INVESTIGATING EPHEMERAL STREAM CHANNEL RESTORATION:

FROM PRIORITIZATION TO IMPLEMENTATION

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ABSTRACT

INVESTIGATING EPHEMERAL STREAM CHANNEL RESTORATION:

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ADAM BRINGHURST

Ephemeral stream channels (ESC) flow following precipitation events. ESC are dry most of the year. Recently, efforts to restore ESC have begun to increase. Recognized as a fundamental part of stream restoration planning is appropriate site selection. For restoration, there are methods to prioritize perennial streams, wetlands, riparian vegetation, springs, and watersheds. However, there are no methods to prioritize ESC. This research applied a mixed-method approach to answer the following: 1) What criteria are used to prioritize stream sites? 2) How can those criteria be applied to ESC? 3) How can ESC criteria be modeled spatially to identify priority restoration sites? I conducted interviews with stream restoration experts and analyzed the qualitative results using thematic methods. I developed a list of criteria used by river restoration experts in ponderosa pine *(Pinus ponderosa)* forests around the Western United States. I presented the criteria used to select sites to stakeholders, assembled as the comprehensive implementation working group (CIWG), working to support the Four Forest Restoration Initiative (4FRI) in the forests of northern Arizona. The CIWG is responsible for prioritizing ESC for restoration. Through interviews with the CIWG, I developed a site selection method incorporating regional values. This site selection model is a weighted scoring calculation based on a hierarchical approach to identifying and measuring criteria at ESC. I then applied the site selection method to a spatial analysis to rank 163 candidate ESC for restoration. The results of my work showed that the criteria used to measure stream restoration sites depend on the regional values of experts and stakeholders. I found that in the semi-arid forests

of northern Arizona, where ESC are prevalent and perennial streams are rare, the priority was to select sites that increase consumptive water supply in reservoirs, downstream perennial streams, and groundwater. Furthermore, I discovered that spatial analysis measurements of ESC criteria required the development of novel methods. Applying this method requires the participation and support of regional experts and stakeholders to determine important values. This research is critical to developing methods to improve the planning process of ephemeral stream restoration worldwide.

Acknowledgements

In Academia

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In My Profession

As a full-time faculty member in the Civil and Environmental Engineering Department at Northern Arizona University, my Ph.D. career spanned the tenure of two department chairs. Bridget Bero gave me my first shot at teaching and a graduate teaching assistantship to fund my graduate studies. Paul Gremillion, my current department chair, has always supported me. Sometimes I overlooked work responsibilities to focus my efforts on this dissertation, and Paul always encouraged me to finish. I want to thank Mark Lamer, a top-tier engineer, educator, and friend. As a colleague, he has always inspired me to be the best teacher I can be. As a friend, he supported me through many tough times with positivity and joy.

In My Personal Life

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Preface

I present this dissertation in six chapters. There is a comprehensive introduction (Chapter 1) and methods (Chapter 2) chapters. There is a discussion of the results and conclusion (Chapter 6). I wrote the three middle chapters: Chapters 3 through 5, to appear as peer-reviewed journal articles. I have written these chapters to meet the specific author guidelines of three target journals. As such, there will be some redundancy in these three chapters resulting from the combination of journal and university formatting requirements. The submission dates for these journal articles are yet unknown.

Chapter 1-Introduction

Ephemeral Channels are stream channels that flow following periods of precipitation or snowmelt runoff. The channel, or stream bed of ephemeral streams, is above the groundwater surface elevation and does not receive flow inputs from groundwater (Levick et al., 2008). Ephemeral streams are in the highest concentration in the arid and semi-arid regions of the world and can be found on every continent (Datry et al., 2017). Ephemeral riverine ecosystems such as the ephemeral channels that flow through the wet meadow systems in high-elevation semi-arid forests, when wet, provide important hydrological and ecological functions and processes as perennial streams (Levick et al., 2008). These hydrologic functions include the transport of water, sediment, and nutrients. They create hydrologic connectivity when flowing and in cases where flows can access floodplains, there are increased rates of groundwater recharge and both sediment and nutrient storage. Stormwater energy and flood severity are also reduced. Even though flows are infrequent in these systems, they play an important role in fluvial channel form and structure. Additionally, ephemeral channels provide important habitat for the flora and fauna of an area.

The cycle of storage and transport of energy, matter, water, and organisms are all highly dependent on one another. The physical, chemical, and biological processes of these ecosystems work in a delicate balance. The geomorphic and hydrologic processes that occur in high-elevation, semi-arid, upland watersheds drive a cycle of sediment storage and transport. Through hydrologic connectivity matter, energy, and organisms are transported as part of the hydrologic cycle (Boulton et al., 2017). Channels and ephemeral wet meadow systems are formed through the transport and storage of matter as sediment and organic matter. Ephemeral wet meadow systems are formed through geomorphic processes, where stream channels have small cross-sectional areas of flow

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that are easily distributed over densely vegetated floodplains (Jaeger et al., 2017). The accumulation and storage of matter reduces the longitudinal slope of these systems which in turn reduces the stream power and stream velocity, driving additional deposit of matter. The reduced slope thus reduces the energy and severity of flood flows and increases the potential for groundwater storage. The geomorphic processes that drive sediment and organic matter accumulation work in concert to store and cycle energy as well. In ephemeral meadow systems, where sediment and organic matter are stored, stream power as velocity is reduced. But the energy of the food chain is another important function of ephemeral meadow systems. The increase in the storage of organic matter and nutrients in hydric soils drives the nutrient cycle and the storage of energy (von Schiller et al., 2017). The storage of energy in the hydric soils in turn increases the biota of the ephemeral meadow systems which causes an increase of decomposers and producers as riparian vegetation (Sabater et al., 2017).

The cycle of functions and processes at play in the ephemeral meadow systems that maintain the ecological system also provide socially beneficial services. The ecological functions of ephemeral meadow systems can also be measured as benefits that people receive directly from ecological functions (Groot et al., 2002; Palmer et al., 2014; Steward et al., 2012). The Millennium Ecosystem Assessment classifies ecosystem services by their functional significance (MEA, 2005). The functional significance categories are provisioning, regulating, cultural, and supporting services. Examples of provisioning, or services provided by ephemeral meadow systems, is the storage of freshwater as groundwater or the transport of surface water for human consumption (MEA et al., 2005). Regulating services are those which regulate climate, water, nutrient cycle, or flood protection. The properly functioning ephemeral wet meadow systems store carbon and serve as a sink for greenhouse gasses. They regulate water by storing it as groundwater, reducing flood

severity, excess nutrients and other pollutants in water are stored or removed, and erosion is regulated through sediment storage (MEA et al., 2005). Culturally, ephemeral meadow systems played an important role for many of Indigenous peoples around the world. Wetlands and wet meadows are a source of religious and philosophical beliefs and provide recreational opportunities (MEA et al., 2005). Supporting services are those that support the system so that the system can continue to provide ecosystem services to society. Examples of these services are biodiversity, soil formation, and nutrient cycling (MEA et al., 2005). Besides simply supporting a functional ecosystem, these and many other important functions and processes associated with ephemeral meadow systems provide regulating services and provide important services that humanity is dependent upon for greater societal well-being (MEA et al., 2005). These and other ecosystem services are viewed as fundamentally important for human well-being and their value is supported by peoples' willingness to pay for ecosystem services (Chee, 2004; Koundouri et al., 2017). In some cases, the willingness to pay for ecosystem services is being applied as a willingness to pay for restoration efforts (Aguilar et al., 2018; Mueller, 2014).

Globally, like many ecosystems, ephemeral stream channels have become degraded. Specifically, ephemeral channels through wet meadow systems located in semi-arid, high-elevation headwaters have become incised and no longer function or provide important ecological processes or ecosystem services. In the forests of northern Arizona, the degradation of these channels is a long-term problem, based on events that took place over 100 years ago. Excessive cattle grazing, timber harvest, and natural climate fluctuations are the primary causes of the degradation in these systems (Bull, 1997; Pollock et al., 2014; Webb & Hereford, 2001). The loss of vegetative cover, coupled with high-intensity storm events are the primary conditions under which many of the wet meadow systems in the southwest were incised. High velocity, high energy

flows down cut through fluvial soils, which ultimately lowered the groundwater table and ultimately changed the wet meadow ecosystem to what it is today. The channels no longer put water on the floodplains, reducing the storage of energy, sediment, nutrients, and groundwater. Ultimately, the wet meadow ecosystems are degraded and no longer support the processes, functions or provide the ecosystem services that they once did. The cycle of channel incision, or degradation, of wet meadow systems is a natural process of the geomorphic cycle in these systems. However, the anthropogenic drivers of overgrazing and deforestation, coupled with anthropogenic climate change, have pushed many of these systems out of their natural cycle, from which recovery through natural cyclic processes may not be realized (Chiu et al., 2017; Ely, 1997; Perry et al., 2015). Stream channel restoration is a common method used to restore degraded riverine ecosystems.

Stream restoration efforts are increasing, and billions of dollars are spent annually to reverse degradation events of the past and restore ecologically functional processes to riverine systems (Bernhardt et al., 2005; Petty & Thorne, 2005; Wohl et al., 2015). Making efforts to restore degraded systems to a reference condition or a standard of ecological integrity is a common method by which streams are selected (Jungwirth et al., 2002; Palmer et al., 2014; Reynolds & Hessburg, 2005; SER, 2004). Stream restoration efforts are recognized as effective methods for restoring ecosystem functions (Norman et al., 2017; Palmer et al., 2005; Roni et al., 2018) For ephemeral streams and intermittent rivers, there are far fewer papers published on stream restoration projects in these systems than those on perennial streams (Lake et al., 2017). Fortunately, the willingness to pay for the restoration of forested watersheds in the southwest, where there is water scarcity is leading to restoration efforts being made to restore the ephemeral wet meadows of the region (Broadbent et al., 2015; Fredette, 2016; Mueller, 2014).

Justification

In 2009 The United States Forest Service initiated a collaborative landscape-scale restoration called the Four Forest Restoration Initiative (4FRI). It is thought to be the largest restoration effort of its kind, with a stated goal of "restoration of the ponderosa pine forest stretching across northern Arizona" (Fredette, 2016). Through the National Environmental Policy Act (NEPA) process, the development of an Environmental Impact Statement (EIS), and the Record of Decision (ROD); *Phase 1*[1] of the 4FRI identified 39 miles of ephemeral channel, consisting of 163 reaches for restoration (USFS, 2015b). The sites are distributed throughout the Coconino National Forest and the Kaibab National Forest of northern Arizona. The data that accompanied the 163 stream reaches is location, stream length, an estimation of riparian v. non-riparian classification, and the fact that none of the 163 reaches are considered to be in a "proper functioning condition" (MacDonald, 2013). The 4FRI has assembled a group of professionals and stakeholders into a working group. The Comprehensive Implementation Work Group (CIWG) has been tasked with selecting sites for restoration and implementing restoration on the ephemeral channels in Phase 1. One of the problems facing the 4FRI team of forest managers and restoration practitioners is where to start. If money and time were unlimited, there would be no problem in selecting sites, they would simply restore them all. However, since resources and time are limited, there is a need to develop a method for prioritizing sites for restoration (Griscom & Hoglander, personal communication, September 2, 2021).

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[1] Phase 1 of the 4FRI is focused on the Coconino National Forest and the Kaibab National Forest. The Rim Country Project (or Phase 2) is in other National Forests of Arizona but does not identify specific ephemeral channels for restoration.

The theory behind the need for effective site selection is supported by the published literature on ecological restoration. Some excerpts that put the priority on site selection are presented below:

"A primary question in these applications is: given a list of sites deserving of restoration or protection, where is it most important to target resources (Hyman & Leibowitz, 2000)?"

"Deciding where to restore ecosystems for the attainment of multiple services is a key issue for future planning (Trabucchi et al., 2013)."

"Important issues that arise in restoration planning are where to restore first and where we should focus the resources and efforts (Uribe et al., 2014)."

"An urgent question in nature conservation is: where to act first (Orsi et al., 2011)?"

"Deciding where to conduct protection and restoration activities to maximize effectiveness in terms of both ecological and socio-economic returns is a common concern in resource management (Nehlsen, 1997)."

The efforts to restore any of the 163 stream reaches identified by the 4FRI ROD would best be supported by a transparent, easily repeatable site selection method. There are many methods presented in the published literature regarding site selection methods for the restoration of perennial streams. However, a literature review (presented below) uncovered that there are no methods presented in the published literature regarding site selection methods for the restoration of ephemeral channels.

Objectives

The objective of this study is to develop a prioritization method for the selection of ephemeral stream reaches for restoration. The method is transparent and easily repeatable and is tailored to provide decision-makers around the world with an ephemeral stream site selection method. Site selections will ultimately require field investigations, cost analyses, and other measures to select a priority site for restoration. Furthermore, it is the objective of this study to apply regional decision-making values to a spatial analysis tool that can narrow down an extensive list of candidate sites while minimizing the expenditure of resources. To accomplish this, I will answer the following research questions through three phases:

Research Question 1 (RQ1): What factors influence decision-making for restoration initiatives in riverine ecosystems in Ponderosa Pine Forests?

The methods used to address RQ1 follow the flow of Phase I:
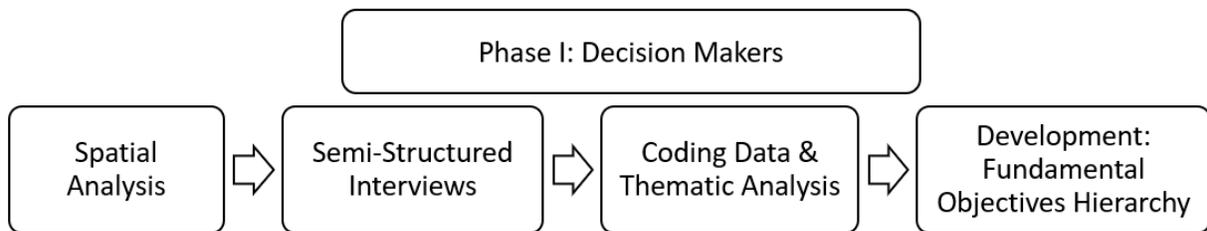
Figure 1 Phase I

1. Perform spatial analysis to find locations ponderosa pine forests occur in U.S. Forest Service (USFS) managed lands.

    a. Contact stream restoration practitioners willing to participate in this research

2. Conduct semi-structured interviews with decision-makers in and around the ponderosa pine forests of North America.

3. Code and Analyze interview transcripts to gain an understanding of deciding factors in the site selection methods.

4. Synthesize the applicable data into an objectives hierarchy.

Research Question 2 (RQ2): How can decision-making factors be developed into a prioritization method for ephemeral stream channel restoration?

The methods used to address RQ2 follow the flow of Phase II:
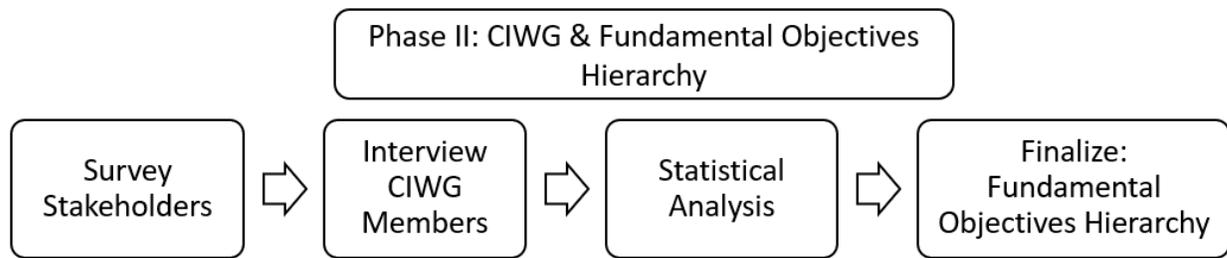
Figure 2 Phase II

1. Survey members of the CIWG.

   a. Find people working in 4FRI on ephemeral stream channel restoration willing to participate in this research.

   b. Identify any deciding factors specific to ephemeral stream channels that were missed by the decision-makers from Phase I.

2. Conduct semi-structured interviews with members of the CIWG to put weighted values on objectives and attributes associated with ephemeral channels.

   a. Perform statistical analysis on numerical values associated with weights and values.

3. Finalize the Fundamental Objectives Hierarchy.

   a. Develop a method by which attributes and objectives can be used to rank priority sites for restoration.

Research Question 3 (RQ3): How can a site prioritization method be modeled using spatial analysis to rank priority sites for restoration?

  The methods used to address RQ3 follow the flow of Phase III:
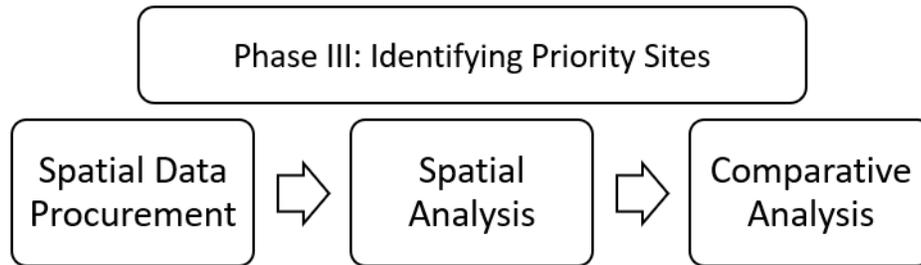
Figure 3 Phase III

1. Create a spatial analysis map to measure the criteria identified by the fundamental objectives hierarchy.

2. Implement a spatial analysis tool that can be used to analyze and prioritize sites for restoration.

3. Compare the results of the CIWG weighted values as applied to the mathematical expression used in the spatial analysis to a recently prepared "letter of request" sent to the Coconino National Forest Supervisor requesting funding and support in the restoration of selected sites.

Literature Review

Introduction

Globally, ephemeral channels and intermittent streams are degraded. Stream channels throughout the southwestern region of the United States, both perennial and intermittent, are incised, degraded, and no longer in proper functional condition. Causes of incision and degradation include but are not limited to, natural geomorphic processes, changes in climate resulting in drought or floods, or land use (Bull, 1997; Pollock et al., 2014; Webb & Hereford, 2001). The channels no longer have access to floodplains or support riparian vegetation (Briggs, 1996). They flow at high velocities, scour out channel bed material, create head cuts, and transport sediment downstream.

Many prioritization methods identified in the literature select sites for ecological restoration. However, there is a noteworthy absence of literature on prioritizing ephemeral stream channels for restoration. This review aims to summarize the literature on different prioritization methods used to select sites for restoration that are analogous to ephemeral channels. In performing a literature search, I aimed to find prioritization methods specific to site selection. Due to the absence of literature on site selection methods for ephemeral stream channel restoration, this literature focused on streams, wetlands, estuaries, riparian corridors, watersheds, and other similar ecological areas due to their similarity with riverine ecosystems. While some components of these methods would not apply to ephemeral channels, like selecting sites to improve spawning salmon habitat, similar factors apply to ephemeral stream channels. In reviewing the literature, I aim to identify decision-making and site selection methods for ephemeral stream channel restoration.

Site Selection Methods

Site selection for restoration takes on many different forms. There are score sheets that produce a score for ranking. There are triage methods that classify sites based on the emergency medicine standards of focusing efforts on sites with a demonstrated need for and with the highest probability

of becoming functionally restored. There are complex mathematical models or software that run algorithms. There is the cost-benefit analysis approach. There are GIS models that also run algebraic analyses of data. Arguably, all site selections apply personal and professional values to sites as criteria that can be measured, and sites are ranked. Some methods use score sheets, and others use GIS software and spatial analysis. The triage method scores and ranks sites. CBA methods score and rank sites with the best effort (cost) to benefit ratio. Moreover, the most complex spatial analysis tools use algorithms to score and rank. It is a decision-making process.

Many sources in the literature identify specific methods for decision-making such as decision support systems (DSS) (Xia et al., 2014), multicriteria decision analysis (MCDA) method (Hermans & Erickson, 2007), and structured decision-making (SDM) (Kozak & Piazza, 2015), are terms, concepts or methods used to take multiple site criteria and measure them to aid in the decision-making process (Chowdary et al., 2013; Convertino et al., 2013; Galatowitsch et al., 1998; Hopfensperger et al., 2007; Llewellyn et al., 1996; Mysiak et al., 2005; Uribe et al., 2014). All site selection methods identified in the literature rely on measuring criteria to find the best site. In this literature review, there are no methods founded on one single decision-making metric.

In my review of the literature, what was being restored or how the site was selected did not change the fact that all methods start with identifying goals or objectives of restoration. Following the identification of goals, it is important to identify the criteria that will measure conditions at a site. After the criteria are measured, scores or data identify the priority site for restoration. I will present and discuss literature that demonstrates methods for site selection. I will highlight how they apply to each of these three steps, 1) establishing goals, 2) measurable criteria, and 3) how sites are ranked, which are fundamental to the site selection process.

Establishing Goals

Goals are critical to restoration planning (Barber & Taylor, 1990; Hobbs, 2007). Bohn & Kershner (2002) attribute several federal mandates for watershed assessment to verify that planners have identified clear goals and objectives before restoration work begins. One of the earliest site selection methods identified was by Llewellyn et al. (1996). In their site selection method, they laid the groundwork for emergent themes of site selection. They identified their overarching goals for restoration. They established their plan for restoration and protection of sites depending on a site's state of ecological function. Their identified geographic location for restoration was immense, wetlands along the Mississippi River Alluvial Plan, and they had to deal with numerous federal, state, and local participants, so they kept their goals very general. There are benefits to keeping the restoration goals broad. However, as site selection methods evolved, there was a call for explicit goals for restoration. Abbruzzes & Leibowitz (1997) developed a synoptic approach to site selection, providing a broad analysis of criteria instead of a detailed analysis. The synoptic approach typically measures change. The change measures the impact over time or a change in ecological function based on the restoration cost. The general objectives and goals must be understood to know what metrics to measure. The first step in their five-step process is to define goals. In an early application of the synoptic approach, the authors asked the primary question, "Given a list of sites deserving of restoration or protection, where is it most important to target resources?" (Hyman & Leibowitz, 2000, p. 23). This paper was one of the first to call out the need for site selection methods. They went on to say that explicitly stating the goals or priorities of restoration are required to guide site selection. McAllister et al. (2000) applied the synoptic approach and followed the steps of the synoptic approach. However, their goal was not explicit in the first step of identifying goals. Their goal was to identify wetlands, which, if restored, would reduce region-wide downstream flooding. The general approach of the synoptic method has

been(White & Fennessy, 2005). The synoptic approach, although not called a cost-benefit analysis (CBA) method, compares the change of two metrics relative to one another. It is very similar to how CBA methods work.

Many CBA methods that measure the ecological benefits apply to site selection. However, not all goals focus on ecological benefits. Randhir et al. (2001) applied CBA to identify watersheds for protection that would increase water quality and water security in a metropolitan area. Neeson et al. (2016) analyzed CBA against the number of stressors at restoration sites. They determined that sites will the least stressors, even if server, would cost less to restore than sites with numerous less severe stressors. Although they were not using CBA for specific site selection decisions, they recommended restoration processes that would reduce or remove the stressors to achieve an end goal. Iftekhar et al. (2017) used a cost-benefit ratio to prioritize sites with the greatest ecological benefit at the lowest cost. Again, the metrics used to measure benefits depend on the development of goals. Rappaport et al. (2015) used CBA in the second step of their site prioritization method. They defined their primary goal and used a multi-step approach to measure their metrics. The first step was to identify areas that showed an urgency for restoration. The urgency for restoration was measured spatially based on habitat changes and connectivity reduction. The second step showed feasibility, which is where they applied CBA. They identified habitats with the highest levels of resilience because those restoration sites would have the best cost-benefit ratio. The application of urgency and feasibility as it was applied here is referred to as the triage method.

The implementation of comprehensive and effective restoration is typically limited by funding, which necessitates the treatment of some sites and abandoning others similar to the methods applied to emergency medicine (Wohl et al., 2005). The triage method was first applied conceptually to ecological restoration by Samaways (2000). As applied to site selection, triage

identifies three options, 1) ecological integrity irretrievably lost, 2) ecological integrity restorable, and 3) ecological integrity intact. Respectively, the options for restoration actions would be 1) do nothing because restoration is not possible, 2) do something because restoration is feasible, and 3) do nothing because restoration is not needed. Although this is a conceptual way of measuring ecological restoration sites, it prioritized being clear with goals. The triage method is typically applied early in analysis and assesses many sites to reduce the number of sites that require additional site-specific data collection. Harris and Olsen, 1997 applied the triage approach to a two-stage process for site selection. In their first stage, they put sites into one of three classifications, 1) preservation or protection, 2) restoration not feasible, and 3) further analysis needed. The preserve and protect is the do nothing because the site is functional. The restoration not feasible classification falls into the do-nothing option because the sites are so badly degraded that they cannot be restored. Finally, the further analysis needed sets these sites up for additional data collection to determine the restoration feasibility. In their second stage, their restoration goals explicitly define the additional data needed for the decision-making process. Hobbs et al. (2003)

applied the triage method to gain additional landscape-scale ecological restoration classifications. They classified the level of need and the probability of success into three sub-categories each: high, medium, and low (fig. 4). Although Hobbs et al. (2003) established this conceptually,

Figure 4 Triage sub-classifications by Hobbs et al. (2003)

they recommend the general goals for this type of application.

Because the triage method is a quick and early assessment of sites, there is a risk of missing sites. Noss et al. (2009) recommended applying the triage method with caution to avoid abandoning potentially important sites or condemning species to extinction. That is why the development of goals is so critical to the site selection process (Barber & Taylor, 1990). Although not explicitly included as part of a method for site selection, the restoration literature repeatedly identifies the importance of setting realistic goals (Hobbs, 2007). General goals can provide the first step in planning a site assessment approach (Harris & Olson, 1997), or they can be specific goals identified after an initial assessment (Hallett et al., 2013; White & Fennessy, 2005). Finally, selecting appropriate criteria to measure site characteristics requires well-defined and understood restoration goals (Convertino et al., 2013; Ehrenfeld, 2000; Laub et al., 2015).

Criteria to Measure

Many synonyms describe the criteria for characterizing a restoration site, such as metrics, attributes, deciding factors, and variables. In this review, I will apply the term criteria to describe these, and other terms used to measure sites. It is critical that the criteria used in a site assessment reduce uncertainty, provide beneficial data and information to increase system and site understanding, and create a measure for evaluation (Convertino et al., 2013). The methods already discussed, the synoptic approach, triage, and CBA, all rely on criteria measurement. In the literature, many site selection methods do not justify their selected criteria. Instead, they apply criteria guided by their project goals or objectives (Comín et al., 2018; Harris & Olson, 1997; Khanday & Javed, 2016; O'Neill et al., 2008; Parker et al., 2016). Others have demonstrated that expert input should guide the development of criteria (Cipollini et al., 2005; Hughes et al., 2023;

Ioana-Toroimac et al., 2017; Walsh et al., 2020; Xia et al., 2014). Moreover, others have put the identification of criteria on stakeholders (Hopfensperger et al., 2007; Kozak & Piazza, 2015; Randhir & Shriver, 2009; Uribe et al., 2014). Independent of how criteria are selected, they are the metric by which sites are measured and ranked. Presented below are examples of methods to select criteria.

Parker et al. (2016) used a very straightforward method to select sites from 68 parcels of riparian habitat selected for conservation. This method took five criteria and applied a rank for each parcel. This method did not identify how the criteria were selected. Gellis et al. (2001) applied weighted factors to demonstrate the importance of select criteria. They assessed eight different sub-watersheds with quantitative physical characteristics and qualitative features. Each was given a priority rank of one to eight. Then scores were summed, and sub-watersheds were ranked. After their initial ranking, they applied weighting factors to some watershed characteristics and features. They developed their criteria based on expert input and included local community stakeholders include weights to demonstrate a level of importance. Johnson et al. (2003) developed a scorecard to be used to assess sites for restoration. They based this method on two categories: existing conditions and post-restoration condition estimations. The scores were simplified to be one of three qualitative assessment values, 0 (poor), 1 (acceptable), and 2 (good).

Not all scoring and ranking techniques are simple. Cipollini et al. (2005) used a weighted scoring method to rank sites using decision methods borrowed from business (Clemen, 2004). Criteria were weighted based on interviews with experts with firsthand knowledge of the region. Their method applied weights to the criteria with decision-making software (https://www.logicaldecisionsshop.com/catalog/). The application of this scoring method to decision-making software included many criteria. It gave them detailed statistical support for many

criteria that led to the final restoration site selection. O'Hanley & Tomberlin (2005) used a decision-making approach to identify priority fish passage barriers for removal. They were critical of overly simplified scoring and ranking schemes in their analysis. They indicated that simple scoring and ranking methods often assess sites without considering other factors in the system. They developed a mathematical optimization model for decision-making that can consider other factors. The criteria that they selected for optimization were based on the best professional judgment or with modeling software. Higgins et al. (2008) developed a CBA method that used criteria as a metric to optimize investments. Their model estimated the total benefit obtained from the proposed investment. Multiple criteria are used to measure the total benefit, requiring considerable expertise. Another consideration with CBA methods is that not all benefits can be measured using standard market values (Iftekhar et al., 2017). In their method, criteria measured by nonmarket techniques are expensive and require specific skills. Liu et al. (2006) used a specific MCDA method called the technique for order of preference by similarity to ideal solutions (TOPSIS). TOPSIS, as applied here, is an MCDA tool that selects the best site from a set of candidate sites based on specific goals with online calculators or other free software. They applied measurements of criteria through spatial analysis. Their method can analyze many potential sites for restoration quickly and efficiently. However, it is more of a screening tool to identify potential wetlands requiring a more detailed investigation.

Stakeholder participation is critical to restoration decision-making (Randhir & Shriver, 2009). Additionally, the probability of success increases with stakeholder support throughout the process (Hopfensperger et al., 2007). Uribe et al. (2014) developed a method that asked stakeholders to create a list of criteria that was important to them. Then the stakeholders were asked to put weights of importance on the criteria. The criteria were measured using spatial

analysis techniques. In a method developed to reduce the total maximum daily load (TMDL) of pollutants in rivers, stakeholders are required by regulation to participate in efforts to reduce pollutants released from their agricultural lands into rivers (Stringfellow, 2008). Creating a scientifically rigorous method that was also easy for stakeholders to understand was essential. They displayed their data using quadrants to simplify stakeholder communication and increase participation. Randhir & Shriver (2009) also relied on stakeholders to select criteria for watershed measurements. A small group of representative stakeholders created a list of criteria, then through an information exchange, the complete group of stakeholders communicated values a

In recent years there has been an increase in the number of methods that use ecosystem services as their criteria (Adame et al., 2015; Cassiano et al., 2013; Comín et al., 2018; Hermoso et al., 2012; Perry et al., 2015; Trabucchi et al., 2014). Ecosystem services (ES) can be summarized as the benefits obtained by humans from nature (MEA et al., 2005). It can be complicated to measure ES (Robertson, 2012). Due to the difficulty of measuring ES as criteria, Comin et al. (2014) prioritized identifying multiple ES-related criteria. Trabucchi et al. (2014) developed a method that quantified and mapped ES. They identified their goals and established their criteria. Hermoso et al. (2012) used systematic rehabilitation planning, which combined CBA and ecosystem science to calculate trade-offs between potential restoration actions. Perry et al. (2015) recommended putting climate change projections into a method. They would prioritize ES that are most vulnerable or resilient to the projected changes.

The identification of criteria is a fundamental part of any site selection method. Scores can be finalized using score sheets, spatial analysis tools, or software. Criteria are measured, and point values calculate a rank and identify a priority location for restoration.

Calculating the Rank

Established in the previous sections of this review is the need to identify goals for restoration and the need to identify the criteria used to measure sites. The criteria used in assessing sites are also valuable tools to measure the success of restoration efforts. Site selection methods start by identifying goals and the appropriate criteria to assess those goals. Following the criteria measure, sites are ranked, selected, or prioritized for restoration. The process for calculating the rank ranges from simple additive function score sheets to complex software and spatial analysis tools.

Figure 5 Yes/No Decision Tree Scorecard from Thompson et al. (2002)

Score sheets are the simplest form of scoring and ranking. The scorecard used in field assessments can be very simple, where values are added up (Johnson et al., 2003). Other scorecard methods apply yes/no answers to a decision tree (fig. 5) (Thompson et al., 2002). A criticism of scorecards is that they tend to be subjective (Beechie et al., 2008). Others criticize them for being too simple (O'Hanley & Tomberlin, 2005).

Another variation in the scoring method is the implementation of weighting factors. Although subjective, weighting factors apply a level of importance to the criteria. Most scoring and ranking methods in this review apply weighting factors to their final calculations. Weights are established by professional judgment or through interviews with experts or stakeholders. Decision or spatial analysis software calculates most metric scores to identify priority sites. Spatial analysis tools allow for the analysis of criteria using algebraic methods, the writing of algorithms, or the use of programming languages built into spatial analysis software (https://desktop.arcgis.com/en/arcmap/latest/analyze/python/a-quick-tour-of-python.htm).

Conclusion

The methods to select priority sites for restoration follow three fundamental stages identified by the literature. The first stage of site selection is the identification of goals. If dealing with many potential sites, or a large geographic region, goals can be general to get started and evolve to become more specific. Specific restoration goals can be established immediately in cases with fewer potential sites or if the area of potential restoration sites is small. Accompanying well-defined goals is the identification of measurable criteria. Many criteria are measured using spatial analysis methods. Although, there are still applications for on-site field measures of essential criteria such as water quality sampling or species identification. However, the criteria are measured, and the sum of criteria values is applied to identify the highest priority site for restoration—the methods for arriving at a final decision range from simple additive functions to complex software models.

The literature reviewed here did not identify ephemeral stream channel methods. There were methods in the literature where riverine and water-related sites were scored lower depending on the permanence of water. Sites with intermittent flows were scored lower than sites with perennial flow (Llewellyn et al., 1996; Thompson et al., 2002). The literature indicates that there has been considerably less restoration work on intermittent rivers and ephemeral streams than on perennial streams (Lake et al., 2017). What is clear from this literature is that developing a site selection method for ephemeral stream channels must have the following components. 1) There needs to be a well-defined goal for restoration. This goal can be general but should become explicit through the process. 2) The selection of criteria to measure sites needs to be identified. These measurements can range from physical, biological, or chemical criteria. Decision-makers can identify criteria to measure the ES of ephemeral stream channels. Although, due to the lack of

research on ephemeral streams (Acuña et al., 2014; Boulton, 2014), ES have not been well developed for ephemeral streams (Koundouri et al., 2017). Additionally, it is important to include stakeholders and experts in the judgment decisions to establish criteria. Depending on resources, any scoring method is reasonable for ephemeral stream channel restoration, whether it be a score sheet, decision analysis software, complex mathematical models, or spatial analysis tool. What is important is that throughout the entire process, the method should be repeatable and transparent. It does not seem that there are old methods and new methods. The site selection method for ecological restoration has evolved to implement different criteria and means of measuring criteria and adding measured data to rank sites.

Study Area

4FRI

Across the state of Arizona, four National Forests began a collaborative, landscape-scale restoration effort to improve forest health called the Four Forest Restoration Initiative (4FRI) that would restore 2.4 million acres of ponderosa pine *(Pinus ponderosa)* forests. The four forests are

Apache-Sitgreaves, Coconino, Kaibab, and Tonto National Forests. The overarching goals of the 4FRI are primarily based on reducing the risk of unnaturally severe catastrophic forest fires. Restoration work includes thinning and burning to restore the structure and composition, reduce fuels and risk of severe forest fires, and restore fire-adapted health to the ponderosa pine forests. Additional goals include providing healthier forests for wildlife and plant biodiversity, creating a sustainable ecosystem, and creating a variety of jobs for the communities near these four forests. In conjunction with the thinning and burning work, restoration efforts are also focused on restoring springs, streams, and watersheds. Trails and roads will be restored or decommissioned. And wildlife habitat will be improved.

Figure 6 Four Forests of Northern Arizona

The planning for the restoration effort followed the National Environmental Policy Act (NEPA) process. A draft environmental impact statement (DEIS) was made available in 2013. In the DEIS, 39 miles of ephemeral channels were identified as candidates for restoration. The 39 miles of ephemeral channel are identified as having "reduced function" and have a desired condition of "Properly Functioning Condition" (USFS, 2013). Following the NEPA process, a final environmental impact statement (FEIS) and a draft Record of Decision (DROD) were released in 2014 (USFS, 2015b, 2015a). Accompanying the FEIS and DROD, a Water Quality and Riparian Areas Specialist's Report was made available (MacDonald, 2014). In this document, details

regarding the location and distribution of the 39 miles of ephemeral channels are presented. There are 32 miles of channels in Coconino National Forest and 7 miles of ephemeral channels in Kaibab National Forest (MacDonald, 2014). The water quality report provided an analysis of all stream reaches in both forests and did not specifically identify the location of the 39 miles of ephemeral channels, although a map showing the location of stream channels was included online as an appendix to the FEIS.

The details and information are specific to the 39 miles of ephemeral channel. They were finally made available as a geographic information system (GIS) spatial analysis map. Data provided with the map attributes such as location, stream reach length, riparian classification (riparian v. non-riparian), and in which national forest they were located revealed that there were163 different stream reaches identified as candidate reaches for restoration. The 163 reaches are distributed throughout both Coconino and Kaibab National Forests. They are in several different hydraulic unit code-6 (HUC-6) watersheds which average around 40,000 acres in area (USFS, 2011). The 4FRI team, in the interest of completing the restoration efforts that have been approved through the NEPA process, has created a working group to identify and prioritize restoration projects. In agreement with the published scientific literature on the value of site selection, the 4FRI effort would benefit

Figure 7 4FRI Boundary Area and Stream Reach Locations (in yellow)

from a transparent and easily repeatable method by which sites can be selected for restoration. The results of the research questions above can be applied directly to a restoration effort where a list of many potential candidates for restoration needs to be prioritized.

In 2017, ephemeral channel restoration work was completed in the Coconino National Forest at Long Valley meadows. The Arizona Elk Society (AES), a stakeholder in the 4FRI, selected the site to support elk habitat (Clark, S., personal communication, March 2, 2023). However, this reach of ephemeral channel restoration was not one of the reaches identified by the 4FRI ROD. There was no supporting documentation or identifiable methods by which the AES and the 4FRI prioritized this site. At another site in the Lake Mary Watershed (also located in the 4FRI), there is evidence from field site investigations that restoration work was completed at one of the head cuts in an ephemeral reach identified by the 4FRI ROD. However, there is no documentation to support the work nor is there any indication that drivers of degradation or watershed scale processes were considered in repairing the headcut. To date, no other restoration efforts are being implemented on the ephemeral channels identified by the 4FRI ROD. Finally, in late fall of 2022, the CIWG drafted a letter to the Coconino National Forest supervisors and the 4FRI team requesting funding to begin restoration work at proposed sites. Based on documents submitted in support of their request to restore sites, the CIWG did not follow a transparent or repeatable method to identify sites for restoration. There is no justification for the sites they are recommending for restoration.

Due to the lack of scientifically supported methods and zero transparency to justify the selction of these sites, there is concern that these sites may not in fact be the best sites for restoration. The literature cited throughout this chapter indicates the need for a method based on well defined goals, professional judgement, stakeholder involvement, and scoring or ranking of

measureable attributes that can be used to prioritize the best sites for restoration. It is with this in mind that this research has been conducted and that the methods presented herein are so important to the 4FRI and other ephemeral stream channel restoration projects around the world.

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Chapter 2-Methods

Summary

The research presented here takes a mixed-method methodology approach, including spatial analysis, semi-structured interviews, online surveys, thematic analysis of qualitative data, and statistical analysis of quantitative data, to answer the following three research questions:

- Research Question 1 (RQ1): What factors influence decision-making for restoration initiatives in riverine ecosystems in Ponderosa Pine Forests?

- Research Question 2 (RQ2): How can decision-making factors be developed into a prioritization method for ephemeral stream channel restoration?

- Research Question 3 (RQ3): How can a site prioritization method be modeled using spatial analysis to rank priority sites for restoration?

I divided the methodological process into three phases (fig. 8). These methods are detailed below. Phase I focused on identifying interview participants, developing interview questions, conducting semi-structured interviews, and analyzing interview data. To protect the rights and welfare of human subjects participating in this research, I followed all Institutional Review Board (IRB) regulations. IRB granted approval for conducting study # 1666943-1 on 11/01/2020. To identify interview participants, I completed a spatial analysis of ponderosa pine *(Pinus Ponderosa)* forests merged with the locations of U.S. National Forests where riverine restoration had been implemented. I conducted interviews, coded responses, and analyzed qualitative data from the interviews. The interview data were used in the initial development of the "fundamental objectives

hierarchy." Following the initial development of the fundamental objectives hierarchy, I created and deployed an online Qualtrics survey to recruit a second group of interview participants.
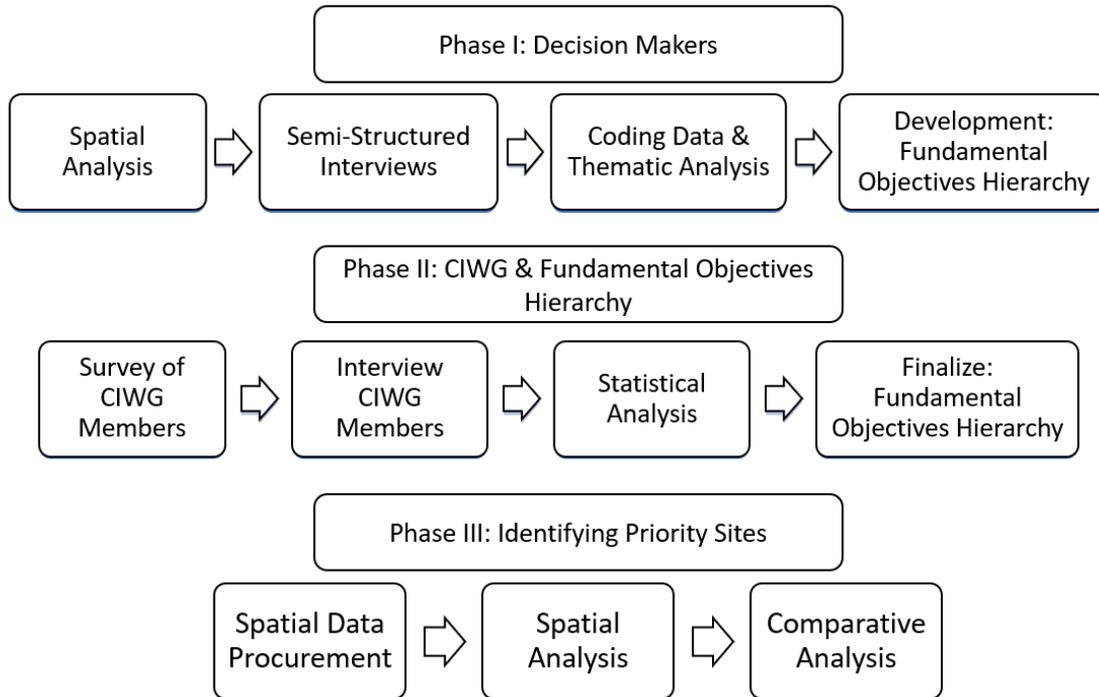
Figure 8 The Phases and Major Steps of the Methods

Phase II focused on the creation and delivery of an online survey, a second round of semi-structured interviews, statistical analysis of quantitative interview data, the finalization of the fundamental objectives hierarchy, and the development of a mathematical expression to apply the scores and weights of the fundamental objectives hierarchy for the prioritization of sites. I sent the survey to stakeholders associated with the Four Forests Restoration Initiative (4FRI) to identify participants willing to participate in semi-structured interviews. The survey also provided additional regional values to further develop the fundamental objectives hierarchy. The second round of interviews was conducted with professionals and stakeholders identified from the 4FRI's Comprehensive Implementation Working Group (CIWG). The CIWG interview participants applied qualitative weights and scores, based on their personal and professional values, to the

objectives and measurable attributes of the fundamental objectives hierarchy. I completed a statistical analysis of the data, then developed a mathematical equation to apply the weights and scores to calculations that would rank each site to finalize the fundamental objectives hierarchy.

Phase III focused on developing a spatial analysis tool that applied the weights and scores of the fundamental objectives hierarchy to the candidate stream reaches to identify the priority channels for restoration. Finally, I compared the results of the spatial analysis to the recently recommended set of ephemeral stream reaches the CIWG petitioned the 4FRI to consider for restoration. Details of these methods are presented below.

Phase I

Search for Interview Participants-Spatial Analysis

Because ephemeral streams of the Southwest United States exist in headwater forests that have a large composition of ponderosa pine trees, I used ponderosa pine forests as the limiting factor for
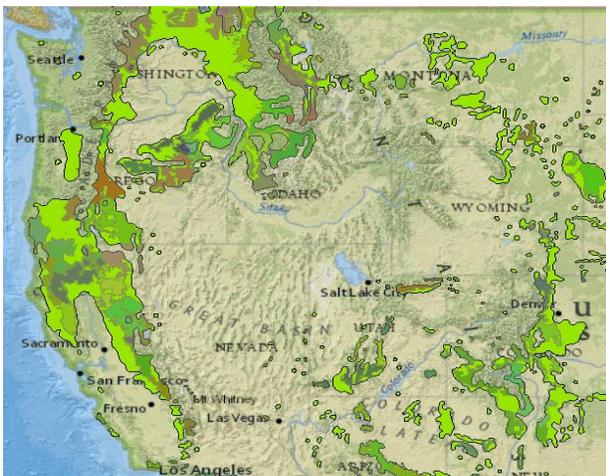
Figure 9 Ponderosa Pine Extent with U.S. Forest Boundaries

identifying where stream restoration is being conducted to search for interview participants. I conducted a spatial analysis to determine the extent of ponderosa pine forests in the United States. Because the U.S. Forest Service holds jurisdiction over many of these forests and is implementing restoration activities, I overlaid ponderosa pine forest map with U.S. Forest Service (USFS) boundary and location polygons using ArcGIS ® software (fig. 9).

Each Forest Service unit's online webpage has a "Managing the Land" tab under which "Resource Management, Planning, and Projects" are found. I searched for each National Forests that is contiguous with ponderosa pine forests. Within the resource management, projects, and planning documents keyword searches for "water," "stream," "wetland," "riparian," "spring," and "river" uncovered many projects that had some component of riverine restoration. The USFS maintains an extensive library of completed and planned project documentation. Restoration projects have a listed "project contact" with telephone and email contact information. I sent project contacts requests to participate in this research. Using the snowball sampling method (Naderifar et al., 2017), I asked all recipients to share our request to participate with other practitioners of riverine restoration who might contribute to this research.   Interview participants were eligible if they identified as "a decision-maker" or had completed riverine-type restoration work in or around National Forests contiguous with ponderosa pine forests. I scheduled interviews with willing participants who provided consent.

Semi-Structured Interviews-Decision-makers

A semi-structured interview approach allowed interview participants to expand beyond a question's typical "what" answer through a casual conversation. Through the semi-structured interview approach, participants were encouraged to justify and explain "why" they selected certain sites (Palic et al., 2016). Semi-structured interviews were conducted remotely using the Zoom ® platform due to its ability to "screen share," record meetings, and provide transcripts of conversations. The general goal of the semi-structured interview was to get the participants to identify the five most important deciding factors they relied on to prioritize one site over another (DiCicco-Bloom & Crabtree, 2006; Kallio et al., 2016). Participants reviewed a list of deciding factors (see Appendix A and then ranked their top five used to prioritize a specific restoration

project they had completed in the past. I also asked them to make a top five ranked list of deciding factors that could be applied, "in general," to any future proposed stream restoration project regardless of its location.

Interview Data Analysis-Qualitative Thematic Analysis

After transcribing interview responses, I coded them with the NVivo software ® following an inductive coding approach (Aberbach & Rockman, 2002; Linneberg & Korsgaard, 2019). From the coded qualitative data, I identified themes that emerged as deciding factors using thematic analysis (Kiger & Varpio, 2020; Lochmiller, 2021). The goal of collecting these data was to apply themes as measurable attributes and objectives to create a fundamental objectives hierarchy, like that of Cipollini et al. (2005).

Development of the Fundamental Objectives Hierarchy

In decision-making, the fundamental objectives are the essential reasons for a decision (Clemen, 2004). The essential reason for prioritization is to identify high-ranking restoration sites from many potential candidate sites. The fundamental objectives hierarchy, taken from business decision-making methods, was first applied to ecological restoration work by Cipollini et al. (2005) to manage prairie openings and can be used visually to represent a multicriteria decision analysis (MCDA) process. The hierarchy is also a building block in developing a mathematical expression to rank candidate restoration sites. In the fundamental objectives hierarchy (fig. 10), the highest-level objective (represented by a rectangle) is to prioritize a site for restoration. The next level of objectives is to prioritize a watershed and to prioritize a stream reach. To prioritize a watershed, measurable attributes (represented by ovals) are used to arrive at an objective. All the identified deciding factors from Phase I interviews were included in the development of the fundamental

objectives hierarchy, either as measurable attributes or as objectives. It is important to note that the list of measurable attributes and objectives could have included other attributes or objectives. However, this list was based on data obtained directly from the decision-maker interviews.
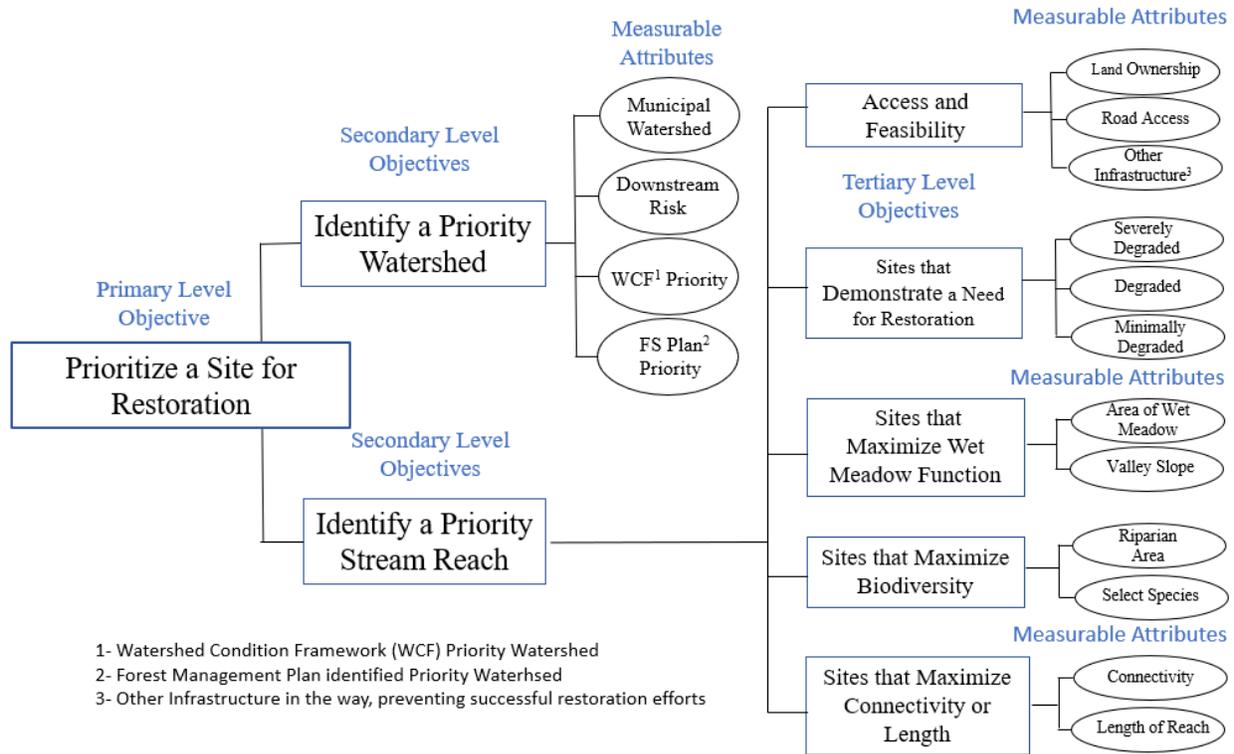
Figure 10 Fundamental Objectives Hierarchy

Assumptions and Manipulations of Data

Several site selection characteristics were omitted (Table 1) from the FOH (fig. 10) to apply the deciding factors to ESC restoration sites. Keystone Species or Single Species, Multiple Aquatic Species, and Recreation each captured the deciding factor for selecting sites specifically for fish. The Do No Harm-Measurable Improvement factor focuses on fish population recovery estimates. Factors with the (✓) were not explicitly included on the FOH because investigators assumed that ESC restoration would produce positive results to satisfy each category independent of site

Table 1 Deciding Factors Omitted from FOH

	Diciding Factors Omitted from FOH
Fish	Keystone Species or Single Species
✓	Climate adaptation and mitigation
*	Cost of restoration project
✓	Soil Health
✓	Water Quality
✓	Water Quantity
Fish	Do No Harm-Measurable Improvement
✓	Forest Health
Fish	Multiple Aquatic Species
Fish	Recreation
✓	Resilience
**	Total Area of Watershed Restored

selection. We omitted the *Cost of the restoration project from the FOH for two reasons. First, estimating restoration costs based on individual sites would require detailed knowledge and understanding of each site and a specific level of expertise in estimating costs for restoration. CIWG members do not have this expertise or the site-specific details of each candidate site on this extensive list of candidate sites (163). Second, estimating the cost should happen after a site is selected for restoration (Adame et al., 2015). Additionally, we omitted **Total Area of Watershed Restored because the schedules and plans for thinning and burning, road decommissioning, and other watershed-scale restoration activities in 4FRI are independent of the ESC restoration (K. Paffett, 2022, USFS, Flagstaff, AZ, personal communication).

The need to identify sites for restoration that would reduce the risk of downstream flooding was added to the FOH. High-intensity rainfall events on severely burned landscapes can lead to significant flooding, property damage, and risk to human health (Xu et al., 2023). Investigators included the regional value of restoring stream channels with the potential to mitigate post-fire flooding in the oval for downstream risk. The desire to restore sites that could prevent downstream risk is especially salient for other semi-arid regions with a correlation between aridity, fire size and intensity, and the concentration of ESC (Grünig et al., 2023).

Phase II

Online Survey-CIWG

In order to apply the objectives and attributes to ephemeral stream channels, I developed an online survey using the Qualtrics ® survey platform (Dillman et al., 2014). We sent the survey to all stakeholders associated with the 4FRI. The goals of the online survey were twofold. The first goal was to identify willing participants for a second round of semi-structured interviews. Second, the goal was to identify any deciding factors for site prioritization pertinent to ephemeral stream channels that the decision-makers may have missed. The results of the survey responses were used to further develop the fundamental objectives hierarchy. Survey participants were asked to provide their contact information if they were willing to participate in a follow-up semi-structured interview to advance this research.

Semi-Structured Interviews Round 2-CIWG

This second round of semi-structured interviews was conducted primarily with members of the CIWG. The CIWG is a working group identified by the 4FRI composed of experts, academics, USFS employees, and others tasked with identifying and prioritizing restoration activities. Through the online survey, additional experts and academics were identified and included in the semi-structured interviews. For the remainder of this paper, any interview participant in the second round of interviews will be referred to as being part of the CIWG. This round of interviews aimed to determine the regionally specific values and the level of importance that the deciding factors of the fundamental objectives hierarchy held for the restoration of ephemeral stream channels in the 4FRI. The semi-structured interview was used to convert regional values and opinions into quantitative scores and weighting factors (Comín et al., 2014; Uribe et al., 2014).

I conducted the semi-structured interviews remotely using the Zoom ® platform due to its ability to "screen share," record meetings, and transcribe conversations. We introduced participants to the

fundamental objectives hierarchy through the screen-sharing option. They were asked to place a point value, indicating the level of importance, to each of the measurable attributes (Ianni & Geneletti, 2010; Stevens, 2011). For any subset of measurable attributes associated with an objective, 100 total points were distributed amongst those attributes. Participants applied their personal and professional valuations to the measurable attributes. Participants then weighted each level of objectives, using the same point distribution that was applied to the attributes.

Statistical Analysis

The data collected through the second round of interviews were analyzed for the quantitative values associated with the scores and weights. First, the sample size of consenting participants from the CIWG (n=15) was analyzed for normal distribution. The data, owing in part to the small sample size, were not normally distributed and therefore could not be interpreted as a measure of probability. However, following work by Praskievicz (2023), the z-scores were used as a method to check for outliers in the data. Based on the analysis, the qualitative values showed some scores or weights with a z-score of >2 or <-2. Values that drifted more than two from the mean were considered outliers and removed from the data set. The scores and weights used in the subsequent spatial analysis are the mean values with the outliers removed.

Finalization of the Fundamental Objectives Hierarchy

Following the scoring and weighting values provided by the CIWG interview participants, the fundamental objectives hierarchy was developed as a calculation tool to apply opinion-based valuation to identify the highest-ranked priority sites. The development began by identifying objectives. In decision-making, the objectives are the reasons the decisions are being made (Clemen, 2004). The lower-level objectives define upper-level objectives. Attributes were

identified to measure the desired objectives above them. Each attribute has a point value indicating its importance in the decision-making process. The sum of the measurable attributes under a given objective is 100, with 100 being the highest level of importance. For example, the objective of identifying a priority watershed is based on the four measurable attributes (fig. 10) and the sum of the associated values is 100.   The sum of points from any sub-objective's measurable attributes is added up and then multiplied by the objective weight as a percentage, or the weight for each objective is divided by 100. Moving from the lowest level attributes up each level of objectives, the summation of attributes, and their multiplication by the weighting factors associated with their objectives, result in a rank value between 0 and 100, where a stream channel site receiving a rank of 100 would be the highest priority site for restoration.

The process by which the fundamental objectives hierarchy is used to rank sites, can be demonstrated using standard mathematical expression. I developed an algebraic equation (Eq. 1), following standard order of operations mathematical expressions. The equation sums the scores of the attributes and applies the weighting factors from the objective. It follows the flow of the fundamental objectives hierarchy from the lowest level to the highest objective.

Equation 1 Mathematical Expression of FOH

$$\left[\left[\left[\sum\left[\sum_{Tertiary\ SR_{attributes}}^{1-5} \times \frac{Tertiary_{OW}}{100}\right]\right] \times \frac{SR_{OW}}{100}\right] + \left[\sum_{WS_{sttributes}} \times \frac{WS_{OW}}{100}\right]\right]$$

Tertiary SR $_{attributes}$ = The Tertiary Attributes under each of the Tertiary Level Objectives
Tertiary$_{OW}$ = The Tertiary Level Objective Weighting Factor
SR$_{OW}$ = The Stream Reach Objective Weighting Factor
WS$_{OW}$ = The Watershed Objective Weighting Factor
WS$_{attributes}$ = The Watershed Attributes

Phase III

Spatial Data: Data Procurement

Phase III consisted of applying the weighted scoring method of the fundamental objectives hierarchy developed in Phase II with spatial analysis to identify the top 10 reaches, from the list of 163, based on the measurable attributes from Phase II. ArcMAP has built-in spatial analysis tools can be used to map algebraic expressions and present ranked values by location (Trabucchi et al., 2014; Uribe et al., 2014). Thus, data layers were combined to measure the representative attributes developed in Phases I & II of the fundamental objectives hierarchy.

Coconino National Forest and Kaibab National Forest boundary polygons obtained from the USFS geospatial data pages were used for the land ownership measurable attribute. The 4FRI geospatial team provided a shapefile with the location and length of each of the 163 stream reaches. The 4FRI library of geospatial data and maps was downloaded online: (https://www.fs.usda.gov/detail/4fri/gis/?cid=fseprd493266); see Table 1 for more details on the 4FRI-related GIS data.

Table 2 GIS Data Sources from 4FRI

Metric	Submetric(s)	Dataset(s)
Boundary	4FRI Project Area	https://www.fs.usda.gov/detail/4fri/gis/?cid=fseprd493266
Streams	FEIS Stream Channel Restoration	https://www.fs.usda.gov/detail/4fri/gis/?cid=fseprd493266
Hydrography	NHD Area	https://www.fs.usda.gov/detail/4fri/gis/?cid=fseprd493266
	NHD Flow Line	
	NHD Point	
	WBD HU12	
Transportation	Bridges Existing	https://www.fs.usda.gov/detail/r3/landmanagement/gis/-?cid=stelprdb5202474
	Road Core Existing	https://www.fs.usda.gov/detail/4fri/gis/?cid=fseprd493266

Other geospatial data layers were obtained through alternative online resources. Table 2 details these data sources used for spatial analysis.

Table 3 Other Online GIS Data Sources

Metric	Submetric(s)	Dataset(s)
Elevation	3DEP Lidar Explorer USGS	https://apps.nationalmap.gov/lidar-explorer/#/
	National Map Viewer-10m DEM	https://apps.nationalmap.gov/viewer/
Ponderosa Pine Extent	Ponderosa Pine Extent	https://databasin.org/datasets/d4651bcaae9645f7afe1a8daa450074e/
Watershed Condition Framework	Watershed Condition Framework (WCF)	https://usfs.maps.arcgis.com/apps/MapSeries/index.html?appid=f4332e5b80c44874952b57e1db0b4407
Wildfire	Wildland Fire Locations	https://data-nifc.opendata.arcgis.com/datasets/nifc::wildland-fire-incident-locations/explore?location=34.188141%2C-109.889615%2C8.57

Spatial Analysis

Data was organized into one map feature using the ArcGIS® 10.8.2 ArcMap® software and projected in the NAD_1983_UTM_Zone_12N coordinate system. The development of the data layers and the necessary analysis required geoprocessing and spatial analysis tools available in ArcMAP®. Each layer was converted into raster data so that the mathematical expression could

be applied, and a ranking of the 163 stream reaches performed. The raster calculator tool in ArcMAP® performs an analysis using map algebra that presents final values across map scale landscapes. The two critical components of the development of the raster calculation equation were manually creating rank values as attribute fields onto each of the selected layers and writing the algebraic expression in Python syntax to implement the calculator interface of ArcMAP.

The ranking of each measurable attributes was completed using values ranging from 0 to 1. In the simplest cases, where there was a measure of yes/no or presence/absence, these layers were given an attribute rank of 0 or 1. For example, if a watershed was identified as a priority by the Watershed Condition Framework (WCF), then it was ranked as 1. Other watersheds not identified as a priority by the WCF received a rank value of 0. For data sets that were more broadly distributed, the quartile data was assessed, and these data were ranked with factors of 0, 0.333, 0.667, and 1. Another example of applying a ranking value was the collection of stream reach lengths. With 163 different stream reach lengths, it was not deemed appropriate or necessary to create 163 differently ranked reaches between 0 and 1. Instead, the quartile data sets were given ranking values. The four quartile groups of stream length were given a rank, from longest to shortest of 1, 0.667, 0.333 or 0, respectively. A unique set of data representing subbasins was created to assess connectivity. Subbasins were given a ranking value of 0, 0.5, or 1. Those with only one stream reach located within its watershed boundary were ranked as a low priority with a ranking value of 0. Subbasins with only 2 stream reaches were given a ranking value of 0.5, and subbasins with more than two were given a ranking value of 1.

Raster layers were generated from the newly created ranking value fields. With every one of the measurable attributes represented in an attribute field as a value between 0 and 1, the rank values were used as a multiplying factor applied to the scores created by the CIWG through the

scoring and weighting interviews. The raster calculator takes a factor of each measurable attribute, multiplies it by the weighting values, and adds them together. The result, a score between 0 and 100, was presented visually on the map. The 163 reaches were ranked following the values established through semi-structured interviews with the members of the CIWG, the application of the scores and weights, and the measurement through spatial analysis.

Comparative Analysis of CIWG Priorities

Near the conclusion of this study, the CIWG sent a proposal to the 4FRI team and USFS leadership, identifying ephemeral channels they recommended as a priority for restoration. Because the CIWG produced a formal recommendation for sites to restore, I compared their recommendations to the results of the spatial analysis tool. The CIWG shared their values and what they considered important in the site selection process through their interviews. In theory, the method developed here to prioritize sites for restoration should match up with the sites they used as priority restoration recommendations. The ranked values from the spatial analysis tool results were used to see if the recommendations document selected high-ranking sites. Then the scores associated with the reaches identified by the CIWG recommendation were quantitatively compared to determine if they aligned with the high-ranking sites based on the data developed through the three phases of the study. Results of these methods are presented in the subsequent chapters.

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CHAPTER 3-PRIORITIZING EPHEMERAL CHANNELS FOR RESTORATION: A REVIEW OF APPLICABLE RIVERINE METHODS FOR SITE PRIORITIZATION

Adam Bringhurst

Abstract

Functional riverine ecosystems provide benefits to their ecosystems and to society. Restoring these ecosystems where they have been degraded is therefore important for the continued purveyance of ecosystem services. Answering the question of "where?" is commonly recognized as a crucial first step in prioritizing restoration sites. We performed a literature review to identify research focusing on prioritization methods to select ephemeral channel sites for restoration. While numerous studies detail various methods of site prioritization used for perennial streams, wetlands, riparian zones, watersheds, and other ecosystems, there is an absence of literature focused on methods for ephemeral stream channel sites. Thus, we evaluated perennial stream restoration prioritization methods as a proxy for a prioritization method that could apply to ephemeral stream channel methods. First, we present common themes found in our review of the stream restoration literature, such as the need for explicit goals, professional judgment, and stakeholder involvement, which can be applied to the planning process associated with ephemeral channel restoration. Second, we selected examples from the literature that demonstrate variations of the decision-support system prioritization strategy. The decision-support strategy can be a simple scoring sheet or a complex mathematical model that applies ecological values through scores and weights of importance to the site to identify the highest priority candidate site for restoration. Lastly, we make recommendations for the development of ephemeral channel site prioritization methods.

Introduction

Intermittent rivers and ephemeral streams (IRES) are found on all continents and are the predominant riverine ecosystems in arid and semi-arid regions (Datry et al., 2017b; Larned et al., 2010). IRES are rivers that cease to flow episodically and at some time the streambed is above the groundwater table (Mcdonough et al., 2011). Intermittent rivers have seasonally continuous flow during wet periods where the groundwater table rises above the channel bed elevation (Boulton et al., 2017; Datry et al., 2017b; Levick et al., 2008). Ephemeral streams only flow following periods of precipitation as rainfall runoff or snowmelt. In high-elevation headwaters of arid and semi-arid regions, IRES are the common riverine features of first order streams (Armstrong et al., 2012; Assendelft & Ilja van Meerveld, 2019). IRES provide ecological benefits, such as water and sediment storage, nutrient cycling, and enhancing human well-being (Levick et al., 2008; Steward et al., 2012). In arid and semi-arid regions, riparian habitat along IRES provides habitat and resources to flora and fauna (Datry et al., 2017b; Levick et al., 2008). Upland IRES in higher elevation headwaters provide important hydrologic functions such as improving sediment and nutrient transport, groundwater recharge, and shallow groundwater storage (Mcdonough et al., 2011). They cycle elements and transport organic matter (Levick et al., 2008), and support biotic diversity and plant communities in riparian environments (Datry et al., 2017b). In addition to ecological function provided to the riverine ecosystems, IRES provide multiple ecosystem services that benefit human well-being (Koundouri et al., 2017). Yet many IRES have become degraded and are no longer ecologically functional (Acuña et al., 2014; Leigh et al., 2016).

Globally, like many ecosystems, degraded riverine ecosystems are being restored (Bernhardt & Palmer, 2011; Powers et al., 2019; Wohl et al., 2015) to bring back structural form and ecological function. Expenditures on the order of billions per year go towards these efforts

(Beller et al., 2016; Bernhardt et al., 2007; Palmer et al., 2005). Stream repair is often focused on single species even though it is broadly accepted that the restoration of watershed-wide systems and processes increases the probability of success (Beechie et al., 2008; Naiman et al., 2012; Palmer et al., 2005, 2014). The term stream restoration is commonly used to describe work related to many riverine systems such as perennial streams, watersheds, wetlands, or riparian zones with common ecological characteristics. Stream restoration can range from passive restoration techniques, where a disturbance, or driving force of degradation, is removed from a riverine system to a complex set of habitat improvements, geomorphic stream form alterations, barrier removals, and other actions. Whatever varied form of implementation, restoration works to improve riverine form and functional ecosystem processes (Palmer et al., 2005; Wohl et al., 2005). Most riverine restoration research focuses on perennial systems. However, stream restoration efforts are slowly shifting their focus to include IRES (Acuña et al., 2014; Lake et al., 2017; Leigh et al., 2016).

In stream restoration efforts, it is widely accepted that selecting the best location for implementing restoration work is an important and necessary first step (Briggs, 1996; Orsi et al., 2011; Roni, Beechie, et al., 2012; Trabucchi et al., 2013; Uribe et al., 2014). The question of "where to restore?" must be understood before deciding "how to restore" (Hyman & Leibowitz, 2000). Additionally, selecting the best location for restoration increases the probability of successful restoration (Bernhardt & Palmer, 2011). In some cases, a watershed analysis, whether it be completed using a tool such as the U.S. Forest Service's Watershed Condition Framework (USFS, 2011) or by other means, may generate a list of candidates identified as potential sites for restoration. If resources such as time and money were not an issue, one could restore all the candidate sites. However, resources are typically finite, and site prioritization is critical for the efficient use of resources. To that end, we conducted a comprehensive review of the literature

focused on prioritization methods specifically intended to select sites for restoration using multiple databases: Web of Science, GeoRef, CAB Abstracts, and Agricultural and Environmental Science Collection. Within these databases, keywords synonymous with "ephemeral streams" were used to capture the concept or related concepts of these channel types. Similarly, keywords synonymous with "restoration" and "decision making" were also used to cast a wide net for any literature discussing the decision-making process for stream channel site selection methods.

We found that there are site selection methods specifically aimed at restoring; perennial streams to benefit fish populations (Beechie et al., 2013; Johnson et al., 2003; Roni, Pess, et al., 2012), wetlands (Brooks et al., 2006; Newbold, 2005), riparian areas (Parker et al., 2016; Timm et al., 2004), and watersheds (Gellis et al., 2001; Solek et al., 2011). However, there is an absence of literature focused on methods to prioritize ephemeral stream channel (ESC) sites for restoration.

Because of the increase in research focus, the growing application of stream restoration efforts to IRES, and the accepted importance of prioritization methods for site selection, we present selected results from the review of site prioritization methods for multiple ecological systems. In this review of methods, we offer findings in two parts. First, emergent themes from the literature pertinent to planning any ecological restoration effort are presented. This review aims to summarize the literature on different prioritization methods used to select sites for restoration that are analogous to ephemeral channels. In performing the literature search, we aimed to find prioritization methods specific to site selection. Due to the absence of literature on site selection methods for ephemeral stream channel restoration, this literature focused on streams, wetlands, estuaries, riparian vegetation, watersheds, and other similar ecological areas due to their similarity with riverine ecosystems. While some components of these methods would not apply to ephemeral channels, like selecting sites to improve spawning salmon habitat, similar factors apply to

ephemeral stream channels. In reviewing the literature, the aim is to identify decision-making and site selection methods that could be applied to ephemeral stream channel restoration. In part two of the review, selected methods that have the potential to apply to the planning process for restoring ESC against the backdrop of a large-scale ESC restoration project in northern Arizona U.S.A. are presented. These methods are synthesized to describe techniques that could be developed for a site prioritization method for the selection of ESC sites. Findings suggest many methods identified in the literature cannot be applied to developing an ESC restoration method because they are too specific to perennial streams, fish, and fish habitats. Thus, selections from the literature that focus on methods that could be applied to the planning process for ephemeral channels are highlighted.

For this study, ephemeral streams are defined as channels that have flow following periods of precipitation as rainfall runoff or snowmelt and their stream bed is higher than the groundwater elevation (Arthington et al., 2014). ESC differ from intermittent rivers which have seasonally continuous flow during wet periods where the groundwater table rises above the channel bed elevation (Boulton et al., 2017; Datry et al., 2017b; Levick et al., 2008). This distinction is important because ESC stay dry longer than intermittent rivers, tend to be valued less by society and may require site assessments that are alternative to conventional methods applied to riverine ecosystems (Boulton, 2014).

Site Selection Methods

Site selection for restoration takes on many different forms. There are score sheets that produce a score for ranking. There are triage methods that classify sites based on the emergency medicine standards of focusing efforts on sites with a demonstrated need for and with the highest probability of becoming functionally restored. There are complex mathematical models or software that run algorithms. There is the cost-benefit analysis approach. There are GIS models that also run

algebraic analyses of data. Arguably, all site selections apply personal and professional values to sites as criteria that can be measured, and sites are ranked. Some methods use score sheets, and others use GIS software and spatial analysis. The triage method scores and ranks sites. CBA methods score and rank sites with the best effort (cost) to benefit ratio. Moreover, the most complex spatial analysis tools use algorithms to score and rank. It is a decision-making process.

Many sources in the literature identify specific methods for decision-making such as decision support systems (DSS) (Xia et al., 2014), multicriteria decision analysis (MCDA) method (Hermans & Erickson, 2007), and structured decision-making (SDM) (Kozak & Piazza, 2015), are terms, concepts, or methods used to take multiple site criteria and measure them to aid in the decision-making process (Chowdary et al., 2013; Convertino et al., 2013; Galatowitsch et al., 1998; Hopfensperger et al., 2007; Llewellyn et al., 1996; Mysiak et al., 2005; Uribe et al., 2014). All site selection methods identified in the literature rely on measuring criteria to find the best site. In this literature review, there are no methods founded on one single decision-making metric. What was being restored or how the site was selected did not change the fact that all methods start with identifying goals or objectives of restoration. Following the identification of goals, it is important to identify the criteria that will measure conditions at a site. After the criteria are measured, scores or data identify the priority site for restoration. Literature that demonstrates methods for site selection is presented and discussed while highlighting how they apply to each of these three steps, 1) establishing goals, 2) measurable criteria, and 3) how sites are ranked, which are fundamental to the site selection process.

Goals are critical to restoration planning (Barber & Taylor, 1990; Hobbs, 2007). Bohn & Kershner (2002) attribute several federal mandates for watershed assessment to verify that planners have identified clear goals and objectives before restoration work begins. One of the

earliest site selection methods identified was by Llewellyn et al. (1996). In their site selection method, they laid the groundwork for emergent themes of site selection. They identified their overarching goals for restoration. They established their plan for restoration and protection of sites depending on a site's state of ecological function. Their identified geographic location for restoration was immense, wetlands along the Mississippi River Alluvial Plan, and they had to deal with numerous federal, state, and local participants, so they kept their goals very general. There are benefits to keeping the restoration goals broad. However, as site selection methods evolved, there was a call for restoration goals to be made explicit. Abbruzzes & Leibowitz (1997) developed a synoptic approach to site selection, providing a broad analysis of criteria instead of a detailed analysis. The synoptic approach typically measures change. The change measures the impact over time or a change in ecological function based on the restoration cost. The general objectives and goals must be understood to know what metrics to measure. The first step in their five-step process is to define goals. In an early application of the synoptic approach, the authors asked the primary question, "[G]iven a list of sites deserving of restoration or protection, where is it most important to target resources?" (Hyman & Leibowitz, 2000, p. 23). This paper was one of the first to call out the need for site selection methods. They went on to say that explicitly stating the goals or priorities of restoration are required to guide site selection. McAllister et al. (2000) applied and followed the steps of the synoptic approach. However, their goal was not explicit in the first step of identifying goals. Instead, it was to identify wetlands, which, if restored, would reduce region-wide downstream flooding. Notwithstanding, the general approach of the synoptic method has been criticized (White & Fennessy, 2005). The synoptic approach, although not called a cost-benefit analysis (CBA) method, compares the change of two metrics relative to one another. It is like how CBA methods work.

Many CBA methods that measure ecological benefits apply to site selection. However, not all goals focus on ecological benefits. Randhir et al. (2001) applied CBA to identify watersheds for protection that would increase water quality and water security in a metropolitan area. Neeson et al. (2016) analyzed CBA against the number of stressors at restoration sites. They determined that sites with the least stressors, even if severe, would cost less to restore than sites with numerous less severe stressors. Although they were not using CBA for specific site selection decisions, they recommended restoration processes that would reduce or remove the stressors to achieve an end goal. Iftekhar et al. (2017) used a cost-benefit ratio to prioritize sites with the greatest ecological benefit at the lowest cost. Again, the metrics used to measure benefits depend on the development of goals. Rappaport et al. (2015) used CBA in the second step of their site prioritization method. They defined their primary goal and used a multi-step approach to measure their metrics. The first step was to identify areas that showed an urgency for restoration. This urgency was measured spatially based on habitat changes and connectivity reduction. The second step showed feasibility, which is where they applied CBA. They identified habitats with the highest levels of resilience because those restoration sites would have the best cost-benefit ratio. The application of urgency and feasibility as it was applied here is referred to as the triage method.

The implementation of comprehensive and effective restoration is typically limited by funding, which necessitates the treatment of some sites and abandoning others similar to the methods applied to emergency medicine (Wohl et al., 2005). The triage method was first applied conceptually to ecological restoration by Samaways (2000). As applied to site selection, triage identifies three options, 1) ecological integrity irretrievably lost, 2) ecological integrity restorable, and 3) ecological integrity intact. Respectively, the options for restoration actions would be 1) do nothing because restoration is not possible, 2) do something because restoration is feasible, and 3)

do nothing because restoration is not needed. Although this is a conceptual way of measuring ecological restoration sites, it prioritized being clear with goals. The triage method is typically applied early in analysis and assesses many sites to reduce the number that require additional site-specific data collection. Harris and Olsen, 1997 applied the triage approach to a two-stage process for site selection. In their first stage, they put sites into one of three classifications: 1) preservation or protection; 2) restoration not feasible; and 3) further analysis needed. The preserve and protect is the do nothing because the site is functional. The restoration not feasible classification falls into the do-nothing option because the sites are so badly degraded that they cannot be restored. Finally, the further analysis needed sets these sites up for additional data collection to determine the restoration feasibility. In their second stage, their restoration goals explicitly define the additional

data needed for the decision-making process. Hobbs et al. (2003) applied the triage method to gain additional landscape-scale ecological restoration classifications. They classified the level of need and the probability of success into three sub-categories each: high, medium, and low (Fig. 11). Although Hobbs et al. (2003) established this conceptually, they recommend the general goals for this type of application.

Figure 11 Triage sub-classifications by Hobbs et al. (2003)

Because the triage method is a quick and early assessment, there is a risk of missing sites. Noss et al. (2009) recommended applying the triage method with caution to avoid abandoning

potentially important sites or condemning species to extinction. That is why the development of goals is so critical to the site selection process (Barber & Taylor, 1990). Although not explicitly included as part of a method for site selection, the restoration literature repeatedly identifies the importance of setting realistic goals (Hobbs, 2007). General goals can provide the first step in planninga site assessment approach (Olson & Harris, 1997), or they can be specific goals identified after an initial assessment (Hallett et al., 2013; White & Fennessy, 2005). Finally, selecting appropriate criteria to measure site characteristics requires well-defined and understood restoration goals (Convertino et al., 2013; Ehrenfeld, 2000; Laub et al., 2015).

Criteria to Measure

Many synonyms describe the criteria for characterizing a restoration site, such as metrics, attributes, deciding factors, and variables. In this review, we apply term criteria to describe these, and other terms used to measure sites. It is critical that the criteria used in a site assessment reduce uncertainty, provide beneficial data and information to increase system and site understanding, and create a measure for evaluation (Convertino et al., 2013). The methods already discussed, the synoptic approach, triage, and CBA, all rely on criteria measurement. In the literature, many site selection methods do not justify their selected criteria. Instead, they apply criteria guided by their project goals or objectives (Comín et al., 2018; Harris & Olson, 1997; Khanday & Javed, 2016; O'Neill et al., 2008; Parker et al., 2016). Others have demonstrated that expert input should guide the development of criteria (Cipollini et al., 2005; Hughes et al., 2023; Ioana-Toroimac et al., 2017; Walsh et al., 2020; Xia et al., 2014). Moreover, others have put the identification of criteria on stakeholders (Hopfensperger et al., 2007; Kozak & Piazza, 2015; Randhir & Shriver, 2009; Uribe

et al., 2014). Independent of how criteria are selected, they are the metric by which sites are measured and ranked. Presented below are examples of methods to select criteria.

Parker et al. (2016) used a straightforward method to select sites from 68 parcels of riparian habitat identified for conservation. This method took five criteria and applied a rank for each parcel. However, this method did not identify how the criteria were selected. Gellis et al. (2001) applied weighted factors to demonstrate the importance of select criteria. They assessed eight different sub-watersheds with quantitative physical characteristics and qualitative features. Each was given a priority rank of one to eight then scores were summed, and sub-watersheds were ranked. After their initial ranking, they applied weighting factors to some watershed characteristics and features. Johnson et al. (2003) developed a scorecard to be used to assess sites for restoration. They based this method on two categories: existing conditions and post-restoration condition estimations. The scores were simplified to be one of three qualitative assessment values, 0 (poor), 1 (acceptable), and 2 (good).

Not all scoring and ranking techniques are simple additive function score sheets. Cipollini et al. (2005) used a weighted scoring method to rank sites using decision methods borrowed from business (Clemen, 2004). Criteria were weighted based on interviews with experts with firsthand knowledge of the region. Their method applied weights to the criteria with decision-making software (https://www.logicaldecisionsshop.com/catalog/). The application of this scoring method to decision-making software included many criteria. It gave detailed statistical support for many criteria that led to the final restoration site selection. O'Hanley & Tomberlin (2005) used a decision-making approach to identify priority fish passage barriers for removal. They were critical of overly simplified scoring and ranking schemes in their analysis. They indicated that simple scoring and ranking methods often assess sites without considering other factors in the system. They developed

a mathematical optimization model for decision-making that can consider other factors. The criteria that they selected for optimization were based on the best professional judgment or with modeling software. Higgins et al. (2008) developed a CBA method that used criteria as a metric to optimize investments. Their model estimated the total benefit obtained from the proposed investment. Multiple criteria are used to measure the total benefit, requiring considerable expertise. Another consideration with CBA methods is that not all benefits can be measured using standard market values (Iftekhar et al., 2017). In their method, criteria measured by nonmarket techniques are expensive and require specific skills. Liu et al. (2006) used a specific MCDA method called the technique for order of preference by similarity to ideal solutions (TOPSIS). TOPSIS, as applied here, is an MCDA tool that selects the best site from a set of candidate sites based on specific goals with online calculators or other free software. They applied measurements of criteria through spatial analysis. Their method can analyze many potential sites for restoration quickly and efficiently. However, it is more of a screening tool to identify potential wetlands requiring a more detailed investigation.

Stakeholder participation is critical to restoration decision-making (Randhir & Shriver, 2009). Additionally, the probability of success increases with stakeholder support throughout the process (Hopfensperger et al., 2007). Uribe et al. (2014) developed a method that asked stakeholders to create a list of important criteria and the weight their importance. The criteria were measured using spatial analysis techniques. In a method developed to reduce the total maximum daily load (TMDL) of pollutants in rivers, stakeholders are required by regulation to participate in efforts to reduce pollutants released from their agricultural lands into rivers (Stringfellow, 2008). Creating a scientifically rigorous method that was also easy for stakeholders to understand was essential. They displayed their data using quadrants to simplify stakeholder communication and

increase participation. Randhir & Shriver (2009) also relied on stakeholders to select criteria for watershed measurements. A small group of representative stakeholders created a list of criteria. Then, through an information exchange, the complete group of stakeholders communicated values, and collectively finalized the criteria.

In recent years there has been an increase in the number of methods that use ecosystem services as their criteria for restoration (Adame et al., 2015; Cassiano et al., 2013; Comín et al., 2018; Hermoso et al., 2012; Perry et al. 2015; Trabucchi et al., 2014). Ecosystem services (ES) can be summarized as the benefits obtained by humans from nature (MEA et al., 2005). It can be complicated to measure ES (Robertson, 2012). Due to the difficulty of measuring ES as criteria, Comin et al. (2014) prioritized identifying multiple ES-related criteria. Trabucchi et al. (2014) developed a method that quantified and mapped ES. They identified their goals and established their criteria. Hermoso et al. (2012) used systematic rehabilitation planning, which combined CBA and ecosystem science to calculate trade-offs between potential restoration actions. Perry et al. (2015) recommended putting climate change projections into a method that would prioritize ES that are most vulnerable or resilient to the projected changes.

The identification of criteria is a fundamental part of any site selection method. Scores can be finalized using score sheets, spatial analysis tools, or software. Criteria are measured, and point values calculate a rank and identify a priority location for restoration.

Calculating the Rank

Established in the previous sections of this review is the need to identify goals for restoration and the need to identify the criteria used to measure sites. The criteria used in assessing sites are also valuable tools to measure the success of restoration efforts. Site selection methods start by identifying goals and the appropriate criteria to assess those goals. Following the criteria measure,

sites are ranked, selected, or prioritized for restoration. The process for calculating the rank ranges from simple additive function score sheets to complex software and spatial analysis tools.

Figure 12 Yes/No Flow Decision Tree Scorecard (Thompson et al. (2002)

Score sheets are the simplest form of scoring and ranking. The scorecard used in field assessments can be very simple, where values are added up (Johnson et al., 2003). Other scorecard methods apply yes/no answers to a decision tree (Fig. 2) (Thompson et al., 2002). Another criticism of scorecards is that they tend to be subjective (Beechie et al., 2008). Others criticize them for being too simple (O'Hanley & Tomberlin, 2005).

Another variation in the scoring method is the implementation of weighting factors. Although subjective, weighting factors apply a level of importance to the criteria. Most scoring and ranking methods in this review apply weighting factors to their final calculations. Weights are established by professional judgment or through interviews with experts or stakeholders. Decision or spatial analysis software calculates most metric scores to identify priority sites. Spatial analysis tools allow for the analysis of criteria using algebraic methods, the writing of algorithms, or the use of programming languages built into spatial analysis software (https://desktop.arcgis.com/en/arcmap/latest/analyze/python/a-quick-tour-of-python.htm

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Discussion

The methods to select priority sites for restoration follow three fundamental stages identified by the literature. The first stage of site selection is the identification of goals. If dealing with many potential sites, or a large geographic region, goals can be general to get started and evolve to become more specific. Specific restoration goals can be established immediately in cases with fewer potential sites or if the area of potential restoration sites is small. Accompanying well-defined goals is the identification of measurable criteria. Many criteria are measured using spatial analysis methods. Although, there are still applications for on-site field measures of essential criteria such as water quality sampling or species identification. However, the criteria are measured, and the sum of criteria values is applied to identify the highest priority site for restoration—the methods for arriving at a final decision range from simple additive functions to complex software models.

The literature reviewed here did not identify ephemeral stream channel methods. In fact, there were methods in the literature where riverine and other water-related sites were scored lower if the water was not perennial (Llewellyn et al., 1996; Thompson et al., 2002). The literature indicates that there has been considerably less restoration work on intermittent rivers and ephemeral streams than on perennial streams (Lake et al., 2017). As efforts accelerate for ESC restoration, developing a site selection prioritization method for these streams must have the three components. First, there needs to be a well-defined goal for restoration. This goal can be general but should become explicit through the process. Second, the selection of criteria to measure sites needs to be identified. These measurements can range from physical, biological, or chemical criteria. Decision-makers can identify criteria to measure the ES of ephemeral stream channels. Although, due to the lack of research on ephemeral streams (Acuña et al., 2014; Boulton, 2014),

ES have not been well developed for ephemeral streams (Koundouri et al., 2017). Lastly, it is important to include stakeholders and experts in the judgment decisions to establish criteria. Depending on resources, any scoring method is reasonable for ephemeral stream channel restoration, whether it be a score sheet, decision analysis software, complex mathematical models, or spatial analysis tool. What is important is that throughout the entire process, the method should be repeatable and transparent. The site selection method for ecological restoration has evolved to implement different criteria and means of measuring criteria and adding measured data to rank sites.

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CHAPTER 4-PRIORITIZATION OF EPHEMERAL CHANNEL RESTORATION SITES: DETERMINING WEIGHTED SCORES AND VALUES THROUGH STAKEHOLDER PARTICIPATION

Abstract

Ecological restoration decisions commonly rely on experts and stakeholders to make planning decisions. Multicriteria Decision Analysis (MCDA) can support decision-making. Many ephemeral streams are degraded and no longer contribute to critical ecological functions. Selecting an ephemeral channel for restoration can be based on different values and multiple site-specific characteristics. Multiple methods have been developed to select the best stream restoration sites. However, there is an absence of methods in the literature to support site prioritization of ephemeral stream channels. Against that backdrop, we ask what deciding factors are used to select sites in ponderosa pine forests and how can the deciding factors be developed into a prioritization method for ephemeral stream channel restoration? To answer this question, we conducted semi-structured interviews with stream restoration experts to create a list of deciding factors to prioritize stream restoration sites in the ponderosa pine forested area around the Western United States. From the list of deciding factors, we created a fundamental objectives hierarchy (FOH) to prioritize ephemeral stream channels for restoration as a case study, we applied our FOH to the 163 ephemeral channels as candidates for restoration in the Four Forest Restoration Initiative (4FRI) in northern Arizona, U.S.A. We interviewed members of the 4FRI Comprehensive Implementation Working Group (CIWG) and developed a weighted scoring method based on the regional values and level of importance they placed on the objectives and measurable attributes of the FOH. We

found that unlike regions with perennial streams where habitat is a driving restoration value, ESC sites would increase water security and reduce the risk of post-wildfire flooding.

Introduction

There are intermittent rivers, and ephemeral streams (IRES) found throughout the arid and semi-arid regions of the world. The National Hydrography Dataset has estimated that 79% of stream channels are intermittent or ephemeral in the Southwestern United States. In this region, Arizona has the highest concentration of IRES, with 94% of the streams classified as such (Levick et al., 2008). Across the globe, in Australia, over 70% of all stream channels are intermittent (Sheldon et al., 2010). IRES serve important hydrologic, geomorphic, and biogeochemical functions, providing habitat and support for flora and fauna (Levick et al., 2008). These channels increase hydrologic connectivity, linking ephemeral, intermittent, and perennial stream channels. Through hydrologic connectivity, water, sediment, nutrients, plant propagules, and other organisms are transported through watersheds during wet periods (Boulton et al., 2017; Levick et al., 2008; von Schiller et al., 2017). During dry periods, sediment and nutrients are stored, and nutrient and organic matter cycling rates are slowed. However, dry periods play a critical role in the ecological processes in IRES (Boulton et al., 2017; von Schiller et al., 2017).

Although it is common for IRES to be referred to interchangeably (Datry et al., 2017), we define intermittent rivers as channels that maintain continuous flow during seasonally wet periods — when the groundwater table is higher than the elevation of the channel bed (Arce et al., 2017; Boulton et al., 2017; Levick et al., 2008) —and ephemeral streams as channels that flow following periods of precipitation runoff (Datry et al., 2017). For the remainder of this paper, we will focus on ephemeral stream channels (ESC) dependent on precipitation runoff events.

Worldwide, ESC are degraded and function poorly (Magand et al., 2020)due to natural and anthropogenic processes. Natural climate fluctuations cause drought and flooding, whereas deforestation, trash dumping, and urbanization not only degrade ESC but also exacerbate natural events (Bull, 1997; Lake et al., 2017; Pollock et al., 2014). Fortunately, stream restoration is an increasingly accepted approach for dealing with degraded riverine ecosystems (Bernhardt et al., 2005; Roni & Beechie, 2012). Efforts aim to restore riverine ecological processes (Beechie et al., 2010), physical hydraulic channel form, or ideally both (Palmer et al., 2014). Fisheries resources in perennial streams are a primary reason for restoration (Roni et al., 2008). Additionally, perennial streams are the typical candidates for restoration because of the importance of water quality and quantity (Flanagan & Richardson, 2010). Conversely, stream channels without perennial flow are perceived as less important (Koundouri et al., 2017). However, recently there has been an increase in restoring ESC (Lake et al., 2017; Magand et al., 2020).

Before implementing restoration efforts, site selection is a necessary first step (Hyman & Leibowitz, 2000; Uribe et al., 2014). Research suggests that proper site selection is crucial to restoration projects to optimize resources, increase benefits gained, and improve stakeholder support (Bernhardt & Palmer, 2011; Hyman & Leibowitz, 2000; Uribe et al., 2014). Many methods developed through ecological restoration efforts that support the decision-making process for site selection exist (Bringhurst, n.d.). They agree on the importance of incorporating professional judgment (Convertino et al., 2013), stakeholder participation (Irwin & Kennedy, 2008), and the need for the development of explicit goals (Barber & Taylor, 1990; Beechie et al., 2008). As part of the planning process, planners must select appropriate attributes that will decrease uncertainty, inform the development of goals, and establish restoration alternatives (Convertino et al., 2013). However, the planning is invariably constrained by uncertainty due to

ever-changing climate projections (Perry et al., 2015), the evolution of stream restoration implementation methods (Wohl et al., 2015), and the complexity of riverine ecosystems (Thoms, 2006). The planning process for selecting restoration sites has also evolved through adaptive management, learning from previously implemented projects, and the continual reevaluation of priorities from increased experience and lessons learned (Hermoso et al., 2012).

Despite gaining popularity, ESC restoration is far behind perennial stream efforts. The number of ESC restoration projects presented in the literature is small compared to works describing perennial stream projects (Lake et al., 2017). Furthermore, relative to the literature that discusses restoration methods, there needs to be more discussion of methods aimed at site selection or the prioritization of riverine sites, whether wetlands, watersheds, riparian areas, or perennial streams. There was nothing in the literature regarding site selection methods for ESC restoration (Bringhurst, n.d.). Given the lack of explicit site prioritization methods for ESC restoration, this study aims to create such a method by answering the following research questions:

- *What site-specific attributes influence decision-making for restoration initiatives in riverine ecosystems in Ponderosa Pine Forests (Pinus Ponderosa)?*

- *How can site-specific attributes be adjusted to meet the planning needs for Ephemeral Stream Channel restoration?*

We answer these questions through a mixed-method approach, including semi-structured interviews, thematic analysis, statistical analysis, and spatial analysis. Using the Four Forest Restoration Initiative (4FRI) as a case study, the multicriteria decision analysis (MCDA) method was applied to the ESC restoration planning phase using attributes (e.g., wet meadow function, riparian vegetation, stream length) to assess the measurable characteristics of individual stream sites. This work draws heavily on the literature regarding site prioritization methods that

recommend transparency and repeatability (Gama et al., 2013; Hermans et al., 2007), the use of professional judgment (Cipollini et al., 2005; Yochum, 2015), stakeholder values (Favretto et al., 2022; Leitch et al., 2019), and scientifically supported data (Beechie et al., 2013).

Case Study 4FRI

In 2009, the United States National Forest Service (USFS) launched the largest forest restoration effort in history, 4FRI, encompassing the National Forests (NF) of northern Arizona (Apache-Sitgreaves NF, Coconino NF, Kaibab NF, and Tonto NF). Over 20 years, this project is slated to restore 2.4 million acres of forest and aims to increase forest health by reducing the risk of catastrophic crown fires through thinning and burning efforts. Forest and watershed restoration efforts reduce the risk of catastrophic crown fires that can have devastating ecological, economic impacts and threaten forest and human health and safety (Allen et al., 2002). Due to the holistic approach required by the National Environmental Policy Act (NEPA) that requires the protection and promotion of biodiversity (Bear, 1994), 4FRI also identified a suite of restoration efforts to create a healthy and sustainable forest-wide ecosystem. Included in that suite of efforts is the restoration of ESC.

This case study was selected because 4FRI identified 39 miles of ESC as candidates for potential restoration. The Final Environmental Impact Statement (FEIS) identified 163 different stream reaches that provided an advanced point from which to start (USFS, 2015a). Having a list of candidates for restoration is beneficial because it provides the opportunity to effect a positive change. However, there is limited information regarding these reaches (USFS, 2015b). Having limited information is problematic because it is critical to know the characteristic, conditions, and available resources at individual sites (Brooks et al., 2006). A detailed understanding of a site's characteristics is vital in developing goals and selecting attributes to prioritize sites. These same

goals and attributes are the metrics used to measure restoration success (Convertino et al., 2013). The goal established by 4FRI to restore the functionality of ephemeral streams (USFS, 2013) needs to be more explicit. Thus, the ESC of 4FRI provides a case study to learn how regional values associated with restored ephemeral channels can be determined and calculated. The lessons from this study can apply to ESC restoration decision-making in other arid and semi-arid regions worldwide.

Phase 1 of 4FRI focuses primarily on the Coconino National Forest and the Kaibab National Forest, which are predominantly ponderosa pine forests. These two forests are located along the Mogollon Rim at elevations averaging 7,000 feet above sea level. Flagstaff, Arizona, is the nearest city (lat. 35° 11' 53.82" N, long. 111° 39' 4.68" W). The region is semi-arid, receiving an average of 20 inches of precipitation yearly. The distribution of precipitation is typically through winter snowfall events and mid to late-summer monsoon-type rainfall events. In Phase I, 163 degraded stream reaches totaling 39 miles were identified as candidate sites for restoration. The headwater ESC identified by 4FRI historically functioned as ephemeral wet meadow ecosystems where water spreads over floodplains, soaks into alluvial soils, and is stored. Healthy wet meadows support a range of native biodiversity, including micro and macro invertebrates and vegetation; they store sediment, nutrients, and other organic matter and reduce the magnitude and energy of downstream flooding (Levick et al., 2008; MacDonald, 2014). However, today the ephemeral channels of these National Forests are degraded by drought or extreme precipitation events, overgrazing, timber harvest, and the construction of roads or railroad spurs to remove timbers (Bull, 1997; Pollock et al., 2014; Webb & Hereford, 2001). Years of degradation have left the ESC in the region not functioning properly. Concentrated flows at high velocity cut deep incisions into areas that have drained the local groundwater storage, altered the riparian vegetation, and increased

the severity of floods and sediment transport. In the Coconino NF, 79% of the 6th-level Hydrologic Unit Code (HUC) watersheds and none of the identified 39 miles of ESC are functioning properly (MacDonald, 2014; Steinke, 2013). To date, no ESC restoration work has been completed. 4FRI has organized experts and stakeholders into the Comprehensive Implementation Working Group (CIWG) and tasked them with identifying and prioritizing ESC and implementing restoration. Their planning process would benefit from an ESC prioritization method.

Methods and Results

Methods and results are presented through two phases (fig. 13) of research. The results of Phase I informed the methods of Phase II. Subsequently, we present the stepwise methods and results.
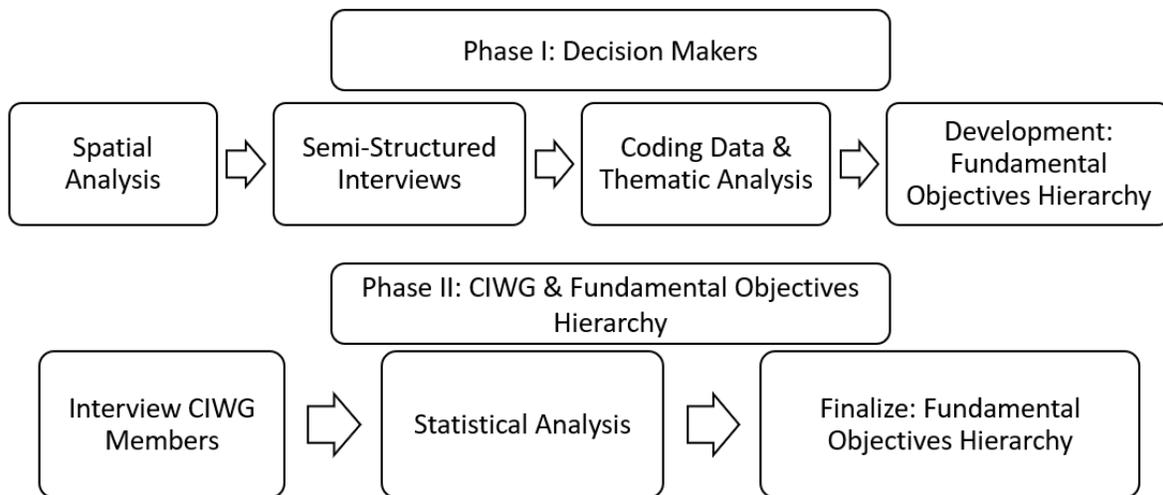
Figure 13 Two Phases of Research

Step 1: Spatial Analysis

To find participants for the semi-structured interviews, we used the unique characteristics of northern Arizona's semi-arid, high-elevation forests to narrow the search using ponderosa pine forests, and U.S. Forest Service (USFS) administered lands as limiting factors for identifying stream restoration professionals. We conducted a spatial analysis to determine the extent of

ponderosa pine forests in the United States. The ponderosa pine forest extent was overlaid with USFS boundary polygons using ArcMAP software.

Each Forest Service unit's online webpage has a "Managing the Land" tab under which "Resource Management, Planning, and Projects" are found (https://www.fs.usda.gov/managing-land). The USFS maintains an extensive library of completed and planned project documentation. Within the resource management, projects, and planning documents, keyword searches for "water," "stream," "wetland," "riparian," "spring," and "river" uncovered many projects that had some component of riverine restoration. Restoration projects have a listed "project contact" with telephone and email contact information. Investigators sent project contacts email requests to participate in this research.

Step 2: Semi-Structured Interviews with Decision-Makers

A semi-structured interview approach allowed participants to expand beyond a question's typical "what" answer through a casual conversation. Participants were encouraged to justify and explain "why" they selected specific sites (Palic et al., 2016). Semi-structured interviews were conducted with participants working firsthand in the site selection process for stream restoration projects in ponderosa pine forests managed by the USFS. This paper refers to the Phase I interview participants as decision-makers. These interviews were conducted remotely using the Zoom ® platform due to its ability to "screen share," record meetings, and provide transcripts of conversations. The general goal of the semi-structured interview was to get the participants to identify the five most important deciding factors they relied on to prioritize one site over another (DiCicco-Bloom & Crabtree, 2006; Kallio et al., 2016). Participants reviewed a list of deciding factors and then ranked their top five used to prioritize a specific restoration project they had

Table 4 Deciding Factors

Deciding Factors
Ease of Access for Restoration Activities
Degree of Degradation
Floodplain Access
Keystone-Single Species
Need for Restoration
Biodiversity
Damage to Infrastructure
Climate adaptation and mitigation
Connectivity of Multiple Sites
Cost of Restoration Project
Soil Health
Water Quality
Water Quantity
Do No Harm-Measurable Improvement
Forest Health
Groundwater Recharge
Multiple aquatic species
Recreation
Resilience
Stream Energy-Gradient/Velocity
Total Area of Watershed Restored
Total Length of Channel Restored

completed in the past. Decision-makers were also asked to make a top five ranked list of deciding factors that could be applied, "in general," to any future proposed stream restoration project regardless of its location.

Interview transcripts were coded using the NVivo software ® through an inductive coding approach (Aberbach & Rockman, 2002; Linneberg & Korsgaard, 2019). Using thematic analysis, we identified themes that emerged as deciding factors from the coded qualitative data (Kiger & Varpio, 2020; Lochmiller, 2021) that are essential criteria to measure restoration sites (Table 4). The goal of collecting these data was to apply the deciding factors as a hierarchical approach to an MCDA method of site prioritization specific to ESC restoration.

Step 3: Development of the Fundamental Objectives Hierarchy

In decision-making, the fundamental objectives are the essential reasons for a decision (Clemen, 2004). The essential reason for prioritization is to identify high-ranking restoration sites from many potential candidate sites. The fundamental objectives hierarchy, taken from business decision-making methods, was first applied to ecological restoration work by Cipollini et al. (2005) to manage prairie openings and can be used visually to represent an MCDA process. The hierarchy is also a building block in developing a mathematical expression to rank candidate restoration sites. In the fundamental objectives hierarchy (FOH), the highest-level objective (represented by a
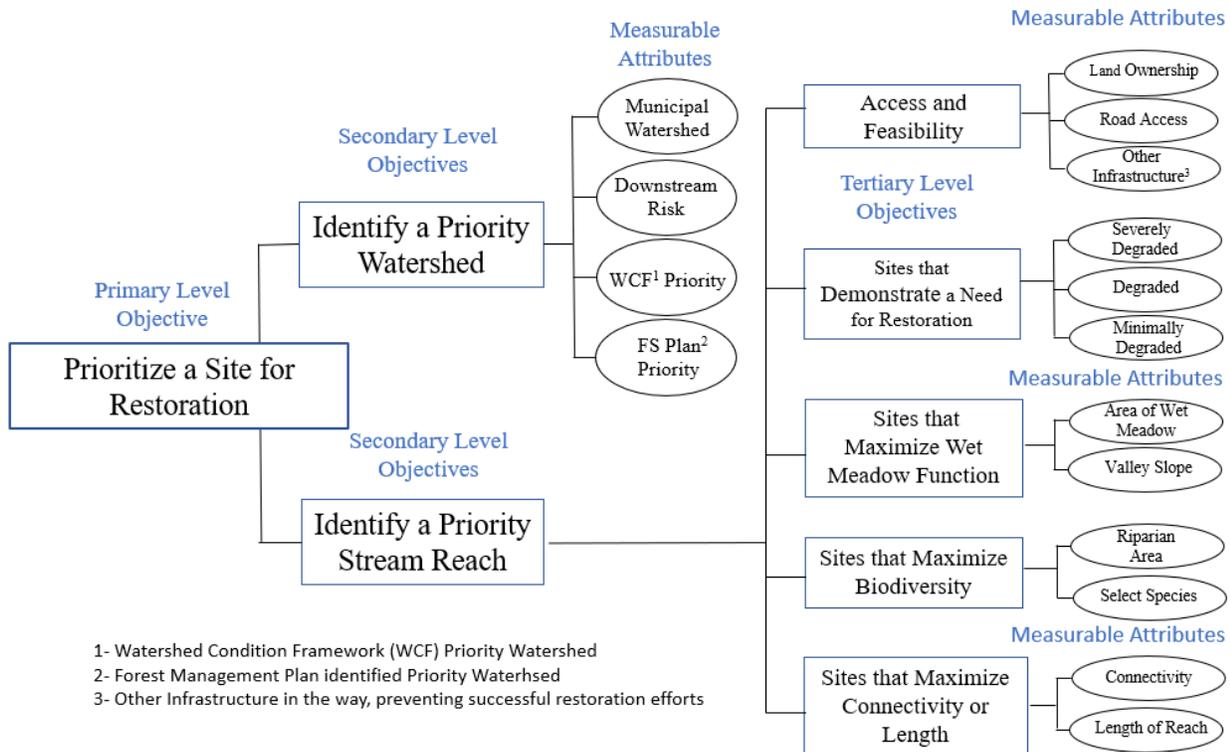
Figure 14 Fundamental Objectives Hierarchy

rectangle) is to prioritize a site for restoration (fig. 14). We developed the FOH from the Phase I interviews by applying the deciding factors as measurable attributes or as objectives. It is important to note that the list of measurable attributes and objectives could have included other attributes or objectives. However, we used this list because it came from data from the decision-maker interviews.

Assumptions and Manipulations of Data

Several site selection characteristics were omitted (Table 5) from the FOH (fig. 14) to apply the deciding factors to ESC restoration sites. Keystone Species or Single Species, Multiple Aquatic Species, and Recreation each captured the deciding factor for selecting sites specifically for fish. The Do No Harm-Measurable Improvement factor focuses on fish population recovery estimates. Factors with the (✓) were not explicitly included on the FOH because investigators assumed that

Table 5 Deciding Factors Omitted from FOH

	Diciding Factors Omitted from FOH
Fish	Keystone Species or Single Species
✓	Climate adaptation and mitigation
*	Cost of restoration project
✓	Soil Health
✓	Water Quality
✓	Water Quantity
Fish	Do No Harm-Measurable Improvement
✓	Forest Health
Fish	Multiple Aquatic Species
Fish	Recreation
✓	Resilience
**	Total Area of Watershed Restored

ESC restoration would produce positive results to satisfy each category independent of site selection. We omitted the *Cost of the restoration project from the FOH for two reasons. First, estimating restoration costs based on individual sites would require detailed knowledge and understanding of each site and a specific level of expertise in estimating costs for restoration. CIWG members do not have this expertise or the site-specific details of each candidate site on this extensive list of candidate sites (163). Second, estimating the cost should happen after a site is selected for restoration (Adame et al., 2015). Additionally, we omitted **Total Area of Watershed Restored because the schedules and plans for thinning and burning, road decommissioning, and other watershed-scale restoration activities in 4FRI are independent of the ESC restoration (K. Paffett, 2022, USFS, Flagstaff, AZ, personal communication).

The need to identify sites for restoration that would reduce the risk of downstream flooding was added to the FOH. High-intensity rainfall events on severely burned landscapes can lead to significant flooding, property damage, and risk to human health (Xu et al., 2023). Investigators included the regional value of restoring stream channels with the potential to mitigate post-fire flooding in the oval for downstream risk. The desire to restore sites that could prevent downstream risk is especially salient for other semi-arid regions with a correlation between aridity, fire size and intensity, and the concentration of ESC (Grünig et al., 2023).

Step 4: Semi-Structured Interviews- CIWG

A second round of semi-structured interviews was then conducted with members of the CIWG. The CIWG is a working group identified by the 4FRI composed of experts, academics, USFS employees, and others tasked with identifying and prioritizing restoration activities. Through the online survey, additional experts and academics were identified and included in the semi-structured interviews. In this paper, we refer to any interview participant in the second round of interviews as part of the CIWG. This round of interviews aimed to determine the regionally specific values and the level of importance that the deciding factors of the FOH held for restoring ephemeral stream channels in the 4FRI. We applied the regional values and opinions from the semi-structured interviews to quantitative scores and weighting factors (Comín et al., 2014; Uribe et al., 2014).

Using the screen-sharing option in Zoom, participants were shown the FOH (fig. 14) and asked to place a point value indicating the level of importance of each of the measurable attributes. We asked participants to distribute one hundred points across any subset of measurable attributes associated with objectives (Ianni & Geneletti, 2010; Stevens, 2011)). Participants applied their personal and professional values to the measurable attributes and weighted the objectives using the same point distribution based on importance.

Statistical Analysis

We analyzed the data collected through the second round of interviews for the quantitative values associated with the scores and weights (Sandelowski, 2000). First, we analyzed the sample size of consenting participants from the CIWG (n=15) for normal distribution. The data, owing in part to the small sample size, were not normally distributed and, therefore, could not be interpreted as a measure of probability. However, following work by Praskievicz (2023), the z-scores were used to check for outliers in the data. Based on the analysis, the qualitative values showed some scores or weights with a z-score of >2 or <-2. Values that drifted more than two from the mean were

considered outliers and removed from the data set. The scores and weights used in the subsequent

spatial analysis are the mean values with the outliers removed.

Step 5: Finalization of the Fundamental Objectives Hierarchy

Following the scoring and weighting values provided by the CIWG participants, we developed the

FOH as a calculation tool to apply opinion-based valuation to rank priority sites. In decision-

making, the objectives are the reasons the decisions are made (Clemen, 2004), with lower-level

objectives defining upper-level objectives. We identified attributes to measure the desired

objectives above them. Each attribute has a point value indicating its importance in the decision-

making process. The sum of the measurable attributes under a given objective is 100, with 100

being the highest level of importance. For example, the objective of identifying a priority

watershed is based on the four measurable attributes (fig. 14), and the sum of the associated values

is 100.   The sum of points from any sub-objective measurable attributes is added up and then

multiplied by the objective weight as a percentage, or the weight for each objective is divided by

100. Moving from the lowest level attributes up each level of objectives, the summation of

attributes, and their multiplication by the weighting factors associated with their objectives, result

in a rank value between 0 and 100, where a stream channel site receiving a rank of 100 would be

the highest priority site for restoration.

The FOH (fig. 15) includes the objectives' attribute scores and weighting factors. The results

demonstrate the importance that regional values hold for the prioritization process. The CIWG

placed a nearly 2:1 importance on selecting ESC using a top-down watershed-scale approach. They

prioritized identifying stream reaches in watersheds that provide source drinking water for

consumptive use and in watersheds that had experienced forest fires. At the stream reach scale, the
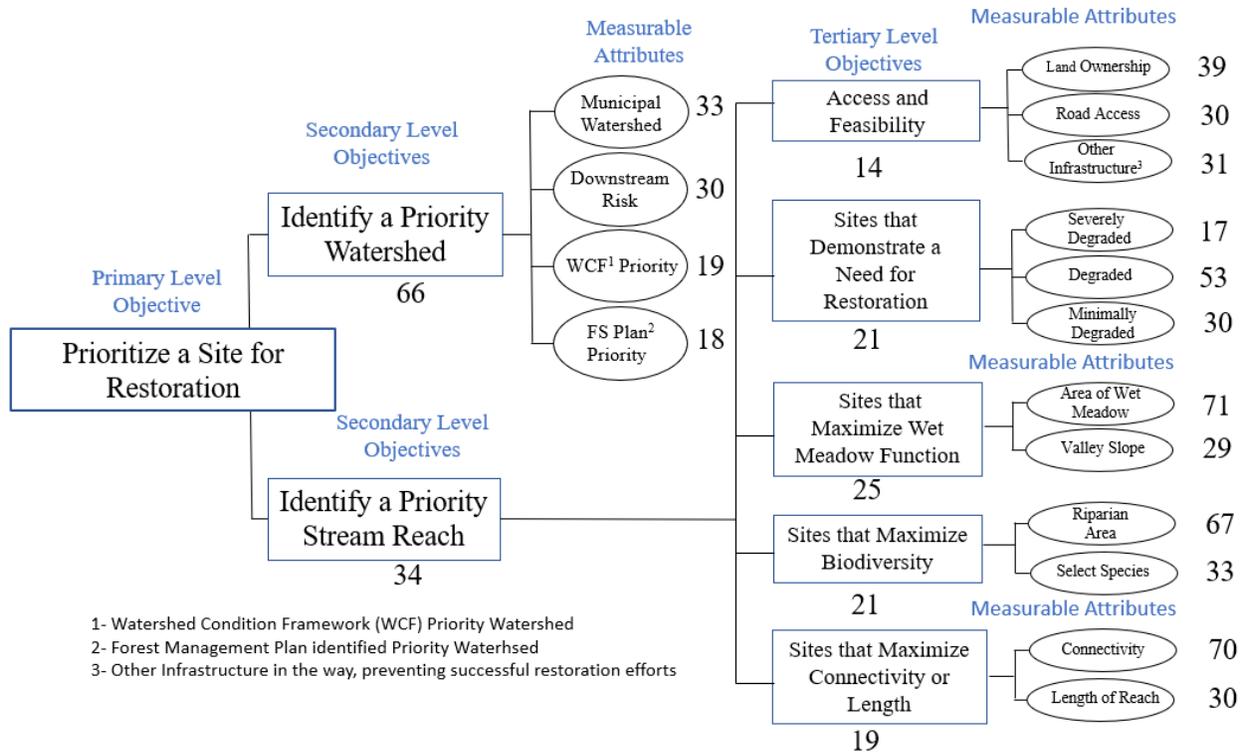
Figure 15 FOH with Weighting Factors and Score

highest weighted objective was to select sites that would maximize wet meadow function. The attribute used to meet that objective was for stream reaches with the largest wet meadow area. Two objectives had the same weighting factor: sites that would maximize biodiversity and sites that

demonstrated a need for restoration. We used the measure of the riparian area as the attribute to select sites that would maximize biodiversity. We identified sites that demonstrate the need for restoration using the degree of degradation. The CIWG prioritized degraded stream reaches with impaired function that were not so severely degraded that they had moved beyond a restorable state (Aronson et al., 1993; Trabucchi et al., 2013). The CIWG weighted stream reaches maximized connectivity next. Finally, participants applied the lowest weighting factor to stream reaches based on the ease of accessibility and where restoration was deemed feasible.

Although a cost-benefit analysis was not part of the weighted scores of the FOH, the CIWG prioritized reaches with road access over those which did not have road access. We based the

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measure of feasibility on in-stream infrastructure. If infrastructure in a stream reach (roads, bridges, culverts) could not be removed, then the CIWG gave those reaches a lower priority.

We demonstrate the process by which the fundamental objectives hierarchy ranks sites through an algebraic equation (Eq. 2) we developed following standard order of operations mathematical expressions. The equation sums the scores of the attributes and applies the weighting factors from the objective. It follows the flow of the FOH from the lowest level to the highest objective.

Equation 2 Mathematical Expression of Scoring and Ranking Matrix

$$\left[\left[\left[\sum\left[\sum_{Tertiary\ SR_{attributes}}^{1-5} \times \frac{Tertiary_{OW}}{100}\right]\right] \times \frac{SR_{OW}}{100}\right] + \left[\sum_{WS_{attributes}} \times \frac{WS_{OW}}{100}\right]\right]$$

Tertiary SR $_{attributes}$ = The Tertiary Attributes under each of the Tertiary Level Objectives
Tertiary$_{OW}$ = The Tertiary Level Objective Weighting Factor
SR$_{OW}$ = The Stream Reach Objective Weighting Factor
WS$_{OW}$ = The Watershed Objective Weighting Factor
WS$_{attributes}$ = The Watershed Attributes

Discussion

This study applied a mixed-method approach to develop a decision-making tool for restoration planning. Semi-structured interviews proved valuable in identifying priority deciding factors used in site selection to restore perennial streams. We used MCDA, based on a business approach to decision-making, to identify restoration objectives and attributes to meet the objectives. This method proved especially beneficial to the planning process of the case study. 4FRI has an extensive list of candidate ESC sites (163) identified for potential restoration. Available data and information are absent specific to the ESC reaches of 4FRI. Without site-specific information, an

efficient method for narrowing down an extensive list of candidate sites will benefit the planning process.

By incorporating professional judgment and stakeholder input, we demonstrated that deciding factors can be adjusted to meet regional values. The decision-makers from Phase I weighted their deciding factors toward restoring perennial streams to benefit fish assemblages. Applying this decision process demonstrated that deciding factors can be adjusted to meet distinct ecological characteristics. We applied the deciding factors from perennial stream regions dominated by high-priority fish to ESC in regions without fish.

Through the second round of interviews, we determined the regional values and opinions of experts and stakeholders are place specific. In arid and semi-arid regions where water is scarce, the highest priorities were on stream reaches, providing source water for consumptive use. The CIWG applied their value of water security by weighting watersheds, and the scores applied to the measurable attributes. Furthermore, the highest weight applied at the stream reach scale was identifying sites that would maximize wet meadow function. Wet meadow function increases groundwater storage, and the delayed release of groundwater from shallow aquifers may further augment the supply of source drinking water in reservoirs (Nash et al., 2018), both of which contribute to increased water security. Besides the value applied to drinking water, there was a high value placed on reducing the risk of flooding in areas impacted by forest fires. The region around 4FRI has experienced forest fires which resulted in extensive damages, including the loss of life, due to post-wildfire flooding (Combrink et al., 2013; Mueller et al., 2018).

The application of this method proves beneficial as a communication tool. The members of the CIWG quickly understood the visual display of the FOH. The visual representation of the hierarchy can improve communications with stakeholders or the public. This transparent and

repeatable method we developed can be used to inform ESC restoration in other arid and semi-arid regions.

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CHAPTER 5-APPLYING STAKEHOLDER VALUES AND WEIGHTED SCORES THROUGH SPATIAL ANALYSIS TO PRIORITIZE EPHEMERAL CHANNEL RESTORATION SITES

Abstract

Ephemeral stream channels are essential ecological components of watersheds. Many of these waterbodies worldwide are degraded and no longer function properly. Stream restoration practices have been applied to many riverine ecosystems to restore valuable processes and functions. However, relative to perennial rivers, there needs to be more work done restoring ephemeral streams. Selecting the best site for restoration is considered a fundamental starting point in planning for restoration. Spatial analysis is a standard tool used in the site selection process. Against that backdrop, we asked how ephemeral streams can be spatially modeled and ranked for prioritization. We used a large-scale ephemeral stream channel restoration project in Arizona, U.S.A., as a case study to answer that question. We used publicly sourced data and standard GIS mapping methods to develop a raster calculator spatial analysis method to measure attributes, apply weighted scores, and rank priority sites for restoration. In this analysis, we developed methods to convert stakeholders' values for ephemeral streams into measurable spatial data. We analyzed 163 candidate ephemeral stream reaches. The results of our analysis identified priority stream reaches with the maximum number of site-specific attributes preferred by stakeholders in the region. Additionally, we discuss how adjustments to the raster calculator equation could apply this method to ephemeral stream restoration projects globally.

Introduction

Globally, like many ecosystems, ephemeral stream channels (ESC) are often degraded (Lake et al., 2017). Specifically, ESC through wet meadow systems in semi-arid, high-elevation headwaters of northern Arizona are incised and no longer function or provide important ecological processes or ecosystem services (MacDonald, 2014; Steinke, 2013). In the forests of northern Arizona, the degradation of these channels is a long-term problem based on events that took place over 100 years ago. Excessive cattle grazing, timber harvesting, transportation infrastructure development, and natural climate fluctuations are the primary causes of the degradation in these systems (Bull, 1997; Pollock et al., 2014; Webb & Hereford, 2001). The loss of vegetative cover and the straightening of streams, coupled with high-intensity storm events, resulted in the incision and degradation of many of the wet meadow systems in the southwest. High velocity, high energy flows down-cut through fluvial soils, ultimately lowering the groundwater table and changing the wet meadow ecosystems to what they are today. The channels no longer distribute water on the floodplains, which reduces the storage of energy, sediment, nutrients, and groundwater (Jaeger et al., 2017; Swanson et al., 2017). The wet meadow ecosystems no longer support the processes, functions, or provide the ecosystem services that they once did. The cycle of channel incision, or degradation, of wet meadow systems is a natural process of the geomorphic cycle in these systems (Bull, 1997; Reneau, 2000). However, the anthropogenic drivers of overgrazing and deforestation, coupled with anthropogenic climate change, have pushed many of these systems out of their natural cycle, from which recovery through natural cyclic processes may not be possible (Chiu et al., 2017; Ely, 1997; Perry et al., 2015).

To counter such degradation, stream restoration efforts are increasing, and billions of dollars are spent annually to reverse ruinous events of the past and restore ecologically functional

processes to riverine systems (Bernhardt et al., 2005; Petty & Thorne, 2005; Wohl et al., 2015). Sites are often selected to restore degraded systems to a reference condition or a standard of ecological integrity (Jungwirth et al., 2002; Palmer et al., 2014; Reynolds & Hessburg, 2005; SER, 2004). Stream restoration efforts are recognized as effective methods for restoring ecosystem functions (Norman et al., 2017; Palmer et al., 2005; Roni et al., 2018). However, by comparison, there is minimal literature explicitly addressing methods for ESC restoration or management (Lake et al., 2017). An essential first step in restoring stream channels is site selection. Prioritizing the best sites will increase the benefits of restoration. The selection of sites can be founded on professional judgment and stakeholder involvement through adaptive management and effective communication (Falkenmark et al., 2004). Deciding where to restore is commonly determined through multiple criteria decisions based on regionally important values (Adem Esmail & Geneletti, 2018). The selection of measurable attributes provides a means by which ecosystems and restoration sites can be characterized and prioritized (Convertino et al., 2013).

Identifying and selecting appropriate ecosystem attributes is critical to understanding a system and identifying priority sites for restoration (Convertino et al., 2013). Multicriteria decision analysis (MCDA) methods are a commonly used to identify quantitative and qualitative attributes (Adem Esmail & Geneletti, 2018). The decision-making process can benefit from MCDA (Hermans & Erickson, 2007) and to measure attributes with differing units of measure (Corsair et al., 2009). MCDA can assess the utility value held by professionals and stakeholders and the importance weighted on measurable attributes (Convertino et al., 2013). In this study, we apply ESC attributes to a spatial analysis method to prioritize ESC restoration sites. Bringhurst et al. (2023) developed attributes, scores, and weighting factors that we applied to this spatial analysis

method to select priority sites based on regional professional judgment and stakeholder engagement.

The watershed-scale approach to restoration is widely accepted as the appropriate scale for restoration planning (Ahn & Kim, 2019; Beechie et al., 2013; O'Connor et al., 2014). The watershed approach to restoration provides an opportunity to identify the underlying alterations to processes that are driving the degradation. It also supports restoring processes over form (Beechie et al., 2010). Watershed scale site selection methods are especially pertinent to lands managed by federal agencies which rely on restoration tools such as the United States Forest Service's (USFS) Watershed Condition Framework (WCF)(USFS, 2011). Thus, we applied the weighting factors from Bringhurst et al. (2023) that prioritized an analysis at the watershed scale.

Mapping is a critical tool for decision-making of spatially explicit factors (Hauck et al., 2013). Spatial analysis and mapping of multiple criteria is a valuable tool for reducing the resources required to prioritize sites (Sarkar et al., 2006), mainly when there are many potential sites to select. In planning for restoration, technical issues arise in developing spatial analysis decision-making systems, such as the availability of data and the methods of measuring identified attributes (Hauck et al., 2013). This study aims to present a spatial analysis method that will reduce the number of potential candidate sites to a more manageable number. This method allowed us to identify higher-priority candidate stream reaches based on the weighted values of professionals and stakeholders using a large-scale restoration effort in the forests of Arizona as a case study. Here, many candidate ESC sites and limited information regarding each site have slowed the planning process for restoration. We used publicly available data to demonstrate a decision-making method for ESC restoration work. We applied a scoring and ranking method (Bringhurst, 2023) to an extensive list of candidate ESC sites. Our desktop assessment identified channels that represent

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the highest restoration values for regional decision-makers. Our study advances the literature on spatial analysis in planning for restoration by creating a method for measuring value-based attributes of ESC.

Methods

Study Area

Near Flagstaff, Arizona, USA (Lat 35°08', Long 111°40'), the United States Forest Service (USFS) and partner organizations aim to restore high-elevation semi-arid forests. The Four Forest Restoration Initiative (4FRI) is a landscape-scale forest restoration project that spans northern Arizona's four forests encompassing 2.4 million acres. Phase 1 of 4FRI is in the Coconino and Kaibab National Forests. The restoration plan focuses on thinning and burning densely overgrown ponderosa pine (*Pinus ponderosa)* forests. Through the National Environmental Policy Act (NEPA) process, which requires maintaining an environment that supports biodiversity (Bear, 1994), 4FRI proposed a suite of restoration efforts, including 39 miles of ESC, identified as 163 individual stream reaches (USFS, 2015). However, there is minimal supporting data or documentation regarding the ESC of 4FRI. The majority flow across historically wet meadows and have become severely incised, resulting in wet meadow dewatering, loss of hydric soil, and riparian biodiversity dependent on proper wet meadow function. The wet meadows no longer store water, sediment, and nutrients, and the severity of downstream flooding has increased. The average annual precipitation for Flagstaff is 21.86 inches, and the precipitation that drives runoff flow in the ESC falls as winter snowfall and high-intensity North American monsoon summer storms.

Figure 16 4FRI Phase I Boundary: Yellow Lines Showing Distribution and Location of 163 ESC reaches

Climate models predict precipitation events in the southwestern United States to increase in intensity and volume (Prein et al., 2017), likely resulting in further degradation.

This study focuses on the ESC, which 4FRI identified as candidates for restoration. 4FRI has assembled a group of professionals and stakeholders into the Comprehensive Implementation Working Group (CIWG) to plan and implement restoration activities on the ESC reaches. Many professionals and stakeholders meet the criteria for both titles and for the remainder of this paper, we refer to them as CIWG. CIWG has collaborated to develop goals, objectives, attributes, and weighted values to prioritize ESC restoration sites.

Measurable Attributes Applied to a Spatial Analysis

This study applies the measurable attributes and weighted scores from the fundamental objectives hierarchy (fig. 17), developed by Bringhurst et al. (2023), to spatial analysis. We employ standard GIS mapping techniques (Thoms et al., 2018) to create new fields for the ranking values applied to the measurable attributes. We converted the fields of ranking values to raster data sets and then applied an algebraic equation to the raster calculator tool in ArcMAP to rank the 163 ESC reaches following the FOH method (Bringhurst et al., 2023). This study demonstrates that regionally

important watershed and stream reach attributes can be measured and ranked using standard GIS mapping techniques in the planning for ESC restoration.
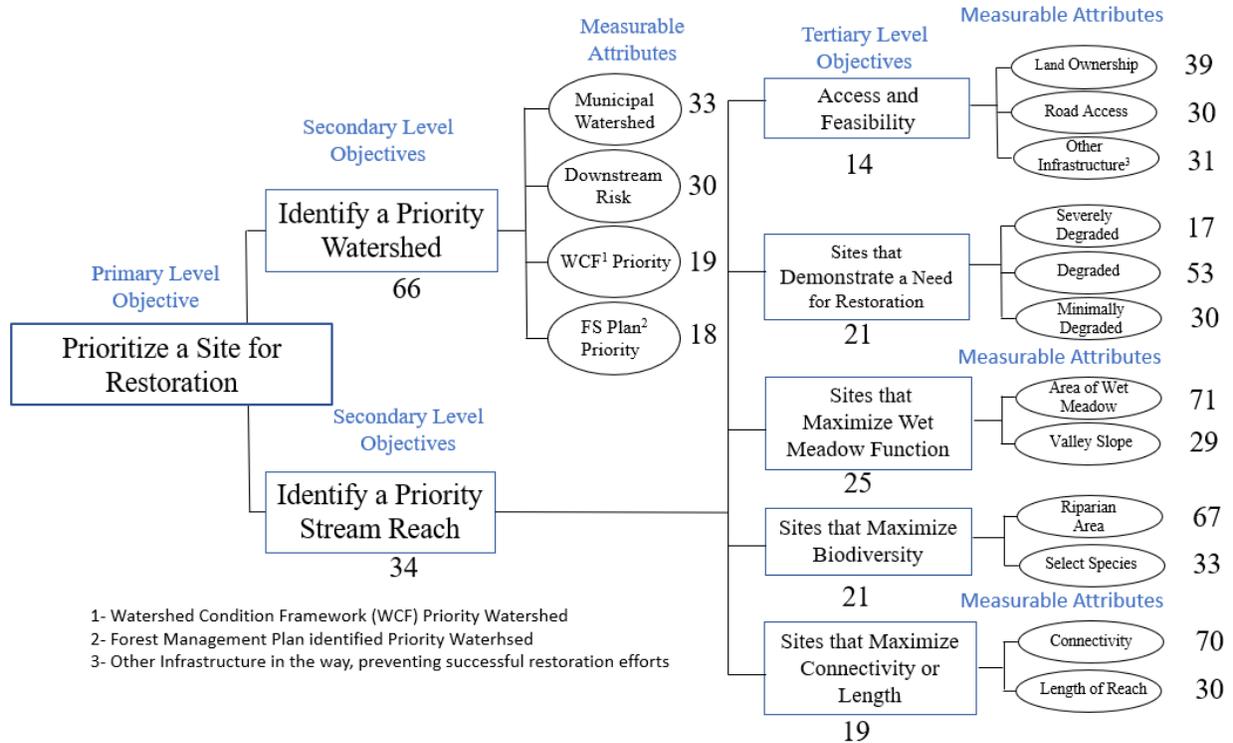
Figure 17-Fundamental Objectives Hierarchy Reprinted with Permission from Bringhurst et al. (2023)

Identifying and Mapping Watershed Attributes

We developed this method using a watershed scale approach to restoration and mapped attributes (using standard GIS mapping techniques). The weighting factors applied by the CIWG demonstrated a nearly 2:1 (fig. 17) level of importance of conducting ESC restoration in priority watersheds (Bringhurst et al., 2023). We measured the attributes selected by the CIWG using standard spatial analysis tools in ArcMAP. There are four attributes identified for the selection of a priority watershed: 1) watersheds that provide water to a downstream drinking water source, either a reservoir or perennial stream from which water is treated and used for drinking; 2) watersheds which reduce the risk of downstream flooding; 3) watersheds that the WCF identifies

and; 4) watersheds identified by an overarching Forest Service management plan. These attributes were measured using a yes-no or presence-absence (MacKenzie, 2005) binomial rank method. Watersheds that met the measurable attribute criteria by the yes-no metric were assigned a ranking value of one. Alternatively, watersheds that did not meet the attribute criteria ranked zero. We discuss the methods for mapping each of these attributes herein.

Municipal Watershed

Water security and supply for consumptive use are critical global issues in arid and semi-arid regions (Daneshi et al., 2021) and in the communities surrounding the forests of 4FRI. To maintain consistency in our analysis, we used the watershed data provided by the USFS's WCF interactive mapper website [for all watershed scale attributes (https://www.fs.usda.gov/naturalresources/watershed/condition_framework.shtml](https://www.fs.usda.gov/naturalresources/watershed/condition_framework.shtml)). The WCF delineated all HUC 6 (Hydrologic Unit Code) watersheds throughout USFS lands. These HUC 6 watersheds range between 10,000 and 40,000 acres in size. In ArcMAP, we identified the municipal water supply reservoirs and perennial streams within them and then used the intersect tool to determine whether any watersheds in 4FRI provide water for consumptive use.

Watershed Condition Framework

In 2015, the U.S. Department of Agriculture created a strategic plan that prioritizes the restoration of watersheds as a core management objective for the National Forests called the WCF (Potyondy & Geier, 2011). The WCF established a process for classifying all USFS watersheds based on their condition. Watershed condition is classified based on 12 indicators, each measured, given a weighted score, and ranked. In addition to classifying watershed conditions, the framework also requires the identification of priority watersheds. In the boundary of 4FRI, the WCF tool

identifies two watersheds as a priority for restoration. The WCF recommends prioritizing the highest class of functional watersheds. However, it allows other priorities to be applied based on professional judgment.

Land and Resource Management Plan

The attribute used for the Forest Service management plan also used the WCF delineated HUC 6 watershed data. The USFS requires each forest to maintain a land management plan. Land management plans are developed to identify desired conditions, objectives, standards, and guidelines for management, protection, and use of the forest or grassland (https://www.fs.usda.gov/main/r1/landmanagement/planning#:~:text=Land%20management%20plans%20(plans)%20are,of%20the%20forest%20or%20grassland). The data and method developed by Bringhurst et al. (2023) demonstrate the value of working in support of an overarching Forest Service land and resource management plan. We identified specific watersheds identified by the Coconino National Forest's Land and Resource Management Plan (LRMP) as priorities. The LRMP specifically identifies watersheds that provide drinking water sources. Additionally, it identifies priority restoration sites that protect people and infrastructure (USFS, 2018).

Downstream Risk

The risk of downstream flooding is another attribute used to select priority watersheds. We considered downstream flooding from the perspective of risk to human health and safety and the risk to infrastructure. In the Forests around 4FRI, the most significant risk of flooding is monsoon rain events on recently burned forests (Edgeley & Colavito, 2022). We applied polygons from the National Interagency Fire Center's historical fire database (https://data-

) and then analyzed the location of any fire boundary using the geospatial analysis intersect tool to identify watersheds that had experienced a fire event. Rankings were applied to support the regional values associated with prioritizing restoration work in watersheds that had burned and had a higher probability of downstream flooding.

Identifying and Mapping Stream Reach Attributes

At the stream reach scale, the spatial analysis ranking method relies on seven measurable attributes to identify a priority stream reach. We ranked streams based on whether they maximized wet meadow function, maximized biodiversity, or maximized connectivity. Other site characteristics measured site access and the presence of infrastructure items in the channels that would prohibit effective restoration. Finally, the FOH from Bringhurst et al. (2023) prioritized identifying sites that demonstrated a need for restoration. We based the need for restoration on measures of the degree of degradation or classification of functional conditions like the WCF (USFS, 2011). However, we left this measurable attribute, as well as others, out of the spatial analysis. We justify decisions of omission herein.

Wet Meadow Function and Biodiversity

Restored wet meadows distribute water laterally across the meadow, restore riparian vegetation, and increase the wet meadow function (Schook et al., 2020). The lateral spread of water increases the horizontal and vertical distribution of water and increases the volume of stored alluvial groundwater, raises the groundwater table, increases the vadose zone, and creates a hydric soil condition that maximizes wet meadow function (Silverman et al., 2019). The highest valued

objective at the stream reach scale that Bringhurst et al. (2023) prioritized was sites that maximized wet meadow function. We delineated wet meadows using the satellite imagery base map available on ArcGIS. Ponderosa pine has encroached on many meadows, making delineating the historic wet meadow extents difficult. To more accurately delineate the wet meadow areas obstructed by trees, we included a 10m digital elevation model (DEM) raster to support our visual identification of the area. The DEM was used to identify the low slope areas of historic wet meadow extents in our delineation effort. We measured the wet meadow function based on size. We concluded that the wet meadow with the largest area would maximize the function.

Functional riparian corridors benefit a biodiverse assemblage of plant and animal species (Sabo et al., 2005). Maximizing biodiversity was valued nearly as highly as maximizing wet meadow function (fig. 17) (Bringhurst et al., 2023). To that end, we applied the value of maximizing biodiversity using riparian vegetation as a proxy. We measured riparian areas based on the estimated extent of vegetation following restoration using the extent of the wet meadow area as the area to which riparian vegetation would propagate (Mitsch et al., 2005). For wet meadow function and biodiversity, we divided the area measurements into quartiles to rank the area data and assigned a ranking value between one and zero to each quartile (Ernon et al., 2019). We ranked the largest areas at one, the smallest areas at zero, and the two middle quartile groups at 0.667 and 0.333, respectively.

Connectivity

Hydrologic connectivity is the transport of matter, energy, and organisms through the movement of water (Leibowitz et al., 2018; Pringle, 2003). Following this definition, connectivity in riverine ecosystems is typically a hydrologic measure of water distribution. Water is distributed

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longitudinally, laterally, and vertically to extend the hydrologic connectivity (Wohl, 2017). However, we were interested in connectivity between multiple sites exhibiting properly functioning conditions. Connectivity can be measured as the spatial arrangement of habitat patches (Leibowitz et al., 2018). Larned et al. (2010) describes the concept of connectivity between habitats in temporary rivers as aquatic-terrestrial habitat mosaics. At an ecological level, sequentially connected restoration sites reduce fragmentation, increase biodiversity and maximize the area of ecosystem process development (Tscharntke et al., 2012). Bringhurst et al. (2023) used sequentially connected restoration sites to develop their site selection method. As a result, we measured connectivity based on the number of connected restoration reaches within a subbasin. We do not dismiss the concept of longitudinal, lateral, and vertical hydrologic connectivity as the typical connectivity measure. The wet meadow function attribute measures hydrologic connectivity for the water-based lateral and vertical distribution of matter, energy, and organisms. Additionally, we considered the attribute associated with maximizing stream length as a surrogate measurement that would improve the longitudinal hydrologic connectivity function (Boulton et al., 2017; Costigan et al., 2017).

The data presented by 4FRI indicates that all 163 reaches are degraded. However, no data supports the functioning condition of other reaches or meadows contiguous with or in the same subbasin as the identified reaches. No condition classification or spatial data is available to document the current functional condition of the ESC. As a result, we could not apply connectivity of proposed restoration sites with sites that were already properly functioning. Instead, we applied our connectivity measure based on the number of candidate sites for restoration on a subbasin level. We delineated subbasins using a watershed spatial analyst tool in ArcMAP, with the concentration points for each subbasin selected at the furthest downstream locations in the stream

reach data (USFS, 2015). We distributed the rank among three different subbasin classifications--subbasins with only one stream were ranked at zero, subbasins with only two at 0.5, and subbasins with more than two at one.

Length of ESC Reach

In ecological restoration, there are cases where decisions are made based on maximizing restored area (Llewellyn et al., 1996; Rappaport et al., 2015; Sethi et al., 2017), maximizing the total restored habitat per length of river (Cote et al., 2009; King & O'Hanley, 2014), or achieving the most benefit gained per cost of restoration effort (Hyman & Leibowitz, 2000; Sethi et al., 2017). 4FRI maintains a publicly available library of GIS data. One of the data sets identifies the 163 stream reaches of 4FRI (https://www.fs.usda.gov/detail/4fri/gis/?cid=fseprd493266). The stream reach length is an attribute of the data layer. The data set had a broad range of reach lengths, so we divided the data into quartile data sets and gave ranking values to each quartile group (Ernon et al., 2019). We distributed ranking values of 1, 0.667, 0.333, and 0 to the four quartile groups of length data.

Access and Feasibility

Restoring sites occupied by infrastructure such as roads, bridges, and culverts is possible. Some restoration projects focus on removing infrastructure (King & O'Hanley, 2014; Roni et al., 2012). We considered the other infrastructure measurable attribute (fig. 17) based on the concept of infrastructure in a stream channel that would reduce the feasibility of restoration. For example, if culverts, roads, and bridges are deemed necessary and not removable. The objective associated with this measurable attribute is to identify sites where restoration is feasible. Feasible is used here to describe restoration sites that do not have infrastructure preventing restoration efforts (Anderson

et al., 2003). We used GIS data provided by the USFS that identified the locations of bridges and culverts in the National Forests of the Southwest Region (https://www.fs.usda.gov/detailfull/r3/landmanagement/gis). However, the data did not identify any bridges or culverts on the 163 stream reaches identified by 4FRI data. Two shapefiles for roads and bridges, also provided as part of the 4FRI GIS data set, showed no bridges on the stream reaches. As a result, the only infrastructure used in the analysis was the road layer provided by 4FRI. We used this layer to rank two different measurable attributes (https://www.fs.usda.gov/detailfull/r3/landmanagement/gis). The road layer, primarily dirt roads, was used to identify stream reaches with roads either crossing them or running parallel in the wet meadow areas. We ranked these using the binomial approach where the desired condition, stream reaches without road crossings, were ranked with a one, and the stream reaches with road crossings were ranked as zero. The stream reaches identified as having roads intersecting them were ranked lower than stream reaches without road crossings. The roads layer also measured reaches which would be considered accessible. The weighted scores associated with the FOH did not attempt to make any cost-benefit analysis of sites. However, the CIWG did recognize that sites accessible to vehicle approach would imply a reduced cost. As a result, the CIWG put a priority on selecting sites that had road access. We created a 400-meter (1/4 mile) buffer on the stream reaches. We considered stream reaches with a road intersecting the 400-meter buffer more accessible because these sites would arguably cost less to transport people, tools, and equipment to restoration sites. Accessible stream reaches were ranked using the binomial system –stream reaches with road access were ranked with a one and those without road access with a zero. The rank values associated with feasibility and access were created from the same layer but converted to distinct

raster datasets. The identified measurable attributes, converted to GIS raster data layers, were used to rank stream reaches.

Measurable Attributes Omitted from the Spatial Analysis

We omitted specific measurable attributes identified on the FOH (fig. 17) from the spatial analysis because; the data were unobtainable as GIS data, they were measurements that spatial analysis could not perform, or data that were so uniformly non-distinguishable across the entire data set that they would neither add nor detract from the analysis. We omitted measurements of the valley slope because the only available DEM data for the area was at the $10m^2$ scale and attempts at measuring slope at this scale provided no discernable slope difference across the stream reaches. Select species were not used in the ranking because there are no specific species identified in the ESC of the area that are a management priority. We omitted land ownership because all the ESC reaches identified for restoration in 4FRI are on USFS-administered lands. Finally, we did not include the need for restoration in the spatial analysis for two reasons. First, there are no methods for accurately measuring the degree of degradation using spatial analysis tools. Second, the documents identifying the target channels indicate they are degraded and need restoration (MacDonald, 2014).

Prioritization Process

We developed an equation (Eq. 3) from the FOH and applied it to the raster calculator tool in ArcMAP to rank 163 ESC reaches (Eq. 1).

Equation 3 Mathematical Expression of Scoring and Ranking Matrix

$$\left[\left[\left[\sum\left[\sum_{Tertiary\ SR_{attributes}}^{1-5} \times \frac{Tertiary_{OW}}{100}\right]\right] \times \frac{SR_{OW}}{100}\right] + \left[\sum_{WS_{sttributes}} \times \frac{WS_{OW}}{100}\right]\right]$$

Tertiary SR $_{attributes}$ = The Tertiary Attributes under each of the Tertiary Level Objectives
Tertiary$_{OW}$ = The Tertiary Level Objective Weighting Factor
SR$_{OW}$ = The Stream Reach Objective Weighting Factor
WS$_{OW}$ = The Watershed Objective Weighting Factor
WS$_{attributes}$ = The Watershed Attributes

Applying attributes and objectives from the FOH will prioritize sites based on a weighted score algorithm. We demonstrate the weighted scoring method with the priority watershed objective. The measurable attributes (circles) prioritize a watershed based on absence-presence ranking factors of 1 or 0. The values of each set of measurable attributes under an objective (rectangles) are summed and multiplied by the weighted value associated with each objective. Using the raster calculator for our spatial analysis applies rank values of attributes to weighted scores to rank each site. We provide an example of the process with a hypothetical score sheet (fig. 18); consider a watershed that: 1) feeds a municipal water source; 2) has not had a forest fire; 3) is identified by the WCF as a priority; and 4) is identified by the Forest's Land Use Management Plan. After inputting all these data rankings, ArcMap's raster calculator tool generated a score of 46.2. Note that a score sheet would not be used in practice because the raster calculator tool in ArcMAP performs the ranking calculations.

Score Sheet

Rank value comes from Spatial Analysis Ranks. The score comes from Attributes. Weight comes from the FOH, as a factor of 100.

Watershed:	Rank Value	X	Score (FOH)	=	Total

1.   Municipal Watershed
Does this watershed provide drinking water?
Rank: yes=1, no=0

	1	X	33	=	33

2.   Downstream Risk
 Has this watershed burned by a forest fire?
Rank: yes=1, no=0

	0	X	30	=	0

3.   Watershed Condition Framework
Is this watershed identified as a WCF Priority?
Rank: yes=1, no=0

	1	X	19	=	19

4.   Land and Use Management Plan
Is this watershed identified as a Land and Use Management Priority?
Rank: yes=1, no=0

	1	X	18	=	18

	Sum Total Column	Σ	70

FOH Weighting Factor x Total Column	66/100	X	70	=	46.2

Figure 18 Watershed Ranked Score Sheet Example

Results

The analysis ranked 163 stream reaches using the weighted values established by semi-structured interviews with stakeholders associated with the CIWG (Bringhurst et al., 2023). Results show that the top 10 reaches, ranked as the highest priority sites for restoration, are in the same HUC 6 watershed. We also find that 19 of the top 20 are in the same priority watershed. Following this

method, a ranking of ESC reaches puts the highest value on restoring stream reaches in a watershed that provides source drinking water.

Discussion

The desktop spatial analysis of an extensive list of candidate sites using the methods described here provided a quick and easy way to create a more manageable list of candidate sites. Developing a model like the one described here has multiple benefits for the user, such as reducing the number of field site visits and the time required to assess many candidate sites. Adjustments to the algorithm could produce alternatives or present multiple scenarios to inform the decision-making process. The spatial data used is readily available through online sources and requires minimal spatial analysis. Regional values used to develop the weighting factors for the prioritization process are specific to this region. As a result of the weights, the stream reaches, which ranked the highest, occurred in only one of the HUC 6 watersheds. The Coconino National Forest management plan

Figure 19 Lake Mary Watershed Top 10 Priority Stream Reaches

and the WCF identified the Lake Mary watershed as a priority as part of their watershed restoration plans because it provides drinking water to the City of Flagstaff. However, a weighted score that repeatedly emphasizes one watershed may result in the omission of stream reaches elsewhere with the potential to restore outstanding ecological value.

Because the algorithm used to score the stream reaches is easily adjustable, we analyzed the stream reaches individually without considering the watershed weights. The analysis results, without watersheds, demonstrated that the channel length was a defining measure for selecting priority ESC reaches. Although the CIWG did not value prioritizing longer reaches of ESC as much as other measurable attributes, the length was a driving factor of the total area for both wet meadow function and riparian area biodiversity. The longer stream reaches flowing through wet meadows produced larger area polygons, translating to higher-ranked stream reaches. The analysis completed to identify priority stream reaches, without considering watershed priority, identified long reaches with road access yet no roads crossing stream channels.

We recommend that the 163 stream reaches identified by 4FRI should be revised. No documented justification exists for how 4FRI identified and selected the 163 reaches. Merging individual stream reaches into subbasin scale restoration projects would benefit the planning process and the resultant restoration. Being limited by the 163 reaches also limits the extent of restoration benefits. Several reaches in the study area would meet the highest priority values not on the candidate list. Specifically, the analysis revealed that there are reaches in the priority watershed that would achieve the restoration goals. Should the weighting factor for the priority watersheds remain the driving factor for restoration, we recommend looking at other sites within that watershed which were not included in the data set but would score higher than others that were. With an algorithm adjustment, the tool developed here can identify high-priority stream reaches in the priority watershed not identified as candidate sites by the original FEIS or ROD of 4FRI.

While this method puts a ranking value on all 163 reaches, it is not a standalone tool for site selection. It reduces the number of candidate sites requiring field data collection. On-site field

investigations required to ground truth the results and collect additional necessary data is required. Specifically, the degree of degradation is a crucial site characteristic to consider in a site prioritization method. This approach results in fewer field sites to visit, fewer field data to collect, and fewer resources required.

Conclusion

Stream restoration is an accepted approach for restoring vital riverine ecosystem processes and functions. Yet, ephemeral stream restoration is in its infancy (Lake et al., 2017). In the field of stream restoration, selecting the best sites is considered critical. Here we present a method to select priority ephemeral streams sites, through spatial analysis. We developed methods to measure unique attributes of ephemeral streams. This method rapidly assesses multiple candidate restoration sites by applying the regional values of stakeholders and decision-makers using standard GIS spatial analysis mapping techniques. The application of MCDA to spatial analysis software reduces the cost associated with field investigations by reducing the number of requisite site visits. Most necessary data is publicly sourced, making spatial analysis an efficient use of resources. Because the regional decision-makers placed a high value on wet meadow function, we applied a novel approach to its measurement. This model could be adjusted to meet other ESC restoration projects' regional values and weights. The spatial analysis demonstrated here can be applied to ESC in other regions for ecological restoration. This type of assessment is an efficient and effective starting point for planning ESC restoration in other arid and semi-arid regions.

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Chapter 7-Discussion of Results and Conclusion

Introduction

The results and discussion presented here followed a mixed-method approach, including spatial analysis, semi-structured interviews, online surveys, thematic analysis of qualitative data, and statistical analysis of quantitative data, to answer the following three research questions:

1. Research Question 1 (RQ1): What factors influence decision-making for restoration initiatives in riverine ecosystems in Ponderosa Pine Forests?

2. Research Question 2 (RQ2): How can decision-making factors be developed into a prioritization method for ephemeral stream channel restoration?

3. Research Question 3 (RQ3): How can a site prioritization method be modeled using spatial analysis to rank priority sites for restoration?

I present the results and discussion following the three phases of the methodology (Fig. 20).
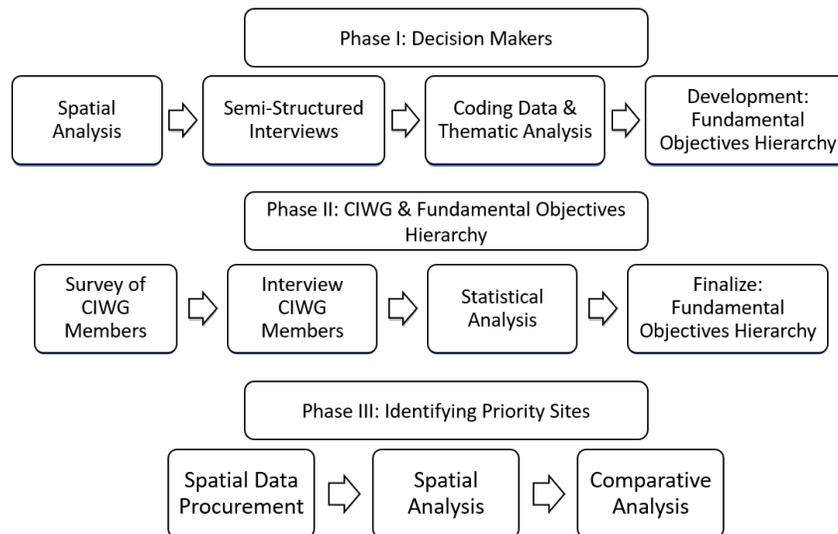
Figure 20 Phases of Research

Phase I

The results of Phase I are maps developed through spatial analysis, qualitative data collected through semi-structured interviews with decision-makers, and the development of the fundamental objectives hierarchy.

Spatial Analysis Maps

An overarching conclusion from the literature review is that professional judgment and expert input are crucial components of a site selection method (Cipollini et al., 2005; Hughes et al., 2023; O'Connor et al., 2014; Orsi et al., 2011; Walsh et al., 2020). I developed this map to limit the search for experts for consultation (fig. 21). Coupled with reports and other documents on water-related restoration efforts in U.S. Forest Service (USFS) managed lands, I could identify willing participants for semi-structured interviews.

Figure 21 Map Used to Locate Interview Participants

Semi-Structured Interviews

Decision-makers identified the level of importance that site-specific criteria had for selecting restoration sites. They applied ranks (1-5) to the most important decision-making factors they considered when selecting stream restoration sites. I coded the qualitative data and analyzed it using a thematic analysis method (Lochmiller, 2021). The results of the interview and the analysis are the deciding factors (Table 6). The semi-structured interview approach was valuable

Table 6 Deciding Factors: Results from Decision-Makers

Deciding Factors
Ease of Access for Restoration Activities
Degree of Degradation
Floodplain Access
Keystone-Single Species
Need for Restoration
Biodiversity
Damage to Infrastructure
Climate adaptation and mitigation
Connectivity of Multiple Sites
Cost of Restoration Project
Soil Health
Water Quality
Water Quantity
Do No Harm-Measurable Improvement
Forest Health
Groundwater Recharge
Multiple aquatic species
Recreation
Resilience
Stream Energy-Gradient/Velocity
Total Area of Watershed Restored
Total Length of Channel Restored

in getting in-depth details from the participants. It also provided information on deciding factors. However, this method was time-consuming, and in the end, many of the interview details were irrelevant to the study. The small sample size limited the ability for the data to be extrapolated, in probabilistic terms, to a predictive list of site selection factors. Even though the sample size was small, the data collected provided a good foundation for developing the fundamental objectives hierarchy. The data which proved to be most beneficial was the top five deciding factors identified by the decision-makers. An online survey could have identified deciding factors instead of semi-structured interviews. Surveys have the potential to get a much larger sample size and produce a robust data set with less invested resources (Bernhardt et al., 2007). However, I chose the interview method because semi-structured interviews provide respondents with the opportunity to expand on answers and the interviewer with the opportunity to ask deeper diving questions where necessary. Additionally, follow-up semi-structured interviews could provide additional details if deemed necessary. The resultant list of deciding factors provides a representative sample of the factors influencing decision-making initiatives for restoration initiatives in riverine ecosystems in ponderosa pine forests.

Deciding Factors to Fundamentals Objective Hierarchy

Deciding factors converted into site-specific criteria are fundamental to selection methods (Convertino et al., 2013). I used the deciding factors to develop the fundamental objectives hierarchy following the work by Cipollini et al. (2005). I developed the fundamental objectives hierarchy with objectives and measurable attributes. The attributes are site-specific criteria that can be measured in a site assessment. Before the deciding factors could be applied to the fundamental objectives, I eliminated several deciding factors from the list. As described in the methods section, deciding factors were omitted from the list that did not apply to ephemeral stream channels, were considered universally applicable to all sites, or were considered too site specific to match the general stage of prioritization.

Table 7 Omitted Deciding Factors

	Diciding Factors Omitted from FOH
Fish	Keystone Species or Single Species
✓	Climate adaptation and mitigation
*	Cost of restoration project
✓	Soil Health
✓	Water Quality
✓	Water Quantity
Fish	Do No Harm-Measurable Improvement
✓	Forest Health
Fish	Multiple Aquatic Species
Fish	Recreation
✓	Resilience
**	Total Area of Watershed Restored

I used the deciding factors to create an online survey. I sent the online survey to the Comprehensive Implementation Working Group (CIWG) members. The survey intended to find willing participants for regionally specific interviews and validate the deciding factors. Specifically, the survey asked participants if there were deciding factors relevant to ephemeral stream channels which were not on the list. The survey results guided the addition of four deciding factors to prioritize sites: 1) that flow into a receiving body of water used for consumption (reservoirs or perennial streams); 2) downstream of recently burned forested areas to reduce the risk of downstream flooding; 3) to include the Watershed Condition Framework (WCF), a watershed restoration guiding document created by the USFS: and 4)in priority firesheds, which are identified by another USFS document for forested areas that have a high risk of burning coupled with a high probability of loss to infrastructure, property, and life from downstream
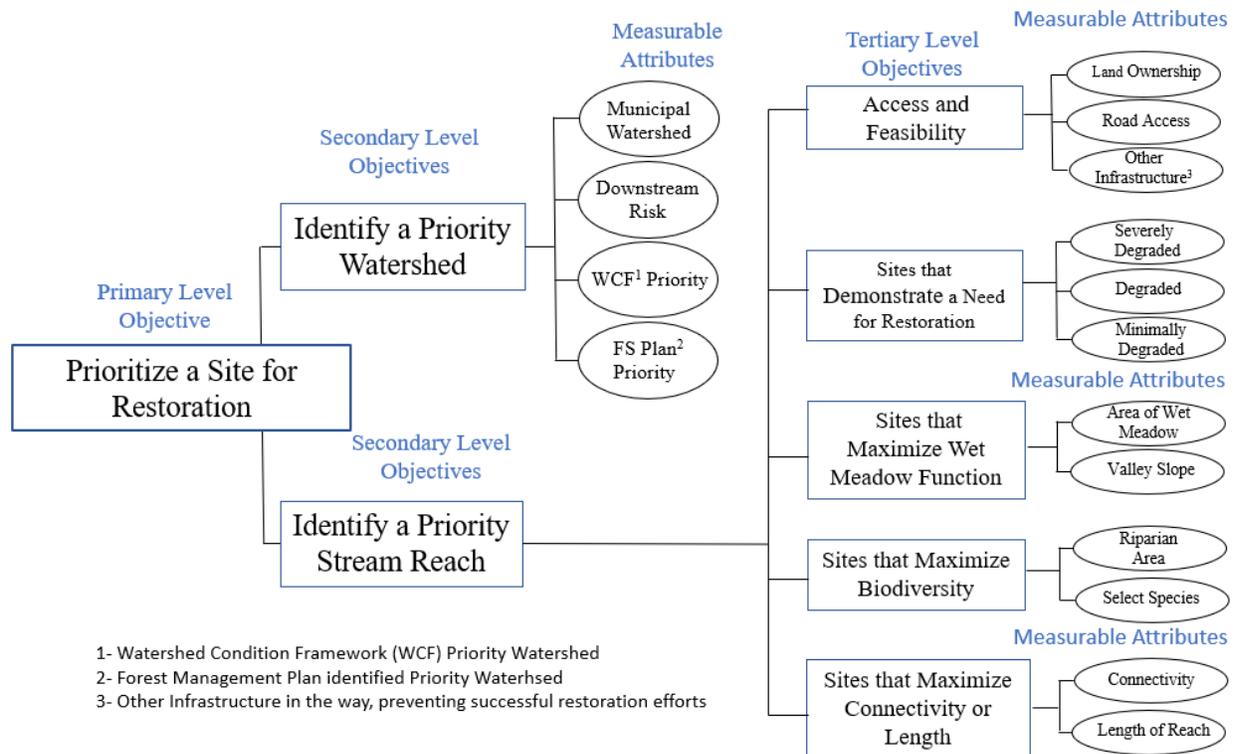
Figure 22 Fundamental Objectives Hierarchy-Phase I

flooding. The additional data provided by the survey resulted in the completion of the first iteration

of the fundamental objectives hierarchy. At this point of the study, the attributes and the objectives

did not have scores or weighting factors (fig.22).

Phase II

Semi-Structured Interviews with the CIWG

There was some overlap between the first two phases. I developed the fundamental objectives

with the survey results sent to CIWG members. Respondents of the survey who were willing to

participate in the semi-structured interviews were contacted, and interviews were scheduled and

completed.

The results of the semi-structured interviews with members of the CIWG represent the

level of importance members of the CIWG held for attributes and objectives. The raw data was

analyzed using a z-score analysis to identify and remove outliers. The data sets presented here contain the mean values with the outliers removed. The scores measure importance out of 100, that the participants determined by sharing personal and professional opinions. The results below follow the data input flow on the fundamental objectives hierarchy. They start with the measurable attributes at the tertiary level and move up to the primary level objective of identifying a priority site for restoration (fig.22). Two of the tertiary-level objectives are based on existing conditions at a site. The two existing conditions objectives are "sites deemed accessible and feasibility of restoration" and "sites that demonstrate a need for restoration." The other three objectives depend on post-restoration estimations.

Tertiary Level Measurable Attributes-Stream Reach

Figure 23 Measurable Attributes Used to Measure Accessibility and the Feasibility of Restoration
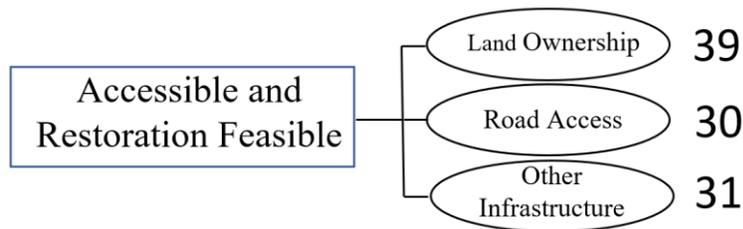
The scores associated with the measurable attributes in the following sections measure the importance held by the CIWG. The most important attributes would receive a 100, and an unimportant attribute would receive a 0.

Sites Deemed Accessible and Restoration Feasible

The scores (fig. 23) are the results of the mean value of all CIWG participants' scoring values. Even though every identified candidate stream reach is located exclusively on USFS-administered lands, participants preferred conducting restoration work on public lands over privately owned

lands. Selecting sites that were deemed accessible and unobstructed by infrastructure that would prohibit effective restoration efforts were nearly equally valued.

Sites that Demonstrate a Need for Restoration

The scores reported for prioritizing sites based on a degree of degradation (fig. 24). The degree of degradation is measured as existing conditions of a pre-restoration state. The participants valued prioritizing degraded sites that, with reasonable effort, could be restored following emergency medicine's triage approach. There was also a high value put on prioritizing only

Figure 24 Measurable Attributes Used to Measure Degree of Degradation

minimally degraded sites. Nevertheless, there were members of the CIWG for whom even the most severely degraded sites were considered a higher priority for restoration efforts.

Sites that Maximize Wet Meadow Function

The following tertiary-level objectives and the respective measurable attributes are based on projected change anticipated following restoration. When measuring the attributes for selecting sites that would ultimately maximize wet meadow function, the CIWG members put significant value on selecting sites with the largest area of restored wet meadow or floodplain (fig. 25). The concept of prioritizing sites that represented the lowest valley slope, stream energy, or velocity received a lower score as a metric for
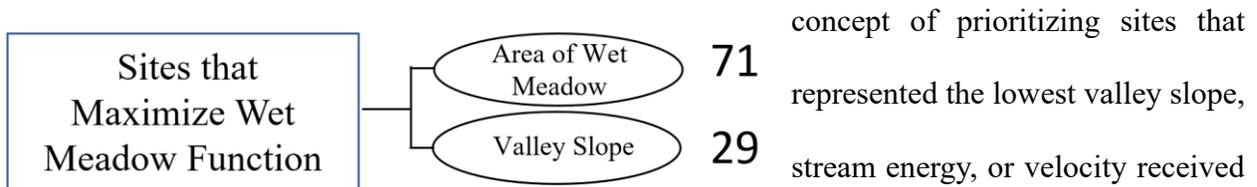
Figure 25 Measurable Attributes Used to Measure Sites that Maximize Wet Meadow Function

selecting sites that would maximize wet meadow function.

Sites that Maximize Biodiversity

Figure 26 Measurable Attributes Used to Measure Sites that Maximize Biodiversity
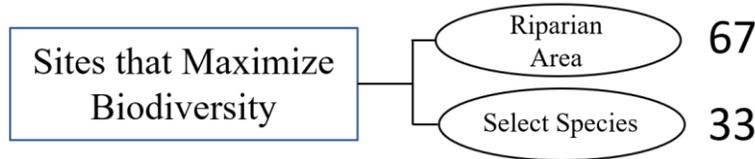
The value that the CIWG members held for riparian vegetation was twice as important as the value they held for prioritizing sites to benefit an identified select species (fig. 26). The total area or restored wet meadow, or floodplain, was the driving factor for selecting sites that would maximize biodiversity.

Sites that Maximize Connectivity or Length

Figure 27 Measurable Attributes Used to Measure Sites that Maximize Connectivity
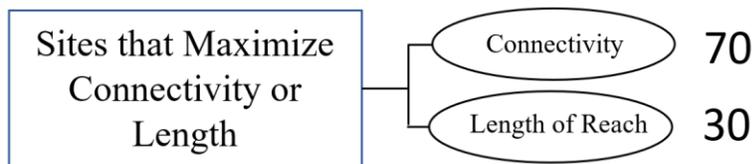
Like the two previous tertiary-level objectives, sites that improved connectivity over sites that maximized the length of the restored channel received higher scores. Here the CIWG participants valued the functional process over the physical form.

Tertiary Level Objectives-Stream Reach

Recall that the values associated with the objectives are weighting factors. There were 100 points for scoring distributed across the five objectives to demonstrate importance. The higher the score, out of 100, the more important that objective. Sites that maximize the wet meadow function hold the highest value (fig. 28). The sites that maximize biodiversity and demonstrate a need for

Accessible and Restoration Feasible	14
Sites that Demonstrate a Need for Restoration	21
Sites that Maximize Wet Meadow Function	25
Sites that Maximize Biodiversity	21
Sites that Maximize Connectivity or Length	19

Figure 28 Tertiary Level Objectives-Stream Reach

restoration are considered equally important by CIWG members. Sites that maximize connectivity were only slightly less important than the sites that maximize biodiversity or demonstrate a need for restoration. The lowest level of importance was for sites that have easy accessibility or where restoration efforts would not be hindered by infrastructure.

Measurable Attributes-Watershed Scale

The value of importance that the members of the CIWG place on watershed selection emphasized prioritizing watersheds that provide drinking water to a municipal surface water reservoir or perennial stream and prioritizing watersheds that non-prescribed wildland fires had previously burned. The priority watersheds identified by the WCF and an individual forest's management plan were of lesser importance yet still valued.

Objectives: Stream Reach v. Watershed

Figure 29 Weighting Factors for Stream Reach v. Watershed Scale
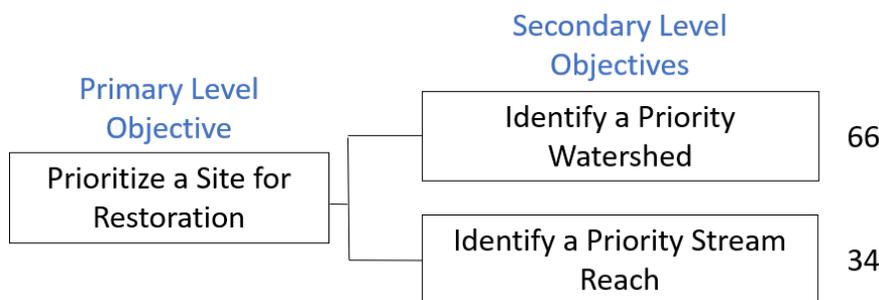
When asked to place a level of importance on stream reaches or watersheds, the members of the CIWG nearly two to one place a higher level of

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importance on watersheds. These scores and weighting factors are applied using algebraic calculation tools in the spatial analysis software. Presented in the next section are the results of the analysis.

Finalizing the Fundamental Objectives Hierarchy

I finalized the fundamental objectives hierarchy by including the scores and weighting factors established through semi-structured interviews. At this stage, it was little more than a score sheet.

$$\left[\left[\left[\sum\left[\sum_{Tertiary\ SR_{attributes}}^{1-5} \times \frac{Tertiary_{OW}}{100}\right]\right] \times \frac{SR_{OW}}{100}\right] + \left[\sum_{WS_{sttributes}} \times \frac{WS_{OW}}{100}\right]\right]$$

Equation 4 Mathematical Expression of FOH Calculation

SR_{OW} = The Stream Reach Objective Weighting Factor
WS_{OW} = The Watershed Objective Weighting Factor
$WS_{attributes}$ = The Watershed Attributes

I developed an equation, described in the methods, that resulted in finalizing the fundamental objectives hierarchy (Eq. 4).

Through surveys, interviews, and data analysis, I developed the fundamental objectives as a weighted scoring site selection method to demonstrate how decision-making factors can be developed into a prioritization method for ephemeral stream channel restoration. With Phase II completed, I needed to demonstrate the fundamental objectives hierarchy using spatial analysis tools.

Phase III

Spatial Data

Large amounts of publicly available geospatial data are made accessible by open data-sharing standards (Stock & Guesgen, 2016). However, some essential data are unavailable in the

Four Forest Restoration Initiative (4FRI) region. The first valuable data for the site selection method would be a complete and accurate digital elevation model (DEM) of the forested areas. In cases where light detection and ranging (LiDAR) data is available, the accuracy can be at the 1m scale (Vaze & Teng, 2007). However, an even more accurate data set would provide valuable information for the decision-making process. Methods such as a total station survey, photogrammetry, or more complete and accurate LiDAR data would benefit this process. The USGS LiDAR data (https://apps.nationalmap.gov/lidar-explorer/#/) indicates 1-meter digital elevation model (DEM) data available for the identified 4FRI area. However, upon closer inspection, data are absent right in the middle of the Phase 1 boundary of the 4FRI area, which renders the 1-meter LiDAR data unusable. As indicated through the first round of interviews with the decision-makers, lower valley slopes have higher priority over steep reaches of channel. Sites with low slope or stream energy have a higher probability of successful restoration. Sites that naturally dissipate floodwater's energy and velocity due to low slope reduce the risk of post-restoration scour events.

As a result of the missing 1m LiDAR data, the best available data was 10m DEM data. Using the 10m resolution limits the ability to measure slope at the necessary scale. Of the 163 stream reaches, 9 were longer than 1 km, and an additional 30 reaches had a length between 0.5 km and 1 km. Most stream reaches identified by the 4FRI Record of Decision (ROD) and geospatial data sets are in relatively flat (low slope) wet meadow systems. The slope, calculated with 10m DEM over a relatively short reach length, does not create a reliable, measurable distinction. Due to the lack of data, and a slope calculation that showed no measurable distinction between the 163 reaches, I omitted the valley slope attribute from the raster calculator analysis tool. The availability of 1m DEM LiDAR data would have provided sufficient information to

measure channel slope and potentially valuable measures used to estimate the degree of degradation, such as depth of incision. Additional geospatial data could have also measured the variation in wet meadow vegetation.

The available satellite imagery for estimating the extent of wet meadows was highly dependent on the imagery provided by ArcMAP. The variation in measurements may need to be

Figure 30 Wet Meadow Riparian Vegetation Based on Satellite Imagery. The years are 2017, 2018, 2020, and 2021 (left to right, then top to bottom). Google Earth, 2023.

revised based on methods and available data. The four images of an ephemeral wet meadow in the Coconino National Forest provide an example of the difficulty of identifying the extent of riparian vegetation in the ephemeral wet meadows (fig. 31). These images are downstream of an ephemeral spring, making the vegetation change more obvious. In many of the degraded wet meadows of the 4FRI, little visual indication demonstrates the change in vegetation type or the extent to which it

would be estimated to change following restoration efforts. The 4FRI GIS data also distinguishes between riparian and non-riparian wet meadow stream reaches in name only. However, verifying this distinction with the available satellite imagery is impossible.

The value the CIWG placed on selecting sites that would maximize biodiversity and increase riparian vegetation could be analyzed more precisely with different methods and classification techniques. A more precise measurement of riparian vegetation could have reduced duplicity in the scoring method.

The Duplicity of Data-Watershed Scale
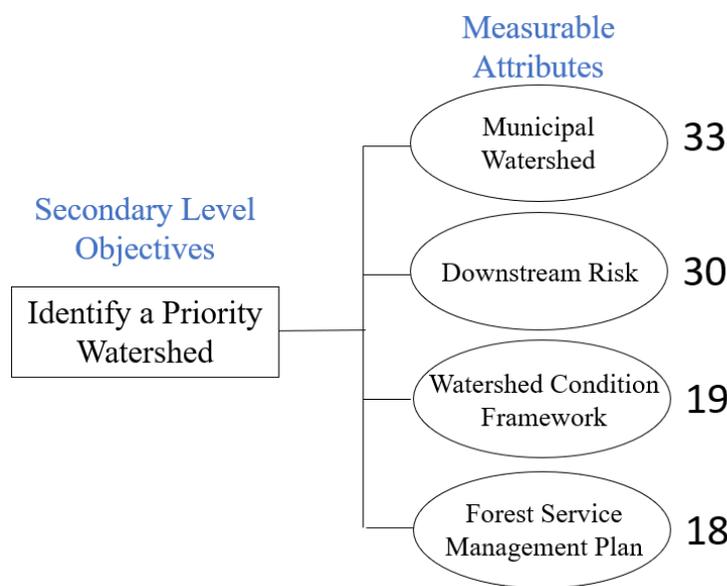
The duplicity of measurable attributes was most evident in selecting priority watersheds. Regional values play a significant role in scoring measurable attributes and applying weighted values to objectives. However, this presented a duplication of data in this data set. Both "decision makers" and members of the CIWG alike put a value on prioritizing watersheds identified by an individual forest's management plan, the Watershed Condition Framework (WCF), and whether a watershed contributes water to a drinking water supply. Because many decision-makers referenced working with overarching restoration goals associated with the USFS administrative unit, the "Land and Resource Management Plan for the Coconino National Forest"

Figure 31 Measurable Attributes for Watershed Scale Objective

was consulted. The Coconino National Forest has a watershed-centric restoration approach in its management plan. The management approach that the Coconino National Forest details:

> *"To enhance the protection of human health and safety, consider watershed treatments such as vegetation thinning, prescribed burning, and channel stabilization where protection of people, structures, and community infrastructure (such as roads, bridges, power corridors, and water supply) in and associated with the wildland-urban interface (WUI) are at risk."*

This statement is like the stated values echoed by the decision-makers. The management plan emphasized restoration work to protect "human health and safety" and "community infrastructure." It also lists specific watersheds that flow into the three municipal surface waters storage watersheds. Finally, it explicitly states that "watershed restoration…should focus on priority *(WCF priority)*…watersheds" (USFS, 2018). With these specifics, an individual forest's management plan might be the only necessary measurable attribute for selecting priority watersheds. However, investigating other management plans from forests around the West revealed that not all Forest Service management plans are created the same. The Coconino National Forest's management plan is very water resource management focused, presumably due to the shortage of water in the region. The specifics of an individual forest's management plan remain an important measurable attribute for prioritizing a watershed. However, the lack of details by some management plans requires considering other metrics in conjunction with the plan.

Like an individual forest's management plan, the WCF, a USFS-created tool for watershed assessment, classification, and prioritization, will be a necessary component of restoration work conducted in USFS-administered lands. The WCF classifies each HUC 6 watershed (average area of 160,000 km^2) based on a "12-Indicator" model assessment. The classification ranks the watersheds into three classes of functionality. The WCF recommends prioritizing Class 1

watershedsfor restoration work. However, the document also provides leeway for watershed prioritization:

> *"the task of identifying watersheds for restoration is left to the discretion of the national forests within the broad framework of national direction, regional emphasis, forest plan direction, resource value, costs, local issues, needs, the amount of NFS lands, and opportunities"* (USFS, 2011, p.11).

This caveat allows each Forest Service unit to prioritize their chosen watersheds. Again, this component of the WCF may make it seem as if a management plan might be the only necessary tool for prioritizing watersheds. However, the WCF measurable attribute was still used in spatial analysis ranking because the interview participants placed value on following the tools developed by the USFS

Table 8 Watershed Condition Classification (USFS, 2011)

Classification	Description
Class 1 (green)	Functioning Properly
Class 2 (yellow)	Functioning at Risk
Class 3 (red)	Impaired Function

Additionally, using the WCF and a management plan may not always duplicate scores. The WCF data is presented graphically with a red, green, and yellow scale (Table 8 and fig. 33), and a star indicates "priority watersheds." In the case of the Lake Mary Watershed (center of image), it has a Class 3 impaired function rating, which would generally indicate it is a low priority for restoration. However, it has been identified, with a star, as a priority because:
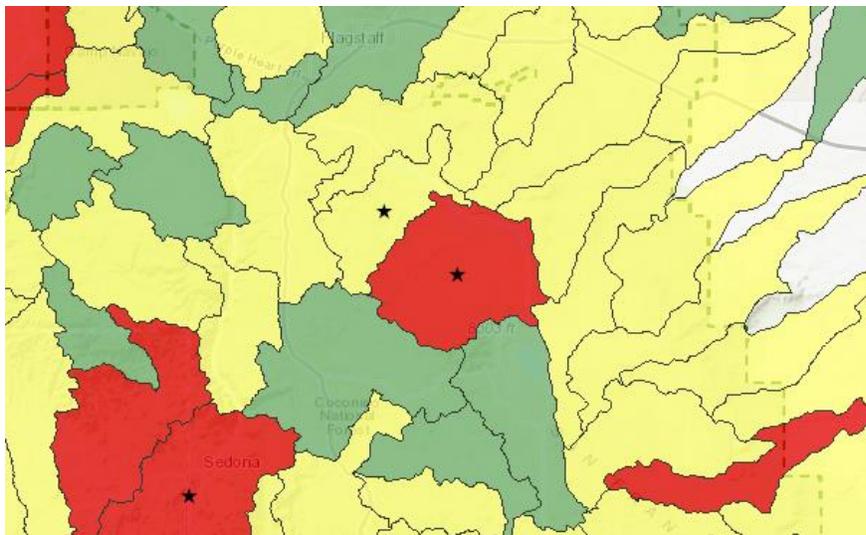

Figure 32 Watershed Condition Framework Map (https://usfs.maps.arcgis.com/apps/MapSeries/index.html?appid=f4 332e5b80c44874952b57e1db0b4407)

"This subwatershed provides municipal water to the City of Flagstaff and is located in the Munds Mountain priority fireshed, and the 4FRI Wildfire Crisis Strategy Priority landscape. There is strong partner interest in aquatic restoration in this subwatershed to improve watershed function and build resiliency to the potential impacts of wildfire and climate change. Many channels in this subwatershed are degraded, and there is an opportunity to improve channel function to promote stable sediment regimes and restore wet meadow and spring environments (Watershed Condition Framework Interactive Map, 2023).

The WCF documentation, used to support the prioritization of individual watersheds, also identified the Lake Mary Watershed as a priority for restoration because it provides municipal water to the City of Flagstaff. The management plan and the WCF remained in the scoring method because of the desire that this method apply to other ephemeral channel regions. Other individual forests do not have watershed restoration plans that are so focused on municipal drinking water, and the WCF only sometimes prioritizes watersheds that provide municipal drinking water too. Finally, because the decision-makers explicitly stated the value of drinking water sources, this measurable attribute remained part of the method. The Coconino National Forest's management plan and the WCF's priority watersheds identified the Lake Mary Watershed as a priority. Nevertheless, the measurable attribute focused on municipal watersheds remains part of the ranking method. The scores applied to the fundamental objectives hierarchy ended up placing 81% of the available scoring for watersheds on the Lake Mary Watershed. That, coupled with the weighting factor that prioritized watershed as nearly twice as important in the ranking process, resulted in all the top 10 ranked stream reaches in the Lake Mary Watershed. It also resulted in overwhelming the value of restoring post-forest fire channels because there have been no fires in the Lake Mary Watershed. Again, the duplicity in this method caused the potential for missing other stream reaches outside the watershed, which might have other values for restoration.

The Duplicity of Data-Stream Reach Scale

At the stream reach scale, additional metrics increased the duplicity of scoring in the ranking effort. Although some data layers were provided ready to use, other data layers required additional development and analysis to meet the measurement needs. The data used to estimate the extent of the wet meadows was developed visually by drawing polygons near the upland and wet meadow interface. The problem of duplicity showed up in this analysis because the wet meadow area used to prioritize sites that maximized wet meadow function was the same area used to prioritize sites that increased biodiversity. If water, through restoration, is put back onto the floodplains, then wet meadow function and riparian vegetation would be returned laterally across the extent of the wet meadows. Both metrics are important to the site selection process. Moreover, each carried a high score and weighting factor. One of the most straightforward metrics measured by the spatial analysis in the scoring and ranking method was the length of each stream reach provided by the 4FRI geospatial team (https://www.fs.usda.gov/detail/4fri/gis/?cid=fseprd493266). However, in the analysis of the stream reaches, it turned out that the reach length was the actual deciding factor for ranking sites. By removing the weights associated with watershed prioritization, the 163 stream reaches were assessed based solely on the measurable attribute scores and the objectives' weights associated with the stream reach branch of the fundamental objectives hierarchy. This analysis showed that the "longer" stream reaches were ranked the highest. The wet meadow area and the riparian vegetation area are dependent on the measure of a stream's length. The observed duplication of metrics was one of many issues that arose in the method. There was a case where two metrics, similar but intended to be different, ended up having a canceling effect on one another.

Nearly as important to the members of the CIWG was the value of selecting sites that do not have infrastructure in the way of restoration. Commonly, culverts, bridges, and low-water road crossings are drivers of degradation in stream reaches and wet meadows. There are restoration

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efforts aimed at removing these obstructions to proper functioning conditions. However, a culvert, bridge, or road may be required to maintain access or transportation services. As a result, removing these transportation-based infrastructure items is not a reasonable approach to restoration. In cases where removing these transportation-based obstructions to restoration is impossible, the restoration effort is likely to be canceled. The USFS also provides a "constructed features" layer of GIS data. This data layer lists constructed features such as bridges and culverts. However, the available data shows no culverts or bridges in the Coconino National Forest. These data may be incomplete, missing altogether, or available elsewhere. Stream reaches with roads crossing them were used in the analysis to indicate "other" infrastructure preventing effective restoration. An "intersect" analysis determined whether a stream reach had a roadway crossing it. Stream reaches without roads crossing them were given a higher-ranking priority. There were two observations associated with the potential for error with this approach. The first is that historically, roads follow stream channels and wet meadows. The wet meadows tend to be flat and relatively straight for long distances. Roadways in wet meadows are drivers of degradation and present a possible hindrance to restoration, like culverts and bridges. Roads traverse many of the wet meadows of the Coconino National Forest, yet they only sometimes cross the stream channel. This analysis identified multiple stream reaches as higher-ranked candidates for restoration work due to access. However, roadways in the wet meadows that did not cross the stream reach did not reduce the ranking as they should have due to the hindrance to restoration efforts that these roads would create. A more complete data set for culverts and bridges would help this analysis. Additionally, an adjusted approach that captures the absence or presence of roadways in wet meadows would add an additional layer of pertinent data to this approach. This analysis method also created a canceling of value for many stream reaches. Stream reaches with road access ranked higher than

those without road access. However, suppose the road crossed a stream reach. In that case, that road that increased priority for access cancels that value by presenting an infrastructure "in the way" problem and decreases the priority. Fortunately, part of the restoration efforts identified by the 4FRI is the decommissioning of roads. This analysis did not include data regarding the relocation and the decommissioning of roads. At the time of this research, it was unclear when the roads would be relocated or decommissioned. This method of site prioritization would benefit from avoiding unnecessary duplication of scores based on the metrics used to assess the measurable attributes.

Data Omitted from the Spatial Analysis

In some cases, data were omitted from the spatial analysis altogether. I omitted attributes due to insufficient available data or reliable spatial analysis methods. I omitted others because they were deemed unnecessary to the analysis.

Decision makers and CIWG members prioritize selecting sites for restoration that meet a demonstrated need for restoration. The 4FRI, in their ROD, indicated that none of the 163 reaches are functioning properly (USFS, 2015b). They are indicating that all the reaches need restoration. The degree of degradation narrows the search for sites needing restoration and identifies sites with the highest likelihood for successful restoration. Like the triage method used in emergency

Table 9 Degree of Degradation Defined

Degree of Degradation	Description and Estimation of Benefits
Minimally degraded	Near proper functioning condition. Minimal restoration effort is required with maximum return to ecological benefit.
Degraded	There is some degradation and a risk of severe degradation without restoration—high return on investment.
Severely Degraded	The effort to restore is cost prohibitive. High risk of failure. Minimal return on investment.

medicine, the reaches range from severely to minimally degraded. The results of the scoring efforts by the CIWG place their values on restoring the degraded reaches. Reaches that are "degraded" can be restored to proper functioning condition but are not "severely degraded" beyond repair. There are no known, accepted methods for estimating the degree of degradation across multiple ecological metrics of ephemeral channels. Spatial analysis methods can estimate erosion loss across landscapes and stream channels (Khanday & Javed, 2016; Trabucchi et al., 2013). However, these methods require site-specific data collection. Neither data are available for the sites identified by the 4FRI. To date, assessing the degree of degradation requires on-site field investigations and analysis. As a result, I omitted the degree of degradation from the spatial analysis tool.

The decision makers' input indicated that the stream restoration site selection should be motivated by creating some restored state for fish. Fisheries biologists, watershed scientists, and hydrologists repeatedly emphasized the value of selecting sites to benefit fish. The fact that there are no fish in the ephemeral channels of the 4FRI did not justify simply disregarding these expert opinions. As previously discussed, the decision-makers emphasis on fish was adjusted to emphasize any priority species. This identification method that would benefit critical habitats or species listed on the Threatened and Endangered (T&E) Species list was considered pertinent to selecting sites for restoration as a surrogate to fish. Selecting sites for restoration that would benefit a priority species was considered a valuable attribute for the fundamental objectives hierarchy. However, the need to include this measurable attribute became unnecessary based on the specific details of T&E species, critical habitat, and the range of Elk *(Cervus Canadensis)*. The range and habitat of Elk are so widely distributed across the 4FRI that there would be no discernible differences between any of the ephemeral channels. Similarly, none of the species listed on the T&E list have a focused habitat associated with the ephemeral wet meadows of the 4FRI. There

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would be no discernible change in ranking by including or excluding T&E species, critical habitat, or elk habitat in the spatial analysis. As a result, I did not include this metric in the final ranking spatial analysis.

Spatial Analysis-Top 10 Ranked Stream Reaches

Figure 33 Top 10 Reaches-All Located in Lake Mary Watershed
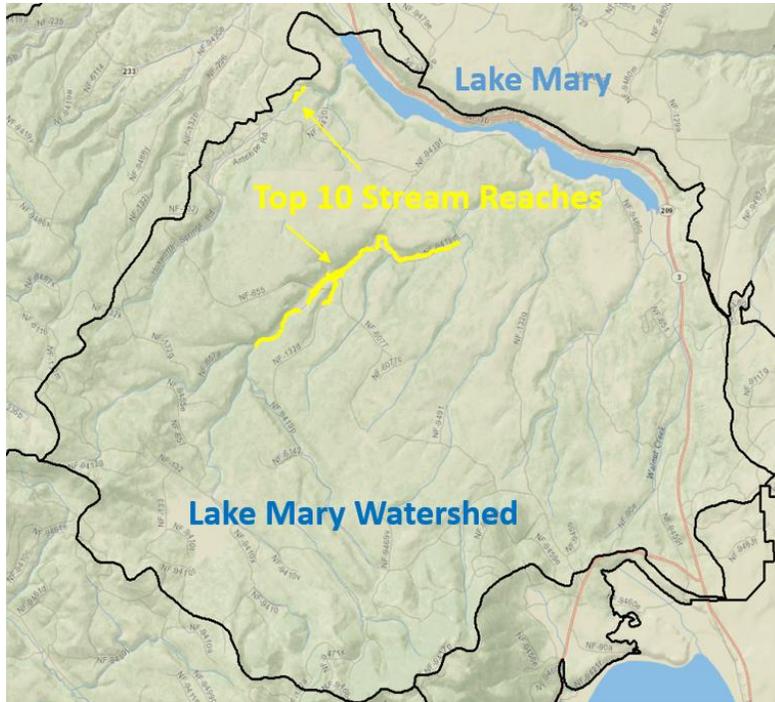
Table 10 Top 10 Stream Reach Ranks-Max Score=86

Rank	FID	Score
1	23	66.38
2	104	66.38
3	36	64.9
4	22	64.26
5	105	64.26
6	106	63.61
7	102	63.47
8	103	63.47
9	57	62.13
10	39	59.23

The results of applying the scores and the weighting factors from the CIWG semi-structured interviews produced scores for all 163 reaches of ephemeral channel identified by the 4FRI ROD. Because there were measurable attributes, and one stream reach objective, omitted from the spatial analysis methods, the maximum possible score would be 86.26 points. The highest score calculated for the 163 stream reaches was 66.38, and two stream reaches scored this highest-ranking value. All top 10 ranked stream reaches, and 19 of the top 20 are in the Lake Mary Watershed (Table 10 and fig. 35). Appendix A provides a complete listing of all stream reach ranks. Appendix B provides a sorted listing of priority ranks.

Comparative Analysis of CIWG Priorities

The CIWG submitted a restoration proposal to the Coconino National Forest and the 4FRI that identified 44 reaches of ephemeral stream channel to be restored. The proposed reaches identified in the CIWG proposal are from the original 163 reaches identified in the 4FRI ROD document. Here, a comparative analysis examines the CIWG proposed reaches and the ranking they received by applying the fundamental objectives hierarchy spatial analysis tool.

The CIWG proposal prioritized the ten highest-ranked reaches. Concerning the next ten (11-20) ranked reaches, they missed four of the reaches ranked by the fundamental objective hierarchy and the spatial analysis. The CIWG proposal also prioritized a reach that ranked 120th. Three subbasins with reaches identified by the CIWG proposal ranked such that all scores were less than 33, which is 36th in the ranking priority.

The 4FRI

Based on the scale of the suite of restoration efforts approved for the 4FRI efforts, this is an ambitious project. The ephemeral channel restoration efforts have been hampered by; uncertainty, and lack of well-defined and explicit goals, transparent and easily repeatable site selection method, a collaborative timing plan to work in concert with the thinning and burning, and road decommissioning efforts. Although the ephemeral channel restoration efforts are beginning to gain traction eight years after the completion of the ROD, there are still barriers standing in the way of initiating and completing the successful restoration of ephemeral channels.

Stream Reach Data-4FRI

The 4FRI undertook a very large-scale restoration effort (Fredette, 2016). The draft environmental impact statement (DEIS), Included the data set representing the 39 miles of ephemeral channel as 163 individual reaches (USFS, 2013). Through the National Environmental Policy Act (NEPA) process, including the final environmental impact statement (FEIS) and the ROD, the data set of ephemeral channels was selected for all alternatives (USFS, 2015b, 2015a). The data set came from the National Hydrography Data (NHD) analysis of all stream channels in the 4FRI area presented in the Water Quality and Riparian Areas Specialist's Report by soil scientist Kit MacDonald. This data set includes 2,197 miles of stream courses (MacDonald, 2013). However, the data set does not explain why or how the 39 miles of stream channels were selected from the 2,197 miles of stream courses. There needs to be documentation and a discernable method to support why these sites were included in the recommendations, from the DEIS through the ROD. The report mentions 77.5 miles of "protected stream courses." Again, there is no description or definition regarding what classifies a stream course as "protected" (MacDonald, 2013).

As has been repeatedly stated throughout this document and in the published literature, there is value in site selection methods that are transparent and easily repeatable (Hyman & Leibowitz, 2000; Nehlsen, 1997; Trabucchi et al., 2013; Uribe et al., 2014). Due to the lack of transparency or any discernible method used to identify and prescribe the 163 stream reaches as candidates for restoration, I recommend that the 4FRI reconsider limiting their efforts to these 163 reaches. The results of the value-based scores and weights established by the CIWG demonstrated a high priority placed on restoring stream reaches in the Lake Mary watershed. Here, the restoration efforts would benefit from selecting other sites in the Lake Mary watershed excluded from the data of the ROD.

Another consideration concerning the 163 reaches is the standard by which "reaches" were initially identified. Among the list of candidate reaches identified as the 163 ephemeral channels, many of these are contiguous with one another. The 4FRI effort would benefit from merging the contiguous reaches and analyzing them as one grouped restoration site instead of multiple sites. One of the stream reaches is 4.5 feet long, and it is contiguous with 14 other reaches. I recommend analyzing this collection of 15 reaches as one site for prioritization analysis. Furthermore, the combined contiguous sites would reduce the cost of completing restoration at one large-scale site instead of multiple small restoration projects.

Well-Defined Goals of Restoration

The stated goal in the 4FRI ROD is to return all 39 miles of ephemeral channel to properly functioning conditions (USFS, 2015b). There is a long-time recognition of the need for explicit, well-defined restoration goals (Barber & Taylor, 1990). Well-defined goals are crucial in the site selection process and valuable evaluation metrics of restoration projects (Bernhardt et al., 2007). Although there are differences between a general goal of restoration and site-specific goals developed after sites are selected for restoration, the 4FRI effort would benefit from a more developed goal for restoration. This goal could include specifics aimed at hydrological and geomorphological processes and functions. They could establish general goals for restoring any site in the 4FRI, but they should develop goals more specific than "proper functioning condition."

The CIWG-Site Selection

The members of the CIWG provided valuable information for the measurable attributes, the scores, and the weighting factors in this research. They were crucial to developing a transparent and easily

repeatable site selection method. This iteration of the site selection method should be adjusted following the above discussion points and recommendations.

In September of 2022, 7 months prior to the development of this site selection method, the CIWG submitted a restoration proposal to the 4FRI leadership and the supervisors of the Coconino National Forest. The CIWG moved forward with a recommendation to the 4FRI and USFS supervisors with a list of recommended sites for restoration. The primary task of the CIWG is to identify and complete "non-thinning and non-burning" restoration projects for the 4FRI. They are making efforts to begin the restoration of ephemeral channels finally. A critical analysis, discussion, and recommendations are presented here with the proposed restoration sites identified in their letter.

Stream Reach Data-CIWG

The CIWG made some beneficial recommendations to the 4FRI, and the Coconino National Forest supervisors supported by the published literature on site selection methods. Concerning the 39 miles of ephemeral channel identified in the 4RI FEIS, the CIWG recognized the need for supporting documentation to guide the restoration of the 163 reaches. Furthermore, they refer to the potential need to work beyond the initial reaches. Here they recognize and recommend the value of completing restoration in contiguous channel reaches not identified by the 4FRI FEIS or ROD. Recognizing the need to restore other ephemeral channels not included in the 163 reaches benefits the site selection process. If the 4FRI and Coconino National Forest supervisors approve the request to complete the restoration of channels not previously identified, this could be a step in the right direction that could potentially open the site selection process to allow for selecting high-value ephemeral channel sites not previously included.
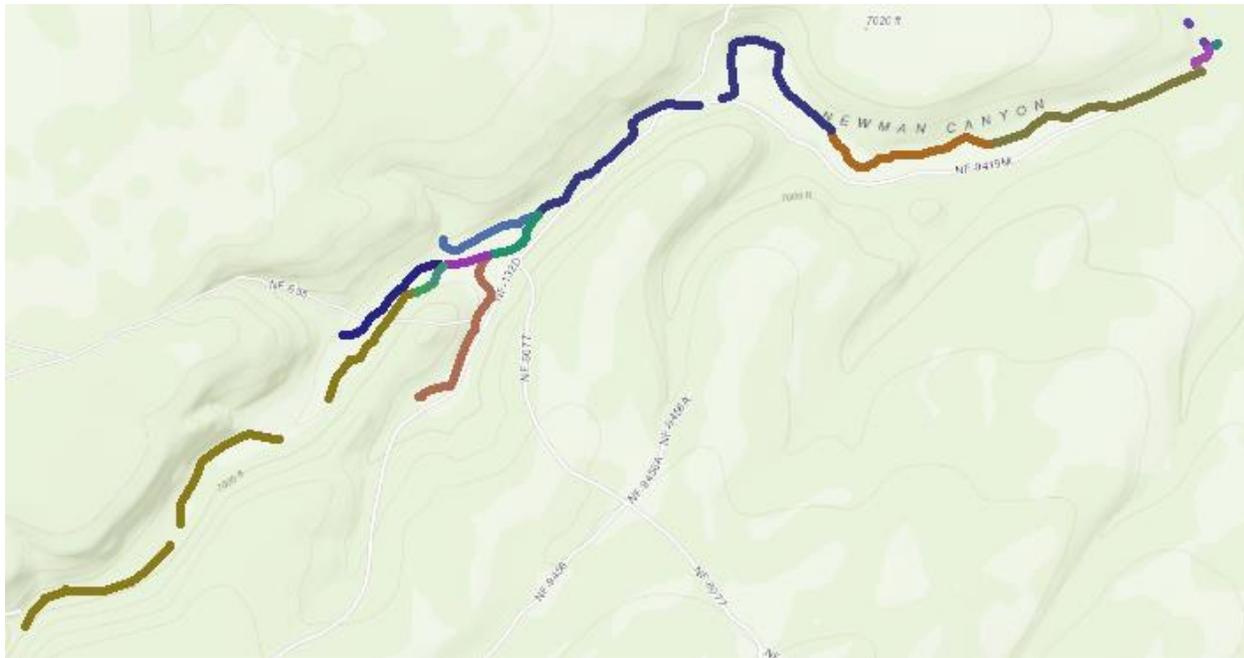
Figure 34 Fifteen Individual Stream Reaches in Newman Canyon

In addition to recognizing the value of prescribing restoration work to reaches that the 4FRI

documentation had not previously identified, the CIWG appears to have grouped contiguous

reaches as one restoration site. It is unclear whether all 15 reaches initially identified in the

Newman Wash area of the 4FRI effort were combined as one reach. What is clear is

that the document recommends Newman Canyon as one of their priority restoration projects.

Suppose it is the case that the CIWG has included all 15 reaches in the prescribed restoration effort

(fig. 36). Combining multiple reaches will maximize wet meadow function, riparian vegetated

area, and channel length restored while selecting a site with road access. One shortcoming of their

restoration effort is that they did not specifically recommend decommissioning the road which

crosses the ephemeral channel of the wet meadow of Newman Wash. Although, this oversight may

have been because the GIS layers identify this road to be decommissioned

(https://www.fs.usda.gov/detail/4fri/gis/?cid=fseprd493266) provided in support of the 4FRI ROD

(USFS, 2015b). The other stream reaches identified by the CIWG appear to have combined contiguous reaches or reaches in the same smaller-scale subbasins as single restoration projects.

Goals

The CIWG identified the failure of the 4FRI documentation to provide specific restoration recommendations or goals. The 4FRI focuses on the general direction to "increase functional condition." The general goals that the CIWG defines are specific to the sites they identify for restoration. They go further in the definition of increasing the functional condition by classifying statements that help describe functional condition goals (Table 11). The efforts undertaken by the CIWG have defined a more explicit set of goals. This improvement to the restoration goals is a step in the right direction. Additionally, their goals could assess the restoration outcomes and monitor the long-term effectiveness of the restoration actions.

Table 11 Explicit Goals Used to Define Functional Condition

Explicit Goals Used to Define Functional Condition
Treating adjacent forests to promote a natural grassland meadow with a sustainable forest density adjacent to the meadow.
Establishing a stable road network that can be used for forestry practices while not promoting channelized flow leading to gully erosion.
Establishing a stable, natural channel that is connected to its floodplain
Establishment of grade control structures to prevent any future channel incision
Arrest channel incision, restore adjacent channel vegetation
Expanding the extent and viability of current riparian vegetation is another goal.
Reduce the head cutting
Provided improved conditions for the establishment of riparian vegetation
Relocate the road out of the valley bottom to restore vegetation and hydrological function to the channel.
Reduce erosion and sediment contributions.

Comparing CIWG Recommendations with Scores and Weights

In the fall of 2022, the CIWG sent a letter to the leadership of the Coconino National Forest and 4FRI. In the letter, the CIWG recommended sites for restoration. Here, I compare the recommendations from that letter to the ranks that the reaches have based on the results of analysis using the fundamental objectives hierarchy. To provide a distinction, I will use the following acronyms: FOH-R and CIWG-R. FOH-R represents the reaches based on ranked scores from the fundamental objectives hierarchy analysis. CIWG-R represents the recommendations from the CIWG.

The CIWG-R recommended the restoration of channels in six distinct areas. They recommended restoration in Marshall Mesa, one reach along Forest Service Road 296, Priest and Howard Draws, The Clark Complex, The Hoxworth Springs (channel), and Newman Canyon (fig. 37). The CIWG-R recommendation did not identify restoration work for individual reaches; instead, they combined contiguous channels and identified multiple reaches at a subbasin scale to increase connectivity between restored and functional wet meadow systems. The clusters of CIWG-R recommendations identify channels outside of Lake Mary Watershed.
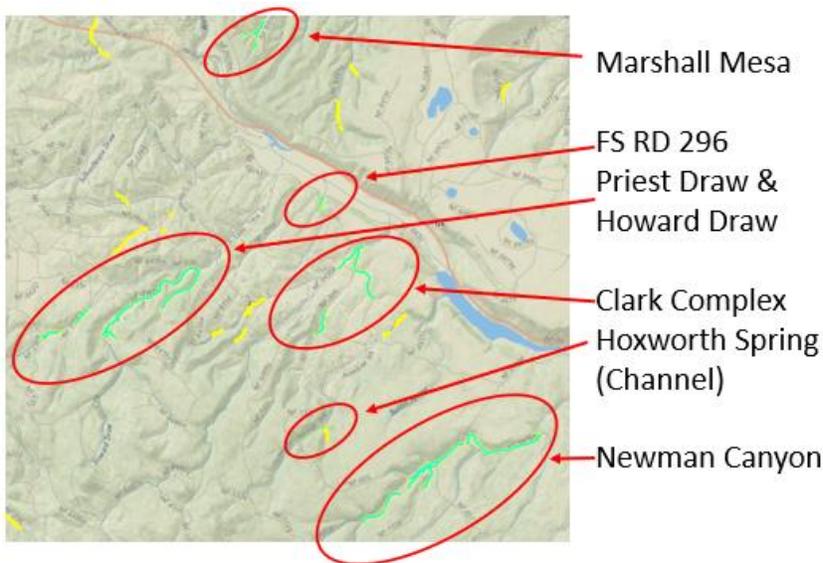
Figure 35 Clusters of CIWG-R Recommended Reaches

The FOH-R prioritized selecting sites in the Lake Mary Watershed because of the values related with watersheds associated with drinking water sources, those prioritized by the WCF, and those prioritized by a forest service's management plan. As a result of the weighting factor put on one watershed, stream reaches in the Lake Mary Watershed achieved a minimum rank of 46/86 simply for being in this watershed. The highest-ranked reach outside the Lake Mary Watershed was 40/86. Of the six clusters of CIWG-R areas, two are in the Lake Mary Watershed. However, the other subbasins are located outside the Lake Mary Watershed. Thus, several lower-ranking reaches were identified as priority reaches by the CIWG-R. The lowest-ranked reach identified by the CIWG proposal document was 7.8/86. The raw data sorted by FOH-R (rank) and CIWG-R (name) is in Appendix C. The data sorted by cluster is provided in Appendix D.

Conclusion

This study illuminates the need for proper planning methods for ephemeral stream channel restoration. The three distinct articles that detail this study identify the limited social recognition and appreciation afforded to ephemeral stream channels and build on that imbalance to emphasize the need for scientifically supported decision-making methods. The first article made the point that site selection methods are critical to the planning phase of stream restoration projects. Furthermore, it identifies the absence of previous discussions on planning methods for ephemeral stream channels. The practices common throughout the site selection literature are the development of goals, the selection of measurable criteria, and methods for applying values for criteria to a ranking system. The development of goals has evolved over years of ecological restoration efforts. Goals need to be founded on both scientific and social needs. They need to be explicit, and they should be used to measure outcomes upon completion. The selection of criteria to measure sites comes from the development of goals. There are two critical considerations to the selection of appropriate

criteria. First, the criteria must be measurable, and the results must provide information to guide the decision-making process. Second, the criteria must be founded on scientifically supported ecological functions and processes, however, fully supported by regional social values. Following goals and measuring site-specific criteria, site selection methods must incorporate regional and scientific values and apply a metric for identifying priority sites for restoration.

The second manuscript highlights the need for professional judgment and expert insights. The information provided through interviews with experts in stream restoration provided a list of fundamental decision-making factors. Through stakeholder participation, I demonstrated how broad expert opinion could be adapted to meet focused regional needs. The collaborative effort resulted in identifying criteria that were deemed socially important in a distinctive region. The method I applied to this process could be adjusted and implemented in other regions where opinions and social needs differ.

This manuscript goes on to demonstrate a calculation method. Regional values informed the scoring metrics that were applied to measurable criteria. Moreover, perceived levels of importance were applied as weighting factors. Furthermore, this manuscript demonstrates a novel calculation method incorporating an expert-informed and stakeholder-supported method for applying weighted objectives and measurable criteria to a site selection method.

The third manuscript focuses on implementing a spatial analysis method for effectively and efficiently applying a site selection method. The spatial analysis tools I developed calculated the ranks of 163 distinct candidate sites for restoration. My analysis applies 16 distinctively measurable criteria and six weighting factor objectives. The analysis was built on open-sourced data and standard GIS mapping techniques. The development of this method, as applied to a large-scale forest restoration project, could be adapted for use elsewhere. Although the site selection and

spatial analysis methods were not novel, it is to apply such efforts on ephemeral stream channels. The application here can inform the decision-making as these ecosystems are increasingly prioritized for restoration.

Key Findings

I identified the need for this dissertation based on the absence of efforts aimed at site selection methods for ephemeral stream channel restoration. The demonstrated need for site selection methods is clear. The scientific value and social perceptions of ephemeral streams are increasing. Accompanying this increase in understanding is an increase in the implementation of stream restoration efforts to restore ephemeral streams. Reflecting on the research questions that motivated this study-- 1) What factors influence decision-making for restoration initiatives in riverine ecosystems in Ponderosa Pine Forests? 2) How can decision-making factors be developed into a prioritization method for ephemeral stream channel restoration? 3) How can a site prioritization method be modeled using spatial analysis to rank priority sites for restoration? – several key findings were produced.

First, the criteria used to measure stream restoration sites is regionally dependent. The overarching regional values of experts and stakeholders are demonstrated by selecting criteria that represent the greatest potential benefit. Additionally, the scores and weighting factors will further demonstrate that regional restoration values are distinctive. As evidenced in Chapter IV, the list of deciding factors developed by experts throughout the extent of ponderosa pine forests in the West differed greatly from the criteria selected by stakeholders in 4FRI. This difference is attributed primarily to the dichotomy between perennially present waters and the absence thereof in regions

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dominated by ephemeral systems. Modifying the fundamental objectives hierarchy to include regionally specific criteria will be necessary if using the methods developed here.

The second finding is that site-specific criteria are distinctive in ephemeral stream systems. There are similarities between perennial and ephemeral systems. While fish habitat is paramount for perennial stream channels, wet meadow function and freshwater provisioning as well as high flood risk areas seem to take precedence in ephemeral stream restoration considerations. This distinction is significant as many interview respondents mentioned that funding is more readily available for habitat restoration. Thus, elevating awareness about the critical role ephemeral streams play for water provisioning and resilience to fire will be important to put such restoration efforts on par with endangered species funding.

Lastly, the concept of spatially modeling the criteria of riverine systems is not new, however, developing a spatial analysis tool for ephemeral streams required a novel measurement method. From a spatial analysis perspective, wet meadow function had not been measured previously. This unique application to ephemeral streams can help advance the various stages of ESC restoration from setting explicit restoration goals, to selecting sites, and seeking support from stakeholders.

Where To Go from Here

The field of stream restoration is growing. The recognition that ephemeral streams have important ecological values is evidenced by the 4FRI effort to restore them. It is critical that planning for the restoration of ecological streams includes the key findings and fundamental themes answered by this study. Planners need to establish well-defined goals based on regional input from experts and stakeholders. Fundamentally, criteria selection is based on regional stakeholder input and founded

on a scientific understanding of ecological processes. The application of ecological processes of ephemeral streams represents a new field of research and application for planning. Finally, the methods for measuring criteria need to be carefully considered.

The aim is for this project to bring attention to ephemeral stream restoration. The restoration of ephemeral streams improves forest health, increases water security, and increases ecosystem services. Research on ephemeral streams, the planning for restoration, and the benefits of their restoration would be appropriate for all branches of ecological restoration professionals.

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Appendix A-Deciding Factors

Deciding Factors for Selecting Restoration Sites	Rank top 5 Specific	Top 5 General
Biodiversity		
Carbon sequestration		
Climate adaptation and mitigation		
Connectivity of Multiple Sites		
Cost of Restoration Project		
Damage to Infrastructure		
Degree of Degradation		
Do No Harm-Measurable Improvement		
Downstream Flooding		
Drivers of Degradation		
Ease of Access for Restoration Activities		
Economics-Other than Cost of Restoration		
Floodplain Access		
Forest Health		
Groundwater Recharge		
Keystone-Single Species		
Multiple aquatic species		
Multiple terrestrial species		
Need for Restoration		
Recreation		
Reduce property loss from soil erosion		
Resilience		
Soil Health		
Stream Energy-Gradient/Velocity		
Total Area of Watershed Restored		
Total Length of Channel Restored		
Water Quality		
Water Quantity		
Other?		

Appendix B-Terms of Search

The databases searched included: Web of Science, GeoRef, CAB Abstracts, and Agricultural and Environmental Science Collection.

Keywords used to capture the concept of ephemeral streams (or related concepts) included: "ephemeral channel" OR "ephemeral channels" OR "ephemeral stream" OR "ephemeral streams" OR "ephemeral river" OR "ephemeral rivers" OR "intermittent stream" OR "intermittent streams" OR "intermittent channel" OR "intermittent channels" OR gully OR gullies OR watershed OR watersheds OR riparian OR streams OR river OR gully OR gullies OR arroyo OR coulee OR runoff OR ephemeral OR catchment

Keywords used to capture the concept of decision-making included: "decision analysis" OR "decision making" OR "decision support systems" OR "decision support" OR "cost analysis" OR "cost benefit" OR "site selection" OR "analytic hierarchy process" OR "hierarchical systems" OR "contingent valuation" OR "prioritization model" OR "prioritization models" OR "prioritization modelling" OR "prioritization tool" OR "prioritization tools" OR "prioritization matrix" OR "prioritization matrices" OR "prioritization system" OR "prioritization systems" OR prioritization OR prioritize OR priorities OR rank OR ranking

Keywords used to capture restoration efforts included: restoration OR restore OR restored OR rehab* OR remediate*

Appendix C-Ranking Data v. CIWG Recommended Sites

Name	Reach	Rank		Name	Reach	Rank
Newman	104	66.38		Clark Complex	27	32.72
Newman	23	66.38		Clark Complex	61	32.72
Newman	36	64.9		Clark Complex	10	32.72
Newman	22	64.26		Clark Complex	24	29.12
Newman	105	64.26		Clark Complex	26	28.47
Newman	106	63.61		Clark Complex	6	26.35
Newman	102	63.47		Clark Complex	62	24.21
Newman	103	63.47		Clark Complex	37	18.49
Newman	57	62.13		FS Rd 296	55	7.8
Hoxworth	67	55.75		Howard	94	31.24
Newman	100	54.97		Howard	13	28.47
Newman	107	54.27		Howard	92	26.35
Hoxworth	68	52.15		Howard	146	25.71
Newman	99	50.72		Howard	14	25.57
Newman	69	50.72		Howard	38	21.31
Clark Complex	27	32.72		Howard	98	21.31
Clark Complex	61	32.72		Howard	9	18.49
Clark Complex	10	32.72		Howard	113	0
Howard	94	31.24		Hoxworth	67	55.75
Priest	96	30.6		Hoxworth	68	52.15
Clark Complex	24	29.12		Marshall Mesa	3	14.46
Howard	13	28.47		Marshall Mesa	52	14.46
Priest	119	28.47		Marshall Mesa	4	10.12
Clark Complex	26	28.47		Newman	104	66.38
Howard	92	26.35		Newman	23	66.38
Clark Complex	6	26.35		Newman	36	64.9
Howard	146	25.71		Newman	22	64.26
Howard	14	25.57		Newman	105	64.26
Clark Complex	62	24.21		Newman	106	63.61
Priest	97	22.09		Newman	102	63.47
Priest	11	22.09		Newman	103	63.47
Priest	12	22.09		Newman	57	62.13
Priest	45	22.09		Newman	100	54.97
Howard	38	21.31		Newman	107	54.27
Howard	98	21.31		Newman	99	50.72
Howard	9	18.49		Newman	69	50.72
Priest	93	18.49		Priest	96	30.6
Priest	15	18.49		Priest	119	28.47
Clark Complex	37	18.49		Priest	97	22.09
Marshall Mesa	3	14.46		Priest	11	22.09
Marshall Mesa	52	14.46		Priest	12	22.09
Marshall Mesa	4	10.12		Priest	45	22.09
FS Rd 296	55	7.8		Priest	93	18.49
Howard	113	0		Priest	15	18.49