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Watershed Management Tools

Hazardous Site Case History, Reference Stream Analysis, and GIS Analysis of Fire Risk

**By
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Bachelor of Science, Geosciences, University of Montana, Missoula MT, 2013

Portfolio

Presented in partial fulfillment of the requirements of the degree of

Master of Science
In Environmental Studies

The University of Montana
Missoula, MT

January 2018

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Watershed Management Tools

Hazardous Site Case History, Reference Stream Analysis, and GIS Analysis of Fire Risk

Portfolio Introduction

I began my graduate career in the Environmental Studies program to advance my knowledge and skills that would allow me to pursue a career in watershed protection. My time in the program taught me various ways in which I could achieve this, along with numerous factors surrounding watershed health. My portfolio reflects the experiences and lessons that I found most interesting: The effects of an industry on a watershed over a long time, and the reaction of the people in the affected area; water quality assessment methods (field and lab); and the use of Geographic Information Technologies.

For the first component, I developed a case study that looks at the history of pollution and cleanup of the kraft pulp and paper mill near Frenchtown, MT. Over the years, wastewater treatment ponds were built in the floodplain of the Clark Fork River. A dike was built to separate the ponds and the river, and maintenance of these ceased after the mill shut down. The contaminated soil left behind from years of operating the mill has the potential to leach into the groundwater. Currently, the site has an ongoing investigation to determine if it qualifies as a Superfund site. In my study, I look closely at the investigation and the community's reaction to the findings. My study also looks at cleanup options that may apply to the site if it becomes a Superfund site. By researching a local, ongoing process, I gathered substantial insight into how a polluted site is dealt with and the players involved in the process.

For the second component, I describe my work with the Montana Department of Environmental Quality in the summer of 2016 characterizing Montana's reference (least impacted) streams. The work provided an insightful experience into field work. Additionally, I worked for the watershed health clinic analyzing algal biomass in the Clark Fork River and the streams assessed during the reference project. The second portion of my portfolio is a reflective essay on my experiences with the DEQ and the subsequent lab work associated with it.

The final component is a reflection of my experience using GIS and working with community organizations to produce maps for different purposes. I assisted Friends of the Bitterroot in an assessment of the 2017 Lolo Peak fire using GIS software. This assessment is used to guide an exploration of the fire's effects on the Lolo Creek Watershed.

This portfolio helped me redefine my career goals and showcase some of the skills I have developed over the course of my time in the program. The case study of the pulp mill and my work with DEQ demonstrate my interest in watersheds and water quality. The work with the DEQ and University of Montana Watershed Health Clinic exhibit my abilities to engage in quality assured field and lab work associated with water quality. Finally, my work using GIS for community organizations shows both my familiarity with GIS tools and interaction with organizations.

Part 1

Hazard Remediation Options For a closed Pulp Mill on the Clark Fork River

ABSTRACT

The Frenchtown Pulp Mill was in operation for over 50 years, producing various paper products, and disposing of the associated wastewater by either directly discharging it into the Clark Fork River during spring high flows, or storing it in a network of waste ponds on site (some of which are in the floodplain). Additionally, the construction of dikes along the river caused alterations to the main channel and floodplain. A preliminary investigation by the EPA confirmed the presence of harmful chemicals in the soil and groundwater at the mill site. This EPA report, along with information gathered from consulting groups, was used to create a profile of the hazards identified at the mill site. By assessing other pulp and paper mill sites undergoing remediation, and several technologies used for specific contaminants, this paper provides useful information on the possible options for remediation at the Frenchtown Pulp Mill.

INTRODUCTION

In 2010, a kraft pulp mill on Western Montana's Clark Fork River ceased operation, starting the process of evaluating how the site should be managed to protect public health and the environment. Since it began operations in 1957, the pulp mill has been the subject of contention for the nearby communities of Missoula and Frenchtown. From fish kills to air pollution, the mill's impacts have drawn heavy criticism over the years, while the mill provided jobs and tax revenue to the local community. For over half a century, the pulp mill was an integral part of life of the people around it, for better or worse. Since the mill has had a series of owners, this paper will refer to it as the Frenchtown pulp mill because of its proximity to that community.

Creating paper products is a water intensive process that produces a large amount of waste. The waste water coming out of a pulp mill contains chemicals that are harmful in high concentrations to both people and the environment. Hence, pulp mills are required to treat their wastewater, and reduce harmful chemicals to acceptable levels.

The Frenchtown pulp mill used an extensive area of the Clark Fork floodplain to treat and store its wastewater until it could be discharged into the Clark Fork River during spring high flows. As a result, an unknown amount of harmful chemicals have entered the surface water downstream and the groundwater under and down-gradient of the mill.

The closing of the pulp mill triggered the federal Superfund process which assesses sites such as this, and if need be, forces the potential responsible parties to clean up hazardous conditions. The site no longer produces paper products, jobs, or tax income for the local communities. The Superfund investigation of the site will determine what needs to be cleaned up, so the land will no longer be a potential health hazard, and could even be redeveloped following remediation of the site.

The mill's history and current situation are not well known to most local citizens. Hence, few people are trying to influence EPA's decisions on how to study and clean up the site. This paper aims to provide information on likely hazards and cleanup options in hopes that more local citizens will pressure EPA for an effective, long term cleanup.

OBJECTIVES

In order to provide useful information on the current status of the pulp mill, this paper will address five objectives:

- 1: Summarize the history of the mill, its expansions throughout the years, and the controversies surrounding the wastes it created.
- 2: Describes the site's geology, hydrology, stream morphology and vegetation from before the mill up to the present and how the mill altered the river's floodplain.
- 3: Analyze the physical and chemical hazards left behind when the mill closed.
- 4: Explore other pulp mills around the country in different stages of closure and clean-up.
- 5: Evaluate different remediation options that may apply to the mill site.

HOW INFORMATION WAS GATHERED

EPA's investigation of the site (Miller 2012) is the main source of information consulted to describe the site. In addition, private consulting reports (Boyd 2016, Daniels 2016), provide information on channel migration and dike stability.

Information was also gathered by looking at studies done at other pulp mill sites, both as a comparison and supplement for data gaps not filled by the information available on the Smurfit-Stone site. River floodplain studies were consulted to examine flood plain ecosystem services lost and other consequences of altering the riparian area occupied by the mill's waste sites. Remediation options were explored using a database provided by EPA (Clu-In 2016) that describes experimental technologies and techniques.

Sources included newspaper articles, scientific journal articles, and online resources.

RESULTS

Objective 1: History of Site

The mill opened in 1957, with a capacity to produce 250 tons of kraft pulp a day. During the first year of operation, the pulp mill dumped untreated wastewater directly into the Clark Fork River, resulting in foam and discoloration as far as 50 miles downstream in Superior, MT (Nielsen 1987). During the summer of 1958, when water levels were low, large numbers of dead fish were reported in the river. This was attributed to unknown toxic elements being discharged by the pulp mill. After extensive backlash from the local community, the first wastewater ponds were constructed. At that time, all the wastewater was stored in these ponds, slowly leaking into the ground water.

Paper production and bleaching began in 1960, increasing production to 450 tons of linerboard and 150 tons of bleached pulp per day. The expansion was done without additional impact studies to the river, and the mill began dumping wastewater into the river during the spring high flows once again (Nielsen 1987). In the fall of 1961, another large fish kill occurred. An impoundment dike was ruptured, expelling around 400 gallons per minute of wastewater for

almost three hours. The company denied responsibility, and little to no response occurred.

In 1962, the Montana State Board of Health issued an official discharge permit to the mill, that allowed them to continuously discharge up to 1000cfs while the river flow was above 10,000 cubic feet per second (Nielsen 1987). In 1965, at the request of the pulp mill, allowable discharge was increased from 1000cfs to 1500cfs. Production capacity increased again to 1150 tpd in 1966 when a second paper machine and two continuous digesters were installed. A primary treatment clarifier was installed in 1969 for the removal of suspended solids before storing wastewater in settling ponds (Miller 2012). Between 1963 and 1978, five more ponds were constructed on the North end of the site (Boyd 2016).

As required under the Clean Water Act of 1972, secondary treatment basins for wastewater were installed in the mid '70s, along with experimental percolation ponds (also called rapid infiltration ponds). After primary and secondary treatment, a third of the effluent was discharged directly into the Clark Fork. The remaining two thirds of wastewater was put into rapid infiltration ponds for disposal. The effluent percolated down into the groundwater and moved to the river. The sediments trapped some of the organic materials in the effluent. At this time, there are over 700 acres of settling ponds. These rapid infiltration ponds were considered experimental, causing controversy over whether they would work or not (Nielsen 1987). A large \$170 million expansion begins in 1977 to increase capacity to 1850tpd. Additionally, a waste wood boiler is installed for generating power (Miller 2012). At the same time, the previously installed rapid infiltration basins began to plug. The materials that were trapped in the sediments clogged the pore spaces, which slowed down infiltration. For the next six years, the mill would attempt to fix the system with no success, and opted for a different means of waste disposal in 1983 (Nielsen 1987).

After several months of debate and controversy, a new permit was issued in 1984 for increased waste discharge (Nielsen 1987). The permit required an intensive survey of the mill's impact, and an environmental impact statement before the permit could be renewed. In the following 18 months, the study was conducted, and when the EIS came out, it claimed that the pulp mill was causing no harm to the river, and the increased discharge could continue.

Environmental groups threatened to sue, stating that the increased discharge constituted degradation. DEQ's lawyer agreed, pushing the mill to negotiate with environmental groups. The resulting permit allowed the mill some increased discharge during a less sensitive time of year.

Following the purchase of the mill by Stone Container Corporation in 1986, negotiations over the new permit were finalized, and with all parties in agreement of the terms, the permit was issued (Nielsen 1987). A color removal treatment system and a facility to recycle old cardboard were built in 1988 and 1990. By 1993, production reached 1900 tpd of kraft pulp from wood chips and recycled cardboard. Sludge dewatering began in 1997 after completion of a new facility for that purpose. Bleaching ended in 1999, and production dropped from 2001 to 2004. The mill eventually shut down in 2010 after declaring bankruptcy, and in 2011, the property was sold to M2Green, a brownfield redevelopment company.

Environmental investigations were completed on the mill site in 1983, 1995, and 2000. These were primarily related to water quality of the Clark Fork due to discharge from the mill. The 1983 study documented various effects of year-round discharge, and areas of concern involving groundwater pollution, air quality and aesthetics of the water. In 1995, the mill was required to locate the mixing zone boundary of the wastewater entering the river, as per the Montana Pollutant Discharge Elimination System (MPDES) permit. This permit required the identification of the groundwater mixing zone in 2000. This boundary was defined where total dissolved solids exceeded 500 mg/L. Groundwater wells were also required to monitor changing level and quality conditions from old well measurements (Miller 2012).

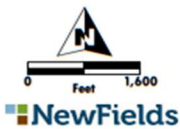
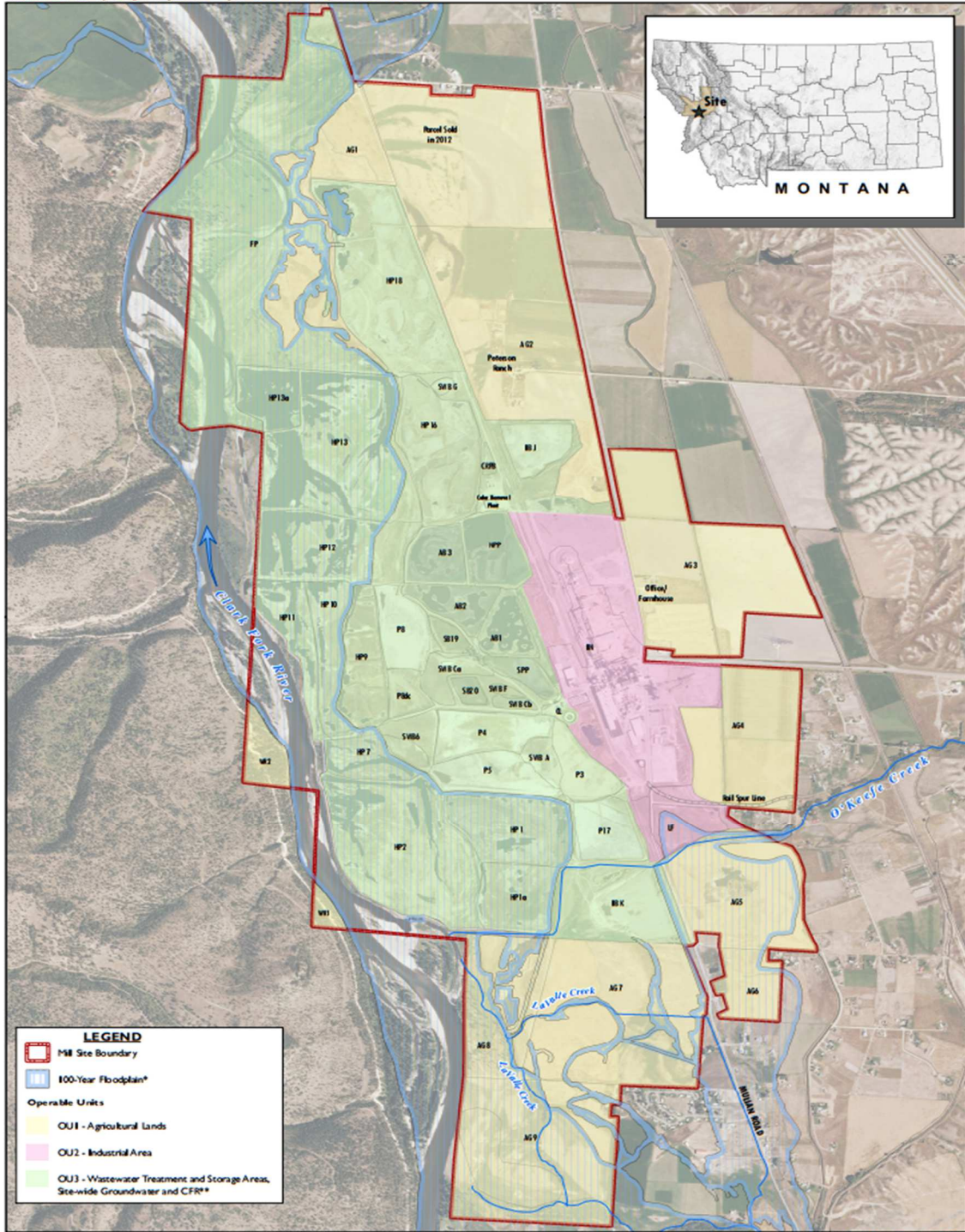
Since operations have ceased at the site, the question of what to do with it has become a cause of concern for local residents. Due to the quantity of waste stored at the site, the site will need to be remediated under the federal or state government superfund process, or privately by the company that now owns the land. Because the Montana Department of Environmental Quality had insufficient funds to address the site, the Environmental Protection Agency was brought in to determine if the site should be a federal superfund site. The current owners, M2Green, have been meeting with EPA, and are said to prefer their own cleanup over a superfund listing (Briggeman 2012).

While not officially listed as a federal superfund site, a similar investigation process is being followed. The site is currently listed as undergoing a remedial investigation, which is separated into two phases. The first phase includes surface soil samples up to seven inches deep, or if contaminants are found, deeper. The investigation also includes collecting samples from 20 groundwater wells on site. It will also include sediment and water samples from the Clark Fork River and neighboring creeks, such as O'Keefe (Miller 2012). As of late October, 2016, EPA proposed to install two deep groundwater wells on the site to check for deep groundwater contamination. Additional soil samples have also been proposed at two additional locations on site (US EPA 2016).

According to an EP News wire in November, 2015, the liable parties signed a deal with EPA, promising a full investigation of the soil, river sediments, groundwater and surface water. They agreed to reimburse EPA for the studies done up to the point of this agreement (Newswire 2015).

For the purpose of the RI, the mill site has been divided into three operable units (Figure 1). The first covers the 1200 acres of agriculture land within the site. The second unit is the 255 acres of the core industrial site. The final operable unit is the 1700 acres of settling ponds and parts of the floodplain that could have been impacted. Each of these operable units will require different kinds of studies and remediation techniques (US EPA 2016).

Sampling continued through 2017, beginning with deep and shallow wells in March. Clark Fork River monitoring was done throughout the summer months and berm inspections that



*Floodplain Source:
As defined by the Federal Emergency
Management Agency (FEMA) 2013
Digital Flood Insurance Rate Map
(DFIRM), (NFIP 2013)
**Where Contaminant of Potential
Concern from the Site have come
to be located in the CFR

Notes
AG - Agricultural Land
AB - Aeration Stabilization Basin
CFR - Clark Fork River
CRPS - Color Removal Plant Basin
CL - Clarifier
FP - Floodplain Area
HP - Hoiking or Storage Pond
IB - Rapid Inflow Basin
LF - Land farm
IN - Industrial Area
NPP - North Polishing Pond
OU - Operable Unit
P - Settling Pond
SB - Spills Basin
SPP - South Polishing Pond
SWS - Solid Waste Basin
WR - West of the Clark Fork River

Site Plan and Operable Units
Former Frenchtown Mill Site
Missoula County, Montana
FIGURE 2-2

Figure 1: Site and Operable Units of the closed Mill on the Clark Fork River.

OU1 is 1200 acres, OU2 is 255 acres, and OU 3 is 1700 acres.

The 100 year floodplain is about half of OU3.

concluded they were in no danger of failing. Plans were also made for the removal of PCB contaminated soils (US EPA 2016).

In the summer of 2017, 6 years after M2Green bought the site, Missoula County sued over delinquent taxes and accused the company of health code violations over the demolition waste sitting on site. (Friesen 2017). Later that year, Wakefield Kennedy, the site holding M2Green's mortgage, settled with the county for nearly \$1 million of the \$1.2 million owed.

Objective 2a: Physical Description of the Site

The Clark Fork River flows through the Missoula Valley from East to West. Between 15,000 and 13,000 years ago, the valley was intermittently flooded up to 3000 feet as the Cordilleran Ice Sheet dammed the river downstream from the valley in Idaho. During this time, fine grained sediments settled over riparian sediments, creating a confining layer 120 to 150 feet thick (Miller 2012). The riparian sediments underneath this confining layer are known as the deep aquifer, and are of unknown thickness. The shallow aquifer was deposited on top of the confining layer, and measures 25 to 35 feet thick.

The elevation of the main industrial area is 30 feet above the Clark Fork River. The depth of the groundwater across the mill site ranges from 6.5 to 26.3 feet below the surface. Hydraulic conductivity, the rate at which water moves through the substrate, was measured as 0.5 cm/s in the shallow aquifer and 350 nanometers/s in the confining layer. The groundwater flows to the Northwest (Miller 2012).

Historic groundwater data on the site is limited to one time measurements of USGS wells during 1961 (USGS 1961a, USGS 1961b and USGS 1961c). Two wells running east to west across the site measure the groundwater at 19ft and 20ft below ground surface. Another well downstream from these measured 23.7ft.

FEMA estimates the 100-year flood flows at the mill site at 67,600 cubic feet per second. The average channel gradient along the mill site is 0.1 percent, with channels exhibiting both meandering and braided channel designs. At the mill site, the river channel is around 400 feet wide, with a bed composed of sand, gravel and cobble (Daniels 2016).

Flow data for the Clark Fork is restricted to a USGS gauging station located above the mill site (below Missoula, NSGS code 12353000). The data goes back as far as 1927 (USGS 2016a). The drainage area at this site is 9,017 square miles. . The mean annual precipitation of the area is 13.81 inches

The highest monthly flow recorded from the available data was 33,970cfs in June of 1972. The lowest flow occurred in August, 1931, with a monthly average of 809.9cfs. The water level of the river at this site has been above the National Weather Service flood stage of 11ft at 4 times in the recorded data (1948, 1972, 1975 and 1997). Flood stage is the height at which the river can inundate areas not normally covered by water (USGS 2016b).

Vegetation along the river consists of various woody riparian species, herbaceous wetlands, and conifer forests in the uplands. Prior to mill construction, the eastern floodplain of the river was covered in open and closed timber stands of cottonwood and ponderosa pine (Boyd2016).

Objective 2b: Alterations of the Floodplain by the Mill

The entire mill site now covers 3150 acres, including 100 acres in the industrial site, most of which was constructed before 1963. In addition to the industrial site, roughly 900 acres between the mill and the river were used as unlined ponds to hold by-products of the pulp and paper-making processes. Unlined ponds were also constructed as waste dumps for general industrial waste created at the mill. Around 1800 acres was purchased as a buffer around the mill due to groundwater contamination. That area is used for cattle grazing and cropland (Miller 2012).

The sludge ponds near the industrial area are around 20-24 acres in total area, ranging in depth from 7-14 feet. The ponds are uncovered and unlined, other than partial wood chip cover at pond 3, and there is no leaching or run-off control systems in place. The waste dumps are also unlined, but all three have an 18-inch clay cover with vegetation growth (Miller 2012).

The mill's waste ponds were built in the river's channel migration zone (CMZ) (Boyd 2016). This is the area adjacent to the river where the river channel has been in the past and has a high chance of moving again in the future. The past migration rates of the river were used to identify an erosion hazard area. Erosion hazard zones are areas that are susceptible to erosion occurring from natural channel movement. The historic migration zone, documented in 1955, 1972, and 2005, was used to map the CMZ, which is located within 257 acres of the mill site (Boyd 2016). 170 acres of the channel migration zone is cut off from the river by dikes used to keep out the high flow flood waters in the spring. It is estimated that the width of the river's CMZ has been reduced by an average of 600ft, with a maximum of 1800ft (Daniels 2016).

Before the mill, the Clark Fork had two large seasonal channels branching off the main channel on the eastern side. An avulsion hazard zone has also been documented, based on the locations of the abandoned channels. This zone is characterized by a possibility for rapid channel course changes or re-flooding of the abandoned channels. These sites extend further out from the HMZ, and take up another 200 acres of the mill site. The different areas of the channel migration zone are delineated in Figure 2. The abandoned channels can be reactivated through flooding, but are considered low risk due to their distance from the main channel (Boyd 2016).

To combat the river's natural tendency for channel migration, the mill management constructed dikes, including 13 acres of armored dikes, and another 41.8 acres of unarmored dikes along the river (Boyd 2016).

By blocking the natural movement of the river, the mill's waste ponds displaced historic and current channels and the riparian area. For instance, the stream corridor (the area that

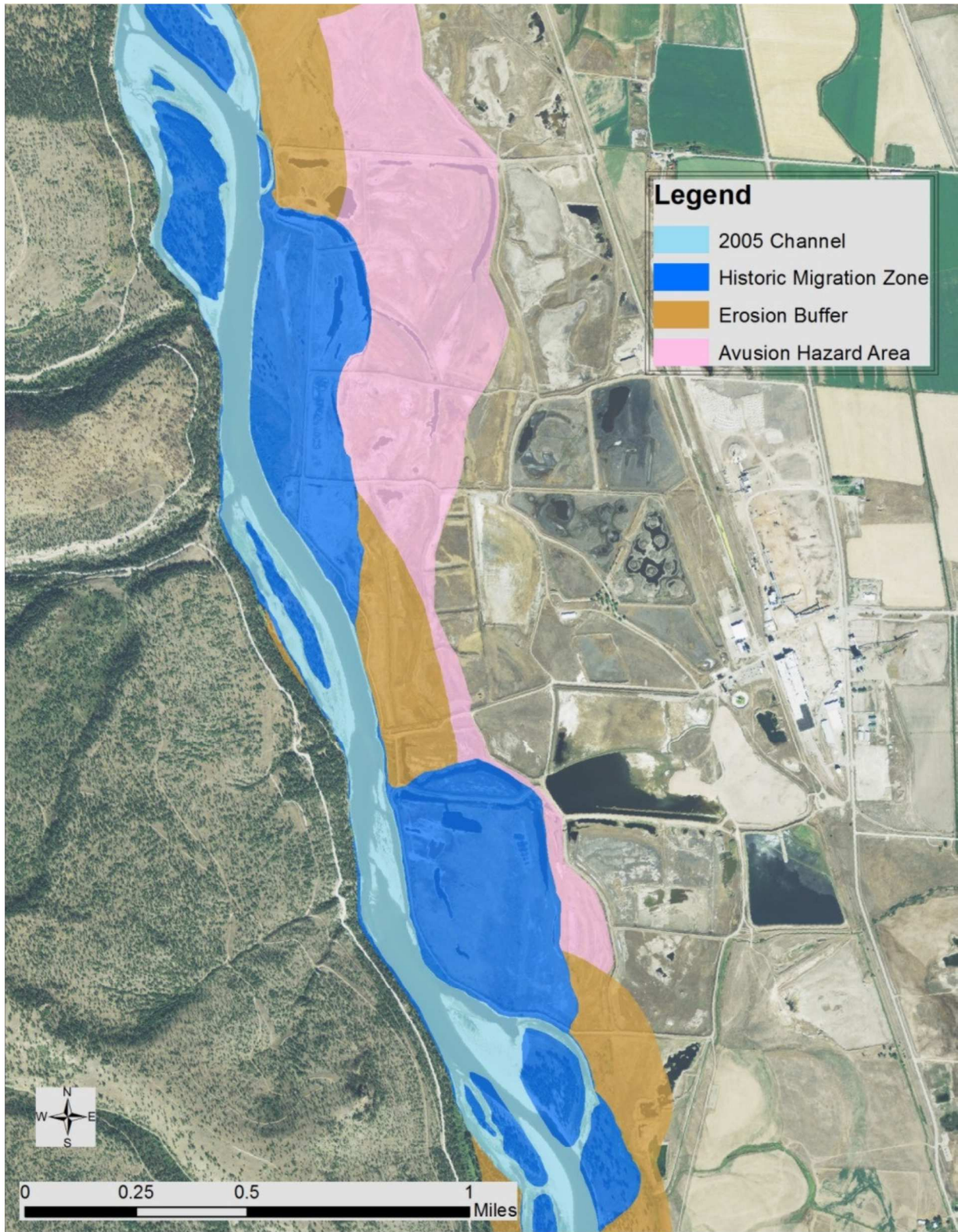


Figure 2 Channel Migration Zone around the Frenchtown Mill Site. It can be observed that old geomorphologic features influenced the shape of the wastewater ponds.

includes the channel, islands, and riparian vegetation) was narrowed from its 1955 width by 500ft in some areas and up to 2000ft in other areas. Seventy acres of high flow seasonal channel were removed (as were 6 acres of sloughs and 180 acres of wooded land cover) (Boyd 2016).

Alterations at the site have also had effects on the riparian areas downstream of the mill's dikes, including narrowing from the 1955 width. Additionally, a small cottonwood forest was developed in the downstream area, and there was an increase in slough area due to the narrowing of the channel (Boyd 2016).

Floodplain isolation along the mill site is the result of two primary dikes, built between 1950 and 1980. The locations of the dikes can be viewed in Figure 3. These dikes are taller and thicker than the secondary dikes, and were built to withstand the river's high flows. The outer dike was built to separate the holding ponds from the Clark Fork River. It was constructed from on-site alluvial material and some rip rap. It measured 20ft high, 15ft wide at the top, with a 2:1 side slope ratio. Dike maintenance ceased in 2007, and the DNRC has classified the dike as a low hazard dam. The inner dike separates the inner mill site from the 100-year floodplain. However, the dike reduced the width of the 100-year floodplain an average of 1800ft, and in some areas as much as 4000ft (Daniels 2016). These dikes cut off a total of 525 acres of the 100-year flood plain; all this lost area is occupied by the wastewater ponds. The dikes reduce the storage capacity of high flows in the flood plain, which increases flood peaks (and flooding) downstream. This in turn increases downcutting and the scouring of the main channel. Groundwater recharge rates can also be affected.

O'Keefe creek, which originally ran through the site area, has been diverted. It no longer has a natural channel that runs into the river. Instead, it has been rerouted along sludge pond 7 and waste water storage pond 2 (Boyd 2016).

Objective 3: Environmental Hazards at the Mill Site

A.) Physical Hazards

Dike failure on site poses an immediate hazard, due to both the proximity of the wastewater ponds, and lack of maintenance on the dikes. Potential causes of dike failure have been evaluated and split into three categories: low, medium and high risk of occurrence. These causes can cause failure by themselves, or as an amalgamation of several (Daniels 2016).

Low risk failure causes include collision of an object into the dike, bottom heave, and over-topping. Medium risk includes tree root damage, slope failure due to foundation destabilization, wave impacts and liquefaction of soils. High risks of failure include the horizontal sliding of the dike, when a flood event raises the pressure against the dike. The foundation of the dike is likely permeable, so under-seepage through it is also considered a high risk. Internal erosion caused via animal burrowing is likely as well. In addition to internal erosion, external erosion is also considered high risk, caused by flowing water along the dike (Daniels 2016).

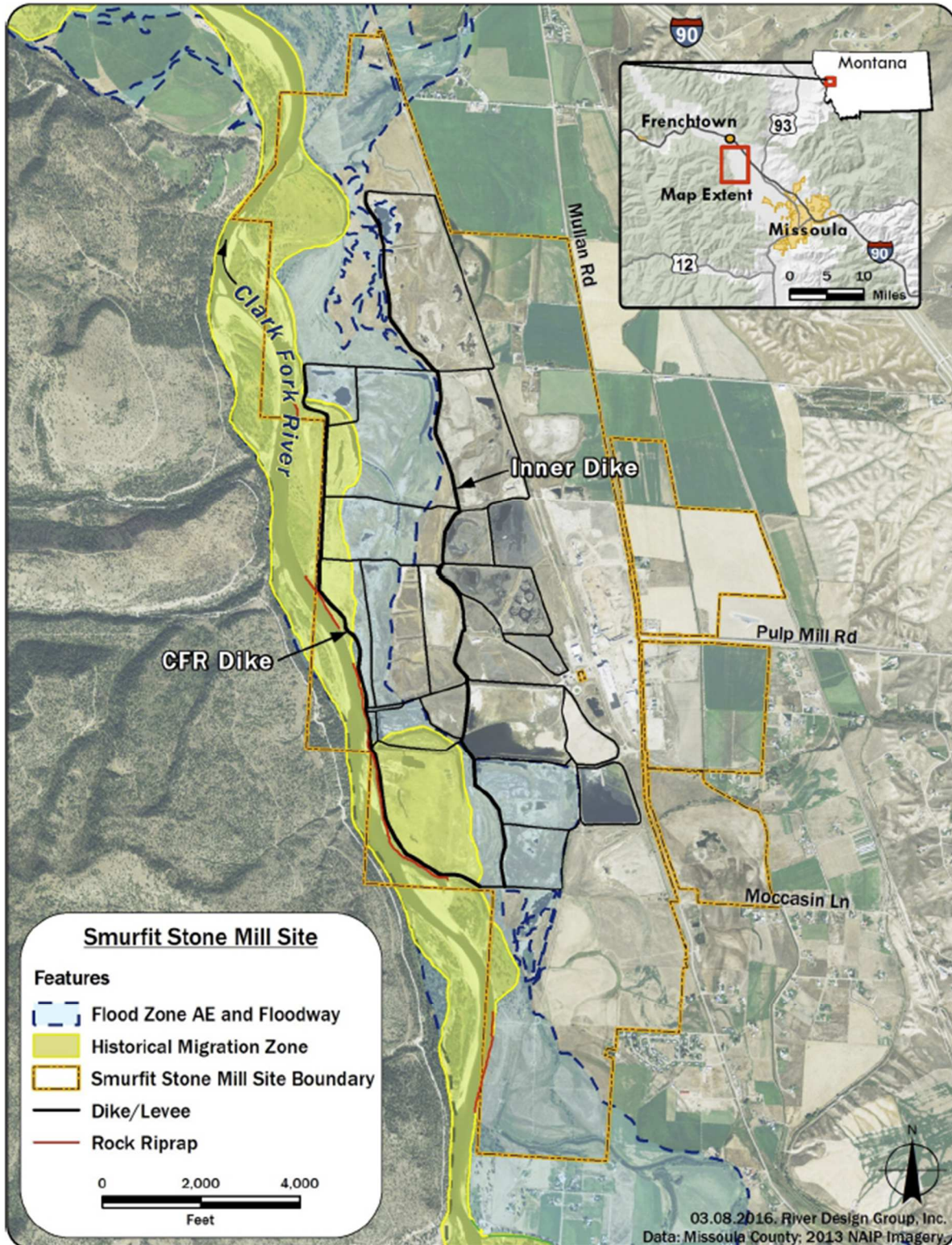


Figure 3: Location of dikes separating the wastewater ponds from each other and from the river. The two primary dikes are labeled in the figure as CFR Dike and Inner Dike.

A study done in the Netherlands of over 1700 failed dikes throughout history showed that 67% of all dike failures were caused by the erosion of the land-facing side of a dike (Van Baars and Kemper 2009). Piping and under-seepage are both reported to occur during a storm or high water. While individual events are unlikely to create slope instability by themselves, continued occurrence and the addition of other failure mechanisms increase the chance of dike failure.

Under-seepage has the potential to cause erosion on the land side of the dike by the formation of sand boils or piping (Ozkan 2003). When the hydrostatic pressure in the wet subsurface becomes greater than the dry soil above it, the water can flow upwards through weak spots that erode soil and carry it to the surface. Sand boils persist until the pressure on the top is equal to the pressure below. This is dangerous because it can cause erosion of the material below the dike, and with enough water from the sand boil, the material of the dike itself.

External erosion along the river-facing side of the dike can occur through both high flows and ice shearing. Throughout the history of the mill, repairs to the rip rap along the water side of the dike have been recorded (Daniels 2016). These SB-310 permits occurred approximately every ten years, with the last permit for repair being issued in 1998, almost 20 years ago. A substantial amount of erosion on the water side of the dike can cause rapid destabilization of the dike.

Internal erosion caused by animal burrows can cause dike failure in several ways. The most significant is in the form of hydraulic alteration (FEMA 2005). By burrowing into the dike, animals can shorten seepage paths or increase seepage volumes, which in turn increase the likelihood of slope failure or of piping within the dike. A collapsed burrow caused by heavy rain or snow melt can lower the crest of the dike or increase slope instability. Without regular inspection and maintenance, the damage from continuous burrowing can result in catastrophic dike failure during a high-water event.

Vertical sliding of the dike is typically caused by over-topping of water that spills onto the land side, causing erosion and a decrease in slope stability. However, according to Daniels, the dikes are considered to be high enough to prevent any over-topping (Daniels 2016). The report is likely referring to horizontal sliding, where water pressure on one side of the dike actually pushes the entire dike, which shears along the layer of sediment underneath it, until it is past the point of structural integrity (Van Baars and Kemper 2015). This type of failure was observed in sections of the New Orleans dike after Hurricane Katrina.

The presence of the dike can be considered a hazard itself due to the ecosystem services that the floodplain provides. A naturally functioning floodplain allows for the reduction of flood damage in other areas, by storing both flood energy and the materials that are associated with an annual flood (Peipoch et al 2015). The shallow aquifer is also better maintained by a connected floodplain. By narrowing the channel and isolating the floodplain, communities downstream face enhanced floods if the dike holds, and chemical contamination if it doesn't.

B.) Chemical Hazards

A preliminary investigation of the site was conducted by URS Operating services under EPA during the week of October 23, 2011. The sample collection team was accompanied by two EPA operatives. A total of 75 samples were collected from the soil surface (17), subsurface (8), groundwater (21), surface water and sediment (20) and 9 QA/QC samples. Samples were chosen based on their proximity to potential waste sources. QA/QC samples of both the soil and groundwater were also collected. The objective was to collect data for a site investigation (SI) and removal assessment (RA) (Miller 2012). Therefore, sample point locations were based on what areas had the highest potential for containing hazardous substances.

The SI determines if further investigation is needed, while the RA decides whether an environmental or human threat exists such that immediate removal is required. These combined studies are meant to first confirm the suspected source area of contaminants, and evaluate them according to EPA's Hazard Ranking System. They are also meant to find out if the contaminants have or are likely to be transported from the site sources into the Clark Fork or O'Keefe Creek. Transportation can occur through erosion or flooding, over the surface or through the ground water. (Miller 2012).

The studies will also evaluate any threats from contaminant exposure to anyone using the local groundwater, and anyone working or assessing the site. Finally, the two studies will document recreational use of the Clark Fork near the vicinity, and any environmental threats. Groundwater will be assessed within a mile radius from site sources. Surface water was investigated up to 15 miles downstream from the probable point of entry (Miller 2012).

Surface soil samples are considered samples that are 0-2 feet below the surface. Subsurface samples are those beneath 2 feet. Ground water samples were collected from existing wells and newly installed monitoring wells. Samples were analyzed for volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), total and dissolved metals, chlorinated dibenzo-p-dioxins, and chlorinated dibenzofurans. Additional information about the substances the EPA tests for can be found in Table 1. These samples were shipped to several different labs for analysis. While 18 sample jars were broken in transit, it was reported that the jars contained enough sample material to still be used. Sampling methods followed the EPA's technical standard operating procedure (Miller 2012).

The unlined ponds are considered potential hazards at the site. For contaminant transport, the surface and groundwater pathways are the primary pathways of concern, with soil and air exposure less likely due to the lack of residential area in the immediate vicinity. Locations were established by their proximity to site sources or pathways. Background samples were collected upstream from the site, away from the wastewater treatment ponds but still on land owned by the mill, to establish a reference measurement, and chemical levels 3x the background sample levels are considered contamination (Miller 2012).

Four sludge ponds identified numerically as 3, 4, 5 and 17 with respective sizes of 20, 23, 24 and 24 acres, were selected as source sites for sampling. Four soil samples were taken from 3

Chemical	Source	Effects	Safe Limit
PCBs	Transfer agent, Insulating fluid, plasticizer	Carcinogen, Liver Damage	0 (0.5 ppb allowed due to limitations on water treatment)
Dioxins (TCDD, PeCDD)	By-product of bleaching paper pulp and waste incineration	Carcinogen	1000 ppt TEQ (Toxic Equivalent) in soil and 100 ppt in sediment
Furans (PeCDF, HxCDF, HpCDF, TCDF)	By-Product	Carcinogen	(dioxin and furans are combined to determine if there levels are below the safe limit)
VOCs (EPA tested for 52 different VOCs and 67 different SemiVOCs)	By-Product of pulping process	Respiratory, allergic or immune effects. Possible carcinogen	Limits depend on the compound being tested, primarily measured in parts per billion.
Metals	By-product of pulping process	Metal poisoning	Limits depend on the metal and whether measurements are for dissolved or total metals

Table 1: Various Substances the EPA tests for at former kraft pulp mill sites

and 17, two from the surface and two from the subsurface. In ponds 4 and 5, two surface samples and one subsurface sample were taken. The results of these samples showed the presence of several contaminants. 4-methylphenol was found in ponds 4 and 5 surface soils, and all four sludge ponds subsurface soils. Isopropylbenzene and phenol were found in the pond 5 subsurface. Elevated metals were found in all four ponds, and were 2x as high in ponds 3 and 17 as in the other ponds. The elevated metals found were barium, cadmium, manganese, and calcium, with an elevated level of arsenic as well. Additional metals were found but not at elevated levels. Dioxins and furans were also found in all four ponds, and the total TCDD had the highest concentrations in ponds 3 and 17 (Miller 2012).

In the 24 acre Emergency spill pond (another source site identified as Pond 8), one surface and one subsurface soil sample were taken from the dry portion of the pond, and only one surface soil sample was taken from the wet area due to safety concerns. The emergency spill pond had contaminated levels of 4-methylphenol, naphthalene, and phenanthrene in its surface soils. There was also benzo(a)pyrene in one surface sample that was higher in concentration than the superfund benchmark. Dioxins and furans were also found in these samples, along with elevated levels of arsenic (Miller 2012).

Three surface soil samples were taken from the site's old soil landfarm area (where contaminated soil was mixed with non-contaminated soil for aeration treatment as a remediation effort), and two surface soil samples were taken from wastewater pond two, a source site also

considered to be at greater risk due to its proximity to the Clark Fork River. These sources did not show an elevated level of metals, but did contain levels of arsenic that were above the benchmark and the presence of dioxins/furans (Miller 2012).

Groundwater samples were taken from both the shallow aquifer and the deep aquifer. Well locations are recorded in Figure 4. Eight samples were taken in temporary monitoring wells that were drilled into the shallow aquifer in areas that were within or down-gradient of source sites. Seven more samples were taken from existing wells in the shallow aquifer that were also down-gradient, near the Clark Fork. The deep aquifer samples (6) were taken from five domestic wells just outside the property boundary, and one supply well on the property (Miller 2012). For comparison, one shallow and one deep aquifer sample were taken up gradient from the mill, outside of the property. This makes 15 shallow aquifer samples taken on site (with one background sample off-site, up gradient), and 1 deep aquifer sample taken on site. The five additional deep aquifer samples were taken down gradient, but were off-site due to accessibility (they were already drilled, but on private land). The background deep aquifer sample was taken on-site, up gradient from any source sites.

The groundwater samples collected during this study exhibited elevated levels of metals (i.e. 3x the level of background sites). These samples were taken from landfills A, 6, E and G, and the aeration basins. Down-gradient from landfill A, a shallow aquifer sample was taken that showed elevated concentrations of acetone, chlorobenzene, ethylbenzene, o-xylene, m,p-xylene and isopropylbenzene. Dioxin/furans were present in all shallow aquifer samples, with the highest levels being down-gradient of sludge pond 3. The most widespread contaminants were iron, arsenic and manganese. As expected, samples further away from the suspected source sites had lower levels of contaminants than those near the sites. There are no known uses of the shallow groundwater at the site, thereby imposing no immediate danger (Miller 2012).

Surface water and settled sediment samples were taken together at eight different locations in the Clark Fork and O'Keefe Creek for a total of 20 samples. Four pairs were taken just downstream of wastewater outfalls on the Clark Fork, and two pairs in O'Keefe Creek. Additionally, a pair of samples between outfalls 2 and 3 was taken from the Clark Fork, and a pair in between outfall 1 and the confluence of O'Keefe creek (Miller 2012).

In four out of these seven Clark Fork locations, elevated levels of manganese were found. In O'Keefe Creek, one of the three samples taken had elevated amounts of aluminum. Sediments that were tested from the Clark Fork also showed elevated levels of metals. Three of the seven samples had elevated calcium, and one sample had elevated chromium and potassium. All surface water samples in both water bodies contained concentrations of arsenic that exceeded both aquatic life and human health standards. Samples at both water bodies showed the presence of dioxins/furans or their congeners (Miller 2012).

Unconfirmed sites (i.e. untested) that could be potential sources of contamination include eleven ponds for wastewater storage, three ponds for wastewater treatment aeration basins, and two polishing ponds. In O'Keefe Creek, the presence of dioxin and furan congeners has been

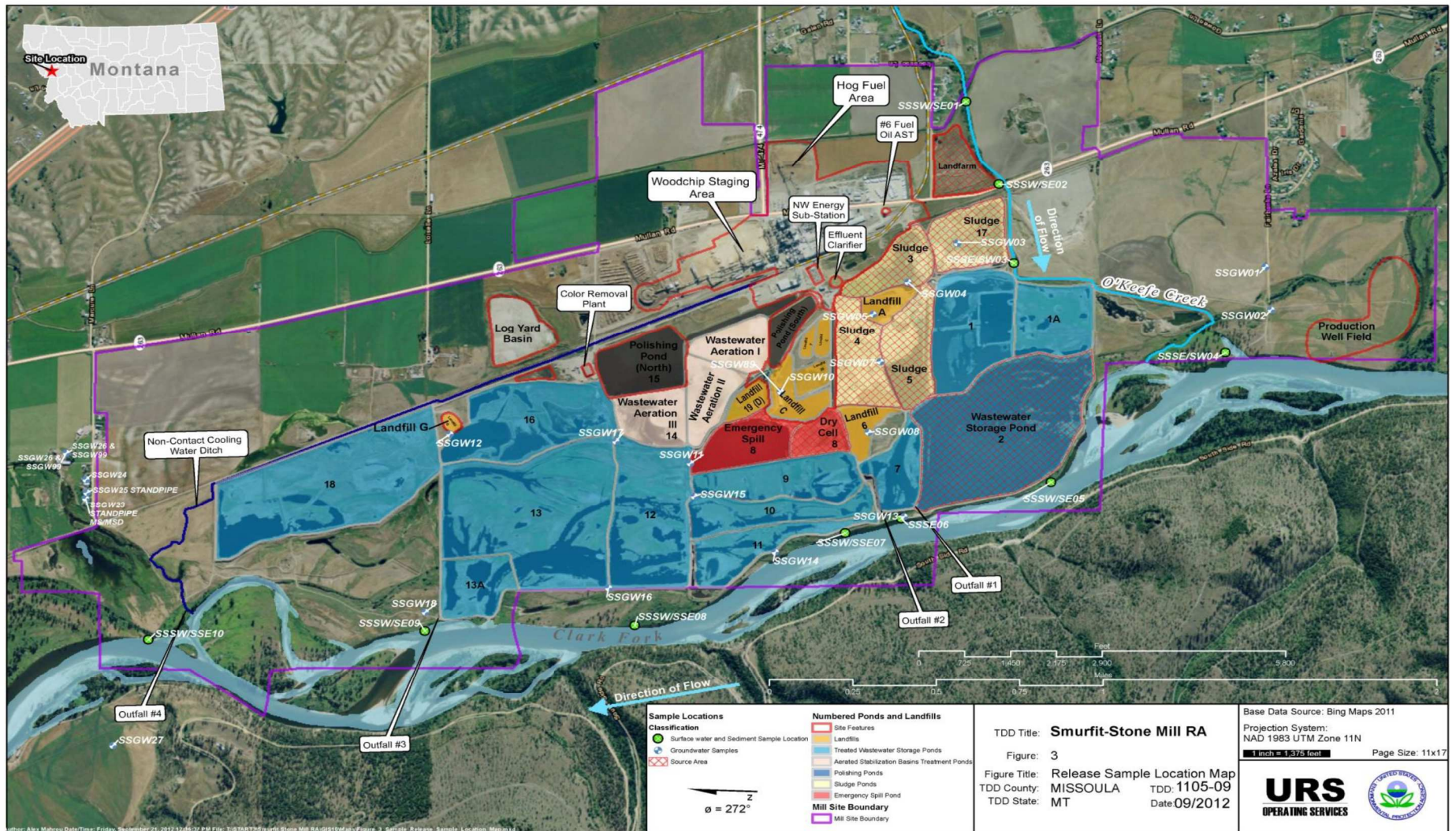


Figure 4: Map of sample locations. Sample codes: The first two S's (SS) are for Smurfit Stone. The remaining letters stand for: SW- Surface Water, GW- Ground Water, SSE- Surface Sediment.

found near the area where the creek runs by sludge pond 7. The study suggests that contaminated dust was transported by wind from the pond into the creek (Miller 2012).

C.) Ecological Disturbance

The alterations of the channel and floodplain have created an unnatural ecological disturbance. The isolation of the floodplain, lack of riparian vegetation, and a simplified aquatic habitat are all the result of constructing the mill site. Ecosystem services that would otherwise exist in the side channels and oxbows are no longer available. These include juvenile fish rearing habitat, macroinvertebrate production, and primary production (Daniels 2016). Due to channelization, O'Keefe creek has experienced down cutting and a loss of riparian vegetation, resulting in poor in-stream habitat conditions (Boyd 2016).

Natural disturbances in the floodplain are necessary to maintain the biodiversity of the entire fluvial ecosystem (Ward et. al. 1999). These areas traditionally have high levels of diversity that rely on flooding and channel migration to create a variety of riparian vegetation in different succession stages. Biodiversity is usually higher in floodplains that are connected to the main channel than those that are not. Connectivity of nutrients, organic matter and organisms between the floodplain and main channel allow different organisms to thrive in the different regions of the riparian area.

Restricting the channel so that it reduces flow variability is a direct cause of losing niche organisms, like plants that colonize newly exposed soil after the spring floods. The loss of these organisms narrows the biodiversity of the riparian area, creating an ideal environment for invasive species (Peipoch et. al. 2015). The presence of rip rap, for example, provides a better habitat for exotic species than does a naturally occurring shoreline. The heterogeneity of a natural system is important to generate resistance to stress factors like invasive species or pollutants.

Objective 4: Contamination and Cleanup Efforts at Other Pulp Mills

The Fox River in Wisconsin is the site of contamination from several kraft pulp mills. Overall, 250,000lbs of PCB have been discharged into the river, contaminating 11 million tons of sediment, with another 160000lbs of PCBs flushed into Green Bay. The sediments in Green Bay are considered unrecoverable, but federal cleanup operations have commenced to remove those still in the river. The current methods involve dredging the river sediments, or capping them where possible (Clean Water Action Council 2016).

The local community had been working to have the contaminants removed since 1985, but an official court ruling that made the companies responsible did not occur until 2013. This site shows the potential impacts of allowing large amounts of contaminants into the river (Clean Water Action Council 2016).

In Washington, a kraft pulp mill owned by Kimberly-Clark, which was in operation for more than 80 years, was shut down in 2012. A year after the shutdown, the plant was

demolished and removed (Cooper-McCorkle 2016). Dioxins were found in an adjacent waterway, as a result of wastewater being dumped directly into the water since the 1930s. These dioxins are traced back to chlorine used in bleaching, and sulfate liquor used to create the pulp from wood. Samples taken on-site revealed dioxin levels ranging from 1ppt to 153ppt (levels above 4 ppt are considered unsafe). Discharged wood pulp on the bottom of Possession Sound has reportedly created a dead-zone for sea life. 4-methylphenol was also found in significant levels (Sheets 2012). Soil contamination from petroleum storage and distribution was also found on-site. Rather than a superfund listing, a clean-up order was issued under state law (Sheets 2012).

The site cleanup caused a debate over whether to replace the surface soils with imported top soil or crushed concrete. Extensive soil and groundwater sampling revealed contamination that resulted in removal of 38000 cubic yards of soil, and 6000 gallons of petroleum-impacted groundwater (Cooper-McCorkle 2016). The contaminated shoreline has yet to be cleaned, but will likely involve full removal of contaminated sediments. Removal of the sediments in the waterway will also likely be required through dredging (Sheets 2012). In 2014, the city of Everett sued the company in charge of the site for failing to clean the site. While the site has now been sold for redevelopment, the company is still required to clean the site (Catchpole 2017). What they decide to replace the removed soil with will depend on what the site is used for in the future.

Not far away, another mill has been undergoing clean up in the city of Port Angeles, at the Rayonier Mill Site. (DoE State of Washington 2016) The mill operated from 1930 to 1997, producing pulp through the sulfite process. Prior to the 1970s, the mill discharged its untreated waste water directly into the local harbor. After that, it treated the waste water using primary and secondary treatment and discharged the treated wastewater through an outfall that ran a mile offshore. The recorded pollutants from the site were PCBs (used as an insulator for electrical equipment), petroleum hydrocarbons, dioxins and furans, lead and arsenic, which are typical of many industrial sites.

After the site was closed, EPA investigated it and concluded it was eligible to be a federal superfund site. The state of Washington opted to clean it up under the Model Toxics Control Act, A Washington state law. Cleanup began in 2010 under an “Agreed Order,” which included a portion of the site considered a study area. This study area consists of 75 acres of the former mill property, and 1300 acres of marine environment. So far, the clean-up of the site has consisted of investigations into soil and groundwater, as well as marine water and sediments. The procedure is very similar to the superfund process, with short term assessments determining if there are emergency action requirements followed by the continuous investigation and clean-up planning. The timeframe of this site can help determine what kind of time frame the Smurfit-Stone site will be looking at, and may allow for some examples of clean-up techniques beyond those already considered. Due to staffing delays and a change in sediment standards, the finishing date of the site’s clean up went from 2020 to 2026 (Gottlieb, 2017).

An ongoing case involving kraft pulp mill pollution can be observed in Pictou County, Nova Scotia. The Abercrombie Point pulp and paper mill went into operation in 1967. The mill released its effluent into the Boat Harbor estuary, causing mass fish kills and health problems for

the people who swam there (Howe 2014). Even though the mill had a treatment facility, the effluent was only placed into settling ponds to lower the temperature before dumping. Surface water samples and groundwater monitoring wells contain contaminated levels of the same metals found in the Smurfit-Stone sludge ponds, waste dumps, and aeration basins.

The Nova Scotia mill is also infamous for its air pollution, which was so bad that tourism guides warned people to avoid the town of Pictou (Howe 2014). In order to address this, a local organization lobbied the government to crack down on the emissions. The mill installed a precipitator to reduce the air pollution (MacIvor 2015). However, a spill caused by a ruptured pipe that leaked 47 million liters of untreated effluent into Boat Harbor may cause the plant to close entirely (Withers 2016). The mill was fined \$225,000 for the spill, under the Canadian Federal Fisheries Act. The Nova Scotia government has now promised to close the mill by 2020. The issue of clean-up has been addressed, but not determined, and the mill continues to produce 90 million liters of effluent every day.

The Abercrombie Point mill illustrates what could have occurred at the Smurfit-Stone mill if discharge was not regulated and water quality not monitored. At Frenchtown mill, the contaminants were housed on-site, and due to the separation of the floodplain from the main channel of the Clark Fork, there was likely less long term pollution to the Clark Fork. Cleanup is likely to be more complicated and far-reaching in Boat Harbor.

Objective 5: Remediation Options for the Frenchtown Pulp Mill

A.) Contaminants

Due to the variety of contaminants on site, several remediation options exist for the site. The goal for this site is ultimately redevelopment, due to the loss of taxes to the town of Frenchtown after the closing of the pulp mill. The three sections of the site, Operable Unit 1 (1200 acres of agriculture land), Operable Unit 2 (225 acres of industrial land) and Operable Unit 3 (the 1700 acres of holding ponds), all have the potential to be redeveloped, if the contamination is cleaned properly. Several remediation technologies have been tested for most of the major contaminants found in the initial investigation.

The most common practice is mechanically removing contaminated material. While this removes the contaminants from the site, it typically only moves them to a repository nearby, out of the floodplain. Many of the following treatment attempt to immobilize or degrade contaminants.

In 2009, a remediation method for the contaminant 4-methylphenol was tested at the Ketchikan Pulp Company site in Alaska. The project used enhanced monitored natural recovery (EMNR,) which consists of a thin layer cap made up of fine to medium grained sand mixed with non-plastic silt (Clu-In 2016). The goal of the EMNR is to create a sediment surface that limits exposure to the contaminated soil underneath it, and in turn improves habitat conditions. The test area was a 27-acre plot located underwater. The delivery mechanism was a derrick barge, and the method was implemented over a 30-day period. After five years, the EMNR was still functioning properly, keeping 4-methylphenol levels under the site-specific sediment quality

values. This material was priced at \$18 per cubic yard.

Isopropyl benzene in situ treatment was tested at a former gasoline station in Delaware County, New York in 2007. The compound being tested was called RegenOx, which rapidly desorbs the contaminants from the soil to the groundwater (Clu-In 2016). The compound then promotes oxidation of the contaminant. The test site was a 30ft by 30ft area with a thickness of 4ft, found 25ft below the surface. The substrate of the area is described as a sandy aquifer. A 38% decrease of petroleum VOC concentration was reported from groundwater samples. While no price was given for the amount of RegenOx used, the study concludes that this treatment can reduce petroleum hydrocarbons by mobilizing them (potentially shifting the problem elsewhere).

Naphthalene was another contaminant tested for in-situ treatment by RegenOx, but additional studies tested other remediation technologies for Naphthalene. In 2010, at a former wood preserving facility in Sandpoint, Idaho, underwent testing for in situ geochemical stabilization (ISGS.) A modified sodium permanganate reacts with the organic constituents in an impacted aquifer, causing a rapid reduction in aquifer permeability and stabilization of non-aqueous phase liquid residuals. Problems during the application of the ISGS caused only 55% of the intended amount to be applied. Despite this, the concentrations of naphthalene, PCP, and polynuclear aromatic hydrocarbons declined by 94%. The non-aqueous phase liquid residuals were no longer present two years after application. Test area dimensions and cost of application were not supplied in this study profile (Clu-In 2016).

Another in-situ treatment study took place to reduce Benzene-toluene-ethylbenzene-xylene, methyl tert-butyl ether and naphthalene, contaminants related to underground petroleum storage was conducted in South Carolina in 2005 (Clu-In 2016). This technique used steam and sodium persulfate injection wells into the soil. Application occurred 8 hours a day for three days and then for another two days one week after the first injection. The persulfate was thermally activated by the steam, which reduced all the contaminants to non-detectable levels. The cost for the entire project was \$15,000, which was concluded to be a cost-effective remediation technique.

A 900-foot-long contaminant plume of manganese, cadmium, iron, and other metals in the groundwater was the subject of one demonstration in 2004 at the Stoller Chemical Site in Jericho, South Carolina (Clu-In 2016). The shallow surface aquifer was 2 to 8 feet below ground surface, overlaying a clay confining layer. The process involved an in situ permeable reactive barrier made up of coastal hay, hardwood and softwood chips, saw dust, limestone, horse manure, and cement kiln dust buried in a trench down gradient from the plume. This material was mixed and incubated on site for 33 days. Barriers in the form of steel sheet pilings were then removed, allowing the groundwater to flow through the mixture. The results showed a decrease of metals ranging from 74% to 96%. It is important to note that because the metals are trapped within the barrier, it is possible that eventually the barrier can become saturated.

The remediation of both manganese and arsenic was demonstrated at the Oak Manor Municipal Utility District Facility in Alvin, Texas, in 2008. Over 35 million gallons of groundwater were treated in this study, which used in situ chemical treatment through adsorption

vessels with an iron based media. These vessels measured 63 by 86 inches, and averaged a flow rate of 129 gallons per minute. Arsenic levels were reduced by 96% and manganese levels were reduced by 97%. The capital investment for the system, was about \$180,000, and had minor additional costs for media replacement, disposal or labor (Clu-In 2016).

Arsenic treatment methods are primarily meant for drinking water, while groundwater remediation uses the already mentioned permeable reactive barrier. A study done in 2004 at ATOFINA Chemicals Inc. superfund site in Tacoma, WA, tested an in-situ remediation of contaminated groundwater (Clu-In 2016). The process used a hydrogen peroxide solution followed by a ferric chloride solution injected into the shallow aquifer to precipitate dissolved arsenic out of the groundwater. In three to ninth months, the site showed an 85% to 99% reduction of arsenic in the groundwater. The arsenic must still be removed, making this a short-term solution for creating drinking water.

At the Arsenic Removal Treatment Technology Demonstration Project Site, a large coagulation /filtration system was able to reduce arsenic concentrations by 25%. This system used contact tanks and filtration vessels, utilizing a pre-chlorination system, iron addition system, and a recycle system. The system requires a \$334,297 capital investment.

Remediation of dioxins and furans was tested ex situ in 2001 at the Hazen Research Center and MinergyGlassPack Test Center in Wisconsin (Clu-In 2016). The process took contaminated river sediments and first dried them in a dryer with the capacity of 14 pounds an hour. The dried sediment was then put into a glass furnace for 6 hours. The furnace is capable of processing 2 tons per day. The end product removed or destroyed 99.9995% of dioxins, furans, and PCBs, and created a glass aggregate that could be reused. This process is likely both high cost and high energy that can only accommodate small amounts of contaminated soil at a time.

Manganese had several demonstrations of removal or remediation methods, most of them tested at former mines. Because these sites dealt with acid mine drainage, their profiles will be omitted in favor of sites that dealt primarily with groundwater contamination.

It is important to note that with many of these treatments, the contaminants are primarily just trapped. These trapping mechanisms run the risk of becoming saturated or breached from earth movements.

B.) Reducing impacts of dikes

The dike running along the Clark Fork River would need to have maintenance reestablished for it to continue to be effective. However, removal of portions or all of the dike (after the wastewater ponds are cleaned up) could serve ecological purposes, as the historic floodplain would no longer be isolated from the main channel. This would not only have an ecological benefit, but would also dissipate flood energy that would otherwise be transferred downstream to less protected areas.

CONCLUSIONS

Objective 1

The history of the mill is well documented, which allowed for an extensive description of the site's expansions and controversies through the years. The only information that was lacking was the inside operations of the company's management and their plans and reactions to the communities. The recent studies of the alteration of the landscape provided an exceptional source for examining the extent of the pulp mill's influence.

Objective 2

The nature of the site was not extensively profiled before mill construction began. Despite this, a basic profile could be constructed of the area, based on current data and historic photos. The ongoing investigation will likely shed more light into subjects such as geomorphology and hydrogeology.

Objective 3

With the still ongoing investigation by EPA, the preliminary study the agency conducted provides an idea on what further studies are needed. Source points of contaminants were confirmed, as well as the groundwater pathways that carry them away from the sources. The identification of the various contaminants and their locations will be important to both future sampling, and eventual cleanup of the site. It is important to note that these samples do not characterize the extent of contaminations, they only confirm the presence of them in the location sampled. Assessment of dike stability is important to deciding the time frame for emergency remediation actions. The lack of maintenance on these dikes is troubling and has the potential to spread the contaminants within the site downstream if the dikes were to be breached. Ecological disturbances are also an important consideration when looking at future plans for the site. When the mill was constructed, it severely reduced the ecological potential of that area.

Objective 4

The information gathered on other pulp mill sites in different stages was valuable to get a perspective on possible threats from the Smurfit-Stone mill, and to supply ideas on how to best deal with the eventual conclusion of EPA investigation. The other sites explored were also in different geographic settings, but faced many of the same problems of contamination and pollution, revealing a deeper problem with the industry itself. The cleanups are costly, and prevent use of the contaminated lands until they have been remediated, which could take many years to accomplish, and may require perpetual care.

Objective 5

Remediation options are difficult to predict at this stage in the investigation, but some technologies may prove useful when the extent of cleanup is known. If it is determined to be

necessary to remove an extensive area of contaminants, many of these options may not be cost effective. If smaller patches of soil and groundwater are all that need to be removed, some of the technologies and techniques provided by EPA database may be appropriate.

Overall Conclusion

Most pulp and paper mills produce large amounts of waste, and the Frenchtown mill was no exception. Over the course of its operating years, it released large amounts of waste water into the Clark Fork River, spewed toxins into the air from material burned in the wood boiler, and left contaminated water and waste in the land around the mill. In addition to the pollution it produced, the location of the mill altered the natural landscape and ecology around it. The closing of the mill was not an end, but a beginning. It marks the start of returning the landscape to a condition that can support wildlife and human uses.

Recommendations

While preliminary testing shows evidence of contaminants, further testing is needed to determine the full extent of the contamination. Testing in all potential sources should be conducted, as well as more complete groundwater profiles of both contamination and flow direction. Treatment ponds will need to be fully characterized to determine just how much of the site contains contaminations. Clean up and remediation is likely, but the extent that will be necessary is unknown. The technologies explored in this paper may be viable options when the time comes, or there may be other, unmentioned methods that could be more appropriate.

While further investigation is ongoing, the dikes should be closely monitored to avoid any breaches that could occur due to disrepair. Considerations should be seriously considered to remove at least the outer dikes when remediation is complete, in order to restore the floodplain.

To restore its ecologic potential, I feel the Clark Fork should be reconnected with the isolated floodplain and CMZ after the removal of contaminated sediments. This will promote restoration of natural riparian vegetation and reestablishment of off-channel habitat. Main channel habitat may also be restored through the reduction of bed scouring and downcutting. Improving fish habitat should be a priority since the Clark Fork is listed as a nodal habitat for endangered bull trout (Miller 2012).

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Part 2

Developing Water Quality Standards for Montana Ecoregions Based On Least Impacted Streams

INTRODUCTION

The Montana Department of Environmental Quality stream reference project began at its current capacity in 2000, as a continuation of work done in 1992 (Suplee et al. 2005). The purpose of the project is to characterize the state's least impacted streams and use those characteristics to set restoration goals for impacted streams. In addition, this information is used in setting water quality standards for parameters that vary greatly by ecoregion (such as nutrients).

STUDY DESIGN

Site Selection

Reference streams are selected based on their condition in relation to human-caused changes. There are two tiers that a stream can be chosen from: Tier 1: Natural Condition, where there are no detectable human-caused changes and Tier 2: Minimally Impacted Conditions, where the biotic community structure is not affected by the actions of people (Suplee et al. 2005). Tier 3 streams are those that are considered to be moderately impacted and cannot be chosen as reference streams. Additional evaluation criteria includes:

- Watershed road density
- Percent land use in agriculture
- Logging Density and impacts
- Grazing impacts
- Presence of mines
- Presence of point sources

The presence of active or inactive mines is an important factor in selection, as the level of metals in reference streams is useful in assessing the impacts of mining (Suplee et al. 2005).

The list of streams that were either tier 1 or tier 2 was further subdivided by ecoregion. In Montana, there are 7 classifications used: Northern Rockies, Middle Rockies, Canadian Rockies, Idaho Batholith, Transitional (between mountains and plains), Northwest Glaciated Plains and Northwest Great Plains.

The DEQ's Water Quality Planning Division selects a list of streams to be characterized in a given season. The list is confined to regions in either the western or the eastern sides of the state, which ideally are alternated each year. The streams that are chosen can either be sites that were visited previously or candidate sites that have yet to have their first visit. The distribution goal for new to revisits is half new streams and half revisited streams.

For the 2016 season, in which I participated, the streams visited were predominantly on the western side of the state in the Northern and Canadian Rockies ecoregions and the transitional zone.

Field Details

The order in which these sites were visited was determined by how quickly our team could get from finishing up one site to reaching the next one. Availability of lodging and resources were also factored into the order of the visits. The nature of the sampling required us to return to the DEQ in Helena several times throughout the season. A typical cycle would start in Helena, then we would travel to 3-4 reference sites before returning. Due to the time it took to travel, hike and locate the site, and the sampling itself, each reference site took 2 days to sample.

Field Protocol Details

The site sampling process gathered data on the physical, chemical, and biological characteristics of the site. Once the site was located, the team began each of our separate duties. These were determined during our training on the first creek, where all the sampling was demonstrated to us by the project leaders, Rosie Sada and Michael Suplee of the DEQ's Water Planning Division who have conducted the reference project since 2000. Training continued for the first four sites, until everyone was confident that we would be able to profile the rest of the sites over the rest of the season.

Sada and Suplee selected the center point of each reach to be sampled and gave the field crew the latitude and longitude of this center point. Water samples that would be used for the chemical profile were taken first, to avoid any contamination of the water from other interactions with the creek. Water samples were collected to measure metals, nutrients and suspended particles. Water samples were also collected for phytoplankton, which involved pumping water through a filter. During this time, I used a multi-parameter meter to record the temperature, dissolved oxygen, turbidity and conductivity. Once we finished water sampling, we determined the length of the study area (the reach) by measuring the average wetted width of the stream. This was multiplied by 40 to determine the full length of the reach (up to 500 meters). If that number was higher than 500 meters, we would continue with a more limited procedure.

The study reach was divided into 10 sections, with eleven transects labeled A,B, C,D,E,F,G,H,I,J and K, with the center transect being the F-site. These were marked out by myself and another member of the team. Once this was completed, the other two members of the team began their specific sampling at each transect, starting at the farthest downstream transect (transect A) to avoid contaminating other transects. Before I began my transect sampling, I gathered settled sediment samples at three separate locations, ideally where the stream velocity was low enough for fine sediment to settle out. This sample was later analyzed for metals.

Sampling at each transect was split into three sections, left, right and center. We each had a different section at each transect, and the section would cycle so that each person was sampling a different section of the stream at each transect. The other members of the team collected macroinvertebrates and attached algal biomass, while I collected periphyton (attached algae) for taxonomic analysis. Additionally, I would conduct a visual aquatic survey at each transect, and take several photographs of the transect and anything of interest near each transect (such as natural features like beaver dams, or human features that may be influencing the stream).

Periphyton is the algal portion of benthic biofilm which is a mixture of algae, cyanobacteria and heterotrophs. It sticks to rocks, wood or plant material and was collected from these. For woody material or plants, I would cut a portion of it away and store it in a vial. Rocks were not taken entirely, but instead had the periphyton scrubbed off and put into the sample tube. The sample from each transect was placed into the same sample tube to make a composite sample of the entire reach. Ideally, all types of substrate would be sampled to get the full diversity of species present.

The visual aquatic summary was conducted at each transect and included 5 meters up and downstream from the transect marker. The survey estimated the distribution of macrophytes, moss and algae (classified as either biofilm or filamentous). The growth stage was noted as growing, mature, or decaying for each category. Any macrophytes were identified, as well as the presence of any other life found, such as fish or invertebrates. Finally, the photographs were taken before moving onto the next transect.

When each person was done with in-stream sample collecting, this usually marked the end of the first day. Upon returning the second day, one teammate would identify the plant life that grew in the riparian area of the reach, while the other teammate and I conducted a survey of the geomorphology of the reach using the Rosgen approach (Rosgen 1998).

We would begin by measuring the discharge of the stream (this step was sometimes done the previous day), which could change depending on the weather of the day. A sudden storm could alter the discharge rate considerably, so we had to be careful to make note of conditions when we measured discharge. We used a water flow meter and a wading rod to measure discharge, and a tape measure to note where along the stream the discharge measurement was taking place. The wading rod was used to measure depth of water, and was adjusted to place the flow meter at the appropriate position (about 60% of the depth). The average discharge was measured over a 10 second cycle and recorded. This was done across the stream, from wetted edge to wetted edge, and an overall average discharge was calculated from these measurements.

The profile was done using a laser finder survey tool, and measuring rods for the width and depth. We would begin by finding a suitable section of the reach, then identifying its bank-full stage. The bank-full stage is the highest depth the creek reaches during spring peak flow in most years. During training, we learned the signs that mark the bank-full, such as a line of lichen/non-lichen on rocks, or the progression of the point bar.

The width of the stream at bank-full was measured, and based on this measurement, we determined the distribution of measurements that would be taken between the bank-full width markers. A measuring tape was set across the two markers to create a profile line. The laser level device would be set on a tripod near the profile line, but high enough to accommodate the flood prone area, which was determined as being twice the depth of the deepest bank-full measurement. A series of measurements were made from bank-full to bank-full marks, using a laser catcher on a retractable pole with depth markings on it. One person would operate the pole, while the other recorded the depth measurements and directed where the measurements would take place. Additional measurements included the wetted edge on both sides, and what was

expected to be the deepest point in the profile.

The flood prone area, as described earlier, was found by multiplying the deepest point of the stream (at bank-full) by two, and locating where this measurement was on the land. Depending on the stream, the flood prone area could be narrow, or it could go beyond the range that we're able to measure (which would be marked as >100m length).

Our next step in constructing the geomorphic profile was to determine the slope down the length of the reach. The tools we used were a bubble level, laser distance finder, and a pre measured height on each of our bodies. We would use these tools to measure the height drop from transect to transect, which we could then use to determine the average slope for the entire reach.

The final step in the geomorphologic profile was determining the average size of substrate. This was done at each transect, from bank-full to bank-full. A random sampling of the substrate was picked and measured. Clay, sand, and various size classifications for rocks were noted, and the median size was the substrate selected to represent the stream reach. Using the bank-full profile, slope, and substrate sample, we were able to classify the stream using Rosgen's classification (Rosgen 1998).

The last task our team completed at each reference site was to decide whether the stream was a tier one or tier two stream, determined by point system based on the noticeable impacts to the stream.

During the fall after the field season was done, I assisted in analyzing the algae biomass samples collected under the supervision of Vicki Watson. Algal biomass was measured based on chlorophyll A and ash free dry weight. These were based on standard methods with the chlorophyll method modified according to the protocol of Sartory and Grobbelaar (1984). These measurements of algal biomass were added to the rest of the data we collected over the summer at each site.

PERSONAL REFLECTION

Being part of the stream reference team gave me both experience in field and lab work. Learning about the process of determining water quality will provide insight into both what it takes to acquire useful and legally defensible data, but also the limitations of field sampling. Maintaining the health of a watershed has many requirements, and benefits immensely from having reference systems that inform water quality standards, and also procedures that allow for the determination of whether a system meets those standards.

The reference project would likely benefit from additional visits to streams within the same season. This will give the team an idea of the cycles of growth and changes in flow the streams go through from an earlier point in the season to a later point. This would give a more complete picture of the stream as what can be expected when applying that information to other streams. It will also help for future visits, which may occur in different parts of the season than the previous visit.

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Part 3

Assessing Fire Risk and Damage Using GIS in the Lolo Creek Watershed

INTRODUCTION

Geographic Information Systems (GIS) can be an important tool in exploring and analyzing spatial relationships. The recent Lolo Peak Fire presented an opportunity to test the knowledge I have gained in pursuit of the GIS certificate and to engage with a local organization.

The Friends of the Bitterroot were interested in looking at several different aspects of the fire, such as the relationship between property ownership and fire progression and severity. I took the opportunity to explore the burn area using GIS tools, and apply what I did for them to an assessment of the fire's effect on the Lolo Creek watershed.

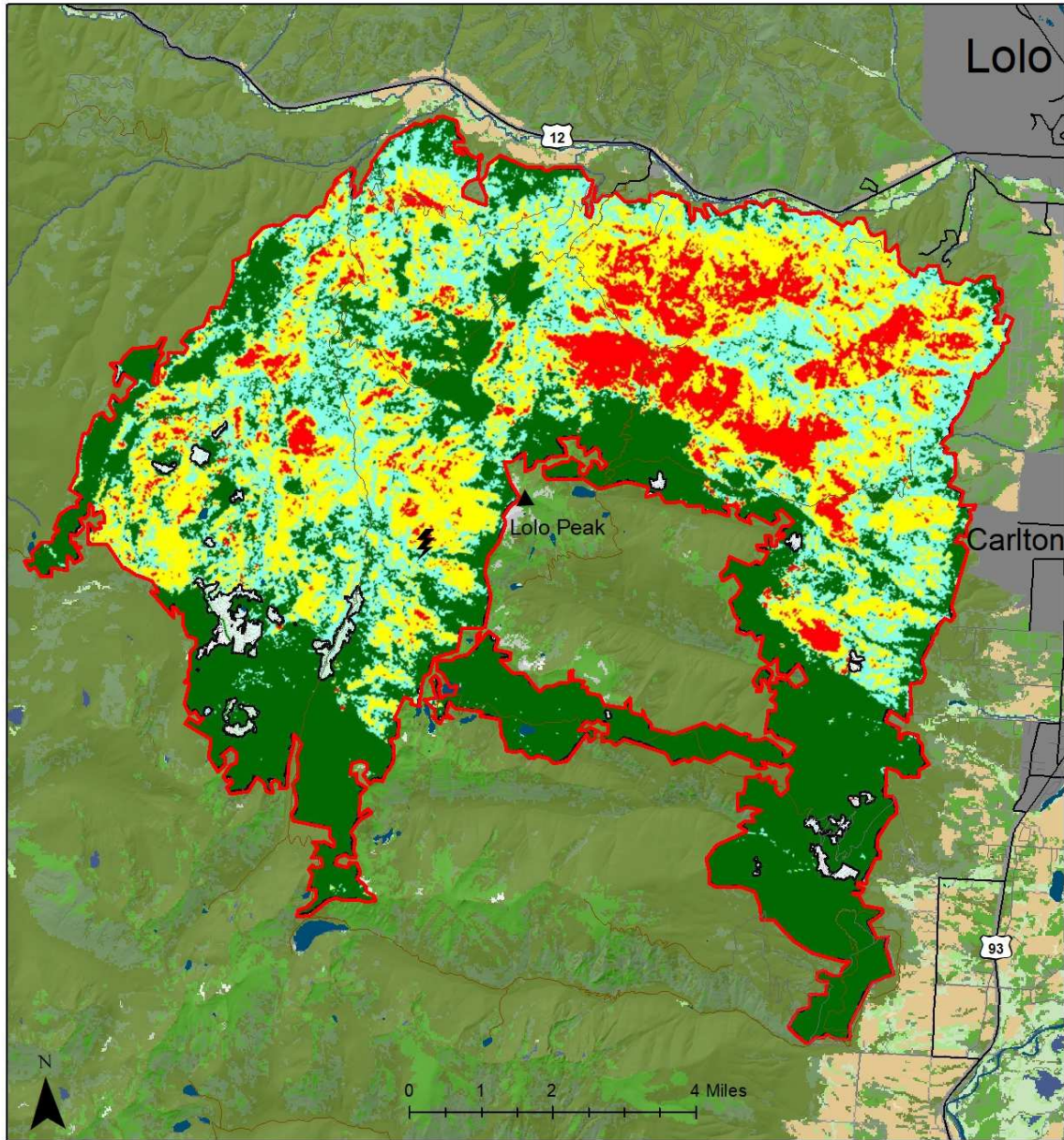
Through a combination of spatial analysis and literature review, I describe possible impacts of the fire on Lolo Creek and its tributaries that were in the burn area. I also followed a methodology that maps areas of fire risk, which can be applied to other watersheds to determine streams at risk of fire damage in the future.

Description of 2017 Lolo Peak Fire

On July 15th, 2017, a lightning strike started a fire on the western side of Lolo Peak near Lolo, Montana. Fire crews quickly closed several trails and roads in the Lolo National Forest and the Bitterroot National Forest. The fire spread west, and in the beginning of August, fire crews began constructing dozer and hand lines and planning fire lines to keep the fire from burning homes along highway 12 to the north of the fire (InciWeb 2017).

The fire continued to spread north, nearly reaching Highway 12 and moving east along the northern slope of the mountain. The dozer lines kept the fire from moving too far east, where the towns of Lolo and Carlton stood. Instead, the fire moved south along the eastern slopes of the mountains. By September, the fire had burned 39,400 acres and was 31% contained (Mtn News, 2017). The fire would continue to burn south with a small section burning from the western portion to the eastern portion, leaving a patch of unburned area in the center, north of Sweeney Peak. By the end of September, the fire perimeter was no longer growing (InciWeb 2017). The entire burned area encompassed 53,436 acres (Figure 1).

There are several creeks in the burned area, most of which are tributaries of Lolo Creek, which runs east to west along Highway 12 at the northern end of the fire perimeter. Mormon Creek, Mill Creek, Tevis Creek, Cedar Creek, South Fork of Lolo Creek, Johny Creek, and Dick Creek had all or most of their watersheds in the burn area. Other creeks that flow down the eastern slopes to the Bitterroot River were also affected. These are McClain Creek, Carlton Creek, One Horse Creek, and Sweeney Creek. There are several alpine lakes that were either directly in the burn area or close by.



Severity of the 2017 Lolo Peak Fire near Lolo, Montana



Figure 1: The extent and burn severity of the 2017 Lolo Peak Fire. Severity data was taken from the National Forest Service map and georeferenced in ArcMap. The fire burned 53,436 acres over the course of about 3 months. The burned area was almost entirely in either the Lolo National Forest or the Bitterroot National Forest. The black lightning bolt shows start point.

GOALS OF THE GIS ANALYSIS

The Friends of the Bitterroot requested a GIS analysis to look more closely at the areas burned and the progression of the fire. I decided to approach this by doing a Multiple Criteria Evaluation (Malczewski, 1999) to determine areas where fires were more likely to start and spread. A MCE is done by assigning weights to different factors based on their strength of contribution to the item being studied (in this case, fire risk). The weighted factors are then combined to create a range of values that will reflect the strength of all the factors. This can also be adjusted to a binary analysis where the criteria are separated into being met entirely or not. For this study, a range of values was used to show areas of different risk. An MCE that is used for spatial analysis will result in a map that shows the range of values in a raster grid.

The MCE was done in two parts, with one evaluation exploring ignition risk and the other exploring spread risk. This was done because roads and trails provide both a means to create fires with increased traffic, but also provide access for fire crews. The assessment was meant to provide ignition and spread risk maps that could then be compared to the actual Lolo Peak Fire to determine the usefulness of the method. Additionally, I used GIS to determine damage to the different watersheds in the area.

Therefore, the three main goals of this analysis are:

1. Address a local group's concerns and questions regarding the 2017 Lolo Peak Fire.
2. Assess fire prediction methods using GIS and compare them to the Lolo Peak Fire and other historical fires.
3. Conduct a literature review and spatial analysis to determine which watersheds will be damaged and what effects this damage will cause.

METHODS OF GIS ANALYSIS

Gathering Data

The data used in these studies came from multiple sources. A Digital Elevation Model (DEM) was gathered from the USGS National Map website. Land classification data were taken from the National Land Classification Dataset, found on the Multi-Resolution Land Characteristics Consortium (MRLC) website. Data such as roads, town areas, wind speeds, and waterways were gathered from the Montana State Library, accessed through the Geographic Information Clearinghouse website. Forest data, such as trails, historic fire extents, and the boundaries of the districts were gathered from the Forest Service, from each national forest's respective website.

Data Limitations

Certain factors that affect the risk of fire were difficult to represent in the assessment. Spatial data can be limited temporally, which doesn't have large effects on static data such as the DEM or land classification, but creates problems when attempting to incorporate wind speeds or soil moisture. Data are also limited by scale. Comparisons are more accurate when all the data are of the same resolution, and finer resolution allows for a better assessment. Finally, data can

come from different sources, which can lead to different orientation of the data based on the coordinate system. This problem is the most easily correctable, as there are tools in ArcMap that align data to the same coordinate system. However, this can cause problems at larger scales.

Manipulating Data

Data management and manipulation were accomplished with ArcMap. The first step was to project everything into the same map projection and “clip the data down” to only include the study area. This was done using the clip and project tool in of ArcMap.

The DEM was used to calculate slope and aspect of the area. Road features, which were separated between rural and highways, were joined together. Trail features of both forests were also joined together. The Cost Distance tool was used on the roads and trails, which created a raster layer that shows the distance away from roads and trails, taking into account the changes in elevation.

Features were first represented by their distinct classes, such as the various land classifications, or by a range of values, such as slopes between five and fifteen degrees. These representations were then given a numbered weight based on their level of influence over fire risk. This was done using the Reclassify tool. Weights were assigned values similar to those found in Gai et. al. (2011). However, the weights for trail and road distance ranges were given both positive and negative values, depending on whether ignition or spread risk was being determined.

For the spread risk assessment, roads and trails were classified with positive values and the consideration of transportation speeds and roadside firefighting (Akay 2015). Figure 2 shows two tables that list the influencing factors and their given weights for ignition risk and spread risk. The difference in values, other than positive or negative, represents the higher likelihood of ignition in areas people frequent.

The reclassified features were then added together using the raster calculator tool. The result was a range of values represented as a color gradient from green (less risk) to red (more risk).

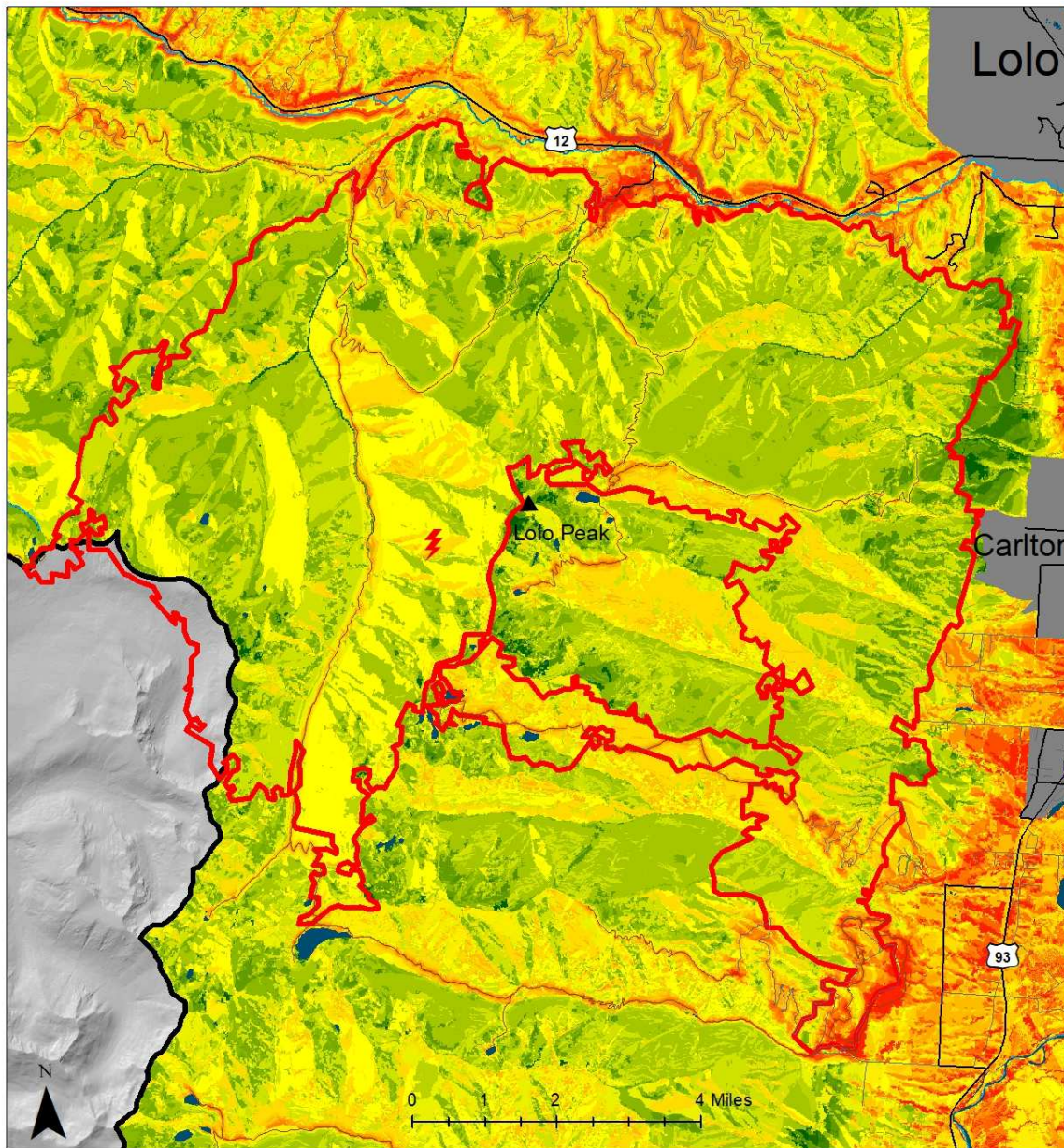
RESULTS

MCE of Fire Risk

The MCE produced two risk maps that represent the risk of fire ignition from both natural or human causes, and the risk of fire spread which considered the suppression abilities of fire fighters. In Figure 3, we see the fire ignition risk around the area of the Lolo Peak Fire. The approximate location of the lightning strike and the perimeter of the burn area are also represented in the map. Here we can see that the highest fire risk areas are around Highway 12 and the rural roads near the towns. Trails and south facing slopes are the areas of higher risk found within the national forest. It can be observed that the area where the fire started had a higher risk for fire ignition than the surrounding area.

Variable	Class	Weight	Variable	Class	Weight
Land Classification	Water	0	Land Classification	Water	0
	Developed	1		Developed	1
	Barren	1		Barren	1
	Deciduous Forest	8		Deciduous Forest	8
	Evergreen Forest	10		Evergreen Forest	10
	Mixed Forest	9		Mixed Forest	9
	Shrubs	6		Shrubs	6
	Grasses	7		Grasses	7
	Agriculture	2		Agriculture	2
	Wetlands	1		Wetlands	1
Slope	>5	1	Slope	>5	1
	5-15	3		5-15	3
	15-25	5		15-25	5
	25-35	7		25-35	7
	>35	10		>35	10
Aspect	North	1	Aspect	North	1
	East	3		East	3
	West	5		West	5
	South	7		South	7
Distance to Trails	<10	7	Distance to Trails	<10	-5
	10-20	5		10-20	-4
	20-50	3		20-50	-3
	50-100	1		50-100	-2
	>100	0		>100	0
Distance to Rural Roads	<50	7	Distance to Rural Roads	<50	-7
	50-100	5		50-100	-5
	100-150	3		100-150	-3
	150-200	1		150-200	-1
	>200	0		>200	0
Distance to Highways	<50	9	Distance to Highways	<50	-5
	50-100	7		50-100	-4
	100-150	5		100-150	-3
	150-200	3		150-200	-2
	>200	0		>200	0

Figure 2: Table 1 (left) shows the weights given to factors that influence the risk of fire ignition. Table 2 (right) shows those weights given to risk of fire spread. Natural factors such as land type and slope are identical, while roads and trails are different. This is to indicate the increased chances of ignition were people are more likely to be, but also the use of these same roads and trails for fire suppression. These values were modified from those used in Gai et al 2011.



Fire Ignition Risk Around Lolo Peak, MT



Figure 3: Risk of fire ignition in the area of Lolo Peak. The 2017 Lolo Peak fire is represented by the red outline and its starting point as a red lightning bolt near the center of the map. Areas of highest risk are located near roads and trails due to the increased likelihood of people.

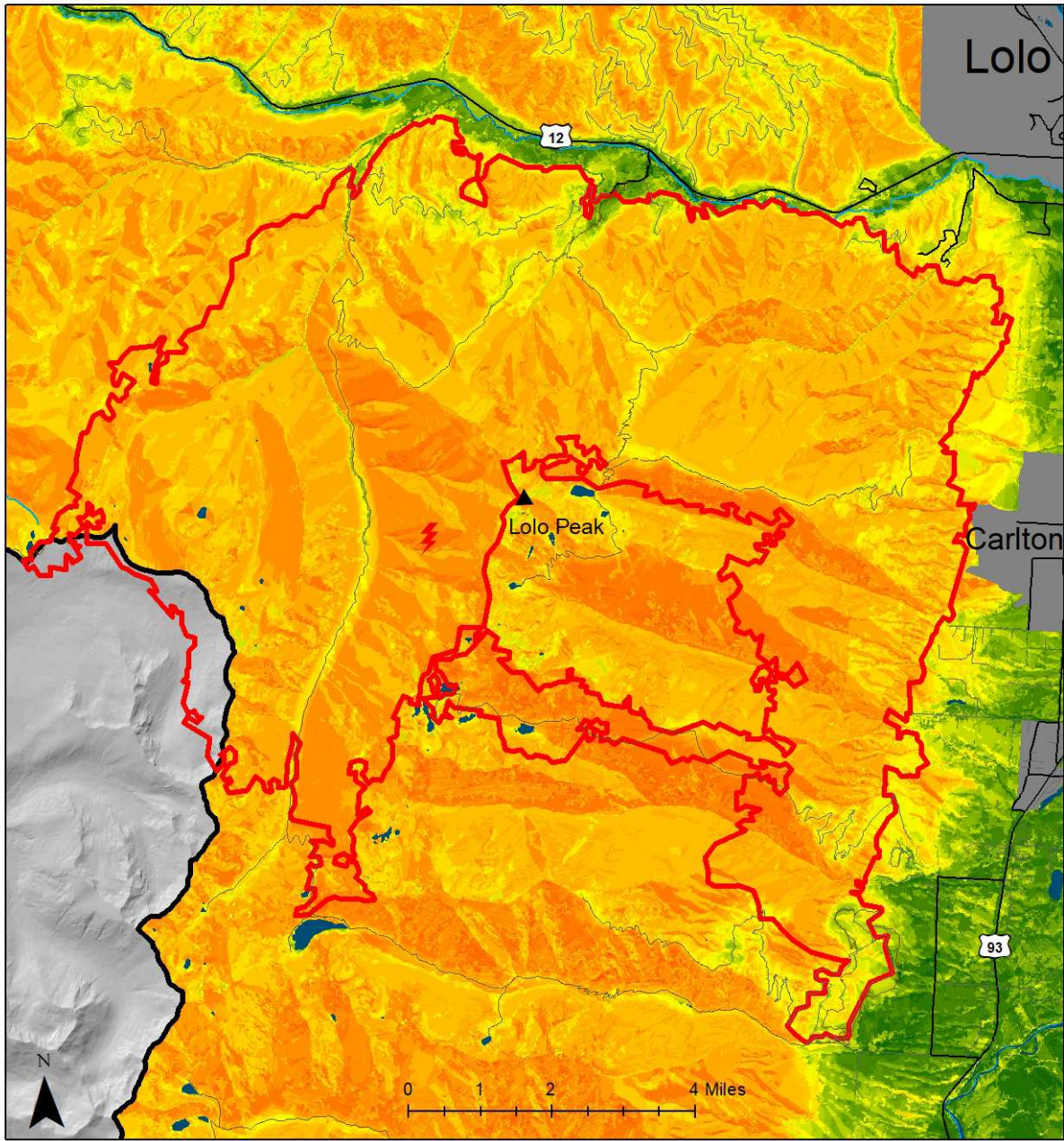
Figure 4 shows the spread risk of fire around Lolo Peak. As expected, the areas with more roads have a smaller risk of fire spreading. These areas also have lower risk due to slope and vegetation type. The areas with limited access (national forest lands) show a high risk of fire spreading. Trails and roads sometimes predicted barriers in some areas such as the north area of the fire, but due to dozer and hand lines being constructed away from the trails as the fire progressed, they may not be accurate representations of fire spread barriers.

In Figure 5 and 6, the ignition and spread risk assessments are applied to a larger area. The same trends appear, with ignition risk being higher near roads and trails, and spread risk higher away from roads and trails. These two maps were used to compare these risk assessments to historic fires in the area. Figure 7 shows fires from 1980 to 2007 and the 2017 Lolo Peak Fire. Both human and naturally caused fires are represented.

The human caused fires observed in this area are all near roads, but do not spread far. Both human-caused and natural fires have perimeters that stop at roads, while the locations of trails do not seem to have an effect on the burn area. The locations of the starting points of the fires were not available, so it is difficult to determine the level of ignition risk these fires started in.

Figure 8 is a map of the different land types classified by the NLCD in the area of the Lolo Peak Fire. The burned area is predominantly coniferous evergreen forests. In some areas where the land type is classified as shrubs there are less severe burns, such as the visible checkerboard pattern in the northern section and the north side of the creek in the northeastern burn area, while in other areas the severity is higher, such as the western side of South Lolo Creek (west of the checkerboard pattern).

The creeks in the burn area are mapped in Figure 9, along with the burn severity. It can be observed that large areas of certain creek's drainages are moderately to severely burned. Figure 10 shows the watersheds of these creeks (in the 12 digit Hydrologic Unit Code). Using the burn parameter and severity data, along with watershed boundaries, the total acres burned and acres severely burned of each watershed was calculated. This is displayed in a table in Figure 11.



Fire Spread Risk Around Lolo Peak, MT

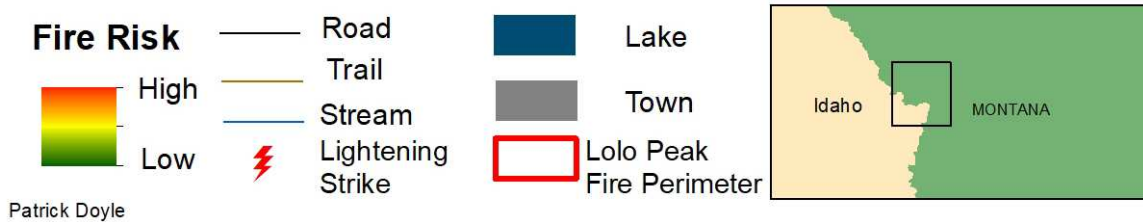
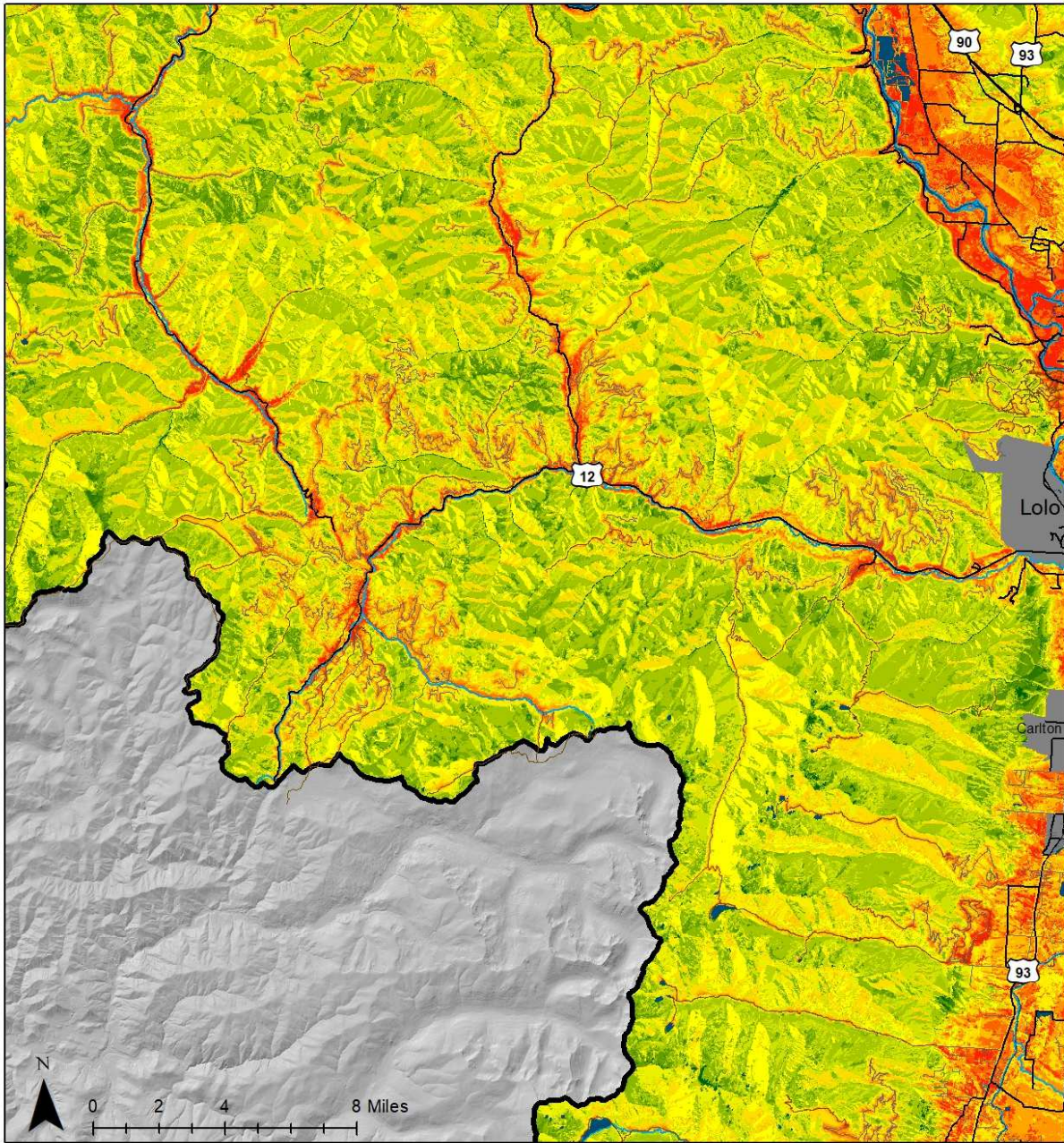
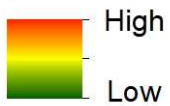


Figure 4: The fire spread risk around Lolo Peak. The 2017 Lolo Peak Fire perimeter and starting location are also represented. Risk areas do not predict fire progression, due to factors such as wind speed and the fire suppression activities.



Fire Ignition Risk Near Lolo, MT

Fire Risk



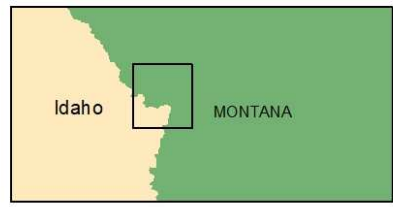
— Road

— Trail

— Stream

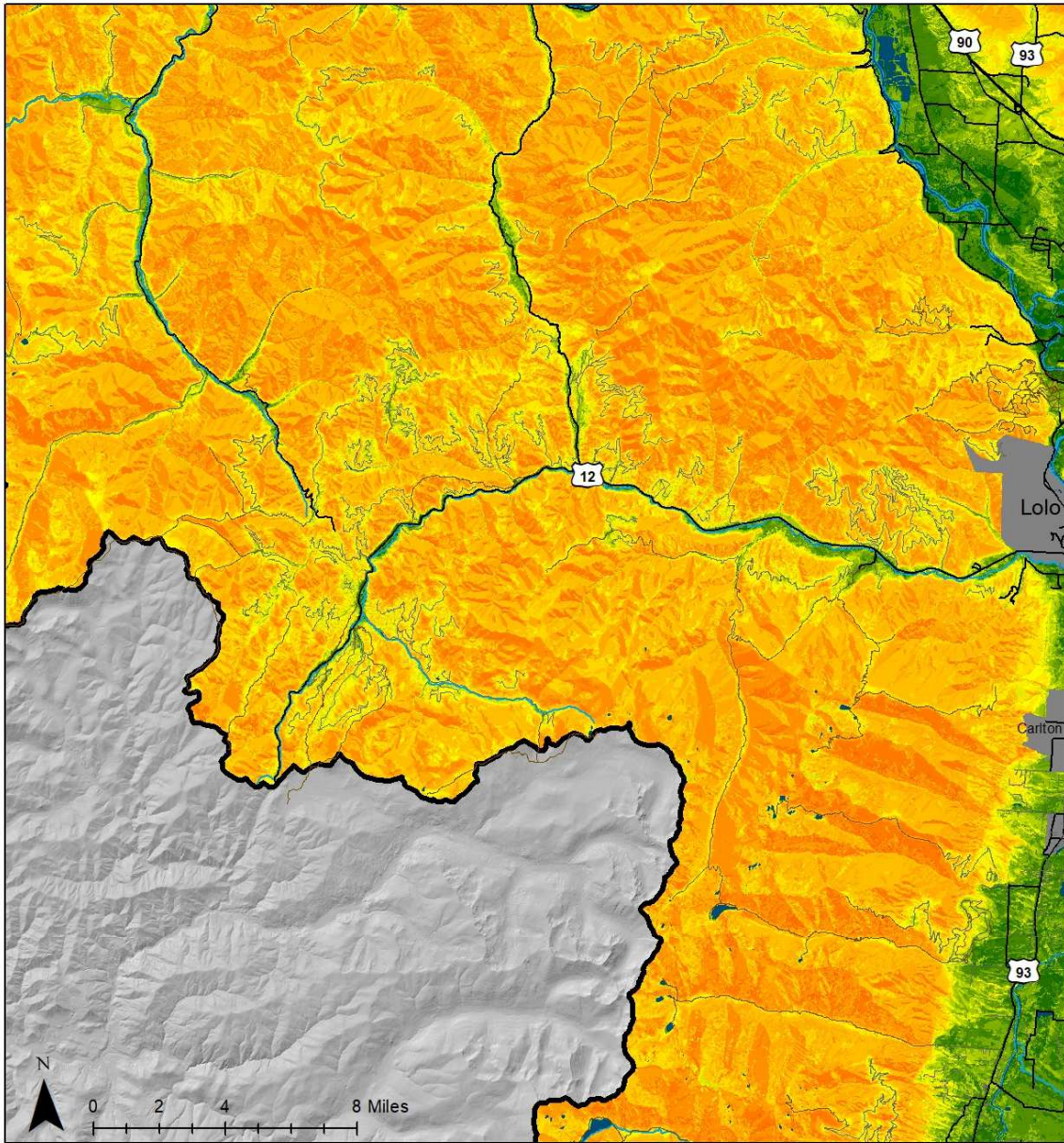
■ Lake

■ Town



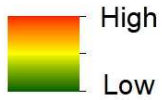
Patrick Doyle

Figure 5: Ignition risk in the area west of Lolo, primarily part of the Lolo National Forest. Areas of increased risk are those near roads and trails.



Fire Spread Risk Near Lolo, MT

Fire Risk



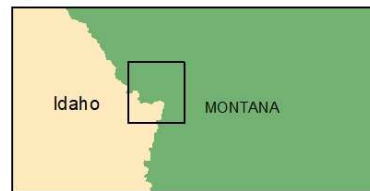
— Road

— Trail

— Stream

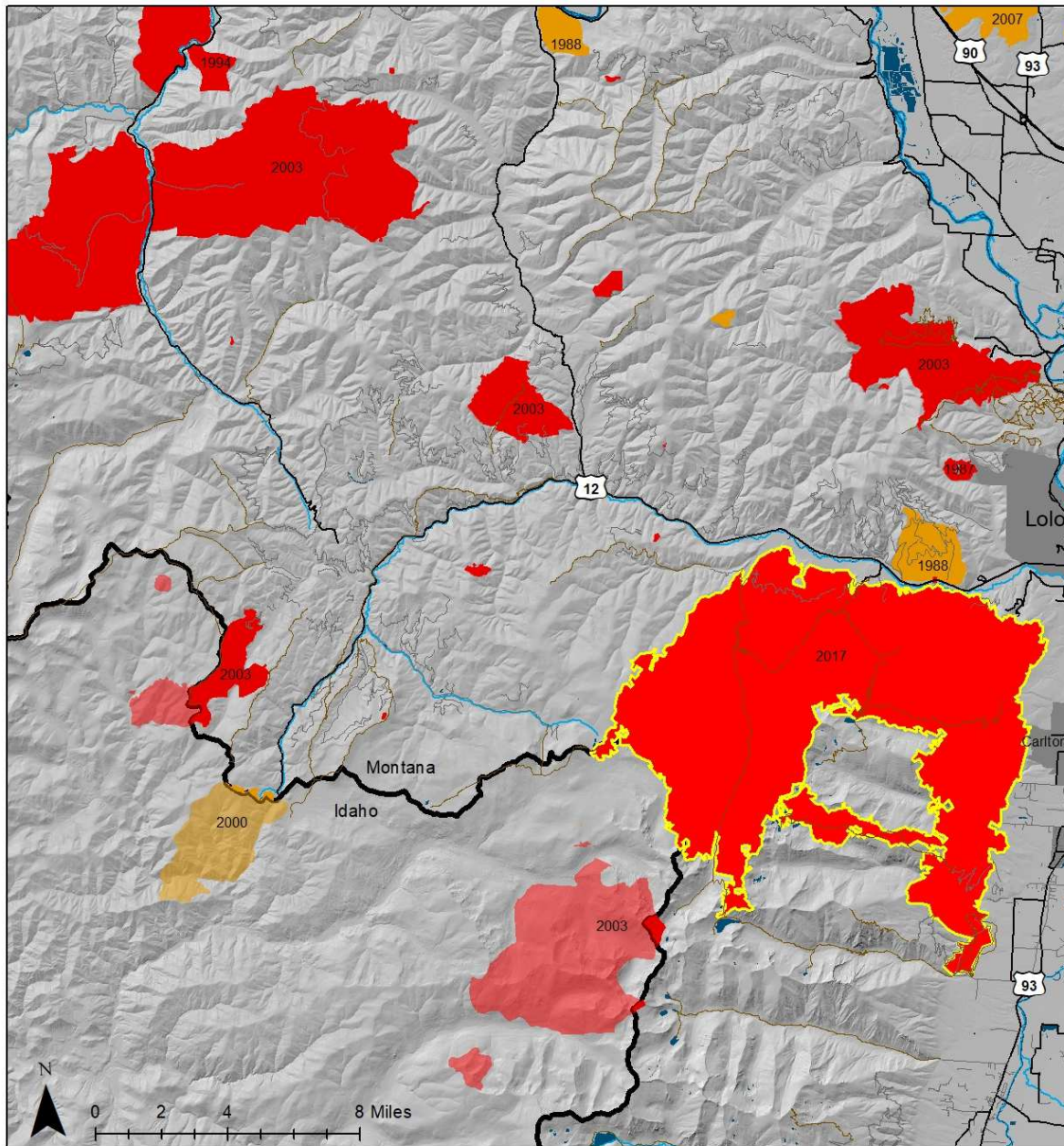
■ Lake

■ Town



Patrick Doyle

Figure 6: Fire spread risk west of Lolo in the Lolo National Forest. Areas of high risk are more remote with south facing slopes having the highest risk. Firefighters moving along roads make these areas less likely for fire spreading.



**Historic Fires
1980-2007**

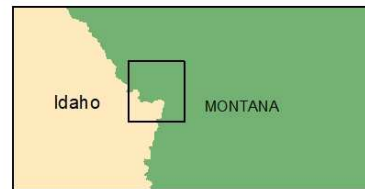
- Natural Caused
- Human Caused

2017

- Lolo Peak Fire

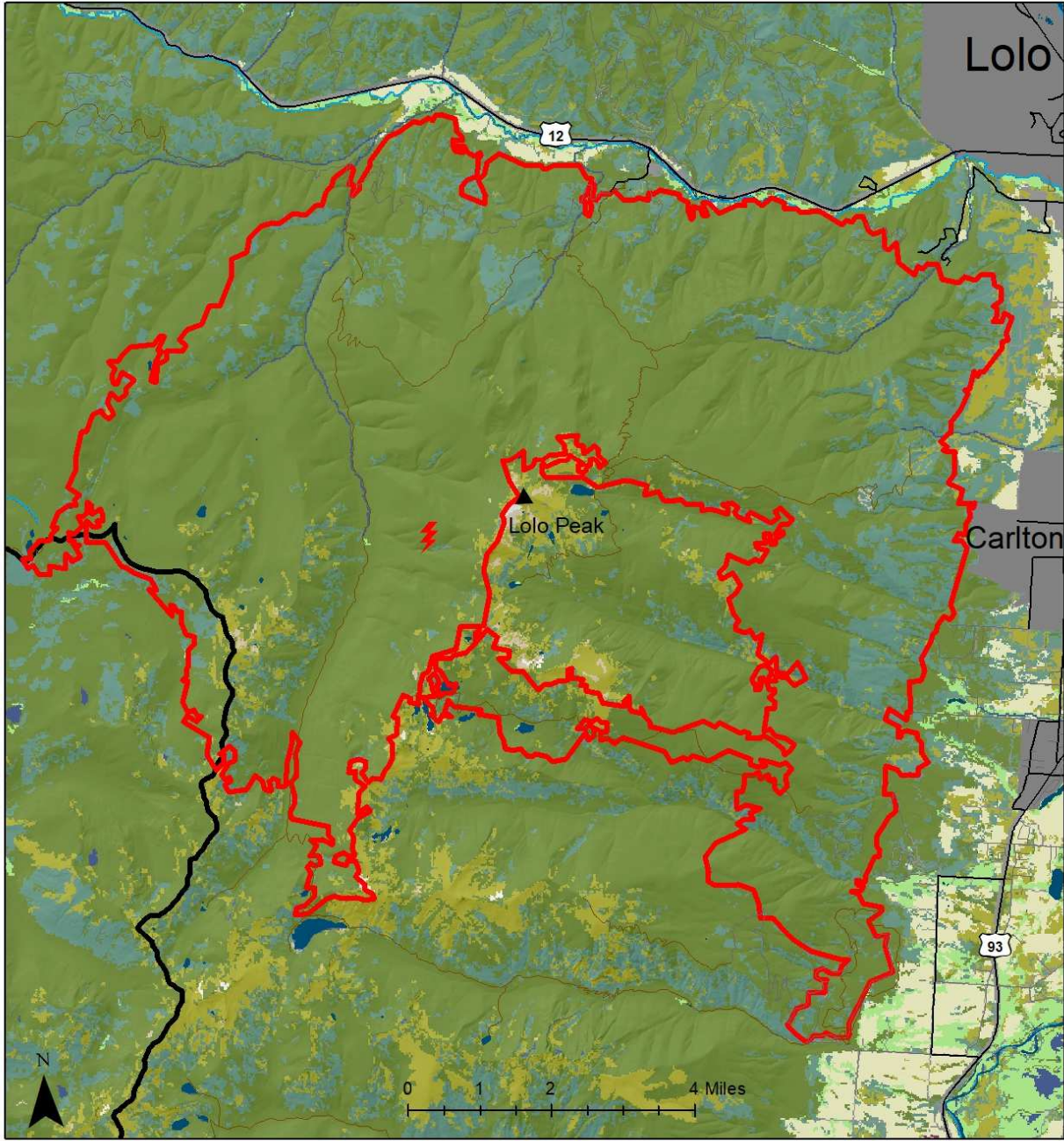
Fire History Near Lolo, MT

- Road
- Trail
- Stream
- Lake
- Town



Patrick Doyle

Figure 7: Historic fires in the larger area being assessed for ignition and spread risk. Data available from 1980-2007, and the 2017 Lolo Peak Fire was georeferenced from an existing Forest Service Map.

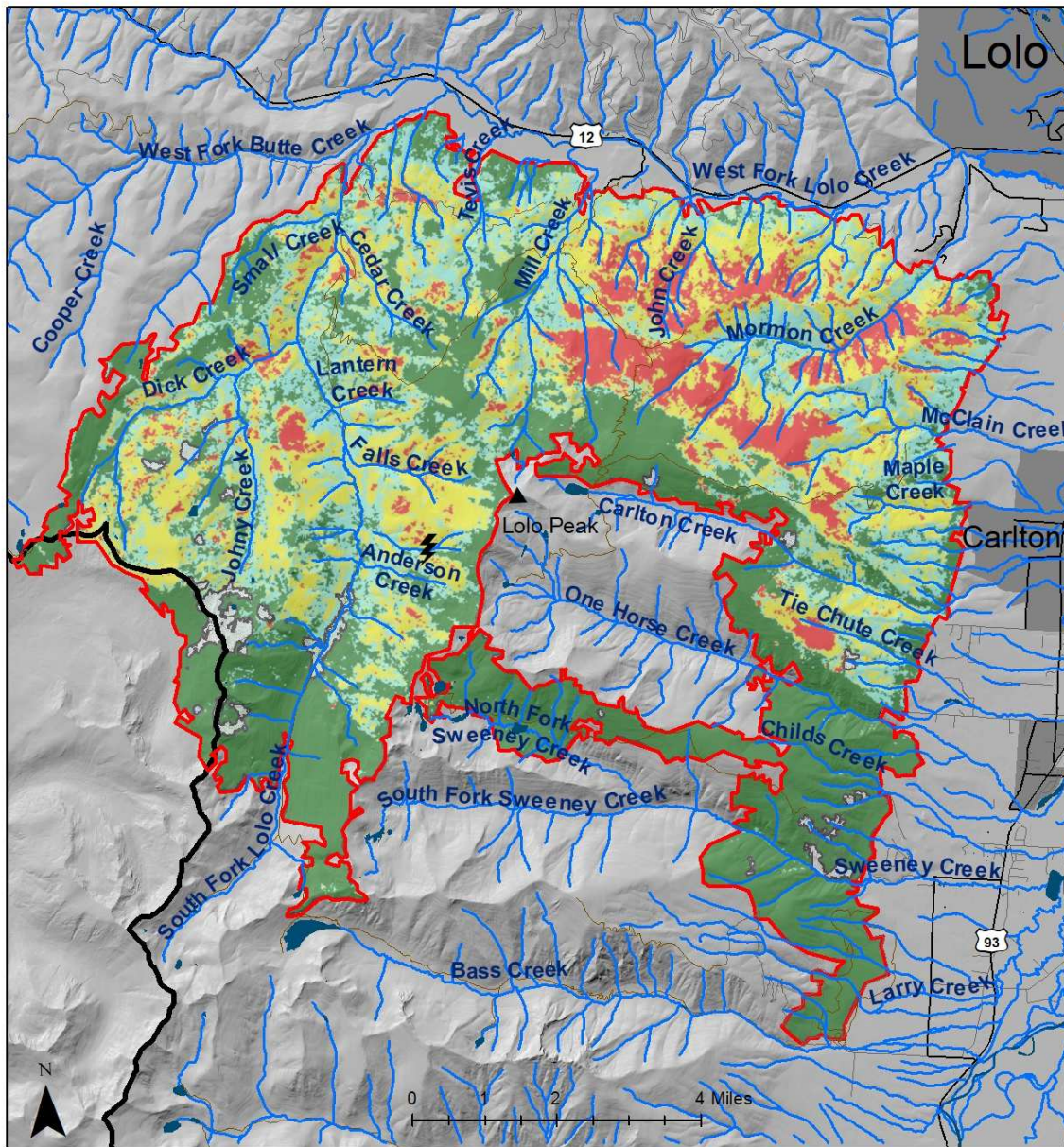


Land Type Around Lolo Peak, MT



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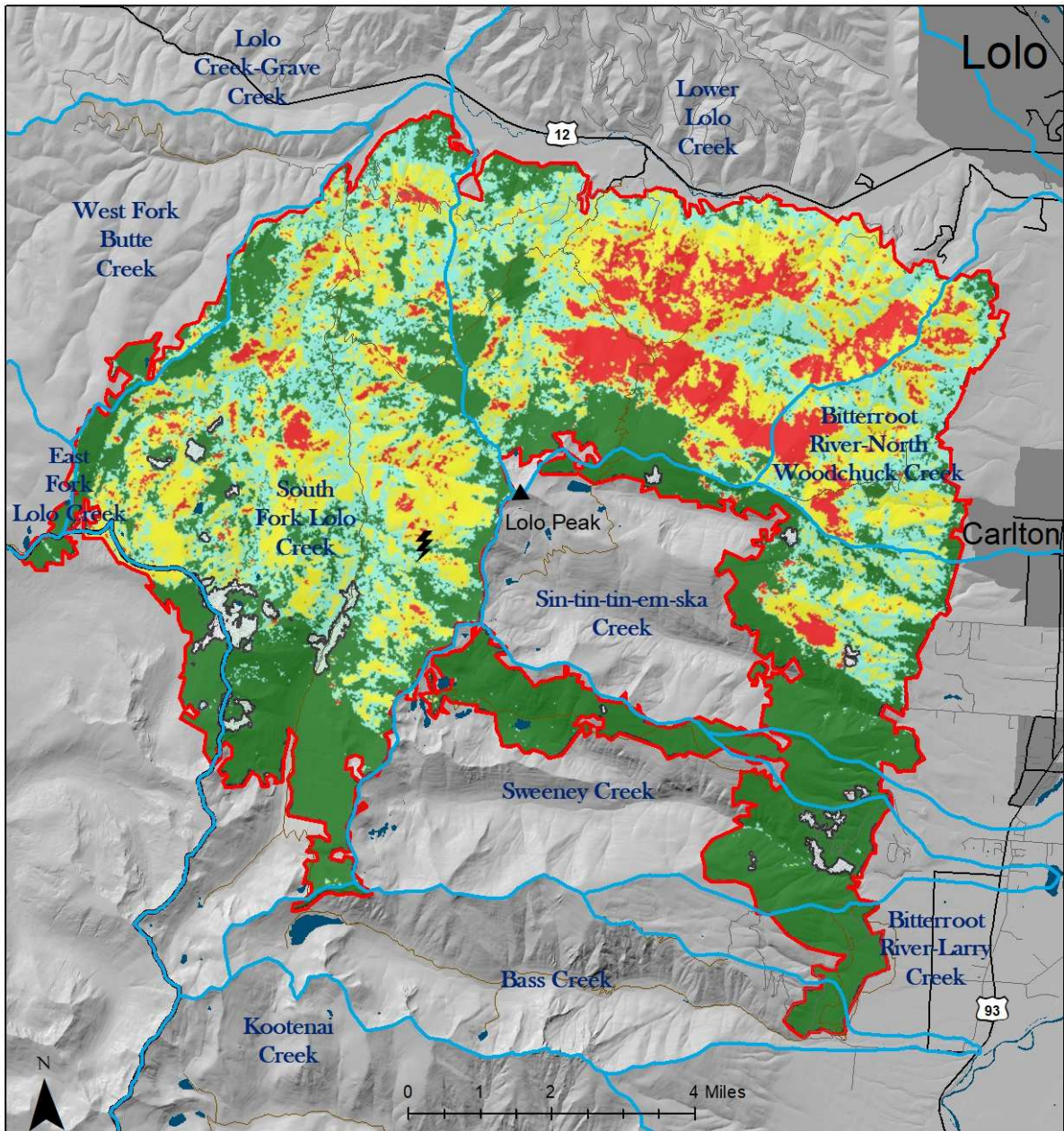
Figure 8: Land Classification around Lolo Peak. Coniferous forests are the predominant land type in the area (Land type taken from the 2011 NLCD).



Creeks In or Near Lolo Peak Fire, Montana



Figure 9: Creeks in the area of the 2017 Lolo Peak Fire. Many creeks in the northern section of the burned area had most of their drainage areas burned.



Watersheds Around Lolo Peak Fire, Montana



Figure 10: Watersheds in the area of the 2017 Lolo Peak Fire, identified by 12 digit Hydrologic Unit Code names. The damage to watersheds will be most prominent in the South Fork of Lolo Creek watershed and Lower Lolo Creek watershed.

Watershed	Burned area (acres)	High severity burned area (acres)	Total Watershed Area (acres)	Percent of Watershed area burned	Percent of Burned area with high severity burns	Percent of Watershed area with high severity burns
South Fork Lolo Creek	21527	711	24876	87	3	3
Lower Lolo Creek	13810	2711	31812	43	20	9
Bitterroot River-North Woodchuck Creek	4525	592	36099	13	13	2
Sin-tin-tin-em-ska Creek	5556	154	18344	30	3	1
Sweeney Creek	3880	1	12174	32	0	<1
Bitterroot River-Larry Creek	1562	1	32353	5	0	<1
Bass Creek	377	<1	9261	4	0	<1
West Fork Butte Creek	451	6	11446	4	1	<1
East Fork Lolo Creek	94	<1	20418	<1	0	<1

Figure 11: Burned and high severity burned acres in watersheds affected by the 2017 Lolo Peak Fire.

Discussion

Risk Assessment

The risk assessment developed for this study was designed to create quick assessments with easily obtainable information using ArcMap. A national forest has many factors that influence fire risk, and dryer seasons have an even greater risk.

In the case of the 2017 Lolo Peak Fire, this risk assessment had an elevated risk of ignition in the area of the lightning strike. However, due to the remoteness and land cover type,

ignition may likely have occurred anywhere that lightning struck the ground. Data on where lightning occurs would be useful to further determine the accuracy of the ignition risk. The spread of the fire was fairly accurate for the overall area but not the progression. Wind played a large part in the speed and direction of the fire's progression. Unfortunately wind is difficult to model in a spatial analysis, particularly during a fire.

Due to the homogenous land cover type in the burn area, it is difficult to assess how much of an influence it played on the burn severity. However, the eastern shrub-land area of the burn area, the north side of Mormon Creek and the shrub-land in the checkerboard pattern in the north section all experienced less severe burns than the forested lands around them. This is important because higher burn severity may result in degradation to the local watersheds.

Fire Impacts on Watersheds and Water quality

Watershed management can benefit from fire prediction maps such as the one used in this study because wildland fires have both immediate and delayed effects on watersheds. During the fire, air and water temperatures are higher closer to the fire. Water chemistry changes can occur as smoke and gases are diffused into the water (Spencer, 2003). These changes can kill fish and macroinvertebrates. After fire has burned the area, the following winter will exhibit a difference in snow accumulation -- it may increase due to decreased canopy cover (Shu-ren 2003) or it may decrease by opening slopes up to increased wind. In the spring, the snow will melt sooner, causing earlier and more severe floods (Shu-ren 2003).

Often the greatest impacts involve water quality and peak flow (Tecele 2015). While plant species closer to water undergo rapid regrowth (Kobziar, 2006), much of the remaining burn area takes longer to regrow. Vegetation is important because it intercepts and reduces precipitation reaching the ground (Tecele 2015). Overland flow increases in burned areas as a result of the lost vegetation, which has an effect on the water temperature (Barkely 2013). The level of influence depends on the severity of the fire, the nature of the vegetation cover, and the physical and chemical nature of the burned area (Tecele 2015).

Physical water quality problems of a stream after a fire usually involve erosion and sediment yield, turbidity, flooding, increased water temperature and changes in soil physical characteristics (Tecele 2015). Sediment accumulations can take decades or even longer to recover to pre-fire conditions (Barkley 2013). More severe and widespread fires produce a greater variability in sediment loads (Drohan 2009). Degradation of the channel through undercutting can also occur during this time.

Increases in sediment loading affect fish and macroinvertebrate communities by burying eggs or substrate where eggs are laid, while the higher increases in water temperature make the area less habitable (Barkley 2013). Changes in sediment and vegetation cover, as well as increases in woody debris will have an effect on the macroinvertebrate populations to the point that the post-fire communities will be very different from the pre-fire community (Drohan 2009). Sedimentation also decreases the amount of periphyton in the stream (Spencer 2003).

Chemical changes in water quality will also degrade a stream after a fire. The increased overland flow delivers a high amount of macronutrients, micronutrients, basic and acidic ions, for years after the fire (Spencer 2003). This may increase the production of algae, decrease oxygen levels and increase biological oxygen demand (Teclé 2015). Increased algae growth causes the food supply for macroinvertebrates to shift to algae rather than terrestrial litter (Spencer 2003).

The effects on smaller tributaries in higher elevations will transfer down to the lower areas such as Lolo Creek and the Bitterroot watershed (Barkley 2013). Increases in nutrient loading, water temperature, and woody debris will likely affect both fish and macroinvertebrate communities in the lower water bodies. Increases in nutrient loading can also occur from the fire's large amount of ash material. This material can settle into water ways well outside the catchment area (Spencer 2003). The alpine lakes around the area are likely to see increased nutrients and algae due to ash settling in them.

Creeks in watersheds that had more severe burns will likely see greater impacts. This includes Mormon Creek, Mill Creek, and Carlton Creek. Increased nutrient loading from all of Lolo Creek's tributaries could cause the total maximum daily load for nutrients to be surpassed. The Bitterroot and Clark Fork Rivers will likely see increased algae growth from both the tributaries transporting nutrients and the ash settling in the area. Increased sedimentation may cause problems to fish communities in Lolo Creek. An earlier and more intense peak flow is also likely to occur.

Erosion Models

There are a number of erosion models that can be used to determine how much erosion is expected after a fire. Many of the models are limited and can only predict a small simple slope. However, they do offer insight into what may be expected in the watersheds affected by high severity burns.

The Erosion Risk Management Tool (ERMiT) uses the climate, soil texture, rock content, vegetation, hill slope and length and the burn severity to predict erosion for the first five years after a fire. The horizontal length is limited to 1000 feet, and the climate data were limited for the Lolo Peak area. The prediction of the model for a section of high burn severity by Mormon Creek can be found in Figure 13. According to this model, there is not a high chance of excessive erosion. However, if applied to the entire high severity burn area (2711 acres in the Lower Lolo Creek watershed), the sediment eroded from these areas could be over 200 tons. So while the model is limited, it provides a base line of what could be expected in terms of erosion.

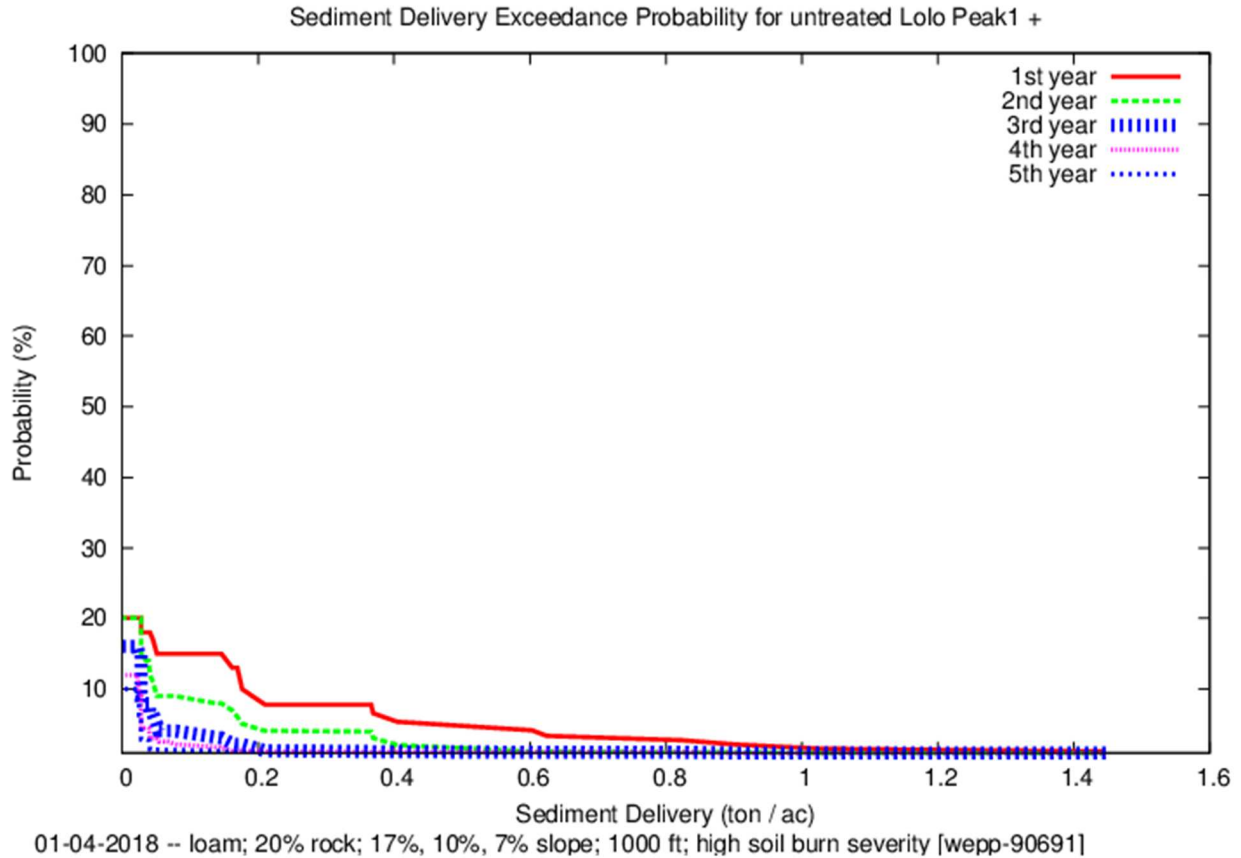


Figure 2: The prediction of the ERMiT model for a slope above Mormon Creek.

CONCLUSION

GIS has many applications in guiding watershed monitoring and predicting changes after fires. Using techniques such as the MCE allows the raw spatial data to be used for many different analyses. This study has shown that fires can easily spread through most land cover types, and riparian areas in semi-arid mountain areas are susceptible to major wild fire.

The Lolo Peak fire will likely have lasting effects on the Lolo Creek watershed due to its size and severity. Through my work assisting the Friends of the Bitterroot, I have gained insight into the effects fire has on watersheds, and the abilities of GIS to predict fire risk zones and paths.

RECOMMENDATION

The risk assessment highlights the susceptibility that remote forested locations have to fire. While these fires may be good for the overall health of the forest, they may pose short term dangers to watersheds and the people downstream of the fire. People living in these areas should

be made aware of the risks of earlier flooding and erosion. Changes in the watershed may also result in difficulties for irrigation and fishing.

The risk assessment provides a way for non-professionals to get an idea of what they can expect in terms of forest fire risks and impacts beyond the warnings and reports issued by the Forest Service. Local watershed organizations may want to request such visual, map-based information from the Forest Service or hire a consultant to produce such maps.

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Portfolio Conclusion

My goals for my Master's work were to develop skills and knowledge in order to have a career working to protect watersheds. Through the course of the program, the skills and knowledge I sought grew beyond my original intentions. The fulfillment of the program's multiple requirements allowed me to explore various approaches to protecting watersheds, and my portfolio describes the three that I found most interesting.

The first piece of my portfolio used many different information sources to analyze the events around a closed kraft pulp mill on the Clark Fork River and the ways in which this industry can pose a threat to both human and environmental health. I also learned about the ways in which local organizations like the Missoula Water Quality Advisory Council deal with the damage left behind by the industrial processes. Finally, I learned about the methodology used by the EPA and MDEQ when dealing with sites that may qualify as Superfund sites.

Working for the DEQ gave me insight into water quality assessment methods, and the extensive planning and execution involved in statewide water quality monitoring and protection programs. I learned field procedures and the importance of quality assurance and quality control, as well as time management both in the field and laboratory. I considered this opportunity to be of great value moving forward with a career involving water quality.

Geographic Information Systems began as a mild interest at the beginning of the program, but as I learned more about the possibilities of GIS, it became a major focus of my graduate career. In addition to completing the Environmental Studies Master's program, I completed the certificate in GIS Science and Technologies. Applying the tools I learned in GIS to watershed protection has become a major priority for me.

My GIS project involving the Friends of the Bitterroot put many of the GIS skills I learned into a real-world application. By combining that work with my interests in watersheds, I created my third portfolio piece, which granted me insight into the impacts of wild fires and fire management on the watershed. This project also allowed me to engage with another community organization.

The skills and knowledge I have gained throughout the program I believe has prepared me for a career in the conservation of watersheds and water resources. I am excited to apply myself in solving real world problems that threaten the quality and supply of water in Montana that we sometimes take for granted.