EXPANDING MONITORING AND PERFORMANCE TO DYNAMIC STREAM SYSTEMS

Pre-Conference Workshop at the National Stream Restoration Conference
Baltimore, MD
August 21, 2023

Lead Instructor – Organizer

Samuel Leberg (ORISE Fellow at the EPA, Leberg.Samuel@epa.gov)

Presenters

Matthew Hubbard - Ecotone, Inc.
Caroline Nash-CK Blueshift, LLC
Art Parola-University of Eastern Kentucky
Bob Siegfried- Resource Environmental Solutions
Brian Topping-US EPA

Panelists

Will Harman-Stream Mechanics
Nick Ozburn - USACE, Baltimore District
Ellen Wohl- Colorado State University
Jason York – Michael Baker International

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Special Session Overview: Expanding Monitoring and Performance to Dynamic Stream Systems

Abstract

Historically, compensatory mitigation has discouraged restoration of dynamic and multithread stream systems (i.e. streams that may change significantly between monitoring periods) largely because the majority of performance standards and monitoring requirements were designed with relatively static, single thread channels in mind. However, the restoration of dynamic and multithread systems (including stream wetland complexes, Stage 0, beaver related, and valley restoration) has grown in frequency and been shown to achieve high ecological lift. Accommodating these restoration methods and outcomes in compensatory mitigation projects requires new regulatory tools including performance standards and monitoring requirements appropriate for dynamic and multithread systems. This special session aims to begin to fill those gaps and produce a report from the conference session as a public resource/reference.

In this session we will first present two examples of dynamic stream restoration projects in different parts of the country including their monitoring strategies and results. We will then present a potential monitoring strategy for identifying points of concern in large dynamic systems using holistic assessments instead of, or in combination with, plot and transect assessments. The final two sessions will explore approaches for adaptive management of dynamic sites and specifically how beaver could be managed in these dynamic systems (and in traditional restorations) by adapting performance standards to a changing stream. In addition to the presenters there will be a consistent panel who lead off the discussions and provided additional depth of review for each presentation. Each session will be followed by an initial response by our standing panel before opening up to general questions, comments and suggestions from the audience. The panel will also contribute to finalizing the resulting report from the session.

Session Overview

Section Title and Presenter	Start Time	Description
Section 1: Introduction **Sam Leberg, ORISE (EPA)**	8:30	20-minute summary of pre-conference performance document and general session overview
Section 2: Example of dynamic stream valley project in the eastern US **Art Parola, University of Louisville**	8:50	10-minute presentations, followed by 10-minutes for panel responses and Q&A
Section 3: Adapting Monitoring protocols to dynamic rangeland restoration projects **Caroline Nash, CK Blueshift LLC**	9:10	
Section 4: Monitoring for Dynamic Alluvial Valley Mitigation Projects **Bob Siegfried, RES**	9:30	

Section Title and Presenter	Start Time	Description
Break	9:50	10-minute break
Section 5: Beaver Colonization: Performance Standards and Mitigation Credits-Valuing System Complexity Matthew Hubbard, Ecotone Inc.	10:00	10-minute presentations, followed by 10-minutes for panel responses and Q&A
Section 6: Alternative Endpoints and Adaptive Management Brian Topping, EPA	10:20	
Section 7: Q&A/Discussion	10:40	30-minute facilitated discussion between audience, panelists, and speakers.
Final Thoughts	11:10	5-minute Session Summary

Expanding Monitoring and Performance to Dynamic Alluvial Valleys

Sam Leberg

Oak Ridge Institute for Science and Education Fellow at the EPA

Photo Credit: Palmer Hough

Panel Description

- Brief introduction and background
- 5 presenters
  - 10-minute presentations
  - Input from the standing panel
  - Audience feedback and Q&A
- Conclude with an overall discussion of the practice
  - Final thoughts

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Section 7: Q&A/Discussion	10:40
Final Thoughts	11:10

Panel Introductions

- Ellen Wohl is a professor in the Department of Geosciences at Colorado State University and a University Distinguished Professor. Her research focuses on physical processes and forms in river channels and floodplains, and how these interact with biogeochemistry and ecological and human communities. She has conducted field research in diverse environments around the world.

- Will Harman has 32 years of experience in fluvial geomorphology and stream restoration. He is currently the owner of Stream Mechanics where he focuses on improving stream restoration and mitigation through the development of assessment and design-review tools, including the Stream Functions Pyramid Framework. More recently, he co-developed the Stream Quantification Tool (SQT) to measure functional lift from stream restoration projects and functional loss from permitted impacts.

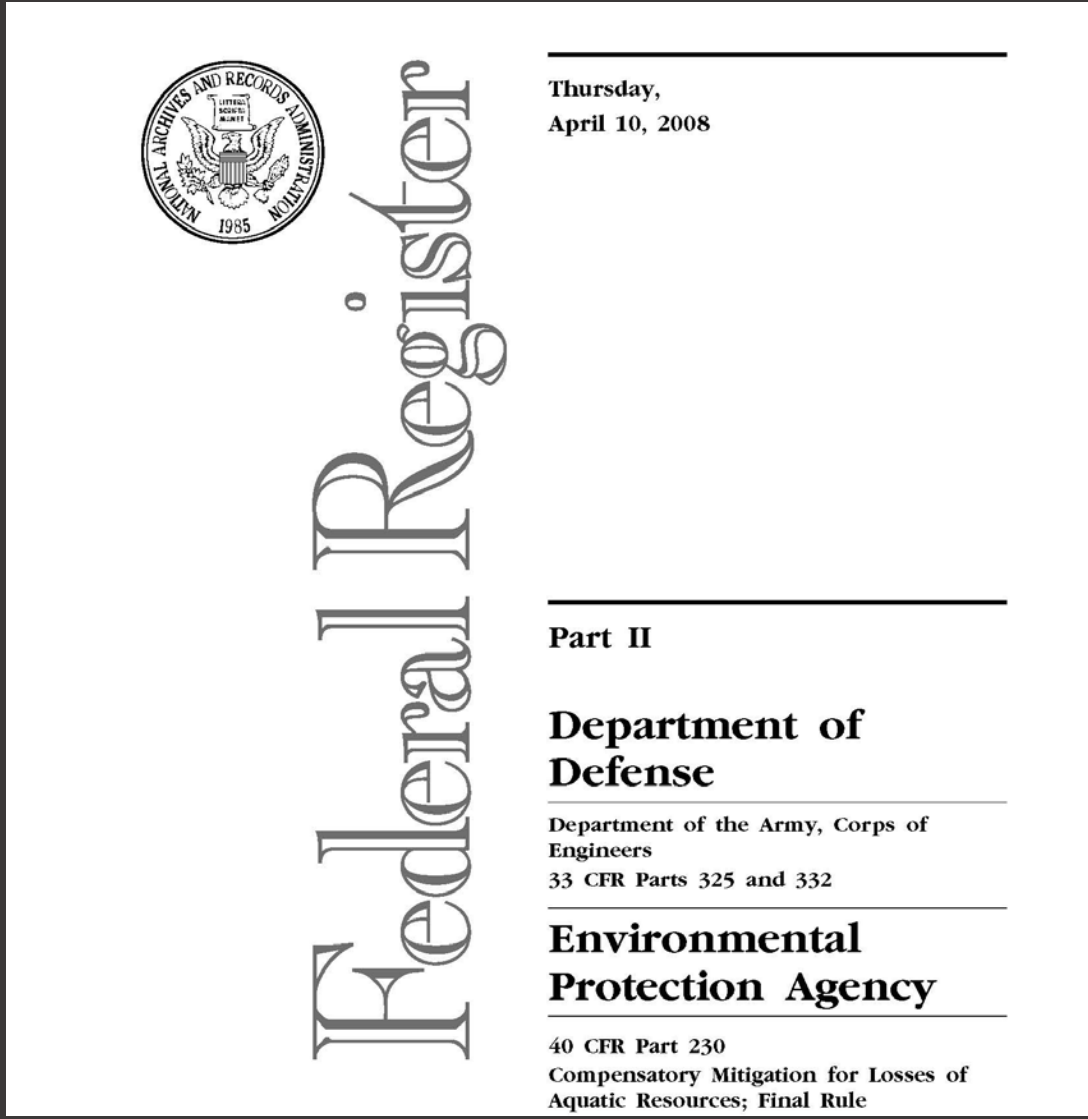
Panel Introductions

- Nick Ozburn has served at the Corps Baltimore District Regulatory Branch for 10 years. In that time, he has worked on mitigation banks, infrastructure projects, stream restoration reviews, and mitigation process development. Nick spent his early career delivering mitigation projects for the Kentucky In-lieu fee program

- Jason York is an Environmental Scientist for Michael Baker Intl. (MBI) in Asheville, NC where he oversees MBI’s NC Certified Laboratory for Population Studies of Benthic Macroinvertebrates. His recent work involves the development of software for the analysis of pre and post construction macroinvertebrate data in order to help define biological success criteria for restoration projects in the Mid-Atlantic region.

Stream Compensatory Mitigation

- Compensatory Mitigation required for dredge and fill impacts under Section 404 of the Clean Water Act
- 2008 Mitigation Rule
    - Standardized review and approval
- Monitoring requirements and performance standards central to the evaluation of compensatory mitigation projects



Federal Register

Thursday,
April 10, 2008

Part II

Department of Defense

Department of the Army, Corps of Engineers
33 CFR Parts 325 and 332

Environmental Protection Agency

40 CFR Part 230
Compensatory Mitigation for Losses of Aquatic Resources; Final Rule

Stream Compensatory Mitigation

- Stream mitigation practices have focused on stream stability and form, particularly perennial single-thread transport channels
  - Determining compliance is relatively straightforward
- Existing mitigation protocols increase time and effort required for reviewing other stream types and restoration approaches
  - Limited best practices for process-based frameworks
  - No standard methodology for addressing healthy dynamism including beaver
  - Metrics lacking for retentive and multi-thread systems

Retentive Streams *(Dynamic Alluvial Valleys)*

- Retentive, multithread systems
  - Retentive, multi-thread systems much more prevalent pre-anthropogenic disturbance
    - Wohl et al. 2021, Walter and Merritts 2008, Cluer and Thorne 2014
  - Restoration of these systems may result in significant ecological uplift
    - Powers et al 2019, Braccia et al. 2023, Cluer and Thorne 2014

What is needed?

- Regulators and mitigation providers need tools to monitor and evaluate retentive systems
  - Inform other steps in mitigation review
- Healthy dynamic systems will naturally experience shifting habitats across their site
  - Requires an approach addressing a range of potential outcomes
- Design considerations are important for successful implementation

Conference Report

- "Expanding Monitoring and Performance to Dynamic Alluvial Valleys"
- This report provides a resource for the stream compensatory mitigation community to consider when proposing or evaluating dynamic alluvial valleys
- Sections
  - Design Considerations
  - Monitoring Considerations
  - Performance Metrics
  - Adaptive Management

Methodology

- Created a series of questions to examine performance standards & monitoring requirements
  - Identify other areas where changes are needed
- Conducted semi-structured interviews with 60 participants concurrently with literature review
- Regulators (18)
  - EPA
  - Corps
  - States
- Practitioners (27) & academics (15)

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Megan Fitzgerald and Christine Mazzarella (Environmental Protection Agency [EPA]) Region 3); Eric Somerville and Bill Ainslie (EPA Region 4), Kerryann Weaver (EPA Region 5); Aaron Blair and Rachel Harrington (EPA Region 8); Joseph Morgan, Melissa Scianni, and Jennifer Siu (EPA Region 9); Tracie Nadeau (EPA Region 10); David Olson (United States Army Corps of Engineers [USACE] Headquarters); Nick Ozburn (USACE Baltimore District); Justin Hammonds and Adam White (USACE Savannah District); Todd Tugwell (USACE Wilmington District); April Marcangelli (USACE St. Paul District); Michelle Mattson (USACE Institute of Water Resources); Periann Russell (North Carolina Department of Environmental Quality); Dave Goerman (Pennsylvania Department of Environmental Protection); Joe Berg (Biohabitats Inc.); Caroline Nash (CK Blueshift LLC); Ellen Wohl and Jeremy Sueltenfuss (Colorado State University); Amy Braccia (Eastern Kentucky University); Cidney Jones and Rich Starr (Ecosystem Planning & Restoration); Jason Coleman and Matthew Hubbard (Ecotone, Inc.); Paul Mayer (EPA Office of Research and Development); Lucy Harrington (GEI Consultants); Mike "Rocky" Hrachovec (HydroGeoLogic, Inc.); Benjamin Ehrhart and Ward Oberholtzer (LandStudies, Inc./Century Engineering); Ashton Bunce, Jeanette Blank, Leah Swartz, and Wendy Weaver (Montana Freshwater Partners); Bob Siegfried, Katie Wolff, Michael Sachs, and Matthew Stahman (Resource Environmental Solutions); Adam Riggsbee (RiverBank Conservation); Eric Stein (Southern California Coastal Water Research Project); Will Harman (Stream Mechanics); Lindsay Teunis (SWCA Environmental Consultants); Art Parola, Jesse Robinson, Michael Croasdaile (University of Louisville); Gordon Grant, Paul Powers, Johan Hogervorst, and Rebecca Flitcroft (United States Department of Agriculture Forest Service); Joseph Wheaton (Utah State University); Alex Fremier (Washington State University); Peter Skidmore (Walton Family Foundation); AJ Jones and Joe Rudolph (Wolf Water Resources); Janine Castro (United States Fish and Wildlife Service); and Barbara Doll (North Carolina State University). Thank you also to Brian Topping (EPA) for mentorship and support throughout the development of the report and my ORISE fellowship at EPA.

Workshop Session Goals

- We are hoping to identify important and indicative metrics to assess dynamic streams
- Any input on our performance document would be greatly appreciated
- We are looking for audience input in all areas, but our focus is on metrics and performance, not:
  - Jurisdiction
  - Crediting and ratios
  - In or out-of-kind compensation

Dynamic Alluvial Valleys (DAVs)

- Stream System, not a design practice

- Depositional/retentive systems within the stream network whose form is dominated by biological drivers (vegetation, beaver, etc)

- May be multithreaded, and the location and relative coverage of specific habitats may change between monitoring periods

- Defined by four key processes

DAV: Key Processes

- **Extensive lateral and vertical connectivity**-Biologically active surface and subsurface connectivity is maintained even during baseflow conditions
- **Creation and maintenance of diverse habitats**-The channel and the floodplain are a part of a united mosaic of streams and wetlands
- **Retention of materials**-The valley retains sediment and organic matter. Areas vary but majority of features and habitats within the channel and on the floodplain are depositional
- **Abundant biological communities**-The valley supports an abundant (often diverse) biological community that contributes to the form of the valley

Design Considerations

- Not every site can support the restoration of a DAV.
  - DAVs require significant space to accommodate high flows while retaining material
  - DAVs are appropriate to restore in relatively wide, lower gradient valleys, in either current or historical depositional areas
- Necessary to determine potential endpoints and trajectories for a given project

Dynamic Alluvial Valley(DAV) Failure Points

Key Processes of DAV lost	Failure Point(s)
Loss of extensive lateral and vertical connectivity	Failure of valley-wide grade control(s)
Loss of habitat diversity	Failure to account for channel drying and loss of water
	Failure to account for excessive deposition
Loss of net retentive valley	Failure to design transitions with upstream and downstream reaches
	Failure to account for excessive erosion
Loss of biological communities	Failure to establish desirable vegetative communities
	Failure to design for poor water quality

Monitoring Procedures

- Valley-wide transects

- Large site-scale assessments
  - GIS, LiDAR, and drone-based photography
  - Hydraulics and geomorphological, some vegetation metrics

- Random grid-based sampling (Hinshaw et al. 2022)
  - Encompassing in-channel and floodplain
  - Geomorphology and biological metrics

- eDNA monitoring
  - Amphibians and fish, some macroinvertebrate metrics.

Performance Metrics

Key Process	Parameter	Indicator	Target	Timing	Notes & Considerations
Extensive Lateral and Vertical Connectivity	**Floodplain Connectivity**	Flooding/Inundation frequency, duration, and/or aerial extent; stream gage, ground water wells, water presence sensors, other continuous monitoring	Floodplain inundation events or duration in a normal flow year	Monitored in all years	Low bank height associated with baseflow channel and increased potential for multiple overtopping events per year. Similarly associated with a lack of incision. Indicative of a large flood-prone area. Specifics will vary by region. As used by practitioners in Pennsylvania, 4 times per year in a normal year, coupled with visual evidence of floodplain inundation in spring season.
Creation and Maintenance of Diverse Habitats	**Depth Diversity**	Coefficient of Variation of Depth DEMs or multispectral imagery via green wavelength LiDAR; number and variation of depth classes	Increase compared to pre-project conditions; Meeting or exceeding reference conditions	Monitored in all years	Depth diversity indicates in-channel habitat and variable zones for temperature and sediment deposition. A matrix of stream depth can be created with aerial and multispectral imagery. Different depths can then be classified, and variation quantified. Restored DAVs should result in a high diversity of depths though specific targets would be regionally-dependent.
Retention of Materials	**Carbon Retention**	Visual, photo station or otherwise	60% of monitoring stations, pieces of LWD retaining CPOM	Monitored in all years	This metric target would demonstrate that a site can retain carbon but would not necessarily demonstrate successive carbon retention. The target will vary by region and site-specific conditions and should only apply to a normal flow year.
Abundant Biological Communities	**Amphibian Communities**	Native abundance	Native quantity increase compared to control reach	Monitored in all years after the first	Retentive systems will result in a larger wetted area that may support more amphibians. Particularly in headwater streams, amphibian metrics may more reliable than fish metrics. For amphibian metrics, sample the perimeter of the reach as well as the underside of logs.

Metric Prioritization

Key Process	Stream Function Pyramid Level	SFAM Key Functions	Parameter	Indicator	Citation
Extensive Lateral and Vertical Connectivity	Hydraulics	Surface water storage, sub/surface transfer, flow variation, sustain trophic structure, nutrient cycling, chemical regulation, thermal regulation	Groundwater and Surface Water Exchange	Monitoring wells	Robinson Fork Mitigation Bank, Quaker Mitigation Bank
	Geomorphology	Surface water storage, flow variation, sediment continuity, create and maintain habitat	Lateral Migration	Bank Erodibility Hazard Index (BEHI)	Upper Susquehanna River Mitigation Bank-Phase 2, Codorus Creek Stream & Wetland Bank
	Physicochemical	Surface water storage, sub/surface transfer, flow variation, thermal regulation,	Temperature	Surface or mean water temperature through water column- DM, MWAT, monthly average (summer or winter)	Great Pee Dee Mitigation Bank, Upper Susquehanna River Mitigation Bank-Phase 2, Pollock et al. 2003

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- Feedback Form
  - Please fill it out
  - Return to us

Resilient Dynamic Restorations: The Example of Slabcamp Creek

National Stream Restoration Conference 2023

Expanding Performance and Monitoring to Dynamic Stream Systems

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University of Louisville Stream Institute

Project Sponsors & Collaborators

Slabcamp and Stonecoal Creek Restoration

Kentucky Department of Fish and Wildlife Resources, In-Lieu Fee Program
Kentucky Transportation Cabinet
US Forest Service – Daniel Boone National Forest
U.S. Environmental Protection Agency (National Office, Region 04)
U.S. Fish and Wildlife Service
Kentucky Waterways Alliance
Eastern Kentucky University

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Slabcamp Creek
Daniel Boone National Forest, Eastern Kentucky

Pre-Restoration Condition

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Pre-Restoration Condition

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Impairment – High-Stress Export System

- Incised High-Stress Channel
- Scoured bedrock or frequently mobilized channel bed material
- Poor Habitat and Habitat Diversity
- Poor connectivity of channel to floodplain
- Poor connectivity of the channel to the valley groundwater system
- Dry floodplain - No rootzone saturation
- Channel dried nearly every year.

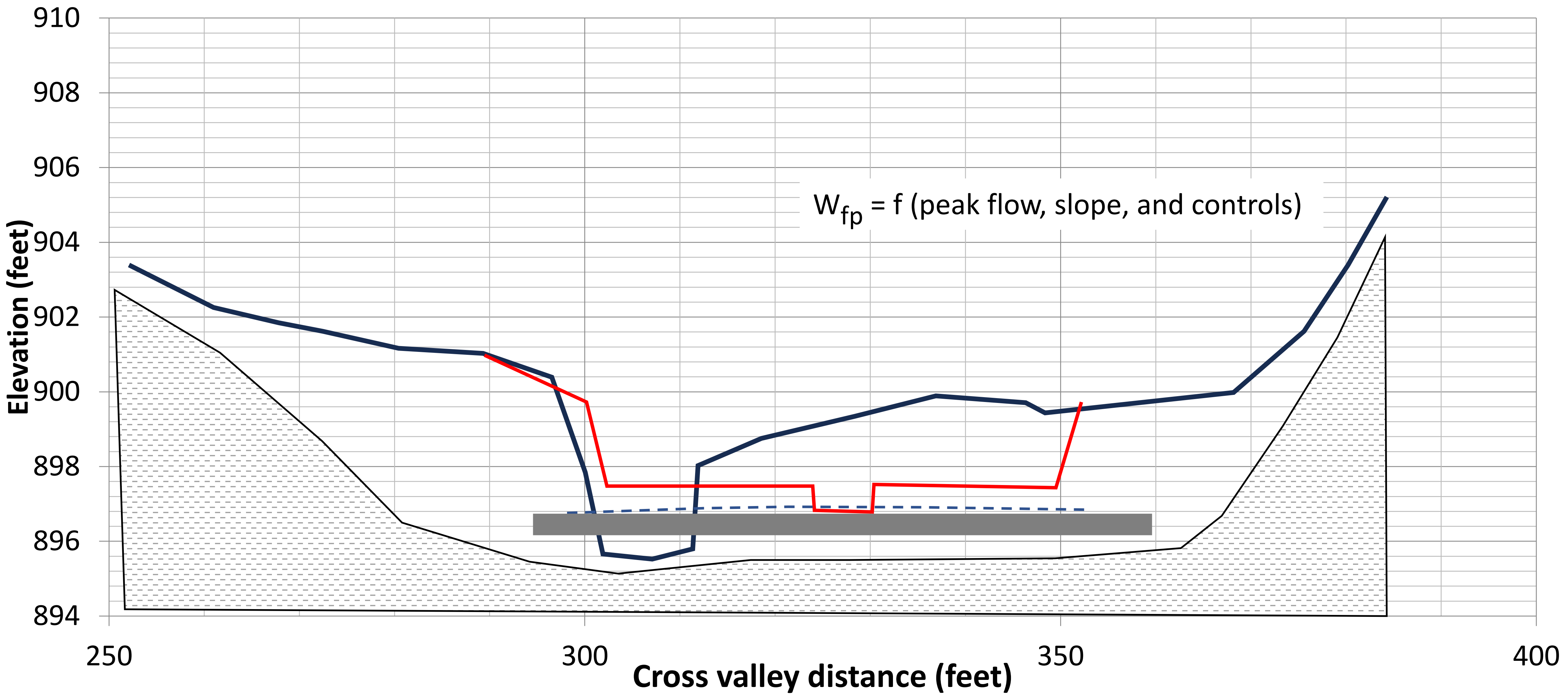
Mitigation Goals

- Robust and sustainable streams and wetlands that are stable but not static

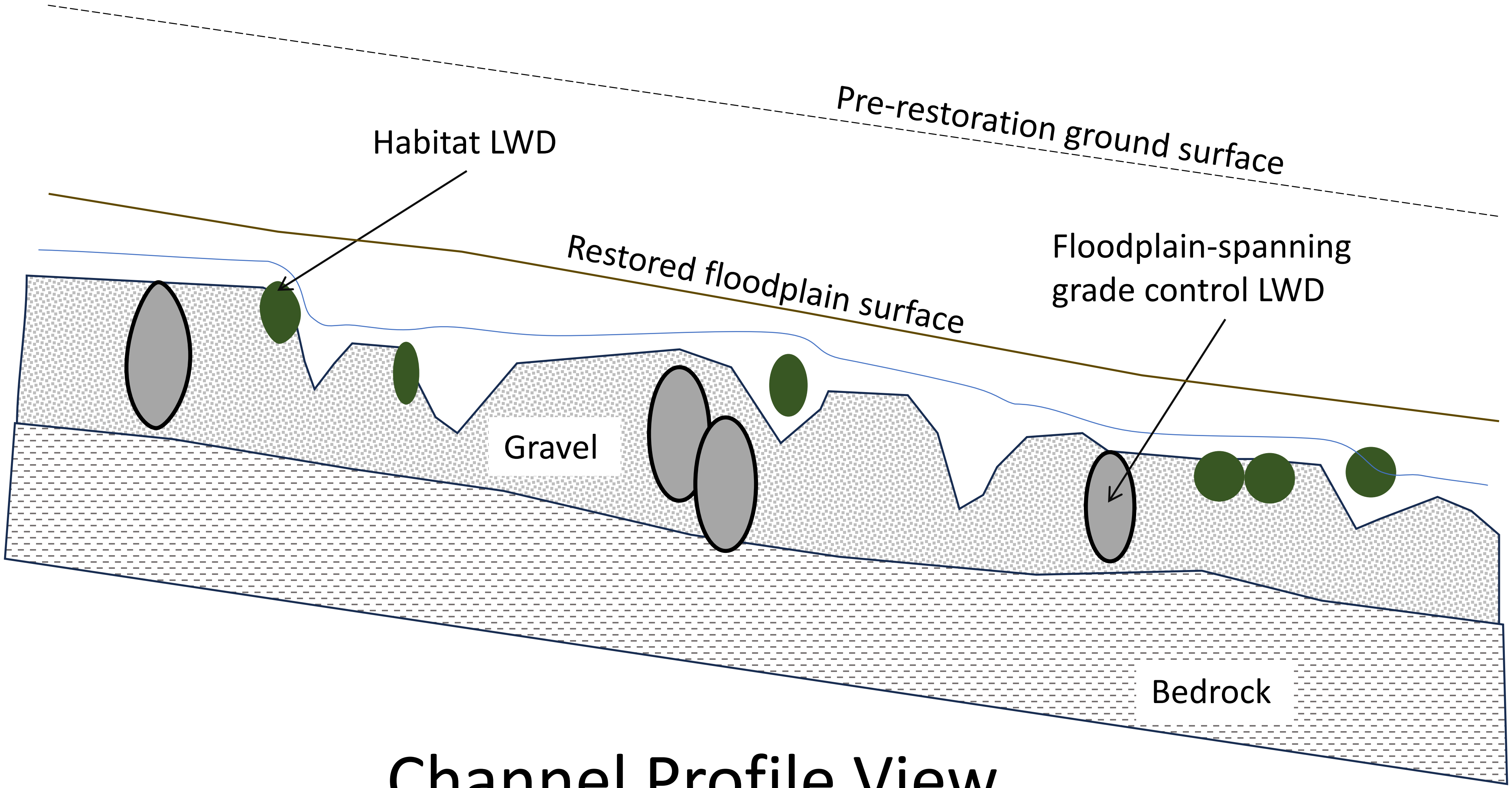
- Minimize the need for repairs

- Design high-quality channel and floodplain systems that restore lost ecological functions

Valley Cross Section



LWD Grade Control and Habitat



Channel Profile View

Baseflow maintaining GW surface

- In plant rootzone
- Sufficiently high for FP wetland soil development

Stable epifaunal substrate

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Success Criteria

Define a range of potential acceptable outcomes.

Develop flexibility in success criteria and crediting.

Define Unacceptable Failure Modes

Morphologic

- Systematic channel incision – loss of vertical controls and high stress
- Excessive floodplain surface and/or bank erosion – high shear stress
- Channel and floodplain buried in sediment – high sediment load

Hydrologic – needs to match site-specific conditions

- Channel dries – loss of groundwater controls or flow
- Floodplain dries – reduced groundwater level

Failure Modes

Habitat

- Frequent movement of bed material – unstable epifaunal substrate
- Shift in vegetation from wet to dry species
- Loss of habitat diversity

Obion Creek, Hickman County, Kentucky

Bacon Ridge Restoration
Coastal Plain, Maryland

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Upper Peninsula, Michigan

Photo by Joshua Cohen, Michigan Natural Features Inventory.

South Fork Curry's Fork, Oldham County, Kentucky

Slabcamp Creek Tributary, Moorehead, Kentucky

Slabcamp Creek Tributary, Moorehead, Kentucky

Some important notes:

- **Dynamic floodplains** can occupy a fraction of the valley bottom – they do not need to span the entire valley and rarely do.
- **Keep an open mind about the slope range for DAVs**:
  - maximum gradient (slope) = function (peak flood flows, floodplain width, and type of vertical controls)
  - 0.5% is a very high gradient for a large river.
  - Stream-wetland complexes have been found on streams at 15% slopes and 10-foot-wide valleys in very small catchments.

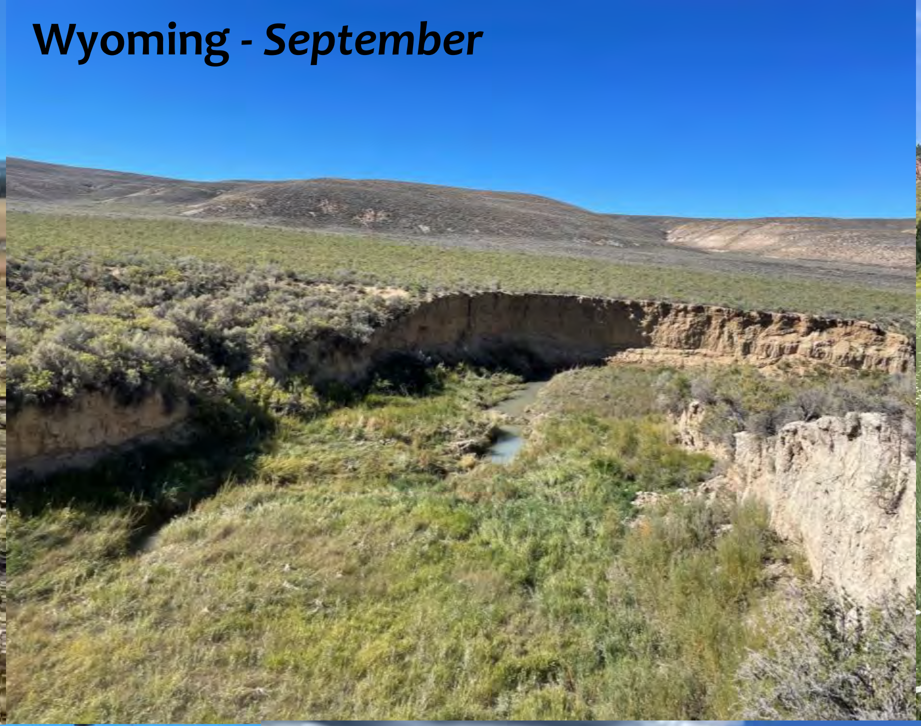
Adapting monitoring protocols to dynamic rangeland restoration projects

Caroline S. Nash, PhD

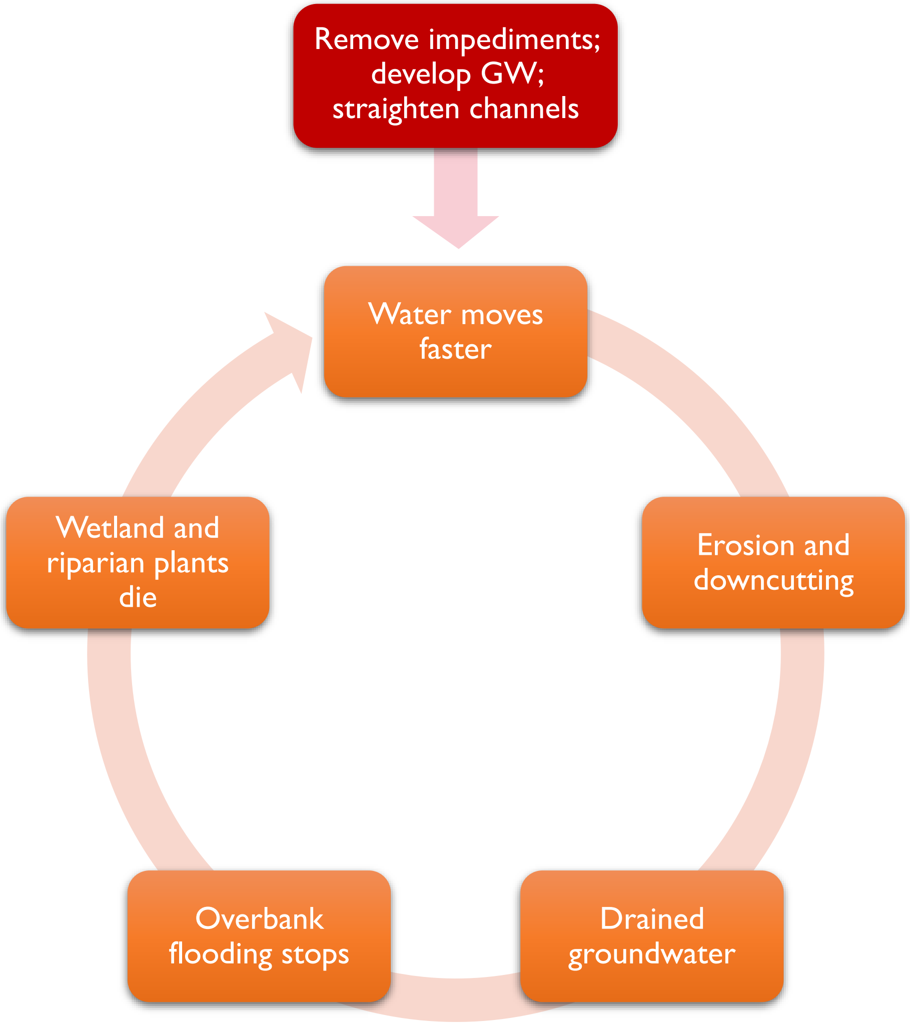
National Stream Restoration Conference | August 21, 2023

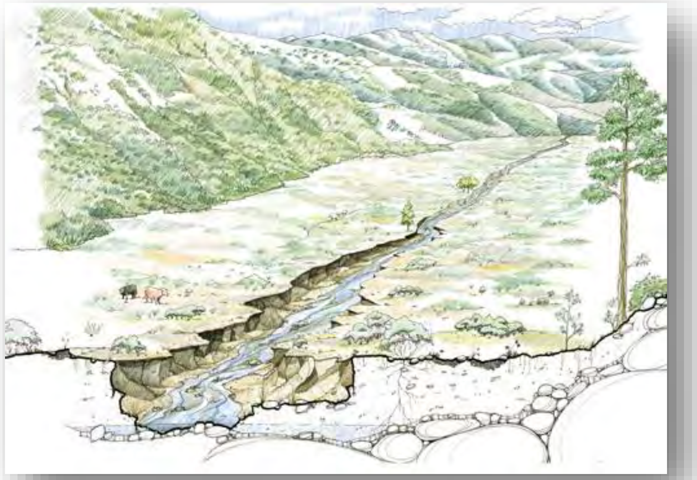
Expanding monitoring and performance to dynamic stream systems

CK BLUESHIFT Culp & Kelly LLP

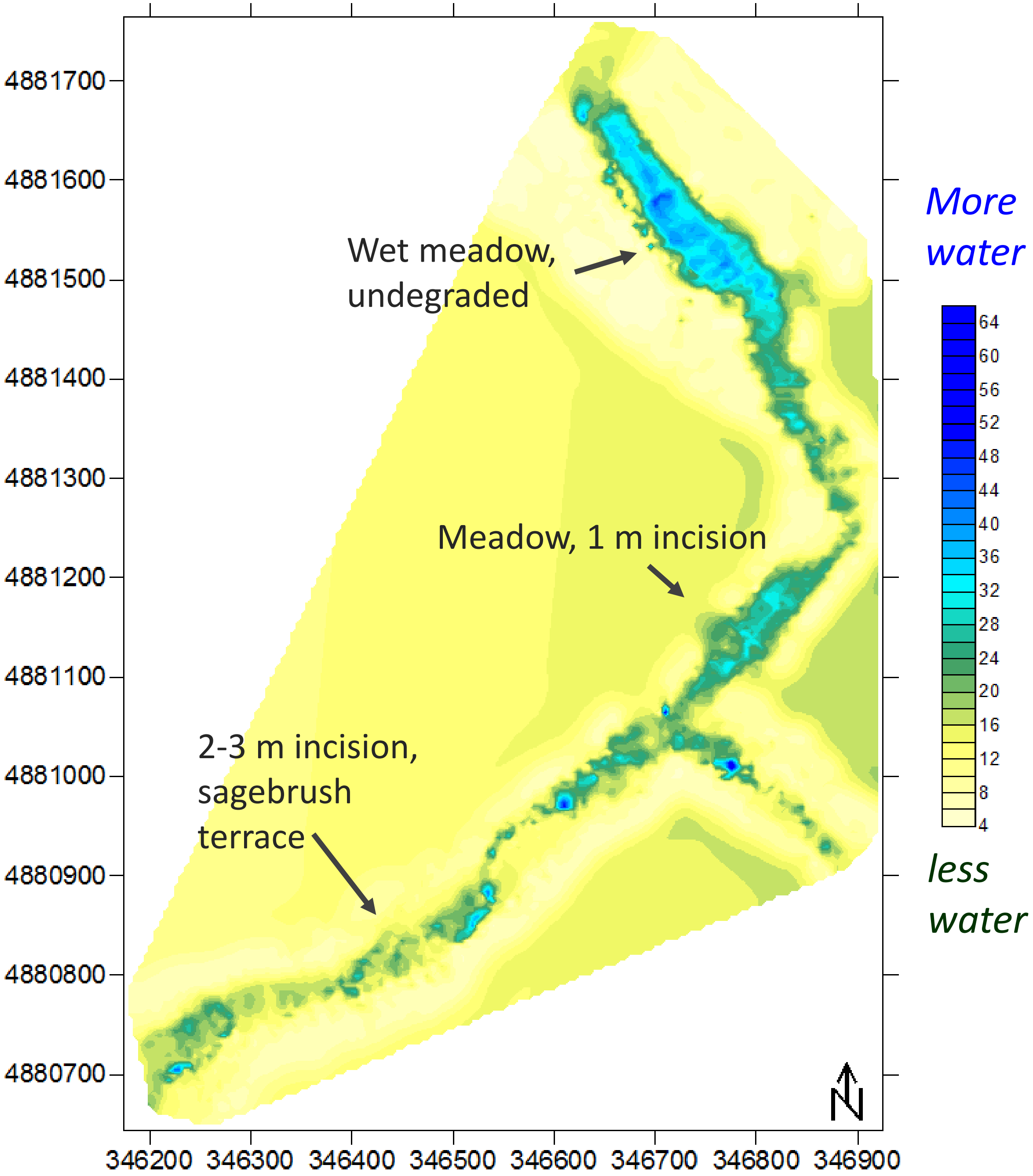


It’s dry
It’s degraded
It’s everywhere


Remove impediments; develop GW; straighten channels
Water moves faster
Erosion and downcutting
Drained groundwater
Overbank flooding stops
Wetland and riparian plants die

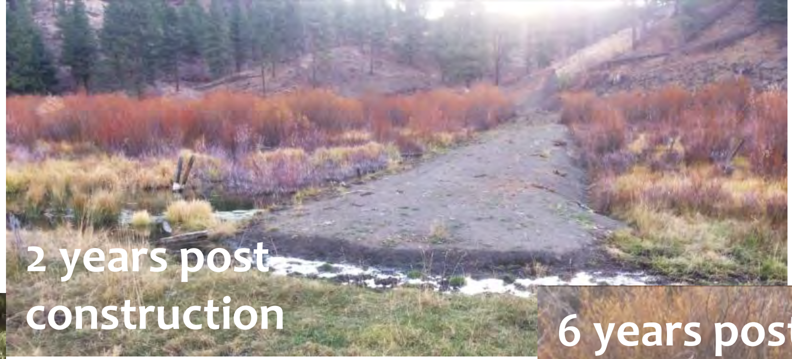


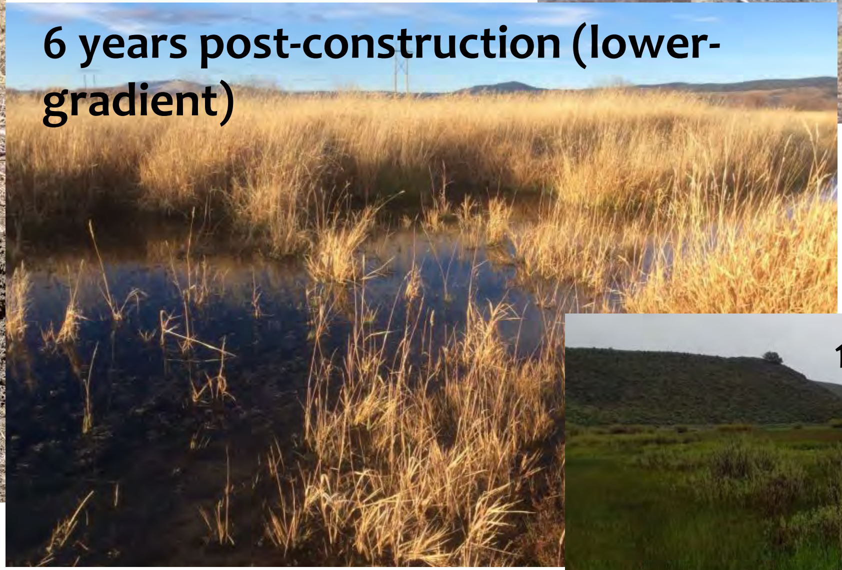
Channel incision drains plant-available water



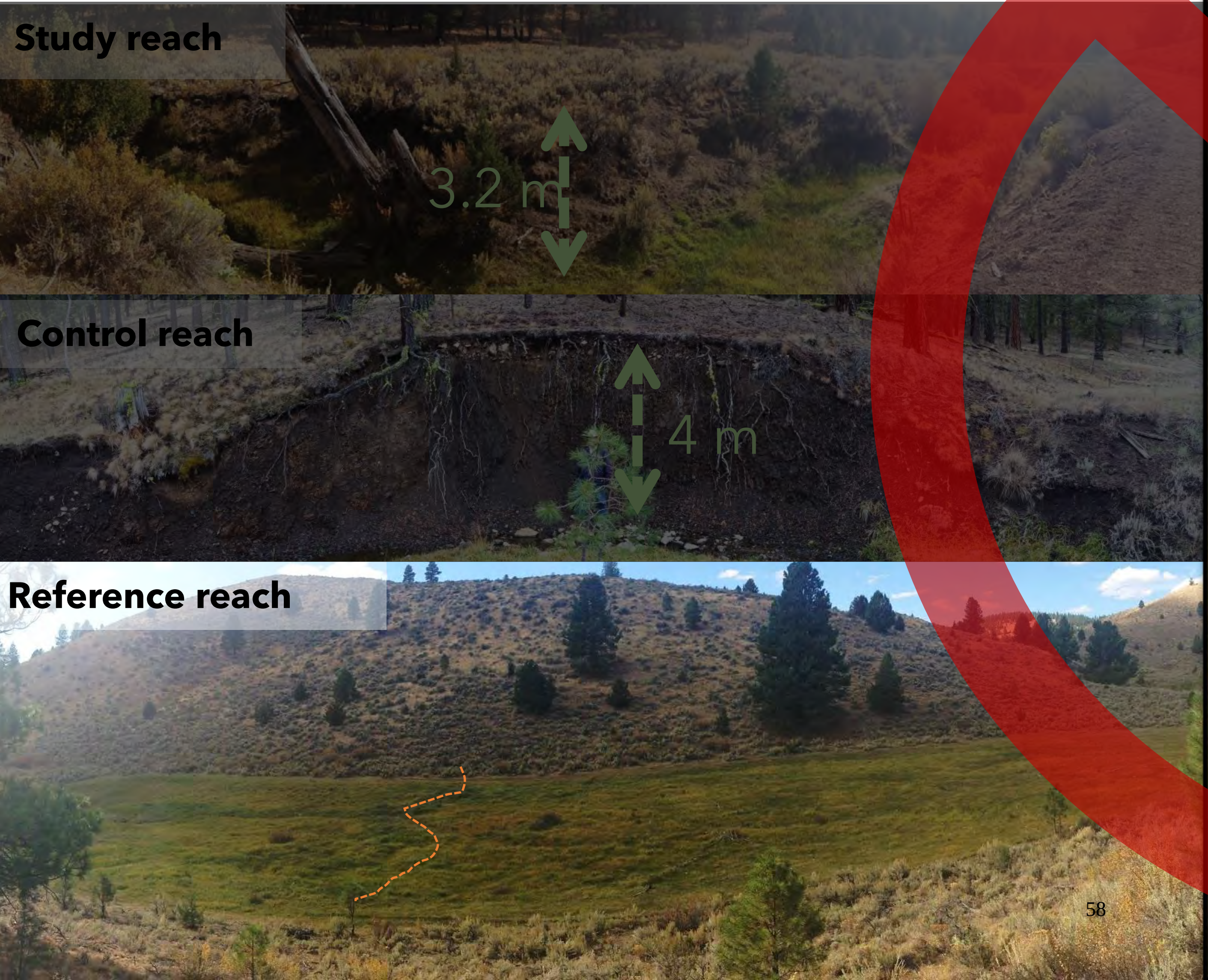
Grant County, Oregon

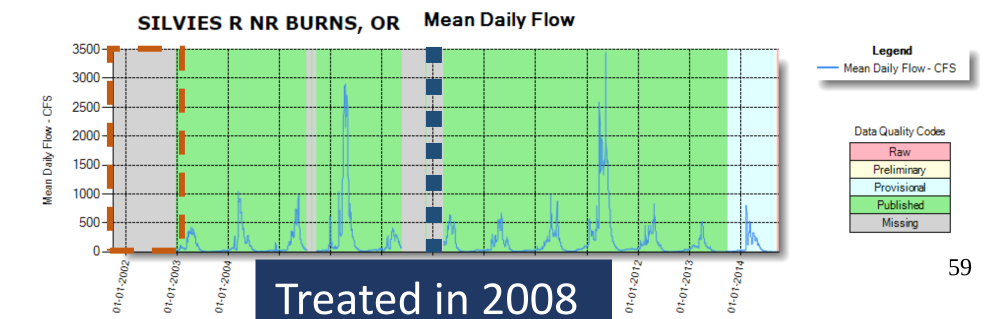
Peak Flow (April 16)





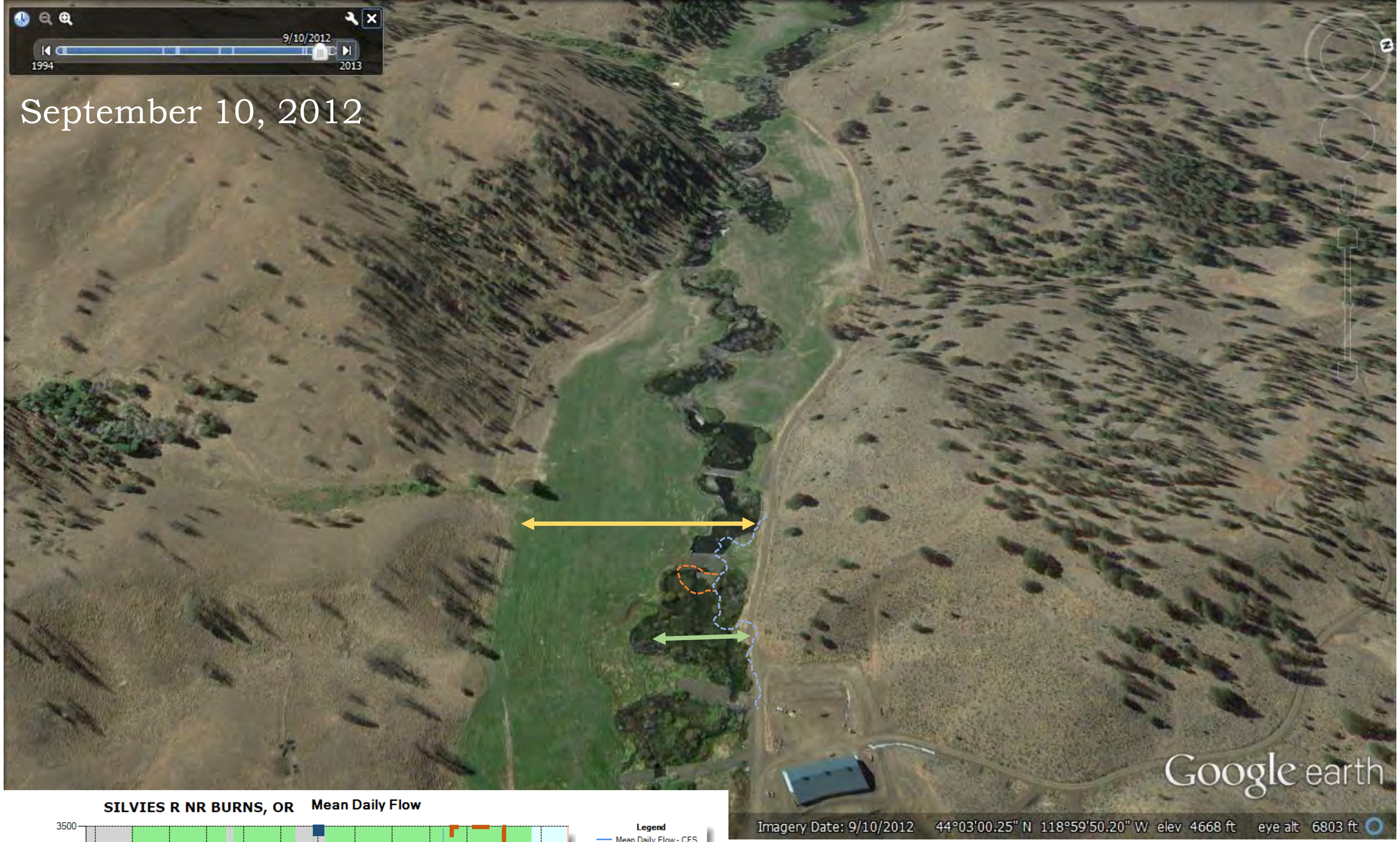
Monitoring Protocol

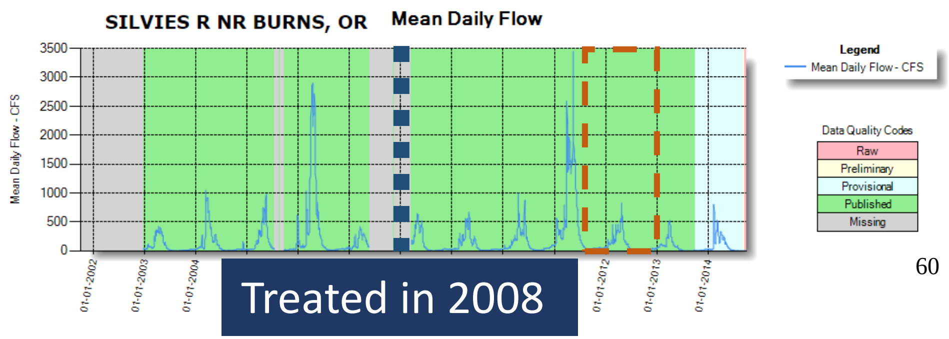




4 years prior to treatment

Camp Creek
Silvies River Basin, OR

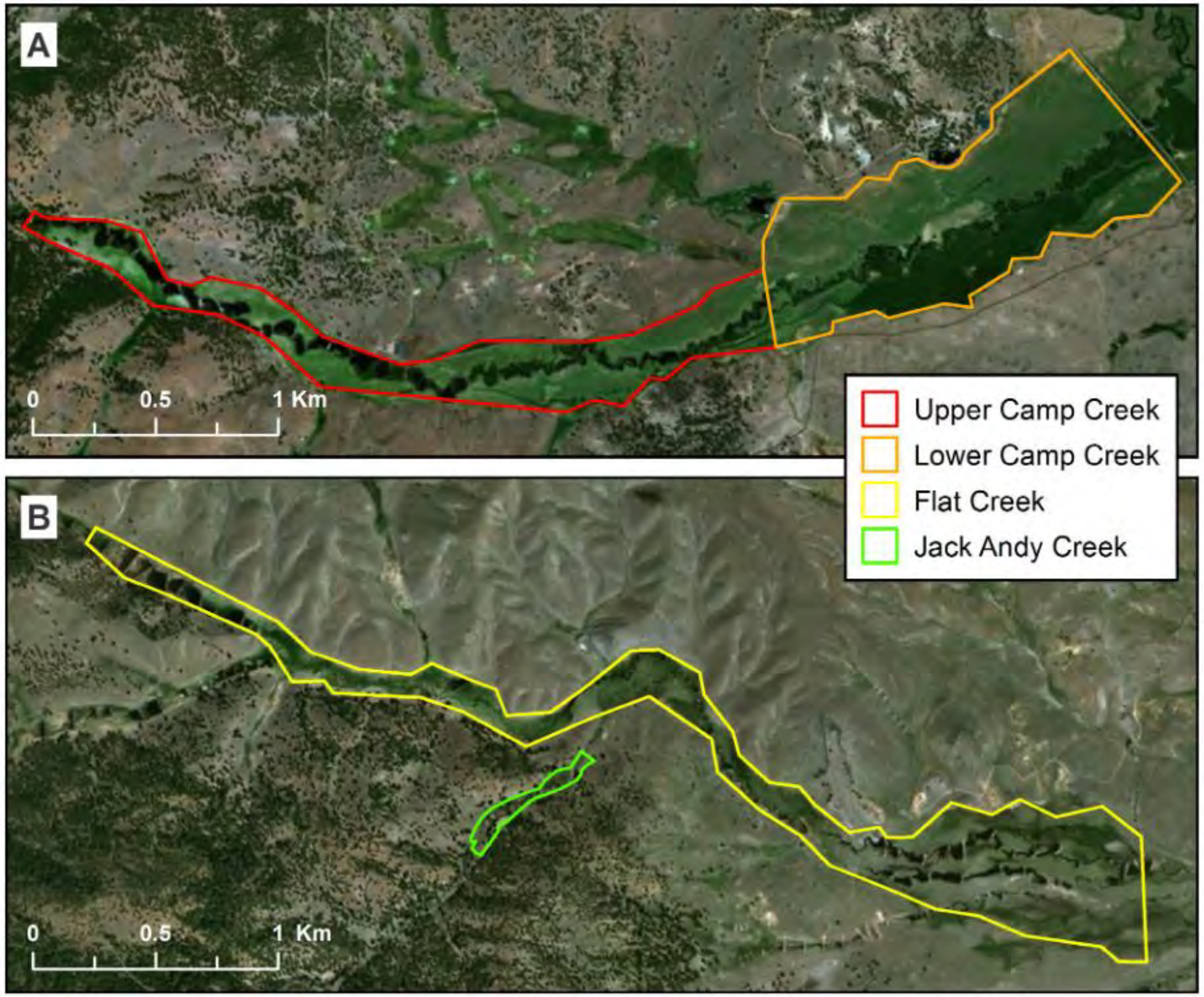


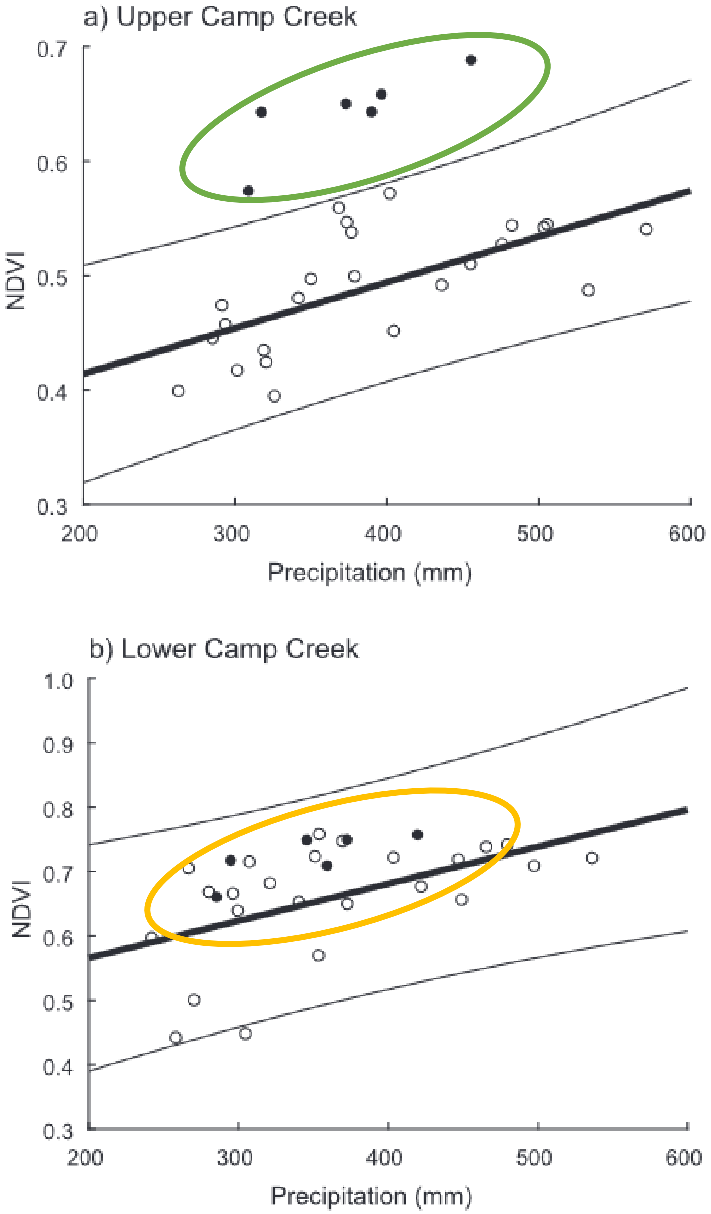


4.5 years after treatment

Camp Creek
Silvies River Basin, OR

NDVI + Precip Analysis





"effective"

"ineffective"

Hausner et. al 2018, *Assessing the Effectiveness of riparian restoration projects using Landsat and precipitation data from the cloud-computing application ClimateEngine.org,* Ecological Engineering, 120, 432-400

Rosebud County, Montana

Monitoring Protocol

5 GW wells (2 transects)

3 camera trap precip gages

3 camera trap flow gages

10 temp. sensors
(flow presence/absence)


September 2021
2023-06


2020-03


2023-06


2019-10


2023-06

Takeaways, to date

- Measure time in terms of geomorphically effective events, not years
- Know your mechanisms; Monitor your mechanisms
- Metrics must match mechanisms; beware the non-normalized
- The entire reach is your population till proven otherwise
- There is no right way to monitor a stream well, but no effective way is fast or easy.
- If your goal is dynamic streams, expect dynamic goals and outcomes.
- Don’t underestimate the power of narrative information

Photo courtesy Torin Foster (@thenikonsniper)

Thank you!

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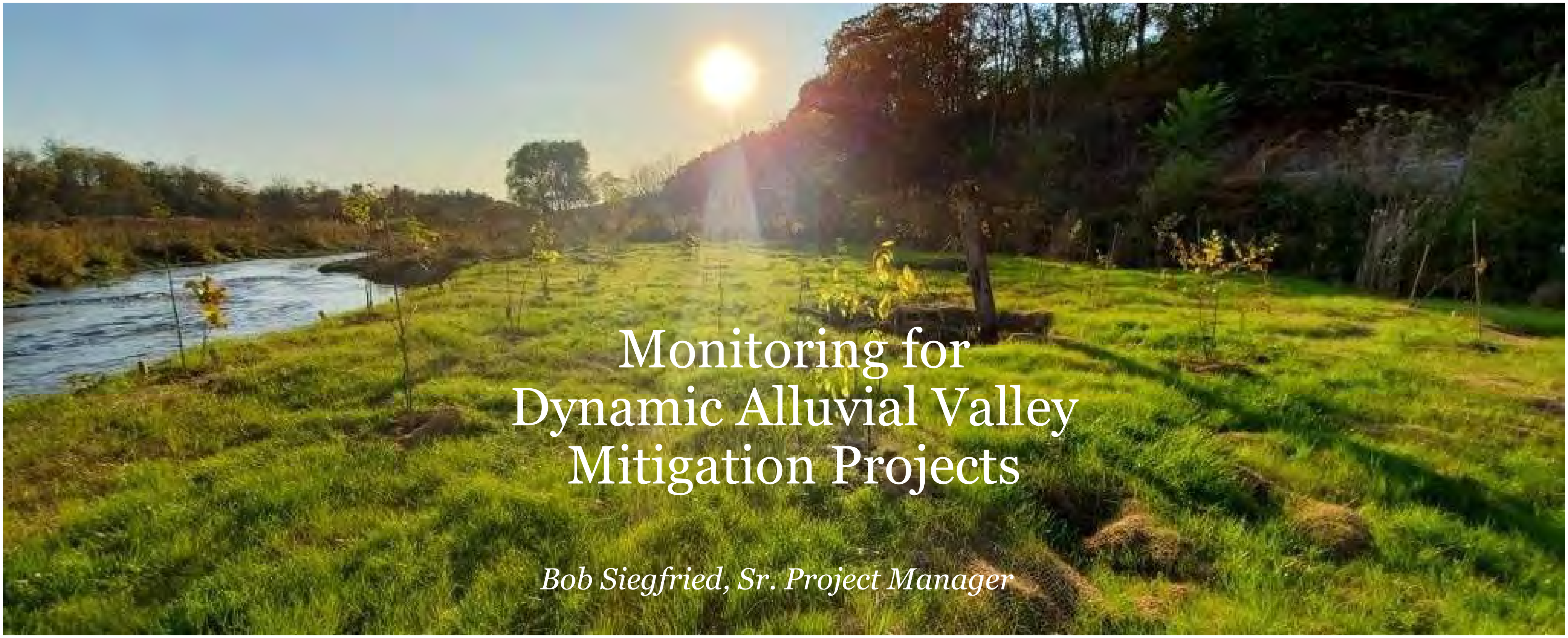

Monitoring for Dynamic Alluvial Valley Mitigation Projects

Bob Siegfried, Sr. Project Manager

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Restoring a resilient earth
for a modern world

Challenges to DAV Mitigation Monitoring

Dynamic Alluvial Valley Mitigation

- Legacy Sediment Removal
- Stage Zero Restoration
- "Messy" River
- Dam Removal
- Beaver Influenced Sites
  - Beaver Analog Projects
  - Beaver Accommodating Designs
  - Beaver **Invaded** Sites

Challenges of Applying Traditional Methods

- **Channel Metrics**
  - Static Cross Sections and Profile
  - Static Planform
- **Riparian and Floodplain Metrics**
  - Static Acreages
  - Specified Hydrology
  - Fixed Vegetation Community
- **Biological Metrics**
  - Habitat Assessments
  - Benthic Metrics

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Drawbacks of Traditional Mitigation Monitoring

- **Not Holistic**
  - Points, Plots, Cross Sections, Profile
  - Detailed Data of < 5% of Site
  - No Systemwide Understanding
- **Not Transparent**
  - 90+% of Site NOT Evaluated
  - Problems Easy to Miss or Hide
- **Not Efficient**
  - 100s of Cross sections, Photos, Etc.
  - Difficult to Review
  - Not Focused on Critical Information

New Concepts in Mitigation Monitoring

Existing Approach to "Static" Projects

- **Not Holistic**
  - Points, Plots, Cross Sections, Profile
  - Detailed Data of < 5% of Site
  - No Systemwide Understanding
  - Not Suitable
- **Not Transpare**
  - 90+% of Site
  - Problems Easy to Miss or Hide
- **Not Efficient**
  - 100s of Cross sections, Photos, Etc.
  - Difficult to Review
  - Not Focused on Critical Information

Proposed For DAV Projects

- **Holistic**
  - Focus on Big Picture
  - Evaluate Entire Site
  - Understand System
- **Transparent**
  - Don't Miss Issues
  - Nothing to Hide
  - Identify Trends – Good and Bad
- **Efficient**
  - Collect Detailed Data on Problem Areas
  - More Relevant Data for Reviewer

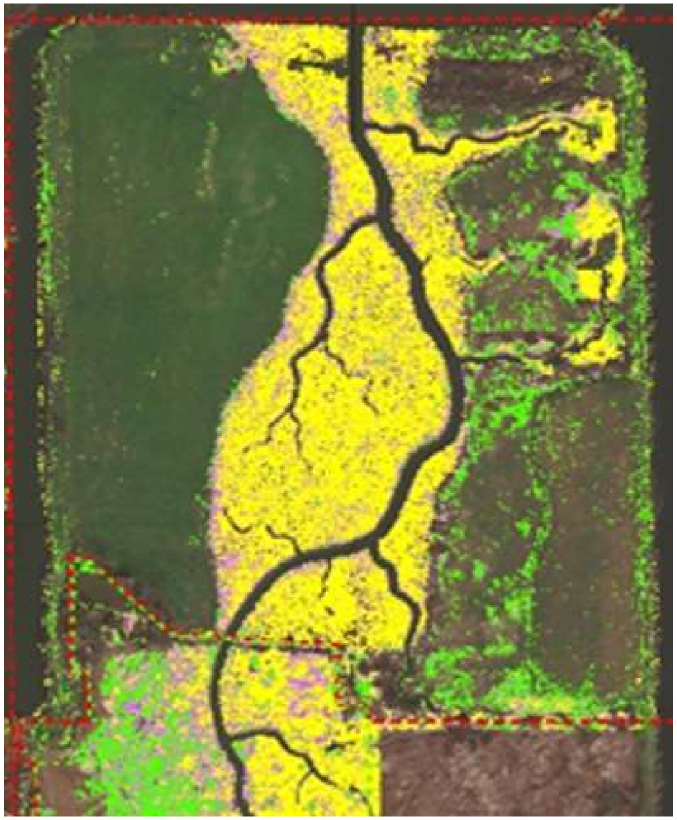
Holistic “Big Picture” Monitoring

Mapping Vegetation Communities

Holistic Approach to Vegetation

- Acquire Drone Imagery
- Collect Classification Data
  - eCognition Software
- Map Communities
- Determine Percent Cover Including Bare Ground and Open Water

Tidal Marsh Mapped with eCognition



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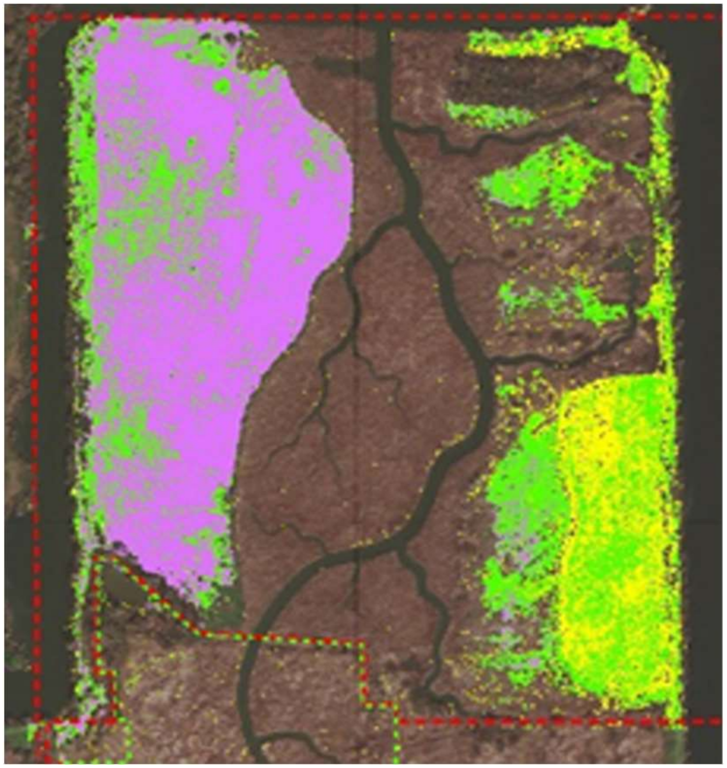
Mapping Invasive Species

Holistic Approach to Vegetation

- Field Identify Invasive Species
- Collect Classification Data
- Produce Detailed Maps
- Track Trends over Space and Time
- Improved Data Quality and Trend Detection
- Reduce Field Labor & Bias
- Improve Control Programs

Invasive Species Mapped with eCognition



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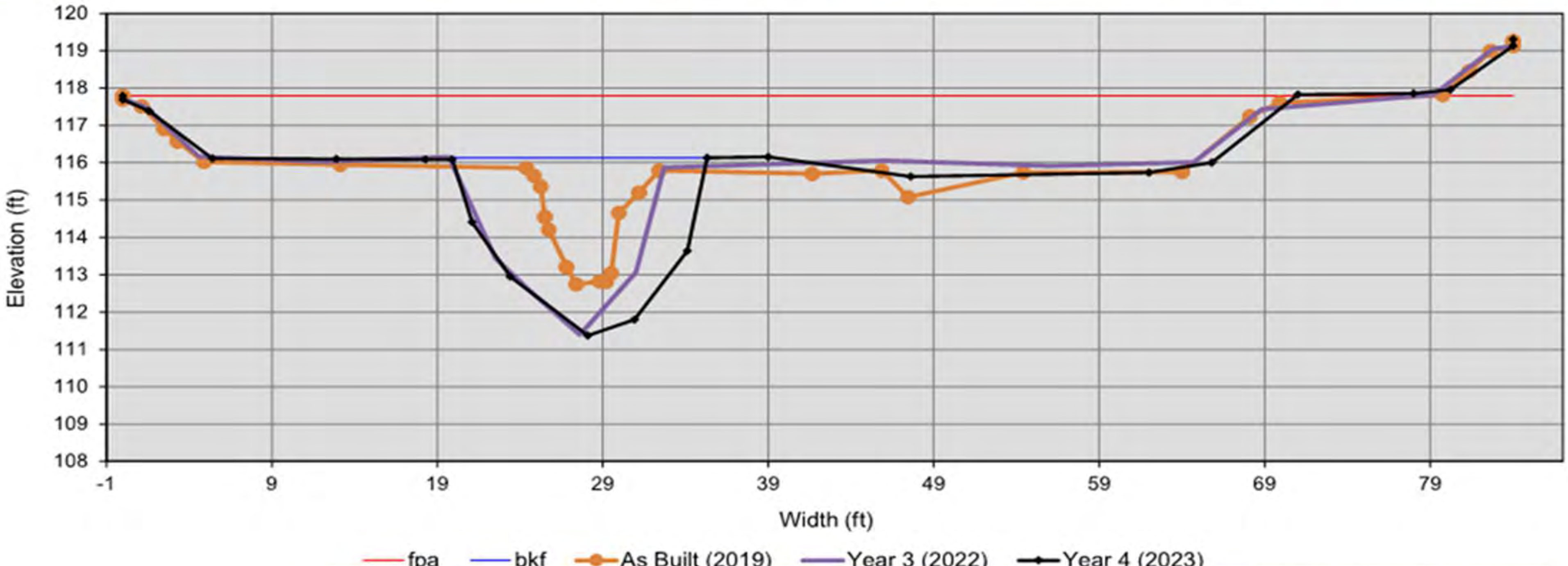
Dynamic Channel Monitoring

Holistic, Transparent, & Efficient



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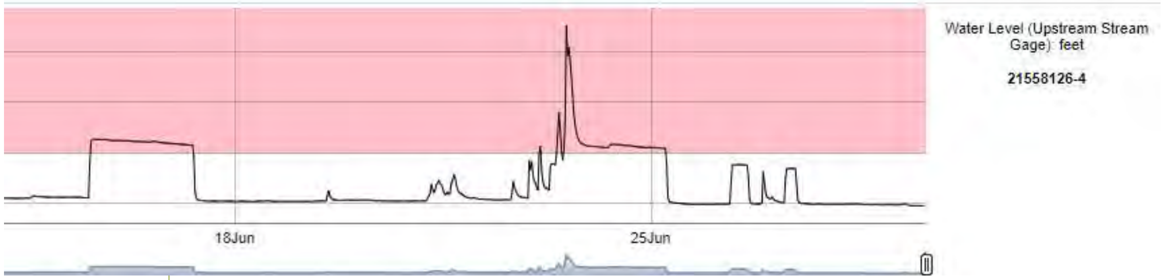
Dynamic Channel Monitoring

Holistic, Transparent, & Efficient

- Use Aerial Imagery to Identify System Wide Changes
- Track Changes Over Time
- Take Measurements from Orthophotos Mosaics
- Field Inspect Significant Trends
- Leads to Proper Interpretation of Trends and Changes

Real-Time Remote Monitoring

- **Stream Gages & Groundwater Wells**
- Real Time Data Online
- Text Alerts = React in Real Time
- Identify
  - Bankfull / Floods
  - Beaver Damming
  - Dam Release
- More Focus On The Data
- Reduced Labor For Travel To Sites
- **Time Lapse & Game Cameras**
- **NO3, DO, Temperature Probes**



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Environmental DNA (eDNA)

- Presence/Absence Survey / Archival
- Search Water, Soil Or Air
- Fish, Amphibians, Macrobenthos
- Specific Species or Entire Community
- Dam Removal / Fish Passage
    - Sample Before to Show Presence
    - Sample After to Show Passage
- Rare Species
    - Screening with eDNA
    - Sampling where eDNA was Positive
- Community Response
    - Track Community Changes Over Time

Dynamic System or System Failure?

DAV Functions and Failure Modes

- **Lateral and Vertical Connectivity**
  - Valley Wide Grade Control Failure
- **Diversity of Habitats**
  - Loss of Hydrology / Flow
  - Excessive Sedimentation
- **Net Retention Valley**
  - Failure of Valley Transitions
  - Excessive Erosion
- **Support Biological Communities**
  - Loss of Vegetation
  - Loss of Water Quality / Fish /Benthos

Monitoring of Failure Modes

- **Aerial Imagery**
- **Real Time Stream and Wetland Monitoring (Flow, Temp., DO, pH)**
- **eDNA**

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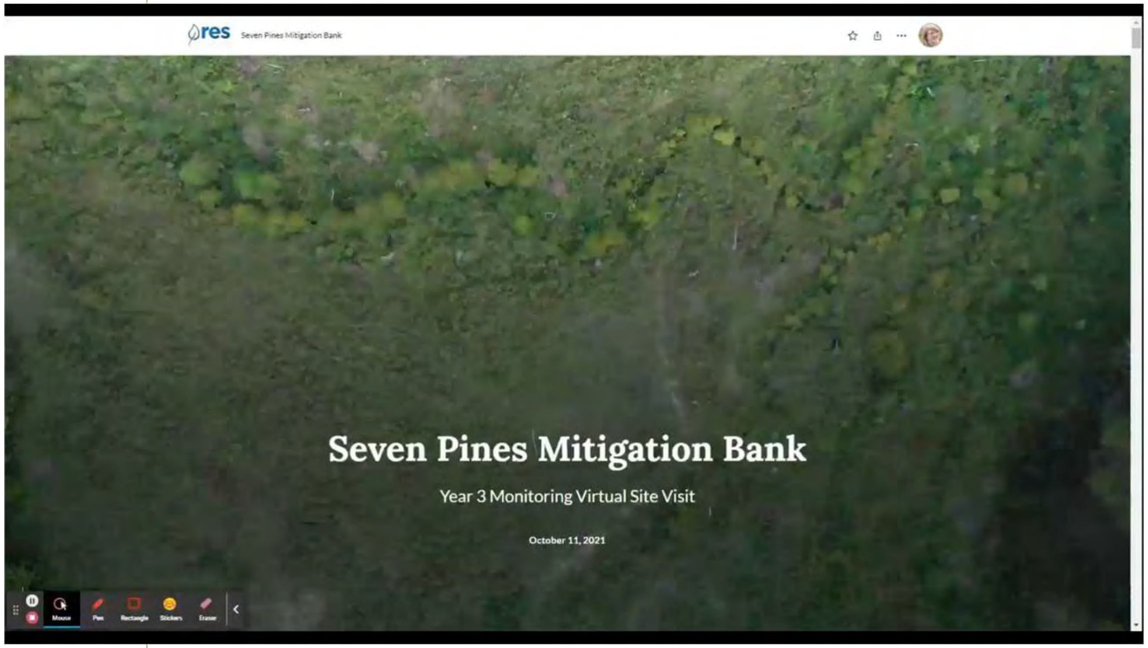
Is Data Delivery A Challenge?

Challenges

- PDF Reports Lose Much of the Detail
- Drone Images are Large (GB)
- RIBITS, FOIA, and Public Access
- Staff Skills Sets

Solutions

- Access to Real-Time Data Dashboards
- GIS StoryMaps
  - Integrating Data Types
  - Engaging with Viewer
- Google "Streetview" Type Products



Questions? / Contacts

Mitigation Needs To Move Away From Historically Static Monitoring Approaches That Were Designed For Small Sites And Toward A Holistic, Transparent And Efficient Approach Suited To Landscape Scale Mitigation And Restoration

Bob Siegfried

Sr. Project Manager

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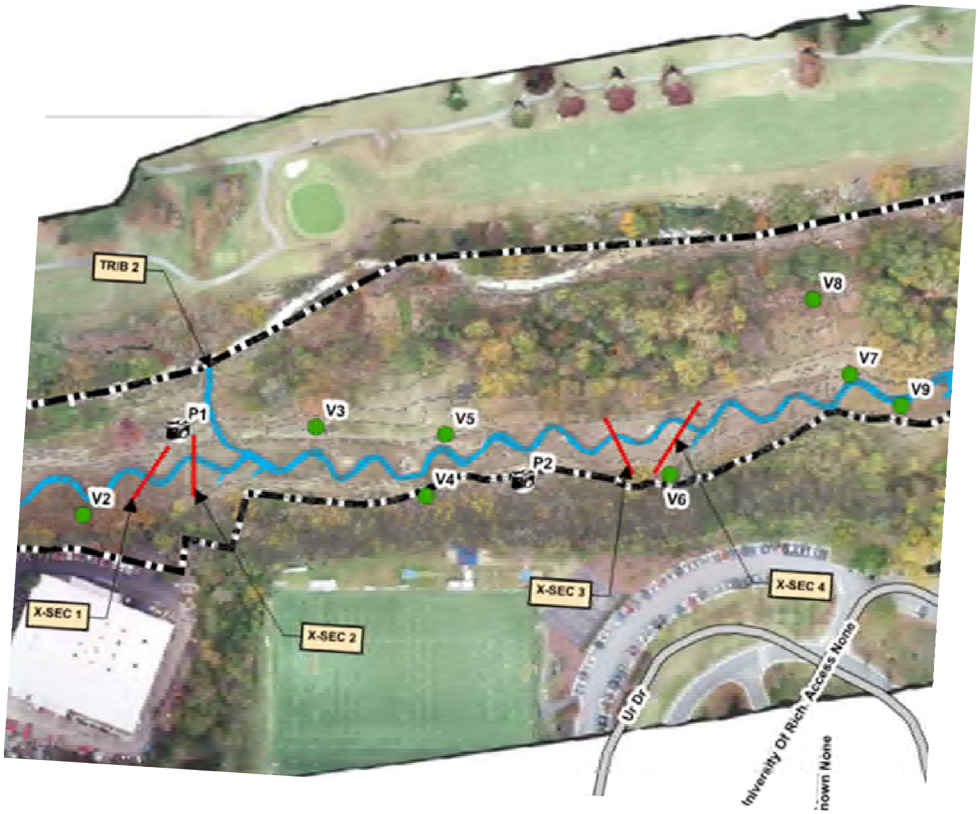
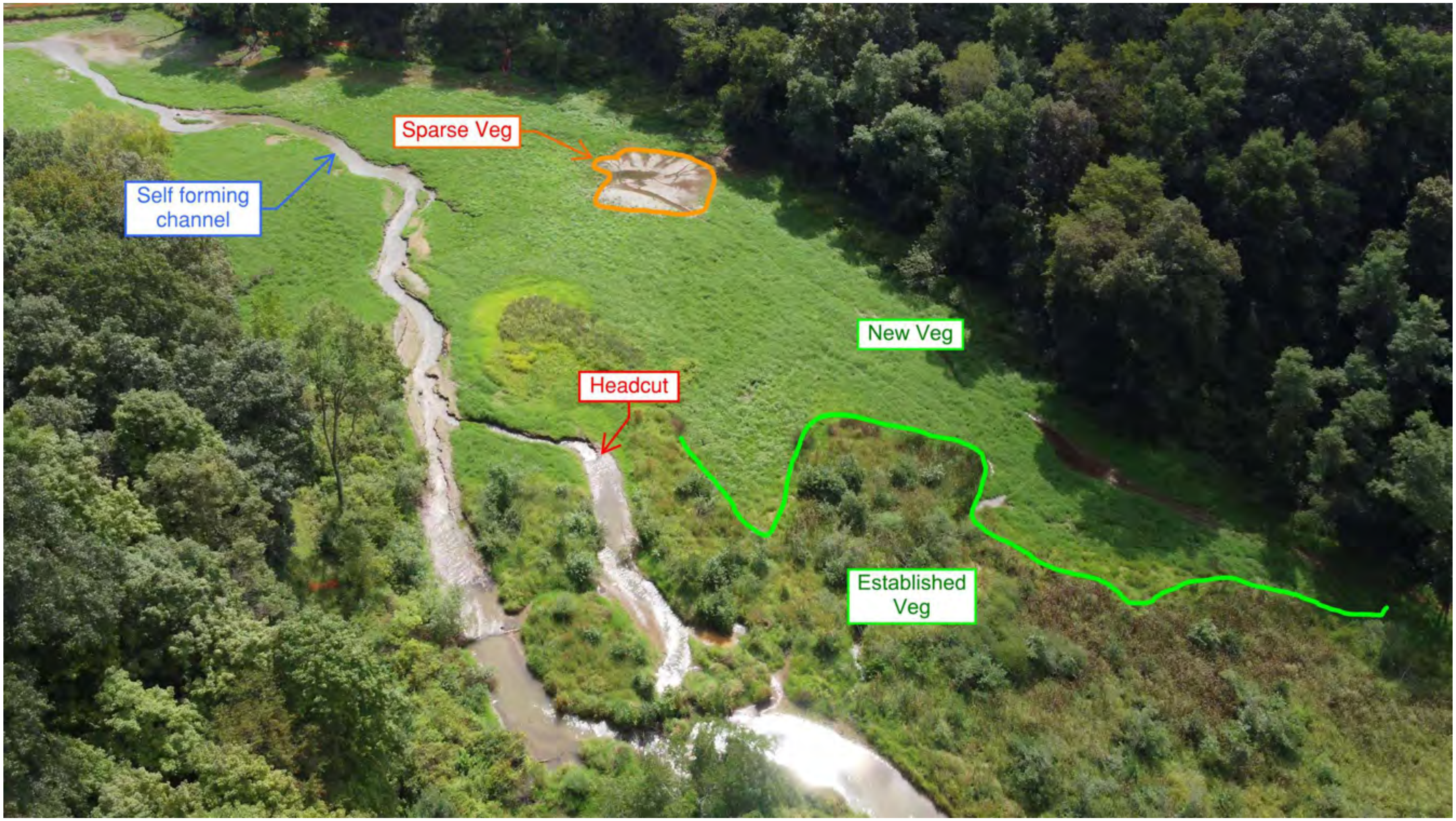
Current Methods for Vegetation Cover



Scientific Name	Common Name	Veg Plots 1	2	3	4	5	6	7	8	9
		Plot Locations UPL	WET	UPL	WET	UPL	UPL	WET	UPL	WET
Agrostis gigantea	Red top	10		40						
Ampelopsis brevipedunculata	Porcelain-berry			5	1		**55**	2	2	
Asclepias syriaca	Milkweed	3								
Boehmeria cylindrica	Falsenetle					1				
Calamagrostis canadensis	Canadian bluejoint	5								
Campsis radicans	Trumpet Creeper								2	
Carex lurida	Shallow sedge		5	5	2	7	10	20	**5**	20
Carex vulpinoidea	Fox sedge					5		20	5	
Chasmanthium latifolium	River oats	5				15	5			
Dichanthelium clandestinum	Deertongue			5	2	2	5			3
Eurybia divaricata	White wood aster		7	2				5		10
Eupatorium capillifolium	Dog-Fennel								2	
Eupatorium perfoliatum	Common Boneset								5	
Glechoma hederacea	Ground-ivy						15		10	
Helianthus angustifolius	Narrow-leafed sunflower						2			
Impatiens capensis	Spotted jewelweed	10	5		1	2			5	15
Ipomoea purpurea	Morning glory		2		1		1			2
Juncus effusus	Common rush	**5**	**50**	**50**	**90**	**70**	**5**	**40**	50	40
Leersia oryzoides	Rice cut grass	**40**								
Lespedeza cuneata	Chinese bush clover			2		10		2		
Lonicera japonica	Japanease honeysuckle						2			
Mikania scanden	Climbing hempweed							2		
Mimulus ringens	Monkey flower		3							
Persicaria sagitata	Arrow-leaf tearthumb	40								
Phalaris arundinacea	Reed canary grass						7			
Poa pratensis	Kentucky bluegrass		3							
Phytolacca americana	American pokeweed						2			
Rumex crispus	Curly dock		5		1	2	5			3
Schizachyrium scoparium	Little Bluestem								10	
Scirpus atrovirens	Dark-green bulrush									3
Securigera varia	Crown vetch			1						
Schoenoplectus tabernaemontani	Softstem Bulrush		3							
Total Percent Cover of 5 ft Radius		118	83	110	98	114	114	91	96	96
Total Percent Native Cover of 5 ft Radius		118	83	103	97	104	59	87	94	96
Sepecies Diversity		8	9	8	7	9	12	7	10	8
Invasive Species Percent Cover		0	0	7	1	10	55	4	2	0
Greater than 60% Non-Invasive Vegetation Cover		YES	YES	YES	YES	YES	NO	YES	YES	YES

Big Picture – Drill Down to Areas of Concern



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Beaver Colonization

Performance Standards and Mitigation Credits
Valuing System Complexity

ecotone
ecological restoration

Presented by:

Matt Hubbard, PWS
Technical Solutions Manager
Ecotone, LLC
mhubbard@ecotoneinc.com

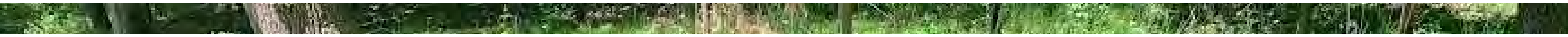
“A self-organized system can’t be understood by trying to reduce it to the smallest piece and integrate it up–it doesn’t work that way,” Norman said, explaining Allen’s perspective. “And that’s unsettling. He’s basically saying to you, what you’re doing is internally consistent as far as you take it, but you’re not going where you think you’re going.”

“Even if you sit down and look at a table of numbers, it’s actually a narrative, what’s going on in your consciousness is a narrative about you encountering this.”

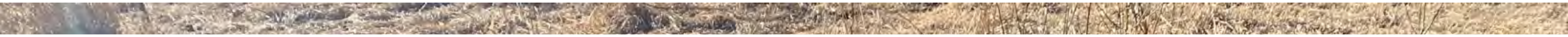
Mitigation Site Credits are Value Judgements
How do we value beaver?

Example Beaver at a Mitigation Site

- Braid channel formed – lateral movement of stream resource across the floodplain.
- The dimension is changing.
- The profile may change.
- The pattern is done.
- How do I measure /categorize this?
  - Stream-wetland beans
  - PEM, PFO beans

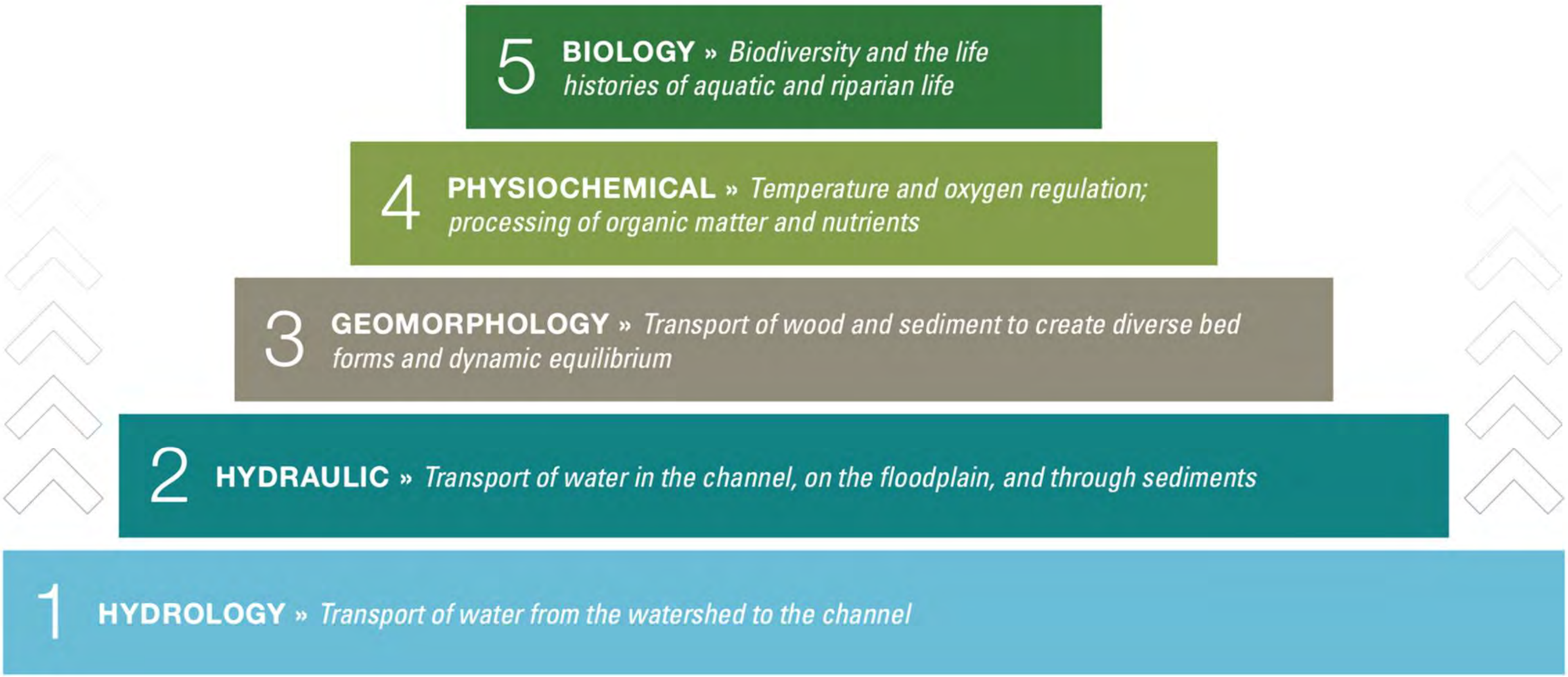


Beaver are coming to a completed stream site near you!



Beaver are rodents.

Impacts of Beaver
Performance Standards & Mitigation Credits



Impacts of Beaver
Hydraulics (MD tool)

- Bank Height Ratio
- Entrenchment Ratio
- Vertical Stability
- Floodplain Drainage

Impacts of Beaver
Geomorphology (MD tool)

- Riparian Vegetation
- Dominant Bank Erosion Potential
- Lateral Stability Extent
- Shelter for Fish and Macros
- Pool to Pool Spacing
- Pool Max Depth Variability
- Transport Sediment and Wood

Impacts of Beaver
Physicochemical (MD)

- Water Appearance and Nutrient Enrichment
- Detritus (No sediment)

Impacts of Beaver
Biology (MD)

- Macroinvertebrate Abundance
- Macroinvertebrate Tolerance
- Fish Presence

The beaver is a keystone species. Their skills as foresters and engineers create and maintain ponds and wetlands, which increase biodiversity, purify water, and prevent large-scale flooding.
They provide refuge during fires.
A rodent as a keystone species.

Value Judgements

- Hydraulics: Positive
  - *"Extensive Lateral and Vertical Connectivity"*
- Geomorphology:
  - *Negative –Lateral stability, pool to pool spacing,*
  - *Positive – woody debris, shelter, and max depth variability*
  - *"Creation and Maintenance of Diverse Habitats"*
- Physicochemical: Positive
  - *"Retention of Materials"*
- Biology: Positive – Keystone Species
  - *Abundant biological communities*

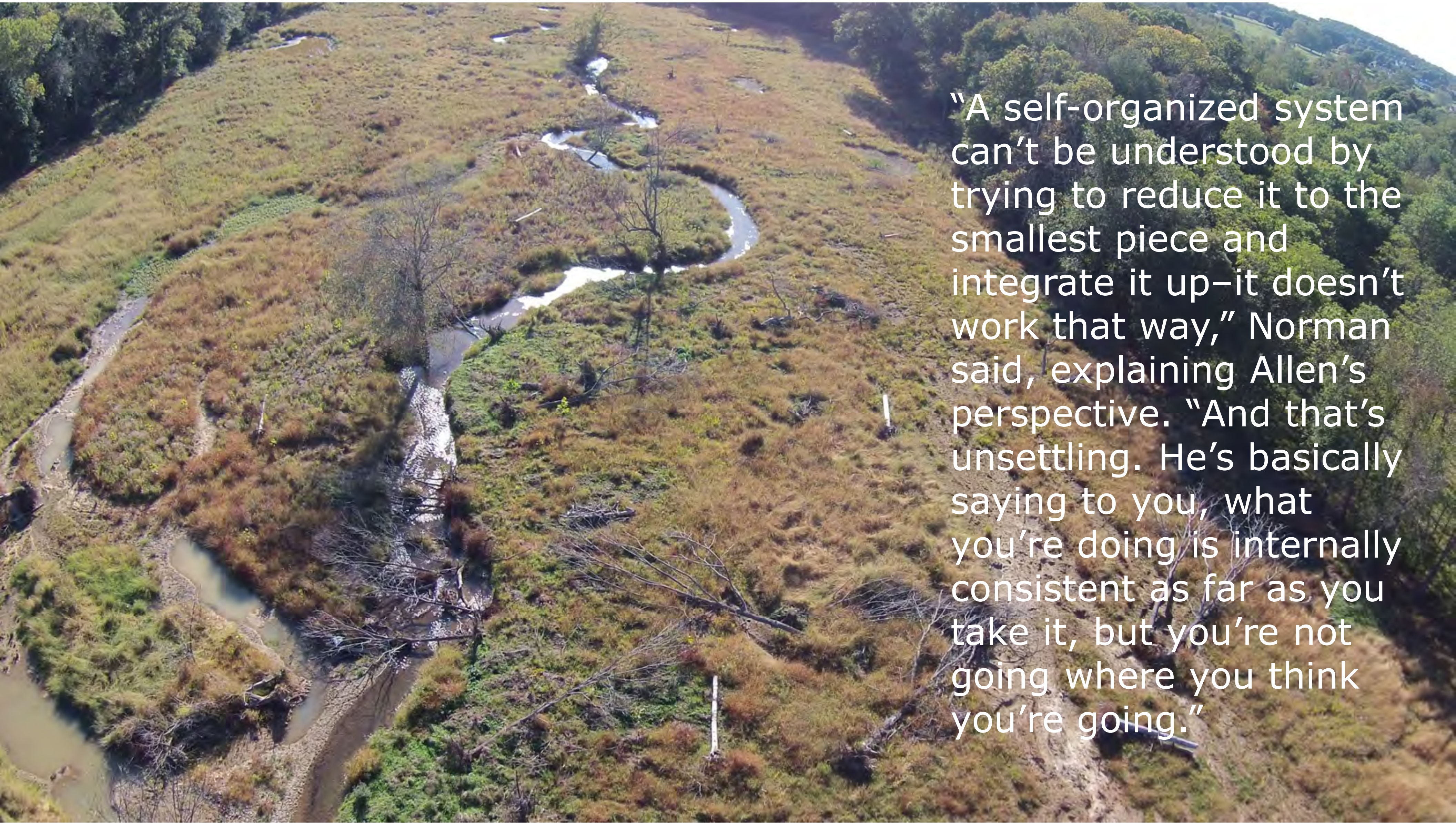
Value Judgements
Retentive Systems

Biology/Ecology drives the complexity of the physical system.

Crediting Outcomes & Endpoints

Complexity

- Extensive lateral and vertical connectivity: Hydrologic connectivity is extensive across the site and biologically active subsurface connectivity is maintained even during baseflow conditions. Surface-subsurface interaction decreases overall temperature, increases carbon retention, and increases benthic uplift. Frequent floodplain access increases genetic diversity and overall biotic uplift, and similarly increases the retentive capacity of the system.
- Creation and Maintenance of Diverse Habitats: The channel and the floodplain are a part of a united system as a mosaic of streams and wetlands. Off channel habitat is prevalent containing both wetlands and open water (permanent or seasonal). Large wood is prevalent wherever naturally supported by the watershed.
- Retention of materials: The valley (as a whole) retains sediment and fine organic matter. Erosional and depositional features are present throughout the site but the preponderance of features and habitats within the channel and on the floodplain are depositional. A retentive system allows for soil to form on the floodplains and for greater processing of nutrients and contaminants in the channel, hyporheic zone, wetlands, and riparian soils.
- Abundant biological communities: The valley supports an abundant (often diverse) biological community that contributes to the form of the valley. DAV evolution is primarily driven by biology (Castro and Thorne 2019). Therefore, although an abundant biological community is indicative of many other processes, it is also an evolutionary process in and of itself. Furthermore, a healthy biological community indicates that water quality is acceptable.
- DAV may not be the original stream design but may result from evolutionary shifts or from dam construction by beavers.



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Levels are criteria for observation - values drive criteria and our subjective measures of success.
Value:
• The richness of connections as the basis for evaluating functioning ecological systems that provide diversity and resilience.
• Complexity of the whole not complicated data collections of the parts.
• Beaver – Keystone Rodent


Thank You

Adaptive Management

& Alternative Endpoints

NSRC – August 2023

Brian Topping, EPA
Sam Leberg, Oak Ridge Institute for Science and Education Fellow at EPA

Adaptive Management – Mitigation Rule Text

A management strategy to address unforeseen changes in site conditions or other components of the compensatory mitigation project, including the party or parties responsible for implementing adaptive management measures. The adaptive management plan will guide decisions for revising compensatory mitigation plans and implementing measures to address both foreseeable and unforeseen circumstances that adversely affect compensatory mitigation success. (See § 332.7(c).)

33CFR 332.4 (c)(12) / 40 CFR 230.94 (c)(12)

Adaptive Management – In Practice

- When to:
    - Replant
    - Regrade
    - Remove invasives
    - Reenforce structures
- Allow for natural:
    - Marsh migration from sea level rise

Adaptive Management – In Practice

- When to:
  - Replant
  - Regrade
  - Remove invasives
  - Reenforce structures

- Allow for natural:
  - Marsh migration from sea level rise

- All of these assume:
  - The design will be self sustaining
  - The design will provide the highest and desired functions
  - Monitoring if the design was maintained shows success of the project
  - Any change from the design is undesirable

Alternative Endpoints

Dynamic Alluvial Valleys(DAVs) are expected to evolve

→ Designed outcome may not match site in all or any years

→May still provide high-quality DAV aquatic habitats

What other endpoints are 1) plausible, and 2) acceptable

What are the signs of failure to establish a DAV?

If an alternative endpoint is formed/forming, are changes to monitoring requirements and/or performance standards needed?

		Expected/designed Endpoint	Alternative Endpoints	
			Acceptable Endpoints	Unacceptable endpoints
Example 1	**Extensive Lateral and Vertical Connectivity– Vegetation**	**Wet meadow:** Performance standards include aerial dominance by herbaceous species and presence of hydrophytic vegetation, with limits on invasive species coverage. If floodplain is inundated (i.e., regular overtopping flows) for extended periods during monitoring, percent coverage by herbaceous species may be reduced.	**Riparian forested wetlands:** Performance standards include hydrophytic vegetation and typical tree metrics (e.g., minimum woody stems per acre, species diversity and composition, growth or size and nonnative species limits). Wetland species are represented.	**Upland community:** Community is dominated by upland species. Hydrophytic and wetland species are not present or are minimally represented, indicating that the site is not connected vertically.
			Scrub-shrub: Performance standards include presence of hydrophytic vegetation and typical shrub metrics (e.g., minimum stems per acre, species diversity and composition and nonnative species limits). Wetland species are represented.	**Minimal or bare community:** Soil bare in many areas with fresh deposition or erosion across the site. Suggests that design failures (e.g., boundary stresses, bank heights, soil compaction, etc.) are limiting vegetation establishment and the site is not appropriately connected laterally or vertically.
			Vegetation managed by beaver: Performance standards include the presence or dominance of hydrophytic vegetation. Floodplain is likely to be inundated for extensive periods, reducing shrub and woody vegetation coverage. Wetland species are represented.	

		Expected/designed Endpoint	Alternative Endpoints	
			Acceptable Endpoints	**Unacceptable endpoints**
Example 2	**Retention of Materials–Morphology**	**Stable functional multithread retentive system with active floodplain:** Headcuts and bank erosion are limited (either via valley-wide grade control or natural geomorphic controls) and complimented by depositional areas within the site. Performance standards include sediment retention, low shear stress and velocities.	**Stable functional single-thread reach with active floodplain:** Site is satisfying retentive performance standards (sediment retention, low shear stress and velocities). The site is not incising; headcuts and headcut potential are limited by the presence of valley-wide grade control.	**Unstable or non-functional system with single or multi-thread channels:** Site is failing to meet performance standards (sediment retention, low shear stress and velocities). Valley-wide grade control fails or the stream incises and the floodplain is inactive. Indicates that the stream is not laterally connected and does not retain sediment or organic materials.
			Stable, functional system managed by beaver: Site is satisfying retentive performance standards (sediment retention, low shear stress and velocities). The site is not degrading; headcuts and headcut potential are limited by stable grade control. Potential hydrologic trespass is monitored and managed effectively.	**Unstable or non-functional system managed by beaver:** Site is failing to meet performance standards (sediment retention, low shear stress, and velocities) or the site is degrading (e.g., avulsions leading to site wide loss of grade control). Valley-wide grade control fails, or hydrologic trespass is extensive. Indicates that a stream is not sustainably net retentive.

Dynamic Alluvial Valley(DAV) Failure Points

Key Processes of DAV lost	Failure Point(s)
Loss of extensive lateral and vertical connectivity	Failure of valley-wide grade control(s)
Loss of habitat diversity	Failure to account for channel drying and loss of water
	Failure to account for excessive deposition
Loss of net retentive valley	Failure to design transitions with upstream and downstream reaches
	Failure to account for excessive erosion
Loss of biological communities	Failure to establish desirable vegetative communities
	Failure to design for poor water quality

Adaptive Management Using Alternative Endpoints

- Identify the alternatives up front
  - Acceptable
  - Unacceptable

- What does failure to establish a DAV look like?

- If/When monitoring requirements or performance standards change?

- Changes in assumptions:
  - The ~~design~~ DAV will be self sustaining even though the specific locations of habitats may change
  - A ~~design~~ DAV will provide the highest and desired functions
  - Monitoring if ~~the design~~ the key processes of a DAV was created and maintained shows success of the project
  - Any change ~~from the design~~ towards an unacceptable endpoint or failure point is bad

Discussion

Feedback, Suggestions, Ideas:

Sam Leberg Leberg.Samuel@epa.gov

Brian Topping Topping.Brian@epa.gov

Summary of Workshop Discussion

Expanding Performance and Monitoring to Dynamic Stream Systems

August 21, 2021

On August 21, 2023, six speakers and four panelists conducted a pre-conference workshop titled, “Expanding Performance and Monitoring to Dynamic Stream Systems” during the National Stream Restoration Conference. Prior to the session, a performance and monitoring document “Expanding Monitoring and Performance to Dynamic Alluvial Valleys” was shared with all participants. A major goal of this session was to elicit feedback on the document and presentations from conference attendees and how to apply performance and monitoring to dynamic alluvial valleys (DAVs). Feedback was received after each presentation and at the end of the session, with a feedback document, and in the next three weeks following the conference. The following comments and recommendations represent this combined feedback. This and additional feedback will be collected and compiled for any potential future revisions of the project document.

Overall Document and Word Choice

Participants suggested that the alternative endpoints table (Table 1) could be presented more effectively as a flowchart. Participants suggested that the document should include a consolidated table as opposed to (or in addition to) Table 2, 3, and 4 in the document, as this would make it easier to locate all information relative to each metric.

Participants further identified that the document terms of “success” and “failure” were unclear and suggested that further context be provided for their definition and use in the discussion section of each metric. Additionally, multiple participants expressed concern with the term “stability” used in the document as it is frequently associated with static conditions. Although the term is used in the document in relation to the four key DAV processes, the connotation may cause confusion.

Site Selection and Design

Participants recommended further emphasizing constraints to site selection for dynamic alluvial valleys. Firstly, that when these systems are an explicit goal of restoration, lateral space is required (particularly for beaver colonization). However, the document should emphasize that practitioners will often not have access to/control over the entire river valley, and need to access enough space to support the project and key DAV functions. Due the size, bed materials, and hydrology of the site, the slope limit for stability may vary considerably and the site may or may not be low-gradient. Attendees further recommended emphasizing that resistance can increase biodiversity.

Performance and Monitoring

Attendees presented several broad and specific recommendations for performance metrics. Generally, participants recommended that there should be more specific metrics for riparian vegetation performance. To that end, participants identified that extensive vertical connectivity (a goal of DAV restoration) and soil saturation may control invasive species and thus may meet existing invasive species performance standards. However, this may be a limited trend and not necessarily applicable nationwide. There was also a concern that the focus of the document was largely on forested systems with a regular supply of large wood. Practitioners suggested that an example of prairie streams or similar systems would provide context to the larger applicability of the document.

Some participants expressed concern with the Fish Passage metric for beaver-colonized streams, citing the growing literature consensus that while beaver dams may act as a short-term barrier for certain life stages, the net effect of beaver dams on fish species is generally net positive. However, the focus of the literature is largely on salmonids and other sport fish and ecological trends may not be constant across species. Furthermore, the two indicators of fish passage (species richness and target species presence) are fairly low resolution and are intended to indicate that beaver dams are not creating relatively depauperate areas in a specific stream. It may be necessary to modify fish passage metrics or add further clarification of use and expectation in future drafts.

Participants had several specific recommendations for the biotic performance of Dynamic Alluvial Valleys, including researching the applicability of a biological condition gradient to these systems. As DAVs may be multithreaded, participants suggested that EPT and related criteria should only be applied to the primary channels. Furthermore, participants recommended that assessments of other, more intermittent channels should include composition metrics of taxa capable of producing multiple generations in a year (e.g., % Diptera, % chironomids, chironomid IBI, etc.). Participants recommended that incorporating Odonata and Megaloptera may be effective for assessing lentic conditions that may be present off-channel and within channels during some portion of the year (Megaloptera are also a good indicator of an intact riparian zone). Finally, participants suggest that the temperature metric would be more useful as a binary of adverse or not adverse to aquatic life.

Participants gave several recommendations to drone use in restoration monitoring. Firstly, monitoring for geomorphology and habitat patches is likely most appropriate during the winter leaf off period, while vegetation monitoring is more effective during the summer season. Furthermore, effective vegetation monitoring requires ground truthing. Finally, drones may not be allowed in all sites or regions.

Future Directions

Session participants generally expressed interest in more examples for stream types across the United States (including in arid environments, drainages with less large wood, and applied broadly to more lotic systems). Furthermore, participants suggested applying the performance and monitoring recommendations in the document to other regulatory frameworks like the Endangered Species Act. Participants were interested in how crediting protocols would apply to DAVs, and made multiple suggestions. Firstly, as DAVs include stream and wetland habitat they could be packaged as both, and sold as either classification. Finally, if the crediting protocol allows it, the restored DAV could justify a higher credit value if the stakeholders are able to demonstrate which functions have been lost for both streams and wetlands within a specific watershed and how the project replaces those functions.

EXPANDING MONITORING AND PERFORMANCE TO DYNAMIC ALLUVIAL VALLEYS

Samuel Leberg (ORISE Participant at the EPA, Leberg.Samuel@epa.gov)

August 2023

Executive Summary

To date, compensatory mitigation to offset unavoidable impacts to streams authorized under Section 404 of the Clean Water Act has primarily included the restoration of single-thread transport reaches. The monitoring requirements and performance standards associated with these stream compensatory mitigation efforts included measures of stream channel form and stability for single-thread channels. However, when the restored stream is designed or evolves to be a stable retentive, multithread, or beaver managed stream system, in other words a dynamic alluvial valley, alternative monitoring requirements and performance standards are needed. This report provides a resource for the stream compensatory mitigation community to consider when proposing or evaluating dynamic alluvial valleys. It summarizes the cumulative input of 42 semi-structured interviews with 60 participants representing regulators (18), practitioners (27), and academicians (15), and literature review. First, this report defines dynamic alluvial valleys, including their potential uplift and where their restoration should be encouraged. Then this report identifies how the flexibility to set alternative endpoints for stream mitigation maintains high standards for mitigation performance while also allowing for a range of ecologically beneficial outcomes. Metrics to consider for dynamic alluvial valleys are described and considerations provided for how these may be used in performance standards. Additional metrics are provided specific to sites colonized by dam-building beaver, and metric selection and prioritization are discussed. Finally, this report presents a hypothetical scenario showing how alternative endpoints can be developed to provide the regulatory flexibility to allow for high functioning dynamic systems whether they are exactly as designed and predicted or not.

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Terminology

Dynamic Alluvial Valley (DAV)- Dynamic alluvial valley is a term to be used within the context of compensatory mitigation. DAVs are depositional valley segments within the stream network whose form is dominated by biological forces (vegetation growth, large wood, beaver, etc). A DAV has extensive lateral and vertical hydrologic connectivity, a diverse patchwork of wetland, channel, and off channel habitats. It is generally retentive of both sediment and organic matter and has abundant biological communities. DAVs include stream wetland complexes, beaver dam complexes, and similar systems (Section 1).

Ecosystem Services- Benefits derived from the function of ecosystems that are conferred on human populations (e.g., improvement of water quality, flood attenuation, fisheries uplift, etc.)

Environmental DNA (eDNA)- Environmental DNA refers to trace DNA collected from sediment, soil, or water and not directly from one or more organism(s). eDNA assessment identifies the organisms of interest present on a site by matching characteristic DNA sequences to a known library of taxa for the region (known as DNA metabarcoding).

Hydraulic trespass- Water entering properties adjacent to the site due to on-site modifications to water storage or flow velocity. In this report, it is used to refer to flooding changes induced by beaver.

In-lieu fee (ILF) programs- ILF programs are established by a public agency or non-profit organization and sell credits to permittees (to compensate for aquatic resource impacts). The sponsor collects these funds (typically from multiple permittees) and commits them to performing mitigation activities. Typically, ILF mitigation occurs off-site and after the permitted impacts have occurred.

Interviewees- Term refers to the collection of regulators, practitioners, and academicians who participated in semi-structured interviews to provide input on this report.

Mitigation banks- Projects where aquatic resource conservation has been initiated in advance of permitted losses of aquatic resource functions or services. The bank Sponsor, and not the permittee is responsible for the success of the bank. Mitigation banks typically provide off-site compensation for multiple permitted actions. Bank operation is governed by an instrument that the Sponsor drafts and is subject to approval by USACE and other members of the IRT.

Performance standards- Performance standards are used to evaluate whether a project is evolving into the intended natural resource and providing desired aquatic resource functions/services/conditions. Performance standards should be objective, verifiable, measurable (quantitative OR qualitative), repeatable, and measured with a reasonable amount of effort. The 2008 Mitigation Rule defines them as ecologically based standards that will be used to determine whether the compensatory mitigation project is achieving its objectives (33CFR 332.4 (c)(9) / 40 CFR 230.94 (c)(9)).

Synoptic Monitoring/Synoptic Decrease- In-stream synoptic monitoring typically refers to monitoring upstream and downstream to determine change in a variable. It is an effective monitoring tool to determine how nutrients are being processed and how temperature changes as a result of stream restoration actions. Synoptic decrease (monitored from the most upstream to most downstream end of the restored site) is used in this paper as a target for temperature, conductivity, nitrogen, and phosphorus.

Commonly Used Abbreviations

Dynamic Alluvial Valley (DAV)

Environmental Deoxyribonucleic Acid (eDNA)

Environmental Protection Agency (EPA)

Geographic Information Systems (GIS)

Interagency Review Team (IRT)

Light Detection and Ranging (LiDAR)

United States Army Corps of Engineers (USACE)

1. Background

In 2008, the Corps and EPA issued joint regulations regarding compensatory mitigation for unavoidable impacts to wetlands, streams, and other aquatic resources known as the Mitigation Rule. The Mitigation Rule standardized the review and approval process for mitigation banks and in-lieu fee (ILF) programs and clarified the requirements for compensatory mitigation (see 33 CFR Part 332 and 40 CFR Part 230, Subpart J). The Mitigation Rule places monitoring requirements (33CFR 332.4 (c)(10)/ 40 CFR 230.94 (c)(10)) and performance standards (33CFR 332.4 (c)(9)/ 40 CFR 230.94 (c)(9)) as central to the evaluation of compensatory mitigation projects. Specific parameters or metrics are identified during project design and review for monitoring. Monitoring may begin before project implementation and always occurs post construction for a set number of years. Performance standards are the defined targets that must be met within defined time periods that will demonstrate the compensatory mitigation project is achieving its objectives. Information collected during monitoring is used to determine if the compensatory mitigation project is on track to meet performance standards and if adaptive management is needed.

The amount of compensatory mitigation occuring in streams has grown dramatically since 2000 and most of the growth occurred in the eastern U.S. (Lave and Doyle 2021). During this time, stream mitigation practices, monitoring requirements, and performance standards have included a strong focus on stream stability and form with a focus on single-thread channels transporting all the water and sediment entering the reach through the reach. Determining compliance with performance standards is relatively straight forward when assessing the stability and form of these single-thread channels.

However, there has been growing recognition that the restoration of other stream types is desired ecologically but is unintentionally discouraged by existing protocols that tend to only work on single-thread perennial transport reaches. In wide alluvial valleys with low sediment supply, stream/wetland complexes were once much more prevalent (Wohl et al. 2022, Walter and Merritts 2008), and their restoration may lead to significant biological uplift (Braccia et al. 2023). Rewetted multi-threaded historical valleys with retentive areas may experience significant ecological uplift (Cluer and Thorne 2014, Powers et al. 2019). Overall, reestablishing lateral and vertical hydrologic connectivity where possible may lead to significant improvement and expansion of ecosystem services. Though these streams have regional nomenclature, they will be grouped together and referred to as dynamic alluvial valleys for the purposes of this report.

Dynamic alluvial valleys (DAVs) are defined as depositional/retentive systems within the stream network whose form is dominated by biological drivers (vegetation, large wood, beaver, etc., see high biological influence streams in Castro and Thorne 2019). DAVs may be multithreaded, and the location and relative coverage of specific habitats may change between monitoring periods. The key processes of these systems are:

- Extensive lateral and vertical connectivity: Hydrologic connectivity is extensive across the site and biologically active subsurface connectivity is maintained even during baseflow conditions. Surface-subsurface interaction decreases overall temperature, increases carbon retention, and increases benthic uplift. Frequent floodplain access increases genetic diversity and overall biotic uplift, and similarly increases the retentive capacity of the system.
- Creation and Maintenance of Diverse Habitats: The channel and the floodplain are a part of a united system as a mosaic of streams and wetlands. Off channel habitat is prevalent

containing both wetlands and open water (permanent or seasonal). Large wood is prevalent wherever naturally supported by the watershed.

- Retention of materials: The valley (as a whole) retains sediment and fine organic matter. Erosional and depositional features are present throughout the site but the preponderance of features and habitats within the channel and on the floodplain are depositional. A retentive system allows for soil to form on the floodplains and for greater processing of nutrients and contaminants in the channel, hyporheic zone, wetlands, and riparian soils.
- Abundant biological communities: The valley supports an abundant (often diverse) biological community that contributes to the form of the valley. DAV evolution is primarily driven by biology (Castro and Thorne 2019). Therefore, although an abundant biological community is indicative of many other processes, it is also an evolutionary process in and of itself and can be a significant driver of process and form (e.g., tree growth and large wood movement frequently determines the number of channels and islands in forested anastomosed systems with low banks).

The described key processes operate at a large-scale and represent a multitude of other channel and floodplain processes. For example, to restore the process of creating and maintaining diverse habitat, a practitioner may need to restore large wood storage and transport processes (when large wood recruitment is naturally supported by the watershed). Additionally, the four key processes refer to the character of the valley generally and may not describe all reaches. As this type of restoration proceeds in a large valley, there may be steeper headwater reaches and side channels flowing into the valley where alluvial fans may be restored to provide grade control and transitions to the valley bottom.

There is not one specific restoration approach that may yield DAVs. Historic wetland complexes can be reestablished by excavating legacy sediment to buried wetland soils (Walter and Merritts 2008). The stream bed could be raised to reconnect historic flow paths and increase floodplain connectivity (Powers et al. 2019). Moreover, a DAV may not be the original stream design but may result from evolutionary shifts or from dam construction by beavers (Castro and Throne 2019).

The emphasis of current mitigation protocols on form and stability of a single channel can create barriers for approaches that intentionally create DAVs and for the evaluation of DAVs generally. For example, if there are multiple channels which channel gets assessed? Also, should the assessed channel be scored as unstable if a new channel becomes dominant due to vegetation growth or large wood movement? Furthermore, current mitigation protocols penalize or even prohibit changes from the original design due to beaver and other evolutionary processes.

To allow for a broader range of stream restoration projects to be used as compensatory mitigation, regulators and mitigation providers need tools to monitor and evaluate the performance of DAVs. To inform this shift, several semi-structured interviews with experienced regulators, practitioners, and researchers were conducted concurrently with a comprehensive literature review to identify the common recommendations for evaluating DAVs for stream mitigation.

While the focus of this effort has been on monitoring and performance assessment, two other aspects of the mitigation process were found to be inseparably bound up. First, healthy DAVs will naturally experience shifting habitats across their site, which may increase due to the periodic dam building, maintenance, abandonment, and dam failures associated with beaver activity. This dynamic system requires the development of an approach for addressing a range of potential outcomes to monitor and evaluate. Second, the interviewee’s approaches for designing and building DAVs emphasized the importance of site investigations and design, but supporting information necessary for successful implementation is currently lacking. Below are design considerations, monitoring strategies, performance metrics, and adaptive management approaches applicable to restoration of DAVs.

2. Design Considerations

2.1 General Considerations

As stated above, there are multiple restoration approaches that may yield dynamic alluvial valleys (DAVs). In fact, a DAV may not be the originally intended design but may emerge over time as a result of complex geological, geomorphic, and biological drivers (Wohl et al. 2021). When specifically designing for a DAV, the design should target the four key processes identified in Section 1 (extensive lateral and vertical connectivity, creation and maintenance of habitat diversity, retention of materials, and abundant biological communities). In the terminology of process-based design, as described by Ciotti et al. (2021), the four key valley processes represent the four interdependent components of process-based design; space represented by the establishment of extensive lateral and vertical connectivity, energy represented by the retention of materials on site, materials represented by the creation and maintenance of habitat diversity, and time represented by the support of abundant biological communities.

Furthermore, the basic DAV design should encompass all flows (baseflow and 100-year or greater events), that can be predicted with two-dimensional modeling. Modeling should factor in expected changes in flow ranges due to climate change. Designing for a broad range of flows can ensure extensive connectivity throughout most of the year (space and time) and stability as a system that can adjust and absorb changes from large events (materials and time). Another key DAV design feature is low bank heights that accommodate a range of flows reaching across the site (energy), increasing lateral connectivity (space) and increasing wetted area and off-channel habitat (space and time). Modeling should be used to confirm that shear stresses are low enough to accommodate flows and retain material on the site.

2.2 Site Assessment and Eligibility

During the site evaluation process, it is necessary to identify site characteristics and constraints as this allows practitioners and regulators to determine whether restoring a DAV is appropriate for the site. Not every site can support the restoration of a DAV. DAVs are appropriate to restore in relatively wide, lower gradient valleys, in either current or historical (prior to anthropogenic disturbance) depositional valleys (Wohl et al. 2021). DAVs require significant space to accommodate high flows without increasing shear stress beyond the ability of the vegetation and substrate to recover. Furthermore, space is required to allow for diverse habitat, including off-channel wetlands. DAVs are depositional, so there must be available material to deposit, and depositional areas that are accounted for. Gradient should be low relative to the region. Finally, there must be the potential to create transitions between the DAV and areas upstream and downstream or for there to be existing geomorphic controls. Practitioners can assess historic condition of a given valley, assessed by excavation, soil borings, or other techniques to identify valley stratigraphy (Walter and Merritts 2008; Powers et al. 2019)

Furthermore, identifying specific limitations of the site or landscape context is important. Species of concern on the site may limit the amount of earth work allowed on site or the seasonality of such work. Flood risk immediately upstream, downstream, or on neighboring parcels may affect the margin of safety requested for any design and allowable range site conditions. Sediment load coming into the site and expectations for the future will affect the design and long-term sustainability of any site. Presence of beaver in the watershed or region and likelihood of colonization should also be considered when developing the design for any stream restoration project, not just DAVs. If beaver are likely to colonize, the project should be designed and monitored with the expectation that they will colonize the site. This would include identifying and designating areas where beaver would not be welcome (e.g., at the edge of the site causing flooding outside site boundaries without landowner permission) or where flooding may damage infrastructure (Wheaton 2013). By anticipating beaver-induced shifts, practitioners can alleviate undesirable loss of planted trees, vertical instability induced by avulsions around beaver dams, and hydrologic trespass onto private property.

2.3 Failure Points

As the systems discussed in this document may change between monitoring periods in the number, size, and position of channels and other habitat units, it is important to reframe how regulators and sponsors define success and failure. In many existing protocols success is maintaining a stable site that matches the design, but a stable DAV may not match the initial design. DAVs may be considered established and stable so long as they do not hit any specific point of failure, representing a loss of the trajectory towards a loss of one or more of the four defining processes of DAVs extensive lateral and vertical connectivity, creation and maintenance of diverse habitat, retention of materials, and abundant biological communities). These failure points are informed by recommendations from multiple interviewees, but none more so than Art Parola, Jesse Robinson, Michael Croasdaile at the University of Louisville Stream Institute.

The failure points include (but may not be limited to): failure of valley-wide grade control, channel drying or loss of water, excessive erosion or deposition, failure to design transitions between upstream and downstream areas, a failure to establish desirable vegetative communities, and poor water quality. Failure points should be addressed proactively during the design period, and some may also be addressable through adaptive management actions and further performance standards and monitoring to assess whether a restored site is stable.

2.3.1 Loss of lateral and vertical connectivity:

Failure of valley-wide grade controls. In areas where there is no naturally occurring geomorphic control at the downstream end of the site (e.g., an alluvial fan), valley-wide grade control will likely need to be constructed. Valley-wide grade control is typically constructed with buried rocks or wood to remain in-place and resist channel flanking and excessive floodplain erosion (Hawley et al. 2018). Whether valley-wide grade control is geomorphic or constructed with buried logs or rocks, it is essential that it is stable during large floods which ensures that the bulk of the material on site is retained and not mobilized. Valley wide grade control may be entirely buried and invisible post-construction and is not meant to hold specific habitats or structures in a single location but provide a protection to the site as whole from large erosive forces from flooding and the progression of headcuts across the site or from downstream. If the valley-wide grade controls fail, the system is not likely to remain connected laterally which will then prevent it from being retentive, and also lose habitat diversity (Section 1). Boundary stresses can be modeled during design to ensure that valley-wide grade control can encompass all flows and is not susceptible to outflanking. Performance metrics should also be selected that monitor for the stability of downstream grade control.

2.3.2 Loss of habitat diversity:

Failure to account for channel drying and loss of water. As a result of restoration activities, channel drying across the site during periods of normal rainfall can be a major stressor for aquatic communities and indicates that the system likely cannot support diverse aquatic habitats or abundant biological communities. If the DAV was restored by raising the streambed, there is potential for the channel to be “perched” (i.e. the water table was not raised along with the channel). For this restoration practice, the design process should evaluate the potential for increased channel drying. Channel drying may also be a result of a failure to connect the baseflow channel to the valley aquifer during design. During monitoring, performance standards should evaluate the surface water/groundwater connection by comparing water levels or documenting hydrophytic vegetation.

Failure to account for excessive deposition. In the case of excessive deposition across the site, sediment supply upstream of the site is higher than the design can accommodate and is reducing the quality and quantity of habitat in the site. High sediment loads must be addressed proactively during the design phase and site must be large enough to handle the sediment supply and continue to support diverse habitats. Design standards to address upstream sediment supplies should be tailored to the project area. Habitat diversity is lost as sediment fills in pools and off-channel habitat, which in turn means an abundant biological community is unsupported (Section 1).

2.3.3 Loss of net retentive valley:

Failure to design transitions with upstream and downstream reaches. When restoring DAVs, it is essential to address differences between the flow velocity, sediment load, and transport capacity of the areas up- and downstream of the restored site. In doing so, practitioners work to ensure that the site remains retentive which also allows it to continue to support diverse habitat and abundant biological communities (Section 1). In certain cases, a practitioner may be able to reconnect and restore the entire valley with natural geomorphic grade control (e.g., river confluences, alluvial fans, bedrock controls, etc.) at the downstream end. At that scale, assuming flows are diffuse with large floodplain diversity, transition zones may not need to be intensively designed, project risk may be relatively low, and the whole valley may be truly dynamic. In this case, it may be necessary to regularly identify whether portions of the floodplain graded are being accessed as planned, and whether the valley more closely represents historic conditions (Powers et al. 2019).

However, dynamic stream restoration practitioners may not always be able to restore the entire stream valley and may need to ensure that the evolving system does not significantly impact the areas beyond project boundaries. For example, a restored stream wetland complex may directly feed into an unrestored, incised transport reach downstream. If proper protections are not addressed, headcuts can move through the restored site, eroding sediment rapidly and resulting in an incised and entrenched stream. There are multiple methods of addressing landscape impacts during the design phase. One of these methods is to place valley wide grade control including the use of buried logs at the downstream end of the site and grading alluvial fans at the upstream end. Another method is to grade the entire project reach in a stepwise fashion. In these cases, it is then essential to monitor vertical migration to ensure rapid avulsion does not occur. If risk can be minimized with design considerations it may reduce the number of specific morphological performance targets needed.

Failure to account for excessive erosion: DAVs will naturally have erosion and deposition at points across the valley, on a whole there should be more depositional areas than erosional and no erosional feature should exhibit continued growth across the site. Erosion becomes a failure point when the valley is no longer net retentive. In the case of excessive erosion, flood velocities and/or boundary stress exceed the resistance of channel and floodplain material. This indicates that the stream is not sufficiently laterally connected and will not remain retentive or maintain aquatic habitat diversity (Section 1). During the design phase, high velocities can be accounted for using 2-D modeling and may require wood or rock reinforcement for control points. This failure point can be monitored by measuring vertical drop over grade control or utilizing the Bank Erodibility Hazard Index (BEHI).

2.3.4 Loss of biological communities:

Failure to Establish desirable vegetative communities. As stated above, DAV evolution should be primarily driven by biological community interactions (Section 1). Therefore, a desirable vegetative community is one that interacts with groundwater and is abundant. A failure point is reached if the vegetative community is dominated by minimal species, large patches of bare ground or open water, or the majority of riparian vegetation is upland that does not interact with groundwater.

There are many instances where undesirable vegetative communities can be addressed proactively during the design and construction phase. Two-dimensional hydraulic modeling can identify areas of high boundary stress that may make it difficult for vegetation to establish. Initial field surveys can additionally determine if soils are suitable for hydrophytic vegetation establishment. Finally, construction practices which compact soil (and limit vegetation establishment) should be avoided and/or corrected. Wetland vegetation is generally a good indicator as a performance standard as it also indicates that there is a water table near the surface and that flood velocities do not exceed stability thresholds.

Failure to design for poor water quality. Poor water quality (including turbidity, nutrients, pesticides, and other pollutants) can limit the abundance or diversity of aquatic taxa. Water quality is a failure point if it is insufficient to support target communities. In many cases, this issue can be addressed by properly surveying sites, identifying pollutant sources, and determining whether a given site will have limited potential for abundant biological communities. Additionally, practitioners need to ensure that the materials used on site support biological communities and that those materials do not contribute to poor water quality.

2.4. *Alternative Endpoints*

Restoration projects are typically built to a specific design, which may sometimes be adjusted during the construction phase, but has a single intended design endpoint. Monitoring strategies and performance standards are developed to ensure the intended design endpoint was achieved representing both the design and the functions restored. However, DAVs are expected to evolve, and the restored site may follow a different trajectory than anticipated and still produce high quality DAV aquatic habitats. Based on knowledge of the site, practitioners should work with regulators to identify what other endpoints are 1) plausible, and 2) acceptable. An example including endpoints for a theoretical dynamic stream mitigation project is outlined in Table 1.

In this example, practitioners have designed an anastomosing stream-wetland complex and representative performance standards are selected (wet meadow performance standards and multithread retentive performance standards; Table 1). Several possible states have been identified as acceptable and unacceptable for each of the four key DAV processes. For example, should the site evolve into a single-thread complex, corresponding performance standards can be applied, so long as the site remains relatively stable and does not trend towards an unacceptable process endpoint (e.g., a lack of vertical connectivity indicated by a vegetation community that does not interact with groundwater). Identification of potential alternative endpoints, and monitoring that can distinguish among endpoints, is critical for development of effective data collection efforts that inform monitoring and adaptive management strategies.

Table 1. *An example framework for a theoretical stream mitigation project with both expected and alternative endpoints.*

<table>
<tr><th rowspan="2"></th><th rowspan="2">Expected/designed Endpoint</th><th colspan="2">Alternative Endpoints</th></tr>
<tr><th>Acceptable Endpoints</th><th>Unacceptable endpoints</th></tr>
<tr><td rowspan="3">Extensive Lateral and Vertical Connectivity– Vegetation</td><td rowspan="3">Wet meadow: Performance standards include aerial dominance by herbaceous species and presence of hydrophytic vegetation, with limits on invasive species coverage. If floodplain is inundated (i.e., regular overtopping flows) for extended periods during monitoring, percent coverage by herbaceous species may be reduced.</td><td>Riparian forested wetlands: Performance standards include hydrophytic vegetation and typical tree metrics (e.g., minimum woody stems per acre, species diversity and composition, growth or size and nonnative species limits). Wetland species are represented.</td><td rowspan="2">Upland community: Community is dominated by upland species. Hydrophytic and wetland species are not present or are minimally represented, indicating that the site is not connected vertically.</td></tr>
<tr><td>Scrub-shrub: Performance standards include presence of hydrophytic vegetation and typical shrub metrics (e.g., minimum stems per acre, species diversity and composition and nonnative species limits). Wetland species are represented.</td></tr>
<tr><td>Vegetation managed by beaver: Performance standards include the presence or dominance of hydrophytic vegetation. Floodplain is likely to be inundated for extensive periods, reducing shrub and woody vegetation coverage. Wetland species are represented.</td><td>Minimal or bare community: Soil bare in many areas with fresh deposition or erosion across the site. Suggests that design failures (e.g., boundary stresses, bank heights, soil compaction, etc.) are limiting vegetation establishment and the site is not appropriately connected laterally or vertically.</td></tr>
</table>

	Expected/designed Endpoint	Alternative Endpoints	
		Acceptable Endpoints	Unacceptable endpoints
Retention of Materials–Morphology	**Stable functional multithread retentive system with active floodplain:** Headcuts and bank erosion are limited (either via valley-wide grade control or natural geomorphic controls) and complimented by depositional areas within the site. Performance standards include sediment retention, low shear stress and velocities.	**Stable functional single-thread reach with active floodplain:** Site is satisfying retentive performance standards (sediment retention, low shear stress and velocities). The site is not incising; headcuts and headcut potential are limited by the presence of valley-wide grade control.	**Unstable or non-functional system with single or multi-thread channels:** Site is failing to meet performance standards (sediment retention, low shear stress and velocities). Valley-wide grade control fails or the stream incises and the floodplain is inactive. Indicates that the stream is not laterally connected and does not retain sediment or organic materials.
		Stable, functional system managed by beaver: Site is satisfying retentive performance standards (sediment retention, low shear stress and velocities). The site is not degrading; headcuts and headcut potential are limited by stable grade control. Potential hydrologic trespass is monitored and managed effectively.	**Unstable or non-functional system managed by beaver:** Site is failing to meet performance standards (sediment retention, low shear stress, and velocities) or the site is degrading (e.g., avulsions leading to site wide loss of grade control). Valley-wide grade control fails, or hydrologic trespass is extensive. Indicates that a stream is not sustainably net retentive.
Creation and Maintenance of Diverse Habitats	**Multithread stream-wetland complex:** Performance standards include high in-channel habitat diversity, increased wetted area (including off-channel habitat) compared to pre-construction conditions, and increased floodplain diversity compared to pre-construction conditions	**Single-thread stream-wetland complex:** Site evolves into a single-thread wetland complex. Performance standards include high pool and depth diversity, increased wetted area (including off-channel habitat and wetlands) compared to pre-construction conditions, and increased floodplain diversity compared to pre-project conditions.	**Non-functional channel habitat:** Site does not retain, or transport material as designed resulting in the homogenization of stream channel(s). Site cannot satisfy in-channel, pool, or depth diversity performance standards.
		Beaver wetland complex: The site is colonized by beaver and is not degrading. Performance standards include high pool and depth diversity, increased wetted area (including off-channel habitat and wetlands) compared to pre-construction conditions, and increased floodplain diversity compared to pre-construction conditions.	**Non-functional off-channel habitat:** Wetted area does not increase compared to pre-construction conditions or is not maintained between monitoring periods. Off-channel habitat and floodplain diversity are not sustainable, and the site cannot demonstrate habitat diversity.

<table>
<tr><th rowspan="2"></th><th rowspan="2">Expected/designed Endpoint</th><th colspan="2">Alternative Endpoints</th></tr>
<tr><th>Acceptable Endpoints</th><th>Unacceptable endpoints</th></tr>
<tr><td rowspan="2">Abundant Biological Communities</td><td rowspan="2">Abundant invertebrate assemblages: Increased wetted area and habitat diversity facilitates a greater abundance of macroinvertebrates. Performance standards include increased invertebrate abundance compared to pre-construction conditions, in addition to measures of richness to ensure species evenness. Invertebrate standards may be coupled with either fish or amphibian abundance standards. Assessment is per valley length, across the whole site, or other approach to capture whole site comparison of abundance.</td><td>Abundant amphibian assemblages:
Increased wetted area and off-channel habitat facilitate increased habitat for amphibians. Performance standards include increased invertebrate abundance compared to pre-construction conditions, in addition to measures of richness to ensure species evenness. May be coupled with invertebrate performance standards.</td><td>Depauperate biological communities: Monitored assemblage (or assemblages) fails to meet the abundance or richness of pre-construction conditions. Biota resembles an unrestored reach.</td></tr>
<tr><td>Abundant fish assemblages:
Increased pool diversity facilitates a greater abundance of fishes. Performance standards include increased fish abundance compared to pre-construction conditions and may also include measures of richness. Fish standards may be coupled with invertebrate abundance standards.</td><td>Invasive or uneven biological communities: Monitored assemblage (or assemblages) reaches or exceeds the abundance of pre-construction conditions but is uneven. Assemblage is overrepresented by few species. Richness resembles an unrestored reach.</td></tr>
</table>

3. Monitoring Strategies

Currently, dynamic alluvial valleys (DAVs) lack a recognized functional or conditional assessment methodology used in the regulatory program, and many existing methodologies are designed for single-thread transport reaches focusing on the channel and growth of a riparian forest. Evaluative methods for DAVs need to assess valley-scale changes, and valley scale monitoring strategies need to be identified. In some cases, existing monitoring strategies may be tailored to work for DAVs and in other cases different monitoring strategies would be more effective. Below are recommendations for monitoring strategies from interviews and literature.

Traditional mitigation monitoring incorporates the use of channel-wide transects including a certain length of the riparian area. Transects based on channel width may fail to capture indicators that key processes of DAVs have been restored. By extending transects through the length of the valley at strategic locations (so that they may bisect a diversity of habitats) certain variables may be better captured and returned to over time. These variables include macroinvertebrates, fishes, water depth, depth to groundwater, and sub-surface temperature.

Interviewees suggested that on-the-ground sampling could also be conducted via random site identification sampling (Hinshaw et al. 2022). In this scenario, a grid is laid across the valley, and a certain number of cells are randomly selected either within the channel, on the floodplain, or both. The percentage of cells required for statistical coverage has not been determined, but Hinshaw et al (2022) topographically surveyed 40 $42m^2$ plots across a $0.45km^2$ valley and measured canopy cover, wood volume, flow depth and velocity, organic cover, and sediment grain size. Generally, this method is likely also effective for hydraulic and habitat metrics. It was additionally noted by interviewees that macroinvertebrates could be surveyed via this method.

Practitioners, academicians, and regulators suggested that solely utilizing ground sampling may not accurately quantify DAV evolution and may fail to capture failure points. While on-site visits and the strategic replacement of transects and/or grid cells may partially alleviate these issues, interviewees generally recommended that dynamic restorations be monitored using site-scale monitoring (i.e., aerial photography or LiDAR; Iskin and Wohl 2023). By obtaining large scale point-in-time snapshots, regulators and project sponsors may be able to better understand how a site is changing and identify problem areas. Additionally, these snapshots may better detect changes in the proportion of habitat types and contextualize localized erosion or deposition that would be concerning if not seen in the context of the whole site.

Furthermore, individual interviewees have experienced how fixed plots and transects can misrepresent vegetation diversity on site. With appropriate ground truthing, vegetative assessment could be conducted with remote sensing data, including RGB wavelength, multispectral, and other LiDAR sensors. If resolution is not high enough to determine taxonomic diversity, it may still identify total vegetative coverage and strata development (i.e., percentage of herbaceous, shrub, and tree cover). Otherwise, vegetation may be assessed via random site identification, or by aggregating transects to compare overall site diversity.

Without an intensive sampling design that captures intra-channel variability as well as off-channel diversity, standard biological monitoring strategies may not accurately sample DAVs (Braccia et al. 2023). Interviewees and literature review supported the use of Environmental DNA (eDNA; DNA extracted from environmental samples including water and sediment that is shed by organisms) and DNA Metabarcoding (the use of characteristic sequences of DNA to identify taxa from eDNA or aggregated bulk samples) to supplement the monitoring of biological communities where practical (Liu et al. 2020, Flitcroft et al. 2022). These techniques are generally less time- and effort-intensive, require less expertise to identify species, and have been used to detect the presence of target species as well as the composition of bulk samples (Liu et al. 2020, Bruce et al. 2021). eDNA has been shown to be especially effective at determining the presence of hard-to-detect species (Eiler et al. 2018). However, while DNA methods are effective for detecting presence and absence before and after restoration, quantifying abundance of taxa is much less accurate and difficult to interpret (Lamb et al. 2019; Liu et al. 2020). Therefore, abundance parameters as well as indices of biotic integrity (and other multi-metric indices) may require traditional sampling methodologies.

Several best practices have been defined for both eDNA sampling and DNA metabarcoding (Helbing and Hobbs 2019, Bruce et al. 2021). To obtain accurate presence data, samples must be taken without disturbing the substrate and must be carefully preserved (Bruce et al. 2021). DNA-based assessments will generally benefit from the use of controls for false detections and negatives (Helbing and Hobbs 2019, Bruce et al. 2021). Importantly, eDNA and DNA metabarcoding assessments will only be effective where there is an existing library of genetic reference material for the area (Liu et al. 2020, Bruce et al. 2021). At this time, the use of these technologies may be best as supplemental to other assessments of biotic communities.

It is important to note that none of the described methods should be used in isolation. Valley-scale transects may accurately quantify lateral variability, random site sampling may provide a better understanding of longitudinal variation, large valley-scale snapshots may provide an accurate picture of site evolution and identify failure points, while DNA-based methodologies can supplement other biological sampling to provide an accurate understanding of species presence. These methods can be used together and be supplemented by traditional monitoring strategies to quantify overall conditions of a DAV.

4. Performance Metrics

4.1 *Metrics for a dynamic alluvial valley*

From the interviews and literature review performance metrics were selected that represented four key processes of dynamic alluvial valleys (DAVs): extensive lateral and vertical connectivity, creation and maintenance of diverse habitats, retention of materials, and abundant biological communities. Metrics that apply to DAVs and not a specific restoration approach were selected. As budgets and project needs vary, the following are a resource for IRT members to pick from to gauge project success and create effective performance standards. Metrics are first organized according to key functions then alphabetically (Table 2, Table 3).

Table 2 *Parameters, indicators, targets, timing, and notes & considerations suggested for DAV stream mitigation. Parameters are selected that represent retentive, slow-moving, and often multi-threaded systems and are organized according to DAV key functions. Indicators that can be assessed with random grid-based sampling are noted with . Indicators that can be assessed with drone-based imagery, GIS, and/or LiDAR are noted with . If an indicator can be assessed with eDNA sampling it is noted with . Indicators appropriate for sites colonized by beaver are noted with a .*

Key Process	Parameter	Indicator	Target	Timing	Notes & Considerations
Extensive Lateral and Vertical Connectivity	**Conductivity**	Water quality meters/loggers	Synoptic Decrease	After year 2	Will not be used in low-conductivity streams or streams where solute pollution is not an issue. A decrease in conductivity will likely be measurable where streams are either connected to groundwater, are retentive, or both. Surface water/groundwater interactions may not develop the first years after restoration.
			Decrease compared to pre-project condition		
			Decrease compared to control reach		
	Floodplain Connectivity	Bank height; Bank Height Ratio	Bank height < 1 ft; BHR < 1	Monitored in all years	Low bank height associated with increased potential for multiple overtopping events per year and high connectivity. Similarly associated with a lack of incision.
		Entrenchment Ratio (ER)	ER >2.2	Monitored in all years	Indicative of a large flood-prone area. Not an applicable metric when valley is constricted by natural topography. If the goal is to measure floodplain access, floodplain inundation (number of yearly overtopping events) is more specific and direct. Multiple SQTs do not apply this metric to multithreaded streams.
		Flooding/Inundation frequency, duration, and/or aerial extent; stream gage, ground water wells, water presence sensors, other continuous monitoring	Floodplain inundation events or duration in a normal flow year	Monitored in all years	Indicative of a large flood-prone area frequently laterally connected. Specifics will vary by region. As used by practitioners in Pennsylvania, 4 times per year in a normal year, coupled with visual evidence of floodplain inundation in spring season.
		Normalized Vegetative Development or Greenness Index	Increase across the valley compared to pre-project condition, particularly during dry season monitoring; Index values meeting or exceeding reference reach	Monitored in all years	Indices use color bands from a digital image, where greenness indicates vegetative growth. Indicates that a greater percentage of the valley is wetter for longer, and that vegetation is responding.

Key Process	Parameter	Indicator	Target	Timing	Notes & Considerations
Extensive Lateral and Vertical Connectivity	**Floodplain Stability**	Vertical bed stability	No vertical bed instability at any permanent valley grade control structures	Monitored in all years	Valley grade control structures (often buried logs) allow the site to evolve and reach dynamic equilibrium while minimally affecting downstream reaches. Monitoring vertical instability at grade control structures ensures that the site will not experience rapid headcuts. Used where rapid vertical incision is a concern (e.g., with legacy sediment present). In some stream restorations valley-wide grade control will not be necessary.
	Groundwater and Surface Water Exchange	Monitoring wells	Groundwater within 1 foot of surface elevation for consecutive days or a certain percentage of the monitoring period over X percent of the floodplain	Monitored in all years	There is a large variation for the specific target, but this metric would indicate maintenance of high groundwater table and assume greater GW/SW exchange. Could also use wetland hydrology standard.
		Tracers; seepage meters; piezometers	Increased exchange and residence time compared to pre-project conditions	Monitored in all years	Tracers and seepage meters could be used to show GW/SW mixing and increased residence time.
	Lateral Migration	Bank Erodibility Hazard Index (BEHI)	Low or very low; if bank heights less than 12 inches; automatically low	Monitored in all years	Monitored when lateral migration is a concern (property boundaries, important riparian habitat, etc.), or when sediment erosion would result in pollutant loading. While the banks of many of these projects will be primarily comprised of soft alluvium, low banks and low shear stress should ensure a low BEHI. Other metrics that indicate bank instability may be more indicative of overall function.
		Greenline Stability Rating (GSR)	High (7-8) to Excellent (9-10)		GSR is an index rating dependent on the calculated stability of vegetation in the greenline (vascular plants in or near the water's edge). GSR is likely a more effective measure of stability for multithread streams and streams where some erosion is expected. Currently limited to western streams with catalogued vegetation ratings and is less effective when the gradient is greater than 4%.

<table>
<tr><th>Key Process</th><th>Parameter</th><th>Indicator</th><th>Target</th><th>Timing</th><th>Notes & Considerations</th></tr>
<tr><td rowspan="6">Extensive Lateral and Vertical Connectivity</td><td rowspan="3">Temperature</td><td rowspan="3">Surface or mean water temperature through water column</td><td>Synoptic decrease</td><td rowspan="3">After year 2</td><td rowspan="3">Will not be used where temperature pollution is not an issue. A decrease in temperature will likely be measurable where streams are connected to groundwater, but this could also indicate a high degree of shading. During the first two monitoring years, shading may be minimal, and groundwater interactions may not be fully established. Vegetation may take longer to establish and shade the reach, but temperature should start to level and cool by year 3.</td></tr>
<tr><td>Decrease compared to pre-project condition</td></tr>
<tr><td>Decrease compared to control reach</td></tr>
<tr><td rowspan="3">Vegetation</td><td>Hydrophyte Cover Index (HCI)</td><td>HCI>50%</td><td>Monitored in all years after the first</td><td rowspan="3">By incorporating a metric indicating a wetland vegetative condition, stakeholders account for low shear stress, greater flood prone area, suitable soil, and increased groundwater exchange. While the proper soil texture and character may not be initially present, soils may be placed during construction using local materials. Furthermore, wetland vegetation presence indicates greater soil stability, nutrient uptake and water residence time. The specific metric chosen may depend on regional wetland definitions. HCIs and PIs do not represent all possible metrics indicating wetland condition.</td></tr>
<tr><td rowspan="2">Prevalence Index (PI)</td><td>Decrease compared to pre-project conditions</td><td rowspan="2">Monitored in all years after the first</td></tr>
<tr><td>≤ 3.0</td></tr>
<tr><td rowspan="3">Creation and Maintenance of Diverse Habitats</td><td rowspan="3">Depth Diversity</td><td>Coefficient of Variation of Depth</td><td rowspan="3">Increase compared to pre-project conditions; Meeting or exceeding reference conditions</td><td rowspan="3">Monitored in all years</td><td rowspan="2">Depth diversity indicates in-channel habitat and variable zones for temperature and sediment deposition. A matrix of stream depth can be created with aerial and multispectral imagery. Different depths can then be classified, and variation quantified. Restored DAVs should result in a high diversity of depths though specific numerical targets would be regionally-dependent.</td></tr>
<tr><td>DEMs or multispectral imagery via green wavelength LiDAR; number and variation of depth classes</td></tr>
<tr><td>Hydromorphological index of diversity (HMID)</td><td>By coupling depth diversity with flow diversity, hydraulic diversity can be quantified with the HMID. This allows for the creation of specific, quantifiable regional targets for monitoring</td></tr>
</table>

Key Process	Parameter	Indicator	Target	Timing	Notes & Considerations
Creation and Maintenance of Diverse Habitats	**Depth Diversity**	Pool Max Depth Ratio (max pool depth/mean riffle depth)	High variability of ratios	Monitored in all years	Lacking high-resolution imagery or a reference site, depth variability may be assessed with the Pool Max Depth Ratio. This dimensionless ratio measures mean max pool depth over the corresponding mean riffle depth and can use numerical targets based on substrate. Traditionally, targets for mean pool max depth ratio are generally 1.5 in gravel streams and 1.2 in sandy streams, though these targets measure well-formed pools. For DAVs, pool max depth ratio may be better used by measuring the ratio at corresponding riffles and pools and observing the range of ratios. A high variability of ratios suggests that there is a corresponding variety in pool habitat and sediment regime diversity
	Floodplain Diversity	Patch diversity; class interspersion and juxtaposition	Increase compared to pre-project conditions; meeting or exceeding reference conditions.	Monitored in all years	The floodplain diversity metric targets habitat diversity outside of the channel(s). This measurement method would require a classification of different floodplain habitat types (including but not limited to downed logs and other LWD, mounds, sloughs, oxbows, other off-channel wetlands, and relict side channels). Restored streams are expected to have a high diversity of classes, and high interspersion and juxtaposition between classes. Specific targets will be regionally dependent and may depend on whether an existing reference stream can be found, or a historic reference can be modeled.
		Visually with cross-sections, aerial imagery, or bathymetric LiDAR			When classifying imagery is difficult (i.e., imagery lacks appropriate resolution), floodplain diversity may be assessed and classified visually. A consistent methodology should be developed beforehand including specific off-channel habitats to be included.
	Flow Diversity	Stream gages; flow meters	Increase compared to pre-project conditions; Meeting or exceeding reference conditions	Monitored in all years	The flow diversity metric targets habitat within the channel(s) and the creation of zones for sediment transport and deposition. Specific targets will be regionally dependent, but high flow diversity is indicative of a natural stream-wetland complex.

Key Process	Parameter	Indicator	Target	Timing	Notes & Considerations
Creation and Maintenance of Diverse Habitats	**Channel Habitat Diversity**	Large Woody Debris (Wohl LWD Assessment, LWDI, or other large wood assessment)	Minimum 25% increase in the amount of wood retained compared to pre-project conditions	By the first monitoring year. Monitored in all years	Indicative of habitat complexity retention in areas of large wood recruitment. Additionally provides surfaces for sediment and carbon retention. This metric will not be applicable where wood recruitment is low. In those cases, a different habitat diversity metric may be more applicable.
		Channel bed pebble counts	Increase in post construction substrate diversity	By the last monitoring year. Could potentially observe earlier	Analyzed by collecting 100 pebbles from the wetted perimeter of sampling reaches. An increase in pebble diversity indicates that the site has variable zones of flow speed and habitat diversity. May be used where wood recruitment is lower.
			Successive monitoring demonstrates at least no difference, and possible increase in habitat diversity	Monitored in all years after the first, comparing total retention	
	Temperature Diversity	Temperature across the reach; loggers, drone, or meters	Variation increase compared to pre-project conditions	After year 2	Indicative of hyporheic exchange, and the creation of thermal refuges as well as habitat diversity. During the first two monitoring years, shading may be minimal, and groundwater interactions may not be fully established. Thermal Infrared is effective at measuring water surface temperature variations, particularly hyporheic upwelling and cold-water inputs.
		Thermal Infrared LiDAR			

Key Process	Parameter	Indicator	Target	Timing	Notes & Considerations
Retention of Materials	**Carbon Retention**	Visual, photo station or otherwise	60% of monitoring stations, pieces of LWD retaining CPOM	Monitored in all years	This metric target would demonstrate that a site can retain carbon but would not necessarily demonstrate that carbon is being retained successively between monitoring periods. The target will vary by region and site-specific conditions and should only apply to a normal flow year.
			Station average demonstrates increased retention of CPOM from year to year	Monitoring year 2 and onwards	This metric target would demonstrate that a site is successively retaining carbon. An increase in station average can mean that stations that were previously not retaining carbon are now doing so. The target will vary by region and site-specific conditions and should only apply to a normal flow year.
		Abundance of collector-gatherers	Increase compared to pre-project conditions; meeting or exceeding reference conditions	Monitoring year 2 and onwards	With increased presence of fine benthic organic matter (FBOM) there should be a corresponding increase in collector gatherers. If there is enough coarse particulate organic matter, there may be a similar increase in shredders.
	Flow Dynamics	Net spinning caddisfly abundance	Increase compared to pre-project	Monitored in all years after the first	Indicators of low shear stress, and conditions supportive of biological improvement, but may also indicate nutrient enrichment.
	Habitat Stability	Stability pebble counts (pit traps)	Minimum transport of gravel, less than 50% of gravel observed as compared to a control reach	Monitored in all years	Indicates that sediment is being retained and that channel bed particles above a target size class are not being transported. These metrics will not apply to sediment poor systems.
		Percentage Gastropoda or genus-level scrapers	Increase in the proportion of Gastropoda by abundance compared to pre-project or reference reach using a diverse set of habitats to sum to 1m^2	By the second monitoring year	Increased scraper percentage is indicative of low shear stress, biofilm development, and biological uplift. It can also be indicative of areas with high sun exposure and low shading as well as potential nutrient enrichment.

Key Process	Parameter	Indicator	Target	Timing	Notes & Considerations
Retention of Materials	Nitrogen	Field test kits	Synoptic decrease	Monitored in all years	Reductions in nitrogen concentrations indicate that any of several possible functions have been restored including sediment retention and hyporheic reconnection. Specific laboratory examination is dependent on the nitrous analyte used (total dissolved Nitrogen, N-NO3, NH4, etc.) which is in turn influenced by surrounding land use and the goals of the restoration. It is also possible to use handheld water quality meters and taken synoptic measures, but in most cases, repeated lab analysis is more accurate.
		Laboratory analysis	Decrease compared to pre-project condition		
			Decrease compared to control reach		
			Synoptic decrease		
	Phosphorus	Field test kits	Synoptic decrease	Monitored in all years	Among other techniques, Laboratory analysis can use autoanalyzers mass spectrometry elemental analysis to determined concentration of dissolved phosphorus. It is also possible to use handheld water quality meters or photometers and taken synoptic measures, but in most cases, repeated lab analysis is more accurate.
		Laboratory analysis	Decrease compared to pre-project condition		
			Decrease compared to control reach		
	Sediment Retention	Tiles (or similar surface) placed above baseflow in the floodplain at the top and bottom of the reach	Decrease in visible sediment from the top to bottom of the reach	Monitored in all years	These metrics will not apply to sediment poor systems, where retention would be better measured with visible carbon retention. May be more difficult to measure once vegetation gets established
		Abundance of burrowing/sediment-loving taxa	Increase compared to pre-project condition	After year 2	With the increased retentive capacity of these systems including fine benthic organic matter, sediment-loving taxa should increase in abundance.

Key Process	Parameter	Indicator	Target	Timing	Notes & Considerations
Abundant Biological Communities	**Amphibian Communities**	Native abundance	Native quantity increase compared to control reach	Monitored in all years after the first	Retentive systems will typically result in a larger wetted area that may support more amphibians. Particularly in headwater streams, amphibian metrics may more reliable than fish metrics. For amphibian metrics, sampling the perimeter of the reach as well as the underside of logs and rocks will reveal more amphibians. If measuring, per unit effort or relative to valley length recommended.
		Salamander/amphibian IBI	Index value increase compared to pre-project conditions		Using amphibian IBI or richness should ensure that the site is responding to increased habitat diversity and that there were not water quality concerns that were improperly addressed. IBI metrics will need to be available for regional amphibians.
		Taxa richness	Increase compared to pre-project conditions		
	Fish Communities	Native abundance	Native quantity increase compared to control reach	Monitored in all years after the first	Increased wetted area and habitat diversity may increase fish abundance and diversity in addition to macroinvertebrates and amphibians. Lacking a regional curve for retentive systems, direct measures of abundance and diversity are likely more effective at gauging the quality of the restoration than IBIs.
		Taxa richness	Increase compared to control reach		
			Increase compared to pre-project conditions		
		Target fish abundance	Increase compared to control reach		

Key Process	Parameter	Indicator	Target	Timing	Notes & Considerations
Abundant Biological Communities	**Macroinvertebrate Communities**	Total Abundance	Increase compared to reference reach; increase compared to pre-project conditions	Monitored in all years after the first	Increased wetted area and habitat diversity should correlate with an increased overall abundance of macroinvertebrates demonstrating that site has trophic support.
		O/E richness of Genera	Similar to or greater than reference reach		Lacking a regional curve based on functional curves. Pairing individual abundance or generic richness with Pielou's index or percent of dominant genera ensures improvement without one or two taxa dominating.
			Increase compared to pre-project condition		
		Richness of Genera	Increase in overall richness compared to pre-project		
			Generic richness similar to reference reach		
		Pielou's Index	Increase in Evenness compared to pre-project conditions		
			Evenness similar to reference reach		
		Percent dominant genera	Decrease compared to pre-project condition		
			Percent of dominant taxa similar to reference reach		
		Genus-level EPT richness	Increase in EPT genera by richness compared to pre-project		Used when water quality is a goal of restoration. Indicative of fast-flowing cold-water streams, used here to support cold water system even in depositional reach.
			EPT genera similar or greater than reference reach		
	Vegetation	Percentage of bare ground	Decrease compared to pre-project	Monitored in all years after the first	Indicative of increased biological uplift. Not descriptive of vegetative type but may indicate when trending towards an unacceptable endpoint.
		Percentage of native vegetation	Increase compared to pre-project and continued maintenance	Monitored in all years after the first	Specific targets for percentage of native vegetation (or conversely the percentage of non-native vegetation) will vary by region and monitoring period.

- 4.2 *Additional Considerations for Beaver*

  While many of the metrics in Table 2 apply to beaver-colonized streams in addition to DAVs, there may be additional metrics to monitor if beaver colonize a site. Beaver colonization will frequently change the extent of flooding, aggradation rates, and water quality. Therefore, if beaver colonization occurs unexpectedly, additional monitoring and modeling may be required to ensure that the site is not reaching any point of failure. Additionally, regulators may need to reexamine the project's initial goals and determine if further metrics are required to make sure that the site is functioning as intended. For example, if one of the site goals was to increase habitat for fish species, it may be necessary to monitor fish passage and dissolved oxygen (to ensure that fish have refuge from any anoxic areas). Table 3 represents metrics that would be monitored only in the presence of beaver dams.

Table 3. *Parameters, indicators, targets, and notes & considerations specific to beaver-colonized streams. Indicators that can be assessed with random grid-based sampling are noted with . Indicators that can be assessed with drone-based imagery, GIS, and/or LiDAR are noted with . If an indicator can be assessed with eDNA sampling it is noted with .*

Key Process	Parameter	Indicator	Target	Notes & Considerations
Extensive Lateral and Vertical Connectivity	**Floodplain Expansion**	Flooding extent	Extent of current (and future) flooding minimal outside of project boundaries.	Metric would be coupled with efforts during design to outline where beaver flooding may cross site boundaries and or affect infrastructure. By consistently measuring flooding extent and modeling future extent practitioners can respond with flow devices, beaver deceivers, and beaver removal as appropriate.
	Groundwater Recharge	Gross groundwater recharge	Groundwater recharge shown to be positive	Beaver dams often raise the water table and recharge aquifers. In regions with draining aquifers, this metric demonstrates uplift.

Key Process	Parameter	Indicator	Target	Notes & Considerations
Retention of Materials	**Beaver Dam Stability**	Visual or photographic; identification of potential failure zones with modeling	Beaver dams relatively stable	Complete stabilization of beaver dams may not be realistic or desirable. However, where stream banks are in danger of eroding from avulsion or side cutting, or when a blowout could cause damage outside of site boundaries, stability and erodibility potential may be assessed. If a potential hazard is identified, dams can be supported with vertical wooden posts or logs. This may extend the lifespan of a structure and allow vegetation to colonize and further stabilize the reach. Stabilization of dams may not be necessary when projects are restored with the 100-year flood in mind or are restored over an entire valley with grade control. If there are downstream property concerns, it may only be necessary to monitor the most downstream dam, as it would be most likely to influence reaches downstream of the site.
			Most downstream beaver dam relatively stable	
	Temperature	Water quality meter; water quality loggers	Reach average similar to pre-colonization, or to pre-project conditions	Used when lowering temperature or providing habitat for salmonid species (or other coldwater species) is one of the goals/concerns of the mitigation. Temperature may be higher in ponds but may show little difference elsewhere in the reach.
			Synoptic warming not significantly greater than control reach	
	Water Storage	Wetted area	Increase from pre-colonization condition, or pre-construction conditions	Beaver dams have a documented impact on surface water storage. Particularly beneficial in areas with less water availability. It is essential to include all off-channel wetted habitat in this measurement.

Key Process	Parameter	Indicator	Target	Notes & Considerations
Abundant Biological Communities	**Dissolved Oxygen**	Water quality meter	>5 mg/L dissolved oxygen	Based on thresholds of hypoxia in freshwater, though this varies widely based on what is typical for the region (i.e., temperature and salinity).
	Fish Passage	Species richness	Richness is similar above and below dams	Used when encouraging biodiversity is a goal of the mitigation. This metric considers the effect of the dams on fish passage specifically.
		Target fish presence	Target species is present above beaver and below beaver dams	Used when providing habitat for certain fish species is a goal of the mitigation. This metric considers effects of beaver dams on fish movement.

4.3. *Metric Selection and Prioritization*

The performance metrics presented in Table 2 and Table 3 are not intended to describe all potential performance metrics and should not be used in their entirety for any one project. Instead, these metrics address aspects of DAVs rarely found in current stream mitigation protocols. If a restored DAV evolves into a single-thread transport reach over a portion of the project, existing performance metrics may be appropriate to monitor that reach. Furthermore, restorations may be multimodal (including reaches restored with form and stability-based restoration as well as DAV restoration), and the metrics above do not preclude the use of other metrics. Not all measures will be appropriate for a given project, and all targets should consider the regional context. For example, if a regionally specific biologic index is available that applies to slow-moving retentive systems it may be more appropriate than the biological metrics listed.

Metrics should be selected according to the overall restoration goals and not solely the short-term geomorphic goals. Furthermore, metrics that are direct indicators of function and that are straightforward measures, should be prioritized. Metrics should be selected to indicate that a site is fully functional across the four key processes of DAVs (Extensive lateral and vertical connectivity, creation and maintenance of diverse habitats, retention of materials, and abundant biological communities) and to indicate whether a site is reaching a particular failure point (see Section 2.3). Some selected parameters and indicators may represent multiple key processes or failure points. For organizational ease, parameters are sorted according to their most representative key process. To contextualize which functions are indicated by a given parameter metrics are organized using the key processes described in this report and two assessment frameworks (Table 4):

- The four key DAV processes described above (extensive lateral and vertical connectivity, creation and maintenance of diverse habitats, retention of materials, and abundant biological communities).
- The Stream Functions Pyramid divides indicators by whether they are more related to hydrology (defined as the transport of water from the watershed to the channel), hydraulics (defined as the transport of water through the channel, on the floodplain, and through sediments), geomorphology (defined as the transport of wood and sediment to create diverse bed forms and dynamic equilibrium), physicochemistry (defined as the regulation of temperature and oxygen, as well as the processing of organic matter and nutrients), and biology (defined as the biodiversity and the life histories of aquatic and riparian life).
- The Stream Function Assessment Method (SFAM; Nadeau et al. 2020) has been developed primarily in the Pacific Northwest. SFAM identifies a series of 11 key functions: surface water storage, sub/surface transfer, flow variation, sediment continuity, substrate mobility, maintain biodiversity, create and maintain habitat, sustain trophic structure, nutrient cycling, chemical regulation, thermal regulation. (More detailed definitions of each of these functions in Section 2.2 of the SFAM User Manual)

Table 4 is intended to describe how a given parameter indicates function in multiple frameworks but is not intended to act as a complete cross-referencing between those frameworks. For example, an abundant or diverse amphibian community is on the biology level of the SFP, and for the SFAM indicates that the site is functioning in terms of surface water storage, maintaining biodiversity and sustaining trophic structure. Whether the framework focuses on the functional character of the parameter itself, or what the parameter indicates about valley functions or processes as a whole, an essential step in metric selection is to ensure that the key functions/processes of the system being restored are represented in the collection of metrics assessed. Regardless of the assessment framework used, it is essential that the selected frameworks represent a range of functions.

Table 4. *Metrics suggested for the restoration of DAVs and for beaver colonization of restored streams. SFAM functions and potential driving processes are included for each corresponding parameter and measurement method. If the metric has known usage in stream mitigation, those citations are included. Otherwise, corresponding literature references are included. Indicators that can be assessed with random grid-based sampling are noted with . Indicators that can be assessed with drone-based imagery, GIS, and/or LiDAR are noted with . If an indicator can be assessed with eDNA sampling it is noted with . Indicators appropriate for sites colonized by beaver are noted with a .*

Key Process	Stream Function Pyramid Level	SFAM Key Functions	Parameter	Indicator	Citation
Extensive Lateral and Vertical Connectivity	Hydraulics	Surface water storage, flow variation, maintain biodiversity create and maintain habitat	Floodplain Connectivity	Bank height; Bank Height Ratio	Great Pee Dee Mitigation Bank
				Entrenchment Ratio (ER)	Great Pee Dee Mitigation Bank
				Flooding/Inundation frequency, duration, and/or aerial extent; stream gage, ground water wells, water presence sensors, other continuous monitoring	Codorus Creek Stream & Wetland Bank
			Floodplain Expansion	Flooding extent	Wheaton 2013
		Surface water storage, sub/surface transfer, flow variation, sustain trophic structure, nutrient cycling, chemical regulation, thermal regulation	Groundwater and Surface Water Exchange	Monitoring wells	Robinson Fork Mitigation Bank, Quaker Mitigation Bank
		Sub/surface transfer, flow variation, sustain trophic structure, nutrient cycling, chemical regulation, thermal regulation		Tracers; seepage meters; piezometers	Hatch et al. 2006
		Sub/surface transfer, surface water storage, create and maintain habitat, chemical regulation, thermal regulation	Groundwater Recharge	Gross groundwater recharge	Bobst et al. 2022, Pollock et al. 2003

Key Process	Stream Function Pyramid Level	SFAM Key Functions	Parameter	Indicator	Citation
Extensive Lateral and Vertical Connectivity	Geomorphology	Flow variation, sediment continuity, sediment mobility	Floodplain Stability	Vertical bed stability	Robinson Fork Mitigation Bank, Quaker Mitigation Bank, Laurel Hill Creek Mitigation Bank
		Surface water storage, flow variation, sediment continuity, create and maintain habitat	Lateral Migration	Bank Erodibility Hazard Index (BEHI)	Upper Susquehanna River Mitigation Bank-Phase 2, Codorus Creek Stream & Wetland Bank
	Physicochemical	Surface water storage, sub/surface transfer, sediment continuity, maintain biodiversity, nutrient cycling, chemical regulation	Conductivity	Water quality loggers/meters	Great Pee Dee Mitigation Bank, Briggs et al. 2019
		Surface water storage, sub/surface transfer, flow variation, thermal regulation,	Temperature	Surface or mean water temperature through water column- DM, MWAT, monthly average (summer or winter)	Great Pee Dee Mitigation Bank, Upper Susquehanna River Mitigation Bank-Phase 2, Pollock et al. 2003
	Biology	Surface water storage, sub/surface transfer, sediment continuity, maintain biodiversity	Floodplain Connectivity	Normalized Vegetative Development or Greenness Index	Rhew et al. 2012
			Lateral Migration	Greenline Stability Rating (GSR)	U.S Army Corps of Engineers 2020.
			Vegetation	Hydrophyte Cover Index (HCI)	Laurel Hill Creek Mitigation Bank, Robinson Fork Mitigation Bank
				Prevalence Index (PI)	

Key Process	Stream Function Pyramid Level	SFAM Key Functions	Parameter	Indicator	Citation
Creation and Maintenance of Diverse Habitats	Hydraulics	Surface water storage, flow variation, sediment continuity	Depth Diversity	Coefficient of Variation of Depth	Stewardson 2005
				DEMs or multispectral imagery via green wavelength LiDAR; number and variation of depth classes	Iskin and Wohl 2023
				Hydromorphological index of diversity (HMID)	Gostner et al. 2013
				Pool Max Depth Ratio (mean pool depth/mean riffle depth)	Harman et al. 2012
		Surface water storage, flow variation, sediment continuity	Flow Diversity	Stream gages; flow meters	Gostner et al. 2013
	Geomorphology	Surface water storage, sub/surface transfer, flow variation, sediment continuity, sediment mobility, create and maintain habitat	Channel Habitat Diversity	Large Woody Debris (Wohl LWD Assessment, LWDI, or other large wood assessment	Great Pee Dee Mitigation Bank
		Flow variation, sediment continuity, sediment mobility, create and maintain habitat		Channel bed pebble counts	Robinson Fork Mitigation Bank, Laurel Hill Creek
		Flow variation, create and maintain habitat	Floodplain Diversity	Patch diversity; class interspersion and juxtaposition	Robinson Fork Mitigation Bank
				Visually with cross-sections, aerial imagery, or LiDAR	

Key Process	Stream Function Pyramid Level	SFAM Key Functions	Parameter	Indicator	Citation
Creation and Maintenance of Diverse Habitats	Physicochemical	Sub/surface transfer, surface water storage, flow variation, thermal regime	Temperature Diversity	Temperature across the reach; loggers, drone, or meters	Poole and Berman 2001
				Thermal Infrared LiDAR	
Retention of Materials	Hydraulics	Surface water storage, flow variation, sediment mobility, create and maintain habitat, chemical regulation, thermal regulation	Water Storage	Wetted area	Karran et al. 2017
	Geomorphology	Flow variation, sediment continuity, sediment mobility, create and maintain habitat	Beaver Dam Stability	Visual or photographic; identification of potential failure zones with modeling	Great Pee Dee Mitigation Bank
		Surface water storage, flow variation, sediment continuity, sediment mobility	Habitat Stability	Stability pebble counts (pit traps)	Kondolf 1997
			Sediment Retention	Tiles (or similar surface) placed above baseflow in the floodplain at the top and bottom of the reach	Robinson Fork Mitigation Bank

Key Process	Stream Function Pyramid Level	SFAM Key Functions	Parameter	Indicator	Citation
Retention of Materials	Physicochemical	Flow variation, sediment continuity, sediment mobility, create and maintain habitat, sustain trophic structure, nutrient cycling	Carbon Retention	Visual, photo station or otherwise	Quaker Mitigation Bank, Robinson Fork Mitigation Bank
		Surface water storage, sub/surface transfer, sediment continuity, chemical regulation	Contaminant Concentration	Sediment cores; X-ray fluorescence analyzer	Briggs et al. 2019
		Nutrient cycling, chemical regulation, thermal regulation	Nitrogen	Field test kits	Great Pee Dee Mitigation Bank
				Laboratory analysis	
			Phosphorus	Field test kits	Klotz 1998
				Laboratory analysis	
	Biology	Flow variation, sediment continuity, sediment mobility, maintain biodiversity, sustain trophic structure	Carbon Retention	Abundance of collector-gatherers	Poff et al. 2006
		Surface water storage, flow variation, sediment continuity, sediment mobility, maintain biodiversity	Flow Dynamics	Netspinning Caddisfly Abundance	Albertson et al. 2014
		Maintain biodiversity, surface water storage, sustain trophic structure	Habitat Stability	Percentage Gastropoda or genus-level scrapers	Lu et al. 2019
		Surface water storage, flow variation, sediment continuity, sediment mobility, create and maintain habitat	Sediment Retention	Abundance of burrowing/sediment-loving taxa	Poff et al. 2006

Key Process	Stream Function Pyramid Level	SFAM Key Functions	Parameter	Indicator	Citation
Abundant Biological Communities	Geomorphology	Flow variation, maintain biodiversity, create and maintain habitat	Fish Passage	Species richness	O'Connor et al. 2022
				Target fish presence	
	Physicochemical	Flow variation, maintain biodiversity, create and maintain habitat, chemical regulation, thermal regulation	Dissolved Oxygen	Water quality meter	Great Pee Dee Mitigation Bank
	Biology	Surface water storage, maintain biodiversity, sustain trophic structure	Amphibian Communities	Native abundance	Romansic et al. 2021
				Salamander/amphibian IBI	Micacchion 2012
				Taxa richness	
		Maintain biodiversity, sustain trophic structure	Fish Communities	Native abundance	Robinson Fork Mitigation Bank, Quaker Mitigation Bank
				Taxa Richness	
		Flow variation, maintain biodiversity, create and maintain habitat		Target fish abundance	
		Sustain trophic structure	Macroinvertebrate Communities	Total Abundance	Braccia et al. 2023
		Maintain biodiversity		O/E richness of Genera	Somerville and Pond 2022
				Richness of Genera	

Key Process	Parameter	Indicator	Target	Timing	Notes & Considerations
Abundant Biological Communities	Biology	Maintain biodiversity, sustain trophic structure	Macroinvertebrate Communities	Pielou's Index	Lu et al. 2019
				Percent dominant genera	
		Maintain biodiversity, thermal regulation, chemical regulation		Genus-level EPT richness	Somerville and Pond 2022
		Maintain biodiversity, create and maintain habitat, sustain trophic structure, nutrient cycling, chemical regulation, thermal regulation	Vegetation	Percentage of bare ground	Laurel Hill Creek Mitigation Bank
				Percentage of native vegetation	

5. Further Application

The performance and monitoring suggestions in this document have the potential to create evaluative flexibility outside of the design and restoration of dynamic alluvial valleys (DAVs). If the goals of the mitigation are fulfilled, there is the potential for regulators to use alternative endpoints and other indicators of function to allow for shifts in the restored stream when those shifts result in similar or greater functional benefit. For example, the metrics that were identified as appropriate for beaver (Table 2, Table 3) are also applicable to beaver-colonized systems that were not initially DAVs. Thus, if metrics demonstrate that a beaver colonized site has greater (or equivalent) ecosystem function and is not reaching a failure point (Section 2.3), beaver may be allowed to remain. Additionally, alternative metrics and endpoints may be used when a DAV is not the intended form of a restored stream but is instead the result of natural evolutionary processes, and functional equivalence or increase is demonstrated.

Increased evaluative flexibility requires careful consideration by regulators. Importantly, alternative endpoints and regulatory flexibility do not preclude important jurisdictional, crediting, and procedural concerns. As in every case it is essential that the mitigation project is fulfilling its goals. Furthermore, practitioners should be able to demonstrate equivalent or increased function of an alternative stream trajectory if a new trajectory is to be evaluated as successful. Below is an example of how this process can operate.

5.1 Example: A Single-Thread Perennial Stream evolves into a dynamic alluvial valley

In this example, a practitioner restored a coastal plain stream approximately 5000 feet in length. The stream was restored using an emphasis on channel form and stability. Planning, monitoring, and evaluation were similarly tied to form and stability. The specific success criteria represent two functions: Stability and Maintenance of Stream Form (Rosgen C or E Channel) and Floodplain Access (two Bankfull events observed over five years of monitoring). During the monitoring period, the site evolves into a DAV. Rather than require intervention to reorient the site to a pre-DAV state, the practitioners and sponsors show that the project can demonstrate the same functions as the designed endpoint as a DAV through the documentation of alternative acceptable endpoints:

Table 5. *Alternative endpoints for an example coastal plain stream designed with an emphasis on form and stability.*

	Expected/Designed Endpoint	Alternative Endpoints	
		Acceptable Endpoints	**Unacceptable endpoints**
Stability and Maintenance of Stream Form	**Rosgen Channel Type C or E:** as indicated by longitudinal profile and cross-sections. Photographs indicate little aggradation or degradation	**Rosgen Channel Type DA:** as indicated by the longitudinal profile and cross-sections. May be induced by beaver. No headcuts forming at downstream end of site.	**Entrenchment ratio is <2.2:** Conditions indicated that the sight is entrenching and is therefore not accessing the floodplain as designed. Conditions are inappropriate for C, E, and DA channels.

	Expected/Designed Endpoint	Alternative Endpoints	
		Acceptable Endpoints	Unacceptable endpoints
Floodplain Access	**Regular Bankfull Events:** The site has two or more documented Bankfull events over a 5-year monitoring period.	**Extensive Lateral Connectivity as a DAV:** Vegetation coverage is represented by wetland species. The floodplain is inundated regularly. The site has increased lateral flooding extent and duration. The site is not degrading.	**Unstable or Incised system with single or multi-thread channels:** Site is failing to connect to the floodplain-valley-wide grade control fails or the stream incises, and the floodplain is inactive. Indicates that the stream is not laterally connected and does not demonstrate habitat diversity.
		Floodplain access facilitated by beaver: After beaver colonize, site is satisfying performance standards. The site is not degrading; headcuts and headcut potential are limited. Potential hydrologic trespass is monitored and managed effectively.	**Unstable or non-functional system managed by beaver:** Beaver colonization leads to the failure of valley-wide grade control, or hydrologic trespass is extensive. Indicates that a stream is not sustainably maintaining lateral and vertical connections or net retentive and will lose habitat diversity.

In addition to including the alternative endpoints for the metrics used in the initial single-thread perennial stream state, a practitioner may choose (or an IRT may require a practitioner) to include additional metrics specific to a DAV (Table 2). These metrics may be focused on the four key processes of DAVs or to demonstrate that the DAV has increased specific functions of the system. The additional metrics may be used as part of the SFP, SFAM, or a different evaluative framework (Table 4).

6. Works Cited

Table 6 *Mitigation banks cited for performance metrics and monitoring strategies. State, date established, and RIBITS link are included.*

Mitigation Bank Name	State	Date Established	RIBITS Link
Upper Susquehanna River Mitigation Bank- Phase 2	Pennsylvania	06/20/2013	https://ribits.ops.usace.army.mil/ords/f?p=107:10:::::P10_BANK_ID:2857
Quaker Mitigation Bank	Pennsylvania	05/31/2020	https://ribits.ops.usace.army.mil/ords/f?p=107:10:::::P10_BANK_ID:5284
Codorus Creek Stream & Wetland Bank	Pennsylvania	06/27/2019	https://ribits.ops.usace.army.mil/ords/f?p=107:10:::::P10_BANK_ID:4606
Robinson Fork Mitigation Bank	Pennsylvania	09/01/2015	https://ribits.ops.usace.army.mil/ords/f?p=107:10:::::P10_BANK_ID:3249
Laurel Hill Creek Mitigation Bank	Pennsylvania	12/20/2019	https://ribits.ops.usace.army.mil/ords/f?p=107:10:::::P10_BANK_ID:5267
Great Pee Dee Mitigation Bank	South Carolina	02/08/2021	https://ribits.ops.usace.army.mil/ords/f?p=107:10:::::P10_BANK_ID:4881

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