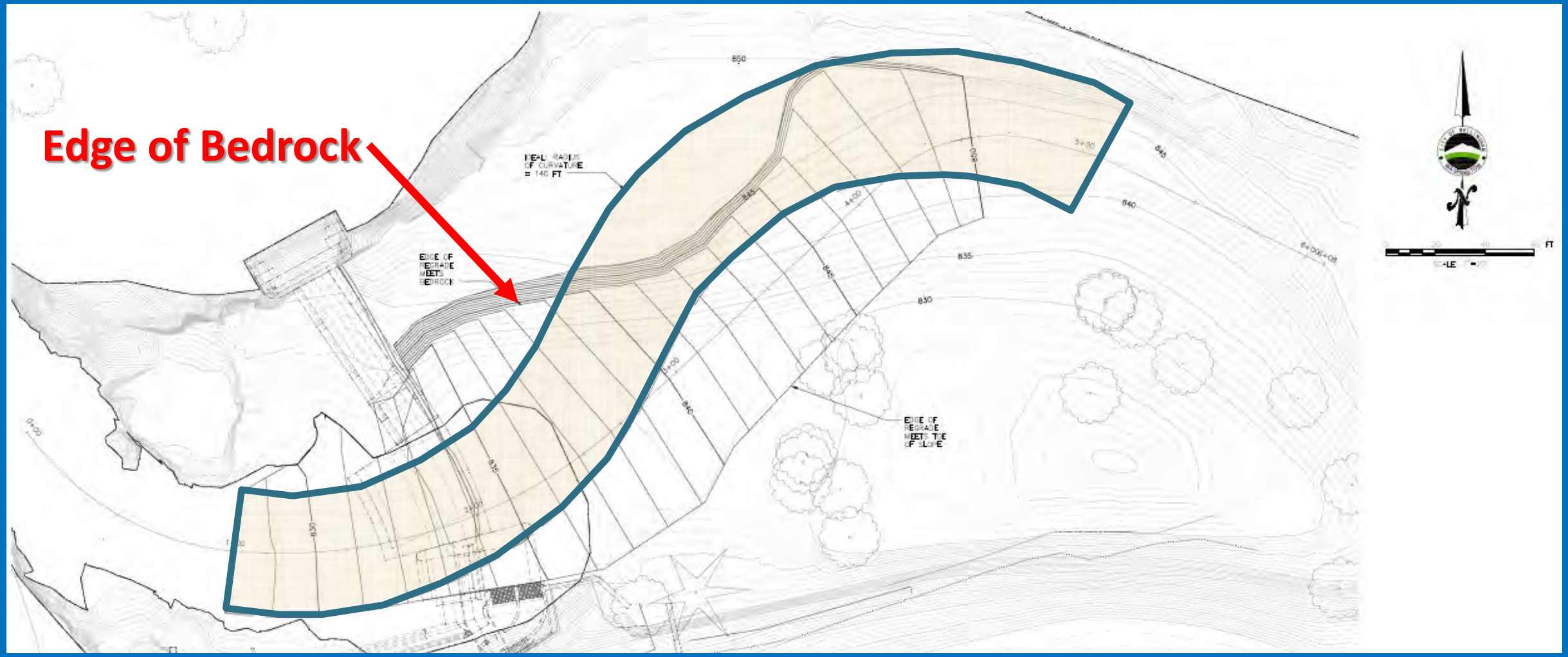
Design Options

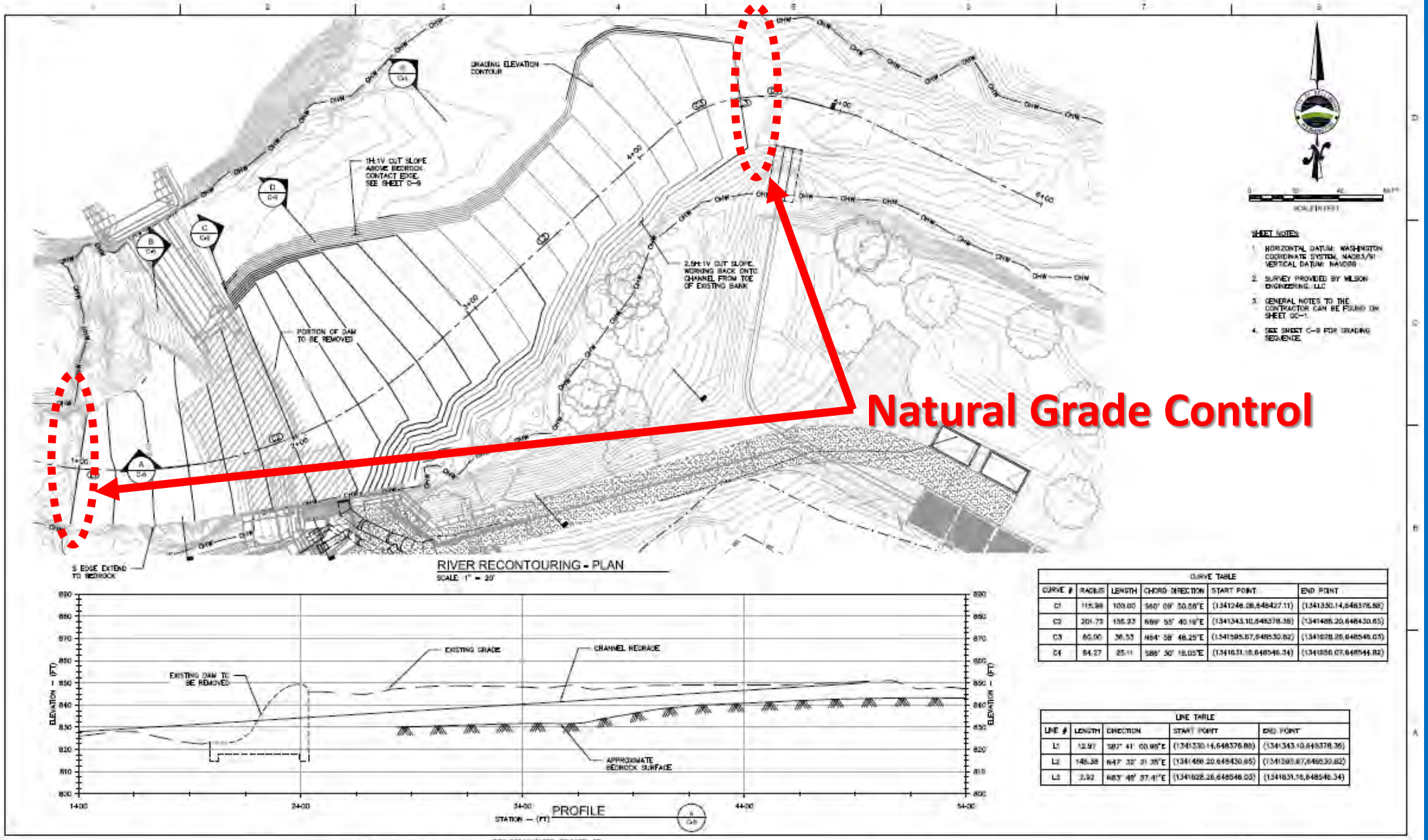
- Bombproof Not Feasible (Rocks Too Big)
  - Adjustable Required
- Four General Options:
  - Boulders Distributed Over Reach (Roughened Channel Analog)
  - Larger Discrete Boulder Clusters/Jams
  - Cross-Channel Jammed Steps
  - Cross-Channel Boulder Field 'Steps'

Selected Boulder Jam:

- **Design Elements Included:**
  - **River Bottom Planform**
  - **Spacing, Boulder Sizes, Scouring, Construction**
  - **Riverbed Stability/Natural Armoring Between Jams**
  - **Riverbank Conditions For Fish Passage, Stability**
  - **Add Extra Boulders to U/S & D/S Grade Controls**
- **Assume Local Adjustment Within Jams Will Occur**

Planform Layout: Ideal vs. Real World…





CURVE TABLE					
CURVE #	RADIUS	LENGTH	CHORD DIRECTION	START POINT	END POINT
C1	115.98	100.00	S60° 09' 50.58"E	(1341246.08,648427.11)	(1341330.14,648376.88)
C2	201.73	156.23	N69° 53' 40.19"E	(1341343.10,648378.38)	(1341488.20,648430.65)
C3	80.00	36.53	N64° 38' 48.25"E	(1341595.67,648530.82)	(1341628.26,648546.03)
C4	64.27	25.11	S88° 30' 18.05"E	(1341631.16,648546.34)	(1341656.07,648544.82)

LINE TABLE				
LINE #	LENGTH	DIRECTION	START POINT	END POINT
L1	12.97	S87° 41' 00.98"E	(1341330.14,648376.88)	(1341343.10,648378.38)
L2	145.38	N47° 32' 21.35"E	(1341488.20,648430.65)	(1341595.67,648530.82)
L3	2.92	N83° 48' 37.41"E	(1341628.26,648546.03)	(1341631.16,648546.34)

Resource Consultants, Inc.
REDMOND, WA.

HDR

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ISSUE	DATE	DESCRIPTION

PROJECT MANAGER	ED ZAPEL, PE
DESIGNED BY	P. DAVRIES
CHECKED BY	S. BECK
DRAWN BY	J. SCHULZ
PROJECT NUMBER	10092926

MIDDLE FORK NOOKSACK RIVER
FISH PASSAGE PROJECT
CITY OF BELLINGHAM
PUBLIC WORKS

CIVIL
RIVER MODIFICATION
RIVER RECONTOURING
PLAN AND PROFILE

FILENAME: C-05.dwg
SCALE: AS SHOWN
PLATE C-5

Uncertainty re. Boulder Sizing.....

Bradley & Mears (1980)
GSA Bull Pt II 91:1057-1090

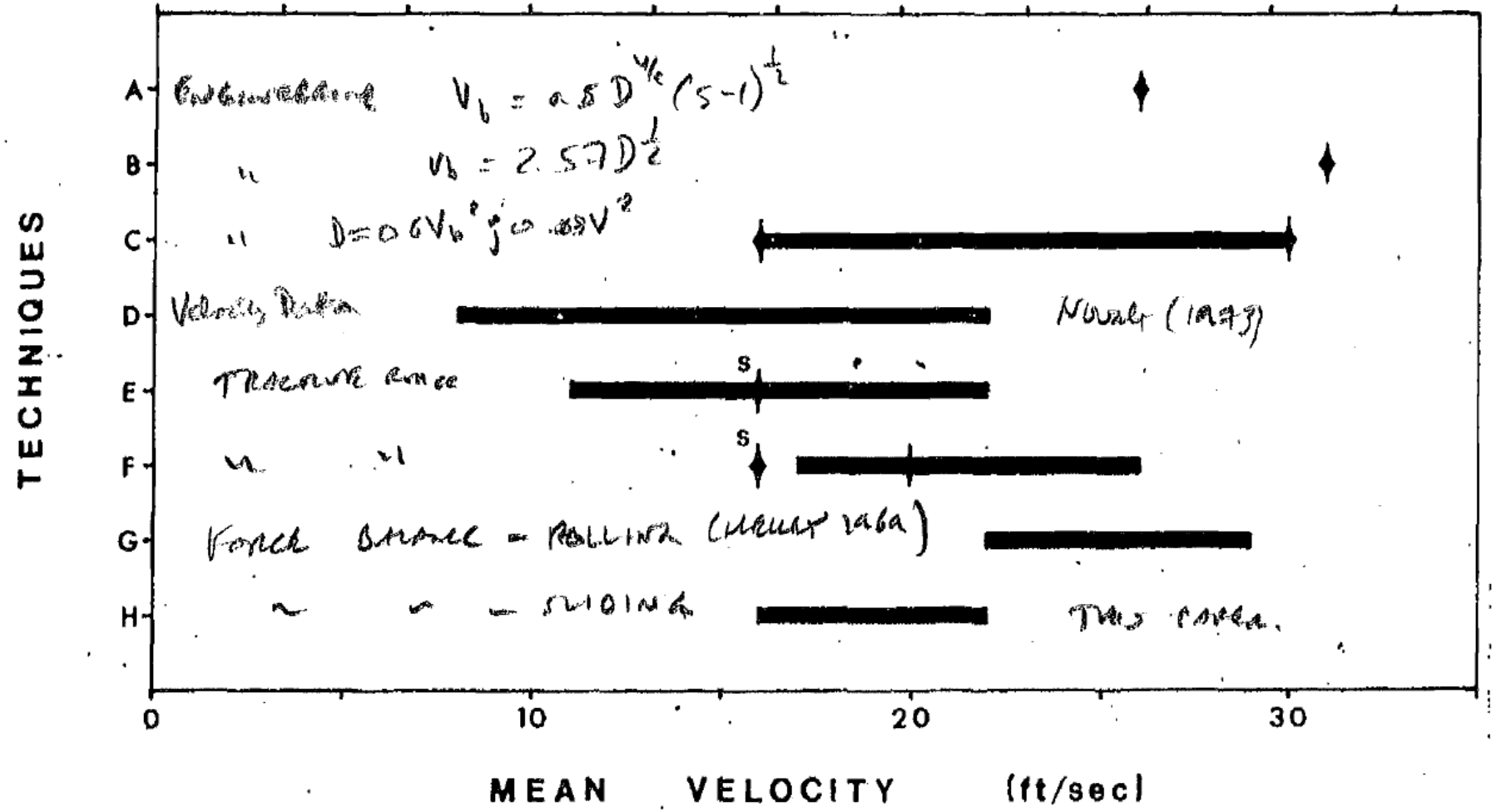
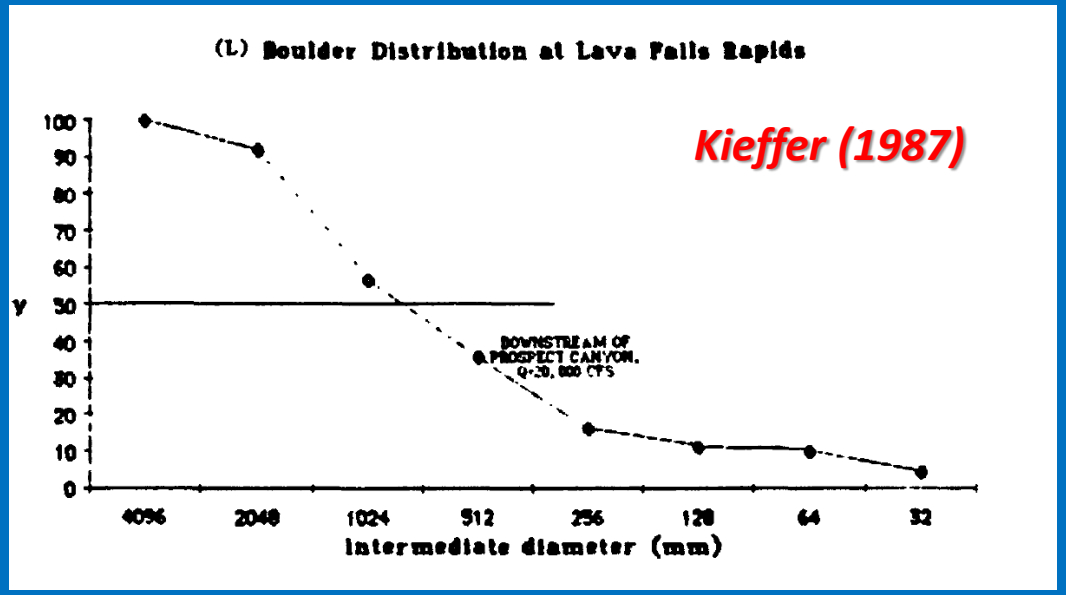
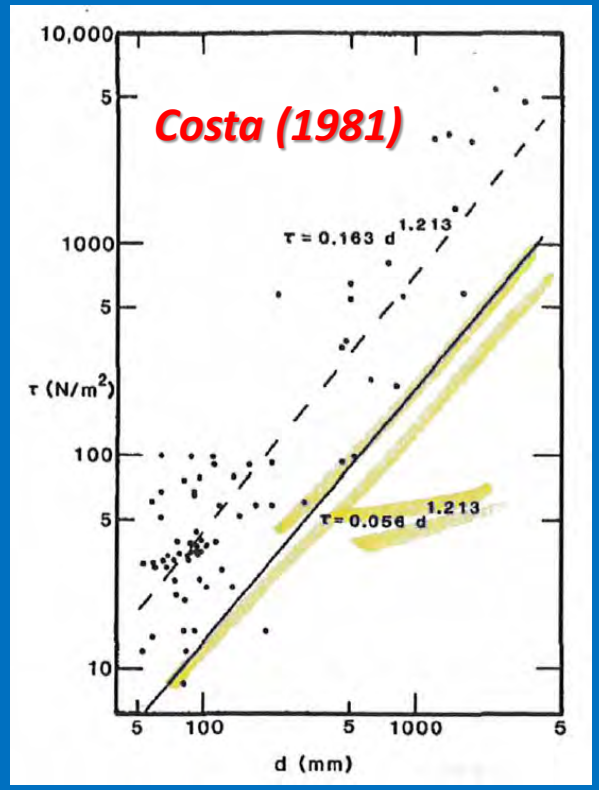
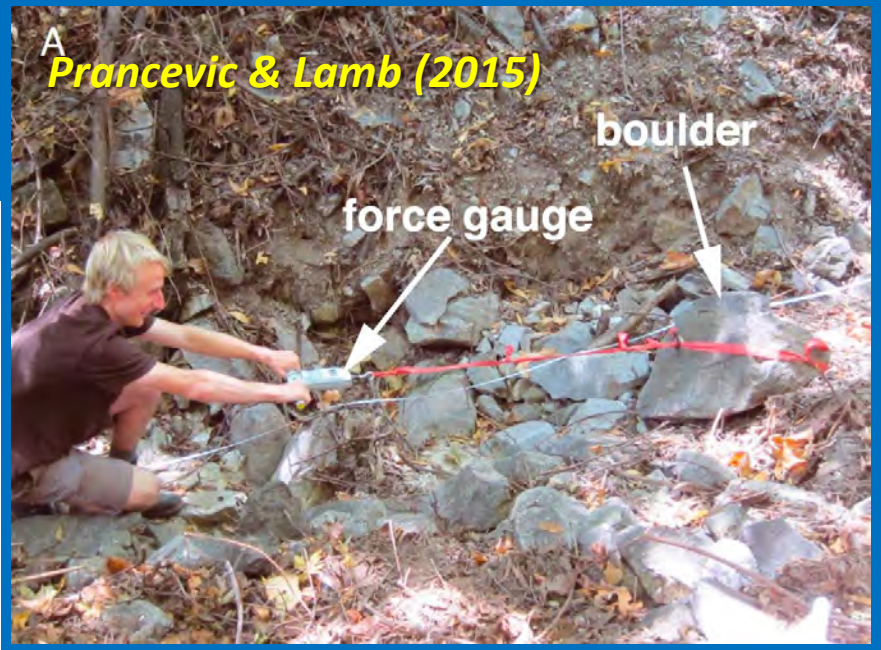


Figure 4. Mean velocities predicted to move 188-cm (6.2-ft) boulders; diamonds for those calculated by formulas, S for Shields criterion. Data in Table 1.

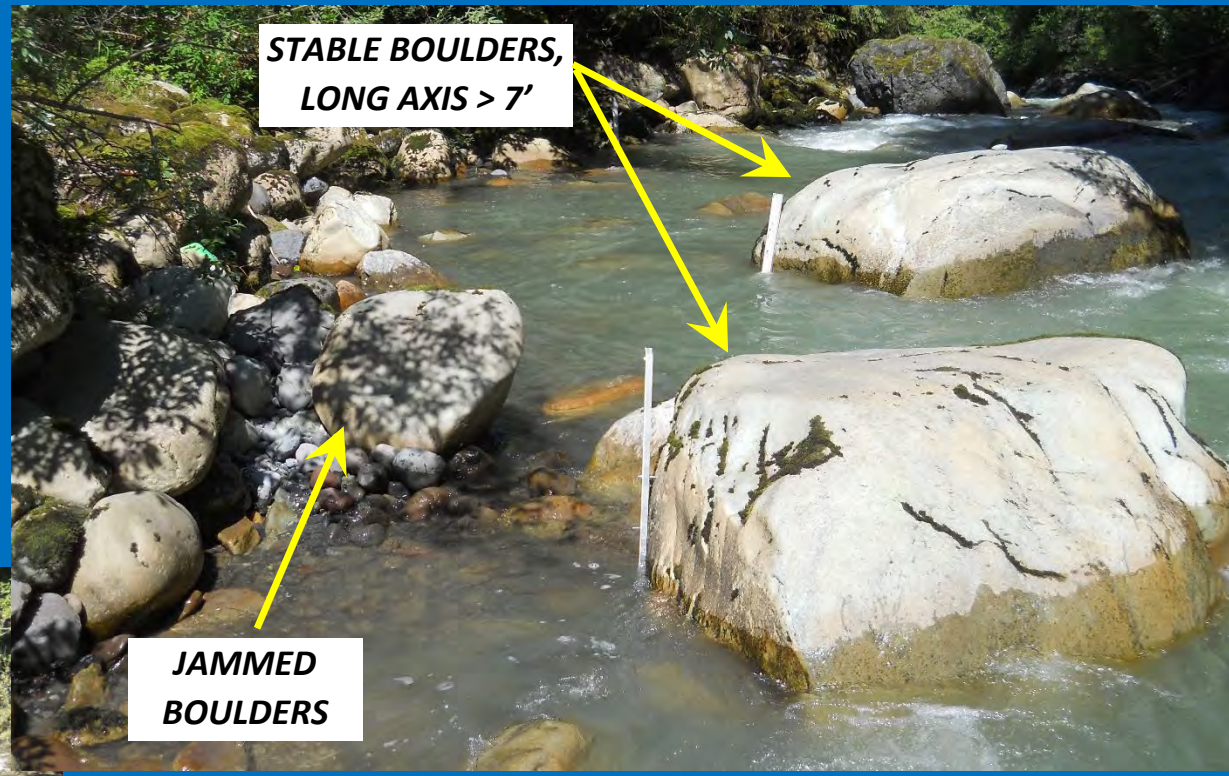
Support From Analytic, Laboratory, & Field Studies

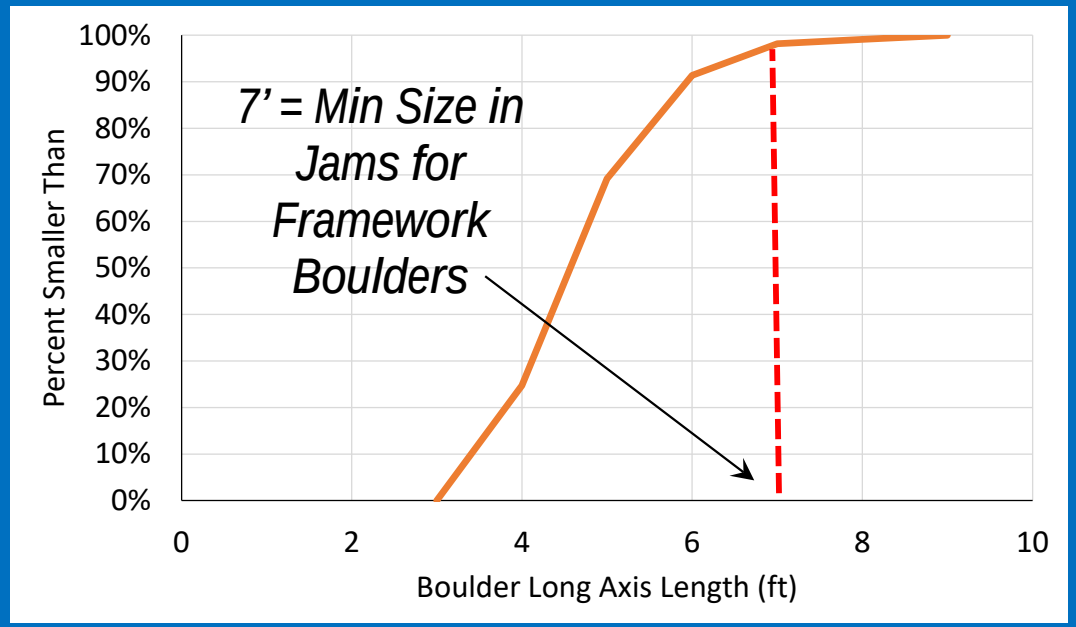




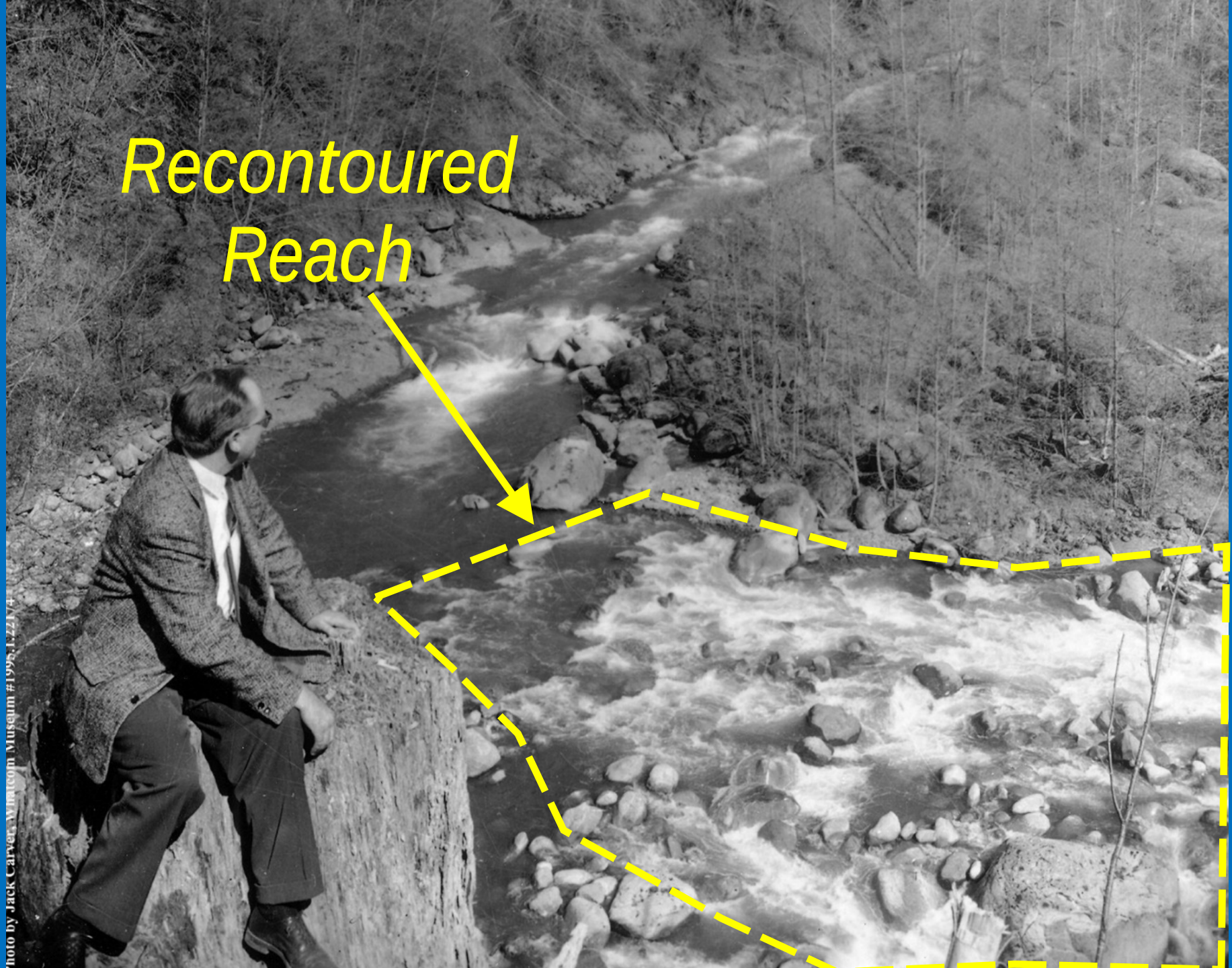


Stable Boulder Design Based on Force Balance & Jamming Research, Corroborated With Field Measurements of Jammed/Unstable Boulders in Confined Reach U/S and Dam Sediment Wedge

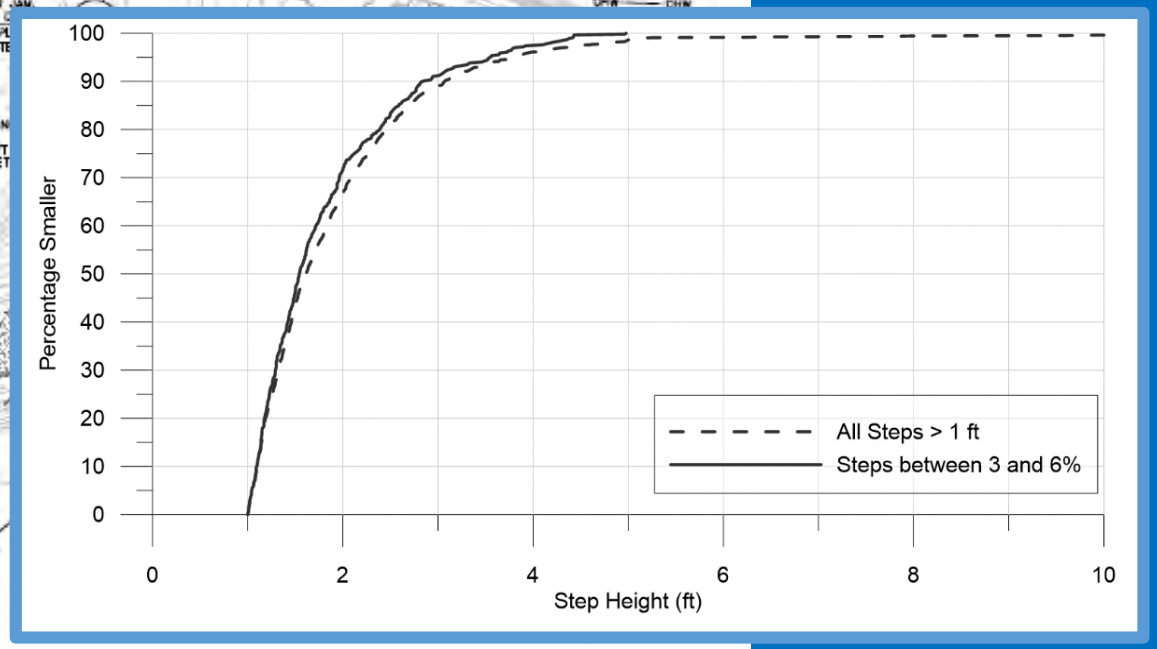


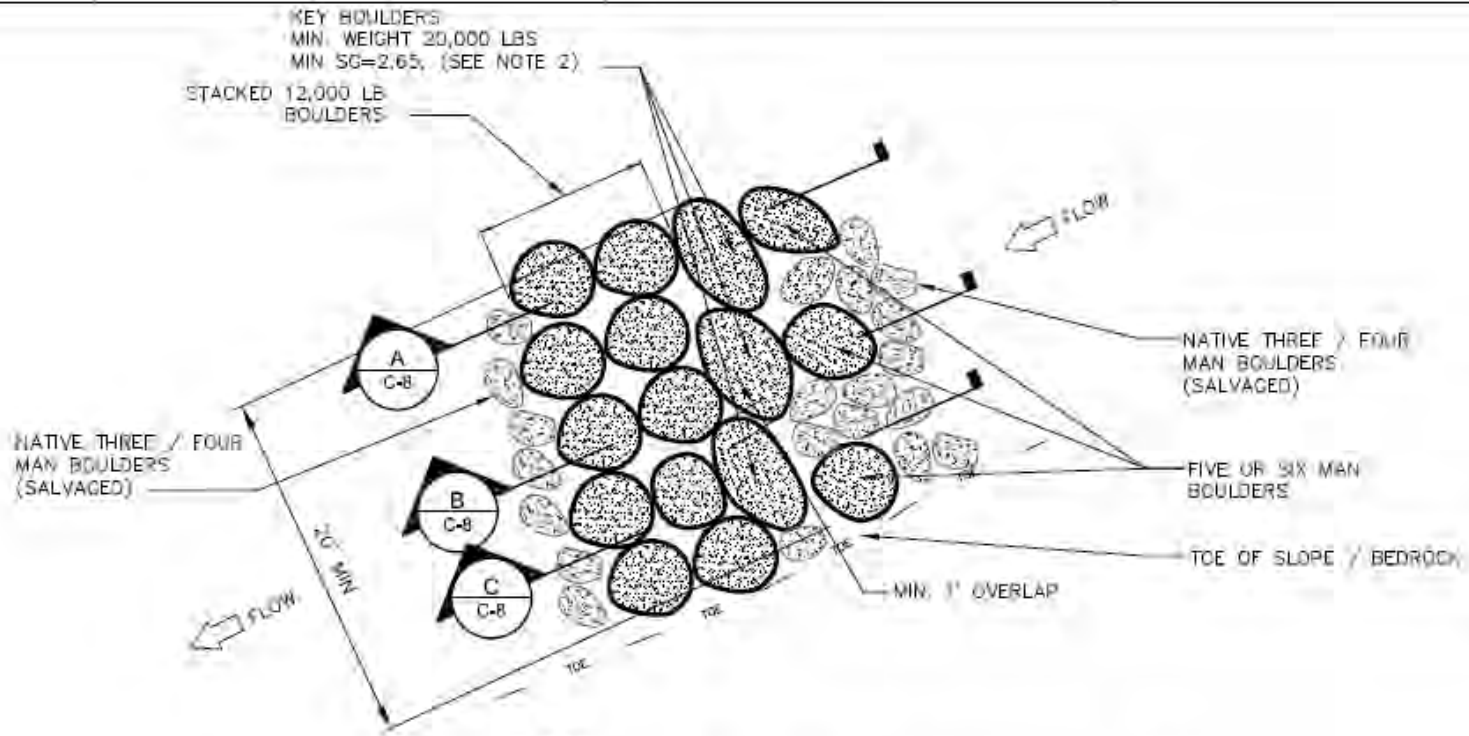


Boulder Jams Were Present Historically, Too

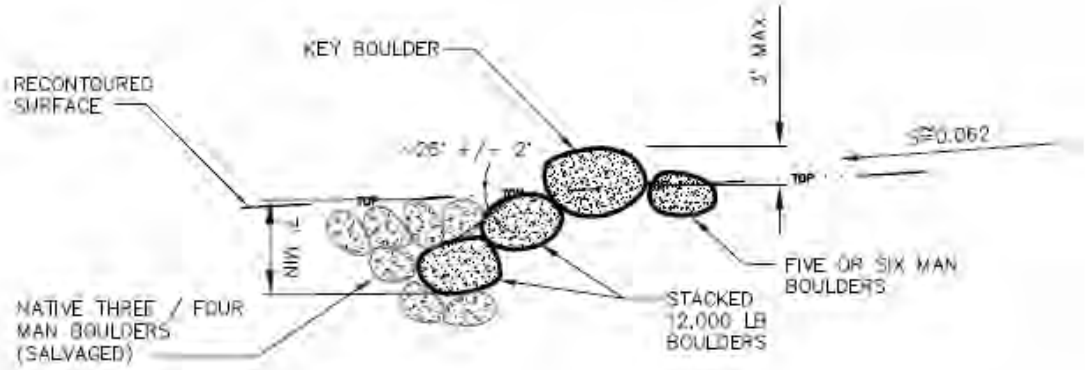


PLACE SIX 12,000 LB BOULDERS IN TWO STAGGERED ROWS OF THREE ACROSS CONTROL, BLEND IN WITH EXISTING BOULDERS, AS DIRECTED BY ENGINEER IN THE FIELD, EMBED MIN 30% INTO RIVERBED
OUTFALL STRUCTURE, SEE SHEET C-3
SALVAGED BOULDERS (SEE NOTE 1)
BOULDER JAM, MID CHANNEL (TYP OF 1) (SEE NOTE 2)
PLACE EXTRA 20,000 LB BOULDER AGAINST BEDROCK, WITH SUPPORTING SIX-MAN BOULDERS
PLACE FOUR 12,000 LB BOULDERS IN TWO STAGGERED ROWS ACROSS CONTROL, BLEND IN WITH EXISTING BOULDERS, AS DIRECTED BY ENGINEER IN THE FIELD, EMBED MIN 30% INTO RIVERBED
ROCK PLACEMENT ENDS AT UPSTREAM END OF CONCRETE
BOULDER PLACEMENT - PLAN
SCALE: 1" = 20'


Percentage Smaller
Step Height (ft)
All Steps > 1 ft
Steps between 3 and 6%



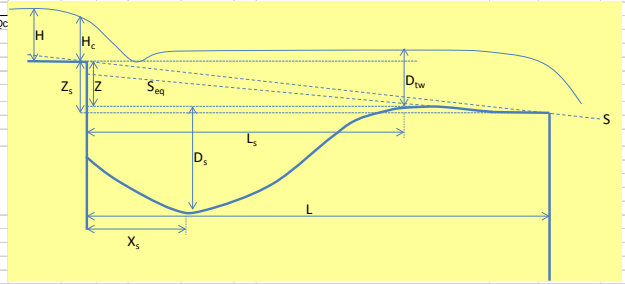
PLAN
BOULDER JAM, SIDE OF CHANNEL (1 / C-7)
SCALE: 1" = 10'



SECTION
BOULDER JAM, SIDE OF CHANNEL (A / C-8)
SCALE: 1" = 10'

SCOUR DOWNSTREAM OF WEIRS/SILLS
M Fk Nooksack: Boulder Sill - HECRAS Sta 7.9081

Input			Source
Q=	13700	cfs	100-yr flood, HECRAS Qc
WEIR Width W=	64	ft	design variable
CHANNEL WIDTH =	64	ft	Survey Data
Weir Streamwise Length=	30	ft	design variable
Tau*cr=	0.03		
Tailwater depth D_{tw}=	14.3	ft	HECRAS Output
Step Spacing L=	54	ft	design variable
Channel Slope S=	0.05600		HECRAS Output
Submerged spec grav (S_s-1)=	1.65		
D16=	153	mm	design variable; bedload (all)
D50 =	305	mm	
D84=	458	mm	
D90=	549	mm	
D95=	610	mm	
Weir Ht above bed Dp (z)=	3	ft	design variable
face angle from horiz=	90	deg	design variable
Upstream Head=	14.30	ft	HECRAS Output
Z1-Z2=	3	ft	head drop



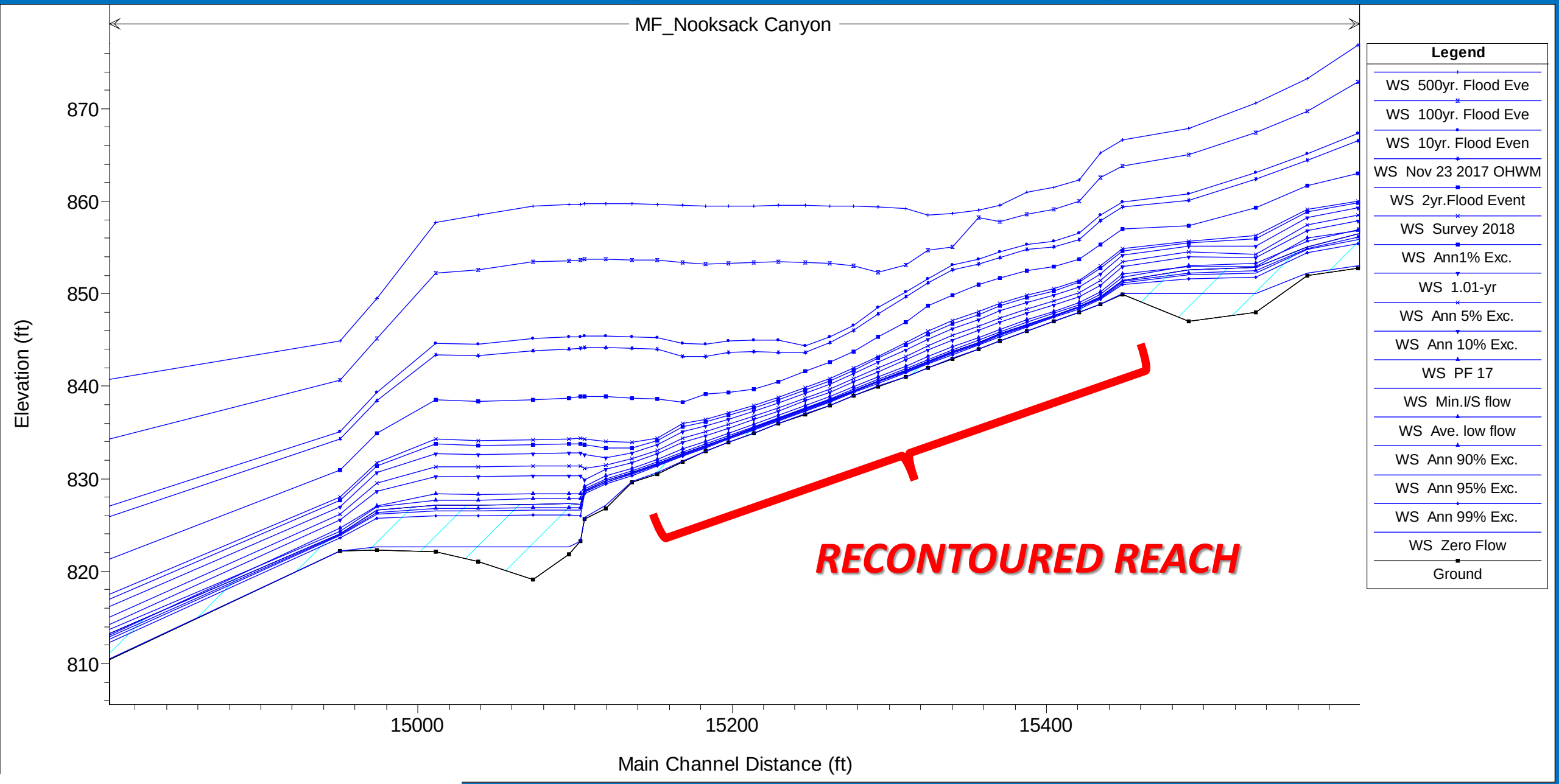
Miscellaneous Calculated		
weir crest depth H_c =	11.2	ft
weir crest velocity Vo=	19.0	ft/s
Upstream Velocity=	15.0	ft/s
Upstream unit Q=	214.1	ft2/s

Lenzi et al. (2003): Minimum Sill Distance to Maximize Scour Depth

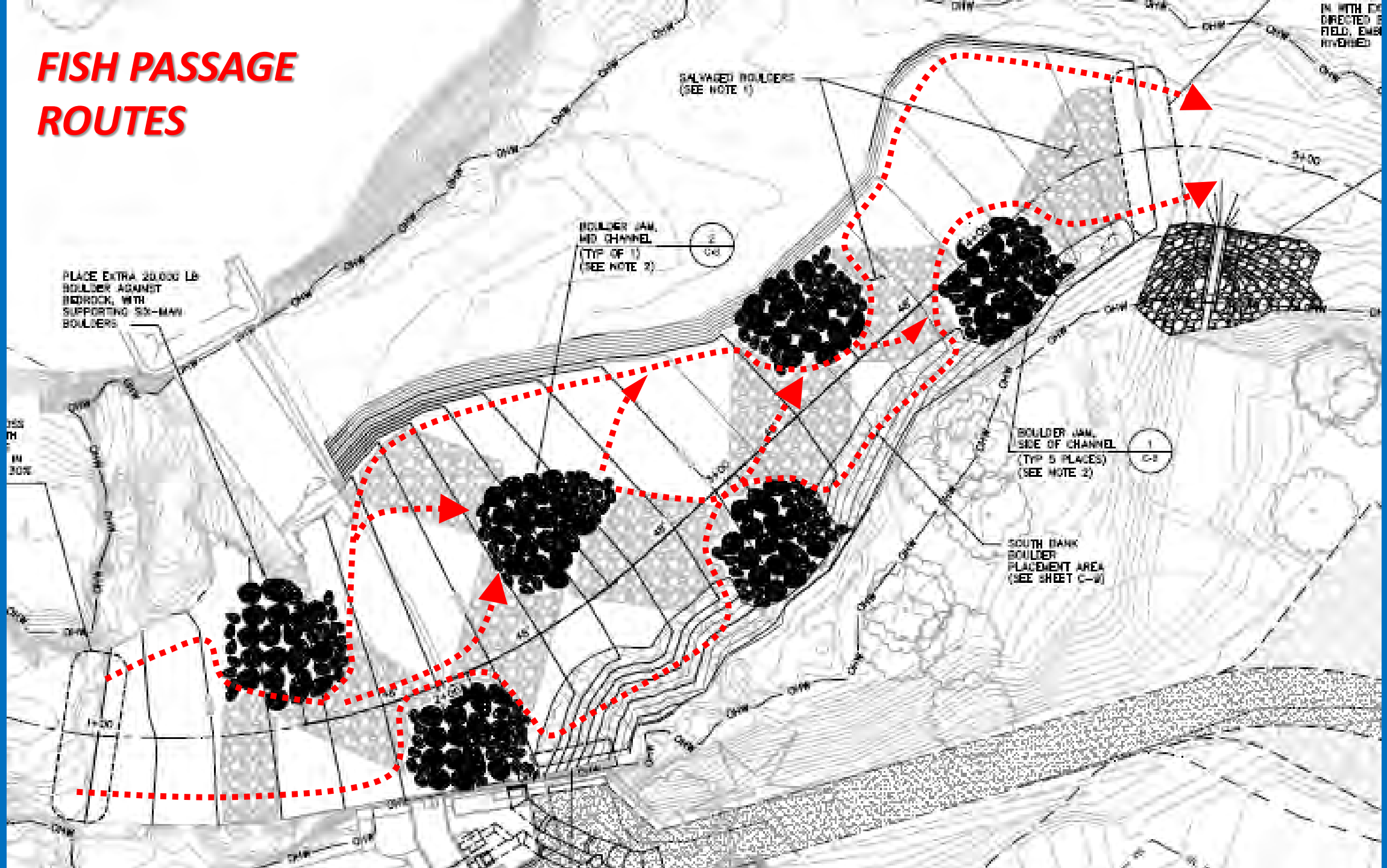
L_{min}= 22 ft

Summary	Scour Depth Ds (ft)	Scour Hole Length Ls (ft)	Scour hole slope S
Lenzi et al. (2002) a1=z	7.7	58	0.132
Pagliara (2013) sloping block ramp based on S	*14.9*	*70*	
Gaudio & Marion low gradient a1=z	4.8	37	
Marion et al. (2004) a1=z	4.5	34	
Comiti et al (2006)	13.2	100	
Italians, Max[(a1=(S-Seq)L)	7.4	56	
D'agostino & Ferro (2004)	17.1	129	
Jager (1939)	2.9	22	
Schoklitsch (1932)	26.1	198	
Blue Italic = independent of particle size:			
Reclamation (1984)	*16.4*	*124*	
D'agostino & Ferro (2004) simple	*11.3*	*85*	
Marion et la. (2006)	*11.8*	*89*	

Backwater & Flow Divergence Help Stability, Too… ☺



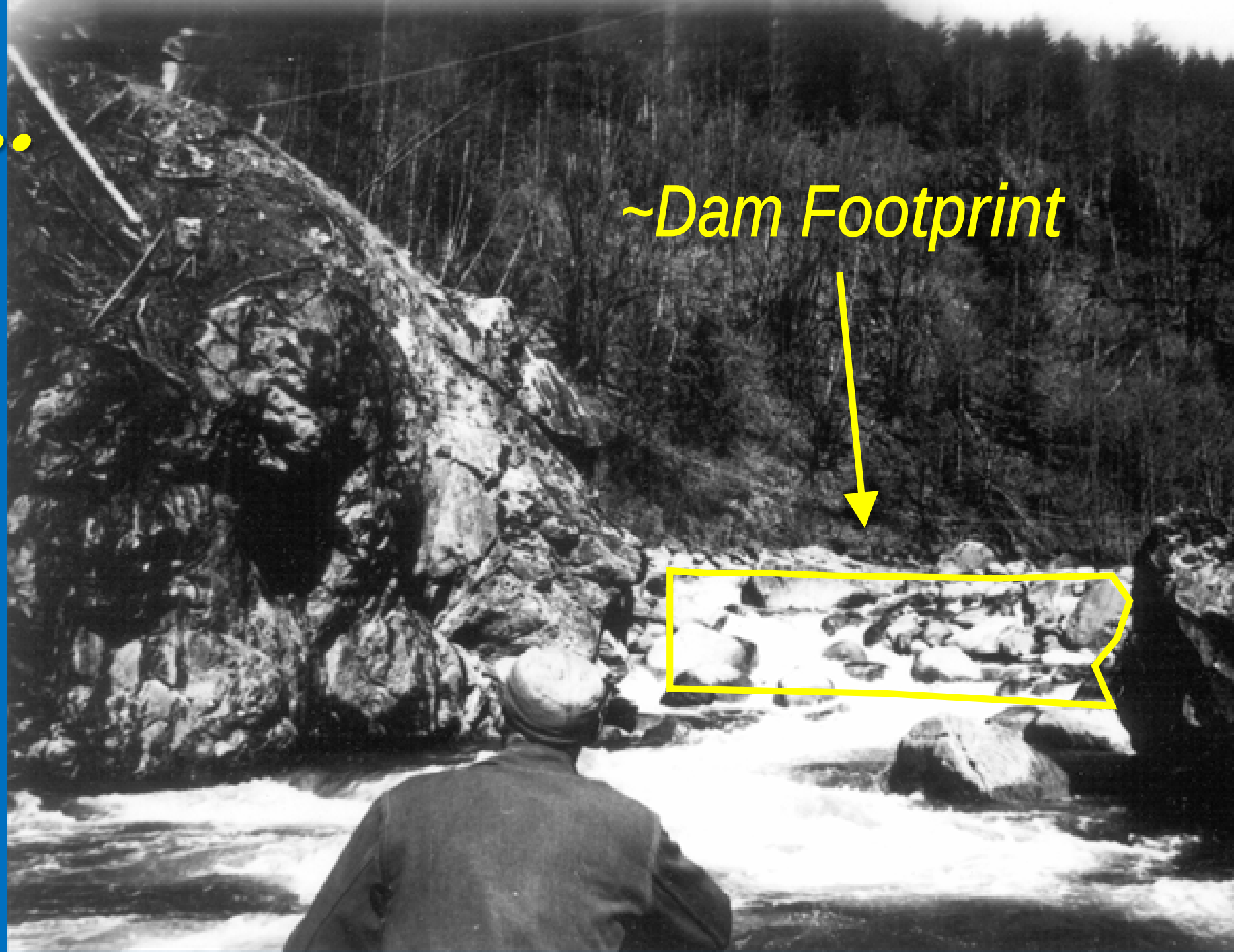
FISH PASSAGE ROUTES



Before...

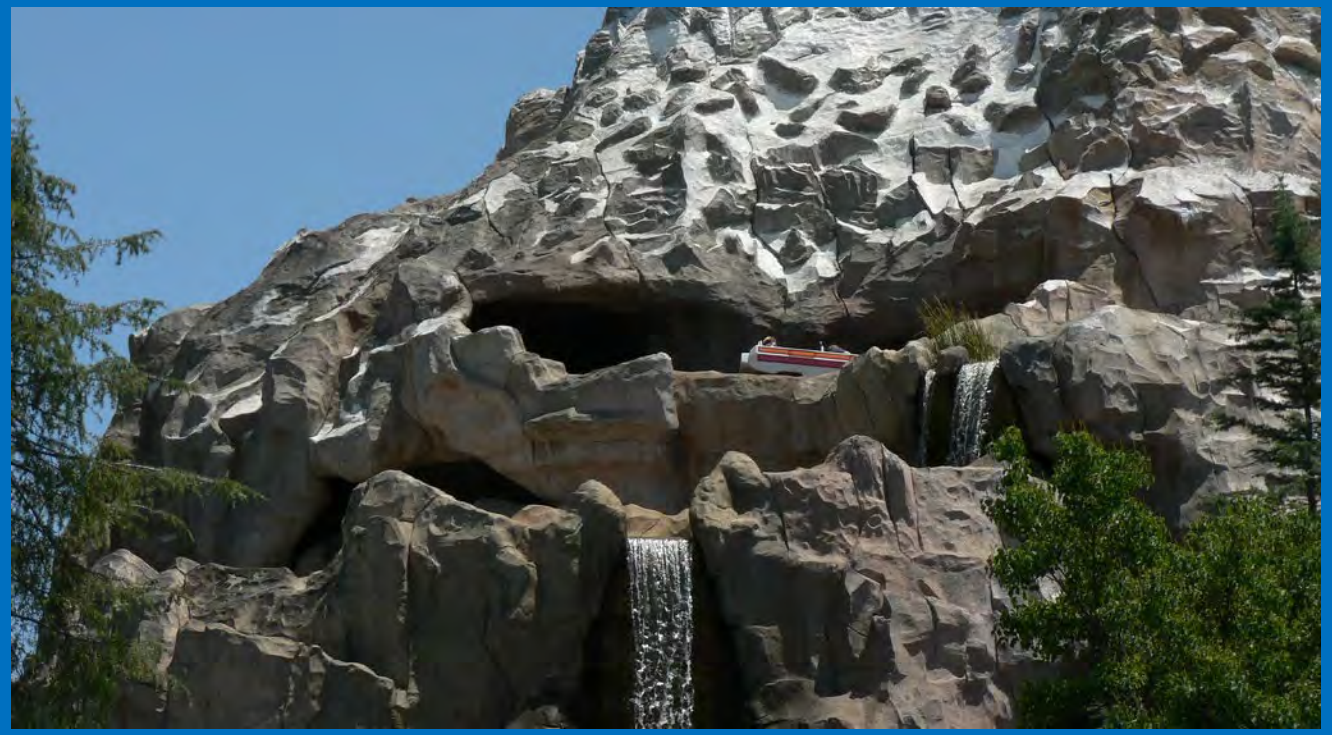
After?

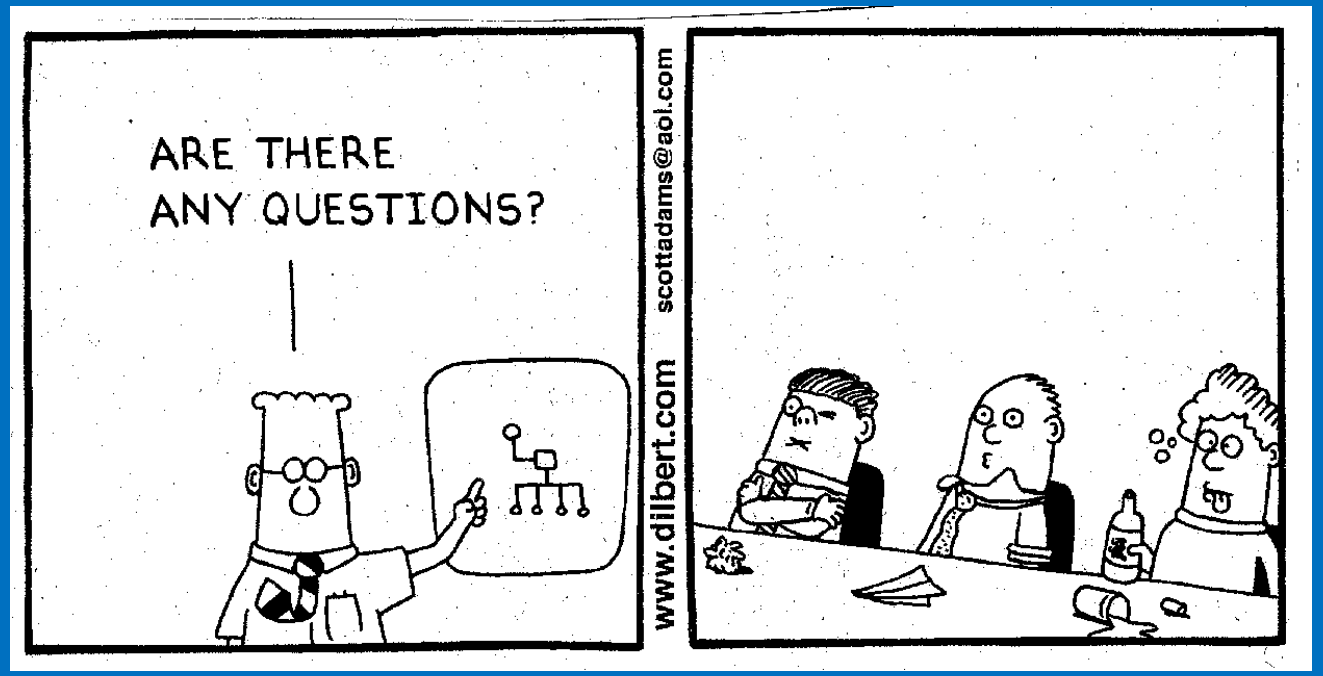
“Plan B”...



Managing Expectations…

I AM AN
ENGINEER
TO SAVE TIME,
LET'S JUST ASSUME
THAT I AM
NEVER WRONG





IMPERIAL ROMAN DEPARTMENT OF PARKS AND LAND MANAGEMENT
IT'S SETTLED, THEN -- WE'LL HAVE A CONTROLLED ERUPTION AT POMPEII.
THAVES 7-24

Questions?

Fish Passage During Construction