Pressing Lower Gallatin Valley Environmental Issues

2023 - MSU Land Resources Capstone
Led by William Kleindl, PhD.

Early in the spring of 2023, Dr. Kleindl contacted many local environmental leaders and managers and provided them with the following prompt. –

We recognize that you have limited staff, and when you have critical management questions that require complex solutions, you will often subsidize your staff with consultants. These consultants apply very special skills to the issue at hand, and once that project is complete, the consultants leave your service. However, there are likely other management questions that have not elevated to a level where you engage expensive consultants. Still, you likely wish you had time to learn more to make informed decisions in the future. We want to offer our service to address these issues. Therefore, we would like you to meet our Spring 2023 LRES Capstone Class to present these issues. Our students will spend the semester looking into the related peer-reviewed and gray literature and, where appropriate, provide some initial analysis. We will present our findings with a presentation and documentation at the end of the semester.

On February 8, 2023, the Spring LRES Capstone class met with local environmental leaders and managers. The following is a very brief summary of what they presented:

Torie Haraldson and Eric Trum DEQ – Wetland section water quality standards TMDL implementation.

- DEQ has about $1mil/year available to address TMDL issues within the state, yet they have a difficult time finding individuals to take advantage of these funds
  - How do you convince people to maintain water quality? Incentive-based approach.
  - What are the barriers to getting people to take action?
- Where should projects that address water pollution be prioritized, given trends in environmental change?
- What are the most efficient measures of restoration effects on water quality? Results/ Foot or square foot. BMPs as a proxy to actual actions. (number of cows vs. bottles of samples)
- Nutrient mobility mapping from source to ground/surface water disconnect between standards for ground and surface water.

Travis Horton (and others) Gallatin County *Director of Environmental Health Services*

- Managing water quality and quantity is really managing people. There is a psychology-sociology human dimension, for instance, developing pressure starting to come up against more environmentally sensitive areas.
- Septic has minimum criteria for drainage, but there are limits due to high groundwater. If that happens, they go to the health board to fix it. Usually through sand mounds. So that they can get 40 inches of separation from groundwater. Sand mounds are common knowledge, but no proof that sand mounds meet that standard.
- Groundwater flow maps are important, but not all the county is developed.
- The seasonal flux of nutrients. Low in high water, high in low water.

Addi Jaden Parks

- Park Planning and citizen engagement - Bozeman Parks and Recreation say sensitive areas are not parks. Instead, the HOA is responsible for maintaining the sensitive area. But does that work? See PROST (https://www.bozeman.net/departments/community-development/planning/community-plans-documents-reports).
- For instance, in Missoula and other places, steep slopes, wetlands, and streams are parks, but where is there room for other park amenities like basketball courts?
- How do we blend these? How do we meet the criteria set in the new PRAT plan? SITES like LEEDS. Prat - https://engage.bozeman.net/pratplan.
- What are critical lands? Are they more important than parklands? Again, this is an ecosystem question.

Karen Boyd Geomorphologists

- Natural storage. Saturate the sponge (more water-holding capacity in soils).
- Before starting a project, she asks: "How is this system broken, and what drove that break? Can we fix the stressor before we restore the system?"
- The big fix for our region is more floodplain connectivity with channels.
- How does the historic landscape interact with the current landscape?
- What are the mechanisms to instream flow? Wetlands are integrated into human processes. Can we do two things at the same time?

Lilly McLain Gallatin watershed council

- Rocky Creek (East Gallatin River) near MSU Ag station Ms. McLain wants the railroad, MSU, and property owners to work on restoring this section of the river. But it needs the county floodplain commission, MSU, City, and Rail to board. Every project has opportunities and constraints. Lilly and her team need talking points and data to help convince those players to be involved.
- What are the most effective ways to measure project success?
- How do we define critical lands? Can these definitions be shared in these reg updates?
- Bozeman Code updates. Better language is needed to protect existing trees, wetlands, watercourses, and open space. There is a green infrastructure toolkit (from somewhere) that can help.
- Can Gallatin Valley be nutrient neutral?
- Why aren't folks coming to conservation meetings?

Russel Smith – Bozeman Stormwater.

- What does the literature say about stormwater retention/detention ability to manage nutrients? Especially around high groundwater.
- Are stormwater retention/detention structures performing to their design?

Haile Houghton Gallatin Valley Land Trust.

- How does increase recreational use affect on plant community on Pete's Hill?
- Trail management has a positive/negative effect on the environment.

On May 3. 2023, the Capstone students met with these leaders and several members of the general public to present their findings. The following document provides the details they introduced in the presentations. The document is a combination of separate papers from five groups and is organized as follows:

1.0 Strategies for Identifying and Protecting Sensitive Lands in the Gallatin Valley

Ali Doggett, Daniel Engen, Paige Schlegel, Zach Horsman

Given the rapidly escalating development pressures currently facing Gallatin County, planners must deal with the challenge of balancing urban and economic development with the preservation of regional ecosystem integrity, and the conservation of natural resources. In a practical sense, this entails the allocation of resources toward preserving environmental areas critical to the integrity of natural ecosystems and human well-being. However, difficulties surrounding this task have raised questions from various officials from the Montana DEQ and Bozeman Parks Dept and the Bozeman Watershed Council at our February 8, 2023 meeting. This review aims to answer three of these questions. First, a clear definition of what constitutes an "environmentally sensitive land" will be provided, along with several examples of how other municipalities codified definitions of sensitive lands in their respective zoning codes. Using case studies from Washington State and Colorado, we will examine where previous efforts to protect sensitive lands have succeeded or failed. Finally, we will describe specific methods and frameworks of sensitive land identification and suggest how Bozeman might successfully designate and protect sensitive lands provided.

What are sensitive lands?

Regardless of how carefully conceived a city's comprehensive plan may be, the pressures of an expanding population inevitably entail the conversion of *some* natural or agricultural land to urban use. Recognizing this, many plans call for selective preservation of certain natural areas, often designated as some variant of 'Critical Areas' or 'Environmentally Sensitive Areas'. The terms used to refer to these areas vary, and the criteria used to designate such areas are not consistent, however, the broad intent behind such designations is to conserve "*landscape elements considered particularly important to the maintenance of biodiversity, water quality, and other natural resources, particularly as they contribute to human well-being"* (Jennings and Reganold, 1991).

Environmental, Cultural, and Economic Components of Sensitive Lands

The landscapes surrounding us are integral to all aspects of life. These lands' supportive services extend much further than human activity and are intricately intertwined. By separating these services into overarching concepts, a more comprehensive analysis can be constructed. Environmental, cultural, and economic sensitivities are highly relevant in conversations about sensitive lands and can be considered the three pillars of this discussion(Corral & Acosta, 2017). The environmental component involves identifying areas that require protection due to higher ecological sensitivity. Preserving fragile ecosystems maintains their natural balance and minimizes habitat fragmentation while simultaneously preserving both water quality and water quantity. Culturally, sensitive land delineation aims to recognize the cultural importance of community involvement in the decisions surrounding land usage. Landscapes hold significant social and cultural value related not only to the recreational opportunities they provide but also to traditional uses and customary rights to the land. The public's perspective and interests must be considered when deciding what defines a sensitive land. The economic pillar considers the monetary value of land that comes from its potential for agriculture, forestry, water filtration, and mining among other uses. Balancing economic development with environmental conservation is difficult and complex as the long-term benefits of both actions must be considered. Sensitive land delineation is therefore crucial because it outlines the areas that are suitable for sustainable development that supports the economy while preventing land use changes that could cause irreparable environmental damage, which in turn affects the livelihood of the community.

An academic framework for classifying environmentally sensitive lands

Despite the importance of such designations in sparing sensitive ecosystems from development, the question of what exactly defines an 'environmentally sensitive area' (ESA) remains unanswered. Nearly every comprehensive plan published in the past 50 years provides a different definition for what constitutes an ESA, and some plans omit clear definitions entirely (Jennings, 2007).

A useful framework for classifying different types of ESAs is described in Steiner et al., (2000). Four categories of ESAs are suggested: *natural hazard areas, ecologically critical areas, perceptual and cultural areas, and natural resource areas* (Figure 1). *Natural hazard areas* consist of lands with a higher likelihood of a natural hazard occurring (i.e., landslide, flood, earthquake damage) that may result in the loss of life and property if developed. In the context of Gallatin Valley, this means areas vulnerable to flooding, wildfire, or landslides. *Ecologically critical areas* typically refer to riparian and wildlife habitat areas, however, the importance of including areas necessary to maintain the essential character and integrity of the environment is also noted. *Perceptual and cultural areas* consist of areas containing significant scenic or cultural resources Finally, *natural resource areas* consist of lands capable of provisioning commodities such as timber, minerals, water, or agricultural products.

Case Studies: The Variability of Factors Included in Critical Land Considerations

The selection of which sensitive areas to protect will vary depending on the environmental, cultural, and economic constraints found between regions. The State of California has an extensive protection plan regarding oil spills and their potential to adversely affect the 400 designated sensitive areas of California's coastal region (Price & Klumpp, 2005). The oil spills in the late 1960s in the California area spurred the creation of a contingency plan in the case of an oil spill and since then the plan has evolved with the best available science (Lindstedt-Siva, 1977). The recreational and commercial value of California's coast and the protection of the sensitive areas and intact habitat were the priorities that framed this plan considering the environmental, cultural, and economic importance of those areas.

The State of Washington's State Environmental Policy Act (SEPA), mandates that a standardized environmental impact statement be created for projects meeting a tightly defined threshold for the significance of its environmental impact (RCW 43.21C.031). SEPA codifies a definition of 'critical areas' – its preferred term for ESAs. It also provides 'Best Available Science' citations to be used in designating such areas, as well as long lists of definitions for each term used in the law (Washington State Office of Community Development, 2002). In these regulations, *critical areas* are defined as *"... the following areas and ecosystems: (a) wetlands, (b) areas with critical recharging effect on aquifers used for potable water, (c) fish and wildlife habitat conservation areas, (d) frequently flooded areas, and (e) geologically hazardous areas"* (RCW 36.70A.30). The definition also specifies that these cannot be applied to man-made features such as irrigation ditches. To yield real-world results, the bill adopts an approach of delegation of authority to counties and municipalities, as facilitated by the legal framework of the bill. (Jennings et al., 1988).

Why have previous efforts failed or succeeded?

While zoning policies and development regulations undoubtedly serve a vital role in sparing sensitive lands from development, doubts have been raised surrounding the real-world effectiveness of such policies. In a review of efforts undertaken by Whitman County toward the implementation of SEPA in Washington State, Jennings and Reganold, (1988) describe a "substantial difference between governmental policies and actual conditions in Whitman County concerning ESLs" (Jennings and Reganold, 1988). This gap between policy and implementation was attributed to Whitman County's possession of "neither the fiscal resources nor the technical expertise" required to carry out its obligations under SEPA. Other counties in Washington show similar patterns. Nearly twenty years after the bill passed, only eight of thirty-one counties in the state used the provisions of the bill to designate critical areas, opting instead to forgo the complicated legal procedures and use specific criteria to designate critical areas (Jennings et al., 1988).

Despite the ubiquity of environmental review procedures in the state, development continues to chip away at the remnants of wetlands and riparian areas throughout Puget Sound (Figure 1). Development across the Front Range urban corridor in Colorado shows a similar pattern, despite zoning regulations which, ideally, limit or prohibit development in wetlands or other sensitive areas (Colorado 1975 Wetland Protection Act). While a thorough analysis of the efficacy of sensitive area protection policies lies beyond the scope of this review, a simple conclusion can be drawn from a broad view of these data: *zoning laws and regulations are insufficient as a tool to rely upon as a sole method of conservation of sensitive lands*. Given the limited influence of zoning regulations outside the jurisdiction of the City of Bozeman and considering the prevalence of regulation-averse political attitudes among Montana residents, alternative approaches to sensitive land protection might be considered.

Concerns surrounding the rapid growth of Bozeman are nothing new. Yet, other rapidly growing cities in the Rocky Mountains have already undergone decades of extraordinary growth while preserving a considerable portion of wetlands, riparian areas, and wildlife habitat – namely Boulder, Colorado. Originally founded as a mining camp in 1858 by gold prospectors, Boulder today closely resembles Bozeman. Both compose semi-arid Rocky Mountain upper-basin cities in transition from resource extraction-based to industrial and lifestyle-based economies. Crucially, however, Boulder hit its exponential growth phase 40 years before Bozeman did, and today supports 341,000 residents throughout the county while maintaining extensive tracts of open space, wildlife habitat, and protected wetlands.

Concerned with the impacts of rapid growth and development throughout the 1960s, planners and conservation organizations-initiated efforts to protect wildlife habitat and agricultural lands through both public and private initiatives. In 1967, a one percent local sales tax was adopted, and the proceeds were used to fund the acquisition and management of open space lands both within and outside city boundaries. This "open space fund" was further supplemented by a 1971 referendum amending the city charter which empowered the city government to issue "open space bonds" for the purchase of land (Wright, 2014). In 1978, the first "Boulder Valley Comprehensive Plan" was produced via the joint efforts of the city and county. Since then, regular revisions to this comprehensive plan have expanded and elaborated upon this original intent. The current Comprehensive Plan contains both elaborated principles intended to guide future urban growth and spatially explicit maps of prime agricultural land, natural hazard areas, riparian corridors, wetlands, wildlife habitat, and other natural areas deemed worthy of special consideration (Figure 2). Countless references are made to these maps in city zoning regulations, and stringent review processes are initiated whenever a proposed development falls within such designated areas.

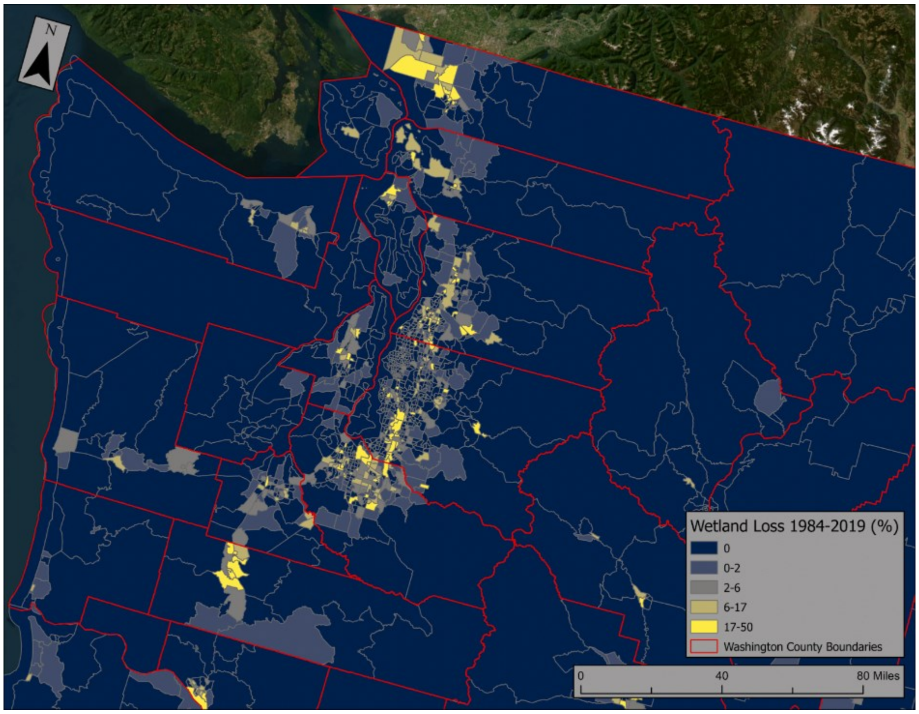

Figure 1: Wetland and riparian area conversion to impervious surfaces by census tract (data sourced from USFWS, 2020)

Crucially, the approach taken by Boulder represents a sober recognition of the necessity for proactive, private sector-type approaches to land conservation. The City of Boulder's Open Space Program effectively functions as a fusion between a real estate brokerage firm, a public land trust, and a land management agency. Through its efforts, by 1992, 34,000 acres were protected for $79 million. This acreage has since increased to 46,000 (Wright, 2014). While we do not necessarily propose the City of Bozeman spend upwards of $100 million buying up all the sensitive lands in Gallatin Valley, city officials might consider similar initiatives at a reduced scope. Given the affluence of its residents and the importance of an intact environment to the quality of life in the Gallatin Valley, one can imagine support for the use of public funds for the protection of sensitive lands. Interestingly, the economics of such an approach can ultimately save the city money in the long run. One city planner in Boulder estimated the costs of maintaining open space at $75 an acre, whereas providing full city services to residential development ran up to $44,000 per acre (Wright, 2014). Similar fiscal savings to the tune of billions of dollars have been realized in New York. Public funds raised in New York City are used to pay farmers higher up in the New York municipal watershed to maintain stream buffers and take sensitive lands out of production, thus maintaining water quality and sparing New York the necessity to spend billions on water treatment plants (EDF, 2018).

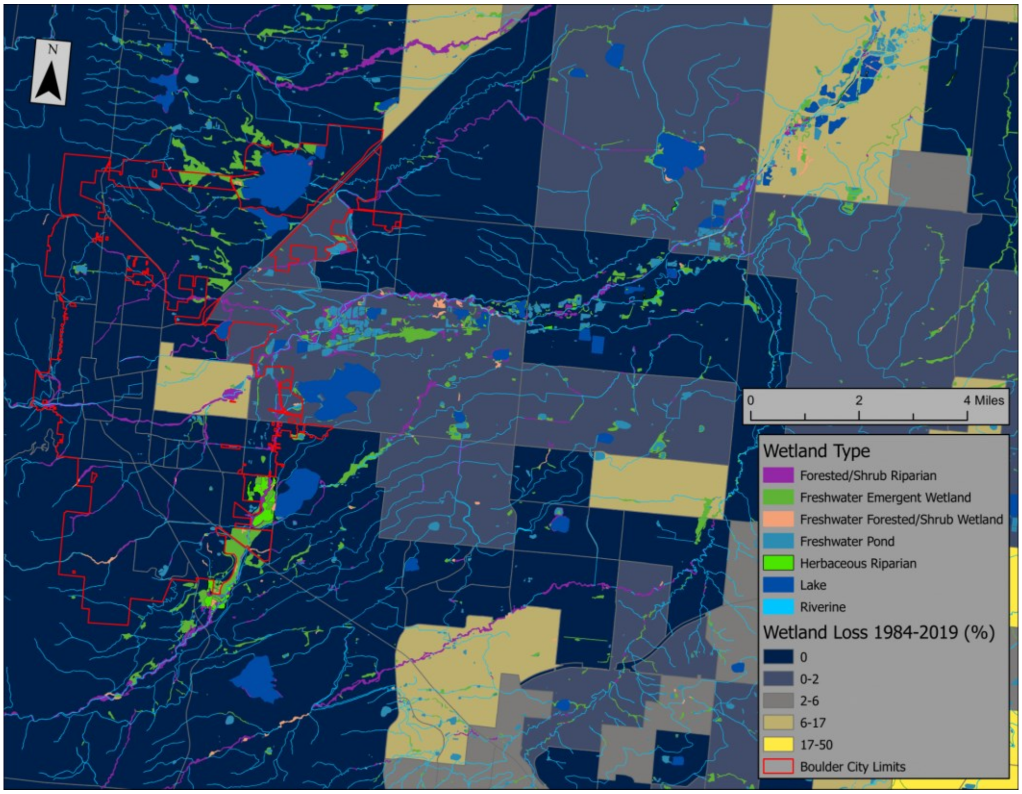

Figure 2: Present-day wetland and riparian areas near Boulder, CO, and wetland and riparian area conversion to impervious surfaces by census tract (data sourced from USFWS, 2020)

Bozeman today finds itself in a remarkably similar situation to that of Boulder in the 1950s. Except for those areas already developed, many wetlands and riparian areas in the Gallatin Valley remain intact and functional (Figure 3).

If 70 years of development in the Boulder Valley is any guide to Bozeman's future, there exists a real possibility that sensitive lands can be conserved while still accommodating a much greater population. Protecting these lands will require close coordination between private and public entities, and the pursuit of both regulatory and non-regulatory means of land protection. Consideration should be given to outright purchase of lands containing wetlands, riparian areas, or wildlife habitat. If land acquisition is not an option, perhaps programs subsidizing conservation easements or paying landowners to maintain stream buffers and wetlands might be considered. As one Colorado rancher so elegantly put it, *"Open space is great, but you have to buy it"* (Wright, 2014).

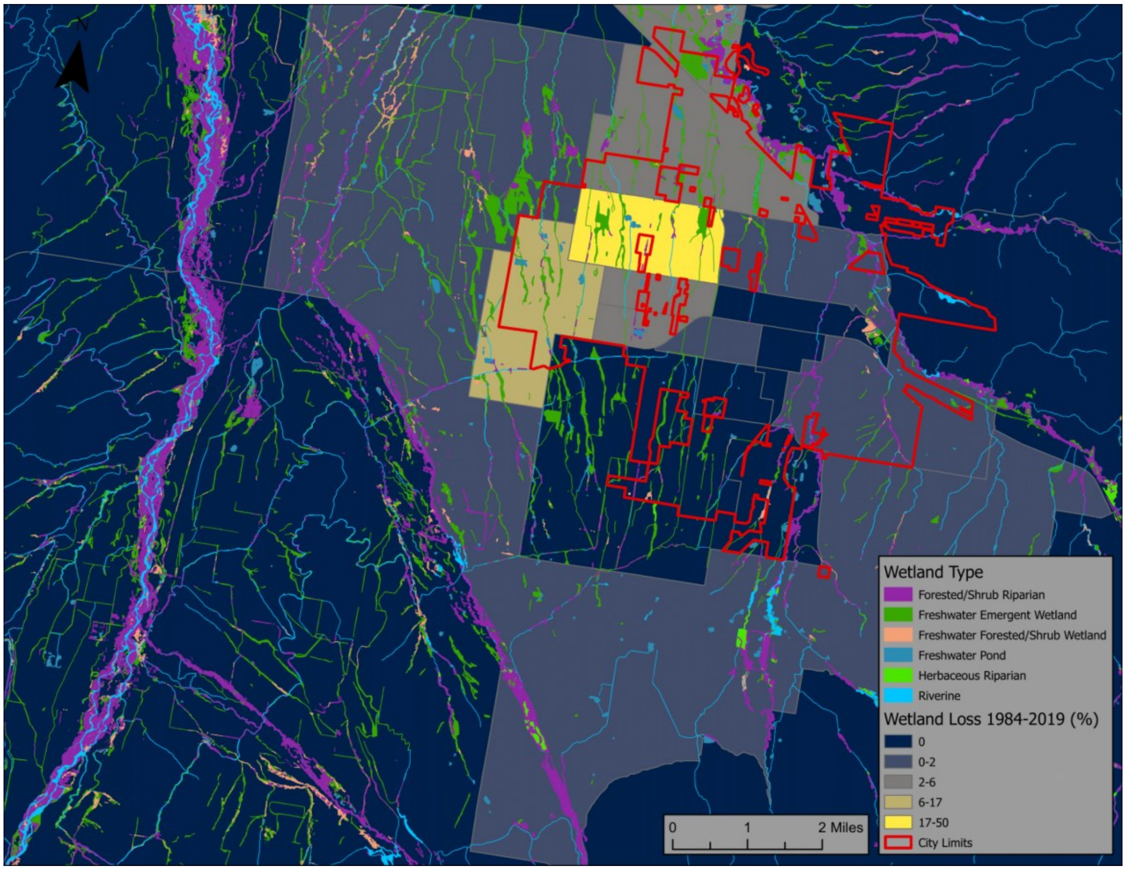

Figure 3: Present-day wetland and riparian areas near Boulder, CO, and wetland and riparian area conversion to impervious surfaces by census tract (data sourced from USFWS, 2020)

Applications to Bozeman

Measurable parameters of a landscape are the backbone of critical analysis. By evaluating the quantifiable characteristics of a given area of land, an index value of criticality can be assigned and used to guide decision-making for the land. Because these landscapes are highly variable, especially in a location like Bozeman, the availability of measurable attributes will depend on the location. In wetland areas, quantifiable parameters could include groundwater recharge and discharge, sediment stabilization, biodiversity index, and flood flow alteration (*Novitzki, 1997*). In a valuable watershed location, measurements might include the water retention of the land along with local precipitation in the area and the vegetation that is present. Calculating the potential change of these factors after development is also important to consider when evaluating how critical the area is (Conrad & Intern, 2020). The degree of potential forest fragmentation, vegetative loss, and soil turnover that would accompany proposed developmental plans are measurable values that can aid in the assignment of a critical value to the land (Reinmann et al., 2020). A discrete measurement of the number of threatened or endangered species of plants and animals in each area of land is also an informative parameter that can be used to evaluate its importance (Kondratyeva et al., 2020).

Identification of Environmental Sensitive Lands in Bozeman

These tools can be applied to watersheds around Bozeman to assess their functionality. The watershed that services Bozeman is highly fragile and at risk of damage without more regulation of surrounding urbanization. A study done by Susan McIlroy at the University of California, Berkeley targeted the Sourdough Creek Watershed that encompasses Bozeman to understand the relationship between land use, geomorphology, and aquatic habitat in the watershed (McIlroy et al., 2008). The Sourdough Watershed is a mixed-use watershed and is a prevalent location for recreational use and housing development which adds to its importance to the Bozeman citizens. This study concluded that addressing the challenges accompanying a growing population in the Intermountain West will be crucial for stream management and the health of every area serviced by this watershed (McIlroy et al., 2008). Urbanization of watersheds like Sourdough, which are important to both hydrologic services and human recreation, results in severe degradation of the areas serviced by the watershed. This case study identifies the Sourdough watershed as a sensitive land that is at risk from urban development and emphasizes the importance of paying attention to this area and similar ones.

Case Studies of Tech and Methodologies

As climatic regime shifts alter urban water quality and quantity, the proper identification of these "critical lands" is more important than ever. As such, the creation of new standards ***must not fail*** where past attempts have fallen. Modern studies are placing increasing importance on methodology and overall watershed processing; breaking down the constituents of a system to isolate more direct sources of issues.

Recent advances in geospatial modeling and access to vast archives of water data have enabled a more widespread use in recent years. Spatial analysis has proven useful for local mitigation, and its application for sensitive land identification has been proven to be successful with menial accuracy (Parsa, 2011). Though promising, the current expectancy for its accuracy is not secure enough to stand alone in the identification of sensitive lands. When isolating a *specific* component in a vast system, accuracy and precision are incredibly important for success. To properly answer the question "What updates do you recommend to Bozeman's UDC?" These two factors must be improved.

While the conservation of agricultural land is essential to the maintenance of the rural character of the Gallatin Valley, runoff from these areas constitutes a significant source of pollution for local waterways. A study done by Kumar in 2021 attempted to identify "critical zones" along the major waterway in the treatment area. Their primary source of pollution was determined to come from the agricultural systems neighboring the riparian areas of their waterway, though the severity of the pollution varied along the longitudinal aspect of the stream, forcing project managers to find ways to identify the most sensitive areas along the stream's length. To do this, researchers designed two management frameworks designed to assist decision-making. The DSS (Decision Support System) and AHP (Analytical Hierarchy Process) were designed to limit uncertainty and relate qualitative and quantitative values of interest, these two methods were utilized to identify sensitive areas, and specific landowners were then asked to mitigate their use of fertilizer, percent of arable land cover, and presence of native species in favor of reducing nitrogen [N] and phosphorus [P] loading to the waterway. At the end of their monitoring period, N had decreased by 29% and P had decreased by 38%, showing the direct impact of their actions on the stream's water quality.

In another study, researchers attempted to create a measurable scale for both qualitative and quantitative variables of interest, which was called the HSPF model (Hydrologic Simulation Program FORTRAN) (Bello, 2019). This model allowed for the hydrologic breakdown of different "regions" in a watershed, which could then be measured for variables of interest and compared to other regions within the watershed. Once data was collected and organized, a dataset for the whole watershed could then be continually updated and monitored to determine which lands were sensitive, and which lands were either improving or declining in terms after the application of mitigation attempts. The creation of a single dataset for all variables of interest in a system, both qualitative and quantitative is uncommon in ecological assessments and projects; the application of this concept to Bozeman mitigation attempts is likely to decrease the chance of any impacts from confounding or counteracting variables, reducing uncertainty in the identification of critical lands.

Connections Between the Three Pillars of Critical Land Classification

Though the application of technology can enable a much wider range of techniques, a purely scientific approach cannot solve these issues in isolation. We believe that the underrepresentation of social connectivity and economic stability in the consideration of environmental planning success is responsible for the historic failures to protect sensitive lands One study implied the missing components from socio-environmental issues to be "technical (inexactness), methodological (unreliability), epistemological (ignorance), and societal dimensions (social robustness)" (Corral and Acosta, 2017).

Ecological Sensitivity

The concept of ecological sensitivity refers to how susceptible an ecosystem is to disturbance or damage. Natural systems inherently have different levels of resilience, and certain areas are undoubtedly more vulnerable to negative impacts from land use changes like development or cultivation. Consideration of ecosystem size, complexity, diversity, and hydrologic functions determines the sensitivity of the area and therefore the overall resilience. For example, an isolated wetland ecosystem with limited biodiversity and physical function would likely have higher ecological sensitivity than a large and interconnected forest with more biodiversity and ecosystem functions.

To assess the extent to which any given ecosystem is "sensitive," frameworks can be set up that integrate collected data and samples and evaluate the correlating sensitivity by comparing them to standard values. One such framework was developed by the U.S. National Oceanic and Atmospheric Administration (NOAA) and is called the Environmental Sensitivity Index (ESI). The ESI system identifies ecosystems that are particularly sensitive and includes guidelines on how to address these issues. This tool is primarily map-based and uses data on the physical and biological characteristics of coastal areas to assign relative sensitivity values of these regions to environmental hazards like oil spills (*Environmental Sensitivity Index*, 2023). The Habitat Risk Assessment (HRA) is another framework that has been used to predict the potential impacts that development projects could have on terrestrial ecosystems. This method utilizes parameters like habitat size and quality, as well as endangered species' presence and severity of likely habitat fragmentation or destruction (Arkema, 2014). Several recent studies have proposed additional frameworks that build on these concepts of ecological sensitivity while fitting them to their specific areas of concern. A 2019 study in Environmental Management introduced a framework that uses measures of water quality, sediment quality, and sensitive species presence to gauge the ecological sensitivity of estuaries in New Zealand (Wells et al., 2019).

Social Sensitivity

Equally as important in environmental planning is the consideration of public opinion, in one study done by city planners, a Decision Support System (DSS) was designed as a step for public and stakeholder opinion consideration in new environmental assessment projects. To do this city planners created "multi-criteria analysis and focus group sessions" designed to express stakeholder concerns so that plausible policy alternatives could be created. This created a sense of "environmental governance" between stakeholders and decision-makers, increasing social and economic trust. A visual model of this approach can be seen in Figure 4. Their specific goal was to "represent a range of scientific challenges that cannot be coped with by simple mathematical precision" (Corral & Hernandez, 2017), in this way, their study serves to quantify social and environmental connectivity to apply it as a crucial step in environmental planning; to reduce *uncertainty* in the preservation of sensitive lands.

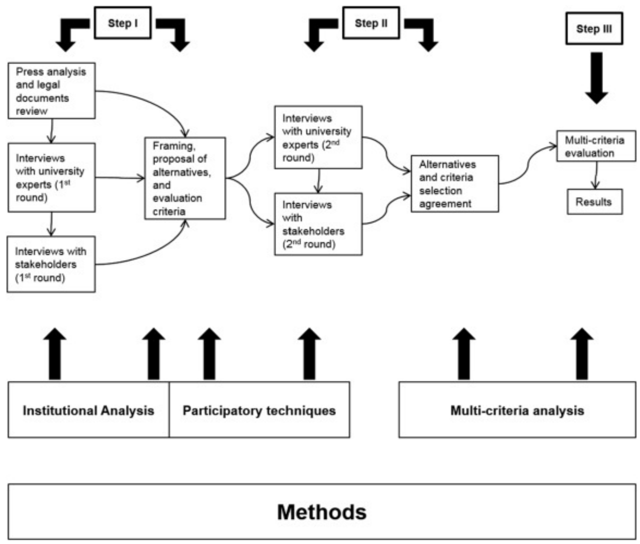

Figure 4: Visual Schematic for integrating social governance and values into ecological decision-making (Corral, Hernadez, 2017).

A primary concern of our local city planners was the acceptance of assessment results might be jeopardized by a lack of consensus on the validity of the criteria used during the assessment in this instance implying the validity of criteria of stakeholders in comparison to those of citizens. They used Social Sensitivity Analysis (SSA) to ensure community validation of results (SA) and new inputs (DSS). By doing this, they were able to preserve local economic stability through direct communications with stakeholders, as well as social connectivity between local city planners and average citizens.

Another study by Corral and Acosta, continued to expand on the above ideas, focusing on how to overcome differing opinions in a just and effective way. They used SSA, SA, and DSS, as well as a "One Factor at a Time Approach" to dissect and process layers of social involvement and concern. Their completed integrated assessment methodology can be seen below.

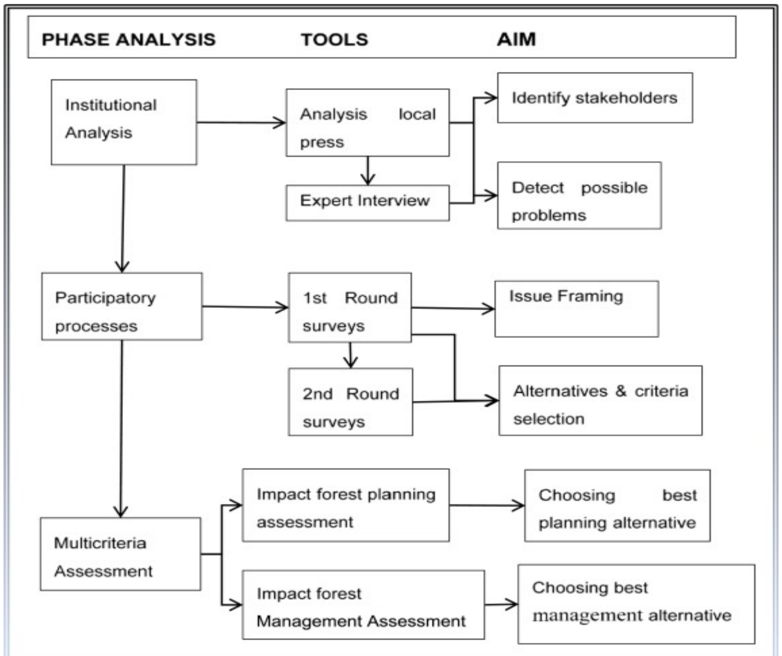

Figure 5: Visual schematic showing the cyclic nature of social and economic components in environmental decision-making. Source: Adapted from Corral and Acosta (2015)

Economic Sensitivity

All actions surrounding land use and zoning must take economic conditions into heavy consideration. As was made clear in our meeting, the primary anthropogenic nitrogen and phosphorus sources in the West Fork watershed are associated with "resort and residential development" and wastewater from septic systems and wastewater effluent from the Big Sky Golf Course (Blue Water Task Force, (GRTF) 2014). There are no point sources identified in the West Fork watershed. Septic systems in the West Gallatin Watershed are displayed in Figure 6 (produced by GRTF, 2019). As this section was being discussed, our group was concerned about how 'extreme' our viewpoints would be; our main concern being the feasibility of shifting discussion surrounding economic benefits in a government setting, in an ever-growing and developing area. Ultimately, it was determined that the historic concern for this exact discussion is what has led, in part, to our current situation. As such, the next discussion of Bozeman's economics is skiing, specifically at Big Sky. Well documented over the past few years has been the contamination of Bozeman's watershed with anthropogenic inputs of [N] and [P] through various point and nonpoint sources into waterways. Specifically, it was found that Big Sky had been improperly storing septic waste in unlined holding ponds (Cottonwood Law, 2021-2023).

Though Big Sky is a booming source of tourism, community involvement, and enjoyment, and seems generally harmless; the lack of responsibility forced onto these large businesses can be incredibly detrimental. Septic tanks were a clear source of concern for various city planners during our meeting with decision-makers, and storage ponds like these are equally so. While Bozeman cannot threaten the skiing industry, it is worth standing up now to prevent future repetitions of this incident, after all, the identification of sensitive land is meaningless if you have no method for penalizing those directly responsible for the sensitivity of an area.

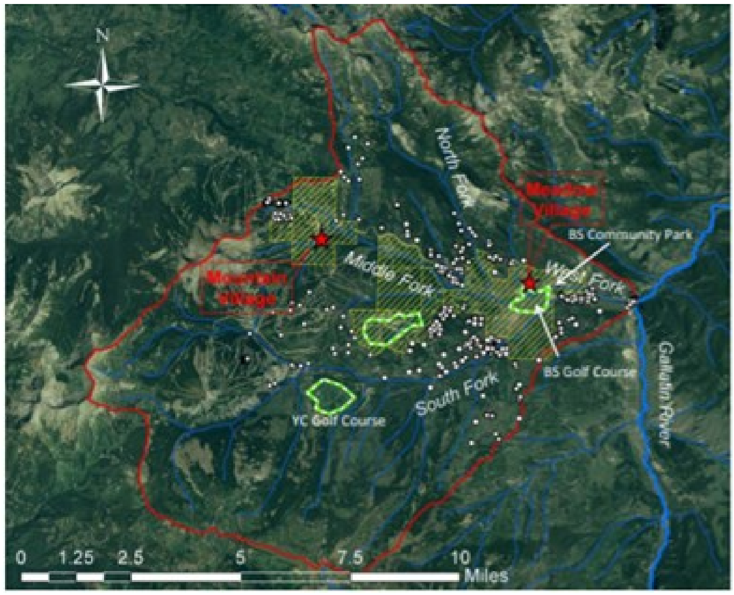

Figure 6: Map displaying septic tanks (white dots), golf courses (green), across the whole Big Sky Watershed.

Bozeman Application(s)

As explained in our meeting with city planners and decision-makers, a major concern for Bozeman's longevity and stability is it's rapidly depleting water quality and quantity. As expressed, rapid development, urban and agricultural runoff, contamination, and decreasing snowpack in alpine regions are all placing a major strain on Bozeman's water supply. Now understanding the complexity of these issues, case studies have proved valuable in identifying valid and improper methodologies to account for this complexity.

A study done in 2015 by Scarborough, Porter, and Stewart focused on the "security of water for urban cities" in the context of the rising demand and variable local water supply. To achieve this researchers used a Systems Dynamic Modelling Approach (SDM) which combined *economic, social, and environmental* variables to explore the *sensitivity* of water planning over time. For this study, economic variables of interest were "social discount rates" and "water security index" which measured the ratio of stored water to annual use. These variables aimed to combine environmental and economic considerations to then provide policymakers with an analysis of levels of influence of economic vs. Environmental vs. Social parameters on infrastructure changes. To do this, planners need to determine their preferred "mix" of trade-offs. The culmination of this was to produce various graphs showing quantified results of certain management options in consideration of economic, social, and environmental factors. Each specific trade-off was then easily visually assessed, allowing for reduced uncertainty and increasing the simplicity of their future monitoring needs.

Conclusion

The delineation of sensitive lands through environmental, social, and economic analysis is a critical step towards improved sustainability of land use management in Bozeman. This review highlights the importance of considering the environmental management issues facing Bozeman through economic, cultural, and environmental lenses to gain a comprehensive understanding of everything that is supported by an area of land. By reevaluating legislative priorities to focus on the preservation and conservation of sensitive lands, progress can be made to ensure that the natural resources and ecological systems that so heavily support the Bozeman community are protected in the interest of future generations. This review was built to guide policymakers, land use planners, and community members of Bozeman toward more educated discussions of how to proceed with development plans. By providing a framework for the identification and protection of lands that are considered sensitive, better-informed decisions can be made that balance environmental, social, and economic considerations. As such, the findings of this study can be used as a valuable resource for guiding land use practices and promoting the health of both the Bozeman community and the encompassing ecosystem.

Author Contribution

All authors contributed to the development of this document and comparisons of sensitive land governing decisions were analyzed by Daniel Engen and Zach Horsman. Discussion and analysis of the three pillars of critical lands were done by Ali Doggett and Paige Schlegel. All authors worked equally on the first draft and consistently completed work at a similar level of involvement. All authors worked on the editing of our final document and approved the final manuscript.

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2.0 Actions to Improve Bozeman Water Storage and Quality

Ryder Bechtold, Russell Conti, Dylan Roide, Laine Young

Background

In February 2023, students enrolled in the Land Resources and Environmental Sciences (LRES) Capstone class with Montana State University met with city and state representatives influencing management practices in Bozeman, Montana. These individuals proposed questions about water quality concerns that they need help analyzing and addressing. First, Russell Smith from the Bozeman Stormwater Division asked the class about the function of retention and detention management practices. He emphasized the importance of these structures in managing excess nutrients in Bozeman when they perform as designed. However, these systems may not be performing as designed. Relative to the area, high groundwater tables cause a challenge to maximize the reduction of contamination outputs in local waterways because of increased surface and sub-surface water interactions and a lack of a vadose zone that acts as a natural filter for water. Torie Haraldson from the Montana Department of Environmental Quality then asked where water quality projects should be prioritized, given the increasing complications related to environmental changes. This paper aims to answer these questions regarding potential methods to improve water quality.

Introduction

By increasing water storage, implementing various filtration processes, and determining viable project site locations, we can evaluate water quality changes over time to specify improvement areas that benefit Bozeman. This paper introduces integrating a series of constructed wetlands, retention/detention structures, Beaver Dam Analogs (BDAs), and engineered soils into city parks to increase water connectivity and intercept as much water contamination as possible. These retention structures have the potential to capture large amounts of water, increase groundwater and surface water storage, promote wildlife habitat, and reduce pollutants. These benefits are possible because biofiltration processes can occur before the water enters large streams by serving similar functions found in a capable vadose zone.

Stormwater Management

Infrastructure development increases the need for water resources, whereas warming temperatures from climate change likely contribute to further limiting those resources because of decreased water storage. The increase in urbanization leads to strains on the local water quality due to the increased abundance of contamination inputs while extending draining from the local water supply. Effectively, these factors lead to decreased access to the freshwater supply and can create positive feedbacks that further diminish water quality. Reducing water quality impacts visual water aesthetics, human health, and ecosystem health. Adding new buildings, roads, and pavements creates impervious structures that alter the local water cycle. These structures lead to shifts in natural flow paths naturally found in natural soils, and the excess urban water follows pipe routes into nearby streams. These shifts restrict potential ground infiltration, further hindering groundwater recharge. Stormwater management systems function to reduce the impacts of city flooding and surface runoff. City officials aim to counter the increased water interception from impervious surfaces. This process releases excess nutrients, sediments, chemical pollutants, and pathogens into waterways (Keena et al., 2022). Furthermore, water runoff from residential areas and agricultural lands has led to elevated nitrogen levels in local channels, mainly due to fertilizer, pet waste, and yard waste inputs.

The City of Bozeman experiences problems with stormwater pollution removal because most of the city comprises areas where the groundwater table is close to the land surface (Figure 1). This groundwater risk assessment map demonstrates the low groundwater levels in and around the City of Bozeman. Most of the measured water depths in the mapped area are less than 10 feet, with no groundwater measurements over 20 feet. These large areas of high groundwater play a role in pollution exchange within these zones and cause low natural soil filtration, increasing non-point source contamination. Shallow groundwater heights have many implications for stormwater drainage and treatment practices (Jefferson et al., 2017). Soils in these areas become quickly saturated with water, and there is little to no soil infiltration, leading to excess water runoff. The large volumes of stormwater generated can damage property and infrastructure, which can cause erosion, leading to increased sedimentation in streams. These damages to the environment occur because of low water retention periods, further expediting water runoff potential, which contributes to the influx of higher concentrations of nutrients in groundwater and outflows (Thompson et al., 2021). Pollution can be challenging to manage in these high-water table sites. Under these conditions, treatment practices using water-sensitive urban design (WSUD) methods may be less successful. Techniques including infiltration through swale-trench systems, permeable pavements, rain gardens, and bioretention areas are less successful when high groundwater is present (Locatelli et al., 2017). Given these management complications, it is increasingly important to take action to implement water filtration and storage structures to combat the challenges present in water quality conservation.

TMDL Exceedance

Increasing urban development in the Gallatin Valley will continue to negatively impact the local water supply in terms of quality and quantity. For the Gallatin Watershed to maintain water quality, implementing government regulations occurs to improve water quality by issuing total maximum daily load (TMDL) standards for pollutants (Table 2). A TMDL quantifies the total amount of a pollutant to be within a body of water without violating the set water quality standards (MTDEQ, 2013a). To address areas where the water quality standards have exceeded one or more of the TMDLs for the Lower Gallatin Watershed, the Greater Gallatin Watershed Council created the Lower Gallatin Water Restoration Plan in 2014. The document lays out a plan to address the water quality concerns by proposing restoration strategies to improve water quality (Table 1) (Dunn et al., 2014). Here we focused on these Bozeman streams: Bozeman Creek, Bridger Creek, Mandeville Creek, Upper East Gallatin River, and Middle East Gallatin River. In addition, evaluations occurred for the general effects of proposed restorations from the Lower Gallatin Water Restoration Plan (Table 2). The evaluation was completed by comparing 2004-2011 water quality data, from the Lower Gallatin Planning Area TMDL and Framework Water Quality Improvement Plan (MTDEQ, 2013b), compared to the 2018-2020 water quality data reported in the Gallatin Local Water Quality District (GLWQD) State of the Waters Report (Table 2)(GLWQD, 2021a). The 2014 Lower Gallatin Watershed Restoration Plan identifies the percentage of pollutant reduction needed to adhere to TMDL levels and proposes solutions for water quality improvements (See Table 1). Since its implementation in 2014, Bozeman area streams have seen a general increase in water quality, as displayed in the GLWQD 2020 State of the Waters Report (Table 2).

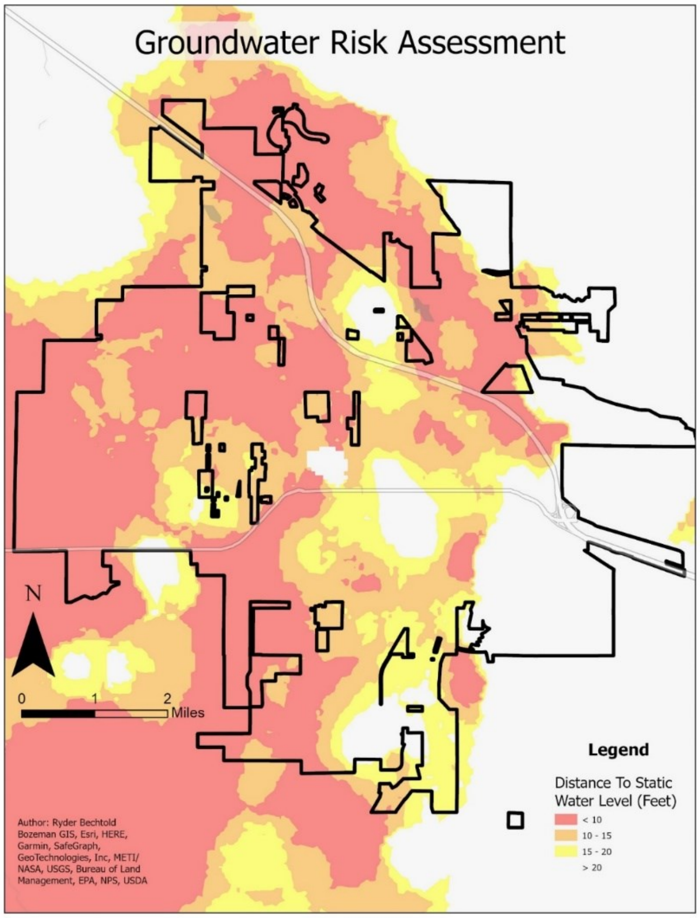

Figure 1: Groundwater risk assessment using kriging interpolation of static water level (SWL) from Montana Ground Water Information Center (GWIC) well data in the Bozeman area. This map is for general reference purposes only and may not reflect true SWL at any location.

Table 1: All five streams within the Bozeman zone with associated water quality impairment, including nitrate + nitrite (NO_3+NO_2), total nitrogen (TN), total phosphorus (TP), and E. Coli. The table outlines the percentage of pollutant reduction required to adhere to the TMDL and displays the proposed actions (Dunn et al., 2014).

Bozeman zone Lower Gallatin Watershed Restoration Plans			
Stream	Imparment	Percent Reduction	Treatment
Bozeman Creek	TN	63%	Residential, Urban, Agricultural, and Forestry BMPs, Onsite subsurface wastewater treatment system upgrades
	E. Coli	15%	Residential, Urban, and Agricultural BMPs
Bridger Creek	NO_3+NO_2	0%	No action needed
Mandeville Creek	TN	81%	Residential, Urban, and Agricultural BMPs
	TP	65%	
Upper East Gallatin River	TN	17%	Residential, Urban, and Agricultural BMPs
	TP	0%	No action needed
Middle East Gallatin River	TN	78%	Agricultural BMPs, Residential & Urban BMPs, City of Bozeman Water Reclamation Facility upgrades
	TP	76%	City of Bozeman Water Reclamation Facility upgrades

The 2020 report found that Bozeman Creek continues to have Total Nitrogen (TN) concentrations above the TMDL target, with two or more monthly measurements exceeding the acceptable standard (Table 2). Bozeman Creek experienced a decrease in E. Coli, with values below the target TMDL. Bridger Creek successfully decreased nitrate and nitrite concentrations and had no values above the TMDL target. Mandeville Creek saw no increase in water quality since the implementation of the TMDL. Expressed by TN and Total Phosphorous (TP) having two or more monthly values above TMDL targets and one monthly value exceeding the TMDL target for E. Coli (GLWQD, 2021a). The TMDLs represent no water quality improvements for TN and TP, indicating potential pathogen impairments not present in the 2013 report. Note that the evaluation of E. Coli was insufficient for Mandeville Creek in the 2013 MTDEQ report. The Upper East Gallatin River obtained water quality values below the TMDL target for TN and TP and maintained E. Coli values below target values. Similarly, the Middle East Gallatin River lowered its TP concentrations to levels below the target TMDL and only had one monthly value above the TN target set by the TMDL (GLWQD, 2021b).

Table 2: Water quality data compiled from the Lower Gallatin Planning Area TMDL and Framework Water Quality Improvement Plan and 2020 State of the Waters report for Bozeman Creek, Bridger Creek, Mandeville Creek, Upper East Gallatin River (Rocky Creek & Bear Creek confluence to Bridger Creek), and the Middle East Gallatin River (Bridger Creek to Smith Creek). Water quality data includes nitrate plus nitrite (NO_3+NO_2), total nitrogen (TN), and total phosphorus (TP) with units of mg L^{-1}. Pathogen evaluation occurs through the quantification of E. Coli in units of colony-forming units per 100 mL (MTDEQ, 2013a). Therefore, green represents below the TMDL target, yellow represents one monthly measurement above the TMDL target, and red represents two or more monthly measurements above the TMDL target.

MTDEQ: 2004-2011 Water Quality Data					
Stream	Site ID	TMDLs	TN	TP	E. Coli
Bozeman Creek	BOZMC00	TN, E. Coli	Above	Below	Below
Bridger Creek	BRIDC01	NO_3+NO_2	Above	Below	NA
Mandeville Creek	MANV01	TN, TP	Above	Above	NA
Upper East Gallatin at Kelly Canyon rd	EGALMSU	TN, TP	Above	Above	NA
Middle East Gallatin at Springhill rd	EGALUSGS	TN, TP	Above	Above	NA
GLWQD: 2020 Water Quality Status					
Bozeman Creek at Tuckerman Park	BOZMC03	TN, E. Coli	Above	Below	Below
Bozeman Creek at mouth	BOZMC00	TN, E. Coli	Above	Below	Below
Bridger Creek	BRIDC01	NO_3+NO_2	Below	Below	Below
Mandeville Creek	MANV01	TN, TP	Above	Above	Above
Upper East Gallatin at Kelly Canyon rd	EGALMSU	TN, TP	Below	Below	Below
Middle East Gallatin at Springhill rd	EGALUSGS	TN, TP	Above	Below	Below

Proposed action

Detention Basins and Retention Ponds:

Detention basins and retention ponds are human-constructed water features utilized in many watersheds to hold water for varying amounts of time to decrease the number of contaminants that flow into waterways downstream from sites. Detention ponds reduce water outflow temporarily to minimize flooding and disturbances downstream when significant water flushes can potentially increase the transport of harmful pollutants (Roy et al., 2008). Retention ponds typically hold water for an extended period and promote groundwater recharge, pollution removal through natural biological activity in the water/soil, filtration in the vadose zone of the surrounding soil, and from the nutrient uptake of plants. Long-term retention periods and increased surface area effectively remove particulate matter, metals, hydrocarbons, nitrate, and phosphate (Olson, 2020).

Furthermore, retention ponds (water gardens) have multipurpose functions that attenuate stormwater and natural water flows. These infiltration structures increase water surface area and act as "bioretention areas," often relying on engineered soils. Systems provide opportunities to increase aquatic vegetation and infiltration to reduce runoff and remove unwanted contaminants (Zeleňáková et al., 2017). Similarly, BDAs fulfill similar processes as water gardens and detention basons. Implementing BDAs increases stream roughness, stream connectivity to the floodplain, riparian recruitment, and water infiltration (Westbrook et al., 2006). Using BDAs in small urban streams can help simulate natural stream function and maximize the productivity of the stream.

Soil Filtration Medium

Incorporating new filtration media from current literature into retention and detention ponding and wetland structures shows the potential to maximize the biological removal and filtration of water pollutants. These filtration media serve as a "pre-treatment" for water before they reach longer-term storage areas or connect to large streams and simulate water filtration processes that occur throughout adequate vadose zones. New innovative green technologies, such as phytoremediation, have gained a reputation because of the ability to implement environmental management practices with relatively low operational costs (Prasada et al., 2021). Water treatment and conservation can be increasingly successful when they contain the appropriate plant species (including native species to the Bozeman area) that can grow sufficiently with variable influent concentrations and produce a large biomass to remove contamination load in the water. These plants can be used for water treatment in constructed wetlands to increase productivity (Prasada et al., 2021). Constructed wetlands (CW) demonstrate to be an economically viable management approach. When maintained correctly, CWs can remove many suspended solids and nutrients through biological processes that rely on extended water retention times, aquatic plants, and microbial communities that degrade harmful contaminants.

Recent studies have shown that nitrogen removal processes are typically much slower than other pollutants. Sequestration rates depend highly on surrounding biological factors such as vegetation, soil aeration, soil filtration media, and concentration of pollutants that affect levels of absorption and denitrification. Furthermore, research has shown that poor nitrogen removal is often found in bioretention systems due to the influx of groundwater and reduced denitrification conditions (Wang et al., 2022). Bioretention systems show higher nitrogen removal rates when carbon sources are modified. These bioretention systems have the potential to significantly increase the growth of riparian plants by altering soil media by increasing organic matter in soils. In a study conducted in 2022 assessing remediation practices for vacant lands using urban runoff pollutant removal techniques, nitrate removal rates in sandy-loam soils with higher permeability range from 60-80% removal rates, and soils with lower permeability and higher retention demonstrate removal exceeding 83%. Deeper plant rooting depths increase the ability of nitrogen removal rates by up to 93% (Wang et al., 2022). Studies show that management practices that increase plant biomass and root depth will improve water retention and maximize nutrient removal.

Biochar is a method that has been gaining attention as a stormwater filtration medium because of its versatility, minimal maintenance, low cost, and medium selectivity to target specific pollutants. Biochar consists of a burned organic material primarily composed of carbon and other particular elements in lesser amounts. The benefits of biochar include enhancing soil structure, filtration, and increasing aggregation due to increased water retention. Filtration through biochar also decreases acidity, reduces nitrous oxide emissions, regulates nitrogen leaching, improves electrical conductivity, and aids microbial communities (Minnesota Pollution Control Agency, 2023). Adding Biochar filters to water storage structures as a filtration unit can be used in other sediment filters or as hanging filters in catch basins (Minnesota Pollution Control Agency, 2023). Biochar can retain pollutants such as nitrogen, metals, and organics. While filtering out harmful pathogens, it can sequester carbon when used in soil or filtration media. Understanding the benefits of biochar, we can implement its use in bioengineered soils within the retention ponds and water detention systems.

A new filtration medium consisting of blanked filters containing bio-sorption activated medium (BAM) is being studied and shows potential to remove pollutants, mainly nitrogen, from stormwater (Wen et al., 2020). A recent study showed that integrating BAM into a stormwater inlet pipe in a fluctuating groundwater table environment resulted in significant nutrient load reductions. Researchers performed this experiment using a filter layer containing a mixture of sand, clay, and recycled tire crumb placed underneath the topsoil. This mixture can maintain infiltration rates and retain moisture for extended periods, aiding in the survival and development of microbial communities necessary for denitrification (Wen et al., 2020). As groundwater intrusions became more severe, the total nitrogen content increased, and the influx of nitrogen from groundwater disturbed the microbial environment. However, the groundwater intrusions became stable over more extended periods resulting in the microbial community being able to adapt, allowing the restoration of nitrogen removal. In addition, depending on the depth of the filter medium, it could also select for ammonia removal, showing the potential to remove contaminants of concern before they reach receiving water bodies, even in a high water table environment (Wen et al., 2020).

Discussion

Detention Basins and Retention Ponds

Except for Mandeville Creek, the water quality trend after issuing 2013 TMDLs, and restoration implementation has been relatively positive. It could indicate successful mitigation, restoration, and monitoring practices that have improved water quality for Bozeman area streams. These results highlight the need for minor urban tributary stream improvements within Bozeman. Mandeville Creek may act as a flagship stream, indicating the need to focus on small streams and stormwater system upgrades (See Table 2). Implementing these actions may help improve city water quality by limiting the effects of death by a thousand cuts regarding polluted urban streams. Taking conscious efforts to increase stream residence time, restore stream connectivity, and increase stream roughness will help aid water infiltration rates and the natural removal of pollutants (Figure 3-4). Small stream restoration actions can focus on low to medium-flow streams and stormwater flow paths that pass through Bozeman public parks and show potential for installation of retention ponds (i.e., water gardens or beaver dam analogs). These structures aim to increase riparian vegetation development and the ability to inundate a more significant area during high flows (See Figure 4). In addition, they can allow for the land to act as a biofilter and water collection device that recharges Bozeman's aquifers with clean water. By implementing these management practices on public parkland, city ownership of the property allows for better management and maintenance of the restoration practices. This results in the protection and enhancement of wildlife habitat, increased retention and filtration, and increased recreational and aesthetic opportunity within the local community.

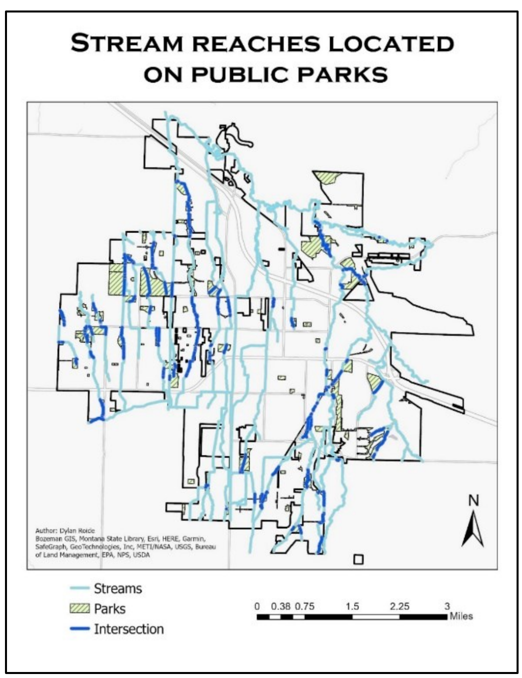

Figure 2: Bozeman, Montana Stream sections located on public park property. Addresses the Montana Department of Environmental Quality question, "Where should the prioritization of water quality projects occur given increasing complications related to environmental changes?"

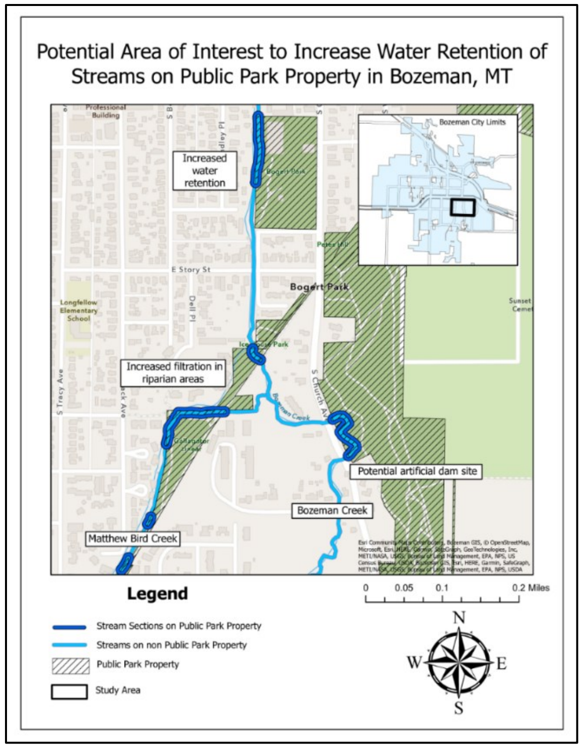

Figure 3: Potential area to implement retention/detention management practices on stream paths in public parks. Proposed approaches provide increased scope for natural filtration and storage.

Based on the reviewed literature, the pollution removal and success rate of the structures studied are related to the volume of water runoff due to impervious surfaces, mean residence time, water storage surface area, and the amount of vegetation and microbial support at a given site. For example, increasing the residence time of polluted water increases sedimentation and assists in the growth of riparian plants that enhance water quality through soil filtration and nutrient uptake. Contrastingly, a high groundwater table causes reductions of unsaturated soils necessary to sort out pollutants before they enter the vadose zone. In the case of Bozeman's shallow groundwater issue, water gardens, beaver dam analogs, and detention basins potentially increase the surface area of water to remove pollutants before they enter into the groundwater and large streams.

The City of Bozeman would benefit from implementing new filtration technology, vegetation development, and ponding/wetland structures to maximize water residence time and biofiltration potential. In addition, when observing sites with significant contaminant discharges, hypothesizes state that constructing a series of water-holding systems to increase water connectivity provides a positive function. These constructions would increase water retention and pollution removal while decreasing discharge rates.

Soil Filtration Medium

Making alterations to the soil within inlet zones by incorporating engineered sediments, installing biofilters, and constructing wetlands show the potential to increase water quality. However, a significant issue with these methods is maintenance. Many of these methods require replacement material over varying periods to mimic natural disturbance periods. Biofilters, biofilms, and riparian plants become clogged and saturated with time, and their function continuously diminishes until maintenance. Additional biofilter units can treat water before, during, or after interacting with water-storing structures. Overall, adding filtration units to specific, easily accessible locations (for maintenance) acts as extra filtration parameters to ensure significant contamination removal from the water. Also, biofilters aid microbial communities during fluctuating environmental conditions that further assist in eliminating various water contaminants (Wen et al., 2020).

Biological filters mainly rely on plant and microbe communities to degrade, capture, and remove highly toxic volatile organic compounds, heavy metals, excess nutrients, and pathogens to increase the quality of the environment (Pachaiappan et al., 2022). Figure 2 assesses Bozeman City limits for non-point pollution risk on a high to moderate scale. High-risk areas identified by this analysis show potential locations to implement Biochar, BAM, and other tools to reduce non-point source pollution from entering Bozeman waterways.

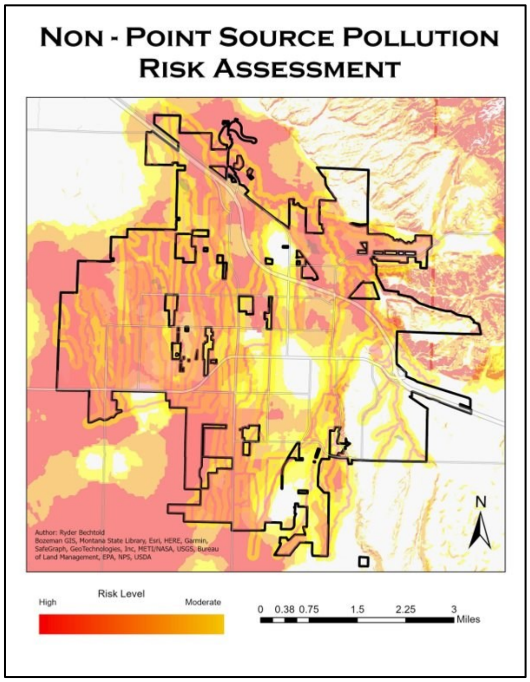

Figure 4: A risk assessment of Non–point source pollution of Bozeman MT created by overlaying Stream and River Risk (based on distance from the stream. High Risk (0ft -100ft), Moderate Risk (100ft – 500ft), Low Risk (500ft – 5000ft)), Soils over 60% sand (created using NRSC soil survey), Ground Water Risk (Fig A.6) and Slope Risk (Slope risk classified as Low (10% –15%), Moderate (15% - 25), and High (25% - 60%). Slopes less than 10% tend to have lesser risk. Considering slopes above 60% was not applicable, as these slopes have no development. This map is for general reference purposes only and may not reflect actual risk at any location.

Conclusion

Combining these strategies can potentially increase the clean water supply in and around Bozeman while decreasing the pollution of Bozeman's natural groundwater storage. Utilizing water gardens, detention basins, constructed wetlands, engineered soils, and other strategies that focus on increasing surface water storage to expand filtration surface area proves beneficial. Placing these structures into city park areas within Bozeman would be a good practice to intercept surrounding pollution inputs. The described filtration units could aid officials and representatives dealing with these issues in increasing clean water access. Implementing these strategies is increasingly important as land use changes, infrastructure, and populations continue to rise.

Author Contributions

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Laine Young, Russell Conti, Ryder Bechtold, and Dylan Roide. Ryder Bechtold and Dylan Roide performed geospatial data collection and analysis. The first draft of the manuscript was written by Laine Young, Russell Conti, Ryder Bechtold, and Dylan Roide. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript

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3.0 Prioritization of Wetland Restoration and Protection within Gallatin Valley, MT

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Preface:

On February 8, 2023, the MSU Land Resources and Environmental Sciences Capstone class met with local conservation and regulatory groups to discuss their natural resource-related questions and concerns in the Gallatin Valley. During the meeting, several questions relating to the potential for water retention and natural storage via wetland restoration (Karen Boyd, geomorphologist) and restoration prioritization given environmental change (Torie Haraldson and Eric Trum, MT DEQ) were posed. We aim to answer these critical questions and facilitate an increased understanding of the primary environmental challenges impacting the Gallatin Valley. More specifically, we will consider the benefits of wetland and riparian systems and propose approaches to prioritizing restoration efforts within these systems. Prioritization approaches will be regarded from ecologic, anthropogenic, and economic standpoints relevant to local land managers and governmental agencies.

Introduction:

Wetlands and riparian areas are critical natural areas that provide many essential ecosystem services. Watersheds containing wetlands capture more surface water from precipitation and flood events, slowing the release of water into downstream flows and thereby increasing local water storage (Martinez-Martinez et al., 2014). Sharing characteristics with terrestrial ecosystems, wetlands also facilitate several biological and hydrological processes, including water filtration and groundwater replenishment (National Academies Press, 1995).

In addition to providing nutrient and pollutant removal and increasing water infiltration and storage, wetlands also represent crucial habitats for numerous animal and plant genera. The ability of wetlands to minimize the severity of climate-driven events such as floods and drought also makes them highly important from an anthropogenic standpoint. Given their regional significance, humans must utilize and manage wetlands in an economically, politically, and socially viable manner. Further, these decisions should be viewed from a watershed-scale perspective and consider a wide range of ecological data.

As climate change and rapid shifts in land use continue to reduce ecological services and functions, the protection and restoration of wetland and riparian areas must be prioritized, especially in the wetland-rich Gallatin Valley. Over the past several decades, rapid urban expansion and population growth have resulted in the dredging and filling of many acres of wetlands and the degradation of many key riparian areas. Preserving intact ecological structure and function in these ecologically significant areas represents a critical step in sustainably developing this valley and maintaining the numerous species that live here (Nixon, 2020).

Understanding these complex systems and previous land management history is essential in prioritizing certain ecologically important areas for protection and restoration. When faced with the challenge of maintaining aquatic ecosystem health in the Gallatin Valley, looking at various approaches applied elsewhere is beneficial. Moreover, developing a framework for what constitutes an ecologically important area and considering a wide range of strategies and previously implemented projects can lend insight into the most effective ways to pursue the restoration of these lands.

Ecological Considerations

The following are several ecology-based methods used to prioritize the management of wetlands, particularly those occurring in upper watersheds.

Management of Upper Watershed Wetlands:

Wetlands are a critical source of flood risk reduction. Hey and Philippi (1995) used the Upper Mississippi River Basin as a case study to understand the impacts that wetlands can have across the waterway gradient. The authors argue that restoring wetlands in upland watersheds is particularly important for flood reduction. Headwater wetlands have the most significant potential to store water before it reaches downstream areas. This reduction in flood risk is achieved by wetlands' ability to store and slowly release water downstream, thereby buffering against extreme runoff events. The authors of this study conclude that upper watershed restoration and protection is an effective management tool for ensuring the ecosystem services these wetlands provide remain functional.

In addition to this service, many communities that rely on upper watersheds for municipal and agricultural water use can benefit from the increased water infiltration and storage that wetlands provide. This is especially true in areas with yearly flows that peak in the spring and early summer and low flows that prevent municipal or agricultural water consumption later in the year. Bhattarai et al. (2020) provide a comprehensive review of the scientific literature on the role of wetlands in water storage. The authors begin by highlighting the importance of wetlands for water storage, noting their ability to retain and slowly release significant quantities of water during dry periods. The article also explores various factors that influence water storage in wetlands. Wetland type, for example, is an essential determinant of water storage capacity, with different wetlands having varying degrees of water retention ability. Location is also crucial, as wetlands in areas with high rainfall or near large rivers tend to have higher water storage capacity than those in arid regions. These factors occur proportionally higher in upper watersheds. Less disturbed wetlands occurring higher in the watershed often provide more significant storage potential. Strategic protection from a disturbance in these areas can have a proportionally more substantial impact.

White and Fennessy (2005) aimed to develop a model to identify areas within a watershed with the highest potential for wetland restoration based on landscape and hydrological parameters. This GIS-based model is used to predict the suitability for wetland restoration across a watershed. Environmental indicators include soil type, land use, and topography. Filters are also applied that narrow the potential sites by assessing their potential to contribute to water resource integrity once restored. The model was used in two watersheds in the Midwestern U.S. and indicated that areas with the highest potential for wetland restoration had low topographic relief, increased soil moisture, and low levels of current land use. The study suggests that the model can help identify potential wetland restoration sites, prioritize restoration efforts, and inform land-use decisions at the watershed scale. These results further support focusing protection and restoration efforts on wetlands in upper watersheds, where current land use is typically lowest. Saunders et al. (2002) also present freshwater conservation and protection strategies, including project design and implementation of different methods across watersheds. The authors highlight the unique challenges of freshwater conservation, including connectivity, hydrological regimes, and the need for multidisciplinary approaches. Their work further exemplifies the complexity of wetland protection and the need for holistic approaches to management.

Though upper watersheds are prime candidates for wetland protection and conservation, the waterways of the U.S. cannot be thought of as individual pieces in management but rather as a connected system with landscape-wide impacts. Bach (2011) presents the idea of integrated river basin management (IRBM) for the sustainable use of water resources at both national and transboundary levels. An IRBM management approach accounts for the connectedness of all waters and the need for management practices that cross state and national lines. Though upper watersheds are the ideal candidates for wetland management, lower watersheds must be considered, as the impacts of management will be felt throughout. Bach states that IRBM is most effective when "different scales of the river basin are taken into account, embedding watershed management in river basin management." (Bach, 2011). Implementing strategic wetland protection with resources such as the model developed by White and Fennessy to determine the most viable locations while maintaining a holistic view of water movement and connectedness may be the most effective method for protecting and utilizing the services provided by wetlands.

Application to Gallatin Valley:

At the scale of the Gallatin Watershed, the Story Mill wetland restoration site in the City of Bozeman provides an ideal example of lower watershed wetland management within the Lower Gallatin Watershed. The park's wetland acts as a wildlife corridor between the Bridger and Gallatin Mountain ranges and provides a habitat for many birds, beavers, amphibians, and other organisms (EPA, 2015). Wetlands along Bozeman (Sourdough) Creek in the Gallatin National Forest provide examples of upper watershed sites. The Gallatin Local Water Quality District (GLWQC) released an assessment detailing the value of these wetlands for wildlife habitat, erosion control, floodwater storage, groundwater storage, and water purification of wetlands and riparian resources in Bozeman Creek (Gallatin Local Water Quality District, 2004). The assessment found that the historical extent of aquatic habitat in the Gallatin Valley may have been around 59,849 acres, while in 2001, that figure was 13,924. The authors attribute much of this wetland and riparian habitat loss to agricultural and urban development. The assessment recommends that wetland sites within the Bozeman Creek drainage be preserved and protected from future land use change due to the essential ecological and ecosystem services they provide for the Bozeman area (Gallatin Local Water Quality District, 2004).

The Story Mill and Bozeman Creek wetland sites requiring protection or restoration within the Gallatin Valley highlight the need to prioritize managing wetland areas locally. The previous research and tools presented above indicate that considering locational value should play a large part in determining the prioritization of projects. While both the Story Mill and Bozeman Creek sites have a value of their own, restoring and protecting degraded areas and locations that may occupy private property may prove much more resource intensive. Moreover, protecting sites upstream that have yet to be disturbed may prove to be a better use of resources and produce a more considerable impact. With the rapid development of the City of Bozeman and the Gallatin Valley, the decline in wetland sites seen historically will only increase without management that protects and restores these valuable assets.

General Applications:

Utilizing a strategic approach toward management and protection to determine the most viable locations for projects will yield the most significant impact toward continued utilization of wetland services. First, wetland management should look at areas longitudinally across the watershed, considering upper and lower wetlands. Each wetland should be assessed individually, considering impacts on riparian organisms, the ecosystem services provided, and the economic feasibility of undertaking protection or restoration. Models like the one developed by White and Fennessy (2005) can be utilized at this stage to aid in incorporating landscape and hydrological considerations through GIS data into the decision. Then, a review of the large-scale impacts of management along the waterway and across boundaries can be achieved using the IRBM model, where effects downstream are considered when making decisions upstream.

Catching pollutants and nutrients early in the water flow down the watershed is another benefit of wetlands higher in the stream reach. An increase in riparian and wetland buffers located within the upper reaches of watersheds will allow for the filtration of unwanted water-transported pollutants as they are taken up before they can impact ecosystems downstream. Increases in water storage and infiltration further upstream in the watershed provide groundwater recharge to ecosystems with high biological richness in these upper stream reaches and increase water security to communities. Water regulation through wetlands provides added security against intense flooding during significant runoff events, protecting communities and resources downstream. These factors make wetlands in upper watersheds prime candidates for increased protection and restoration to ensure their services can be utilized in the future with increasing human disturbance.

Anthropogenic Considerations

The following are potential ways to meet increasing anthropogenic water demands through natural wetland storage and prioritize restoration projects that maximize this goal.

Human Water Use:

Issues surrounding the disturbance of wetlands and increased urban water use across the Western U.S. and worldwide could be mutually benefited, through restoration, by the ability for these wetland systems to be restored and to function past a needed threshold (Stoker et al., 2019). In recent decades, there has been a growing demand for anthropogenic water use. To meet that demand, there has been an increase in groundwater extraction. Previous research has established that increased human land use negatively correlates with aboveground flow and belowground storage (Giordano, 2009). Case studies and emerging knowledge of wetland water storage potential and human water use will help identify ways similar efforts could be applied to increase the natural storage of groundwater in the Gallatin Valley.

Several previous studies have explored the topic of wetlands and natural water storage. One such study took place in the Murray-Darling Basin in Australia, where researchers assessed the ability and potential of wetland systems to serve as intermediate water storage. The main objective was to determine the success of maintaining essential ecological functions from the wetlands while using the ecosystem to aid in maintaining the water supply for agriculture (Ning et al., 2012). They found potential environmental benefits from water inundation within the wetlands and limited water loss from agricultural removals of stored water. Another possible solution to water demands was the ability of wetland storage to increase the synchronicity of water demands and water availability for environmental and agricultural purposes (Ning et al., 2012). For example, when water demand is generally high for irrigation use in the summer, water can be pulled from wetland storage captured during high spring flows rather than relying on high flows late in the summer. This change in water use timing could help resource managers better plan for natural and anthropogenic water needs during low flow. While these wetland properties are beneficial, there is still a need for effective ways of identifying the wetland area(s) that would be most beneficial to the local region and methods to evaluate and maintain that wetland water storage.

Prioritization for Natural Storage:

On-site monitoring of hydrologic characteristics becomes limited by monetary and time constraints as the assessment scale increases. Monitoring is also not a reasonable approach for projects focused on new wetland conservation or creation (Finlayson, 2003). However, modeling and simulations can estimate the impacts of wetland creation, restoration, or removal on water quality and quantity in the wetland and throughout a watershed system (Cui et al., 2021; Wang et al., 2010). One such tool that can be used to estimate the impacts of management decisions and projects is the Soil and Water Assessment Tool (SWAT). SWAT is a model that uses hydrologic, geologic, and soil components to predict outcomes of different wetland functions and sizes within a given watershed (Wang et al., 2010). It combines this information with land use and regional weather data to better predict project effects. Results of the SWAT simulation for this study area were expressed as a percentage of wetland area lost or restored needed to see relevant and measurable changes, either increasing or decreasing, in wetland and watershed functions.

Newer models and simulations are being researched to address more specific wetland restoration goals and site prioritization. The multicriteria-spatial decision support system (MC-SDSS) is a simulating restoration tool aimed at reducing the adverse effects of drought through wetlands (Maleki et al., 2018). A primary objective of the study was to identify and prioritize wetland areas that would provide long-term water conservation and storage. This specific goal can be more directly used to increase natural wetland groundwater storage in the Gallatin Valley. Spatial data from remote sensing technology combined with a weighted criteria list, social participation, and expert knowledge allows for more alternative restoration efforts to be judged for overall effectiveness (Maleki et al., 2018). This method is highly flexible in how weights are assigned to variables. This allows prioritized areas to change along with the changes in resource manager goals rather than in response to them. Areas of prioritization can be determined systematically based on evidence from ecologic principles that protect wetland functions that provide valuable services.

Economic Considerations

The following are several examples of economic-based approaches to prioritize restoration and conservation projects. We first consider natural climate solutions, which can be used to evaluate projects over environmental degradation and economic costs. Secondly, we review cost/benefit analysis and prioritization matrix-based approaches used to assess potential restoration projects economically.

Natural Climate Solutions Approaches:

When choosing between several aquatic restoration efforts, it is essential to consider the extent of environmental degradation. While an area exhibiting only moderate levels of human-caused disturbance will often recover with minor restoration, restoring a heavily damaged area requires time, money, and future maintenance. Due to this disparity, the three general methods for conserving ecosystem health involve protection (or preservation), enhancement, and restoration (Cook-Patton et al., 2021). These methods encompass all levels of ecosystem health, as it is recommended that productive ecosystems should be protected from future harm, mildly damaged ecosystems should be slightly enhanced, and fully damaged ecosystems would require large-scale restoration efforts.

The division of potential projects into protection, enhancement, and restoration and the subsequent evaluation of these projects are based on the concept of natural climate solutions (NCS). NCS is a holistic approach centered around combating the adverse effects of climate change by capturing and sequestering carbon, decreasing greenhouse gas (GHG) emissions, and promoting overall ecosystem health (Griscom et al., 2017). These solutions, which can be broadly split into those focusing on conservation (protection), land stewardship and effective land management (enhancement), and restoration, are effective catalysts for climate change mitigation when working with limited resources (most notably money and time) (Griscom et al., 2017). While the overarching goals of NCS involve climate change mitigation and global GHG reduction, they rely on well-managed and fully functioning ecosystems to do so. Implementing NCS solutions in the Gallatin Valley would limit our contribution to global warming and protect the natural resources and regional biodiversity that residents and tourists value.

As each potential NCS project exists on a different timeframe, is based on a different budget, and aims to accomplish other goals, deciding between multiple proposals can be challenging. It is proposed that the evaluation of several potential NCS projects should be based on (1) the magnitude and (2) immediacy of mitigation potential, (3) cost-effectiveness, and (4) co-benefits (Cook-Patton et al., 2021). The first of these factors, the magnitude of mitigation potential, refers to the net carbon benefit of the project, measured either in terms of decreased emissions or increased sequestration. The quantification of carbon benefit provides an excellent initial baseline with which to assess the ecological use of a project, as the framework of an NCS-based solution inherently leverages healthy ecosystems to provide these benefits. This also compares different environmental areas of interest, such as specific wetlands or riparian areas in the Gallatin Valley. The second aspect that should be considered is the projected time frame of an NCS project. Choosing projects that provide results within the next ten years is recommended over choosing those operating on longer time scales or waiting for an ideal project to arise. Similarly, it is also essential to consider the permanence of any future project and avoid those that may be easily reverted by future anthropogenic activity.

The third factor to consider is project cost. As funding for conservation efforts is generally limited, targeting projects with low associated budgets is often preferable to choosing large-scale, cost-intensive projects. This is relevant in the Gallatin Valley, where land managers must oversee a high quantity of natural land while operating on a finite budget. The final factor that should be considered is project co-benefits. Consisting of elements such as increased human health, promotion of indigenous values and culture, and increased ecosystem services and local diversity, co-benefits add a lot to the outcome of a project. Still, they are the hardest of the four factors to quantify effectively (Cook-Patton et al., 2021). While it is acknowledged that these pieces are all interrelated, determining how to weigh each and compare potential projects represents an important step in conserving our natural lands when working with limited resources. Such approaches are also recommended in areas facing rapid land-use shifts, which directly applies to the fill of wetlands in the Gallatin Valley.

When to Prioritize Protection:

Using this framework, it has been argued that funding should be first allocated towards protection, then enhancement (often via land management change), and finally towards restoration. This proposed order is based on comparing the ecological return on investment and estimated cost across projects. While projects centered around protection and restoration provide the highest value at the lowest price, they are often limited in the number of potential projects and individual project scope (Cook-Patton et al., 2021). Considering the rapid development in the Gallatin Valley and the subsequent filling of wetlands, it would make sense to allocate significant funding to protect these areas. As natural lands in Montana are primarily protected through governmental initiatives on public lands and conservation easements managed by land trusts on private lands, potential projects could increase support and participation in these actions. Projects involving the zoning of municipal lands and those in soon-to-be-developed areas are also crucial in protecting wetlands and riparian areas. Additional support for protecting intact wetlands comes from a study published in 2019, which found that soil organic carbon and overall productivity were significantly decreased in fully restored wetlands compared to those with minimal damage (Xu et al., 2019).

Additionally, conservation efforts should be focused on areas that could lose the most, either in terms of captured carbon or overall ecosystem function. In the Gallatin Valley, wetlands and riparian areas are two of the most productive regions, which should therefore be given the highest priority. Many target areas in the Gallatin Valley have already been identified through a mapping effort led by the Gallatin Local Water Quality District (GLWQD) in 2004. This initiative, which identified several key riparian and wetland areas that should be protected from development, found that East Gallatin, Rocky Creek, and Bozeman Creek were the most susceptible to degradation and should be given high priority. While much land use change has occurred since 2004, this remains a good starting point for wetland conservation and restoration.

When to Prioritize Restoration:

While protecting and managing natural lands is critical in sustainably developing the Gallatin Valley, returning ecological value to degraded lands is also necessary. Although it is up to nine times costlier than prevention, restoration may cause the most considerable impact depending on the ecosystem. The potential benefit of any single project and the associated cost also occur as a function of overall ecosystem damage, as land degradation occurs on a broad spectrum (Cook-Patton et al., 2021). Estimates of project costs are also very site-specific, and comparing project costs across different ecosystems is likely inappropriate. Finally, as these projects often involve land-use changes and ecosystem restructuring, it is recommended that project planning exists both locally and at a landscape scale.

Cost-Benefit Analysis (CBA):

While numerous factors must be considered in restoration project prioritization, the most frequently used approaches generally involve comparing ecological benefits produced to the total project cost. One often utilized method is a cost/benefit analysis (CBA), which is essentially a simulation that takes estimated project cost and expected economic value produced into account (Wainaina et al., 2020). If multiple potential projects are simulated with CBAs, the economic viability of these undertakings can be compared. While this approach has the potential to be highly effective, it assumes that the monetary short and long-term benefits of restoration (increased ecosystem services, tourism, recreation, property values, and human enjoyment of natural lands) can be calculated (Wainaina et al., 2020). While these calculations have been utilized in the cost assessments of several Montana-based restoration projects, many of the parameters used were taken from studies conducted in other states. These parameters, therefore, may only be relevant at a regional scale (Wagner & Shropshire, 2009). Despite these apparent drawbacks, CBA-based approaches to restoration prioritization have been implemented in several previous studies, some of which have used remote sensing-derived land use data as a proxy for in-person measurements (Li et al., 2022).

Prioritization Matrix:

An additional framework frequently used to prioritize restoration efforts and requires less predicted data requires comparing ecological services produced to the project cost. While this approach can be implemented in several ways, it is broadly based on systematic conservation planning. This multidisciplinary, iterative approach is based on protecting resources needed to sustain biodiversity (Kukkala & Moilanen, 2013). While this can take many forms in practice, several studies have implemented an approach centered around ranking ecosystem services and the associated costs required to maintain them in a system (Mu et al., 2022). The projects with the lowest price and highest ecological service rank are chosen. Additionally, ranking under this approach includes factors outside of biodiversity potential, as land use and several other variables are commonly used. This general framework would work well in a sparsely populated area such as the Gallatin Valley, as ecosystem services are often a primary driver of management decisions (Kunard, 2017).

Conclusion:

This paper addressed important questions centered around natural water storage and prioritization of restoration and conservation efforts. Wetlands and riparian areas are valuable resources and provide many ecosystem functions and services. Given the rapid environmental change, properly managing these areas is critical in ensuring water quality and availability. Evaluating wetland protection and restoration's ecologic, anthropogenic, and economic factors is crucial in effectively prioritizing and managing these areas. Several tradeoffs must be considered when prioritizing multiple regional and task-dependent restoration projects.

When evaluating the best locations for conservation or restoration projects, we propose beginning with a landscape-scale ecological health assessment via GIS analysis and integrated river models. Next, we suggest incorporating anthropogenic impacts and water use into the prioritization plan. This can be effectively achieved with the MC-SDSS model, which could integrate Gallatin Valley's extensive remote sensing and GIS-derived data products in a flexible, user-defined way. Finally, we recommend an evaluation of the economic viability of potential projects, which can be accomplished by using NCS and prioritization matrices. We propose that combining these techniques will result in informed and strategic conservation approaches that will facilitate the health of ecological services benefiting humans and other organisms.

Using this framework, we suggest undertaking a mix of conservation and restoration projects in the Gallatin Valley, thereby simultaneously protecting intact lands and improving degraded ones. We propose Bozeman Creek, Story Mill Wetlands, and Rocky Creek as suitable sites for conservation and restoration, as all three of these lands provide essential ecological and anthropogenic benefits and are economically viable in scope. Considering the magnitude of these areas, we propose that further in-depth analysis should use the above framework to determine the exact project areas.

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4.0 Natural Storage and Floodplain Restoration: Restoration Potential for Rocky Creek and Methods for Assessing Project Success

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INTRODUCTION:

Water scarcity is an ongoing concern in the American West, where a drying landscape and an increasing population collide with water quantity and quality. As more people move to Western cities, the water demand rises while the water supply decreases. Land managers are exploring natural solutions for increasing water supply and improving water quality to address this challenge.

On February 8, 2023, the Montana State University (MSU) Environmental Science Capstone class met with Gallatin Valley land managers who expressed concerns about water quantity and quality. Lilly McLane from the Gallatin Watershed Council briefly presented a potential floodplain and stream restoration project on the Rocky Creek section of the East Gallatin River. This project could increase water quality and natural storage in the headwaters of the East Gallatin River. The project has many stakeholders, including MSU, adjacent landowners, and the BNSF Railway Company, who all have some relationship with this section of the river. Ms. McLane asked the Capstone class to assist in developing arguments to convince MSU and adjacent landowners to be involved. Finally, Ms. McLane requested methods to determine the most effective ways to measure project success.

The Rocky Creek site (Figure 1) is an excellent location for a restoration project. It can enhance riparian and floodplain habitat, water quality, natural storage, and knowledge of effective restoration methods. To help address Ms. McLane's request, we will also address two questions brought to the meeting by Karen Boyd. Ms. Boyd, a fluvial geomorphologist, asked, "How does the historic landscape interact with the current landscape," and "Can these different aspects be integrated, leading to process-driven restoration?" We can better ecological health and ecosystem services across Gallatin Valley by applying the answers to these questions.

Landowners may hesitate to participate in the restoration project due to the high associated costs and negative connotations. However, educating them on the benefits and processes of stream and floodplain restoration may help persuade them to pursue restoration to improve water quality and quantity. In this paper, we will answer Ms. Boyd's questions regarding the Rocky Creek floodplain restoration project discussed by Ms. McLane. Additionally, this paper provides talking points for Ms. McLane to help convince stakeholders to agree to participate in floodplain and stream restoration. Finally, this paper includes methods for measuring the success of floodplain and stream restoration projects in the Gallatin Valley using the Rocky Creek site as an example.

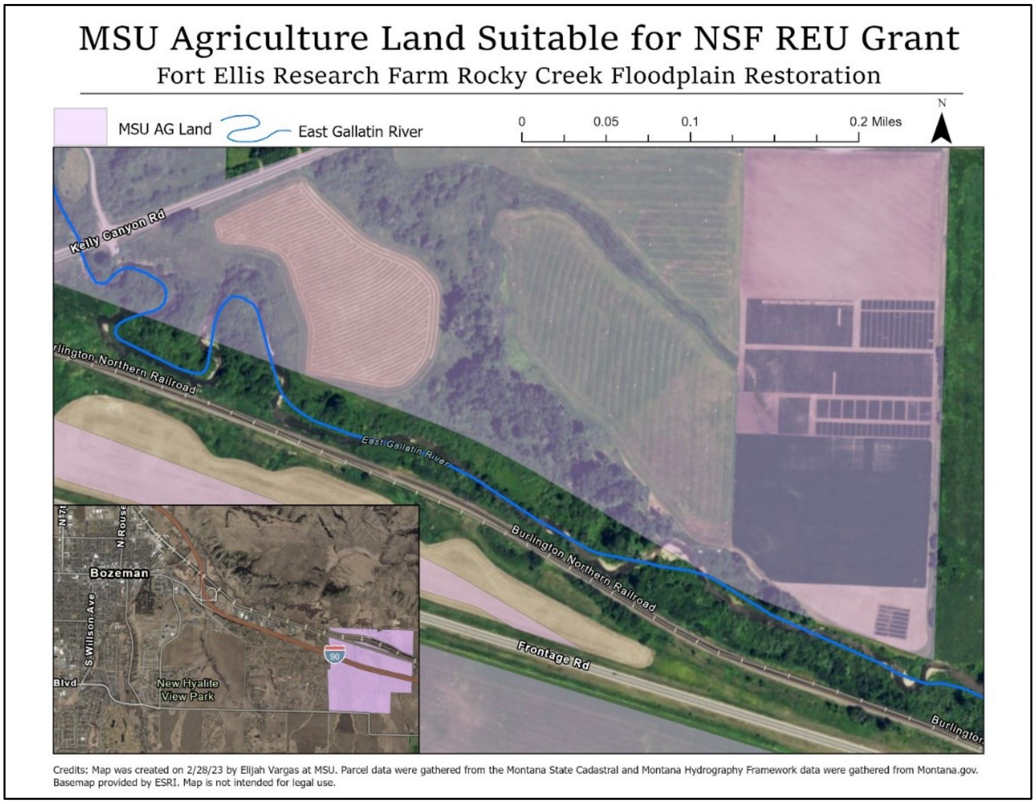

Figure 1: Fort Ellis Research Farm extent. Suitable land for floodplain and stream restoration.

SUMMARY OF RELEVANT LITERATURE AND APPROACHES:

Process-Driven Restoration and Opportunities

"How does the historic landscape interact with the current one?" Ms. Boyd's question is relevant to process-driven restoration. Process-driven restoration is a methodical sequence of steps implemented to help restore a site to its maximum potential. There are two essential aspects of process-driven restoration. The first is utilizing multiple spatial and temporal scales to conduct a landscape assessment that compares historical and current conditions. Historic landscapes are great reference points because they often have lower levels of disturbances, leading to higher maximum potential. By recognizing the potential of the past ecosystem, restoration efforts increase ecosystem function and services. The second aspect is considering the human constraints that limit the ecological potential of a site. Anthropogenic influences like buildings, roads, and trails limit restoration potential.

Process-driven restoration utilizes spatial and temporal scales to assess the conditions of landscapes. The usage of a landscape assessment enables the identification of a list of priority areas. Landscape assessments must cover several spatial scales to accurately assess an ecosystem's functionality. More extensive, entire-stream ecosystem assessments will help develop a foundational understanding of the ecosystem. A smaller, more focused assessment identifies areas and land-use practices that help account for the alteration of vital ecological functions. Temporal scales are another crucial aspect of process-driven restoration. Using pre-development, current, and future land use/land cover plans, people can assess the comparative risk of process alteration from pre-development to current and future conditions (Gersib, R.A., 2001).

Process-driven restoration aims to consider the complexity of systems while also understanding that human constraints can affect a site's ecological potential. When planning a restoration project, the next step after a landscape assessment is to consider the constraints and create boundaries for solutions. Constraints include not only anthropogenic influence but also the disturbance regime. Recognizing the type of infrastructure and how it interacts with the landscape can help establish project guidelines. Boundaries considering human constraints can help design restoration efforts consistent with altered physical and ecological potential (Beechie et al., 2010). One can apply the following restoration methods to achieve the maximum ecological potential of a system without destroying necessary human infrastructure.

Restoration Methods

Restoring a degraded riparian zone could involve implementing robust riparian buffers, reconnecting the floodplain to the stream, and using Beaver Dam Analogs (BDAs) to improve ecosystem functions and services. Riparian buffers are among the most effective restoration techniques for reducing floods, increasing water quality, decreasing erosion, and increasing natural storage (Hook, 2003). BDAs can increase natural storage by attenuating the water table when it declines during late-season flows (Puttock et al., 2017; Westbrook et al., 2006). Spreading basins could increase the residence time of water on the floodplain, which may result in increased recharge (Parul, 2017). These methods of restoring riparian zones could improve the functioning of an ecosystem, leading to several benefits, including increased natural storage.

A robust riparian buffer / corridor can be beneficial. Chesapeake Bay's extensive restoration efforts have been the focus of restoration-based research. Despite the significant investment in research and repair, the area has reached a threshold where it is taking an immense effort to change back to a former ecological state (Hook, 2003). The most effective restoration techniques were riparian buffers along streams feeding the lakes. Thousands of lakes with decreased algal abundance and increased biodiversity show that nutrient levels are dropping due to stream restoration efforts (Moore et al., 2018). Implementing riparian buffers may also be an effective technique in other restoration efforts, such as the proposed project on Rocky Creek.

Considering the constraints and boundaries when planning a restoration project is crucial to achieving the maximum ecological potential of a system. Dams created by beavers increase water depth and width while slowing stream velocity (Stout et al., 2017). Additionally, beaver dams have been found to elevate the water table during high and low flows and increase water storage (Puttock et al., 2017; Westbrook et al., 2006). However, extensive trapping of beavers for the European fur trade in the Greater Yellowstone Ecosystem led to the abandonment of beaver dams and the loss of beavers themselves (Yellowstone National Park et al., 1990). Reintroducing beavers may only sometimes be feasible due to human constraints and attitudes toward beavers (Jonker et al., 2006). One innovative solution that may help increase natural storage within the boundaries of human constraints are Beaver Dam Analogs (BDAs). BDAs are permeable instream structures made up of branches, mud, and rock to mimic the function of beavers (Munir & Westbrook, 2021). BDAs can increase natural storage by attenuating the water table when it declines during late-season flows (Puttock et al., 2017; Westbrook et al., 2006).

BDAs are a potential solution to reduce a stream's sediment-holding capacity and increase hyporheic flow. The Hyporheic zone is where surface water and groundwater start to mix below and near the stream; this zone is critical to solute processing which can lead to improvements in the hydraulic and ecological function of the stream (Wade et al., 2020). BDAs allow stream velocity to decrease, allowing sediment to fall out of suspension and build up behind the BDA itself (Wade et al., 2020). By doing this, we can see more streambed and stream topography diversity, resulting in pools, riffles, point bars, and stream meandering over time (Wade et al., 2020). These features can induce differences in hydraulic head, which drive surface water into hyporheic zones, thus resulting in more hyporheic flow (Boano et al., 2014; Wade et al., 2020). An increase in hyporheic flow due to BDAs benefits the riparian zones' vegetation and soil health, increasing bank stability.

A study on different configurations of BDAs in a low-order stream near Calgary, Alberta, observed an immediate water table rise following the installation of BDAs (Munir & Westbrook, 2021). Munir & Westbrook (2021) looked at three different configurations of BDAs. These included a single BDA configuration, a double BDA configuration, and a triple BDA configuration. The single-BDA configuration lowered the stream stage and flow peaks below and raised low flows (Munir & Westbrook, 2021). This was an expected result for the single BDA configuration; however, the authors explain that the double configuration did not perform as expected. The double configuration was a series of two BDAs in succession, which dampened peaks during storm events; however, it did not raise stream stage or low flows. However, the double configuration is on a steeper section of the stream. Finally, the triple configuration also provided some unexpected results: During storm events, the stream gauges below the triple configuration showed higher stream stages and flows than the upstream gauge. This could result from the increased connectivity between the stream channel and groundwater in the riparian area. While Munir & Westbrook (2021) concluded that future research should further explore the dynamics of the stream-riparian hydrological connection, they did see a rise in the water table, which was most significant within 2 meters from the stream.

Reconnecting floodplains to streams can improve various ecosystem functions, including reducing floods, increasing the exchange of water and nutrients, increasing water quality, decreasing erosion, and increasing natural storage (Loos & Shader, 2016). A floodplain is a relatively flat area adjacent to a stream that receives sediment deposition during high flow events that exceed bank full (Bren, 1993). Floods cause lots of damage to crops and infrastructure, and reconnecting streams to floodplains can help mitigate flood effects. In 2016, flooding caused 7.96 billion dollars of damage (Loos & Shader, 2016). Woody species in the floodplain and riparian areas add more surface roughness for deposition and bank stabilization during high-to-peak flow events (Swanson et al., 2017). Riparian areas are the zone nearest the stream; therefore, they are influenced by their proximity to the stream (Bren, 1993).

Riparian areas and floodplains are interconnected systems. Tockner & Stanford (2002) reported that 46% of riparian areas in the United States are classified as 'intensively cultivated'. Meaning their functions have been degraded due to agricultural use of the floodplain. An ecologically functional floodplain is connected to the adjacent stream. Any high-flow or significant precipitation event could result in water and sediment deposited onto the floodplain. Restoration would be beneficial if high-flow events do not inundate the floodplain (Loos & Shader, 2016).

Reconnecting the floodplain and stream are essential to have a functioning system. Utilizing spreading basins is a restoration method that helps increase the water in the aquifer. This method uses floodplains to inject water through the soil back into the aquifer. The effectiveness of spreading basins depends on the infiltration rate, the percolation rate, and the capacity for horizontal water movement through the soil (Parul, 2017). This method proved to be more practical when the water on the floodplain carried less sediment. Spreading basins may be an effective tool for increasing natural storage on Rocky Creek when floods occur with more floodplain connection to the stream.

The clay-based soils in the valley and the high number of suspended solids exceeding the TMDL will limit the effectiveness of spreading basins.

Measuring Project Success

During the meeting with Gallatin Valley land managers, Ms. McLane asked, "What are the most effective ways to measure project success?" Measures of project success will be critical in securing funding and support for a proposed restoration project on Rocky Creek. Quantifying restoration using different measures of success creates a better understanding of the restoration practices implemented. Restoration techniques can be modified using this understanding to increase the success of future restoration projects in the area.

Schulz-Zunkel et al. (2022) state that streams and floodplains are among the most dynamic natural ecosystems that offer unique functions and services. Restoration is an effort to recover degraded, damaged, or destroyed ecosystems, which means addressing the underlying causes of degradation, such as flow regulation, reduced habitat diversity, and reduced connectivity, rather than just treating the symptoms of a compromised system (Schulz-Zunkel et al., 2022). Furthermore, monitoring may help educate the public and stakeholders on the importance of these restoration practices. An interdisciplinary approach to monitoring restoration practices is necessary, given the multiple drivers of a healthy stream and floodplain ecosystem.

Following the completion of the 'Wilde Mulde' project in Germany, Schulz-Zunkel et al. (2022) performed interdisciplinary monitoring of several indicators to help better quantify if the restoration effort succeeded. This monitoring is performed by assessing the success of serval indicators looked at, with several individual indicators that characterize several main categories (composite indicators). The first composite indicator was abiotic, which included several individual indicators of flow velocity, flow diversity, diversity of riverbed topography, sediment diversity, reducing flow resistance, and hydromorphological diversity. The second composite indicator was biological, which assessed the individual indicators of the ecosystem (metabolism) respiration, benthic food web, macroinvertebrates, fish, macrophytes, dragonflies, carabids, vegetation, and birds. The composite indicator of socio-economic included the individual indicators of acceptance, minimizing conflicts, and public awareness. Last, an ecosystem service indicator of the aesthetic quality of the landscape was used with individual indicators of provision of habitats, retention of nutrients, retention of sediments, and landscape aesthetic quality (Schulz-Zunkel et al., 2022). They applied interdisciplinary monitoring to two different restoration practices of increasing large wood in the river and removing riprap from stream banks. One should apply a similar comprehensive approach to evaluate the restoration practices outlined in the Gallatin Watershed Council's restoration plan for Rocky Creek.

A BACI design assessed these two restoration practices used in the 'Wilde Mulde' project (before vs. after, control vs. impact). The control sites were stream sections where restoration practices were not implemented. Positive changes observed from the restored (impact) site to the control site were deemed restoration success. For each of the individual indicators chosen, sampling plots were randomly chosen along the restored and non-restored sections of the stream. To statistically test the effect of the different restoration practices, each of the chosen composite indicators and their individual indicators was then applied to a separate generalized linear model with the same basic structure for each. The two main effects of before-after (BA) and a control-impact (CI) were also used with an interaction term between BA and CI terms. Then, by examining the individual indicators for each composite indicator, the overall effect of the composite indicator is determined. Due to the complexities of the composite socio-economic indicator, a rating scale determines the success of each individual indicator.

The Gallatin Watershed Council has addressed several areas of concern in Rocky Creek, including channel entrenchment, increased sediment levels, and decreased base flow of Rocky Creek (Dunn et al., 2014). Two restoration methods discussed earlier in this paper, riparian buffer enhancement and the construction of BDAs on Rocky Creek, could be beneficial in addressing these issues. A similar interdisciplinary monitoring approach can assess the success of a restoration project on Rocky Creek. Using the same composite indicators of abiotic, biological, socio-economic, and ecosystem services, we can better understand the effects of restoration implemented on Rocky Creek. The individual indicators used for Rocky Creek could be similar to the ones used above, with a few exceptions in the biological indicators. The biological indicators need modification to represent a healthy stream ecosystem in the Greater Yellowstone Region.

DISCUSSION:

McLane at the Gallatin Watershed Council requested talking points to help create a proposal for MSU to participate in a restoration project. A floodplain and stream restoration project on the Rocky Creek reach (see Figure 1) that runs through Fort Ellis Research Farm would increase the capacity of the system to perform ecosystem services and provide undergraduate students with research opportunities. Additionally, floodplain and stream restoration on this reach would support the goals of the Montana Department of Environmental Quality's (MT DEQ) 2015 State Water Plan and align with President Biden's Nature-based solutions to fight climate change, strengthen communities, and support local economies. MSU could increase the viability of a floodplain restoration project by applying for the National Science Foundation Research Experiences for Undergraduates (NSF REU) grant.

Montana Department of Natural Resources and Conservation (MT DNRC) prepared the Montana State Water Plan (2015) to provide a comprehensive overview of Montana's water resources and develop a proactive plan for sustainable management. The plan serves as a guide for water resource management and provides a framework for future planning and decision-making related to water resources. The program recommends integrating natural storage, such as riparian areas, floodplains, and wetlands, creating a longer residence time to promote groundwater recharge (Montana DNRC, 2014, pg. 69). To achieve the goals of the Montana State Water Plan, one could apply the restoration methods discussed above as techniques to restore Rocky Creek.

During COP27 in November of 2022, the Biden-Harris Administration released the Nature-Based Solutions (NBS) Roadmap. The roadmap seeks to utilize natural systems and processes to mitigate and adapt to the impacts of climate change (House, 2022). One of the key strategies outlined in the roadmap is to restore and protect natural ecosystems, including wetlands and floodplains, which can help reduce the risk and severity of floods and droughts. Floodplain restoration projects also align with the goals of the NBS Roadmap because they can help to strengthen local communities and economies by providing opportunities for local employment and educational experiences, improving water quality, and increasing biodiversity.

In addition to supporting Bozeman's ability to achieve the goals stated in the Montana State Water Plan and aligning with the goals stated in the NBS Roadmap, floodplain restoration would also increase the capacity of the system to provide ecosystem services. Ecosystem services are the set of natural ecosystem functions that maintain the health and well-being of humans and can be critical to our survival or the enhancement of our natural systems. Ecosystem services associated with a floodplain restoration project on Rocky Creek include drought mitigation, flood mitigation, and water purification (Kremen, 2005). Riparian vegetation and non-degraded soils increase water infiltration during high-flow events and slowly release the water, acting as natural storage for late-season flows and preventing the damaging effects of spring floods (Locke, 1999). Additionally, riparian vegetation prevents excessive sediment, nutrients, and contaminants from entering the stream (Locke, 1999).

MSU could apply for the Research Experiences for Undergraduates (REU) grant, a program created by the National Science Foundation (NSF). NSF administers the REU Sites grant annually to initiate and conduct research projects involving undergraduate students (National Science Foundation (NSF), 2022). This program seeks to engage students who may need more undergraduate research opportunities. Sites may be in a single department or offer interdisciplinary research opportunities. The typical REU site will host 8-10 students yearly and typically receive $80,000-$130,000 annually. MSU does not currently have a site for long-term ecological monitoring and research. A floodplain and stream restoration would provide an adequate site for undergraduate research about long-term ecological change. One could also use the site to study how a riparian buffer can reduce sediment inputs from agricultural land. This research would be useful as it is common in the Gallatin Valley and Montana for agricultural land to be adjacent to streams.

The railroad, road development, and the adjacent agricultural land have confined Rocky Creek from its original channel migration zone. Restoring the floodplain would allow the stream to reconnect with more of its historical channel migration zone, which is essential for a stream's health and biodiversity (Kremen, 2005). Restoring the floodplain would mitigate the risk of floods and droughts in the area, which aligns with the goals of the Montana State Water

Plan and the NBS Roadmap. Restoring the floodplain will also increase the capacity of the system to provide ecosystem services. As mentioned earlier, ecosystem services associated with the floodplain restoration project on Rocky Creek would include drought mitigation, flood mitigation, and purification of water through the adjacent riparian area would increase the capacity of the system to reduce floods and droughts while increasing its ability to filter sediment runoff from the non-irrigated hay pasture that is immediately adjacent to the river. These ecosystem services will help support local communities and economies by providing opportunities for employment and educational experiences, improving water quality, and increasing biodiversity. In addition, it may help mitigate the negative impacts of climate change on the region and provide an example for future restoration projects.

CONCLUSION:

Like many other cities in the American West, Bozeman will continue to face water quality and quantity issues without proper management of the critical ecosystems that help maintain this vital resource. The essential ecosystem services and functions that riparian buffers and floodplains provide in maintaining water quality and quantity will only be effective with the proper restoration methods. Implementing riparian buffers and installing BDAs can help improve the condition of Rocky Creek, which is one of the many impaired streams in the Bozeman area. More importantly, this restoration can increase ecosystem functions and services. The likelihood of the restoration site reaching its full potential is small without proper monitoring. Monitoring and quantifying the effects of restoration practices can better inform land managers about the implemented restoration practices and if modifications will be needed. Monitoring and quantification can also gain the public and stakeholders' support for further restoration. Implementing the restoration methods and the interdisciplinary monitoring techniques discussed above may help land managers maximize the ecological potential within the current human constraints.

In the case of Rocky Creek, without support from prominent stakeholders like MSU, the restoration planned, will never reach its full potential because of the constraints on the stream. When creating a proposal to MSU, we recommend that the focus encompasses MSU's ability to qualify for the NSF REU grant. This grant would reduce the project's cost and provide undergraduate research opportunities. MSU currently has no opportunities for undergraduate students to do long-term ecological monitoring so this project would benefit the University. In addition, another factor that may increase MSU's willingness to complete a floodplain restoration is that the project would support and align with the goals of the MT State Water Plan and the Biden-Harris Administration's NBS Roadmap. Finally, the project may be more supported and successful if more upstream landowners are willing to participate in floodplain restoration. The two properties immediately adjacent to the east of the site are "farmstead-rural" property types (Montana State Library, 2022). These landowners' involvement may increase the University's willingness to participate in a floodplain restoration project.

Rabi Phelan contributed to the process-driven restoration section. Tyler Boyd and Noah Majerus created the restoration method section. Kevin Sheridan and Haley Buckbee were the authors responsible for the measures of the project success section. Elijah Vargas was the author of the discussion section. Kevin Sheridan and Elijah Vargas oversaw and organized the paper.

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5.0 Environmental Impacts of Outdoor Recreation and Community Involvement

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Bozeman, Montana, is renowned for its scenic natural setting and countless outdoor recreation offerings. Residents highly value outdoor recreation, with one survey finding that 97% of respondents visit parks, trails, and other recreational facilities within the City of Bozeman during a typical year (ETC Institute, 2022). Access to outdoor recreation provides residents a wide range of benefits, including enhanced health and wellness and better overall quality of life. Those who engage in physical activities like walking, running, or biking in a natural setting will experience health and wellness benefits beyond those brought on by the movement (Hartig et al., 1991). From a health and happiness perspective, providing public access to high-quality outdoor recreation should be facilitated whenever possible. However, it is also essential to consider this from an environmental perspective. The development and use of recreational infrastructure have impacts on the surrounding environment. These impacts are often detrimental and can result in severe environmental problems if not managed appropriately. Recreation managers must seek to maintain healthy ecosystem processes within recreational areas since these processes determine the quality of the recreational experience. The management goals for conserving a natural resource are not inherently in line with the management goals for developing and maintaining recreational opportunities. Effective management must include careful consideration of the tradeoffs to find an appropriate balance.

During our meeting with local resource managers in the Gallatin Valley, Haile Houghton, the 2023 Big Sky Watershed Corps Member at the Gallatin Valley Land Trust, asked, "Exactly how does recreation impact local trails?" Trails are a vital component of the Gallatin Valley recreational inventory. This paper will explore how recreation impacts trails and local ecosystems, how the public can maintain these systems, and provide actionable items that resource managers could practically utilize.

Plant Pathogens

Recreation within the greater Bozeman area impacts surrounding biotic communities and pedological processes. These impacts result from the direct wear on trails from hikers and bikers and the myriad of secondary effects, such as the introduction of malignant foreign biological pathogens and materials discarded by the public. The first implication of recreation on trail health is the spread of plant diseases. In a 2010 paper discussing the impacts of recreation on vegetation and soil health, the spread of various plant pathogens, including *Phytophthora ramorum*, negatively affected plant communities (Pickering et al., 2010). *P. ramorum* is a pathogen that causes sudden death and damage in oaks and several native and ornamental woody species throughout the country. Although this specific pathogen does not occur in Montana, many other harmful plant pathogens do exist in our state. For example, larch and lodgepole needle cast has been found southeast of Helena (Montana DNRC, 2015). These needle cast pathogens are fungi that humans can spread within recreational areas.

Figure 1. lodgepole pine needle cast (*Lophodermella concolor*) symptoms, Jane Taylor, USDA Forest Service, Bugwood.org

Bozeman hosts many trails in the foothills of the Bridgers that are popular for hikers and bikers. But these recreational opportunities are also potential vectors for plant pathogens. Awareness of the potential harm recreation can have on local plant species is essential.

Soil Compaction

Hiking and biking can also impact soil health through compaction, erosion, and trail widening (Pickering et al., 2010). Over time, evidence of compaction from individual recreators becomes apparent. Compacted soils have altered soil structure that features reduced pore space. Pore space influences how and to what degree water, gas, and nutrients can move within the soil. Plants have difficulty growing in compacted soils since water and nutrients are less mobile, and plant roots can often be physically constrained (Queensland, 2013). Compaction reduces plant diversity and changes the species composition surrounding trails, as the different soil environment supports plants tolerant of those conditions. Erosion can expose bedrock and reduce the soil depth available for plant roots. It can also affect water runoff and widen trails. Trails with steeper slopes are more susceptible to erosion caused by recreation, though the type of recreation matters. Hiking creates more sediment loss and dispersal than mountain biking, but the intensity of mountain biking affects the levels of erosion. Table 1 shows the various effects of recreation on soil health (Leung and Marion, 2000).

Table 1- Ecological Impacts of Soil Degradation Due to Recreation (directly from Leung and Marion, 2000)

	Ecological component			
	Soil	**Vegetation**	**Wildlife**	**Water**
Direct effects	Soil compaction Loss of organic litter Loss of mineral soil	Reduced height and vigor Loss of ground vegetation cover Loss of fragile species Loss of trees and shrubs Tree trunk damage Introduction of exotic species	Habitat alteration Loss of habitats Introduction of exotic species Wildlife harassment Modification of wildlife behavior Displacement from food, water and shelter	Introduction of exotic species Increased turbidity Increased nutrient inputs Increased levels of pathogenic bacteria Altered water quality
Indirect/ derivative effects	Reduced soil moisture Reduced soil pore space Accelerated soil erosion Altered soil microbial activities	Composition change Altered microclimate Accelerated soil erosion	Reduced health and fitness Reduced reproduction rates Increased mortality Composition change	Reduced health of aquatic ecosystems Composition change Excessive algal growth

Limiting trail use during and after precipitation events can prevent soil compaction and erosion. Awareness of this effect on trail health can help Bozeman residents do their part to protect vegetation on the perimeter of popular local trails. A way to increase public knowledge might include posting a sign at trailheads.

Compounding Impacts

Changing plant species composition has impacts on the local ecosystem. Plant size and growth rate, especially stunted by soil compaction due to recreation, help determine ecosystem productivity (Chapin 2003). A reduction in plant species diversity leads to decreased decomposition and nitrogen mineralization, impacting local wildlife and ecosystem microorganisms (Ouyang 2016).

Plant community and soil health are imperative to keep Bozeman's trails healthy and able to support diverse types of recreation for all its residents. The compounding effects of recreation are important when looking at multi-use trails such as Peets Hill and Bozeman Creek. Hiking and mountain biking are manageable independently, but when trails not explicitly designed for mountain biking are exposed to regular riders, the combinations of erosion, compaction, invasive species, and pathogen effects are even more detrimental to plant and soil health. Effective management of these trails must address compounding effects into their plans.

Evaluating Impacts

There are variable management styles to tackle large-scale trail maintenance projects. Some might try to quantify all variables involved in trail health. While this is effective, it's not very time or resource efficient. A better method might involve creating parameters for ranking trail health within an area. This would still help allocate resources effectively while saving time and money. One management scale divides ecosystem health into four stages with increasing levels of native plant community health degradation (Togisbayeva, et al., 2022): Stage 1 describes the entire state. Trails cover no more than 15% of the area, and plant cover is not very disturbed. No weeds are found. Stage 2 describes the disturbed state. Trampled vegetation covers up to 30% of the area, and more weeds are found. Stage 3 describes the severely disturbed state, where the area is trampled up to 50%, and there is no undergrowth. There is a reduction in plant species diversity and plant cover. Finally, stage 4 describes the degradation of the vegetation cover state. At this stage, no new plants are growing, and the area is trampled up to 100%. This stage can be further divided due to the types of vegetation present and the age of the area. Togisbayeva et al., (2022) claims once the third stage of degradation is identified, there must be a reduction in recreation to maintain the plant species present. Stage 4 is consistent with biodiversity loss and severe ecological consequences of degradation. A rating system like this might be beneficial for Bozeman to assess trails and natural areas where recreation is frequent. A ranking system of the areas at highest risk of degradation would allow for management to prioritize where to put time and resources into maintenance and keep Bozeman healthier overall.

Ranking systems could be put into place for lower-ranked disturbed trails with minimal labor with signs at trailheads and/or trail surveys on popular local trails. Signs could have a sliding arrow where community members could adjust to reflect that day's conditions. This would reduce recreation in muddy conditions and would prevent soil compaction. Also, trail surveys would provide data for maintenance professionals and city planners to make adequate management decisions. And the community would carry this mindset into other trails that might not be as popular. Even with no signs at distant trailheads, Bozeman locals would know to check trail conditions because such signs exist at the M Trail or Peet's Hill. Involving the community, or using citizen science principles, to monitor trails could prove to be an effective method of maintaining Bozeman's most treasured recreational areas. Citizen Science-based monitoring of pathogens, compaction, and vegetative community integrity presents an effective strategy wherein these issues can be quantified and acted upon by resource managers.

What is Citizen Science?

Citizen Science can have many different meanings dependent on the specific ways in which it is implemented, but at its most base level, it is defined as being the practice by which scientists and resource managers can crowdsource the collection of data or the monitoring of conditions through the participation of the public by non-scientist citizens for resource management and/or scientific research. When it comes to natural resource management and research in general, the application of Citizen science can have a substantial number of benefits for both managers and the public in the realms of public engagement and enhanced management outcomes.

The practice of Citizen Science has been used to significant effect in the conduction of a great many scientific endeavors all over the country throughout modern history. The "North American Bird Phenology Program" is often considered to be the first example of formalized Citizen Science being used in the collection of scientific data (Zelt et al., 2012). Founded in 1883 by Wells Woodbridge Cook, this program consisted of the establishment of a network of ornithological observers who collected bird migration data which was then collected and used to study the migration patterns of American bird species. This is a wonderful example of the effective use of Citizen Science as researchers were able to collect a large dataset of migratory data using a volunteer network of 3000 volunteers at its peak across the country (Zelt et al., 2012). Another notable example of Citizen Science in action is the "Monarch Watch" program. This program is a more recent example (being started in 1992) which consists of a network of citizen scientists who monitor the Monarch butterfly along its fall migration south towards Mexico. This program has allowed for expanded monitoring of endangered species (Davis, 2015) in addition to promoting species viability through the encouragement of planting milkweed, a vital food source for the species.

One of the main strengths of the Citizen Science approach is that it allows researchers and managers to access a potentially expansive pool of labor and resources that they might not otherwise be able to access on their own. Another positive of this kind of methodology is that it can allow for the concentration of data collection over a great area in a relatively brief period; time being a critical resource for most research, especially for graduate and post-graduate studies which are often constrained to just a few years. However, the most impactful effect of Citizen Science is that it brings many more people into the scientific process, gives them a greater connection to the kind of work being done in the natural sciences, and increases interest in the long-term success of these kinds of projects (Garbarino & Mason, 2016).

The increased labor provided by citizen science outreach programs can drastically reduce the amount of time it takes to complete scientific endeavors (Garbarino & Mason, 2016). For example, a city's parks and recreation department have limited expertise and staff to monitor the city's wetlands. Limited labor may result in reduced quality of monitoring data and diminished their capacity to manage these systems. However, if the city were able to recruit citizen scientists in the form of retirees looking to give back to their community and high schoolers looking to get some community service hours, the parks and recreation department could increase their capacity to monitor these wetlands and make more effective management decisions. If citizen scientists monitor their local wetlands they could, after a small amount of training from the full-time employees, collect data relevant to wetland management, expand datasets and reduce management overheads (Garbarino & Mason, 2016). The expansion in remote sensing and information technologies have increased citizen science programs by integrating homes computers or smartphones (Lucrezi, 2021).

While the benefits of establishing citizen scientist programs are of clear value to land resources managers, the greatest benefit of these kinds of organizations is that they increase public interest in local management issues and help to foster a greater sense of community ownership of said issues. One of the most common issues expressed by local managers regarding issues of management and outreach is that they are unable to generate the kind of public interest and involvement in the conduction of said management. It may be that the community simply don't know how to get involved with programs in any meaningful way. Citizen Science programs are an excellent way to provide the public with specific opportunities to get involved with that management in a hands-on way with clear outcomes. Once people is involved with the management of their local natural systems, they are much more likely to feel a direct connection with and care about the outcomes of those systems; this opens them up more to the idea of contributing to calls for public input by local managers and to advocating for the meaningful conservation of these natural spaces (Roche et al., 2022).

Solutions For Effective Management

The management and monitoring of Bozeman's trail system provide an excellent opportunity to utilize the tool of Citizen Science for enhanced outcomes. There are over two hundred trails which when combined include nearly a thousand miles in Gallatin County (Trails Advisory Committee, 2001). The maintenance of these trails is an effort shared by organizations and management agencies including the U.S. Forest Service, the Gallatin Valley Land Trust, the Bozeman Recreation and Parks Advisory Board, and many others. Volunteer-based trail maintenance projects are essential in accomplishing necessary upkeep since land management agencies typically have limited funding and resources available to devote to these tasks. The accomplishments of these volunteer groups are notable examples of the benefits of leveraging community support.

Trail User Surveys

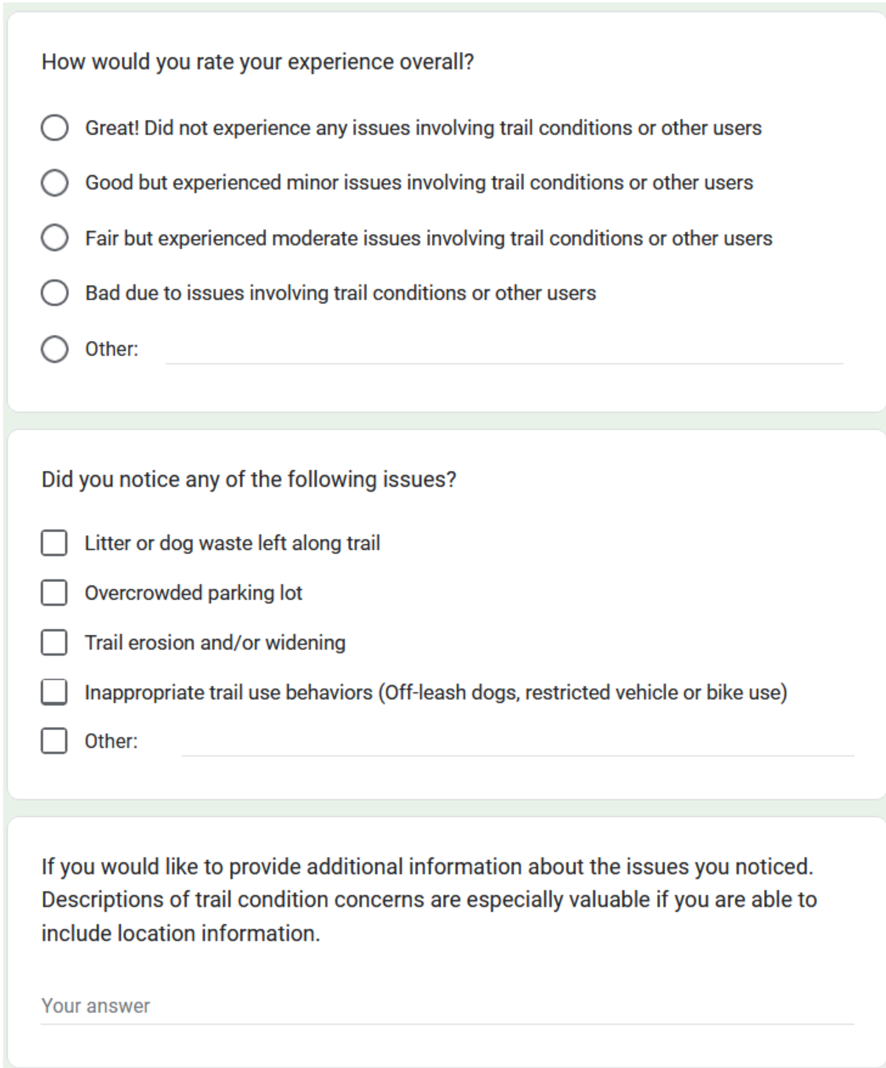
A trail user survey will give the public an opportunity to provide comments about the conditions of Gallatin Valley hiking trails and about any environmental impacts they notice (Figure 2). The survey responses will provide data that can be collected and synthesized by managers and then used to identify maintenance needs and inform management strategy changes. Official trail assessments are usually conducted by trained land management agency officials for planning purposes. Trail user surveys should not be intended to replace official trail assessments. The survey should be designed to collect data about general conditions and the user's experience. Survey questions can refer to trail conditions, quality of the experience, frequency of an individual's trail use, and temporal usage patterns. Data from user surveys is useful in gaining support for trail projects from local municipalities and property owners and providing evidence supporting funding/grant requests (Bergman et al., 2016).

Figure 2. Example Trail User Survey. Developed by Cassie Birch 2023. Survey Link

Feedback from users and community input helps decision-makers gauge the needs of the community and allows the development of plans that better fulfill these needs. Many governmental planning processes are required to have opportunities for public comment. However, many public officials feel that public participation rates are too low. Previous methods for obtaining public feedback about trails have resulted in limited participation. For example, during the development of the 2001 Gallatin County Trails Plan, the trails committee sought to obtain public input to help assess the trail development-related priorities of the community. The committee hosted four open houses and advertisements in newspaper ads and flyers. Attendees were asked to fill out Trail Ideas input forms which included a priority ranking section and a general comment section. The compiled results indicated that recreation is the highest priority trail function and walking, running, and hiking were the highest priority desired use. (Trails Advisory Committee, 2001) These results were based on only 45 correctly completed Trail Idea forms. In 2022, a robust 6-paged mail survey was developed for the City of Bozeman Parks and Recreation Department. The purpose of this survey was to collect data about the respondent's recreation-related priorities. The survey developers determined that the 401 completed and returned surveys were a large enough sample size to be appropriately representative of the community. 62% of respondents identified trails as one of the top four recreation amenities that were most important to them (ETC Institute, 2022). Both surveys provided valuable insights and confirmed that trails are especially important to the residents of Gallatin Valley. Though these surveys addressed related topics and were both aimed at gathering input from the same population, they obtained quite different numbers of responses. This was likely due to their use of the two different distribution methods. In most cases, it is easier for a resident to fill out and return a mail survey within 2 weeks than it is for them to attend a meeting to complete a survey.

Promoting higher levels of participation through user-friendly methods should be a priority. Requiring a person to fill out and return a mail survey or attend a public event can act as barriers to public participation. Every step that a person must take to complete an action is a chance to lose them. Therefore, we recommend placing trail information and a scannable QR code that links to a trail user survey at trailheads. This will help capture information from actual trail users since anyone who can access the trail and has an internet-capable cell phone, can also access the survey.

The survey should be short and the information accompanying it should inform the users that they can access and complete it from their phones while at the trailhead. This method is accessible and user-friendly for both the survey taker and those managing the data. When compared with traditional survey methods, online surveys tend to have lower research costs and shorter implementation times. The data obtained is also easier to analyze. (Wu et al., 2022) There are many options available for online surveys and data collection including free ones such as Google Forms (Figure 3). Using Google Forms, survey data can be accessed, and survey questions can be updated in real-time.



How would you rate your experience overall?

- ◯ Great! Did not experience any issues involving trail conditions or other users
- ◯ Good but experienced minor issues involving trail conditions or other users
- ◯ Fair but experienced moderate issues involving trail conditions or other users
- ◯ Bad due to issues involving trail conditions or other users
- ◯ Other: ____________

Did you notice any of the following issues?

- ☐ Litter or dog waste left along trail
- ☐ Overcrowded parking lot
- ☐ Trail erosion and/or widening
- ☐ Inappropriate trail use behaviors (Off-leash dogs, restricted vehicle or bike use)
- ☐ Other: ____________

If you would like to provide additional information about the issues you noticed. Descriptions of trail condition concerns are especially valuable if you are able to include location information.

Your answer

Figure 3. Sample questions from our example trail user survey. Cassie Birch 2023.

Using trail user surveys on an ongoing basis will provide data on the results of management activities performed. As we have discussed, the environmental impacts of recreation on trails are a result of human behavior. These impacts can be managed by preventing or reducing certain behaviors. This can be accomplished by promoting voluntary actions and through mandatory regulations. Of the 205 trails in the Bozeman area, 166 of them are within the Gallatin National Forest. (Trails Advisory Committee, 2001) The U.S. Forest Service has the authority to implement mandatory seasonal restrictions, mandatory use restrictions, closures, re-routes, and additional development. These actions are typically outlined per the latest approved forest planning documents. Mandatory trail regulations are intended to achieve a variety of goals including reducing erosion, protecting watersheds and sensitive species, and reducing trail congestion (U.S. Department of Agriculture, 2020).

Where mandatory compliance may not be appropriate, achieving high levels of voluntary participation becomes the key factor for success. Promoting voluntary environmentally friendly practices will help combat the environmental impacts of recreation while allowing the community to feel more involved in the process. Protecting the environment is everyone's responsibility. The efficacy of these initiatives is often dependent on the level of voluntary participation. Managers can promote voluntary participation in actions that help maintain trails by posting information about the issue and recommended actions. Several organizations and trail managers are using trailhead signs to inform users about trail conditions related to mud and recommend user actions (Figure 4).

Figure 4. Muddy Trails Meter. Town of Blacksburg Virginia. Photo Credit: Chris Partovi 09/13/2022

Signage can address any issue of concern for a particular trail. As shown in the Muddy Trails Meter example, signage should include information about the issue and recommend voluntary actions that help mitigate these issues. Program efficacy can and should be assessed by analyzing changes in the data from the trail user survey program. The data can be used to track changes over time for that specific trail as well as to compare changes across several trails. This will give managers a chance to launch a program or try out a new management strategy at one trail and then evaluate the results by comparing the data to a similar trail. For many programs, there are few opportunities to make data-based decisions simply because the managers do not have the necessary data. Maintaining a program that collects and publishes ongoing trail user survey data can encourage and facilitate additional program establishment and trials by other organizations that may not have the resources to do data collection themselves. These kinds of collaborations will help increase the body of knowledge about trail conservation and recreational management practices. A successful user-trail survey plan has the potential to benefit both Bozeman-trail users and the conservation community. However, can a voluntary program maintain enough dedicated participants to provide the level of data needed?

For any voluntary program, it is important to consider the level of participation necessary to achieve its desired results. Drivers of public participation can include public awareness, incentives, community support and partnerships, and additional perceived benefits. Developing and implementing marketing strategies can help with participation. Collecting participation data and analyzing participation responses to initiative marketing, outreach, and involvement activities will help managers design strategies that increase participation rates. In the marketing world, the bandwagon effect is "the phenomenon of collective consumption behavior which emulates the actions of others, and represents one's social status, the belonging of a particular group, and conspicuous consumption." (Kang and Ma, 2020). Most conservation programs do not view the public as a pool of potential consumers. However, the marketing strategies designed to increase consumption of a certain product or service are likely just as applicable to increasing participation. Large corporations invest heavily in market research and there is a wealth of data available in the form of academic studies of marketing strategies. Program managers need to understand that collecting data about participation rates will allow them to make data-driven decisions that support participant acquisition and management. Making this data publicly available has benefits beyond the initiative or program itself, as it will allow others to replicate similar activities to benefit other important initiatives. Additionally, publishing data about program progress and participation could help participants feel that their involvement is more appreciated.

Demographic Inclusivity in Public Engagement and Management

The responses to the Bozeman lands protection plan public survey were predominantly answered by one demographic: white residents over 55 years old. It is not just Bozeman that faces low public involvement in environmental matters. With warmer regional temperatures due to climate change, environmental conservation is becoming important for future environmental and community health. Public engagement in these efforts is essential, yet Native Americans have demonstrated limited involvement with environmental planning. Why is this the case, and what are the impacts, especially on their water quality for example?

In Native American communities, cultural dynamics and social interactions are vastly different from non-native communities. The repercussions of forced assimilation into Western education and the loss of cultural traditions have had long-lasting historical trauma. Even today, Native Americans are still in the process of healing, especially regarding education. (Hill, 2020). The social interactions of traditional cultural norms with new Western societal practices can have negative effects on decision-making and the speed of environmental and economic progress.

An example observed personally is the teasing clan system practiced by the Apsaalooke (Crow natives). This type of learning is meant to help one another by saying something to cause embarrassment or humiliation. Teasing is done to correct unusual, ill, or unwanted behavior such as being conceded or depressed (Real Bird, 1997). Yet, this practice can have negative effects on a person's mental health through the fear of failure from applying oneself or not wanting to stand out from others. In an educational setting, the teasing system can make one content with mediocrity, and the normality of being "bad" at school. A community where it is almost "normal" to be bad at school, causes individuals to think they are not smart, halting the pursuit of learning.

This could also be detrimental to participation in an environmental cause. Participation itself might cause one to 'stand out.' This cultural difference has negative impacts on the environment, especially in areas in and around reservations, and on non-reservation land Indigenous people live. For example, the Crow reservation is experiencing harmful pathogens in treated drinking water and well water (Richards, 2018). For the Apsalooke people, a limited understanding of water insecurity and potential negative effects is very prevalent. The insecurity of water is coupled with a lack of financial resources and poor management. One concept to help improve this cultural restriction on Bozeman trail systems is holistic management (Richards et al., 2021).

Holistic management in a basic context is a decision-making framework focusing on a bottom-up type approach (Carter et al., 2023). The approach was originally applied to manage livestock, starting by identifying the stakeholders, assets, and goals before ever looking at the environmental system processes. An example of this could be asking, "How can I improve the soil health?" thinking of microbes, water infiltration capacity, and rate to improve vegetation. After the soil, it is observed to start going up the food chain from soil microbe health to vegetation, and this improves insect health, and upward toward mammal health. Holistic management aims to fix soil, vegetation, insects, and mammals, which in the end benefits us.

Holistic management is not just applicable to managing livestock. There are also less studied social, cultural, and psychological aspects of holistic management. It is purely a technique of looking at the big picture of systems in their entirety and not just a specific component. This can be applied to any realm of intended improvement, like Bozeman's trail systems.

Going back to the question of how to increase the public involvement of Indigenous people, a base must be set to start making decisions. Environmental education must be set at the college, high school, or middle school level. Efforts should also be directed toward enhancing the learning process itself. For instance, the teasing clan example highlights how young people's outlook on schooling can lead them to give up easily when faced with difficulties, feeling inadequate, and unintelligent. However, experiencing such emotions is a natural part of the learning process and should not discourage individuals from pursuing their education. That can be better explained by looking at other holistic aspects.

The holistic view can be made to zoom out even further than managing the land to the people themselves. The study of people and the other aspects of holistic decision-making may be the greatest investment to benefit ecosystem improvement of any realm such as Bozeman trail systems. If social, cultural, and psychological aspects of people in diverse groups and communities are studied, the result will only be beneficial.

The management of public trail systems provides managers with a unique set of challenges related to monitoring and management while having access to a limited resource pool. The integration of holistic management principles allows for a more adaptive and nuanced set of management strategies to be utilized. Recruiting members of the public to assist with the monitoring and management of trail systems and local resources allows for an opportunity to benefit both managers and the public. These efforts provide an effective route for engagement and inclusion with all aspects of Bozeman's community and involve them with the management process.

Conclusion

Outdoor recreation is a fundamental component of Bozeman's culture. Locals and tourists alike value the town's readily accessible natural spaces and the scenic beauty engendered therein. But, recreation in these cherished natural spaces comes with an array of environmental impacts. Recreation has the potential to spread plant pathogens to surrounding ecosystems with recreators acting as vectors. Frequent, repetitive recreational use of public trails increases soil compaction and erosion. Considering Bozeman is home to a rapidly growing population, the negative impacts associated with the recreational use of trail systems as laid out in this paper will only be magnified over time. The way to effectively mitigate this growing problem is to implement management guidelines that involve usage trends to predict how trail systems might look in the future. Managers can then practically address the ecological and pedological consequences of frequent recreation. Involving members of the local community in environmental preservation through the effective usage of Citizen Science principles and techniques could prove to be of great benefit to Bozeman's trail system and its managers. With adequate data collection and management as facilitated by direct engagement with the public, local managers will have the capacity to generate a database that can be utilized to address future environmental management issues. Holistic management principles can also be utilized through community engagement to ensure inclusion and accessibility to all demographics. Engagement with different demographic groups from around Bozeman provides managers with an excellent opportunity to expand the environmental education base of the community. It also ensures accurate data that is vital to predicting future recreational trends. The City of Bozeman must be able to find a healthy balance between protecting the ecosystems of its scenic natural areas while still ensuring the public retains access to outdoor recreational opportunities. Access to the outdoors is a core value held by many Bozeman residents and an integral aspect of the city's culture, but it must be done responsibly. If local managers can utilize the concepts and applications discussed in this paper, practical solutions to this problem can be found in the effective use of community resources.

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