Nature Like Fishways:
Modern Perspectives and Techniques

A Workshop at the 41st Annual Salmonid Restoration Conference
Santa Rosa, California, March 26-29, 2024

Workshop Coordinators:

- Tyler Kreider, PE, *Kleinschmidt*
- Mike Garello, PE, *HDR, Inc.*
- Mike Love, PE, *Michael Love & Associates*

This instructor-led workshop, organized by the American Fisheries Society–Bioengineering Section, with funding from the Resources Legacy Fund, to presents a two-day-nature-like fishway workshop. This in-person workshop took place over two days and was instructed by several leading practitioners in the field of Nature Like Fishways (NLF) implementation, including representatives from both private and public agencies. The list of speakers includes Michael Garello (HDR), Michael Love (MLA), Jesus Morales (U.S. Fish and Wildlife Service), Tyler Kreider (Kleinschmidt), Bjorn Lake (NOAA Fisheries), Barry Chilibeck (Northwest Hydraulic Consultants), Brian Cluer (NOAA Fisheries), and Marcin Whitman (retired California Department of Fish & Wildlife). The goal of the workshop was to share knowledge of nature-like fishway design and long-term stability observations among practitioners, regulators, and operators to improve the collective awareness of contemporary NLF science and design methodologies to ultimately provide more effective and sustainable passage for fish. This workshop included the following topics:

- History and state of nature-like fishways
- Application of NLFs to natural and built environments
- Site reconnaissance, project assessment, project development
- Identifying data and modeling needs and necessary in-field data collection
- Example design methods, practices, constraints, and uncertainties—also highlight current/ forthcoming design guidance documents
- Construction methods and oversight
- Monitoring
- Lessons learned from previously constructed NLFs
- Risk evaluation in NLF Design
- Getting the right rocks and placing them for long-term stability

Presentations

- **Advances in Fish Passage and Habitat Restoration**
  Brian Cluer, Ph.D., *NOAA Fisheries – West Coast Region*……Slide 8
- **Upstream Fish Passage Overview**……Slide 44
- **History of Fish Passage and NLF Evolution**……Slide 58
- **Watershed Approach**……Slide 96
- **Types of Barriers**……Slide 116
- **What are NLFs?**……Slide 122

SALMONID RESTORATION FEDERATION NATURE-LIKE FISHWAYS WORKSHOP

U.S. Fish & Wildlife Service — Department of the Interior

NOAA Fisheries — National Oceanic and Atmospheric Administration, U.S. Department of Commerce

Department of Water Resources — State of California

American Fisheries Society — Bioengineering Section

California Department of Fish and Wildlife

Kleinschmidt

HDR

Michael Love & Associates — *Hydrologic Solutions*

WELCOME & ICEBREAKER

- Introductions
- Workshop and Venue Logistics
- Icebreaker

WORKSHOP AGENDA

DAY 1

01 Introductions and Workshop Logistics

02 The History of NLF Design and Available Resources

03 Site Selection & NLF Hybridization

04 Pre-Design Objective-setting, Risk Assessment and Geomorphology

05 Optional Site Visit

DAY 2

06 Design, Monitoring, and Maintenance

07 Contracting & Implementation

INTRODUCTION SESSION

01 Advances in fish passage and habitat restoration

02 Upstream Fish Passage Overview

03 History of Fish Passage and NLF Evolution

04 Available Fish Passage Design Guidelines and Resources

05 Conclusions and Q&A

Advances in fish passage and habitat restoration

NLF Workshop @ 2024 SRF Conference

Brian Cluer Ph.D. – Fluvial Geomorphologist NOAA Fisheries – West Coast Region

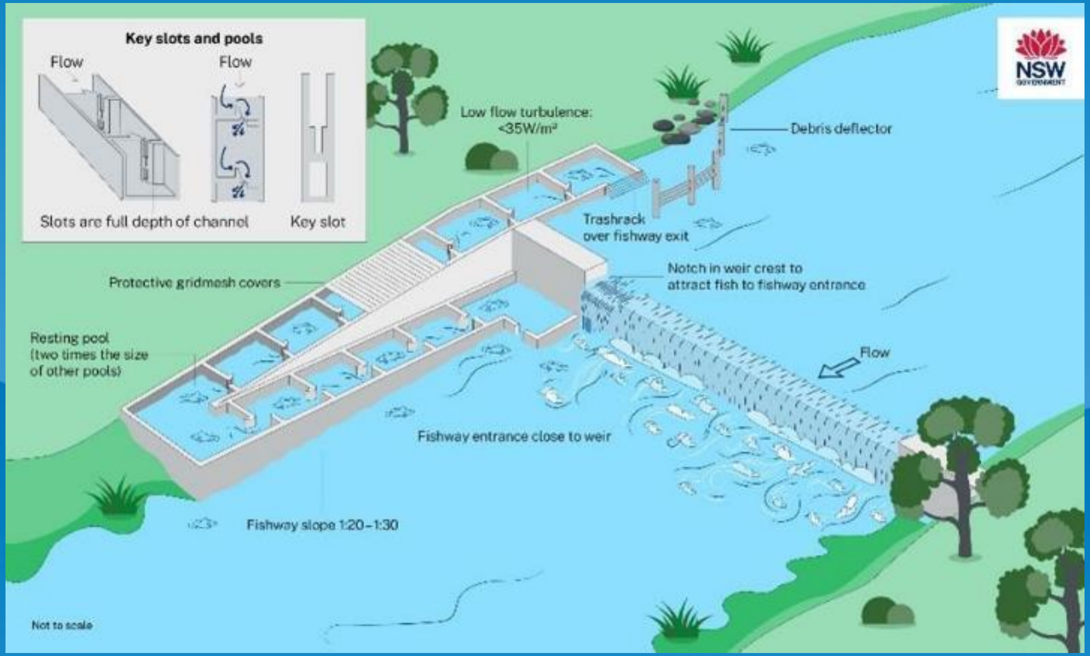
FISH and FISHERIES

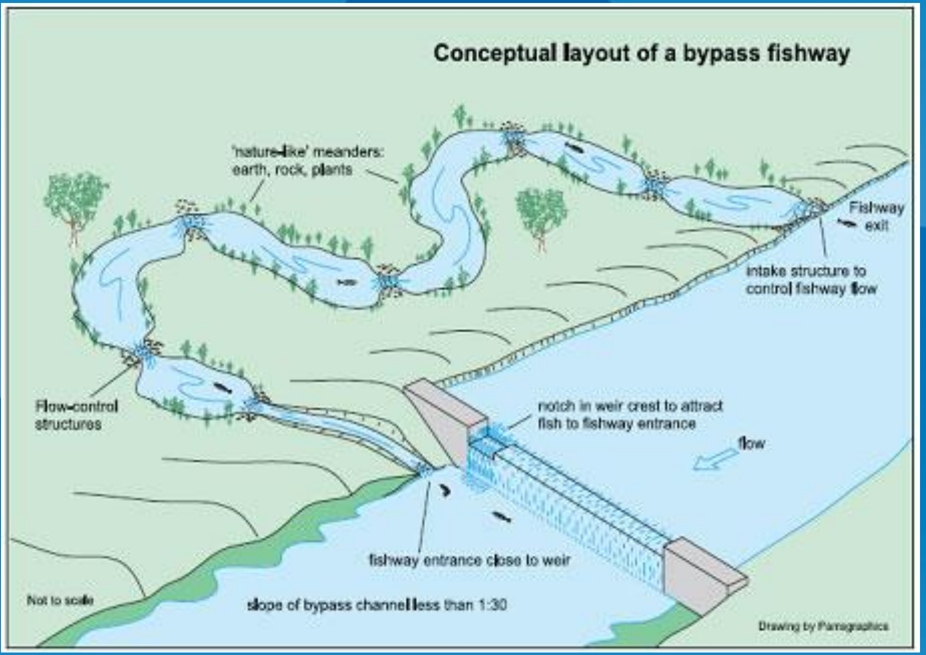
ORIGINAL ARTICLE | Open Access

The future of fish passage science, engineering, and practice

Ana T. Silva, Martyn C. Lucas, Theodore Castro-Santos, Christos Katopodis, Lee J. Baumgartner, Jason D. Thiem, Kim Aarestrup, Paulo S. Pompeu, Gordon C. O'Brien, Douglas C. Braun, Nicholas J. Burnett, David Z. Zhu, Hans-Petter Fjeldstad, Torbjørn Forseth, Nallamuthu Rajaratnam, John G. Williams, Steven J. Cooke ... See fewer authors

First published: 28 November 2017 | https://doi.org/10.1111/faf.12258 | Citations: 296





Three concepts that help us work with nature to achieve more effective, resilient and sustainable solutions in river management and restoration.

Shifting Baseline

- explains why we often don't understand antecedent conditions, which leads to mis-diagnosing the problem and applying ineffective or unsustainable solutions

Stream Evolution Model

- a conceptual framework for a river's potential that helps us set more effective restoration goals

Salmon Foodscape

- the idea that habitat diversity over space and time is key to salmon population viability, if fish can track the resources

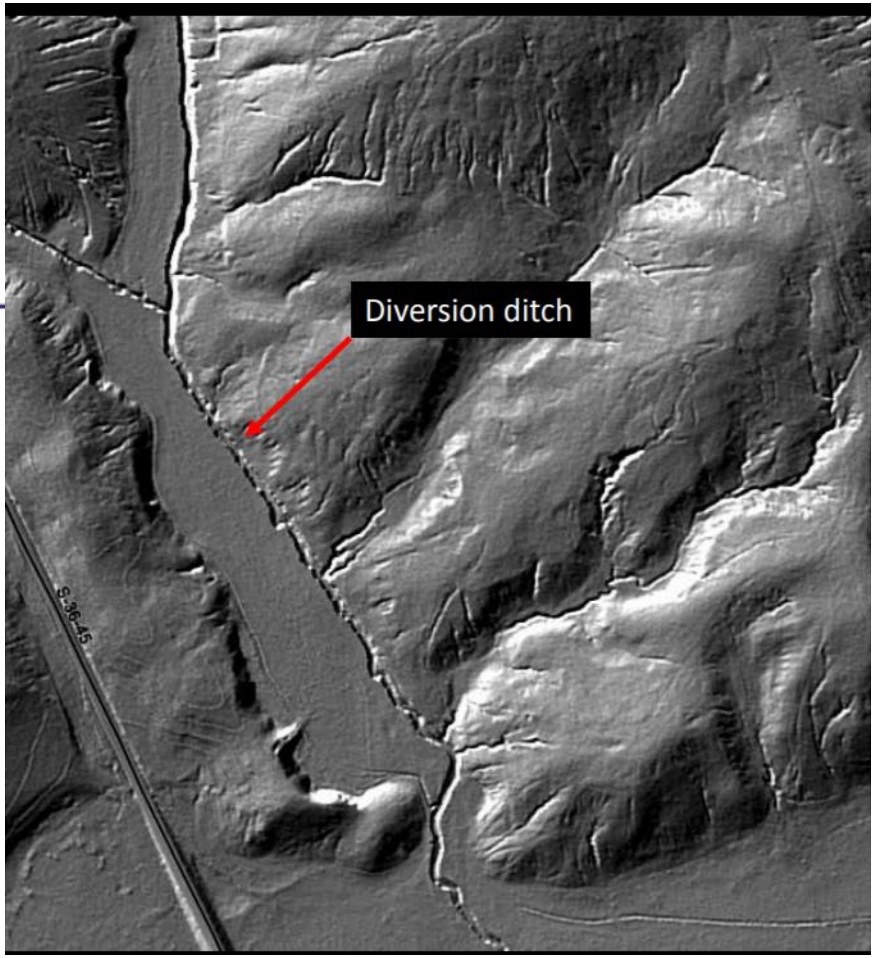
REVIEWS REVIEWS REVIEWS

Shifting baseline syndrome: causes, consequences, and implications

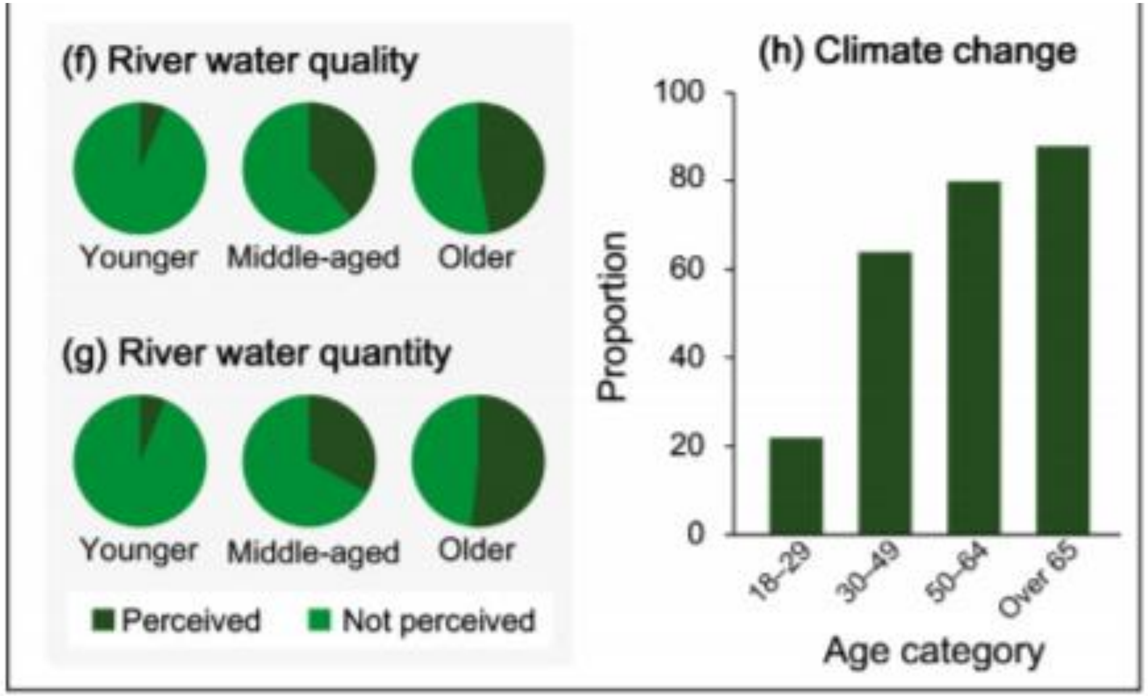
Masashi Soga[1*] and Kevin J Gaston[2]

With ongoing environmental degradation at local, regional, and global scales, people's accepted thresholds for environmental conditions are continually being lowered. In the absence of past information or experience with historical conditions, members of each new generation accept the situation in which they were raised as being normal. This psychological and sociological phenomenon is termed shifting baseline syndrome (SBS), which is increasingly recognized as one of the fundamental obstacles to addressing a wide range of today's global environmental issues. Yet our understanding of this phenomenon remains incomplete. We provide an overview of the nature and extent of SBS and propose a conceptual framework for understanding its causes, consequences, and implications. We suggest that there are several self-reinforcing feedback loops that allow the consequences of SBS to further accelerate SBS through progressive environmental degradation. Such negative implications highlight the urgent need to dedicate considerable effort to preventing and ultimately reversing SBS.

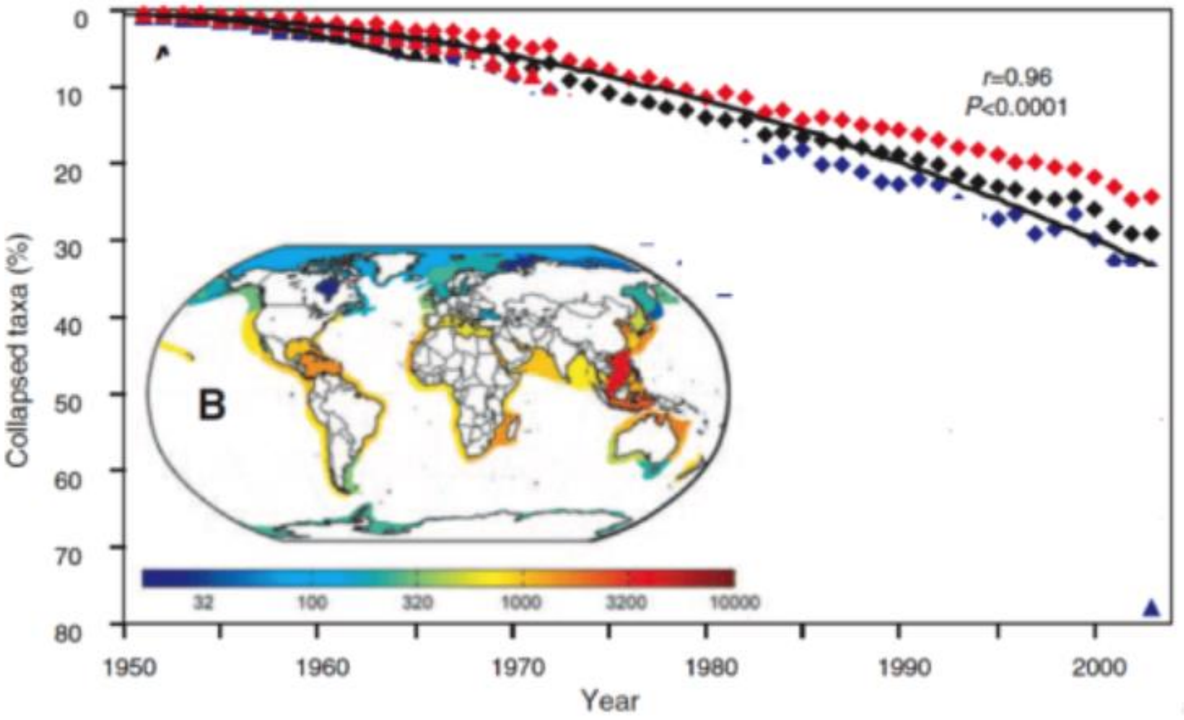
Front Ecol Environ 2018; 16(4):222–230, doi:10.1002/fee.1794



SBS occurs when conditions of the natural environment gradually degrade over time, yet people (local citizens, natural resource users, policy makers) falsely perceive less change because they are not aware of, or fail to recall accurately, what the natural environment was like in the past.



Younger residents, compared to older ones, perceived a lesser degree of change in the availability of local water resources and water quality.

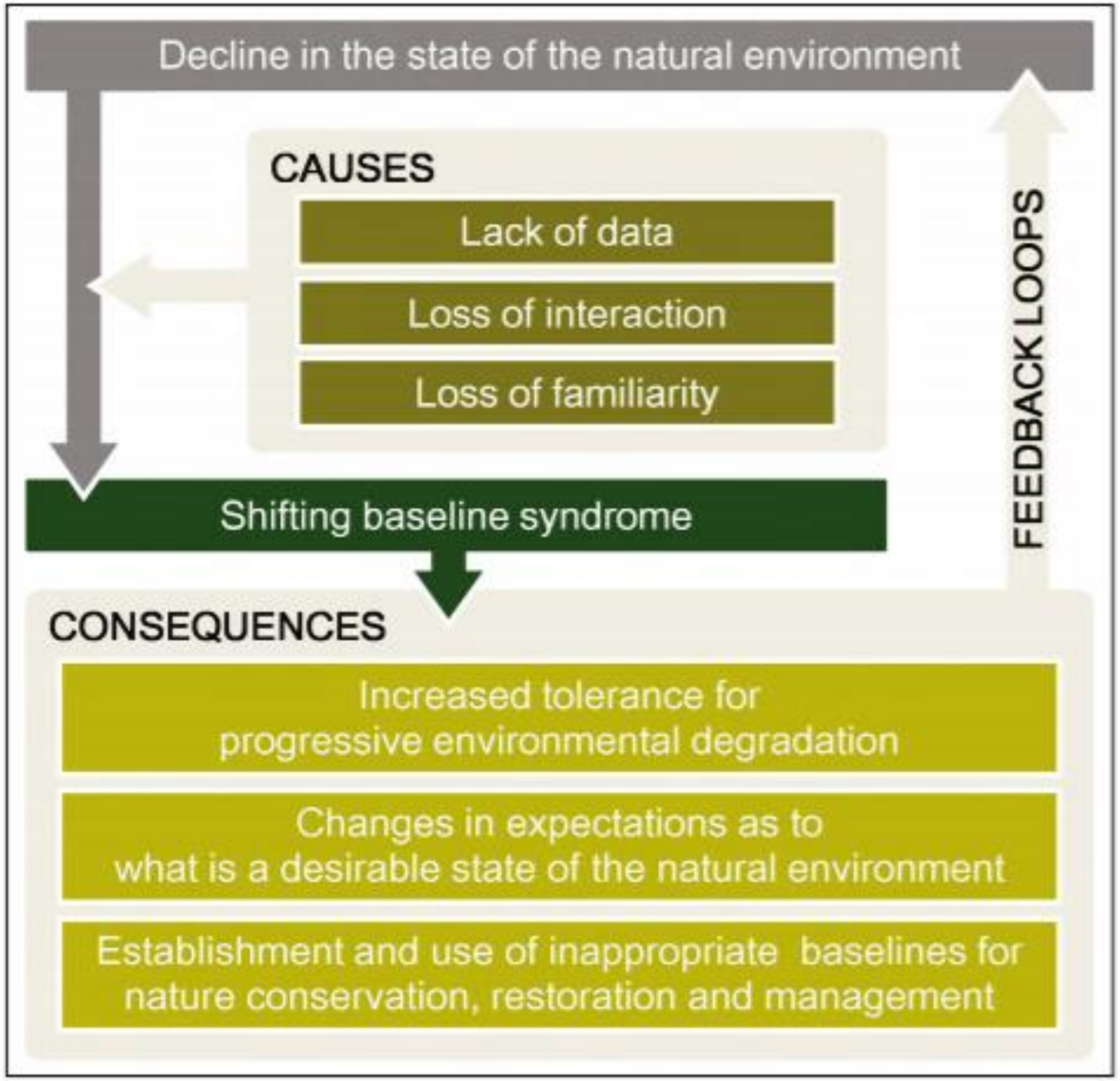


The first documented cases of SBS are in fisheries stock reports.

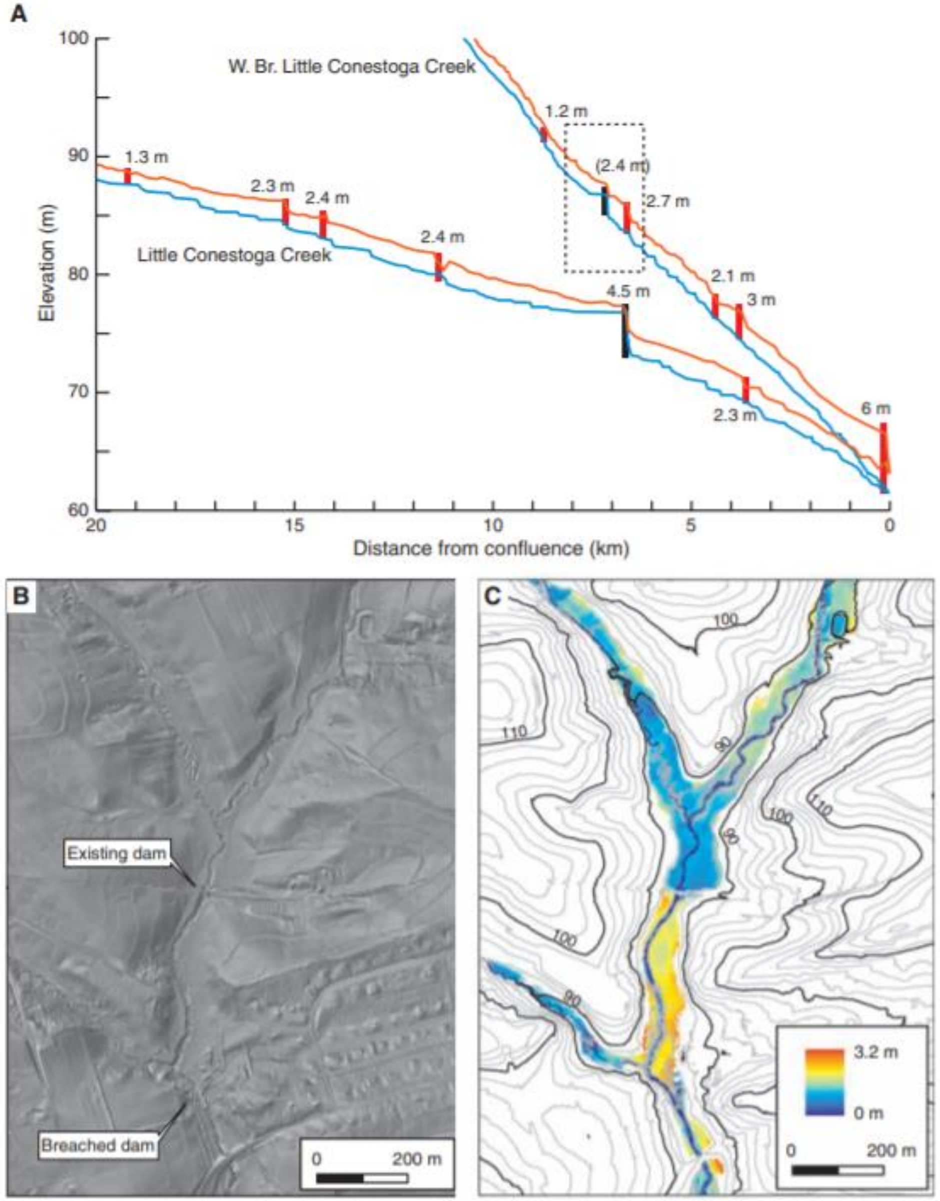
Each generation of managers set lower *sustainable* harvest targets as stocks progressively diminished.

- SBS feedback loop: progressively diminishing perception of natural, and good.
- Leads to insufficient restoration targets.

Shifting baseline syndrome



SBS in River Management:



Walter, R.C. and Merritts, D.J., 2008. Natural streams and the legacy of water-powered mills. *Science*, *319*(5861), pp.299-304.

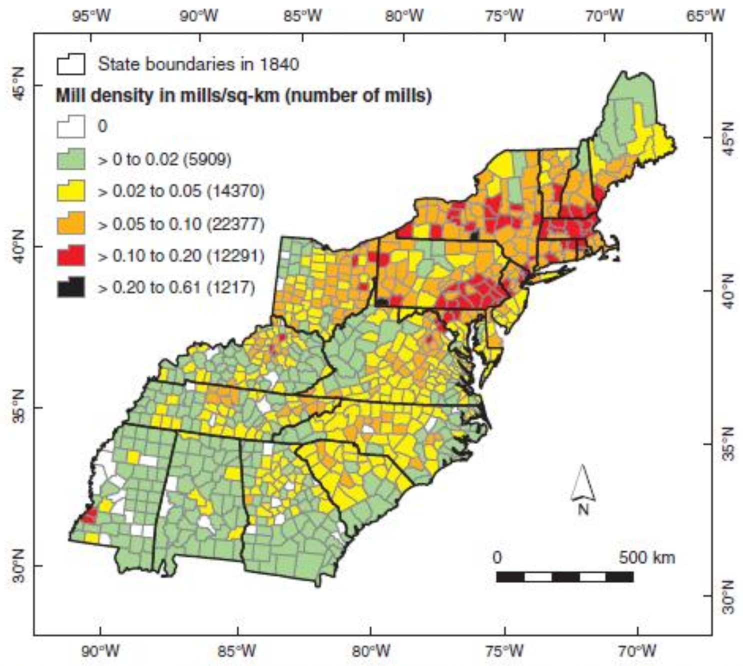


Fig. 1. Density of water-powered mills along eastern U.S. streams by 1840 by county (872 county boundaries are shown for 1840). The highest densities are in the Piedmont and the Ridge-and-Valley physiographic provinces of Maryland, Pennsylvania, New York, and central New England.

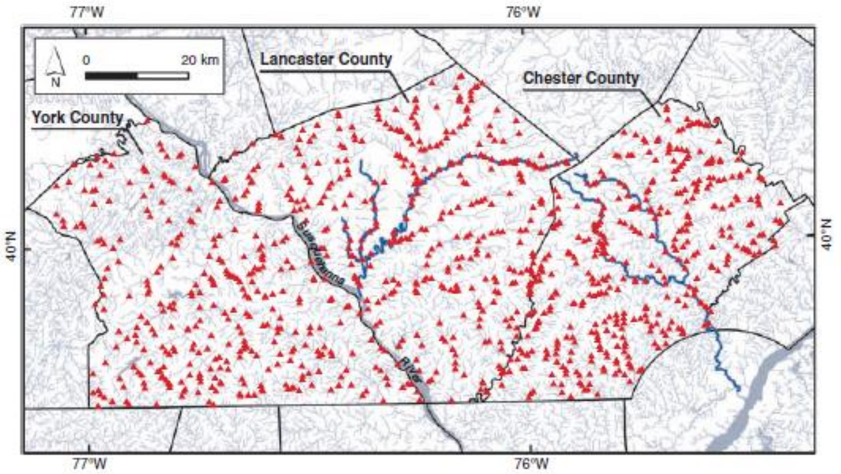
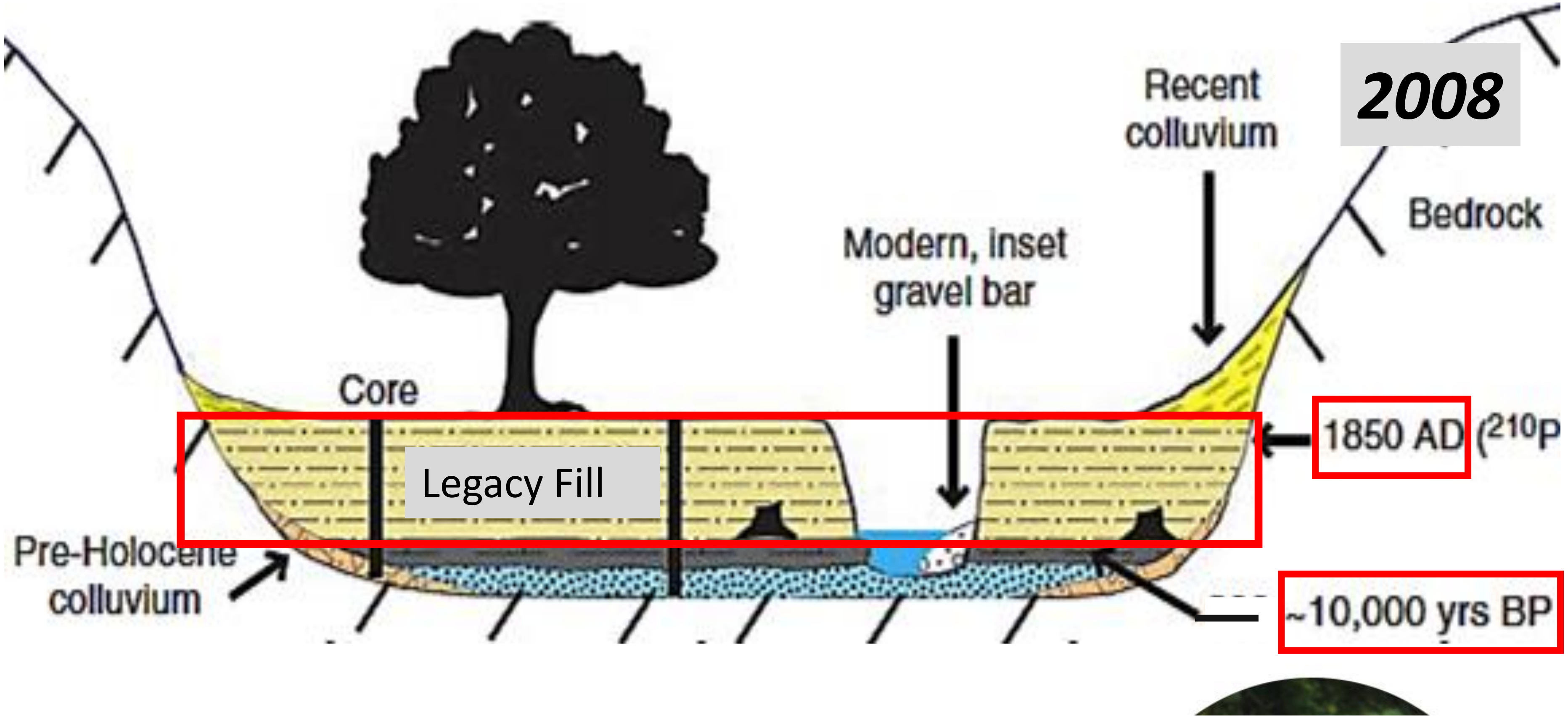


Fig. 2. Historic 19th-century milldams (triangles) on Piedmont streams in York, Lancaster, and Chester counties, southeastern Pennsylvania, located from >100 large-scale township maps dating to 1876 (York), 1875 (Lancaster), and 1847 (Chester). The total number of dams shown is 1025. Main stems of Conestoga (Lancaster) and Brandywine (Chester) rivers are highlighted in dark blue.



Upended the prevailing view of channel / floodplain interactions. Validated the idea of Stage 0.

Solution: exhume the buried river wetland corridor

It took heavy machines to remove the thousands of tons of legacy sediment that had buried Big Spring Run. The sediment was ultimately used as fill beneath a new building. LANDSTUDIES

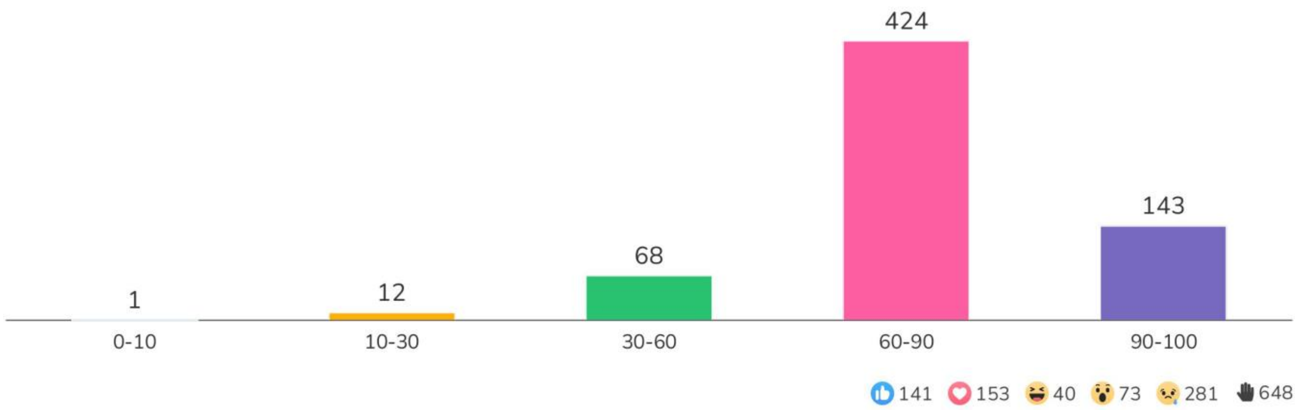
Shifting Baseline: applied to river restoration

- Effective restoration - need to understand the history of natural processes as well as the anthropogenic land use history
- Risk 1 - not seeing, or misdiagnosing, the problem
- Risk 2 - implementing projects that are not effective, resilient to changes nor self sustaining

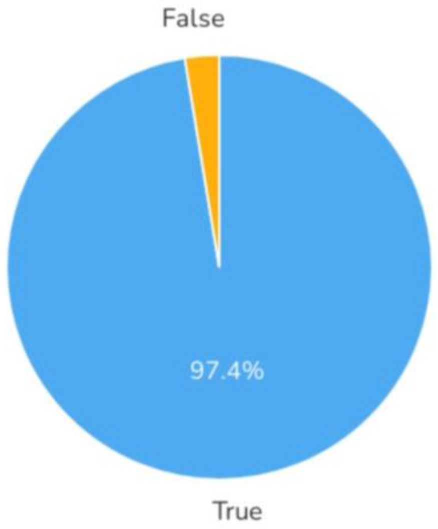
Restoring Riverscapes

https://www.restoringriverscapes.org/

What percentage of floodplains across the Western US riverscapes are disconnected?



Most Western US riverscapes are degraded



- Most valley bottoms are private
- Inspiring projects on
  - public lands and trust lands
  - Ag lands
  - retired lands and wastelands
  - Municipal – Urban

RIVER RESEARCH AND APPLICATIONS

River Res. Applic. (2013)

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A STREAM EVOLUTION MODEL INTEGRATING HABITAT AND ECOSYSTEM BENEFITS

B. CLUER[a]* and C. THORNE[b]

[a] *Fluvial Geomorphologist, Southwest Region, NOAA's National Marine Fisheries Service, Santa Rosa, California, USA*

[b] *Chair of Physical Geography, University of Nottingham, Nottingham, UK*

SEM

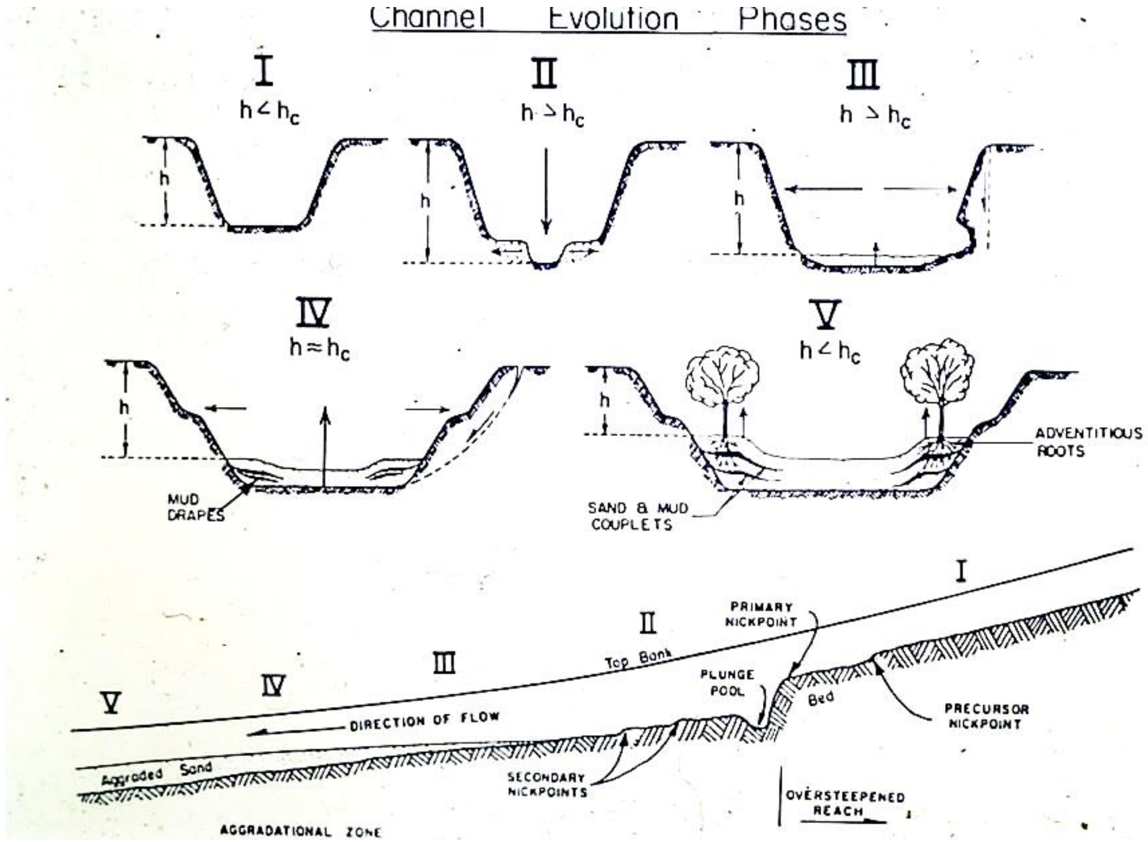
1. Update and extend earlier channel evolution models.
2. Include river corridor, floodplain.
3. Link ecological functions to fluvial stages.
4. Guidance for more effective restoration.

For decades, … associated with lowerin… d Channel Evolution M… ion Model includes a p… nts stream evolution as a… e common sequence, ski…

The hydro… ing ranges and qualities… om recent literature to … l values of different evol… lerstanding of the ecological status of contemporary, managed rivers compared with their historical, unmanaged counterparts. The potential utility of the Stream Evolution Model, with its interpretation of habitat and ecosystem benefits includes improved river management decision making with respect to future capital investment not only in aquatic, riparian and floodplain conservation and restoration but also in interventions intended to promote species recovery. Copyright © 2013 John Wiley & Sons, Ltd.

KEY WORDS: Stream Evolution Model (SEM); channel evolution; freshwater ecology; habitat; conservation; river management; restoration: climate resilience

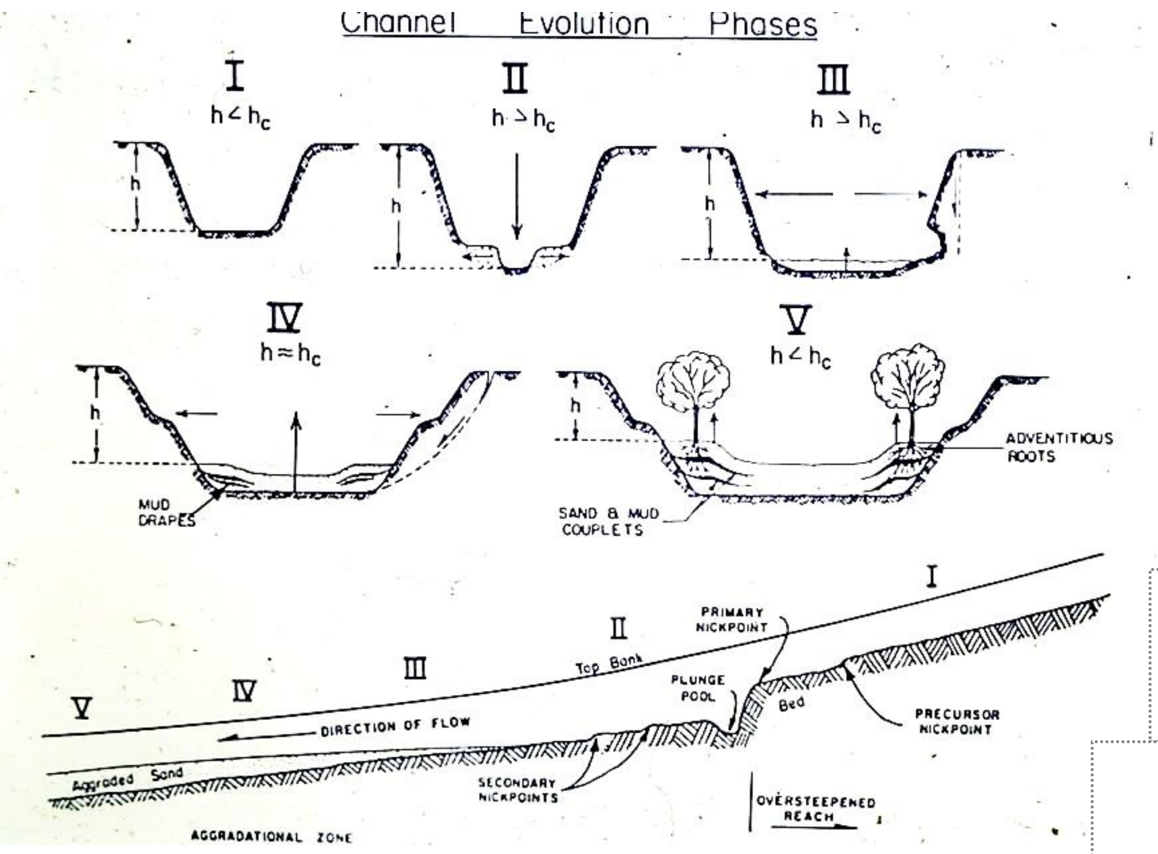
Received 1 November 2012; Accepted 13 November 2012



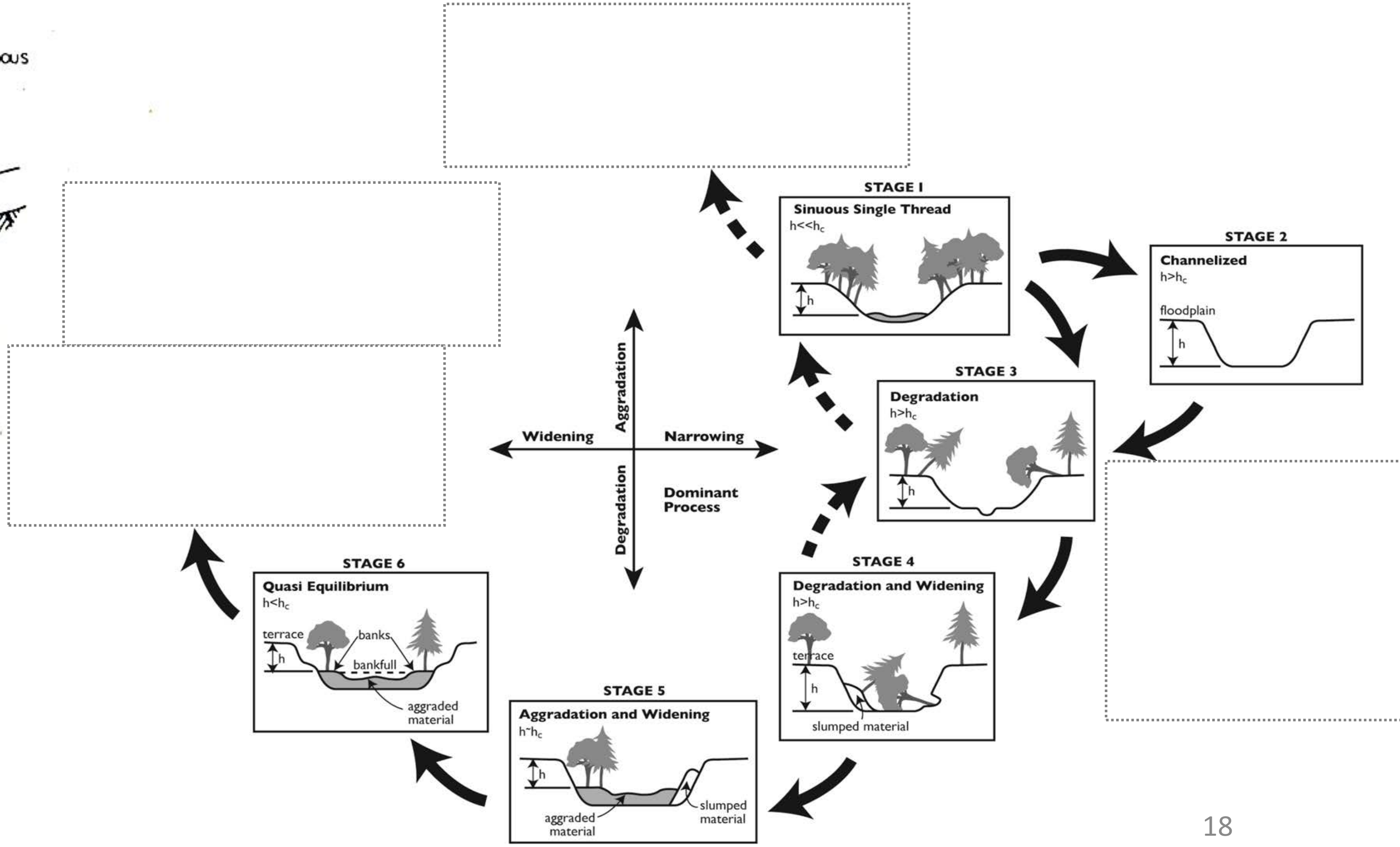
Cross sections

Long profile

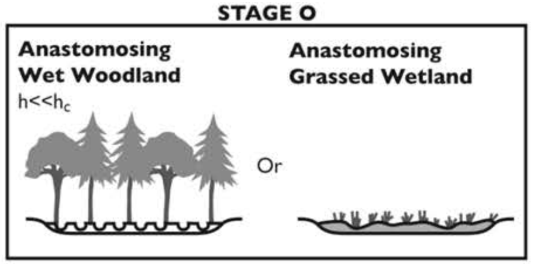
Schumm et al 1984

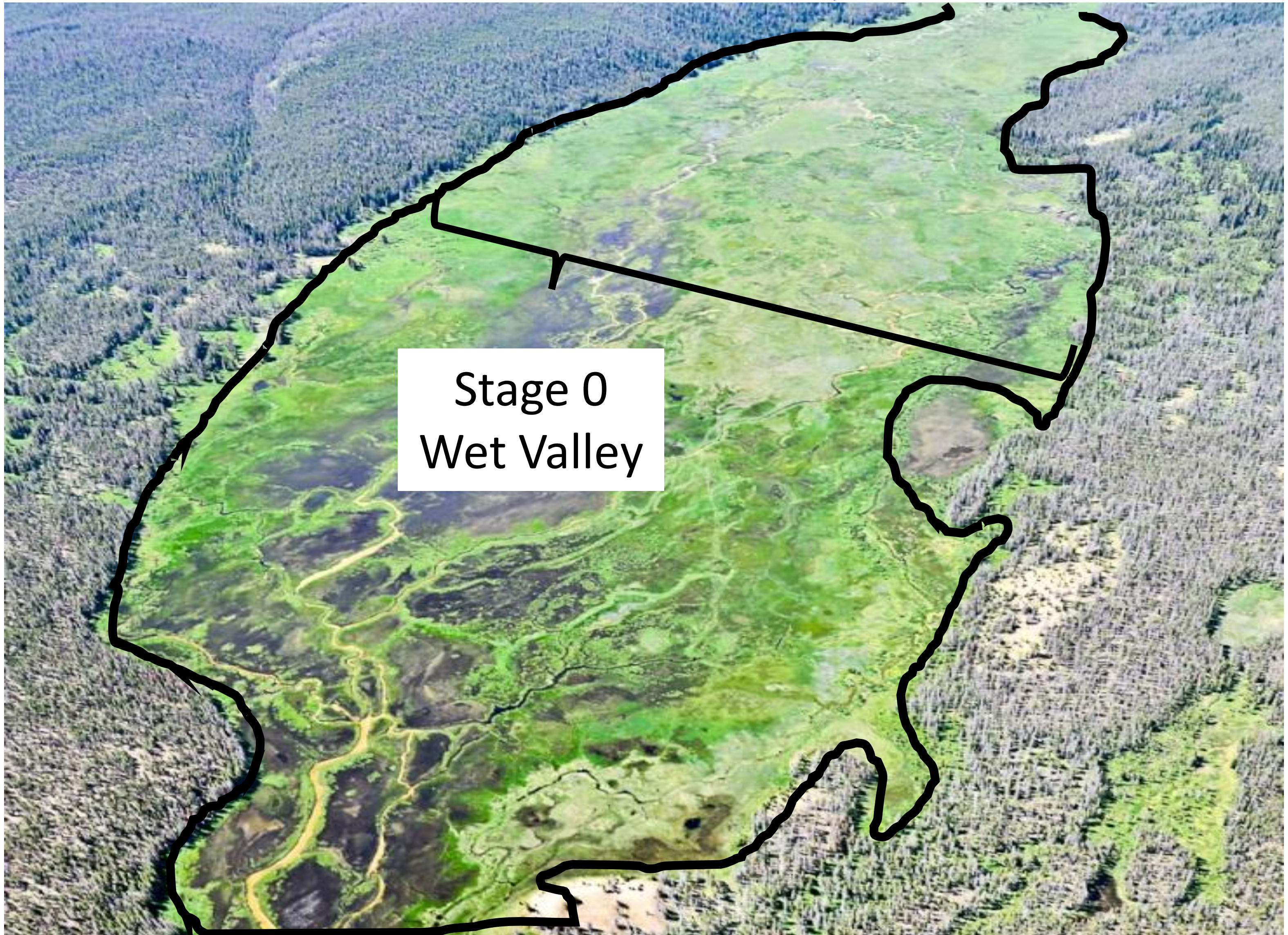


Schumm et al 1984

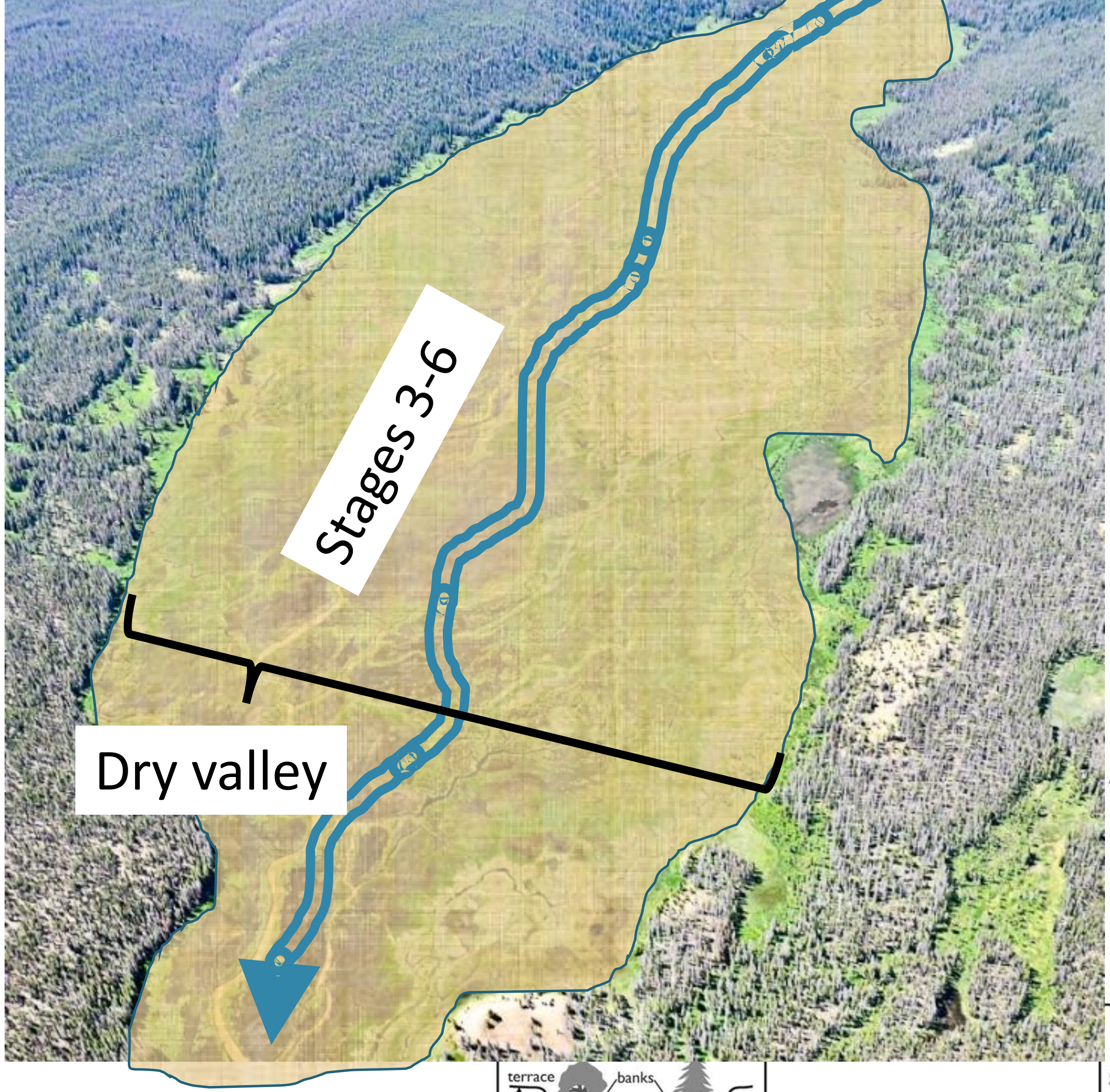


Scale

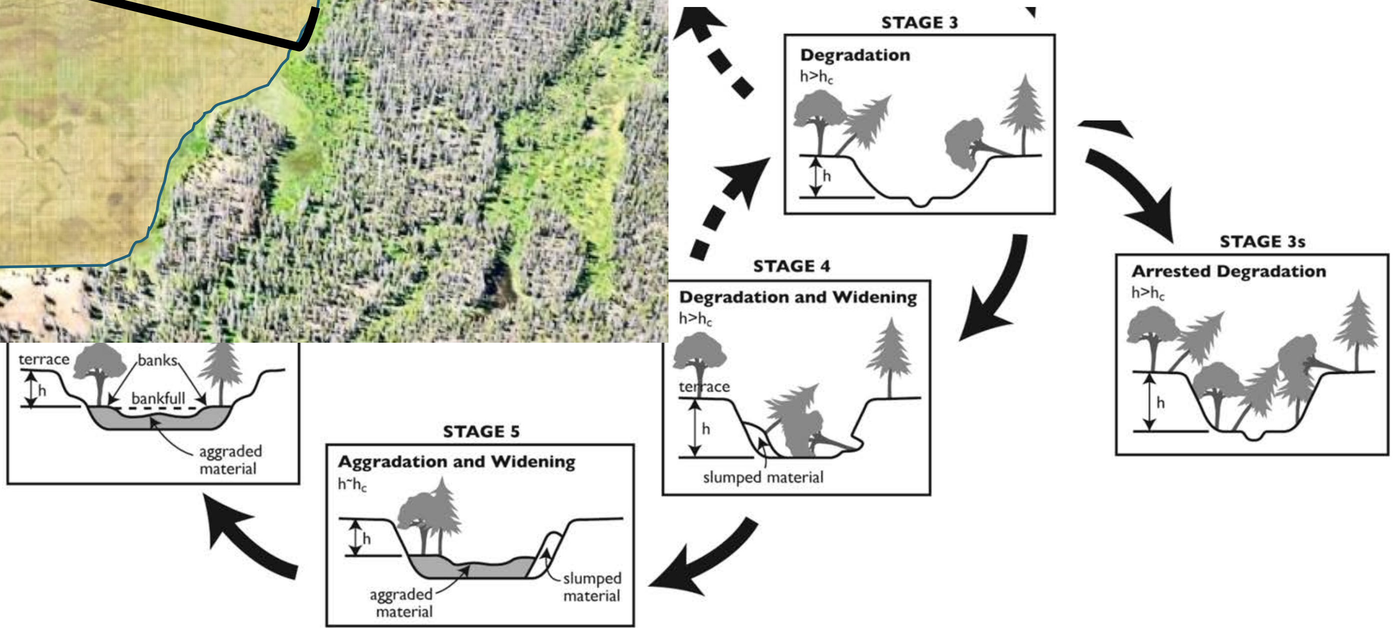

STAGE 0
Anastomosing Wet Woodland
$h<<h_c$
Or
Anastomosing Grassed Wetland


Stage 0
Wet Valley

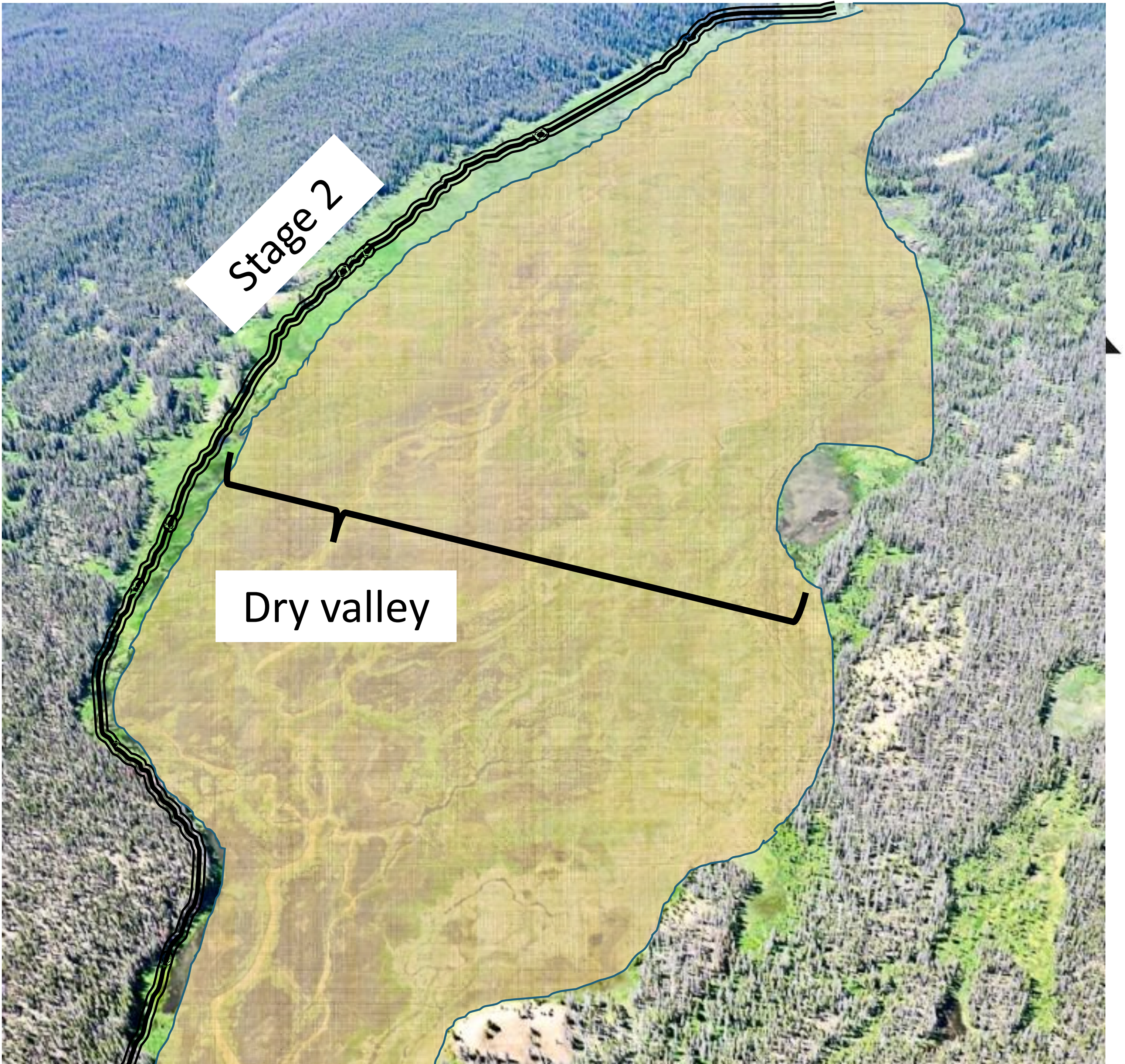
Scale



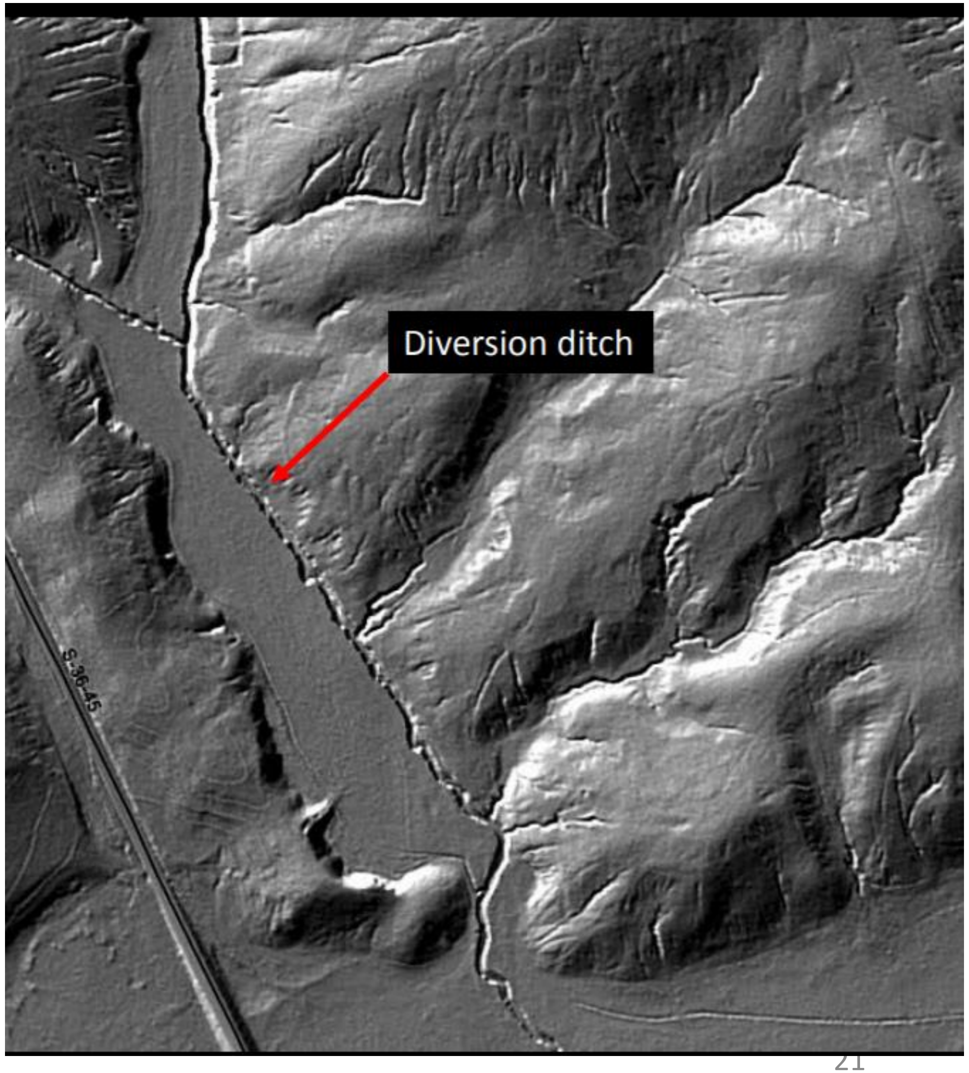
Dry valley, deep channel, narrow riparian belt.
Potential floodplain channels.



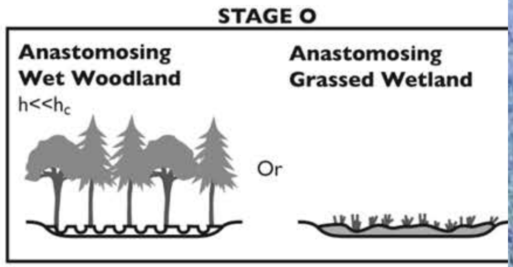
Cluer and Thorne, RRA, 2013

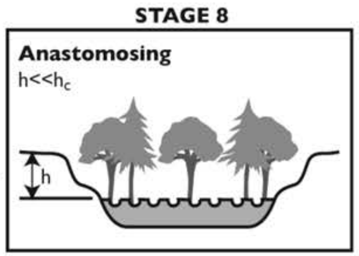


Commonly observed anthropogenic channel location.

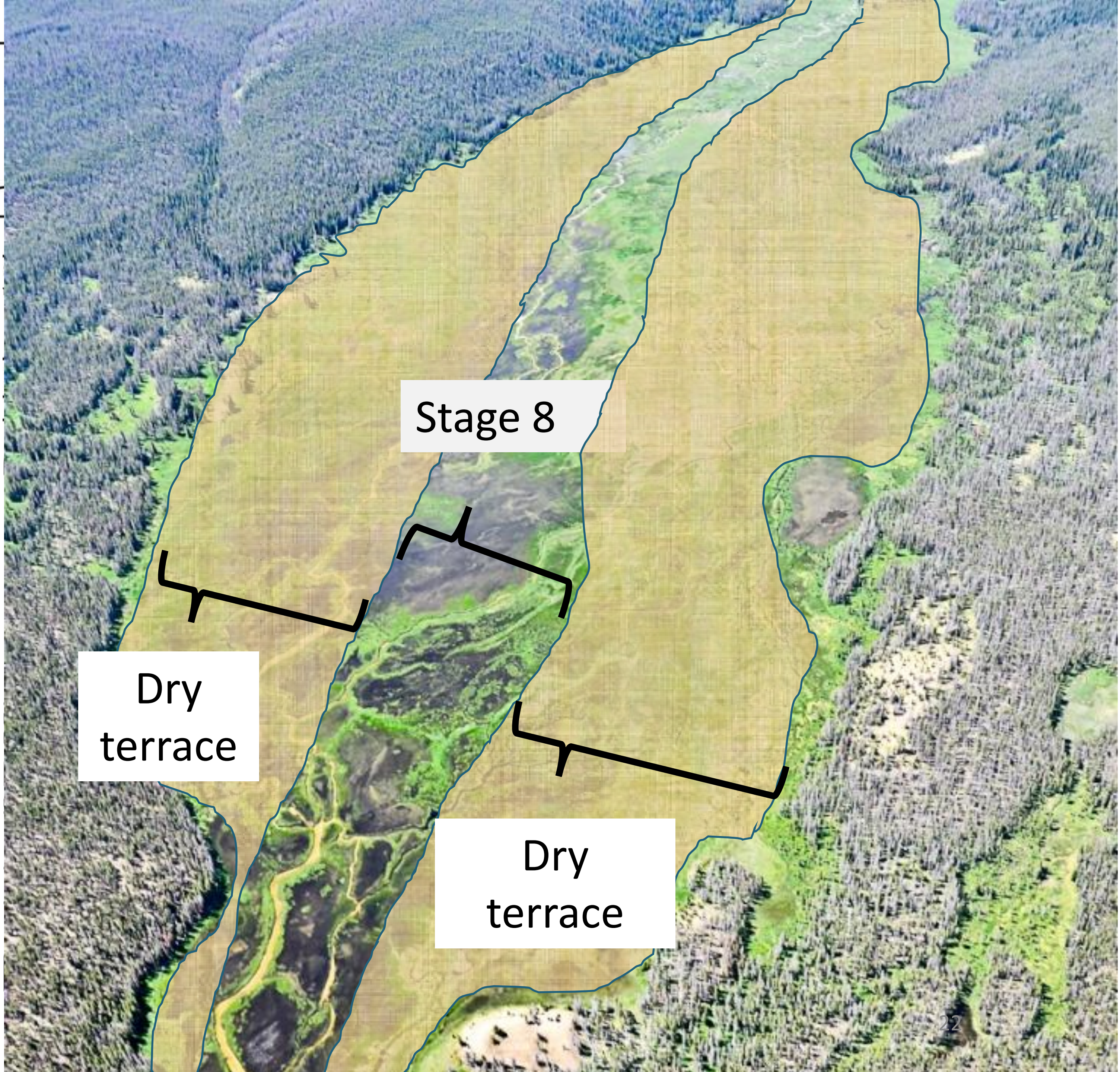


Scale



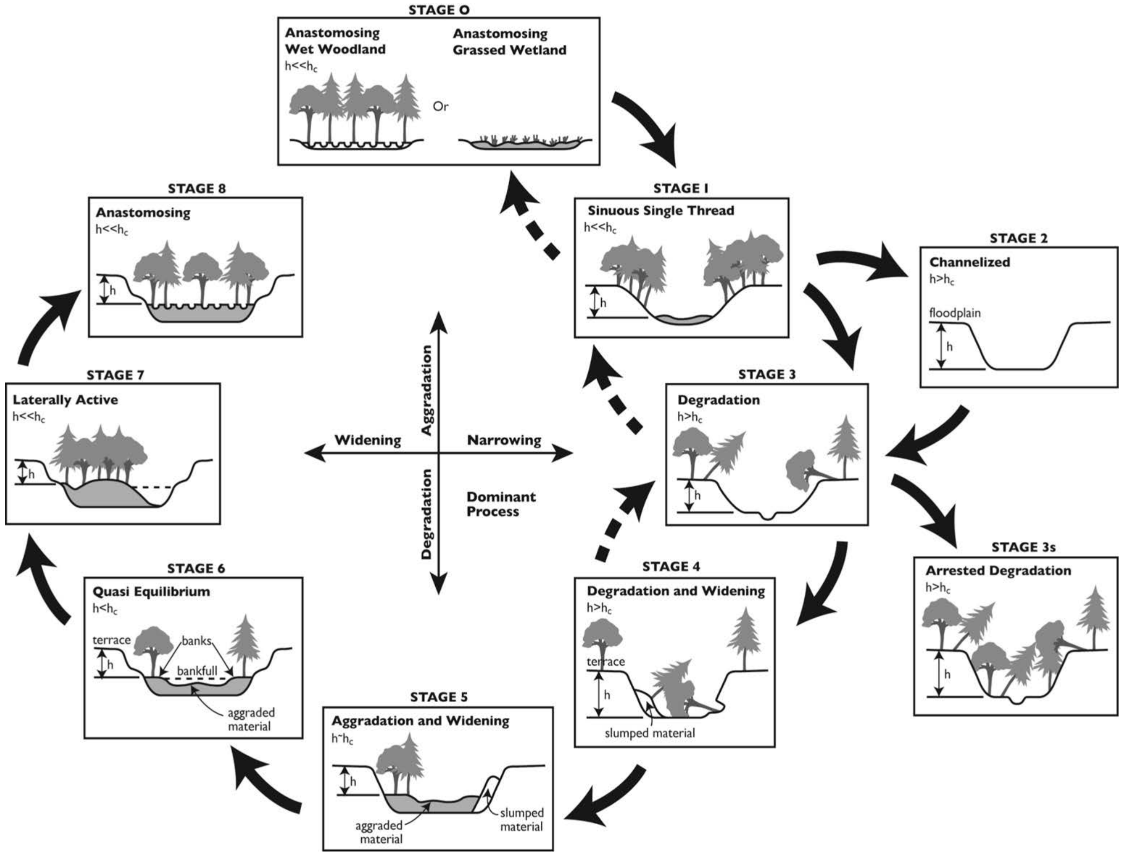


Stage 8:
Scaled down
Lower elevation

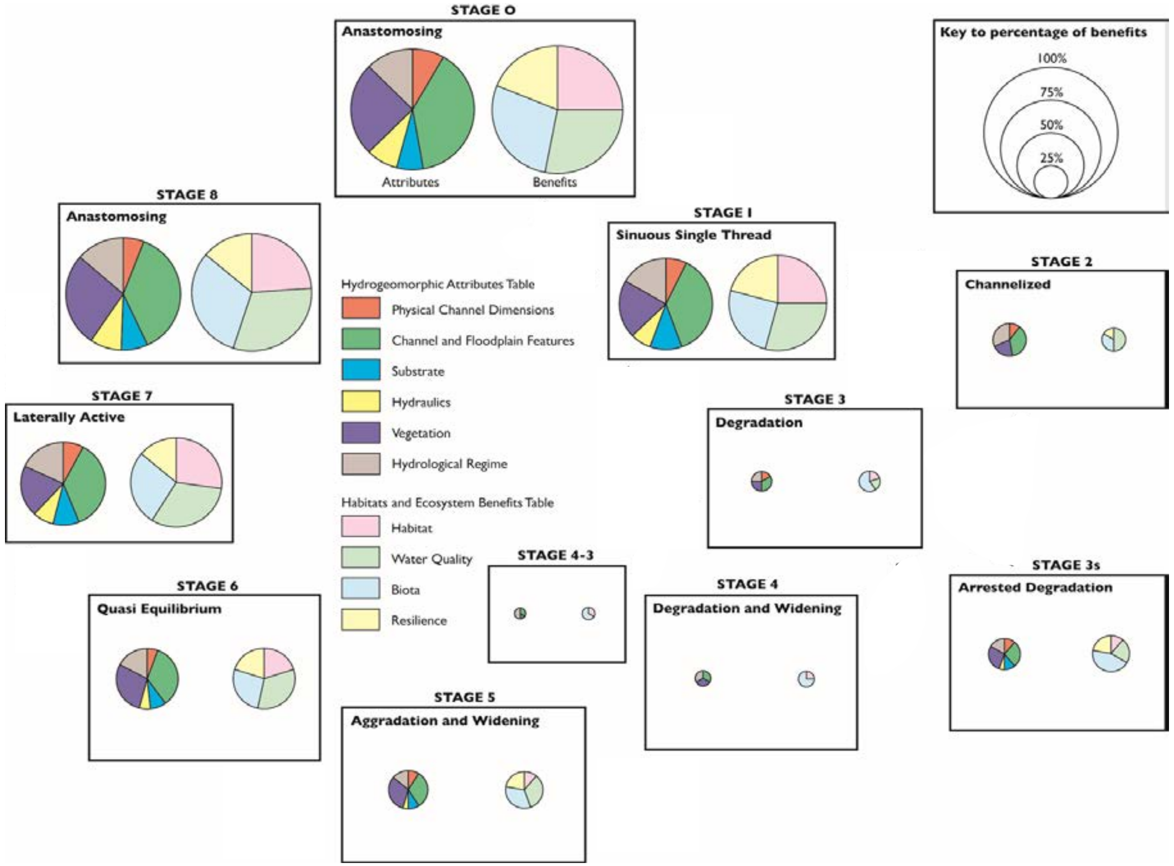


Stages Linked to Habitat Quality and Other Ecosystem Benefits

Principles of functional ecology: the potential for a stream to support large, rich, diverse, and resilient ecosystems increases with scale, morphological diversity, and hydroperiod.

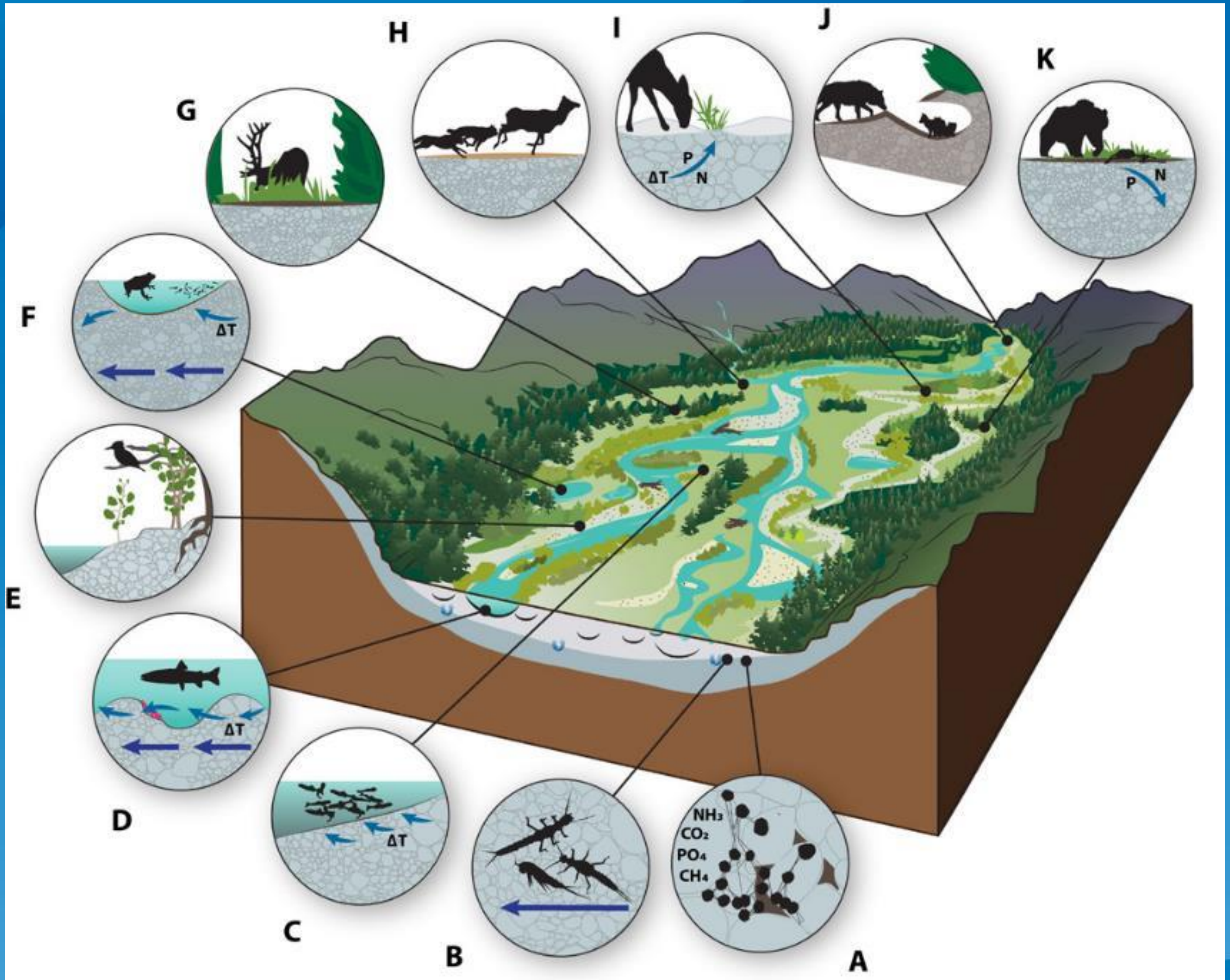


Cluer and Thorne, RRA, 2013

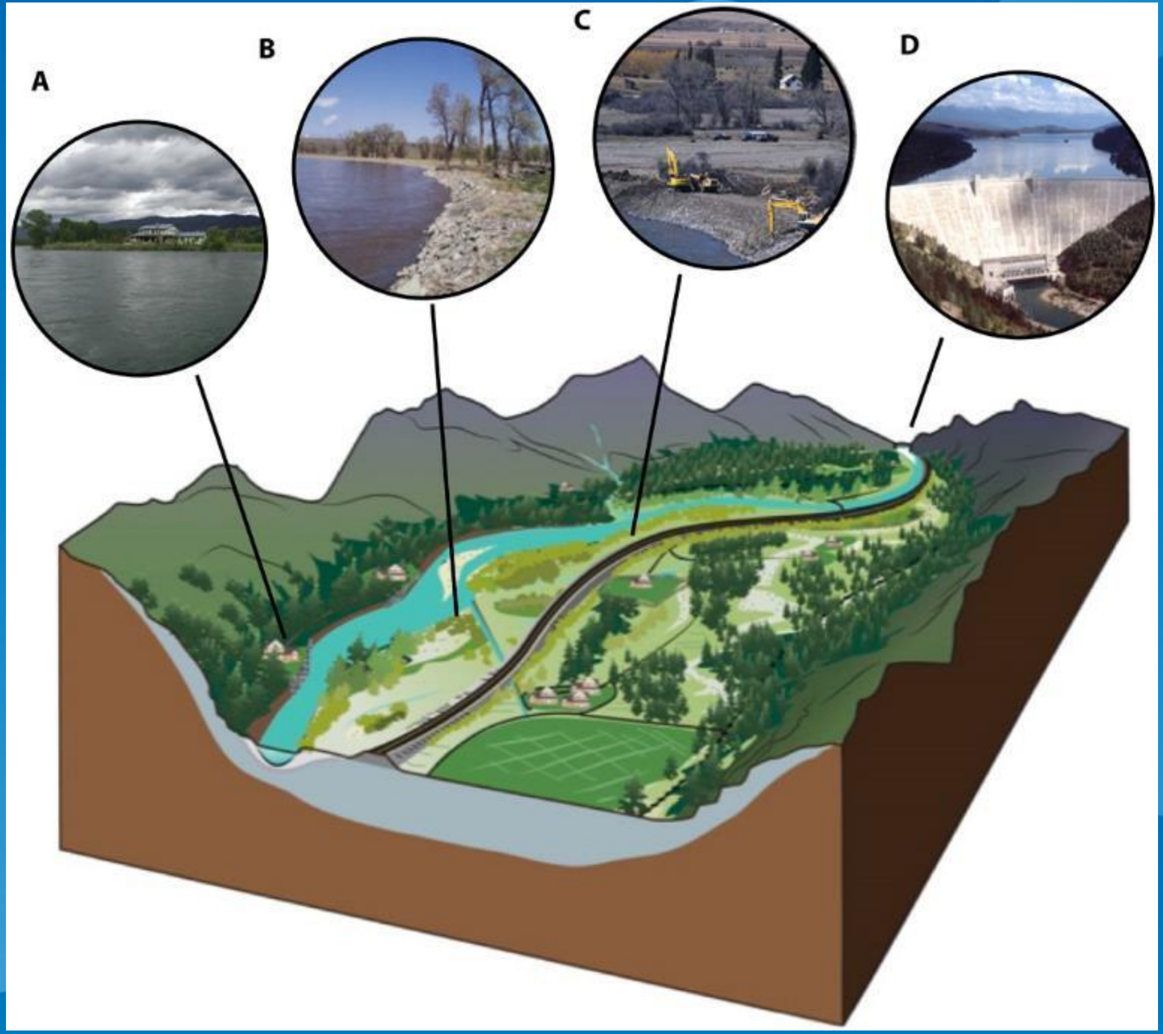


Key source: Thorpe et al. 2010. Linking Ecosystem Services, Rehabilitation, and River Hydrogeomorphology. BioScience

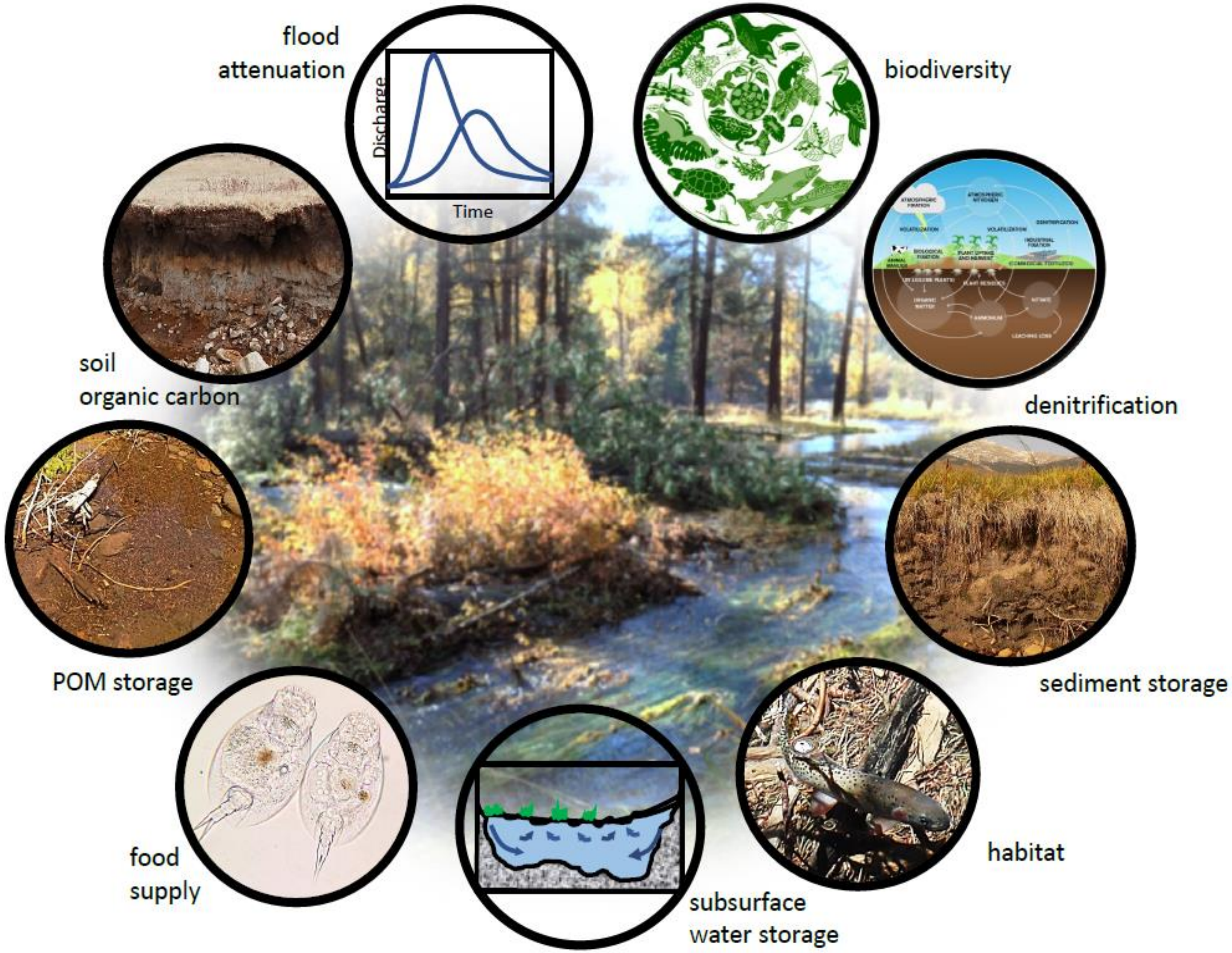
Floodplain is the ecological nexus of regional biodiversity.



Floodplain as affected by human structures.

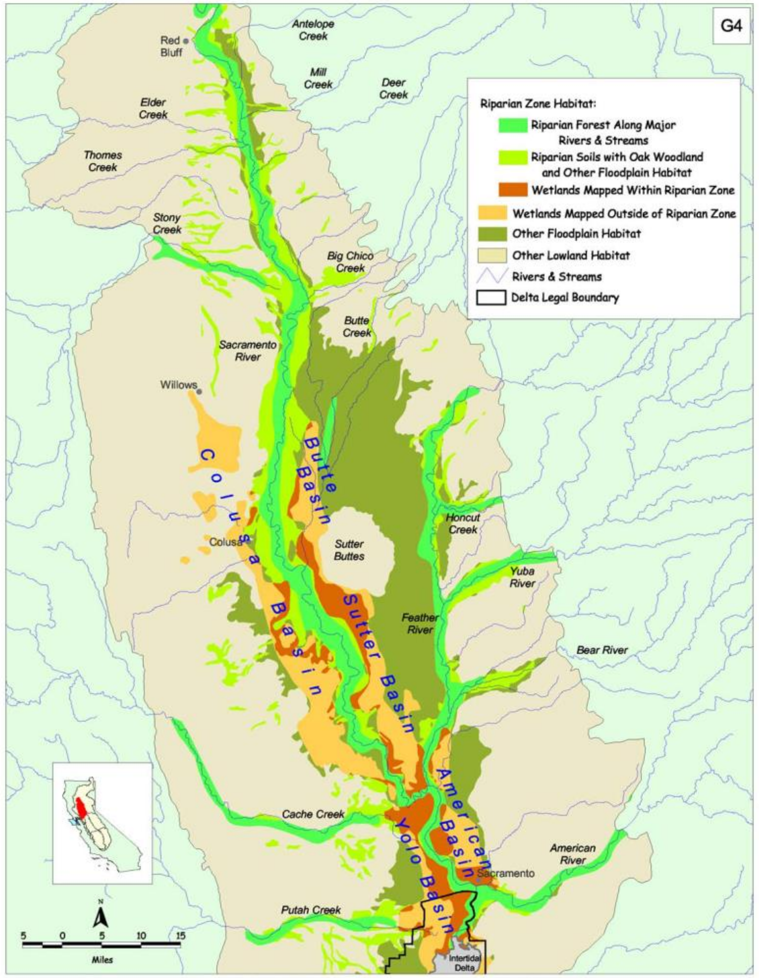


F. Richard Hauer et al. Sci Adv 2016


flood
attenuation
Discharge
Time
biodiversity
denitrification
sediment storage
habitat
subsurface
water storage
food
supply
POM storage
soil
organic carbon

Historical Central Valley Salmonid Habitat:

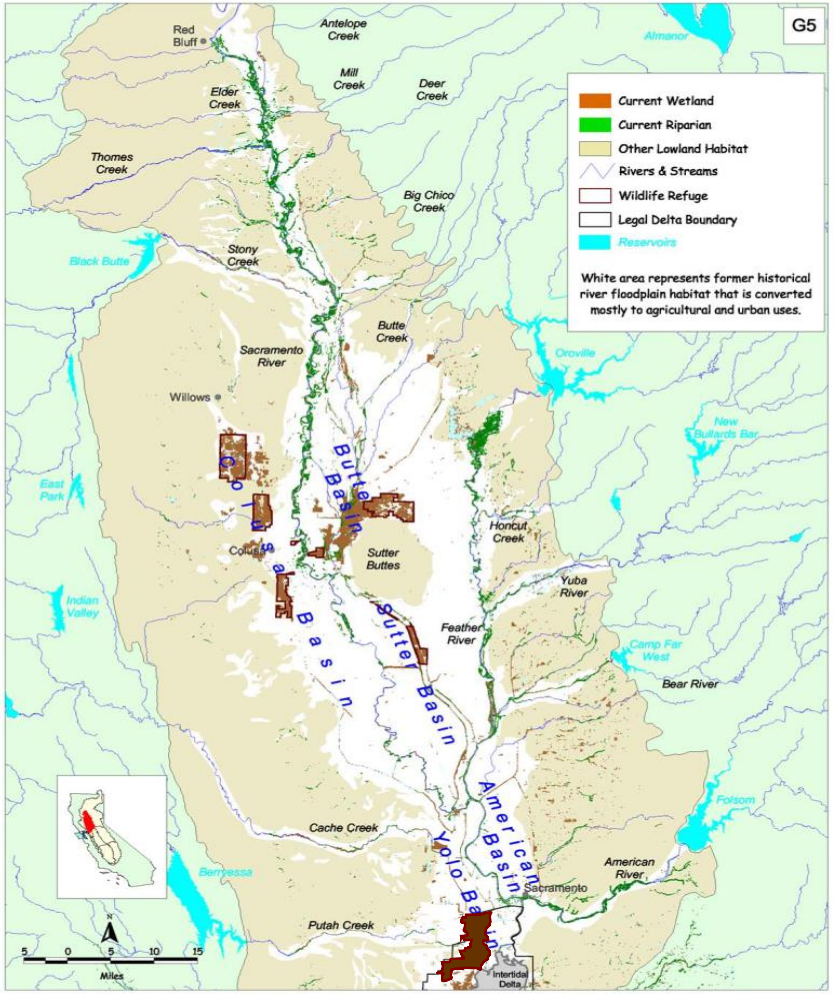
- Floodplain [4,450 mi^2]
- Streams [17,200 miles]



Sacramento Valley Historical River Floodplain Ecosystem

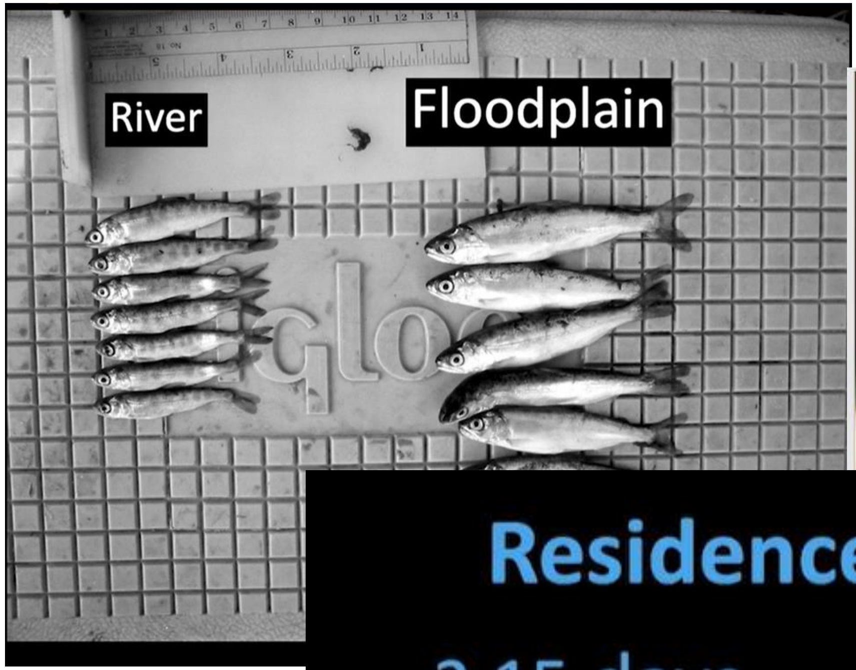
Today Central Valley:

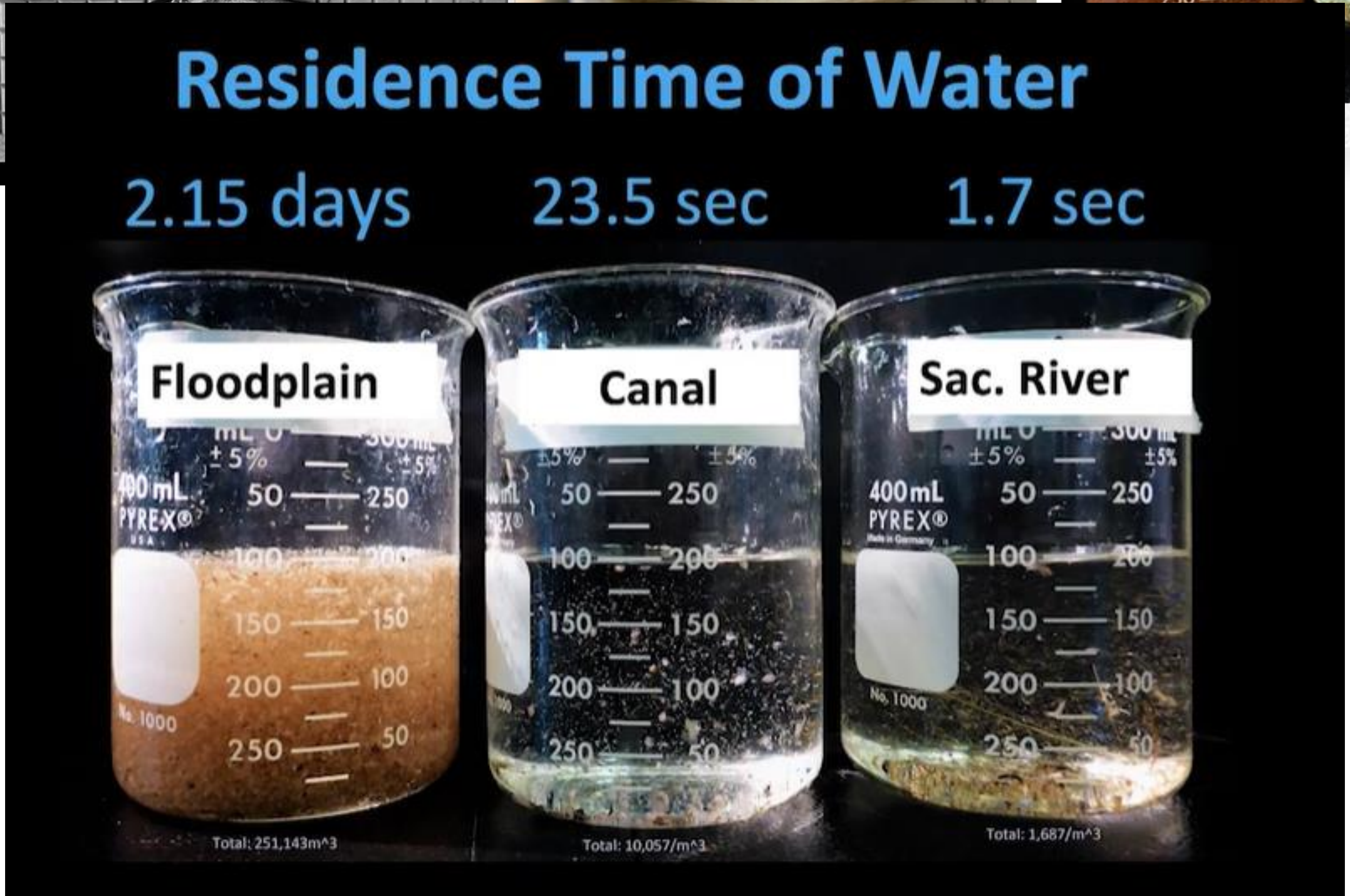
~95% of floodplains disconnected
~97% stream habitat is behind dams

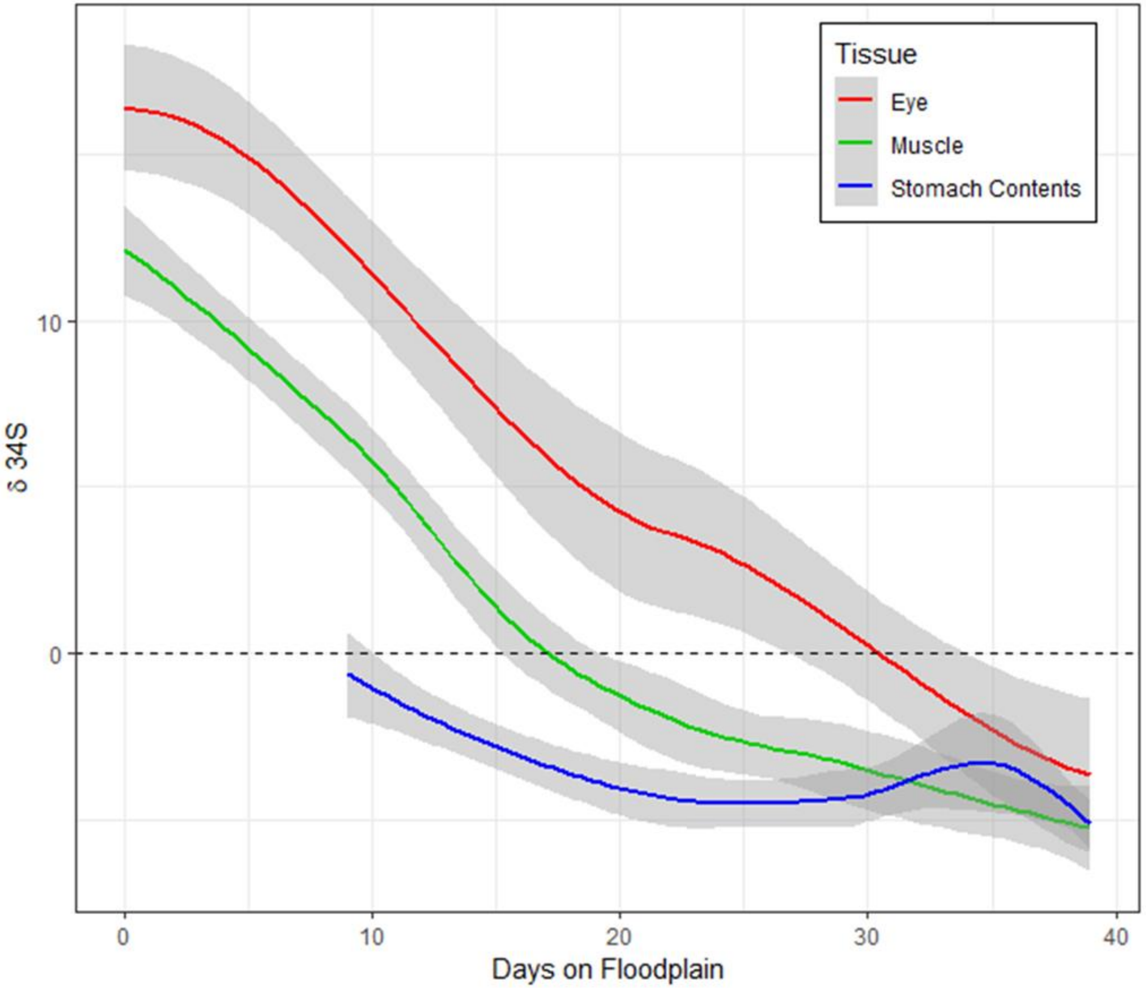


Sacramento Valley Current River Floodplain Ecosystem

Floodplains = Food







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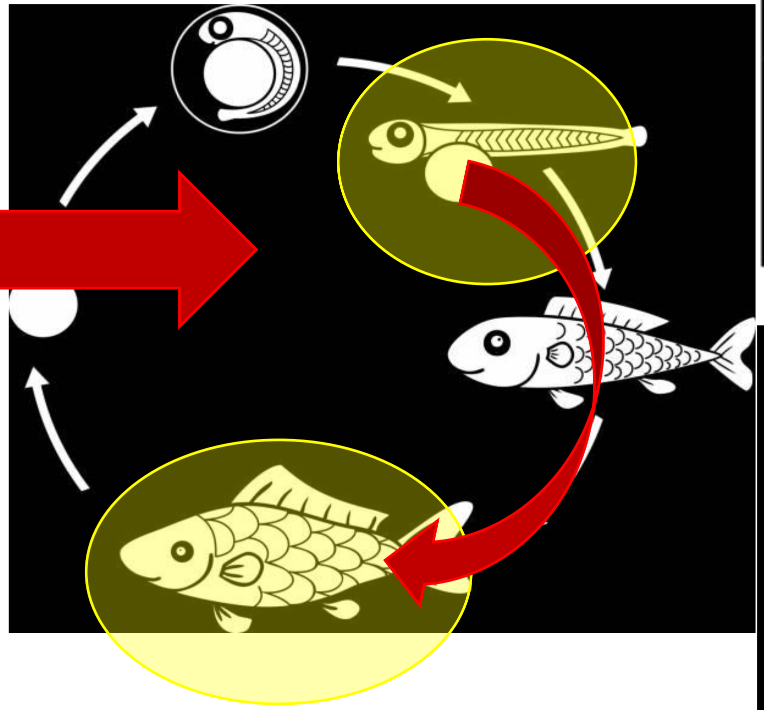
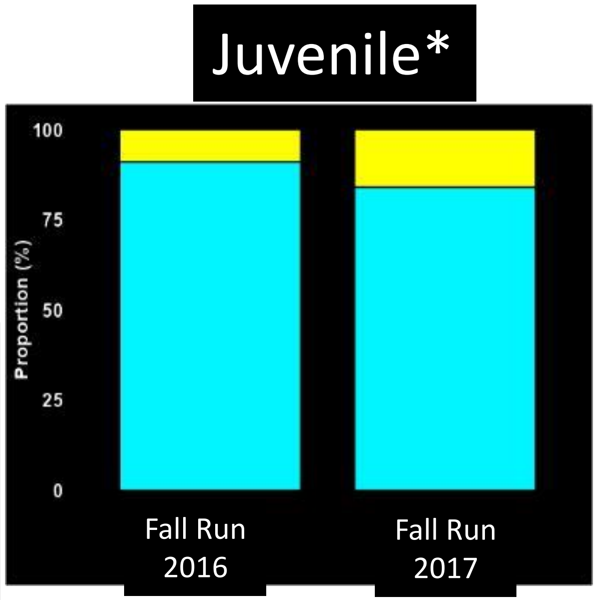
NOAA

University of Essex




Juvenile*
100
75
50
25
0
Proportion (%)
Fall Run 2016
Fall Run 2017

[redacted]

Foodscapes for Salmon and Other Mobile Consumers in River Networks

Gabriel J. Rossi, J. Ryan Bellmore, Jonathan B. Armstrong, Carson Jeffres, Sean M. Naman, Stephanie M. Carlson, Theodore E. Grantham, Matthew J. Kaylor, Seth White, Jacob Katz, Mary E. Power

doi: https://doi.org/10.1101/2023.08.30.555604

This article is a preprint and has not been certified by peer review [what does this mean?].

A more explicit focus on the spatio-temporal dynamics of food webs that sustain salmon (e.g. foodscapes), would benefit the field of process-based restoration.

For any given combination of (a) river system and (b) consumer, the foodscape managers can ask: how have patterns and processes affecting food abundance, food accessibility, and the energetic costs of foraging been altered by human modification of the river system, and how can they be recovered?

How should novel foodscapes, which leverage anthropogenically modified landscapes to take advantage of foraging opportunities, be balanced against work to restore an historic foodscape?

Box 2. Consumer life histories interact with foodscapes to create complex growth trajectories.

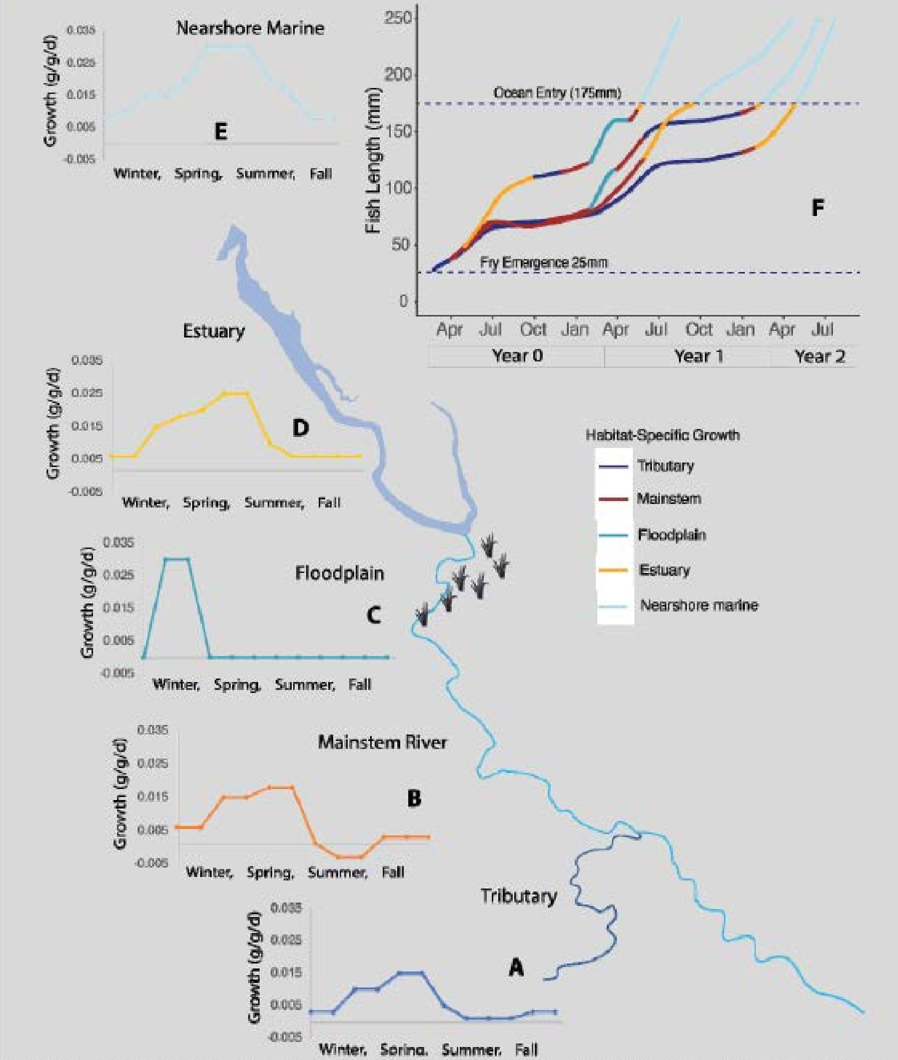
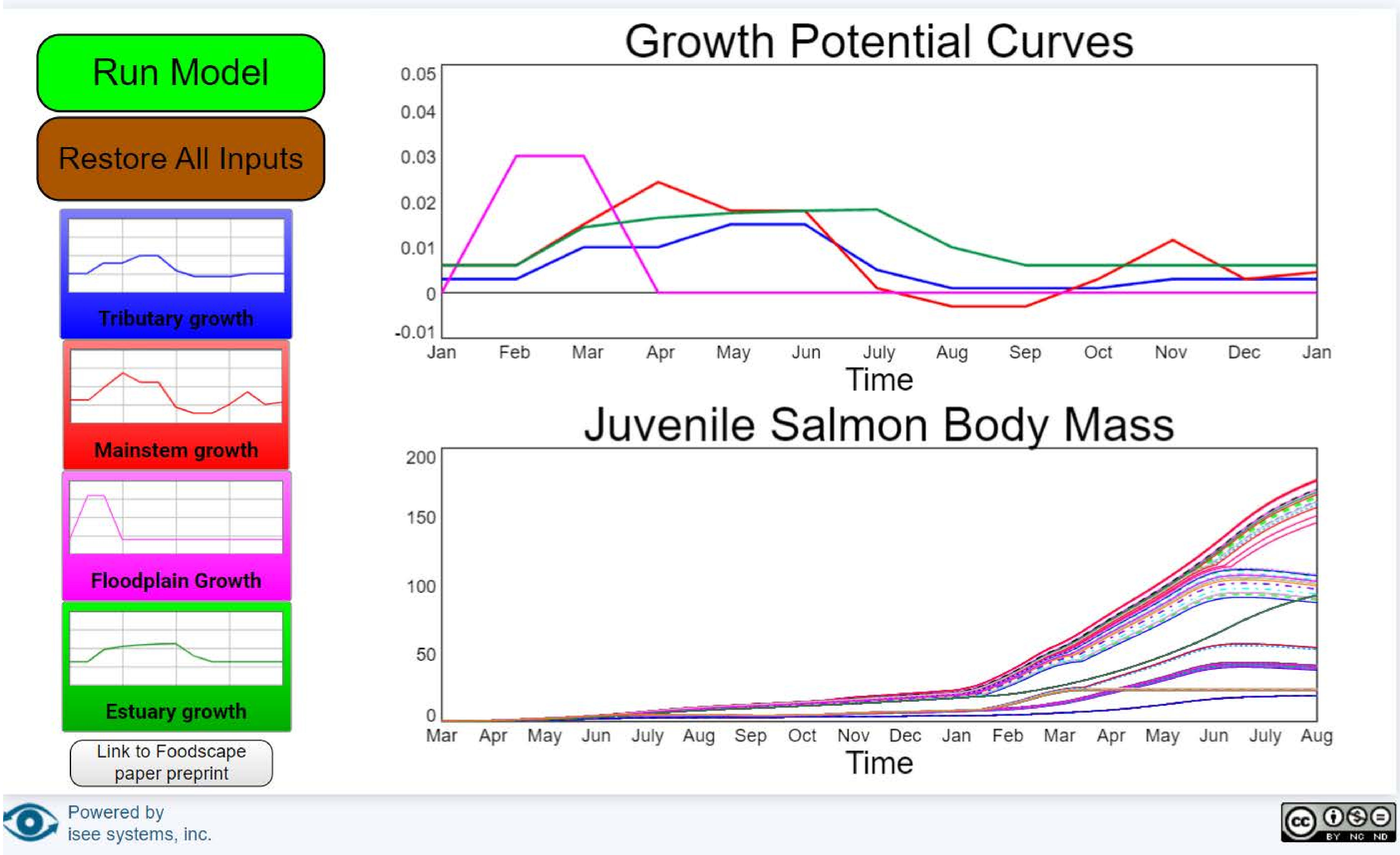
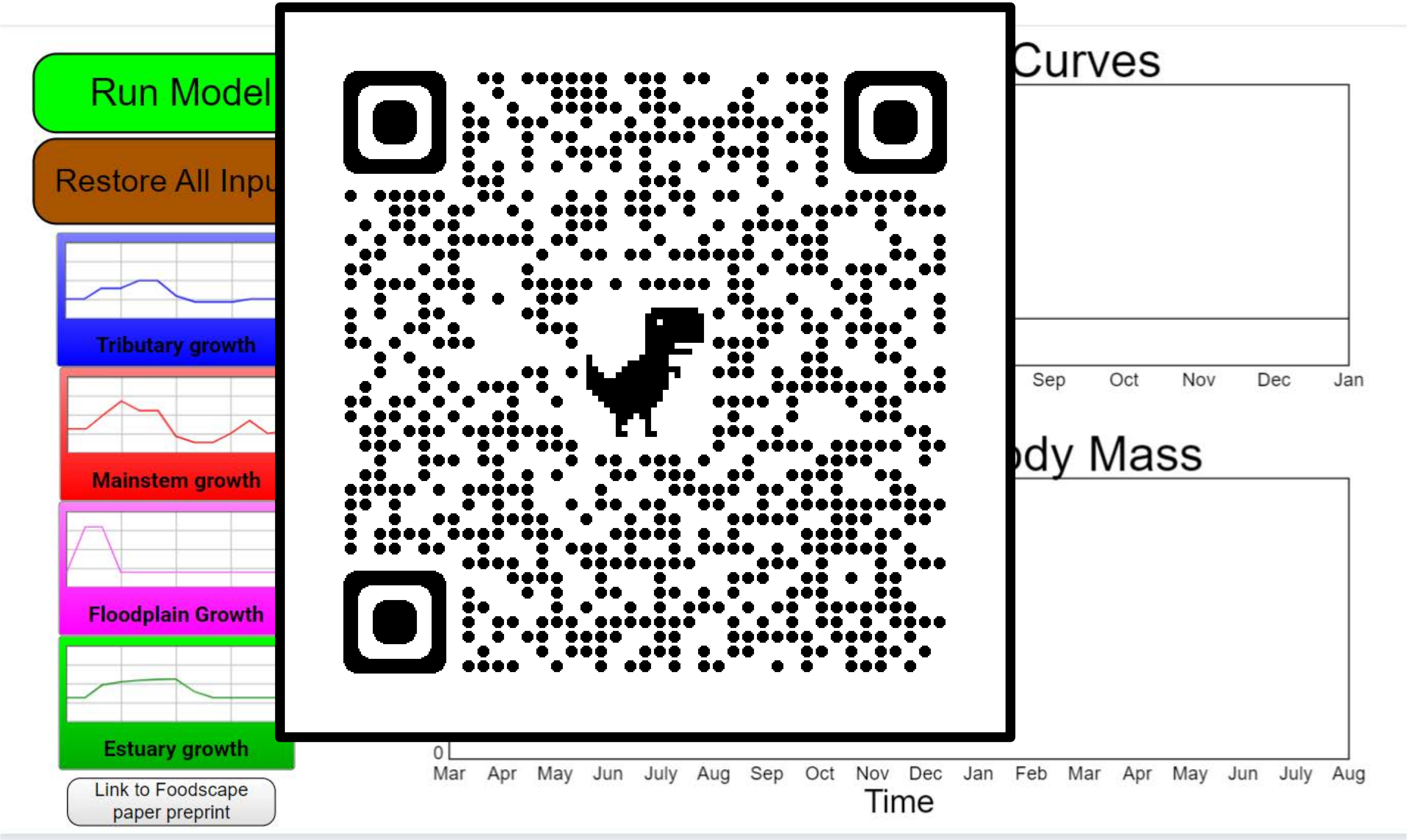


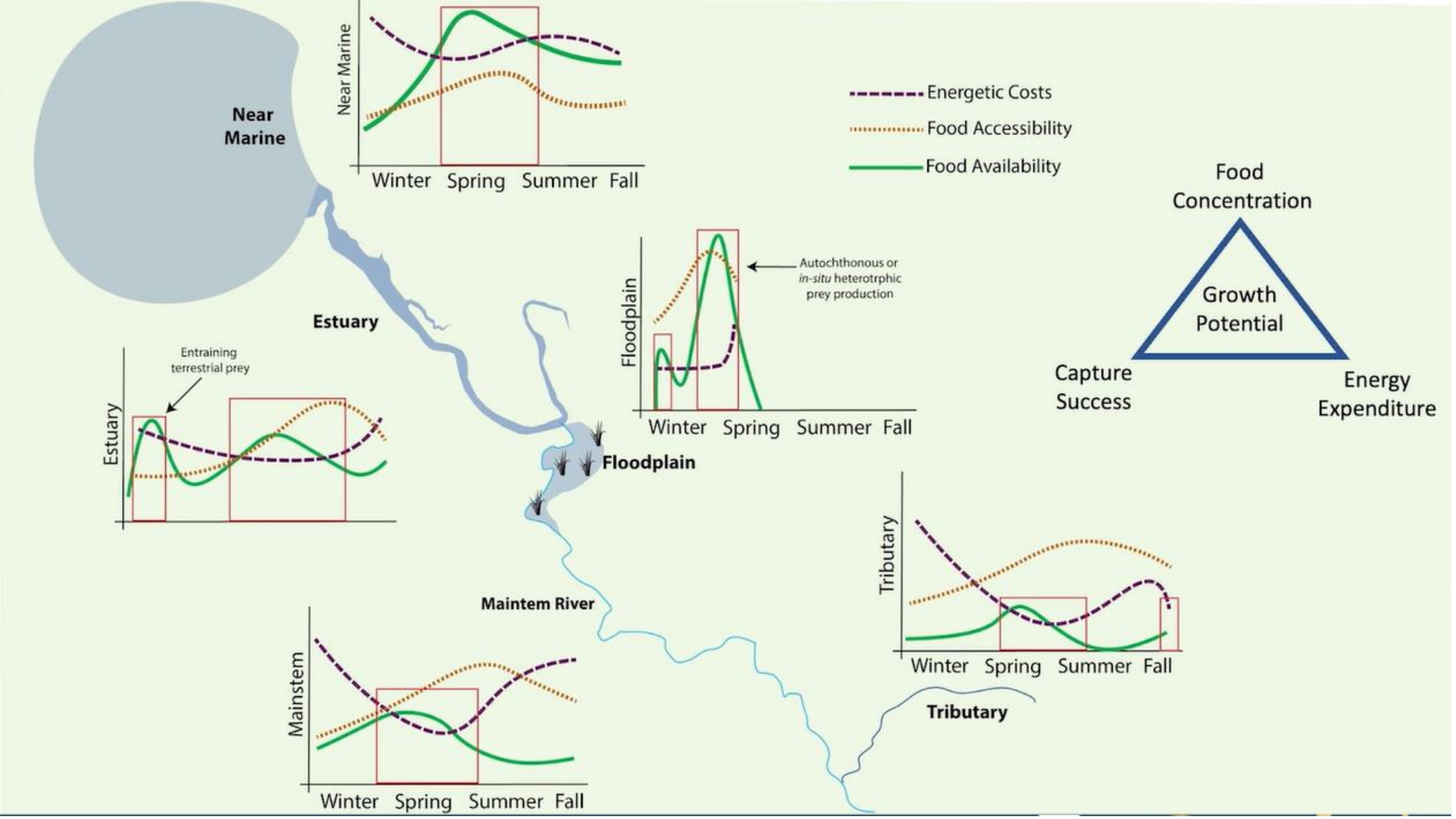
Figure B2. Asynchronous cycles in food availability, food accessibility, and energetic costs (Box 1) result in distinct patterns of fish growth potential across the riverscape (Panels a-e). Individual fish with different seasonal-spatial patterns of habitat use (life histories strategies) will experience different

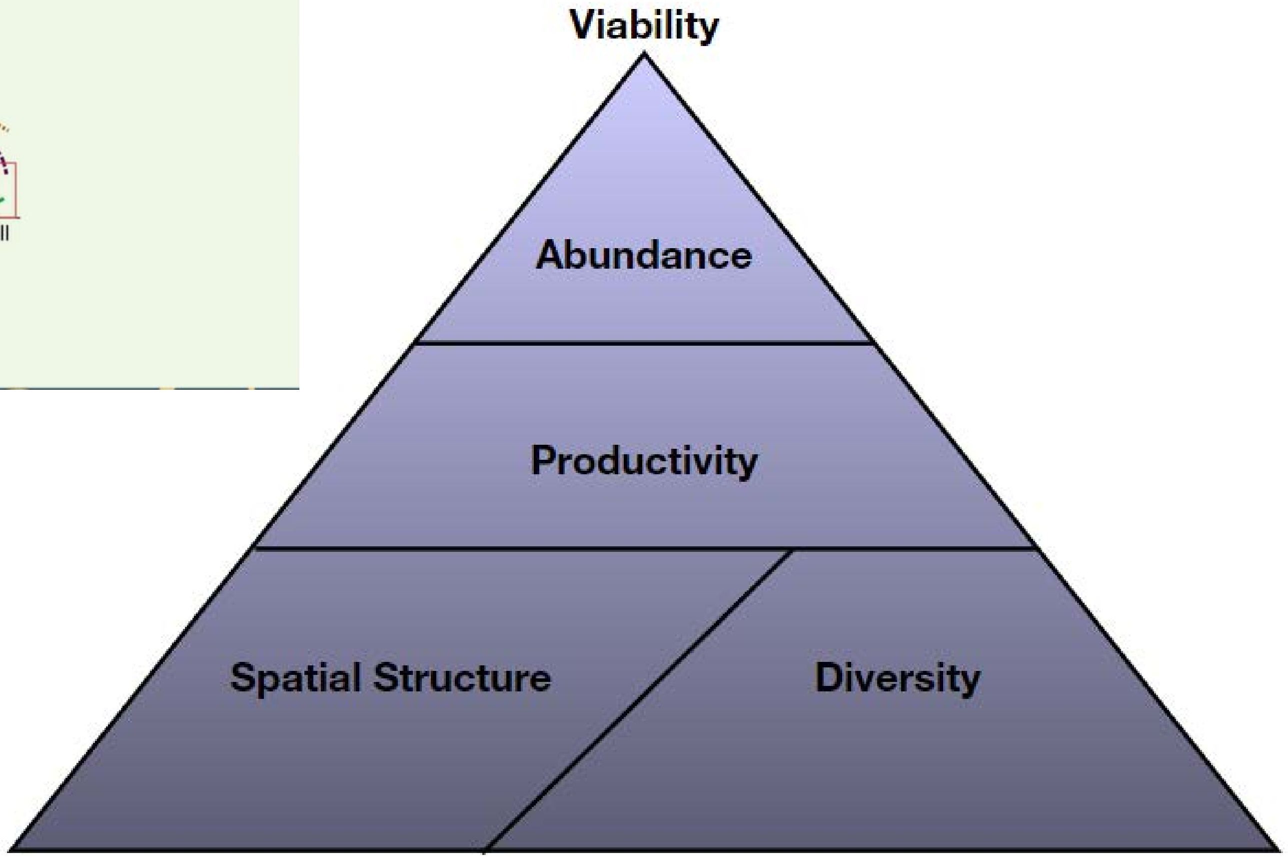

Run Model
Restore All Inputs
Tributary growth
Mainstem growth
Floodplain Growth
Estuary growth
Link to Foodscape paper preprint
Growth Potential Curves
0.05
0.04
0.03
0.02
0.01
0
-0.01
Jan Feb Mar Apr May Jun July Aug Sep Oct Nov Dec Jan
Time
Juvenile Salmon Body Mass
200
150
100
50
0
Mar Apr May Jun July Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun July Aug
Time
Powered by
isee systems, inc.

https://exchange.iseesystems.com/public/ryan-bellmore/fish-foodscape-ibm-example/index.html#page1

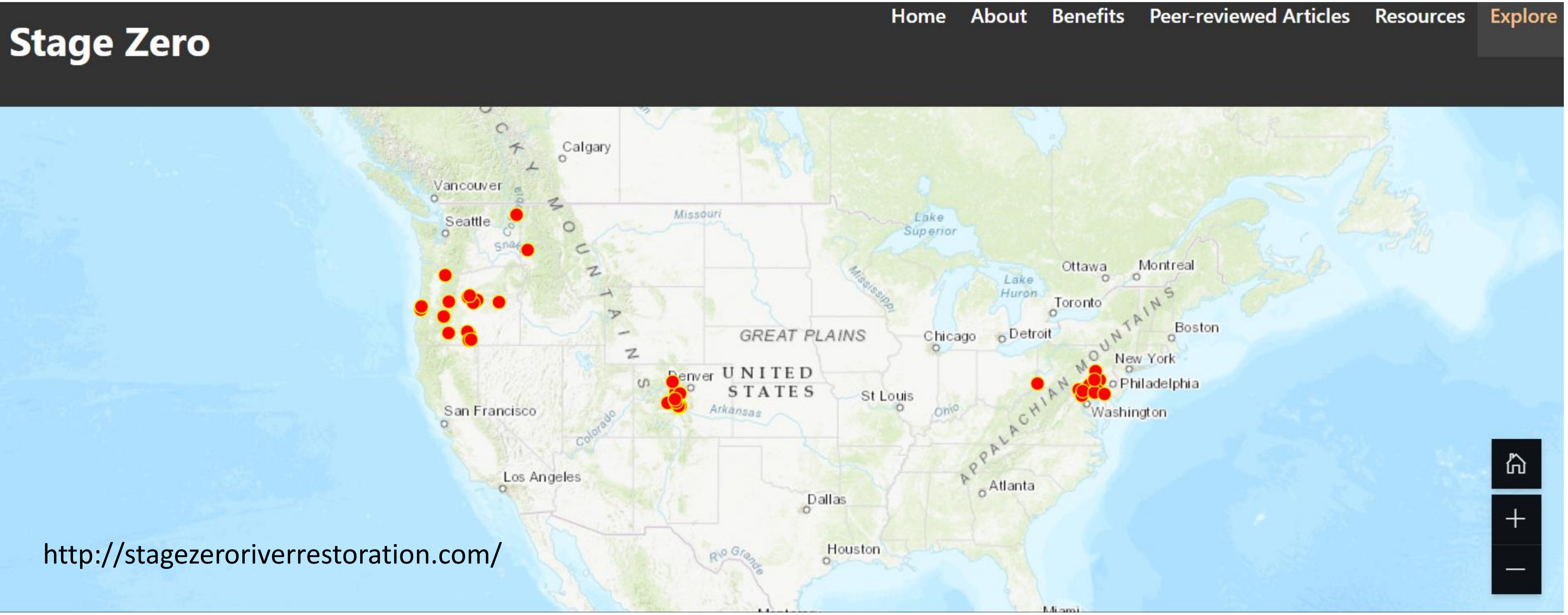


Population biology



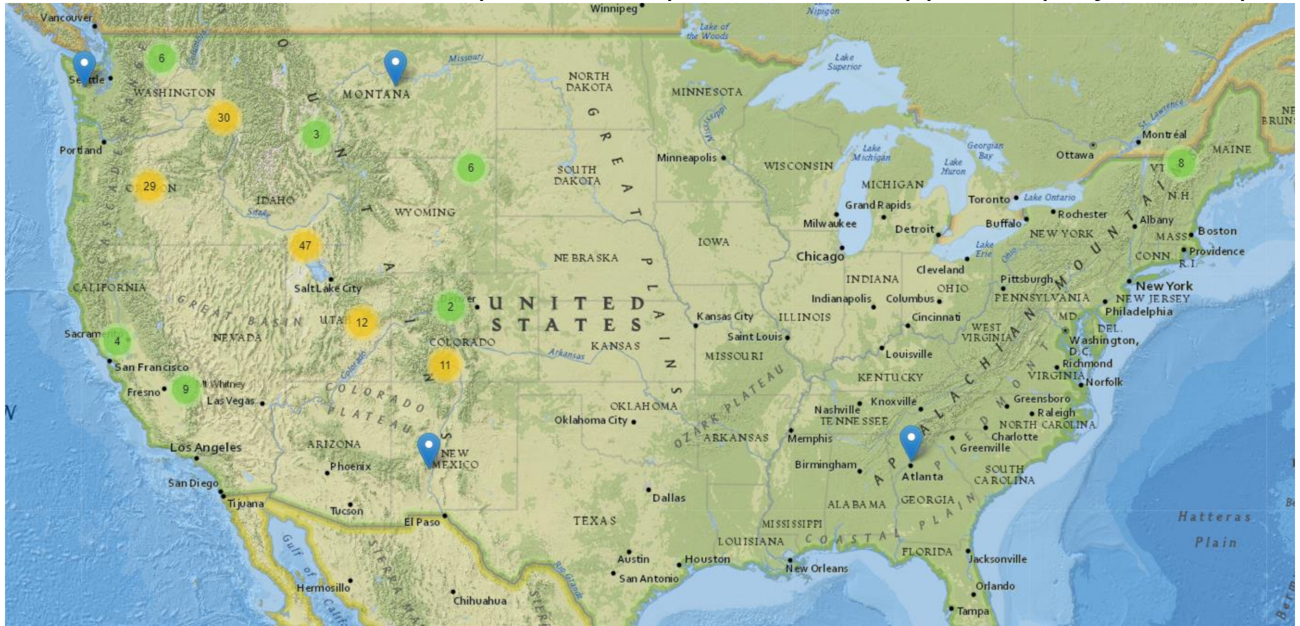


Williams et al. In Preparation



http://stagezeroriverrestoration.com/

https://bda-explorer.herokuapp.com/projects/map



Reconnecting historic habitat

Whychus Creek, Deschutes Land Trust's Whychus Canyon Preserve

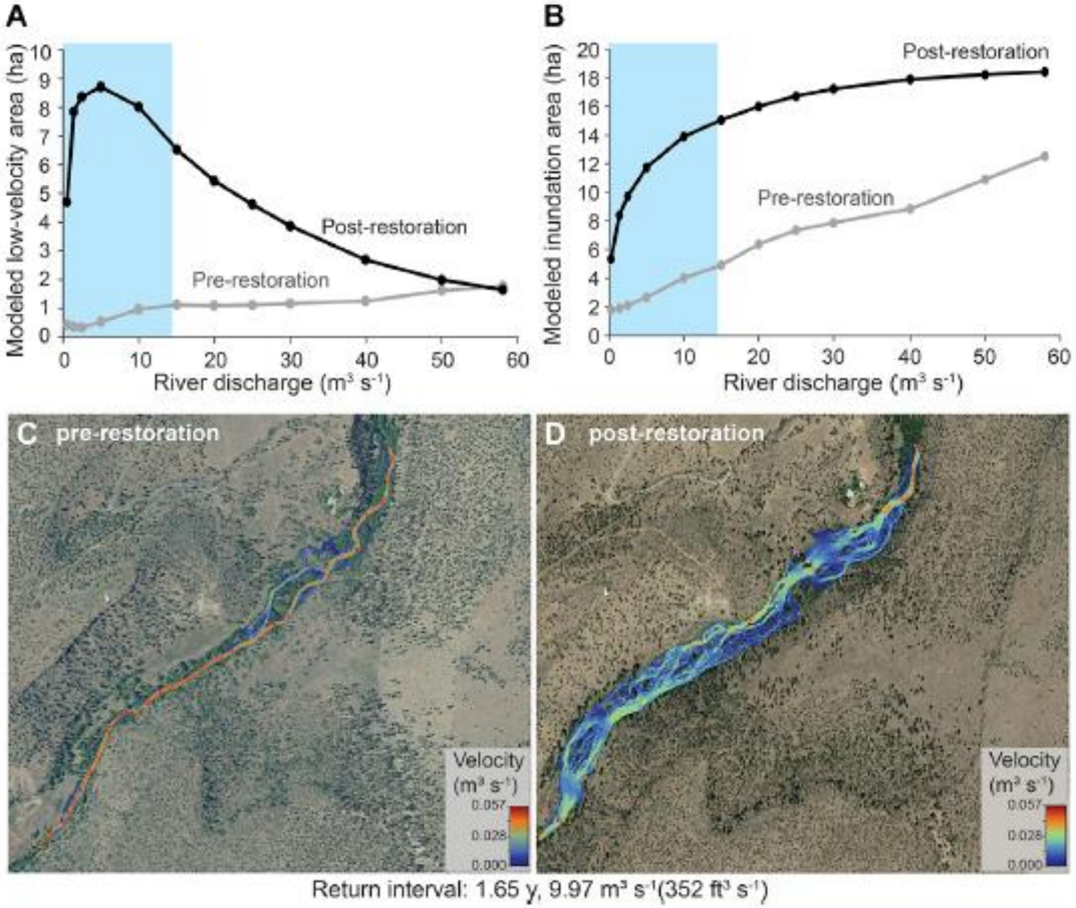
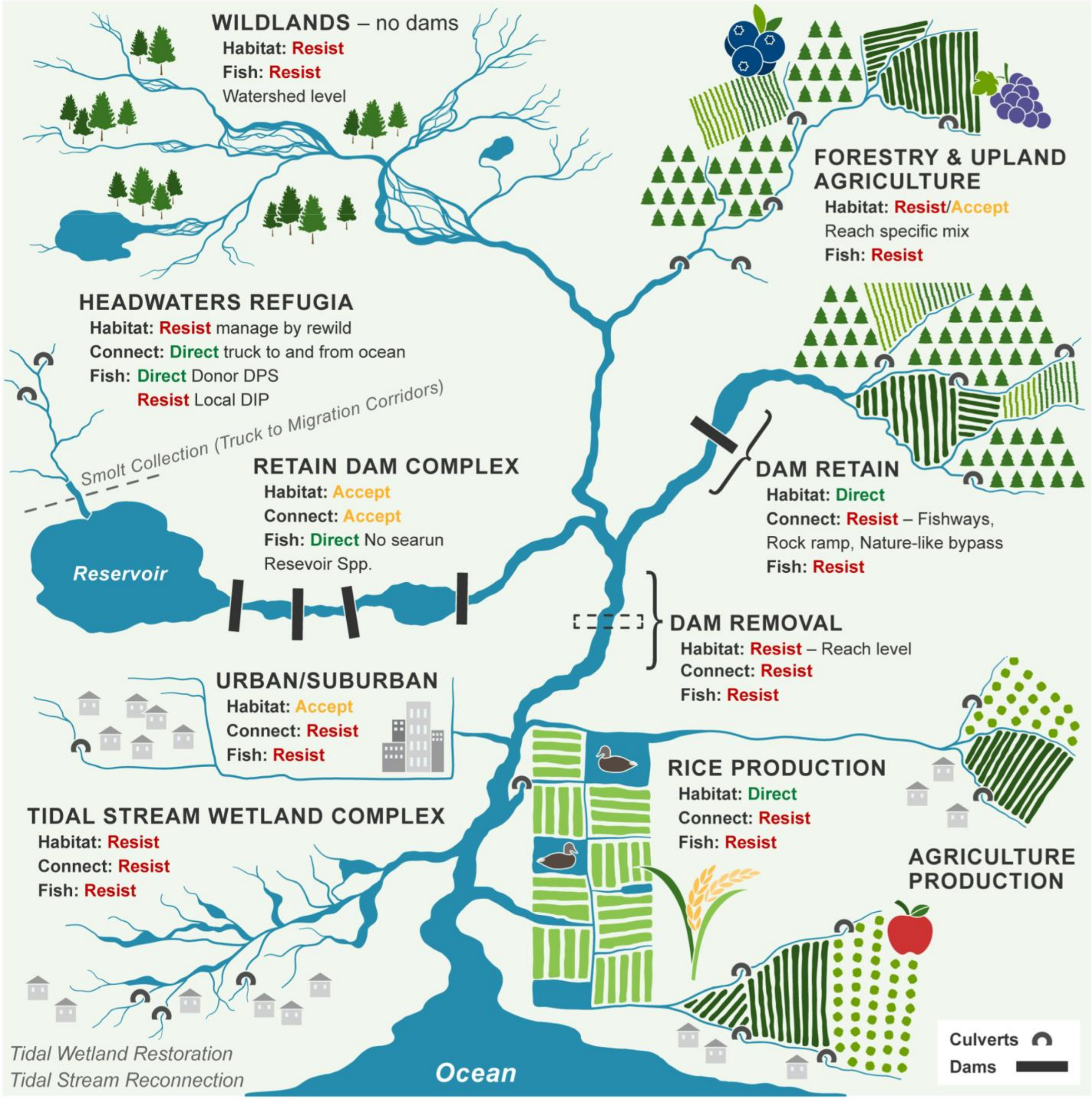


FIGURE 13 | Velocity modeling at the Whychus Creek at Whychus Canyon restoration site show: **(A)** suitable juvenile salmonid rearing habitat for the pre- and post-restoration conditions (blueshaded area delineates flow conditions for rearing); **(B)** modeled inundation area across river discharge levels for pre and post-restoration valley configurations; **(C)** mapped pre-restoration velocity for one commonly occurring winter flow of 10 cms, and; **(D)** mapped post-restoration velocity for one commonly occurring winter flow of 10 cms.

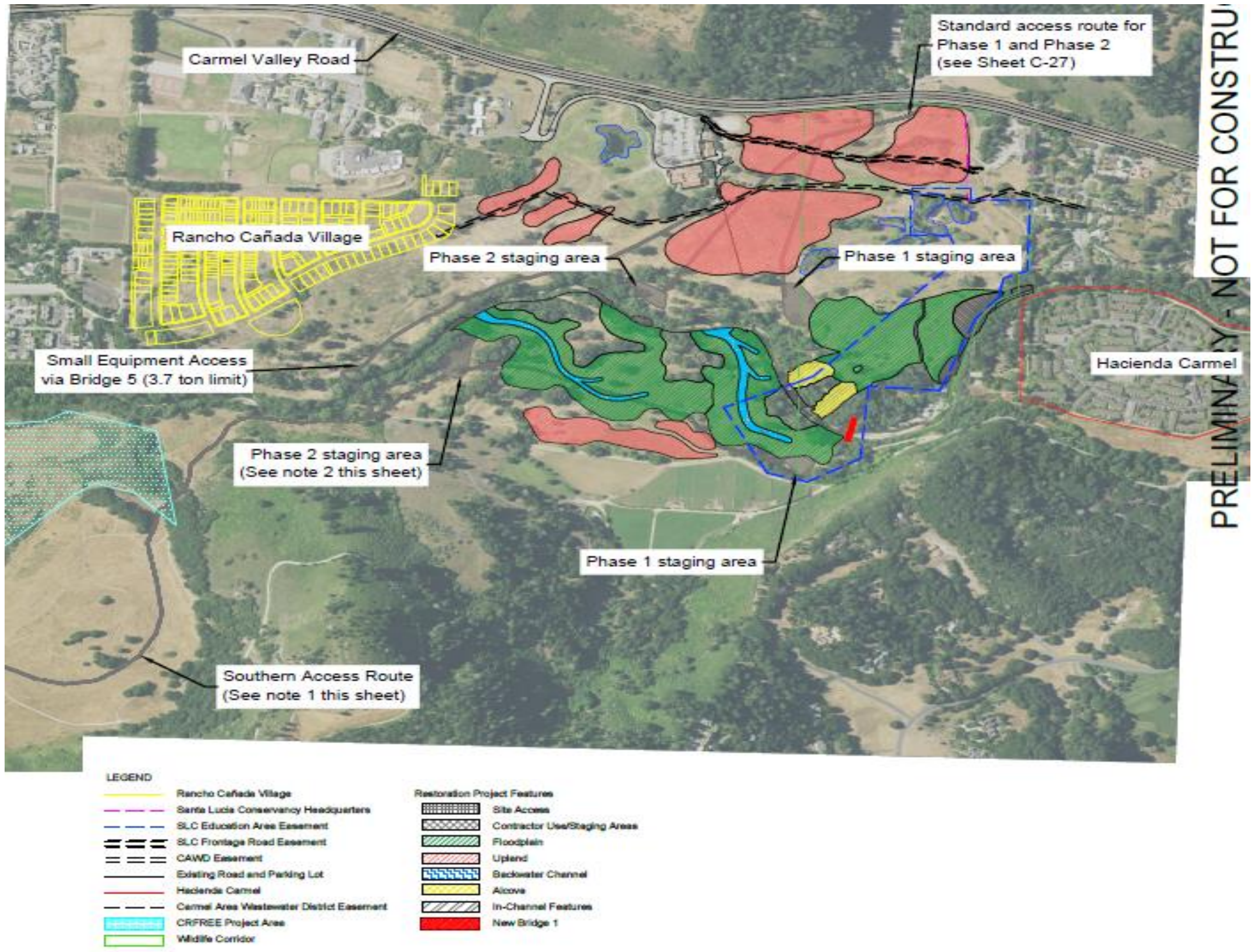
Novel access to historical habitat.

A drone view of floodwaters from the Sacramento River overtopping the Fremont Weir in Yolo County. DWR/2019



Kocik et al 2022. Salmon on the edge

Novel habitat.



Summary:

- Fish passage and restoration practices have added fundamental dimensions
  - Micro – Reach – Watershed – Time
- Multidisciplinary science
- Opportunities and challenges

Sources:

- Kocik et al 2022
- Walter and Merritts 2008
- Cluer and Thorne 2014
- Silva et al 2017
- Soga and Gaston 2016
- Schumm et al 1984
- Jeffres et al in prep
- Rosi et al in press
- Hauer et al 2016
- Wohl et al 2021
- Williams in prep

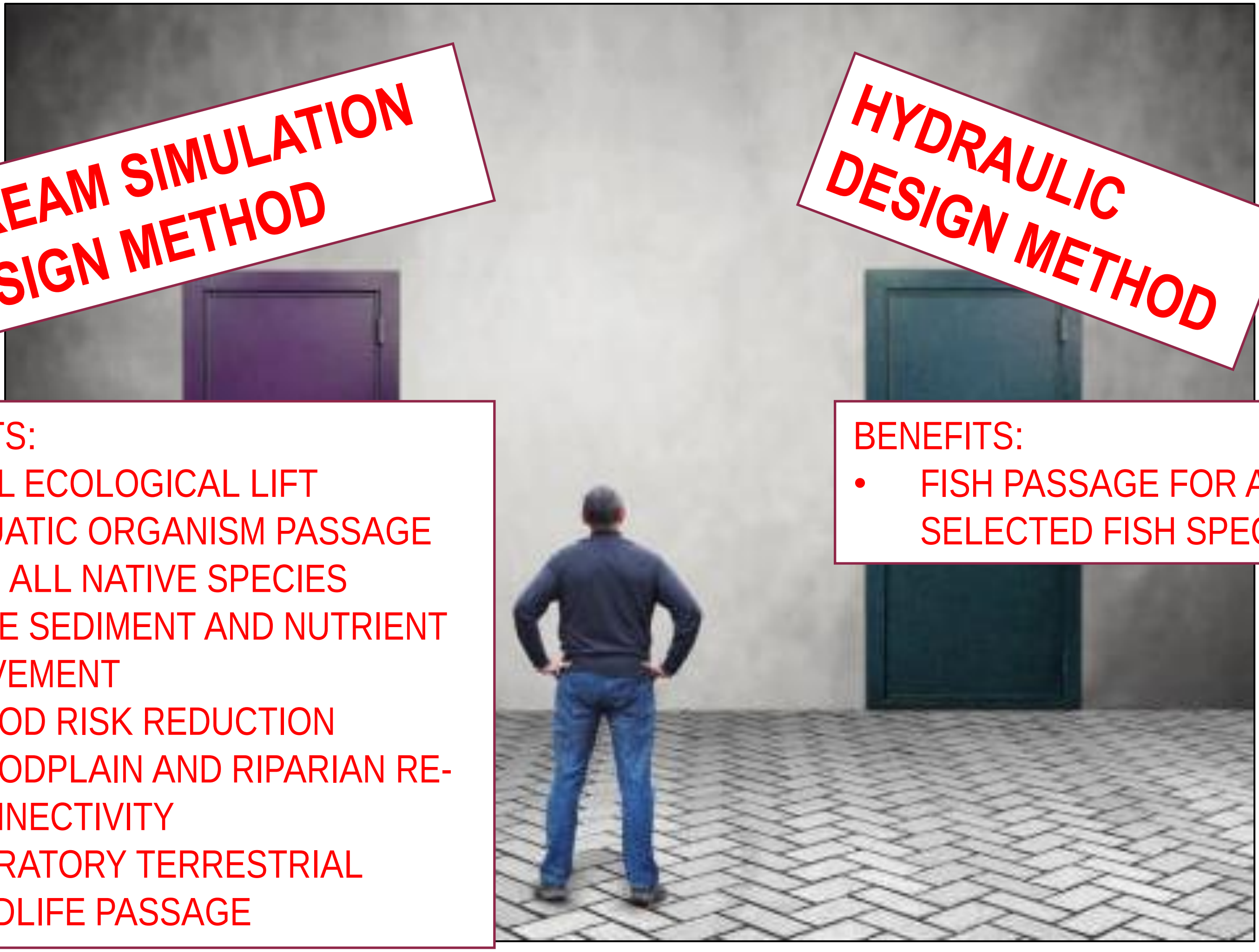
Questions ?

02

UPSTREAM FISH PASSAGE OVERVIEW

- Stream Simulation Design Methodology vs Hydraulic Design Methodology
- Zone of Passage
- Nature-like Fishways
  - Definition
  - General Pros and Cons

THERE ARE TWO OVERARCHING AND DISTINCT METHODOLOGIES FOR ACHIEVING VARYING DEGREES OF STREAM RESTORATION AT A SITE



STREAM SIMULATION DESIGN METHOD

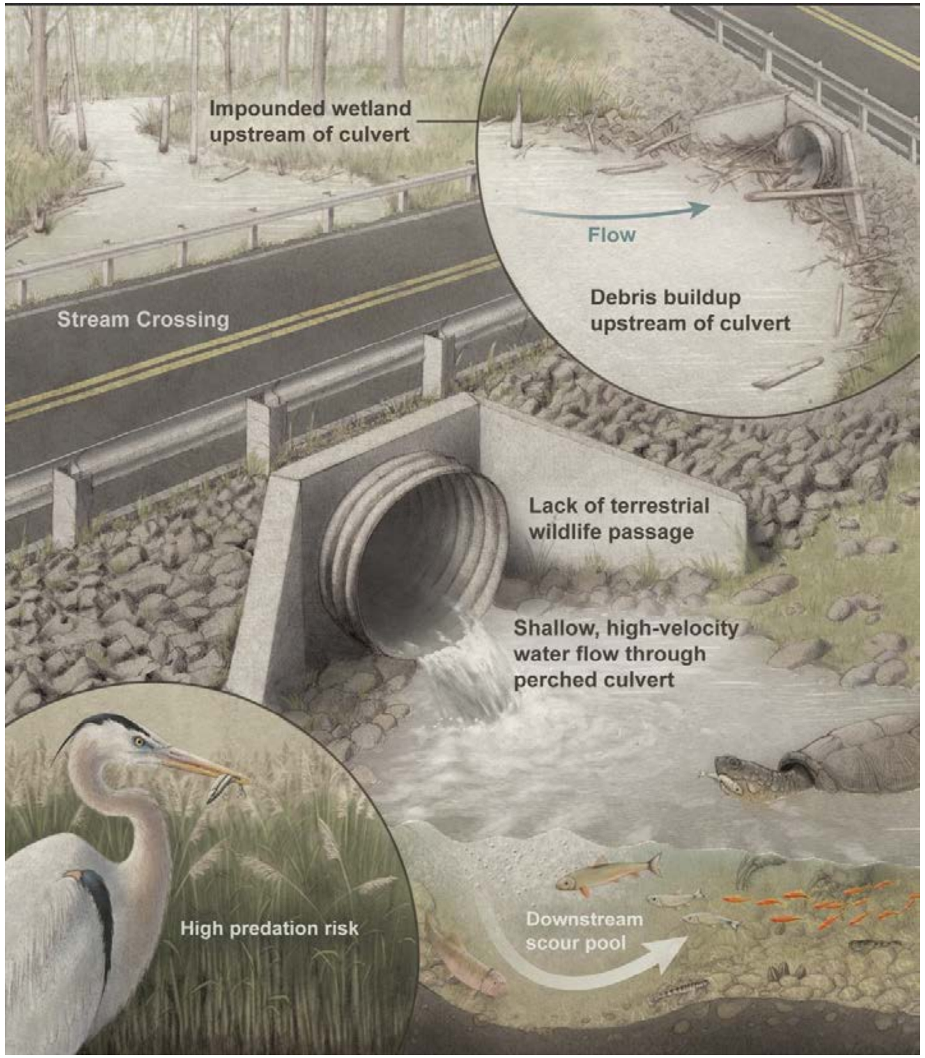
BENEFITS:
- FULL ECOLOGICAL LIFT
- AQUATIC ORGANISM PASSAGE FOR ALL NATIVE SPECIES
- FREE SEDIMENT AND NUTRIENT MOVEMENT
- FLOOD RISK REDUCTION
- FLOODPLAIN AND RIPARIAN RE-CONNECTIVITY
- MIGRATORY TERRESTRIAL WILDLIFE PASSAGE

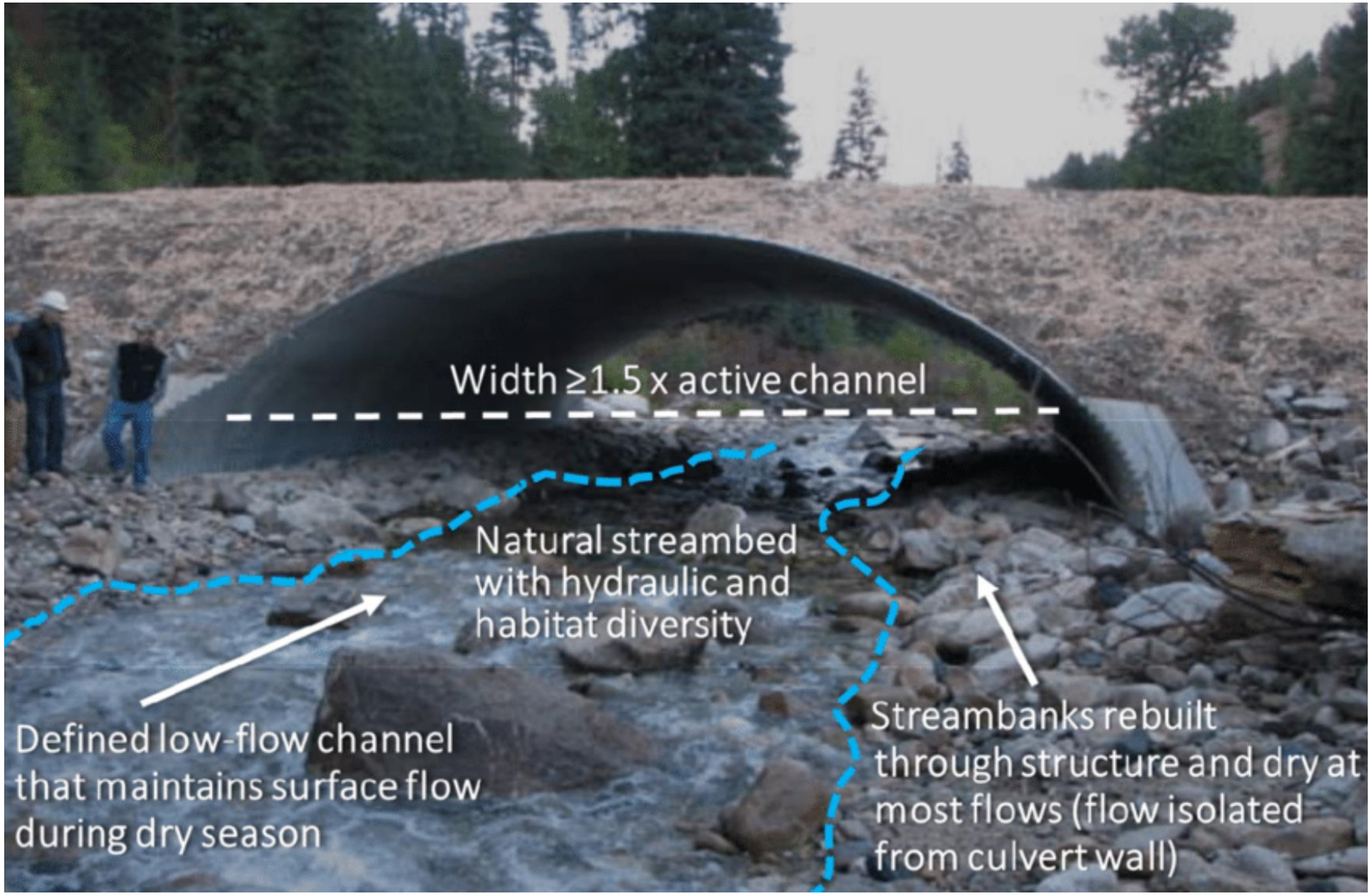
HYDRAULIC DESIGN METHOD

BENEFITS:
- FISH PASSAGE FOR A SELECTED FISH SPECIES

THERE ARE TWO OVERARCHING AND DISTINCT METHODOLOGIES FOR ACHIEVING VARYING DEGREES OF STREAM RESTORATION AT A SITE

STREAM SIMULATION DESIGN METHODOLOGY





SSM AQUATIC BENEFITS

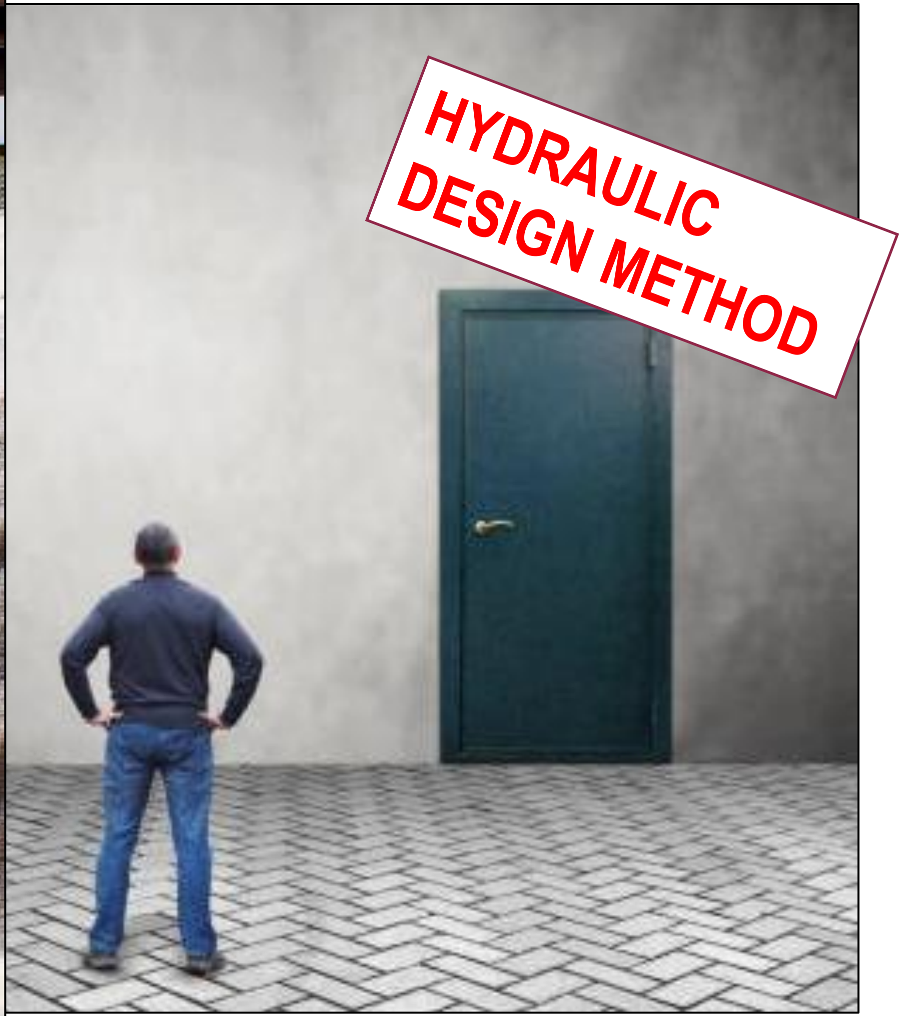
If designed correctly, all native aquatic organisms, even the small-bodied, weak-swimming species, should be able to swim through the restored stream section without additional difficulty when compared to the downstream and upstream natural reaches.

↑MUSSEL POPULATION = ↑WATER QUALITY

SMALL-BODIED FISH ALSO NEED TO MOVE!

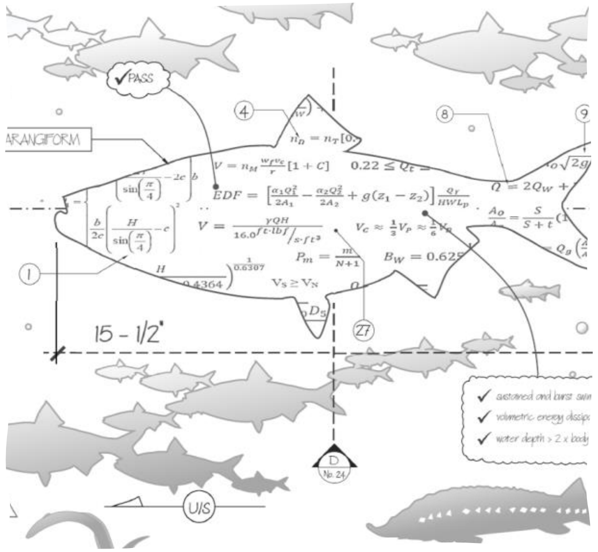
Figure 1.3—A broken-rays mussel uses a mantle-flap lure to attract host darter that it will infect with glochidia. Photo: Chris Barnhart, Missouri State University.

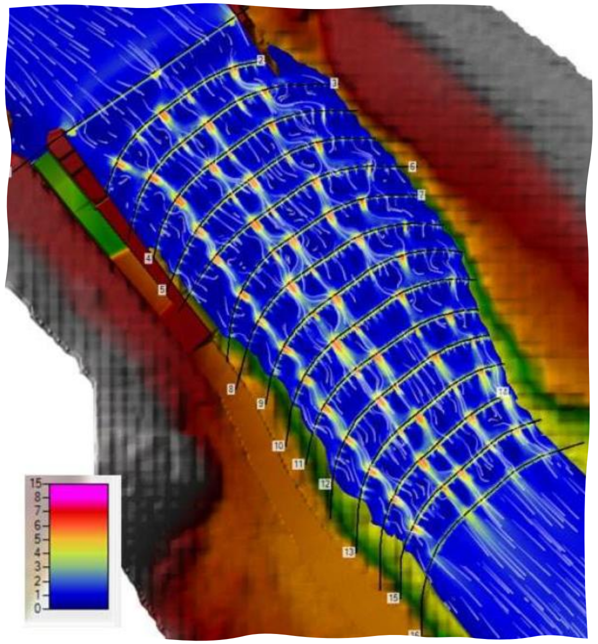
THERE ARE TWO OVERARCHING AND DISTINCT METHODOLOGIES FOR ACHIEVING VARYING DEGREES OF STREAM RESTORATION AT A SITE

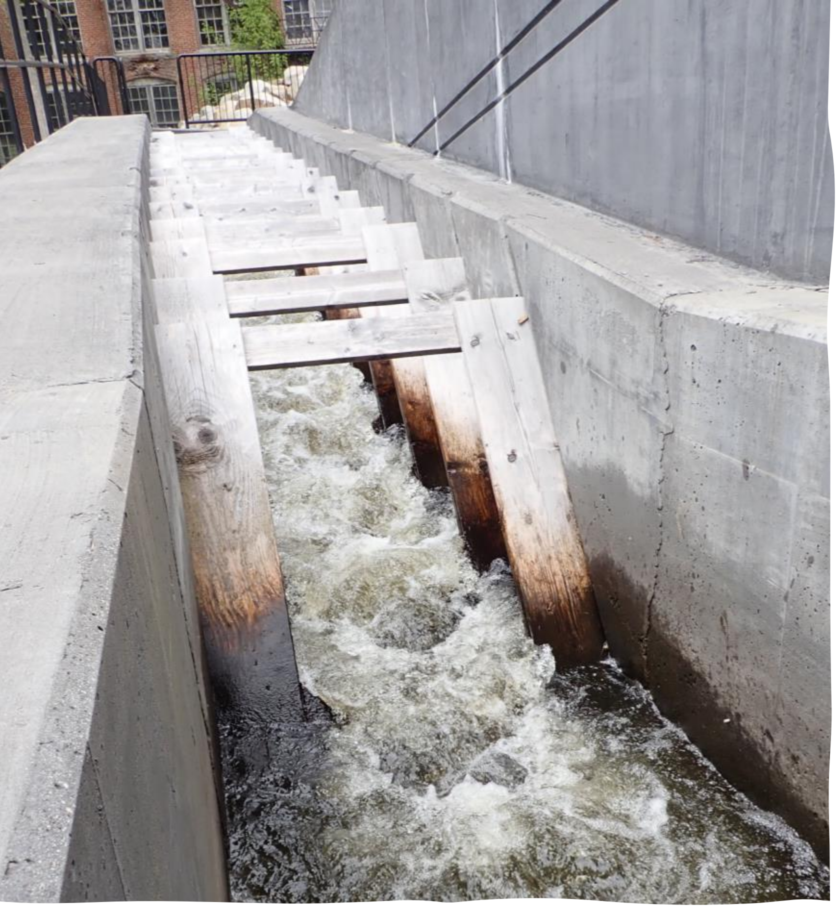
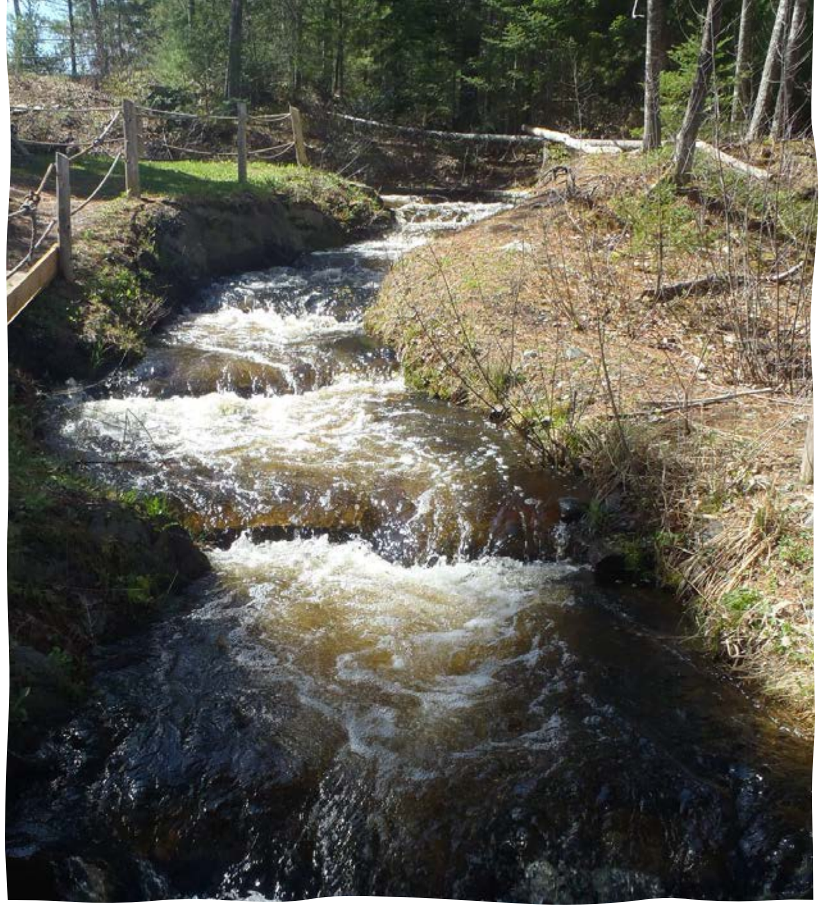


THE HYDRAULIC DESIGN METHOD

The HDM is a design strategy that targets distinct species of fish without necessarily accounting or designing for the natural and geomorphic requirements of the river system or the non-target species.





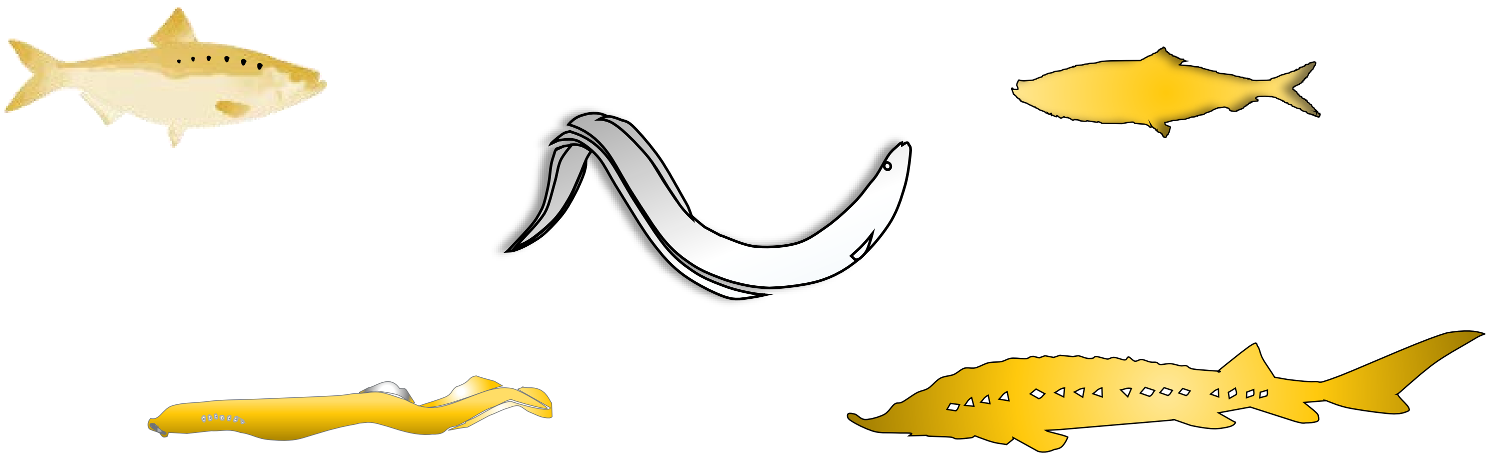

Fishways designed using HDM aim to provide *zones of passage* for the suite of target species and/or life stages

ZONE OF PASSAGE

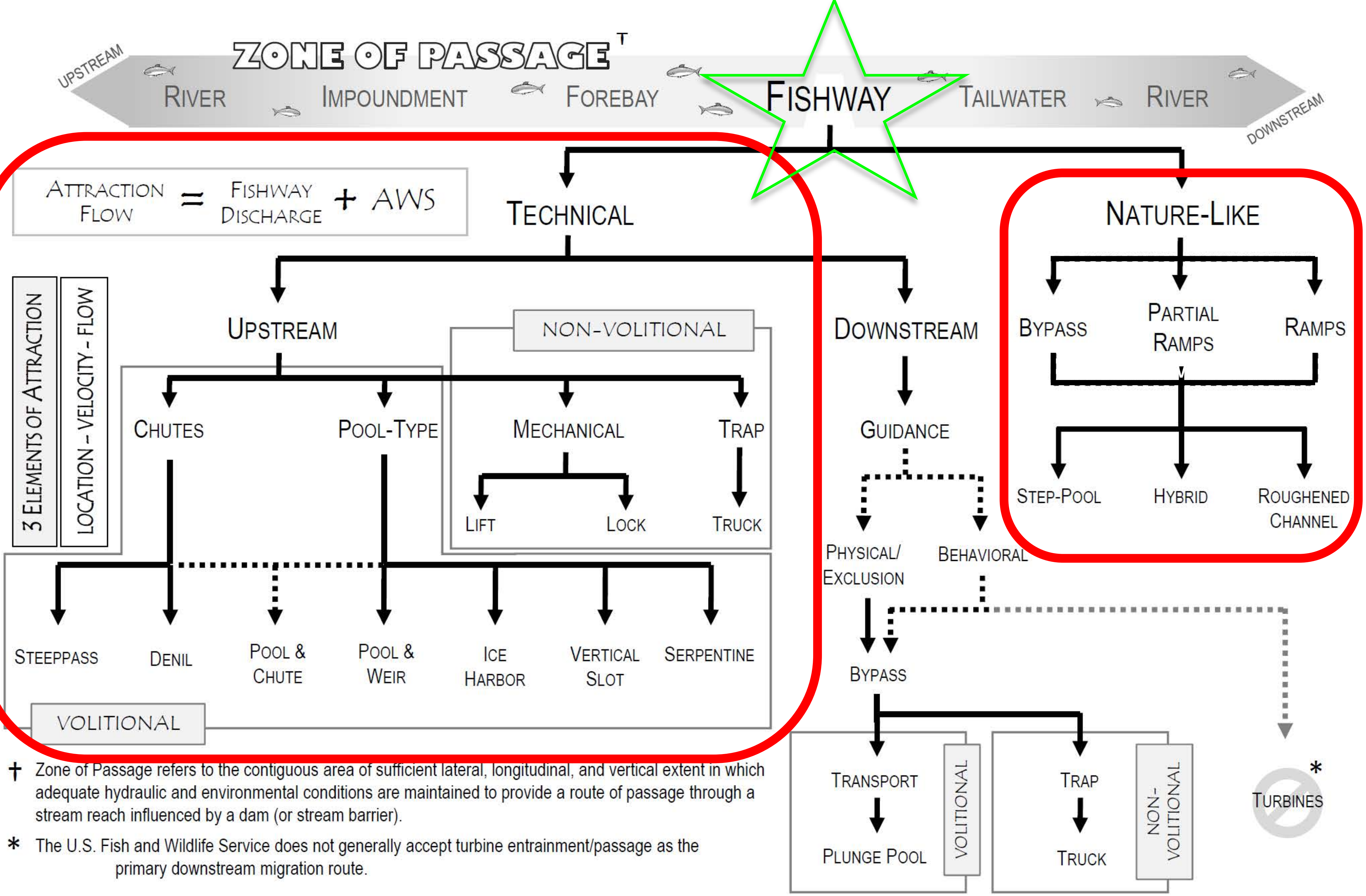
A contiguous area of sufficient lateral, longitudinal, and vertical extent in which adequate hydraulic and environmental conditions are maintained to provide a route of passage through a stream reach influenced by a human-made barrier

When applying HDM, we must first and foremost understand the swimming capabilities and biological behaviors of the suite of TARGET species at each of their life stages

Swim Speed Categories:



FISH SELECTIVITY IS INEVITABLE

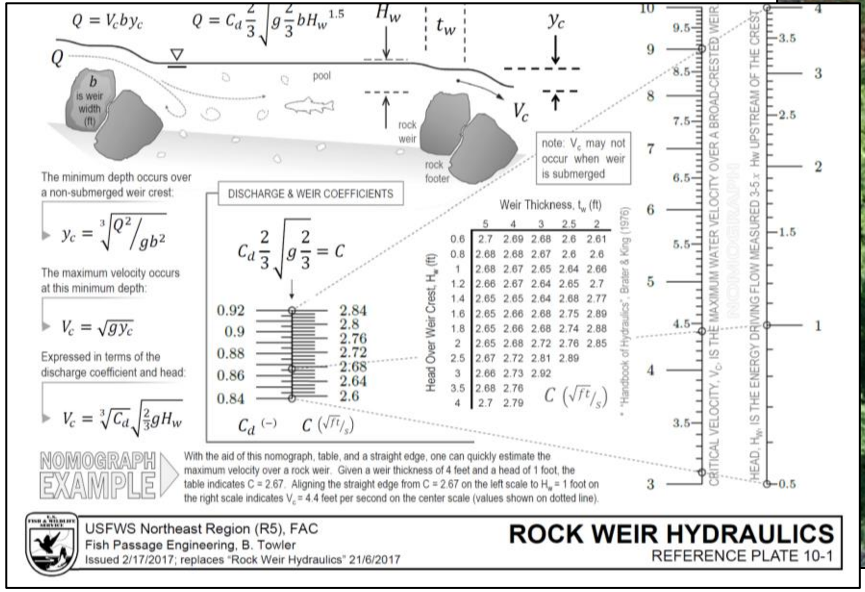


† Zone of Passage refers to the contiguous area of sufficient lateral, longitudinal, and vertical extent in which adequate hydraulic and environmental conditions are maintained to provide a route of passage through a stream reach influenced by a dam (or stream barrier).

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

THE HYDRAULIC DESIGN METHOD

All engineered fishways, INCLUDING NATURE-LIKE FISHWAYS, are designed with HDM



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

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

The maximum velocity occurs at this minimum depth:

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

Expressed in terms of the discharge coefficient and head:

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

DISCHARGE & WEIR COEFFICIENTS

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

C_d (–)	C ($\sqrt{ft}/s$)
0.92	2.84
0.9	2.8
	2.76
0.88	2.72
	2.68
0.86	2.64
0.84	2.6

Weir Thickness, t_w (ft)

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			

C ($\sqrt{ft}/s$)

* "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 2/17/2017; replaces "Rock Weir Hydraulics" 21/6/2017

ROCK WEIR HYDRAULICS
REFERENCE PLATE 10-1

WHAT IS A NATURE-LIKE FISHWAY?

Constructed fish passage structures that mimic morphodynamic components of natural fish habitat (Katopodis 2012), such as substrate clusters, pools, riffles, steps, rapids, and other natural materials to create diverse physical and hydraulic conditions intended to provide efficient passage to a **targeted** group of aquatic organisms and/or specific life stages, including migratory and (sometimes) resident fish assemblages.

Nature-like Fishways

PROS:

- Established, ancient technique for providing fish passage
- If designed appropriately, it can provide passage to a wide range of fish species (i.e., low species selectivity)
- Often provides multiple pathways at a given flow rate compared to other traditional fishway options
- Aesthetically pleasing to the eye
- Generally low maintenance needs and easy access

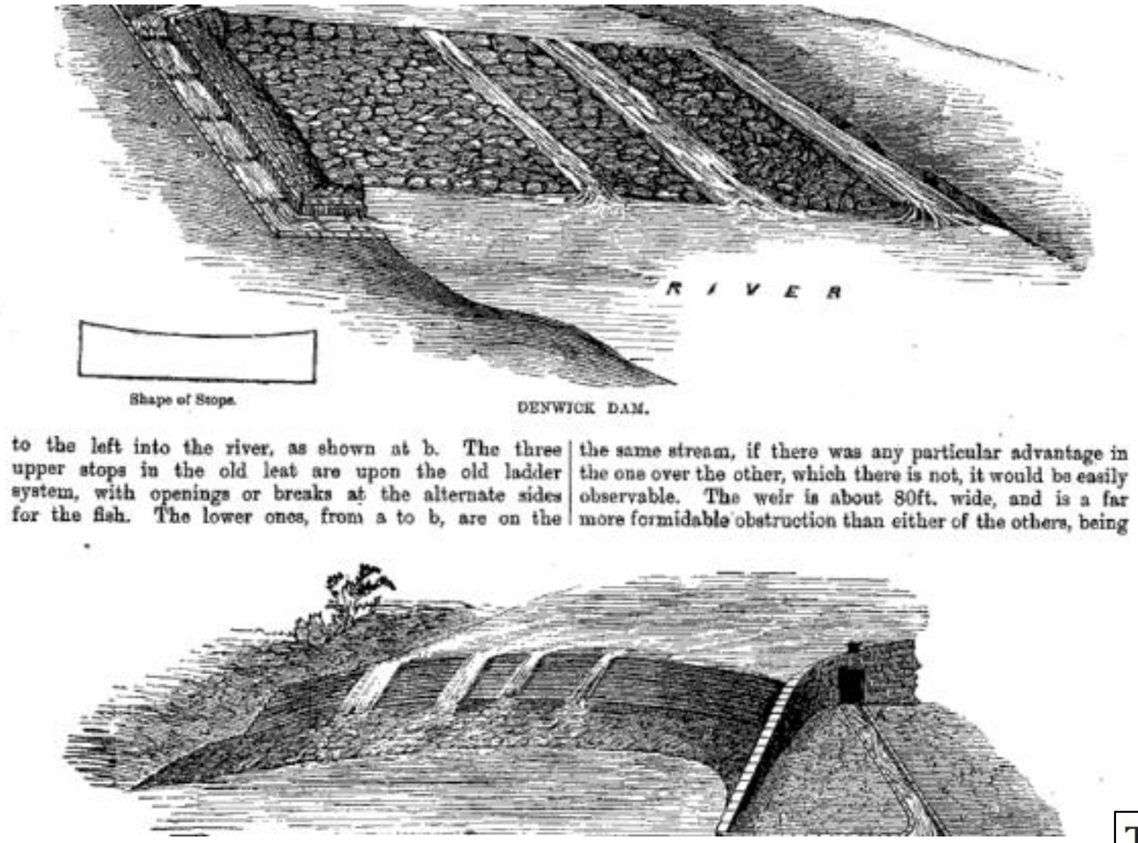
Nature-like Fishways

CONS:

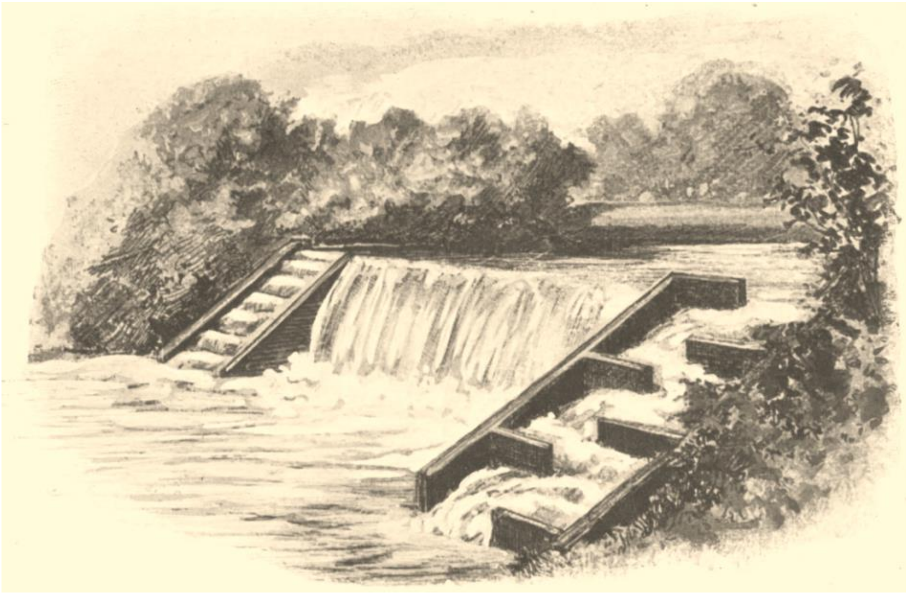
- These are generally more expensive $$$ than any other fish passage alternative
- Larger footprint (aka, real estate)
- Difficulty to stop any invasives from moving through it
- Large bed mobilizing events can lead to deposition or blockage that often results in costly cleanups and/or repairs

03

HISTORY OF FISH PASSAGE AND NLF EVOLUTION

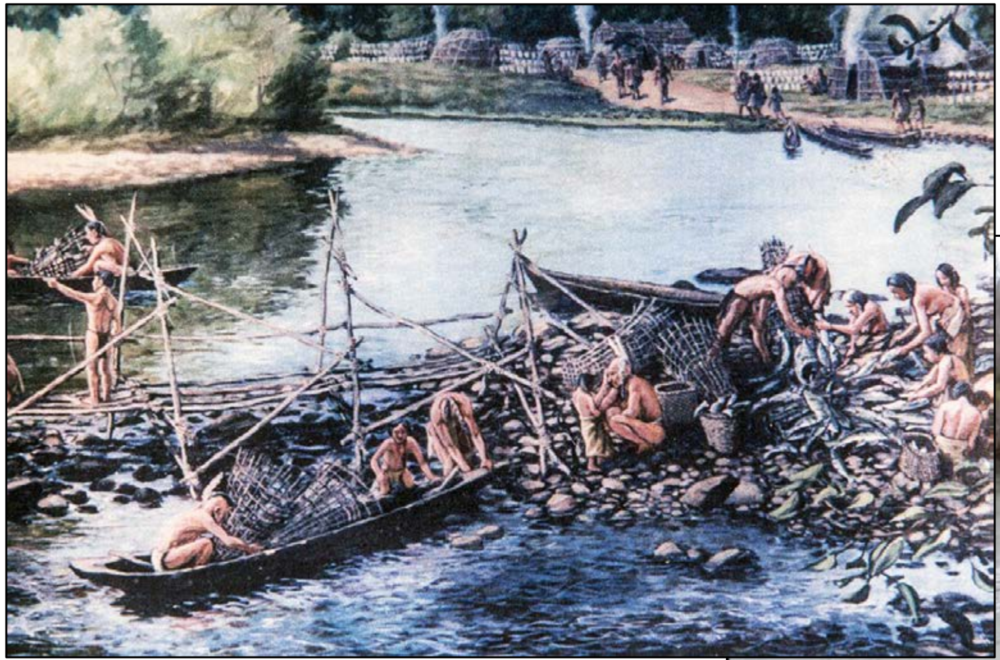


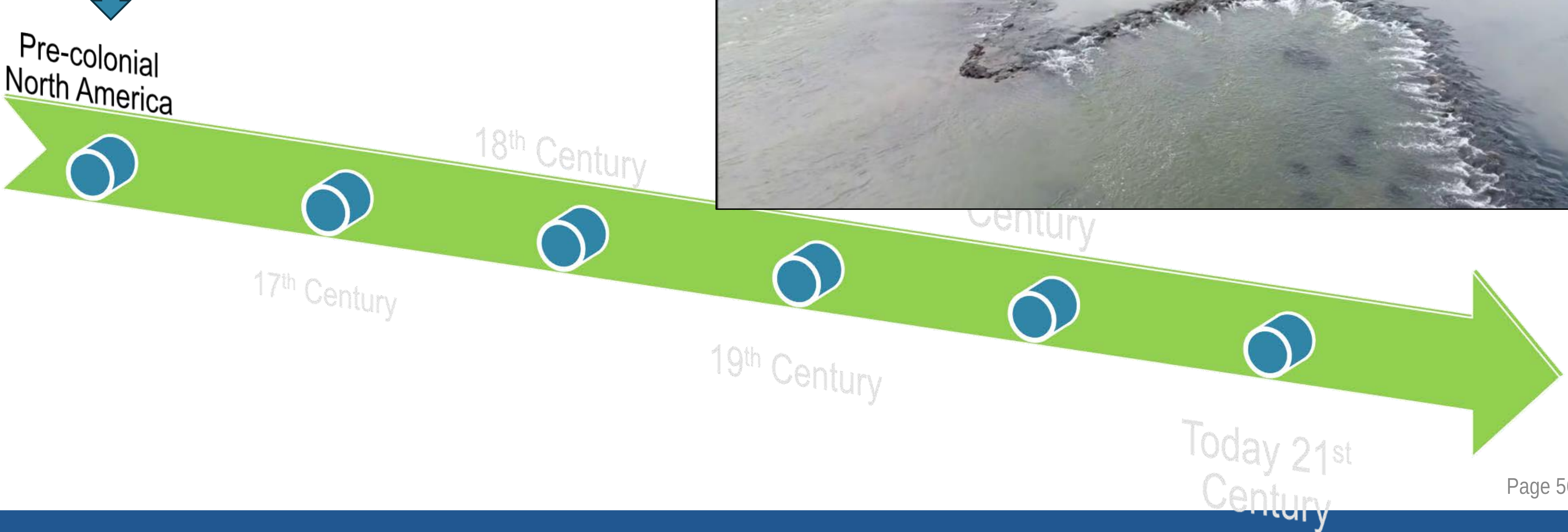
to the left into the river, as shown at b. The three upper stops in the old leat are upon the old ladder system, with openings or breaks at the alternate sides for the fish. The lower ones, from a to b, are on the the same stream, if there was any particular advantage in the one over the other, which there is not, it would be easily observable. The weir is about 80ft. wide, and is a far more formidable obstruction than either of the others, being



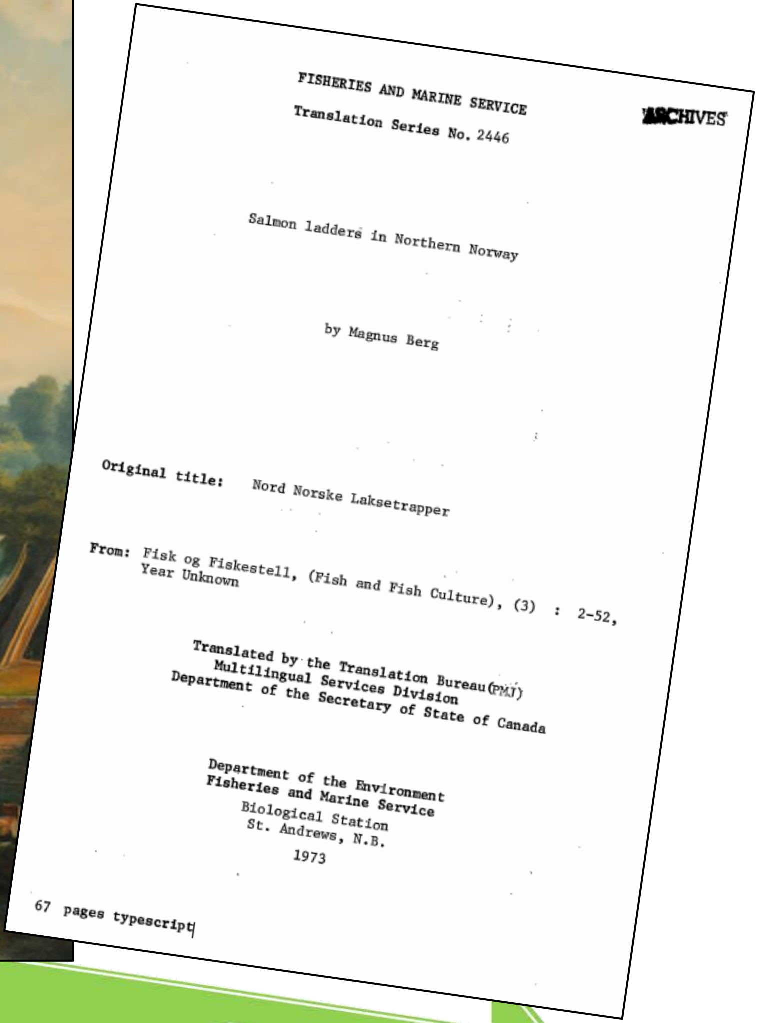
The development of fish passage research in a historical context

Christos Katopodis[a,*], John G. Williams[b,1] 2011




Pre-colonial North America
17th Century
18th Century
19th Century
Century
Today 21st Century

Salmon ladders in 17th century France


FISHERIES AND MARINE SERVICE

Translation Series No. 2446

ARCHIVES

Salmon ladders in Northern Norway

by Magnus Berg

Original title: Nord Norske Laksetrapper

From: Fisk og Fiskestell, (Fish and Fish Culture), (3) : 2-52, Year Unknown

Translated by the Translation Bureau (PMJ)
Multilingual Services Division
Department of the Secretary of State of Canada

Department of the Environment
Fisheries and Marine Service
Biological Station
St. Andrews, N.B.
1973

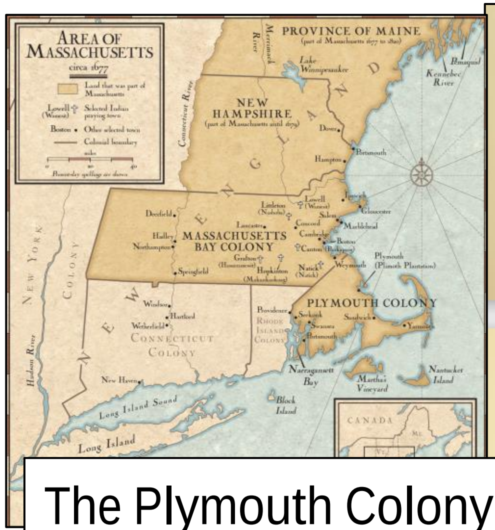
67 pages typescript

Pre-colonial North America

17th Century

19th Century

Today 21st Century



The Plymouth Colony passed a law in 1709 prohibiting the construction of weirs that would impact fish passing during their seasonal migrations

1709.

AN ACT to prevent Nuisances by Hedges, Wears, and other incumbrances obstructing the passage of Fish in Rivers.

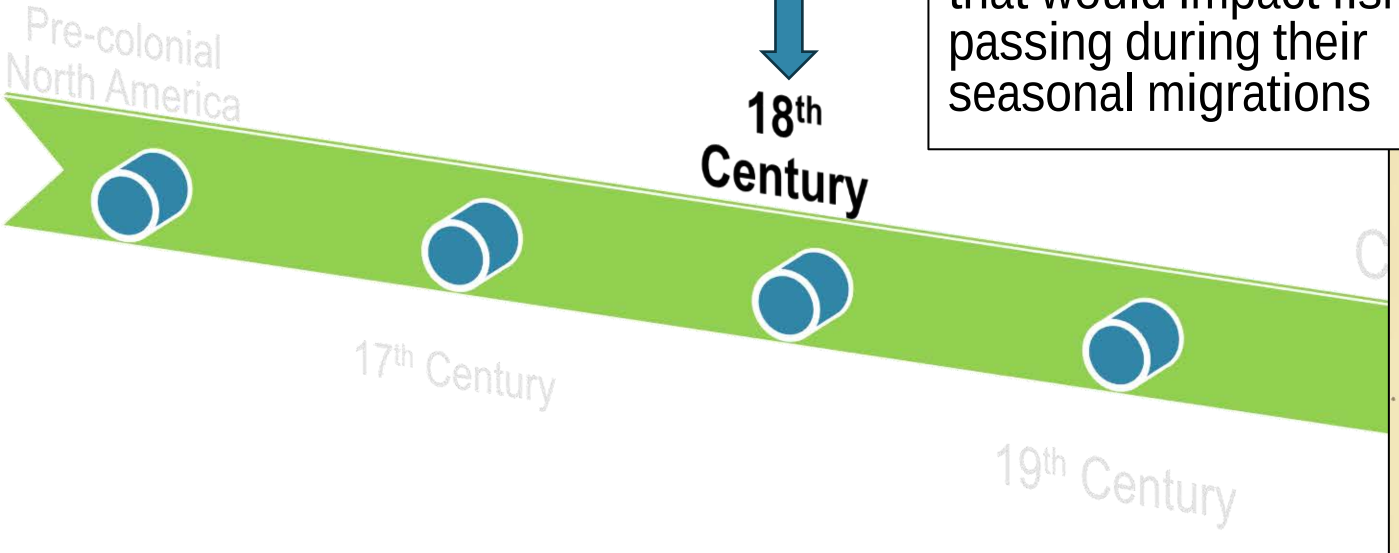
(Page 162, ch. 3.) *Be it enacted*, That no wears, hedges, fish-garths, stakes, kiddles, or other disturbance or incumbrance shall be set, erected or made, on or across any river, to the stopping, obstruct-

8 LAWS RELATING TO

ing, or straitning of the natural or usual course and passage of fish in their seasons, or spring of the year, without the approbation and allowance first had and obtained from the general sessions of the peace in the same county; who are hereby authorized and impowered, on application made to them at their sessions, to grant liberty for the same, or to deny it, as they shall see it to bee either a public good or damage; and so yearly from time to time, to be allowed or disallowed, as they shall direct.

And that all wears, hedges, fish-garths, stakes, kiddles, or other incumbrance whatsoever, set up and made, or hereafter to be levied, set up or made in, on or across any river, to the straitning, obstructing and stopping the natural, common or usual passage of fish in the spring or proper seasons of the year, without approbation or allowance first had and obtained for the same, in manner as in and by this act is directed, are declared to be a common nusance, and shall be demolished and pulled down, not to be again repaired or amended. And that on complaint made to the general sessions of the peace, or to any two justices of the peace, *quorum unus*, in their respective counties; a writ shall be granted to the sheriff or constable of the town where the nusance is done, to cause the party or parties complained of to be examined; and upon conviction to remove the same; and to command suitable assistance therefor, at the cost and charge of the person or persons so offending.

Provided, That nothing herein contained, shall be construed to extend to the pulling down or demolishing of any mill-dam already made, or that shall hereafter be lawfully and orderly made.



"Cape Cod Ladder"

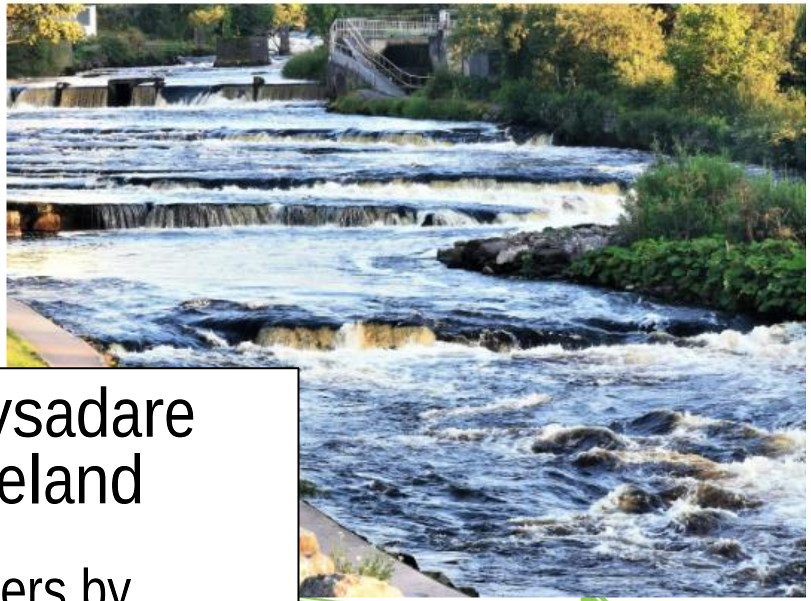
Historically, harvested alewives were salted or smoked, and packed in barrels to be shipped overseas as a reliable and inexpensive food. COURTESY OF NOBLEBORO HISTORICAL SOCIETY

River herring harvest in the Damariscotta River, ME since 1806

19th Century

Today 21st Century

- Fisheries Act of 1842 (Ireland)
- Fisheries Act of 1868 (Canada)



Pre-colonial North America

17th Century

18th Century

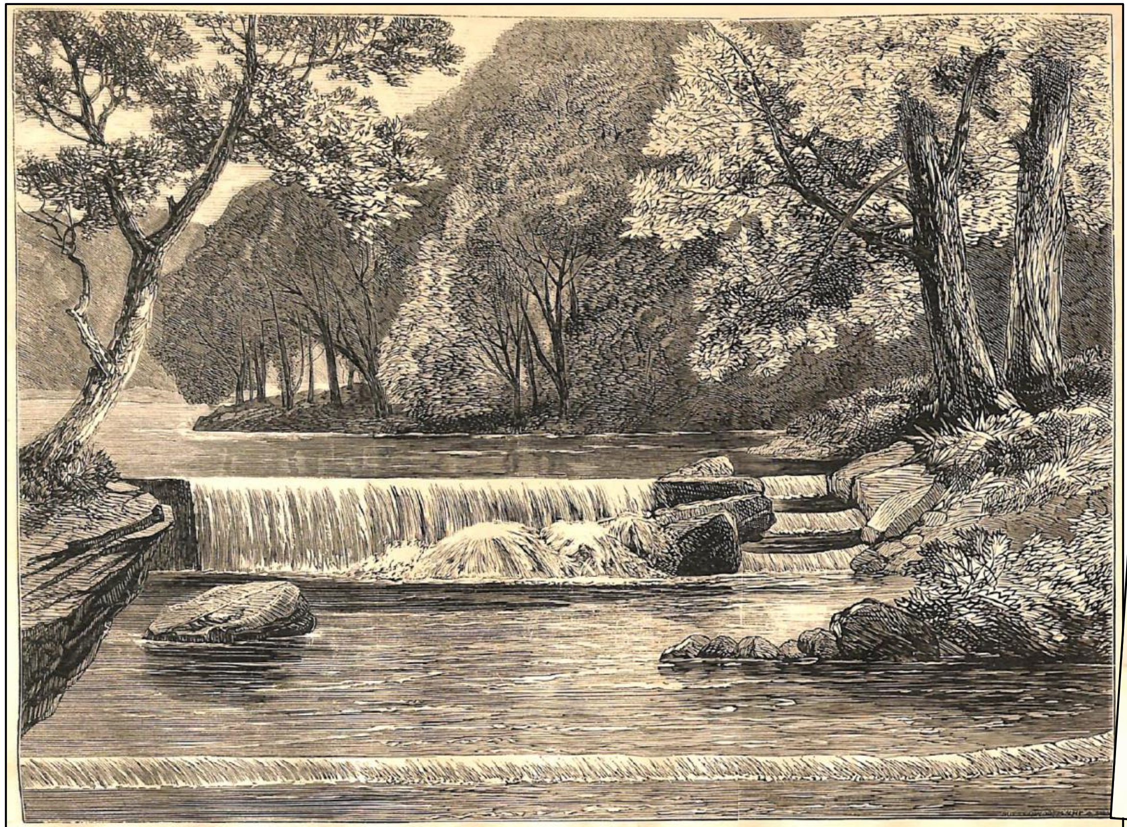
19th Century

Today 21st Century

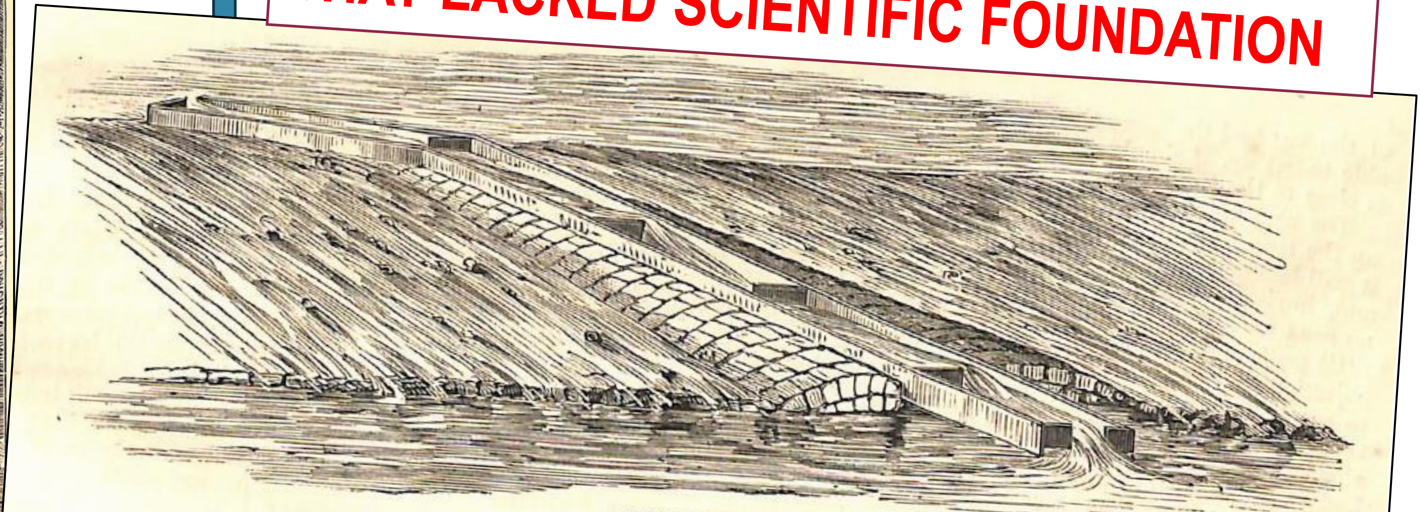
1852 Ballysadare River in Ireland

Salmon ladders by strategically blasting pools into the falls

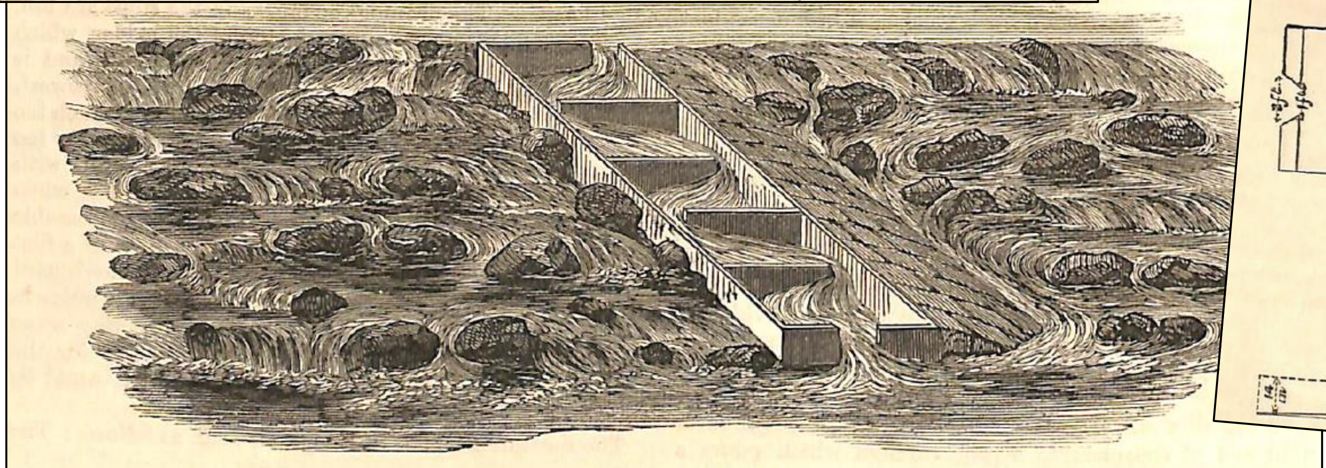
THE RESULT:
MANY DIFFERENT AND POORLY STANDARIZED FISH LADDER DESIGNS THAT LACKED SCIENTIFIC FOUNDATION



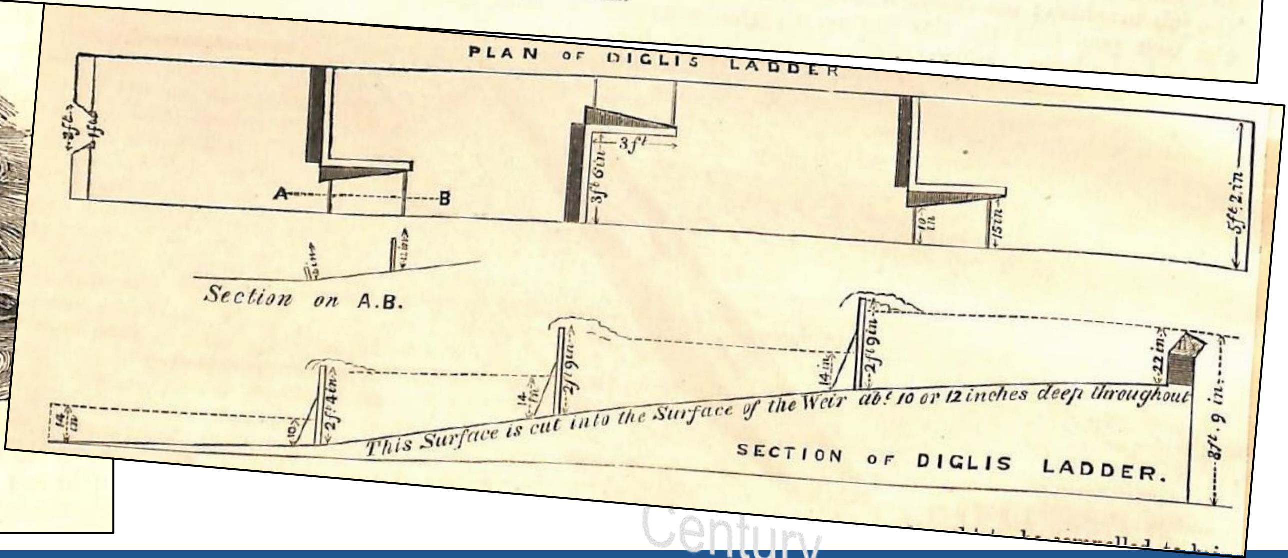
BRAAN WEIR AND FISH PASS.

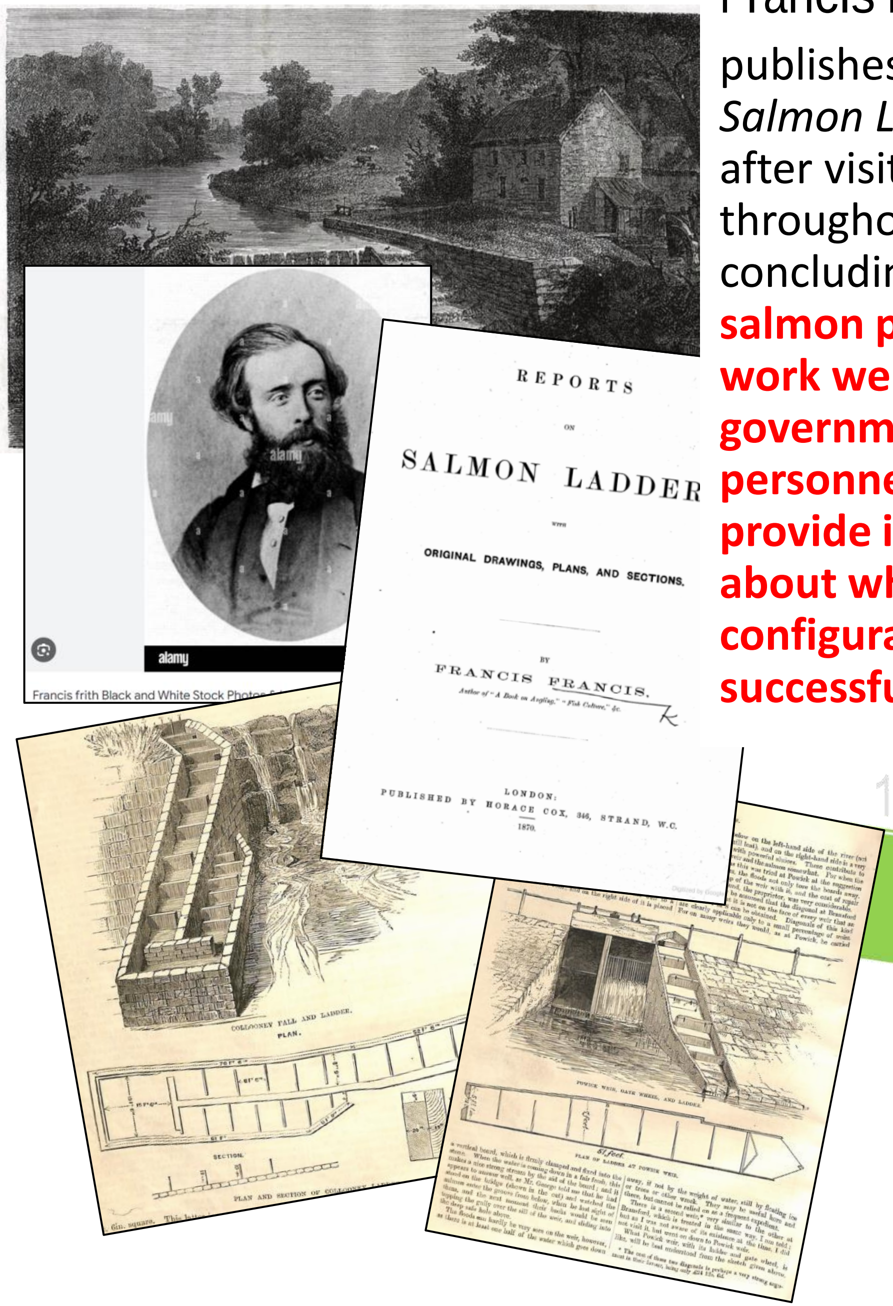


HOLT WEIR.



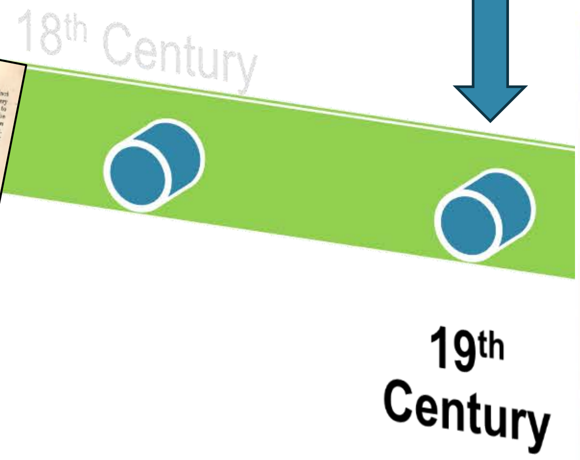
LINCOMBE WEIR.





Francis Francis

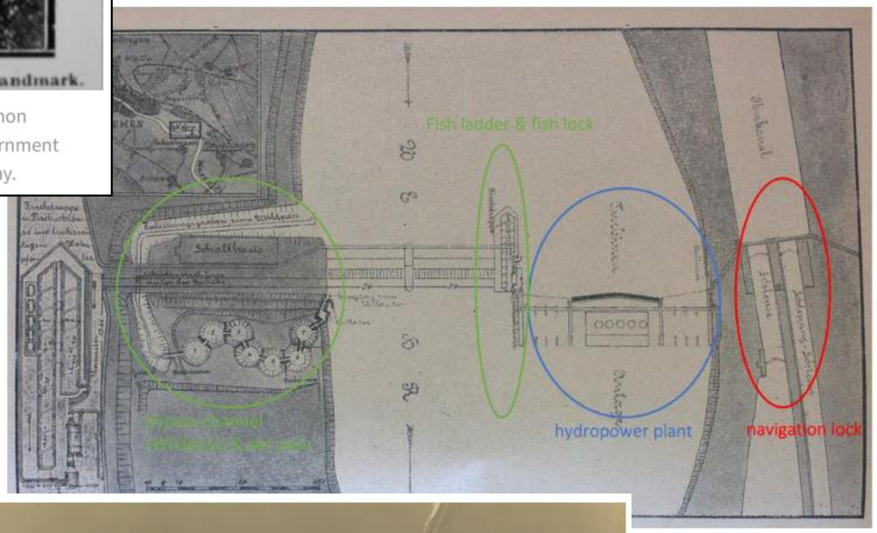
publishes *Reports on Salmon Ladders* (1870) after visiting sites throughout the UK and concluding that **most salmon passes did not work well because governmental fishery personnel did not provide information about what fishway configurations were successful at passing fish**



Portrait from an obituary for Anthon Landmark (1842–1932), the government inspector of fisheries from Norway.

Anthon Landmark

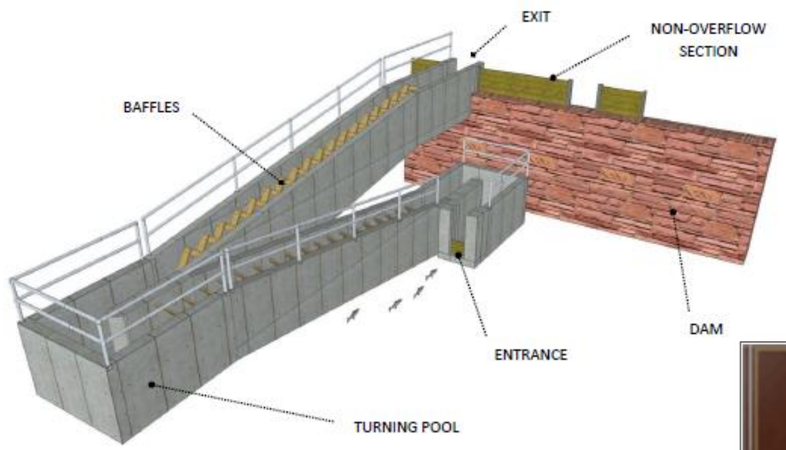
was Norway's most important fisheries inspector and played a crucial role in the improvements to salmon ladders at the turn of the 20th century

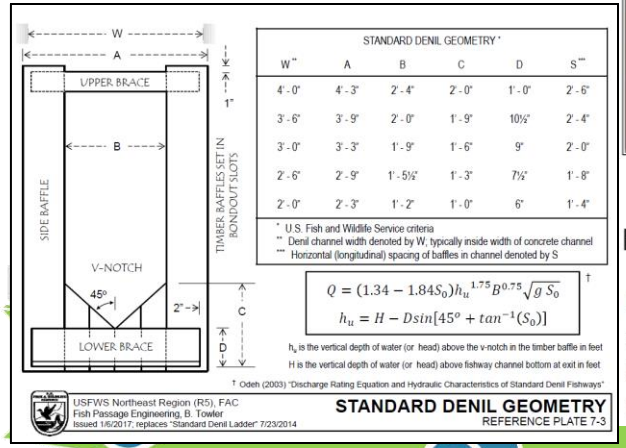


The bypass channel (*Wildpass*) at the Hemelinger Dam with its extensive and light-filled basins—a design that bears Landmark's signature.

Belgian scientist Gustave Denil

in 1909 publishes his findings on a novel chute-type fish passage structure designed to pass salmonids (i.e., the Denil Fishway)





STANDARD DENIL GEOMETRY *

W **	A	B	C	D	S ***
4' - 0"	4' - 3"	2' - 4"	2' - 0"	1' - 0"	2' - 6"
3' - 6"	3' - 9"	2' - 0"	1' - 9"	10½"	2' - 4"
3' - 0"	3' - 3"	1' - 9"	1' - 6"	9"	2' - 0"
2' - 6"	2' - 9"	1' - 5½"	1' - 3"	7½"	1' - 8"
2' - 0"	2' - 3"	1' - 2"	1' - 0"	6"	1' - 4"

* U.S. Fish and Wildlife Service criteria
** Denil channel width denoted by W; typically inside width of concrete channel
*** Horizontal (longitudinal) spacing of baffles in channel denoted by S

$$Q = (1.34 - 1.84S_0)h_u^{1.75}B^{0.75}\sqrt{g\,S_0}$$ †

$$h_u = H - D\sin[45^o + \tan^{-1}(S_0)]$$

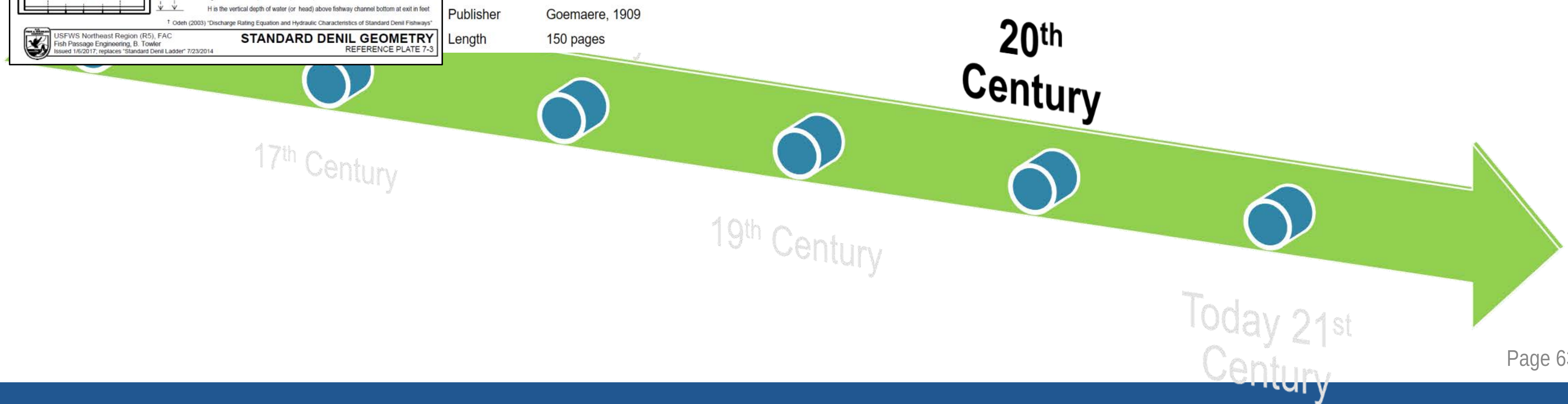
h_u is the vertical depth of water (or head) above the v-notch in the timber baffle in feet
H is the vertical depth of water (or head) above fishway channel bottom at exit in feet

† Odeh (2003) "Discharge Rating Equation and Hydraulic Characteristics of Standard Denil Fishways"

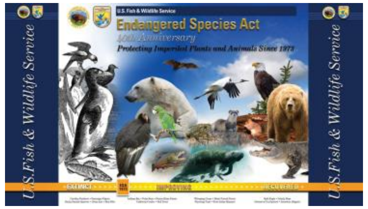
G. Denil
Goemaere, 1909 - 150 pages

Bibliographic information

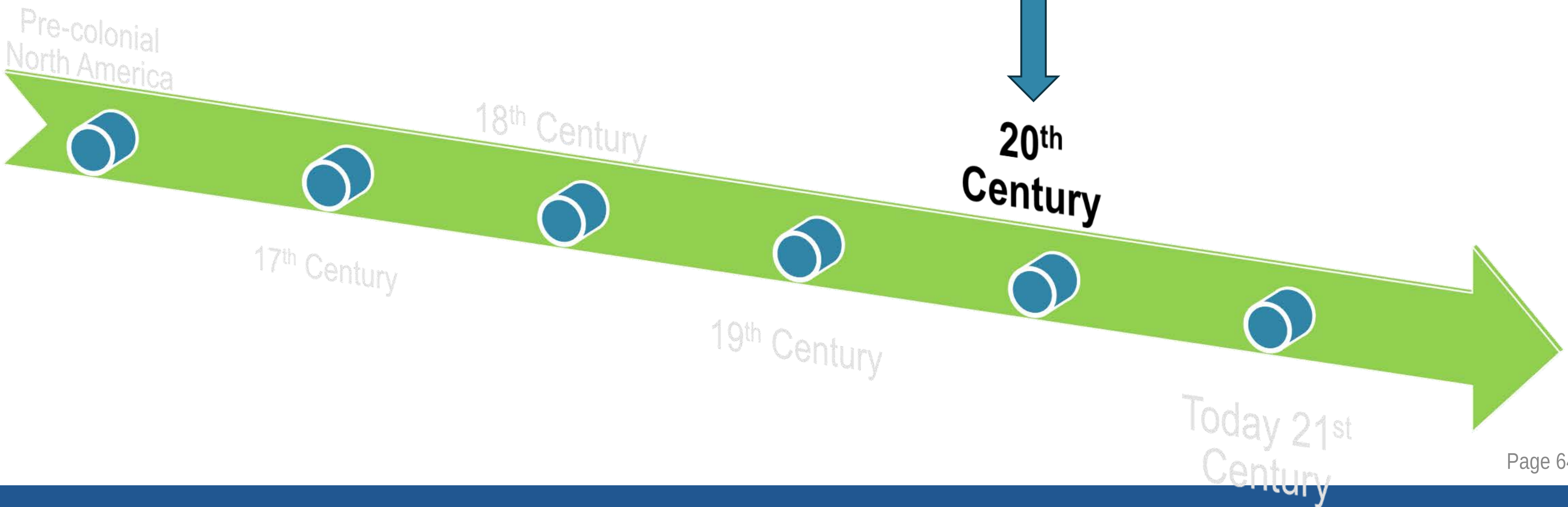
Title	Les échelles à poissons et leur application aux barrages de Meuse et d'Ourthe
Author	G. Denil
Publisher	Goemaere, 1909
Length	150 pages



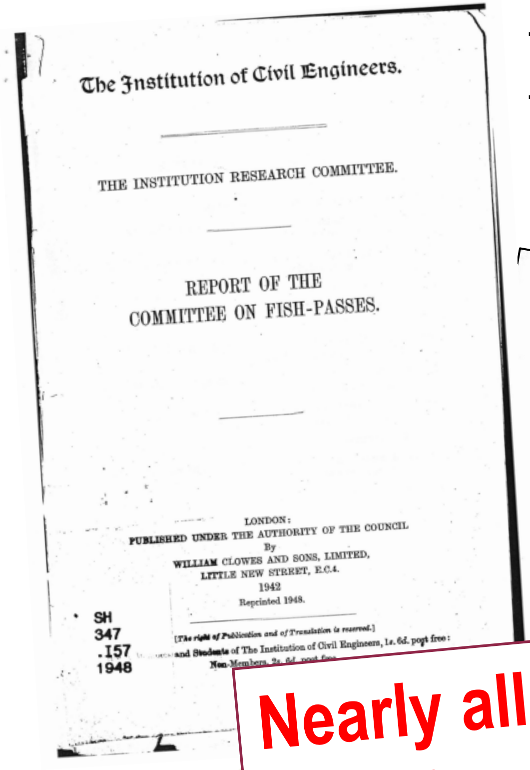
In the U.S.A.



- The Federal Power Act (1920)
- The Anadromous Fish Conservation Act (1965)
- The Endangered Species Act (1973)
- The Northwest Electric Power and Planning Act (1981)



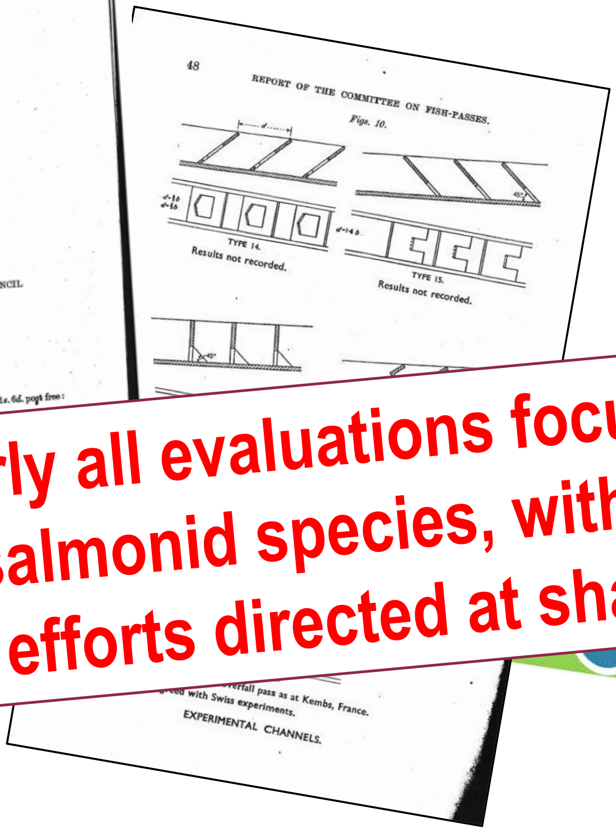
Beginning in the 1940s, Europe and North America experienced a boom in field and laboratory testing of available fishway designs (e.g., 1942 *Report of the Committee of Fish- passes)*


The Institution of Civil Engineers.

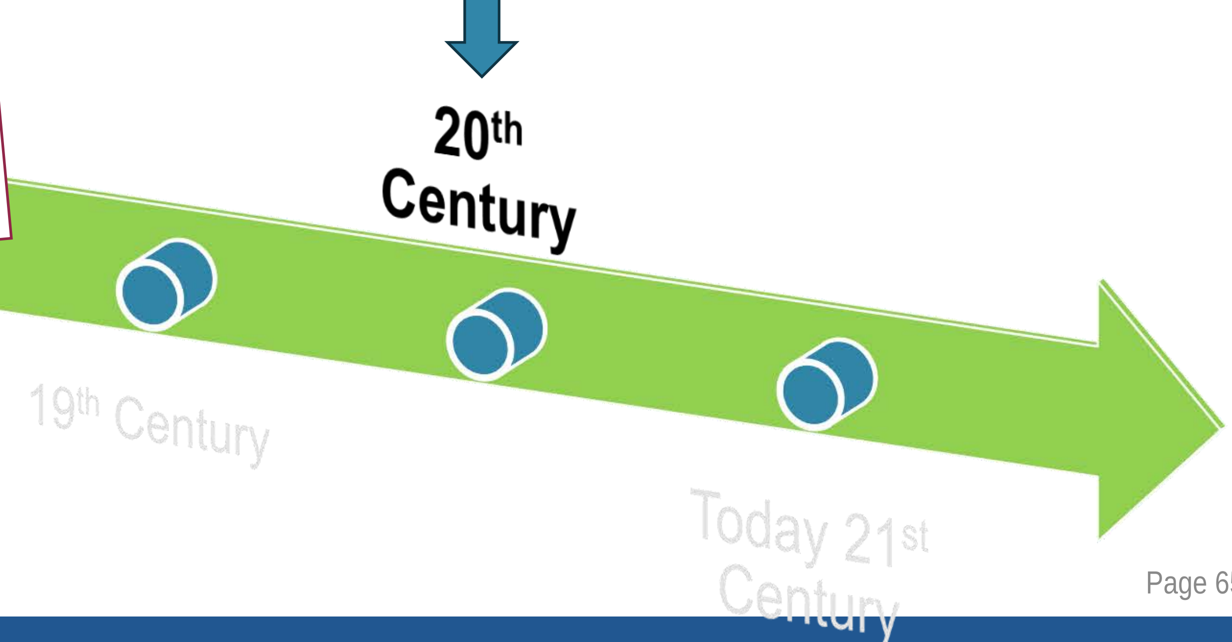
THE INSTITUTION RESEARCH COMMITTEE.

REPORT OF THE
COMMITTEE ON FISH-PASSES.

LONDON:
PUBLISHED UNDER THE AUTHORITY OF THE COUNCIL
By
WILLIAM CLOWES AND SONS, LIMITED,
LITTLE NEW STREET, E.C.4.
1942
Reprinted 1948.

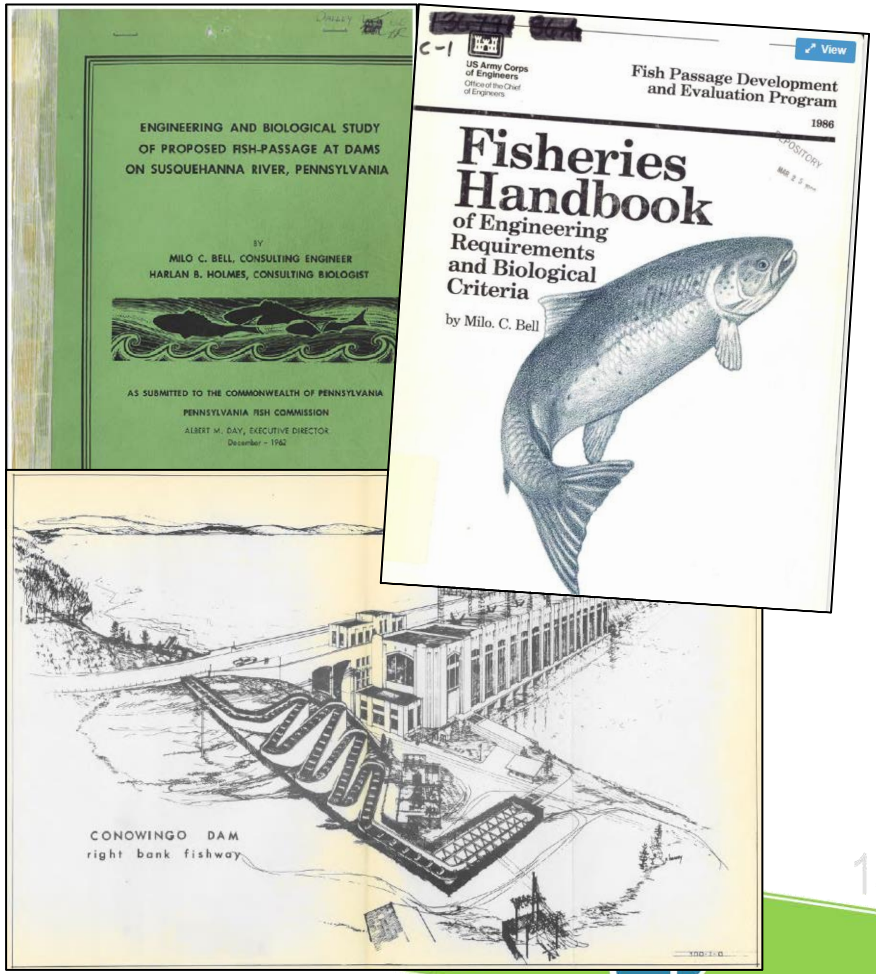


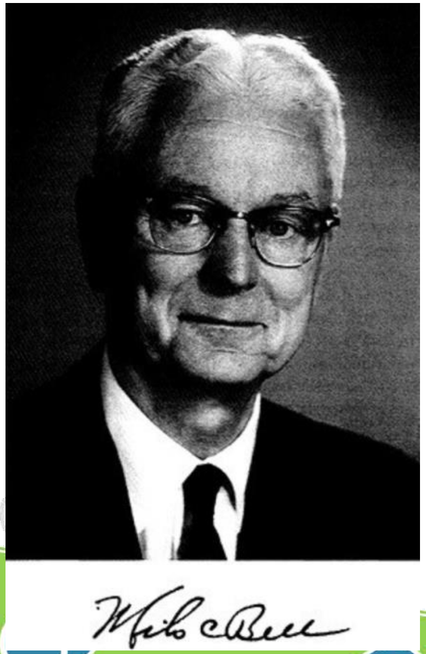
Nearly all evaluations focused on salmonid species, with a few efforts directed at shad

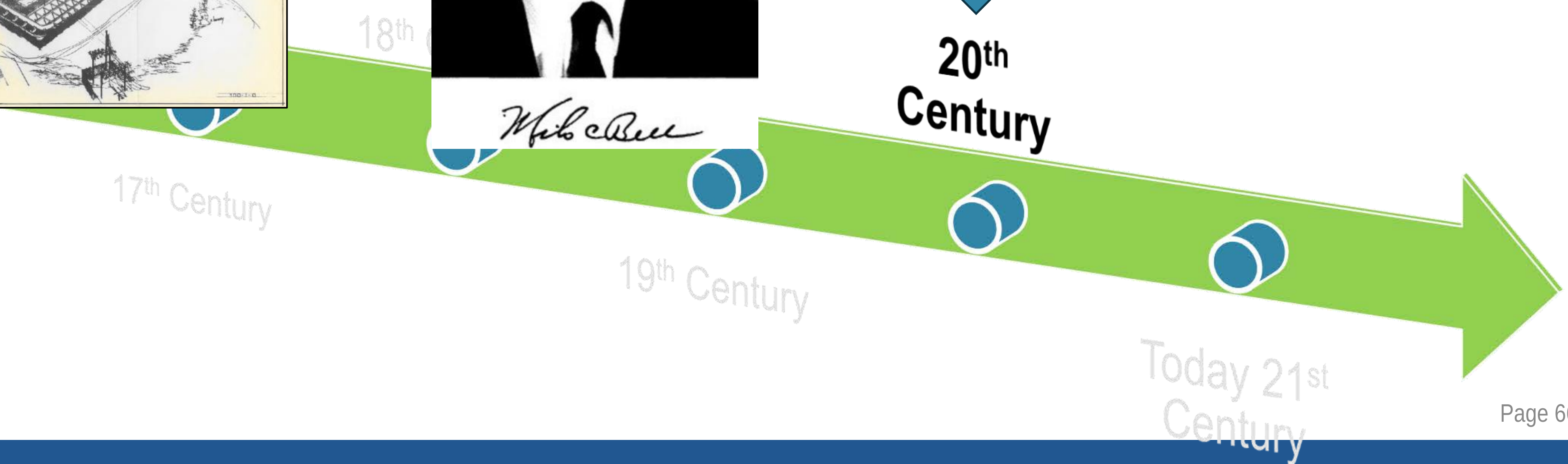


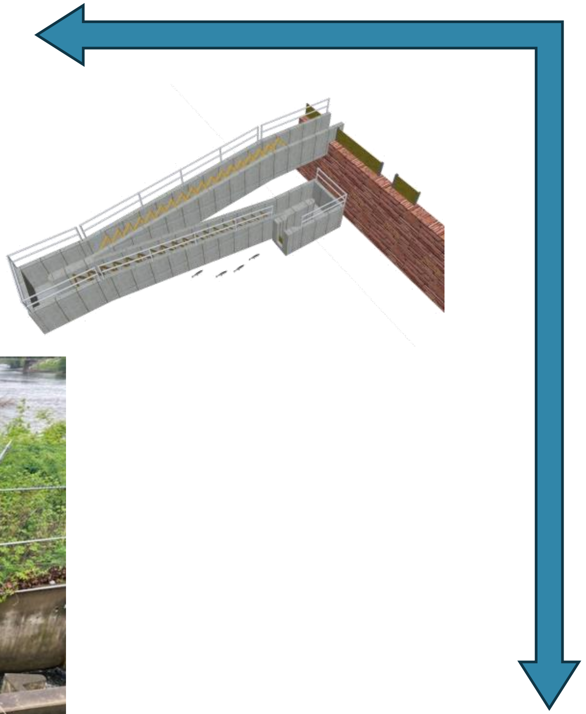
Mechanical engineer Milo C. Bell

from 1949 to 1992 acted as a consultant to the USACE on fish passage solutions at various dams in the Columbia River. In 1986 published his *Fisheries Handbook*

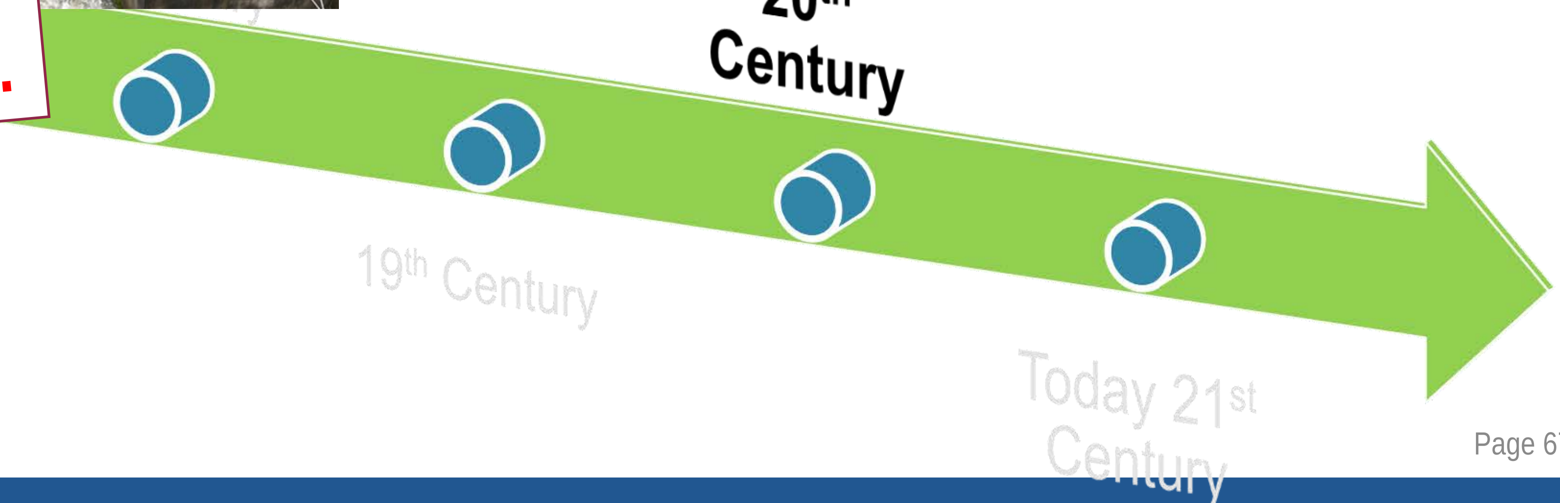




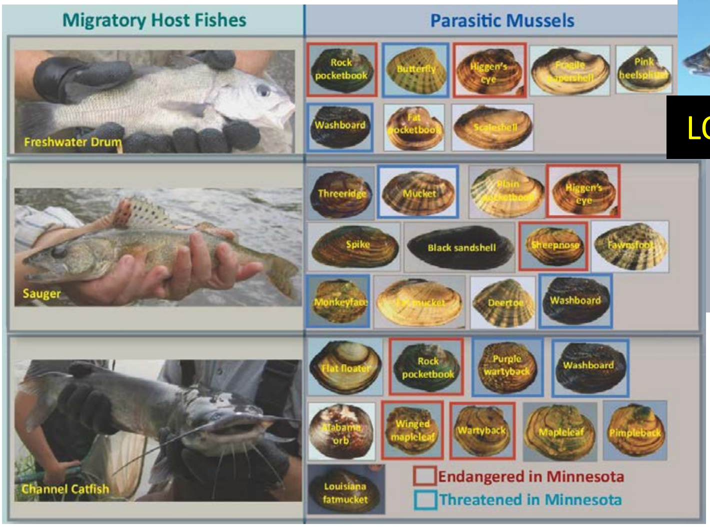


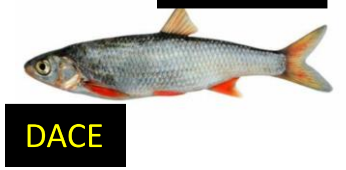


The 20th century saw a proliferation of technical fishways across the U.S.



POTAMODROMOUS SPECIES

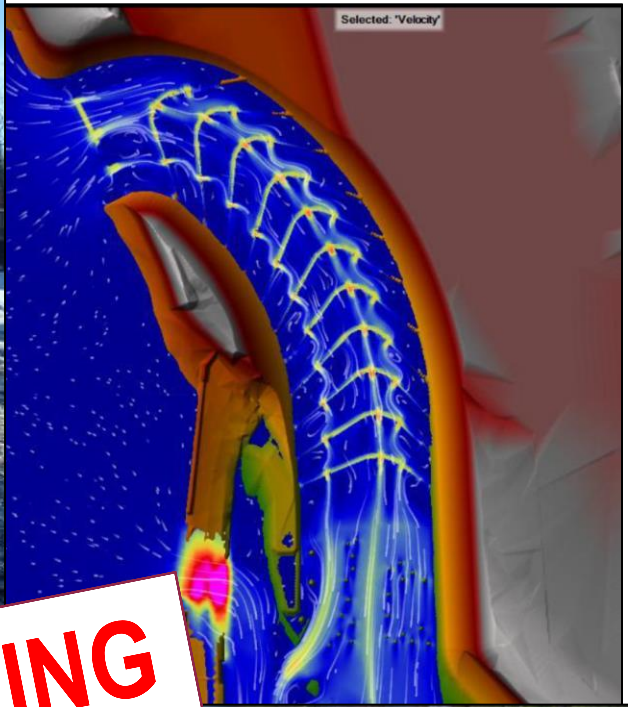




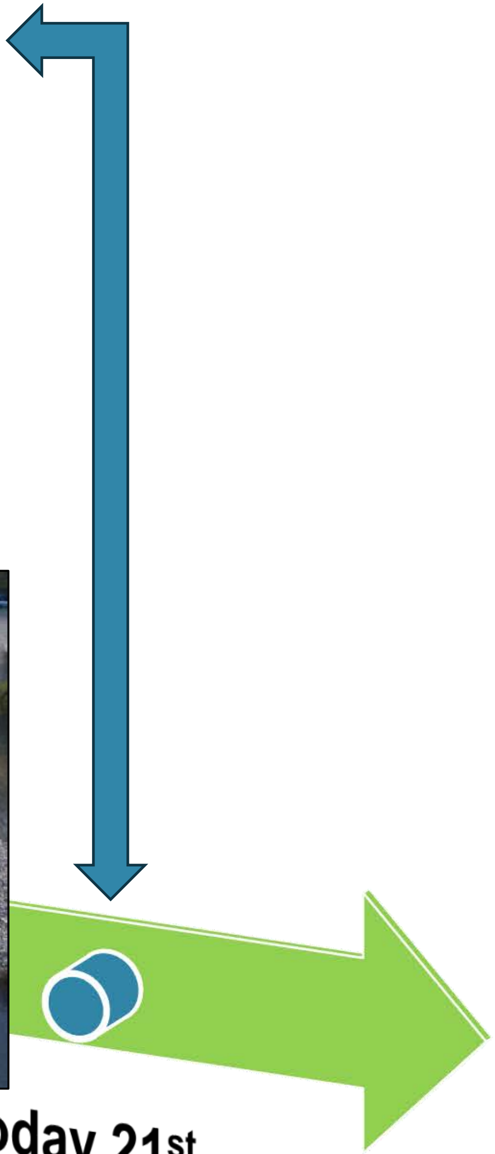
AMPHIDRAMOUS SPECIES

NEWFOUND ATTENTION ON SMALL-BODIED, FRESHWATER "RIVERINE" FISH SPECIES


R&D
NEW ERA OF R&D!
Control Panel
Screened Y Valve
Eel Ramp
Entrance Pinch Valve
Chamber
Exit Pinch Valve
Pre-colonial North America
17th Century
18th Century
19th Century
20th Century
Today 21st Century

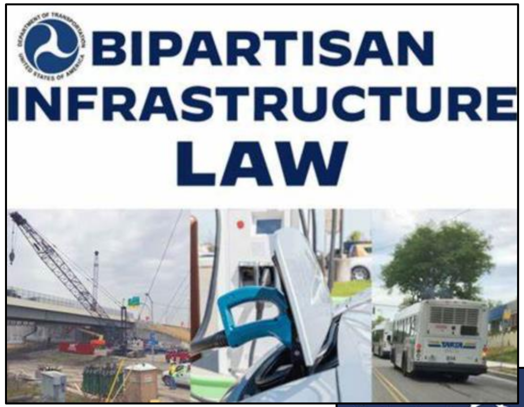


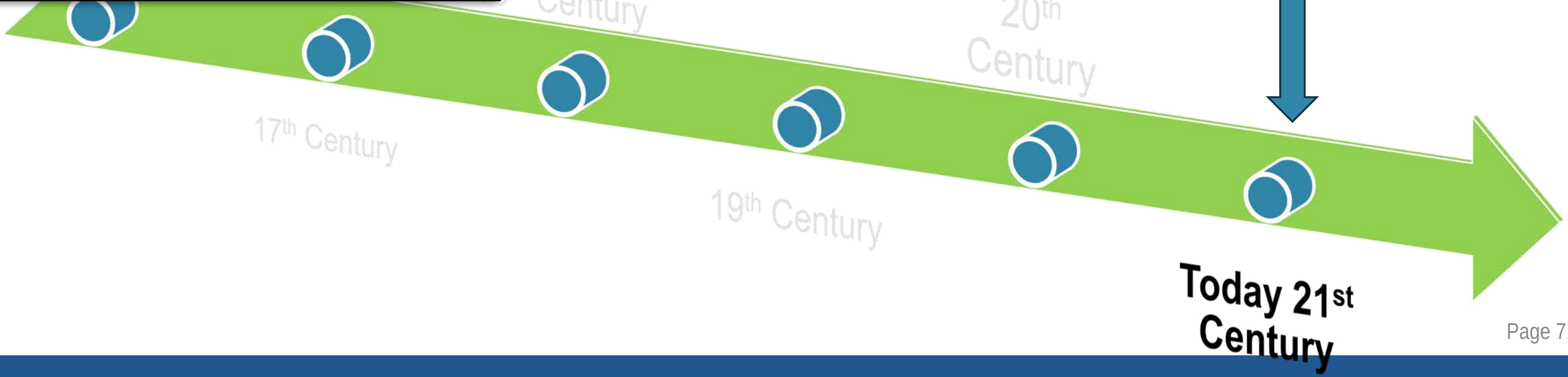
NLFs ARE MAKING A COMEBACK!



Today 21st Century

ONCE IN A LIFETIME OPPORTUNITY!





04

HISTORICAL AND AVAILABLE DESIGN GUIDELINES

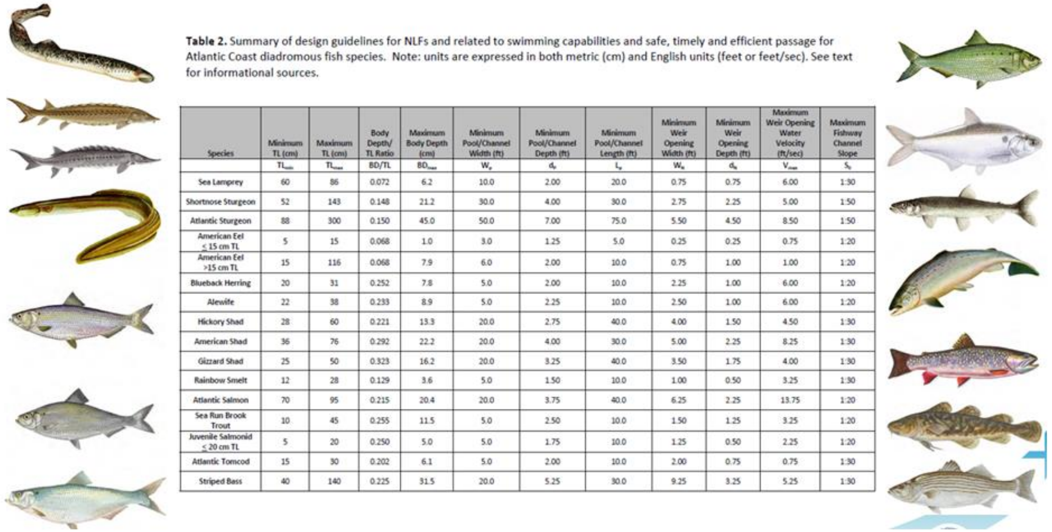
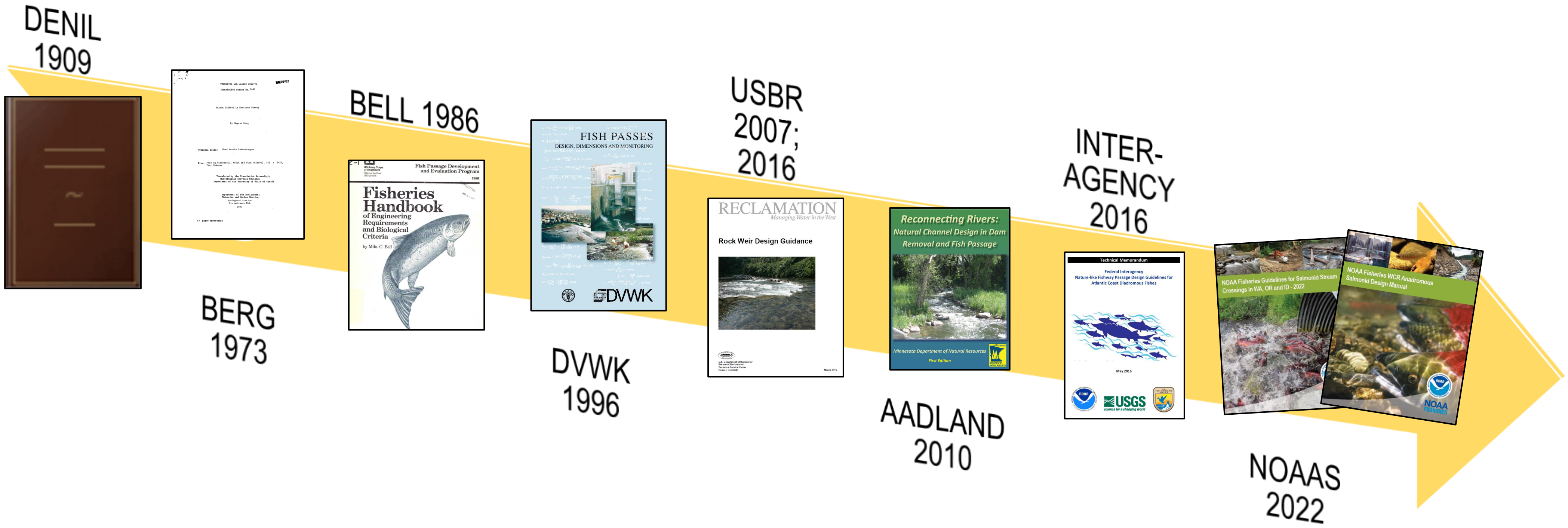


Table 2. Summary of design guidelines for NLFs and related to swimming capabilities and safe, timely and efficient passage for Atlantic Coast diadromous fish species. Note: units are expressed in both metric (cm) and English units (feet or feet/sec). See text for informational sources.

Species	Minimum TL (cm)	Maximum TL (cm)	Body Depth/ TL Ratio	Maximum Body Depth (cm)	Minimum Pool/Channel Width (ft)	Minimum Pool/Channel Depth (ft)	Minimum Pool/Channel Length (ft)	Minimum Weir Opening Width (ft)	Minimum Weir Opening Depth (ft)	Maximum Weir Opening Water Velocity (ft/sec)	Maximum Fishway Channel Slope
	TL_{min}	TL_{max}	BD/TL	BD_{max}	W_p	d_p	L_p	W_w	d_w	V_{max}	S_o
Sea Lamprey	60	86	0.072	6.2	10.0	2.00	20.0	0.75	0.75	6.00	1:30
Shortnose Sturgeon	52	143	0.148	21.2	30.0	4.00	30.0	2.75	2.25	5.00	1:50
Atlantic Sturgeon	88	300	0.150	45.0	50.0	7.00	75.0	5.50	4.50	8.50	1:50
American Eel ≤ 15 cm TL	5	15	0.068	1.0	3.0	1.25	5.0	0.25	0.25	0.75	1:20
American Eel >15 cm TL	15	116	0.068	7.9	6.0	2.00	10.0	0.75	1.00	1.00	1:20
Blueback Herring	20	31	0.252	7.8	5.0	2.00	10.0	2.25	1.00	6.00	1:20
Alewife	22	38	0.233	8.9	5.0	2.25	10.0	2.50	1.00	6.00	1:20
Hickory Shad	28	60	0.221	13.3	20.0	2.75	40.0	4.00	1.50	4.50	1:30
American Shad	36	76	0.292	22.2	20.0	4.00	30.0	5.00	2.25	8.25	1:30
Gizzard Shad	25	50	0.323	16.2	20.0	3.25	40.0	3.50	1.75	4.00	1:30
Rainbow Smelt	12	28	0.129	3.6	5.0	1.50	10.0	1.00	0.50	3.25	1:30
Atlantic Salmon	70	95	0.215	20.4	20.0	3.75	40.0	6.25	2.25	13.75	1:20
Sea Run Brook Trout	10	45	0.255	11.5	5.0	2.50	10.0	1.50	1.25	3.25	1:20
Juvenile Salmonid ≤ 20 cm TL	5	20	0.250	5.0	5.0	1.75	10.0	1.25	0.50	2.25	1:20
Atlantic Tomcod	15	30	0.202	6.1	5.0	2.00	10.0	2.00	0.75	0.75	1:30
Striped Bass	40	140	0.225	31.5	20.0	5.25	30.0	9.25	3.25	5.25	1:30

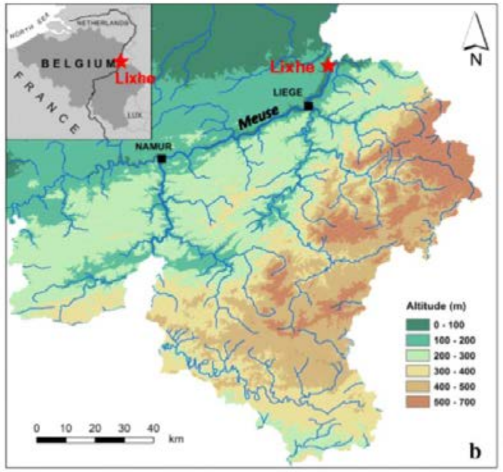
- Early Fish Passage Design Guidance
- Published NLF Design Guidelines
- Importance of the “research loop”

FISH PASSAGE DESIGN GUIDELINES

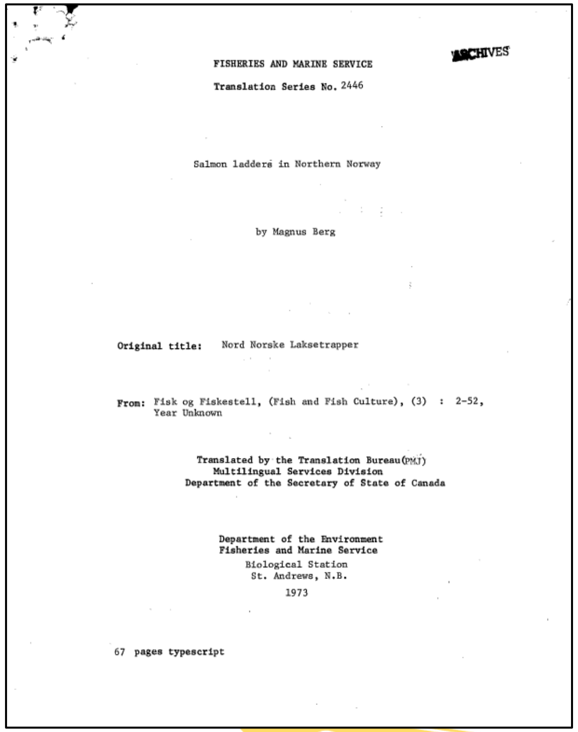


FISH PASSAGE DESIGN GUIDELINES

In 1909 Belgian scientist Gustave Denil published the book *Fish Ladders and Their Application to the Meuse and Ourthe Dams* in the Meuse River in Belgium



FISH PASSAGE DESIGN GUIDELINES


FISHERIES AND MARINE SERVICE
Translation Series No. 2446

ARCHIVES

Salmon ladders in Northern Norway

by Magnus Berg

Original title: Nord Norske Laksetrapper

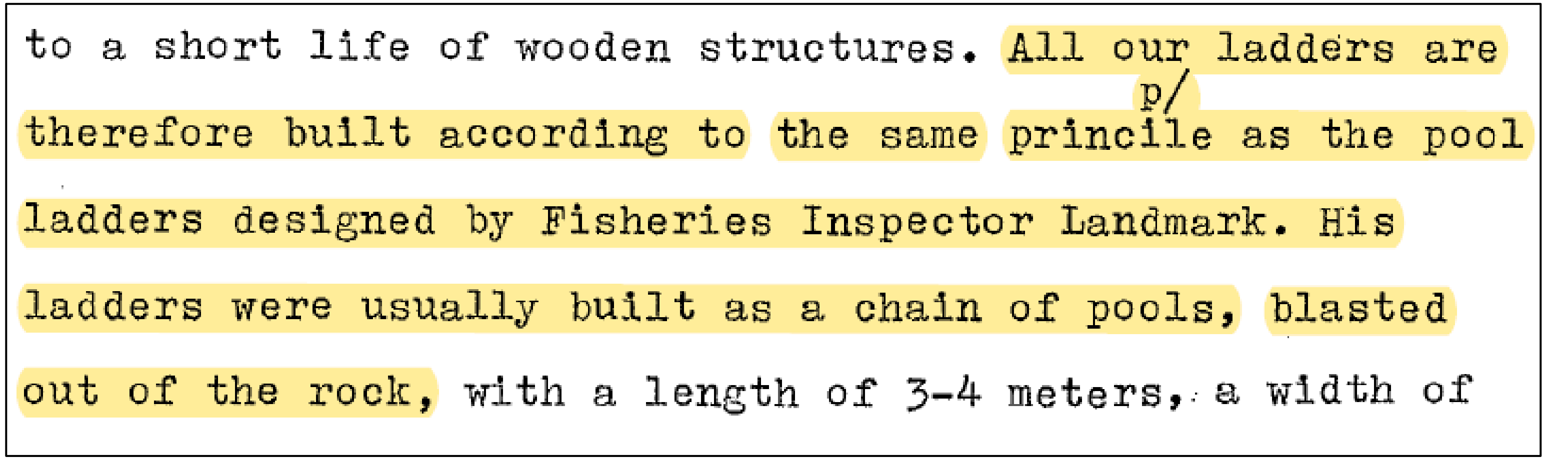
From: Fisk og Fiskestell, (Fish and Fish Culture), (3) : 2-52,
Year Unknown

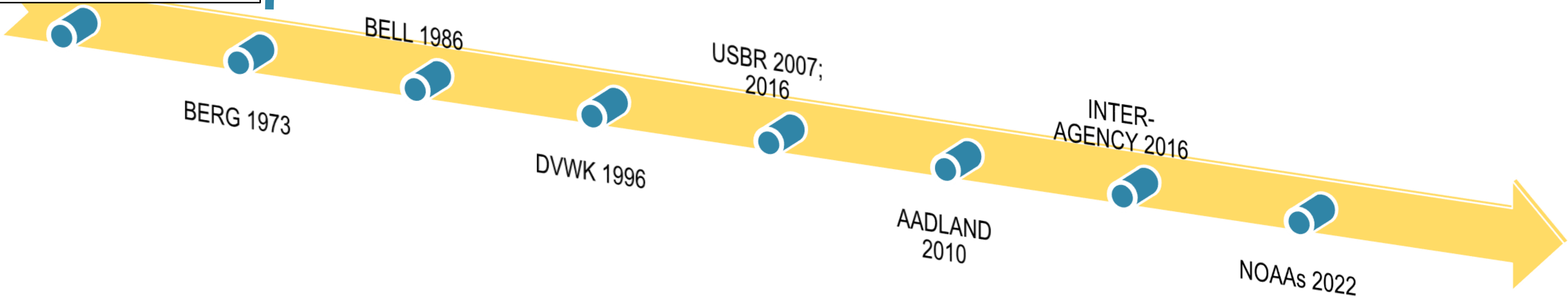
Translated by the Translation Bureau (PMJ)
Multilingual Services Division
Department of the Secretary of State of Canada

Department of the Environment
Fisheries and Marine Service
Biological Station
St. Andrews, N.B.
1973

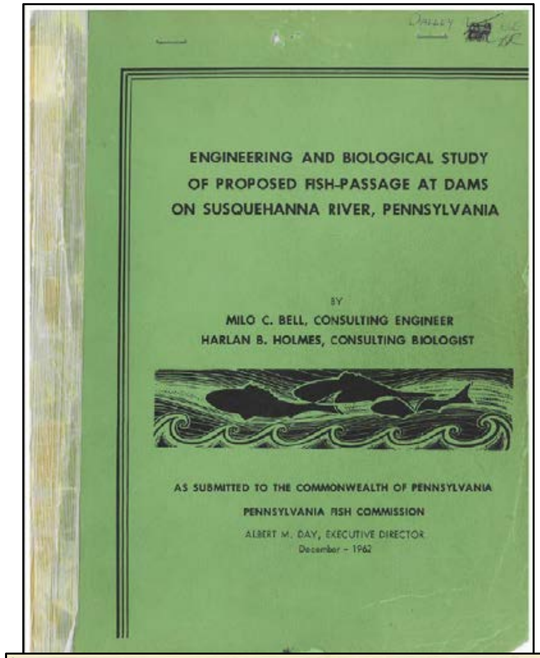
67 pages typescript

In 1973 the Norwegian Magnus Berg published his own report on salmon ladders in northern Norway

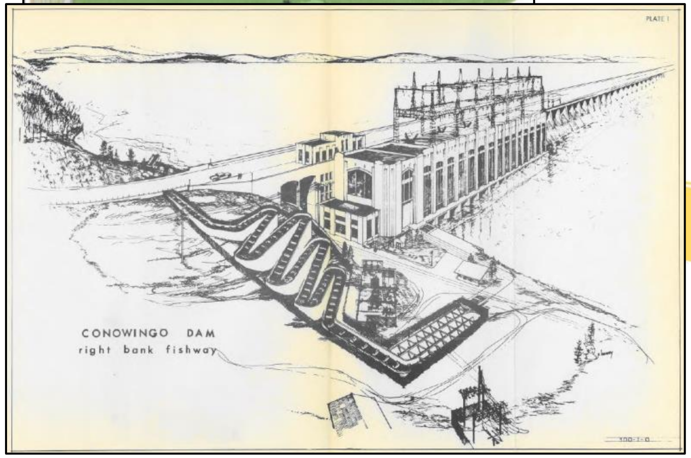

to a short life of wooden structures. All our ladders are therefore built according to the same princile as the pool ladders designed by Fisheries Inspector Landmark. His ladders were usually built as a chain of pools, blasted out of the rock, with a length of 3-4 meters, a width of



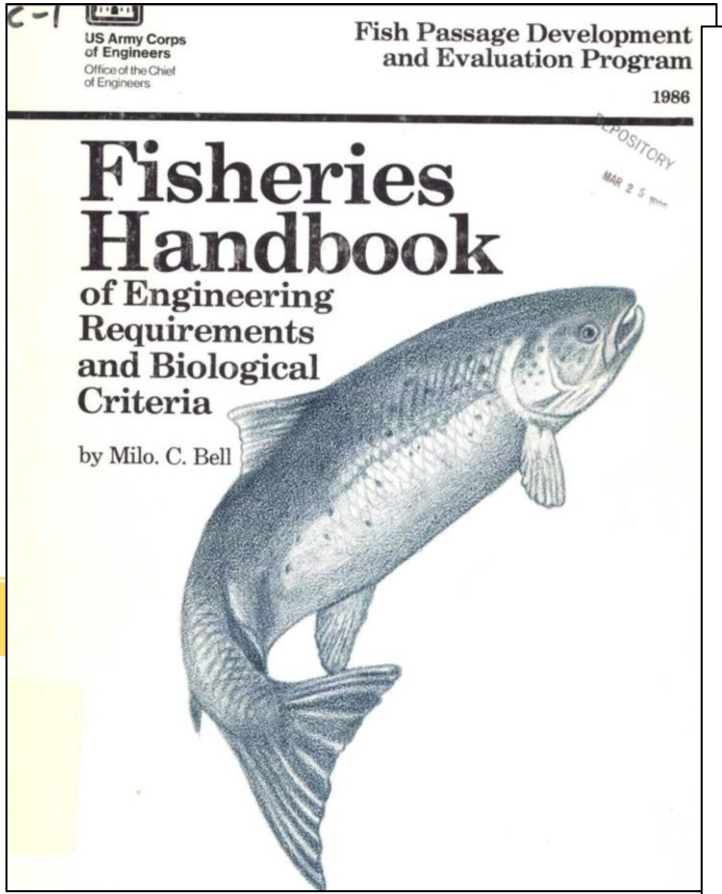
FISH PASSAGE DESIGN GUIDELINES

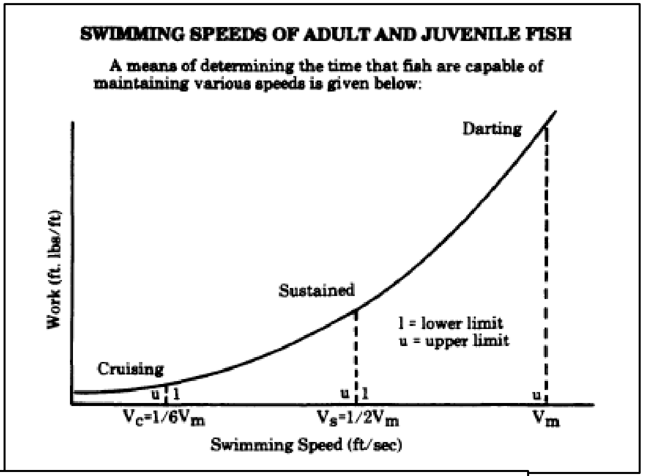


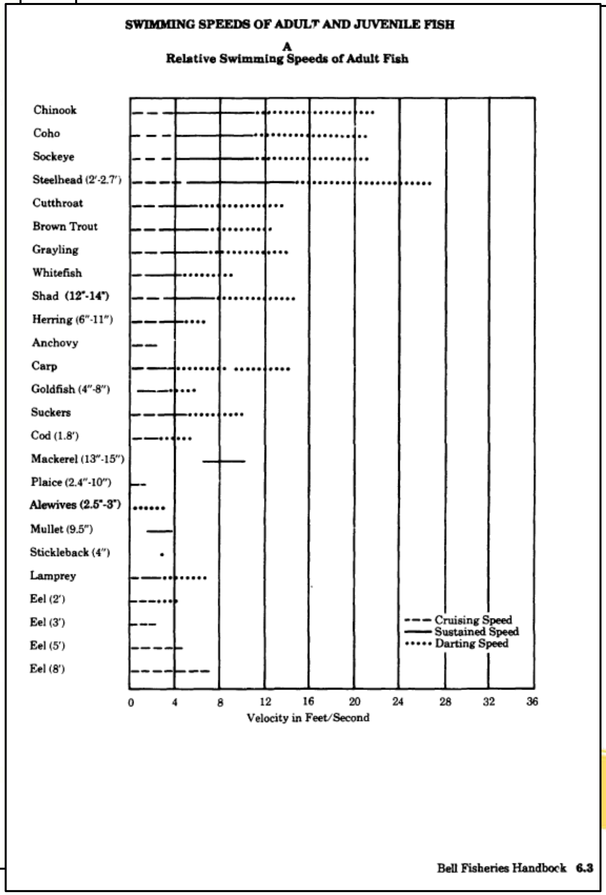
Mechanical engineer Milo C. Bell is renown for his **six decades of work, starting in the 1930's, to** restore and protect the salmon migratory runs along the Pacific Coast of North America, specifically in the Columbia River



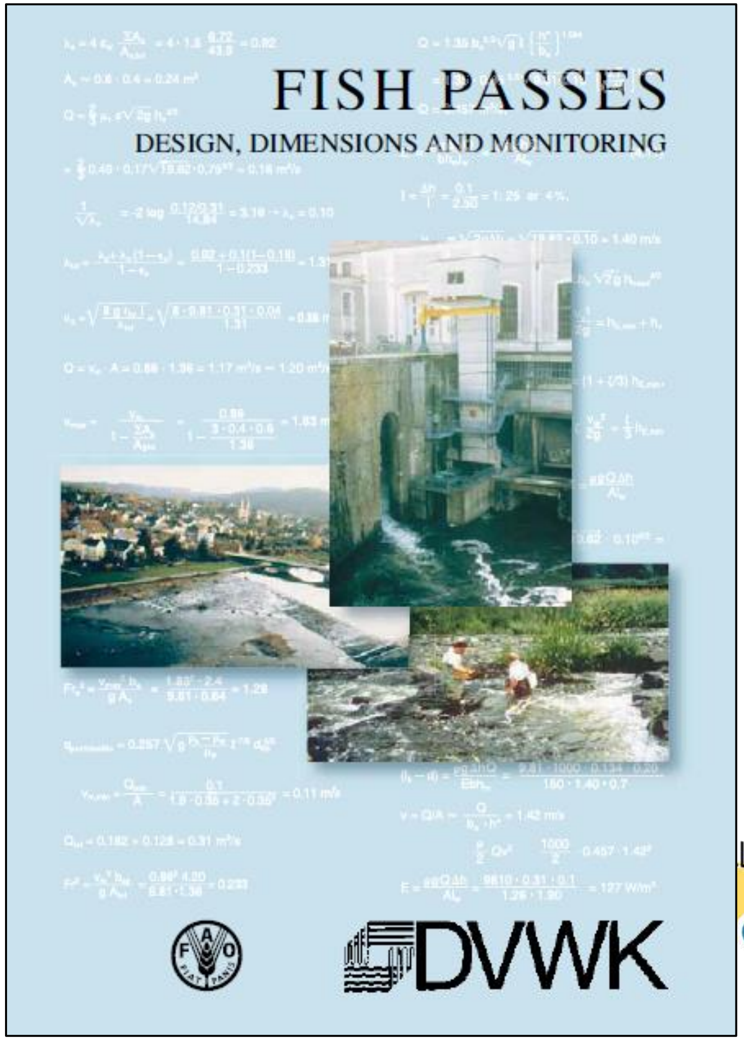
BELL 1986



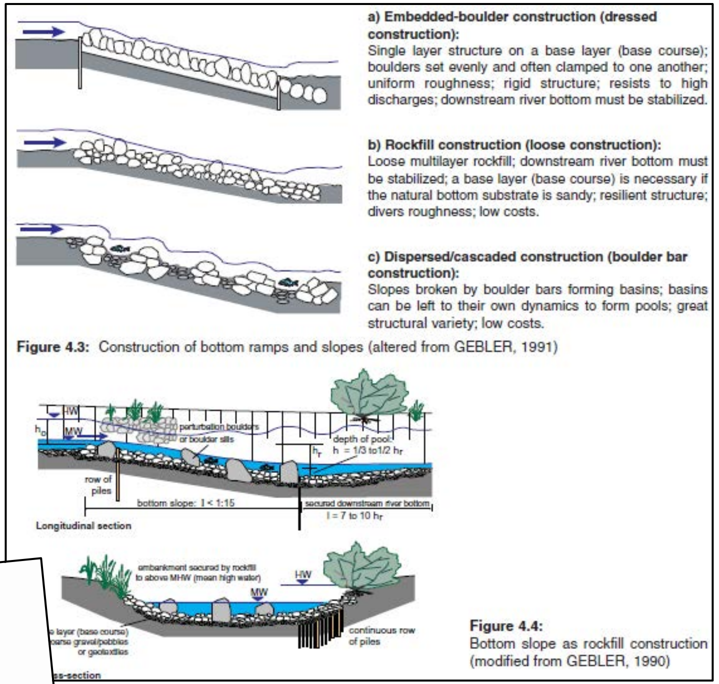




FISH PASSAGE DESIGN GUIDELINES



This 1996 *Fish Passes: Design, Dimensions and Monitoring* document is a comprehensive design manual for designing, constructing and monitoring fish passage facilities. The document refers to NLFs as **“close**-to-**nature types of fish passes”.**



a) Embedded-boulder construction (dressed construction):
Single layer structure on a base layer (base course); boulders set evenly and often clamped to one another; uniform roughness; rigid structure; resists to high discharges; downstream river bottom must be stabilized.

b) Rockfill construction (loose construction):
Loose multilayer rockfill; downstream river bottom must be stabilized; a base layer (base course) is necessary if the natural bottom substrate is sandy; resilient structure; divers roughness; low costs.

c) Dispersed/cascaded construction (boulder bar construction):
Slopes broken by boulder bars forming basins; basins can be left to their own dynamics to form pools; great structural variety; low costs.

Figure 4.3: Construction of bottom ramps and slopes (altered from GEBLER, 1991)

Figure 4.4: Bottom slope as rockfill construction (modified from GEBLER, 1990)

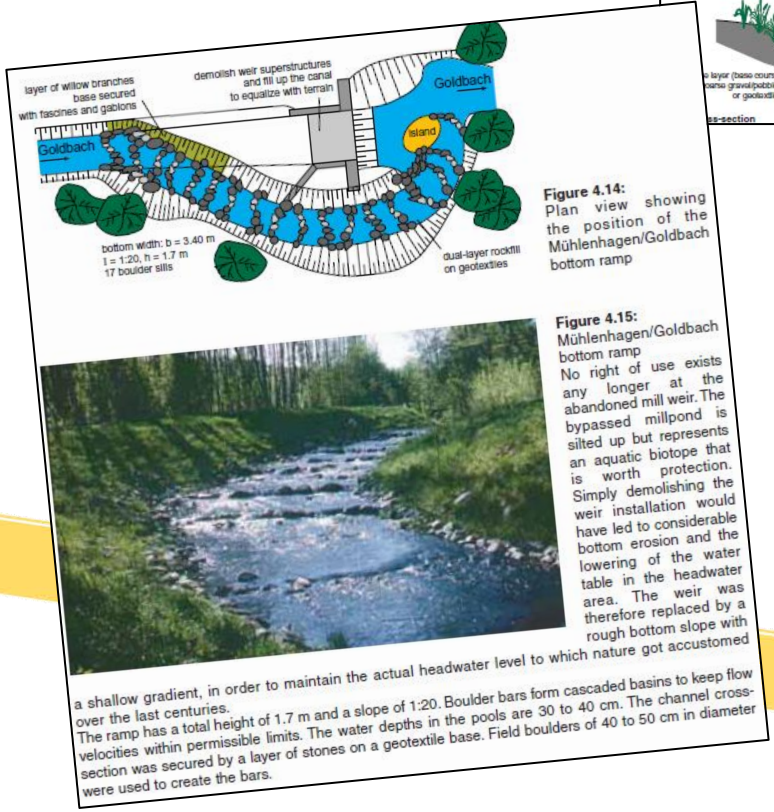
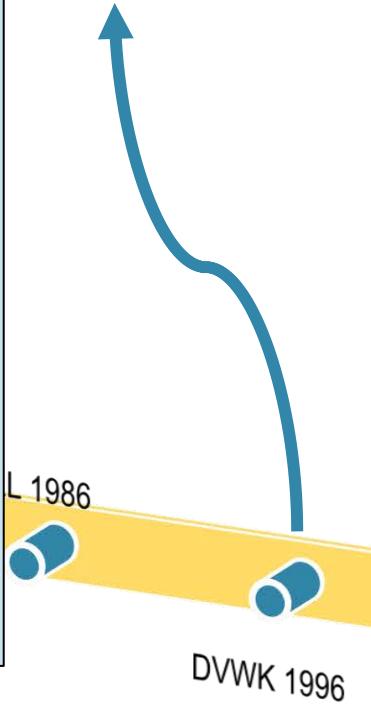


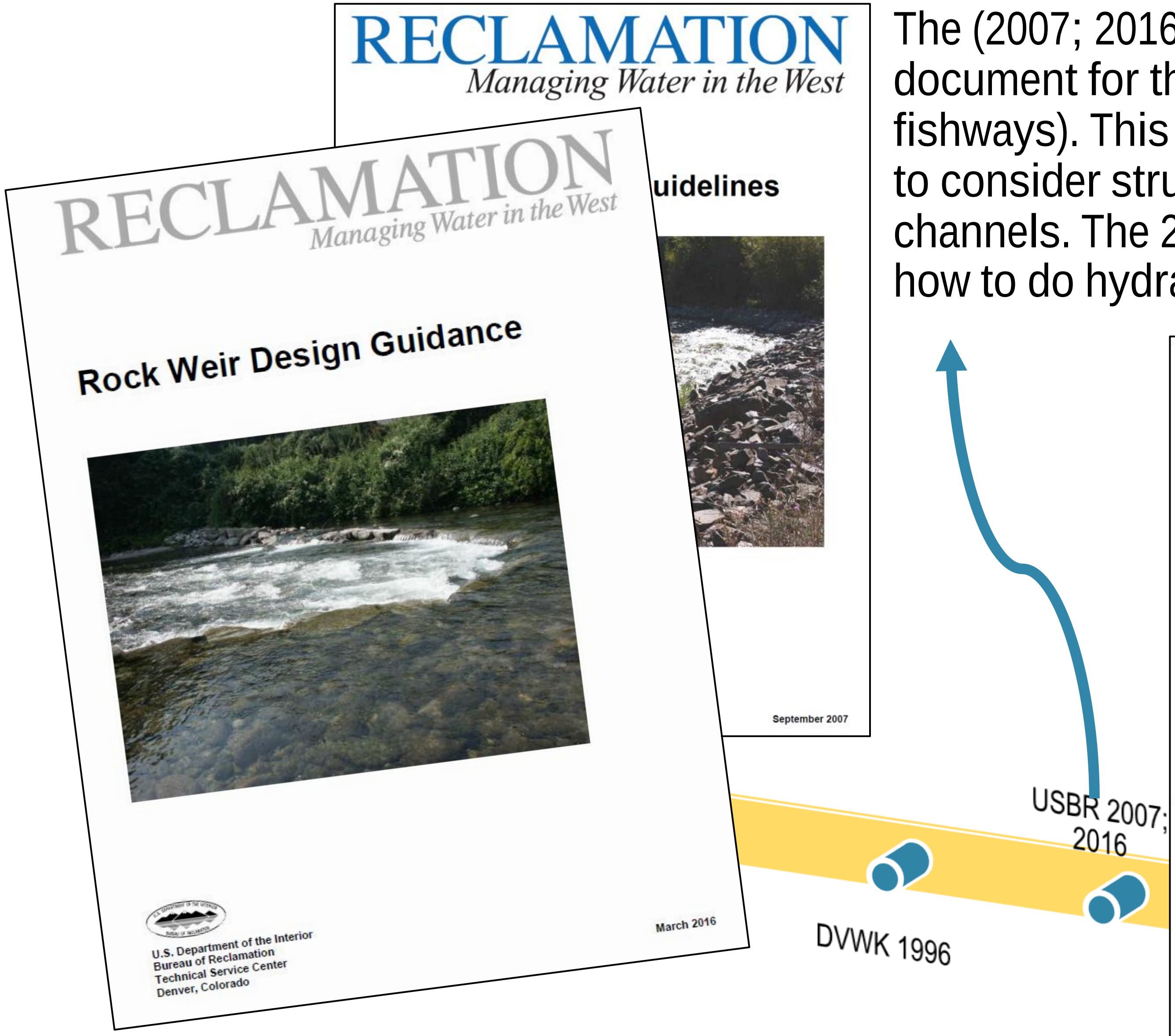
Figure 4.14: Plan view showing the position of the Mühlenhagen/Goldbach bottom ramp

Figure 4.15: Mühlenhagen/Goldbach bottom ramp
No right of use exists any longer at the abandoned mill weir. The bypassed millpond is silted up but represents an aquatic biotope that is worth protection. Simply demolishing the weir installation would have led to considerable bottom erosion and the lowering of the water table in the headwater area. The weir was therefore replaced by a rough bottom slope with a shallow gradient, in order to maintain the actual headwater level to which nature got accustomed over the last centuries.

The ramp has a total height of 1.7 m and a slope of 1:20. Boulder bars form cascaded basins to keep flow velocities within permissible limits. The water depths in the pools are 30 to 40 cm. The channel cross-section was secured by a layer of stones on a geotextile base. Field boulders of 40 to 50 cm in diameter were used to create the bars.



FISH PASSAGE DESIGN GUIDELINES



The (2007; 2016) *USBR Rock Ramp Design Guidelines* is a guidance document for the design of constructed channels (a.k.a., nature-like fishways). This document provides comprehensive guidance on how to consider structural stability in the design process of constructed channels. The 2016 revised version added substantial information on how to do hydraulic modeling in a design of NLFs.

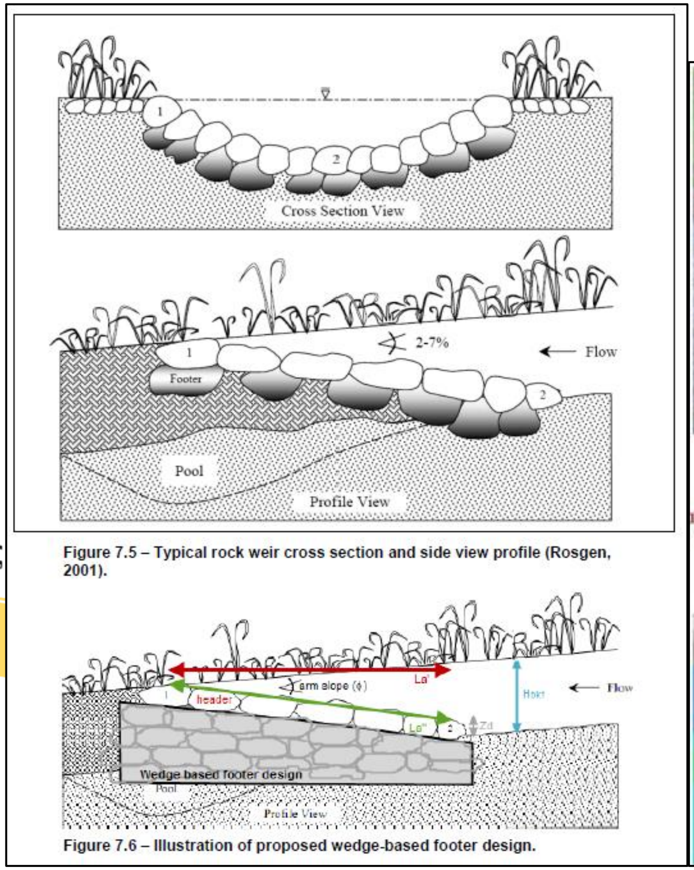
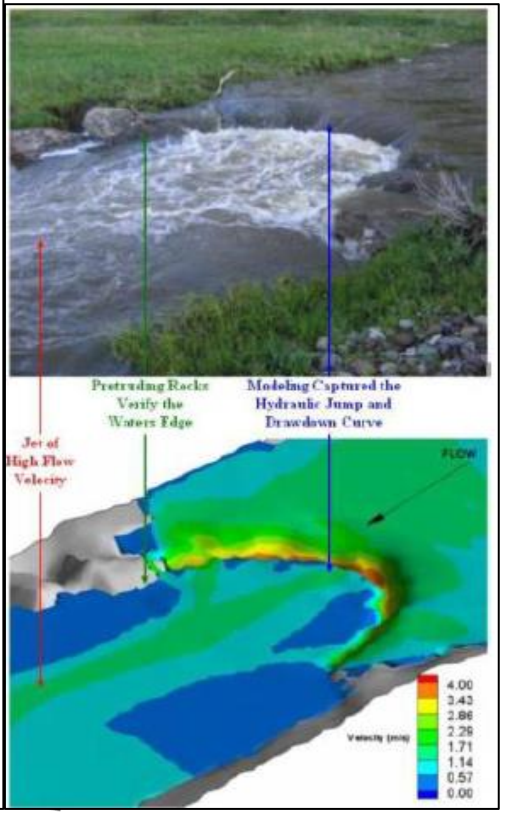
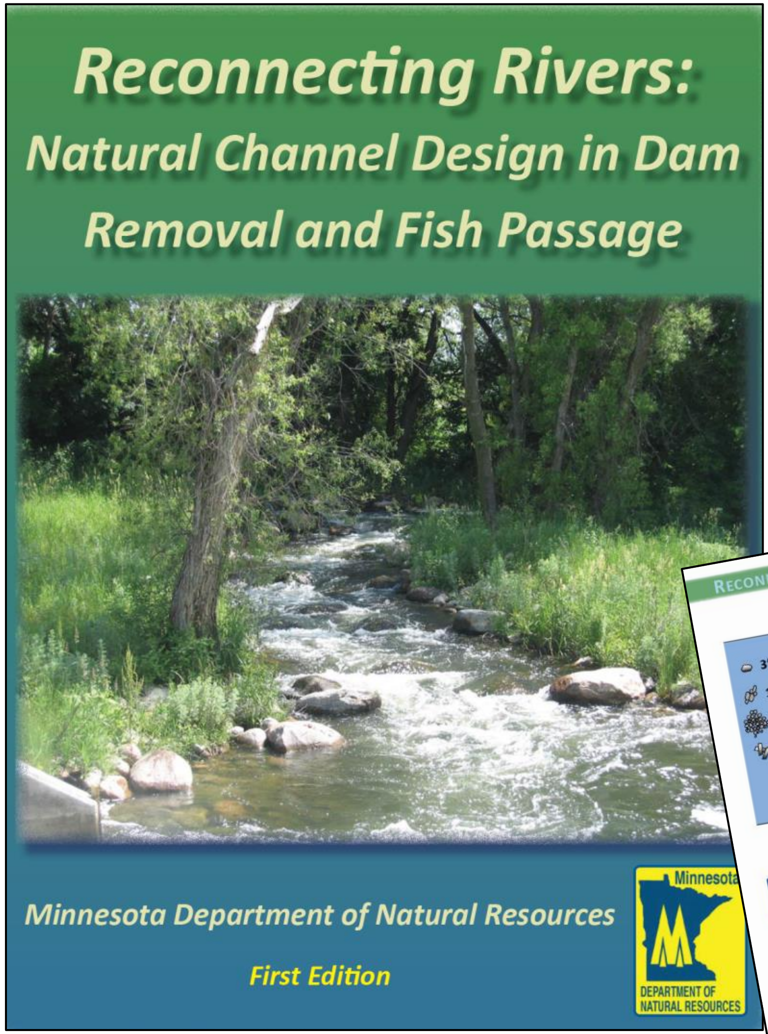


Figure 7.5 – Typical rock weir cross section and side view profile (Rosgen, 2001).

Figure 7.6 – Illustration of proposed wedge-based footer design.



FISH PASSAGE DESIGN GUIDELINES



In 2010 Dr. Luther Aadland published a seminal design guideline for the constructions of NLFs titled *Reconnecting Rivers: Natural Channel Design in Dam Removal and Fish Passage*. Split into two chapters, Aadland differentiates between full stream restoration through dam removal versus the installation of nature-like fishways. In contrast with the USBR 2007, Aadland 2010 spends less time in design specifications for the structural stability of the ramp, and calls attention towards the ecological lift and fish passage considerations that a design team needs to take when building a nature-like fishway. The document also offers a list of case studies and their actual project costs.


RECONNECTING RIVERS

Figure 54. Generalized conceptual design of the Rock Arch Rapids developed by the author.

slope is reduced to overall river slope during larger flood events. High dams that do not submerge have maximum shear stress during record events requiring larger stone or reduced slope.

Two approaches have been used for sizing stone in the base of the rapids. Rapids designed using both techniques have endured numerous floods without apparent movement of stones. The Army Corps of Engineers (ACOE 1991) unit discharge technique is:

$D_{30} = 1.95\, s^{0.555} q^{0.667} / g^{0.333}$ and $D_{50} = D_{30} * 1.22$

where s = slope, q = unit discharge (cfs/ft), and g = gravitational constant (32.174 ft/s²)

Engineers Manual EM 1110-2-1601 that gives this equation recommends use of angular stone or 25% larger diameters for rounded stone. Rock used in most of these projects has been fieldstone, which is more rounded than quarry stone but in the large gradations, is still somewhat angular and has been stable. Since canoeists and kayakers use these rapids, quarry stone presents problems due to sharp edges that can rip keels. Quarry stone also lacks the aesthetics of natural fieldstone. Engineers Manual EM 1110-2-1601 also recommends use of filter fabric under the stone. However, most applications of the Rock Arch Rapids have been built in flowing water and have not used filter fabric, as it would be very difficult to place in larger rivers like the Red River of the North and has not proven to be necessary or desirable.

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AADLAND
2010

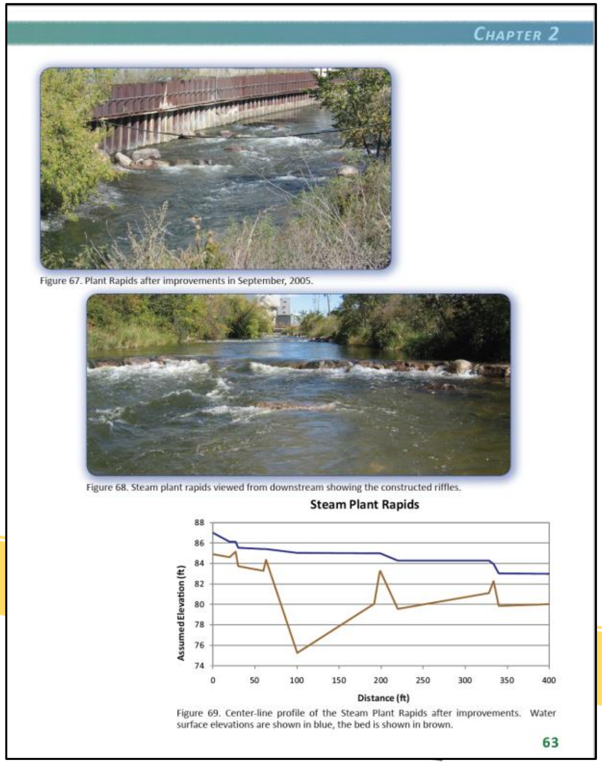
CHAPTER 2

Figure 67. Plant Rapids after improvements in September, 2005.

Figure 68. Steam plant rapids viewed from downstream showing the constructed riffles.

Figure 69. Center-line profile of the Steam Plant Rapids after improvements. Water surface elevations are shown in blue, the bed is shown in brown.

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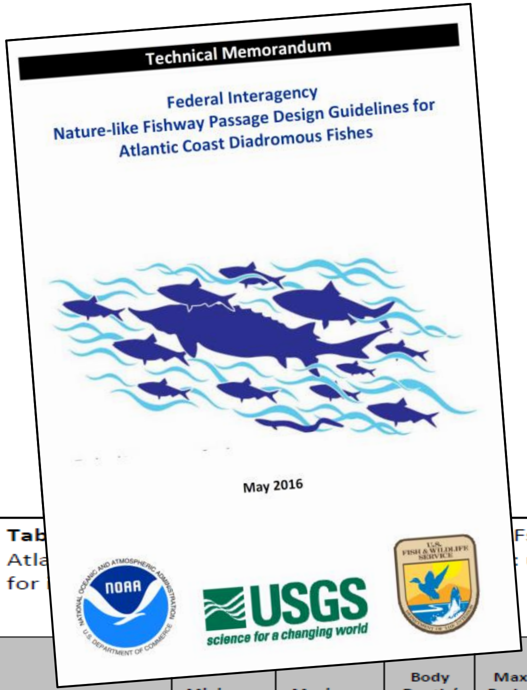
FISH PASSAGE DESIGN GUIDELINES



In 2016 staff from the National Marine Fisheries Service (NMFS), the U.S. Geological Survey (USGS) and the U.S. Fish and Wildlife Service (USFWS) collaborated to develop passage design guidance for use by engineers and other restoration practitioners considering and designing nature-**like fishways (NLFs). The focus of this document centers on the target fish species'** biological attributes that the design team needs to consider when designing and building an NLF.

Tab ... Fs and related to swimming capabilities and safe, timely and efficient passage for Atla ... units are expressed in both metric (cm) and English units (feet or feet/sec). See text for ...

Species	Minimum TL (cm)	Maximum TL (cm)	Body Depth/ TL Ratio	Maximum Body Depth (cm)	Minimum Pool/Channel Width (ft)	Minimum Pool/Channel Depth (ft)	Minimum Pool/Channel Length (ft)	Minimum Weir Opening Width (ft)	Minimum Weir Opening Depth (ft)	Maximum Weir Opening Water Velocity (ft/sec)	Maximum Fishway Channel Slope
	TL_{min}	TL_{max}	BD/TL	BD_{max}	W_p	d_P	L_P	W_N	d_N	V_{max}	S_0
Sea Lamprey	60	86	0.072	6.2	10.0	2.00	20.0	0.75	0.75	6.00	1:30
Shortnose Sturgeon	52	143	0.148	21.2	30.0	4.00	30.0	2.75	2.25	5.00	1:50
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Atlantic Tomcod	15	30	0.202	6.1	5.0	2.00	10.0	2.00	0.75	0.75	1:30
Striped Bass	40	140	0.225	31.5	20.0	5.25	30.0	9.25	3.25	5.25	1:30

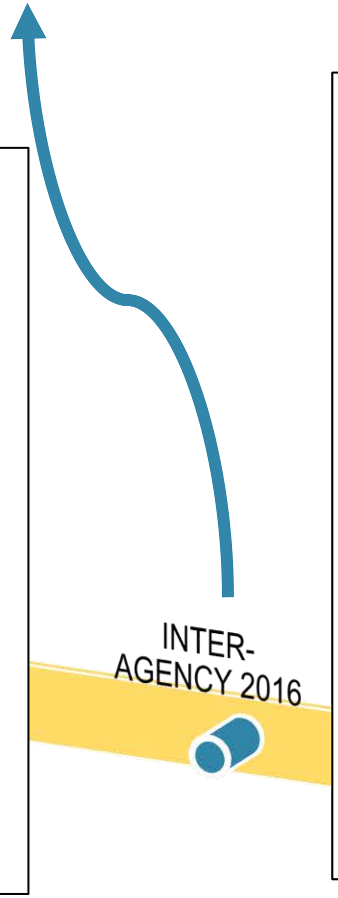
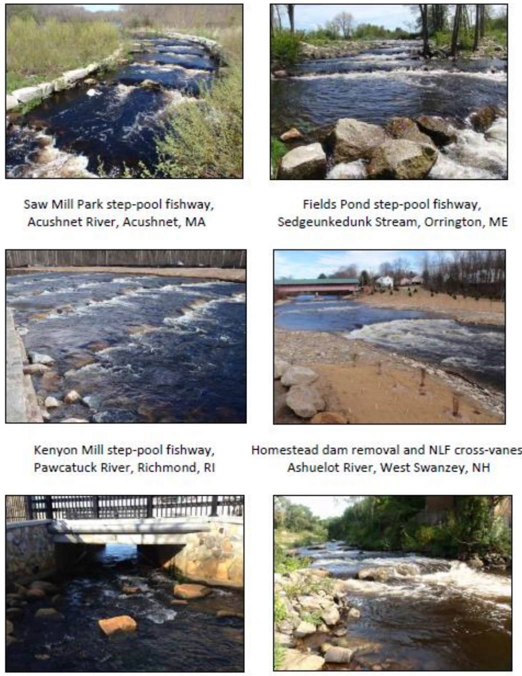


Figure 2. Captioned photographs of nature-like fishways (NLFs) in the Northeast targeting passage of Atlantic coast diadromous fishes (Photo sources: J. Turek, M. Bernier)



Saw Mill Park step-pool fishway, Acushnet River, Acushnet, MA

Fields Pond step-pool fishway, Sedgeunkedunk Stream, Orrington, ME

Kenyon Mill step-pool fishway, Pawcatuck River, Richmond, RI

Homestead dam removal and NLF cross-vanes, Ashuelot River, West Swanzey, NH

Water Street tidal rock ramp, Town Brook, Plymouth, MA

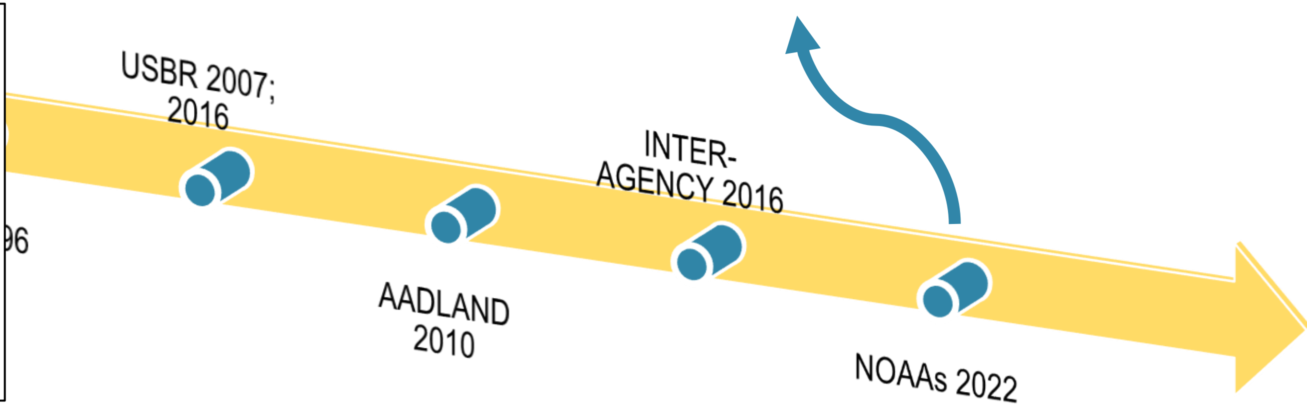
Lower Shannock Falls NLF weirs, Pawcatuck River, Richmond, RI

FISH PASSAGE DESIGN GUIDELINES

West Coast NOAA was very busy in 2022 when it published a series of guideline **documents that covered a wide range of topics affecting the region's fisheries (e.g.,** fishways, stream simulation, climate change considerations, etc.). The *NOAA Fisheries Guidelines for Salmonid Stream Crossings in WA, OR and ID* provides design guidance **on what it refers to as "constructed channels" (a.k.a., nature**-like fishways).

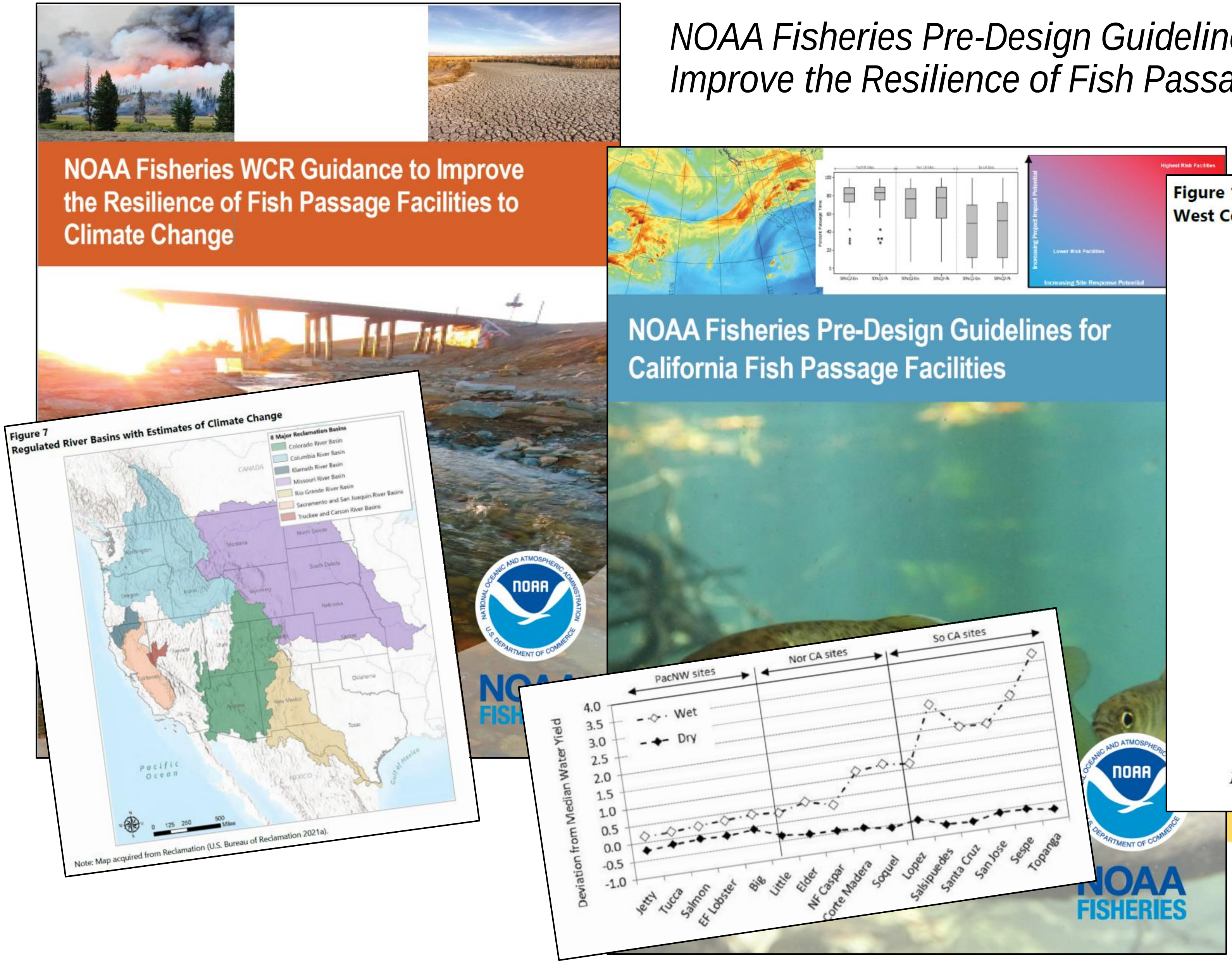
The *NOAA Fisheries WCR Anadromous Salmonid Design Manual* briefly covers the topic of NLFs as viable options for providing fish passage, but warns the reader about **assuming that these are necessarily better options than other "traditional methods":**

> Nature-like fishways are thought to facilitate the passage of a wide assemblage of fish and aquatic species, sometimes purported to provide better passage than traditional methods (fish ladders). However, Castro-Santos (2011) concluded that **nature-like fishway designs evaluated in his study were not superior to traditional fish ladders for the 23 fish species from the northeastern United States** (of those that were evaluated). More recently, Landsman et al. (2018) compared the passage of salmonid and non-salmonid species at nature-like fishway and pool-and-weir fishways in eastern Canada and reported similar results. Nature-like fishways have been observed to pass anadromous and resident salmonids with varying degrees of success at projects of varying hydraulic complexity (Aarestrup et al. 2003; Calles and Greenberg 2005, 2009; Dodd et al. 2017).



FISH PASSAGE PRE-DESIGN GUIDELINES

NOAA Fisheries Pre-Design Guidelines for CA Fish Passage Facilities and to Improve the Resilience of Fish Passage Facilities to Climate Change



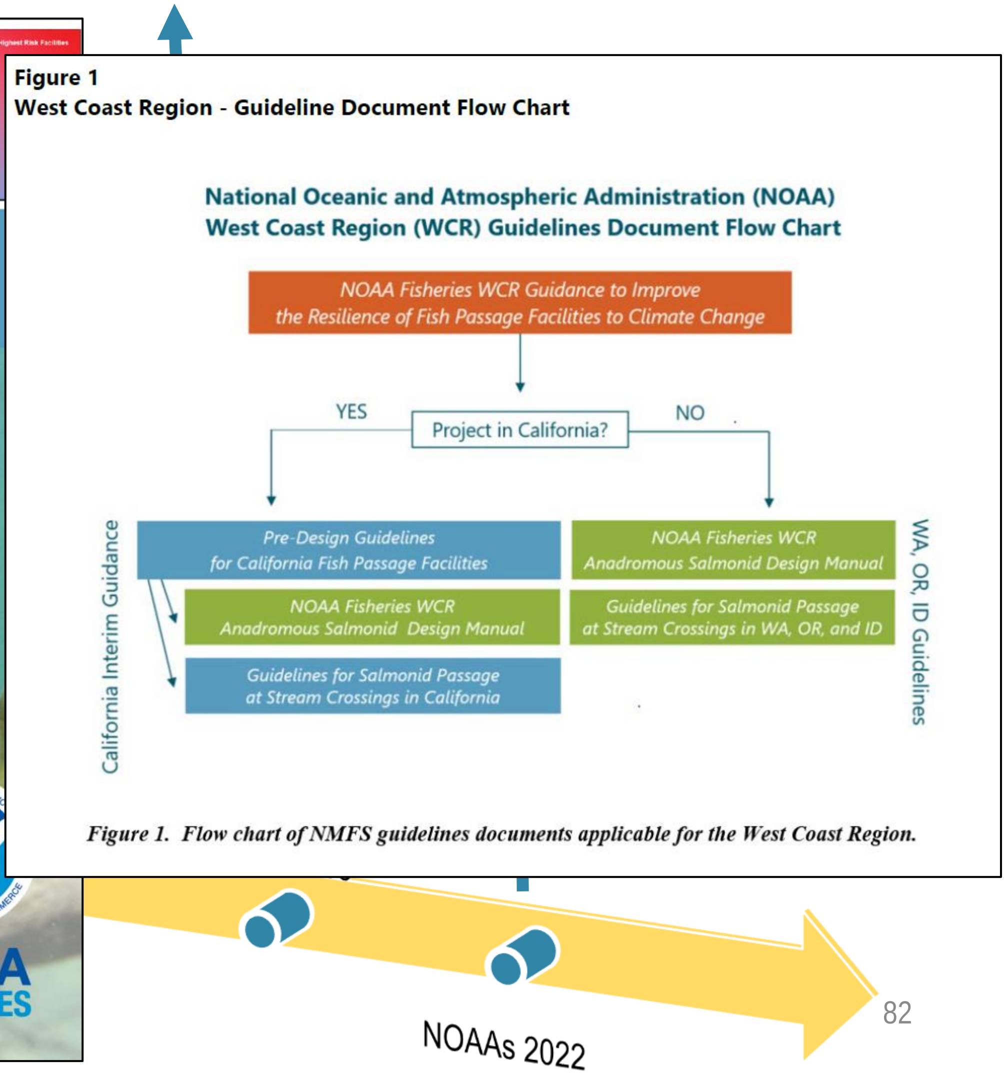
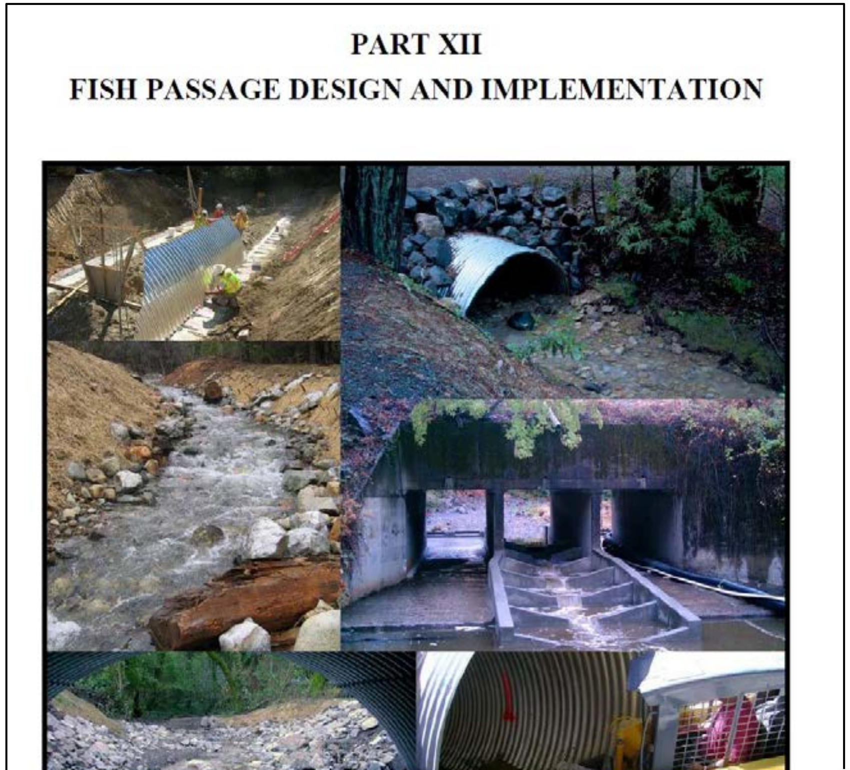
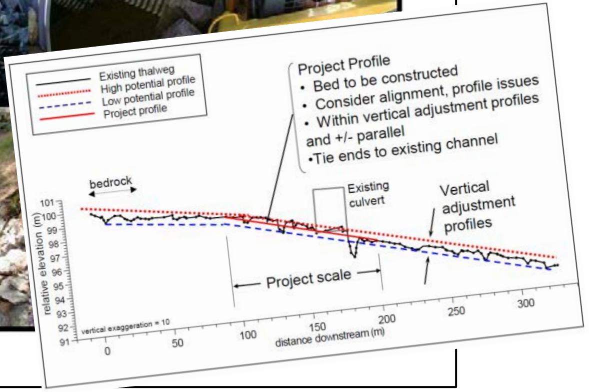


Figure 1. Flow chart of NMFS guidelines documents applicable for the West Coast Region.

CALIFORNIA FISH PASSAGE DESIGN GUIDELINES


PART XII
FISH PASSAGE DESIGN AND IMPLEMENTATION



California Fish & Wildlife (CFW) *Part XII: Fish Passage Design and Implementation*

Under the *Profile Control* section, the document covers many of the design principles applicable for NLFs.

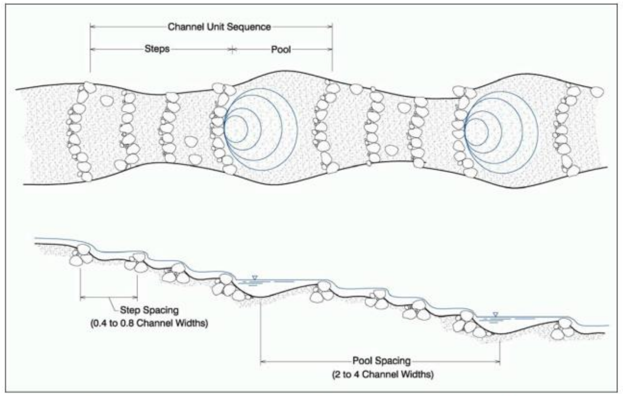


Figure XII-24. Step-pool channel sequence that includes larger pools every 2 to 4 channel widths, as described by Grant et al. (1990).

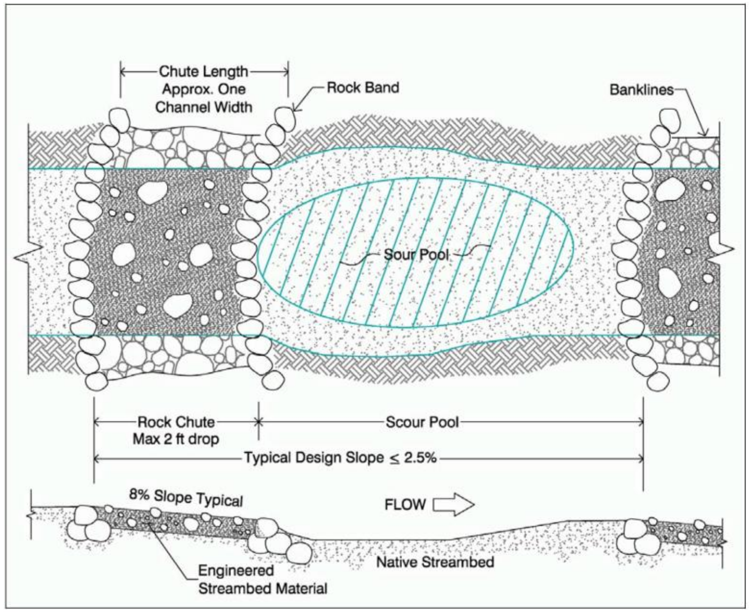


Figure XII-33. Typical chute with unarmored pool in plan and section.

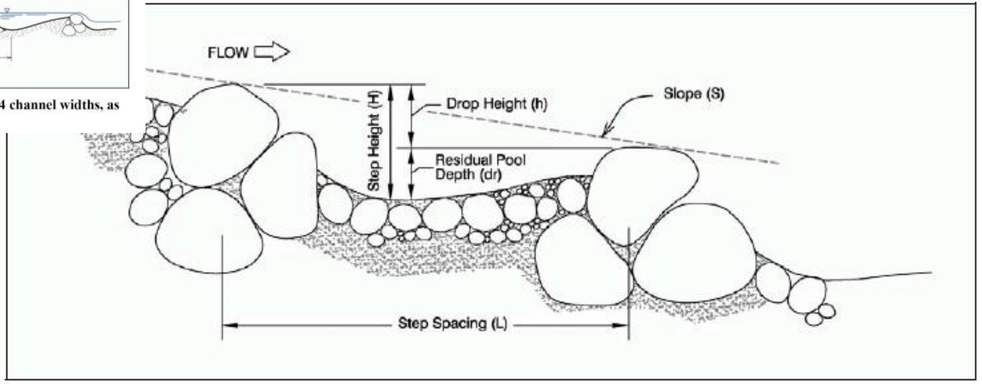
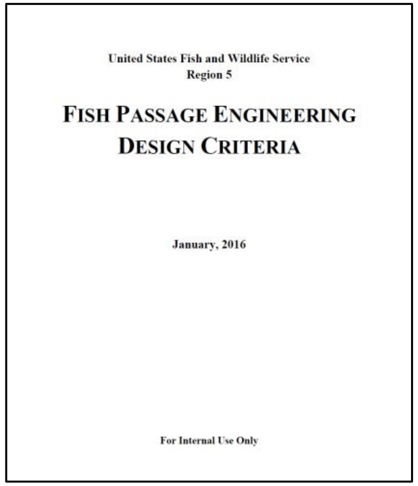


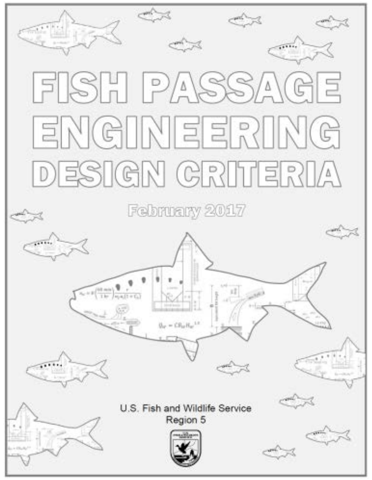
Figure XII-23. Dimensions used to describe a step-pool channel in profile.

USFWS/NOAA EAST COAST FISH PASSAGE ENGINEERING DESIGN GUIDELINES

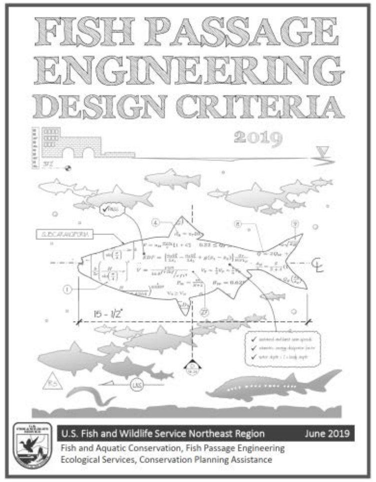
2016



2017

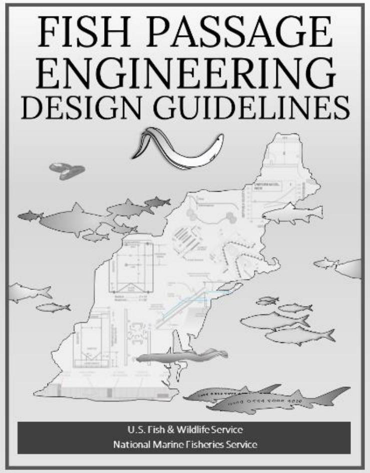


2019



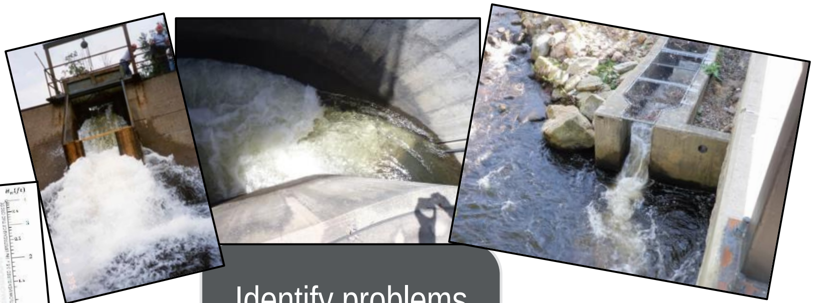
2025

2025?



RESEARCH LOOP

WE STILL HAVEN'T FIGURED IT OUT!

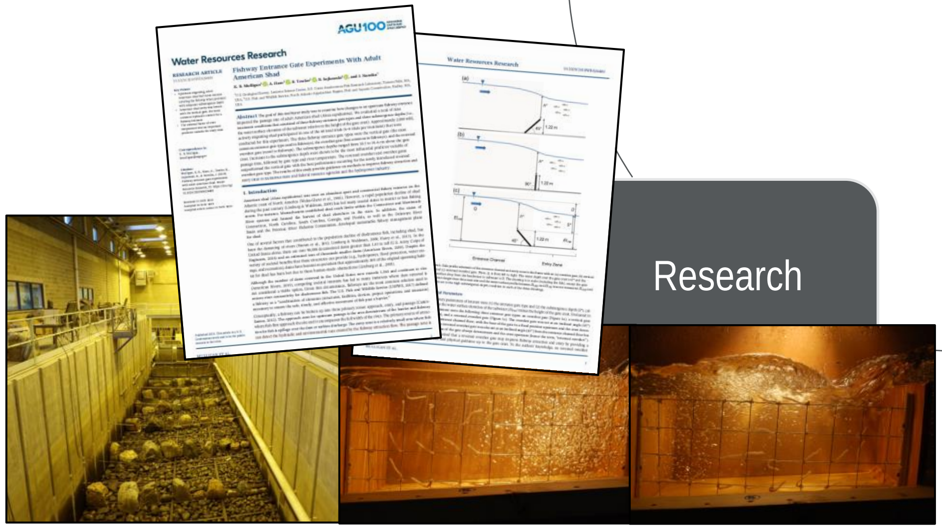


Identify problems through monitoring and collaborations

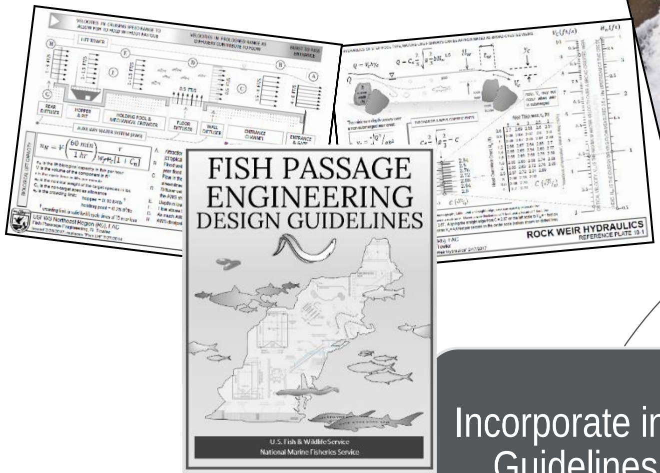
Literature reviews

Find information gaps

Research



Incorporate into Guidelines



EXAMPLE

In 2021 the USGS Conte Laboratory in Turners Falls, MA evaluated the impact of available submergence depth through a notch when attempting to pass American shad.

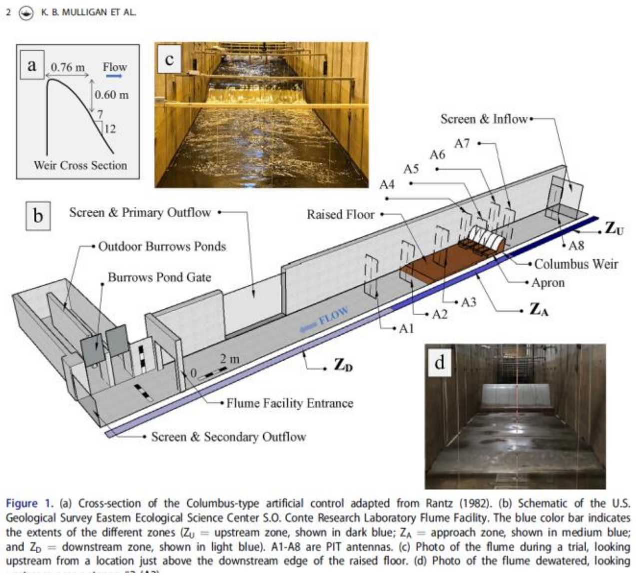
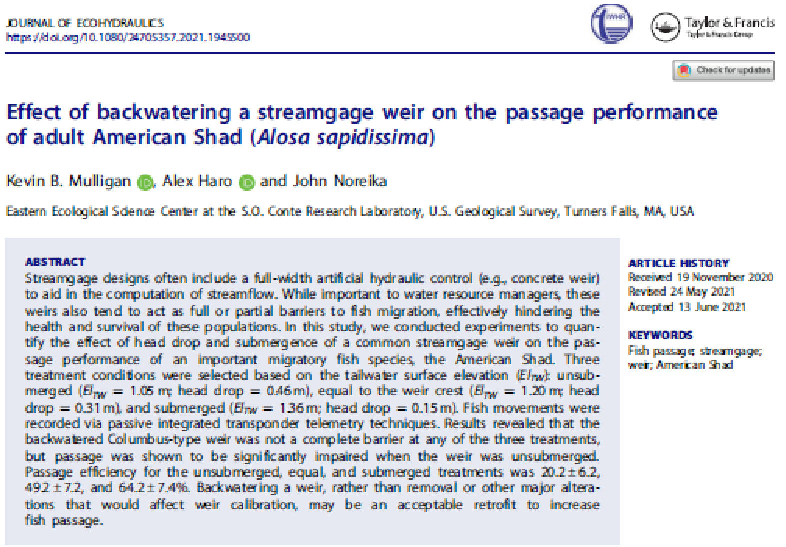


Figure 1. (a) Cross-section of the Columbus-type artificial control adapted from Rantz (1982). (b) Schematic of the U.S. Geological Survey Eastern Ecological Science Center S.O. Conte Research Laboratory Flume Facility. The blue color bar indicates the extents of the different zones (Z_U = upstream zone, shown in dark blue; Z_A = approach zone, shown in medium blue; and Z_D = downstream zone, shown in light blue). A1-A8 are PIT antennas. (c) Photo of the flume during a trial, looking upstream from a location just above the downstream edge of the raised floor. (d) Photo of the flume dewatered, looking



JOURNAL OF ECOHYDRAULICS
https://doi.org/10.1080/24705357.2021.1945500
Taylor & Francis
Check for updates

Effect of backwatering a streamgage weir on the passage performance of adult American Shad (*Alosa sapidissima*)

Kevin B. Mulligan, Alex Haro and John Noreika

Eastern Ecological Science Center at the S.O. Conte Research Laboratory, U.S. Geological Survey, Turners Falls, MA, USA

ABSTRACT

Streamgage designs often include a full-width artificial hydraulic control (e.g., concrete weir) to aid in the computation of streamflow. While important to water resource managers, these weirs also tend to act as full or partial barriers to fish migration, effectively hindering the health and survival of these populations. In this study, we conducted experiments to quantify the effect of head drop and submergence of a common streamgage weir on the passage performance of an important migratory fish species, the American Shad. Three treatment conditions were selected based on the tailwater surface elevation (El_{TW}): unsubmerged (El_{TW} = 1.05 m; head drop = 0.46 m), equal to the weir crest (El_{TW} = 1.20 m; head drop = 0.31 m), and submerged (El_{TW} = 1.36 m; head drop = 0.15 m). Fish movements were recorded via passive integrated transponder telemetry techniques. Results revealed that the backwatered Columbus-type weir was not a complete barrier at any of the three treatments, but passage was shown to be significantly impaired when the weir was unsubmerged. Passage efficiency for the unsubmerged, equal, and submerged treatments was 20.2 ± 6.2, 49.2 ± 7.2, and 64.2 ± 7.4%. Backwatering a weir, rather than removal or other major alterations that would affect weir calibration, may be an acceptable retrofit to increase fish passage.

ARTICLE HISTORY
Received 19 November 2020
Revised 24 May 2021
Accepted 13 June 2021

KEYWORDS
Fish passage; streamgage; weir; American Shad

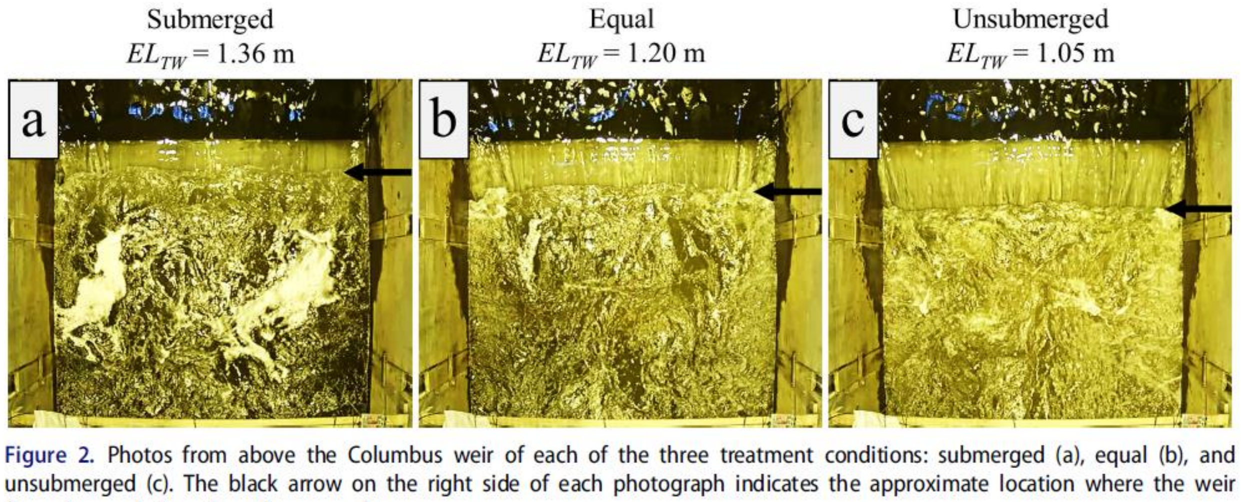
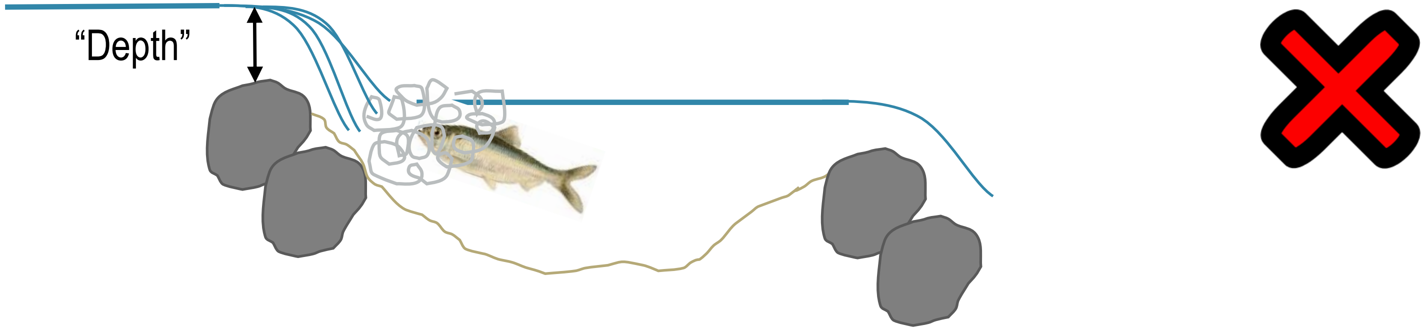
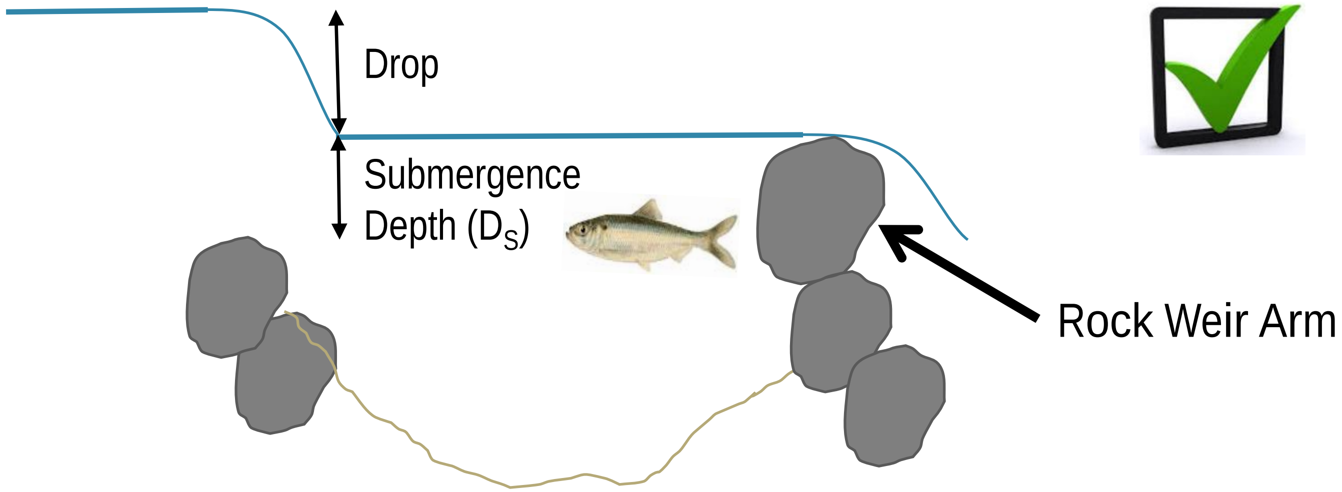


Figure 2. Photos from above the Columbus weir of each of the three treatment conditions: submerged (a), equal (b), and unsubmerged (c). The black arrow on the right side of each photograph indicates the approximate location where the weir

SUBMERGENCE DEPTH FOR PASSING ALOSINES



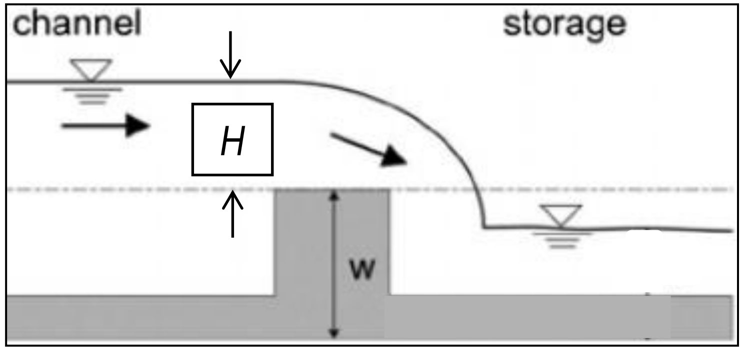
Plunging Flow



Streaming Flow

SUBMERGENCE DEPTH FOR PASSING ALOSINES

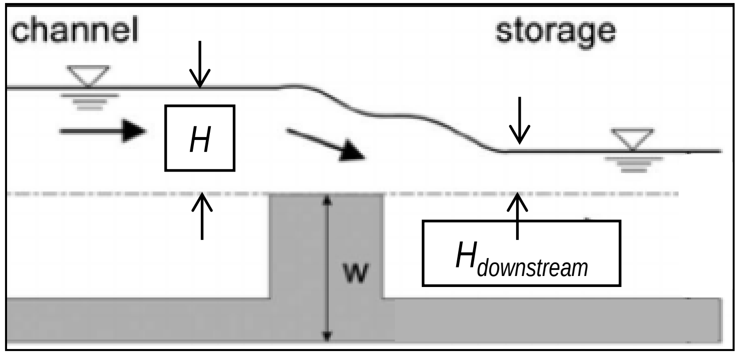
Typical Free Weir Flow



$$Q_{free\ flow} = \frac{2}{3} C_1 b \sqrt{2g} H^{\frac{3}{2}}$$

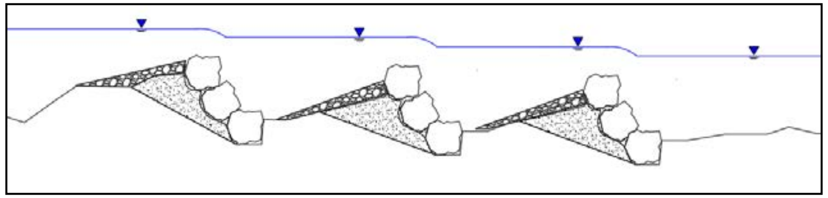
$$C_1 = 0.602 + 0.083 \left(\frac{H}{W}\right)$$

Typical NLF Submerged Flow

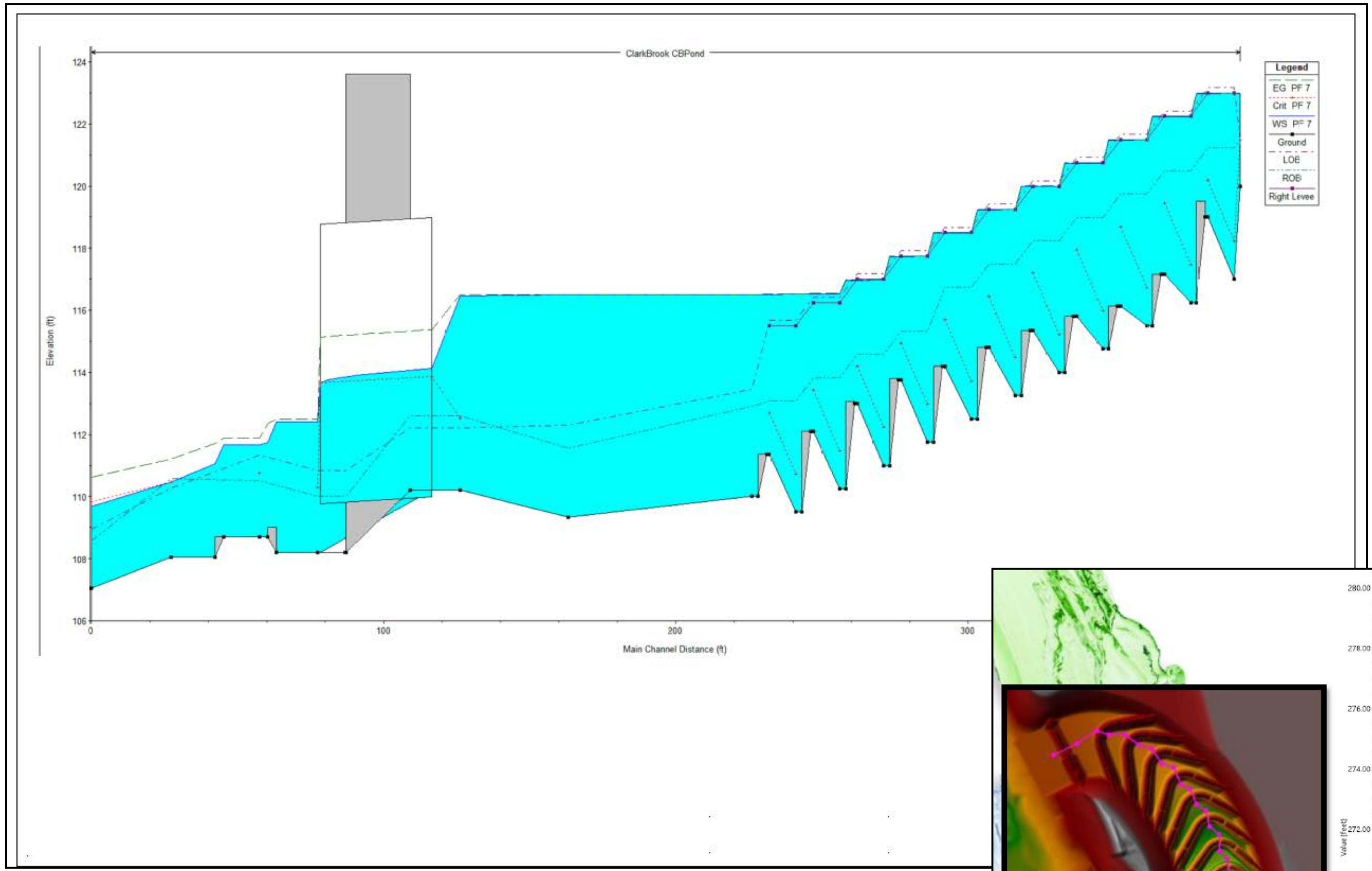


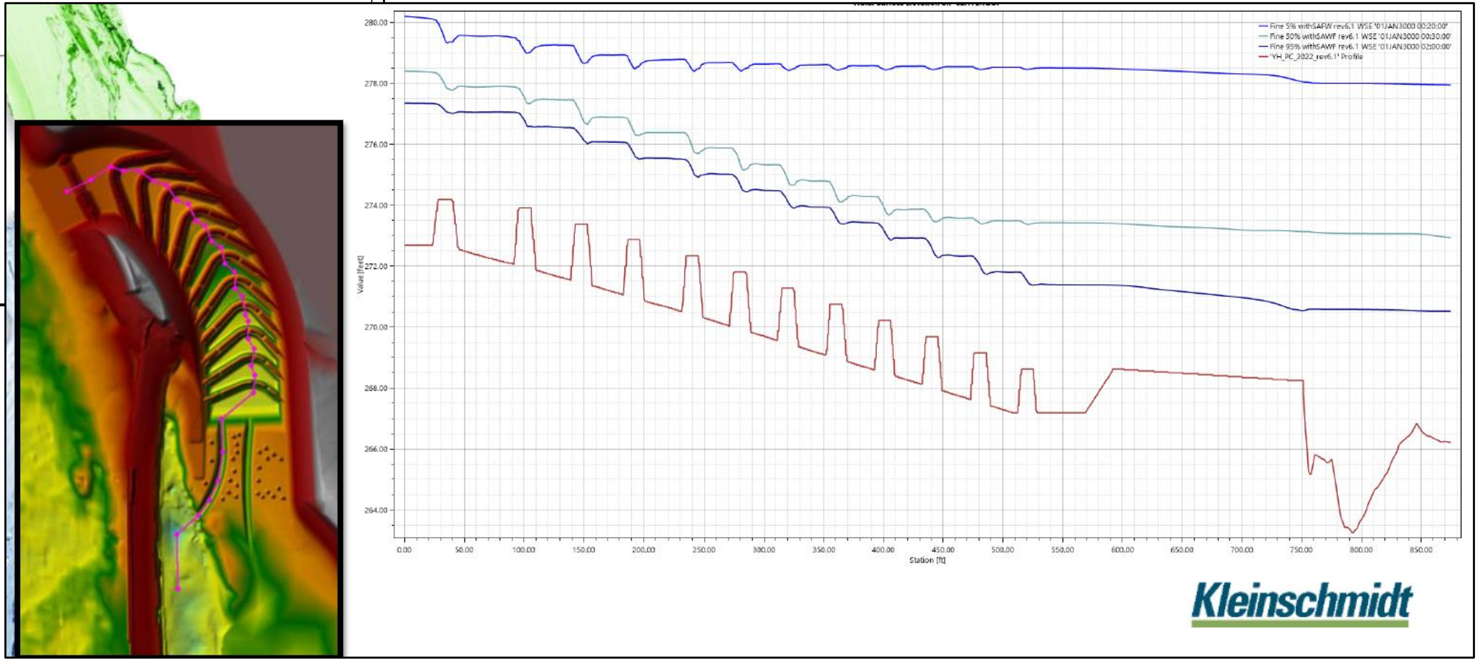
$$Q_{submerged} = Q_{free\ flow} (1 - \left(\frac{H_{downstream}}{H}\right)^{\frac{3}{2}})^{0.385}$$

Note: Submergence Depth (D_S) = $H_{downstream}$



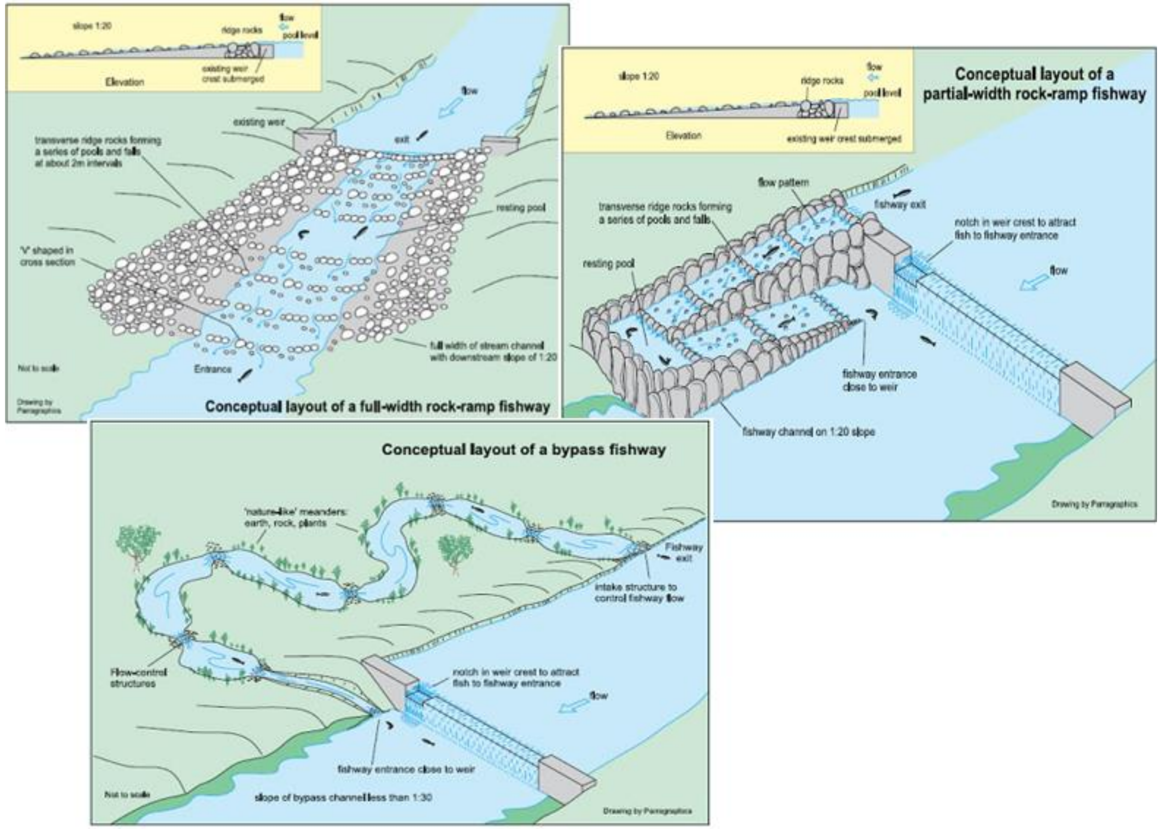
SUBMERGENCE DEPTH FOR PASSING ALOSINES



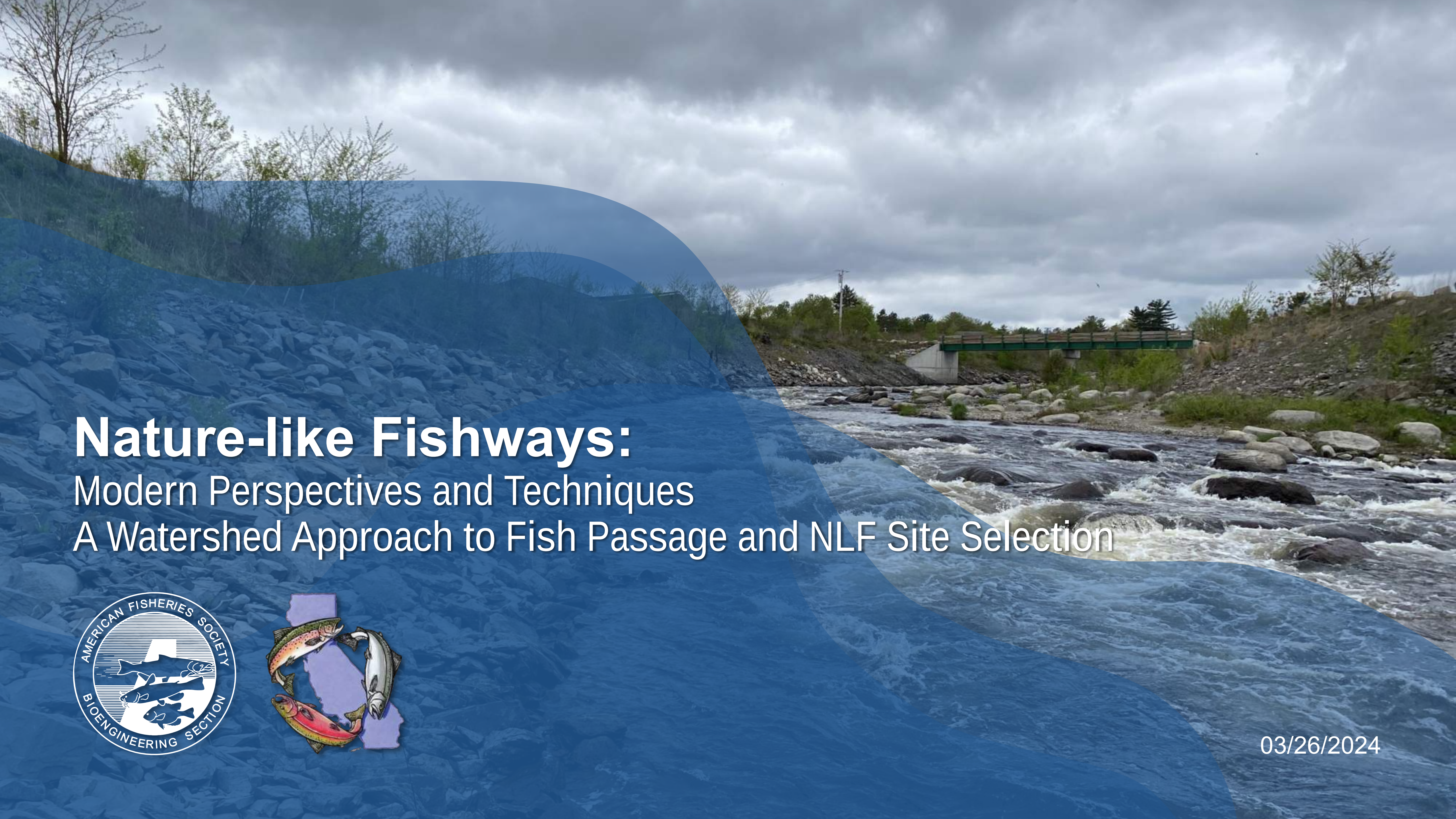


Kleinschmidt

05



CONCLUSION AND Q&A

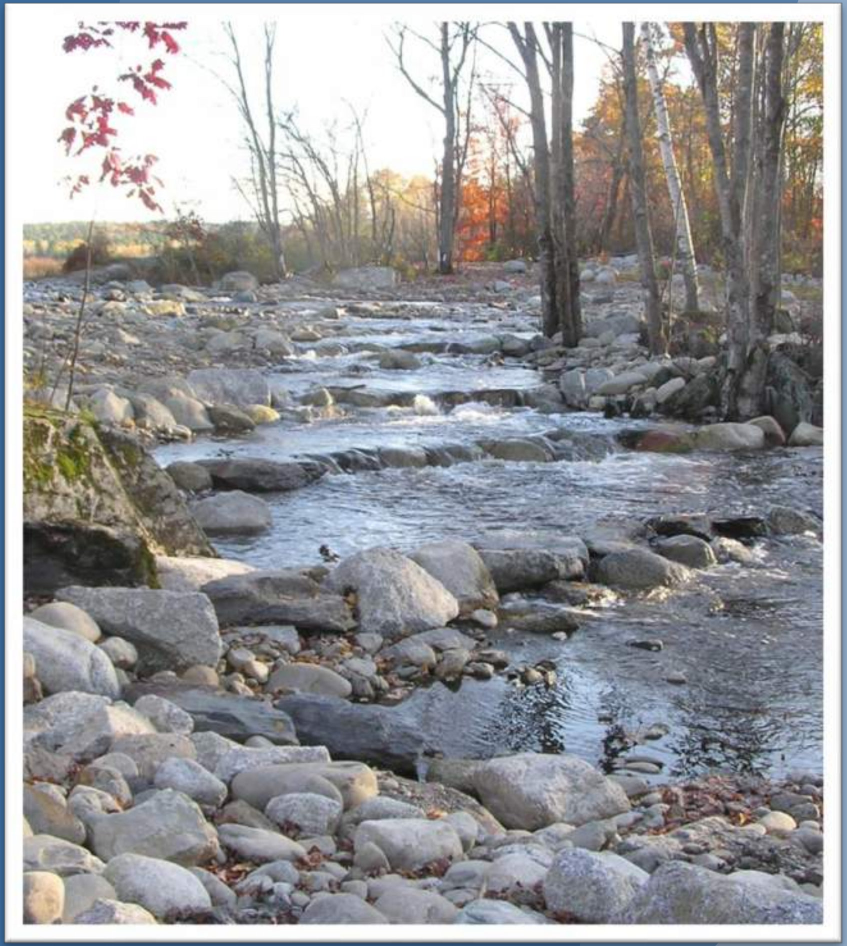


Nature-like Fishways:

Modern Perspectives and Techniques
A Watershed Approach to Fish Passage and NLF Site Selection

AMERICAN FISHERIES SOCIETY BIOENGINEERING SECTION

03/26/2024



01 Watershed Approach

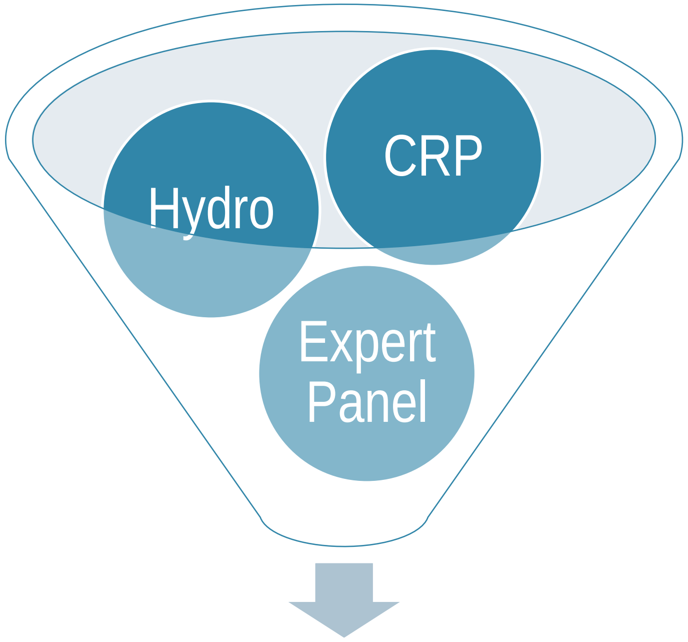
02 Assessment Exercise

03 Types of Barriers

04 What is Nature-Like?

05 Site Selection Exercise

01



Key Recommendation: Formalize a Watershed Approach

Watershed Approach

Programmatic Review

- Purpose: Evaluation of existing programs that do fish passage
- Process: Present a dog and pony show to an expert review panel
- Result: Panels provides recommendations and NMFS' develops action plan

Unified Federal Policy for Ensuring a Watershed Approach to Federal Land and Resource Management

(65 FR 62565)

A framework to guide watershed management that:

(1) uses watershed assessments to determine existing and reference conditions;

(2) incorporates assessment results into resource management planning; and

(3) fosters collaboration with all landowners in the watershed.

The framework considers both ground and surface water flow within a hydrologically defined geographical area.

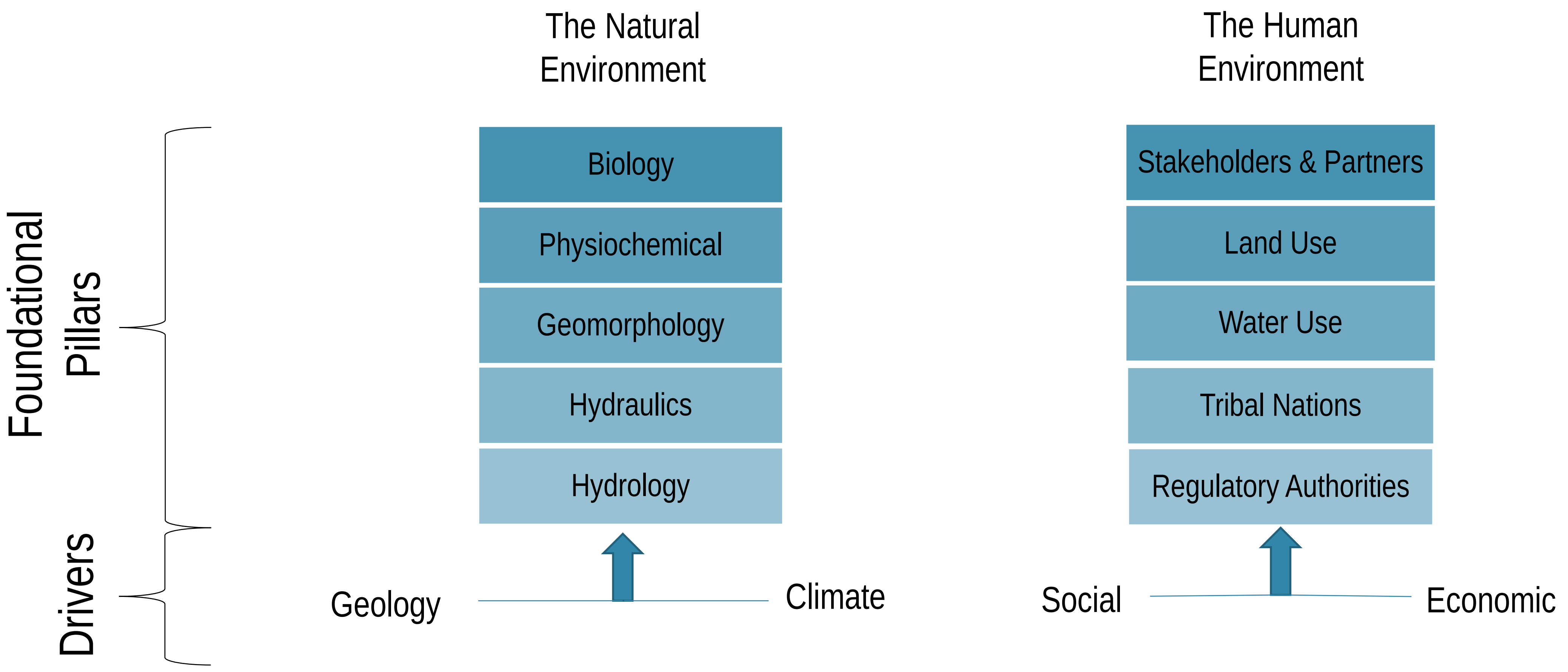
Our Watershed Approach for Fish Passage Definition

A framework to guide NOAA Fisheries fish passage-related activities in a watershed, that where possible and when appropriate,

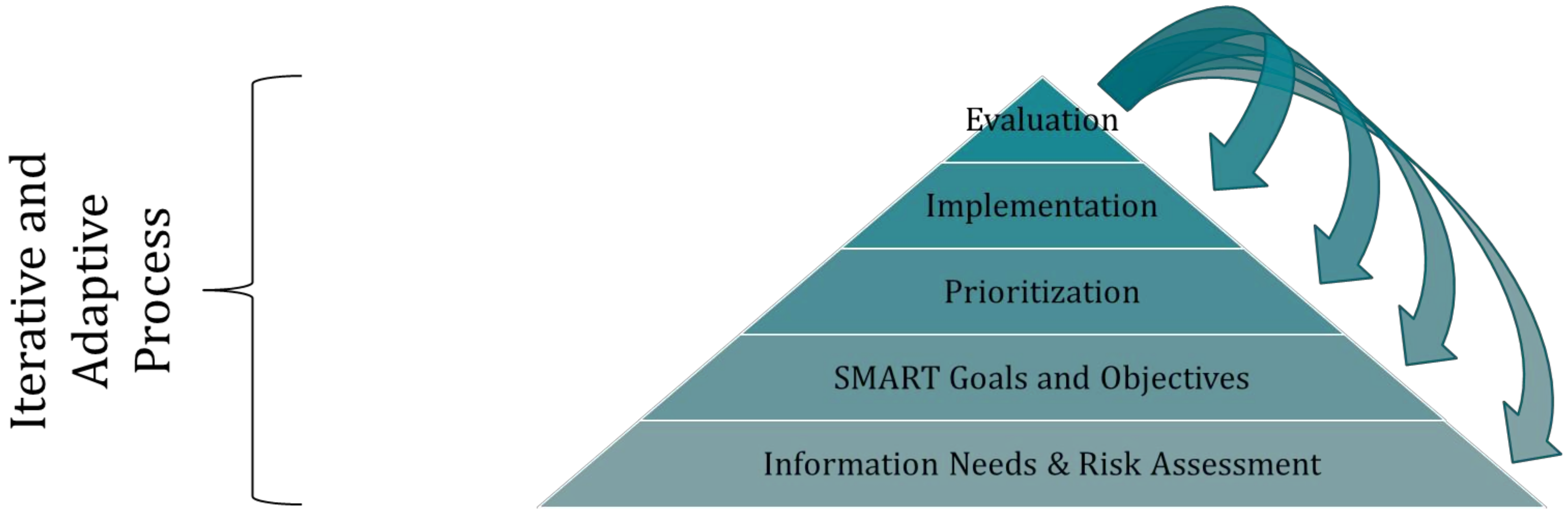
(1) uses watershed assessments to determine existing and reference conditions;
(2) incorporates assessment results into resource management planning;
(3) fosters collaboration with all stakeholders and tribes in the watershed;
(4) uses a holistic view (e.g., headwaters to ocean) for fish passage;
(5) considers future environmental conditions based on climate change and watershed development potential; and
(6) optimizes how NOAA Fisheries applies its full suite of authorities and programs to achieve recovery, conservation, and sustainability of NOAA Fisheries trust resources.

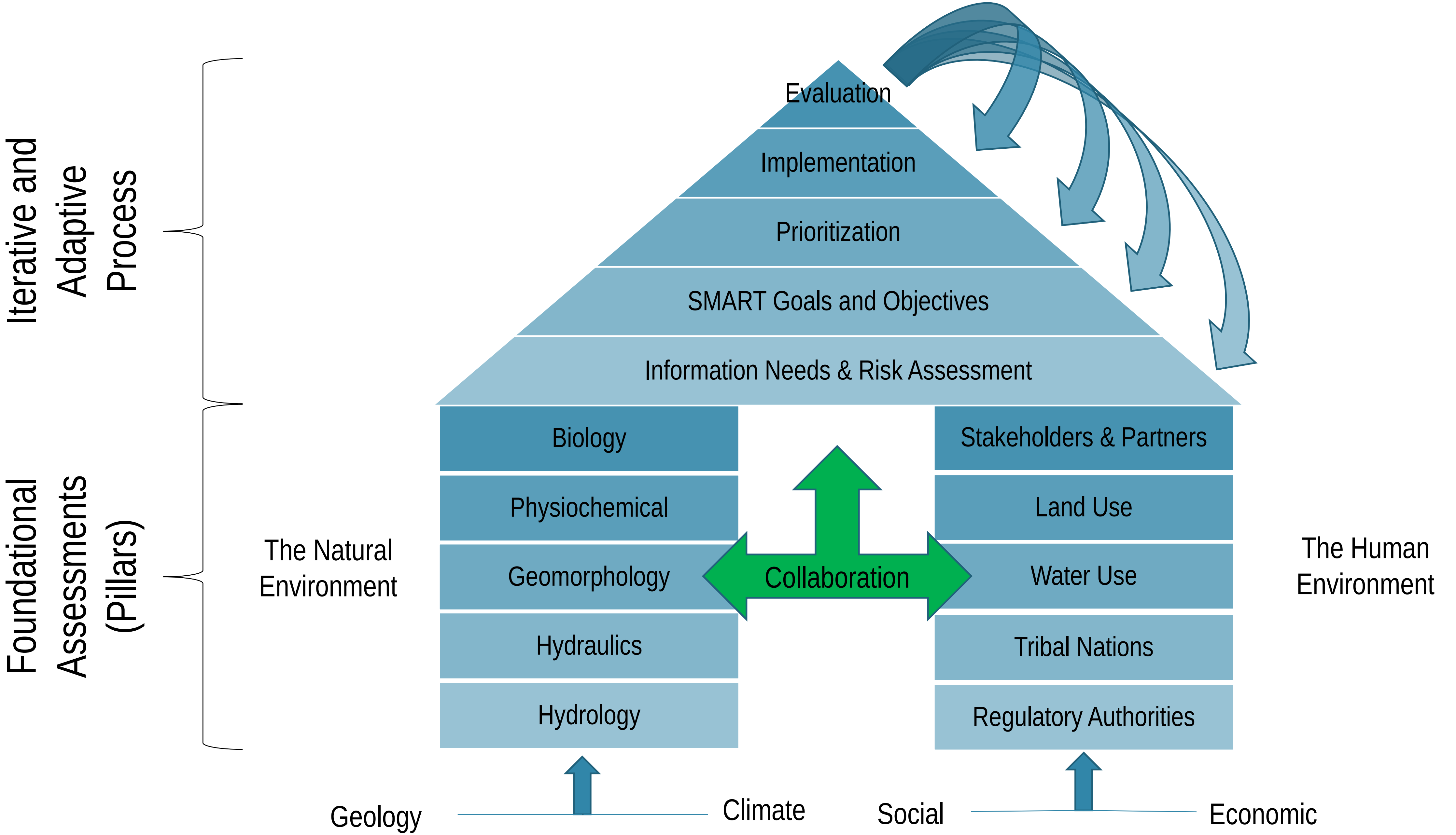
This framework considers both ground and surface water flow within a hydrologically defined geographical area.

Watershed Assessments



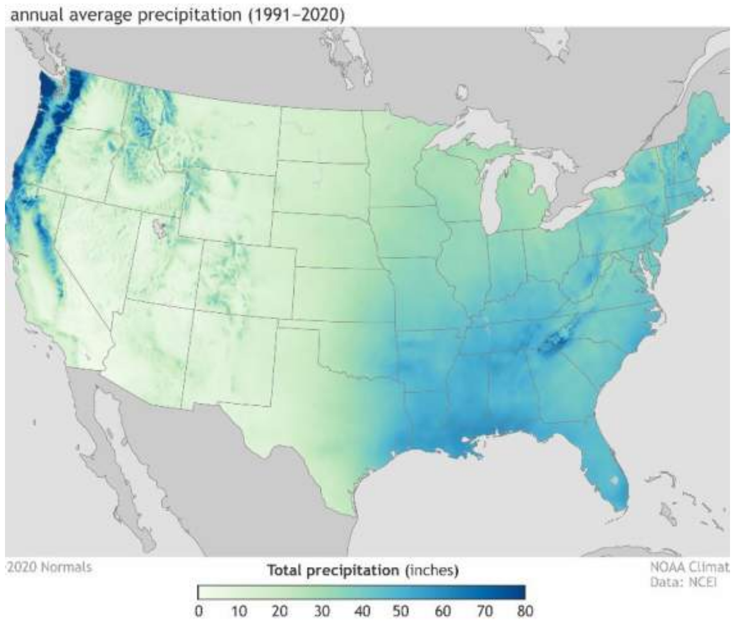
Fish Passage Planning and Implementation



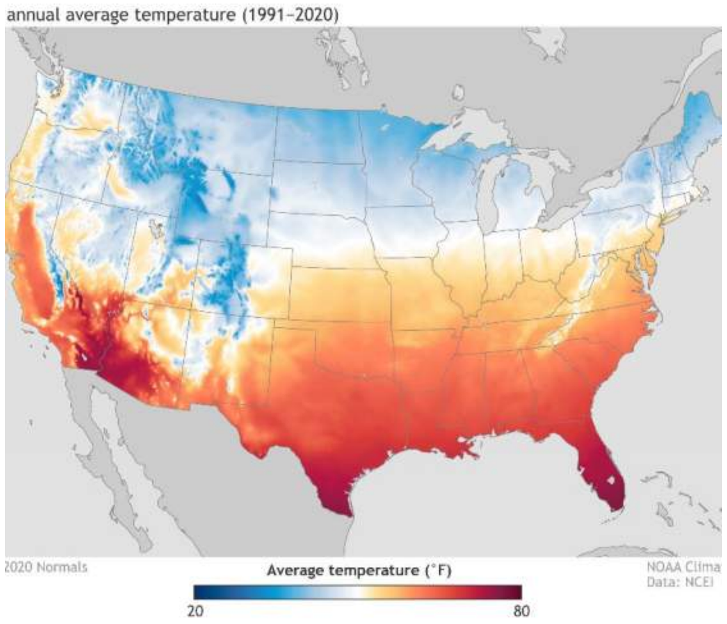

Iterative and Adaptive Process
Foundational Assessments (Pillars)
Evaluation
Implementation
Prioritization
SMART Goals and Objectives
Information Needs & Risk Assessment
Biology
Physiochemical
Geomorphology
Hydraulics
Hydrology
Stakeholders & Partners
Land Use
Water Use
Tribal Nations
Regulatory Authorities
Collaboration
The Natural Environment
The Human Environment
Geology
Climate
Social
Economic

Natural Environment Drivers

Geology and Climate



Precipitation



Temperature

Ecoregion

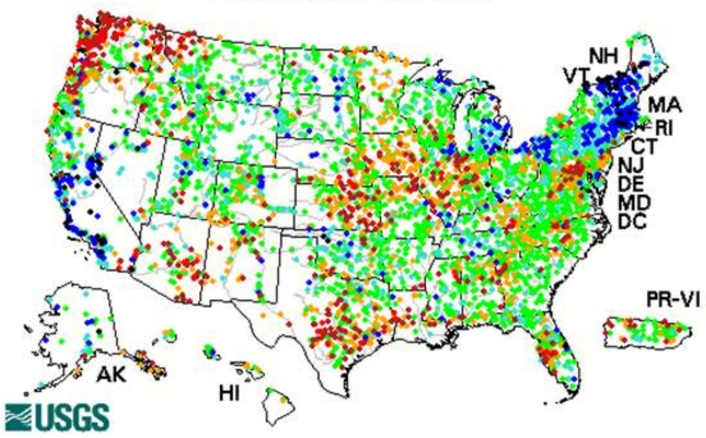
Hydrology

USGS Current Water Data for the Nation

--- Predefined displays ---
Introduction go

Daily Streamflow Conditions

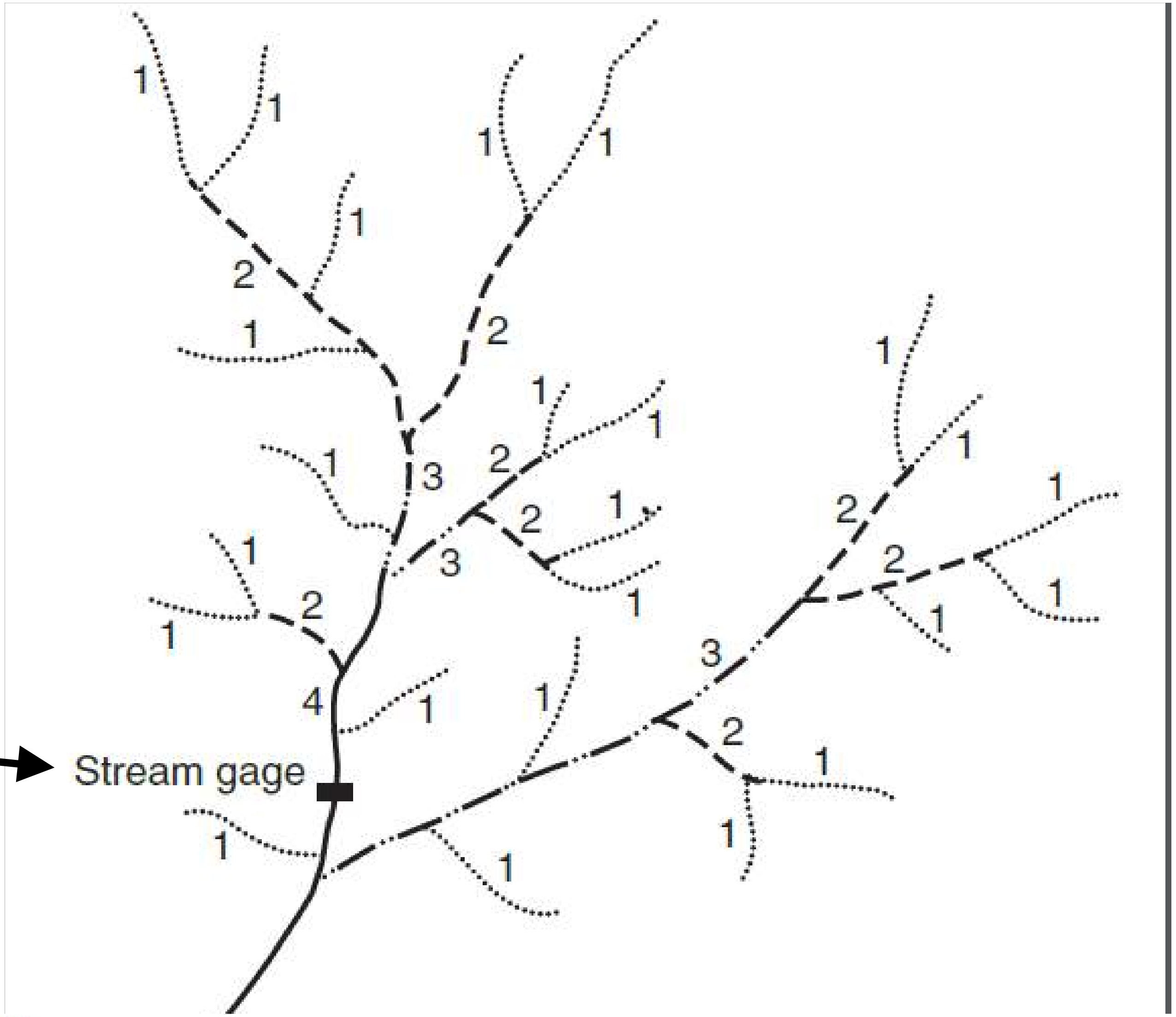
Friday, July 28, 2023 09:30ET



Explanation

- High
- > 90th percentile
- 76th - 90th percentile
- 25th - 75th percentile
- 10th - 24th percentile
- < 10th percentile
- Low
- Not ranked

The colored dots on this map depict streamflow conditions as a percentile, which is computed from the period of record for the current day of the year. Only stations with at least 30 years of record are used.
The **gray circles** indicate other stations that were not ranked in percentiles either because they have fewer than 30 years of record or because they report parameters other than streamflow. Some stations, for example, measure stage only.

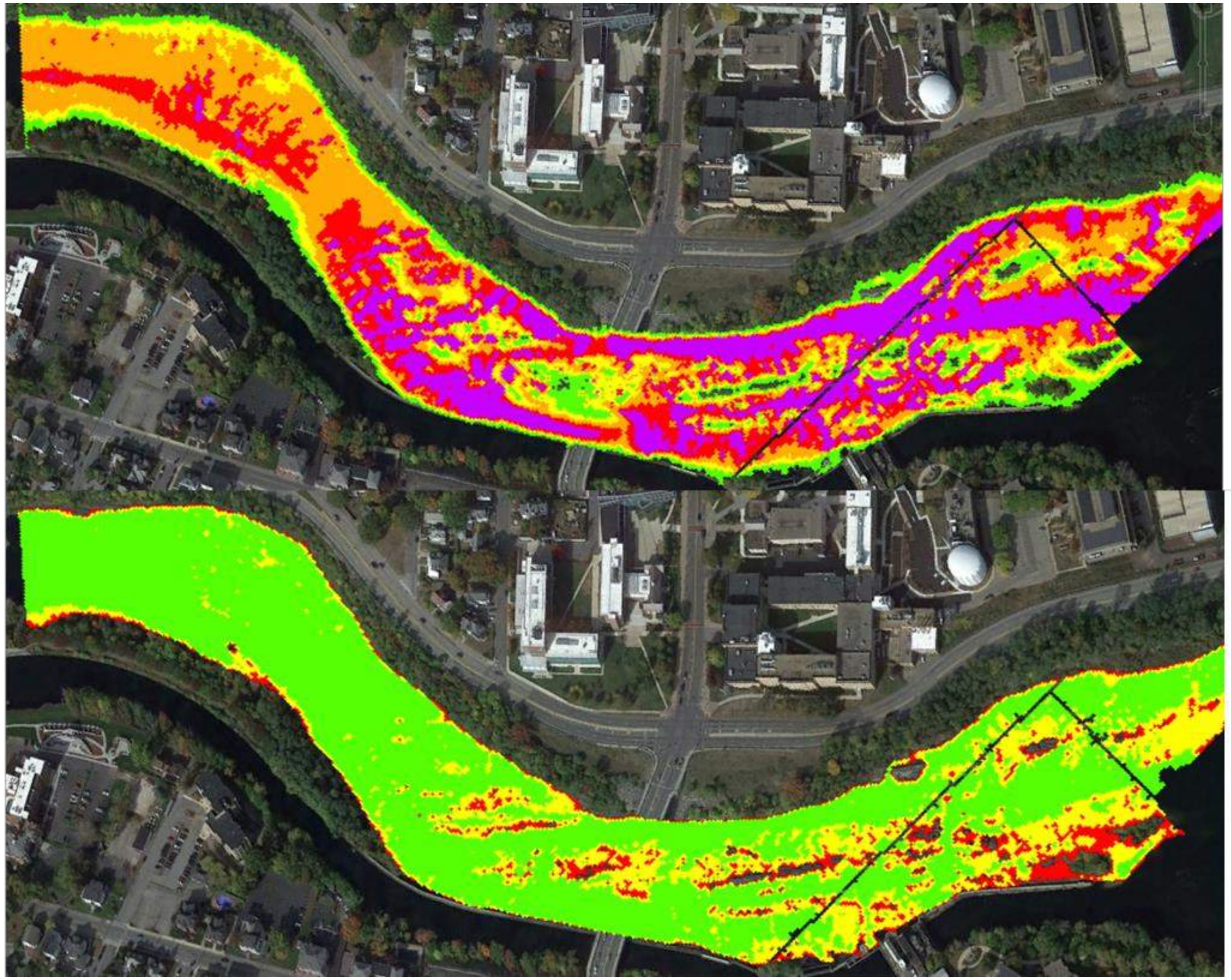


Hydraulics

8,000 cfs Bypass Flow

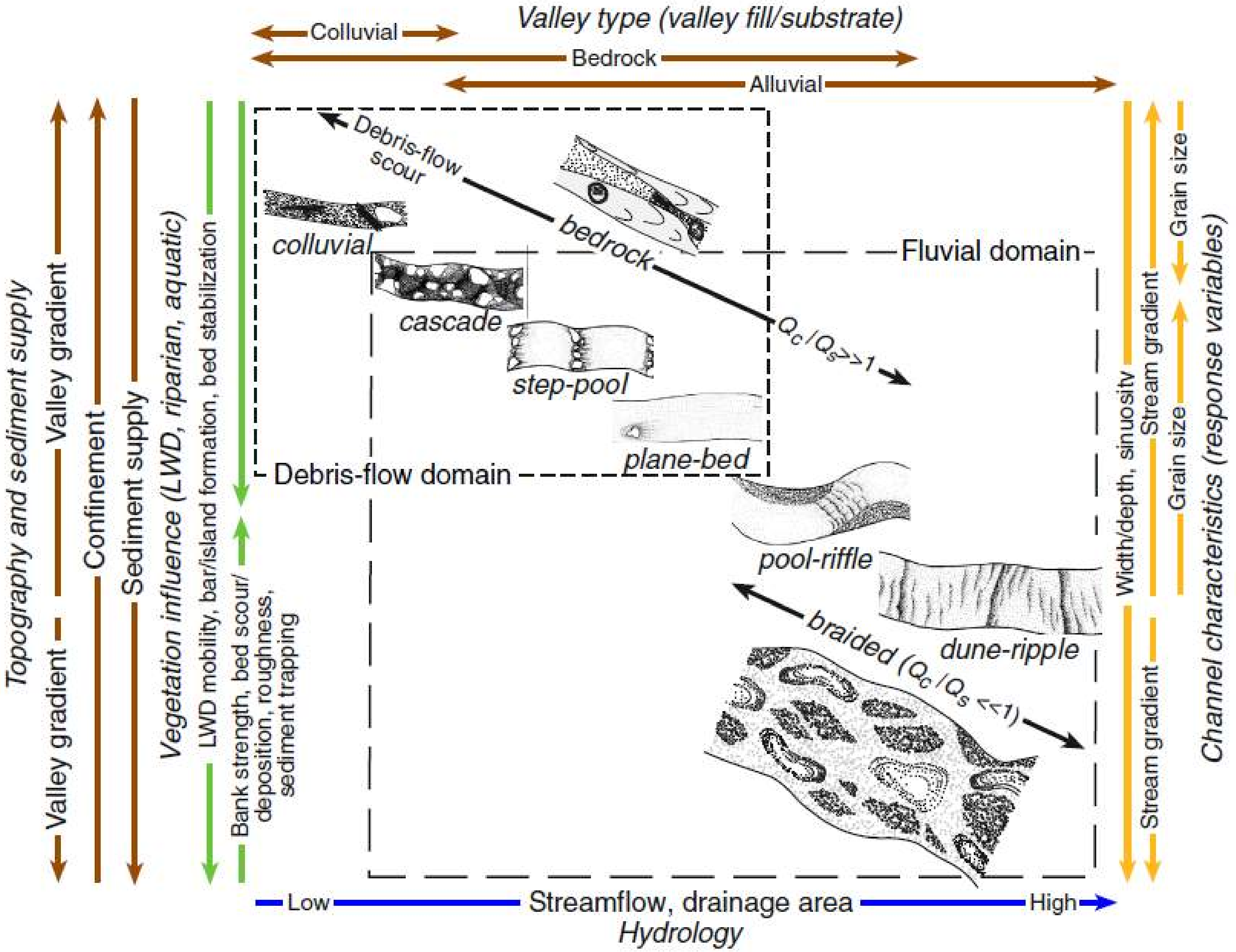
Velocity
- < 2 fps
- 2-4 fps
- 4-6 fps
- 6-8 fps
- > 8 fps

Depth
- < 1 ft
- 1-2.5 ft
- > 2.5 ft

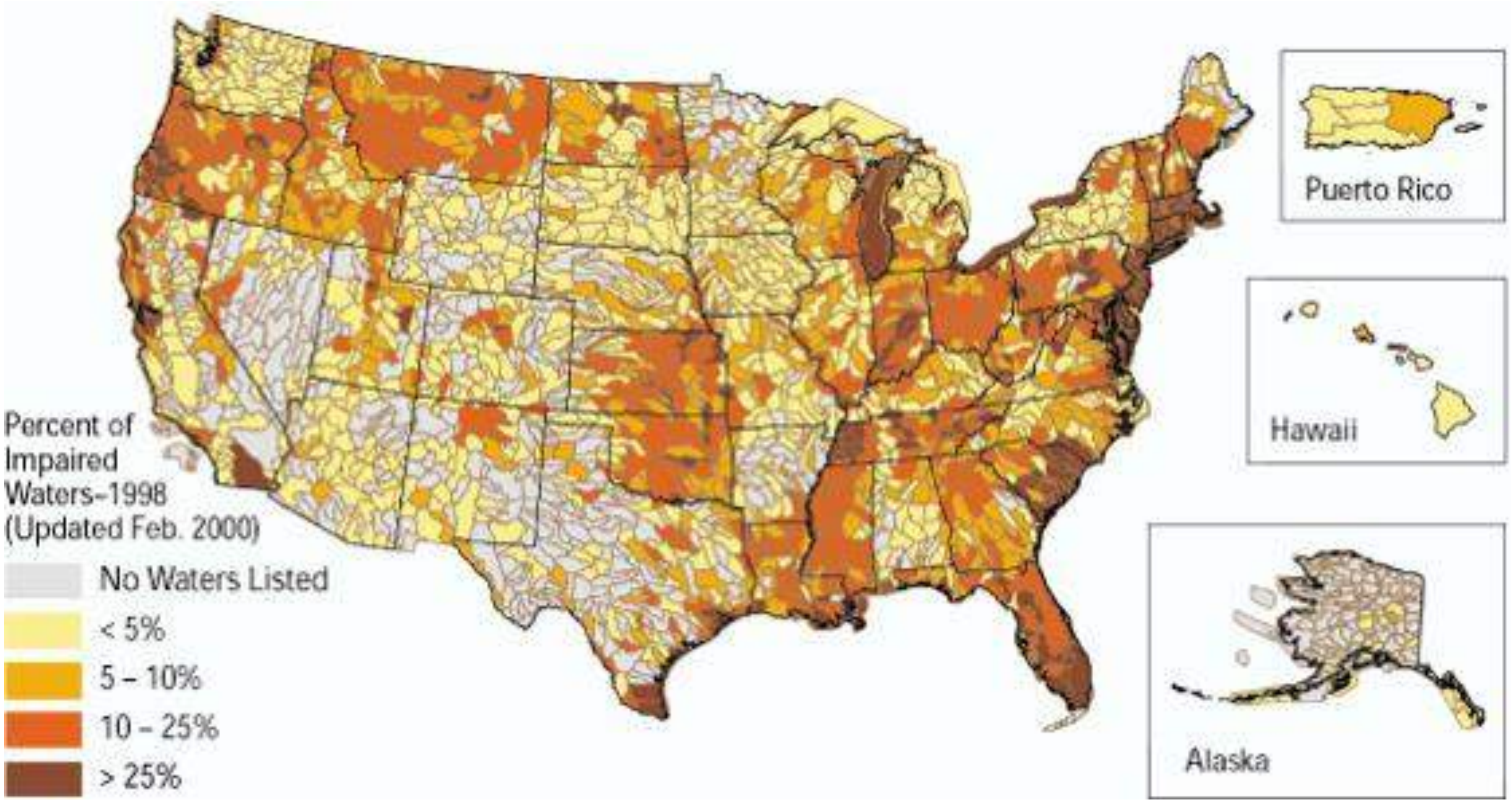


Geomorphology

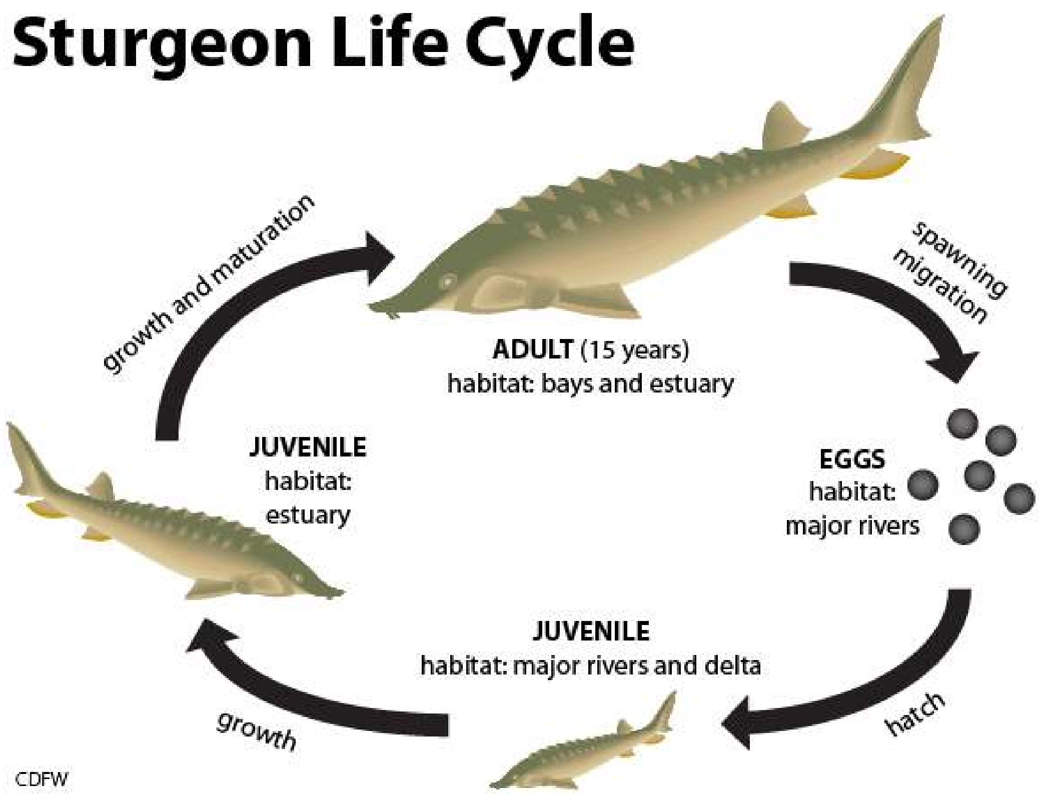
- Imposed basin conditions govern channel characteristics and reach-scale morphology, as illustrated with channel types.
- Buffington and Montgomery 2022

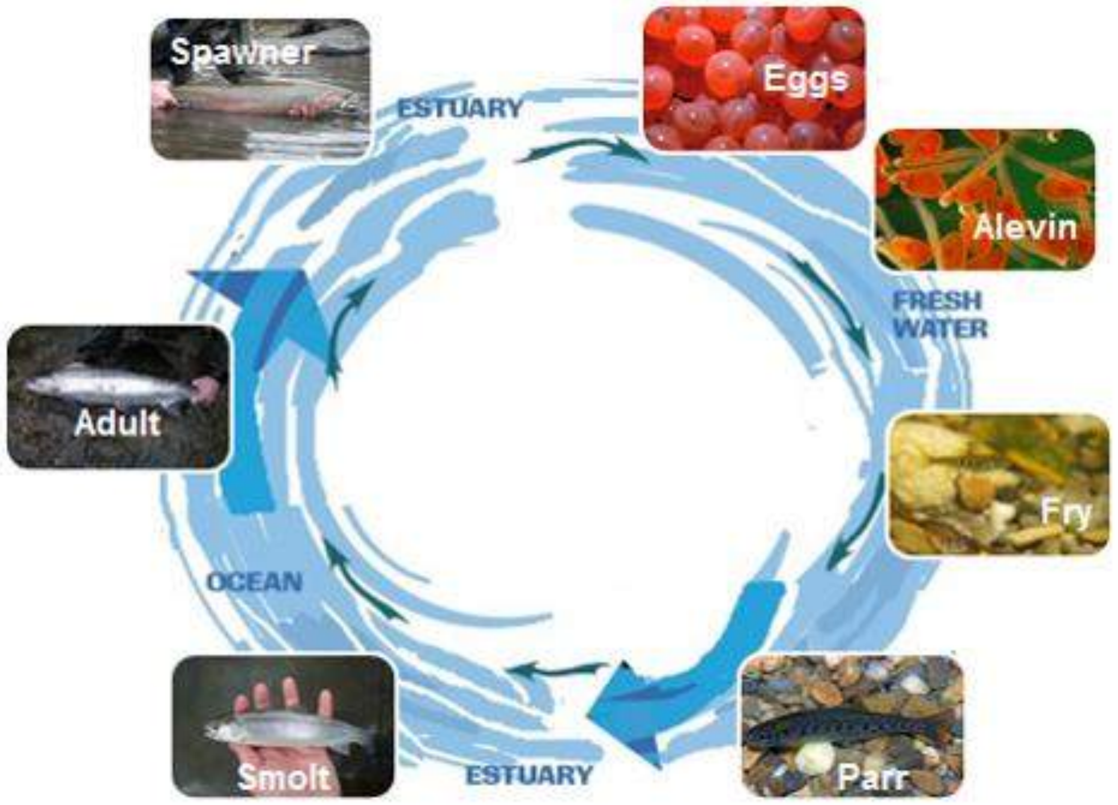


Physiochemical



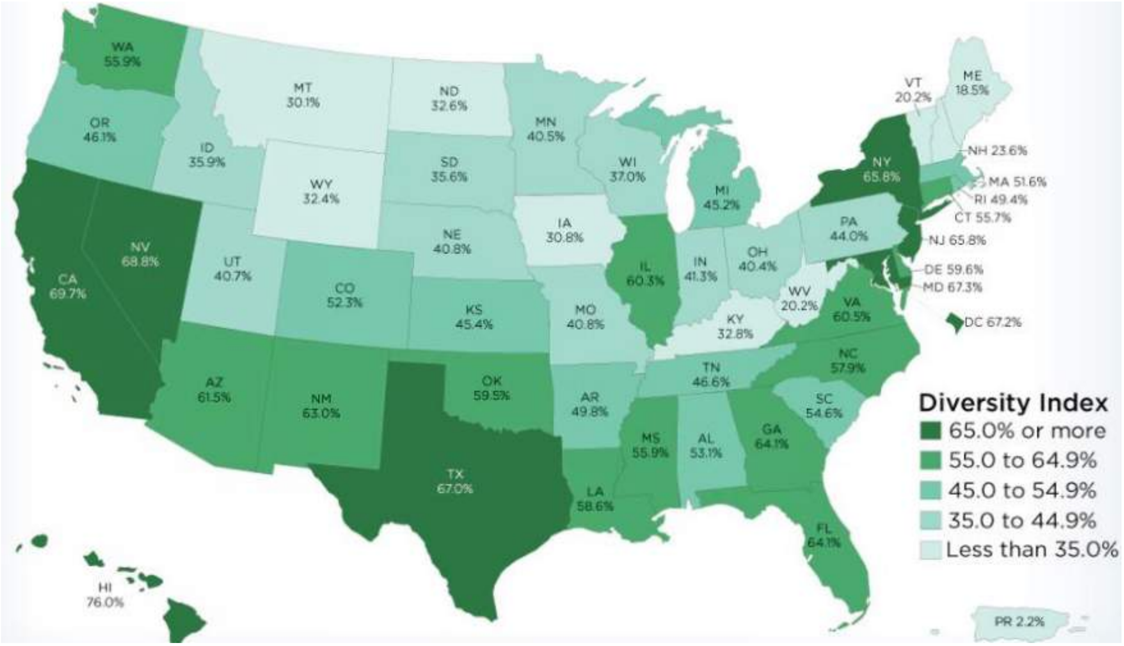
Biology



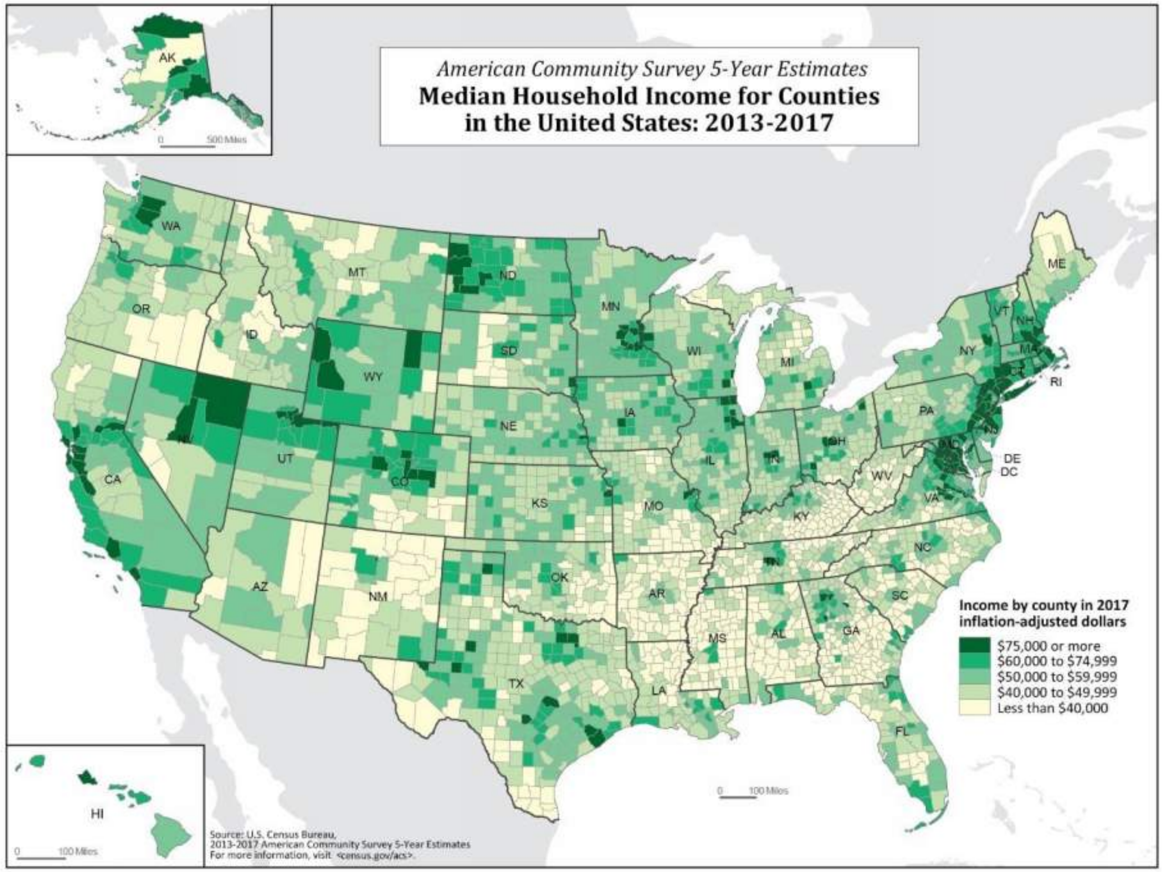


Salmon Life Cycle

Human Environment Drivers



Social



Economic

Regulatory Authorities

ESA 50

NEPA
National Environmental Policy Act

City of Santa Rosa

CalEPA
California Environmental Protection Agency

CALIFORNIA AIR RESOURCES BOARD

CALIFORNIA natural resources AGENCY

STATE OF CALIFORNIA ENERGY COMMISSION

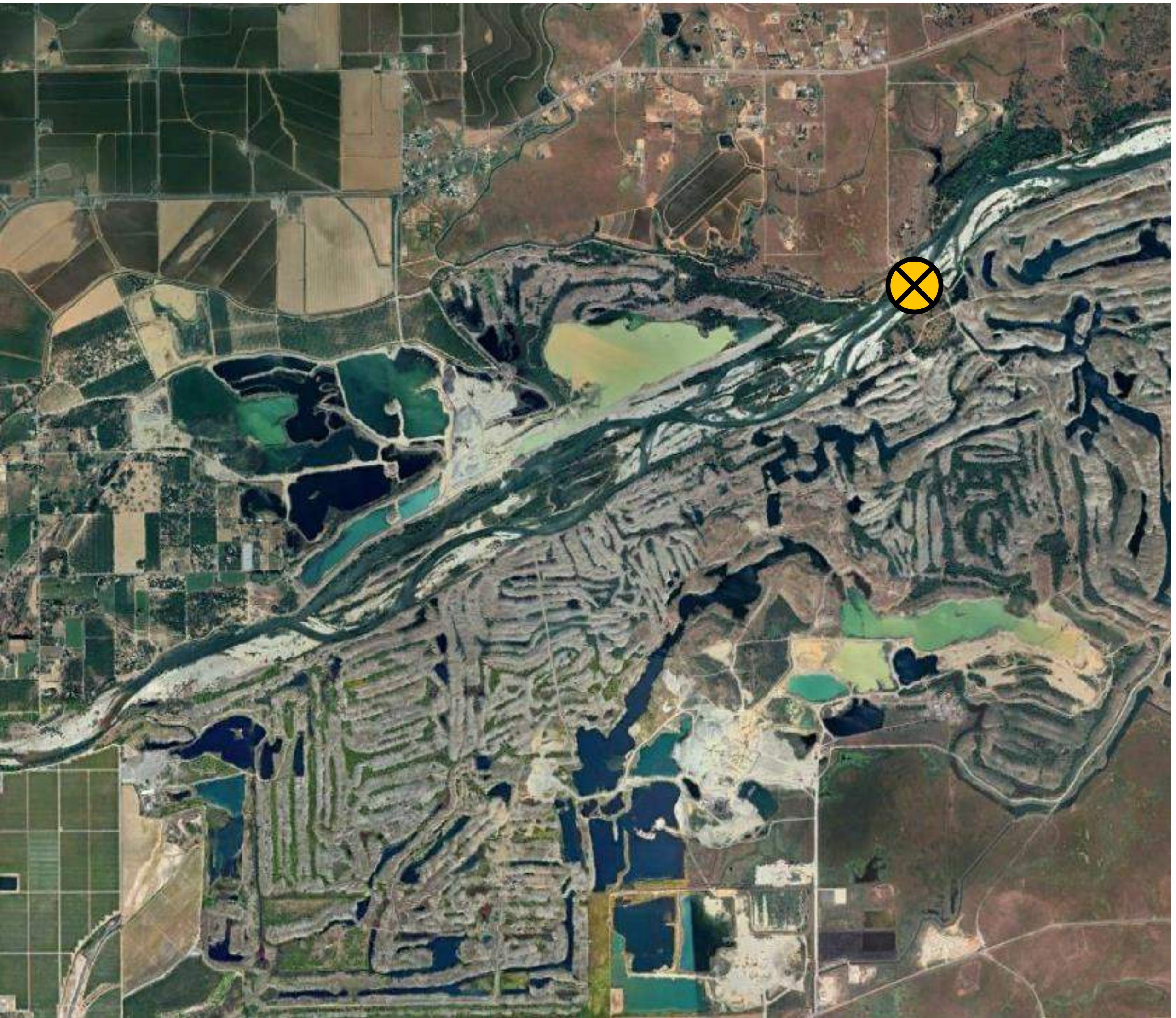
PUBLIC UTILITIES COMMISSION STATE OF CALIFORNIA

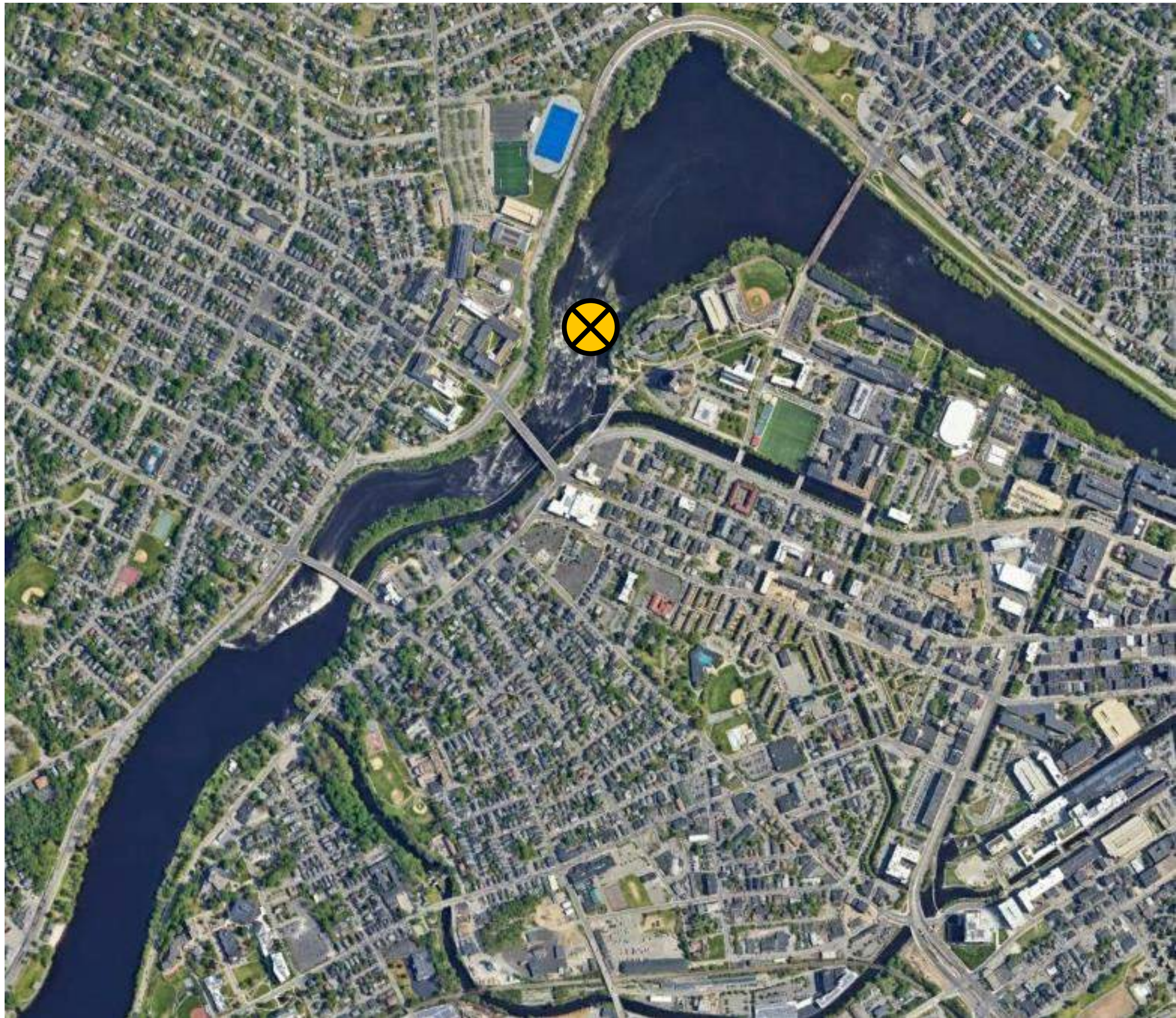
California ISO

OFFICE OF THE ATTORNEY GENERAL CALIFORNIA DEPARTMENT OF JUSTICE

Tribal Nations

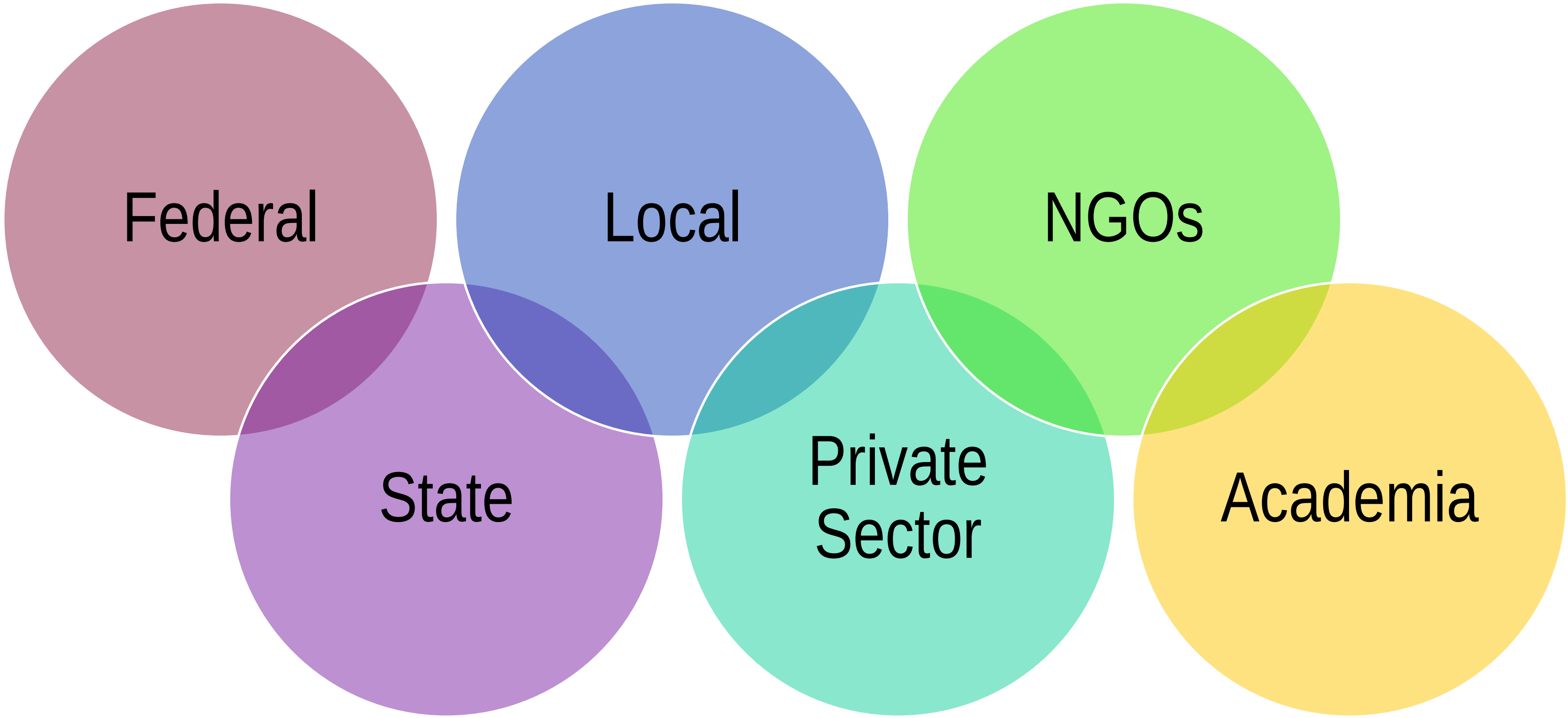
Land Uses





Water Uses

Partners and Stakeholders



02

Watershed Assessment Exercise

- Split up into 8 groups
- Discuss watershed assessments
- Report Out

Watershed Assessment Group Exercise

1. What assessment components are you most and least comfortable with? Why?
2. Is this specific to one watershed or true across multiple watersheds you work in? Why?
3. Do you invest more resources into components you are more familiar with or less familiar with?
4. How do you assess the components you are least comfortable with and fill the gaps where needed?

The Natural Environment	The Human Environment
Biology	Stakeholders & Partners
Physiochemical	Land Use
Geomorphology	Water Use
Hydraulics	Tribal Nations
Hydrology	Regulatory Authorities

03

Types of Barriers

- Dams
- Road Crossings
- Natural Barriers

Recreation Dams

Strong Candidate

- Small systems
- Low-head
- Responsive water level
- O&M needs to be minimized
- Aesthetics
- No competing use constraints

Irrigation/Water Supply Dams

Good Candidate

- Responsive water level
- Low-head
- Remote

Hydroelectric Dams

Candidate

- Variable head
- Run-of-river
- Hydro operations may improve attraction to the entrance if located properly

Navigational Dams

Fair Candidate

- Large systems
- Sand bed rivers
- High tailwater fluctuations
- Inconsistent attraction flow

Storage Dams

Usually a Bad Idea

- Compromised habitat
- Insufficient hydrology
- High head

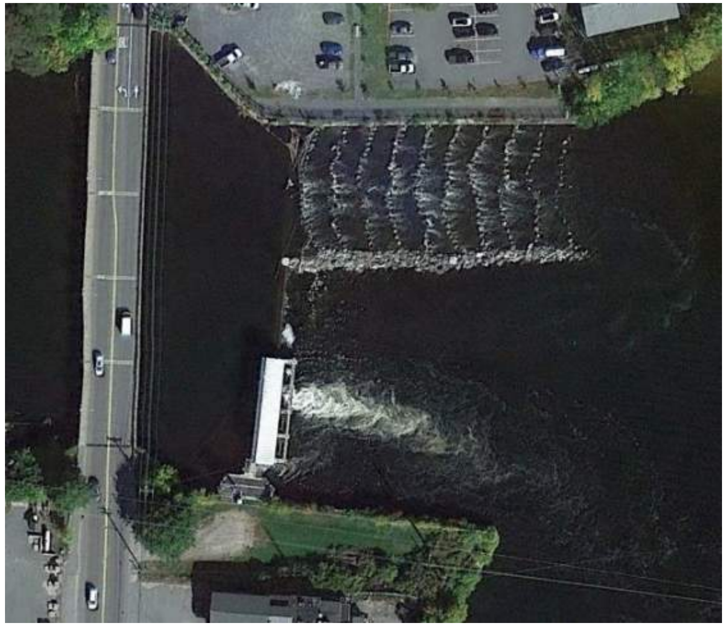
04

What are NLFs?

- Planform type
- Channel type
- What are we mimicking?

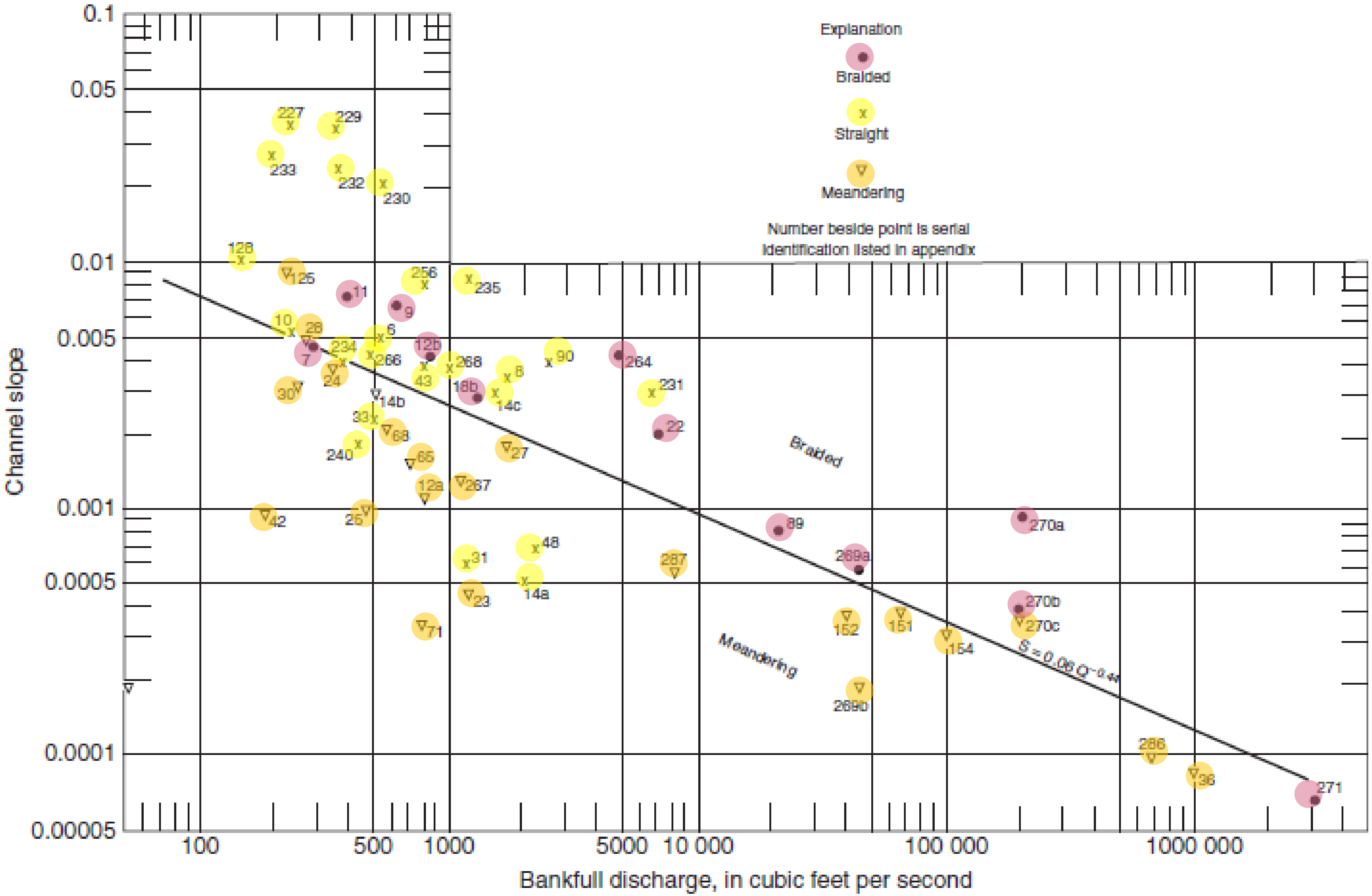
Nature-like Fishway in Planform

Bypass



Partial Width

Full Width



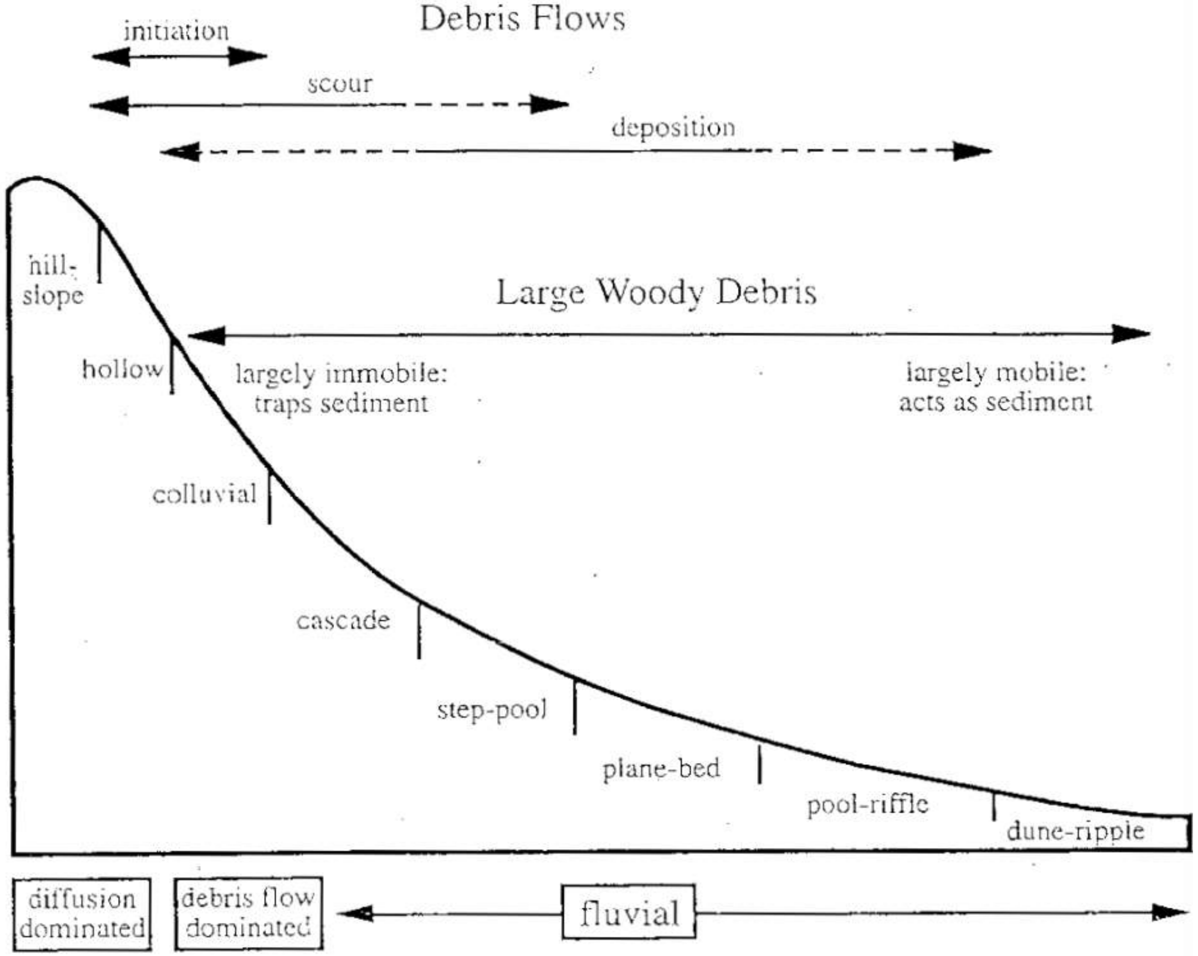
Channel Planform Pattern as a function of channel slope and bankfull discharge

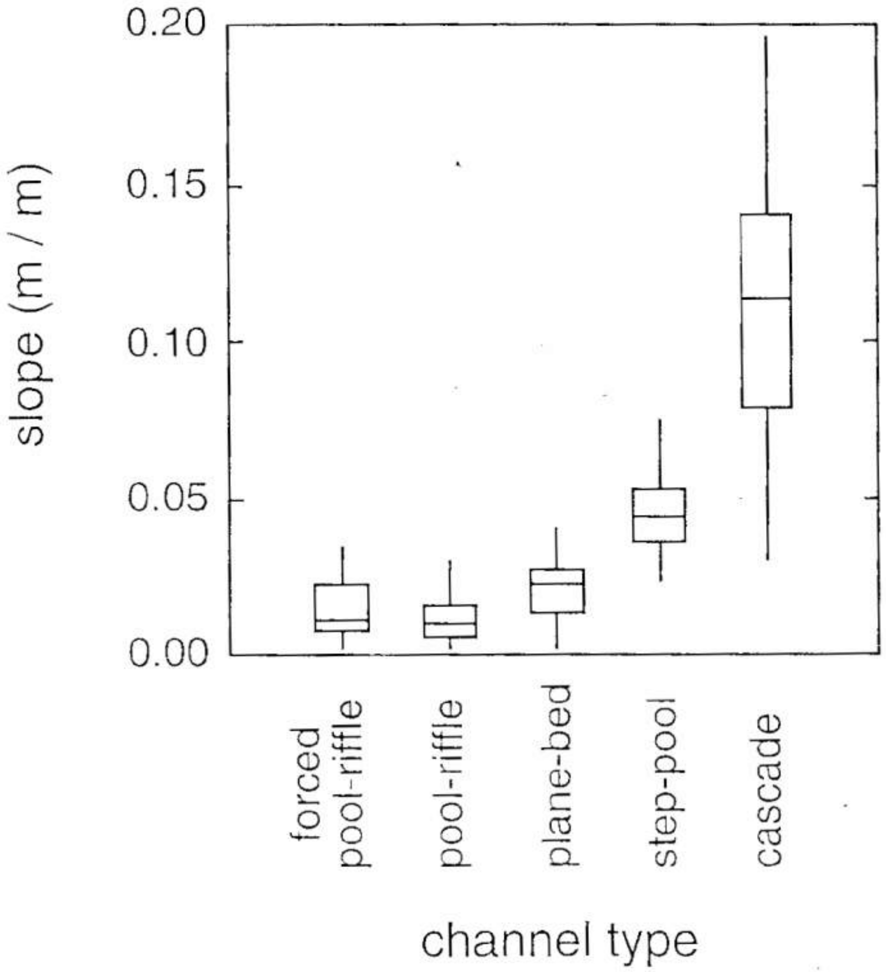
Nature-like Fishway Channel Types

Roughened Channel

Step Pool Channel

Channel Reach Morphology in Mountain Drainage Basins – Montgomery & Buffington 1997





Cascades

8 – 26% Slope

- Continuous macroscale turbulence from boulder and bedrock roughness
- Low bankfull width-to-depth ratio
  - ($6 < w/h < 14$)
- Low relative submergence ratio
  - ($3 < h/D_{50} < 7$)
- Limited sediment storage
- Confined valleys
- Boulder supply from landslide, debris flows and mega-floods

Step Pools

3 – 8% slope

- Sequence of steps and scour pools formed by wood debris, bedrock, or jammed boulders
- Low bankfull width-to-depth ratio
  - ($9 < w/h < 19$)
- Low relative submergence ratio
  - ($3 < h/D_{50} < 7$)
- Limited sediment storage
- Confined valleys
- Pools typically 1 to 4 stream widths apart

Plane-bed

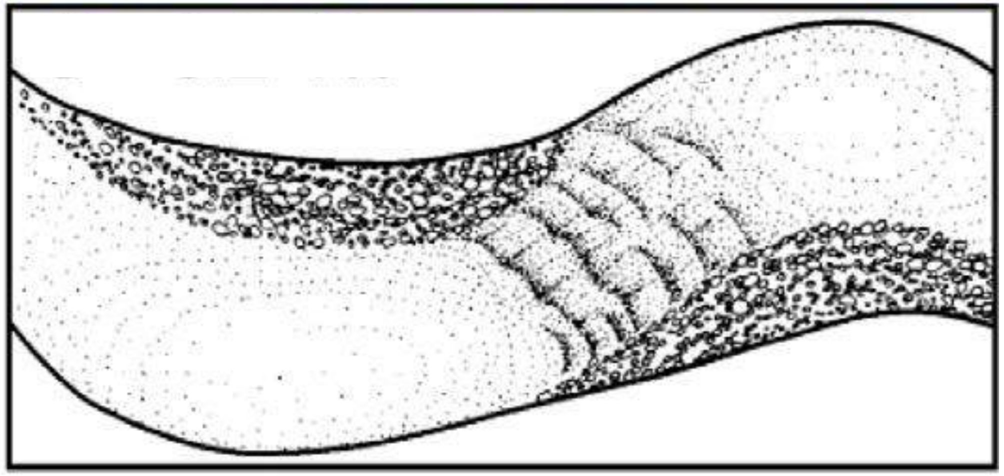
1 – 3% slope

- Glide, run, or riffle morphology without pool or bar features
- Gravel/cobble bed with occasional boulders and ephemeral sand deposits
- Low bankfull width-to-depth ratio
  - ($12 < w/h < 24$)
- Low relative submergence ratio
  - ($5 < h/D_{50} < 11$)
- Variable valley confinement

Pool-Riffle

0.2 – 1% slope

- Alternating pool and bar topography
- Gravel/cobble/sand bed material
- Moderate bankfull width-to-depth ratio
  - (15 < w/h < 33)
- Large relative submergence ratio
  - (13 < h/D_{50} < 40)
- Unconfined



*Buffington and Montgomery 2022


Bedrock

05

Site Selection

Exercise

- Split up into 8 groups
- Discuss site selection
- Report Out

Site Selection Exercise

Based on personal experience

1. What led you to select a Nature-Like Fishway (NLF)?
2. What information did you not have, but still made a decision to design a NLF?
3. What has stopped you from selecting a NLF?
4. What were the risks and opportunities in implementing a NLF?