An Investigation of Stage 0 Restoration in California and Oregon

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Abstract

Stream restoration efforts have increasingly started to focus on management actions that restore ecological function rather than focusing on species-specific habitat needs. Restoration practitioners in the Pacific Northwest have implemented numerous large-scale floodplain restoration projects to restore stream function at the valley scale. Some of these projects attempt to restore streams to a “stage 0” state – an unconfined, anastomosing, multi-threaded network of channels with high groundwater connectivity. This paper examines projects seeking to restore stream reaches to stage 0 in California and Oregon and summarizes the approaches and monitoring strategies used in an effort to better understand how restoration practitioners are implementing and assessing this novel approach.

Contents

Introduction

Land use change, fragmentation, and simplification of river ecosystems globally have resulted in changes to physical processes, habitats, and a loss of biodiversity (Poff et al. 2007). In the last decade, stream restoration efforts have begun to focus on projects that restore natural processes in stream ecosystems rather than focusing on habitat objectives targeted at individual species with the goal of creating a diversity of habitat conditions to which native species are adapted (Kauffman et al. 1997; Beechie et al. 2010; Kondolf et al. 2013; Wohl et al. 2015). Recently, restoration practitioners in the Pacific Northwest have started to focus on larger-scale floodplain restoration projects (Beechie et al. 2010; Powers et al. 2019). These efforts have been informed, in part, by new evidence that suggests increased floodplain productivity may be beneficial to the growth of juvenile salmonids, which are often the targets of stream restoration actions and restoration funding (Limm & Marchetti 2009; Katz et al. 2017).

In the past decade, floodplain restoration practices have coincided with theoretical developments in channel evolution models that target the importance of floodplains for ecological productivity and river dynamics. Cluer and Thorne (2013) added to existing channel evolution models by including the “stage 0” evolutionary phase, defined as an unconfined, anastomosing, multi-threaded network of channels with high groundwater connectivity (Figure 1). This stream form is hypothesized to have been widespread throughout the Pacific Northwest prior to European settlement and provides a previously absent reference condition for restoration efforts in depositional valleys (Walter & Merritts 2008; Woelfle-Erskine et al. 2012; Cluer B. & Thorne C. 2013). Stage 0 streams are predicted to maximally buffer against disturbance by diffusing flood pulses across the entire valley floor, raising groundwater elevations, and maintaining a diversity of habitat types, resulting in high biodiversity (Cluer B. & Thorne C.

2013; Castro & Thorne 2019). These theoretical ecosystem attributes have made restoration to stage 0 a popular topic within the restoration community as evidenced by symposia dedicated to stage 0 at regional river restoration conferences like River Restoration Northwest and the Salmonid Restoration Federation Conference. Restoration practitioners have developed and implemented multiple valley-scale restoration projects to address stream incision and floodplain disconnection by removing man-made structures like berms and levees that channelize rivers, filling incised stream channels, and increasing roughness to re-establish floodplain connectivity and habitat complexity (Brignon et al. In Prep.; Bianco 2018). However, there is a paucity of literature that refers to stage 0 floodplain restoration or project outcomes.

The goals of this paper are to 1) query floodplain restoration projects in California and Oregon to identify those seeking to restore stream reaches to stage 0 conditions; 2) identify the restoration techniques used and summarize key project attributes; and 3) compare and contrast monitoring methods used to evaluate project outcomes. With stage 0 restoration seemingly gaining momentum, understanding how projects are being implemented and monitored across a diversity of ecosystems is critical in evaluating the practice.

Methods

Defining "Stage 0 Restoration"

"Stage 0 restoration" is difficult to define at present given the lack of available literature on the technique and the fact that the original term "stage 0" defines a stage of stream evolution and thus the intended outcome of restoration actions rather than a restoration technique itself. Cluer and Thorne (2013) define the stage 0 phase of their stream evolution model as a "dynamically meta-stable network of anabranching channels" where "floods are diffused over full width of floodplain" and where a high water table is maintained. To define stage 0 restoration for the purposes of this research I relied on a definition developed by practitioners in Oregon as part of workshops held in an ongoing effort to develop a programmatic monitoring plan for stage 0 restoration by the United States Forest Service (USFS). Participants were directed to define their objectives for the restoration actions and a discussion was held to reach consensus on a collaborative definition for "stage 0 restoration" (Brignon et al. In Prep.). The workshop participants defined stage 0 restoration as "a valley-scale, process-based (hydrologic, geologic and biological) approach that aims to reestablish depositional environments to maximize longitudinal, lateral and vertical connectivity at base flows, and facilitate development of dynamic, self-forming and self-sustaining wetland-stream complexes" (Figure 2).

Identifying projects

Given the relative novelty of stage 0 restoration, potential projects were identified primarily through contact with restoration practitioners in California and Oregon, since most documentation is only available as grey literature. Potential projects in Oregon were identified as part of a synthesis effort currently underway that seeks to evaluate effects of stage 0 restoration actions at a regional scale (Personal communication Rebecca Flitcroft, 2020). All projects occurred on USFS federal lands, were self-identified by restoration practitioners as Stage 0 projects, and represent a diversity of sizes and outcome goals. Planning, implementation, and monitoring data were assembled for each project, as available. In addition, presentations given by practitioners about individual projects were reviewed where available.

Potential project identification in California required networking among restoration practitioners. Three phases of this networking included 1) outreach at a workshop on stage 0 restoration at a regionally relevant conference; 2) tracing direct contacts and “leads” among practitioners; and 3) web and other online searches for stage 0 restoration projects.

The first phase of stage 0 project identification in CA occurred at a workshop titled “Restoring to Stage 0” at the 2019 Salmonid Restoration Federation Conference (Cluer et al. 2019). These projects were self-identified by practitioners and represent a diversity of participants (i.e., resource agencies, non-governmental organizations, tribes, consultants, and contractors), methods, and outcome goals. Project documents such as design, permitting, and monitoring reports were collected directly from practitioners or through online media.

The second phase of the project consisted of reaching out to other practitioners, referred to by workshop attendees, who may be attempting to restore stream reaches to a stage 0 state.

The final phase of stage 0 project identification in CA was completed using a literature search in Web of Science and Google Scholar using the following search terms: “Stage 0” California, “floodplain restoration” California, “anabranching” California restoration, and “channel fill” California restoration. Given the contemporary nature of this type of restoration and the likelihood of documents to be in gray literature, these search terms were also used with Google.

Documentation for the projects identified through the OR and CA search efforts were collected and assessed to determine 1) if the project met the definition of stage 0 restoration utilized for this study and 2) if sufficient empirical data were available to inform further analysis.

To assess if projects met the chosen definition of stage 0 restoration, project design and planning documents were evaluated to determine if 1) the project attempted to restore at the spatial extent of the valley scale; 2) if the project outcome was intended to be processed based;

and 3) if the outcome was intended to be self-formed and self-sustaining. For each point of evaluation, specific definitions provided by Brignon et al. (In Prep.) were utilized.

Empirical data required for a project to be considered includes elements like project location, area of project, restoration techniques used, and annual rainfall. Additionally, information regarding one or more monitoring approaches needed to be available, though given the contemporary nature of stage 0 restoration, results weren't required as recent projects may have ongoing monitoring.

Datasets

Information from each project was extracted and summarized into two tables. The first table was adapted from Powers et al. (2019) and includes project attributes that summarize climatic and geomorphic conditions at each site. The attributes include: location, ecoregion, hydrology, mean annual precipitation, drainage area, base flow, valley type, valley slope, and valley width.

The second table was adapted from the synthesis monitoring efforts led by the USFS that grouped available datasets into the following categories: biological monitoring, water quality, ground water, physical characteristics, surface water, elevations, LiDAR (Light Detection and Ranging), and pictures. Biological monitoring involves sampling for fish or other wildlife and may include macroinvertebrate sampling, environmental DNA (eDNA), spawning surveys, movement tracking with Passive Integrated Transponder (PIT) tags, smolt trapping, snorkel surveys or mussel or bird surveys. Water quality monitoring may contain temperature, dissolved oxygen, isotopes, conductivity or nitrogen monitoring. Ground water monitoring may utilize ground water wells or piezometers. Physical characteristics include physical habitat metrics such as large woody debris distribution or volume, substrate quantity or quality or bankfull measurements. Surface water monitoring includes depth or flow. Riparian vegetation encompasses any measurement of vegetative change. Elevation monitoring comprises of transects or point elevation measurements. In addition to the above attributes, date of project completion and a summary of duration of monitoring (if available) were included.

Analysis

Projects were summarized and tabulated to compare among sites. Project attributes, implementation, methods, and monitoring were evaluated across available projects. Graphics were used to compare and contrast monitoring methods, as well as project attributes.

Results

Projects

A total of 39 projects were assembled and considered for this project (17 in OR and 22 in CA) (Table 1). Ten projects, six in Oregon and four in California met the requirements for this review and were used in the analysis (Table 1). Projects were excluded because they either failed to meet the definition of stage 0 restoration used for this study or they lacked sufficient empirical data for analysis. Selected projects varied in size, restoration technique, and ecological setting (Table 2). Project implementation dates ranged from 2011-2021 with the bulk of projects completed since 2015. The oldest project, Willow Creek in California was the outlier completed in 2011. While this project – amongst others – was completed before the coining of the term “stage 0,” it was included because it meets the definition of stage 0 restoration used in this study and is used as an example of a stage 0 stream reach (Cluer et al. 2019).

Two projects in California – Indian Creek and Confluence Meadow – have yet to be implemented but are incorporated in this analysis based on their design documents (Table 1). In both cases, the projects have been funded and permitting has been completed, making their implementation imminent, with work on one of these projects starting in Fall 2020. Considering these projects was important because they illustrate a shift in restoration techniques used in California; however, they are not part of the monitoring analysis as monitoring has not been completed, though known pre-project monitoring/data collection is presented in the summary table.

Of the ten projects, most were designed using the Geomorphic Grade Line (GGL) approach (Table 2). This approach utilizes Geographic Information Systems to develop a cut and fill plan to restore depositional valleys to a common grade that is then allowed to self-adjust to natural geomorphic processes over time (Powers et al. 2019). The GGL approach is intensive in nature and uses heavy equipment to “reset” the entire valley floor, typically disturbing a large portion of the valley floor. All of the projects located in Oregon were designed – at least in part – using GGL, while only one future project in California utilized this technique. Other, less intensive actions, included the use of beaver dam analogs (BDAs) (Wheaton et al. 2019) and a barrier removal project coupled with land use change (California State Parks 2010) (Table 2). The Confluence Meadow project in California uses a similarly intensive channel fill resembling GGL, though with borrow sites from higher elevation areas rather than a complete valley regrade calculation (Sloat 2017).

Project valley widths ranged from 115m to 500m and drainage basins ranged from 9.3 km^2 to 652 km^2 (Table 2) Valley width and basin size was distributed relatively evenly between the two states (Table 2). All valley slopes were less than 2% (Table 2), though it is worth noting that Powers et al. (2019) list a GGL project with a valley slope of 7% that was not included in my study (Three Mile Creek, OR).

Precipitation varied amongst projects with California projects tending to receive less rain than projects in Oregon, though baseflow wasn't reported in some projects (Table 2). California projects were more likely to be focused on streams that are intermittent in some years or seasonally (Table 2).

Monitoring

Water

Of the eight completed projects analyzed for monitoring information, each included some type of surface water measurement. Discharge or water depth data were collected at all sites and water quality information (typically temperature) was collected at most sites (88%) (Tables 3, 5). Isotope and conductivity data were collected at the Staley and Coal Creek projects in Oregon as part of an ongoing, intensive, before-after-control-impact study, though results are unavailable at this time (U.S. Forest Service 2018; table 5).

Over a third of completed projects (38%) measured groundwater depth using groundwater wells (Table 3). Groundwater measurements were used in the South Fork, Five Mile Bell, and Whychus Creek projects. Shallow groundwater and high hyporheic exchange are a hallmark of stage 0 channels with vertical connectivity at base flows being a key objective. Implemented projects have shown decreases in groundwater depth post restoration (Figure 4).

Form

Photos were used in each project analyzed, though methods regarding photo site selection varied considerably. Photos ranged from opportunistic captures, to the use of trail cameras for time lapse series, to photo points, to aerial photos captured by unmanned aerial vehicles (UAV) (Figure 5). Perle (2019) used UAV photography to document a 20% increase in riparian vegetation cover classes at the Wychus Creek project one year post implementation. Scott and Collins (2019) used aerial photos coupled with field surveys in an attempt to document pre- and post-project change in Deer Creek. While they note that management actions increased wood loading and habitat heterogeneity, Deer Creek had not been subject to a large enough flow event to naturally adjust the project site at their time of reporting.

Physical characteristic monitoring and LiDAR were used at 75% of all completed projects (Table 3). Only half of projects surveyed surface elevations, they were all in Oregon and relied on transects or points to document morphological change over time (Table 3). In most cases, multiple elements were sampled either at points on a transect, or within randomly distributed grids or points, looking at factors such as whether the point was aquatic or terrestrial, substrate size, large woody debris (LWD) distribution, elevation and biological measures – macroinvertebrates or vegetation – within each point or grid sampled (Table 6).

Geomorphic grade line projects (Powers et al. 2019) utilized LiDAR for planning purposes. A Digital Elevation Model (DEM) is used to define a desirable elevation that is then projected across the valley floor to create a target surface for cut and fill. LiDAR and a resulting DEM could be used in post-implementation comparison, though practitioners have yet to use post-project LiDAR to quantify change within project boundaries.

Function

Biological and vegetation monitoring were used in 88% of projects (Table 3). Biological monitoring techniques varied widely across projects and between California and Oregon with more intensive monitoring occurring in Oregon, specifically at the Whychus, South Fork McKenzie, Coal and Staley projects (Table 3). Five of six projects in Oregon sampled macroinvertebrates, while none of the California projects did (Table 4). Macroinvertebrate sampling techniques were included in transect or point monitoring with macroinvertebrates collected in wetted channels (table 6).

Projects analyzed used multiple methods to assess fish abundance and habitat use, including snorkel surveys, redd/spawner surveys, PIT tagging, electrofishing and minnow trapping (Tables 3, 4). Telemetry data (PIT tagging) from Willow Creek and spawner surveys from Deer Creek documented successful post-project recolonization of habitats where target species were previously thought to be extirpated (Prunuske Chatham, Inc. & UC Cooperative Extension/CA Sea Grant 2014; Meyer 2018). Juvenile fish surveys in Whychus Creek found a greater abundance of salmonids in treated versus untreated stream reaches, though nearly all individuals in this study were from reintroduction stocking efforts (Perle 2019). Environmental DNA (eDNA) sampling is an emerging technique that can provide a snapshot of species richness and presence depending on the temporal and spatial sampling methods used. Two projects utilized eDNA to assess fish and amphibian presence; however, neither reported results. eDNA can also be a useful tool to assess macroinvertebrate diversity, though no projects utilized the tool for that purpose (Roni et al. 2019).

Of the projects queried, nearly all (88%) looked at riparian vegetation change over time. While some projects only looked at post-management change, others looked at pre- and post-management conditions. Patch surveys and transects were used, as well as aerial photos (Tables 3, 4, 6).

Discussion

Projects

Many valley-scale floodplain restoration projects have been completed both in California and Oregon in the last decade, though there is a contrast in the techniques and terminology used. Projects meeting the applied definition of stage 0 in California have utilized less intensive management actions like BDAs until now, though this seems to be changing as two projects using a valley-grading approach are undergoing implementation (Confluence Meadow and Indian Creek).

Concurrent with the development of Cluer and Thorne's (2013) Steam Evolution Model, USFS practitioners in Oregon were working to restore incised depositional valleys at the valley scale using process-based restoration, though without the stage 0 restoration moniker (Brignon et al. In Prep.). Powers et al. (2019) note that nearly 20 completed projects in the Pacific Northwest used the GGL approach, suggesting a situation where practitioners and theory were co-evolving as a result of the growing focus on process-based restoration. These practitioners have embraced the stage 0 terminology (Powers et al. 2019).

In California, other types of intensive floodplain restoration techniques that are not designed to achieve a stage 0 stream condition have been used, the foremost being the pond and plug technique used in montane meadow restoration efforts (Figure 2) (Rosgen 1997). Although a census of pond and plug projects were not the purview of this report, because the pond and plug technique does not meet the process-based definition used to select projects, the Center for Watershed Sciences (2020) reports close to 100 of these projects in California. The stated goals of this technique are somewhat similar to stage 0 with management activities seeking to reconnect floodplains and restore hydrologic function (Lindquist & Wilcox 2000; Hammersmark et al. 2008; Tague et al. 2008). This technique involves creation of earthen plugs in incised stream reaches to distribute flow out of incised channels and onto the historic floodplain (Lindquist & Wilcox 2000). Fill material is sourced from the incised channel or occasionally the floodplain and results in a string of small, open water ponds between the plugs. Projects are typically implemented at the valley scale and are generally intensive, utilizing heavy equipment, and, creating significant disturbance during implementation (Pope et al. 2015). This last point suggests that the scale or intensive nature of valley recontouring as used in the GGL approach shouldn't be a deterrent to more intensive stage 0 restoration in California.

While studies of pond and plug projects reveal higher groundwater levels, increased water storage, and more frequent floodplain inundation post project (Hammersmark et al. 2008; Tague et al. 2008; Hunt et al. 2018), concerns remain about the use of restoration features novel to local processes and their long-term viability (Natali & Kondolf 2018). Questions have also been raised about the ecological function of meadows post pond and plug treatments. Pope et al. (2015) found greater plant biomass in meadows treated with pond and plug, but found that soil carbon, wetland habitat and herbaceous cover did not differ between treated and untreated meadows, though their study did not do a before/after comparison of project sites. These findings suggest a cautious approach to intensive floodplain restoration, such as stage 0 restoration, and a need for investments in long-term intensive monitoring.

Monitoring

Stage 0 stream reaches exhibit different spatial extents and breadths of habitat types than single thread channels. As a result, many stream monitoring techniques – especially in the Pacific Northwest – that have been developed in wadable streams with a focus on salmonid habitat values may not adequately capture the habitat diversity of stage 0 reaches (Powers et al. 2019; Roni et al. 2019). Additionally, with process-based restoration there is a potentially unknowable temporal aspect specific to each project site that will play an important role in site evolution. The primary goal of process-based restoration is the reestablishment of interrupted ecological processes and functions that have led to degraded ecosystems (Beechie et al. 2010). With the majority of projects surveyed being completed in just the last 5-10 years, understanding how management actions are affecting ecosystem benefits may not be possible for some time as biological elements take time to establish.

Monitoring results reported to date have shown that many of the physical objectives of stage 0 have developed post project, including 1) elevated water tables in (figure 4) 2) an increase in habitat diversity (Ciotti et al. In Prep.; Perle 2019; Scott & Collins 2019), and 3) LWD retention (Perle 2019; Scott & Collins 2019), which suggests – at least in the short term – that implementation has been successful. The only project using BDAs reported significant aggradation of the incised channel, meeting a key implementation objective (Ciotti et al. In Prep.). Initial monitoring results show promise in stage 0 restoration meeting project objectives, but longer-term datasets are needed. Biologic components are theorized to play an important role in stage 0 formation (Cluer B. & Thorne C. 2013; Castro & Thorne 2019).

One of the promises of stage 0 restoration is the reestablishment of habitats with maximum complexity and a diversity of habitats that support large numbers of different species while being highly resilient to natural disturbance. As such, biological monitoring that improves our understanding of biotic responses to stage 0 restoration is critical in assessing ecological function and the effectiveness of this approach. Projects with more intensive monitoring efforts like Whychus Creek, South Fork McKenzie, Coal Creek, Deer Creek, and Staley Creek may help fill information gaps as results become available.

A study on primary productivity in Whychus Creek has shown increases in cold water diatoms and a higher autotrophic index in post-project reaches compared to a reference reach (Edwards et al. 2020). Additionally, macroinvertebrate richness increased as did the number of sensitive Trichoptera, Ephemeroptera, and Plecoptera taxa (Perle 2019). Both results suggest restoration is meeting project objectives, at least in the short term.

Unsurprisingly, many of the projects surveyed listed improvements to fish habitat as an important objective. It is generally accepted that fish growth rates are increased with access to floodplains (Limm & Marchetti 2009; Witmore 2014; Katz et al. 2017), though studies looking at fish growth in stage 0 reaches specifically have not been completed. A key stakeholder concern with stage 0 restoration is the potential negative impact to ESA-listed salmonids, specifically regarding fish passage and stranding potential (Bianco 2018). Monitoring data can help reduce these concerns by assessing population abundance and diversity or by documenting migration success via telemetry data as has been done on multiple projects. Initial results from Whychus Creek suggest that juvenile fish are utilizing a restored stage 0 reach more than an unrestored reference reach (Perle 2019). Salmonids have been documented spawning in restored reaches of multiple projects and telemetry data has demonstrated successful passage through restored reaches (Prunuske Chatham, Inc. & UC Cooperative Extension/CA Sea Grant 2014; Meyer 2018).

Strengths and Limitations of this project

Identification of projects in Oregon was limited to existing data compiled by Brignon et al. (In Prep.). Other stage 0 projects may have been completed in Oregon, especially the use of

BDAs, which may or may not meet the definition of stage 0 used for this study. Project identification in California could have been improved through additional outreach to practitioners in montane meadow ecosystems, as there may be additional projects that fit the applied definition of stage 0 restoration despite not utilizing that terminology.

Collection of monitoring data was based on available information related to projects. It is possible that additional uncoordinated monitoring efforts are taking place. For example, fisheries monitoring, such as spawner or snorkel surveys conducted by state or tribal fisheries agencies, may be taking place within the same stream systems as part of wider monitoring efforts.

Conclusion

Stage 0 restoration management actions varied from intensive valley grading with heavy equipment to hand-installed beaver dam analogs, though little information exists on what level of intervention may be appropriate given site-specific variables. Increased knowledge from monitoring and improved efficiencies in monitoring can help provide a greater return for investment on restoration funding (Nichols & Williams 2006). Stage 0 restoration and other large-scale floodplain restoration projects are being used widely in Oregon and California, but there is a lack of completed studies to evaluate how effective restoration actions have been in the long term.

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Figures

Oregon	California
Coal Creek*	Ash Creek
Deep Creek	Big Meadows
Deer Creek*	Bogard-McKenzie
Dick Creek	Burney Gardens
Dog Creek	Butte Creek
Five Mile Bell*	Clarks Creek
Grizzly Creek	Confluence Meadow*
LeClerc Creek	Doty Ravine*
Lost Creek	Grouse Creek
McKay Creek	Harlow Meadow
Shingle Mill Creek	Horse Meadow
South Fork McKenzie*	Humbug Creek
Staley Creek*	Indian Creek*
Three Mile Creek	Kegg Meadow
Toggle Meadow	Lower Butte Creek
Whychus Creek*	Mcbride
Wooley Creek	Perrazo Meadows
	Red Clover/McReynolds
	Rose
	Roy's Redwood**
	Sears Point**
	Willow Creek*
* - Selected for this study. ** - In planning	

Table 1: Floodplain restoration projects considered for further analysis as part of this study

Location	State	Type of Stage 0	Restoration technique	Date completed	Ecoregion	Hydrology	Mean annual rainfall (mm)	Drainage area (km2)	Base flow (cms)	Valley type	Valley Slope (%)	Valley width (m)
Coal Creek	OR	restore floodplain connectivity	GGL	2019	Western Cascades - Lowlands and Valleys	Rain with rain on snow	1,500-2,000	56	UR	Alluvial fan	< 2	160
Deer Creek	OR	restore floodplain connectivity	GGL	2016	Western Cascades - Montane Highlands	Rain with rain on snow	2800	60	UR	Unconfined	1.8	140
Five Mile Bell	OR	restore floodplain connectivity	Multiple phases, GGL in later phases	2013-2020	Oregon Coast Range - Coastal Lowlands	Rain dominated	1,500-2,000	20.6	0.5	Lacustrine	0.02	200
South Fork McKenzie	OR	restore floodplain connectivity	GGL	2017-2020	Western Cascades - Lowlands and Valleys	Reservoir controlled	2,000-2,500	9.3	0.8	Alluvial fan	0.75	500
Staley Creek	OR	restore floodplain connectivity	GGL	2017-2018	Western Cascades - Lowlands and Valleys	Rain with rain on snow	1,500-2,000	105.2	0.8	Unconfined	2	240
Whychus Creek	OR	restore floodplain connectivity	GGL	2013-2014	Ponderosa Pine/ Bitterbrush - woodland	Glacial with rain on snow	500-750	652.7	0.7	Unconfined	0.9	120
Confluence Meadow*	CA	restore floodplain connectivity	Called Pond and plug but full channel fill and valley grading w/ long profile	2021	Cascades - California Cascades Eastside Conifer Forest	Snow dominated	760	400	Intermittent	Unconfined	0.1	446
Doty Ravine	CA	restore floodplain connectivity	BDAs, repopulated with beaver naturally, levee removal, incremental approach	2016	Central California Valley - Northern terraces	Rain dominated	550- 900	62	UR	Unconfined	UR	160
Indian Creek*	CA	restore floodplain connectivity	GGL	2020	Klamath Mountains/ California High North Coast Range - Eastern Klamath low elevation forests	Rain with rain on snow	960-1300	88	UR/Intermittent	Unconfined	0.2	200
Willow Creek	CA	Passive, Barrier removal	Land use change, reestablished longitudinal connectivity	2011	Coast Range - Coastal Franciscan Redwood Forest	Rain dominated	1370	22	UR/Intermittent	Unconfined	0.5	115

UR - unreported   * - Yet to be implemented

Table 2: Project attributes for stage 0 restoration projects analyzed in this study

Location	Monitoring Plan	Biological monitoring	Water quality monitoring	Ground water	Physical characteristics	Surface water	Riparian Vegetation	Elevations	Lidar	Pictures
		May include: macroinvertebrates; eDNA; spawning surveys; snorkel surveys for fish; mussel surveys	**May include: temperature; isotopes; conductivity; nitrogen**	**May include: wells**	**May include: physical habitat metrics such as LWD or substrate; bankfull measurement**	**May include: depth; flow**		**May include: geomorphic transects; randomly selected elevation points**		**May include: photo points; general project photos**
Oregon										
Coal Creek	X	X	X		X	X	X		X	X
Deer Creek	X	X	X		X	X	X		X	X
Five Mile Bell				X		X	X	X	X	X
South Fork McKenzie	X	X	X	X	X	X	X	X	X	X
Staley Creek	X	X	X		X	X	X	X	X	X
Whychus Creek	X	X	X	X	X	X	X	X	X	X
California										
Confluence Meadow*		TBD	TBD	TBD	X	TBD	TBD	X		X
Doty Ravine		X	X		X	X	X			X
Indian Creek*		TBD	TBD	X	TBD	X	TBD	X	X	X
Willow Creek		X	X			X				X
Proportion of projects using technique		88%	88%	38%	75%	100%	88%	50%	75%	100%
		* Pre-project data only. Not included in proportion								

Table 3: Monitoring efforts across stage 0 restoration projects in California and Oregon

Location	Macroinvertebrates	eDNA	Fish sampling, Spawner, Snorkel Surveys	Mussel Surveys
Oregon				
Coal Creek	X		X	
Deer Creek	X		X	
Five Mile Bell				
South Fork McKenzie	X	X	X	X
Staley Creek	X		X	
Whychus Creek	X		X	
California				
Doty Ravine		X		
Willow Creek			X	

Table 4: Biological monitoring information collected by the eight completed stage 0 restoration projects

Location	Groundwater	SurfaceWater Depth	Water velocity	Water Temperature
Oregon				
Coal Creek		X	X	X
Deer Creek		X	X	X
Five Mile Bell	X	X		
South Fork McKenzie	X	X	X	X
Staley Creek		X	X	X
Whychus Creek	X	X	X	X
California				
Doty Ravine			X	
Willow Creek			X	X

Table 5: Water monitoring information collected by the eight completed stage 0 restoration projects

Location	Sample Design	Vegetation	Elevation	Surface water (Flow, temp, or depth)	Subtrate	Geomorphic Features	LWD	Macroinvertebrates	Photos
Oregon									
Coal Creek	Patch	X	X	X	X		X	X	X
Deer Creek	Transect	X		X	X	X	X		X
Five Mile Bell	Transect	X							
South Fork McKenzie	Transect	X	X	X	X	X	X		X
Staley Creek	Patch	X		X	X		X	X	X

Table 6: Information collected by projects during patch and/or transect sampling

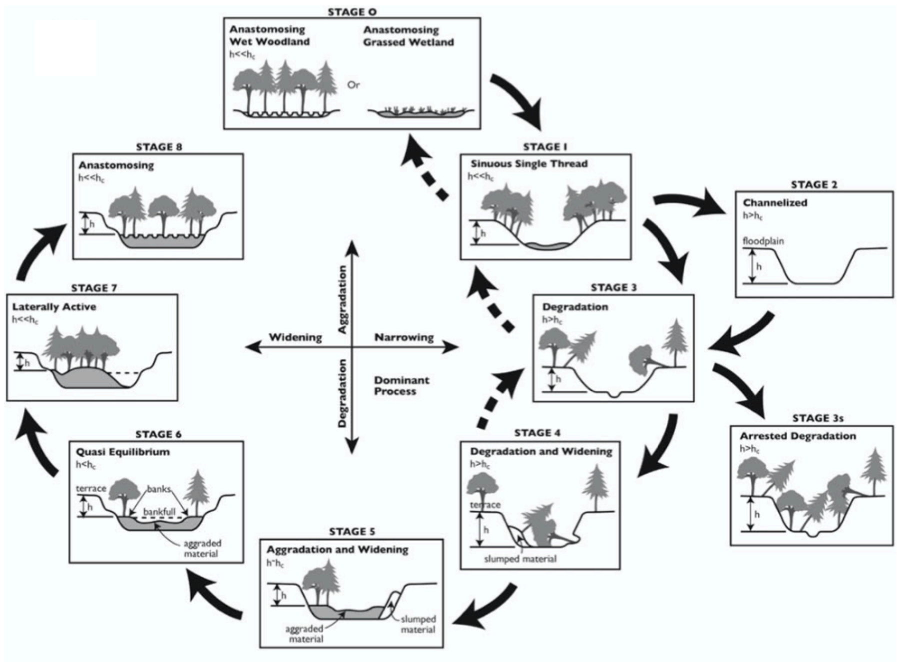

Figure 1: Cluer and Thorne's (2013) stream evolution model which introduced stage 0

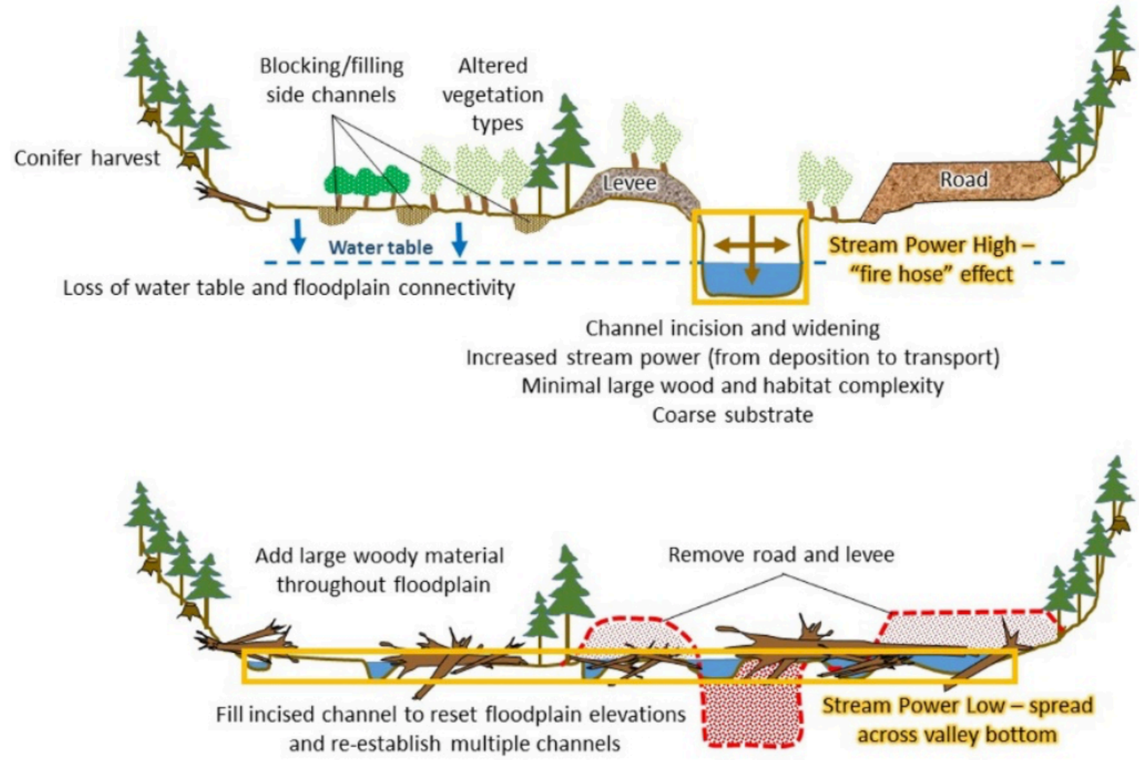

Figure 2: A conceptual illustration of "stage 0 restoration" from Meyer (2018). This illustration most closely resembles the Geomorphic Grade Line management approach (Powers et al. 2019).

Figure 3: An example of "pond and plug" floodplain restoration on McReynolds Creek in the Sierra Nevada Mountains, California from Wilcox (2010)

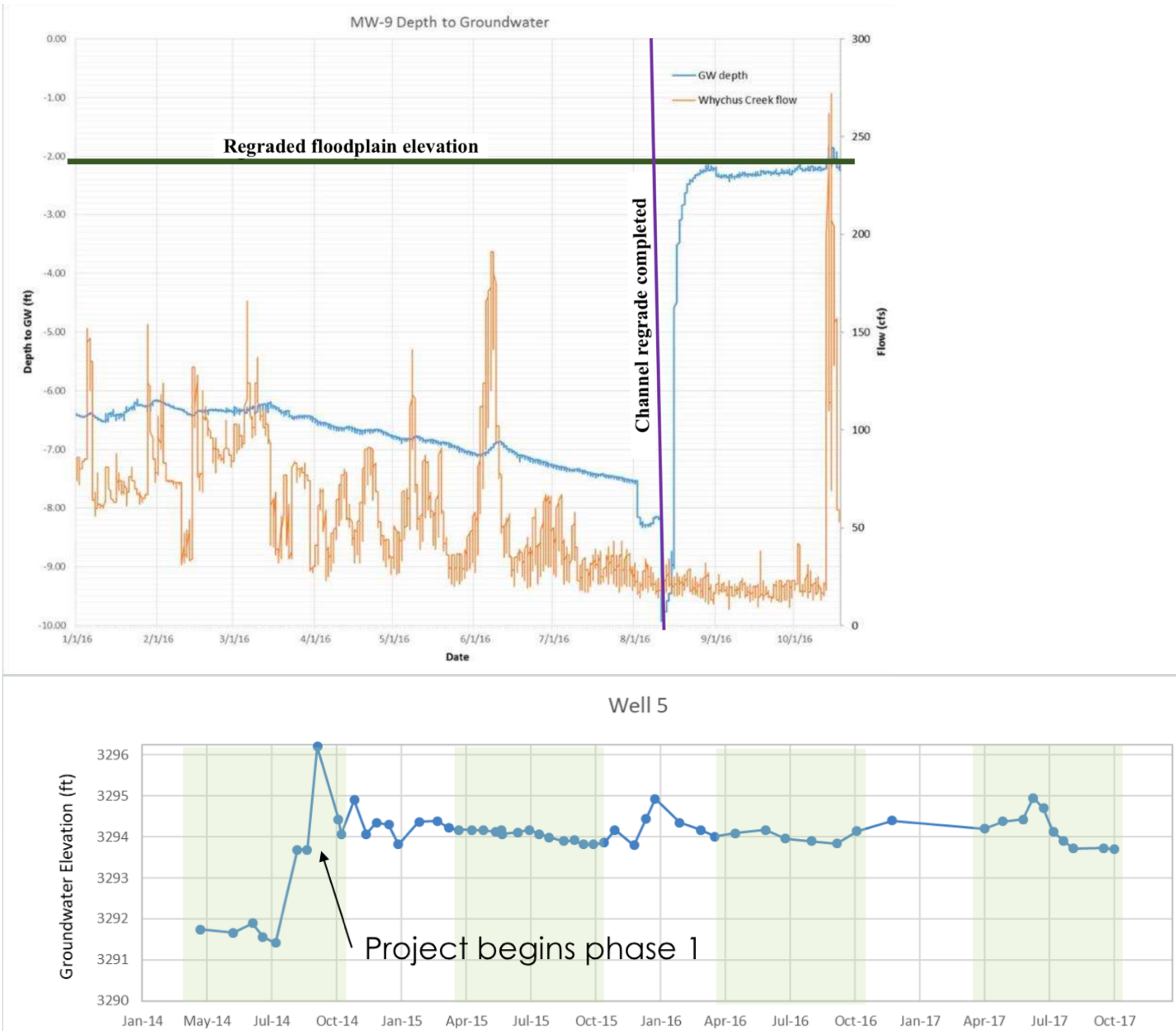

Figure 4: Top: Groundwater response to channel regrading in Whychus Creek, Oregon adapted from Burns (2019) Bottom: response to channel regrading in Five Mile Bell from "Five Mile Bell Floodplain Connectivity, 2018 Monitoring Report" (2018)

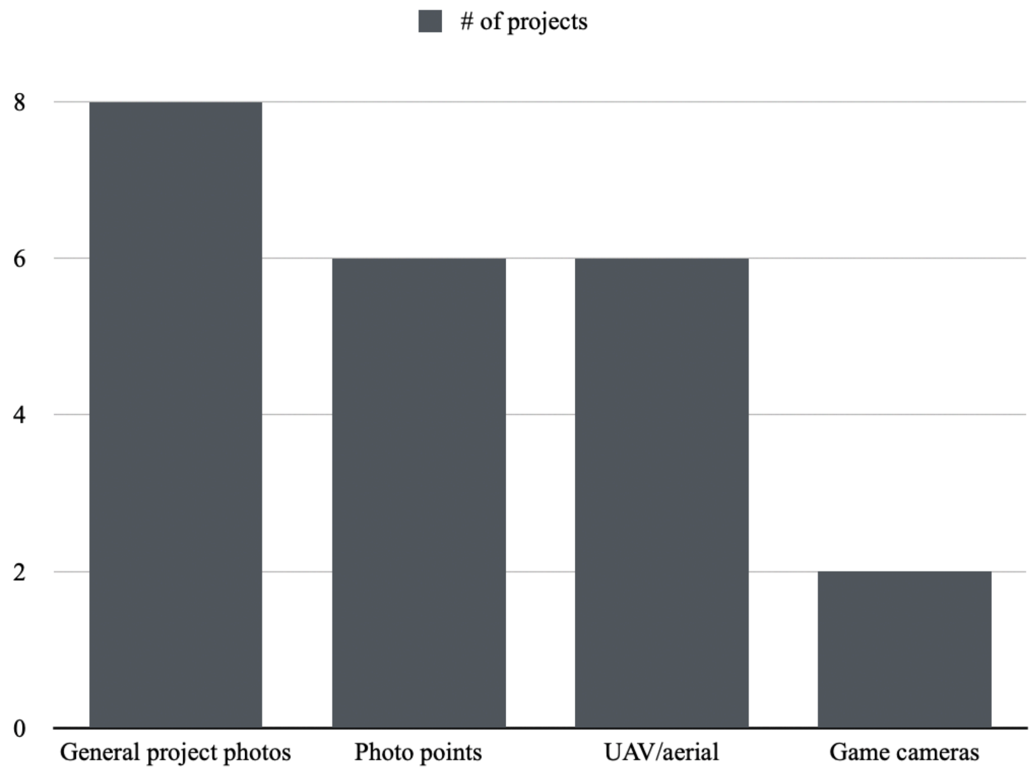

Figure 5: All projects used some form of photo monitoring, but methodology varied