

Research Agenda

Process-based Riverscape Restoration

This research agenda identifies priority questions about the strategies, outcomes, and impacts of process-based restoration.

Objectives

The goal of this research agenda is to articulate priority research topics related to process-based riverscape restoration that, if conducted and shared with key audiences, could increase the scale, pace, and effectiveness of restoration on public lands in the West. The research agenda may be useful in guiding grant-making and funding decisions for organizations and agencies that support research. It may also be useful to practitioners as they design, implement, and monitor projects.

Methodology

These research questions were developed and refined by a group of scientists, federal agency staff, public utilities, non-profit organizations, and funders at a workshop in August 2024. The workshop was facilitated by Meridian Institute with funding from Walton Family Foundation. Participants were encouraged to share priority research questions prior to the workshop. Meridian then compiled those questions into a draft research agenda that was discussed and refined at the workshop and through a subsequent round of written feedback from workshop participants.

This process considered the research needs and ideas from technical experts as well as practitioners and decision-makers. As a result, the final research questions focus on applied science. The research questions help test assumptions about the benefits of process-based restoration, address perceptions that may serve as barriers to process-based restoration, and/or document or quantify outcomes that might support incentivizing future funding and support.

Criteria

The research questions included in this agenda meet the following criteria:

- **Focuses on process-based restoration.** Focusing on processes, rather than specific approaches and structures, is true to the method and helps inform expectations. There is a range of terminology and degrees of specificity when discussing riverscape health, process-based restoration, and specific restoration strategies and tools. This research agenda

focuses on process-based restoration that builds on the riverscape health principles.¹ When and where useful, they may focus on questions related specifically to low-tech process-based restoration (LTPBR), a subset of process-based restoration practices that emphasizes scalability.

- **Relevant to a decision-making audience.** The resulting research would provide information that could support decision-making by a specific audience or answer a question critical to increasing the pace, scale, and effectiveness of process-based restoration in the Western US.
- **Matches the “burden of proof” required by the audience.** The research questions, considerations, and goals included in this agenda are intended to match the “burden of proof” required by the intended audiences. Some audiences will be best served by academic studies that undergo the peer review process. Peer review research, while the gold standard, can be slow, inaccessible, or unnecessary for some audiences. In addition to rigorous scientific research, there is a need for adaptive monitoring, science communication, case studies, or other information distillation/translation for specific audiences. Focusing on high-level concepts (e.g., resilience, complexity, safety in redundancy) may be an effective way to communicate information across sites and audiences.

Acronyms

Acronyms used in this research agenda are summarized in the table below.

ACRONYM	FULL NAME
AOP	Aquatic Organism Passage
BDA	Beaver Dam Analogue
CWA	Clean Water Act
ESA	Endangered Species Act
GIS	Geographic Information System
LTPBR	Low-Tech Process-Based Restoration
NOAA	National Oceanic and Atmospheric Administration
PALS	Post-Assisted Log Structures
PBR	Process-Based Restoration

¹ Riverscape health principles suggest that healthy riverscapes have space to interact within their valley bottom; natural flow, sediment, and vegetation regimes unique to the biophysical setting and river type; and structure that forces diversity and creates varied residence times for water, sediment and vegetation. Source: The Principles of Riverscape Health, Al-Chokhachy et. al. publication forthcoming in WIREs Water.

Research Questions, Audiences, and Goals

Below is a concise summary of key research questions, along with an explanation of the audience and potential usefulness of the resulting research.

This research agenda is intended to support decision-making to increase the pace, scale, and effectiveness of riverscape restoration on public lands. As a result, it is broadly organized into restoration benefits that might be compelling to unlock funding or build support (e.g., carbon storage, sediment capture, etc.) and concerns that might limit or slow projects (e.g., changes to hydrology that might affect water rights, etc.). Each research question identifies priority audiences and goals for the research.

Appendix A describes additional research questions related to these topics as well as specific research considerations. There are also important research questions that focus on project design, site selection, monitoring, and long-term maintenance that are included in Appendix B. They are designed to adaptively inform the practitioner community and guide continuous learning and improvement.

RESEARCH QUESTIONS	AUDIENCES AND GOALS
<p>1. Sediment capture What are the quantifiable sediment capture benefits from process-based riverscape restoration? What is the effect of PBR on the gradation of sediment erosion and deposit throughout the floodplain? How quickly are impacts realized and over what period of time do they persist?</p>	<p>Public utility decision-makers and Section 319 of the CWA grant reviewers. Water utilities and Section 319 grant reviewers are both interested in quantifiable sediment capture impacts on water quality. There is a need for additional studies that quantify sediment capture benefits associated with PBR, including both short- and long-term studies. Water utilities are interested in studies that translate sediment capture benefits into avoided water treatment or other costs (e.g., reservoir dredging).</p>
<p>2. Fire resilience Does PBR result in wildfire risk reduction benefits?</p>	<p>Agency decision-makers who fund fire prevention and fire recovery. Additional research on the connection between fire and PBR could strengthen the evidence base and potentially enable greater use of fire-related funding for PBR. Future studies should explore context-specific factors such as geography, vegetation mosaics, and beaver presence. There is already some evidence on the relationship between fire resilience and PBR, so communications activities could complement future studies.</p>

3. Water balance and flow

What are the effects of process-based riverscape restoration on streamflow and water balance?

Specifically, what effects can we expect to see with different approaches/structures over varying scales through time on different landscapes?

How much water are riparian plants using and how does that interact with water rights?

Regulators, water users, and policymakers. In some states and situations, questions about the impacts of restoration on water balance and flow are raising concerns about potential implications for water rights. There is a need for additional context- and location-specific studies in different geographies with enough replication in methods to draw comparisons. Additional research and studies could clarify the spatial and temporal impacts of PBR on water balance and seasonal flow. Potential studies could be physics-based, use empirical models, or remote sensing.

4. Soil carbon

Does PBR influence rates of carbon capture?

Agency decision-makers. Agency decision-makers may be more inclined to direct funding and resources towards PBR projects if they understand the evidence base for impacts on carbon storage (i.e., vegetative biomass on floodplains, large wood accumulations in channels/floodplains, etc.). Existing research on PBR’s relationship to landscape-level carbon capture could be communicated to this audience.

Carbon market buyers. Potential carbon market buyers require finer resolution and additional quantification on carbon storage outcomes and longevity.

5. Temperature and dissolved oxygen

What are the impacts of PBR on water temperature?

What are the impacts of PBR on dissolved oxygen following wildfires when additional ash is in the water?

Regulating agencies and fish and wildlife agencies. Wildlife management agencies may be inclined to support restoration if there is evidence of temperature and dissolved oxygen benefits to specific species, particularly native fish. Additional studies focusing on temperature range through seasons, not just maximum and minimum annual temperatures, would be valuable.

6. Economic value of ecosystem services

What is the economic value of ecosystem services provided by restored and healthy riverscapes, including impacts/benefits to water quality, streamflow, and carbon and sediment capture?

Conservation finance buyers, sellers, and brokers. Both private and public entities looking for mitigation banking credits or to pilot other conservation finance models (e.g., green resilience bonds) that may be interested in PBR outcomes and have a lower burden of proof for verified ecosystem benefits. Existing evidence may be packaged for these audiences, or in some cases, new research may be required.

Ecosystem service market participants. Determine the metrics needed to quantify ecosystem service benefits and improve the current tools for anticipated benefits.

7. Aquatic organism passage

What are the effects of multiple LTPBR structures on aquatic organism passage (AOP)?
 Are there design criteria that can mitigate passage impacts?
 How does AOP change across the flow regime?

Fish biologists, project designers and consultants, and ESA regulators. Studies already exist on the relationship between AOP and beaver mimicry structures or beaver dams on a small scale. Additional studies could focus on population level and riverscape scale (i.e., across 10s to 100s of BDAs).

8. Vegetation

What do we know about native and invasive vegetation return after PBR projects?
 How far from projects do PBR influences affect vegetation?

Biologists and ESA regulators. Although they are less pressing, there are also questions about PBR projects and vegetation changes that could have implications for agency support and approval of projects.

9. Social and policy dynamics

What are private landowners' concerns about riverscape restoration? Specifically, how do perceptions of beavers impact participation?
 Can federal agencies put policies in place to protect restoration projects from beaver trapping, motorized recreation, and off-leash dogs?

Landowners. There is evidence that private landowners and other key constituencies have negative associations or concerns with beavers due to typical conflicts they can cause (e.g., blocking culverts and flooding), so they may be reluctant to participate in or have projects on their property or lands they lease. Further studies to understand how to address their concerns about coexistence with financial and expertise support could inform engagement strategies.

Federal agency decision-makers. The success of some PBR projects may depend on the ability to prevent damage or negative impacts from other public land user groups following project implementation.

Strengthening Research and Monitoring Coordination

In addition to identifying specific research questions, this process also highlighted specific opportunities for **how** research and monitoring might be conducted to support learning across geographies and restoration practitioners going forward. Below is a summary of specific suggestions and recommendations for both practitioners and researchers:

- **Test and refine research needs with key audiences.** A good next step would be to test and refine the research questions outlined in this document with the specific decision-making audiences. They would likely have additional suggestions for research questions, identify what is already known about the topic, weigh in on research design, identify real-world study opportunities, and articulate the best communication channels or formats.
- **Ongoing opportunities to coordinate and share research.** An annual research conference or regular calls among the research and practitioner community would support ongoing information sharing and coordination.
- **Increase coordination across research approaches.** Because of the tremendous bio-geographic variability across the West, research on impacts and outcomes is often highly geographically specific. For many of these research questions to be answered, standard approaches to monitoring and research would allow for the greatest insights. There are many existing studies that will provide insights into the research questions and could be even more impactful if expanded to multiple geographies or contexts.
- **Cost-effective and impactful monitoring strategies.** As part of the research questions submitted, there are outstanding questions about the cost and effectiveness of current monitoring options, including for sediment, carbon, hydrologic, habitat, and other topics. It could be useful to summarize the current tools, their cost, and their utility.

Appendix A: Additional Research Questions and Considerations

Below is a more comprehensive list of priority questions and specific research considerations for each topic. These detailed research questions were submitted by participants in the August 2024 meeting. We are preserving this additional detail because it may be useful for researchers, funders, and practitioners as they begin the design studies focused on the audiences and goals listed above.

SEDIMENT AND WATER QUALITY

Additional Research questions

Additional sub-questions related to sediment include:

- How much sediment is stirred up during project construction?
 - What are ways to alleviate impacts to downstream water users?
- How is the gradation of sediment distributed along a riverscape that has been restored??
- Does sediment capture ultimately reach equilibrium in terms of inflow/outflow?
 - Does the restoration approach affect how long the sediment is stored? What maintenance, either human or natural, is needed to maintain PBR features and sediment storage?
- How does scale impact sediment capture?

Specific research considerations

If the goal of research on sediment capture is to reduce impacts to water treatment and reservoir infilling, research could include:

- Context-specific studies with similar riverscape processes will enable comparison across sites and more useful findings.
- There may be study sites with existing upstream sediment monitoring (e.g., near a reservoir managed by a public utility).
- Future research could build on current sediment monitoring partnerships (e.g., Joel Sholtes, Colorado State University and EcoMetrics sediment monitoring).

FIRE RESILIENCE

Additional Research questions

Specific sub-questions related to fire risk and PBR include:

- Can we predict or model which LTPBR or beaver sites will be fire-resistant prior to wildfire via antecedent vegetation health indicators, geomorphic complexity, etc.?

- How does what we know about wildfire and PBR inform fire-fighting strategies?
- How does scale impact fire response?

Specific Research Considerations

During the discussion, participants shared some specific ideas for research on the relationship between PBR and fire:

- Future studies could build upon existing research (e.g., Emily Fairfax) looking at fire effects in different geographies with beaver complexes present. Context-specific studies are important because fire behavior is likely to be sensitive to beaver presence, vegetation, mosaics, and other factors.
- There are also opportunities for new methodologies or data sources to inform our understanding of fire and PBR, including ground-truthing remote sensing data and utilizing electric utilities fire modeling.
- Communication of existing research is a near-term opportunity. Communication methods discussed included field tours so decision-makers can see the impacts for themselves, choosing messengers that are trustworthy and can speak to empirical evidence through interviews and presentations and creating short films capturing these stories.

SOIL CARBON

Additional Research questions

Specific sub-questions related to soil carbon quantification include the following:

- What is the *rate* of carbon capture and what variables influence carbon generation and carbon capture?
- What is the *cost* of carbon capture via PBR and how does that compare to cost from forest, range, or other carbon capture strategies?
- What is the relationship between *scale* of restoration and soil carbon benefits?

There is also a need to clarify what we already know and what do we still need to know:

- What does existing data and science tell us about the relationship between re-wetting floodplains, plant growth/productivity, and captured carbon? Do existing metrics/measurements exist?
- What level of resolution and quantification of soil carbon changes from PBR projects and/or healthy, complex riverscapes are necessary to build confidence and integrity in a market for carbon?

Specific Research Considerations

- It may be challenging (expensive, time-intensive) to conduct research specifically linking specific restoration approaches (e.g., BDAs) to soil carbon change. Instead, it may be better to focus on systems-level changes. This could build upon existing research (e.g., Katherine

Linger, University of Colorado and Ellen Wohl, Colorado State University) quantifying soil carbon change.

Natural healthy and complex systems (not just human-designed projects) can be a good study tool for soil carbon.

ECONOMIC VALUE OF ECOSYSTEM SERVICES

Additional Research questions

In addition to quantifying specific ecosystem service benefits, there were specific sub-questions on translating those benefits into financial incentives:

- What impacts/benefits can we demonstrate in the short-term to capitalize on private investors' current readiness while also building a system for monitoring and measuring these impacts/benefits in the long-term?
- Is there a compelling story that can be told to encourage corporate investment without requiring project managers to quantify and guarantee specific benefits?

WATER BALANCE AND FLOW

Additional Research questions

There were several sub-questions that seek to apply what we learn about water balance and flow to water rights implications:

- Based on our understanding of water balance and flow, do PBR projects potentially impact downstream water rights?
- What are the options when additional storage is required?
- How do we quantify and communicate the evapotranspiration consumption of these riparian plants across different settings?

Specific Research Considerations

- Project managers noted that often concerns about water rights arise in the first few days after a project is implemented. There may be a communication opportunity to get ahead of or assuage these concerns by explaining the water balance over time.

AQUATIC ORGANISM PASSAGE

Additional Research Questions

- At the structure scale, how does creating “connectivity pathways” (mimicking beaver canals) in structures affect AOP?
 - How is AOP influenced by the type of structure?
- How are aquatic organisms using “holding ponds” between structures during drought periods? What are the consequences if holding ponds are not included?

- At the riverscape scale, what factors/characteristics are influencing AOP?
 - Over what time periods?
 - How is AOP affected by PBR in dryland systems with intermittent stream connectivity?
- Is there an opportunity to use barriers intended to keep out invasives to also accelerate habitat recovery for fish species upstream?
- Can shifting the focus to annual and multi-year flow variability alleviate concerns when AOP is hampered at some flows? What do we know about the interrelationship of fish and beavers that can inform project design?

Specific Research Considerations

- The NOAA study Pollock et al. (2022), examined fish movement past 2 BDAs; PBR projects often involve the construction of 10s if not 100s of BDAs. Future studies should focus on evaluating the effect of BDAs on the same spatial scales at which PBR/LTPBR projects are commonly implemented.
- There is a need to balance research meant to inform single-species management (e.g., for ESA-listed species) and research on ecosystem-level biodiversity.

VEGETATION

Additional Research Questions

Specific sub-questions related to native/invasive vegetation include:

- What are the structural and species assemblage impacts of PBR projects?
- What re-seeding practices are best for encouraging native vegetation colonization?
- How far from PBR structures/complexes are there differences in vegetation?
- How long do those differences last?
 - What design and implementation variables influence this (e.g., scale)?

Specific Research Considerations

- Research should utilize existing project infrastructure and remote sensing.

Appendix B: Project Methods Research Questions

In addition to discussing benefits and potential impacts, a number of research questions were identified that can support practitioners in improving the design, implementation, and maintenance of process-based restoration techniques. These research questions will strengthen and support current projects and incorporate adaptive learning mechanisms for ongoing experimentation and improvement.

General Audiences:

- Project designers, managers, and developers
- Federal agencies who might be selecting sites and prioritizing projects

Site Selection and Project Design

There is an overarching question that can guide continuous learning and improvement:

Are the designs being developed and implemented leading to expected outcomes?

While that overarching question can guide project design, monitoring, learning, and adaptation, a few specific sub-topics point to specific areas where there are near-term opportunities for studies or research:

- **Study natural systems, not just human-driven restoration projects.** Looking to natural systems to study the relationships between species and their habitat and ecosystem function is advantageous over just studying the impacts of human-driven restoration projects. By better understanding, for example, beaver complexes and then attempting to mimic those ecosystems through restoration, practitioners can be more informed about the ultimate restoration goal and the “climax” version of the project.
- **Improving design by mimicking beavers:** What specific components of beaver ecosystem engineering, and in what spatial configurations, result in the highest amount of different key ecosystem services / climate mitigation benefits?
- What are we missing in beaver mimicry that would elevate PBR project performance (e.g., Canal analogs, thinned trees, scheduled maintenance, more/fewer anchoring structures, higher density of structures)?
- **Site selection/prioritization:** How do we identify and prioritize restoration in highly variable landscapes from headwaters to alluvial plains?
 - What factors are linked to successful outcomes?

- What are the social factors enabling project success (e.g., staff capacity, existing relationships) and how can project developers identify these factors in other potential project locations?
- **Design support tools:** What are the best tools for design support?
 - For example, GIS tools, what are the pros and cons of various methodologies?
 - Can cloud computing/AI predict LTPBR structure placement?
 - Is Lidar useful for evaluating sediment capture?

Long-Term Maintenance

There are also a number of research questions that could strengthen the practitioner community's ability to plan for the long-term maintenance and stewardship of PBR projects. Specifically:

- What factors contribute to self-sustaining outcomes (e.g., beaver repopulation) and variances in stewardship and maintenance need and cost?
- What stewardship is needed to increase and maintain benefits from riverscape restoration over decades?
- What are the long-term maintenance requirements of these projects, what are the associated costs, and how do the implementation approaches and physical environment influence that?
- What can project proponents expect/plan for the long-term cost and labor of adaptively managing projects after implementation? How long should "long-term monitoring and maintenance" last?
- How can PBR experts help shape funding streams to better align with long-term needs?