MSU-Land Resource and Environmental Studies 2016 Story Mill Final Report

Prof: William Kleindl

The Fall 2016 Land Resources and Environmental Services (LRES) Capstone Class focused on ecosystem services provided by the wetlands and riparian areas within the City of Bozeman. Bozeman Creek and the East Gallatin River within the City limits are listed as polluted for total nitrogen and sediment under the TMDL criteria established by the State of Montana. The City of Bozeman and Trust for Public Land enhanced a wetland and several riparian areas within the future site of the Story Mill Community Park with the intent to reduce some of these pollutants. Early in the semester, the class met with Maddy Pope from Trust for Public Lands, Kyle Mehrens and Myanna Rice from the City of Bozeman, Steve Carpenedo from Montana Department of Environmental Quality, Rich McEldowney from Confluence Consulting, and Lynn Bacon from Tarraquatic Consulting to hear what questions and concerns that these agencies and consultants have regarding the wetlands and riparian areas within he Story Mill and other means to leverage the City's ecological infrastructure to reduce the pollutants within City's streams. These questions help guide the students to define and determine the extent of the ecological services that the Story Mill restoration and future community park will provide to the City of Bozeman to reduce listed pollutants from our area's streams. They also assessed other options to reduce the source of these pollutants. The Class prepared five separate group projects to address these questions. The following are the final reports of the student groups and will provide:

- Social and environmental interface at Story Mill,
- Water quality and Story Mill wetland,
- Story Mill's restoration: evaluating success,
- The assignment of riparian buffer zone pollution attenuation in the Gallatin Valley,
- Application of green infrastructure in Bozeman: A GIS suitability model approach, and
- A copy of the class' final presentation

Social and Environmental Interface at Story Mill

Jessica Chrisp, Hannah Johnson, Willy Carter

Introduction

The Story Mill area, in the northeast corner of Bozeman, has an interesting past, present and ostensibly, future. It has been altered greatly from its natural state through homesteading, agriculture, and industry. As Bozeman expanded, the Story Mill area has remained largely undeveloped. Recently the Trust for Public Land purchased the site to develop a regional park, and along with this development was the restoration of a floodplain and wetland habitats. The restoration of this site was important not only for the restoration of a wetland environment, but also as an example of the importance of wetlands to our community. However, the Story Mill park and wetland enhancement project balances some strikingly diverse and occasionally conflicting goals. The wetlands are promised to improve water quality (Story Mill Fact Sheet 2015) and provide valuable habitat for wildlife, but human visitors might disturb wildlife, cause erosion, and trample vegetation. Further housing development in the area could limit wildlife migration to and from the park by cutting off corridors that connect the wetlands to the Story Mill hills and the Bridger mountain range. While the Story Mill wetlands can be used as a demonstrative natural area to make visitors care about wetlands which are not normally accessible, it is not the intent of the future park to sacrifice the function and habitat of the wetlands to this cause. Using careful planning, we can honor our cultural values to minimize impacts to the wetland and its wildlife while still providing a recreation area where citizens can relax, gather, and learn about wetlands. This paper will illuminate some of those planning needs in the context of our community.

Figure 1: The Conceptual Park Plan visual from the Trust for Public Land (Trust for Public Land, 2015)

The shape of the Story Mill Community Park, as seen in the Conceptual Park Plan (Figure 1), portrays a simple reality: a rigidly outlined patch of undeveloped land surrounded by urban infrastructure. A glance at the map of the Story Mill Community Park plan shows hard lines surrounding the open fields and rehabilitated wetlands. However, nature doesn't work in straight lines, nor does it recognize borders. Its ambiguous characteristics, mixed with the structure of the community around it, influence the complexity of the parks goals, both social and ecological. In order to understand these goals, it is crucial to understand the constraints placed on the area through historical land use decisions.

Site History

At the end of the last ice age large alluvial fans of glacial outwash formed in the Gallatin Valley. Over the next few thousand years, a fertile soil profile developed over this foundation via sedimentary and aeolian deposits creating a thick loam over coarse sand and gravel (USDA, 2016). Topographical indentations combined with soil characteristics and contact with a low water table produced an area of sustained saturation for enough of the year to promote a hydrophilic vegetation community. With the help of the annual spring surface water input from streams and precipitation, a stable wetland habitat was formed. This hydrology was later altered by settlers.

Meriwether Lewis was the first known white man to see the valley in 1805, and thanks to his lavish descriptions of the area, settlement soon followed (Strahn, 1996). With the coming of the railroad to the valley, Nelson Story began a flour mill operation. A two-mile-long canal was excavated to divert water from Bozeman Creek, Rocky Creek, and Bridger Creek. Thanks to Nelson Story, Bozeman became a prosperous community, at great ecological cost to the wetland area.

Throughout Bozeman's post-settlement history, water has been at the core of most issues, and tracing its usage through time can help us understand the current state of the Story Mill wetland. In most cases, new water rights claims served to deplete the many wetlands of surface water, but the irrigation canal that ran along the base of Story Hills may have fed the Story Mill wetlands by increasing groundwater discharge to the wetland area. To better understand this concept of water use through Bozeman's history, it's important to look to the history of the law that dictates water use in the West. The Prior Appropriation Doctrine came about in the latter half of the 19th century and quickly became the norm for most of the Western U.S. It basically states on a "first in time, first in right" basis that whoever got there first has rights to as much water as they want, whenever they want it. There are hundreds of water rights upstream of the Story Mill area, meaning hundreds of different sources of potential pollution feeding into the wetland habitat, including the City of Bozeman itself, and its stormwater system that drains right into Bozeman Creek. This also meant hundreds of different sources of depletion of the water that the wetland depends on (Carter, 2016).

As ecological awareness grew, further aspects of regulation were added to the Prior Appropriation Doctrine that are applicable to assessing the health of the water that flows in and around the restoration site (Carter, 2016). The Endangered Species Act, a federal mandate placed in 1973, ensures the conservation of the habitat for listed species. Public Recreation Claims could potentially be obtained for the Story Mill Community Park to prevent upstream water rights holders from taking so much water out that, even on high water years, there is not enough flow to fill the backwater slough. The problem with all this is that the basic foundation of “first in time, first in right” inherent in the Prior Appropriation Doctrine still takes priority in the eyes of the law. This leaves the Story Mill wetland site at permanent risk (Carter, 2016).

Aside from the use of water upstream, there have been issues in other realms outside of water law with serious detrimental potential to the health of the wetland site. For example, in 1945 the Idaho Pole Co. began operation just north of the site, and was later targeted by the EPA as a superfund site (EPA, 2016). The plant treated wood poles with a variety of highly toxic chemicals, including pentachlorophenol, which contaminated the soil and groundwater for years. The Clean Water Act was passed by the Federal Government in 1972, and the property was declared a superfund site in 1986, but the wood treatment at the plant continued until 1997. According to the EPA, the efforts during operation to contain contamination of the groundwater, such as an “interceptor trench”, were deemed ineffective and the harmful chemicals were continually recorded as moving through the groundwater away from the site, and on to the neighboring land (EPA, 2016).

Changing Approaches to Land Use

At some point in the 20th century a shift began to occur in a portion of the population’s mentality towards nature, which unfolded into the environmental movement. Aldo Leopold’s book “Sand County Almanac”, and Rachel Carson’s “Silent Spring” were some of the iconic influences defining the growing ideal that we needed to stop neglecting the health of the planet. In the incessantly developing West, few better places exist for this mentality than Bozeman, and the Story Mill Community Park project is a direct result of this ethic. Bozeman is small enough, and surrounded by enough natural beauty, that the benefits of incorporating nature back into society can be directly observed. Story Mill Community Park is an example of how these ideals manifest.

Integrating Parks with Wildlife

To begin it is important to stress that maintaining habitats is far less expensive than trying to recreate them later. In many cases, recreated habitat is expensive and either is not as productive as the original habitat, or fails completely in its attempt to provide for the needs of the wildlife in question (Opdam et al. 2011). A multitude of species are already taking advantage of the Story Mill Wetlands and have begun to establish a foothold in this new environment.

Even though only a small percentage of Montana is considered to be ‘wetland habitat’ there are a variety of organisms that benefit from, or require this type of habitat. The rehabilitation of this wetland to Gallatin County is very beneficial to promote biodiversity for wetland organisms. In Gallatin County there are a variety of wildlife that either require wetlands or can take advantage of a wetland environment, some of which are at risk of losing their habitat. In Table 1 the fauna that are considered “species of concern” by the Montana Natural Heritage Program are listed. The creation of Story Mill wetlands is extremely important for these sensitive animals and other more common wetland species.

Species (common)	Species (scientific)	% of MT That is Breeding Range	Habitat
Hoary Bat	*Lasiurus cinereus*	100%	Riparian and Forest
Great Blue Heron	*Ardea herodias*	100%	Riparian Forest
Veery	*Catharus fuscescens*	100%	Riparian Forest
Yellow-billed Cuckoo	*Coccyzus americanus*	50%	Prairie Riparian Forest
Bobolink	*Dolichonyx oryzivorus*	100%	Moist Grassland
Black-necked Stilt	*Himantopus mexicanus*	8%	Wetlands
Western Toad	*Anaxyrus boreas*	38%	Wetlands, Floodplain pools
Plains Spadefoot	*Spea bombifrons*	73%	Wetlands, Floodplain pools
Brush-footed Butterflies	*Nymphalidae*	12%	Montane Wetland

Table 1 Species described as “species of concern” by Montana Natural Heritage Program. (MNHP 2016)

Bozeman City code states that all parks must be surrounded by an access road. The addition of any road into a new environment is not without consequences. Direct death of wildlife due to road traffic is a concern, but most likely casualties will be minimal until housing development around the park increases. Another serious issue is the mere existence of the road and its effect on wildlife nesting and mating. It has been well documented that traffic can have serious effects on bird abundance and richness (Summers et al., 2011). The construction of the road and sound of traffic once the road is completed will create loud noises which discourage wildlife nesting. The most effective way to prevent the loss of nesting habitat is to document areas with high abundance of nesting birds, establish appropriate buffers and to redirect roads to create distance between traffic and nesting habitat. By conducting research before road plans are complete, roads can be better adapted to areas important for biota life cycles.

Another more expensive and invasive approach to protect wildlife from anthropogenic influences is the construction of wildlife corridors. In this case, specifically a connection between the restored wetlands and the Story Hills immediately to the east of the site. The Story Hills area is one of the last natural habitats left near the wetland that has not had large anthropogenic influences. Luckily these areas are owned by the Gallatin Valley Land Trust and are currently protected for recreation and wildlife use. These areas are ideal for corridor implementation. Wildlife corridors are areas that safely connect two sections of wildlife habitat that, for various reasons have been or will be cut off due to human interaction (NSW 2004). An example would be a series of fencing or blockades that would funnel wildlife to a land bridge that is built over, or below a road or highway; that would allow for safe passage for animals that would normally either risk interaction with vehicles or for animals that would typically completely avoid the road. Wildlife corridors promote biodiversity of both plants and animals by providing a connection between fragmented habitats that without intervention could become isolated. In many cases, isolated populations become stressed due to disease and lack of genetic diversity (NSW 2004). In the worst case scenarios local extinction occurs. Wetland habitats provide habitat refuge as upland habitat losses have occurred in the United States (Deneen 1998). Use of these wildlife corridors should be encouraged and Story Mill wetland is a good candidate for implementation.

Some studies have shown that wildlife corridors and land bridges can have negative impacts, the most troublesome being that it can become a prey trap. As predators learn the habits of other animals, it becomes easy to predict when and where their prey will make use of the habitat connection (Little et al. 2002). The best ways to combat this issue include; providing multiple areas for wildlife to cross traffic, and to make the corridors as large as possible. Some of these wildlife would include deer, small rodents and birds. These innovations make it more difficult for predators to corner prey and provide more cover for wildlife that requires concealment as a main mode of defense.

Vegetation is a very important part of any habitat, including wetlands. Oftentimes vegetation is not interpreted as wildlife in the eyes of the public, and the need to protect these non-mobile organisms can be overlooked. Plants are often damaged unintentionally, by people straying off designated paths, but the most detrimental cause is the introduction of non-native species to a new area. Something as simple as wearing the same boots to different places can have strong negative impacts on native plants and native plant diversity (van Kleunen et al., 2015). With the addition of traffic, the chances of seed dispersal increase significantly. As vehicles travel through any area they can accumulate seeds that attach to tires, mud and other parts of the automobile. The vehicles then become vectors moving seeds and pollen long distances to detach in new areas (Zwaenepoel et al. 2006). This can have a significant negative impact on native vegetation, particularly in areas where native vegetation is only beginning to establish a foothold in a newly populated or restored environment.

One way to minimize foreign seed dispersal is to encourage citizens with a vehicle to use a washing station when entering the park. Even on a volunteer-only basis, this can dramatically decrease the amount of non-native and invasive species entering the area (Rothlisberger 2010). Another way to prevent seeds from reaching areas where they could germinate and reproduce is by making it difficult for off-roading by adding blockades or obstructions that make it challenging for a vehicle to go off the designated road. Adding designated parking spots in multiple areas may also encourage citizens to stop in those areas instead of trying to find off-trail areas to park. To truly make this site a natural wetland that the City of Bozeman desires, the addition and protection of vegetation native to this area must be a key aspect in continuing its restoration.

The largest impact to native wildlife, excluding invasive, is the introduction of trails into the wetland ecosystem. The environmental impact associated with trails is largely associated with off-trail behavior. When hikers stray from the trail, their passage can result in trampled vegetation, soil erosion, and ultimately negative impacts on water quality (Guo et al. 2015). In a town consistently ranked as one of the “best places to live” for outdoor enthusiasts (Dyckman

2013), it would be reasonable to expect that residents might exhibit above-average trail etiquette, but Guo et al. (2015) found that people who hike more often are actually more likely to indicate that they would hike off-trail in a stated choice survey. According to the same stated-choice survey, hikers are most likely to leave the trail when the trail itself exhibits degradation: muddiness or erosion (Guo et al. 2015). Therefore, designing trails that stand up to local conditions is an important and relevant step towards reducing off-trail behaviors. A common method for managing visitor behavior is displaying educational signage. Counterintuitively, Guo found that participants who viewed an educational message were actually more likely to indicate that they would hike off-trail. In light of these findings, trail development at Story Mill should focus on the infrastructure of trails primarily as a means of encouraging visitors to stay on trail.

To minimize the impact of trails, one must consider the width of the trails, the areas they might fragment, and type of surface used. Unhardened trails, like dirt single-track, have the least impact on vegetation (Ballantine and Pickering 2015), but are subject to erosion and degradation. Since unhardened trails get muddy, hikers are more likely to exhibit off-trail behavior. Therefore, in a high-traffic park with sensitive wetlands like Story Mill, trails with hardened surfaces are preferable. The current plans for trails are all hardened surfaces: asphalt, decomposed granite, and wood, as seen in Figure 2. These selected surface types will help to prevent degradation.

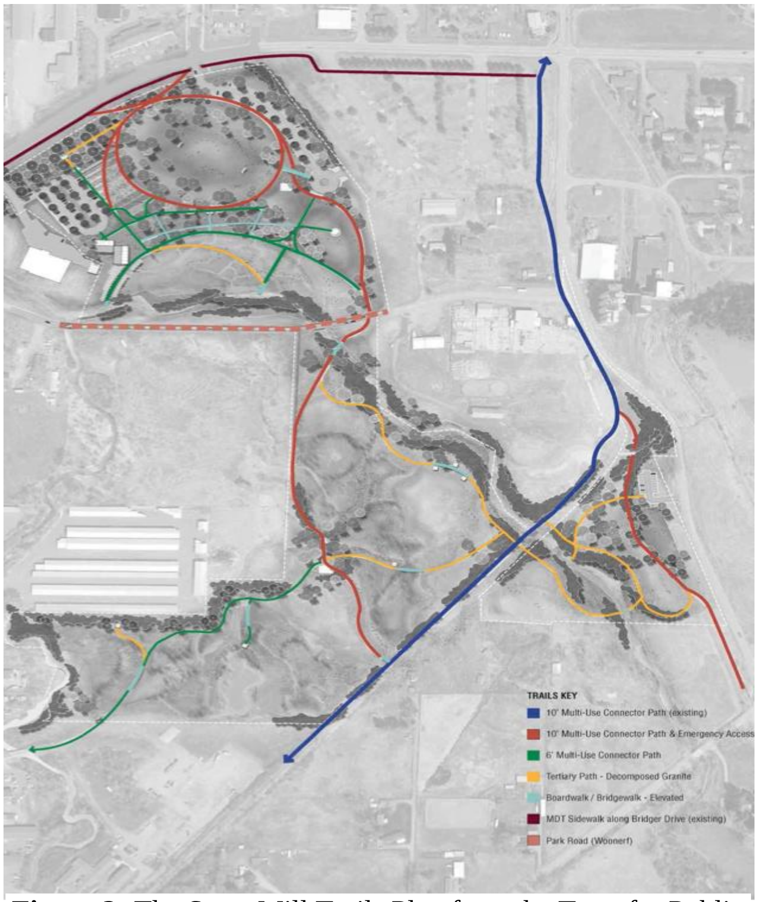

Figure 2: The Story Mill Trails Plan from the Trust for Public Land

However, it is important to note that trails with hardened surfaces often encourage invasive rather than native species; careful management would be required to promote native species next to the trails. As human traffic through the park increases, trails would have to be monitored meticulously in order to prevent the spread of weeds. This is partially because weed seeds can travel long distances on hikers' clothing, particularly fleecy fabrics which are commonly used for outdoor recreation in cool climates (Ansong et al. 2016). Visitors' cars also act as vectors for weed transport; of the many seeds that researchers find on car tires, under wheel hubs, and on car grilles, over 90% are weed seeds (Ansong and Pickering 2013). Maintenance of native species could require pulling invasive species, herbicide application, seeding with native species, or monitoring of soil and water characteristics to ensure optimal conditions for native vegetation. Accidental transport of weed seeds necessitates continuous monitoring of species composition to prevent invasion of noxious weeds.

Some of the trails at Story Mill are planned to be boardwalks. These raised surfaces are ideal because some vegetation can grow underneath the path when constructed from metal grates, which let through sufficient light, (Ballantine and Pickering 2015) and hikers are less likely to wander off-trail; the addition of railings can further discourage off-trail behaviors. It is likely that cost is a limiting factor for the inclusion of boardwalks as they are much more expensive to install than, for example, crushed gravel trails. To ensure low environmental impacts from trails, the boardwalks must not be constructed from wood treated with chromated copper arsenate (CCA). Particularly after abrasion from foot traffic, the chromium, copper, and arsenate can contaminate the soil under and near the boardwalk (Lebow and Foster 2005). There are new lumber treatments available based mostly on copper which are considered less toxic than lumber treated with CCA, but these treatments cost more with prices 15-30% higher (Keiley 2003). Metal grates are a lower-cost alternative for boardwalks. Although aesthetically rather unappealing, metal grates let more light through to plants underneath the boardwalk, allowing the ecosystem to be more productive.

Placing trails parallel to contours is another best practice for sustainability (Ballantine and Pickering 2015), but the relatively flat contours at Story Mill render this a moot point. The paths planned closest to the active wetlands and the riparian zone should be reviewed to ensure they are clear of the floodplain. Trails on the floodplain would be subject to erosion and degradation.

While off-trail behavior is more concerning from a biochemical perspective, litter also constitutes a potential problem as activity increases at Story Mill. Fortunately, research indicates that littering can be reduced using social norms; when subjects observe someone picking up litter in a mostly clean environment, they are much less likely to litter when they encounter the opportunity (Reno et al. 1993). Therefore, if a few key volunteers keep the park free from litter and are seen doing so, the Trust for Public Land will be able to maintain a culture that litters infrequently. Litter can also be prevented by the regular placement of trash-cans. However, much like the battle against invasive species, the battle against litter is a practice that will continue through the lifespan of the park, so long as the ecological integrity is valued.

The Story Mill wetlands have been protected partially for the ecosystem services a wetland can provide, but also because of a fortuitous cultural fascination with wildlife. In fact, the community park will include features like bird watching blinds and observation platforms (Story Mill Fact Sheet 2015). While this may seem to promote a cohesive vision of recreation and protection, this once again presents the difficulty of balancing somewhat contradictory goals for the Story Mill Community Park. When birders locate a species of interest, like nesting sandhill cranes or bald eagles, large numbers of observers follow their every move through binoculars. This phenomenon of mass-observation is exacerbated by social media; birders can share the location of their finds instantly with one another. While a few observers would be harmless for the birds, the constant observation raises ambient anxiety for the birds (Burger et al. 1995). For some species, this means that parents or offspring suffer from malnutrition because they hunt less when stressed. Some species have even shown abandonment behavior when highly stressed. (Burger et al. 1995). Human activity also impacts food sources for predators like hawks; the prey hides from noisy humans and thus is hidden when hawks come looking.

Ecotourists can coexist with birds as long as avian welfare is considered in management plans. Since each species is affected by humans at a different distance, managers can attend to what proximities produce changes in behavior for target species. If Sandhill cranes are of special interest, for example, their habits could be observed in the area with people at various proximities and then park rules could be adjusted to protect the birds if they are being disturbed. Modifications like the suggested bird blinds may help to decrease bird anxiety; limiting off-trail behavior can also help to regulate human distance from birds.

Conclusions and Recommendations

Taking into account the legacy of disturbance that has occurred at Story Mill, it seems reasonable to re-assess the criteria for the success of the park. The ecological goals of the park are attainable, but wetlands and riparian habitats are complex ecosystems that take a long time to reach their fragile functioning state. It is hard to say if and when the ecological goals will ever fully be attained. The aim should not necessarily be to restore a pristine ideal. Instead, the restoration efforts incorporated in the park plan should be seen as a key element in achieving conservation and natural resource management goals for the City (Halme et al., 2013), as well as emphasizing public education. Since it is the largest public park of its kind around in the area, it can also set an example for more projects like it in the future. Incorporating the history of the area, and placing it on a timescale will open the public’s eyes to the complexity of ecosystems. Acknowledging it as a restoration of a severely damaged urban ecosystem will legitimize the slow ecological processes leading back towards a healthy state, and give the public who utilize the park an elevated perspective on the importance of nature. Ideally, this park will blend the ever-evolving social and environmental interface here in Bozeman.

Ultimately, to navigate challenges associated with balancing ecological and social goals, stakeholders must actively engage the public (Yung et al. 2016). When visitors at the park feel that they, too, are stakeholders and that the park reflects their values, they are more likely to care for this novel ecosystem; Story Mill Community Park would be considered a “novel ecosystem” because it was created by human agency. Once again, Story Mill is off to a good start since public opinion was actively sought and incorporated into the park design. It is in Bozeman City’s plans to incorporate housing around the park, the addition of wildlife corridors will provide the best protection for wildlife once these structures are built. If plans for wildlife corridors are built into city planning for the area surrounding the new park, the impact on wildlife can be significantly diminished. Areas where the corridor would be most effective can be used, rather than merely the area available after development has already occurred. This may also allow leeway on housing regulations, if proven that measurements to lower impacts on wildlife and habitat have already taken place.

The thoughtful goals constructed for Story Mill Community Park are ecologically progressive compared to other park designs. However, some of the social goals present serious conflict with the ecological goals. This is not necessarily a bad thing; in fact, the contradictory nature of these goals forces stakeholders to have more in-depth conversations about what the park will mean for our community. When assessing the success of the park, it is important to remember that the goals and objectives exist under a complex system of constraints, spanning history, science, and culture. By finding the interstices of these goals, Story Mill Community Park can achieve success as defined by our community values.

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Water Quality and Story Mill Wetland

Hayden Altenburg, Shijia Luo, Paul Rychener, Melissa Marlen

Introduction

An extraordinary amount of pressure has been placed on the quality of our water resources as industrial and agricultural activities expand to meet increasing population growth in urbanized settings. Despite our reliance on fresh water, our actions have severely degraded both the quality and quantity of rivers and streams. A nationwide assessment of streams in the U.S. found that 42% of stream lengths were in poor condition, with the most widespread stressors identified as nitrogen (N), phosphorus (P), streambed sediments, and riparian disturbance (Paulsen et al., 2006). Increased sediment loads create impermeable streambeds and reduce recharge of groundwater. Excessive phosphorus inputs from human activities such as fertilizer use in agricultural lands (Carpenter, 2005) and sewage discharge through stormwater flow and groundwater flow are further decreasing water quality by causing algae blooms, resulting in low levels of dissolved oxygen in the water. Oxygen depletion causes fish kill and decreases species diversity. Further, some types of algae release toxins that endanger wildlife and human health when water is used for drinking or recreation. Wetlands have also been severely impacted, 50% of wetland habitat has been lost due to draining, filling of soil, and excavation in the lower 48 states of the U.S. (Batzer et al., 2014; Dahl, 1990). This has resulted in efforts to restore and protect the highly valued services of streams and wetlands that have been degraded, damaged, or destroyed.

Wetlands are closely related to the survival and development of human beings (Chen, Z.M. et al., 2008). Wetlands are one of the most ecologically diverse environments and provide many resources for human production and life. The environmental function and benefits provided by wetlands cannot be replaced by other systems in the aspects of controlling floods, regulating runoff, controlling pollution, adjusting climate, and decreasing soil erosion. Therefore, wetlands are praised as "Earth, kidneys" (Cherubini et al., 2008).

Bozeman’s population increases at a rate of 4.2% per year and suffers from water pollution problems (Dietrich, 2016). The Montana Department of Environmental Quality (DEQ) Watershed Management Section leads the Total Maximum Daily Load (TMDL) program, which determines sources of pollution that enters the streams, rivers and lakes across the state and defines allowable levels of pollution that our waters can sustain and still support our needs. Under the TMDL program, Bozeman Creek/East Fork Gallatin is considered impaired due to inputs of nonpoint source pollution from urban stormwater runoff and agricultural practices. This research paper focuses on the following questions:

1) What are the ecological services provided by Story Mill Wetlands and riparian areas and what are the effects of water quantity on these systems?

2) How can we better manage water quantity and nutrient loading at Story Mill with the use of upstream constructed wetlands and riparian corridor enhancements?

3) Can sediment loads be reduced with the current improvements at Story Mill, and what effect does the Backwater Slough have?

4) How is phosphorus retained at Story Mill and how can phosphorus retention be quantified?

Effect of Water Quantity On Story Mill

This reduction in wetland quality was an incentive for the purchase of Story Mill Wetlands. The site has had very dynamic land use history consisting of ditching, draining and filling (Deford, 2014; Kramer, 2014) for homesteading, ranching, and stock ponds. The wetland at Story Mill Community Park can improve soil environment, purify water quality, prevent pollution and regulate ecological balance. This regulation improves the quality of wetlands, which is beneficial to water circulation and the protection of biological diversity.

Wetlands can store water in a role similar to a reservoir. During a flood period, wetlands accumulate water and slowly release water in the dry season, improving water retention for the watershed. If quantity of water is too high, the maximization storage will be exceeded and will not accept additional flood water. If quantity of water is too little, the wildlife and vegetation would not survive and the balance in the Story Mill wetlands would be harmed, decreasing its function.

Ecological Services from Story Mill Wetlands

Story Mill wetland provides a multitude of invaluable ecosystem services including:

Groundwater Recharge and Discharge: Some wetlands help to recharge and maintain groundwater levels, while other wetlands discharge groundwater to streams, helping to maintain baseline flow and reduce flooding (Wright et al., 2006).

Flood Protection: Wetlands act as a reservoir, storing rainfall, snowmelt, and floodwater and then slowly releases this water. Vegetation slows the speed of runoff and distributes it over the floodplain. Wetlands can collect and counteract the increased runoff from buildings and pavement in urban areas. (USEPA, n.d.)

Provision of Available Resources: Wetlands can give us a wide range of products, including wood and medicinal materials.

Maintaining the Microclimate: Wetlands can affect the microclimate. Wetlands become water vapor by evaporation, and then in the form of precipitation down to the surrounding areas, to maintain local humidity and rainfall, affecting the lives of local people, industrial, and agricultural production.

Wildlife Habitat: Wetlands provide habitat for many bird, fish, and amphibians; many of which are rare and endangered species. Migratory birds rely heavily on wetlands for a variety of functions, including feeding, breeding, and nesting (NCSU Water Quality Group, n.d.). Wetlands can also function as wildlife corridors.

Retention and Transformation of Toxins and Impurities: As water containing contaminants (pesticides, domestic sewage, metals, and industrial discharges) passes through wetlands, the rate of flow slows down and toxins/impurities accumulate (NCSU Water Quality Group, n.d.). In addition, wetland plants, such as reed and water lake lotus, can effectively absorb toxic substances.

Retention of Nutrients and Sediment: Excess nutrients and sediment in water flowing through the wetland can accumulate in wetland vegetation or the wetland sediment layer, leading to the purification of downstream water.

Erosion Protection: Wetland vegetation roots stabilize stream banks, absorb energy from water and prevent erosion (USEPA, n.d.), thus improving water quality and protecting agricultural production.

Tourism and Aesthetics: Wetlands are a rich and natural beauty with great opportunities for sightseeing, bird watching, and entertainment.

Education and Scientific Research: Complex wetland ecosystems contain rich flora and fauna, and valuable endangered species that play an important role in natural science education and research. Some wetlands also retain valuable historical and cultural sites.

Inline Wetland Treatment Systems

Implementation of constructed riparian wetland networks may help to provide additional ecosystem regulating services along Bozeman Creek, which has been listed on the Montana DEQ 303d due to various urban non-point pollution sources that impact the 14-mile stream segment. While the City of Bozeman is making adjustments to roadway infrastructure to accommodate increased traffic and implementing improvements to best management practice (BMP) operations, the addition of these in stream riparian wetland treatment systems would likely help to alleviate some of the nutrient and sediment loading concerns affecting Bozeman Creek before reaching Story Mill.

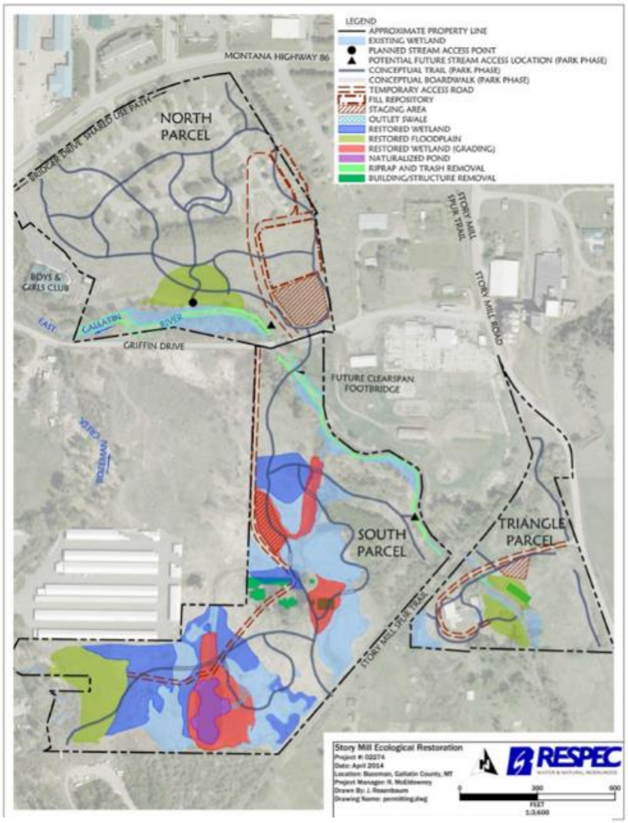
Wetlands and wetland networks improve water quality within urban areas (Helfield et al., 1997). Constructed wetland (CW) networks also reduce diffuse non-point source pollution along the length of an impaired river corridor. Wetland systems are effective in treating organic matter, nitrogen and phosphorus, and decrease the concentrations of heavy metals, organic chemicals, and pathogens (Haberl et al., 2003). CW systems improve water quality and control the transport of nutrients and urban pollutants downstream by reducing stream velocity as stormwater reaches the CW where roughness from aquatic and riparian vegetation reduces stream velocity and settles the suspended sediments and captures nutrients in CWs (Jones, 1996). New regulations in the United States, aiming to protect natural wetlands, now restrict their use for stormwater runoff (Debusk et al. 1996). Typically, CW's do not have the full range of ecological functions of natural wetlands; CWs are instead designed specifically for flood control and water quality purposes (U.S. EPA, 1993). However, these projects can also accomplish multiple urban use objectives by providing increased wildlife habitat, improved landscape value, and enhance recreational opportunities. Constructed wetland systems provide different characteristics regarding their ability to retain nutrients depending upon factors including water chemistry, hydrology, sediment, and plant typology.

With current restoration projects underway at Bogert Park, future plans to widen Rouse Ave., and discussion of purchasing land near city hall (BCEC, 2012); a great opportunity exists for the application of inline stream treatment processes that could enhance sediment and nutrient holding capacity to prevent further degradation downstream. Over the years, the ecological value of Bozeman Creek has been diminished, while the floodplain/riparian corridor has undergone significant development. Throughout the downtown area, opportunities for community recreation and aesthetic enjoyment are limited or nonexistent (Confluence Consulting et al., 2012). The once meandering stream channel of Bozeman Creek has undergone human alteration throughout most of the city limits into a straightened and simplified ditch channel with a series of culverts and pipes that transport stream flow beneath downtown Bozeman streets and parking lots. The highest level of impairment occurs on a 1-mile reach of the stream between Story Street and Peach Street where the stream has been channelized and armored, has limited riparian vegetation and has been piped beneath parking lots and downtown buildings.

An enhancement project for Bogert Park has been scheduled to begin in the Fall of 2016, with plans to reconstruct approximately 800 ft. of Bozeman Creek in order to return the system to a more natural and ecologically productive condition. The current restoration objective will be accomplished by incorporating two stream meanders into the park, constructing an inset floodplain to increase flood storage, and incorporating native streamside vegetation to aid in nutrient retention and sediment control during flooding. This particular restoration project has been identified as a high priority by the Bozeman Creek Enhancement Committee due to the level of impairment within the stream reach and the value it provides for area residents (BCEC, 2012). Future restoration efforts could incorporate constructed riparian wetland networks within the stream corridor to help alleviate downstream nutrient loading concerns and attenuate flooding events. Typically self-maintaining CWs are designed to emulate the functions of natural wetland marshes, swamps, and bogs. The success and self-maintaining attributes of these CW treatment systems rely on a functioning association between plants, water, and microbial communities. Marshes offer the most potential for water treatment because the emergent and submergent plant communities are well adapted to fluctuations in water level and are more tolerant of high nutrient and pollution concentrations (Hammer, 1989). Previous research has shown that helophyte plant species are most applicable in wastewater treatment systems and the most frequently chosen species include: reeds, rushes and cattails (Stottmeister et al., 2003). Ultimately, the selection of plant species used within locally implemented CWs should be referenced from nearby natural wetland systems containing established plant communities that are adapted to local climate and soil conditions. Optimal environmental conditions must also be maintained for desirable microbial populations to effectively manage a wetland system for wastewater treatment.

Riparian Corridor Revegetation

Buffer enhancements involve creation and widening of existing riparian zones, improving stream bank stability and provide a natural filter for sediment and nutrients from upland runoff (Ranalli et.al., 2010). These regions also decrease potential for groundwater contamination, through increased plant uptake of nutrients that would otherwise leach below the plant-rooting zone. Without access to floodplains, stormwater runoff is often trapped within the stream channel, causing an increase in erosion of the channel bed and banks, degraded water quality and loss of in-stream habitat (Mcmillan et al., 2014). Floodplains provide hydraulic relief for streams, attenuating flood flows, recharging groundwater, assimilating nutrients and harboring many species of flora and fauna (Thompson et al., 2011). Space constraints often limit the efforts of urban restoration projects to reconnect a stream with its floodplain, however; careful consideration needs to be taken to attempt to restore some floodplain access back into an impaired stream.



(Fig.1) Source: *Repec Consulting & Services, 2014.*

A delay in the development of the Montana Department of Transportation (MDT) Rouse Avenue reconstruction project, initially planned for 2015, presents a great opportunity to restore structure and function to Bozeman Creek along a developing traffic corridor within downtown Bozeman. Initial road expansion plans from the MDT provide no enhancements to improve or maintain the current condition of the stream, although the project could substantially increase the transport of pollutants into the nearby stream from increased automobile traffic. Depending upon the outcome of right-of-way negotiations that involve the acquisition of homes along Rouse Avenue, there may be an opportunity to reposition the roadway further away from the stream allowing for restructuring of the channel to reintroduce meander bends and reconnect the stream with the floodplain/riparian zone. These additional efforts could help to reduce downstream transport of pollutants and alleviate flooding concerns from the highly impervious downtown Bozeman area. Similar efforts could also be proved useful on a parcel of land near city hall that may be purchased by the City, where improved floodplain access and stream bank revegetation practices could help alleviate pollution inputs to Bozeman Creek and further reduce flooding concerns through the highly channelized and tunneled downtown area. The proposed restoration project is likely to result in an improvement to downstream water quality near Story Mill through a decrease in N, P and sediment transport. The intended goal of the wetland/riparian network is to reduce peak stream flows in order to facilitate plant uptake of nutrients, to allow suspended sediments to settle, and to extend the flow duration within the stream by increasing groundwater recharge before reaching Story Mill.

Sediment Accumulation at Story Mill

As previously stated, there are many ways to reduce nutrient and sediment loads upstream before it reaches the newly developed park at Story Mill, so what beneficial use can Story Mill provide to reduce sediment loads? The main goal stated by The Trust for Public Land (TPL) for Story Mill Wetland is, "In consideration of site constraints and other project goals, restore and protect on-site natural processes necessary for a functioning riparian and wetland system" (Respec Consulting, 2014). Respec Consulting worked with TPL to enhance on-site wetlands. As previously stated, Montana DEQ has confirmed that sediment loads in Bozeman Creek are 37% above the TMDL limit and is currently listed as "impaired for sediment" (Respec, 2014). To mitigate this issue, Respec Consulting increased the hydrologic connectivity of the south west corner of the property, located on the Turner parcel adjacent to Bozeman Creek by excavating 6,200 cubic yards of topsoil to lower the land elevation closer to the standing water table to re-establish wetland properties (Respec Consulting, 2015). This slough is designed to capture two-year and greater flood events based on the elevation of the border of the slough relative to the elevation of the water flowing through Bozeman Creek during that flood event. The area for this "backwater slough" is within the green polygon, highlighted by the red box (Figure 1). This area can capture moving water from a flood event, reducing the velocity of the water and providing the opportunity for sediments and other contaminants to settle out. This periodic deposition of sediment can help improve water quality downstream as well as improve soil quality within the slough. Since the excavation, there has been very little flooding within the backwater slough which has made soil development a slow process. When the slough was excavated, it was dug down to a coarse sandy horizon in the soil profile. This improved the mechanical function of the wetland, but changed the ecological function. This coarse sand soil allows for rapid drainage of the backwater slough, creating a less hospitable habitat than most hydrophilic plants inhabit. This has made the revegetation efforts challenging for the area. In 2013, TerraAquatic worked with TPL to establish a vegetation management plan that will enhance desirable vegetation and decrease undesirable plant species. The intent of the Story Mill Vegetation Plan is to create a living document that will adapt to changing site conditions and evolving development plans by the TPL. Methods of vegetation control included biocontrol, chemical control (selective herbicide application), and mechanical pulling of weeds (TerraAquatic, 2013). The success of the revegetation efforts should be documented as well as population growth or depletion of invasive species to know whether the site is naturally attenuating back to the desired wetland population. This slough helps reduce sediment loads during flood events, but currently no plan is in place to reduce sediment loads during non-peak flows in Bozeman Creek, creating a need for increased riparian corridor revegetation plan as previously stated.

Wetland Phosphorus Retention

Retention is defined as the capacity of a wetland to remove water column phosphorus and/or other nutrients through chemical, physical, and biological processes and hold it in a form not readily released under normal conditions (Reddy et al., 1999). Phosphorus retention in wetlands decreases the load to downstream aquatic systems and improves water quality. Biotic and abiotic processes regulate P retention. Biotic processes include assimilation by vegetation and microorganisms creating a short-term storage of P; abiotic processes include adsorption of soluble P by soils and sedimentation of particulate P creating a long-term storage of P.

Macrophytes uptake inorganic P forms through their roots and/or foliage and converts it into organic phosphorus for growth. Phosphorus uptake is highest during the peak-growing season, followed by decrease in the fall and winter. Before fall senescence of the macrophytes, the majority of P is transferred from aboveground biomass (shoots and leaves) to belowground biomass (roots and rhizomes) where it is stored and used during early spring growth (Reddy, 1999). Due to rapid turnover in aboveground biomass, P storage is short term and it is estimated that 35 to 75% of the P is released back into the water column when vegetative decomposition occurs (Richardson, 1985). Roots decompose underground and contribute refractory residuals to subsurface soils while aboveground biomass decomposition also contributes refractory residuals on the soil and sediment surface; these contributions provide long-term storage of P in the wetland (Howard-Williams, 1985).

Microorganisms can regulate P concentrations in the water column by assimilating both organic and inorganic forms of P. In a study by Sloey et al. (1978) about 60% of P retention was attributed to microorganisms in wetlands. When macrophytes begin to decompose, P is released into the water column and utilized by microorganisms living on the surface of vegetation, while benthic microorganisms living on the sediment surface utilize P found in the sediment and the water column and assimilate the P into their biomass during growth. Wetlands that receive water with high concentrations of P will increase the amount of P assimilated by microorganisms with little evidence of rapid P release to the water column, whereas in oligotrophic conditions, it was found that P would be released into the water column and decrease amount of P assimilated by microorganisms (Howard-Williams 1985).

The adhesion of P to different elements in wetlands is referred to as adsorption. Under acidic conditions, Fe and Al hydrous oxides will bind with inorganic phosphates to form insoluble precipitates (Dunne et al. 2005). In soils dominated by Fe minerals, reduction of the soluble ferrous oxyhydroxides compounds results in amorphous reduced ferrous compounds with greater surface areas for phosphorus sorption reactions to occur (Reddy et al., 1995). Although these sites have increased sorption sites for P these sites have lower P bonding energies, thus desorption potential is high. Whereas in oxidized soils, less P will be adsorbed, but it will be held more tightly. Under alkaline conditions, precipitation as insoluble Ca-phosphates becomes more dominant (Reddy et al., 1999). In wetlands, retention by soils will only occur when inorganic P is in direct contact with the adsorbent, so P in the water column must diffuse into underlying soils or sediments before it can be retained. This diffusion will only occur if the water column has

(Jamieson et al., 2002). If water column P concentrations are lower than the pore-water concentration sediments will release P rather than retain it.

Sedimentation (also referred to as accretion) occurs when incoming water velocity is reduced by wetland vegetation and incoming particulate P, organic matter, and sediment from the water column is trapped and accumulates (Dunne et al., 2005). Sediment accumulation increases soil mass and provides a long-term storage of P and other nutrients in the wetland. During low flow, wetlands behave as sediment traps and resuspension of settled sediments is unlikely unless there is high flow velocity, possibly caused by an extreme weather event (Reddy et al., 1999). Disturbance of sedimentation by living organisms can stir up accumulated sediment and contribute P from pore-water and particulate P in sediment to the water column but it also greatly increases the oxidized layer at the sediment-water interface and increases P retention (Howard-Williams 1985).

Methods to Measure Wetland Phosphorus Retention in Story Mill Wetland

Laboratory experiments and field methods can be used to estimate phosphorus retention in Story Mill Wetland. These methodologies include measuring changes in P concentration in the sediment pore-water column in a laboratory and using sedimentation rates in the field to estimate P accumulation in sediments.

Phosphorus Retention Laboratory Method: Sediment Column Studies

The sediment column studies method was used by Reddy et al. (1995) where intact sediment cores were collected to estimate P retention of wetland systems. Phosphorus retention of the sediments were calculated with this equation:

$$P_r = AC - P^1$$

Where P_r = phosphorus retention by sediment, mg P m^{-2}; A = phosphorus retention coefficient, L m^{-2}; C = water column phosphorus concentration, mg L^{-1}; P^1 = phosphorus release potential in ambient conditions, mg m^{-2}. "A" accounts for the effect of P diffusion from the water column and P sorption by sediments, it was found to be independent of sediment type and is dependent on P concentration of the water column. The equation above yields an indication of threshold concentration (equilibrium P concentrations) where P retention equals P release ($P_r = 0$).

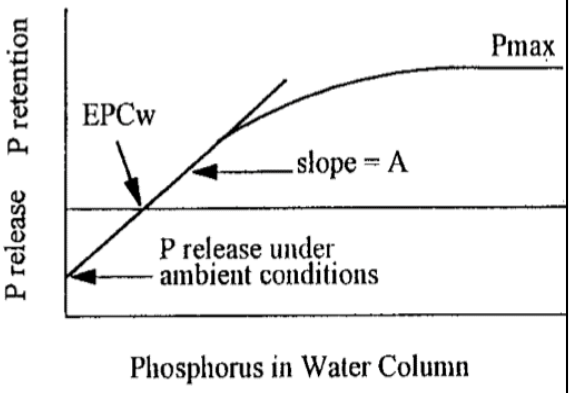


Figure 3. Phosphorus retention isotherm. P_{max} = phosphorus retention maximum. Source: Reddy et al., 1999

$$P^1 = AC$$

$$EPC_w = P^1/A$$

Where EPC_w = threshold concentration, mg L^{-1}. Threshold concentration (EPC_w), also known as the equilibrium P concentration, is the P in sediment pore-water in equilibrium with P adsorbed by the sediment, or when adsorption equals desorption at which point sediments neither function as a source nor as a sink of P.

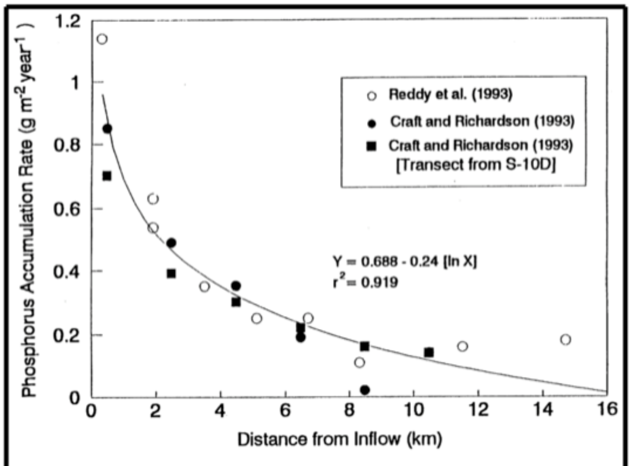


Figure 2. P accretion rates. Source: Reddy et al., 1999

Water column P concentrations that are greater than EPC$_w$ suggest net P retention by sediments while water column P concentrations that are less than EPC$_w$ suggest net P release by sediments (Dunne et al., 2005). This can be observed in what is called an adsorption isotherm shown in Figure 3. Adsorption isotherms of sediment are measured by mixing water containing a known P concentration with a known amount of sediment from the wetland and shaking for a 24-hour period. Phosphorus not recovered in solution is considered adsorbed by the sediment. Repeating this process with varying water column P concentrations results in an adsorption isotherm, where the y-axis shows P adsorbed by sediment and the x-axis shows water column P concentration (Reddy et al., 1999). The sediment column method of measuring P retention has the advantage that it includes the effect of diffusion of water column P into the sediment and other processes including uptake of P by algae/vegetation, physico-chemical properties, and bioturbation) at the sediment-water interface on P retention (Reddy et al., 1995).

Phosphorus Retention Field Method

Sedimentation rate is an effective way of estimating total P accumulation in Story Mill's backwater slough. Phosphorus removed from the water column is both assimilated in the wetland biota and accumulated in the sediments and with this methodology it is assumed if vegetation and water storages are stable in the wetland than P lost from water column will be found in the wetland sediments. A relationship between sedimentation rate and P sediment retention is used to determine P accretion rates in wetlands. Sedimentation rate will be measured by placing hard sediment plates on the sediment surface of the Backwater Slough; as water comes in, sediment will settle and accumulate and the depth on the plate must be measured periodically. Sediment plates are inexpensive and easy to use although the plates can be undercut by water flow (Thomas, 2004). Phosphorus accretion rates are calculated with this equation:

$$J = kC$$

Where J = phosphorus daily accretion rate, g m^{-2} d^{-1}, k = first-order areal rate, constant, m d^{-1}; C = phosphorus concentration, g m^{-3}. Prior research has found that the P accretion rate shows an exponential decrease with increasing distance from the water inflow source, shown in Figure 2. The above equation needs to be altered to show this observed exponential decrease. The equation used to calculate P accretion and that shows the exponential decrease is:

$$J = kC_i \exp [(-kW/Q)\ x]$$

Where C$_i$ = inlet P concentration, g m^3; W = wetland width, m; Q = water flow rate, m^3 d^{-1}; x = travel distance, m. P accretion rates will not be the same throughout the entire wetland, there is a strong spatial distribution of accretion rates. If the exponential accretion rate is averaged over the entire wetland, one mean accretion rate is produced, but now it depends on the hydraulic loading rate and inlet P concentration. This equation is:

$$J = qC_i\,[1 - \exp(-k/q)]$$

Where J = average P daily accretion rate over the wetland, g m^{-2} d^{-1}; q = hydraulic loading rate, m d^{-1} (Reddy et al., 1999).

Discussion

Bozeman Creek and the East Gallatin River receive significant contributions of sediment and nitrates that are a concern to the Montana DEQ, primarily due to urban runoff of fertilizer from nearby residential homes and agricultural lands, along with sewage discharge. Although contribution of phosphorus is not a main focus of the MT DEQ, it is still an issue that must be considered for Bozeman water quality. Riparian zones and wetlands have been shown to play a vital part in decreasing the nonpoint source pollution that enters urban streams as an end of catchment measure to improve water quality. The ecosystem services at Story Mill Wetland provides clean water, controls flooding, protects from erosion, transforms toxins, retains nutrients and sediments, maintains the microclimate, provides habitat for wildlife, recreation for tourists, and provides excellent opportunities for community education and scientific research.

A network of inline surface flow constructed wetlands proposed within this research project will likely result in a sustained improvement to downstream water quality through a reduction in the transport of nonpoint source pollutants and sediment along Bozeman Creek. The intended goal of this wetland network is to reduce peak stream flows to facilitate plant uptake of nutrients and settling of suspended sediments and also to extend the flow duration within the stream by increasing groundwater recharge. Constructed wetland networks have more recently been recognized as an extremely useful tool for water quality managers helping to lay the groundwork for future stream restoration projects.

The TPL has successfully enhanced the hydrologic connectivity between Bozeman Creek and the Backwater Slough. Peak flows that carry an increased amount of sediment have the ability to deposit sediment into the slough through the reduction in velocity of water movement that will aid in the development of a rich organic A horizon. This A horizon buildup will help improve the ecological function of this newly developed wetland system, providing a habitat for hydrophilic wetland species to establish. While current conditions of the Backwater Slough are in a transitional period with revegetation efforts, careful management and monitoring of species is important to determine whether the slough is naturally attenuating back to a functioning wetland system. This functioning wetland vegetation is important for the reduction in velocity of water movement within the slough to allow for sedimentation to occur. Collecting data on sediment loads during flood events above and below the Backwater Slough would be useful information, to quantify the reduction of sediment, to find out what is the return on the investment for the TPL. This can be done cheaply, by hiring MSU students to collect sediment data during peak flooding season.

Phosphorus dynamics in wetlands involves complex physical, chemical, and biological processes occurring in water columns, sediments, vegetation, and microorganisms. Phosphorus retention in wetlands is achieved with a combination of abiotic and biotic processes and can increase water quality downstream. Abiotic processes provide a long-term storage of phosphorus through adsorption and sedimentation; biotic processes provide a short-term storage of phosphorus through assimilation by vegetation and microorganisms. When quantifying phosphorus accumulation is important to understand and consider all of the factors. At Story Mill it is recommended to place sediment plates in the Backwater Slough to get an accurate estimate of total phosphorus accumulation at Story Mill.

Water quality depletion from non-point source pollution and sediment is a major concern with rising population growth, protecting our stream corridors is imperative. This can be done through increasing the hydrologic connectivity and establishing vegetation to Story Mill wetlands, as well as increasing the sinuosity within the stream corridors to increase the stream to vegetation contact.

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Story Mill's Restoration: Evaluating Success

Kory Kirby, Jeremiah Mathis, and Zachary Eddy

Introduction

Wetland ecosystems function to cycle nutrients, regulate floods, clean water, provide crucial habitat, and hold cultural values like recreation, education, and beauty (Gardner et al. 2015). Traditionally, the public has viewed wetlands as 'wastelands', with no economic value unless drained and converted to arable land (Adger and Luttrell 2000). This portrayal resulted in almost 50% of all wetlands in the contiguous U.S. to be excavated, drained, and filled (Batzer and Sharitz 2014; Dahl 1990). The alarming rate of wetland loss in the United States gained attention in the 1950's and 60's which led to environmental regulations such as the Clean Water Act and the North American Wetlands Conservation Act. This change in policies has since resulted in efforts to restore, and protect the highly-valued wetland structure and functions that have been degraded, damaged, or destroyed (Mitsch and Gosselink 2000).

It's now understood that wetlands aren't 'wastelands', they instead provide an assortment of ecosystem services of considerable value to all people. With these services in mind the community, Bozeman, MT, is now focusing on the wetland and riparian areas of Story Mill. Story Mill lies between two headwater streams: Bozeman Creek and the East Gallatin River (Deford 2015). Story Mill's legacy of rich historical heritage for the Gallatin Valley extends back to the late 1800's when Nelson Story began shipping locally grown wheat and flour to much of the world. Since then, Story Mill's dynamic land use has partially consisted of ditching, draining and filling; industrial activities that have seemingly ignored the wetland's structure and function (Kramer 2014; Batzer and Sharitz 2014).

Story Mill has been undergoing drastic changes for the last hundred years (Kramer 2014). Today, Story Mill is a 50-acre parcel undergoing restoration and conversion into a public park by the Trust for Public Land (TPL) and the City of Bozeman. However, some questions that arise are: how should Story Mill be restored? To what historic state, why restore at all, and for whom is this for? Managers currently involved in the restoration project have acknowledged that goals are always context- and stakeholder-dependent, and thus have established their own plan and direction of action. With consideration of site constraints and other project goals, the TPLs overarching goal is to restore and protect on-site natural processes necessary for a functioning riparian and wetland system (Respec Consulting & Services 2014). This paper investigates if stakeholder goals are met alongside TPL's overarching goal.

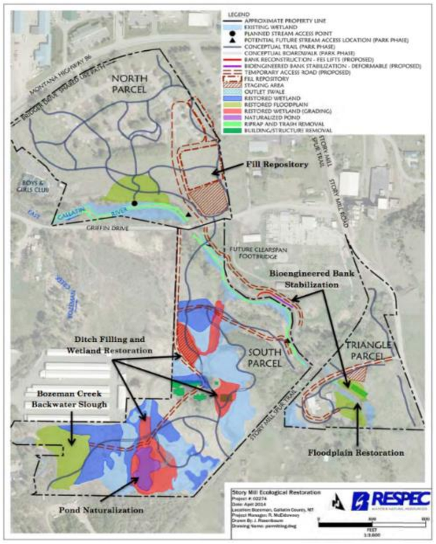


Figure 1 – Overview of Story Mill

Two locations on the East Gallatin River (Triangle Parcel; North Parcel) and one on Bozeman Creek (South Parcel) were identified to excavate around 3 acres of soil to restore floodplains, and establish a slough along Bozeman Creek that will help meet the goals of the restoration project (*Fig.* 1). The idea is to reconnect Bozeman Creek and the East Gallatin River to floodplains. The reestablishment of this, in turn will increase hydraulic connectivity between the riparian zones and Story Mill's wetland. With this reconnection, a goal of increasing water quality and nutrient cycling would be met.

The East Gallatin River did not have as much connectivity as desired by stakeholders. To help accommodate this issue, 1.6 acres of new floodplain area was established. The implementation on the South Parcel of Bozeman Creek Backwater Slough (BCBS), was constructed by excavating ~6200 yds^3 of soil (depth of 5 feet; 1.5 acres) to essentially establish a side channel for Bozeman Creek (Respec Consulting & Services 2015). The restored floodplains at Story Mill were also designed to improve surface water quality by enabling Bozeman Creek and the East Gallatin River to spread over a much greater area during flood events (Trust for Public Land 2014). This increase in acreage of floodplain will establish more water to soil contact, thus binding and storing more pollutants. Soil saturation levels will also increase resulting in anaerobic conditions that allow microbes to denitrify (e.g., conversion of nitrate N [NO_3^-] to nitrogen gas [N_2]) nitrate (Sylvia, Hartel, and Zuberer 2005), hopefully lowering these waterways TMDL standard for nitrates.

Additional floodplain acreage is expected to provide the service of attenuating downstream flood flows which trap fine sediments that are harmful to fish habitats. Stakeholders will need to establish a monitoring plan for sediment entering the floodplains and the BCBS because sediment from these waterways will accumulate over time, eventually resulting in the need to dredge the floodplains. The slough is designed to allow for desired levels of hydraulic connectivity, which drives these ecosystem services. For this reason alone, management cannot be ignored for the slough and the floodplains.

This research paper is focused towards addressing manager's questions, that are concerned with cost and benefits of restoration techniques:

1) Is the Bozeman Creek Backwater Slough providing the desired services? Are these specific services in conflict with Story Mill's overall structure and function?
2) How do we measure effectiveness of the engineered slough, and the two floodplains at capturing suspended sediments from erosion and non-point pollution, from our local waterways?
3) What are some best management practices for the floodplains and the slough?

Wetland Nutrient Cycling

Nutrient cycling is the process in which nutrients move from abiotic forms to plant-available biotic forms. This movement of nutrients, essential for life is fundamentally driven by microbial communities (Batzer and Sharitz 2014). However, steady state nutrient cycles can take up to centuries, even millennia to establish (Schlesinger and Bernhardt 2013).

Wetland sediments primarily consist of three components: (1) organic matter (e.g., decomposing plant and animal tissue); inorganic matter (e.g., metal oxides, hydroxides, and carbonates); and (3) particulate mineral matter (e.g., sands, silts, and clays). Under the forces of sedimentation, these components pack tightly together leaving only small spaces between particles, called pore volume. When sediments become inundated, these pore spaces become occupied by water. The proportion of air and water per volume of wetland sediments depends on substrate type (e.g., silt, sand, and coarser material) (Batzer and Sharitz 2014; Buscot and Varma 2005). The available pore volume influences the rate and depth to which oxygen can enter wetland sediments.

Biogeochemical processes are influenced by the rate of oxygen diffusion, mass flow with water, or plants allowing for the movement of oxygen between alternating wet/dry phases. The presence or absence of oxygen drives reduction-oxidation (redox) reactions that dominate nutrient cycling in aquatic sediments (Canfield and Thamdrup 2009). When a sediment is saturated, oxygen diffuses about 10^4 times more slowly in water than in air, this limited supply of free oxygen often results in an aerobic surface layer (oxidized), and an underlying anaerobic layer (reduced). The depth of these two layers strongly influences nutrient cycling processes with the presence or absence of free oxygen for microbes to access (Batzer and Sharitz 2014). Redox reactions require an electron donor and an electron acceptor, one substance is oxidized, and the other is reduced. When oxygen is used an electron acceptor, it allows bacteria to breakdown organic matter to carbon dioxide with the maximum yield of energy. Carbon as an energy source in organic matter must be accessible. In the absence of oxygen many different electron acceptors are available for the bacteria. These different acceptors allow bacteria to thrive in anaerobic conditions. After oxygen, nitrate is next highest yield of energy for an electron acceptor where nitrate is reduced from NO_3^- to N_2 gas (Batzer and Sharitz 2014; Sylvia, Hartel, and Zuberer 2005). Denitrifying bacteria prefer to use oxygen as their electron acceptor when both are available, because oxygen has a higher maximum yield of energy. Denitrifying bacteria engage in aerobic respiration when oxygen is available, but switch to anaerobic respiration when oxygen is not (Gottschalk 2012). Thus, anaerobic conditions are necessary for denitrification.

Comparing Optimal Conditions for services desired to Story Mill

For future disturbance, we focus our attention to the BCBS. The BCBS is expected to provide services like sediment capture and water quality improvements by holding and infiltrating nutrients (Trust for Public Land 2014). This results in biogeochemical processes like, nitrogen and carbon cycling that are acknowledged as critical ecosystem services for a full structural, and functional wetland (Batzer and Sharitz 2014). This section addresses if the BCBS is providing the desired services, and if these specific services in conflict with Story Mill's overall structure and function. Optimal conditions for services like; nitrogen cycling, carbon storage, pollutant sorption, will be analyzed and compared to the environmental conditions at Story Mill.

Denitrification in the BCBS, and the restored floodplains represent a net loss of nitrate from Bozeman Creek and the East Gallatin River. It's been shown that alternating periods of saturated soils, and non-saturated soils will create the greatest loss of N_2 to the atmosphere

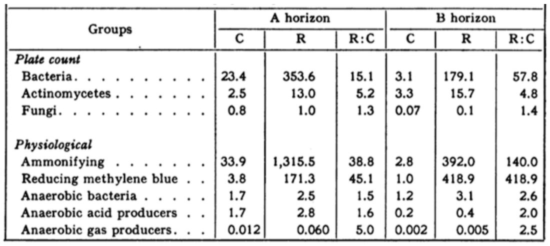
(Reddy and Patrick 1975). The slough, and the floodplains were created to undergo phases of wet and dry sediments from the flooding of Bozeman Creek and the East Gallatin River altering hydraulic connectivity, creating conditions that will maximize denitrification. The alteration is a high level of importance for management purposes.

The levels of nitrate recorded in Bozeman Creek, above and below Story Mill should show a net loss meeting restoration goals. One potential limiting factor for BCBS to denitrify and store pollutants, is the soil/sediment substrates below the slough. In the soil matrix three particle sizes dictate soil texture. The sand fraction has a diameter of 63-2000 µm, the silt fraction 2-63 µm, and the clay fraction is anything less than 2 µm. The proportion of each particle size defines the soil texture which affects biotic and abiotic processes. Sandy soils have larger pores, and thus have a higher total available volume for water and air resulting in more percolation and evaporation. Clays on the other end of the spectrum have smaller capillary pores that hold water longer, have lower aeration and water circulation. Since the particle size ratios influence microbe's ability to oxidize and reduce, these processes drive biogeochemical cycles in soils (Buscot and Varma 2005). Thus, denitrification, and sorption of infiltrating nutrients maybe limited by BCBS's current soil substrates, and lack of soil organic matter (SOM) due to excavation. As SOM increases the BCBS function will also increase.

Below the BCBS, the C horizon is primarily sand deposits from Bozeman Creek, or the tertiary alluvial fan deposit which fills most of the Gallatin Valley (Lonn and English 2002; *Fig.* 2). With these substrates in mind, the ability of the slough to hold onto pollutants may be limited. Over time the ability of the slough to store these pollutants will increase as the slough captures sediment. However, there comes a point when the sediment may off-set the hydrology and the slough will be full. Dredging may then be required to remove the sediment to increase saturation levels again to result in denitrification. This dredging will come at the pricey cost of removing more organic matter.

Figure 2. Three inches of topsoil fill, on top of sand deposits from Bozeman Creek

The creation of the BCBS removed a thickened A horizon representing about hundred years of soil development (land use history from Kramer, 2014). With the removal came loss of plant-soil interactions, soil nutrients, microclimates, soil structure, organic matter, microbes (mycorrhizae and nitrogen-fixing bacteria), and niche habitat for a variety of biota. It has been documented that excavation has altered nutrient cycling and microbial ecology (Falk et al. 2006). Story Mill stakeholders understood these losses, and are now relying on ecological succession (time) to reestablish wetland structure and function in the BCBS.



Groups	A horizon			B horizon		
	C	R	R:C	C	R	R:C
Plate count						
Bacteria.	23.4	353.6	15.1	3.1	179.1	57.8
Actinomycetes	2.5	13.0	5.2	3.3	15.7	4.8
Fungi.	0.8	1.0	1.3	0.07	0.1	1.4
Physiological						
Ammonifying	33.9	1,315.5	38.8	2.8	392.0	140.0
Reducing methylene blue . .	3.8	171.3	45.1	1.0	418.9	418.9
Anaerobic bacteria	1.7	2.5	1.5	1.2	3.1	2.6
Anaerobic acid producers . .	1.7	2.8	1.6	0.2	0.4	2.0
Anaerobic gas producers. . .	0.012	0.060	5.0	0.002	0.005	2.5

Table 1. – The incidence of certain groups of soil micro-organisms on the roots of yellow birch seedlings growing in two soil horizons. R is rhizosphere soil; C is control soil (Ivarson and Katznelson 1960).

However, when considering site constraints this lag phase in succession to a fully functioning state could be in estimated many decades, even a century, instead of years (Christopher 2014). Management for the potential of BCBS to denitrify and store pollutants, is mitigated by the soil properties within Story Mill's soil profile. So, when reaching management decisions for the BCBS there must be a consideration for the removal of A and B horizons in the soil profile, and the lack of microbial establishment in the layer that the BCBS was established on.

The greatest reservoir of biological diversity is thought to be soil microbial communities (Berendsen, Pieterse, and Bakker 2012). Furthermore, when considering the entire soil matrix, microbes are primarily found in the rhizosphere in O and A horizons (*Table. 1* from, Ivarson and Katznelson 1960). The rhizosphere is the plant influenced environment that extends around each root (1-5 mm). The rhizosphere effect has a significant impact on microbial communities by releasing nutrients, controlling temperature, influence moisture, and pH to create more optimal conditions (Berendsen, Pieterse, and Bakker 2012). The rhizosphere could be thought of as the "oasis in a dessert" for microbes in a soil, referred to as the rhizosphere effect. Table 1 displays these vast differences where microbes are found across a soil profile. In the A horizon 15 times more bacteria were found in the rhizosphere soil relative to the control soil, and 57 times greater in the B horizon (Ivarson and Katznelson 1960). The excavation process at Story Mill has essentially scrapped off the organic rich A and the B horizons; as well as, all the microbes in the soil profile. What was left was an undeveloped C horizon with minimal rhizosphere establishment. Over time, soil horizons will form and plant-soil interactions will establish, creating more optimal conditions for microbes to cycle nutrients. However, the time of this succession at Story Mill is unknown. For this reason, soil surveys with carbon inventories should be performed during synoptic events. The surveys and inventories should be done at peak flows/saturation and low flows to profile the sequestration capabilities in the phases of saturated and unsaturated events throughout the year.

As mentioned earlier, when a soil is saturated oxygen diffuses so much more slowly in water than in air. This causes low carbon decomposition rates, because maximum efficiency of microbial decomposition pathways is lessened (Schlesinger and Bernhardt 2013; Coletti et al. 2013). In turn, this reduces microbial growth and activity, and leads to very low carbon mineralization and high carbon sequestration capacity (Batzer and Sharitz 2014). Through photosynthesis, plants acquire carbon in their biomass and they respire carbon to the atmosphere. Carbon in plant tissue is then added to the soil as litter when the plants die and decompose, becoming detritus. SOM is the primary pool in which carbon is stored in the soil. Built up through decomposing plant and animal residual tissues, microbes (protozoa, nematodes, fungi, and bacteria), and carbon from the mineral soil particles have accumulated together in the soil (Ecological Society of America 2000). Plants and microbes control the biogeochemistry of aquatic ecosystems while enduring limited oxygen supplies. Saturated soils with the correct vegetation can thus sequester large amounts of carbon, increasing SOM, nutrients, and trace elements that form our wetlands (Schlesinger and Bernhardt 2013). Therefore, high levels of carbon storage in wetlands can be associated to high SOM. High SOM creates many desirable biological, chemical, and physical properties to soils. Monitoring if SOM is accumulating and to what extent, illustrates a level of success at Story Mill wetland.

According to pertinent research, carbon storage, and SOM should be expected to increase in the slough and floodplains over time (Schlesinger and Bernhardt 2013). As SOM increases, the services desired can also be considered to increase. This relationship should be thought of from three different perspectives biological, chemical, and physical. Biologically, increasing SOM provides a slowly available carbon and energy source to support large, diverse, metabolically active microbial communities. Chemically, SOM can account for 20-80% of the Cation Exchange Capacity (CEC) in a soil which buffers pH change, causing better water quality control and allowing for more denitrification (optimal pH 6-8). A higher CEC also provides a slower release of organically bound nutrients like; nitrogen, phosphorus and sulfur which in turn help plants thrive in the slough. CEC also accelerates the rate of mineral weathering and horizon development. This creates more optimal conditions for microbes to cycle nutrients. Higher levels of CEC also account for more sorption of pollutants. This higher level of sorption causes a loss of bioavailability of toxic xenobiotics which are harmful to human health and expensive to remediate. Physically, SOM decreases bulk density which increases pore space maximizing water holding capacity, resulting in greater water residence time (Sylvia, Hartel, and Zuberer 2005). As vegetation is established in the slough, soil horizon development should increase (Brady and Weil 2000) along with the rhizosphere effect (Berendsen, Pieterse, and Bakker 2012), hopefully resulting in overall increase of services desired.

We believe the slough is addressing many the goals set by stakeholders. However, due to the sandy/gravely parent material, non-optimal conditions for microbial communities and low pollutant sorption capabilities are present at Story Mill. These geomorphic constraints hinder SOM development. Thus, limiting the services of the services of BCBS. Substrate analysis below the other two floodplains is limited, and extrapolating similar themes from the slough, to the North and Triangle parcel floodplains will require more data on what the soil/sediments are like at these locations. The model type of data collection at Story Mill is shown to be in its infancy. This points to limited resources for management and monitoring.

We recommend the following physical data collections and soil analysis for the BCBS and floodplains which can be then implemented into a monitoring plan to quantify success: Carbon & Nitrogen inventories, Loss on Ignition (Organic Matter), Cation exchange capacity, Anion exchange capacity, and CO_2 fluxes via LiCor.

Sediment Storage in Story Mill's Floodplains and Slough

As we further investigate optimal biotic and abiotic conditions for each of the desired ecosystem services (nitrogen cycling, carbon cycling, water quality improvement, and sediment capture), we can ask site-specific questions that directly relate to TMDL standards. Questions such as, how effective is the engineered slough and the two floodplains at capturing suspended sediments from erosion? As well as point and non-point pollution, from our local waterways. At what rate is carbon accumulating, which effects the ability of the slough and flood plains to cycle nutrients?

What is an efficient and cost effective way to measure this? All types of sediment transported by surface water directly affects TMDL for water quality standards. Sediment impairments to Bozeman Creek and East Gallatin River include total nitrogen, total phosphorous, E. coli, and sediment. All these impairments can be transported through surface waterways as bed-load, suspended-load, and dissolved-load depending on the variability of flood events. Bed-load consists of larger sized particles located on the streambed that are transported with large events unlike suspended sediment which is a finer particle that is carried throughout the water column by water turbulence. Dissolved sediments are ions that are chemically bound in water and can be found throughout the water column. Measurements of sediment transport requires many simplifying assumptions because the conditions of streams are ever-changing and include such variables as climate, vegetation, anthropogenic influences, erosion rates, and slope ("Sediment Load" 2014; Bartram and Ballance 1996).

Direct measurements should be made immediately after excavation to begin to understand the types of sediments captured by the BCBS. Table 2 summarizes four common methods used to measure sediment 1) automatic sediment sampler, 2) instantaneous grab samplers, 3) hand corer sampler, and 4) sediment trap.

Sediment samples could be collected from within the constructed floodplains and BCBS; and within Bozeman Creek and the East Gallatin River. These measurements should be taken from monitoring points directly upstream and downstream of the park. Collecting samples during a runoff period with an automatic or grab sediment samplers could help establish a sediment transport budget to give a general idea of what types of suspended sediments (pollutants, nutrients, and minerals) are being transported and deposited (Bartram and Ballance 1996).

Table 2: Sediment Samplers (Bartram and Ballance 1996)

	Type of sediment sampled	Cost range	Operation and management	Location of sampler
Automatic sediment sampler	Dissolved and Suspended	$4,000 & up	Automatically pumps up the sample from flowing water and can store many samples which could show the variation in concentration of sediment over storm events and seasons.	BCBS, upstream and downstream of BCBS
Water column grab sampler, NTU meters, Imhoff Cones	Dissolved and Suspended	$300	This is hand-held devices for measuring suspended sediment in shallow waters. Sediment collected by these devices should be done several times across storm or runoff events to provide for more reliable estimates.	Directly upstream and downstream of Story Mill
Hand core or dredge sampler	Bedload	$30-$500	Can be used in shallow water and depositional areas. Several samples should be taken with increasing distance from the inlet to the BCBS to understand newly deposited sediment.	BCBS and floodplains
Sediment trap	Suspended	$500 & up	A stationary sediment trap could be used to directly measure sediment from depositional areas.	BCBS, floodplains

These devices are relatively inexpensive but require many hours to maintain the equipment, collect the data, analyze sediment material, manage sediment traps, and manage sloughs. Collaboration with Montana State University students helps to minimize the cost of these measurements and provide a ‘hands on’ learning experience. It is important to collect this type of data as soon as possible, and most likely for the next several years so there could be strong correlations to management, effectiveness, and design of the restoration. With quality data objectives met specific stakeholder questions would be answered more accurately.

Perception of Success and Concluding Thoughts

Does the management at Story Mill restoration serve for wetland ecosystem functions and services? For the stakeholders, is the current level of monitoring and management acceptable? How accurately are management efforts being implemented at Story Mill?

TPL would like to incorporate a living classroom project. This project envisions, “Story Mill Community Park as a destination for community members, visitors, researchers, teachers, students, and families to explore nature and learn about the importance of protecting water, wetlands and streams in our urban areas.” This vision goes a bit further, by placing a long-term stream and groundwater-monitoring plan. During the past two years, TPL has been partnered with the Greater Gallatin Watershed Council (GGWC) and conducted a ground and stream water monitoring on site. These efforts were performed with funding from the DEQ Wetlands Program, to help understand groundwater movement (Trust for Public Land 2014). With a ‘living classroom’ TPL has come up with creative ways of collecting data and involving the local community. If the community develops a strong relationship to Story Mill’s wetlands, then the level of success will reach a shared perception in Bozeman.

Seniors in Land Resource and Environmental Science department, within the College of Agriculture, at MSU were presented a unique opportunity during the Fall of 2016 to view the extent of restoration efforts at Story Mill. This example of outreach shows that collaborative efforts with MSU and the Gallatin community is incorporating available resources creatively, and at a low cost to build capacity and share a vision for long-term monitoring (Trust for Public Land 2014). Through the DEQ’s 319-grant program, the GGWC has secured funding for continued ground and stream water monitoring at the Story Mill site through the 2017 season (Respec Consulting & Services 2014). Synoptic monitoring provides a before, during, and after record of restoration impacts, and thus influences the perceived level of success. The TPL will gather information to inform restoration assessment. Long-term monitoring will show how resource management on Story Mill is reacting for the desired ecosystem services. Monitoring is crucial when considering a future for this restoration; the continued long-term monitoring depends on a high level of sustained commitment, capacity, and resources used by stakeholders. Story Mill’s monitoring will help stakeholders to discern if the best management practices were successful. Currently, it appears that the results are beginning to coincide with the stakeholder’s goals. This level of success is due, in part, to the established collaborative outreach and commitment within the City of Bozeman.

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The assignment of riparian buffer zone pollution attenuation in the Gallatin Valley

Benjamin M. Farrick, Edward M. Johnson

Introduction

The City of Bozeman, Montana is currently experiencing dramatic population growth – from 28,000 inhabitants to almost 40,000 between 2000 and 2013. This type of growth is associated with increasing urban development in formerly agricultural or natural areas; the boom has provided an opportunity for the community to actively guide the development of this burgeoning city and promote sustainable and eco-friendly urban areas. Located at the headwaters of the Missouri River system, water quality is an obvious concern for Bozeman and downstream communities; the US Environmental Protection Agency (USEPA) already considers two of the watersheds that encompass Bozeman to be impaired. With increasing urban development, we will likely see increases in pollution from point and non-point sources, which can contribute up to a third of the annual pollution load in urban stream environments (Ellis 1991). The East Gallatin River and Bozeman Creek watersheds contribute to drinking water sources for downstream towns, and are fed by streams coming from both the Bridger and Gallatin mountain ranges. These streams are also known to be impaired for both recreation and aquatic life due to excess nutrients in the form of nitrogen, phosphorus, and sediment. Some fraction of this impairment stems from urban related runoff and stormwater, as well as municipal sewage effluence (EPA 2016). This type of pollution is not unique to Bozeman, or even the US, the Scottish EPA in a 1996 study indicated that 20% of all water quality failures are due to urban non-point sources (Scotland EPA 2016). Clearly, identifying these non-point pollution sources and mitigating their effect on water quality is essential to maintaining waters in compliance with the Clean Water Act (CWA) - Section 319 that mandates that states address nonpoint source pollutants during their assessment of waters and the development of Total Maximum Daily Load (TMDL) criteria.

Reconciling the need for increased housing and development with a need to maintain high water quality for downstream users falls onto the City, which must take measures to reduce impairment in the East Gallatin and Bozeman Creek catchments, as well as strive to fall below TMDL requirements set forth by the state, with Federal guidance. One of the tools at the City’s disposal is zoning regulation - all of which are laid out in the Bozeman Municipal Code (BMC). Maintaining water quality - and natural spaces - during accelerated urban growth are challenges, but ones that may be simultaneously addressed by the consideration of riverine wetlands in the context of zoning regulation.

Urban surface water runoff is strongly correlated with elevated amounts of pollution and can be calculated as a function of impervious surfaces (Taebi and Droste 2004). Bozeman has a well-documented GIS-based record of impermeable surfaces inside the study area. It is with this information we hope to establish a relationship of runoff pollution entering into the East Gallatin and Bozeman Creeks as a function of these impermeable surfaces, sorted by municipal zoning type. Once this relationship between impervious surface and each zoning type has been established, we can recommend the capacity of the valley to support additional growth or the magnitude of measures needed in anticipation of future development with regards to existing natural and potential constructed wetlands.

Riparian corridors and wetlands are known to attenuate nitrogen, phosphorus and sediment runoff (Lee, Isenhart, and Schultz 2003; Mitsch et al. 2014; Mitsch et al. 2005; Tournebize, Chaumont, and Mander 2016). The City of Bozeman is attempting to take advantage of these ecosystem functions to address their in-stream nutrient concentrations. The ecosystem functions of riverine wetlands were a primary factor in improving a wetland on the northern fringe of Bozeman – the Story Mill project. The Gallatin Valley Land Trust (GVLT) in conjunction with the Trust for Public Land (TPL) improved wetlands in this area, which involved installing several backwater slough areas. This project removed soil to bring groundwater closer to the soil surface, and helped to restore the hydrology of the area by converting a detention pond to a more natural pond with an outflow. However, there is riparian ecosystem throughout Bozeman's contributing watersheds that already provide this ecological service. How do we quantitatively assess the benefit of riparian areas around Bozeman? Will they continue to provide measurable benefit once the City becomes highly developed? This paper seeks to answer those questions with the support of relevant literature and a quantitative assessment of the potential reduction of non-point pollutants by riparian areas in the upper East Gallatin River and Bozeman Creek watersheds (see appendix 1a – watershed boundaries).

Background

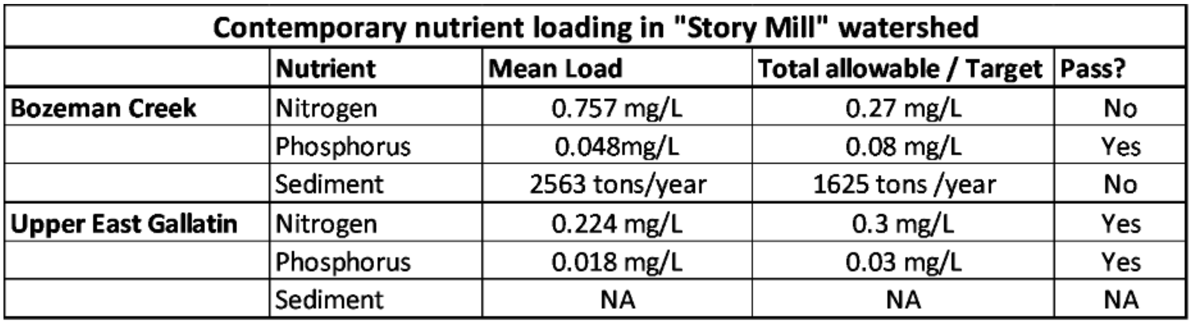
Non-point source urban runoff

Watersheds that experience urbanization are characterized with increases in impervious surfaces and stream channelization (Taebi and Droste 2004). Inside these urban watersheds, the majority of pollutants that enter stream flow do so during the rising limb of the storm hydrograph - which is known as the first flush effect (Cordery 1977; Hathaway et al. 2012). Contributing to this is the high channelization found in urban environments from storm sewers and culverts, combined with large areas of impervious surfaces that provide little to no stormwater signal attenuation (Mannina and Viviani 2010). The effect of this alteration is that non-point pollutants in urban environments are unlikely to be intercepted by wetlands before entering streams. Unlike point sources, the diffuse nature of impervious surface runoff makes identifying and quantifying this effect difficult. In Bozeman, stormwater runoff has led to TMDL requirements for the East Gallatin River being exceeded for nitrogen and sediments. Possible countermeasures that can be enacted in Bozeman are a combination of additional constructed wetlands – similar to Story Mill - and development of different zoning laws that recognize surface runoff is not intercepted in many urban developments. Currently, Bozeman only has wetland protection that is required by the standards of the Army Corps of Engineers and the EPA in the form of building and development setbacks. This leaves room for alterations that could reduce this effect at the cost of development opportunities ("Mini TOC: Chapter 38 - UNIFIED DEVELOPMENT CODE | Code of Ordinances | Bozeman, MT | Municode Library" 2016).

Current Water Quality Conditions

Table 1 outlines the current surface water quality condition of the East Gallatin River and Bozeman Creek as well as their TMDL Limits, and whether or not each stream meets those limits.

Table 1



Contemporary nutrient loading in "Story Mill" watershed				
	Nutrient	**Mean Load**	**Total allowable / Target**	**Pass?**
Bozeman Creek	Nitrogen	0.757 mg/L	0.27 mg/L	No
	Phosphorus	0.048mg/L	0.08 mg/L	Yes
	Sediment	2563 tons/year	1625 tons /year	No
Upper East Gallatin	Nitrogen	0.224 mg/L	0.3 mg/L	Yes
	Phosphorus	0.018 mg/L	0.03 mg/L	Yes
	Sediment	NA	NA	NA

Bozeman Creek is not currently meeting target levels of total nitrogen, which is 0.27 mg/L – while the current mean load is 0.757 mg/L (MT-DEQ 2016) These target levels have been set to limit detrimental effects on aquatic life, recreation, and "primary contact" – i.e. skin to water contact. Dissolved ammonia nitrogen can be toxic to aquatic life, and ingested nitrate can disrupt hemoglobin function in infants. Additionally, excess nitrogen can feed algae blooms that produce toxic chemicals (MT-DEQ 2016). These effects are detrimental to the possible uses of Bozeman Creek for drinking water, recreation, and aquatic habitat. Phosphorous is detrimental to water quality in many of the same ways as nitrogen, it is typically a limiting nutrient for bacteria, algae, and macrophytes, and can cause undesirable algal blooms when it is introduced in high quantities – which is why P in the East Gallatin River is listed as a nutrient of concern, despite the fact that it is currently meeting target levels. The target value for phosphorus in the upper East Gallatin River is .03 mg/L, while the current value is .018 mg/L.

Increased sediment loading in streams and rivers can create physical changes, such as bed aggradation, compaction, and habitat alterations; sediment also contributes to chemical changes in the water. An analysis of freshly deposited wetland sediments found high levels of organic material, nutrients (up to 15.8 g total nitrogen/kg of sediment and 1.48 g total phosphorus/kg of sediment) and metals (up to 547 mg/kg of Zn and 97 mg/kg of Cu: Tu et al. 2014). Bozeman Creek is the only water body within our study area that has a TMDL established for sediment, there is currently an estimated annual load of 2,563 tons which needs to be reduced by 37 % to 1,625 tons/year in order to restore desirable conditions for aquatic life.

One of the ways that these pollutants can be addressed is through ecosystem services, specifically provided by riparian buffer functions. Riparian areas are transitional ecosystems which exist as boundaries between upland and aquatic ecosystems, and as such, their soils and vegetation are a combination of both wetland and upland varieties. Their adjacency to stream corridors allows these areas to intercept a large portion of surface water during rain events. During these times the dense vegetation and increased roughness of riparian areas can slow water movement, which allows sediment, nutrients, and pollutants to fall out of suspension before they enter streams and rivers - effectively providing a pollution "buffer". In our study area the Montana Natural Heritage Society has developed spatial information on the location, extent, and types of wetlands and riparian areas. Riparian areas are different from palustrine wetlands in that they include some upland species of vegetation, and that they often receive overbank flow during peak discharge events – but are not inundated with water at other times of the year, while palustrine wetlands are permanently or intermittently flooded and populated by hydrophytes.

There is a wealth of published data on pollution attenuation in riparian areas – we will pick the most relevant studies to estimate the function of riparian buffers in the Gallatin Valley.

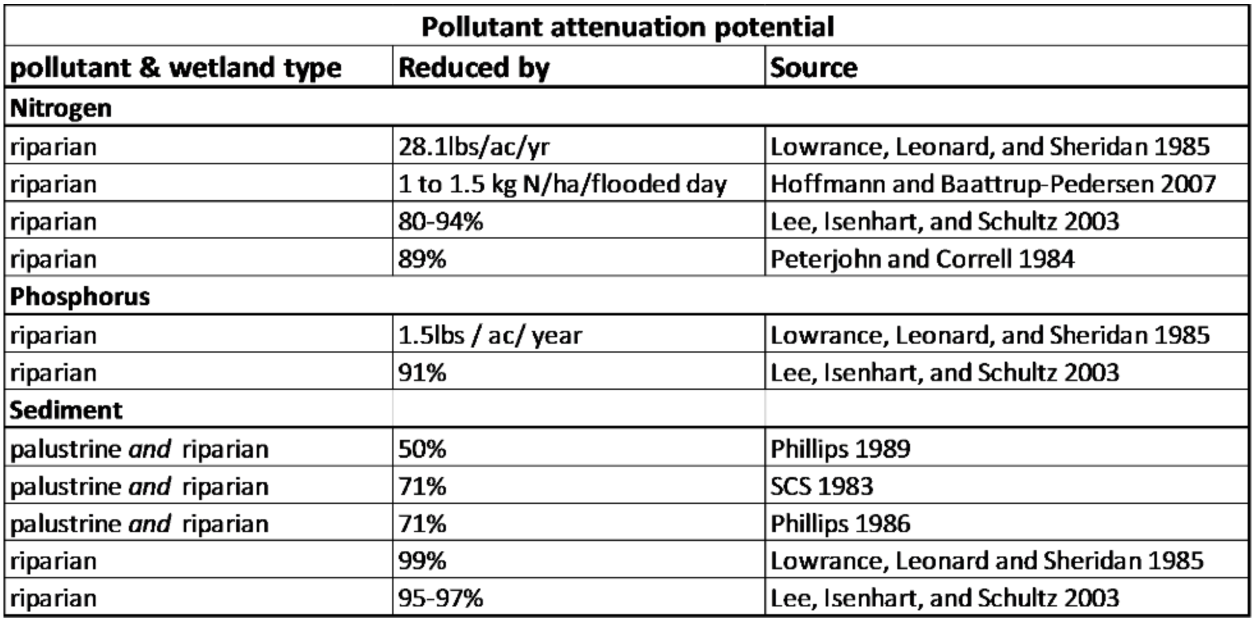
Reduction of N, P and Sediment in Riparian Areas

A study of riparian forests in the Little River watershed in Georgia found that total nitrogen was reduced by 28.1 lbs./acre/year (Lowrance, Leonard, and Sheridan 1985) via denitrification in saturated wetland and riparian soils. Despite this study being in Georgia, it has relevance in the Gallatin valley due to the spatial arrangement of riparian forest and agricultural land. Both watersheds have bands of riparian forest adjacent to streams, with agricultural land or pasture above in the uplands. There is likely a higher nitrogen input from land use in the study site since row crops are more predominate in GA than here, where the bulk of uplands are pasture and rangeland which don't require fertilization. Another study involving the construction of riverine wetlands - in Ohio - saw a reduction of Nitrate by 35% between inflow and outflow areas (Mitsch et al. 2005). Because these were created wetlands, they are directly applicable to the improvement of the Story Mill wetland areas. For the freshwater wetlands in our study area, a Danish study appears to be relevant – in their pursuit of quantifying the function of Danish wetlands they assigned values of 1 or 1.5 kg N/ha/flooded day depending on whether the nitrogen levels were below or above 5 mg/L, respectively (Hoffmann and Baattrup-Pedersen 2007). Yet another study found that riparian forests populated with deciduous broad leaf trees sequestered 89% of total N in a small (16.3 ha) sub-watershed of the Rhode river in MD (Peterjohn and Correll 1984). This study is probably the most applicable to the Gallatin Valley because it focuses specifically on upland riparian buffers – while the others involve more wetlands. Table 2 summarizes the range of total nitrogen removed in riparian areas according to this literature.

Constructed wetlands can retain up to 70% of phosphorous over the initial ten years since their construction (Tu et al. 2014). These wetlands are comparable to the improved areas of Story Mill, as their construction is similar. Notably in that the soil was removed in order to bring the water table closer to the surface. But the wetlands referenced by Tu et al. was notably different than Story Mill wetlands as theirs had continuous surface flow due to pumping of river water. This value of 70% P reduction was also found in constructed wetlands in the Mitsch et al. (2005) study. Their study on the Little River in GA found that 1.5 lbs./acre/year of phosphorous was retained during their study. Another study done in Story County Iowa tested the difference in nutrient retention between different types of riparian buffers, and found that the a 16 meter wide mixture of woody trees, shrubs, and switchgrass removed 91% of the total P moving through the riparian buffer (Lee, Isenhart, and Schultz 2003). Table 2 summarizes the range of total nitrogen removed in riparian areas according to these sources.

A case study of sediment budgeting in the Tar River of North Carolina indicated that 71% of sedimentation in streams was deposited in floodplains or palustrine wetlands. The Little River GA study (Lee, Isenhart, and Schultz 2003) also measured sediment storage within the catchment, and found that the percent of upland soil erosion delivered to the mouth of the catchment averaged out to one percent annually - a 99% reduction from overland flow (Lowrance, Leonard, and Sheridan 1985). The Story Co. Iowa study also measured the effect of a multi-species riparian buffer on sediment entrapment and found values ranging from 95 to 97 percent reduction in sediment from overland flow to instream flow (Lee, Isenhart, and Schultz 2003). In order to estimate the reduction in sediment by palustrine wetlands, a study on constructed wetlands in Ohio should be informative. This study looked at the sediment retention in two 1-ha constructed wetlands for ten years after their construction, and found that the ponds retained 47% of all sediment that entered the system (Harter and Mitsch 2003). This study has a direct connection to the Story Mill improved wetland area since both were constructed and manually vegetated. Table 2 summarizes the range of total nitrogen removed in riparian areas according to literature sources. These reduction values are direct quotes from their respective papers, thus the units are not consistent.

Table 2



Pollutant attenuation potential		
pollutant & wetland type	**Reduced by**	**Source**
Nitrogen		
riparian	28.1lbs/ac/yr	Lowrance, Leonard, and Sheridan 1985
riparian	1 to 1.5 kg N/ha/flooded day	Hoffmann and Baattrup-Pedersen 2007
riparian	80-94%	Lee, Isenhart, and Schultz 2003
riparian	89%	Peterjohn and Correll 1984
Phosphorus		
riparian	1.5lbs / ac/ year	Lowrance, Leonard, and Sheridan 1985
riparian	91%	Lee, Isenhart, and Schultz 2003
Sediment		
palustrine *and* riparian	50%	Phillips 1989
palustrine *and* riparian	71%	SCS 1983
palustrine *and* riparian	71%	Phillips 1986
riparian	99%	Lowrance, Leonard and Sheridan 1985
riparian	95-97%	Lee, Isenhart, and Schultz 2003

Methods and Analysis

Land use and pollution

Expected pollution loading in surface runoff was determined by estimating the annual volume of water discharged from the study area as surface flow, and then partitioning it by zoning type. This surface water flow for the watershed was determined as effective precipitation calculated using methods developed by the Natural Resources Conservation Service (Steenhuis et al. 1995), aggregated over a water year. Afterwards an expected concentration coefficient was obtained from the EPA's National Urban Runoff Program (NURP) (EPA-NURP 1983) documentation which aids in determining the total mass of material leaving a land use class (Figure 1). Each zoning class was evaluated for the expected runoff fraction from its permeable and impermeable surfaces to determine the total amount of water that will enter into the stream channel each year. These aggregate masses were then area-normalized to create a final mass-area relationship for each zone, essentially, pollution loads were attributed to area of impervious surface in the upland, based on zoning districts.

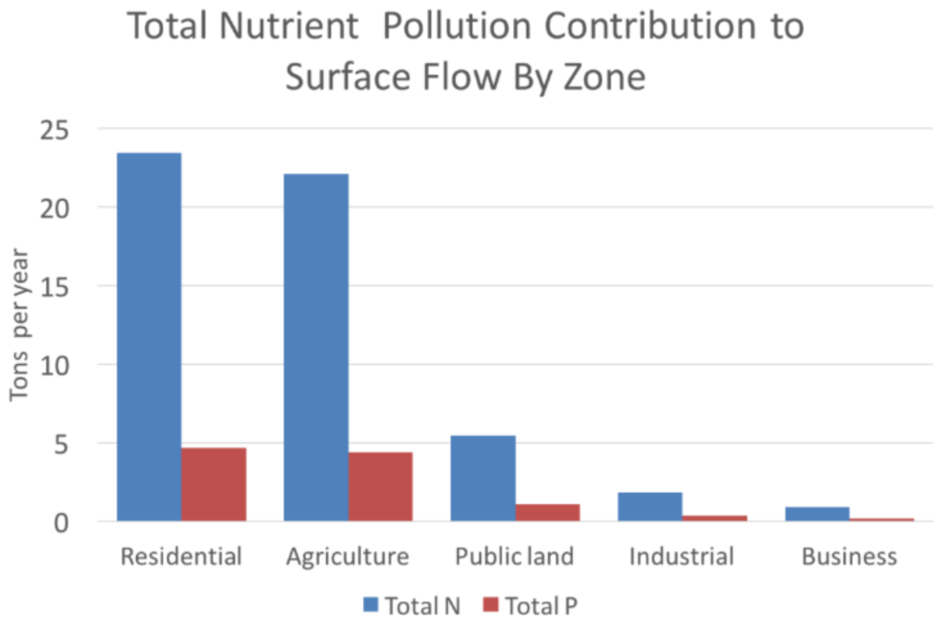


Figure 2.Total Nutrients contributed by land use class (Source: EPA-NURP 1983)

The breakdown of the spatial origin of the nutrient pollution suggests that the two largest contributors to nitrogen and phosphorus pollution in the watershed are residential housing and agricultural activities, respectively. This is consistent with agricultural and residential land uses predominating within the watershed. Because much of the nutrient pollution originates from land outside the jurisdiction of the municipal government, this would suggest that the City's future development plans should reduce the total area utilized for residential development expansion. Activities outside of City limits, such as agricultural cannot be addressed by regulatory efforts on behalf of the City, which precludes much of the land use contributing to nutrient pollution. If the City chooses to utilize constructed wetland systems to attenuate this contribution, it would be of great benefit for the City to seek the cooperation of the Gallatin County and private landowners on a voluntary basis to this end. The methods and implementation of such cooperation falls outside the scope of this paper.

Sediment deposition paints a different picture; much of the sediment introduced into the watershed originates from upland erosional activates, of which is construction and landscaping activities that create bare soil surfaces are major contributors. Direct contribution by stormwater hydraulic working of undisturbed urban permeable surfaces makes up little total expected load. Total potential sediment runoff in the Bozeman Creek drainage is 2,563 tons per year. Of this mass, 117 tons are suspected to originate from soil surface disturbances from the current 300 acres of land under active development. This represents a challenge for the City to meet target TMDLs for Bozeman Creek through efforts inside its borders. Structures similar in construction and intent as the back water slough at the Story Mill study site show promise to reach this goal. However, the design of said slough is expected to operate in this capacity for 2-year storm events. This periodicity is insufficient to accomplish the goal of reducing sediment loading needed if this method is to be implemented at a larger scale in the watershed. Hard-infrastructure remedies such as sediment traps and temporary water permeable barriers during construction are currently implemented by the City. Expansion of these measures or construction of hybrid stormwater sewer- wetland structures could be part of the City's methodology Again, the social and engineering aspects of said structures is beyond the scope of this paper.

Riparian retention calculation

Knowing the in stream values for nutrients, along with the likely percent reduction in those nutrients, and values for the percentage of stream buffered by a riparian area, we can back-calculate the amount of nutrients attenuated by these riparian buffers. We can assume that the percent of buffered stream length has reduced pollution by some amount, that is, the total percent attenuated is the percent of buffered stream length multiplied by the reduction factor. From there we can determine the amount reduced in mg/L using the following weighted average.

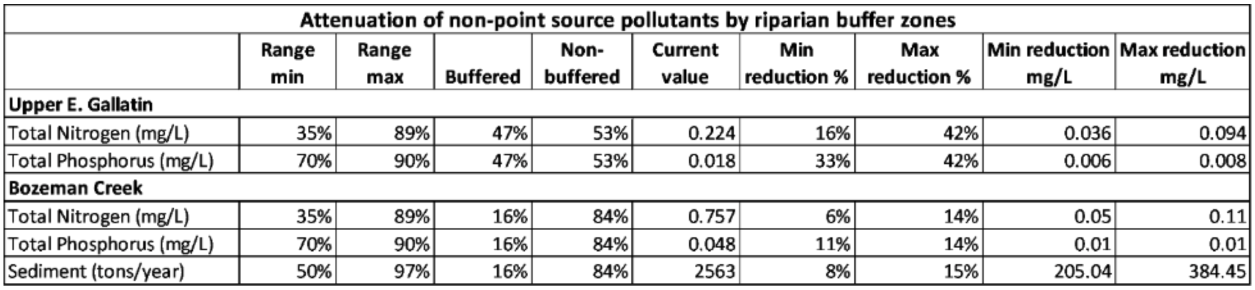
$$\frac{[(\%\boldsymbol{Cbuffered} * \%\boldsymbol{Rbuffered}) + (\%\boldsymbol{C} * \%\boldsymbol{R})]}{\mathbf{100}} = \%\,\boldsymbol{Reduction}$$

Where $\%\mathbf{C}_{\mathbf{buffered}}$ is percent of stream corridor with a riparian buffer, $\%\mathbf{C}$ is the percent corridor without buffer, and $\%\mathbf{R}_{\mathbf{buffered}}$ is the percent reduction in some pollutant by a riparian buffer zone. %**R** is the percent reduction of a pollutant by a non-buffered upland.

Results

Applying the calculation above to Bozeman Creek and the East Gallatin River, we can estimate the range of pollution reduction provided by riparian buffer zones (Table 3).

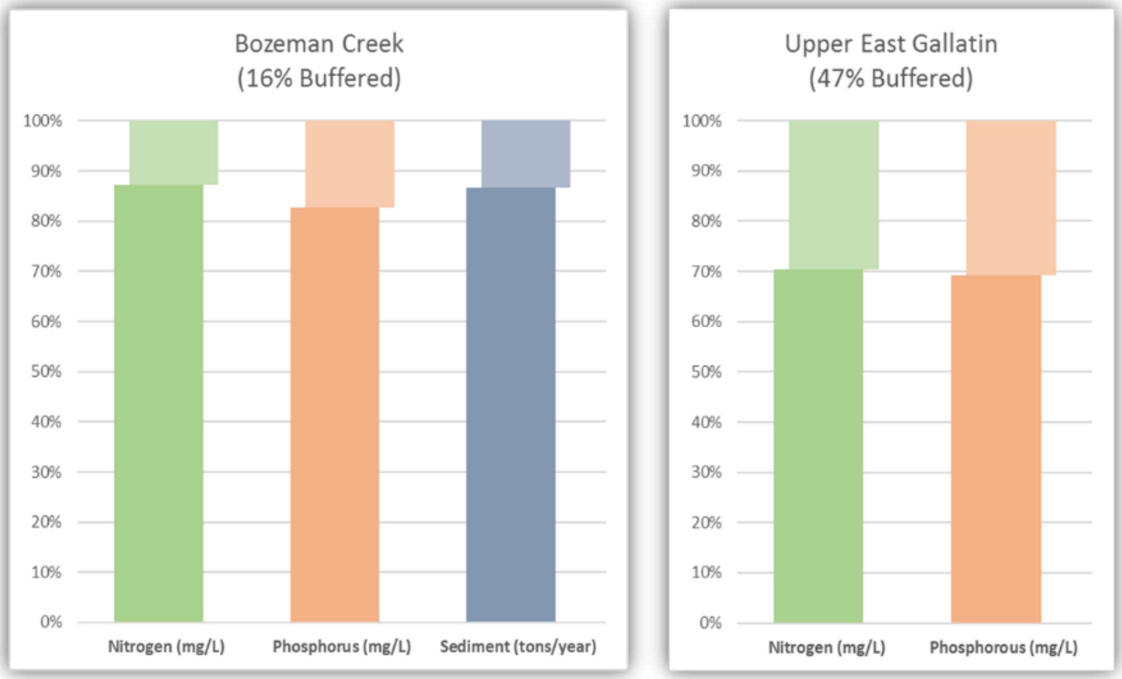
Table 3



Attenuation of non-point source pollutants by riparian buffer zones

	Range min	Range max	Buffered	Non-buffered	Current value	Min reduction %	Max reduction %	Min reduction mg/L	Max reduction mg/L
Upper E. Gallatin									
Total Nitrogen (mg/L)	35%	89%	47%	53%	0.224	16%	42%	0.036	0.094
Total Phosphorus (mg/L)	70%	90%	47%	53%	0.018	33%	42%	0.006	0.008
Bozeman Creek									
Total Nitrogen (mg/L)	35%	89%	16%	84%	0.757	6%	14%	0.05	0.11
Total Phosphorus (mg/L)	70%	90%	16%	84%	0.048	11%	14%	0.01	0.01
Sediment (tons/year)	50%	97%	16%	84%	2563	8%	15%	205.04	384.45

These pollution reduction calculations indicate that the existing buffer zones on both these streams may reduce nitrogen by a maximum of 0.1 mg/L, and phosphorus by 0.0068 to 0.0076 mg/L. Sediment reduction on Bozeman Creek ranges from 204 to 396 tons / year. These values represent percent reductions of 42%, 14%, and 15% of potential N, P, and sediment loads, respectively. This data is shown below in Figures 2 and 3 below.



Figures 2 and 3. The solid color portion of these histograms can be thought of as representing the measured values for N, P, and sediment in each stream, while the opaque and offset portion represents the potential in stream load reduced by the function of riparian buffer areas.

It’s important to mention that these methods and the results rely on the following assumptions:

- All of the studies referenced for percent reduction values from the literature are translatable to the two watersheds in this study,
- Net movement of pollution from the uplands is spatially consistent across the entire watershed, this doesn’t recognize that certain parts of the watershed may contribute more or less pollution, and that presence or absence of wetlands adjacent to these areas would have more impact on the total in stream concentration.
- Any reaches that are not forested riparian buffer do not attenuate any of the surface runoff (%R of 0). And, this method assumes all inputs are surface sheet flow and cannot account for any water that might bypass riparian buffers completely via sewers or as channelized surface flow in swales.
- The magnitude of a nonpoint source pollutant is a function of both land area and use
- Impervious surfaces can be used as a metric to predict the amount pollution runoff into streams in urban watersheds.
- Stormwater effluent from Bozeman has concentrations similar to those reported by the EPA NURP source data used for this empirical analysis methodology.

Discussion

Given the assumptions and limitations of this analysis, these results show that riparian buffers may strongly contribute to the reduction of pollutants. And this pollution reduction effect is increased dramatically by the proportion of the stream which has a riparian buffer zone, as shown in Figures 2 and 3. But, there are some limitations on the application of this model. Observed loading in the stream have been established via monitoring by personnel in support of the regulatory process surrounding the TMDL of the East Gallatin River and Bozeman Creek; but the model used to predict the load contributed by the City is based on meta-analysis of research in a wide range of locations. Each study referenced in this paper was conducted on a site with different patterns of human behavior, geologic structure, and water regime. In the course of a social dialogue, these results need to be interpreted within that framework. An appropriate context to present this research is as a tool to guide stakeholders - including the general public – to inform urban planning into the future. For example, the area immediately surrounding the Story Mill study site is currently zoned for medium density residential. Our expectation is that the pollution load generated during this development will produce 2.21 kilograms per acre of sediment into an already non-compliant stream. This represents a challenge for the City to meet target TMDLs for Bozeman Creek through efforts inside its borders. Structures similar in construction and intent as the back water slough at the Story Mill study site show promise to reach this goal. However, the design of said slough is expected to operate in this capacity for 2-year storm events. This periodicity is insufficient to accomplish the goal of reducing sediment loading needed if this method is to be implemented at a larger scale in the watershed. Hard-infrastructure remedies such as sediment traps and temporary water permeable barriers during construction are currently implemented by the City. Expansion of these measures or construction of hybrid stormwater sewer- wetland structures could be part of the City's methodology. The City may also choose to change the zoning regulations to incorporate stormwater pollution countermeasures like improvement of adjacent riparian buffer areas, at the expense of high value real estate. Increasing the density of the housing created would provide developers with a higher rate of return on their investments to offset this incurred expense, but the public may not be willing to have high density housing going forward in Bozeman's growth. Balancing these wants with the need to reduce the load placed on the East Gallatin River can be better informed with these predictions of the impacts land use has on pollution entering our rivers, and the beneficial ecosystem services of riparian areas.

As a modern, growing city, Bozeman has an obligation to downstream water users and to future generations of Montanans. Challenges associated with increases in global population, such as providing food and clean water are reflected in the challenges we face in the Gallatin valley. We must house, feed, and provide clean water to the growing population, to do one at the expense of another is easy; in concert, these issues become more than the sum of their parts. Ultimately, the scientific literature supports the idea that riparian buffer areas should be valued for the reduction of pollutants and benefits that they have on water quality, and that there is potential for development of impervious surface as a useful metric for estimating upland pollution offloading during urban growth. Clearly riparian buffers can be a contributor to water quality and should be considered during development adjacent to our waterways. These buffers may not only help in achieving mandatory TMDL guidelines, but provide other desirable functions such as increased habitat for wildlife, recreation, and aesthetics.

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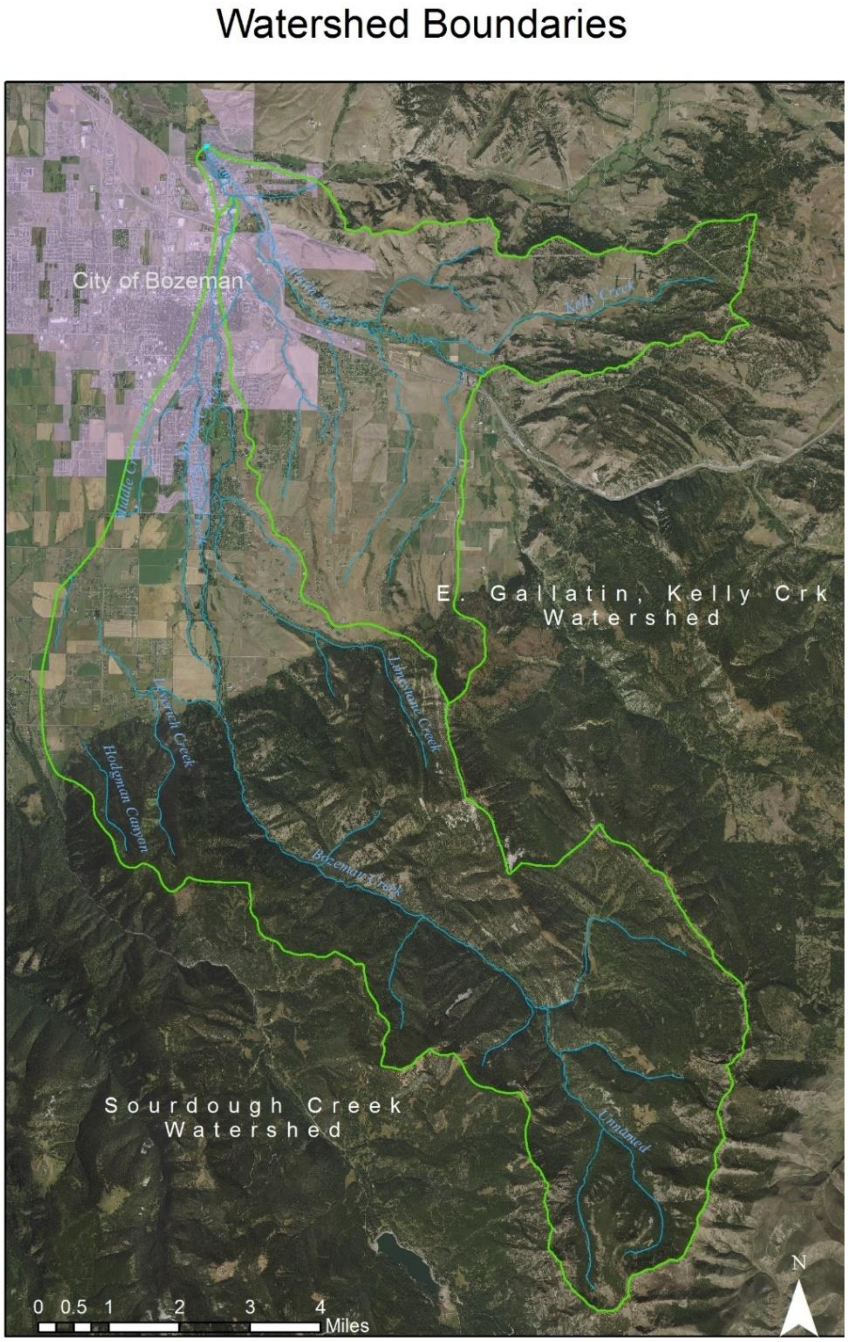
Appendix 1a – watershed boundaries



Appendix 1b – Story Mill area and wetlands


Story Mill Area and Wetlands

Application of Green Infrastructure in Bozeman: A GIS Suitability Model Approach

Emma Bode, Connor Mertz, Chance Noffsinger, Joe Rizzi

Introduction

Gallatin County is currently the fastest growing county in Montana, primarily fueled by the growth of Bozeman. Population growth and increased urban area have led to the impairment of the freshwater systems around the City. Urbanization can directly affect streams through channelization, the removal of woody debris, and simplification and homogenization of stream habitat. The urbanization of streams can also alter the hydrology by replacing native vegetation with parking lots, shopping centers, and buildings that create impervious area. Riverine ecosystems provide services such as maintaining water quality and quantity, food production, and recreation yet most large river ecosystems are disturbed by anthropogenic disturbance and as these ecosystems are impaired, so are the services they provide[1]. The City of Bozeman lies in the headwaters of the Missouri River watershed where cumulative ecological damage is less severe.

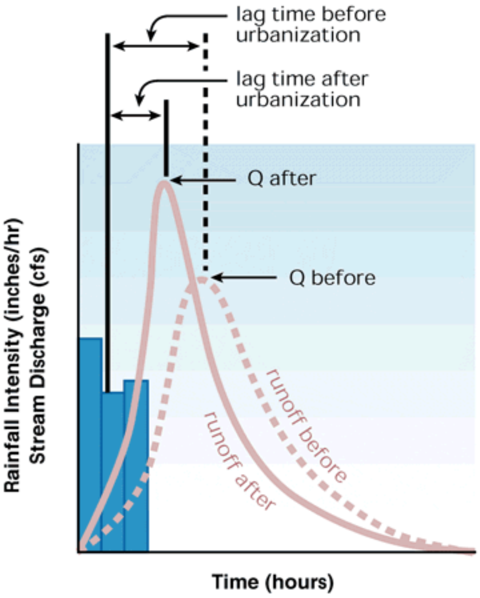


Figure 3: Natural and Urban Hydrographs

With an expanding city, impervious surfaces become increasingly prevalent. Impervious surfaces prevent stormwater from infiltrating into natural soil systems where soil can filter sediment and pollutants[2,3]. When compared to non-urbanized systems, urban systems have larger and more frequent peak flow events leading to increased flooding risks and pollutants entering natural waterways[4]. Figure 1 illustrates the change in a typical stream hydrograph as a watershed becomes more urbanized. The urbanization of Bozeman has ultimately led to the impairment of Bozeman Creek and its watershed. In the past several years, the City has taken steps to address this impairment by rehabilitating Story Mill.

The Story Mill Park area is a substantial wetland system within the Bozeman City limits and occurs at the confluence of the East Gallatin River and Bozeman Creek. Both of these streams are listed as impaired by the EPA. Over the past one hundred and fifty years, the watershed has been directly manipulated through the drainage and filling of the Story Mill wetlands, and channelization of Bozeman Creek. Channelization speeds up the water velocity, creates erosion problems downstream, and isolates the stream from its floodplain. The City has spent approximately $700,000 to rehabilitate the Story Mill wetlands and floodplains to address these water quality issues through a natural, passive system. Ideally, the rehabilitation and enhancement of the Story Mill wetlands and floodplains will reestablish ecosystem services such as enhanced nutrient attenuation, carbon sequestration, and sediment management. This rehabilitation, however, may not be large enough to mitigate all the negative effects of urbanization, such as upstream channelization and growing water quality concerns associated with stormwater. In order to meet the EPA water quality standards, we recommend that the City of Bozeman further address the sources of pollution above the Story Mill Park.

The City is already under pressure to update its current infrastructure to adjust for the demands of an increasing population. Here we consider the implementation of green infrastructure systems around the City to mitigate nonpoint source pollutants associated with Bozeman. The inevitable update of the City's infrastructure in the coming decades provides an extraordinary opportunity to address water quality issues through the implementation of green infrastructure.

Here we explored potential types of green infrastructure to implement in Bozeman, defined and characterized urban catchment basins by their relative pollutant contributions, and determined the most effective sites for implementing green infrastructure systems within city limits to further reduce pollutant loads.

Characterizing Urban Pollutants

The Environmental Protection Agency (EPA) provides guidance to assess the water quality around the US to determine if it meets the standards set by the Clean Water Act (CWA). The EPA provides guidance for states to develop water pollution standards known as Total Maximum Daily Load (TMDL). TMDLs specify the total amount of pollution a water body can legally receive while still meeting water quality standards. The Montana Department of Environmental Quality (DEQ) reported to the EPA in 2013 that Bozeman Creek was impaired by *Escherichia Coli* (*E. Coli*), sedimentation and siltation, and total nitrogen loading because they exceed their respective TMDLs[5].

Nonpoint sources of polluted urban runoff can be difficult to characterize due to temporal and spatial variability within urban systems[6]. Mixing of land use within a city is extensive and numerous pollutants from multiple sources may be found in a single area. Temporal variation arises from seasonality, local weather events, and irregular activities such as fertilization and construction projects[6,7].

Nitrogen and phosphorus are the target nutrient pollutants impairing Bozeman Creek. These nutrient pollutants are typically sourced from construction sites, lawn fertilizer, pet waste, and leaked sewage in urban settings. They are also associated with agricultural activities, primarily fertilization and livestock production[8]. Anthropogenic-sourced nitrogen and phosphorus pollution is typically associated with eutrophication of freshwater systems. Heavy nutrient loads in a system may lead to the alteration of stream communities, toxic algal blooms, oxygen depletion of the system, and ultimately fish kills. Excessive nutrient concentrations may also impair water quality and taste[9].

Sediment pollutants are derived from streets, parking lots, rooftops, construction sites, vacant lots, and landscaped grounds. These sediments are subject to further contamination from the spillage of hydrocarbons, atmospheric deposition, and fertilizer applications. In addition, sediments may carry metals, nutrients, organochlorines, and other toxins that pose as health threats to both humans and freshwater organisms[7]. Contaminated sediments threaten the physical, chemical, and biological integrity of freshwater ecosystems[10]. Unlike other dissolved pollutants, which are subject to dilution, sediments concentrate above aquatic systems in traditional stormwater retention systems. In the event of a major outwash, these sediments have the potential to shock load freshwater systems.

Pathogens, particularly *E. Coli*, are obvious human health concerns in drinking water as well as to recreational water users. In Bozeman, livestock and dog feces are primary sources of fecal coliform. Oil, grease, and other hydrocarbon pollutants are categorized as ‘floatables.’ These pollutants are associated with leaks and spills from automobiles and other equipment operations. The introduction of ‘floatable’ pollutants to aquatic systems impairs ecosystem health and contaminates drinking water[9]. Green infrastructure systems reduce pollutant loads in urban runoff before they reach stream systems, alleviating downstream water treatment costs by pre-treating non-point source pollution.

Green Infrastructure

Green infrastructure utilizes ecosystem services provided by natural environments to alleviate pollutant loads. Green infrastructure consists of natural or engineered areas of land designed to leverage natural ecosystem function to mitigate urban pollution closer to its source[11]. Large-scale green infrastructure includes parks, wetlands, open spaces, drainage ways, and floodplains, all of which can be integrated within urban landscapes to form large functioning urban ecosystems that perform beneficial services. This services include improving air and water quality, reducing flooding risks, mitigating heat island effect in urban centers, and enhancing overall community livability[12]. Large-scale green infrastructure works to restore and enhance beneficial ecological services that are missing or impaired as a result of urbanization. Small-scale green infrastructure is the use of location-specific engineered structures, which mitigate the harmful effects of large amounts of impervious surfaces and non-point source pollution. Some recommendations for small-scale green infrastructure that could be implemented in Bozeman are listed below.

Permeable paving consists of a range of materials that can be used to slow stormwater runoff, increase stormwater infiltration, and decrease the amount of sediments and pollutants that enter natural waterways. Permeable pavers reestablish a more natural water cycle by allowing stormwater to infiltrate through the underlying soil and recharge groundwater. Permeable paving includes porous pavement and laid pavers on sidewalks or green alleys to decrease impervious areas of highly urbanized systems. Permeable pavers however, are only effective at treating the area they cover and not the water moving off adjacent impermeable surfaces due to their slow infiltration rate. Other considerations are that permeable pavers are more susceptible to shifting caused by the freeze-thaw cycle in Bozeman and can present problems with snow removal[13].

Street-side stormwater planters are designed to treat stormwater runoff from the street, sidewalk, and adjacent private properties. Storm water enters the planter from a gutter on the street and then is dispersed over the media where it infiltrates the soil and exits through a drain system underground. The street-side stormwater planters are designed to use vegetation, which includes grasses, perennials, shrubs, and a select number of trees, to reduce nutrient concentration through plant uptake. Stormwater planters should be located on the downhill end of a city block. **Bump out stormwater planters** are essentially larger versions of street-side stormwater planters; however, they extend into the street and cover the zone that would be used for parking. They can be designed to handle larger amounts of water than street-side planters while also easing the flow of traffic. The bump out system can hold all the vegetation of the street-side planters in addition to flowers and various tree species[13].

Green gutters are smaller version of stormwater planters designed to treat less water. They are placed in a street between the road and sidewalk and, act as a bioretention facility that can treat runoff from the street, sidewalk, and adjacent private development. They reduce the effects of flooding and decrease the amount of pollutants that enter the natural waterways. They are best used in conjunctions with native grasses but other plants may be used as well. **Tree trench/pit** are essentially the same concept but are slightly larger to accommodate trees[13].

Disconnected downspouts are a way of redirecting the water off of a roof onto a permeable surface like a lawn or garden. Disconnected downspouts reduce peak stormwater runoff and sediment loads by allowing water to infiltrate into soil or collect in wet ponds. Disconnected downspouts are good ways for local residence to reduce stormwater runoff and they can also be designed to move water into creative landscaping ideas like backyard ponds and waterfalls[14].

Stormwater detention ponds are designed to treat water from roofs, roads and parking lots. They slow the overall speed of the water, which reduces runoff and allows sediments and nutrients to settle before they enter natural waterways. Detention ponds are already a popular way for new developments to treat storm water because, although more expensive, they can be constructed underground so other infrastructure like parks or playgrounds can be built above[13]. Detention ponds are often utilized to meet the Bozeman City mandate that all new developments treat their stormwater and are not prevalent in older structures because the City does not extend this requirement to prior development[15].

The ideal type of green infrastructure to implement depends on the location, the climate, water treatment needs, and budget. For Bozeman, special consideration for semi-arid climates should be taken into account to minimize water loss through evapotranspiration by utilizing native vegetation. More in-depth directions for construction and implementation of the described green infrastructure are available through the Ultra Urban Green Infrastructure Guidelines Manual[13].

Bozeman Stormwater Management

The Bozeman stormwater master plan lays out two approaches to treating contaminated stormwater: first, a development-based approach, where stormwater treatment facilities are built as new developments are constructed and second, a regional approach where larger stormwater treatment facilities are built to treat stormwater before it reaches Bozeman Creek or other adjacent rivers. Disadvantages are associated with both strategies. For example, the development-based approach is expensive and will only work for new or redeveloped areas of Bozeman; whereas, the regional approach requires large amounts of land for the facility and a working staff that the City of Bozeman does not have money to support according to the stormwater master plan. This master plan recommends implementing a combination of both management techniques; however, no plan is in place for constructing a regional facility that would treat Bozeman's contaminated stormwater. Green infrastructure still requires a maintenance cost, but less than a regional facility while providing services such as parks, animal habitat, and a closer connection to nature. Therefore, the establishment of green infrastructure throughout the city could replace Bozeman's need for a new regional stormwater treatment facility. This approach along with an effort to re-vegetate and restore areas along Rouse Avenue and Bozeman Creek could be a solution to prevent flooding, slow peak runoff, and increase water quality.

GIS as a Tool

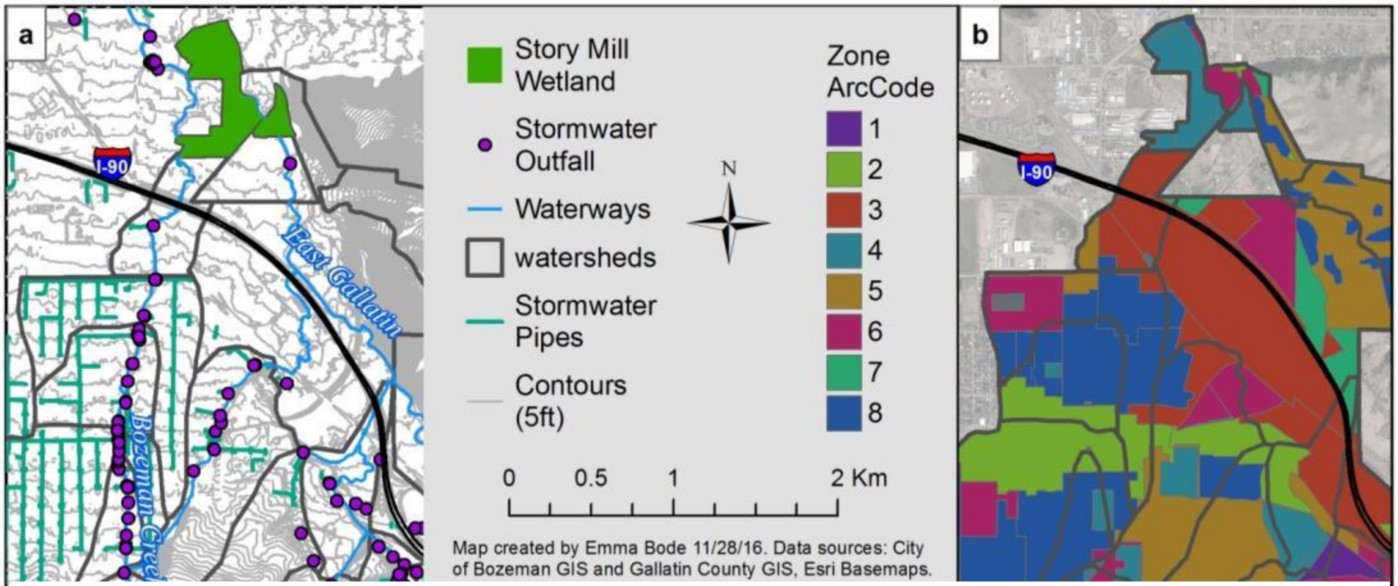
A suitability analysis using a geospatial information system (GIS) can provide Bozeman's city planners with a tool that integrates both spatial and storm water data to determine the optimum sites and quantities of green infrastructure. A suitability analysis is a GIS approach to determining the optimal location for a desired land use based on defined requirements, preferences, or predictors[16]. Suitability analyses are feasible when the available data has distinct boundaries, there is specific criteria for a suitable site, and the criteria can be ranked by importance[17]. The pinnacle of suitability analyses for stormwater management is the SUSTAIN model developed by the EPA[18]. This model incorporates hydrologic variables and quantitative pollutant measurements to determine precise predictions of event flows and pollutant loads tailored to specific urban areas. Due to constraints in time and information, we used a simplified model called weighted linear combination. Weighted linear combination is a two-step analysis that provides a more qualitative assessment of site suitability while maintaining a high level of complexity and preference. In the first stage of the analysis, specialists identify all variables affecting site suitability for a proposed land use and then rank suitability of each land cover from least to most suitable. Not all variables are as important in the final decision, so the ranked variables are then weighted by importance. Weighting each variable allows decision makers to incorporate preference into the model[16]. We used this model to determine which municipal catchment basins that drain into the Bozeman Creek are the greatest contributors to water quality degradation and therefore should be targeted with green infrastructure systems?

Methods

We built a framework for a weighted linear combination suitability analysis of the portion of the Bozeman municipality that drains into Story Mill. The purpose of the analysis was to locate which catchment basins, as determined by the urban storm water drainage system and the local topology, contributed the greatest amount of water pollution to Bozeman Creek.

All GIS data was obtained from the City of Bozeman and Gallatin County GIS services. The analysis used only vector data, which allowed us to incorporate the available shape files directly into the GIS. We used the stormwater drainage layer, a streams layer, and a topographic contours layer a zoning districts layer, and a city parks layer[19].

To determine which zones were the greatest polluters, we needed to specify zones our model should compare. We delineated nested catchment basins within the City, based on the City's stormwater drainage infrastructure and topography using the contours and storm water



Map created by Emma Bode 11/28/16. Data sources: City of Bozeman GIS and Gallatin County GIS, Esri Basemaps.

Figure 4a: layers used to delineate catchment basins. 2b: The area of each zone within each catchment basin was multiplied by that zone type's pollution value (See table3 for ArcCodes).

drainage layers. The stormwater management infrastructure of Bozeman consists of a series of drains and underground pipes that transport stormwater off impervious surfaces and into the stream systems passing through the City. These pipe systems create numerous urban catchment basins that concentrate stormwater flows to specific output points where they are discharged into streams. Catchment basins were digitized such that all water within the polygon drained to the lowest point in the polygon (Figure 1a). Outfall zones in the stormwater drainage infrastructure layer are the lowest points in each catchment basin. Due to the immense number of outfall points, we generalized areas of outfall to make the delineation more manageable in the time allotted for this project.

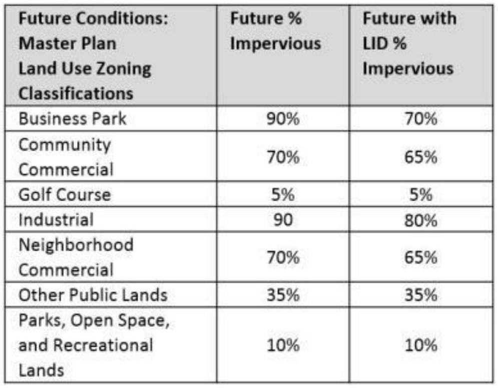
Our model targets four main urban pollutants derived from the Bozeman urban: nutrients, sediments, ‘floatables,’ and fecal coliform. Pollution scores were given to each city zone type (described below) based on the expected prevalence of these factors in that zone. Sediment and nutrient loads present the greatest water quality challenge for the City of Bozeman. Given this management preference, we weighted the sediment and nutrients variables most heavily followed by the percent impervious area. Water flows faster over impervious areas and, with greater velocity, can carry a greater sediment load to streams. Weighting variables depend entirely on the City’s interests. Our weighting system is flexible and can be readjusted to prioritize any one of the variables.

The weighted pollution values for each zone were multiplied by the size of each zone and then summed for all zones within each nested catchment basin (Figure 2b). This provides a qualitative measure of how much pollution each catchment basin contributes to Bozeman Creek. Due to the nature of watershed delineation, not all catchment basins are the same size. This creates an issue when interpreting the severity of water pollution generated within each catchment basin because larger basins will inherently have larger pollution values. Thus, each pollution value was normalized to the area of the catchment basin. The resulting map depicts the pollution generated per square kilometer per basin.

Weighting System

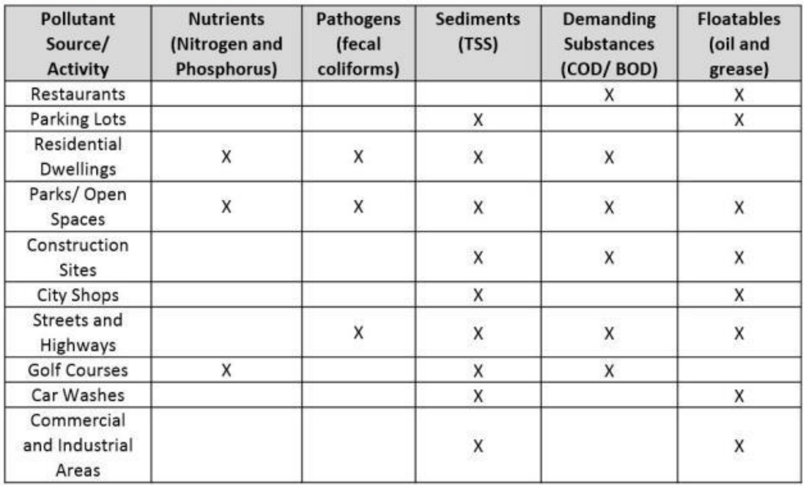
In order to evaluate for pollutant ‘hotspots’ within the model, we employed a weighting system. Based on their pollutant contributions, each zone within city limits was assigned a score of 0-2 (0-low/none, 1-moderate, 2-high) in the following categories: percent impervious area, nutrients, sediment, pathogens, and ‘floatables’ such as oil and grease. Categories were assigned

Table 1 - Percent impervious area sourced from Bozeman Stormwater Master Plan Table B 2-2



Future Conditions: Master Plan Land Use Zoning Classifications	Future % Impervious	Future with LID % Impervious
Business Park	90%	70%
Community Commercial	70%	65%
Golf Course	5%	5%
Industrial	90	80%
Neighborhood Commercial	70%	65%
Other Public Lands	35%	35%
Parks, Open Space, and Recreational Lands	10%	10%

Table 2 - Expected pollutant sources, sourced from Bozeman Stormwater Master Plan Table 4.2-2



Pollutant Source/ Activity	Nutrients (Nitrogen and Phosphorus)	Pathogens (fecal coliforms)	Sediments (TSS)	Demanding Substances (COD/ BOD)	Floatables (oil and grease)
Restaurants				X	X
Parking Lots			X		X
Residential Dwellings	X	X	X	X	
Parks/ Open Spaces	X	X	X	X	X
Construction Sites			X	X	X
City Shops			X		X
Streets and Highways		X	X	X	X
Golf Courses	X		X	X	
Car Washes			X		X
Commercial and Industrial Areas			X		X

different weights within the GIS model in accordance to the management objectives of the City. Our model places more emphasis on sediment and nutrient pollutants because the City identified these as the pollutants of highest concern; however, weights can be easily adjusted. Bozeman's zoning types were condensed into eight general land use categories to improve the manageability of our model. Ultimately, each zone is associated with a total pollutant score, derived from the sum of the scores produced from each category. Data concerning the percent impervious area for each zoning type was located in the City of Bozeman Master Water plan (Table 1). Percent impervious area was calculated by the City based on land use types from the City's 2020 Master Plan Map[15]. Our model used the 'future % impervious' figures rather than 'future with LID (low impact development)' figures in order to assess a worst case-scenario situation. The following guidelines were used to score the impervious surface category: 0-33% impervious = 0, 34-66% impervious = 1, 67-100% impervious = 2. In general, commercial and industrial zones exhibit the greatest proportion of impervious surfaces (roof area, parking lots, etc.) relative to residential zones and parks. The pollutants present in each of the eight general land use categories we designated were determined using the expected pollutant sources provided in the Bozeman Stormwater Master Plan (Table 2).

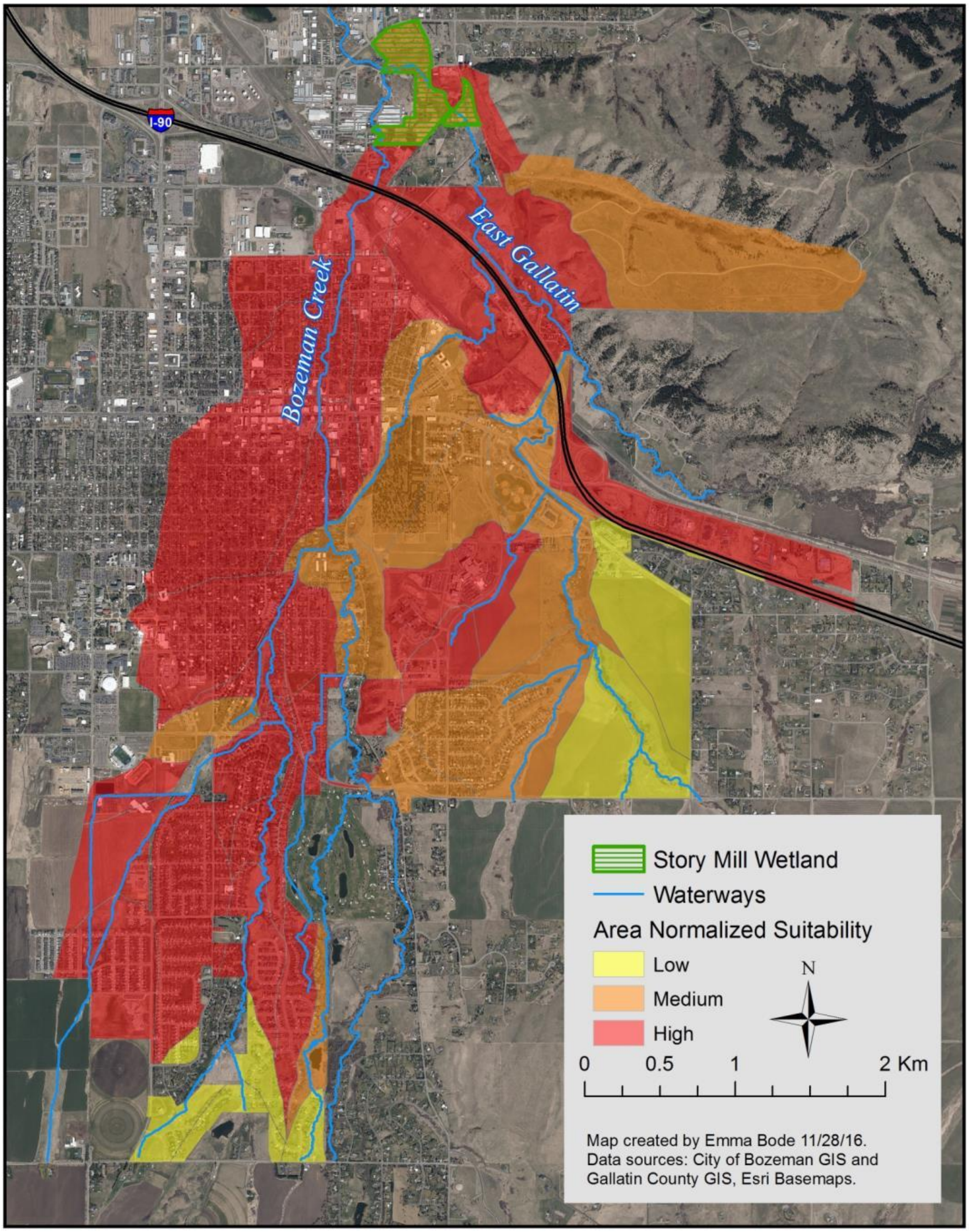
Contribution scores for each pollutant type were estimated on a more qualitative basis (Table 3), taking into account City data (See Tables 1 and 2), our literary review, and our own personal observation of pollution. For example, pathogen (fecal coliform) pollutants are typically associated with animal feces, and therefore are expected to originate primarily from parks and residential lawns. Sediment pollution is associated with nearly all land use types, while nutrient pollution is typically sourced from fertilization of lawns and green spaces (Table 3)[15].

Table 3 – Pollutant Semi-Quantitative Scores

	Zoning	**ArcCode**	**Nutrients**	**Sediment**	**Pathogens**	**Floatables**	**% Impervious**	**Totals**
Business Park	B-P	1	0	1	0	2	2	5
Commercial	B-1, B-2, B-2M, B-3, UMU	2	0	2	0	2	2	6
Industrial	M-1, M-2	3	0	2	0	2	2	6
Parks & Open Space	GIS Layer	4	2	0	2	0	0	4
Public Institutions	PLI	5	1	1	0	1	1	4
Residential Infill	R-4, R-5, R-O, REMH	6	0	1	1	2	1	5
Residential Limited	R-1	7	1	0	0	0	1	2
Suburban Residential	R-2, R-3, RS, NEHMU, HMU, NC, REMU	8	1	2	1	1	1	6

Results

The sub-basins generating the greatest amount of pollution were those in Downtown Bozeman and in the communities south of Kagy Blvd. The catchment basins on the southern and eastern peripherals of the contributing area to Story Mill had the lowest pollution levels. The Story Hills catchment basin north of town received a medium suitability rating despite having



Map created by Emma Bode 11/28/16.
Data sources: City of Bozeman GIS and Gallatin County GIS, Esri Basemaps.

Figure 5: Suitability Analysis for Green Infrastructure. The suitability layer provides a qualitative measure of how much pollution each catchment basin contributes to waterways

almost no development (Figure 3). It is reasonable that Bozeman Creek running from College Ave. to Oak St. would be the most impaired due to the high ratings of the surrounding downtown area. It is not surprising that those catchment basins furthest from the center of town and away from the most concentrated urbanization would receive the lowest ratings. Basing stormwater pollution levels off of zoning districts was successful given our time constraints. Zoning districts, however, are imperfect pollution proxies. They can only represent the City's vision for development and not the current development. This caused an inaccurate classification of the Story Hills which are zoned as a residential area but have little actual development, because of the conservation easements owned by the Gallatin Valley Land Trust.

The catchment basins generating the greatest amount of pollution were those in Downtown and Southeast Bozeman. The catchment basins over Montana State University, Pete's Hill, and South 3rd Ave had the lowest pollution levels. It is logical that downtown would have a high sediment load due to its high urbanization and percent impervious area. The high rating for southeast Bozeman is speculative and warrants further investigation of our model. More Bozeman specific knowledge of the pollutant loads of each zoning district would support a superior product. The size of the catchment basins makes further interpretation difficult. In future analyses, we recommend delineating smaller basins and using true water quality measurements from water samples along city waterways.

Based on our findings, the catchment basins that generate the most sediment, and thus would be most suitable for intervention via green infrastructure are in downtown Bozeman and southeast Bozeman. While the accuracy of this study could be greatly improved with more detailed data, the project provides a framework and methodology for performing a green infrastructure suitability analysis for the Bozeman Municipality. Implementing a comprehensive monitoring system such as SUSTAIN[18], may be beyond the scope of Bozeman's interests.

Discussion

This project explored potential green infrastructure to implement in Bozeman, defined and characterized urban catchment basins by their relative pollutant contributions, and determined the most effective sites for implementing green infrastructure systems within city limits to further reduce pollutant loads. While the accuracy of this study could be greatly improved with more detailed data, the project provides a framework and methodology for a suitability analysis for the implementation of green infrastructure in the Bozeman municipality. More site-specific knowledge of the pollutant loads in each catchment basin would support a superior suitability analysis. Water quality monitoring stations at each outfall zone along the stormwater system, could provide this valuable data. From a construction and management perspective, there are many factors that must be considered when implementing green infrastructure systems in an urban system. These include but are not limited to: construction expenses, maintenance expenses, property rights, proximity to existing infrastructure and utilities, and water rights[13]. Provided more time and resources, these constraints could be incorporated into the model to provide a both a suitability and feasibility component.

With respect to future water quality management practices, there are three considerations to keep in mind when moving forward[11]. First, conservation goals today can be uncoordinated, reactive, site specific, and narrowly focused. The rehabilitation of Story Mill wetland and riparian areas is in response to the water quality issues currently faced in the City of Bozeman, and in the future it is beneficial to think more holistically and plan for future environmental quality issues. Second, conservation plans can be segregated from growth management and land use planning. Determining the optimum locations for the implementation of green infrastructure benefits both the city budget and Gallatin Valley water quality. Third, conservation efforts are rarely prioritized when funding is cut or the economy takes a turn for the worst. With a budget stretched thin by city growth, a model approach such as with will provide Bozeman an effective means to implement green infrastructure.

Currently, the City of Bozeman monitors stormwater quality annually at two points, one residential and one industrial. Both sampling points are within the City under manhole covers and are designed to be representative of the area from which they are sampled. At these points the City measures total suspended solids, oil and grease, total nitrogen, total phosphorus, metals and pH[20]. Water quality monitoring stations at each outfall zone along the stormwater system, however, would provide valuable data for a more informed suitability analysis. With a budget stretched thin by city growth, Bozeman could implement green infrastructure in the most effective means possible by determining optimum locations that benefit both the City budget and Gallatin Valley water quality.

Our model serves merely as a framework to address the specific concerns and limitations of the City's stormwater management decisions. The decision of whether or not to implement green infrastructure and reduce pollutant loads is a matter of the City's budget and priorities regarding water quality issues. Green infrastructure can mitigate the impacts of urbanization. Given the value Bozeman citizens place on environmental quality and the cost the City would spend mitigating water pollution through other methods, green infrastructure may be an ideal solution to its water quality issues.

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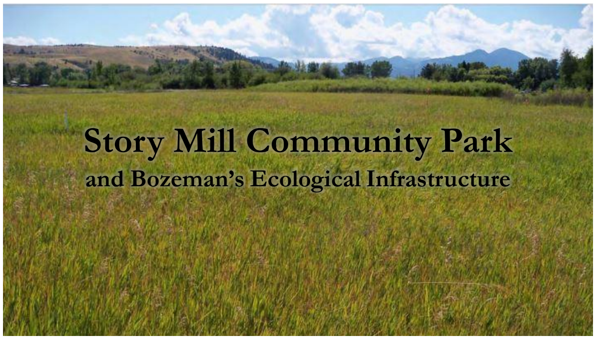


Story Mill Community Park

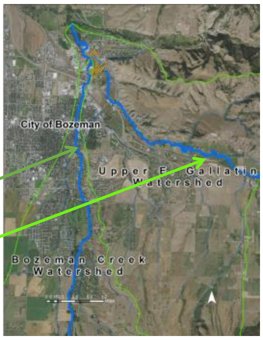
and Bozeman's Ecological Infrastructure

Urban Ecosystem

- Over time urbanization hardened ecosystem
- Story Mill became agro-industry center
- Changes in economics and land use opened that area for redevelopment

Urban Ecosystem

Urbanization and Water Quality



- Total Maximum Daily Load (TMDL's) Provide water quality targets
- Large impetus for Story Mill project
- Bozeman (Sourdough) Creek
  - **Impaired for total nitrogen and sediment**
- Upper East Gallatin River
  - **Impaired for nitrate and nitrite but not total N**

Investigated Topics

- Water quality
- Pollution budgeting
- Application of green infrastructure
- Social and environmental interface

Investigated Topics

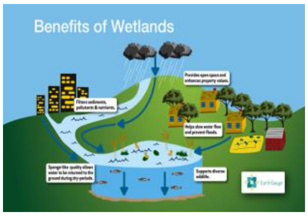
- Water quality
- Pollution budgeting
- Application of green infrastructure
- Social and environmental interface

Bozeman's Wetlands and Riparian Areas Provide Ecological Services

Regulating Services
- Nutrient Attenuation
- Sediment Reduction
- Water Management

Provisioning Services
- Drinking Water
- Fishing
- Hunting

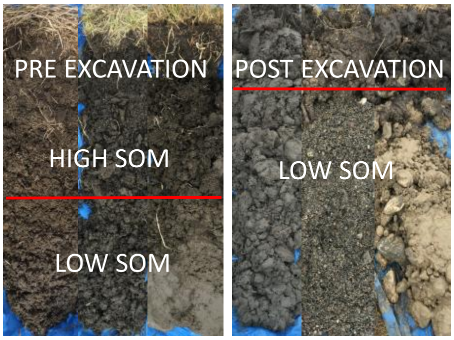
Cultural Services
- Aesthetic
- Recreational
- Educational



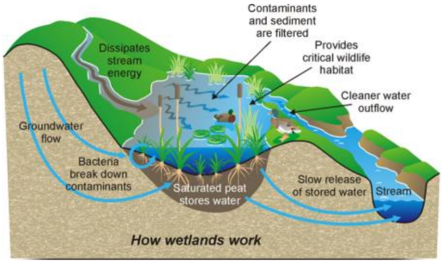
August, 2014

October, 2014

Bozeman Creek Backwater Slough

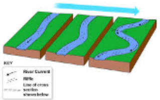


Wetland Sediment Storage



Sediment at Story Mill

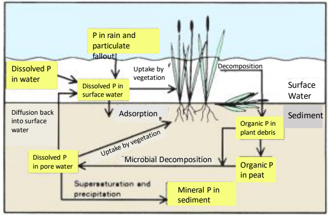
- 37% above TMDL limits.
- Bozeman Backwater Slough design
- Increase effect of BBS
- Improve function of Bozeman Creek through rechanneling



Eutrophication

- Excessive phosphorus damages water quality
- Sewage discharge entering Bozeman Creek and the East Gallatin River will eventually reach Story Mill Wetland

Wetland Phosphorus Retention



- Biotic Processes: Uptake by vegetation and microorganisms
- Abiotic Processes: Adsorption of dissolved P and sedimentation of particulate P

Quantifying Phosphorus Retention at Story Mill

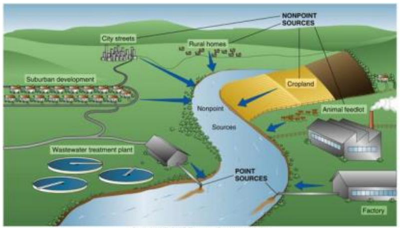
- Sedimentation rate can be used to quantify phosphorus accumulation rate
- It is recommended that 20 sediment plates should be used to get an accurate average phosphorus accumulation rate

Investigated Topics

- Water quality
- Pollution budgeting
- Application of green infrastructure
- Social and environmental interface

How much pollution is entering our streams?

- Urban and agricultural land use increases nutrients and sediment
- Point and Non-Point Sources



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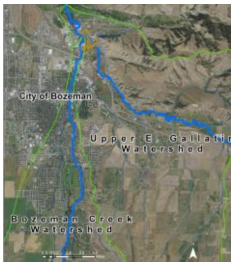
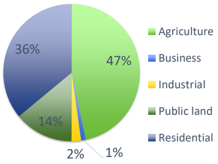
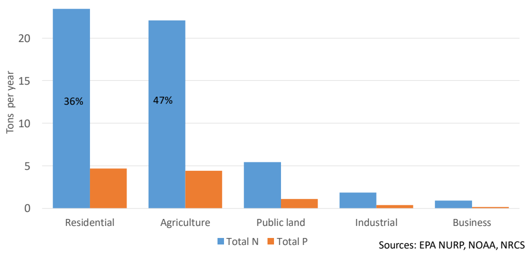
Land use in the Bozeman Creek watershed





EPA National Data: Total Nutrient Pollution Contribution to Surface Flow by Zone



Sources: EPA NURP, NOAA, NRCS

Stream Sediment Pollution in Bozeman

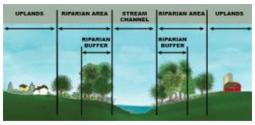
- **Disturbed Soil Surface** (development, plowing, logging) contributes bulk of instream sediment source (EPA)
  ~117 pounds/acre/year
- Lesser extent – lawn and roadways

Here we have **2,563 tons/year** of sediment in Bozeman Creek (MT-DEQ)
~300 acres active development

So **17 tons/year** of sediment enter streams from **development**!

Riparian areas are pollution buffers

- They transition between upland and aquatic ecosystems
- Trap sediment and nutrients that pass through them



Can we quantify this effect?

- A GIS analysis indicates 16% of Bozeman Creek and 47% of the upper East Gallatin has forested riparian buffer
- A literature search allows us to estimate N, P, and sediment reduction
- We know how much pollution is in each stream

The answer is yes!

Can we quantify this effect?

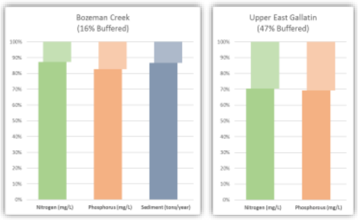
We know:
- Riparian areas reduce total P by up to 90% from runoff
- The length of the stream with riparian buffer (16%)
- The length without buffer (84%)
- The total length of the stream
- Measured values of P in the Bozeman Creek from MT Department of Environmental Quality

We assume:
- that the non-point pollution is evenly distributed
- That point source inputs are not counted
- That non buffered areas do not attenuate pollution

Then:
- We project how much pollution the buffers may have removed

[(16*90) + (84*0)]/100 = 14.4% reduction

Riparian buffers are significant



Given our assumptions!
- Increasing riparian buffering to 39% for Bozeman Creek would reduce sediment loads below TMDL limits
- Increased to 79%, it would reduce N below TMDLs

Investigated Topics

- Water quality
- Pollution budgeting
- Application of green infrastructure
- Social and environmental interface

Pollution Reduction

- $700,000 project to address water quality
- Addressing the source vs. symptoms
- Mitigate nonpoint source pollutants
- Watershed approach to restore riverine systems

Green Infrastructure

- Infrastructure that mitigates and filters the impacts of runoff from impervious surfaces
- Green infrastructure provides various beneficial services including:
  - Improved air and water quality
  - Reduced flooding risks
  - Overall enhancement of community livability

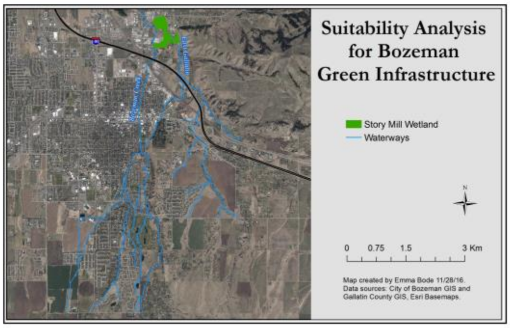
Source: Denver ultra urban green infrastructure guidelines

GIS Model Scores

- Categorized to 8 general zones
  - Industrial, parks & open space, residential infill, business park, commercial, public institutions, suburban residential, residential limited
- Scores based on Bozeman water plan, literature review, qualitative observation

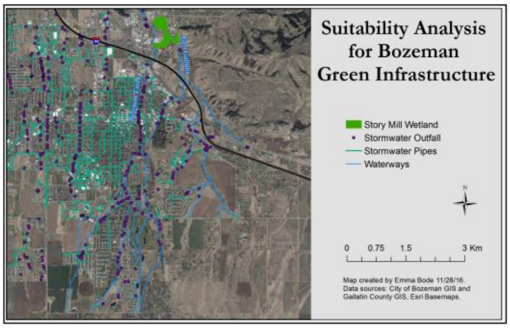
Semi-quantitative analysis: 0 – low, 1 – moderate, 2 – high

	Zoning	Nutrients	Sediment	Pathogens	Floatables	% Impervious	Totals
Industrial	M-1, M-2	0	2	0	2	2	6
Parks & Open Space	GIS Layer	2	0	2	0	0	4
Residential Infill	R-4, R-5, R-O, REMH	0	1	1	2	1	5



Suitability Analysis for Bozeman Green Infrastructure

Map created by Emma Bode 11/28/16.
Data sources: City of Bozeman GIS and Gallatin County GIS, Esri Basemaps.



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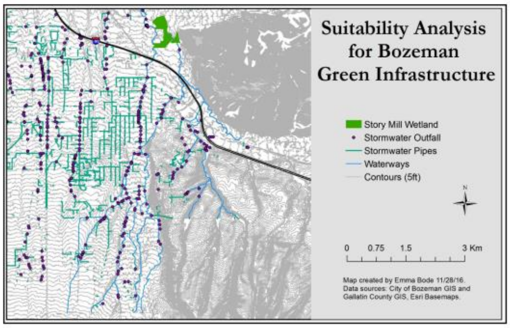

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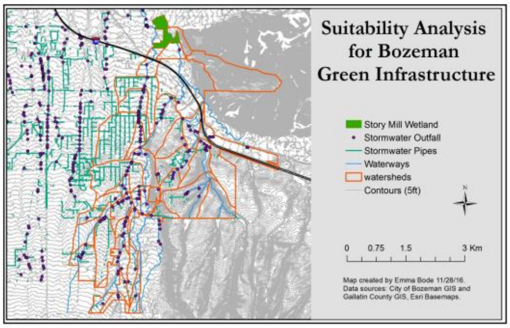

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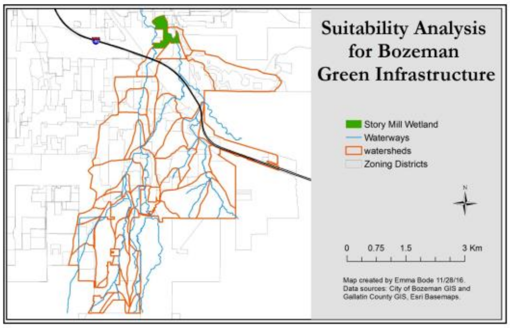

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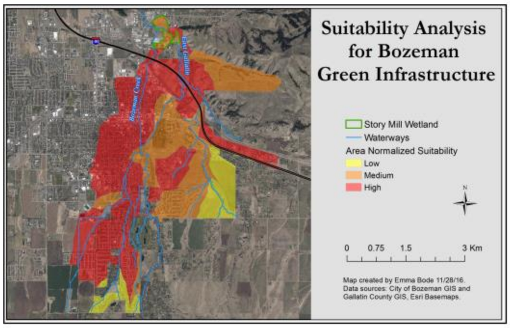

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Investigated Topics

- Water quality
- Pollution budgeting
- Application of green infrastructure
- Social and environmental interface

Story Mill Park is about People as well as Wetlands

- The park is being created because of our community values.
- We value wetlands both for services and as a wildlife refuge.
- This park is about more than the wetlands; it's also a place for recreation and education.

People and Wetlands:

A Complex Relationship

- When people stray from trails, they can cause erosion, thus impacting water quality.
- People can transport weed seeds on their clothing and vehicles.
- As our population increases, development will increase impervious surfaces and cut off wildlife corridors.

Wetland Species: Gallatin Valley

Great Blue Heron
Western Toad
Orchid
Annual Indian Paintbrush

… and many more!

Reciprocal Benefits of Wildlife Protection

- Incorporating wildlife corridors before urbanization.
- Research native species and least detrimental placement of roads.
- Use raised walkways and hardened trails.

Story Mill: Concluding Thoughts

- Bozeman's development as an aid or hindrance to wetland services
- Balancing human needs and ecological values
- Story Mill Community Park showcases our ideals