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Eagle Creek Post-Fire Monitoring for Water Temperature & Water Stage

Sylas Daughtrey
Portland State University

Portland State University & USGS

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Submitted by:
Sylas Daughtrey
Advisor: Dr Joseph Maser
Co-Advisor: Dr. Heejun Chang
Committee Member: Dr. Kelly Gleason
Community Partner: Marc Stewart (USGS)

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Abstract

When investigating forested watersheds devastated by wildfire, the wide range of disturbance can lead to altering hydrological effects through the loss in ground cover vegetation, canopy cover, while also disrupting soil characteristics. Within the Pacific Northwest, forested drainages affected by post-fire disturbance are further altered in areas that experience seasonal rainfall and snow melt events. When looking at the post-fire sloped areas of Eagle Creek and Tanner Creek within the Columbia Gorge of Oregon, the loss of ground cover and organic matter throughout these two watersheds pose a legitimate concern for erosion events as well as hydrological changes due to sediment transport and increased surface water runoff. With the loss of ground cover due to fire, the reduction in rainfall interception and surface water storage elevates the chances of rapid runoff further increasing the volume of surface water runoff. This post-fire decrease in ground cover protection against persistent rainfall raises the chances of soil detachment by overland flow eventually leading to erosion concerns within a given area of the landscape. Differences in fire severity throughout these drainages also increase a risk of altering the forested landscape and pose future risks of erosion and public safety knowing these areas were heavily used prior to the 2017 Eagle Creek forest fire. This project examines the importance of monitoring the hydrological effects, including stream temperature and surface water stream levels following a forest fire. The data collected through this ongoing project have produced a set hydrologic data for water stream levels as well as water temperature readings. The data sets are compiled with regional weather service data to help understand potential relationships between water stage levels and precipitation as well as relationships between local air temperature fluctuations and stream temperature. This report also presents the overall process involved when collecting data regarding the potential changes in sediment loads, surface water storage, and increased surface water runoff. The overall goal of this project and report is to collect and analyze baseline data for monitoring post-fire effects for both Eagle Creek and Tanner Creek watersheds. Helping to understand these post-fire hydrologic responses can also help provide data for effective risk management within a popular publicly accessible area.

Introduction

Forest fires are a common occurrence throughout the Pacific Northwest and can lead to significant change on any given landscape. Fire not only initiates changes in ecosystems that affect the composition, structure, and patterns of vegetation on the landscape (Neary, 2011), but it also affects soil and water resources of ecosystems that are critical to overall functions and processes (Debano et al. 1998). Post-fire disturbance can also lead to the drainage area of a watershed to experience notable and potential everlasting changes to the terrain and surrounding vegetation. These post-fire effects are a result from different levels of burn severity that are determined from a variety of fire intensity factors that including heat, fire height, understory conditions, weather conditions, and duration. Once a forest fire has established itself, the level of fire intensity in turn leads to the overall level of burn severity and disturbance within a given area (*figure: 1*). Fire intensity and burn severity within a given watershed can alter forested ecosystem characteristics such as seasonal snow melt, rainfall water absorption, and soil permeability. These factors can lead to short and potentially long lasting impacts when examining burn severity which in turn reflects the overall risk and occurrence of flash floods, debris flows, landslides, and rockslides (USDA, 2018). Because forests act as a natural water filter and storage system, they help keep water clear, regulate streamflow and reduce flooding. When damaged by catastrophic fire, forests lose their ability to absorb and filter rainfall. The consequences can be runoff that fouls streams and rivers with mud, soil and debris (Fry, 2017). These post-fire effects further influence the rate of succession, the hydrologic cycle of a watershed, and the regeneration of a burned forest (USDA, 2005) . As displayed in figure(s) 2 & 3, post-fire effects can result in removing the top layer of organic rich soil while increasing the water repellant layer (*figure: 2*). This reduction in soil organic matter further increases the chance of higher runoff and erosion (*figure: 3*) during seasonal rainfall and storm events (USDA, 2015). This report will

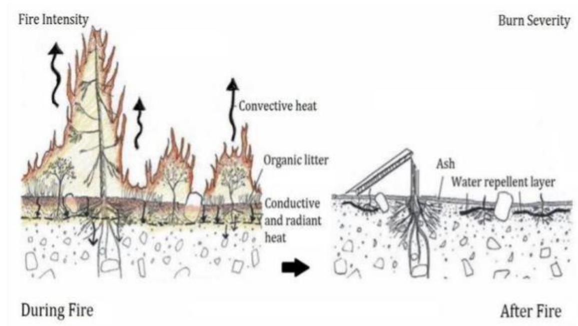

Figure 1: Outline how fire intensity shapes burn severity. USDA, 2015

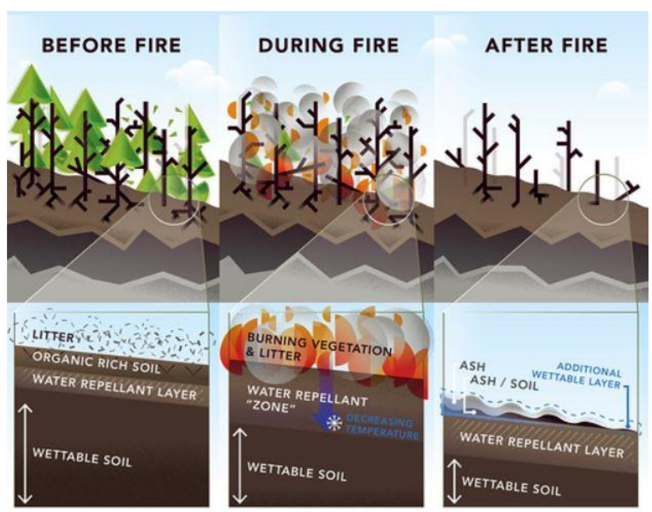

Figure 2: Post-fire effects on litter and soil layers (Photo: American Forest Federation)

provide an outline and reasoning for establishing a time series of data collection for water temperature and water stage levels at Eagle Creek after the Eagle Creek fire of 2017. Working with the U.S. Geological Survey in cooperation with the U.S. Department of Agriculture, U.S. Forest Service, and the Oregon Department of Fish & Wildlife, the overall goal of monitoring the post-fire hydrologic cycle is to collect base-line data to document, record, in regards to understanding possible hydrologic changes such as water stage levels and water temperature within this National Scenic area of the Columbia Gorge.

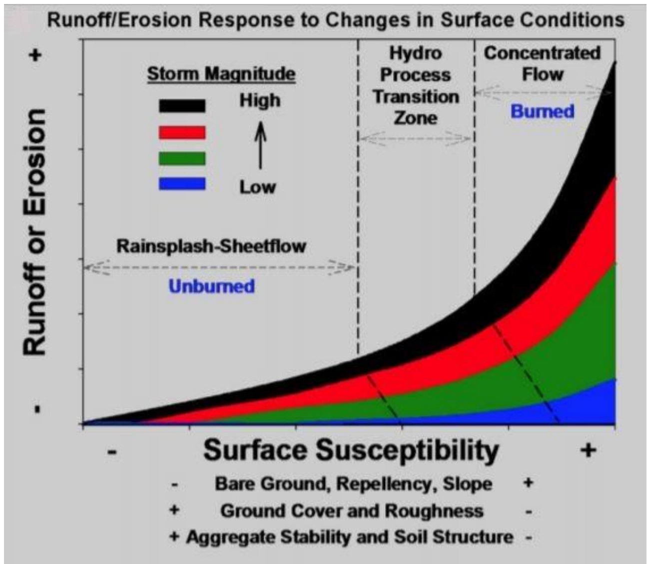

Figure 3: Runoff and erosion response model for pre and post-fire surface conditions (Miller et al., 2013)

By establishing this base-line for data collection within the Eagle Creek watershed, the data from this project is a foundation for gaining knowledge of these watersheds affected by the Eagle Creek fire. In addition, it will also help provide a model and assessment of how to install a fast and accurate data collection and monitoring gage in a post-fire affected area.

Fire Intensity and Fire Severity

When discussing the effects of fire on soil and water resources it is important to differentiate between fire intensity and fire severity because they are not the same (Hartford and Frandsen 1992). Fire intensity is a term that is used to describe the rate at which a fire produces thermal energy (Brown and Davis 1973). It is also referred to as the energy or heat released during various phases of a fire and is determined by the type of fuel available and how fast this fuel burns (Ngole-Jeme, 2019). As depicted in *figure: 4, fire intensity* is most frequently quantified in terms of fire line intensity because this measure is related to 'flame length', which is easily measured (DeBano et al. 1998). *Fire severity*, on the other hand, is a more qualitative term that is used to describe ecosystem responses to fire and is particularly useful for describing the effects of fire on the soil and water system (Simard 1991). High severity changes in the soil are sometimes related to high intensity fires, however, low intensity smoldering fires in roots or duff can cause extensive soil heating and produce large changes in the nearby mineral soil (USDA, 2005). As described in a USDA 'Wildland Fire in Ecosystems' report (2005), the level of fire severity depends upon:

- Length of time fuel accumulates between fires and the amount of these accumulated fuels that are combusted during a fire (Wells and others 1979).

- Properties of the fuels (size, flammability, moisture content, mineral content) that are available for burning.
- The effect of fuels on fire behavior during the ignition and combustion of these fuels.
- Heat transfer in the soil during the combustion of aboveground fuels and surface organic layers.

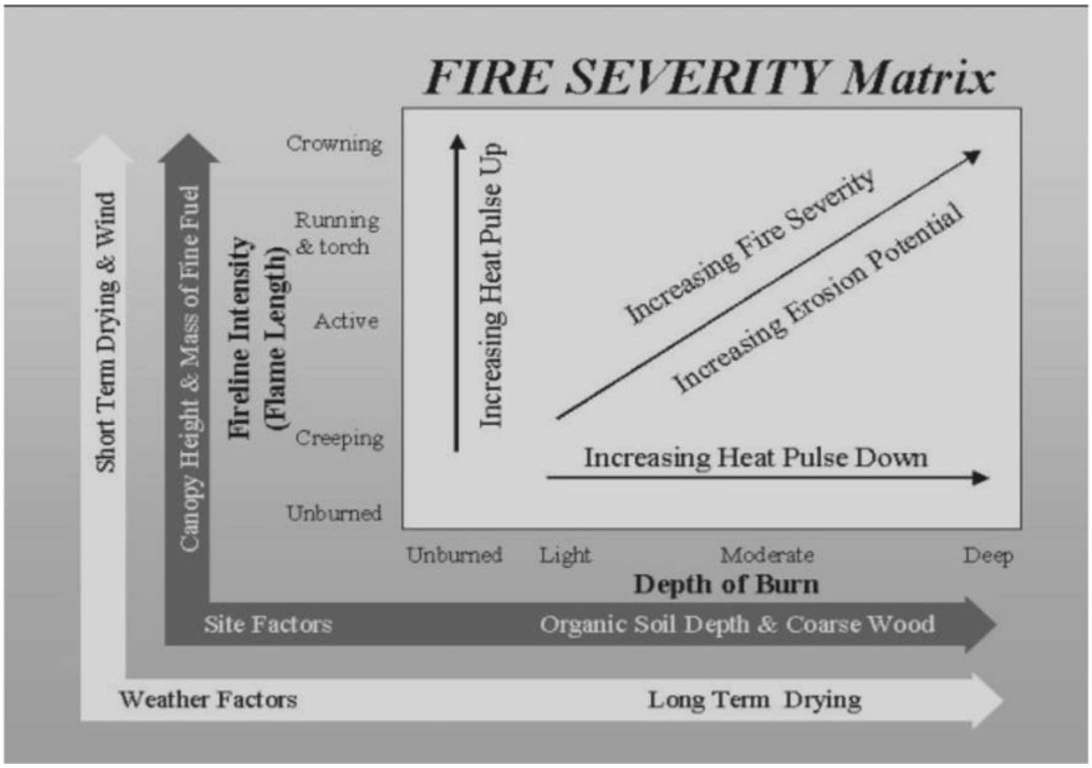

Figure 4: Fire Severity Matrix depicting weather and site factors associated with fire intensity and severity (USDA, 2005)

As shown in *figure (4*), fire severity is determined through a series of factors regarding how surrounding weather and site conditions determine forest fire intensity and fire severity. An area has to be wet enough to grow fuels and dry enough for them to burn, and how this plays out, and combines with ignition, affects the fire's characteristics (Pyne, 2010). How hot a forest fire burns, sometimes referred to as the 'heat pulse' (*figure: 4),* can vary on its depth and height when relating to the intensity of a fire. Factors that affect these heat pulses are soil organic matter depth, canopy height, forest fuels, weather conditions, and seasonal temperatures. When looking at how intense heat pulse travels in height (line intensity and flame length), weather and site factors such as wind, canopy height, and the amount of fine fuel are key factors. For example, with high winds, large amounts of dry fuel, and a short canopy length, the heat pulse is increased, and the possibility of crowning becomes more likely. When observing the effects of heat pulse on soil depth, weather and site conditions are a key influence in determining the depth of the burn. Factors such as the depth of organic soil, accumulated coarse woody debris, and weather conditions, all come into play when factoring in the depth of heat pulse. A forest floor with large amounts of woody debris, an increased depth of organic soil matter, and a long period of dry weather conditions all contribute to an ideal increase in fire intensity depth. Fire intensity increases with increase in dry vegetation cover because of availability of fuel (Ngole-Jeme, 2019). On any site, all levels of fire severity will be present over large scales of space and time, but characteristically in different proportions (Agee, 1993).

In contrast to prescribed burning, wildfire often has a major effect on soil and watershed processes, leading to increased sensitivity in the burned site to vegetative loss, increased runoff, erosion, reduced land stability, and adverse aquatic ecosystem impacts (Agee 1993). The occurrence of soil burn severity takes place as a result of fire causing dead plant debris on the soil surface to burn, releasing waxy substances that coat soil particles -- basically "shrink-wrapping" the soil and filling in the pores that allow water to soak in during rain events (USDA, 2018). The term "shrink-wrapping", often referred to as soil convection, is also described as the result of catastrophic wildfire that affects forests by essentially baking the ground below, causing it to become a hard-packed layer that will not absorb moisture (Fry, 2017). These series of post-fire soil characteristics result in the overall disruption to soil sorption qualities and can affect the overall regeneration of productive soil properties such as water infiltration, organic matter accumulation, and moisture retention. The total sorption capacity of a soil is a function of the sum of the individual sorption capacities of various soil components (clay content, organic matter content, and sesquioxides) and properties including soil texture (Lair, 2007). However, depending on the soil's clay fraction, sand size, and silt factors, the overall soil sorption capacity is greatly determined on the overall coarseness of post-fire soils (Ngole-Jeme, 2019).

Fire Impacts of Soils

The overall definition of soil is: the unconsolidated, variable-thickness layer of mineral and organic matter on the Earth's surface that forms the interface between the geosphere and the atmosphere (USDA, 2005). From a result of physical, chemical, and biological processes functioning simultaneously on geologic parent material over long periods (Singer and Munns 1996), soil is formed where there is continual interaction between the soil system and the biotic (faunal and floral), climatic (atmospheric and hydrologic), and topographic components of the environment (USDA, 2005).

The dynamics of the forest floor are responsible for the accumulation of organic matter, which provides a major storage reservoir for nutrients that are cycled within natural ecosystems (USDA, 2005). The amount of aboveground and belowground organic matter varies widely between different vegetation types depending upon the temperature and moisture conditions prevailing in a particular area (DeBano et al. 1998). In warmer, moist climates, decay plays the dominant role in organic matter recycling, except in soils that are predominantly saturated (in other words, hydric soils) (Harvey, 1994).

Because of the interdependency between fire severity and ecosystem response, the fire-related changes associated with different intensities and severities of burn produce diverse responses in the water, soil, floral, and faunal components of the burned ecosystems (USDA, 2005). As Keeley (2009) explains, burn severity can be described as the degree to which an area has been altered or disrupted by the fire; these observed effects often vary within the area and between different ecosystems. If the temperature remains low enough, fire enriches the soil by releasing nutrients bound in accumulated vegetation and litter (*figure: 5*). In

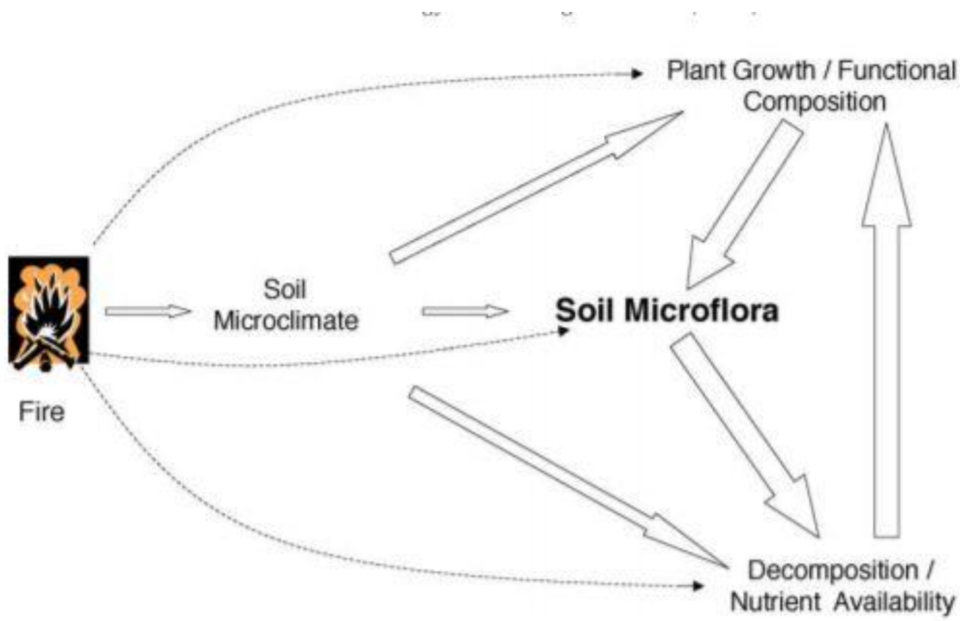

Figure 5: Conceptual model of the effects of fire on forest ecosystems. Dotted arrows denote immediate short-term effects of fire on vegetation and soil organisms, which are transitory in nature. These include selective mortality of plants and soil microorganisms and nutrient release from combustion of organic matter. The influence of fire on soil microclimate (temperature, moisture, insolation) is the midterm mechanism driving changes in the soil microflora and vegetation (denoted by thin, block arrows), as well as changes in rates of ecosystem processes such as decomposition and nutrient mineralization (denoted by medium, block arrows). However, over time, strong feedbacks develop among the soil microflora (composition and activity), decomposition and nutrient availability, and plant growth and functional composition (grass vs. shrub, vs. tree; N fixer vs. non-N fixer). These feedbacks (denoted by thick, block arrows), caused indirectly by the fire, are primarily responsible for the long-term stability of the ecosystem. In the absence of reoccurring fire, plant succession results in changes in plant growth and functional composition, altering these feedbacks, and creating a new ecosystem state. The relative strength of the longer term interactions is noted by the thickness of the block arrows. (Hart, 2005)

contrast, a hot and intense fire can harm beneficial microbes and fine plant roots (Smith, 2016). Post-fire soil responses are determined through the amount of energy that is radiated downward from the combination of burning and combustion of fuel sources on the surface layer. In general, the magnitude of change in individual soil properties is largely dependent upon the amount of energy radiated onto the soil surface, and subsequently transferred downward into the underlying duff and mineral soil. This radiated heat increases the temperature and causes changes in organic matter and other soil properties (USDA, 2005).

When examining post-fire affected areas, the surrounding appearance of the forest understory (vegetation, litter, duff, upper soil layers) is taken into consideration when determining the classification of fire severity. When looking at fire intensity, the energy that is released from organic matter during the combustion process refers to the intensity of the fire while it is active (Keeley, 2009). However, it is not always possible to estimate the effects of fire on soil and vegetation when these effects are judged by only fire intensity measurements because other factors can overwhelm fire behavior. Fire intensity is the key factor in determining the overall fire burn severity and its effects on the functioning of the surrounding ecosystems. The interaction between soil and vegetative regeneration of root systems, combined with infiltration during normal precipitation events, greatly determines how quickly a forest floor and its natural accumulation of organic matter regenerate over the course of a given period. The range of fire effects on soil resources can be expected to vary measurements because other factors can overwhelm fire behavior. Fire intensity is the key directly with the depth of burn as reflected in the amount of duff consumed and degree of large woody fuel consumption (Ryan, 2002). Fire severity is then established by estimating the soil temperatures and the level of impact for soil properties using given threshold characteristics for specific soils and the surrounding vegetation. Once established, a burn severity level can help provide a model for a particular burned area for greater accuracy in determining runoff estimates, peak flow concerns, regeneration timeframes, and succession lag times. These total nutrient losses, or gains, which occur on a given site during a fire, help provide the condition of the soil and the key factors involved in the productivity of forest ecosystems and the hydrologic functioning of watersheds (USDA, 2005).

Fire Impacts to Hillside Erosion

Erosion is a natural process occurring on landscapes at different rates and scales depending on geology, topography, vegetation, and climate (USDA, 2005). The impacts of fire on soil systems can lead to undesired changes in site productivity, biological diversity, and watershed hydrologic response. Soil structure facilitates the infiltration and percolation of water through the soil profile, thereby reducing surface runoff and erosion (USDA, 2005). With the loss of organic matter such as roots, surface litter, and native vegetation, the erosion of soil occurs due to the lack of infiltration during seasonal rainfall and snowmelt events (Robichaud, 2015). This loss of organic matter, combined with erosion, poses a similar consequence to soil infiltration and percolation of the landscape and post-fire recovery (*figures: 2,3*). Watersheds recently burned by wildfires are recognized as having an increased susceptibility to debris flow occurrence; however, these debris flows often decrease over time due to restoration of hydrologic function as vegetative cover and soil infiltration functioning return to pre-fire conditions (De Graff, 2018). As De Graff (2018) has stated, later periods of debris flow susceptibility is largely attributable to the fire-induced tree mortality and subsequent decay of tree root networks decreasing soil strength on steep hillslopes, which produces an increased likelihood of debris flow occurrence 3 to 10 or more years after the wildfire (*figure: 6)*. Established wooden root systems from trees and other woody plants help to provide a reinforcement or pseudo-cohesion to the soil mass (Gray and Megahan, 1981). This reinforcement of root systems from surrounding vegetation and trees helps to provide shear strength of soils that are mantled on steep slopes. Fire-killed trees begin having decreasing root strength a year or two after the fire (Regelbrugge and Conard, 1993). In a manner similar to a clear-cut harvest unit, post-fire woody root-decay begins in the weeks of its first year after burned trees are consumed by the wildfire but slows by the fourth year. (DeGraff, 2018). This loss of trees and root-decay will differ in areas of a mosaic of unburned, slightly burned, to severely burned areas.

Figure 6: Eagle Creek Fire post-fire. USGS, 2018

Biological and Ecological Effects from Forest Fire

Fire is a dynamic process that continuously shapes plant communities (Pyne 1982). Vegetation provides the fuel that makes fire possible, so we can view fire effects on vegetation as an interaction rather than just a unidirectional effect (Agee, 1993). Fire is also an ecological shape-shifter; as a reaction, not a substance, fire is what its circumstances make it (Pyne, 2010). When looking at the immediate transformation on the landscape after a forest fire, the introduction and phases of succession begin to take place. Plant communities (*figure:7*) reflect species assemblages in transition, each reacting with different lag times to past changes in climate, and disturbance (Agee, 1993). These lag times of growth and change within a post-fire landscape are often referred to as the concept and series of succession that takes place within a burned area. The species and plant characteristics define individual responses relative to the responses of associated species (Agee, 1993). One model developed and defined by Rowe (1993) lists succession as five defined categories of plant response and how disturbance helps to categorize specific characteristics related to fire regimes (e.g., register category):

1. *Invaders*. Highly dispersive, pioneering fugitives with short lived disseminules. Plants such as fireweed (*Epilobium angustifolium*), Scouler's willow (*Salix scouleriana*), and cottonwood (*Populus spp*.) are typical invaders, generally needing disturbance to occupy a site.
2. *Evaders*. This category includes species with relatively long lived propagules that are stored in the soil or canopy. The species thus evades elimination from the site. Daubenmire's "germination" and "serotinous cone" adaptations both fit the evader category.
3. *Avoiders*. These are generally shade-tolerant, late successional species that slowly reinvade burned areas and have essentially no adaptation to fire. Hemlocks (*Tsuga spp.*), western juniper (*Juniperus occidentalis*), and subalpine fir (*Abies lasiocarpa*) are good examples of avoider species. Herbaceous species with reproductive parts in the litter layer are likely to be killed even by low intensity fires (Flinn and Wein 1977), and would also be classified as avoiders.
4. *Resistors.* These are species that can survive low intensity fires relatively unscathed. Thick-barked species, such as Douglas-fir, ponderosa pine, and western larch, are resistors.
5. *Endurers*. These species have the ability to resprout from the rood crown, lateral roots, or the aerial crown. Oaks, Pacific madrone (*Arbutus menziesii*), and various shrub species are among the many species classed as endurers in the Pacific Northwest.


Figure 7: Fireweed on Eagle Creek (USDA, 2019)

As Agee (1993) points out, these 5 general categories can be used to develop a generalized response to fire regimes; a low severity fire will favor resistors, while a high severity fire will favor invaders, evaders, and endurers.

Fire Impacts on Hydrology

The hydrologic cycle within a given watershed is known to consistently change due to physical processes involved in moisture flux transfer such as: interception, evapotranspiration, soil moisture changes, surface runoff, infiltration, percolation, interflow, groundwater storage, and channel routing (Evans, 1996). The hydrologic processes of interception, infiltration, and evapotranspiration all play a key part in establishing, supporting, and contributing to the regeneration of vegetative communities. Rainfall events infiltrated into the soil and the baseflow of surrounding perennial streams is sustained between storms when a watershed's rate of infiltration through its organic matter is not disturbed (USDA,2005). This gives a watershed the ability to absorb excess rainfall during seasonal events and prevent increased erosion events. Sediment transport through increased soil surface runoff is also decreased due to absorption qualities related to vegetation density and organic matter (USDA, 2005). High severity wildfire in a healthy watershed can destroy and alter the physical soil properties, the vegetative community, and litter layer accumulation. The interrelationship between riparian area and surrounding watershed is most sensitive to natural and human related disturbances, including fire (DeBano and Neary 1996). The cumulative effects of forest fire, such as percolation, and the capacities of soil absorption, can change a healthy productive watershed to poor condition. With watershed conditions altered after a forest fire, post-fire hydrologic conditions on the surrounding landscape can pose increases in the amount of overland flow, erosion, and soil loss (Neary, 2003; Hohner, 2019). These fire-related effects are the beginning stages of altering the hydrologic responses to precipitation and snow melt within a watershed.

The streamflow discharge of a given watershed fluctuates throughout any given season depending on weather events, precipitation duration, and storm intensity. These changes affect the baseflow, stormflow, and combination of the two when calculating water volume within a given stream or river. Intense, short duration storms that are characterized by high rainfall intensity and low volume have been associated with high stream peak flows and significant erosion events after fires (Neary, 1999). With the lack of soil permeability due to post-fire effects, infiltration, interception, and evapotranspiration are reduced, further increasing the likeliness of overland flow. This in turn also increases the likeliness of more surface water runoff from perennial streams leading to an increase in streamflow discharge. Regarding the time of flow, information on this topic is limited, but some researchers note that streamflow from burned watersheds often responds to rainfall inputs faster than watersheds supporting a protective vegetative cover, producing streamflow events where time-to-peak is earlier (Brooks, 2003). Seasonal timing of snowmelt can also be affected due to post-fire events. Early snowmelt can be initiated by lower snow reflectivity (albedo) caused by blackened trees and increased surface exposure where vegetative cover has been eliminated (Gleason et al 2013, Helvey, 1973). The combined effects of a loss of vegetative cover, a decrease in the accumulations of litter and other decomposed organic matter on the soil surface, are among the hydrologic causative mechanisms for the increase in streamflow discharge (Pyne, 1996, DeBano, 1998,).

Fire Impacts on Stream Water Temperature

Stream temperature is the most critical determinant of habitat quality for many aquatic organisms, including fish, insects, zooplankton, and phytoplankton, with most species limiting their thermal exposure to a narrow temperature range (Beitinger and Fitzpatrick, 1979). Stream temperature is also fundamental to water quality and is responsible for driving a variety of biotic and abiotic processes in lotic systems (Wagner, 2014). With the removal of streambank vegetation and riparian shading during fire disturbance, water temperatures can quickly rise, further causing thermal pollution to occur, which in turn can increase biological activity in a stream (DeBano, et al. 1998). It is noted that this immediate temperature change in aquatic systems during a wildfire is controlled by convection, the fire's intensity, and the volume of water in the burned region (Rieman and Clayton 1997). Stream temperature levels can also influence the dissolved oxygen concentration, nutrient uptake/release rates from sediments, and the physiology (activity, metabolism, growth, and reproduction) of plants and animals (Hamid, 2020). These long-term increases or rapid fluctuations in stream temperature following natural fire disturbances may have adverse effects on life history patterns of aquatic biota (Gresswell, 1999). These rapid fluctuations in stream temperature are known to lead to stress for many species and influence the spatial heterogeneity of stream ecosystems (DeWeber, 2014).

Common changes in post-fire stream temperature can occur when shading from overstory vegetation is reduced, which increases solar radiation inputs to the stream surface (Isaak et al., 2010). Regarding how post-fire disturbance has the potential to influence stream temperature, it is important to note that these post-fire effects often differ between streams. For example, some studies show that wildfire can increase temperatures in aquatic ecosystems from 0° to 15°C on short and protracted time scales (Gresswell 1999, Isaak et al. 2010). This increase in stream temperature can also be influenced by fire intensity and the volume of water within a burned region or stream (Rieman and Clayton 1997). However, the effects of wildfire across a burned landscape are often heterogeneous, leading to disparate local alterations in stream temperatures (Beakes, 2014). As Beakes, 2014 discusses, fire, through removing riparian vegetation, leads to increased light, thereby warming stream temperatures. With the increase in solar radiation due to the loss of riparian stream shading, and potential low stream and pool levels during summer months, post-fire effects can have an immediate influence on raising stream temperature levels.

Eagle Creek Project

When the Eagle Creek fire erupted on September 2, 2017, it was not only a surreal story to the many hikers and public patrons who visit the area for a day hike, it was also a shocking reality to the many surrounding residents throughout Hood River County as well as across the Columbia River in North Bonneville. The news stories of how it happened, a high school teenager throwing fireworks into the canyon that drains the Eagle Creek watershed, were continuously repeated for weeks. In the hours that followed the start of the fire, the U.S. Forest Service and Hood River County Sheriff's Office worked side by side to fight the fire and rescue more than 170 hikers. Once the fire established itself, it quickly spread over the many hillsides of the Columbia Gorge and into neighboring stream valleys and small tucked-away canyons. Within 24 hours the fire was so serious that Kate Brown, Oregon's Governor, issued the 'Conflagration Act' due to the threat to life and property. Ash and smoke began to fill the air to a point where it could be felt from miles away as Multnomah County residents were showered with flakes of ash and smoke nearly 45 miles west of Eagle Creek. Within three days, the fire had consumed approximately 10,000 acres of wilderness, resulted in the closure of Interstate 84, and caused level 3 evacuations ("Evacuate Now, Leave Immediately!") for nearly 400 homes. By September 4, east winds and excessive heat pushed the rapidly growing blaze west across the ridges of the National Scenic Area. In the days that followed, the fire became a 48,000-acre conflagration that rained ash down on Portland and smoldered near the city's water supply at Bull Run. The fire caused the closure of transportation arteries through the only sea-level route in the Cascades Mountain Range: Interstate 84, the Union Pacific railroad, and even the Columbia River (USDA, 2019). Containment of the Eagle Creek fire was accomplished on November 20, 2017 and encompassed nearly 49,000 acres costing roughly $22 million in state and federal funds (OregonLive, 2017).

In the beginning stages and growth of the Eagle Creek fire, the establishment of the Burned Area Emergency Response (BAER) team was implemented to address a variety of disciplines related to the impacts of the fire. Starting with the U.S. Forest Service, a team of specialists was assembled who were familiar in disciplines such as soils, geology, hydrology, engineering, botany, recreation, archaeology, and fisheries, along with GIS support and public information officers. According to the USFS, the BAER Program addresses post-fire emergency stabilization of these and other post wildfire problems in order to protect public safety and prevent further degradation of the landscape, and to mitigate post-fire damages to cultural resources (NIFC, 2020).

Though this fire was relatively small in size—49,000 acres when compared to the yearly wildfires of California (10 million acres in 2017)—it was a fire that affected many residents within the Columbia Gorge and surrounding areas such as Portland. I was one of these individuals who was affected personally as I felt a connection to this area of Eagle Creek as it was a place I would frequent a few times a year. According to USFS data, the Eagle Creek trailhead was one of the most frequented hikes in the Columbia Gorge prior to the Eagle Creek fire event of 2017. It was also known for its abundance of stunning views, deep canyon hillsides, varieties of vegetative communities, and countless waterfalls.

Eagle Creek & Tanner Creek Watersheds

Eagle Creek is a 12-mile long stream located in the Columbia Gorge, Oregon. Running as a perennial stream, its drainage encompasses approximately 22,400 acres and is one of the many tributaries of the Lower Columbia River. The creek runs through the Mark O. Hatfield

Figure 8: Topographical boundary map of Mark O. Hatfield Wilderness watershed area, Columbia Gorge, OR Source: USDA

Wilderness (*figure: 8*) which covers 65,822 acres and is part of the Mt. Hood Wilderness area (USDA, 2018). The creek's confluence with the Columbia River is located within the Cascade Locks jurisdiction of Hood River County just upstream of the Army Corp of Engineers'

Bonneville Dam. Eagle Creek is also home to the Cascade Fish Hatchery which is operated by the Oregon Department of Fish & Wildlife (ODFW).

The climate of Eagle Creek consists of all four seasons to different degrees. With a yearly average temperature of 52˚F, summers are typically hot and dry due to the western Pacific Coast Range shielding the basin from the moist Pacific Ocean air. Average summer highs range from 65˚F to 77˚F. However, it is not uncommon for this area of the National Scenic Columbia Gorge to have a string of summer temperatures that stretch into the mid to high 90's between June and August. Winter months show average lows between 31˚F and 33˚F with annual snowfall and a string of colder temperatures that sometimes result in large ice displays surrounding the many waterfall features of the Columbia Gorge canyon basalt walls (USDA, 2018). As Chaney (1918) describes, the Eagle Creek geological formation is exposed along the bottom of the gorge from Warrendale to Viento on the Oregon side with a corresponding distribution on the north side of the river. It is the oldest basalt formation recognized in the region and is brought to the surface in the axis of the great north-south anticline which is the backbone of this portion of the range. The walls of the surrounding Columbia Gorge rise steeply, especially on the Oregon side, where cliffs of basalt rise more than 2,000 feet almost vertically (Chaney, 1918).

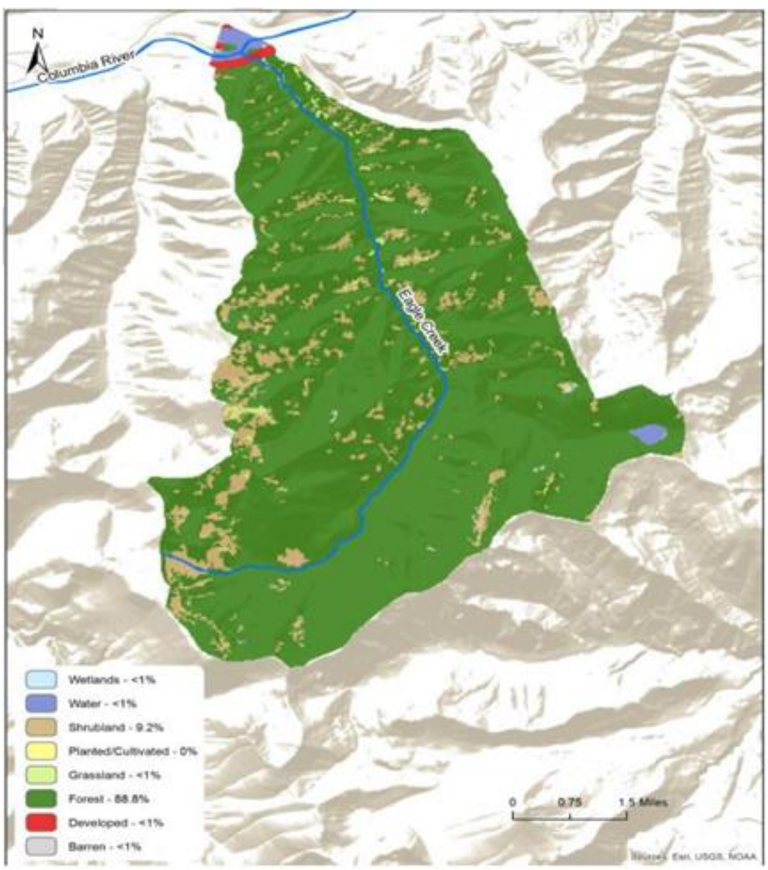

Figure 9: Eagle Creek watershed vegetation map, Source: EPA, 2019

A recent assessment conducted by the Northwest Power and Conservation Council (NPCC) (2018) defines the majority of the Mark E. Hatfield area and surrounding watersheds in mid-seral stage forest reserves, with some sizeable late-successional stage forest stands largely along canyon bottoms at the upper elevations. The NPCC report goes on to explain how the upper stream elevations (Elevation range for Eagle Creek 70ft-4600ft) in the Hatfield Wilderness and Columbia River Gorge National Scenic Area are in a nearly undisturbed condition, with many diverse habitats interspersed within coniferous forest. Forest communities include riparian hardwoods including red alder, big leaf maple, black cottonwood, Oregon ash, and varied wetlands along the Columbia River that change rapidly to upland western hemlock forest in the west and Douglas-fir, grand fir and Oregon oak/ponderosa pine forests on the east. The numerous abrupt topographic and climate changes along this stretch of the Gorge have created a patchwork of diverse habitats in closer proximity than found elsewhere in the Cascades (USFS, 1998). These include basalt cliffs, talus and scree slopes, low elevation forested slopes, wet meadows, dryland balds, riparian woodlands, and subalpine communities on the higher peaks. These habitats add niche diversity to the watershed and are responsible for the large number of sensitive plant and lichen species (NPCC, 2018). Prior to the Eagle Creek fire, Eagle Creek contained a mix of forest (89%) and shrubland (9%) (*figure: 9*) covered the steep slopes (EPA, 2019).

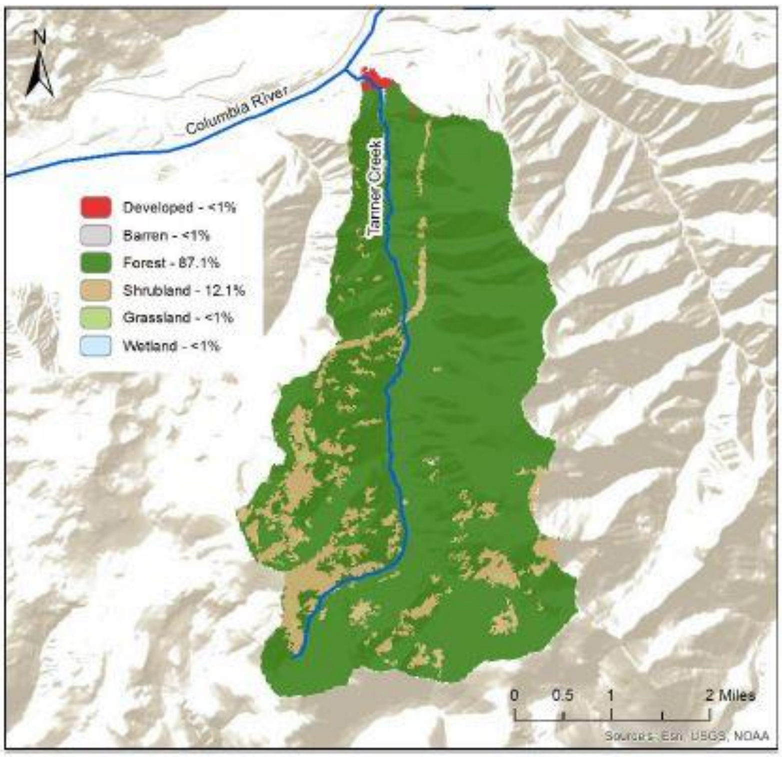

Figure 10: Tanner Creek watershed vegetation map, Source: EPA, 2019

West of Eagle Creek, The Tanner Creek watershed (*figure: 10)* abuts the Eagle Creek watershed and originates from a groundwater spring below Tanner Butte on the southern bank of the Columbia River Gorge (NPCC, 2018, EPA, 2019). The watershed runs approximately 6.5 miles, encompasses nearly 9,220 acres, and contains similar topography to the Eagle Creek watershed. Forest cover (87%) predominates in the basin (*figure: 10*); shrubland (12%) grows on portions of the upper and middle watershed (EPA, 2019).

Fire suppression throughout the Columbia River National Scenic Area has altered forest ecology compared to the natural and historical conditions of the surrounding tributaries such as the Eagle Creek watershed (NPCC, 2018). In 1902, fires burned over 100,000 acres in the Columbia River Gorge. Since then, fire has been suppressed to protect loss of human life, property, and transportation infrastructure (USFS, 1998, NPCC, 2018). With the absence of low-intensity fire, a steadily increasing fuel load raises the risk of high intensity catastrophic fire events and increases risk in areas that did not traditionally incur much fire damage, such as canyon riparian areas, cliffs, and talus slopes commonly found within the Eagle Creek and Tanner Creek watersheds (NPCC, 2018).

Watershed Parameter	**Eagle Creek**	**Tanner Creek**
Drainage Area	34.6 sq miles	14.4 sq miles
Mean Basin Slope	25.9 degrees	24.7 degrees
Mean Basin Elevation	2690 feet	2590 feet
Maximum Basin Elevation	4890 feet	4480 feet
Mean Annual Precipitation	109 inches	118 inches
Area Covered by Forest	90.1%	87%

Figure 11: Eagle Creek watershed and Tanner Creek watershed parameter comparisons, Source: USGS StreamStats, 2020

The Eagle Creek watershed and Tanner Creek watershed display similar characteristics (*figure: 11*) when comparing mean basin slope, elevation, and forest cover. Both are cold water streams with annual precipitation for both watersheds favoring Tanner Creek by an amount of 9 inches for a difference of +7.6%. However, the Eagle Creek watershed is nearly 60% larger than the Tanner Creek drainage area with its total stream length stretching approximately 11 miles compared to 6.5 miles for Tanner Creek (EPA, 2019).

According to the U.S. Geological Survey (USGS) StreamStats page, the 95% base-flow duration for Eagle Creek is noted as 12.1 ft^3/s (cfs). Tanner Creek, with a smaller drainage area, is shown with a 95% base-flow of 4.39 ft^3/s (cfs) (USGS, 2020).

Weather Conditions for Eagle Creek 2017

Weather conditions throughout the summer of 2017 recorded very little precipitation leading up to the Eagle Creek fire (*figure: 12*). According to the U.S. Climate Data (2020), the area of Cascade Locks, just east of Eagle Creek, recorded a total amount of precipitation for July and August of 2017 to be 0.09 inch. This amount of precipitation is below the monthly average of 1.19 in. (2016) and 1.60 in. (2015) (US Climate Data, 2020). Due to the prolonged months of dry climate and a string of 90+ degree days throughout the month of August, the Eagle Creek area was dry and noted by the USDA as a ‘tinderbox’ once the fire was started.

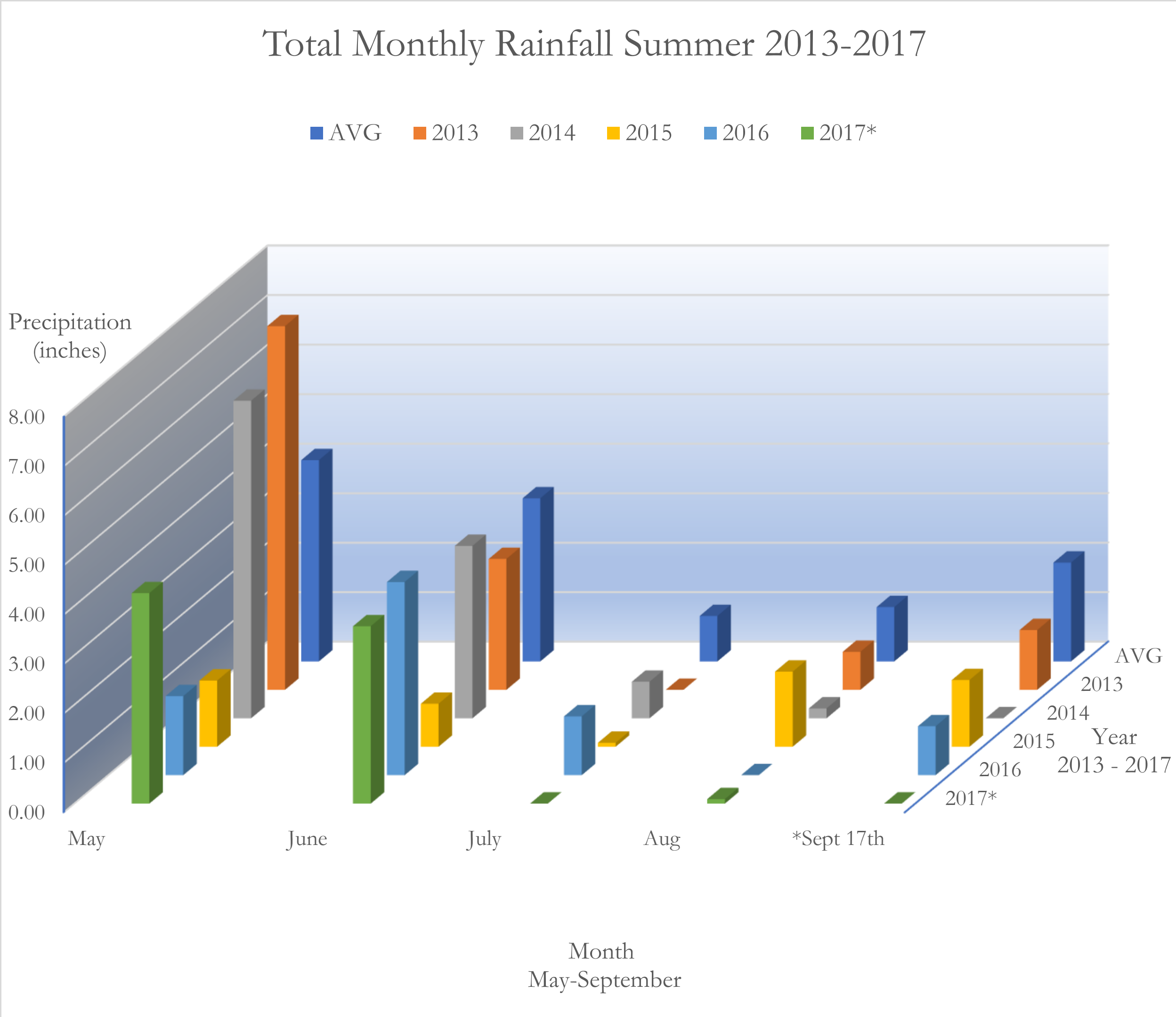

*Figure 12: Total monthly precipitation in inches (2013-2017) for Cascade Locks, Or *Rainfall till September 17th. Source: USCD, 2020*

Eagle Creek Ecological Impacts Post Fire

The fire interval in the West Cascades can vary from 100-400 year intervals. Vegetation types within the fire perimeter consisted of “Western Hemlock Zone” (37,418 acres), “Pacific Fir Zone” (9,706 acres), “Grand Fir Zone” (880 acres), “Douglas-Fir Zone” (500 acres), “Steppe” (174 acres), “Mountain Hemlock Zone” (58 acres), with 51 acres of other vegetation types (USDA, 2018). Throughout the Eagle Creek fire area, data shows numerous areas (*figure: 13*) in which high severity fire burn occurred including large amounts of the Eagle Creek canyon watershed and the adjoining Tanner Creek drainage. According the USDA Soil Burn Severity (SBS) map (*figure: 13*), the degree to which soil properties had changed within the Eagle Creek Fire perimeter showed an estimated 45% of high or moderate SBS (BAER, 2018). Prior to the Eagle Creek Fire, large amounts of riparian vegetation cover shaded Eagle Creek and its tributaries except for portions of middle and lower Eagle Creek (EPA, 2019). Post-fire analysis conducted by the U.S. Forest service shows large extents of Eagle Creek were moderately (yellow) or severely burned (red) in tributaries to Eagle Creek and middle and upper Eagle Creek, meaning the fire consumed at least 80% of the ground cover and surface organic matter (*figure: 13*). Much of the riparian zone corridor along lower Eagle Creek, however, experienced "undetectable disturbance" in terms of loss of vegetation (USDA, 2018). A GIS analysis of the Burn Severity Assessment data indicated that 23% of the riparian

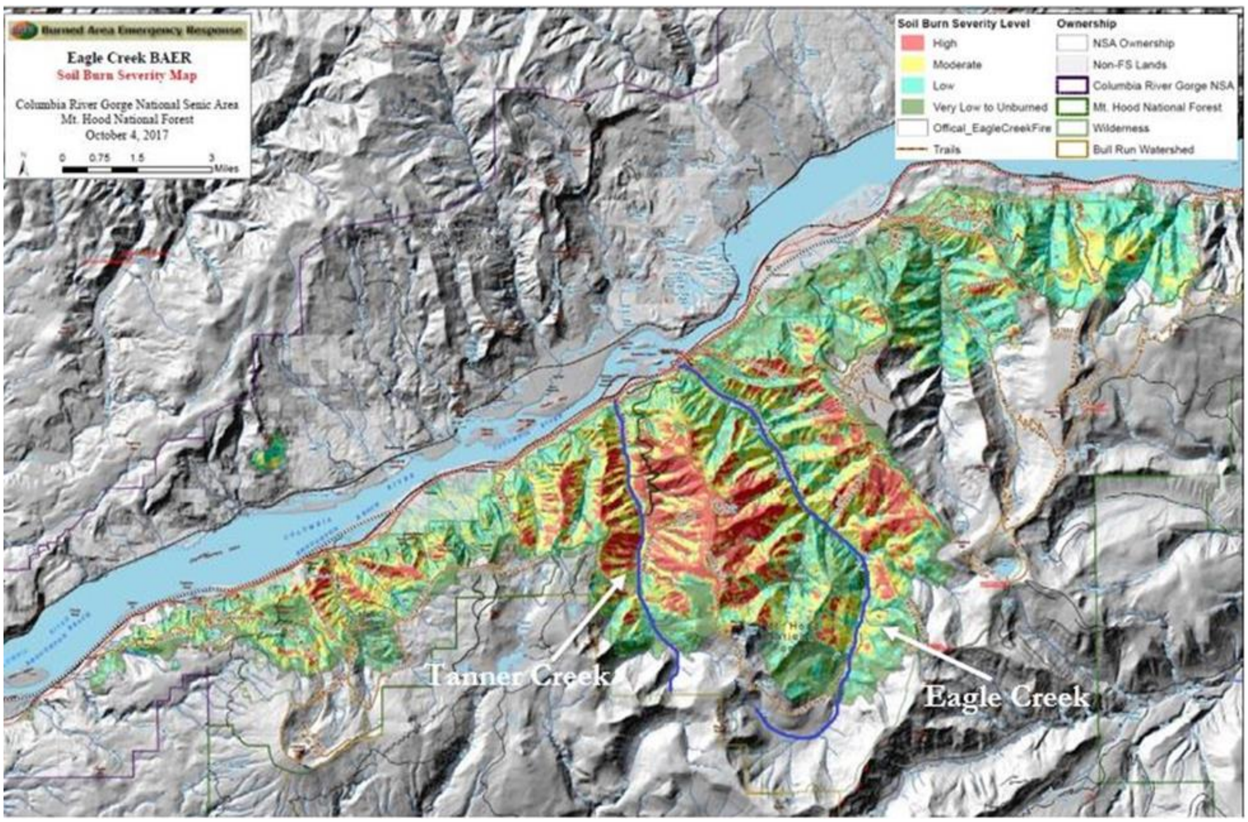

Figure 13: Fire burn severity map for Eagle Creek and Tanner Creek Watersheds. USDA, 2018

zone suffered low severity fire disturbance, 24% experienced moderate severity disturbance, and 5% experienced high severity disturbance (EPA, 2019).

Within the Tanner Creek basin, Burn Severity Assessment data (*figure: 13*) indicated that 14% of the riparian zone suffered low severity fire disturbance, 31% experienced moderate severity disturbance, and 12% experienced high severity disturbance (EPA, 2019).

During a typical rain event water does not have the ability to infiltrate into the soil in areas with high or moderate SBS. This further increases the chance of surface water promoting erosion and downstream flooding. Soil debris flow models developed by USDA and USGS indicate that relative to pre-fire conditions, erosion rates are expected to increase from near zero to 4.1 tons per acre in Eagle Creek, and 7.1 tons in the Tanner Creek watershed (USDA, 2018). With the potential rise in landslides, rockfall, and surface water runoff, the dangers and risks to the public increase in areas where foot traffic is greatest.

Post Fire Hydrology Effects in Eagle Creek

Pre-fire, vegetative and ground flora layers acted as a natural sponge, absorbing water during rainfall events and helping to promote the infiltration into the surrounding soil and

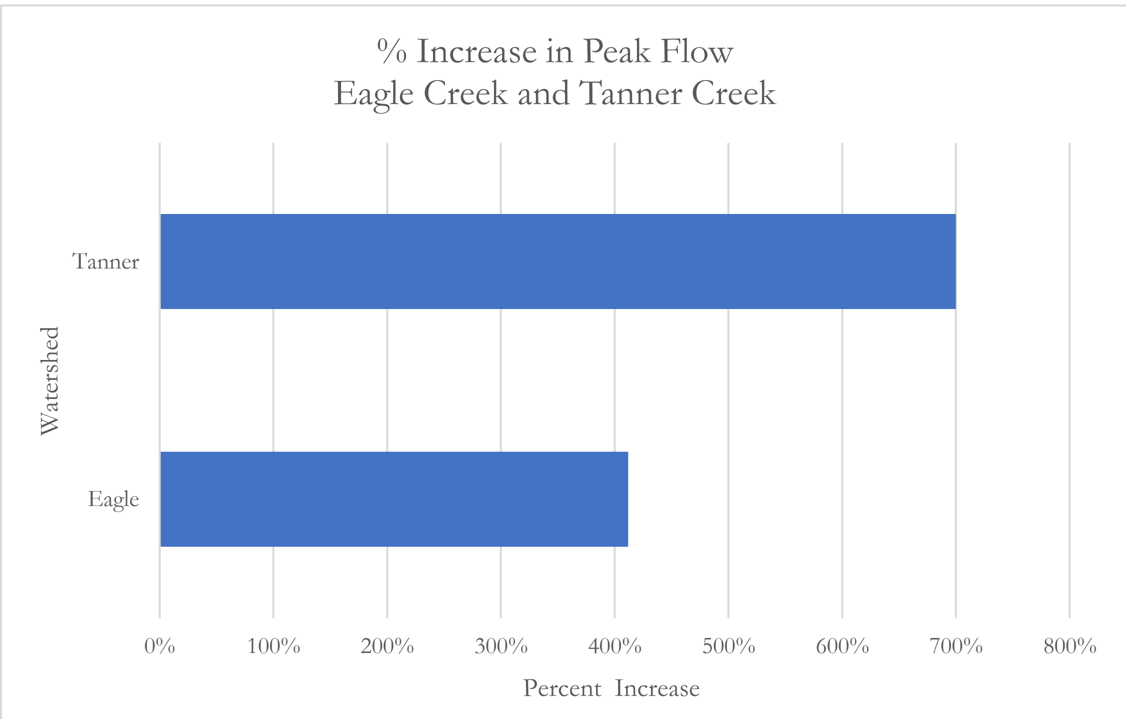

Figure 14: Projected Percent Increase in Flood Flows (Model for 10-year, 24-hour precipitation event) (USDA, 2018)

landscape. Loss of surface cover in combination with water repellent soils that no longer absorb water results in increased flooding, particularly in areas of high soil burn severity (USDA, 2018). Using projected modeled data, the USDA predicts a 412% rise in peak flow events for Eagle Creek and a 700% rise in peak flow events for Tanner Creek based on a 10-yr, 24-hour precipitation event (*figure: 14*). In areas where recreation use is high these increases in flood potential could be devastating to people and could also cause overtopping and failure of culverts (USDA, 2018). Post-fire hydrology of water stage levels, and median discharge within the fire perimeter also have the potential to change within these fire impacted watersheds.

Post Fire Soil and Geological Effects in Eagle Creek

Post-fire damaged soils have low strength, high root mortality, and increased rates of water runoff and erosion which lead to the potential for debris flows. As described earlier, an estimated 45% of the area within the Eagle Creek Fire perimeter (*figure: 13*) had high or

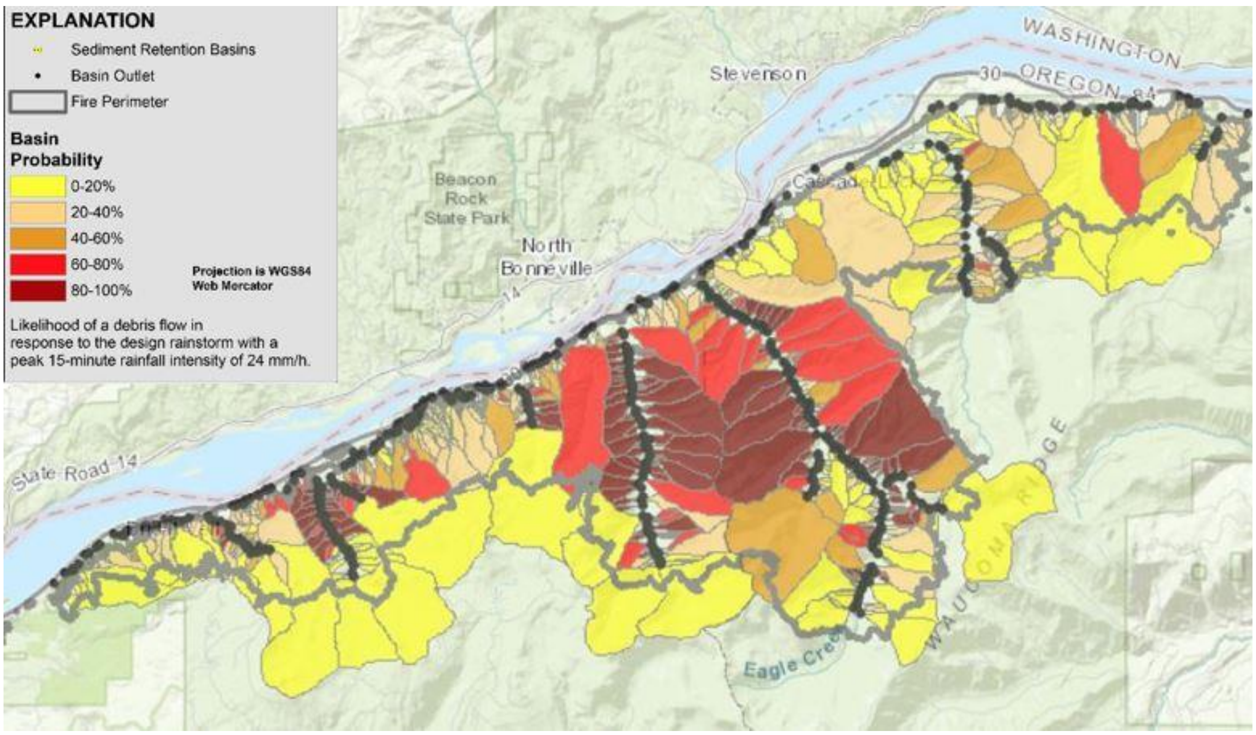

Figure 15: Projection of Basin Erosion for Mark E. Hatfield wilderness watersheds (USGS, 2018)

moderate SBS and those areas may have developed water repellent soils as a result of the fire (USDA, 2018). The U.S. Geological Survey (USGS) used the SBS map in their modeling to predict risk of debris flow (*figure: 15*). They found that 31% of the drainages are at high risk of debris flow, 42% are at moderate risk, and 27% are at low risk. The highest risk for debris flow was found in Eagle, Tanner, Moffett, McCord, Horsetail and Oneonta drainages, all located in the Mark O. Hatfield Wilderness. While ground observations and model results indicate an increase in debris flow initiation in the headwaters, it is unlikely that they will run out to the I-84 corridor (USDA, 2018). However, there is a chance that debris will collect and create debris dams and subsequently dislodge during storms when stream discharge is at a maximum. These debris dam outburst floods could pose serious risk to anyone downstream during high flow events since they carry logs, rocks, and a deluge of mud and water and could affect I-84, Highway 30 and/or the railroad (USDA, 2018).

Rockfall also poses a serious threat to people recreating on trails, at viewing locations, and along the Historic Columbia River Highway 30. Rockslides have already deposited piles of gravel to boulder-sized rock fragments onto the Historic Highway and onto trails (USDA, 2018).

Rockfall and treefall at Multnomah Falls are predicted to increase due to fire damaged trees, and loose, mobilized rock. A rockfall fence, located above the lower viewing platform, has already been weakened by post-fire debris and needs repair. Due to the towering vertical cliffs at Multnomah Falls and the high visitation of the site, the BAER team proposed rockfall mitigation measures to protect life, safety, and property. Options for reducing post-fire peak stream flows, soil erosion, and debris flow potential are limited due to the nature of the burn and slope characteristics. As a result, Value at Risk models (VARS) provide treatment recommendations and mitigation measures to minimize loss of life and damage. VARS primarily focus on mitigations that include closures, warning signs, and public safety approaches such as installation of an early warning system to notify areas when damaging storms may be approaching (USDA, 2018).

Beginning Stages of Eagle Creek Project

In October 2017, the U.S. Geological Survey, in cooperation with the USFS and NOAA, visited the closed area to conduct three discharge measurements, along with water quality samples, at Oneonta, Eagle, and Tanner Creeks. Through my employment at the USGS, I heard about first-hand encounters with the Eagle Creek fire—the continuous landscape of burned trees along Interstate 84, the heavily burned and moss-less canyon at Oneonta Creek, and the desolate and smoldering hillsides near the trailhead at Eagle Creek. As the stories continued to unfold from the news, acquaintances, and colleagues of the Eagle Creek fire BAER team, it began to stir more of an interest for me. I needed to see it for myself. In late 2017 I was asked to conduct a discharge measurement on the Columbia River below Bonneville Dam by motorized boat. This was my first chance to see the numerous scars of the Eagle Creek fire from the vantage point of the Columbia River. I tried to comprehend the continuous patches of browned tree canopy showing how the fire jumped into areas throughout the gorge by heavy winds. It was at this point in which my interest grew from an onlooker to a person wanting

Figure 16: USGS conducting survey for potential installation of water stage gage at Eagle Creek, 2017

to be involved in potential research within the watershed with the hopes of adding to the knowledge of fire effects in small watersheds.

In early October of 2017 I began to reach out to colleagues within the USGS regarding potential hydrological data collection that could be placed in Eagle Creek. The interest from many seemed to show promise, but most often it turned into the common question regarding a science-based project, “Who’s going to pay for it, and who’s interested in the data?” This turned into a task of approaching friends and acquaintances at other agencies within the Portland area to see if there was someone who might support this idea of monitoring Eagle Creek water stage levels and temperature. While continuing my search through numerous emails and a few phone calls, a hydrologist with the USFS, Diane Hopster, reached out to me in supporting my effort in installing a water stage gage at Eagle Creek.

Figure 17: USGS Eagle Creek Survey, 2017

In late October of 2017, the USFS Eagle Creek Fire planning director, Robin Shoal, reached out to me and we began discussing necessary paperwork to be filed for field access to the area of Eagle Creek. We then briefly discussed some ideas regarding a potential water stage gage installation and some install location areas that might be of interest. On November 14th, 2017, in cooperation with the U.S. Forest Service (USFS), a reconnaissance survey was conducted by the USGS (*figures: 16,17*) to assess the area of Eagle Creek regarding finding a fixed location for a potential water stage gage. The survey covered roughly one river mile from the mouth of Eagle Creek to the Eagle Creek trailhead.

The location of the sensor and gage box was chosen approximately 200 feet upstream of the Oregon Department of Fish and Wildlife’s (ODFW) Cascade Hatchery intake weir house located on the right riverbank. Looking for and selecting a proper gage pool was necessary to capture lower flows during summer months while also allowing enough area to install the needed recording equipment, with an attached data cable, that would reach approximately 100 ft from its fixed location to a gage box holding a data logger, power, and sensor cord adapter. Once the survey was completed, I contacted the USFS to determine the necessary steps to obtain a special use permit for installing the monitoring equipment. Once the permit was submitted for approval a discussion was started with the USFS Wildlife & Fisheries program manager, Brett Carre, in regard to deploying two sensors which would also include the neighboring watershed west of Eagle Creek, the Tanner Creek watershed. A reconnaissance of Tanner Creek was conducted in late Spring 2018 and an installation area was determined on the right bank approximately 200ft upstream of the Bonneville Hatchery intake weir just downstream of the Munra Falls pedestrian crossing (*figure: 18*). Three to four months after surveying the proposed sites, applying for a special use permit, and numerous emails and phone calls, an agreement was reached: USGS was going to support the project by supplying the needed labor for the gage install ($4,000-5,000), while the USFS would supply two In-Situ® 700 Level Troll sensors to monitor water stage levels and water temperature for both Eagle and Tanner Creek. Construction was scheduled for the fall of 2018.

In the summer of 2018, two In-Situ 700 Level Troll sensors for the two installations on Eagle and Tanner Creek were ordered through USFS funds and picked up by me in late summer with the objective of installing them for the 2019 USGS water year. I then calibrated the sensors over a period of 48hrs by submersing the sensors in a 5 gallon bucket of water and measuring the water surface depth with an engineering tape to compare readings. Water temperature calibrations were then conducted by submersing the level troll into a Fluke® Temperature Calibration Bath and continuously raising the temperature by 1.0 degrees C° from 0.0 - 20.0. A YSI Pro30 thermistor was also used for reference readings during

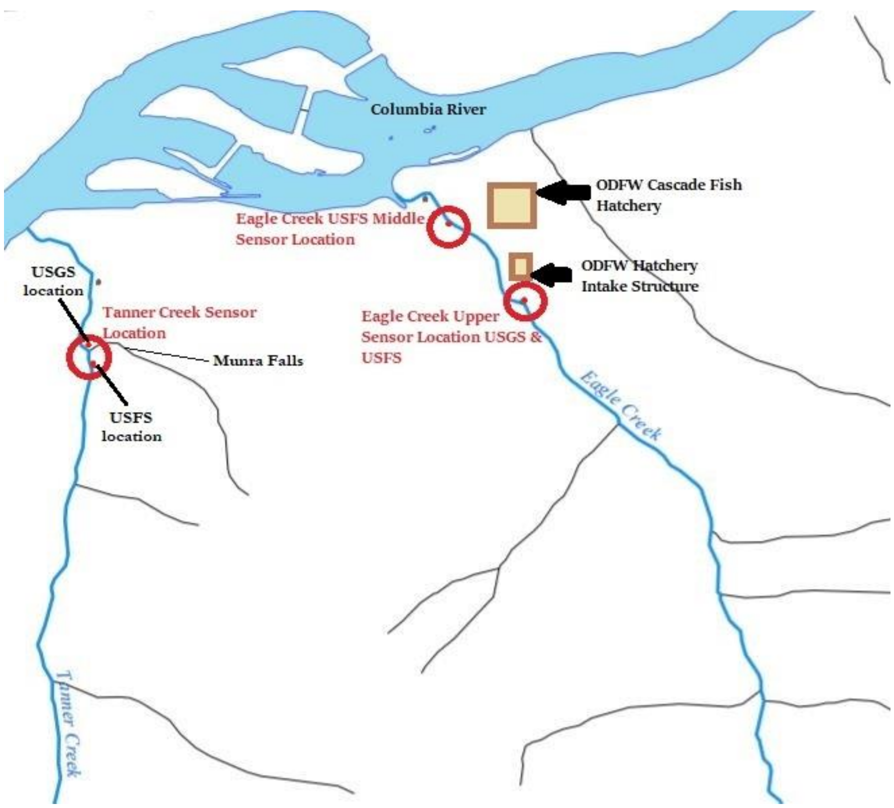

Figure 18: USFS and USGS sensor locations for Eagle Creek & Tanner Creek. Source: USDA

calibration. On November 16, 2018, both sensors were calibrated, installed, tested, and began logging stage and temperature data. Logged data was set using a 15-minute interval and stored directly to the logger. Site visits were then routinely made every 3 months to determine the sensors were working properly while also downloading the logged data.

With hatchery intake weirs at both Eagle Creek (ODFW Cascade Hatchery) and Tanner Creek (ODFW Bonneville Hatchery), USFS installed summer stream temperature sensors (*figure: 18)* throughout summer months of 2001-2008 (*figure: 23)* and again from June 2017- Sept. 2019. Sensors were placed above and below both hatchery intakes at Eagle and Tanner Creek to monitor summer stream temperature fluctuations during hatchery operations. The data collected from these USFS sensors produced a 7 day moving average of daily max stream temperatures to monitor upstream hatchery diversion temperature influence and hatchery discharge temperature for potential mitigation studies and DEQ requirements regarding stream temperatures and water quality standards.

Results

Water Temperature

Data collected in *figure (19)* shows the period of the 2017 Eagle Creek Fire with USFS temperature data located just below the Oregon Department of Fish & Wildlife (ODFW) fish

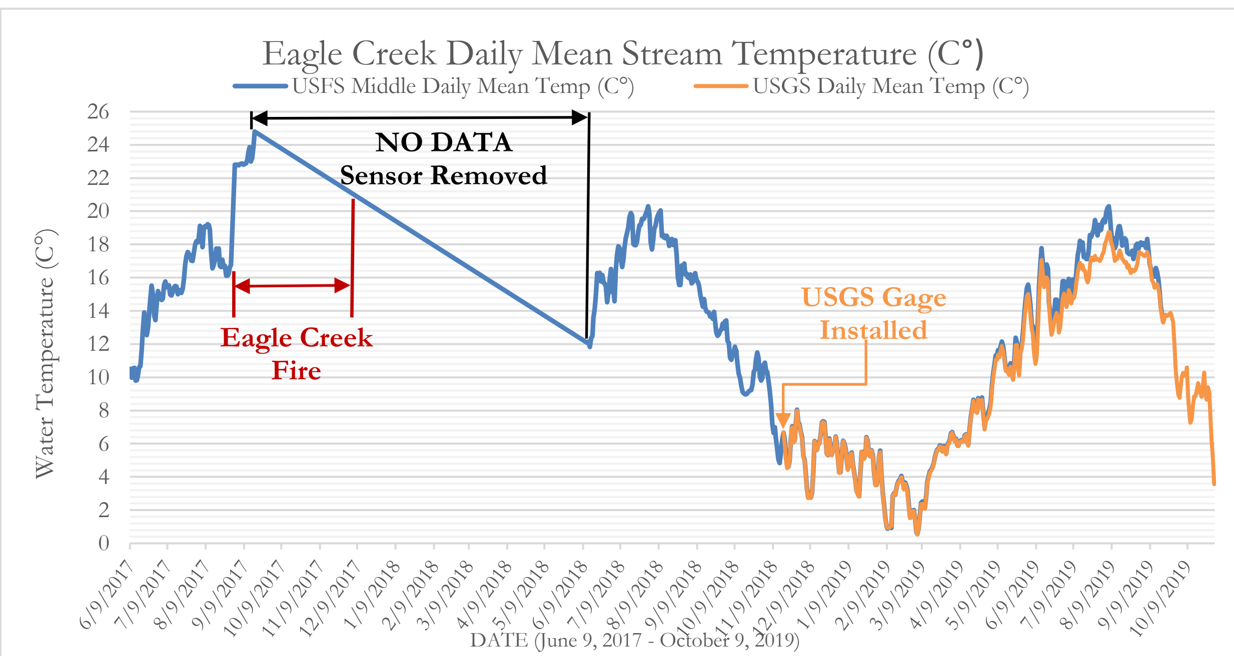

Figure 19: USFS Daily mean water temperature at middle Eagle Creek location vs. USGS daily mean water temperature

hatchery outflow (*figure: 18)* labeled as 'USFS Middle' and USGS temperature data at the upper location of Eagle Creek. The erroneous data period stretches throughout the duration

of the fire, starting on September 2nd, 2017, and extending beyond the fire's duration into the following year on June 25, 2018. This period of data is noted as erroneous data, it is not accurate, and has been altered due to its removal during the Eagle Creek fire. USFS Middle data continues until September 16, 2019 with USGS comparison data from the upper location.

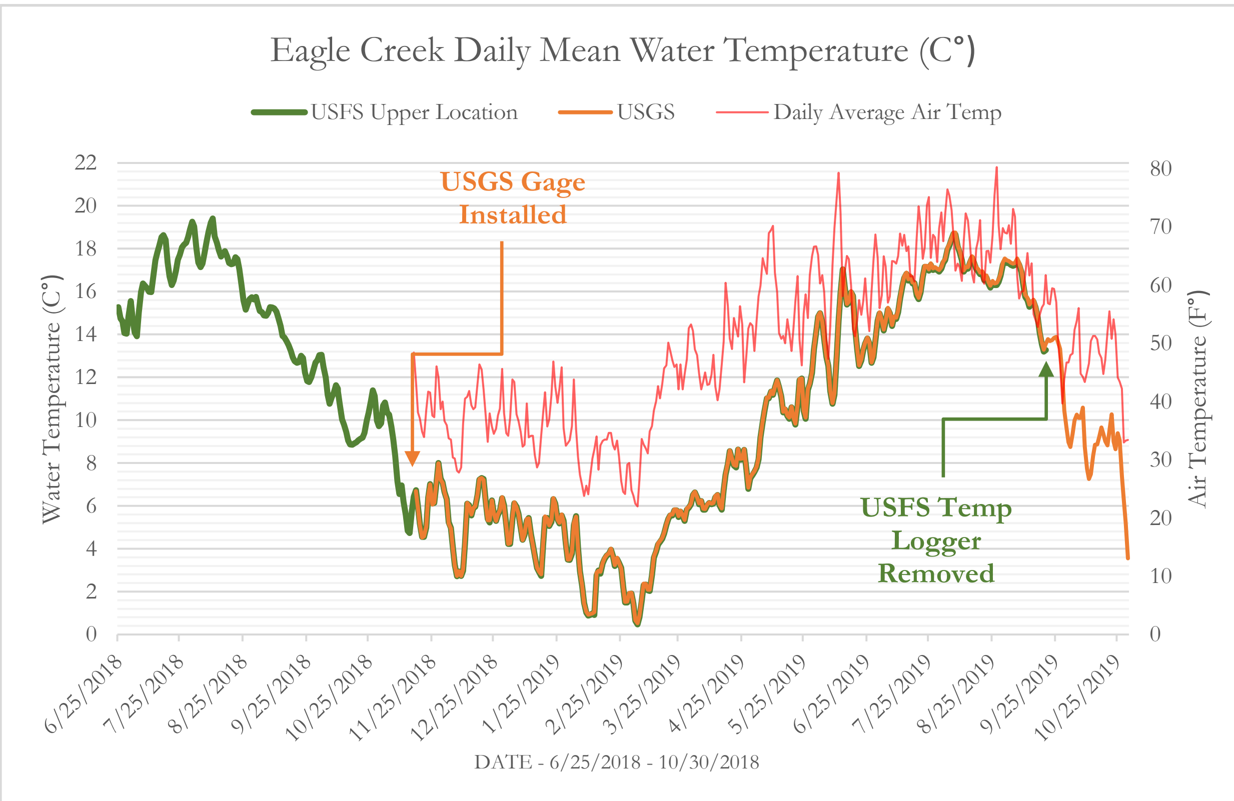

Figure 20: USGS and USFS Eagle Creek daily mean temperature above Cascade Fish Hatchery intake structure with daily average Air Temperature

USGS Eagle Creek temperature data collected above the ODFW Cascade Hatchery intake structure (*figure: 18)* is displayed in comparison to USFS Eagle Creek temperature data (*figure: 20*) at the same location. USFS data collected above the Eagle Creek ODFW Cascade Hatchery structure begins earlier on June 25, 2018 and extends to September 12, 2019. USGS logged data for this report begins on November 16th, 2018 and ends on October 30, 2019. Both sets of Eagle Creek temperature data from the USGS and USFS above the ODFW Cascade Hatchery intake structure are displayed to show comparison with daily average USFS air temperature data (*figure: 20).*

Data collected at both Eagle Creek sites for the USFS and USGS above the Cascade Hatchery intake structure show a similar rise and fall of temperature values with coinciding air temperature values (*figure: 20*). USFS data above the intake structure show a temperature year high of 21.53 C° on August 10, 2018 and 21.5 C on August 6, 2019. USGS data above the intake structure show a year high of 21.4 C on August 10, 2019. Temperature low for 2019 was 0.63 C for USFS data on March 5, 2019 and 0.2 for USGS data readings on March 5, 2019.

USFS water temperature data collected at Tanner Creek with USGS water temperature data at Tanner Creek (*figure: 21)* show similar higher temperature periods throughout summer months (May 2019 - September 2019) and similar lower temperature regimes during fall,

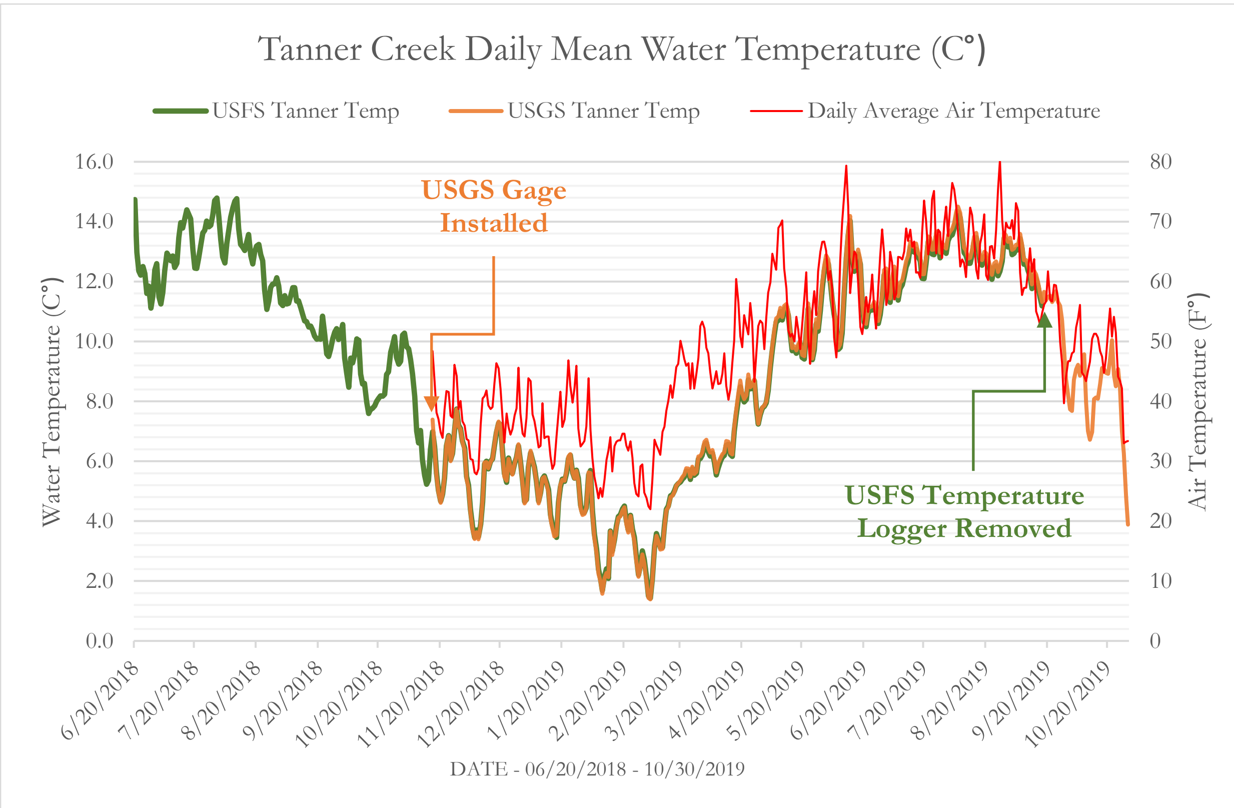

Figure 21: USFS vs. USGS daily mean temperature data comparison for Tanner Creek with daily average air temperature

winter, and spring periods (November 2018 - April 2019). Both data sets are displayed with USFS daily average air temperature values for comparison. A low water temperature of 1.39 C° on March 5, 2019 was recorded for USGS and a low water temperature of 1.40 C° on March 5, 2019 for USFS data. The rise and fall of the USFS and USGS temperature data depict seasonal temperature changes from decreased water flow and higher temperatures during summer months to increased water flow and lower temperatures during winter months. Department of Environmental Quality (DEQ) Upper Eagle Creek daily summer water temperature data *(figure: 23)*, provided by the USFS, is shown from 2001 through 2008 and displays daily average stream water temperatures for June through September months.

There was no data provided from 2009 – 2017 at this location from the USFS or DEQ. On June 25, 2018, USFS installed a stream water temperature sensor for data collection at this location as shown in *figure: 18*.

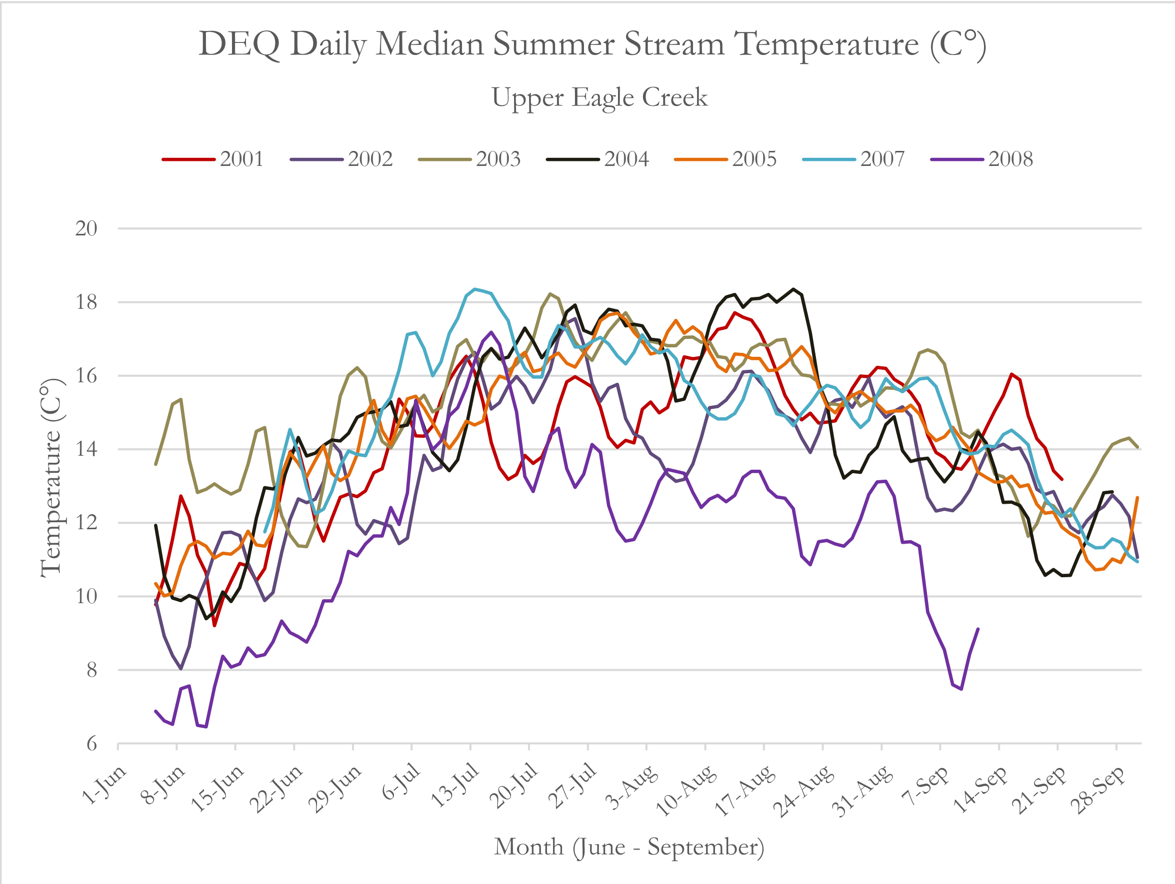

Figure 22: DEQ Upper Eagle Creek monthly median stream temperatures 2001-2008. Source: USFS

Water Stage Levels

Comparison for Eagle Creek and Tanner Creek water stage levels (*figure: 23*) are displayed for the period of November 2018 through October 2019 with daily average USFS precipitation values. Temperature comparisons for both Eagle and Tanner Creek (*figures: 20, 21*) are collected for the same period. USGS daily average water surface levels were collected from November 16, 2018 through October 30, 2019 at both Eagle Creek and Tanner Creek along with daily average precipitation values (*figure: 23)*. USGS surface water level data for Eagle and Tanner Creek are plotted in comparison and show similar increase and decrease in water levels during seasonal events and monthly periods.

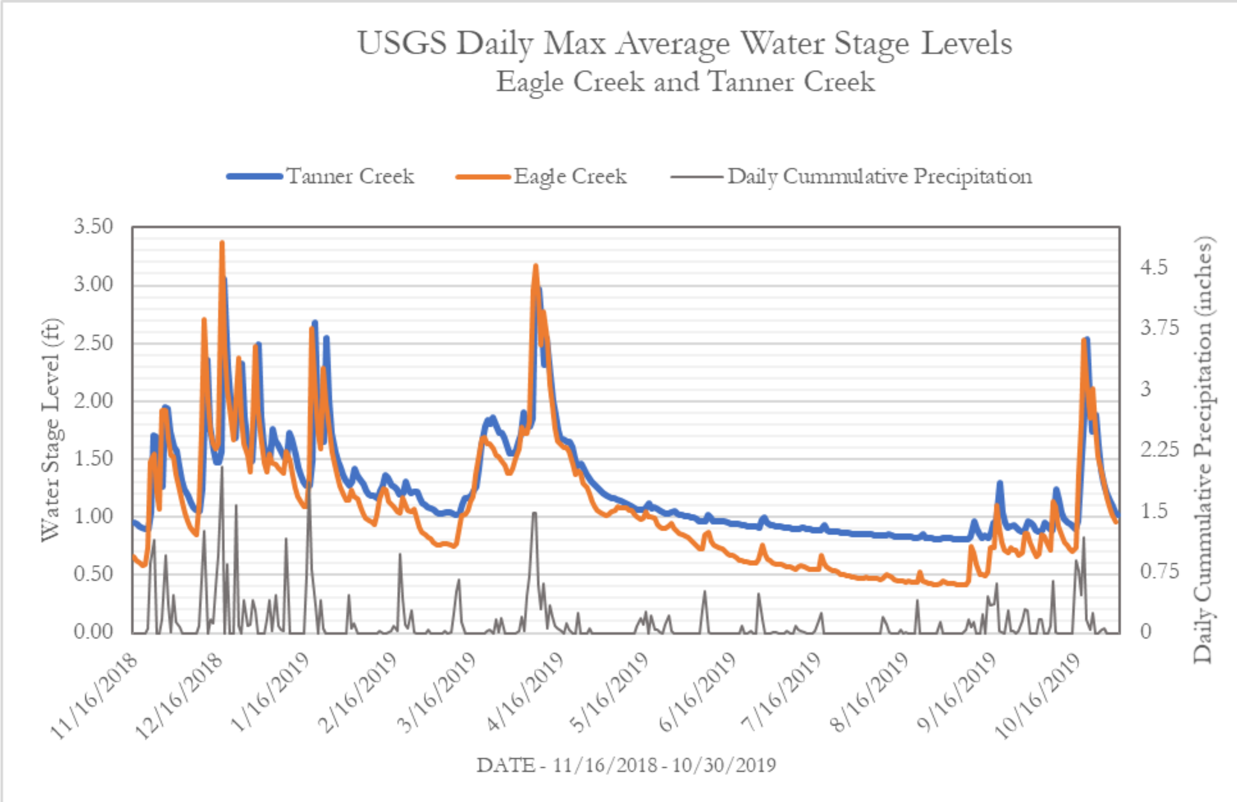

Figure 23: USGS daily max average water stage levels for Eagle and Tanner Creek

Discussion

USFS daily average temperature data at the location of middle Eagle Creek below the Cascade Hatchery outflow (*figure: 19*) is presented in this report for the sole purpose to display the time series of temperature values leading up the Eagle Creek fire as well as when the temperature data was restored on July 1st, 2018. This USFS temperature data set is specifically used in this report to show the overall event of the fire and is for timeline comparisons only as this data set is collected to monitor the Cascade Hatchery outflow temperatures for the Department of Environmental Quality (DEQ) and USFS to comply with hatchery outflow temperature requirements. This data set presents a reference as well as some potential for further research when looking at immediate stream temperature fluctuations related to the Eagle Creek Fire.

When looking at Eagle Creek daily average temperature data sets above the hatchery intake structure (*figure: 20*) for both USGS and USFS, there are strong similarities to the rise and fall of temperature readings. This temperature data set shows seasonal temperature fluctuations throughout 2018 and 2019. These seasonal changes result in higher temperature values in the late spring and summer months (May-Sept) and cooler temperature values during the Fall and Winter months (Oct. - April). Though the USGS data has been collected over a period of just under one year (Nov. 16, 2018 - Oct. 30, 2019), it is important to acknowledge the USFS data collected near the same location provided similar reference readings. Stream temperatures show comparable fluctuations with USFS air temperature data. However, it is important to note that changes in air temperatures under a climate change scenario may not project changes in maximum or minimum weekly stream temperatures (Chang, H. et. al, 2018, Mohseni, O. et. al, 1999). Though the data presented within this report shows daily mean readings, the data collected from these gages also can provide daily minimum and maximum stream temperatures. Some studies suggest maximum and minimum stream temperatures are more important to track than the mean annual stream temperature, since most cold-water streams experience significant changes in minimum weekly stream temperatures (Mohseni, O. et. al, 1999).

USGS and USFS Tanner Creek daily average temperature values (*figure: 21*) show similar temperature fluctuations with cooler temperatures during the fall and winter months (October - April) and rising temperature periods through the summer months (May – September). USFS data shows good stream temperature reference readings when comparing USGS data even though USFS stream temperature data is collected upstream of the Munra Falls tributary while the USGS data set is collected just below Munra Falls (*figure: 18*). Even though Tanner Creek stream temperatures show similar readings for both USGS and USFS

Figure 24: NOAA National Weather Service rapid all weather station on Tanner Ridge. Source: USDA, 2017

sensors, do these different sensor locations provide an argument for if the tributary of Munra Falls poses, or does not pose, a potential influence on USGS stream temperature readings? Though the USFS readings above Munra Falls are similar to USGS readings, it is recommended that this USGS gage be re-installed further upstream from Munra Falls to decrease any opportunity of Munra Falls influence on stream temperature data. Because the USFS sensor has since been removed (9/17/2018), installing the USGS stream temperature gage above Munra Falls would provide a more accurate reference of readings and consistent set of data points when comparing USGS and USFS stream temperatures for further research. When looking at the seasonal air temperatures, Tanner Creek stream temperature data show comparable seasonal fluctuations with USFS air temperature data.

Daily average water stage levels at Tanner Creek are displayed with Eagle Creek water stage levels (*figure: 23)* and show a similar trend to the rise and fall of seasonal events within the Mark O. Hatfield Wilderness. Eagle Creek shows higher water levels during winter events and lower water levels during low water periods over the summer months. What is causing Tanner Creek to stay at higher level during summer months while Eagle Creek drops nearly .50 ft lower in late August and early September? This might likely be due to the influence of Munra falls which feeds into Tanner Creek just upstream of the USGS gage. This location of the Tanner Creek USGS gage will need to be addressed in the future if this gage is to provide more accurate data of surface water levels and temperature fluctuations throughout a given water year period and to better monitor an area with a greater burn severity when compared to the Eagle Creek watershed. In addition, the goal of moving the current USGS gage location at Tanner Creek would be to have a better comparison with Eagle and Herman Creek regarding fire severity effects on water temperature data without the influence of a natural spring water source such as Munra Falls. USFS daily precipitation values show a comparable reference further supporting the relationship to surface water influence on water stage levels for both Eagle and Tanner Creek.

Air temperature and daily precipitation readings were recorded by the Tanner Ridge weather station installed on Oct 31, 2017 (*figure: 24*) by the National Weather Service and Meso West to support better forecasting in the Columbia Gorge. Air temperature and daily precipitation data from this gage provided hourly readings that were converted to daily averages to fit the USGS and USFS data graphs.

USFS water temperature data for the upper Eagle Creek location *(figure: 22)* is presented for reference only in this report. This data set does not pertain to or support the outcome of this report but is displayed as a potential reference for further research if needed and to acknowledge the existence of this temperature data.

The collected results through Nov. 16, 2018 to Oct. 30, 2019 provides a beginning as well as a strong foundation in collecting hydrologic data involving post-fire effects within the Eagle Creek and Tanner Creek watersheds. By moving the Tanner Creek gage further upstream it will help establish a better reference for temperature fluctuations and water surface level changes during seasonal events. The collection of this data at both water sheds will provide a vital resource when looking at the natural succession of riparian growth and its influence on water temperature, the regeneration of the understory and organic matter and its influence on water stage levels during events, and the comparison of both watersheds and their inevitable post-fire recovery.

USGS Interest

The USGS works with partners to monitor, assess, conduct targeted research, and deliver information on a wide range of water resources and conditions including streamflow, groundwater, water quality, and water use and availability (USGS, 2020). The overall goal regarding the USGS and its involvement with this project is establishing a partnership and working relationship with the U.S. Forest Service, Bonneville Hatchery, and ODFW's Cascade Hatchery.

The collection of data throughout this project has been dependent on communicating with multiple agencies, individuals, and working to forge an agreement and interest in the focus of this project: establishing a series of hydrological data collections within the Eagle Creek watershed to record the influence of post-fire conditions in an area that has little to no previous data. The long-term goal regarding the involvement of the USGS is to establish a real-time, continuous stream monitoring gage that can be accessed online by the public, as well as gaining more knowledge of the hydrology and the hydrologic events of the Eagle and Tanner Creek watersheds while they recover from fire disturbance.

Future Ambitions

The outcome of the Eagle and Tanner Creek watersheds will be hydrologically documented through stage levels and temperature readings throughout the water year of 2018 and 2019 (*figures: 20, 21, 23*) . Data from these two installations will be added to the USGS data base for documentation and possible rating development for the Eagle Creek drainage. Looking into the future for these two gages, funding has recently been granted through a USGS-PSU Partnership (UPP) to establish real-time telemetry for a continuous stage gage at Eagle Creek in addition to a third stage gage on Herman Creek, located just east of these two drainages (*figure: 25*). This UPP grant has also allowed both parties to work with the Army Corp of Engineers for a proposal in developing a rapid deployment monitoring gage involving multiple parameters that include turbidity, sediment collection, large surface particle velocity estimates, discharge, and video camera monitoring. The reason for choosing the Herman Creek watershed was because this drainage area was not severely affected by the Eagle Creek fire. This additional set of data poses as a good comparison to Eagle and Tanner Creek as it is located within the Mark O. Hatfield Wilderness boundary, access and installation is ideal, and the Herman Creek drainage is of comparable size with both Eagle and Tanner Creek. The data from Herman Creek will be collected using a similar In-Situ® level sensor with the goal of establishing a comparison site for both burned areas of Eagle and Tanner Creek. With the addition of Herman Creek, all three gages will allow documentation of temperature and stage level differences during storm events as well as seasonal dry spells. As discussed earlier, Munra Falls may pose an influence on temperature

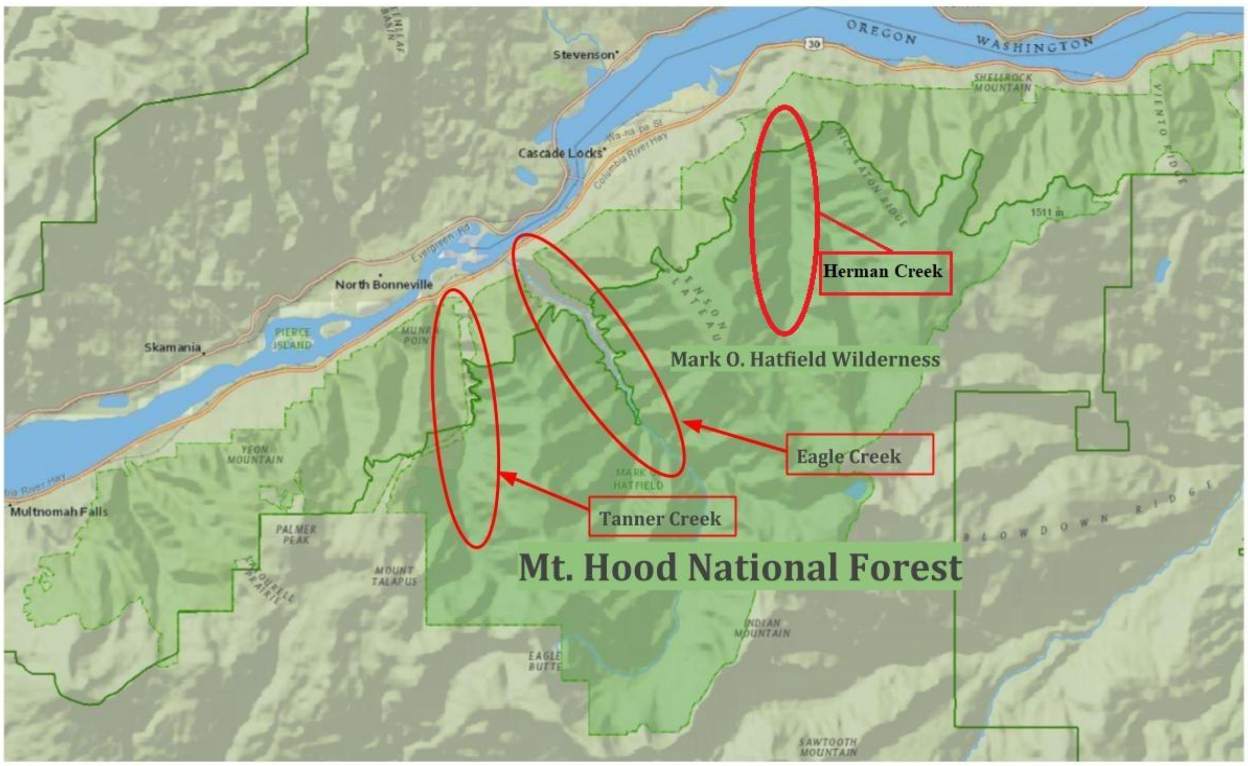

Figure 25: Mark O. Hatfield Wilderness map w/Tanner, Eagle, and Herman Creek outlined. Source: USDA

readings at this specific location because it feeds into Tanner Creek approximately 50ft upstream of the USGS gage; Therefore, the installation area of Tanner Creek for the USGS should be removed and relocated further upstream from its current installation point.

Continuous stream monitoring within the Eagle and Tanner Creek watersheds by the USGS will help provide more insight into post-fire seasonal storm events within the Columbia Gorge. The collection of this hydrologic data will also help to provide information regarding potential hydrological changes when looking at the regeneration of the forest floor and surrounding landscape within Eagle and Tanner Creek.

One of the main goals of this project is to create a joint effort through a collaboration of funding with co-operators in the hopes of establishing a long-term gage at Eagle Creek. When the USGS and USFS began to look at the overall effects of post-fire regarding the Eagle Creek fire, it would have been helpful to have a history of hydrologic data to compare when looking at changes within the geology, water quality, hydrology, and riparian area, and to track the overall changes regarding succession and regeneration of the forest. The hydrologic data presented in this report by both the USFS and the USGS will help support further research into examining post-fire effects within small watersheds. This data will also be used in my own research to create a discharge rating model for hydrologic water stage levels. Another goal of this project is to possibly develop a more streamlined installation process, or rapid deployment, for specific gages to be modelled after Eagle, Tanner, and Herman Creeks. The reason for this is to record and collect sensitive data regarding post-fire effects in forested regions that may involve a study of a particular watershed after a forest fire, forest regeneration efforts, concern for public safety, and to create greater opportunities to record and research hydrologic effects for areas affected by forest fires within the Pacific Northwest.

As mentioned earlier in this report, the suppression of forest fire is a common practice within the Pacific Northwest as well as throughout the U.S. With the amount of forest litter and the potential threat of climate change, previous and current forest management practices may pose a more severe outcome regarding fire in forested areas. The increase of data collection through water stage levels, water quality, and precipitation can provide important data when looking at hydrologic events within a watershed. This data can offer a closer look into measuring post-fire severity, riparian regeneration, and recovery within a forested watershed that has been managed for fire suppression. The model provided through this report offers an ideal way of capturing data within a given watershed with minimal cost.

Further research regarding solar radiation effects on stream water temperature should be considered as both Eagle Creek and Tanner Creek watersheds show similar slope, forest cover (*figure: 11*), and soil burn severity (*figure: 13*). Both watersheds also flow due north possibly limiting the amount of direct solar impacts which may or may not influence stream temperatures during summer months as riparian growth continues to recover. Due to the complex terrain and steep talus slopes within these adjoining basins, sediment accumulation might continue to shape peak flow turbidity levels as well as runoff events which may impact the release of suspended sediment as well as increased hillside erosion throughout steeper sloped areas. An additional research opportunity that these creeks could provide is investigating water consumption throughout the understory vegetation and whether it is influenced by post-fire recovery by looking at the relationship of retained water vs. overland flow throughout precipitation events. This could prove to be important data as it may provide a better overall understanding of the water cycle in both Eagle and Tanner Creek watersheds.

To conclude, three key lessons learned that should be considered for future gages include the process of obtaining proper permitting, easy and continuous access to the site, and most of all, good coordination with multiple individuals and agencies. Of these three areas mentioned, the permitting process was by far one of the most important and time-consuming tasks as it required multiple months to obtain the needed documentation when installing the gage at Eagle Creek. Securing the needed 'special use permit' (SUP) permit from the USDA and USFS took nearly 8 months of phone calls, emails, and paperwork. I feel this factor of permitting is incredibly important to recognize in the future as the delayed process of obtaining a permit may determine the overall outcome of recording important data.

Another lesson learned was the importance of having a sensor that worked efficiently, was dependable, and required minimal maintenance. Some qualities for this particular sensor included an internal battery and the capability for internal storage. Once the In-Situ level troll was set at the proper recording interval, the sensor was shown to have the capability to record and store data for nearly 3-4 years without a single site visit. At a cost of $2,500 for the sensor, operator cable, and programming tool, I found this to be very practical when looking at longevity and specific use.

The installation of these gaging stations went very smoothly after acquiring the right equipment and materials. Even though the installation took only one day for both Eagle and Tanner Creeks, I believe it could have taken much longer if the site had been more remote and the distance from the work vehicle to the gage involved hiking through a forested area.
I feel these two sites were an ideal situation with regards to access, accessibility to work tools, and desirable conditions. Overall, the amount of building material needed for these gages was an average total of $300.00, one day of work (3 USGS employees), and two sensor packages that were roughly a total of $5,000.00 which fit within the budget that was allocated. One action I would take in the future, as I did with this installation, is to bring more material than is needed for the install. This project and installation would easily have been delayed another full day if I found myself without enough proper materials.

Figure 26: Final installation of Eagle Creek Gage, USGS site: 14128850
(Photo: Sylas Daughtrey)

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