Conflict Between Urbanizing Gallatin County and Natural Resources.

MSU-Land Resource and Environmental Studies 2018 Capstone Report

Prof: William Kleindl

The Fall 2018 Land Resources and Environmental Services (LRES) Capstone Class focused on the conflict between urbanizing Gallatin County and its natural resources. Gallatin County, the Cities of Bozeman and Belgrade and the Montana Aquatic Resources Service met with the students early in the semester share their questions and concerns regarding urbanization of the region. These questions help guide the students look deeper into our local issues. The following are the final reports of the student groups and will provide:

- Why We Need Wetlands: Prioritizing Water Resources for the Future of Bozeman
- Application of a Landscape Disturbance Index to Evaluate the Best Places to Develop in Gallatin County, Montana
- Effect of Urbanization on Groundwater Resources in the Gallatin Valley
- Rapid Urbanization: Methods of Mitigating Ecosystem Stressors in the Gallatin Valley of Montana

In late November, the Capstone students presented their findings back to those planners and managers and will follow up with final reports at the end of the semester. The students also presented to the LRES freshmen to show how their education can be beneficial to our community after they finish their degree programs. A PDF of these presentations are also included in a separate file on this website.

Why We Need Wetlands: Prioritizing Water Resources for the Future of Bozeman

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Introduction

Bozeman, Montana, “America’s fastest growing mid-sized city” (Kendall, 2018), has been growing in population at a rate of over 4.3% per year. Between the years of 2000 and 2016, approximately 17,000 new residents moved to the City of Bozeman (Monares, 2018). To accommodate this growth, preemptive planning is critical for effective management of natural resources. Specifically, because of Bozeman’s semi-arid environment, water use efficiency must be prioritized to maximize water resource conservation. Water scarcity will likely be a consequence of the rapid urbanization for residents of Bozeman and the surrounding Gallatin Valley. An additional outcome of this development is that natural wetlands are quickly disappearing - and attempts to replace these wetlands and the ecosystem services that they provide often fall short of community needs and expectations.

Hydrogeologic Setting

Bozeman, Montana and the Gallatin Valley are bordered by four mountain ranges: the Bridger Range to the East, Gallatin Range to the South, Madison Range to the Southwest, and the Tobacco Root Range to the West. Additionally, the Horseshoe Hills border the North side of the Valley and the Madison Plateau borders the West (English & Baker, 2004). At an elevation of 4,800 feet and with an average precipitation of 12-18 inches per year, with a climate characterized by cool, wet winters and warm, dry summers, Bozeman is semi-arid (City of Bozeman Water Department, 2018). This below-national-average precipitation yields little water for the community; however, the mountain ranges receive significantly more precipitation in the form of snow, providing the majority of the city’s drinking water. The primary water source for the City of Bozeman is snowmelt from the Gallatin Range that eventually drains into Sourdough and Hyalite Creeks and provide about 85% of the City’s consumptive water. The remaining 15% comes from a spring at the headwaters of Lyman Creek on the Southwest side of the Bridger Mountains. After this water is treated at either of the two water treatment plants, roughly two billion gallons run through the 253 miles of pipelines beneath the City toward homes and businesses (City of Bozeman Water Department, 2018). The mountain ranges support ground and surface water throughout the valley and the Lower Gallatin Watershed, seen in Figure 1, that support agriculture needs (Hackett, 1960). With the increasing water demand due to population growth and agricultural needs, coupled with the predicted decrease in snowpack water supply because of

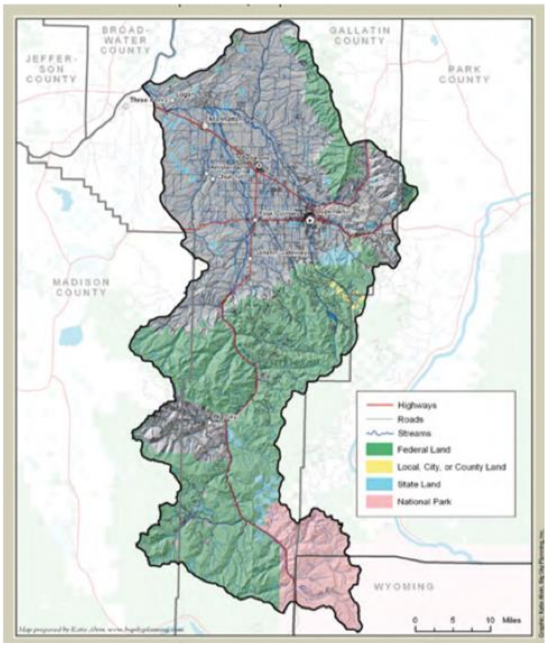

Figure 1. *Map of the Gallatin Watershed (GLWQD, 2017).*

climate change, Bozeman will not meet its water demand as soon as 2030 (City of Bozeman Water Department, 2018).

Bozeman Wetland Services

Wetlands are an often-overlooked resource that is at risk of urbanization. While wetlands may be viewed as major limitations in terms of development, they are the most biodiverse natural systems. Wetlands are described as distinct ecosystems, inundated or saturated by surface or groundwater at a frequency and duration sufficient to support hydrophilic, or water-loving, vegetation (US EPA, 2015). Characterized by hydric soils, these ecosystems are dominated by anaerobic processes below the surface. Consequently, wetlands provide an atypical low-oxygen environment that allows for many natural processes that are dependent on saturated conditions.

Wetlands provide a vast array of ecosystem services, described as processes from the natural environment and properly-functioning ecosystems that directly benefit human well-being. For instance, wetlands in the Bozeman area are an important component of water storage, availability, and quality. In an area where snowmelt is the dominant source of water, local storage of this resource is imperative. In times of high river stage and flooding, typically in the late Spring and early Summer months, wetlands can act as a sponge (Gallatin Local Water Quality District [GLWQD], 2004). They retain the vast influx of water, purify it, recharge the surrounding aquifers and later discharge to our rivers, providing fresh and clean water for months following the climax runoff. Wetlands above cities provide storage while downstream wetlands retain water that runs through the town, filtering out contaminants sourced from urban land cover.

Wetlands filter sediments by providing an environment that can break down pollutants (Matthews & Endress, 2008). They play a role in nutrient and heavy metal retention by trapping excess sediment, which can act as a transport mechanism for metals. There are many wetland plants that can take up these metals, removing them from waterways and supporting human health (Patenaude et al., 2015).

Carbon cycling is also impacted by wetlands; of all the terrestrial ecosystems, wetlands have the highest carbon density (Kayranli et al., 2010). Due to the anoxic conditions, wetlands are typically characterized by a low decomposition rate. Coupling this with their high productivity, wetlands can sequester atmospheric carbon in sediments and detritus, or organic matter (Nahlik & Fennessy, 2016). When assessing their ecological value, it is important to note their function as a carbon sink, especially when considering the mounting impacts of climate change.

The wide-reaching benefits of wetlands are often undervalued; within Montana, they provide essential habitat for several threatened or endangered species, including the piping plover, peregrine falcon, and grizzly bear. Many big game populations depend on resources found in wetlands, such as white-tailed and mule deer, moose, and antelope (Kendy, 1996). Given their contributions to outdoor recreation and game species habitat, wetlands can provide important socioeconomic benefits as well as ecological ones.

Bozeman's Need for Wetland Services

According to the Water Quality Integrated Report (2018), river and stream test results from all waterways in the lower Gallatin Watershed have shown only partial support of aquatic life. Additionally, 82% have shown only partial support of primary contact recreation due, in part, to excess phosphorus, nitrogen, nitrate/nitrite, E. coli, and sedimentation/siltation. By replacing the wetlands with more impervious services through urbanization and development, impairments to flowing surface waters are expected to increase. Natural riparian wetlands have demonstrated 29-85% retention of nitrogen and 100% of phosphorus (Vought et al., 1995). Removal of wetlands in degraded riparian zones could drastically increase nutrient loads into streams, thus lowering water quality in Bozeman and the Gallatin Valley. Yet, in the fall of 2019, 10 acres of wetlands were permitted to be filled for development projects within Bozeman's city limits (Weaver et al., 2018). That's over 7.5 football fields worth of water storage, purification, habitat, and nutrient sink that's stripped away from Bozeman and moved over 90 miles away to Twin Bridges, Montana – the location of the closest wetland mitigation bank within the Upper Missouri Watershed.

Law, Policy, and Regulation

The Clean Water Act (CWA) of 1977 states that the impact to wetlands should be avoided whenever possible. George H.W. Bush considered a suggestion from the National Wetlands Policy Forum and eventually incorporated the "no-net-loss" concept into the Clean Water Act in 1989 (Loudon, 2015). The "no-net-loss" policy affirmed the approach to wetland impacts by first avoiding impacts, minimize unavoidable impacts and mitigate unavoidable impacts through restoration, creation, preservation, and enhancement of wetlands such that there is no-net-loss of wetland area, function and values (services). The United States Army Corps of Engineers in conjunction with the EPA uses a permit system for developers that alter wetland habitat.

Permittees are independently responsible for compensatory mitigation, either by purchasing already-restored acres in a mitigation bank, by hiring a non-profit agency to mitigate for them, typically after the development has occurred (in-lieu mitigation), or by managing mitigation themselves. An important factor within CWA Section 404 is that dredging or filling of a waterbody should not occur if: "1) a practicable alternative exists that is less damaging to the aquatic environment or 2) the nation's waters would be significantly degraded" (US EPA, 2017). Unfortunately, the initial step of avoidance is often overlooked, relying instead on the next step of mitigation (Clare et al., 2011). A report backed by the USACE, Institute for Water Resources, and the EPA declares their adherence to Section 404 by claiming that impacts to wetlands are "avoided and minimized as much as possible" by citing data that show most permits impact less than a tenth of an acre of wetlands (Army Corps of Engineers, 2015). It is unclear whether the same minimization effort was considered for the most recent 10 acres of development and subsequent mitigation in Bozeman.

There are substantial issues surrounding the authoritative framework for no-net-loss by the USACE. The US Government Accountability Office has recognized this, stating that the "Corps of Engineers does not have an effective oversight approach to ensure that compensatory mitigation is occurring" (Government Accountability Office, 2005). The Corps attempts to ensure successful mitigation by requiring periodical monitoring reports from the mitigation agency and conducting compliance inspections on their end. However, they use vague and inconsistent phrasing, such as having higher priority for "substantial mitigation" but do not define what that entails (Government Accountability Office, 2005). The Corps required monitoring reports from 152 permittees that were not utilizing a third-party agency, but evidence suggests they only received 21 monitoring reports, and only conducted compliance inspections on 15 percent of those 152 permits. Of the 60 mitigation banks that the Corps required monitoring reports, 70% submitted at least one report, while evidence suggests that 36% of permit files required from those banks were inspected for compliance (Government

Accountability Office, 2005). The GA Office asserts that “Because [USACE] do not always specify the requirements of compensatory mitigation in the permits, they had no legal recourse for noncompliance” (2005). Whether the Corps has improved their administration of wetland mitigation has not been updated by the GA office, but more recent literature would suggest performance standards are still not consistently met (Clare et al., 2011). This GA Office report is dated but goes to show the USACE has not had a great track record as far as clarity of statements is concerned. These vague and open-ended specifications for mitigation projects can lead to mounting detrimental effects on ecosystem services, and ultimately can result in sweeping violations of the no-net-loss policy, without any legal repercussions.

Wetland mitigation sites are typically monitored for a minimum of five years to determine if they meet ecosystem service performance standards initially decided upon by the EPA and USACE. It is assumed by many assessment protocols, including the Montana Wetland Assessment Protocol (Berglund & McEldowney, 2008) and Washington State version (Washington State Department of Ecology, 2006), that after the first five years of meeting wetland mitigation success criteria, the wetlands will continue to meet these standards indefinitely. However, mitigated wetlands often show signs of a decrease in compliance over time. In 2012, researchers surveyed 30 different compensatory mitigation wetlands that were between 8-20 years post-construction in order to determine if they were, in fact, meeting performance standards (Van den Bosch & Matthews, 2017). Only 65% of these wetlands met project-specific performance standards after the five-year monitoring period; upon return to these sites several years later, only 53% of the performance standards were met. This suggests an overall decrease in performance, in terms of wetland ecosystem function and services. (Clare et al., 2011).

These studies provided evidence for the need of an increased duration of monitoring of constructed compensatory wetlands and emphasized the importance of keeping constructed wetlands as close as possible to natural wetlands. Similarly, one study found that 5 years of monitoring is not sufficient to guarantee the biotic integrity of wetland compensation sites, because vegetation richness often fails to meet performance standards (Robertson et al., 2017). If the City of Bozeman wishes to ensure that mitigation is fully replacing those wetlands which are lost, the monitoring time for such compensatory wetlands should increase in order to improve the success rate of wetland performance and function. A possible option is to require mitigation bank monitoring every year for 5 years, and beyond that every 2 years for a total period of at least 6 years. Ecosystem services could be left to degrade otherwise, if there is no cumulative evidence supporting the need for additional mitigation and restoration efforts.

To protect all these valuable services, it is crucial to consider the scale at which wetland relocation occurs. According to the Montana Department of Transportation, service areas for wetland banks are the geological areas in which permitted impacts can be compensated for in a given bank, and in Montana they are separated into 16 major watersheds (MDT “Wetland Mitigation Program”, 2015). There is a wetland bank located in Twin Bridges, Montana in the Upper Missouri Watershed service area (Figure 2).

The recent fill of ten acres of wetlands in Bozeman is within the Upper Missouri Watershed service area and will be mitigated for by buying wetland credits at the Twin Bridges Wetland Bank located over 90 miles away from their original location. It should be noted that the term ’service area’ means the area the bank serves; it does not mean that it is an area where *ecosystem services* are kept relative throughout. There are negative repercussions associated with mitigating 90 miles away. Among these are the localized loss of ecological services in Bozeman, challenges with relocation of wildlife, and the outsourcing of highly valued socioeconomic benefits, to name just a few. Spatially shifting our mitigated wetlands to Twin Bridges calls into question the validity of the term ‘mitigation’: at what scale does effective management of our aquatic resources exist?

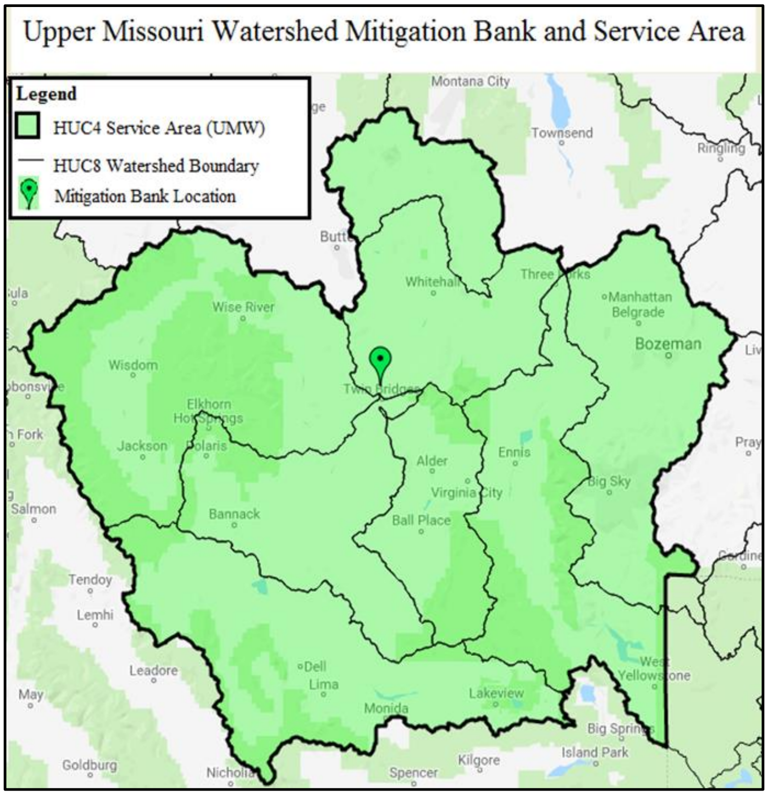

Figure 2. *Displays one of the 16 service areas in Montana, the Upper Missouri Watershed (UMW) amongst the mitigation bank, Bozeman, and smaller HUC8 watersheds. Source: RIBITS, 2018*

The Benefits of Localizing Mitigation

The satisfaction of the ‘no-net-loss’ requirement of the Clean Water Act hinges on several assumptions. The first is that the ensuing mitigation project will be successful and meet all outlined performance standards upon completion (US EPA, 2014). Secondly, it is assumed that the parameters used to define success for a mitigation project will be appropriate. As previously mentioned, studies have shown that a key factor in wetland mitigation success is proximity to the impact site.

The likelihood of meeting these end goals is greatly enhanced by constructing the compensatory wetland near the damaged wetland it is replacing (Kozich & Halvorsen, 2012; Murphy, et al., 2009). Often, this is referred to as the ‘environmentally preferable method’ of wetlands mitigation, where the compensatory wetland is constructed on-site. When determining the location of compensatory mitigation projects, the EPA emphasizes taking a “watershed approach” for the purpose of maintaining hydrologic integrity (US EPA, 2014). The scale of this approach and the definition of the watershed should be considered for future land use decisions in the Bozeman area, for numerous reasons.

There are many benefits to keeping compensatory wetlands projects localized. For example, a 2017 study found that compensatory wetlands constructed near their natural counterparts performed much better with respect to floristic quality than those that were nonadjacent (Van den Bosch & Matthews, 2017). This suggests that proximity plays a crucial role in the successful restoration of wetland plant communities, which contribute to the integrity of wetland systems and improvement of local water quality. There is further supporting evidence of this from Kozich and Halvorsen (2012): they found that on-site wetland restoration projects were far more likely to be compliant with performance standards than wetlands that were newly created elsewhere.

Other comparative studies have found that if a mitigation wetland is constructed too far away, it results in exacerbated loss of ecological services (Balcombe et al., 2005). A glaring example is the hydrologic functions that are removed from a landscape when a wetland is filled; as mentioned previously, wetlands are incredibly important to water quality, availability, and storage. They filter contaminants, acting like a sponge during times of high flows, and replenish groundwater aquifers. When a compensatory wetland is constructed off-site, the community must find a replacement for these functions elsewhere, and this often puts more pressure on local water treatment facilities – especially in rapidly-growing urban areas such as Bozeman.

There is also the problem of wildlife relocation. It is unreasonable to assume that wildlife populations dependent on local wetland habitat will be able to migrate to a new wetland project nearly 100 miles away. It is likely that the local wildlife will simple lose density through extirpation. Within Montana, wetlands provide critical habitat for several threatened or endangered species. The U.S. Fish and Wildlife Service estimates that up to 43 percent of threatened and endangered species rely directly or indirectly on wetlands for survival (US EPA, 2014). If development needs determine that filling a wetland is the only option, the most beneficial action for local wildlife species is on-site mitigation to alleviate permanent habitat loss.

It is unfortunate that the relocation of Bozeman, Montana's wetlands over 90 miles away is not a rare case of off-site compensation; frequently, mitigation projects are not adjacent to the ecosystems they are supposed to be replacing (Murphy et al., 2009). Further complications arise when compensatory wetlands for several different development projects are condensed into one centrally-located site, employing a "two birds with one stone" approach. This exhibits a blatant lack of consideration for different types of wetlands and their varying functions, as these ecosystems are highly complex. It is resulting in far greater losses of ecological services, even with the guarantee that the mitigation efforts will meet project goals (Murphy et al., 2009). Additionally, on-site mitigation projects provide a much better reference site to judge the success of restoration – there is massive variation across any landscape, involving vegetation, hydrologic regimes, and soil types. When mitigation projects take place miles away, it becomes increasingly difficult to establish appropriate parameters for success.

There are several socioeconomic benefits that come with on-site wetlands mitigation, in addition to ecological ones. In many areas, the mitigation industry has been privatized, and it would be more beneficial to keep that funding circulating in Bozeman rather than outsourcing it to other areas such as Twin Bridges. Construction of local mitigation wetlands also creates jobs, which would be a welcome addition in the face of rampant urban growth, and it would boost the local economy. Finally, it is important to consider the long-term effects: the greater the population in Bozeman, the more reliance the city will have on water treatment facilities and services. Maintaining urban wetlands within Bozeman city limits will have long-lasting positive impacts on the community, especially ecological services involving water quality and storage. This will result in the city saving money in the long run and can alleviate pressure on our current water treatment centers as it has with the local Story Mill wetland effort.

A compensatory wetland must be constructed within the same service area as the site being damaged; however, service area size can vary greatly depending on the location and overseeing agency (see Figure 2). The U.S. Army Corps of Engineers maintains that wetland mitigation requirements are satisfied by relocating them to Twin Bridges; however, though it is legal to continue mitigation there, it would be much more beneficial to require on-site mitigation projects for future development in Bozeman. All too often, the no-net-loss policy is being violated due to poor prioritization. For example, one study found that local control over wetland mitigation may place little value in hydrologic function and ecological services, and instead the decision of where to mitigate is strongly influenced by administrative boundaries (BenDor & Brozović, 2007). These are practices best avoided in the future, given the rising dependence of Bozeman's population on the services provided by our remaining wetland resources.

The United States Geological Survey created a hierarchical system to better define and classify water resources, typically referred to as Hydrologic Unit Codes (HUC). These unit codes range in scale from subwatershed all the way up to the regional scale. Currently, Bozeman's wetland resources are being managed at the HUC4 subregion scale that are about 16,800 square mile area (see Figure 2). Recall, the EPA encourages management agencies to adopt a watershed approach when determining locations for compensatory wetlands, which is more appropriate to a HUC10 scale, or about 227 square miles. Based on this reasoning, HUC4 is too large of a scale to be truly effective at upholding the no-net-loss policy; to meet a watershed approach it is suggested here that future mitigation projects in Bozeman be managed at a minimum of HUC10.

Future Mitigation in the Bozeman Area: Prioritizing Avoidance

As previously mentioned, the first and arguably most important step, avoidance, is often ignored during wetland mitigation projects (Clare et al., 2011). While "no-net-loss" aims to ensure that filled wetlands are replaced, it is unsure that reconstructed wetlands are providing the same quality of ecosystem services as the natural wetland itself. This policy only "ensures wetlands conservation at minimum economic and political cost" (Clare et al., 2011). The Army Corps of Engineers denies less than one percent of permits, only further perpetuating the notion that compensation, over avoidance or minimization, is the preferred mechanism for achieving the "no-net-loss" goal. Five key factors were determined as critical to the shift from avoidance toward compensation (adapted from Clare et al., 2011):

a. A lack of agreement on what constitutes "avoidance";
b. Land-use planners do not identify and prioritize wetlands in advance of development;
c. Wetlands are economically undervalued;
d. The belief that technology can solve problems with wetland creation and restoration, resulting in exacerbated wetland loss;
e. Requirements for compensation are inadequately enforced.

These factors can be addressed at a local scale in order to prioritize avoidance, such as using land use analysis to determine areas with highly valued wetlands. Development could potentially be prohibited in these areas, forcing developers to look elsewhere and protecting our remaining natural wetlands. This could change the future of development in Bozeman to reflect the proper value of our natural resources.

Bozeman City Municipal Code

Bozeman's current municipal code outlining review standards for the approval of activity in a regulated wetland concur with CWA Section 404, which states the mitigation sequence as 1) avoidance, 2) minimization, and 3) compensation. However, the municipal code employs the use of the word "or," and does not emphasize that these review standards should follow a sequential order, leaving it open to the developer to choose whatever step is most convenient for them. The review standards read as follows:

"The review authority may approve, conditionally approve or deny a regulated activity in a regulated wetland if:

> 1. *The applicant has demonstrated that all adverse impacts on a wetland have been avoided; or*
> 2. *The applicant has demonstrated that any adverse impact on a wetland has been minimized…, or*
> 3. *The applicant has demonstrated that the project is in the public interest… "(Bozeman City Ordinance, 2018).*

To further protect Bozeman's aquatic resources, it is recommended that the language of this ordinance be altered to reflect the sequential nature of wetlands mitigation. The highest priority should be placed in avoidance of existing wetlands.

Wetland Rating Assessment and Enforcement of a Critical Area Ordinance

A wetland rating system such as that used by Washington State could be helpful in identifying wetland sensitivity, rarity, and functions and can aid local agencies and governments in protecting and managing wetlands. This rating system separates wetlands into four different categories based on a functional score determined by "their sensitivity to disturbance, their significance, their rarity, our ability to replace them, and the functions they provide" (Clare et al., 2011). Based on the category that a wetland is placed in, actions to protect these higher priority wetlands can be taken. For example, the City of Bellingham, Washington uses this rating system to protect wetlands through their Critical Area Ordinance (Ch. 16.55 Critical Areas | Bellingham Municipal Code). In this ordinance, areas that have been determined as critical are allowed limited impacts and alterations by regulating land use and development using permits. To retain a permit, one must show "an inability to avoid or reduce impacts, before restoration and compensation of impacts will be allowed" (Ch. 16.55 Critical Areas | Bellingham Municipal Code).

Similarly, Klickitat County, Washington use their Critical Area Ordinance to "provide guidance for protecting those wetlands necessary to maintain the public health, safety, and welfare" (Sauter et al., 2017). This includes wetlands that greatly reduce erosion, siltation, flooding, and water pollution, as well as those that provide critical fish and wildlife habitat and aquifer recharge. If impacts are unavoidable and compensatory mitigation must occur, the ordinance states that "[if] mitigation is located off-site, the wetland mitigation plan shall assess whether an appropriate location has been identified to adequately replace lost wetland functions at the site of impact." Should Bozeman choose to adopt its own Critical Area Ordinance or follow a wetland rating system such as the example shown below, the protection of wetlands could be greatly increased.

Wetland Classification

These local governments use Washington State's Wetland Rating System that assesses wetlands and places them into four categories based on their size, functions, services, and rareness. The local governments then can use these categories to determine buffer size and mitigation replacement ratios. To provide our local Gallatin Valley governments an example of how this could assist with their wetland management we adapted the 1991 Washington State Wetlands Rating System for Eastern Washington (McMillan, 1991) for use in Gallatin County, MT. Washington State currently uses an updated 2014 version (Hruby, 2014), however we used the simplified 1991 method because it is more conducive for a spatial analysis, while the 2014 version is more focused towards on-site analysis. This rating system was used as a guide and several shapefiles were overlaid to create a map of various resources, land uses, and important features across Gallatin County. Next, the adapted scoring of the Washington rating system was modified to score Gallatin County's wetlands. This system differentiated wetlands into four distinct groups of 1-4. Each class had different broad definitions to assist in understanding the rating system. Category 1 wetlands are uncommon and comprise a small percentage of the wetlands in the state while containing habitat for rare or endangered species or providing irreplaceable functions and services that are unable to be replicated within a human lifetime. Wetlands classified as Category 2 are difficult to replace, as well as provide many ecosystem functions and services. Category 3 wetlands provide important functions and services; while more common, they tend to be smaller and less diverse than Category 2 wetlands. Category 4 wetlands are small, isolated, lack diversity, and should be capable of replication in a mitigation bank (McMillan, 1991) Determining between class two and three was beyond the scope of this spatial exercise, so they were categorized together. These sensitivity rankings can be used by managers to determine wetlands fit for consideration of mitigation.

To categorize Gallatin County's wetlands, shapefiles containing pertinent information were utilized, such as: land cover, National Wetland Inventory (NWI) classification, urban areas, occurrences of threatened or endangered species, and presences of rare or special species to Montana. Any wetlands that had occurrences of threatened or endangered plant species, wildlife, or fish were categorized as Class 1. Sites rated as high-quality native wetlands by the Natural Heritage Program or documented as migratory bird habitat were also classified as Category 1 wetlands by the Washington rating system; however, these shapefiles were not included in the assessment for Gallatin County, due to inability to find appropriate shapefiles. Category 2/3 wetlands are determined by containing state listed sensitive plants, wildlife, and fish (McMillan, 1991). Differentiating between Category 2 and 3 requires data collected from on-site visits which were not performed for this study, contributing to the decision to merge wetlands of Categories 2 and 3. Lastly, Category 4 wetlands were classified as less than 2 acres and hydrologically isolated, however, because of the scope of this project, we made some assumptions about hydrological connectivity. If, and when, this project moves forward, we would refine these parameters.

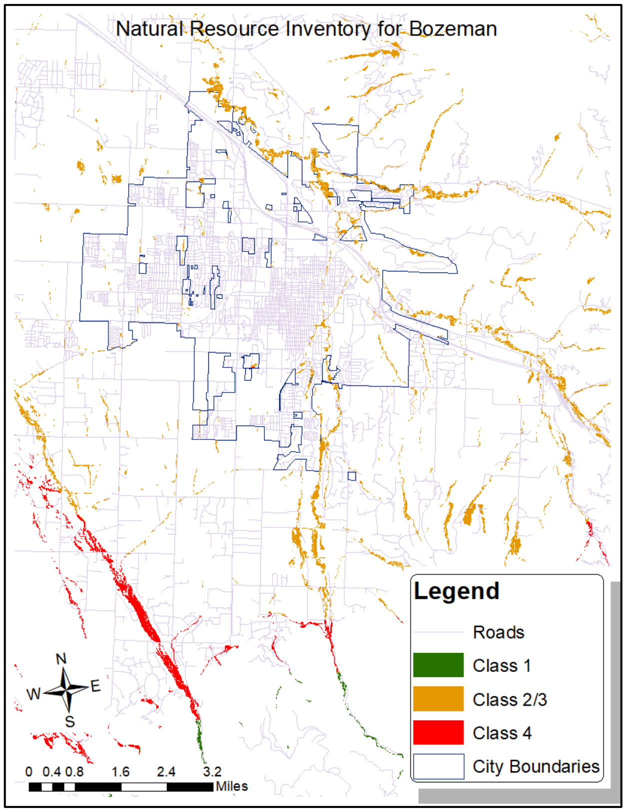

Figure 3. *Wetlands surrounding Bozeman, Montana.*

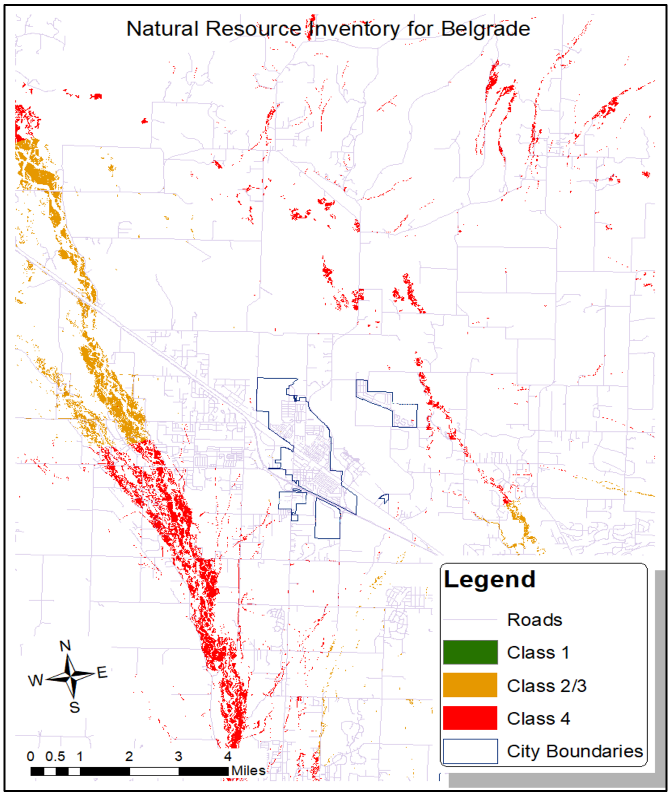

Figure 4. *Wetlands surrounding Belgrade, Montana.*

Use of Wetland Classification

Once the category of each wetland was calculated, the Washington assessment provided buffer or set-back size and replacement ratios for mitigation banking. Replacement ratios are meant to guide the full replacement of wetlands damaged by necessary and unavoidable impacts. Buffers that should be in place for each class are as follows: Category 1 buffer (width of 200-300 ft), Category 2 (100-200 ft), Category 3 (50-100ft), and Category 4 (25-50 ft). Transforming this to the simplified model meant slightly altering the buffer zones and ratios (Table 1). In the Washington assessment, replacement ratios for Category 2 and 3 are grouped together based on plant type, forming the basis for the combination of Categories 2 and 3 for the Montana assessment.

Table 1. Proposed buffer zone width and replacement ratios for classified wetlands of Montana

Category	Purposed Buffer Zones (ft)	Proposed Replacement Ratios
I	200-300	6:1
II	50-200	Forested 3:1
III		Scrub-Shrub 2:1
		Emergent 1:5:1
IV	25-50	1.25:1

The resulting maps do not simulate the appropriate buffer zone for each category, but this could be implemented for future zoning plans (see Figures 3, 4). Figure 3 shows the wetlands surrounding Bozeman: there is an obvious lack of class one wetlands in this figure, but they appear further to the south within the Gallatin Range. Closer to the Bozeman City limits, there is a shift toward Category 2/3 wetlands in the draft effort, as there are occurrences of rare plant species, such as whitebark pine or slender Indian paintbrush. Most of Bozeman's wetlands are classified as Category 2/3, with the highest density of wetlands along the Northeastern border of the city limits. Figure 4 shows the wetlands surrounding Belgrade, most of which are categorized as Category 4 in the draft effort because they lack occurrences of important plant species. Belgrade's city limits can extend nearly two miles before encountering large densities of higher prioritized wetlands. When coupled, these maps represent a possible classification of wetlands providing the most ecosystem services to Gallatin County. These maps can be used in the future to aid in predicting which wetlands will be impacted first with urbanization in the county and can assist in the protection and conservation of high-value wetlands.

Challenges with the Adaptation

Due to the limitation of scope in this effort, the proposed categorization is necessarily simplified; therefore, the resulting maps could be considered as an approach toward best mitigation practices as our area becomes more populated. These maps should be used as guidance when determining appropriate replacement ratios and width of wetland buffers. It should also be understood that this simplistic model over-assigned the density of Category 4 wetlands, and in truth some of them may be Category 2/3 based poor information on hydrologic connectivity. If this system is implemented the results of a wetland must be confirmed with on-the-ground data before land management decisions are made about the wetland in question. The simplification detailed above also causes several wetlands to be unclassified, because only three parameters existed to sort each wetland and there were some that did not fulfil any of those requirements. The end decision of the authors was to classify these as Category 4, because while they were larger than 2 acres they did not contain critical habitat for endangered species or occurrences of species that are of high conservation interest in Montana. To see which wetlands remained unclassified, access the unclassified map layer.

Development of more detailed understanding of wetlands will greatly improve the accuracy of this model. Areas of focus should especially include the occurrence and density of invasive species, community diversity, and habitat features. This data will allow the use of the on-site determination to differentiate between Categories 2 and 3, as well as shift some Category 4 wetlands into a more accurate classification. This version of the Washington wetland assessment tool was used because of its relative simplicity compared to newer versions. This classifying scheme (see Table 1) will be essential for future assessments that are developed to protect local wetland and riparian ecosystems of Gallatin County.

Conclusions

Bozeman's rapidly growing population continues to threaten natural resources in the surrounding area, especially aquatic resources. Wetlands have been shown to store and purify significant amounts of water, as well as provide many other ecosystem services that the 47,000 people in Bozeman currently benefit from. Bozeman has already lost substantial natural wetland acreage due to a reliance on the mitigation aspect of “no-net-loss”; its residents will not receive these benefits unless the policies surrounding mitigation are revised and enforced. There is a major loss of ecosystem services from Bozeman when its wetlands are filled and mitigated in Twin Bridges. Planners in Bozeman should make allowances for not only the conservation of existing wetlands, but localized mitigation of any wetlands filled for unavoidable development needs. Wetlands have a higher success rate for meeting compliance standards when ecosystem functions are replaced in a localized manner. Furthermore, it is highly beneficial to Bozeman’s residents to localize these replacement hydrologic functions.

If Bozeman’s population continues to grow at its current rate, wetlands will continue to be impacted as will their ability to provide ecological services to rising demand in the coming years. Changes in current water resource management policy should consider the remarkable benefits that could arise from keeping wetlands local. Other things to take into consideration are:

the possibility of creating a mitigation bank directly near Bozeman for future wetland mitigation and altering the scale of future management decisions to take a small-scale watershed approach - as recommended by the EPA. Additionally, the maps provided in this report can be utilized for future land-use decisions and can assist land managers with prioritizing avoidance of the most critical wetland ecosystems as Bozeman continues to grow and develop.

An important factor influencing the migration rate to Bozeman is its natural beauty and recreational landscape, both of which are augmented by the presence of wetlands. The whole of Montana has been dubbed “the last best place” because of this concept of untouched nature, and it would certainly be a shame for that to no longer apply to Bozeman in the future. This furthers the importance of keeping our remaining wetlands intact for future generations.

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Application of a Landscape Disturbance Index to Evaluate the Best Places to Develop in Gallatin County, Montana

Brody Wallace, Eric Stratton, and Laura Mooney

Introduction

Bozeman, Montana is growing at a rate of 4.2%, and is the fastest growing micropolitan area in the U.S. with receiving almost 4,000 new residents from 2016-2017 (U.S. Census Bureau, 2018). The U.S. Census Bureau estimates the Gallatin County will have 55,000 new residents by 2045 (Kendall et al., 2018). Although this growth does indicate a strong economy, the opportunities for its residents comes with an environmental penalty. This increased urbanization has expanded onto historic agriculture lands and natural areas. Wetlands are an example of a natural area that has a very important part of an ecosystem. They provide many ecosystem services including, aquifer recharge, water storage, flood control, sediment control, nutrient removal, erosion control, habitat for wildlife and plants, recreation, and visual and aesthetic pleasure (City of Bozeman, 2016). Undeveloped areas adjacent to development can also experience secondary effects that originate from the development. The greater the development, the greater the intensity of impacts. These impacts come from a combination of air and waterborne pollutants, physical damage, and changes in the suite of environmental conditions (Brown et al., 2005).

The policy of no-net loss of wetlands was initiated under President George H. W. Bush in 1988. This executive order requires no-net-loss of wetland area, functions and values. If wetlands are filled under benefit of federal permits, that fill must be mitigated for to ensure no-net-loss. Wetland banks are intended to provide mitigation by selling credits for that acreage with the intention of replacing total acres of wetlands and the functions and values of those wetlands that are lost (Sibbing, n.d.). Here in Bozeman, the closest wetland mitigation bank is 90 miles away.

As recently as 2018, the U.S. Army Corps of Engineers permitted the fill of over 10 acres of wetlands in Bozeman for residential and commercial development (Weaver et al., 2018). The loss of wetlands has the potential to negatively impacts local aquatic functions in the Gallatin Valley. For instance, development on wetlands can decrease surface water storage and groundwater recharge. As impervious area increases, the velocity and volume of surface runoff increases and there is a corresponding decrease in infiltration (Arnold et al., 1996). Additionally, as these wetlands are turned to residential areas, there is a decrease in the ability of the landscape to remove excess nutrients and pollutants. There is also an increase in nutrients from the overuse of lawn fertilizers. The Department of Environmental Quality already determined that 14 tributaries of the Gallatin River do not meet the applicable water quality standards due to excessive sediment and nutrients (Bullock et al., 2013). As Gallatin Valley continues to grow, the problems with water storage, nutrient removal and atheistic pleasure will increase. It is important for our City to be active about these problems and not reactive when the issues require attention. To respond to the growth in Gallatin County it will become essential to develop growth plans to ensure the least impact options regarding soil, wetland, and forest quality be taken in Gallatin County as it continues to grow.

Project Idea

Since development is inevitable we are interested in finding the least impact locations for future development within Gallatin County. We will focus on using Geographical Information Systems (GIS) approach to create a land disturbance index (LDI) that will aid in Gallatin

County’s developmental planning. Our criteria for the best places to develop includes avoiding wetlands, prime farmland; land that is available and has the best combination of physical and chemical properties for producing food, feed, forage, fiber, or oilseed crops (National Resources Inventory, 1997), and preferably on already disturbed land. We plan to use current development mechanisms that are being employed in the City in combination with parameters we think are important to consider. Our parameters will be combined in GIS to create a land disturbance index. This method assigns numerical values to various types of land (agricultural, urban, natural, etc.), therefore allowing planners to assess environmental quality over a spatial scale. Using this method of assessment, planners can make more informed decisions about land use. They can also use LDI values to determine the overall quality of different types of landscape, and how changes might affect the system. Planners may consider the level of disturbance in different areas, or the distance between higher levels of disturbance, to evaluate human impact. This method may also indicate when and where mitigation efforts are most needed. Maps created using the LDI method may assist in urban planning, as they provide a quantified and easily understandable compilation of environmental quality and anthropogenic impacts (Decker et al., 2017). Using preexisting data layers such as soils, wetlands, land use/cover, waterways, roads, and digital elevation models, a model of optimal land use will be developed. The model will emphasize preservation of prime farmland, wetlands, and existing greenspace while identifying the best areas for residential and commercial development. Land disturbance indexes have been used to reflect land use and determine the least or most human impacted areas. The LDI can then be used to recommend sites for development based on their land disturbance values.

LDI Development

Urban planning that considers possible environmental damages can be cost effective over time. For the most effective results, planners and scientists suggest that cities shouldn’t plan to avoid building challenges and increase the ease of growth, but to maximize the overall productivity of the land. By doing this, planners may be able to find a balance between sustainable growth and meeting the greater needs of the community (McCormack, 1974). In Bozeman, city planning ideas do not need to be completely reimagined. Other cities have had success in city planning through strategic zoning, regulations, and mapping. Emulating places that have been through intense growth periods and still retained healthy wetlands and maximized ecosystem productivity may save Gallatin County planners time, money and reduce the need for a trial-and-error approach. Wetlands, for instance, are protected by local, state, and federal laws. Applicants with development proposals that may adversely affect wetlands must apply mitigation sequencing before permitting agencies consider compensatory mitigation options. In Washington, permitting agencies require applicants to show that they have followed the mitigation sequence and worked first to avoid and minimize impacts to wetlands wherever practicable.

Mitigation sequencing includes:

1. **Avoiding the impact** altogether by not taking a certain action or parts of an action.
2. **Minimizing impacts** by limiting the degree or magnitude of the action and its implementation by using appropriate technology, or by taking affirmative steps to avoid or reduce impacts.
3. **Rectifying the impact** by repairing, rehabilitating, or restoring the affected environment.
4. **Reducing or eliminating the impact over time** through preservation and maintenance operations during the life of the action.
5. **Compensating for the impact** by replacing, enhancing, or providing substitute resources or environments.
6. **Monitoring the impact** and taking appropriate corrective measures.

Avoiding and minimizing impacts becomes even more important when rare, high quality, or difficult to replace resources are involved (Washington State Dept. of Ecology, n.d.). Avoidance is often overlooked in the City of Bozeman even though wetlands provide benefits to the ecosystem. Because of this issue, we placed greater importance on the protection of wetlands when building our LDI. Using the LDI to evaluate where wetlands occur around the county can help developers better achieve avoidance rather than relying on the later steps of mitigation or compensation. Similarly, other factors can also be prioritized when defining LDI values which is why we created three separate scenarios with the LDI framework that we built. The three scenarios specifically highlight different land uses that might receive higher values depending on the user's interests. The first scenario focused on placing value on farmland, forests, and wetlands. This scenario represents where development is most suitable when considering all parameters important. Our second scenario placed importance on just the farmlands. This would be useful for developers as they continue to expand west of Bozeman because there is an abundance of prime farmland that they would remove from the agricultural economy of the County. The scenario prioritizes prime farmland might steer development away from this fertile land, and to areas that were previously degraded, or have less of an agriculture potential. The third scenario we made prioritizes forests and wetlands. This would most likely be used by developers or city planners that are most concerned with the loss of ecosystem services from our immediate surrounding. As mentioned earlier, ecosystem services are vital to any city and become increasingly important as the population in Gallatin County continues to grow. The flexibility of the model we built makes it easy to change any of the LDI values to better suit any user's needs. This also allows for the framework to be continually improved and adapted as the needs of the county develop and change.

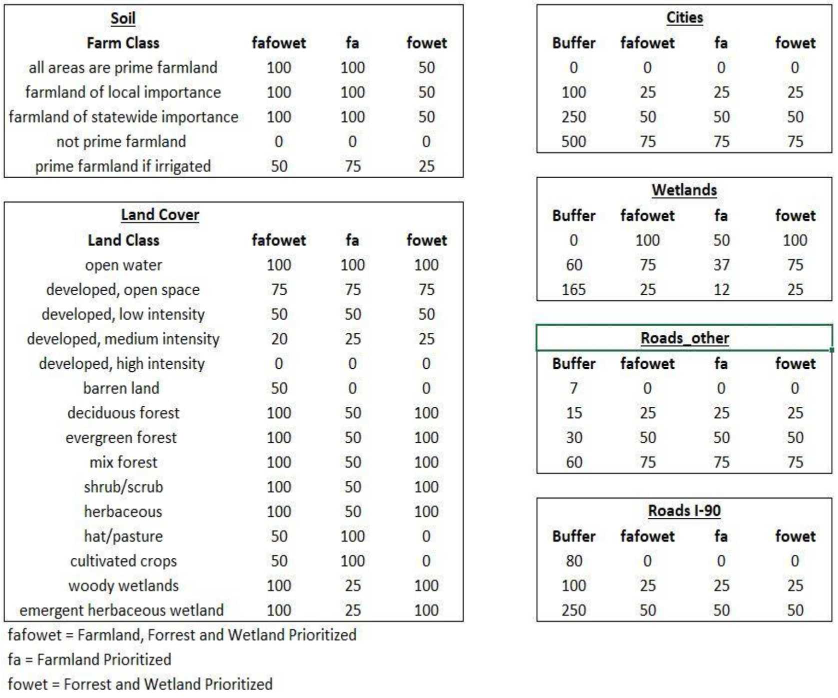
Methods

Conceptually the LDI is a simple process. All layers used: soils, wetlands, land cover, City boundaries, and roads in the LDI were converted to a raster projected in NAD 83 Montana state plane with 30 by 30-meter cells. Each cell in all layers were assigned a value of 0-100 with 0 being completely degraded land and 100 being prime land in the farm land scenario (Table 1). The rasterized layers were then run through a cell statistic tool and a mean value for each cell location was calculated into a new raster that was the basis for the LDI. After which a DEM of Gallatin County was built using a mosaic of National Elevation Datasets. This DEM was used to build a slope raster that was used to mask slopes at or greater than 15%, the max slope to be considered for development in the model. Although on a macro scale of the project the LDI is straightforward, considerable and specific preparation had to be done on each layer used to build the LDI.

Soil:

Soils data was acquired for the Gallatin County from Web soil survey (Gallatin County GIS, 2005). This layer did not have the soil suitability for farming, so that data was obtained from the NRCS (NRCS, n.d.), converted to a table, and joined to the Gallatin County Soil data. This added a "farm class", attribute to every soil in the county. The farm class attribute was then reclassed and used in the statistic step of the LDI model.

Table 1: Compilation of the LDI values that we assigned different land classes. The three scenarios we modeled are shown as fa, fowet, and fafowet. Fa is where only farmlands, fowet has forest and wetlands, and fafowet has farmlands, forests, and wetlands prioritized.



Soil

Farm Class	fafowet	fa	fowet
all areas are prime farmland	100	100	50
farmland of local importance	100	100	50
farmland of statewide importance	100	100	50
not prime farmland	0	0	0
prime farmland if irrigated	50	75	25

Land Cover

Land Class	fafowet	fa	fowet
open water	100	100	100
developed, open space	75	75	75
developed, low intensity	50	50	50
developed, medium intensity	20	25	25
developed, high intensity	0	0	0
barren land	50	0	0
deciduous forest	100	50	100
evergreen forest	100	50	100
mix forest	100	50	100
shrub/scrub	100	50	100
herbaceous	100	50	100
hat/pasture	50	100	0
cultivated crops	50	100	0
woody wetlands	100	25	100
emergent herbaceous wetland	100	25	100

fafowet = Farmland, Forrest and Wetland Prioritized
fa = Farmland Prioritized
fowet = Forrest and Wetland Prioritized

Cities

Buffer	fafowet	fa	fowet
0	0	0	0
100	25	25	25
250	50	50	50
500	75	75	75

Wetlands

Buffer	fafowet	fa	fowet
0	100	50	100
60	75	37	75
165	25	12	25

Roads_other

Buffer	fafowet	fa	fowet
7	0	0	0
15	25	25	25
30	50	50	50
60	75	75	75

Roads I-90

Buffer	fafowet	fa	fowet
80	0	0	0
100	25	25	25
250	50	50	50

Land Cover:

The National Land Cover Database (MRLC, 2013) was the least cumbersome and only required a reclassification of land cover categories to LDI values. The values that were chosen are arbitrary and based on what we thought needed the most protection and which areas are the most degraded. Land cover values can be easily changed to place more value on different land classifications.

Wetlands

Wetland data was obtained from the National Wetlands Inventory (USFWS, 2018). We decided to remove any wetlands less than 2 acres because they are not deemed as important for ecosystem services. If we did not limit the minimum size of the wetlands, our LDI would show the entire county covered in wetlands with the buffer size we chose. This layer was dissolved by wetland type and buffered by 60m and 165M. These buffer sizes came from a study by Semlitsch and Jensen (2001) that found that the zone within 164M of the wetland encompassed 95% of wetland population. The 165M buffer represents the core habitat of species that live in the wetland.

Cities

The City boundaries of Bozeman, Belgrade, Manhattan, and West Yellowstone obtained from the Gallatin County GIS data page (Gallatin County GIS, 2018). The layer was dissolved to a single city boundary attribute to remove excess attribute data. After which 100m, 250m, and 500m disturbance buffer were created to represent the decrease level of disturbance as distances from the city limits increase. Each buffer zone then had areas of overlapping buffers erased. For example, the buffer areas of the city limits were removed from the 100m buffer so that there would be no overlapping of data when the layer was rasterized and assigned LDI values.

Roads

Using Road data from Gallatin County GIS (Gallatin County GIS, 2018) dirt roads, driveways, and roads within city limits, were the LDI score was already 0, were removed to prevent redundancy and to acknowledge that a dirt road in the woods would have a negligible impact when compared to a major road. Using aerial imagery, the average width of the different road types was measured and used to make a buffer that represent the actual size of the feature because the layer consisted of line features which does not contain any width information. I-90 was removed from the trimmed road data and converted to its own individual layer as it is a major highway and needed a larger buffer than smaller roads. 1-90 received a buffer of 100M and 250M to emphasize the importance of protecting areas further from the road corridor. The smaller roads were given a buffered at 60M and 30M based on the findings from a study by C. Murcia (1995).

Results

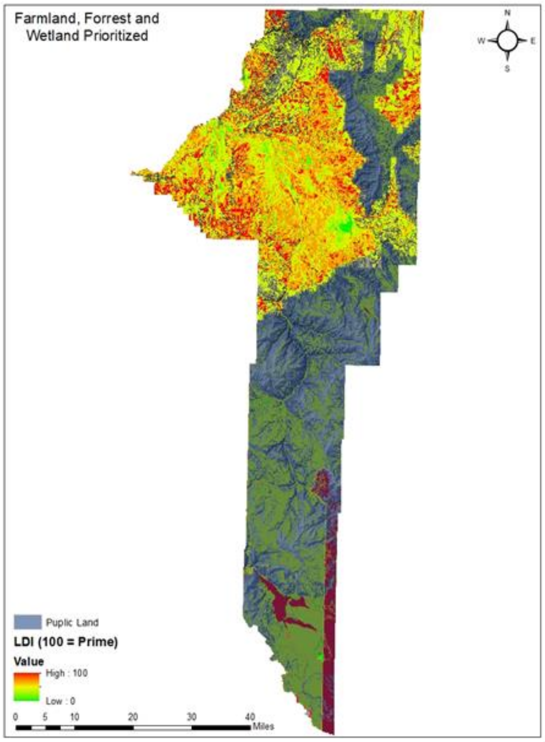


Figure 1: Farmland, Forests and wetlands are prioritized

Using the LDI Framework, three land use scenarios were mapped. A model that represents conservation of both farmland, wetlands, and forest (Figure 1), a model that prioritizes farmland (Figure 2), and a model that prioritizes forest and wetlands (Figure 3). Areas of red are areas with high LDI scores indicating that they are lowest human disturbance. Areas in green have a low LDI indicating that they are already disturbed and should be considered for development. Intermediate areas are represented in yellow. The translucent blue layer represents private land. The grey area are zones were the slope is at or above 15% and were not factored into the LDI. The above maps highlight how robust the model is. Scoring can easily be adjusted to represent the needs and priorities of the community and decision makers.

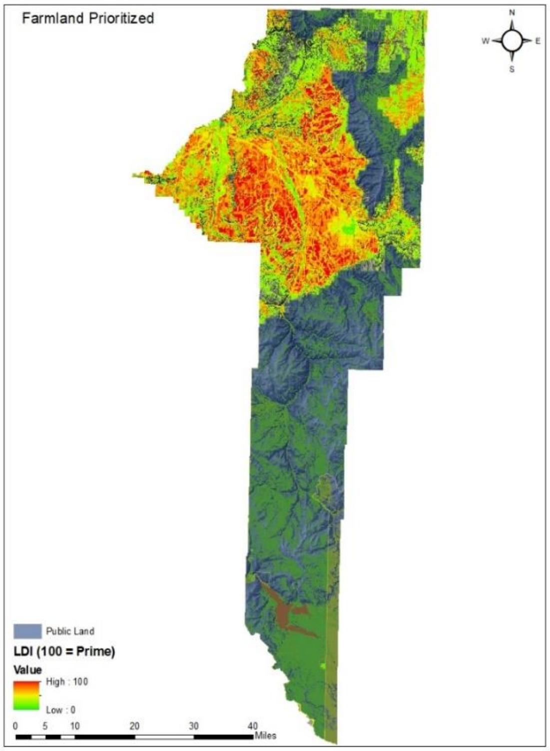


Figure 2: Farmland Prioritized

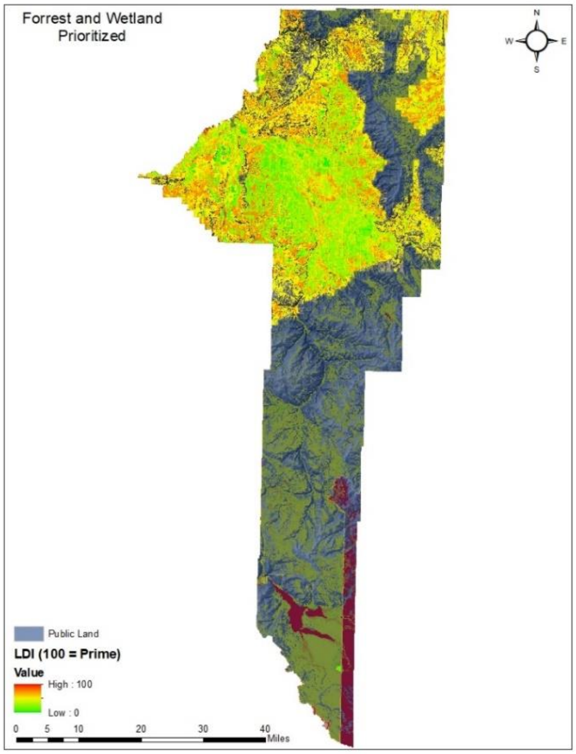


Figure 3: Forrest and Wetland Prioritized

Discussion

The spreading urbanization coupled with the effects of population growth seen in the Gallatin Valley require us to proactively plan land and resource use. To ensure a more sustainable future, land developers must have a way to evaluate ecosystem quality and services to develop around them before permanent degradation occurs. The purpose of this planning is not just to preserve natural lands and essential resources and ecosystem services for growing population, but to shape the future of our communities as directed by public input.

Land degradation can be driven by several factors, one of the most prominent of which being urbanization. Construction projects, transportation infrastructure, poor management of resources, and simply the increased population density all pose significant ecosystem threats. These activities can lead to soil contamination, loss of local biodiversity, erosion, water and air quality concerns, and loss of recreation areas. Most studies on this matter highlight the need for balance; to maintain a healthy ecosystem through urbanization, we must plan to protect valuable natural functions while, at the same time, balancing them against the competing objectives of urban developers (Oliveira et al., 2018). This method often prioritizes the protection of fertile soils, large green areas, and the ecosystem services they provide. While land use planning for urbanization regarding limiting environmental degradation is not a new subject, there is evidence that planners did not begin to proactively consider these issues until at least the early 2000s. Rather than more passively including environmental concerns among other plans, researchers have increasingly begun to focus more on sustainability and controlling environmental damages. In more recent year’s land use plans and research began to consider more specific issues, such as water quality and climate change. Currently, research has turned toward studying the linkages between land-use planning and ecosystem degradation to evaluate best management practices (Oliveira et al., 2018).

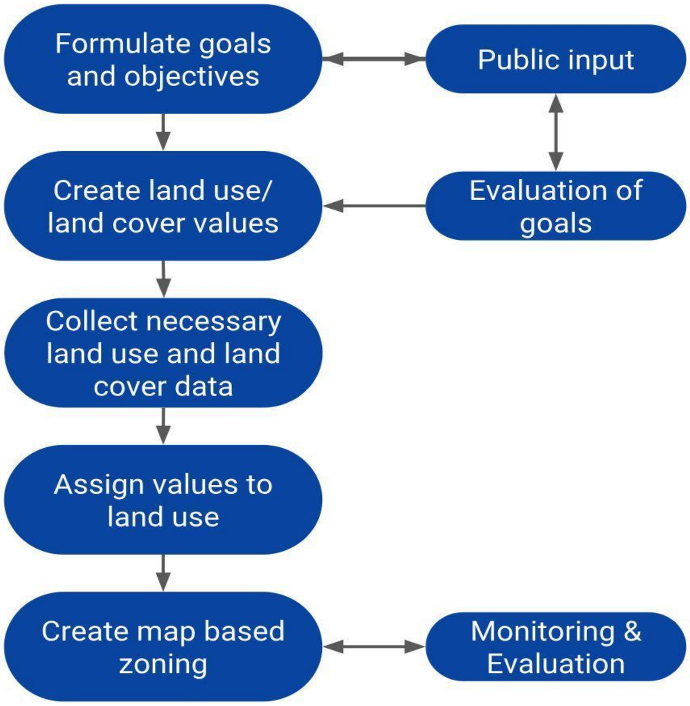


Figure 4: This shows the workflow of developing an LDI for a specific need.

The methods presented in this paper were intended to emulate those studies that were conducted with the goal of proactively considering specific environmental concerns to promote sustainability. The LDI was performed to not only determine what damages have already been inflicted upon the land by urbanization, but also to evaluate the best possible course of action that planners could take to minimize their environmental impacts. Figure 4 shows our recommended approach building an accurate LDI for Gallatin County's needs. Planners begin by clearly defining goals and objectives, in an iterative process with public input. This step will prioritize lands, such as forests, riparian areas, wetlands or, agricultural lands, to be protected through zoning options. Public input provides important guidance in the early stages of the goals and objectives of development to create an accurate LDI.

Once goals are defined, LDI values can be assigned. Areas that were earlier defined as high priority for protection will receive the highest values. For example, if the original goal was to protect wetlands, these are the regions in the map that would receive the maximum LDI value. Other areas can be valued lower, whether they are mid-range valued open areas or urban areas. This system will provide a scale like that seen in the above maps. Buffer sizes can also be set based on more specific needs or habitat sizes. Once values are assigned, they can be plugged into the map template, and provide a visualization of the originally defined goals.

The resulting map can be used to create zoning and ordinance plans for future urbanization. For example, if the original goal was to protect wetlands, these areas would show up as red on the map, indicating areas to avoid development (see Figure 3). These are areas that might be zoned for low-density to no development, as they provide multiple ecosystem services necessary for a growing community like Bozeman. The oranges and yellows on the LDI in Figures 1-3 represent the mid-range values. These are areas where urbanization would be okay, but perhaps low-density development would be preferable. The lowest values that were assigned earlier in the process -- those areas that were already damaged or otherwise not deemed valuable to the original goals -- would appear in green. These are the areas that could be zoned for the highest density of urbanization, as these were defined as the least concern for development or the most degraded areas.

Using this method, towns in the Gallatin Valley may begin to grow in more sustainable ways. Development will be carefully planned based on prioritizing and protecting various resources instead of developing more randomly. This would not only save natural areas for local enjoyment and use, but it would also preserve necessary ecosystem services for a growing county. This would also save money that would otherwise be spent on remediation and mitigation once environmental issues were of concern.

There are some potential limitations to this method. First, the most recent map layers must be used to create the most accurate depiction of current land-use. For example, there are a few notable areas in the maps above where development has already occurred, such as Four Corners and Big Sky, but it is not reflected in currently available layers. This may be remedied if base layers were collected for the project as opposed to using publicly available information. This would also remedy other issues; for example, not all development was included in the maps above as unincorporated areas or those developments that are currently out of city limits were not available at the time of creation.

Despite these limitations, this method could have great outcomes if performed with greater resources and budget. With more accurate map layers, a more detailed LDI can be created. The same method can be applied at a larger or smaller scale, depending on the goals of the project. If city/county zoning is based wholly on LDI maps, city planners can effectively build around and account for sensitive areas or build over previously damaged areas.

Conclusion

Gallatin Valley could potentially face several environmental crises caused by unchecked growth and poorly planned development. The early signs of these problems are already visible in the growing need for more water and natural resources to sustain such population change. However, as the town grows with little heed for land-use planning regarding environmental concerns, more and more of these natural resources are being damaged, covered up, or destroyed entirely. Eventually, it will be too late to proactively plan for sustainable growth, and the costs and losses will be greater because of it.

We can learn from other cities have experienced such growing pains already, and they can be used as examples. Methods have been created and successfully applied to plan and evaluate the sustainability of urban growth. Using the LDI we built, we have a framework that can be applied to several scenarios and used to map out the best growth paths for towns in the Gallatin Valley. The model that was created as a part of this project can be used as a template to keep track of current land degradation and ensure the best land management practices for future growth.

By basing zoning and ordinances on such a growth model, the Gallatin Valley may begin to see much more sustainable growth. By prioritizing ecosystem health, agricultural land, wetland preservation, or other qualities well before development occurs, we may begin to plan around them instead of damaging or filling them in. Considering the quality and services that the land may or may not provide before urbanization intensifies could lead to a more sustainable future for the entire valley.

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Effect of Urbanization on Groundwater Resources in the Gallatin Valley

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Introduction

In agreement with the pressures that exist globally with population growth and natural resource utilization, the trends of population growth in the Gallatin Valley bring an urgent need for careful planning of water allocation and protection. The valley is situated between the Bridger, Gallatin, and Madison mountain ranges. The Gallatin River, a sub-basin of the Upper Missouri, is the largest order stream in the area, flowing north into the greater valley at Gallatin gateway. It is runoff dependent and heavily influenced by snowpack quantity and melt timing. The Gallatin River is met by many streams that flow out of the north end of Gallatin Range and out of the west and south aspects of the Bridger range. Three significant streams that flow into the Gallatin River are Hyalite Creek, Bozeman Creek, and Lyman Spring, and they are listed as Bozeman's current water sources according to the 2017 Water Quality Report (City of Bozeman, 2017). Hyalite Creek and Bozeman Creek are both runoff driven out of the Gallatin Range, and Lyman Spring is a spring creek driven by groundwater pressure coming from the Bridger range. Although these are currently viable water sources for Bozeman, it is predicted that there will be a water shortage if the city population continues to grow at current rates. Beneath the Gallatin Valley is an alluvium-based aquifer consisting of alluvium, material left by streams, and it is highly permeable to water infiltration (Kendy & Bredehoeft, 2006).

Demographic studies show that the Gallatin Valley underwent population increases upwards of thirty percent in the decade from 1990 to 2000 and in 2017 experienced an average annual growth rate of 3.67 percent (Beland, 2001). Population increases are followed by a variation of demands for water use in agriculture, municipal needs within a community and its residents, and requirements for ecological and recreational values of our waters. This paper seeks to assess variables that contribute to groundwater recharge and discuss the contemporary issues associated with them, to better understand the relationship between urbanization and water use and give insight on potential solutions to questions surrounding the subject. Answering the three following questions concerning urban development and the connectedness of groundwater to surface water in the Gallatin Valley will help achieve this goal:

1) How will changes in land cover affect water movement and groundwater recharge?
2) How do changes in irrigation methods affect recharge of groundwater?
3) How can groundwater pumping and the addition of exempt wells across the Gallatin Valley affect groundwater levels?

> *"Increasing population numbers, expanding areas of irrigated agriculture and economic development are drivers for an ever-increasing demand for water worldwide . . . The resulting lowering of groundwater levels can have devastating effects on natural stream flow, groundwater fed wetlands and related ecosystems,"* (Wada et al., 2010).

Changes in Surface Cover

Understanding how groundwater is affected by various factors is imperative for forecasting potential water use scenarios, and for influencing potential management and water budgeting plans in the future. Recharge is dependent on water use through evapotranspiration, seasonal precipitation concerning amounts and distribution across different surfaces, and "the capacity of the ground-water reservoir to store additional water" (Hackett et al., 1960). Land use change in the Gallatin Valley has seen trends from natural land to agriculture and now to developed urban areas. With this growth comes the need to examine water use and patterns of watershed recharge as a function of land cover. One major factor of land cover in water balances is the effect of impervious surfaces.

As an area experiences urbanization, there are increases in surfaces such as roads, parking lots, buildings, and other developments. These surfaces reduce the amount of storm water that can infiltrate into the groundwater supply and most of the water that would have infiltrated ends up as surface runoff. Changing land from agricultural, wetland, and forest systems to urban areas can alter hydrologic conditions present by typically increasing "the volume and rate of surface runoff and [decreasing] groundwater recharge and base flow" (Tang et al., 2005). Each definitive type of land use has a range of imperviousness, and each cover type affects watershed recharge through infiltration of storm-water. By understanding how land use is changing in the valley, and whether there are patterns associated with this change, potential distributions of future land use can be accounted for and reviewed.

Changes in Irrigation

Agriculture is a significant contributor to water use around the world and has a pronounced effect in more arid regions. In Montana, there are roughly 1.8 million acres of irrigated land as of 2013 (USDA, 2013). On this irrigated land roughly 2.5 million acre-feet of water, approximately 815 million gallons of water, is applied each year (USDA, 2013). Most of this water comes from surface water diversion. In 2013, roughly 54,000 acre-feet, 3%, of water used for irrigation was groundwater (USDA, 2013). This number has been decreasing since 2003 when approximately 96,000 acre-feet, 4.5% of irrigation water, was supplied by groundwater utilization (USDA, 2003).

Currently, three methods of irrigation are widely used throughout the United States: flood irrigation, sprinkler irrigation, and drip irrigation. Each type of irrigation has several subcategories, but they are negligible for the context of this study. Flood irrigation involves either diverting water from a nearby source or pumping water from a groundwater source and flooding the field with a layer of water. This layer of water then percolates down to the root zone where it is absorbed by the plants. It is currently the most common method in Montana being utilized on roughly 61% of irrigated land (USDA, 2013). One downfall is that flood irrigation is 50% efficient, meaning that only 50% of the water applied reaches the root zone (Water Resources, Development and Management Service, 1989). The rest of the water is lost to evaporation and percolation below the root zone. Although it has low efficiency, some of the water that reaches the root will go past the root zone and reenter the aquifer, allowing for groundwater recharge. In recent years as a response to its inefficiency, there has been a shift towards sprinkler irrigation. The generally accepted efficiency of sprinkler irrigation ranges from 70-90%, depending on a few variables such as height of sprinkler, and pressure of application (Rajan et al., 2011). Though the sprinklers are more efficient, less groundwater recharge occurs.

Groundwater Pumping

Groundwater is greatly relied on for agriculture, public supply, and industrial uses. However, a common concern in this resource development is the effect groundwater pumping has on surface flows. In fact, basin-wide groundwater development would occur over several decades, meaning the effects of surface flow depletion would go unnoticed for many years in the future (Barlow & Leake, 2012). Groundwater and surface water greatly correlate with each other, depending on the depth of the groundwater table below and the state of the connection between the two. There are two outcomes that the flow of water from above would cause: the surface water body either drains or recharges the aquifer (Brunner et al., 2008). If the groundwater table keeps lowering, then the discharge to the surface water will decrease.

In 1993 the Upper Missouri Basin was legislatively closed to any new surface water appropriations, causing any new development to rely on groundwater as their water supply (Dunne et al., 2016). Like many of the other U.S. western states, Montana has exempt well provisions. These exempt wells refer “to groundwater withdrawals that are exempt from one or more state law requirements that apply to water withdrawals generally” (Richardson, 2012). Under Montana’s Water Use Act, there are three processes a well must follow to get exempt from any permits that are required: the withdrawal rate does not exceed thirty-five gallons per minute, the annual withdrawal does not exceed ten acre-feet per year, and the well cannot be located within a controlled groundwater area (Ziemer et al., 2012). As Montana’s population increases, so has the number of exempt wells drilled each year. “Out of Montana's 56 counties, forty percent of exempt wells developed between 1991 and 2010 were concentrated in the four fastest-growing counties: Ravalli, Flathead, Gallatin, and Lewis and Clark” (Ziemer et al., 2012). This expansion has raised concerns for senior water rights becoming impaired by the effects of many exempt wells cumulatively causing a large withdrawal. Montana alone has been circling this issue since the 1980s, with organizations and stakeholders wanting to propose several possible solutions. The City of Belgrade also relies on groundwater for their water source, which can only be recharged from water seeping down from higher elevated landscapes. The addition of exempt wells across the valley adds further pressure on balancing water supply needs without lowering groundwater levels.

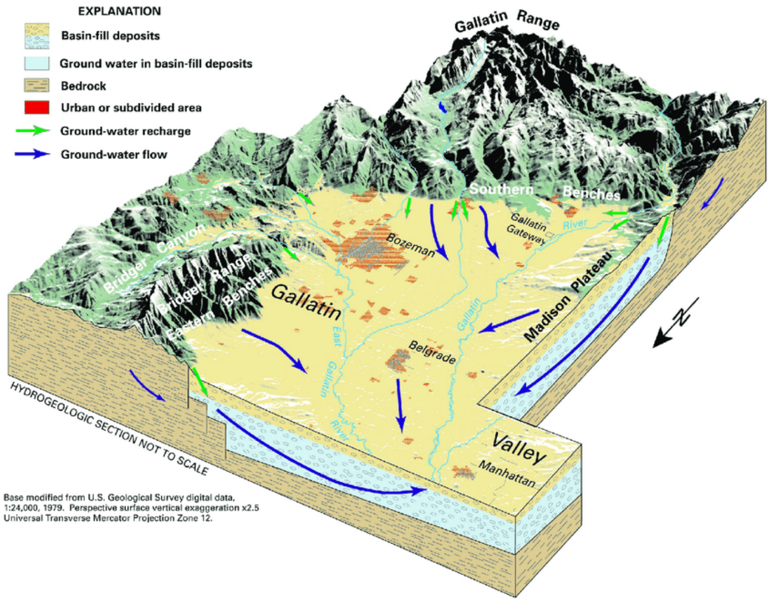

Figure 1. Groundwater Movement in Gallatin Valley

Methods

To begin understanding the surface cover and irrigation aspects of the groundwater issue simplified models were applied to begin quantifying these issues. By quantifying each we can numerically begin to see the bigger picture of the groundwater situation. Concerning surface cover, an SCS runoff curve was applied to look at storm water runoff for a single precipitation event. With irrigation, an equation was developed to quantify how much groundwater recharge occurs in the Gallatin Valley under each flood and sprinkler irrigation to better comprehend how changes in these methods would impact the hydrology of the system. Apart from using models to analyze the Gallatin Valley, outside research was investigated to see how groundwater is being handled elsewhere. This modeling and research is not completely conclusive and points to more questions that must be asked, but it does develop the issue and gives insight as to how groundwater can be approached and understood by management.

Monitoring Land Use Change and Calculating Storm Event Runoff

To understanding how changes in land use and land cover affect surface storm water runoff in Bozeman, Land Use and Land Cover data was retrieved from the National Land Cover Database for the years 2001, 2006 and 2011 (MRLC, 2011), and were manipulated using ArcGIS Version 10.6. For this analysis, the area of study was the Bozeman City limits. Land classifications were reclassified to represent 8 classes of Land cover, within the study area (City limits) and percent cover of each classification was recorded for each year that data was available for. The land classification categories were, Low Developed (0-19% Impervious area), Medium Developed (20-49% Impervious Area), High Developed (50-79% Impervious Area), Very High Developed (80-100% Impervious Area), Agriculture, Forested, Natural Land, and Wetlands. Once percent land cover for each class had been calculated, a weighted Curve Number

(CN) was calculated for each year. Soil Conservation Survey Curve Number Method (Equation 1) is a method of calculating runoff (Q_{runoff}), which considers precipitation (P), soil hydrologic groups, land cover classification, and hydrologic condition of the soil.

Equation 1: Runoff as a function of CN

$$Q_{Runoff} = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Curve Numbers (CN) are a range of coefficients from 30-100 that represent the relative runoff potential of a catchment area. Lower curve numbers indicate low potential runoff, while higher curve numbers represent high runoff potential for a storm event. From the weighted curve numbers, the potential maximum retention after runoff begins (S) (Equation 3), and Initial Abstractions (I_a) (the maximum amount of storm water that is absorbed by a soil without producing any runoff) can be calculated.

Equation 2: Maximum Retention after Runoff Begins

$$S = \frac{1000}{CN} - 10$$

Equation 3: Initial Abstractions

$$I_a = 0.2 \times S$$

For this scenario, precipitation was derived from meteorological data for Bozeman from 2001, 2006 and 2011. Single 24-hour storm events that took place around the same time each year (13 June 2001 - 1.28 inches, 9 June 2006 – 1.23 inches, and 7 June 2011 – 1.22 inches) under similar hydrologic conditions were averaged to maintain consistency in runoff calculations. Therefore, we used an average of 1.24 inches was the accepted precipitation for this analysis.

Irrigation Groundwater Recharge Method

With the irrigation model, the first goal was to generate an equation that could accurately describe water use given all the variables that affect groundwater recharge through irrigation. The variables that were considered were area of application (A) in acres, irrigation type (Gravity (g), Sprinkler (s)), rate of water application on the field (R) in acre-feet per acre, and groundwater recharge rate (Rc). All these variables were combined into one equation shown below where (i) stands for a generalized irrigation type and Tw stands for total water taken out of the system.

Equation 4:

$$Tw = \sum [(Ai*Ri) - Rc]$$

The first part of the equation (AiRi) calculates the total amount of water applied to the field. The recharge coefficient was then applied to the end to deduct the amount of water that returns to the hydrologic system allowing for a calculation of the amount of water used for irrigation for all methods of irrigation. Rc is not a constant therefore it must be calculated for each irrigation type using the equation as follows since each method of irrigation has different efficiencies.

Equation 5:

$$RC = \Sigma\ ((AiRi\ (1-Ei)) - Eo) + Gri)$$

In the case of equation 5, (E) stands for the efficiency of each irrigation method and (Gr) represents the percentage of water that percolates past the root zone and reaches groundwater. Eo calculates the equation using a version of the Penman-Monteith equation using temperature data (Linacre, 1977). The equation is shown below. Tm is defined as the average Temperature (*T*) + .006h where h is the elevation in meters. *Td* is the dew point temperature and *A* is the latitude (Linacre, 1977). This equation generates evaporation is mm day^{-1}. Therefore, by dividing by 0.312 yields the results in acre-feet per growing season based on a 95-day growing season.

Equation 6: $Eo= (700\ Tm/ (100-A)+15(T-Td))/ (80-T)$

Gr is not a constant and therefore has to be calculated by the equation below.

Equation 7: $Gr= \Sigma(((AiRiEi)*Ml*D)-St)$

Ml represents the antecedent moisture level of the soil. For the context of this model, there are only two levels of moisture: wet and dry. For dry conditions, the value of *Ml* is 1 meaning all the water that no water is restricted from flowing, however for wet conditions the value of *Ml* decreases to 0.8. This is because it was found that 20% less water percolates to 150 cm with a wet antecedent moisture level (Mark Andrew Schaffer, 2011). *St* is referring to the soil texture, meaning a sand, silt or loam. Each of these soils has a different water holding capacity. It was found by a study done in California that loam, which is the most common soil type in the Gallatin Valley has a water holding capacity of 1.5 inches of water per 36 inches (90 cm) of soil (Marsha Mathews et al., 2016). *D* represents the number of days at each antecedent moisture level. It was found that Gallatin County received rain on average 120 days out of the year (Montana Climate Office, 2010).

Observed values were found in the USDA agricultural censuses so the calculations were verified. To verify the calculations and calibrate the model, both observed and calculated values were plotted on a graph. Watering rates were adjusted slightly to align the calculations for total water applied with the observed values for total water applied. This was done because only average watering rates were given and therefore there was some amount of error.

Once the amount of total water applied was verified, the amount of water that reached the root zone was calculated by multiplying the total water applied by each irrigation method by their respective efficiencies. These values were again summed to give the total amount of water that reached the root zone. From here, the amount of groundwater recharge was calculated using equation 5, 6 and 7. Surface water runoff was calculated using the first part of equation 5. Once this was done, the amount of recharge was subtracted from the total amount of water applied to give the total amount of water used. This procedure was then repeated for each year in the censuses and survey.

Once all the years' water usages were calculated, the next step was to scale the model down to the Gallatin Valley. Gallatin County makes up roughly 1.26% of the state of Montana and based on 2016 statistics from NASS (National Agricultural Statistics Service), the amount of agricultural land is representative of that percentage. Therefore, each step in the procedure above was the recalculated for Gallatin County by multiplying the respective values by 1.26% (0.0126).

There were a few assumptions that were made throughout the modeling process that need to be noted. The first is that the efficiency of the irrigation method is based on the lowest efficiency for the system including the transportation of water to the field. In the case of flood irrigation, the efficiency was the based on the efficiency of transporting water using an unlined ditch. The efficiency of sprinkler irrigation was based on the application efficiency. In both cases, these areas were shown to be where the most amount of water loss happened. The second assumption was that all climate data used was based on yearly averages. This includes temperatures and precipitation amounts.

Results

The models defined in the methods section were carried out and yielded results that indicated potential losses to groundwater recharge in relation to changing land use and shifts in agriculture towards water efficient systems. This data and external studies imply that with urbanization, careful management steps need to be taken to adequately protect and plan for future and present resource use.

Land Use Change

As the population of Bozeman grew by an average of 3.67% annually, it was observed that there was an increase in developed land within the city limits. Developed land increased by 803.72 acres (6.13%) from 2001 to 2006, and another 849.07 acres (6.48%) from 2006 to 2011 (Figures 2, 3, Table 1).

This increase in developed land within the city limits resulted in increasing curve numbers associated with them, due to the nature of the relationship between developed area and increased impervious surfaces. The weighted curve numbers for 2001, 2006 and 2011 are 79.17, 79.7, and 80.21 respectively.

When the 1.24-inch precipitation was applied to these scenarios, there was an increase in surface runoff for the storm events between the changes in land cover. The total precipitation volume for the city limits for the previously stated event was a grand total of 442,470,890.16 US gallons. For the 2001 land cover scenario, about 54.7 million gallons were lost to runoff, in 2006 runoff increased by about 3.77 million gallons from 2001, and in 2011 it increased about another 3.75 million gallons from 2006. In total, over the 10-year study period runoff increased by about 7.52 million gallons (on an increase of about 1.7% of the total runoff) because of increased development and area of impervious surface. More details are available in Table 3.

Figure 2 and 3: Change in Impervious Surface Area from 2001-2006 (left) and 2006-2011 (right)

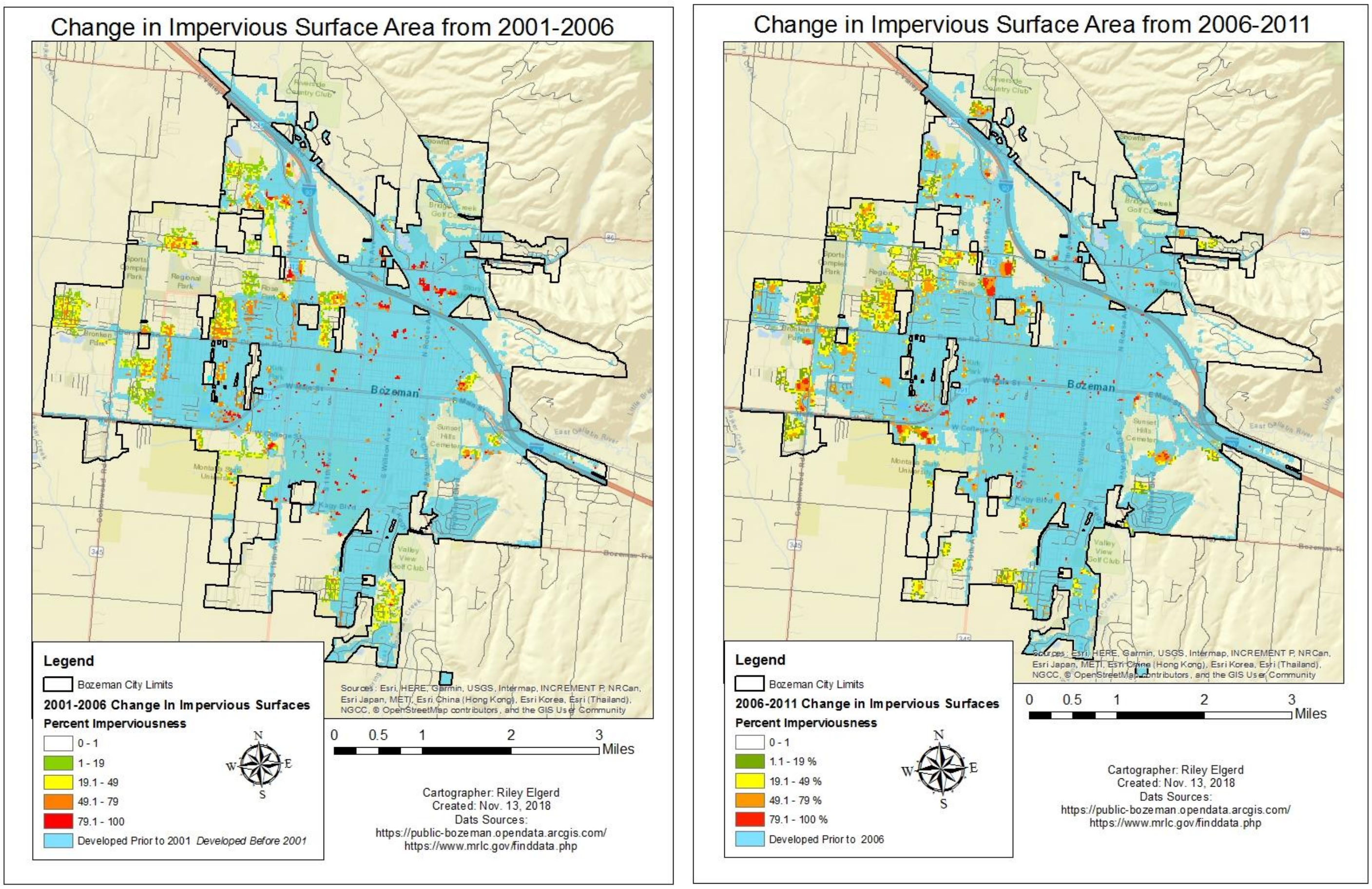

Table 1: Increase in Developed Land in Bozeman

Year	Acres Developed	% Land Cover Developed
2001	6,733.35	51.36%
2006	7,537.07	57.49%
2011	8,386.14	63.97%

Irrigation Change

Table 3 shows the amount of land irrigated by each method over the 4 census years. Some areas of interest are that between 1998 and 2003 there is an increase in the total amount of land irrigated across Gallatin valley followed by a decrease in irrigated land in the following years. Table 4 shows the amount of groundwater used by each irrigation method. Some areas of interest in this table are that irrigation with groundwater decreases for all census years while the amount of surface water used increases between 1998 and 2003 followed by a decrease every census year following.

Table 2: Total Runoff for 1.24-inch Storm Event with Change in Land Cover

Year	Runoff (gallons)	Runoff (acre-ft.)	Percent Runoff of Total Volume
2001	54,648,696.60	167.70	12.35%
2006	58,414,923.25	179.27	13.20%
2011	62,168,915.88	190.79	14.05%

Table 3: The amount of land irrigated by each method for each census year

Date	Total Irrigated Land (acres)	Sprinkler Irrigated Land (acres)	Total gravity Irrigated land (acres)
1998	21,954	7,189	14,765
2003	26,863	9,740	17,158
2008	25,004	11,108	13,896
2013	23,591	10,702	14,422

Table 4: The amount of land irrigated by each source of water for each census year

Date	Irrigated land with groundwater (acres)	Irrigated land with surface water (acres)
1998	1,395	20,559
2003	1,216	25,647
2008	707	24,298
2013	692	22,899

Table 5 shows the calculated amount of water applied to all irrigated lands for each irrigation method. The notable trends in the data are that the total amount of water applied to the irrigated lands as well as the amount of water applied by gravity irrigation decreases each census year. However, the amount of water applied to the irrigated land by sprinklers increases each year until 2013. This is due to the shift in irrigation methods from gravity irrigation to sprinkler irrigation. Table 6 shows the observed amounts of water applied to irrigated lands in Gallatin valley by each method. These values were used to calibrate the model. When comparing tables 5 and 6, the calculated total amount of water applied was relatively close to observed values. However, there are larger discrepancies when comparing the calculated amount of water applied by each irrigation method. This is since the calculated values are calculated using average watering rates which can cause the amount of water to deviate from observed values.

Table 5: Total amounts of calculated water applied, and amounts applied by each irrigation method

Date	Water Applied Calculated (acre-feet)	Water Applied Gravity Calculated (Acre-feet)	Water Applied Sprinkler Calculated (acre-feet)
1998	37437.36	29529.54	7907.82
2003	35708.82	24020.93	11687.88
2008	33616.41	18065.14	15551.27
2013	31590.19	18748.29	12841.90

Table 6: Observed amounts of water for each irrigation method for each census year

Date	Total Water Observed (acre-feet)	Water Applied Gravity Observed (acre-feet)	Water Applied Sprinkler Observed (acre-feet)
1998	37,800	25422.06	12377.94
2003	35,581	22726.68	12901.16
2008	33,525	18631.42	14893.11
2013	31,530	19274.95	14302.86

Table 7 shows the total amount of water returned to the hydrologic system via both surface runoff and groundwater recharge as well as the total amount of water used by irrigation after recharge is considered. Some notable trends are that both amount of water returned to the hydrologic system and total water used decreases continuously over the entire time frame. However, the amount of water returned decreases much faster than the total amount of water used due to the shift in irrigation methods from gravity irrigation to sprinkler irrigation.

Table 7: Amount of water returned to hydrologic system and total water used by irrigation in Gallatin County

Date	Amount of water returned	Total Water Used
1998	9674.47	27762.89
2003	8628.53	27080.28
2008	6592.23	27024.18
2013	5955.61	25634.58

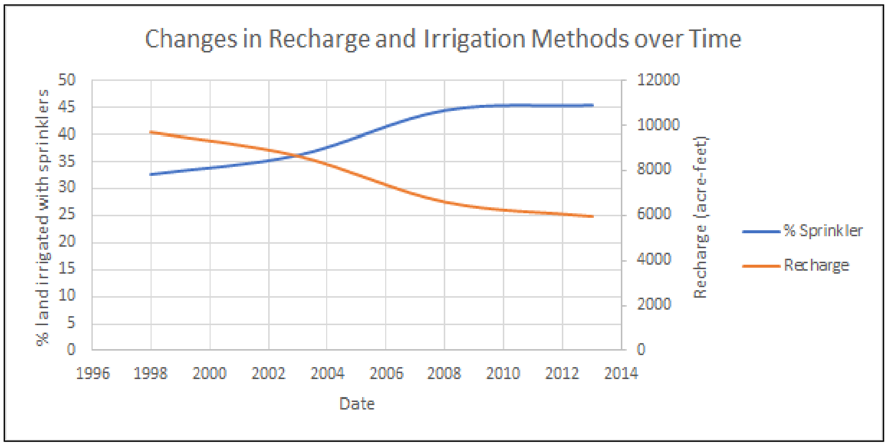

Figure 4: The relationship between method of irrigation and the amount of recharge over time

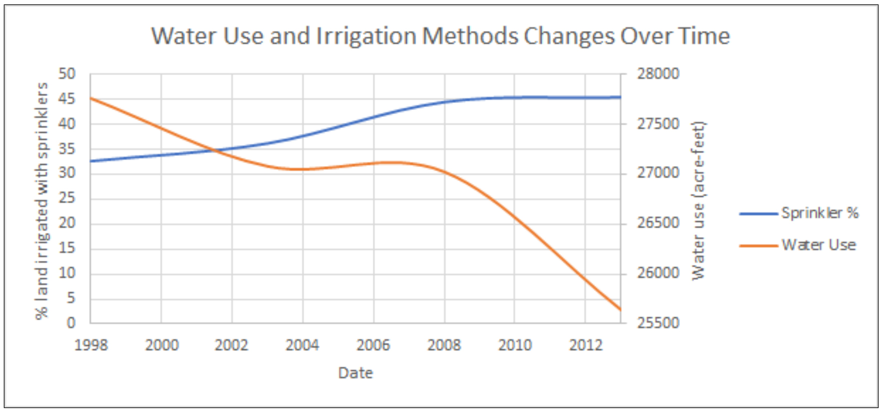

Figure 5: The relationship between methods of irrigation and agricultural water use over time

Discussion on Urbanization and Water Use Effects on Groundwater.

Through modelling and external research, this discussion focuses on groundwater recharge and planning for water supply. Information was gathered on how other cities have faced dwindling water supply and approached the issue, as well as local research and applied modelling on groundwater characteristics and land use interactions. Poor planning of city infrastructure has led to cities facing water supply crisis. In situations such as Cape Town in South Africa or Bangalore in southern India, proactive resource management of water supply wasn't dealt with until a crisis arose and required reactive measures that can only seek to salvage what remains (Roy, 2009).

Gallatin Valley has a significant hydraulic connection between surface water and groundwater, and it appears that "virtually all of the groundwater beneath the valley discharges to the Gallatin River and its tributaries" (Kendy & Bredehoeft, 2006). In part of a 2006 study, Kendy & Bredehoeft looked at the effect that groundwater pumping has on stream flow in the Gallatin Valley. With the hydrologic relationship between surface and ground water, there are essentially two different classifications: gaining and losing. If a stream is gaining, it is receiving water through the discharge of groundwater to the surface, and if a stream is losing, it is recharging groundwater. This is based on the elevation of the water table relative to the elevation of the stream at a given location and can be consistently changing based on the segment of the stream and time of year. In both instances however, stream level can be affected by a change in groundwater. Kendy & Bredehoeft analyzed stream levels at the same time as seasonal groundwater pumping was occurring, and they found that the most important factor on the impact of pumping was the distance it occurred from the stream (Kendy & Bredehoeft, 2006). Stream depletion was in phase with the pumping when the well was close to the stream, but when the well was further from the stream, depletion was more constant over the course of the year not just during the season of pumping. Groundwater pumping mitigation, through the process of pumping water into the ground to artificially recharge levels, would be easier to carry out with wells that are further from streams as depletion would be more constant over the year (Kendy, & Bredehoeft, 2006).

Concerning urban water use, there is a present reliable water yield of 11,500 acre-ft. per year which is sufficient to meet current water demands but is expected to surpass needs between 2030 and 2035 (City of Bozeman, 2016). It is essential to be proactive in expanding resource availability by diversifying sources of water supply within Gallatin County. Under current conditions, storm water is treated for water quality to meet TMDL standards before being released as storm water discharge according to the 2017 Bozeman Storm-water Treatment Plan, which requires a permit from the city. One potential option for diversifying water sources, for either urban or irrigation purposes, could be the retention of storm water through detention facilities which could be implemented downstream from proposed water quality treatment sites, to maintain water quality and current storm water management techniques, with the added benefit of an additional source of water to the current water supply. The goal of using storm water catchments is to temporarily store storm volumes and slow water release in runoff and promote infiltration (Yoder, 2002). A 2012 study determined that increasing development changes natural surfaces to typically impervious ones, and this increases total annual runoff along with spring season flows, and consequently decreases baseflow and groundwater recharge during both dry and wet seasons (He & Hogue, 2012). It is well understood that surface water and groundwater are connected, so as the amount of surface water that is retained in the watershed increases, so will the amount of water held in the aquifer. Detaining storm water in holding ponds could increase groundwater recharge by allowing water to infiltrate back into the aquifer or can be used as a surface water supply rather than flowing out of the system. Added benefits of storm water detention include decreased chance of flood damage of waterways and corridors due to the decreased surface flow from event storm water.

The goal of the irrigation model was to predict the amount of water that would be used for irrigation as well as the amount of water that is returning to the aquifers and hydrologic systems. It was found that agriculture applied roughly 31,000 acre-feet of water in Gallatin County in 2013. However, roughly 6,000 acre-feet of water was returned to either streams or aquifers due to runoff or infiltration. Both total water applied, and amount of water returned have decreased since 1998 from 37,000 acre-feet and 9,700 acre-feet respectively. This change in recharge can be confidently attributed (p=0.004) to a shift from gravity irrigation to the more efficient sprinkler irrigation.

This is not surprising because very little water is applied to the soil with sprinkler systems in comparison to gravity irrigation. With gravity irrigation, large amounts of water are put on the field at once leading to higher volumes of runoff and return to streams as surface runoff. What doesn't run off either evaporates or infiltrates into the soil and eventually into the aquifers if it is not taken up by plants. As flood irrigation has been consistently used in the recent past in Gallatin Valley, it has become a normalized part of the system's hydrology. Kendy and Bredehoeft (2006) state that flood irrigation is an important source of groundwater recharge that maintains late season flows in streams. With sprinkler irrigation however, two factors reduce the amount of water returned to the hydrologic system. First, less water is being applied by sprinkler irrigation systems overall (p= 0.037), and second, that water is being applied over a longer amount of time. The second factor allows for the soil to absorb moisture at a faster rate than with the gravity irrigation that quickly saturates the soil and then slows infiltration. This means that there will be less runoff with the sprinkler irrigation than with gravity irrigation. That partially accounts for why this correlation exists. The first factor however also plays a role in this given that less water is being applied overall, therefore less water can return to the system and be reused later.

In terms of groundwater impact, the model found that an increase in sprinkler irrigation is not significantly affecting the amount of water that returns to the hydrologic system in the form of groundwater (p=0.823). This creates a dilemma. As of 2013, roughly 1,400 acres of land is being irrigated with groundwater which relates to approximately 1,500 acre-feet of water being pumped out of aquifers and roughly 2,700 acre-feet of water was being returned to the aquifers. This difference in the inputs and outputs of water to the aquifer is because much of the water for irrigation is surface water that comes from streams and ditches in the Gallatin Valley. The surface water is being applied to the fields and that surface water is reentering the hydrologic system as groundwater creating a positive accumulation of groundwater in the aquifers. During late spring and early summer, flood irrigation diverts water from streams lowering flows, but in the Gallatin Valley this promotes groundwater recharge that slowly works through the aquifer and eventually discharges back into streams, supporting flow quantities in late parts of the season (Kendy & Bredehoeft, 2006). However, as climate changes, surface water will start to decrease and be harder to access for irrigation due to water rights. This means that more and more people will begin to rely on groundwater, especially in arid and semi-arid areas such as Gallatin County (Zhou et al., 2010).

This is supported by a 2004 study in Star Valley, Wyoming, that looked at a stream response to a shift of irrigation method from flood to sprinkler that occurred in the late 1960s. Ultimately, total annual flow for the stream was found to increase with the change demonstrating that the more efficient method did save water, but the timing of flows was altered (Venn, et al., 2004). In May and June, flows increased 34 percent and 50 percent respectively, and in August and September, flows declined by 15 percent and 14 percent (Venn, et al., 2004).

Both the amount of water coming out of the aquifer and the amount of water returning due to agriculture need to be taken into consideration when looking at the water needs of the city. Two additional considerations that need to be included, is first what depth in the aquifer is the water coming from, and second what is the quality of the water being returned. Gravity irrigation tends to create more polluted runoff than sprinkler irrigation that could affect neighboring streams, for example, nitrate leaching and sedimentation (Porhemmat et al., 2018). Lastly, recharge water percolates to shallow groundwater sources quickly, but may take decades to reach deep aquifers (Bouwer, 1987). This means that as surface water dwindles, wells will need to be dug deeper to ensure that the crops get enough water. However, all the water that is being recharged into the aquifers will take much longer to replenish the groundwater source creating a net loss of the aquifers.

A similar situation as Gallatin Valley exists in the Treasure Valley of Idaho. The Treasure Valley has experienced extensive population growth and urbanization while maintaining heavy agricultural use. The valley has 35% of Idaho’s population with main cities such as Boise, Caldwell, Meridian, and Nampa. Much of the municipal water supply in this region comes from reservoirs and groundwater pumping. A hydrologic project took place to assess water use and risk questions and looked extensively at the aquifer and groundwater levels spatially across the valley (Petrich, 2004). Part of the study used MODFLOW numerical modelling to assess how groundwater would be impacted if all their currently unprocessed groundwater rights were granted and filled. MODFLOW is the hydrologic model that the USGS uses to simulate and predict groundwater conditions by employing code that solves the groundwater equation (USGS, 2018). The modelling suggested future declines were likely to occur ranging from an average of 10 to 40 feet based on spatial location within the valley. Apart from modeling, the study observed water level decline in recent years of 30 to 65 feet in a few locations, but the declines appear to have stopped and stabilized (Petrich, 2004). The modeling was based on data supplied by monitoring wells distributed throughout the valley and a spatial distribution of the groundwater was also developed. This distribution model suggested that some areas of the valley may be available to additional withdrawals without affecting ground water levels but said withdrawals could increase losses in surface waters (Petrich, 2004). In Treasure Valley the main source of ground water recharge to the aquifers is seepage and infiltration from canals and flood-irrigated fields, but a lot of the recharge discharges in surface waters, and only a very small amount entering shallow aquifers ends up reaching deep aquifers (Petrich, 2004).

There is also a pilot project in Washington (Ziemer et al., 2012) for groundwater mitigation which addresses similar issues. Groundwater mitigation is a process that exchanges the water removed from a system in one use by pumping water into the ground and artificially recharging water levels. By having a water exchange, we can set a goal to move water to where it is most needed, then replenish the supply when new users draw water. The idea is to keep the water “banked” before it is designated for any use, to keep the chances of the supply diminishing under the demand.

In May of 2018, the previous public works director Craig Woolard and his department had "adopted a three-pronged approach to the area's water future" (Kendall, 2018). The department's three goals were/are: creating rebates for residences to limit outdoor watering, optimizing existing infrastructure (such as the Sourdough treatment plant), and to develop new sources of water supply. Although Woolard has exited his position as public works director, the approach is still in the works to be starting soon.

Conclusions and Recommendations

To return to our initial three questions concerning surface cover, irrigation method, and exempt well usage all in the context of groundwater, we were able to determine probable outcomes for each issue. With surface cover, as development continues, and impervious surfaces continue to take up more of the landscape, groundwater recharge will decrease and large groundwater losses to runoff will take place during storm events. This is based off the addition of approximately 1600 acres of impervious surfaces that occurred in development from 2001 to 2011 and raised runoff by more than 7 million gallons for a moderate storm event. The modelling and confirming research to address the irrigation question demonstrated that as irrigation method turns over from flood irrigation to sprinkler irrigation, irrigation's contribution to groundwater recharge will decrease. This contribution deviates from the pre-agricultural natural system, but as agriculture has been thoroughly used in the valley, the hydrology and dependent aquatic systems in the valley has become accustomed and dependent on this source of groundwater recharge, and this decrease should be considered a loss to the system. With the final question of exempt wells' impacts, there is insufficient and unavailable data as to the quantities of water utilized by these systems, but it is known that 40% of new exempt wells in Montana each year are drilled in the Gallatin Valley and Montana's three other top growing counties. This implies an increased dependence on groundwater for private use and an additional loss to groundwater in the Gallatin Valley. To best respond to these losses our recommendation is that first sufficient water quantification occur with irrigation and exempt well usage to best predict groundwater futures. Second, detention ponds below storm water treatment sites and the implementation of other green infrastructure should be considered to decrease runoff and promote infiltration and recharge. Finally, through policy and code, groundwater mitigation methods of artificial recharge and groundwater augmentation should be developed and promoted to take a proactive stance in protecting the resource.

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Rapid Urbanization: Methods of Mitigating Ecosystem Stressors in the Gallatin Valley of Montana

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Introduction

Climate change is a well-recognized phenomenon and is associated with significant global consequences. The global climate is becoming warmer, drier, and more variable, but it is not certain what changes will occur on a local scale. Montana, a semi-arid region prone to drought located in the Northern Rocky Mountains of the United States, is especially susceptible to loss of water resources as warming continues and precipitation levels fluctuate. Gallatin County has the highest growth rate in Montana (World Population Review, 2018), but does not currently have sufficient policy and regulation to protect ecosystem services like freshwater from urbanization-induced pressures.

Considering a sustainable future for the Bozeman and Belgrade area within Gallatin County, innovative and enforced change is necessary to accommodate fast-growing cities and natural resources. There are many approaches to mitigate stressors imposed on ecosystem function and structure, including but not exclusive to: 'water-friendly’ city ordinances, revamping of municipal water systems, proactive vegetation planning, as well as wildfire planning are all areas requiring proactivity when designing for the future of Gallatin County.

Regarding changes in climate and urbanization, Montana wildfires are getting bigger, lasting longer, and increasing damage to homes and property (Headwaters Economics, 2018). Fire disturbance across a landscape generates both positive and negative ecological outcomes; however, it also reveals important socioeconomic considerations. Today, society upholds the creation, expansion, and protection of human investments with significant economic value. Homes and property, once established or purchased, are understandably held in higher regard than allowing fire to run its natural course. The wildland-urban interface (WUI) is labeled as the zone where structures and other human developments meet and intermingle with undeveloped wildland or vegetative fuels (Gallatin County Emergency Management, 2016). Preparing for wildfire hazards and examining the risks associated with increased inhabitants in WUI areas in Gallatin Valley and the Bozeman region may help reduce the loss of human assets and limit impacts on valuable water resources while also allowing fire to reestablish a natural disturbance regime.

With the increasing demand to accommodate the consequences of climate change and population growth, the need for city planning to incorporate aspects such as native vegetation in urban areas is apparent, especially in the face of water shortages. By utilizing methods from xeriscaping techniques and ideals outlined by the discipline of urban ecology, cities such as Belgrade can plant native, drought-tolerant species to conserve water and combat low soil quality while simultaneously benefiting food chains and ecosystem structure within an urban interface.

Bozeman’s planning policy and strategy currently follow a 2009 document, the Bozeman Community Plan, which the city is hoping to more effectively utilize and update in the coming months (City of Bozeman, 2018). Combined with continued population growth and environmental changes, the pressure on local water resources is increasing rapidly. This is a multidimensional issue that encompasses many municipal, governmental, economic, and ecological aspects in and around Bozeman and Belgrade. One of the purposes of this paper is to address these issues by presenting green infrastructure-based policy planning in combination with fire risk mitigation, xeriscaping strategies and stricter water management to implement in future community plans to guide Gallatin Valley's growth over the next several decades.

Background

Gallatin County is the ideal location for many recreational and outdoor activities, including fishing, hunting, sports, beautiful landscapes, and a safe community. Because of this, Bozeman and Belgrade, located in Gallatin County, have been and are extremely attractive destinations for both tourists and new residents. In recent years, the population in the county has boomed from 89,513 in 2010 to an estimated 107,810 in July 2017 (U.S. Census Bureau QuickFacts, 2017). Within Gallatin County, the areas around Bozeman and Belgrade are the fastest growing communities in Montana (City of Bozeman, 2016). This population increase results in several positive aspects including but not limited to: urban growth, community development, higher university standards, and an increased economy. It is also paired with difficulties that arise from increased use and reliance on local natural resources necessary for a functional city. One resource that is of significant concern in the Gallatin Valley is freshwater. While these two towns are only separated by a few miles along Interstate 90, their water resources differ dramatically resulting in very different approaches to municipal water management. Bozeman's water supply comes from Lyman Creek, Bozeman Creek, and Sourdough Creek. Lyman Creek makes up roughly 15% of the water resources for Bozeman's municipality and is a groundwater resource from the Bridger Mountains. Bozeman and Sourdough creeks are both surface water sources and make up the remaining 80% of the cities' water budget. Unlike Bozeman, Belgrade's only source of water is groundwater pumped up through wells from the Gallatin Valley Aquifer (Waring et al., 2017).

As with most water systems in densely populated areas, both Bozeman and Belgrade are limited in the amount of water that can be sequestered from their respective sources. Bozeman currently has water resources to yield 11,500 acre-feet per year with the ability to support a population size of 66,000 (City of Bozeman, 2016). With the population currently hovering just above 45,000 in 2017 (U.S. Census Bureau QuickFacts, 2017.), the water supply is not a problem yet. However, population growth is not flattening out in any regard. Rather it is predicted that by 2062 the Bozeman population will rise to somewhere closer to 140,000 requiring a total of 28,700 acre-feet a year, an astonishing 17,750 acre-feet above what resources can currently supply (City of Bozeman, 2016). With a growing population in Bozeman, the demand for water will surpass supply between 2030-2035 (City of Bozeman, 2016), leaving a mere 12 years to prepare and address water management issues.

The City of Bozeman's initial attempts to address future water supply concerns were with its conception and implementation of the Integrated Water Resources Plan (IWRP) (City of Bozeman-Executive Summary, 2013). The plan predicted a water gap of 2,000-18,000 acre-ft, ranging from conservative to more extreme population growth and usage rates. 5 years after the IWRP conception, using Bozeman's most recent population increases, the water gap is estimated to be 17,800 acre-ft by 2042 (City of Bozeman-Executive Summary, 2013). The plan proposed that the best course of action should include a conservation program, adding storage to current systems, creating more capacity in groundwater systems, and other more short-term strategies. The City's website frankly states current supply concerns are worse now than in 2013, adding even after some implementations of the IWRP's smaller scale recommendations, there could be a water shortage in as little as 20 years. Bozeman needs a more productive water conservation infrastructure design to counteract growing supply losses.

Belgrade, similarly, is facing a population increase that will nearly triple their 2010 census population by 2038 (Waring et al., 2017). With such an impending strain on water resources it is imperative to be able to explore potential solutions that can reduce current use as well as expand the resources available of the below ground water source. Belgrade vegetation has access to less available water due to the high permeability of the thin, gravelly soil. This results in a need for urban vegetation to be watered more frequently by the City of Belgrade, adding strain on their only source of water, which predominantly resides underground. Plants of focus to help mitigate this issue are native Montana plants that display tolerance to drought-stricken, shallow, rocky, calcareous soils, as well as provide their own resource allocations to root and water storage (Lesica, 2012; Frisina, 2018). There is current incentive in initiating a new planting regime for the City of Belgrade. The Emerald Ash Borer, a non-native insect to the United States, is causing invasive disturbances across the entirety of Gallatin County and has taken residence in the urban population of Ash trees throughout Bozeman and Belgrade (Trees of old Bozeman at risk, 2015). With the alarming destruction of these trees, it becomes prominently clear that removal of many of the ash trees is necessary to reduce the intensity of the invasive emerald ash borer. Along with removal, the supplemental planting of a high diversity of vegetation that cannot accommodate the pest is going to be a top priority. Again, referring to a high diversity and variety of plants that are native to southwest Montana will reduce the effects of pest infestations, and a dramatic reduction in ash trees should help to reduce or eliminate the dramatic influx of these pests.

Suggested Solutions

To accommodate the issues and limitations described above, a multifaceted approach is suggested. This will require multiple components to addressing the water issue, and with each, an opportunity to consume limited water in the Gallatin County with more intelligence and sustainability.

Domestic Green-infrastructure and Urban Vegetation

Green Infrastructure (GI) has been defined as “an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations” (Benedict, 2002). What this could mean for Bozeman is an increase in its ecosystems’ natural capital, which correlates to the value we assign to the environmental assets that humans rely on (Chenoweth et al., 2018). Increasing natural capital essentially denotes natural resource abundance over deficit, subsequently increasing human services. As population and the need for natural capital (water, parks, clean air, ambient temperature regulation, etc.) increase, the urban environment more obviously becomes a finite land system. Restructuring city planning to incorporate GI increases the potential not only for population growth but also resilience of the urban system (Gómez-Baggethun & Barton, 2013).

GI is not a new idea. The concept, as well as successful designs, have been established in many municipal areas, both large and small (Coutts and Hahn, 2015; Lafortezza et al., 2013; Tzoulas et al., 2007). This puts Bozeman at a significant advantage, enabling it to review the successes and failures of other similar climate, micropolitan, and even metropolitan, areas. No matter how large the city or the problem, GI techniques share a simple common theme: using natural elements and operations to restore natural water management systems. As Bozeman continues to grow, more of the ecosystem services will be lost and ecosystem disservices will increase. GI can mitigate the loss of urban ecosystems and prevent much of the long-term economic and insurance costs that would be accrued by maintaining the current strategy (Gómez-Baggethun & Barton, 2013). Further urbanization leads to decoupling and false independence from the natural ecosystem as technology and built infrastructure increase provisioning of ecosystem services far beyond the city boundaries (Gómez-Baggethun & Barton, 2013). Conservation as well as restoration of urban ecosystem services through GI reduces further ecological detriment and increases the overall health and quality of life of the area's inhabitants.

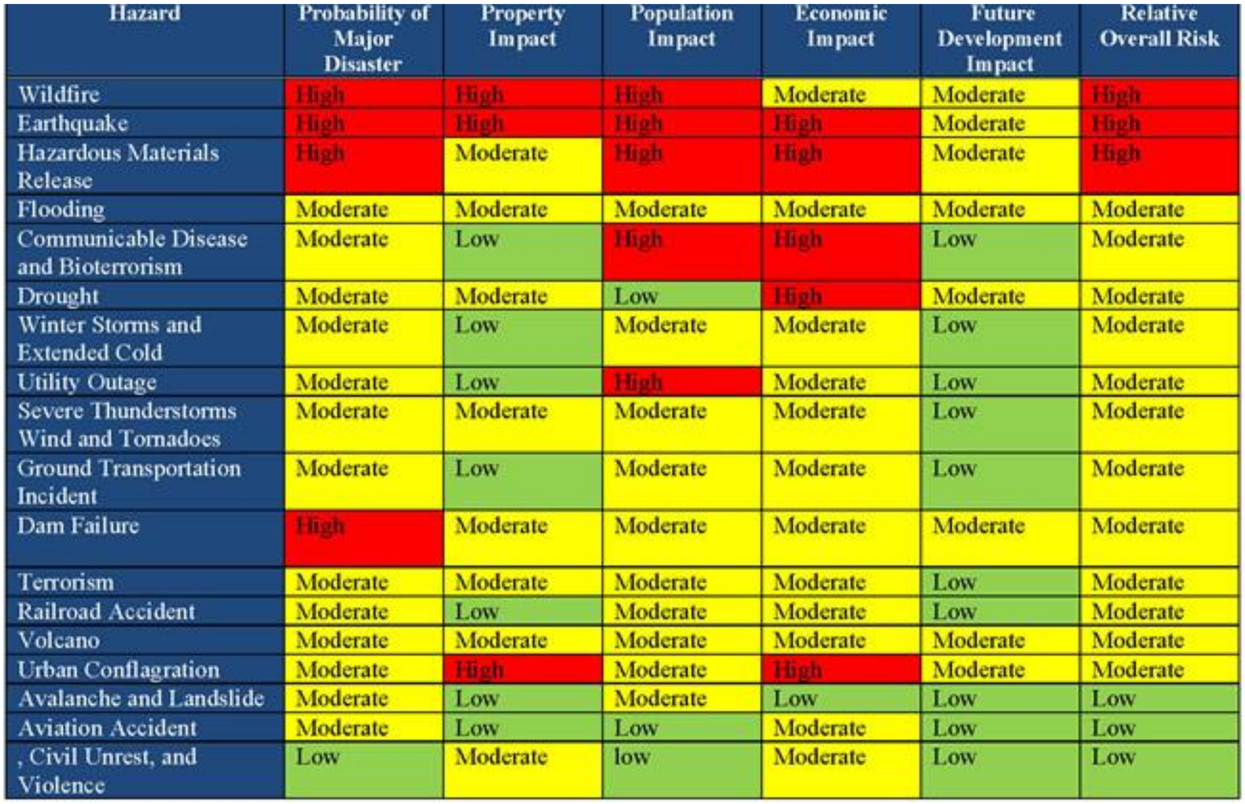
With grim projections for water supply in the Northern Rockies, domestic and municipal water use must be dramatically reduced to avoid infrastructure damage from environmental stressors such as heavy rain events, drought, and source depletion. To mitigate budget limitations but also increase resilience against environmental stressors, Investments in green-based development is a viable option in city planning through incentives, policy, and outreach. Regarding projections of a warming climate, dry conditions due to drought can cause soils to be less permeable, increasing the intensity of heavy rain and flood events by elevating runoff rates (Warziniak et al., 2018). These exaggerated rainfall events damage infrastructures via cracking, flooding, etc. and exacerbate pollution via sediment and dissolved material transport in stormwater. Implementing green-infrastructure maintains the natural hydrologic cycle and minimizes impacts such as these that result from changes in land use (Feng et al., 2016).

Stemming from constructs outlined with Green Infrastructure, vegetation selecting for planting can be organized and selected via three general categories of native vegetation: Gymnosperms (Montana Pines), Woody Magnoliopsids (leafy trees and shrubs), and finally, Herbs (grasses, sedges and forbs) (Lesica, 2012). The benefits to using native plants are economic, in that you can lower water and maintenance costs, enhance real estate values and increase the survivability of the plants longer term. There are also environmental benefits such as improved water and soil conservation, reduced use of petroleum products, improved air quality and carbon sequestration, enhanced urban wildlife habitat, and reduced water contamination (Cashman Nursery, 2016).

Along with methods presented in xeriscaping techniques, the discipline of urban ecology presents concepts aligned with maintaining native structure in urban environments, and the benefits of such practices regarding maintaining pollinator populations, insects, birds and other wildlife. Research presented by urban ecologists at University of Delaware reveals the absolute necessity of native planting in urban environments regarding species diversity, food web interactions, and native songbird success. The research emphasizes the importance of community outreach by becoming familiar with native plants, insect and wildlife species in our own communities (Narango, Tallamy, & Marra, 2017). By consulting with online sources such as National Wildlife Federation and National Audubon Society, city planners and homeowners alike can easily create ecologically sustainable yards, parks and urban landscapes that also support a wide array of native insect and wildlife species, and the information provided within the content is simple to understand. Incentivizing individual properties to apply methods of urban ecology and xeriscaping could boost public awareness and help involve members of the community to save water and support native species from the ground level, up.

Wildland-Urban Interface

Gallatin County ranks third in Montana for most homes built in areas of high or moderate wildfire hazard since 1990 only behind Ravalli and Missoula counties. Nationally, the wildland-urban interface is the fastest growing land use type (Headwaters Economics, 2018). As communities within Gallatin County continue to grow in to surrounding wildlands, the dynamic between wildfire risks and water resource consumption requires consideration. More inhabitants within the WUI leads to more risk and thus more protection for homes and property (Figure 1). It also means new subdivisions will require access to municipal waters and new homes will require a well tapped in to the Gallatin Valley aquifer. With such a dependence on surface waters as the municipal source, the City of Bozeman must be proactive rather than reactive in its approach to maximizing potable water sources in the wake of increased wildfire disturbance potential.



Hazard	Probability of Major Disaster	Property Impact	Population Impact	Economic Impact	Future Development Impact	Relative Overall Risk
Wildfire	High	High	High	Moderate	Moderate	High
Earthquake	High	High	High	High	Moderate	High
Hazardous Materials Release	High	Moderate	High	High	Moderate	High
Flooding	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Communicable Disease and Bioterrorism	Moderate	Low	High	High	Low	Moderate
Drought	Moderate	Moderate	Low	High	Moderate	Moderate
Winter Storms and Extended Cold	Moderate	Low	Moderate	Moderate	Low	Moderate
Utility Outage	Moderate	Low	High	Moderate	Low	Moderate
Severe Thunderstorms Wind and Tornadoes	Moderate	Moderate	Moderate	Moderate	Low	Moderate
Ground Transportation Incident	Moderate	Low	Moderate	Moderate	Low	Moderate
Dam Failure	High	Moderate	Moderate	Moderate	Moderate	Moderate
Terrorism	Moderate	Moderate	Moderate	Moderate	Low	Moderate
Railroad Accident	Moderate	Low	Moderate	Moderate	Low	Moderate
Volcano	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Urban Conflagration	Moderate	High	Moderate	High	Moderate	Moderate
Avalanche and Landslide	Moderate	Low	Moderate	Low	Low	Low
Aviation Accident	Moderate	Low	Low	Moderate	Low	Low
, Civil Unrest, and Violence	Low	Moderate	low	Moderate	Low	Low

Figure 1. Wildfire is a primary risk to Gallatin County. Reprinted from Gallatin County Emergency Management, 2016. Retrieved October 14, 2018 from https://www.readygallatin.com/mitigation/

The 'Bozeman Municipal Watershed Fuels Reduction Project' proposed several years ago provided support for fuel reductions through logging and prescribed burns in the Bozeman (Sourdough) and Hyalite Creek watersheds to limit risk and potential wildfire impacts on Bozeman's drinking water. Many stakeholders, rightfully so, were concerned with sedimentation and pollution impacts apparent in increased road establishment and use for mechanical logging practices--the very impacts associated with wildfire disturbance and thus the proposal for fuel reductions. Ash and sediment deposition from a severe fire event in to Bozeman's municipal creeks would be a major source of contamination to the City's water supply (USDA Forest Service, 2011). When Bozeman's municipal water treatment plant was upgraded to a membrane system in 2014, many of the risks associated with fire disturbance were alleviated. The treatment plant is designed to handle major fluctuations in raw water stemming from wildfire disruption and high turbidity runoffs (HDR Inc., 2018). Though the treatment plant is expected to withstand severe stream loading impacts following a fire, a proactive approach suggests more can be done to further reduce risk on one of Gallatin Valley's most precious resources.

Considerations for protecting and conserving water resources in the Bozeman area include the aforementioned mechanical thinning and prescribed burning, but also hand thinning and the burning of slash piles in watershed areas, water conservation incentives for users, fuel thinning in the WUI where growth is projected to increase to reduce fire danger and water consumption by thick vegetative stands, increased water storage as the climate warms and precipitation patterns change, and implementing a municipal groundwater source.

Municipal Water Management

According to Belgrade's 2017 Water Master Plan, an average of 30% of the water pumped from the 6 (now 7) wells is unaccounted for (Waring et al., 2017). This is mirrored in Bozeman where water loss averages around 20% (DNRC, 2015). While this is lower than Belgrade's 30%, it is still higher than the national average of 16% (EPA, 2015). These gaps in loss percentages reveal that this is an area that can be focused upon and improved. With reducing water loss alone, hundreds of acre-feet would be saved every year, allowing far more efficient water management strategies to take place.

Reducing these losses is by no means easy or simple, but it is possible. While the national average water loss for a municipality is 16%, the EPA estimates that of this percentage, up to 75% is recoverable (EPA, 2015). The question is how to go about implementing recovery plans. In general, water loss is either real loss or apparent loss. Apparent loss indicates unmetered distribution lines, meter errors, or illegal hookups to the water system, while real loss is system leakage. In the case of Bozeman and Belgrade, it is assumed unmetered lines and meter errors make up a negligible part of the water loss leaving the main culprit to be system leakage (Waring et al., 2017).

Conclusion: Application and Proposals for the Gallatin Valley

Green Infrastructure and Vegetation in Domestic Development Ordinances

Current Bozeman ordinances regarding water conservation are minimal and could be reshaped to initiate compulsory activism in sustainability strategies. The only criteria for private development are found in the Unified Development Code regarding landscaping, requiring that the property "include one large canopy tree for each 50 feet of total street frontage", that at least 2/3 of the area be vegetated with "natural grass, vegetative ground cover or other natural living plant materials", and that "all landscaped areas shall be perpetually maintained in a healthy condition" (City of Bozeman, 2018). These ordinances could be evaluated and expanded on to more specifically require reduced water use, using green infrastructure strategies, and reducing fire risk.

Studies show that incorporating appropriate design with native plants can cut down on water usage by 50%, maintenance and labor by 30%, fertilizers by 61%, fuel by 44% and herbicides and pesticides by 22%. (Xeriscaping and Native Plants, 2009) Along with methods presented in xeriscaping techniques, the discipline of urban ecology presents concepts aligned with maintaining native structure in urban environments, and the benefits of such practices regarding maintaining pollinator populations, insects, birds and other wildlife. Advice on techniques for optimizing water use in Gallatin County involve changing the composition of lawns and grass-covered areas from the use of a traditional Kentucky bluegrass to a blend of native fescue grasses (Cashman Nursery, 2016). Much of the research utilized in the discipline of urban planting revolves around the concept of xeriscaping. Xeriscaping can be prioritized into 7 steps: (Xeriscaping and Native Plants, 2009)

1. Plan and design comprehensively
2. Improve soil with amendments
3. Reduce lawn areas
4. Use appropriate plants and group them according to water/environmental needs
5. Irrigate efficiently
6. Use mulches and ground cover
7. Maintain the landscape with regularity

These steps can be initiated by the City and can be implemented onto individual properties using financial incentives to motivate the public. In association with xeriscaping techniques, as mentioned before, resources outlined by the National Wildlife Federation as well as the National Audubon Society can easily help policy makers and citizens alike modify their landscaping focuses to be, not only water-saving, but supportive of local species richness and structure.

Green infrastructure implementation, much like integration of xeriscaping techniques, doesn't inherently resonate with all members, or developers and legislators, of a community. Motivating policy change, even beyond Bozeman, must incorporate some simple points to appropriately address the importance, benefits, and level of application required with the innovations. Below is a list of some of these key items and how some may be addressed with a GI-based policy plan. It is important to recognize that there is not one approach to GI, conservation, acquisition, or preservation that can save the world's freshwater supply. Only a vast combination of unique strategies will promote the ecosystem services and natural capital people need to sustain their growing communities. Small steps can generate a larger change; a few well-placed rain barrels can become trendy and has the potential to inspire members of the public to partake in their own water catchment.

1. Policy posed for both the residents and the policy makers
    a. Final goals need to meet political palatability and the Best Management Practice
    b. Initiate a GI Policy Change campaign alongside an educational campaign of GI
    c. Establish levels of authority that are needed based on the GI
2. Openly announce the problem to the residents and encourage responsible actions with clearly outlined tasks- what can *everyone* do?
    a. Policy prohibiting use of potable water on turf grass
3. Offer alternative practices to direct towards a BMP
    a. If Bozeman does nothing, water is gone by 2020
    b. If 2% of the population installs low-flow shower heads, water is gone by 2021
    c. If all new developments are regulated with GI and grandfathered structural conservation is increased, water is gone by 2050.
4. All rules/procedures must be in place before instituting- provides clear structure for how to follow and why to follow. Start with regulations a for easier record keeping
5. Enforcement must be easy, and maintenance relatively easy
    a. A tiered fee schedule for water use above set quantities
    b. Water allotment based on space, not on plants on type of structure
        i. Same amount of water allocated per 1 acre of turf grass as to 1 acre of drought tolerant plants
    c. Rain barrels maintained by the property owner, bioswales in public median areas maintained by the city

Municipal water planning

Despite the differences in water resources between Bozeman and Belgrade, there are overlaps in management angles that both municipalities can implement to work towards conducting sustainable water management that can be used for many years to come. Regarding reducing real municipal water loss there are a variety of tools available. These include but are not limited to the American Water Works Association's (AWWA) water auditing process, water pressure management, and LeakFinder-ST: Advanced Acoustic Leak Detection System.

Ideally Bozeman and Belgrade would be able to use a combination of these methods to sufficiently decrease their real water losses. However, limitations on available manpower, time, training required to operate, and budget are all factors that play into what is realistic for both municipalities. A good first step would be to conduct a full water audit in the form of the AWWA's M36 model. They are available on the AWWA website and are designed to be used in the standard Microsoft Excel (Chastain-Howley, 2007). Expansions upon the initial release of the program in 2000 have been made in the subsequent years to expand and dive more into the intricacies involved in municipal water balance. In 2008, the AWWA's M36 moved towards putting numbers on apparent and real water loss rather than lumping both types of losses into a single water loss percentage (Almy, 2016). This would be extremely useful in Bozeman and Belgrade as neither city have published specifics on how much water is being lost in either category and have instead gone with the original overall percentage of loss (Chastain-Howley, 2007).

While the software to self-audit are free and available online (Chastain-Howley, 2007) costs can still range from $10,000-50,000 (Almy, 2016) once everything is factored in. Even with high costs, the information provided by the analysis would allow for Bozeman and Belgrade to hone in on exactly where they are losing water in their pipe systems. From the results of an M36 water audit other tools can be prioritized based off what is most valuable and/or feasible for each city.

If the costs of a water audit are too great for either municipality, a second route would be to emphasize the water pressure management, especially if this is something that is already being monitored. In general, there is a direct relationship between pipe pressure and pipe leakage, meaning that the lower the pressure the lower the pipe break frequency and vice versa (Hunaidi et al., 2004). An assumption that flow rate of fluid through an opening is proportional to pressure is utilized in pipe systems but is only valid for a fixed area. A greater area and pressure leads to more fluid flow. However, with pipe leak openings (cracks), greater pressure would cause an expansion in the cracks leading to a greater area. In a scenario such as this, if the assumption described above is in place for measuring the amount of water flowing, results would underestimate the fluid flow in areas where cracks are present (Hunaidi et. al, 2004). To assuage the situation, monitor and fix cracks as soon as detected, as well as keep pressure in the pipes as low as possible while still maintaining function.

Once a water audit is completed, Bozeman and Belgrade can focus on locating leaks using LeakfinderRT™ (Echologics, 2018). or similar technologies, pressure management, night flow analysis, and/or acoustic surveying. An assortment of these methods could be implemented based on what is best suited for either Bozeman or Belgrade.

Wildfire Risk Mitigation in the Wildland-Urban Interface

Based on a proactive approach to promoting water resource protection from wildfire disturbance in Gallatin Valley, several recommendations will be made that may benefit Bozeman both short and long term. First, hand thinning areas with significant ladder fuels, dead materials, and canopy overlap in the appropriate season with ideal weather conditions will help reduce potential fire severity within watershed areas. Leaving significant vegetative buffer zones will prove beneficial in reducing sediment and debris loading from any disturbance. This recommendation would take time to implement and reach a point where there was a valuable impact on the watershed or landscape scales; however, it would alleviate concerns of mechanical thinning and the addition of roads in roadless areas. The next recommendation is to actively thin fuels in WUI areas where projected growth is expected. This tactic would prematurely reduce the risk of losing homes or other structures in the event of a wildfire, potentially allow for the harvest of merchantable timber, and decrease interception and consumption of water by large, mature coniferous trees and other vegetation. Increasing water storage capacities would likely be beneficial to support water distribution in the face of surface water disruption and declines in late season water supply with a warming climate. Overall, wildfire disturbance in the Gallatin Valley is one of the few natural disasters with the potential to impact Bozeman and its’ municipal water supply. Due to this and the fact that municipal water sources will need to increase in future years to support a growing population regardless, the implementation of groundwater sources as a source of municipal water would be very beneficial if the City of Bozeman could obtain the rights to appropriation. This, in turn, would influence Belgrade and its’ reliance on groundwater municipalities thus increasing considerations for another municipal water source, likely surface water, for them. Revealing that Bozeman’s water treatment plant may be able to handle a significant influx of post-burn materials therefore reducing anthropogenic risks, an argument can be made that these suggested measures may still be implemented to reduce pollution impacts from an ecological and biological perspective.

Summary

When addressing the consequences of climate change, population growth and urbanization, it is important to take note of the availability of freshwater within a given landscape. Seeing as how there are solutions accessible to conserve and responsibly consume water on an individual, city and county wide level, there is little excuse in leaving the concerns of our future with water unaddressed. By addressing issues such as fire risk, water municipality, green infrastructure, and urban vegetation, we can begin to establish more modern policy initiatives and can begin to appropriately alleviate pressures on our water sources by urbanization and climate change. By putting the various methods addressed above into sustainable action, the Montana cities of Bozeman and Belgrade can hope to withstand the unavoidable growth that is bound to continue in Gallatin County Montana.

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