**Important of Preserving Green Infrastructure in an Urbanizing Gallatin County.**

The LRES 2021 Spring Capstone Class

Dr. William Kleindl

“Modern communities develop on the skeleton of their infrastructure” (Kramer 2013). This is a quote from the History of Bozeman’s Water System. As the hardscape infrastructure was originally laid out for the City, we built ourselves around those systems to take advantage of services they supply.

Our County is one of the fastest growing communities in America. Even if Gallatin’s growth rate were to level out, the County could receive another 55,000 people by 2045. Half of those arrivals are expected to land in Bozeman. The City projects a need for 12,700 new housing units in Bozeman to fit all those new families. To have the space to build those new homes, developers need anywhere from 1,800 to 3,100 acres. The current supply in city limits for residential development is 1,300 acres. So as the City fills within its boundaries, that population will spill into the County. The City and the County differ in managing natural areas, groundwater, surface water, and open space (and its habitat). These rules are coupled with expanding road networks and their traffic, and sewage and waste management.

The existing natural cover in Lower Gallatin County provides ecological services. As the County and its cities urbanize, there are inevitable impacts on these resources. What happens to the ecological services these natural areas provide? Do the increase? Is there a threshold before they decrease? If they are erased either from direct or indirect impacts, how are these services (e.g., stormwater management) replaced, and at what costs? This interface between the natural and the man-made environment will have many challenges. However, these challenges are very common to land managers and happen all over the United States. These areas provide a green infrastructure that we should use as a skeletal structure for our future metropolitan area. To do this, we must identify and maintain these systems.

This semester we discussed the relationship between ecological structures, the functions these structures support, and the services these functions provide to maintain human well-being. We met with developers in the region and how they work with or around these ecological elements. We talked with green infrastructure specialists in Denver and how their city retrofits ecological elements that have been eliminated. We met with an economist to discuss how these drive the flow of money and a developer that profits from projects that enhance green components. Lastly we talked to journalists on the best way to get this message out to our community decision makers. As the capstone students begin their careers as environmental scientists, they will run into numerous similar problems. Below are four papers developed by the students for this project:

1. Soil Health & Integrity Affect Soils’ Ability to Perform Vital Ecosystem Services: Chase Morgan, Emily Daniels, Emily VandenBerg, Lars Heinstedt, Daniel Huck
2. Urban Growth, the Increase in Impervious Surface, and the Impacts to Groundwater Health: Kaden Beavers, Madeline Beck, Charlie Gurgel, Kelly Hendrix, and Preston Holmgren
3. Maintaining Green Infrastructure in an Urbanizing Bozeman, MT: Rachael Robbins, Colton Komar, Cecily Munro, Kayleigh De Lanoy
4. Understanding and Maintaining Ecosystem Services in the Bozeman Area: Elena Marburger, Ryan Malmquist, Riley Hagan, Terran Wieder

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# Soil Health & Integrity Affect Soils' Ability to Perform Vital Ecosystem Services for Sustainable Cities: Recommendations for an Increasingly Urban Bozeman, Montana

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## Introduction

Soils are the foundations on which cities are built and maintained. A soil's ability to provide ecosystem services within cities is influenced by its integrity and overall health, or the ability "to function as a vital living ecosystem that sustains plants, animals, and humans" (Soil Survey Staff, 2016). The integrity of a soil is its ability to maintain specific structures in order to retain its ecological functions (O'Brien, 2020). When soil integrity is degraded or lost, the soil can no longer efficiently store carbon, hold water, or support biologic activity (O'Brien, 2020) Conversely, healthy soils contain large amounts of organic carbon (NRCS, 2017a), are high in biologic activity from macrofauna and microorganisms (NRCS, 2017b), and are well-structured with appropriate pore-space (NRCS, 2017c).

Rapid urbanization has provoked concern for the future of soil-provided ecosystem services. As the nation's fastest-growing cities boast a 4.5% population growth rate on average, fears regarding sustainability have arisen (Bureau, 2019). The City of Bozeman is a prime example of a rapidly-growing metropolis, which is projected to grow by 27,000 residents by 2045 (Shelly, 2020). The population of the once sleepy Montana town will likely have a population density resembling Salt Lake City, Utah, or Denver, Colorado, in the near future. To address the spike in population and the increasing demand for affordable housing, the City approved a new growth policy in November 2020 to expand its borders and increase within-city density and development (Shelly, 2020). As a companion to this growth policy, Bozeman city managers published a climate plan which operates under the vision of a resilient low-carbon community (City Of Bozeman, 2020). Known as the Bozeman Climate Plan, the City defined many goals to improve city sustainability, which include the ambitious aspiration of carbon neutrality by 2050. To achieve these goals, city managers must consider how to best harness ecosystem services provided by soils, which include clean drinking water, stable ground, and natural infiltration. In this review, we discuss how soil health determines the performance of important ecosystem services and how the City of Bozeman should consider soil health when making development decisions.

## Effects of Soil Health & Integrity on Ecosystem Services

### City-wide Carbon sequestration

*Background & Impact*

The process by which atmospheric carbon ($CO_2$) is removed from the atmosphere and held in a "sink" is referred to as carbon sequestration. Sequestration aids in the mitigation of global warming and is one of the many ecosystem services offered by soils. Sequestration may be the soil function that is most essential to the carbon-neutral goal of the Bozeman Climate Plan. As Bozeman continues to expand its development, city planners need to remain mindful of the long-term repercussions that stem from mismanaged soils. While mismanagement of land and soil can lead to a diminished terrestrial carbon sink, properly managed soil can result in an enhanced terrestrial sink (Allory et al., 2019).

Urbanization can lead to a problem known as soil sealing, which is when an area of land is permanently covered with artificial material such as asphalt, concrete, or structures with a degree of full or partial impermeability (Artmann, 2015). Sealed soils reduce productivity of an area as they can no longer sustain vegetation growth outside of the defiant dandelion sprouting through a concrete crack. Impervious surfaces inhibit the growth of plants leading to a sharp decrease in photosynthetic rates. Without photosynthesis, the soil can no longer uptake $CO_2$ to reduce the atmospheric carbon pool (Lorenz, 2013). As a result, the ability of the soil to sequester carbon is greatly reduced.

The development of infrastructure in urban areas leads to another issue commonly known as the urban heat island effect. Due to factors such as loss of vegetation and increased albedo (the amount of heat energy reflected off a surface), urban areas become significantly warmer compared to surrounding areas that are undeveloped (Hideki & Moriyama, 2020). High temperatures only further exacerbate soils that already have dwindling stocks of soil organic carbon (SOC) and can lead to a further decrease in SOC (J. Huang et al., 2018). The heat island effect leads to lower rates of atmospheric carbon intake and feeds into a positive feedback loop with global implications.

*Future Actions & Recommendations*

In order to adhere to Bozeman's plans for carbon neutrality, it is important to recognize the diminishing impact urban growth has on carbon sequestration. Potential practices for mitigation, such as increasing surface reflectance and the presence of vegetation, are already underway in Bozeman. The City currently boasts 906 acres of parks, more than 24,000 trees, and just under 600 acres of NWI wetlands, including a 14-acre wetland (City Of Bozeman, 2020). In addition, the local Co-Op is setting a prime example for residents and business owners alike with the choice of a green roof on its newest installment. A few green spaces alone may not significantly increase SOC sequestration; however, the culmination of many efforts to reduce sealed soils and the urban heat island effect can improve city-wide carbon neutrality. Furthermore, ongoing collaboration between developers and city planners must remain mindful in regards to the inverse relationship shared by impervious surfaces and soil services.

## Vegetation

*Background and Impact*

Vegetation affects the soil properties of a given site, which then affect the survivability and biodiversity of the associated plant biota. These soil properties include overall soil structure, root density, and infiltration rates. As infrastructure is built on the foundation of soils, interactions with established aboveground vegetation will affect the way the soil functions. For one, roots can increase the movement of water and nutrients through soil by breaking up aggregates and enlarging pore sites, and can efficiently stabilize soil (Angers & Caron, 1998). Differing root types will create lasting changes in soil infiltration rates, as both shrub- and grass-dominant root systems improve infiltration rates in comparison to bare soil (Hao et al., 2020). Leaving soil bare and without root systems can lead to the destabilization of the rhizosphere, which prevents the soil from cycling nutrients and creates unfavorable soil water and aeration conditions (Angers & Caron, 1998). It is necessary to incorporate vegetation wherever bare soil is found in order to promote the many benefits that root systems have to offer.

The incorporation of native, biodiverse vegetation into future developments is essential to ensure healthy soil microbiota and nutrient cycling processes. Turfgrass systems are often implemented into urban settings as a replacement to native grassland communities, and act as an excellent example of how it can degrade soil ecosystem services. Turfgrass systems can cause an increase in soil organic carbon due to irrigation, fertilizer application, and other intensive management practices (Pouyat et al., 2009). Not only does turfgrass require these inputs in greater excess, but these inputs severely affect soil processes. At a global scale, increased area of urbanized soil can lead to greater outputs of greenhouse gas into the atmosphere, but utilizing native vegetation could convert these soils into reliable carbon sinks instead (van Delden et al., 2016). However, a native status of the vegetation may not be a requirement to achieve these benefits. Revegetated urban lots have similar microorganism biodiversity to native soils, while vacant lots and turfgrass lawns exhibit less overall microbial diversity, suggesting that plant biodiversity is the key factor in encouraging a healthy soil biota (Mills et al., 2020).

*Future Actions and Recommendations*

Since implementing multiple plant species in an area can bolster soil health by encouraging a diverse microbial community and a complex root structure, biodiverse vegetation should be incorporated into green spaces wherever possible (Angers & Caron, 1998). These biodiverse plant and soil communities can be further ensured through the use of habitat corridors, or areas set aside for the purpose of connecting a pathway for the local ecosystem to thrive within an urban landscape. These corridors incorporate naturally-developed soils, therefore encouraging the survival of soil taxonomic species that perform important soil biotic functions (Portela et al., 2020). Though corridor implementation may not be possible in the inner city, they can still be implemented in future urban developments that inevitably grow outward into the valley. Local parks and trails with incorporated habitat corridors can provide a source of enrichment for healthy soils and a great recreational opportunity for residents.

### Soil infiltration and stability

*Background & Impact*

The physical soil properties including infiltration and stability serve as passive ecosystem services that should be recognized in Bozeman's expansion. During development, soil structure is damaged by compaction from heavy machinery or lost completely when scraped and stored for later use (Gregory et al., 2006). To remediate this, developers cover the compacted ground with top soil, a lofty mineral-woodchip alternative for a nutrient-rich soil horizon, or redeposit the stored soils and plant aesthetically pleasing landscapes. When soils are disturbed by development, impermeable surfaces are laid for foundations and roadways which increase runoff and decrease groundwater recharge and purity (Han et al., 2017). Runoff on poor soils or impermeable surfaces accumulate debris and pollutants. These harmful contaminants quickly reach nearby waterways through modern cities' drainage systems intended to export rainfall as fast as possible to mitigate urban flooding. However, untreated stormwater shifts pollution to downstream populations and decreases water purity.

Healthy soil ecosystems paired with effective infiltration rates serve to filter overland flow and groundwater by trapping pollutants that are associated with a rapidly developing city. When soil infiltration rates are low due to compaction or microbial ecosystems are lacking, stormwater cannot move through the soil profile effectively. In natural ecosystems, microbial colonies provide ecosystem services such as ground water purification (Vodyanitskii et al., 2016). With healthy soil communities intentionally planned within development, pollutants can be sequestered and reduced to less damaging toxins. All the while, water can infiltrate more efficiently to the valley's groundwater or flow to our downstream neighbors along the Missouri.

*Future Actions & Recommendations*

Bozeman and the Gallatin Valley are at the forefront of its rapid development and have the ability to implement soil ecosystem saving alternatives. Two solutions become apparent when preventing erosion and increasing water purification and infiltration. First, disturbed soils could be restored to mimic wetlands and harness the positive attributes that wetland ecosystems provide. A 2012 study utilized constructed wetlands to improve water qualities from city runoff such as higher pH, less nutrient runoff, and increased dissolved oxygen (L. Huang et al., 2012). The soils in these systems may be more likely to retain water and purify the subsurface flow as it moves through the soil horizons.

Secondly, soil stability can be improved by incorporating diverse plant communities. As the severity and frequency of annual flooding events in this part of the country increase, soil stability should be considered as a safeguard against potential soil loss (Nearing et al., 2004). In every precipitation event, soils are transported from developed areas to waterways and add to sediments behind dams and in the ocean. One major stabilizer to reduce soil erosion could be planting landscape vegetation with diverse root structures. In natural ecosystems, an increase in plant biomass has a direct relationship with soil stability (Pohl et al., 2009). To assure that soils remain in place and maintain effective infiltration rates, Bozeman should prioritize an increase of diverse plant species opposed to a monoculture of aesthetically pleasing plants.

## Composting

### *Background and Impact*

Composting allows organic material to decompose and become available for uptake by plants and other organisms (Portela et al., 2020). Compost, often smelling like potting soil, can be mixed into existing soil to increase nutrients for plant growth, decrease bulk density, increase pore space and water holding capacity, add diversity to microbial communities, and filter toxins (Cogger, 2005; Heyman et al., 2019; Pitt et al., 1999).

Bozeman has developed a composting system but remains relatively small scale. Private composting businesses such as *Yes Composting and Happy Trash*, as well as county operations (Gallatin Waste Management District), have helped move Bozeman, and Gallatin County as a whole, towards greater composting efforts. Both Happy Trash and Yes Composting collect upwards of 15,000 lbs. of waste each week: a combined total of about 780 tons a year. Most of this compost goes back to the consumer for use in greenhouses and personal gardens. Closed-loop services like these allow for trust between customer and provider for a quality and safe product. In addition, by diverting waste from the landfill and using it to grow food and other vegetation, the community directly benefits from this ecosystem service by maintaining and creating open space throughout Gallatin County.

Despite these benefits, compost is a highly variable material in both quality and safety for use as a soil amendment (Heyman et al., 2019). Properties such as organic matter percentage, pH, available nutrients, C:N ratio, heavy metal concentrations, and pathogens are just a few aspects to compost that are highly variable and determine the quality of the compost (Cogger, 2005; Heyman et al., 2019; Pitt et al., 1999). Additionally, the timing and rate of application must be done correctly to increase the effectiveness of the compost (Cogger, 2005; Heyman et al., 2019; Pitt et al., 1999). Simply understanding the properties of compost and how to mitigate its variability vastly reduces any environmental concerns allowing the positives to outweigh the negatives.

### *Future Actions & Recommendations*

Since composting is a priority for Bozeman's Climate Plan, Bozeman must either increase the resources for composting food waste or enhance the biosolids program to meet their 2050 climate goals (*Bozeman Climate Plan | City Of Bozeman*, 2020). Community involvement is the most cost effective option because adding a compost specific trashcan to a household is the most basic form of composting. An increase in community awareness, through proper education, for food composting is a step in the right direction. In addition, there is a need for a more robust system for collecting and processing food waste. Currently, there is not enough compost from food waste to source large development projects effectively. As of now, the only source large enough to supply such high demands is the Logan Landfill, which is restricted from contracting their biosolid compost because of potential health and safety hazards. If the Logan Landfill can produce type "A" biosolid compost (a classification of compost determined safe for public use by the EPA (Walker, 1996)), it would be allowed to contract out its compost.

## Pollutants

### *Background & Impact*

Healthy urban soils prevent high levels of pollutants entering stormwater runoff and downstream communities. As a part of Bozeman's 2020 growth policy, city managers expect to increase open space and park areas, create "walkable neighborhoods", and increase affordable housing (Shelly, 2020). Parks, open spaces, and residential yards are often fertilized to maintain grassy lawns. Nitrogen and phosphorus in fertilizer are essential to plant growth, but over-application pollutes local waterways (Rosen & Horgan, 2005). Excess nitrogen added to a soil cannot be utilized by plants before it is dissolved by surface water runoff or leached into groundwater. Excess nitrates in groundwater cause algal blooms that deplete the water of oxygen necessary for aerobic respiration, affecting populations of aquatic species (US EPA, 2013). Apart from the ecological impacts of nitrate contamination, huge economic losses are associated with nitrate contamination: the MSU Extension service estimates over $1 billion in nitrate has been leached into Montana groundwater (Jones & Olson-Rutz, 2017).

Nitrate leaching causes wide-reaching effects on an ecosystem. The unique properties of a soil determine the extent to which nitrogen and phosphorus are made available to plants, dissolved into runoff, or leached from the soil. For example, soils with coarse textures allow water to percolate downward, leaching dissolved nitrates out of the soil, while finer soils will experience less leaching due to increased water holding capacity (Kerns et al., 2009). Soil organic carbon also prevents leaching, since nitrates adhere to the surface of large organic molecules (Kerns et al., 2009). Additionally, SOC decomposes and contributes nitrates and phosphates to the soil, which reduces overall fertilizer requirements (Jones & Olson-Rutz, 2017). As Bozeman urbanizes, developers alter soil structure through compaction and excavations and inhibit soil functions that prevent nitrate leaching, such as water holding capacity and total SOM content.

### *Future Actions & Recommendations*

Many recommendations for fertilizer application to avoid nitrate contamination exist, but the majority of these recommendations are only applicable in large-scale agriculture. More accessible fertilizer guidelines for residential application should be provided to Bozeman residents. For example, the City could provide new homeowners a pamphlet about urban lawn care with recommendations about timing and amount of fertilizer application. These guidelines should emphasize the importance of conservative fertilizer application and soil health for preventing nitrate leaching in residential areas, and provide developers with specific ways to preserve and increase soil health (such as increasing soil organic matter content) in public parks and neighborhoods.

## Conclusion

Soil is the foundation of all terrestrial ecosystems. Without healthy soils, humans will lose vital ecosystem services that allow our societies to thrive. In cities, soils help maintain a cooler environment, sequester carbon, support healthy vegetation and clean air, and reduce pollution in local waterways. By maintaining these essential soil functions, healthier soil ecosystems can exist within the City; diverse and abundant vegetation will sequester carbon, soil microbes will bind and break down harmful pollutants, and soils will digest more city organic waste. Specifically, the City of Bozeman should commit to the following actions: 1) preserve current green spaces and prioritize increasing green space among new developments, 2) incorporate areas of biodiverse, native vegetation into all city properties and incentivize developers to do the same, 3) consider transforming disturbed, unused areas into constructed wetlands to improve soil and water quality, 4) expand the availability of composting in the greater Bozeman area and increase public awareness of composting services, and 5) provide landowners and developers with specific recommendations regarding lawn fertilizers and ways to avoid stormwater contamination from their properties. By addressing these contributors to soil health, Bozeman can ensure its future as a sustainable city and more easily reach its 2050 Climate Plan goals.

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# Urban Growth, the Increase in Impervious Surface, and the Impacts to Groundwater Health

MSU- Land Resources and Environmental Sciences 2021 Capstone

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## Introduction

By the year 2050, sixty-eight percent of the world's population is predicted to live in an urban area, an increase of thirteen percent from today (*UN*, 2018). In Bozeman, Montana, the rate is even higher with a population of 52,000 in 2021, a number up over forty-one percent in the last decade (*Bozeman Montana Population*, 2021). This population increase puts stress on the regional water resources and, at current growth rate, many areas will have insufficient water for future populations. Urbanization is reported to cause changes to both surface and groundwater in an area, and although this exact change is often difficult to quantify, retroactive moves should be made in urban settings to protect this resource. The Bozeman economy also relies on eco-tourism from fishing, which impacts on groundwater from urbanization could potentially harm. By expanding technologies aimed at increasing permeability of ground surfaces Bozeman and places like it can work to protect this vital resource.

## Background

Large population centers, especially those associated with significant industrial and commercial activity, place considerable stress on the health of regional water resources (Howard, 2002). Groundwater is an important resource not only for aquifer health, but also as a water resource that communities will increase reliance on as surface water becomes unable to support growing populations. In Bozeman, eighty-five percent of municipal water use is currently supplied by Hyalite Reservoir, but the remaining portion is pumped from a spring in the headwaters of Lyman Creek (Leoniak, 2015). Hyalite's limited catchment area means its proportion of our total use will decrease and groundwater use will expand.

Urban landscapes can be characterized by an abundance of impervious surfaces which affect our ecosystems and their resulting function and services. Increasing impervious surfaces, such as streets and buildings, leads to an increase in runoff and a reduction of groundwater infiltration. The greater frequency and severity of flooding can also increase channel erosion and affect stream morphology leading to further degradation of habitats. Expanding the use of green infrastructure solutions which provide permeable surface area is one key method of ensuring urban groundwater systems remain intact and healthy.

Groundwater quality is a broad concept which comprises "the physical, chemical, and biological qualities of groundwater." (Harter, 2003). The main source of pollution to groundwater in any setting comes from improper waste disposal, leaking sewage systems, spills of pollutants during transportation and effluent treatment lagoons (Lerner & Tellam, 1992). Hydrologic impairments compromise one or several of these categories. Pollution groups are separated into point and nonpoint sources, differentiated by the geographic scale of the initial release. Point sources have a specific location (i.e., construction site) while nonpoint sources are spread across a wider area (i.e., road de-icing). Each presents unique management challenges depending on the scope and type of pollutant introduced. While literature describing measurement, documentation, and impact of pollutant damages to the natural world is expansive, intersections between the human world and a polluted ecosystem are not as well documented. Bozeman is in its urbanizing infancy as it fills into the Gallatin Valley (Bozeman Montana Population, 2021). In Bozeman, we are presented with a unique opportunity to implement solutions to pollution and water contamination while development booms, and not as an afterthought.

## Existing Bozeman Policies Affecting Water Quality

As Bozeman increases in its urban expansion, the City contributes to ecosystem change. Community projects including those organized by nonprofit organizations like the Sacajawea Audubon

Society have shown that there is a potential for water quality conservation through wetland restoration. For instance, the Indreland Audubon Wetland Preserve in Bozeman manages forty acres of the city as a wetland, providing important ecosystem services for wildlife and humans alike (Sacajawea Audubon Society, 2020). However, more efforts should be taken by the City and other non-profits to ensure greater protection of water resources.

Bozeman has worked to set aside designations and healthy water guidelines, and as it currently stands, the City of Bozeman Stormwater Division currently labels "sediment, nitrogen and phosphorus, *E. coli*, oil, grease, metals, detergents, and temperature" as specific pollutants that contribute to the City's runoff impact. In that same plan, the City sets aside $1.2 million for annual maintenance required for their management (2017-2021 MS4 General Permit Term, 2019). As the City continues to grow, these costs will incrementally increase, placing a high importance on stormwater management and specifically, sediment runoff.

Road expansion also coincides with ice treatment in the winter. According to long term climate records, Bozeman receives an average annual snowfall of forty-seven inches per year (Western Regional Climate Center, 2016). Snowfall of this intensity requires road management and treatment to allow for safe transportation and commuting. On the Eastern seaboard, warmer weather allows for the use of road salt deicer to manage conditions. This increases salinity in local waterways, where studies have found stream water conductance elevates dramatically in-sync with freezing temperatures and snowstorms (Moore et al., 2019). Cities in climates similar to Bozeman with temperatures persisting below freezing through most of the winter months apply sand for increased tire traction. Between October 2020 and March 2021, 16,106.5 miles of road were sanded in Bozeman alone. At a rate of 800-1,200 lbs per mile, these 8,000 tons of sediment will ultimately end up in the water system. This leads to an increase in turbidity and pressure on already stressed urban streams and irrigation channels (Chang et al. 2021, Moore et al. 2019).

<u>Impact on Structure and Function</u>

Groundwater has a major impact on the volume of water in rivers throughout the year in climates that receive low or inconsistent precipitation. Through its contribution to base flow, groundwater will buffer flow rates in waterways. Groundwater serves as storage for large amounts of meltwater to be released during the dry summer, making it key in maintaining water levels suitable for fish survival (Tague & Grant, 2009). Without groundwater providing a consistent base flow for waterways, recreational activities may not be possible or appealing for many. This could hurt businesses in the area that rely on the valuable eco-tourism industry and diminish the quality of living for individuals that reside in the area. Residents and visitors spend over three million days fishing on Montana's waterways every year, spending approximately $919 million annually in the state; for all outdoor recreation activities in Montana combined, there is $7.1 billion in consumer spending in the state. (Montana Office of Outdoor Recreation & Governor's Office of Economic Development, 2017).

Groundwater fluctuates greatly even in natural settings and is difficult to quantify when land and water use change in a region. An impact may be known, but the ability to quantify the direct result that is had on the urban groundwater is extremely difficult or even impossible. The expanding field of urban groundwater hydrology faces problems in quantifying the extent of structural changes for many reasons (Vázquez-Suñé et al., 2005). When an area continues to develop, areas of free-flowing streams are increasingly channelized, and infiltration into the soil is obstructed by objects or complicated by ground compaction. Additionally, as vegetation is removed from a system, there is a decrease in the uptake of water in zones and water is instead diverted into smaller areas. The overall complexity and natural structure of areas are negatively impacted, and without intervention, these areas may not have any semblance of their previous state.

When areas are increasingly urbanized, point and nonpoint sources of pollution also increase, causing the water in urban settings to decrease in quality. This decrease in quality as well as the act of diverting and channelizing urban water can cause the stream ecosystem to lose a number of species who cannot adapt to the quick change. In addition to the loss of native species, an increase in disturbance will leave areas open to colonization from opportunistic, non-native species. While alone the loss of a species may not be detrimental to the function of that ecosystem, the loss of one species can lead to the loss of others due to the interactions that each species has with each other. When combined over a large area of similarly impacted ecosystem areas, the function of water, in the groundwater and downstream, will see the effects. Urbanization can cause ecosystems to lose any semblance to their previous state, and when the impacts of urban areas are increased, the detrimental impacts to an ecosystem structure and function will be seen.

Ecosystem Services

Ecosystem services are any benefit that humans receive from a natural environment (Daily, 1997). In Bozeman, the inclusion of open space for water to infiltrate significantly benefits services including recreational activities such as fishing and floating, drinking water for residents of the city, and reduced flooding events.

Groundwater is important for recreational activities since it impacts the quantity of base flow waterways experience and the temperatures they exhibit throughout the year. The trout around the Bozeman area are very sensitive to temperature changes and tend to select certain areas within a stream to inhabit and spawn (Coutant, 1975). During winter, groundwater is warmer than both air temperature and the temperature of surface water that enters the waterway. This keeps waterways warm enough for fish species to be able to survive through cold winters. Because of this, groundwater inputs become increasingly vital the higher in latitude a location is; primarily due to the fact that areas of higher latitude typically experience longer lasting and more severe winter conditions (Power et al., 1999). This is a major concern for an area such as Bozeman, where cold weather is common and persists for a sizable portion of the year. Groundwater also serves to cool waterways during extremely warm conditions in summer months. The function and role of groundwater input to waterways is even more apparent when considering climate change as the general trend of warming temperatures leads to a decrease in suitable habitat for fish species (Snyder et al., 2015)**.**

Bozeman is also highly dependent on groundwater for municipal use. Increasing human activity and developments spreading throughout the valley jeopardize groundwater quality through the introduction of carcinogenic pollutants like arsenic and sewer leakage (Cao et al, 2019; Minnig et al, 2018). The increase of such harmful pollutants entering drinking water sources around the Bozeman area would drive up the cost of treating such water and increase the risk of health complications. However, soil acts as a filter for groundwater and can help immobilize pollutants in the soil where microorganisms over time can degrade the pollutants (Keesstra et al., 2012)**.** Therefore, it is vitally important that water from urbanized areas pass through soil and not be merely diverted into waterways that are sources of drinking water.

Allowing water to infiltrate into the ground is also the easiest way to reduce flooding events in urbanized areas. Adopting green infrastructure in urbanized areas reduces peak flow and total volume observed during storm events due to water infiltrating into the ground; this had a reduction effectiveness of more than eighty-five percent (Liu et al., 2014). Reduced flooding is an overlooked service but one that is very valuable to prevent property damage or even loss of life.

Green Infrastructure

Green infrastructure, as defined by Section 502 of the Clean Water Act, is "the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flow to sewer systems or to surface waters" (US EPA, 2015). Due to its diverse nature, green infrastructure can range from individual vegetated road medians to large scale elements that span entire watersheds, encompass techniques spanning hardscapes to green spaces, and have wide ranging operation and maintenance considerations. For example, a hardscape technique such as permeable pavers address a specific need but require continued operation and maintenance costs and have a finite lifetime.

Conversely, green space should ideally be self-maintaining, or require little to no maintenance for continued performance over time but may not address as specific of a need as hardscapes. In the middle may be Green Roofs, which are more self-maintaining than hardscape techniques but require more maintenance than green space.

Proposed Management Approach: Permeable Interlocking Concrete Pavers

To mitigate the impacts of urbanization on groundwater resources, permeable pavement systems should be considered for implementation for all new development projects. Permeable pavement is generally used as a catchall term that applies to multiple different material types, each with their own benefits and trade-offs. The four main categories include porous asphalt, pervious concrete, permeable interlocking concrete pavers (PICP), and others (such as plastic grid pavement systems) (*"Guidance for Usage"*, 2017). The overall aim of any of these materials is to reduce runoff by allowing water to infiltrate through the surface while still providing a surface that can stand up to pedestrian and vehicular traffic. For the purposes of this proposed management approach, PICP will be the primary focus as they are currently the most common system used in Montana ("Montana Post-Construction StormWater BMP Design Guidance Manual," 2017) and offer the greatest flexibility both spatially and visually - important factors when considering both public and private new development installation and retrofitting potential. PICP systems come in a wide range of shapes, sizes, and colors so an aesthetically pleasing design is always possible.

PICP Design

Most system designs consist of the concrete pavers and three "aggregate layers: (1) open-graded bedding course, (2) open-graded base reservoir, and (3) open-graded subbase reservoir"("Montana Post-Construction", 2017). The open-grade bedding course is a highly permeable layer that provides a level surface for the pavers while the base reservoir acts as the structural transition between the base and subbase while also storing runoff. The subbase reservoir provides additional runoff storage with recommended thicknesses varying based on expected traffic load. The underdrain is an optional feature that can be utilized when full infiltration is not possible or not desired, such as when runoff has a high potential to contain any of the aforementioned contaminants such as vehicle oil and grease.

Site Conditions

While PICP installation has already been successful in parts of Bozeman and across Montana, certain site conditions need to be met for them to be the appropriate system of choice. Montana specific guidance is compiled from the *Montana MS4 Post-Construction Best Management Practice Design Guidance Manual* prepared in cooperation with the Montana Department of Environmental Quality (2017). These considerations include contributing drainage area, soil characteristics, depth to groundwater or bedrock, site topography, and surrounding land use considerations. PICPs are most suitable in areas that only receive runoff from other impervious surfaces, and runoff from non-impervious surfaces has more potential for clogging. PICPs can be either full infiltration, partial infiltration that uses both infiltration and an underdrain system, or no infiltration which utilizes an underdrain to discharge 100 percent of the runoff. Partial infiltration systems can be beneficial when the native soils cannot infiltrate the full volume of runoff while no infiltration designs that also include an impermeable layer should be chosen when infiltration has the potential to negatively impact the

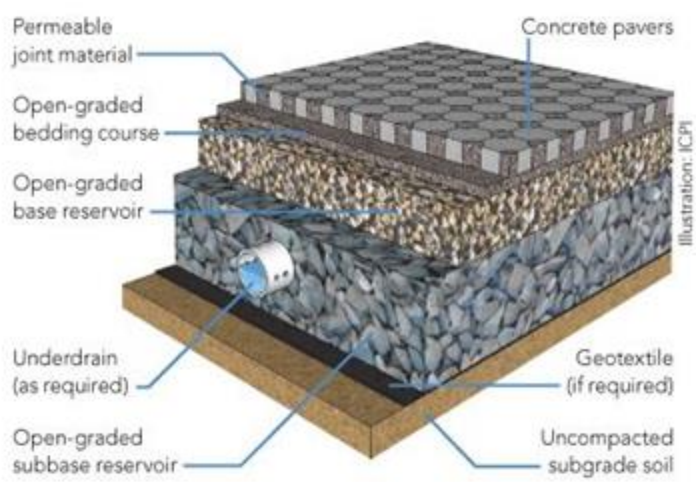

*Figure 1: Cross-section of a PICP stormwater pavement system. Source: ICPI*

ecosystem (such as introduction of pollutants). A minimum of three feet (or one foot for a no infiltration system) is recommended for depth to groundwater from the bottom of the subbase reservoir to ensure that there is sufficient soil for pollutant filtration and to avoid the reduction in infiltration capacity due to a high water table or depth to bedrock. PICPs are not suitable for any steep or eroding landscapes; it is recommended that they be installed on a surface grade between one and six percent. These systems are best suited to pedestrian walkways or areas with low-speed (<40 mph) vehicle traffic. They are not suitable in areas that produce high sediment load due to clogging risk, and if located near a likely source of pollutants, the runoff may need additional treatment or an impermeable layer underlining the system ("Montana Post-Construction", 2017).

<u>Benefits</u>

Depending on the design and site-specific conditions, permeable paving can infiltrate up to eighty percent of the annual rainfall volume, with further improvements possible through the use of adjacent bioswales to catch any resulting overflow (Massachusetts LID, 2014). This reduction in surface runoff leads to greater groundwater recharge and lower peak flow levels. The result is less downstream erosion and flooding risk, returning the system to a less-altered state. Furthermore, the resulting infiltration and filtration through soil also results in PICPs having the ability to remove the "majority of pollutants [including] zinc, copper, phosphorus, and suspended sediments" (Residential and Commercial Developers Fact Sheet, 2012). Furthermore, increased local infiltration can help support the survival of local vegetated communities.

*Figure 2: Permeable paver installation along N 7th Avenue, Bozeman MT. Source: City of Bozeman Stormwater Division, 2018.*

*Figure 3: Completed phase 1 permeable paver system.*

One of the most attractive features of these systems is their land use efficiency and the ability to accomplish "storm water management in areas with different primary purposes" ("Montana Post-Construction", 2017) like parking lots. As a result, previous areas that may have been set aside for detention ponds, storm sewers, or other stormwater systems- including wooded areas and green space- could be preserved, utilized for something else, or retrofitted for increased recreation opportunities. Additionally, twenty-seven LEED (Leadership in Energy and Environmental Design) points are available with the use of PICP providing a further incentive for developers to implement them. When the sub-soil is unfrozen, ice build-up is virtually eliminated on these surfaces resulting in a reduced need to spread salt or sand. This can further decrease the sediment or chemicals that are entering the watershed. If light colored aggregate is chosen, the urban heat island effect can be reduced through evaporation and light, colored aggregates. This technology is also suitable for retrofitting current systems as demonstrated by the City's Midtown Urban Renewal District and Economic Development Division's success in 2018 in improving North 7$^{th}$ Avenue in Bozeman, MT (Fig 2 and 3) ("Stormwater Division | City Of Bozeman", 2018). Along with being ADA compliant, PICP systems comply with U.S. National Pollutant Discharge Elimination System (NPDES) regulations and meet "U.S. EPA stormwater performance criteria as a structural best management practice (BMP) while providing parking, road, and pedestrian surfaces" (Residential, 2012).

Lifetime, Operation, and Maintenance

While there is limited terminal data for PICP, "paver installations have demonstrated life spans that exceed 30 years, as compared to traditional pavement which typically lasts 12-15 years" (US EPA, 2013). To ensure optimum performance it is recommended to vacuum sweep the PICP semi-annually to prevent clogging, conduct an annual inspection of the PICP system and replacement of cracked pavers, and as needed management of potential surrounding vegetation and trash/debris removal ("Montana Post-Construction", 2017). According to the Life-Cycle Cost Management of Interlocking Concrete Block Pavements analysis (2008), it is expected that 2 percent of pavers will become cracked and need replacement after 8 and 28 years, and more significant maintenance of roughly 5 percent of the pavers after 20 and 35 years in areas that may have experienced increased use such as those in the wheel path. Because of their design, cracked or worn pavers can be replaced individually rather than having to replace or repair the entire PICP surface resulting in more targeted and cost-effective management plans.

Limitations

As mentioned previously, not all site locations are suitable for implementation of permeable pavement systems. Landscapes with high potential for significant sediment loads that could result in clogging or sites with steep slopes are not appropriate locations for these systems. However, potential clogging can be mitigated with practices including bioswales adjacent to the PICP systems to trap any coarse sediment before it reaches the pavers. Construction costs can vary widely depending on the design type but typically pervious concretes and porous asphalts cost roughly 50% more in initial costs than traditional materials (Massachusetts LID, 2014). Additionally, PICP requires maintenance strategies different from current stormwater management systems but because these systems can replace other mitigation strategies like detention ponds or reduce the need for large stormwater management structures, lifetime costs of PICP can be cheaper than traditional methods. These systems have been implemented in places like Norway with similar climates, though recommendations for winter operation should be considered. While the pavers can be plowed, skids or rollers on the corners of plow blades are recommended to reduce the potential for chipping. And while initial installation and maintenance costs may be higher than more traditional materials, "when total project costs are factored, PICP may be cheaper than other paving solutions due to multiple benefits [including] gaining stormwater management infrastructure with money spent on paving" (ICPI, 2012).

Why choose PICP

PICP systems represent easy, local solutions that can be implemented at a range of scales - from individual sidewalks and office plazas to whole subdivisions. Bolstering the native ecosystem functions and resulting services including flood risk reduction, pollutant filtration, and recreation opportunities, PICP can help reduce urbanizations impacts on the local hydrological cycle. In our ever-shrinking world, PICP addresses the issues of reduced infiltration without using any additional space, something that is only becoming more crucial. Additionally, the feasibility of implementing these systems has already been demonstrated in Bozeman and the surrounding areas. Whether it be implementation in new developments, or retrofitting some of the most used walkways, PICP should continue to be considered as a lower impact alternative stormwater management strategy.

Conclusion

Urbanization and its effect on groundwater, the local ecosystem, and the resulting services it provides will only continue to grow. These impacts range from shrunken base flows and elevated peak flows, decreased water quality from pollution, and increased flooding risks. These impacts have far reaching effects for many aquatic and riparian organisms including sensitive trout species. Implementation of green infrastructure, be it in the form of hardscapes, green space, or anything in between, can produce cascading positive effects for systems and their inhabitants. Preserving the recreation opportunities that are only afforded through a healthy ecosystem, such as fishing and tourism, bring millions of dollars to the local economy. Furthering community awareness of groundwater issues and their solutions ensures the environmental integrity of our region

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# Maintaining Green Infrastructure in an Urbanizing Bozeman, MT

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## Introduction

As the human population grows exponentially, interactions between nature and humans are increasing. Currently, less than 50% of the world's population live in cities, but this is estimated to increase to 60% in only 30 years (Wilby & Perry, 2006). Across the globe, 423 large cities are nestled inside 36 biodiversity hotspots. The growth trajectory of these cities could lead to 90 percent destruction of natural habitats of endangered species in only a decade (Bloomberg.com, 2018). The global expanse of urbanization has produced challenges for plant communities and the way they are managed (Fineschi & Loreto, 2020). Bozeman, Montana specifically is facing these challenges. Growing at a four percent rate, "the impacts of growth are not only accelerating. The effects are compounding" (Wilkinson, 2019). A population density of 2,587 people per square mile and growing continues to eliminate more natural lands (World Population Review, 2020). If the Bozeman population continues to grow at this rate it would take only 18 years to equal the size of Salt Lake City and 36 years to match the population of present-day Minneapolis proper (Wilkinson, 2019).

The increasing population is causing overlap between natural and urban environments, posing threats such as the introduction of invasive species, loss or degradation of habitat, and a decrease in local biodiversity. Climate change is expected to amplify these issues and even add new threats such as the spread of disease and pests, increased summer drought stress for wetlands and woodland, and sea-level rise threatening rare coastal habitats (Wilby & Perry, 2006). Green infrastructure is paramount in diminishing these threats. Green infrastructure refers to areas in the city where vegetation is interwoven with the city's structure. These green areas have the potential to provide a range of ecosystem services through plant structure and function including improved community mental health and productiveness, increased plant biodiversity providing habitat to local organisms, decreased air and water pollution, and benefits to local soil health, among many others.

As a strongly outdoor-driven community, the City of Bozeman must reassess conservation of green space in the urban setting by considering native or non-native biodiversity, ecosystem services, and management techniques to maintain connectivity to the natural outskirts. Integrating and preserving green spaces within a rapidly growing Bozeman will help to maintain the ecosystem's structure, function, and services. This paper discusses the positive and negative connections between plants and urbanization.

## Plant Communities

A diverse plant community defines a healthy ecosystem by resisting degradation, maintaining its organization over time, and is resilient to stress (Tzoulas et al., 2007). Urbanization is recognized as a major source of species extinction. Global diversity is expected to decrease as a result of increased land-use intensity (Wilby & Perry, 2006). The species-area effect creates a large expanse of impervious surface in urban areas, therefore limiting the space for plants. Most central urban areas are covered by pavement and buildings, leaving less than 20% vegetated area (McKinney, 2008). Of these vegetated areas, structural simplification (limited consideration for functioning plant communities) of vegetation is imposed by ecological, social, economic, and political factors, contributing to the loss of biodiversity (Tzoulas et al., 2007). In addition to expanding urbanization, anthropogenic climate change acts as a further pressure that can change or limit native plant biodiversity (Wilby & Perry, 2006).

While urbanization can have many negative impacts on plants and the environment, there is also potential for plant communities in urban areas to increase local biodiversity, but social factors set a constraint on this opportunity (McKinney, 2008). High spatial habitat heterogeneity offered in urban settings allows nonnative species to replace native species and disperse at a faster rate. Increasing productivity increases biodiversity up to a point, making non-native plant populations a viable substitute for native populations in urban areas. This challenges the social construct of "whether the addition of nonnative species associated with urbanization exceeds the loss of native species to produce a net gain in species richness with urbanization" (McKinney, 2008).

The structure of ecological systems within urban areas is being threatened by environmental impacts such as poor air and water quality, habitat destruction, and altered microclimatic patterns. The urban forest provides an opportunity to balance these effects through a range of ecosystem services. These services include stormwater interception, urban microclimate regulation, air pollution removal, and improved animal habitat (Berland & Manson, 2013). Plants in urban settings also protect the environment from hazards like strong winds, soil and slope erosion, floods, and landslides. The benefits provided by plants in urban settings depend on their relative location within the urbanized area. For example, trees in parks and public areas with high air pollution provide the greatest public-health benefits compared to trees covering impervious surfaces have the greatest impact on storm-water management, and trees near houses contribute to mitigating summertime temperatures (Fineschi & Loreto, 2020). Therefore, urban plant communities are often selected according to plant species to better fulfill environmental services, rather than replicating natural systems.

Management practices such as landscaping residential or commercial areas typically remove shrubs and dead wood and increase grass and herb presence. The ecological simplification of these practices negatively impacts wildlife and leaves a higher potential for disease to wipe out populations (McKinney, 2008). Residential areas are essential to consider for plant management because they make up about half of the urban land area and over half of the new urban growth (Berland & Manson, 2013). Management of vegetation by humans allows cultivated species to overcome natural dispersal and establishment barriers, resulting in higher species richness than nearby natural pools. However, maintaining a high diversity could require irrigation to overcome water limitation, adding to management time and cost (Pearse et al., 2018). Green spaces in urban areas have the potential to provide ecological services, but also have a focus on human preference. High population densities, limited funding, and overuse can make it difficult to maintain the sustainable function of urban forests. Management of urban vegetation can positively influence diversity and function by increasing understory vegetation species richness and remnant trees, but productivity is limited by space (Talal & Santelmann, 2020).

**Air and Water Pollution**

Urban infrastructure, like buildings and roads, can absorb and re-emit heat more than natural landscapes. Therefore, developed areas have higher temperatures than non-developed areas. This is known as the Heat Island Effect. Higher temperatures increase the amount of ground-level ozone (smog) concentrations which significantly reduces air quality. In addition to poor air quality, the heat island effect also creates a higher energy demand to regulate indoor building temperatures, leading to a greater increase in air pollution(Kleerekoper et al., 2012). Urban vegetation provides shade which can help regulate indoor and outdoor temperatures and help to reduce the amount of ground-level smog. Trees regulate air temperature through evapotranspiration. Evapotranspiration is the process of plants absorbing water through their roots and releasing that water as a gas through their leaves. The additional humidity to the atmosphere significantly cools surrounding areas which in turn lowers the amount of ozone in the atmosphere and creates healthier air quality (Kleerekoper et al., 2012). Using vegetation as a form of temperature regulation will reduce energy consumption to maintain building temperatures and will significantly improve urban air quality.

Deciduous trees are a good option for areas where air quality typically improves in the winter and where shade created by trees prevents snow from melting. Bozeman receives roughly 60 inches of snow during the winter, so snow management techniques are a very important aspect when deciding on urban vegetation. Species like Pine are great for filtering particles but do very poorly when exposed to excessive amounts of salt (Barwise & Kumar, 2020). Bozeman does not primarily use salt for roadways; however, many businesses and homeowners use salt to remove ice from walkways. This may be a potential concern when considering appropriate plants. White oak is a species native to Eastern and Central North America that is fairly tolerant to salt-sprays (Moore, 2002). This species would be great for managing air quality in

Bozeman as white oak fares well during the winter. They shed their leaves during the winter allowing for natural snow melt and are reasonably salt tolerant.

Snow melt creates stormwater runoff in the spring. Runoff picks up pollutants such as fertilizers, herbicides, engine oil, and other toxic chemicals then deposits them into waterways like Bozeman Creek. Bozeman Creek is notorious for flooding downtown Bozeman during spring melt and spring rainstorms. Green infrastructures such as permeable pavements, urban tree canopies, rain gardens, and green roofs can all assist in managing excess water in urban areas but also filter runoff to create healthier waterways (Garrison et al., 2012). Permeable pavements are porous pavements on top of soil and gravel that absorb rain and snowmelt. Instead of water collecting over impervious surfaces, permeable pavements allow for water to seep into the soil underneath, capturing pollutants, lowering the amount of standing water, and reducing discharge. Permeable pavements would be specifically beneficial for Bozeman in the winter as these pavements can remove water from their surface possibly reducing winter injuries. They also can store heat easier than nonpermeable surfaces which reduces the need for de-icing techniques. Green roofs are also a great option for stormwater runoff as water can be captured immediately. Water can be removed from these roofs via evapotranspiration. Most water captured by the roof will not enter the stormwater system. Permeable pavers can also be planted or seeded with vegetation to increase infiltration, increase water uptake by plants, redistribute water throughout the urban soil system, and lessen the effects of soil compaction.

**To the Root of it All**

The urban rhizosphere is critical to plant health and urban ecosystem functionality. A plant's performance in an ecosystem heavily relies on root health, its ability to obtain resources, and anchor itself in position (Day & Wiseman, 2014). Urban environments create obstacles relating to plant growth and health. The growth of the plant and its root in turn affect the belowground environment biologically, physically, and chemically (Day & Wiseman, 2014). Bozeman's urban forests and green spaces provide economic benefits, reduce stormwater runoff and erosion, enhance air quality, assist in energy conservation (heat and wind), and provide noise abatement (Davey Resource Group, 2016).

As Bozeman continues to grow, there will be greater demand for water resources, better stormwater management, and housing. Construction and impervious surfaces lead to more compacted soil and decreased infiltration rates. Stormwater detention areas are thought to aid in the mitigation of stormwater. However, their construction often worsens the issue of soil compaction and infiltration surrounding the retention area. Plant roots, specifically trees, are known to increase infiltration rates in soils by as much as 153% in some cases (Bartens et al., 2008). Green infrastructure such as bioswales direct water to a location but do not aid in the distribution of water resources throughout the watershed. Water preferentially flows along the roots of trees and plants. It may be possible to develop a green structure that utilizes this preferential flow path to redistribute water throughout a watershed with minimal human disturbance or construction.

Soil erosion is a major threat to soil function (Ola et al., 2015). Plant canopies can reduce erosion through interception and by decreasing the force that water hits the ground. Water that flows over the ground tends to pick up sediments and deposit them in nearby waterways causing substantial ecological issues. One study conducted in Montana found that a decrease in ground cover from 100% to 1%, caused a 200 times increase in overland flow (Trimble & Mendel, 1995). The soil erosion response to changes in vegetation cover may be affected by any soil property, but mainly shear strength, aggregate stability, and hydraulic function of the soil (Ola et al., 2015). Roots interact with these properties in three main ways: 1) roots and root structure increase the shear strength of soil, 2) roots prevent sediment transport by increasing the number of stable soil aggregates and using root exudates (organic acids) like glue between soil particles, and 3) roots create more pore space and increase surface roughness, decreasing water runoff velocity, and allowing for more infiltration.

Root architecture (lateral and longitudinal growth) may be one plant trait humans can harness to direct root growth and possibly curb soil erosion rates. Studies have shown that root architecture can be manipulated through the placement and availability of nutrients (Fig. 2). Fibrous root systems have been found to increase soil resistance to concentrated flow and taproot systems increase the soil saturated hydraulic conductivity (Ola et al., 2015). Depending on the desired results, plants may be selected for specific purposes based on their primary root architecture and the benefits they provide.

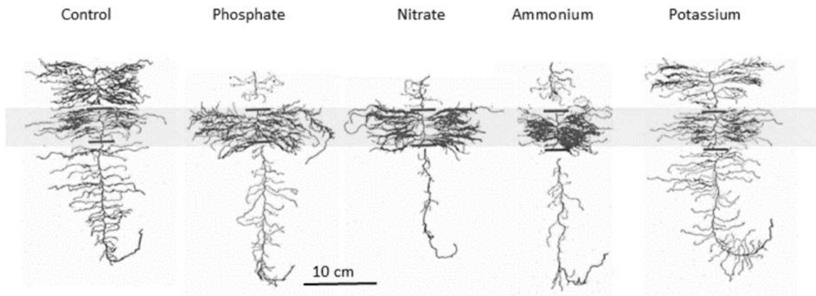


*Figure 2: Effects of different nutrient treatments and placement of nutrients on root architecture. (Ola et al., 2015)*

The urban landscape is filled with root constraints. Solid impediments such as foundations, roads, and rock allow for little to no root exploration by plants. Permeable impediments such as compacted soils or gravels allow for some exploration (Day & Wiseman, 2014). Root growth has been well documented to interfere with urban infrastructures such as utility lines and sewer pipes. Some plants can grow roots in fissures as small as 100 $\mu$m (Zwieniecki & Newton, 1995). As we saw in Figure 2, plant roots search out nutrients which leads to roots proliferating near recent water or sewer pipe leaks. Roots by nature tend to grow radially, which can cause an uplift of curbs, walkways, and roads (Randrup, 2001). There is a need to lessen the cost that roots impose by damaging urban infrastructure.

**The Mental Benefits**

The green spaces found within cities are necessary to improve the mental health of residents in Bozeman. Studies in other cities have suggested that spending time in natural areas is associated with a decrease in mental fatigue and an increase in concentration times (Entrix, 2010). A population with higher concentration and less mental fatigue would be much more productive and lead to a more successful community. People with increased exposure to green space also experience reduced clinical anxiety and mental distress (De Vries et al., 2013). The many mental health benefits provided by green infrastructure make it worth considering and investing in.

A study titled “Nature-based solution for improving mental health and well-being in urban areas” provided a good experiment to study to examine the benefits of green space on mental wellness (Vujcic et al., 2017). In this experiment, stress levels were measured and indicated that groups who spend time in a botanical garden had a significantly larger decrease in stress than those who did not. Exposure to green space in an urban environment and involvement in horticulture therapy showed clear benefits to the mental health of the patients. This study focused on the effects of time spent in botanical gardens but there are similar studies that were conducted in other natural settings.

In general, being around nature has been tied to people with better mental health. Spending time in nature directly correlates with sunlight exposure which has also been shown to improve depression in individuals (Beute & de Kort, 2018). The study patients also displayed a stronger positive reaction to the green space if biodiversity was greater (Fuller et al., 2007). Simply taking a nature walk through an area also showed to decrease depression and the likelihood to feel burned out in everyday life, something that can be very important to people with regular work schedules (Korpela et al., 2016). Taking time to visit available natural space in everyday life seems to better the community that surrounds it and providing this natural space within a city is up to its management.

Green space within cities provides an excellent area to escape a busy workflow, work on mental stability, and make a city look complete. These areas can be parks where the land is set aside for public activities, or just vegetation mixed in with private areas such as business and workspace. Green infrastructure is shown to be very costly to retrofit within a fully developed city which is why planning areas to keep as green space in Bozeman could help save money over time by cutting out the cost of removing hardscape and is key to the city’s success as an established city (Kousky et al., 2013).

Setting aside space in future city plans for green space will provide mental health benefits and allows more opportunity for the city's inhabitants to find an escape. Greenspace will easily improve the livelihood of communities, especially if it is easily accessible (Beute & de Kort, 2018). Because going on nature walks requires less effort than other activities, the inclusion of natural trails within cities should be considered. The river running through Bozeman provides a good natural space for such trails. Having a trail go through the city would make it easily accessible by a large portion of Bozeman’s population. Walking to and from a high-stress environment on these trails could show great decreases in the stress of the population (Korpela et al., 2016).

Botanical gardens and parks may need more maintenance but were also shown to increase positive mental health outcomes. Also, doing tasks in these gardens, such as watering plants and even just looking at the scenery, showed an increase in mental health. Having more gardens and parks would provide employment opportunities for the upkeep of the grounds which are jobs that are proven to help relieve stress and anxiety (Vujcic et al., 2017).

**Conclusions**

Green spaces serve important roles in urban landscapes by providing structure, functions and services. Integrating and preserving green spaces for Bozeman’s future will be beneficial for the human and natural communities. With this integration of green spaces throughout Bozeman, the ecosystem can retain biodiversity which is important for ecosystem function and services as well as maintaining natural connectivity. Semi-permeable pavers, conserved green areas, and the presence of plant roots will aid in stormwater management as the city grows.  Considering specific plants to target air and water pollution and incorporating them into green spaces may help Bozeman curb urban pollution. The above-ground and below-ground effects of plant presence in urban systems have important implications for future infrastructure considerations.

Bozeman’s local government should consider implementing more green spaces and green infrastructure. Preserving greenery on the outskirts of the city and within the city will help to increase connectivity and preserve biodiversity which in turn will help our local ecosystem to function and provide the services we require from it. The cost and effort of converting hardscape to green space prove to be more challenging than setting aside areas specifically for green spaces before major expansion continues. Community health will benefit from the presence of greenery in the inner-city areas. It will be much more cost-effective to implement these systems now, rather than after the city grows.

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# Understanding and Maintaining Ecosystem Services in the Bozeman Area

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## Introduction

As cities grow, natural plant communities are replaced with urban plant compositions. Plant communities outside of urban areas are relied upon to provide food and important natural resources for humans, other animals, and pollinators. Within cities these communities also provide crucial ecological structures, functions, and services that help maintain the well-being of the city's residents.

Ecosystems can be categorized by their structures and functions (Odum, 1953). Ecosystem structure is the composition of an environment's biotic and abiotic factors. The structure of an ecosystem provides the foundation upon which functions and services take place. Biodiversity is a key component of ecosystem structure, especially in actively urbanizing environments because biodiversity aids in the supply of clean air, clean water, wastewater treatment, pest control, and plant pollination (Cresswell and Murphy, 2018). Walters et al. (1970) noted when comparing urban and rural floras, the species richness of urban environments that often exceeded that of the surrounding countryside. This pattern was later confirmed for vascular plants in North America (Dobson et al., 2001; McKinney 2002; Hope et al., 2003). An ecosystem's ability to provide services like the ones mentioned above increases with greater biodiversity which increases the overall benefits of urbanites.

### Urban Ecosystem Services

Ecosystem services are the parts of ecosystems used (actively or passively) to produce human well-being (Fisher et al. 2009). Here we would like to discuss three subcategories of such services: provisioning, regulating, and cultural. A provisioning service is any sort of benefit humans can derive from the environment, including food, water, fuel, fiber, and medicines. A regulating service is the benefit provided by the environment that moderates natural occurrences such as floods, diseases, pests, and climate (Lant et al., 2008). Unlike the other two, cultural ecosystem services are the intangible benefits that we gain from our ecosystems. More specifically, in an urban area like Bozeman, provisioning and regulating services could provide "air filtration, micro-climate regulation, noise reduction, rainwater drainage, sewage treatment, and recreational and cultural values" (Bolund and Hunhammar, 1999). By utilizing these ecosystem services, human comfort and health within an environment is inherently increased.

Urban forests, for instance, help to moderate climate, conserve energy, reduce carbon dioxide, improve water and air quality, control rainfall runoff and flooding, lower noise levels, harbor wildlife, and enhance the attractiveness of cities (Dwyer et al., 1992). Projections indicate that 100 million mature trees in U.S. cities (three trees for every other single-family home) could reduce annual energy use by 30 billion kWh by increasing the amount of shading and wind-shielding elements around adjacent buildings. This would save about 2 billion dollars that would otherwise be used to heat and cool surrounding buildings (Akbari et al., 1998). Often associated with energy savings is an urban forest's ability to act as a carbon dioxide store. Rowntree et al. (1991) reported that at current estimates, U.S. forests store 800 million tons of carbon which account for nearly five percent of all living tree carbon storage across North America. For cities such as Bozeman, whose population has increased by forty-five percent since the publication of the Rowntree estimate, the importance of these urban forests is paramount.

These urban plant environments are not only important for humans, but for wildlife as well. The designated green areas found throughout cities help to promote ecological stability by providing habitat for wildlife, conserving soil, and enhancing the overall biodiversity. (Dwyer et al., 1992). The opportunity to enhance wildlife habitat is a great chance for cities to create programs that both bring community members together and improve the environment around them. Surveys conducted by Shaw et al. (1985) concluded that a majority of individuals living within an urban environment appreciate and enjoy wildlife in their day-to-day lives. An increase in habitat creation and restoration will help to bolster biodiversity and therefore directly increase plant services. With the growing trend of environmental awareness and concern for quality of life in our cities, ecological benefits such as these will increase in significance over time (Dwyer et al., 1992).

**Protecting Cities from Flooding and Water Contamination**

One of the most significant impacts of urbanization is the increase of stormwater runoff caused by impervious surfaces. Impervious surfaces prevent stormwater from infiltrating into the ground, which increases the rate at which stormwater enters streams and water bodies. The increase of impervious areas in urban areas results in a higher percentage of precipitation being converted to surface-runoff, resulting in higher peak flood flows in nearby streams. However, areas covered in vegetation will only shed five to fifteen percent of precipitation as aboveground runoff. That is nearly fifty-five percent less than cities covered in impervious surfaces (Bernatzky, 1983). Urban forests benefit urban environments by supplying natural flood management and water quality maintenance. In cities like Bozeman that are built around natural waterways, natural flood management is invaluable. Urban areas may also exacerbate the damage caused to streams from runoff by funneling together stormwater in their drainage systems which is then released directly into waterways. This has many adverse effects such as an increase in runoff that can physically alter stream channels and cause flooding, severe channel erosion, decreased groundwater recharge, and reduced stream baseflow during dry periods (Schoonover et al., 2006). Impervious surface runoff also mobilizes pollutants that can negatively affect water quality. These include sediments, nutrients, metals, synthetic organics, pathogens, and hydrocarbons which can severely degrade aquatic habitats, making drinking water unsafe. These pollutants can be acutely toxic to aquatic organisms and have been found to pose a significant risk to invertebrate communities (Weston & Lydy, 2014). Excess inputs of nutrients into water bodies can stimulate rapid growth in algae, leading to the depletion of oxygen and possibly eutrophication. These negative aspects of urban runoff make it crucial that stormwater is intercepted before getting into water bodies. Additionally, it has been observed that "combining riparian and roadside buffers for urban forestry can provide substantial improvements to water quality" (Matteo et al., 2006). The inclusion of buffers around all significant water systems as a regulating service will only have positive effects in urban areas.

While aiding in rainwater drainage, protected green zones such as wetlands can also help cities reduce the excess nutrients in water coming from wastewater treatment facilities. Many wetland vascular plants are bioaccumulators, which are plants that can take up and immobilize various pollutants including excess nutrients. The presence of these plants also slows water flow, which allows larger particulates to settle out to the bed of the wetland. Constructed wetlands can be attached to wastewater treatment plants where they are able to retain approximately 96 percent of the nitrogen and phosphorus left in the treated sewage water. This helps to both increase biodiversity and lower the costs of sewage treatment within a city (Ewel, 1997).

Cities are incorporating bioswales that are vegetated swales capable of removing pollutants and sediment from stormwater runoff (Anderson et al., 2016). They include engineered soil and gravel layers, perforated pipe underdrains, and can include overflow structures meant to handle excess stormwater during extreme precipitation events (Wu et al., 2017). Bioswales are essentially biofilters that can also aid in the retention of stormwater. Since bioswales are engineered and not naturally occurring, they can also be highly adaptive and serve various roles. They can be modified to filter runoff from an array of impermeable surfaces including roads, sidewalks, and parking lots. Additionally, bioswales can provide a variety of functions based on how they are designed; it is possible to target individual pollutants by selecting different combinations of plants (Bratieres et al., 2008). Generally, plants can degrade organic pollutants and uptake both macronutrients and heavy metals. However, these abilities vary significantly depending on the species because each species can differ chemically, morphologically, and physiologically (Iason et al., 2012; Keddy, 2017). This includes root exudates which are the substances that are secreted from roots to free up nutrients for the plant to uptake (Read et al., 2008). That is why it is imperative to test which plant species or combination of species will be best to meet the goals that you set for the bioswale. In a study conducted at Montana State University, Carrie Taylor found in her master's thesis that the species *C. aquatilis*, *C. bebbii*, *C. praegracilis*, *C. utriculata*, *S. acutus*, *J. articus*, *J. torreyi*, and *D. cespitosa* could be well suited to remove pollutants in constructed wetlands in the Bozeman area (Taylor, 2009).

Bioswales have been found to effectively reduce contaminant levels. In one study, researchers found that bioswales reduced suspended solids and metals by 81%, hydrocarbons by 82%, and pyrethroid pesticides by 74% (Anderson et al., 2016). Many studies use various grasses in their experiments. Excess nutrients can also be taken up in bioswales. A study conducted in China found that both total nitrogen and phosphorus can be significantly removed in bioswale systems that incorporated a saturated zone (Wu et al., 2017). The researchers also tested whether bioswales that contained both the grass species *Zoysia matrella* and the flower *Iris pseudacorus* outperformed bioswales that only contained *Zoysia matrella*. They found that utilizing a combination of plant species was more effective than using just one to remove excess nutrients. They hypothesized that using combinations of plants that densely covered an area and also had long roots was ideal for removing total phosphorus in a system. The roots also aided in preventing clogging of the bioswale by the creation of macropores in the soil. Although *Iris pseudacorus* is a noxious weed in Montana, this research shows that utilizing a combination of plants can have the greatest performance filtering out pollutants and maintaining bioswale integrity.

Trees are also an important tool to address urban runoff as they intercept rainfall and temporarily retain the rainwater on their surfaces. Green spaces that include trees can "make the watershed more adaptive to handling adverse conditions, such as large storms, nonpoint source pollution, flooding and high winds" (Matteo et al., 2006). Researchers have shown that in a 24-hour storm with 22 mm of rainfall, individual tree canopies can intercept as much as 79% of rainfall (Xiao and McPherson, 2003). They can also direct the intercepted rainwater into the ground via stem flow and take up pollutants and stormwater from their roots. Through evaporation of intercepted precipitation or transpiration, trees can significantly reduce the input water into a system and reduce the urban heat island effect. In one study, researchers showed that trees were able to account for 46% to 72% of total water outputs in vegetated channels (Scharenbroch et al., 2016). They noted that throughout the soil column bioswales were considerably drier than non-swale environments. The researchers found that stomatal conductance was the main factor contributing to how well a tree could transpire water. During the study, they found that elms and ashes were the most effective at reducing stormwater, which is excellent for Bozeman since these trees are already abundant around town. Trees can also reduce the compaction of soils, which is a big issue in urban settings because it limits the amount of water that can infiltrate into the ground. One study conducted in Virginia found that trees' roots can help increase infiltration rates by 153% while also enhancing the groundwater recharge of a bioswale (Bartens et al., 2008). This study is critical because it shows that we may be able to rehabilitate some of our soil infiltration capacities in urban areas.

**Benefits of Urban Green Spaces**

As urbanization in the Bozeman area continues to increase, so will local pollution. The services provided by plant communities within a city can help to lower this pollution. According to estimates made by Fransman (1993), one hectare of mixed forest removes up to 15 tons of particulates from the air every year. Within this forest a single tree can transpire up to 450 liters of water a day, absorbing 1000 megajoules of heat energy and noticeably reducing the temperatures of the city (Hough, 1989). The presence of urban green zones has an obvious indirect impact on the human population. Green zones can also work as a source of noise reduction; one study suggests that a dense gathering of shrubs at least five meters wide can reduce sound levels by up to two decibels, while a thicker shrubbery of 50 meters can reduce sound levels up to three to six decibels (Naturvårdsverket, 1996). Parks and green areas in a city can help provide this service. Parks in urban areas must not only meet the recreational demands of urbanites, but it must also compensate for the negative effects created by structures in these dense urban areas (Almeida et al. (2018). As cities develop, both the maintenance and creation of urban parks must be kept in mind. People benefit from urban parks in a number of ways, including having a place to congregate and practice sports. There are many beneficial opportunities for recreation inside our urban green zones that increase happiness and life improvement. As stated by Botkin and Beveridge (1997), “Vegetation is essential to achieving the quality of life that creates a great city and that makes it possible for people to live a reasonable life within an urban environment.”

. In fact, just being around green spaces can have a positive effect. “Individuals who moved to greener areas had significantly better mental health in all three postmove years” whereas people who moved to developed areas suffered from poor mental health within the year of their move (Alcock et al., 2014). The positive impacts that green spaces have on mental health are from a combination of recreating in green spaces near to the home and the green space that can be observed in neighborhood environments (Nutsford et al., 2013). Green spaces do not just affect mental health; they can also have tangible effects on physical health. Studies have shown that exposure to green spaces reduces the risk of type II diabetes, cardiovascular disease, premature death, preterm birth, stress, and high blood pressure (Suarez et al 2020).

Parks and green areas are also valued on a cultural and recreational scale. Recreational or cultural ecosystem services are defined as "the non-material benefits that people get from ecosystems" (Brambilla & Ronchi 2020). Recreational plant services are considered a form of cultural ecosystem services that are strictly linked to biodiversity. Recreational services depend not only on the type of native plants and organisms but also on the type of audience that is present and what recreational activities they are interested in. Brambilla and Ronchi (2020) conducted a study involving bird species and the services they provided for birdwatchers in Lombardy, Italy. This study found that the number of target bird species was positively affected by shrubland and vineyard cover in municipalities, whereas urbanized areas negatively affected these target bird species by reducing plant species variability. This is an example of how native plant species in municipal areas can positively affect native animal species such as these birds. This provides recreational ecosystem services for birdwatchers in the area not only just by the presence of these species, but also by the presence of the native plant species that provide a base for all other species present in an area (Brambilla & Ronchi 2020).

These services provide important benefits both physically and psychologically. Unfortunately, access to these benefits is often unequally distributed. For example, outdoor recreation opportunities in Oslo, Norway metropolitan areas showed that most of the population has access to areas for daily recreation. However, the access is unequally distributed, with migrants and low-income inhabitants having less access than other population groups (Suarez et al. 2020). When considering this, it becomes obvious that it is necessary to analyze the current and planned greenspaces in Bozeman and determine if the recreational services are equally distributed to the town and if all of Bozeman's civilians have access to recreational services. Bozeman has several areas where urban structures take away from green spaces that would normally be available to a civilian. As Bozeman develops, we need to make sure that all of the areas are constructed with enough green space provided for the homeowners to prevent poor mental health.

**Implementing Urban Green Spaces**

Unfortunately, green spaces are often not valued as highly as suburban development. As populations increase, suburban land development in the Greater Bozeman area will increase correspondingly. This eliminates possible recreation land opportunities and leaves a growing population with fewer cultural-ecological services available to Bozeman's residents. Nature-based recreation in urban areas is important for the well-being of citizens but urban greenspace planning should consider this spatial distribution. Liu et al. (2020) propose a management plan that contains three elements: (a) quantifying the balance of supply-demand at multiple scales; (b) match supply with demand; (c) perform a spatial clustering analysis to meet the supply-demand balance”. Oftentimes recreational services are mapped based on physical attributes such as land cover and topography. In instances like this, the recreational potential of the land is only modeled based on expert judgment and not on public preference. This is an issue that should be avoided while Bozeman develops to make sure that the most sought out land for recreation is cultivated while managing to develop suburban areas that do not conflict with our recreational land use. A method that could be used to avoid recreational land development in ecologically important areas would be to conduct participatory mapping. Participatory mapping data is based on public preferences and can be used to improve proxy-based methods to map the recreational potential of certain land areas (Scholte et al. 2018).

There is a general push to find the easiest and most economic ways to implement services into urban development. For example, Alessio Russo and his colleagues suggest implementing an "edible green infrastructure approach as it can offer improved resilience and quality of life in cities" (Russo et al., 2017). This idea is being supported in Seattle, where efforts are being made to "normalize the production and use of edible landscapes" (McLain et al., 2012). According to a study done, "a vision of urban forests as providers of goods as well as services may provide a more solid foundation for achieving urban sustainability than the current 'hands off' approach to urban forest management." An urban forest is incredibly valuable, as it can be used for house and business sites, urban recreation and maintaining water quality (McLain et al., 2012). If an urban forest is already valued, it might as well provide 'edible green infrastructure' to the city as well.

**Conclusion**

Ecosystem services are often overlooked in the rush to accommodate businesses and housing. According to "The Tragedy of Ecosystem Services", most ecosystem services are declining due to a "complex social trap […] which results in part from the overconsumption of common-pool resources. Additionally, current economic incentives encourage the development of funds of natural capital on private lands for marketable commodities at the expense of ecosystem services" (Lant et al., 2008). If public lands are being allocated to companies for profit with zero consideration of ecosystem services, the services and consequently, the surrounding ecosystem, will suffer. However, this concept is not new. In 1968, Garrett Hardin wrote the paper, "The Tragedy of the Commons", in which he described the issues caused for the environment if everyone thinks only of their own benefit (Hardin, 1968). Although hardly the first to think upon this idea, Hardin expressed the concept in a way that the general public could understand. If ecosystem services are taken for granted, they will quickly begin to disappear and any attempt to backtrack will be extremely costly and could potentially take decades.

The structure, function, and services of plant ecosystems are extremely valuable to rural areas, and are critically important in urban environments. As Bozeman transitions from a rural town to a rapidly urbanizing micro-city, these functions need to be kept at the forefront of the expansion. These services help to save money and energy, help prevent damage from flooding, provide habitat for wildlife, and most importantly gives the opportunity to preserve overall health and well-being. As Bozeman continues to grow, an increased pressure will be placed upon these critical ecosystems. There is a weakening link between everyday human life and our forested surroundings (Grebner et al. 2021). One recommendation for Bozeman developers is to keep green spaces involved in development plans. These spaces are not only beneficial to our city when it comes to aiding in runoff and flood prevention, but they will also help maintain the mental health of civilians near these green spaces. Ecosystem services will not be available to urban environments if they are not actively considered and preserved. It is our responsibility to protect and create new urban plant ecosystems to ensure the overall growth and stability of both ourselves and our environment. It is incredibly important that Bozeman maintains the basic ecosystem functions that many often take for granted.

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