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Analyzing Increases in Impervious Surface and the Effects on Hydrology and Water Quality in Big Sky, Montana

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Abstract:

At a resolution of 30 m, there was a 26% increase in impervious surface in the West Fork of the Gallatin watershed from 1990 to 2005. After assessing the negative effects of impervious surface increase on aquatic systems, this review concludes that freshwater ecosystem health is likely to be the primary object of concern. Specifically, stream biota is negatively affected by reduced base flow and increased sediment loads that result when a watershed is overlaid by more impervious surfaces. Effective impervious surfaces, or impervious surfaces with gray stormwater infrastructure, have the greatest effect on hydrology and thus aquatic communities. Unless stormwater best management practices (BMPs) are implemented, greater increases in impervious surface will further stress freshwater ecosystems in the West Fork watershed and Upper Gallatin River.

1. Introduction

In recent decades, the population of the Rocky Mountain West region has been one of the fastest growing in the United States. One principal reason for this proliferation is the high quality of life associated with abundant natural amenities, which is an attractive feature to new residents and businesses (Hansen *et al.* 2002). However, ecosystem services are being altered by development in communities where large numbers of people are choosing to work and play. Land managers responsible for planning in these communities are concerned that increasing population, rural sprawl, and high levels of outdoor recreation are resulting in degradation to natural amenities and impeding future economic expansion. A crucial challenge, then, is to understand the link between development in local communities and the ecosystem services on which those communities depend, in order to plan for a sustainable environmental and economic future (Clark & Minta 1992).

Big Sky, Montana is considered part of the Greater Yellowstone Ecosystem, one of the largest intact ecosystems in the United States, still possessing all the functional groups it had when Lewis and Clark journeyed west. This helps to make it one of the largest ecosystems in the northern temperate zone on Earth relatively unaltered by humans (Noss *et al.* 2002). Big Sky is also a model scenario of feedbacks between natural amenities and expeditious development. Big Sky Resort was established in the early 1970s when a consortium led by retired TV newscaster Chet Huntley purchased Crail Ranch high in the mountains of southwestern Montana (Gallatin River Task Force 2017). Since then, the locale has seen rapid and extensive growth with the addition of three new ski resorts, golf courses, and associated residential development (Gardner *et al.* 2011).

Human alteration of land cover patterns due to urbanization is one of the most profound impacts on natural ecosystem function (Steffen & Sanderson 2004). An especially notable effect of urbanization is the conversion of naturally vegetated land to impervious surfaces, such as roads, parking lots, roofs, sidewalks, and other human infrastructure (Campos 2008). Impacts on water quality are of exceptional concern in high-elevation ecosystems due to the effects of increased precipitation, steep slopes, limited vegetation, large swaths of exposed bedrock, and shallow soils. Amalgamation of these characteristics typically results in relatively rapid runoff during snowmelt and rainfall (Williams *et. al* 1993; Forney *et al.* 2001). Water quality is also commonly viewed as an integrated environmental indicator of ecosystem function.

This review focuses on increases in impervious surface area in the West Fork of the Gallatin watershed and the potential effects of continued development on water quality and quantity. First, impervious surface increase is quantified within the area of interest. Subsequently, environmental consequences and their mechanisms are explored.

2. The Dynamics of Impervious Surface in the West Fork Watershed

This study focused on the West Fork of the Gallatin River watershed, located in the Rocky Mountains of southwestern Montana (Figure 1). The West Fork drains an area that includes Big Sky, a portion of Moonlight Basin, the Yellowstone Club, and Spanish Peaks resort areas into the Gallatin River, a tributary of the Upper Missouri River (Gardner *et al.* 2011). It is composed of three main tributaries: The Middle Fork, the North Fork, and the South Fork. The West Fork watershed (24,090 ha) is characterized by steep slopes and shallow soils (Campos 2008). Elevations range from approximately 1800 to 3400 m, and average annual precipitation is less than 500 mm near the watershed outlet while exceeding 1270 mm at higher elevations. On average, sixty percent of annual precipitation falls during the winter and spring months (Gardner & McGlynn 2009). Flows at the watershed outlet peak during spring snowmelt, typically occurring in late May or early June. Peak flow is followed by a recession throughout the summer, fall, and winter months. Streams in this watershed range from first-order, boulder dominated mountain streams in the upper elevations to fourth-order, alluvial streams near the outlet. Although most areal development lies within the bounds of the West Fork watershed, there are also many structures and roads just upstream of the confluence with the West Fork (i.e. the Porcupine area). There is also significant development in the western portions of Moonlight Basin lying in the Jack Creek drainage basin; Jack Creek eventually empties into the Madison River.

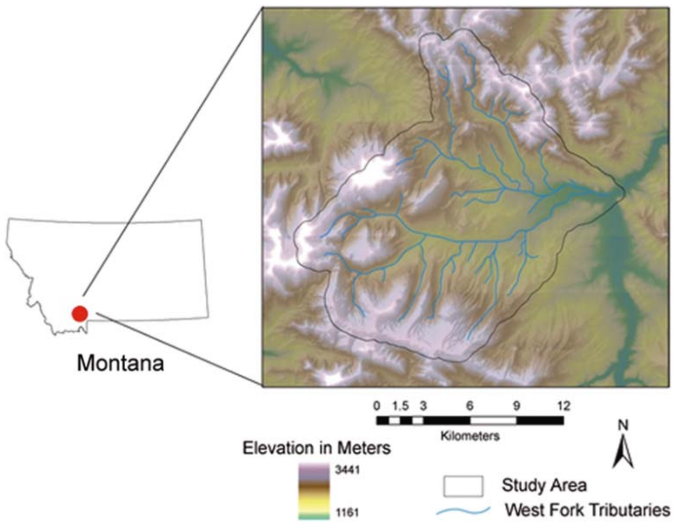

Figure 1: Location of the West Fork of the Gallatin River watershed within the state of Montana. Figure reproduced from Campos (2008).

Impervious surfaces can be defined as any material that prevents the infiltration of water into the soil (Arnold & Gibbons 1996). These surfaces can be natural, such as exposed bedrock, or manmade, such as roads, parking lots, sidewalks, rooftops, and other human infrastructure. The most extensive work specifically characterizing changes in impervious surfaces in the West Fork watershed was a remote sensing effort performed for a Master's of Science Thesis (Campos 2008). These study methods will be briefly described, followed by a summary and discussion of the key findings related to the purposes of this paper.

Campos (2008) used classification of impervious surface area from high-spatial-resolution imagery (LiDAR and Quickbird) to calibrate inference of impervious surface from moderate-resolution imagery (Landsat). Then, this calibration was applied to historical moderate-resolution imagery to assess changes in spatial patterns of mountain resort development over time. The spatial distribution of change was analyzed through a combination of descriptive statistics and classification-tree methods (see Campos 2008 for more detail).

Table 1: Land cover percentages in 1990 Landsat classification (Campos 2008). Impervious surface classification had 90% Producer accuracy (i.e. 10% of ground-referenced impervious surface pixel areas were classified in another category) and 100% User Accuracy (no pixels classified as impervious surface were ground-referenced to be of a different reference class).

Classified as in 1990	**Percent of Land Cover in 1990 (%)**
Grasslands / Shrublands	29
Impervious Surface	19
Forest	51
Water	1

Table 2: The total amount of change that occurred between 1990 and 2005 is broken down into change classes (Campos 2008).

From-To Change Class	Percent of Change (%)
Forests - Impervious	48
Forests - Grasslands	19
Grasslands - Impervious	33

The 2005 classification suggested an 1185 hectare increase of impervious surface since the 1990 classification. Note that this assessment cannot be attributed to an absolute increase of impervious surface area because the 900 m^2 pixel size (30 m × 30 m) resulted in a considerable number of pixels with mixed classes that were classified as impervious if 20% of the pixel was impervious surface. This threshold was chosen to capture the influence of all impervious surfaces including narrow roads, which could have otherwise been excluded.

However, pixels classified as impervious surface occupy a distribution of values between 20 and 100% impervious surface coverage, and it is not unreasonable to assume that the distribution of coverage in 2005 was similar to the distribution in 1990. In fact, there was likely an increase in impervious surface percentage per pixel because of densification of development (Forney *et al.* 2001). An increased area of 1185 hectares influenced at least partially by impervious surface (based on a 900 m^2 resolution) represents 5% of the West Fork watershed. ***At a resolution of 30 meters, there was a 26% increase in impervious surface in the West Fork of the Gallatin watershed from 1990 to 2005.*** 24% of land cover was classified as impervious surface in 2005.

The increase in impervious surface was countered by a 944 ha decrease in forest (67% of total change) and a 270 ha net decrease in grasslands (33% of total change). The conversion of forests and grasslands/shrublands to impervious surfaces was likely a result of land cover changes induced by mountain resort development. While the 19% impervious surface classification in 1990 includes talus and scree and is therefore an imperfect metric of manmade impervious surfaces, the 25.9% increase between 1990 and 2005 was likely entirely anthropogenic because the talus and scree distributions did not change.

Alongside typical impervious surfaces, human-caused marginally pervious surfaces should be remembered as well when assessing watershed impacts. For example, vegetated areas next to highways have been demonstrated to be considerably less permeable than undisturbed sites because highway construction compacts adjacent soils, lowering infiltration rates (Church *et al.* 1999). When highway runoff flows onto the compacted soil it becomes saturated in less time, subsequently acting as an extension of the impervious surface. Other marginally pervious areas include mown grass, shown to possess high runoff coefficients (Leopold 1991), and bare soil (Ross & Dillaha 1993).

In addition to areas of high-density development, like the Mountain Village and the Meadow Village, there are also extensive areas of diffuse development across the West Fork watershed. Diffuse development occurs both on large plots and in the form of small cluster development typical of a resort community. Unsurprisingly, average lot and parcel sizes are quite large. Although increasing lot and parcel size correlates with decreased imperviousness at a site-specific level, imperviousness per capita increases, mostly because of additional roadways necessary to access the spatially-distributed development (EPA 2005).

The data also showed that development of grasslands was disproportionately closer to streams than the average distance-to-stream of grasslands in general. This could be a result of amenity development at or near the water's edge (Williams & McMillan 1983; Williams & Jobes 1990). The proximity of the Meadow Village, a prominent focus of development, to the West Fork certainly accounts for a large portion of this change. Development disproportionately close to streams raises concerns for water quality impacts (Forney *et al.* 2001).

Deforestation can affect a watershed's precipitation processing as well. A mature forest stand retains more rainfall than a typical meadow or field (Booth & Jackson 1997), thus forests are more valuable than grasslands in terms of water retention. 19% of land cover change from 1995-2005 was from forests to grasslands, likely related to development efforts. Conversion from forests to impervious surfaces also significantly outweighed conversion from grasslands to impervious surfaces (48% vs. 33%) (Campos 2008).

3. Effects of Impervious Surfaces on Hydrology

As an area becomes more overlaid by impervious surfaces the water distribution shifts to encompass more surface runoff and less subsurface flow, increasing the efficiency of hydrologic export from a watershed (Putnam 1972; Johnson & Sayre 1973). There is a reduced lag time, or time lapsed from the center of mass of a precipitation event to the hydrograph peak (Shuster *et al.* 2005). The hydrograph also exhibits steeper rising and falling limbs, a result of "flashier" events. Additionally, there is an increased runoff ratio, or the percentage of precipitation allocated to runoff. The West Fork watershed naturally allocates a significant amount of precipitation to runoff because of its steep slopes, exposed bedrock, and limited vegetation, making it naturally susceptible to rapid flushing. With more impervious surface area, this effect is exacerbated. An increased runoff ratio means correspondingly less infiltration, which reduces groundwater recharge and lowers water tables (Arnold & Gibbons 1996). Therefore, there is less, consistent groundwater addition to streamflow (reduced base flow) and more precipitation-event-based additions, commonly referred to as stormwater (Arnold *et al.* 1982). A reduction in base flow can lead to warmer water temperatures, endangering fish and other freshwater species.

The literature suggests that assessments of impervious area could be improved to better predict hydrological impacts. Shuster et al. (2005) argue that instead of measuring impervious surfaces by the total amount in an area (usually expressed as a percentage of an area, as in the Campos thesis), it should be considered in terms of 'effectiveness,' or connectivity. They define effective impervious area as "all impervious surface area that is hydraulically connected (i.e. piped) to a drainage system so as to enhance conveyance of water away from a source area, such as a city street or residential neighborhood;" basically, impervious area equipped with gray stormwater infrastructure ("gray" connoting gray concrete tunnels and storm drains) (EPA 2005). Effective impervious area includes streets and parking lots with curbs or gutters that route runoff to surface waters or treatment plants. Conversely, ineffective impervious surfaces transport runoff to pervious surfaces. These include roofs and parking lots that direct water to grassy areas or biodetention facilities (raingardens) for infiltration. ***In summary, impervious area connected to gray stormwater infrastructure has the greatest impact on watershed hydrology because flow***

is concentrated and conveyed directly into surface waters, bypassing the natural storage mechanisms in soils and groundwater that potentially mitigate downstream flooding and enhance dry-season flows.

Although Campos' (2008) impervious surface measurements were a logical place to start, future research should focus on assessing effective impervious area in the West Fork watershed to better predict hydrological impacts. Brabec *et al.* (2002) posit that direct measurement remains the optimal way of determining effective impervious area. Previous efforts have included field studies, aerial imagery investigations, and stormwater system map-overlaying.

Predictably, suburban and commercial land use types usually have high total impervious area and most studies estimate them to have high effective impervious area as well. The town center of the Meadow Village is the only developed area in the West Fork watershed broadly equipped with gray stormwater infrastructure (Edwards 2017). Its hydrologic closeness to the West Fork of the Gallatin and probabilistically high effective impervious area make it particularly concerning in terms of stormwater pollution.

While some newer subdivisions in the West Fork watershed have been constructed with gray stormwater infrastructure (mostly in the town center of the Meadow Village), many older subdivisions divert stormwater with traditional ditches and culverts. The impacts of this type of ineffective impervious area and lack of formal infrastructure on stormwater pollution are presently unclear. The Big Sky Mountain Village hosts considerable development, receives significant traffic, and is devoid of formal (gray) stormwater infrastructure (Edwards 2017).

These factors as well as its closeness to the Middle Fork of the West Fork of the Gallatin make it a research priority for better understanding stormwater pollution in the West Fork watershed.

4. Effects of Impervious Surfaces on Water Quality and Stream Ecosystems

Water quality refers to the physical, chemical, and biological characteristics of water, and it is usually discussed relative to the requirements of human or ecosystem needs (Brabec *et al.* 2002). Impervious surfaces can lead to changes in water quality by: (1) preventing natural biogeochemical processing of pollutants in the soil by disallowing percolation; and (2) serving as an efficient conveyance of pollutants, including sediment, into waterways (Arnold & Gibbons 1996). When stormwater flows rapidly over impervious surfaces it is a critical conveyance mechanism of toxic pollutants (Jartun *et. al* 2008). Schueler (1994) reviewed 11 studies published before 1995 as evidence that stream quality (defined disparately by different researchers) declines at 10-15% total impervious surface coverage.

Streams in the West Fork watershed have been analyzed through the TMDL (Total Maximum Daily Load) process which determines the maximum amount of a pollutant that a stream can possess without violating the Montana Department of Environmental Quality water quality standards. Three streams are currently impaired: The Middle Fork of the West Fork of the Gallatin River falls below standards for sediment, nutrients, and pathogens; the South Fork of the West Fork does not meet state standards for sediment and nutrients; and the West Fork is impaired in terms of sediment and nutrient loads. Being classified as 'impaired' implies degradation of a beneficial use defined by the Clean Water Act; these three streams are currently classified as ‘not fully supporting’ aquatic life and primary contact recreation (Montana Department of Environmental Quality 2016). While an increase in impervious surfaces has probably not had meaningful effects on high pathogen loads, it may have contributed to sedimentation and nutrient pollution.

When increases in impervious surface affect hydrology and water quality, they also affect aquatic ecosystems. Many watersheds have experienced ecosystem degradation at very similar levels of impervious surface area. Schueler (1994) classifies stream drainages into 3 aquatic ecosystem management categories: ‘stressed’ (1-10% impervious cover); ‘impacted’ (11-25% impervious cover); and ‘degraded’ (26-100% impervious cover). Klein (1979) estimated notable impacts occurring at 10% total watershed imperviousness and ‘severe’ impacts at 30%. Two more studies have noted substantial impacts on base flow and aquatic systems at 10-12% impervious surface area (Booth & Jackson 1997; Wang *et al.* 2001). Schueler (1994) resolves that, “this research, conducted in many geographic areas, concentrating on many different variables, and employing widely different methods, has yielded a surprisingly similar conclusion- stream degradation occurs at relatively low levels of imperviousness (10-20%).” It is necessary to note that the metrics for impervious surface coverage in the West Fork watershed determined by Campos (2008) did not represent total imperviousness for reasons previously stated.

Measures for stream quality typically fall into two categories: biotic and abiotic. Brabec *et al.* (2002) reviewed studies of the effects of impervious surfaces on water quality, and their analysis suggested that impact thresholds for biotic measurements were drastically lower than impact thresholds for chemical and physical measurements (I.e. biotic measurements were measurably more sensitive to lower percentages of impervious area). Impact thresholds for fish and macroinvertebrate diversity and abundance ranged from 3.6-15% impervious surface, fish population health's threshold ranged from 3.6-12%, and macroinvertebrate health declined above 8-15%. Conversely, abiotic measurements like water quality and habitat characteristics had thresholds at 4-50% impervious surface coverage. Chemical water quality measures had higher impact levels as well; oxygen's lowest threshold occurred at 7.5%, while nutrients, phosphorus, eutrophication based on total suspended solids and total phosphate, metals, and zinc all had thresholds ranging from 30-50%, most occurring above 40% Physical variable measurements had less consistency, ranging from 4.6- 50% with high variability. Note that threshold percentages of impervious surface are simply demarcations of degradation. Effects are most likely to occur on a continuum (Shuster *et al.* 2005)

Brabec et al. (2002) postulated that aquatic organisms are more easily affected by imperviousness because they are sensitive to a variety of physical and chemical water quality factors, reflecting the impact of a combination of abiotic alterations that cannot be identified independently. Therefore, degradation of aquatic diversity may be a more sensitive aggregate measure of stream quality degradation. Biota accumulate the influences on stream health over longer periods of time, in contrast to chemical changes that can be discontinuous or episodic in nature (Shaver & Maxted 1995). Aquatic life also appears to be more greatly affected by habitat destruction than water quality (Brabec *et al.* 2002). ***These data suggest that aquatic ecosystems could be the first amenity to suffer in the West Fork watershed and beyond in the Upper***

Gallatin, as they are more sensitive to lower levels of imperviousness. High priorities for understanding the influence of impervious surfaces on the stream ecosystems in the West Fork of the Gallatin are monitoring the potential reduction of natural storage in the watershed and monitoring sedimentation in streams.

4.1 Reduced Base Flow

Poff & Zimmerman (2010) state, "Streamflow is viewed as the 'master variable' that shapes many fundamental ecological characteristics of riverine ecosystems." In a meta-analysis of 165 papers concerning ecological responses to altered flow regimes, 92% of the papers reported negative ecological changes in response to flow alteration; 60% of papers (99) specifically examined flow magnitude (Poff and Zimmerman 2010). Under reduced flows, all 10 responses of fish communities were negative, whether measured by changes in abundance, population demographic parameters, or diversity of assemblages. Diversity showed the most significant decline. There were general declines in macroinvertebrate abundance and diversity in response to decline in flow magnitude as well (Poff & Zimmerman 2010).

Increases in impervious surface area generally reduce the overall percolation of precipitation into soil, thereby reducing groundwater recharge and decreasing longer-term storage in the watershed. Most watershed linear storage models assume that the amount of water coming out of long-term storage (i.e. base flow) is simply a fraction of how much water is in storage originally. Reduced base flow is particularly problematic for aquatic life during late season when the majority of streamflow originates from groundwater.

When base flow is reduced, the smaller volume of water in the stream channel makes the stream more susceptible to solar warming. Many freshwater species have small ranges of water temperatures in which they thrive (Das *et al.* 2004), and can experience significant stress or even extinction following slight increases in water temperature. Unsurprisingly, temperature has been classified as degraded for cold water biota at low levels of impervious surface coverage (12%) (Brabec *et al.* 2002). Warming effects in the West Fork watershed due to reduced base flows will likely be compounded by the disproportionate changes in climate anticipated in high elevation and high latitude ecosystems (Girvetz *et al.* 2012).

Furthermore, warmer water has a decreased capacity to hold oxygen gas. Many freshwater species have small ranges of habitable DO (dissolved oxygen) levels (Das *et al.* 2004), and oxygen consumption rates increase with increasing temperatures, suggesting higher aerobic metabolism (Kutty & Mohamed 1975). This positive feedback loop can lead to severe oxygen stress for biota within warming water bodies. Oxygen levels have been found to be degraded at quite low levels of total impervious surface percentage (10%) (May & Horner 1997).

Flow is also a major determinant of physical habitat in streams, which in turn is a key determinant of species composition. Again, consulting Brabec's (2002) analysis, another stream attribute with low percentages of impervious surfaces required to meet degradation thresholds was large and woody debris (9%), a critical habitat component of aquatic ecosystems. Native aquatic species have primarily evolved life history strategies in direct response to their natural flow regimes (Bunn & Arthington 2002), so changes are likely to shift aquatic communities away from their natural state. Bunn and Arthington (2002) also note that the invasion and success of invasive aquatic species is facilitated by the alteration of flow regime.

4.2 Sedimentation

Three streams in the West Fork watershed are considered impaired by excess sedimentation (Montana Department of Environmental Quality 2016). Direct contributions of channel manipulation and numerous and ubiquitous construction sites are likely causes of this sediment pollution, but increases in impervious surface may also be increasing the efficiency with which sediment from roads and construction is transported into natural waterways.

Increases in impervious surface can contribute to high suspended sediment loads and high bedloads in streams in two ways. Fast-flowing, concentrated stormwater can enter streams, cause high levels of streambank erosion, and increase suspended load. Stormwater can also transport surface, or road-deposited, sediments into streams (Zhao *et al.* 2010). Large precipitation events significantly elevate both types, but this analysis will focus on road-deposited sediments because they can transport a wide variety of pollutants into streams.

While natural systems tend to attenuate sediment, impervious surfaces convey it with significantly less resistance into flowing water bodies. Impervious surfaces reduce a watershed's ability to retain sediment, whether it be from a natural or unnatural source. Road-deposited sediments have been shown to possess high concentrations of a variety of chemicals, including metals, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), heavy metals, and total organic carbon (TOC) (Jartun *et al.* 2008). Road traction sand is a major source of surface sediments on roadways. The "shoulders" of Lone Mountain Trail, the main highway in the West Fork, are often covered in a visible, thick layer of road traction sand. Surface sediments in the West Fork watershed also likely arrive on impervious surfaces by means of vehicles, wind, gravity, and flowing water. Highways and roads are frequently situated next to steep embankments prone to slope failure, an obvious source of sediment. Construction sites are liable to be a point of origin for a great deal of sediment as well; construction activities cause high levels of soil disturbance and are the most significant impact of urbanization on soil (Jartun *et al.* 2008).

Normal runoff can transport sediments covering a significant range of particle sizes, but this range is greatly enhanced during stormwater events in impervious watersheds (Kim & Sansalone 2008). Sediment too large to dissolve in water is often referred to as particulate matter (PM) or suspended solids (SS): the mass (mg) or concentration (mg L^{-1}) of inorganic and organic matter held in the water column of a stream or river by turbulence. Suspended solids are an accepted cause of deteriorated water quality in terms of aesthetics, treatment for water resources, fisheries, and other ecosystems services (Bilotta & Brazier 2008).

Over the last half-century, the effects of suspended solids on aquatic life have been studied intensively throughout the world. Important findings will be relayed in pertinence to the stream ecosystems of the West Fork watershed.

Salmonids play key roles in aquatic ecosystems and support the economies of Big Sky and

Bozeman. They include rainbow, brown, and cutthroat trout, as well as mountain whitefish: the major fish species associated with the upper Gallatin River and the West Fork watershed. Salmonids can be affected by SS in several ways. The most intensively-studied mechanism involves the deposition and settling of SS in gravel-bed rivers like the tributaries of the Upper Gallatin, a major cause of reduced survival and development of salmonid eggs and larvae within redds. SS can block the pores in salmonid redds, restricting transmission of oxygen and carbon dioxide to and from fish eggs. SS can also affect mature fish by clogging their gill structures, interfering with natural movement and migration, causing stress, and suppressing their immune systems (Bilotta & Brazier 2008).

Zooplankton and benthic invertebrates including insects, mollusks, and crustaceans can be highly disturbed by increases in SS as well. SS cause abrasion and scouring, damage respiratory organs, and make organisms more susceptible to predation by dislodging them from stream substrates (Bilotta & Brazier 2008). High levels of SS are particularly harmful to filter-feeding invertebrates because they clog feeding structures, thereby reducing feeding efficiency and growth rates (Bilotta & Brazier 2008). This leads to heightened stress and often death. Decreases in invertebrate diversity and abundance can have cascading effects both up and down the food chain. For example, zooplankton and invertebrates are the main food sources for fish species in the West Fork watershed, and if their abundances decrease then fish abundances would likely decrease as well.

Periphyton (algae attached to stream substrates) and macrophytes (visible plants) are crucial food-sources and oxygen-producers in the stream environment (Bilotta & Brazier 2008).

Suspended solids can have adverse effects on these organisms by reflecting incoming light radiation, reducing the amount of visible light that penetrates through the water column, and thereby reducing their photosynthetic potential. Bottom-up effects directly impact primary consumers and indirectly impact secondary consumers, like fish. Other than reduced light penetration, SS can scour organisms away from streambed substrates, abrasively scrape and damage photosynthetic structures, and negatively affect species abundances by introducing harmful nutrients and toxic compounds into streams via their adsorption onto particle surfaces (Bilotta & Brazier 2008).

All effects of SS on aquatic life are dependent on the concentration, duration of exposure, geochemical composition, and particle size distribution (Bilotta & Brazier 2008). The largest surface and in-stream sediment fluxes are likely to occur during intense periods of snowmelt and big summer rain events.

5. Discussion

A 26% increase in classified impervious surface coverage in the West Fork watershed from 1990 to 2005 represents a growing potential risk to valued watershed ecosystem services, and development has continued expeditiously since 2005. Big Sky Resort's ten-year plan announces $150 million in investment and proclaims the ambition of "Creating the American Alps" (Big Sky Resort 2016), and Bozeman, the feeder-community providing a large percentage of Big Sky's labor force and recreation base, ranked #6 on the U.S. Census list of the fastest-growing small cities in the United States in 2014 (U.S. Census Bureau 2014).

Based on research that has demonstrated the sensitivity of aquatic ecosystems to impervious surfaces in the watershed, deterioration in aquatic community health may reflect the earliest consequences of increasing impervious surface area. Specifically, stream biota is negatively affected by reduced base flow and increased sediment loads that result from increases in impervious surfaces. Impervious surfaces that are directly connected to urban infrastructure via gray stormwater infrastructure may have the most direct effect on aquatic ecosystems, and thus design of storm water control in higher density areas may require more attention in efforts to maintain stream ecosystem integrity. Local and downstream fisheries are of high value to the communities of Big Sky and Bozeman, both economically and socially. If this is the case, community planning should emphasize conservation of the aquatic resource to ensure its maintenance into the future.

Mitigating the detrimental effects of impervious surface and stormwater runoff is accomplished by implementing Best Management Practices (BMPs) and green stormwater infrastructure. BMPs are structural, vegetative, or managerial practices used to treat, prevent, or reduce water pollution. Common features include detention ponds and infiltration basins (EPA 2005). The spatial arrangement of BMPs is important as well; catchments with distributed BMPs have demonstrated significantly greater base flow than catchments with centralized BMPs (Loperfido *et al.* 2014). Green infrastructure, also referred to as low-impact development, include features like rain gardens and bioswales. They reduce and treat stormwater at its source while delivering environmental, social, and economic benefits (EPA 2005). BMPs and green stormwater infrastructure would be most effectively employed in the town center of the Meadow Village because it is equipped with gray stormwater infrastructure. Big Sky's Mountain Village would likely benefit from these implementations as well.

The environmental effects of development and increases in impervious surface will undoubtedly be paired with the effects of a warming climate and shifts in precipitation distribution in Big Sky. This combination makes the system particularly interesting to research scientists and implicates substantial environmental degradation in the next century. If the greater Big Sky community wishes to protect its stream resource, emphasis should be placed on sustainable growth and responsible environmental conservation.

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