

**AN ANALYSIS OF 100 YEARS OF POST-FIRE STREAMFLOW RESPONSES OF
BRITISH COLUMBIA WATERSHEDS**

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Abstract

Wildfires are becoming larger and more severe due to climate change. This trend is destructive to the forest ecosystem, disrupting many eco-hydrologic processes in forested watersheds. Effects can include rapid runoff responses, increased surface runoff, and elevated erosion, leading to lower water quality and long-lasting effects on hydrologic ecosystem services (such as flood regulation). However, post-fire hydrology studies often have variable and contrasting results, making cross-study comparisons difficult. Studies are typically short-term and focused on single wildfire events. This research aims to determine accurate indicators for post-fire flow responses. The study area includes 257 drainage basins (grouped into five ecozones) in British Columbia, Canada, known for its susceptibility to wildfires and floods. The study analyzes wildfire data from 1910 to 2020. Post-fire percent changes for four hydrological metrics (low, high, peak flows and runoff ratio) were calculated using pre-fire and post-fire values for multiple temporal bands. Using streamflow, precipitation, temperature, wildfire perimeters, and topographic data, statistical analyses including hypothesis testing and multiple linear regression were done. The two-sample Kolmogorov-Smirnov test results comparing the fire group against the two control groups resulted in highly variable p-values. Multiple linear regression was done to predict the percent changes for all flows. Regression yielded poor model performance, suggesting that the hydrometeorological parameters alone cannot explain the post-fire changes observed. The most frequently influential watershed indicators in post-fire streamflow responses were percent burn, maximum daily temperature, and elevation. Results across multiple temporal bands, ecozones and hydrological metrics over 100 years will aid future research on the wildfire effects on hydrology in forested watersheds.

Keywords: post-fire hydrology, wildfire impacts, hydrologic ecosystem services

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Chapter 1 Introduction

In recent years, there is an increasing number of wildfires that burn more intensely and longer in many areas worldwide, including Canada, United States, Europe, and Australia (Khaledi, Lane, Nitschke, & Nyman, 2022; Zema, et al., 2020; Niemeyer, Bladon, & Woodsmith, 2020; Wagenbrenner, Ebel, Bladon, & Kinoshita, 2021). The longer, hotter and drier fire seasons combined with climate change impacts, increasing populations, and fire suppression efforts that prevent natural fires and increase forest density (and therefore build up fuel) (Wagenbrenner, Ebel, Bladon, & Kinoshita, 2021; Belongia, Wagner, Seipp, & Ajami, 2023; Robinne, Hallema, Bladon, & Buttle, 2020) lead to more frequent and severe wildfires. In turn, these wildfires can threaten community water supplies, and ecological water systems (Khaledi, Lane, Nitschke, & Nyman, 2022; Zema, et al., 2020; Saxe, Hogue, & Hay, 2018; Loiselle, Du, Alessi, Bladon, & Faramarzi, 2020). More frequent droughts (due to climate change) also enhance these effects, contributing additional stress to the natural hydrologic systems and water supplies (Belongia, Wagner, Seipp, & Ajami, 2023; Newcomer, et al., 2023). Expansion of the wildland-urban interface (WUI), where urban communities intrude into wild forests have also contributed to the higher wildfire risk and human exposure to post-fire impacts (Belongia, Wagner, Seipp, & Ajami, 2023).

Wildfire and floods are often treated separately, but the literature and recent events, particularly in Canada, show their frequent consecutive occurrence, suggesting a need to research the effects of fire on the hydrological impacts, hydrological ecosystem services (HES) and flood risk. HES are defined by as the benefits to the people that are produced by the terrestrial ecosystem and the freshwater, described in greater detail in Section 2.2 (Brauman, Daily, Duarte, & Mooney, 2007). With a higher WUI, the reliance on HES increases (Belongia, Wagner, Seipp,

& Ajami, 2023; Robinne, Hallema, Bladon, & Buttle, 2020). Canada has the third largest freshwater supply in the world which provide 88% of their drinking water and 68% of the hydropower generation (as of 2020). The HES from the Canadian boreal forests is estimated to have a \$72 billion value (2002 CAD) (Robinne, Hallema, Bladon, & Buttle, 2020).

This research focuses on British Columbia (BC), a province in Canada that covers 60 million hectares (149 million acres) of forested land, making up two thirds of the province's total area (Ministry of Forests, British Columbia, 2003). The vast area of forested land makes BC highly susceptible to wildfires. In recent years, BC has experienced devastating wildfires, which were followed by extreme floods.

The past six years have been particularly devastating. On July 7th, 2017, 108 fires started burning almost 7,000 hectares; BC Wildfire Service cited that day as the beginning of the worst wildfire season on record (BC Wildfire Service, 2018), followed by widespread flooding. The 2017 wildfire season displaced 65,000 people (Kehler, 2017), costing more than \$568 million for wildfire response (Cruickshank & Winter, 2018) and more than \$73 million for flood response (Zussman, 2018). The 2017 wildfire season was quickly dwarfed by the 2018 wildfire season, which burned over 1.35 million hectares, costing \$615 million for fire management and suppression efforts (Wang & Strong, 2019). A few years later, the 2021 wildfire season became the third worst on record, with Lytton Creek wildfire cited as the most devastating. On June 29th, 2021, the temperature in Lytton was recorded at 49.6 Celsius, almost five degrees higher than any temperature ever recorded in Canada. On June 30th, the village of Lytton was engulfed in flames within minutes (Lindsay, 2021). In an April 2022 news release, the public safety and solicitor general urged BC residents to prepare for both floods and wildfires by purchasing flood and fire insurance. A representative from the Insurance Bureau of Canada cited the significant

increase in the severity and frequency of floods and wildfires in BC (Public Safety and Solicitor General, 2022). Currently, the 2023 wildfire season is now the worst on record, with projected firefighting costs of \$966 million (CBC News, 2023).

This thesis looks at the hydrological impacts of wildfires that occurred between 1919 – 2020 in BC. The effects of wildfire on streamflow are typically studied by comparing specific metrics before a fire (pre-fire) versus after a fire (post-fire). Pre-fire values are typically averaged over 5 or 10 years, while post-fire values are averaged over 1, 2, or 5 years. This research builds and expands on this method by exploring the following:

1. Effects of fire on multiple hydrological metrics: low flow, high flow, peak flow, and runoff ratio.
2. Effect of time frame over which pre-fire metrics are averaged (1, 5 and 10 years) and post-fire metrics are averaged (1, 2, and 5 years) on flow changes. Studies typically choose one time frame for pre-fire metrics, resulting in three post-fire percent changes (i.e., 10-yr pre-fire vs. 1, 2, and 5 years post-fire). With the added pre-fire time frames, the number of comparative percent changes increases to nine.
3. Effect of fire on streamflow in burnt watersheds versus unburnt watersheds (adding a control group, which is not always considered in the literature).
4. Effect of fire in different parts of BC, using existing groupings of Canadian ecozones. Studies analyzing large areas perform watershed grouping by some form of clustering.
5. Hypothesis testing between fire and control groups, a statistical method used to determine whether a statistically significant difference exists. Recent literature has

not included hypothesis testing in their methods, though hydrologists have cited hypothesis testing as lacking but necessary in the field (Pfister & Kirchner, 2017).

6. Multiple linear regression using independent variables (hydro-meteorological and wildfire data) to predict the hydrological metrics listed in (1).

The multiple analyses performed will shed light on the flood risk indicators after a wildfire and highlight the impacts of study design and provide possible reasons for the contrasting results frequently observed in the literature.

The next chapter includes a literature review outlining the effects of wildfire, descriptions of hydrological ecosystem services (HES), current post-fire hydrology research, leading into the research gap and limitation. Chapter 3 will describe the research methods, which is followed by the results and discussion in Chapter 4.

Chapter 2 Literature Review

2.1 Wildfire Effects and Factors

Low severity wildfires are an important disturbance factor throughout the world, providing beneficial services to forests that include wood production, vegetation renewal, and biodiversity (through the establishment of diverse habitats) (Robinne, Hallema, Bladon, & Buttle, 2020; Papaioannou, Alamanos, & Maris, 2023; Shakesby & Doerr, 2006). The main causes of wildfire are lightning, volcanoes, and human action (Shakesby & Doerr, 2006). The fires included in this study are equally caused by lightning and human action.

Wildfires affect many watershed characteristics, including soil properties, vegetation, and land cover, which subsequently affect hydrological processes such as surface runoff, infiltration, and streamflow (described in the next section) (Papaioannou, Alamanos, & Maris, 2023; Wagenbrenner, Ebel, Bladon, & Kinoshita, 2021).

Vegetation: Wildfires lead to the removal of vegetation and litter cover, changing the microbial and fauna activity, further leading to partly or completely reduced transpiration, interception, and surface water retention and detention (Belongia, Wagner, Seipp, & Ajami, 2023; Shakesby & Doerr, 2006). In unburnt watersheds that are mostly covered by vegetation and litter (over 75% of ground cover), only 2% becomes surface runoff and erosion rates are low (Papaioannou, Alamanos, & Maris, 2023). After a wildfire, this effect is altered, destroying vegetation that would otherwise contribute to water storage and consequently elevating surface runoff that erodes the soil quicker (Belongia, Wagner, Seipp, & Ajami, 2023; Shakesby & Doerr, 2006). Removal of vegetation and litter from the forest floor leaves a bare soil surface, exposed to increased precipitation impact and higher susceptibility to entrainment by runoff. Additionally, altered soil moisture and increased solar heating can lead to earlier and increased snowmelt,

further affecting water quantity. However, the highly variable effects of wildfire on vegetation lead to highly variable magnitudes of post-fire impacts across different watersheds.

Soil: Wildfire impacts on soil structure and properties include reduced soil stability, higher soil erodibility, and altered porosity, organic matter, and soil water repellency, which changes the hydrologic properties of the soil (Shakesby & Doerr, 2006). Soil wettability is one of the most commonly cited wildfire effect to change soil hydrological properties (Shakesby & Doerr, 2006). The type of change and severity to the soil depends on the soil type, type of vegetation/ litter removed, and fire severity (duration and temperature) (Belongia, Wagner, Seipp, & Ajami, 2023). Wildfires can lead to soil water repellency, that can partially or completely reduce soil wetting that can last seconds, months, or years. Studies of coniferous forests in the United States have seen soil water repellency that lasted for as long as 6 years after a fire in some watersheds, and for as little as a few months in other watersheds (Shakesby & Doerr, 2006). Therefore, wildfire impacts on soil repellency vary substantially across studies, which can be attributed to the differences in spatial and temporal scales.

Larger and more severe fires exacerbate the wildfire effects described above, creating negative impacts during and after the fire, that include more toxic smoke, contaminated water, greater magnitude in disruption of hydrological processes, leading to many impacts on water quality, water quantity and water infrastructure (Robinne, Hallema, Bladon, & Buttle, 2020; Belongia, Wagner, Seipp, & Ajami, 2023). Many studies attribute the magnitude and severity of the negative impacts of wildfires to the fire frequency and burn severity (Shakesby & Doerr, 2006; Belongia, Wagner, Seipp, & Ajami, 2023; Wagenbrenner, Ebel, Bladon, & Kinoshita, 2021).

Wildfire Frequency: Wildfire frequency can vary from 6000 years (European temperate forests) to less than 50 years (Australian eucalypt forests) (Shakesby & Doerr, 2006). Fire suppression efforts, common in North America, can affect wildfire frequency, resulting in unintended impacts (such as higher wildfire risk) by increasing the accumulation of fuel through increased forest density and vegetation homogeneity (Shakesby & Doerr, 2006; Papaioannou, Alamanos, & Maris, 2023; Belongia, Wagner, Seipp, & Ajami, 2023; Robinne, Hallema, Bladon, & Buttle, 2020). Reduced wildfire frequency through fire suppression efforts, combined with climate change effects can lead to less frequent but more severe wildfires that have exacerbated wildfire impacts (Robinne, Hallema, Bladon, & Buttle, 2020; Shakesby & Doerr, 2006).

Wildfire Severity: Wildfire burn severity can be classified by the degree of destruction of above ground biomass, which is affected by fuel type and amount, and fire intensity and duration (Shakesby & Doerr, 2006). Burn severity is often cited as a key control on the magnitude of post-fire hydrologic responses; higher burn severity has often been associated with larger changes in water quantity, water quality, and water infrastructure (Belongia, Wagner, Seipp, & Ajami, 2023; Shakesby & Doerr, 2006; Wagenbrenner, Ebel, Bladon, & Kinoshita, 2021; Saxe, Hogue, & Hay, 2018). Though commonly cited as an important factor in post-fire hydrology, burn severity classifications are not always accurate predictors of post-fire changes (Shakesby & Doerr, 2006; Guindon, et al., 2020). In Canada, burn severity had not been fully characterized until recently by Guindon, et al. (2020).

Wildfire effects are plenty, and are interrelated in complex dynamics, with its effects varying per location, lasting as little as days to several years. The direct effects of wildfire described above lead to various post-fire hydrology changes that affect hydrological ecosystem services (HES), described in the next section.

2.2 Hydrologic Ecosystem Services

Ecosystems provide hydrologic services that are interconnected with other types of services that include improved air quality, carbon dioxide sequestration, and soil generation (Brauman, Daily, Duarte, & Mooney, 2007; Robinne, Hallema, Bladon, & Buttle, 2020). The characterization of ecosystem services described here is based on the Millennium Ecosystem Assessment (MA) completed in 2005 by over 1,360 experts internationally, that reviewed the global changes in ecosystems and the associated effects on society. The MA resulted in the characterization of ecosystem services, considered the benchmark for ecosystem services research (The Millenium Ecosystem Assessment, 2005; Brauman, Daily, Duarte, & Mooney, 2007).

Ecosystem services can be categorized into four types: provisioning, regulating, cultural, and supporting. Provisioning services provide goods that are directly used by humans, such as food, water, and timber. Regulating services maintain the environment making it biologically and physically possible for humans to survive, such as climate regulation, disease regulation, and water purification. Cultural services create an environment in which humans want to live, and include recreation, and spiritual, religious, and aesthetic inspirations. Supporting services are the fundamental ecosystem processes that create the services described above; examples include soil formation, and nutrient cycling. This research will focus on hydrologic ecosystem services (HES) (The Millenium Ecosystem Assessment, 2005; Brauman, Daily, Duarte, & Mooney, 2007).

As previously mentioned, HES are defined as the terrestrial ecosystem effects on freshwater that benefit humans (Brauman, Daily, Duarte, & Mooney, 2007; Robinne, Hallema, Bladon, & Buttle, 2020). Examples of HES include water supply for residential use, and flood

damage mitigation. Hydrologic ecosystem services can be categorized into five types: improvement of extractive water supply, improvement of in-stream water supply, water damage mitigation, provision of water-related cultural services, and water-related supporting services (Brauman, Daily, Duarte, & Mooney, 2007; Robinne, Hallema, Bladon, & Buttle, 2020).

As a provisioning service, water supply can be extracted, or used in-stream/ *in-situ*. Extractive uses of water supply include municipal, commercial, agricultural, industrial, and thermoelectric uses. In-stream uses of water supply include hydropower generation, water generation, water recreation and transportation, and freshwater fish production. Water damage mitigation is a regulating ecosystem service, and includes mitigation of flood damage, sedimentation, saltwater intrusion into groundwater, and salinization of dryland. Cultural hydrologic services include tourism, spiritual uses, and aesthetics. Lastly, water-related supporting services are extensive, but includes supply of water for plant growth, and for creating aquatic habitats (Robinne, Hallema, Bladon, & Buttle, 2020; Brauman, Daily, Duarte, & Mooney, 2007; The Millenium Ecosystem Assessment, 2005).

Each HES is described by hydrologic attributes: quantity, quality, location, and timing of flow. In other words, ecosystem hydrologic processes directly affects the hydrologic attributes of quantity, quality, location (upstream/ downstream), and timing, which create the hydrologic ecosystem services received by beneficiaries (Robinne, Hallema, Bladon, & Buttle, 2020; Brauman, Daily, Duarte, & Mooney, 2007). For instance, ecosystem processes such as short- and long-term water storage directly affects hydrological timing (peak flows, base flows, and velocity), providing the hydrologic ecosystem service of water damage mitigation to residents. Therefore, wildfires that affect ecosystem processes create cascading effects on watershed hydrology that subsequently impact the hydrologic ecosystem services described above.

Consequently, knowledge of the post-fire hydrology is essential for maintaining HES in forested watersheds, which is described in the next section.

2.3 Post-Fire Hydrology

Elevated wildfire activity increases concerns related to the short term and long-term effects on water quantity, water quality and water infrastructure (Niemeyer, Bladon, & Woodsmith, 2020; Robinne, Hallema, Bladon, & Buttle, 2020; Wagenbrenner, Ebel, Bladon, & Kinoshita, 2021).

Post-fire water quality effects include the contamination of ground water and surface water that may exceed the capacities of water infrastructure (such as water treatment facility, and water distribution networks), resulting in additional treatment processes, increased costs, and supply disruption (Belongia, Wagner, Seipp, & Ajami, 2023; Papaioannou, Alamanos, & Maris, 2023; Wagenbrenner, Ebel, Bladon, & Kinoshita, 2021). Following a fire, ash, sediments and other contaminants collect on the soil surface, which can be transported by runoff in the first post-fire precipitation events, delivering significant amounts into surface waters (Belongia, Wagner, Seipp, & Ajami, 2023; Wagenbrenner, Ebel, Bladon, & Kinoshita, 2021). Many studies find elevated concentrations of heavy metals, trace elements, nitrogen, phosphorous, organic carbon, and volatile organic compounds (VOCs), detectable in streams within the first 5 years after the fire (Belongia, Wagner, Seipp, & Ajami, 2023; Niemeyer, Bladon, & Woodsmith, 2020; Papaioannou, Alamanos, & Maris, 2023; Robinne, Hallema, Bladon, & Buttle, 2020). Studies have seen water quality recovery to occur within 2 to 3 years, with the most severe effects in the first year; however, even short periods of degraded water quality can result in significant water treatment issues (Belongia, Wagner, Seipp, & Ajami, 2023; Shakesby & Doerr, 2006; Niemeyer, Bladon, & Woodsmith, 2020; Robinne, Hallema, Bladon, & Buttle, 2020; Wagenbrenner, Ebel,

Bladon, & Kinoshita, 2021). Affected areas have had to intermittently cut off water extraction from streams due to the substantial sedimentation and contamination (Belongia, Wagner, Seipp, & Ajami, 2023). Still, post-fire water quality impacts are highly variable, depending on the wildfire severity and specific watershed characteristics (Robinne, Hallema, Bladon, & Buttle, 2020; Shakesby & Doerr, 2006; Papaioannou, Alamanos, & Maris, 2023). Post-fire water quality impacts are also affected by post-fire water quantity impacts, which are wide-ranging.

Post-fire water quantity impacts include alterations in streamflow (such as peak flow and base flow), infiltration, surface runoff, evapotranspiration, interception, and overall hydrologic regimes (timing and magnitude of flows) (Robinne, Hallema, Bladon, & Buttle, 2020; Saxe, Hogue, & Hay, 2018; Belongia, Wagner, Seipp, & Ajami, 2023; Shakesby & Doerr, 2006; Wagenbrenner, Ebel, Bladon, & Kinoshita, 2021). The type and severity of changes are highly variable across studies and are affected by various factors, though infiltration and soil water repellency are commonly cited (Robinne, Hallema, Bladon, & Buttle, 2020; Saxe, Hogue, & Hay, 2018; Shakesby & Doerr, 2006).

Many studies find reduced infiltration in burnt areas compared to unburnt areas (Ebel & Moody, 2013; Shakesby & Doerr, 2006). Suggested causes of reduced infiltration include soil water repellency, compaction from precipitation impact, sealed soil pores by fine ash particles, and the formation of a fungal crust layer (Shakesby & Doerr, 2006). The most commonly cited cause of reduced post-fire infiltration is soil water repellency; however, impact of soil water repellency is difficult to completely separate from other post-fire changes (Ebel & Moody, 2013; Shakesby & Doerr, 2006). The magnitude of post-fire infiltration change can depend on wildfire severity and the resulting removal of vegetation and litter (Robichaud, et al., 2016; Shakesby & Doerr, 2006). For instance, less severe fires may have higher water storage and infiltration

compared to areas that have experienced moderate or high severity fires (Ebel & Moody, 2013; Shakesby & Doerr, 2006). However, post-fire soil repellency is not always found to result in reduced infiltration; some studies found an increase in post-fire infiltration in moderately repellent soils (Ebel & Moody, 2013; Shakesby & Doerr, 2006). Post-fire changes to infiltration inevitably affect the amount of surface runoff as well.

Studies have generally observed higher surface runoff in burnt areas compared to unburnt. Some studies have seen 3 times more runoff in burnt areas, while other have seen 7 times more runoff (Shakesby & Doerr, 2006). In particular, Robichaud, Beyers, & Neary, (2000) found that if the vegetation and litter are reduced by just 10%, surface runoff can increase by more than 70%. The suggested post-fire mechanisms through which runoff is altered are similar to post-fire infiltration and include vegetation/ litter cover, soil compaction by precipitation impact, sealing of pores by fine particles, and formation of surface stone lag (Shakesby & Doerr, 2006). However, as with post-fire infiltration, post-fire surface runoff changes are variable, which may contribute to the overall highly variable findings in post-fire hydrology studies.

Some studies found post-fire increases in annual water yields, low flows, and peak flows that can last up to decades (Niemeyer, Bladon, & Woodsmith, 2020; Wagenbrenner, Ebel, Bladon, & Kinoshita, 2021). Rapid runoff responses and increased surface runoff due to the altered flow regimes were also found in some Canadian watersheds (Robinne, Hallema, Bladon, & Buttle, 2020), while other studies found little or no significant changes to the hydrologic systems post-fire (Bart & Hope, 2010; Zhang, et al., 2017; Rey, Briggs, Walvoord, & Ebel, 2023; Ebel, Wagenbrenner, Kinoshita, & Bladon, 2022). Some studies found contrasting impacts on different hydrological responses, such as increased annual water yields without any detectable change in peak flows (Mahat, Silins, & Anderson, 2016; Robinne, Hallema, Bladon, & Buttle,

2020). Other studies found little or no significant change at all in post-fire hydrology (Saxe, Hogue, & Hay, 2018; Robinne, Hallema, Bladon, & Buttle, 2020), even with wildfires burning up to 50% of the watershed (Newcomer, et al., 2023). Extensive reviews have been done in the literature that highlight the contrasting impacts on post-fire hydrology (and associated HES), necessitating further research (Robinne, Hallema, Bladon, & Buttle, 2020; Saxe, Hogue, & Hay, 2018).

Hydrological impacts of wildfire are influenced by many factors; typical controls that are cited in the literature include fire frequency, fire severity, percent burn (proportion of watershed burned), soil properties, post-fire precipitation timing and magnitude, vegetation recovery patterns, and topographical characteristics such as watershed size, slope, aspect, and elevation (Robinne, Hallema, Bladon, & Buttle, 2020; Saxe, Hogue, & Hay, 2018; Belongia, Wagner, Seipp, & Ajami, 2023; Shakesby & Doerr, 2006; Kinoshita & Hogue, 2011).

Wildfire impacts on post-fire hydrology, through provision of hydrological ecosystem services, have social, economic and environmental risks. The effects of fire described in this chapter can extend the negative impacts beyond the burnt area, causing cascading consequences, impacting many hydrologic ecosystem services that affect downstream communities.

2.4 Research Gap

Post-fire land management focuses on forest regeneration to reduce impact to ecosystems (Niemeyer, Bladon, & Woodsmith, 2020). Accurate predictions of water flow following a fire can help land managers to enact the most appropriate actions to mitigate post-fire degradation and plan the best rehabilitation for a faster watershed recovery (Zema, et al., 2020). Though there has been an increase in the number of post-fire hydrology studies in the recent years, most studies focus on single regions, at small spatial and temporal scales (Robinne, Hallema, Bladon,

& Buttle, 2020; Saxe, Hogue, & Hay, 2018; Shakesby & Doerr, 2006). The lack of long term post-fire studies may be partly attributed to the lack of datasets that contain pre- and post-fire data over a long enough period that allows statistical analysis (Wagenbrenner, Ebel, Bladon, & Kinoshita, 2021). Long term monitoring is commonly cited as severely lacking in post-fire hydrology research (Saxe, Hogue, & Hay, 2018; Robinne, Hallema, Bladon, & Buttle, 2020).

As mentioned in the previous section, studies find highly variable post-fire hydrological responses, creating challenges in interpreting the causes of variability (Robinne, Hallema, Bladon, & Buttle, 2020). Interpretation is particularly difficult in the few long term post-fire hydrology studies (Saxe, Hogue, & Hay, 2018). Study designs are also highly variable (Robinne, Hallema, Bladon, & Buttle, 2020), along with reporting methods of wildfires, hydrological characteristics of watersheds, and of results, necessitating a standardized method for post-fire hydrological analysis, as well as for describing the post-fire environment and findings. For instance, studies comparing pre- and post-fire hydrological responses vary in the temporal scales used for each pre- and post-fire responses, contributing to the variable results observed across studies. Additionally, studies that consider hydrological ecosystem services are lacking, especially for drinking water supply, flood damage mitigation and recreational uses (Robinne, Hallema, Bladon, & Buttle, 2020).

There are extensive studies of post-fire hydrology across small spatial and temporal scales, with a few that span larger spatial and temporal scales. Saxe, Hogue, & Hay, (2018) is one of the few that have studied post-fire streamflow responses over a larger spatial and longer temporal scale, focusing on watersheds in the western region of USA. Their analysis included various trend and regression analyses, however, hypothesis testing was limited, and no control groups were considered. In smaller scale studies that did include a control watershed,

descriptions of how the control group was chosen was lacking; often, the control watershed was simply described as ‘comparable’. Extensive studies such as that done by Saxe, Hogue, & Hay, (2018) has not been done in Canada. This research builds and expands on the methods used by Saxe, Hogue, & Hay, (2018) to analyze the post-fire streamflow responses in the fire-prone province of BC in Canada. The specific research methods and study area are described in the next chapter.

Chapter 3 Methodology

The methods used in this research are based on methods used by Saxe, Hogue, & Hay, (2018) to study controls on post-fire streamflow response in the western US watersheds. This research builds and expands on their methods to study post-fire streamflow response in British Columbia in Canada. The following sections describe the study area, the data collected, and the analysis performed on the data.

3.1 Study Area

The province of BC was chosen as the study area for its susceptibility to wildfires, and the floods that followed in recent years. The 257 drainage basins are grouped into five ecozones (Natural Resources Canada, 2023) accommodating the varying topographical and climatological factors across the province (Figure 1 and Figure 4). The boundaries of the ecozones were obtained from the Terrestrial Ecozones of Canada (Agriculture and Agri-Food Canada, 2016) and describes Ecozones 4, 9, 12, 13, and 14 as the Taiga Plains, Boreal Plains, Boreal Cordillera, Pacific Maritime, and Montane Cordillera. The majority of the province (and therefore, the majority of the data points) belong to ecozones 12, 13 and 14 (Boreal Cordillera, Pacific Maritime, and Montane Cordillera) (see Figure 1). The Pacific Maritime borders the west coast of BC which includes Vancouver Island, covering more than 195,000 km². It is dominated by coastal mountains and glaciers. The Montane Cordillera covers 473,000 km² of central to southeastern BC, which hosts the Columbia and Rocky Mountains.

3.2 Hydrometeorological and Wildfire Data

The hydrometeorological data included are the typical parameters used in the literature and include the following: watershed boundaries, streamflow, precipitation and temperature, wildfire perimeters, and topographic data (area, elevation, slope, and aspect). Due to the lack of

annual data for vegetation and soil between 1910 to 2020, vegetation and soil data were not included in the analysis.

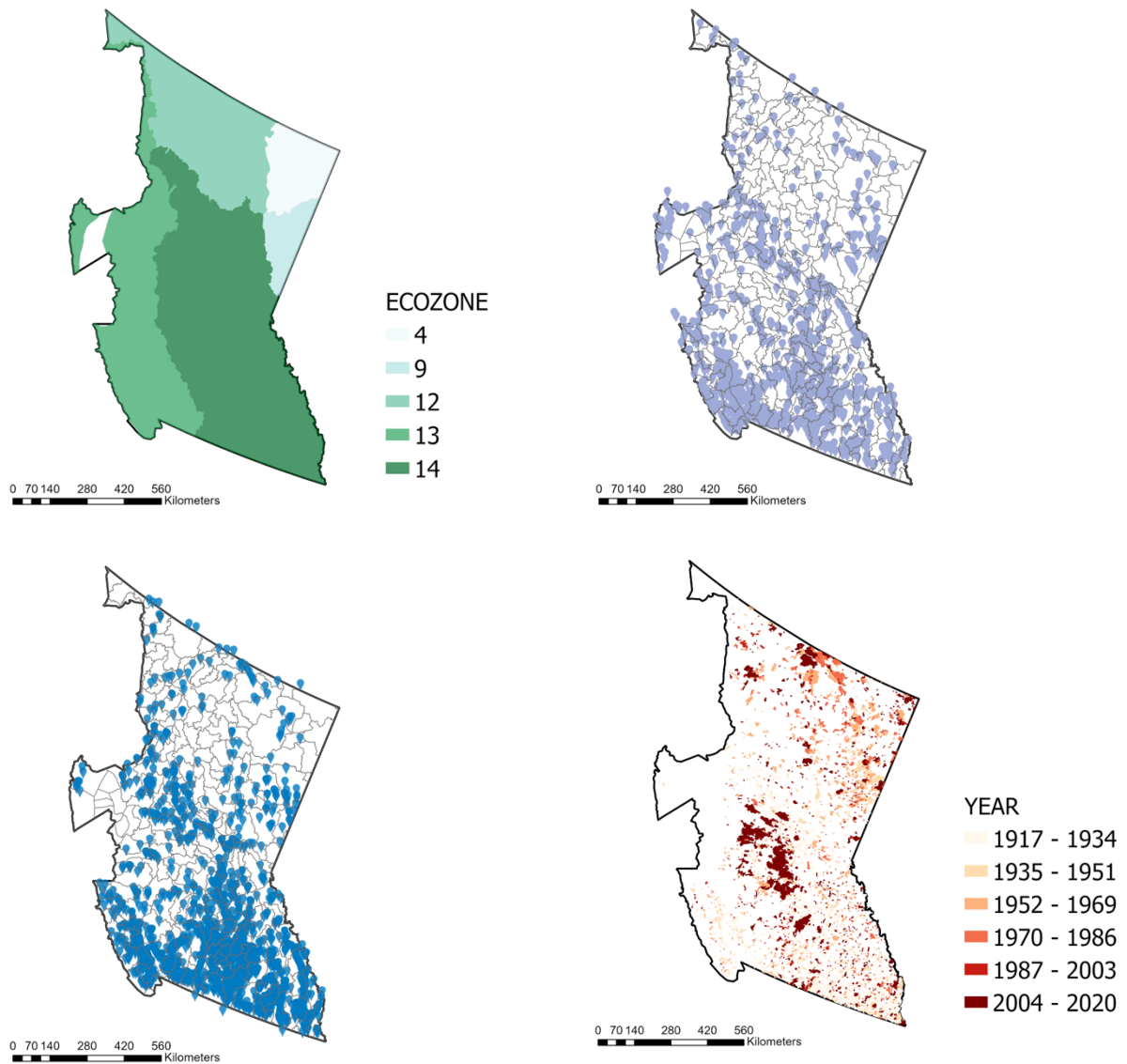


Figure 1: Hydro-meteorological and wildfire data: a) existing ecozones (4, 9, 12, 13, 14) of British Columbia; b) active and inactive precipitation stations with ecoregions shown; c) active and inactive hydro-metric stations with ecoregions shown, and d) wildfire perimeters from 1917 to 2020.

3.2.1 Watersheds

Drainage basin boundaries were obtained from the National Hydro Network (NHN FTP) from the Natural Resources Canada website (Natural Resources Canada, 2018). From the 257 BC watersheds, 181 experienced a burn of greater than 1%.

3.2.2 Streamflow and Precipitation Data

Daily streamflow records from the historical hydrometric database included 2,462 stations (from 190 watersheds) with data from 1910 to 2020 (Environment and Natural Resources Canada, 2023). Pre-fire and post-fire daily flow values were averaged per year per station using the *.mean()* function on python. A sample code calculating post-fire low flow values is shown in Appendix I.

Daily precipitation and temperature data were obtained from the Government of Canada historical database for 1,715 stations for 171 watersheds (Environmental and Natural Resources, 2023). The total annual precipitation was calculated for each station. The maximum temperature was taken to be the highest daily mean temperature of each year. Total annual precipitation and maximum annual temperature for each station were averaged for each ecozone.

3.2.3 Wildfire Data

Wildfire boundaries (Figure 1 (d)) were collected from the Canadian Wildland Fire Information System (CWFIS) with fires occurring from 1919 to 2020 (Natural Resources Canada, 2021). The majority of the fires were obtained from satellite imagery (LANDSAT5) and then digitized.

Wildfires that burned through multiple watersheds were split on ArcGIS by watershed boundaries, resulting in a total of 1,086 fire cases that burned over 1% of the respective watersheds. The 1,086 fire cases represent 624 fire events that included both human- and

lightning-caused fires with percent of watershed area burned (percent burn) ranging from 1 – 92.3%. The number of wildfires is shown per decade, and per ecozone in Figure 2. The size of wildfires over time and per ecozone are shown in Figure 3.

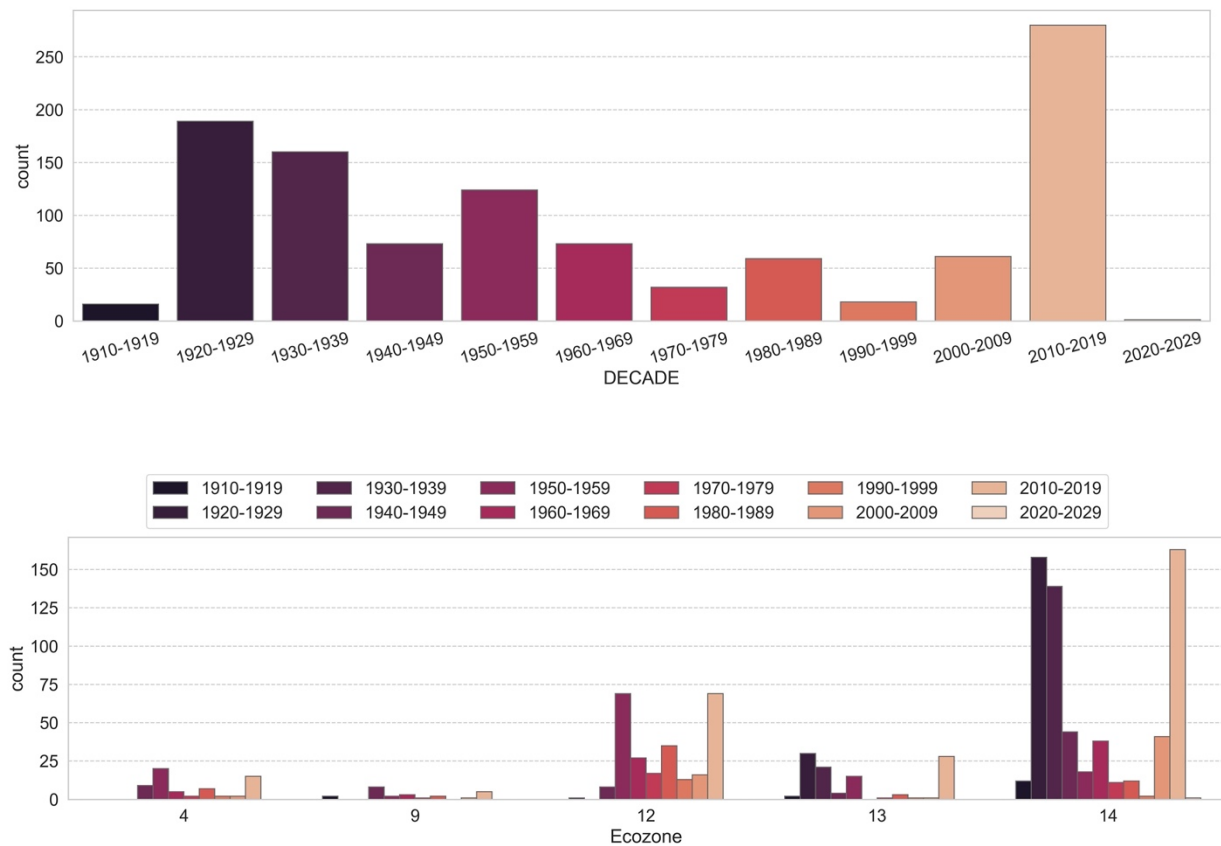


Figure 2: The number of wildfires: per decade (top) and further grouped by ecozone (bottom).

Overall, the number of wildfires over time have decreased, followed by a sharp increase between 2010 and 2019. Broken down by ecozone, ecozones 4 and 9 have had the lowest number of wildfires, which is expected since they occupy the lowest land area in BC. The nearly 200 fires seen in Figure 2 (a) dominated ecozone 14. This ecozone is the largest, and also where the highest count of fires occurred in the most recent decade.

A similar trend is observed for wildfire size (divided by watershed boundaries) in Figure 3, where the top figure shows the wildfire sizes in hectares in each decade, and the bottom shows the wildfire sizes in hectares per ecozone, and then further divided into wildfire per decade. Larger fire sizes have occurred in the last decade; the largest fires occurred in the larger ecozones (12, 13, and 14).

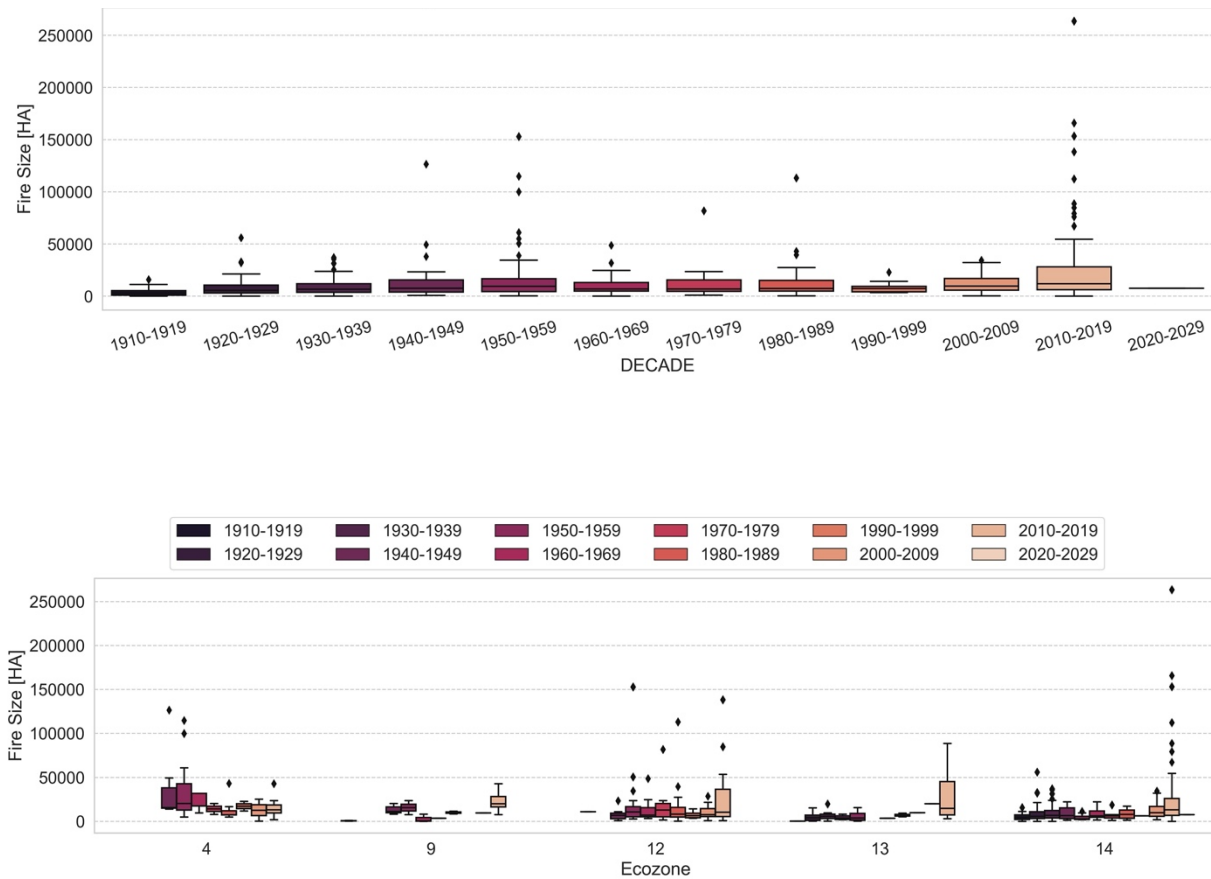


Figure 3: The wildfire size per decade (top) and further grouped by ecozones (bottom).

3.2.4 Topographic Data

Digital elevation model, slope, and aspect of each watershed (Figure 4) were collected from the Natural Resources Canada Topographic Tools and Data Directory and the Government of Canada Geospatial Data Extraction Tool (Natural Resources Canada, 2018; Government of

Canada, 2023). The elevation, slope and aspect maps were in GeoTIFF format with NAD83 CSRS coordinate system and a 0.75 arc seconds image resolution. The majority of the watersheds belong to ecozone 14, which is expected since this is the largest ecozone. Ecozone 9 has the largest range of watershed areas. The elevations tend to increase from ecozones 4, 9, 12 to ecozone 14. Ecozone 13 has the lowest elevations, which is expected since this is the coastal area, with the majority of the BC population residing here. Slope tends to increase from ecozones 4 to 14. Aspect (orientation of slope, measured clockwise from 0 to 360 degrees), is fairly consistent throughout the ecozones. Ecozones 12 and 14 have the highest percent watershed burn (represented by the outliers).

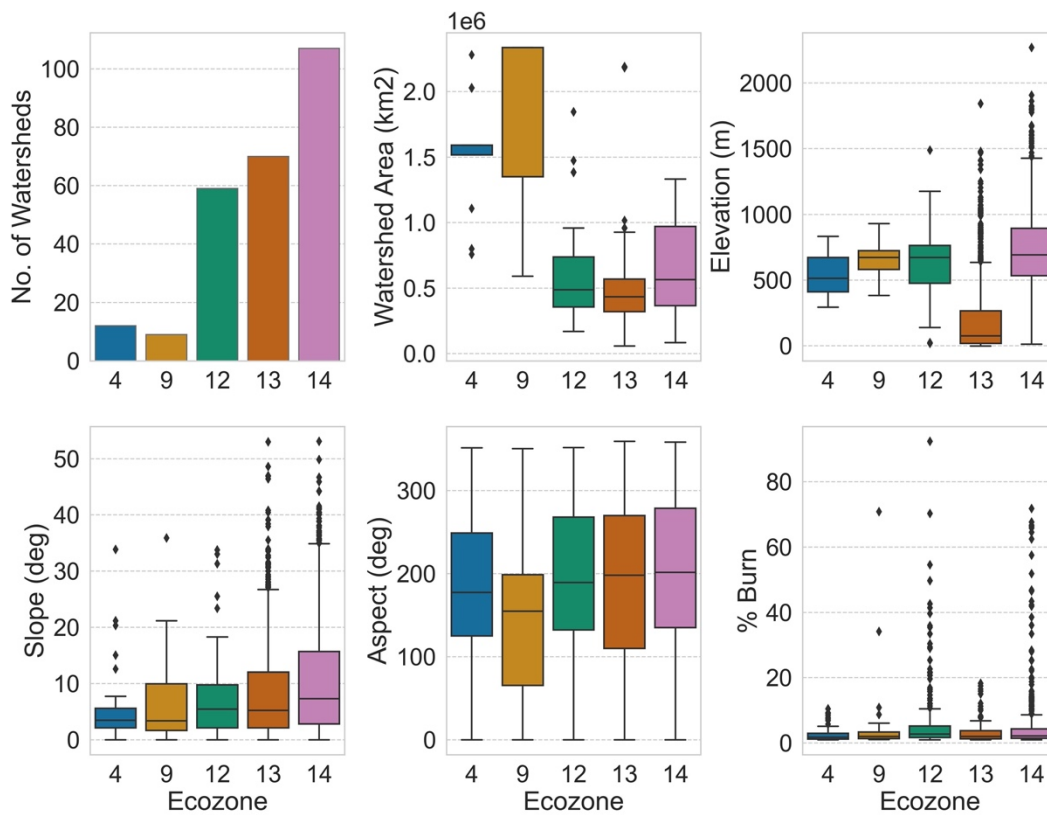


Figure 4: Boxplot of topographical variables: watershed area, elevation, slope, aspect, and percent burn; and number of watersheds, shown per ecozone.

3.3 Hydrological Metrics

Three date ranges were averaged for each pre- and post-fire: 1-, 5- and 10-yr flow averages for pre-fire and 1-, 2- and 5-yr flow averages for post-fire (Figure 6), as was similarly done by (Saxe, Hogue, & Hay, 2018). Percent changes were calculated (using code shown in Appendix II) between multiple pre- and post-fire for each fire event (temporal bands):

1. 1-yr pre-fire vs. 1-yr post-fire
2. 1-yr pre-fire vs 2-yr post fire
3. 1-yr pre-fire vs. 5-yr post fire
4. 5-yr pre-fire vs. 1-yr post-fire
5. 5-yr pre-fire vs. 2-yr post-fire
6. 5-yr pre-fire vs. 5-yr post-fire
7. 10-yr pre-fire vs. 1-yr post-fire
8. 10-yr pre-fire vs. 2-yr post-fire
9. 10-yr pre-fire vs. 5-yr post-fire

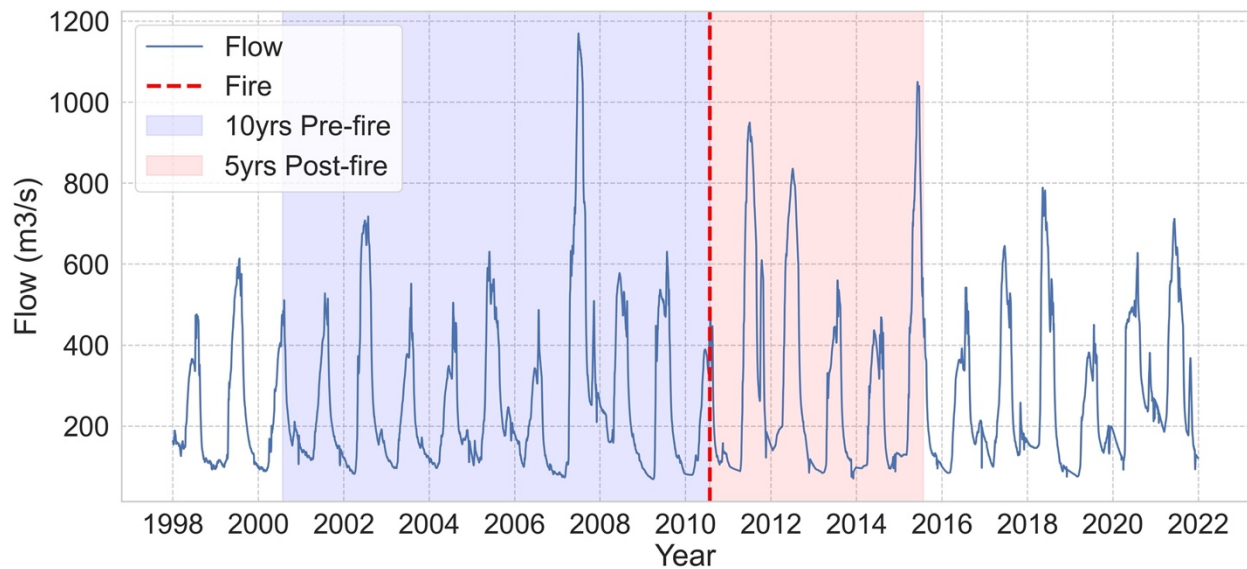


Figure 5: A sample hydrograph (flow versus time) for station 08JC002, showing a single fire in dashed red lines, and 10-years pre-fire shaded in purple and 5-years post-fire shaded in read. Here, pre-fire

metric is averaged over the 10 years, while post-fire metric is averaged over 5 years. The percent change is the percent difference between the averaged 10-yr pre-fire and the 5-yr post-fire.

Response variables had three groups: fire, control by proximity, and control by ecozone.

The response variable for the fire group is the value of that response flow of the stations in the watershed that experienced the fire, averaged per year per watershed per ecozone.

Studies analyzing post-fire hydrology have rarely included control groups in their methods, yet controls are essential for providing validity and reducing bias to the experimental results. Control groups are meant to represent the same characteristics as the experimental group (fire group), except for the variable of interest (in this case, percent burn). Inclusion of a control group helps in drawing unbiased conclusions from the results; specifically, keeping all other variables constant, the resulting changes are more likely to be credited to the percent burn (treatment). However, the choice of control groups, especially in post-fire hydrology is difficult, since it is unlikely for the burnt watershed to have a matching identical unburnt watershed. As such, two controls groups were used in this research: control by proximity, and control by ecozone. Control by proximity uses the neighboring unburnt watersheds (neighboring meaning the directly adjacent watersheds); and was found using code shown in Appendix I and Appendix III. Control by ecozone uses the unburnt watersheds from the same ecozone, as the burnt watershed, using similar code to control by proximity, with slight changes (shown in Appendix IV). The response variable for the control group by proximity is the value of the response flow of the stations in the watersheds directly adjacent to the burnt watershed. For each fire, only neighboring watersheds that did not have a fire on the same day were included. The response variable for the control group by ecozone is the value of the response flow of the stations *not* in the watershed that experienced a fire, but within the same ecozone. Similarly, the control response flow was averaged annually per station, per watershed, per ecozone.

3.3.1 Low, High, and Peak flows

Low and high flows (Figure 6) were calculated and averaged to produce a single value for each fire event, for each pre- and post-fire date range. The low flow value was taken as the average daily mean flow with a 90% exceedance. The high flow was taken as the average daily mean flow with a 10% exceedance. The peak flow was taken as the highest daily mean flow each year. For instance, for one single fire event, the following response flows were calculated:

1. Low flow for 1-, 5-, 10-yr pre-fire
2. Low flow for 1-, 2-, 5-yr post-fire
3. High flow for 1-, 5-, 10-yr pre-fire
4. High flow for 1-, 2-, 5-yr post-fire
5. Peak flow for 1-, 5-, 10-yr pre-fire
6. Peak flow for 1-, 2-, 5-yr post-fire

The control groups would have the same response flows above for each fire event but calculated for the unburnt neighboring watersheds (control by proximity) and for watersheds without the fire within the same ecozone (control by ecozone).

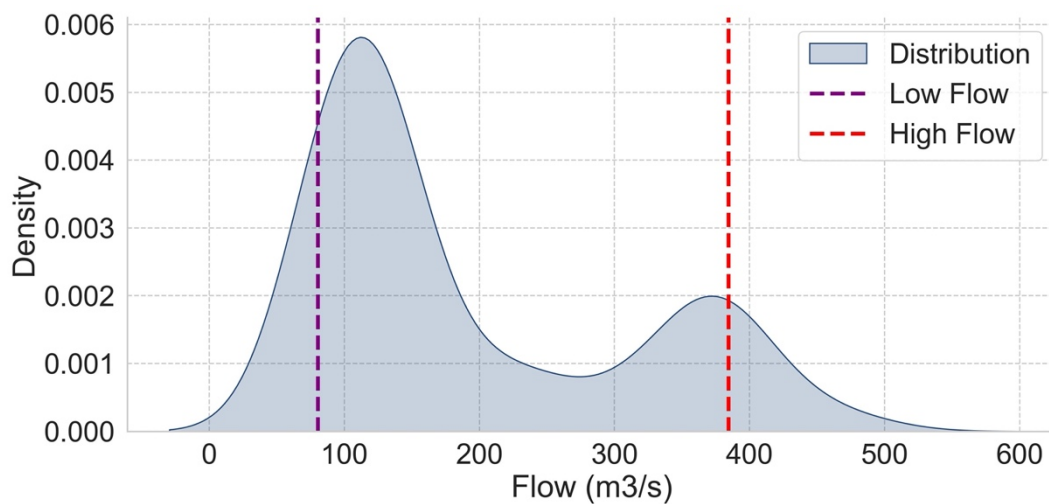


Figure 6: A sample probability density graph of flow for 1 year showing the low flow and high flow. The low flow value, shown in the dashed purple line, is the daily flow with a 90% exceedance. The high flow value, shown in the dashed red line, is the daily flow with a 10% exceedance.

3.3.2 Runoff Ratios

The runoff ratio is defined in Equation 1, where Q_{tot} is the total annual runoff depth (m^3), A_{WS} is watershed area (m^2), and P_{tot} is total annual precipitation (mm).

$$RO = \frac{Q_{tot}/A_{WS}}{P_{tot}} \quad [Eq. 1]$$

Similar to the low, high, and peak flows, runoff ratio was calculated for all the pre- and post-fire ranges for each fire event, for both fire and control groups. Including the runoff ratio allows the implicit control for the expected changing precipitation patterns.

3.4 Statistical Methods

3.4.1 Hypothesis Testing

A hypothesis is a statement about the population. However, it is rare that we have data from the whole population. Therefore, hypothesis testing is a statistical method commonly used to infer conclusions about a population using data from a sample.

Hypothesis testing is fundamental to the scientific method; yet over the last decade, experts in hydrology have repeatedly called for more hypothesis testing in their field (Pfister & Kirchner, 2017). In their paper, they saw an exponential growth of the number of papers mentioning runoff or streamflow, while papers mentioning runoff or streamflow with hypotheses (or hypoth-) remained constant over the 25-year study period.

Hypotheses are typically stated as a pair of mutually exclusive statements: a null hypothesis (H_0), and an alternative hypothesis (H_1). A hypothesis test determines which of the two hypotheses is true; since they are mutually exclusive statements, only one can be true and therefore the rejection of one can imply the support for the other.

In this case, the null hypothesis is that wildfires do not alter on the distribution of the percent change of the hydrological metrics in all the watersheds. The complementary alternative

hypothesis is that wildfires do alter the distribution of percent change of the hydrological metrics in all watersheds. The sample consists of watersheds in BC.

There are many types of hypothesis tests which can have different versions, with different statistics used as a measurement of difference. Here, the two-sample Kolmogorov-Smirnov (KS) test was performed, using the `ks_2samp` function from the SciPy stats package on python, as shown in Appendix V. The KS test is a non-parametric test, meaning it does not make assumptions about the sample distributions, making it suitable for all types of distributions. Specifically, the KS test compares the empirical cumulative distribution functions (eCDFs) of the two samples, by calculating the maximum absolute difference between the eCDFs of the two samples, giving the KS statistic. The KS statistic is then compared to the KS distribution, which depends on a parameter that uses the sample size of the data. The comparison of the KS statistic to the KS distribution provides a p-value. In this case, a 95% confidence level was chosen, therefore if the p-value is less than 0.05, the null hypothesis can be rejected.

To test the hypotheses mentioned above, the two samples that were compared in the two-sample KS test are the fire group and the control groups, for each hydrological metric. From the three options of null and alternative hypotheses available in the SciPy module (The SciPy Community, 2023), the two-sided was chosen on `ks_2samp`, with the following hypotheses definitions:

- H_0 : the two distributions are identical. ($F(x) = G(x)$)
- H_1 : the two distributions are not identical. ($F(x) \neq G(x)$)

3.4.2 Spearman Correlation

Spearman's correlation coefficient (ρ) is non-parametric method to measure the strength of monotonicity between paired data. It assumes interval/ ratio level, or ordinal data, and a

monotonic relationship between the independent and dependent variable. The relationship between the independent and dependent variable can be classified as one of the following: monotonically increasing, monotonically decreasing, or not monotonic. Monotonically increasing means that as the independent variable increases, the dependent variable never decreases. In contrast, monotonically decreasing means that as the independent variable decreases, the dependent variable never increases. Non-monotonic means that as the independent variable increases, the dependent variable increases at times, and decreases at other times.

Spearman's correlation coefficient can range from -1 to +1, with values of +1 suggesting a strong positive monotonic relationship, and values of -1 suggesting a strong negative monotonic relationship. Values of 0 suggest no monotonic relationship.

The Spearman's correlation coefficient also requires a significance test to determine which hypothesis can be rejected:

- H_0 : the paired data do not have a monotonic relationship. ($\rho = 0$)
- H_1 : the paired data do have a monotonic relationship. ($\rho \neq 0$)

If the p-values are less than 0.05, then the null hypothesis can be rejected, and suggest that the paired data have a statistically significant relationship. Spearman correlation was done on python, as shown in Appendix VI.

3.4.3 Regression Analysis

To analyze the percent changes between pre- and post-fire flows, the StatsModels package from Python was used to perform linear regression using one of the most common methods: the ordinary least squares (OLS), as shown in Appendix VII. It is a method used to estimate unknown parameters (known as dependent variables) using known parameters (known as independent variables).

Assumptions of ordinary least squares method are:

1. All independent variables are linearly independent.
2. Errors have a mean zero.
3. Errors are homoscedastic (observations have the same error variance).

Meeting the above assumptions ensure that the regression estimates are optimal, and unbiased.

The performance metric that was used is the R^2 value which represents the coefficient of determination; a higher R^2 value is associated with a better model performance. A better model performance means that the model can predict the percent change of the hydrological metric (dependent variable) using the independent variables. The typical independent variables used in the literature (which are also used here) are percent burn, watershed area, elevation, slope, aspect, total annual precipitation, and maximum temperature. The dependent variables are the percent changes between pre- and post-fire low flow, high flow, peak flow, and runoff ratio for the multiple pre- and post- date ranges. Regression analysis was done for the fire group.

Chapter 4 Results and Discussion

This chapter outlines the results for the various methods performed, followed by a discussion of each. Section 4.1 presents the calculated percent changes of the hydrological metrics per ecozone, per temporal band, and per treatment group (fire vs. controls). Section 4.2 presents the hypothesis testing results comparing the fire group to each of the two control groups. Finally, Section 4.3 presents the analysis of the hydrometeorological parameters and their effect on the hydrological metrics; results of the spearman correlation and multiple linear regression are discussed.

4.1 Hydrological Metric Variability and Analysis

4.1.1 Results

Percent changes comparing the pre-fire and post-fire values (in symmetrical log) for low, high, peak flows and runoff ratio are shown in Figure 7-10, grouped by ecozones for each temporal band. The pre-fire timeframe is represented by the bar colour: 1-yr pre-fire in blue, 5-yr pre-fire in gold and 10-yr pre-fire in green. The post-fire timeframes are represented by the boxplot column: 1-yr post-fire in the first column, 2-yr post-fire in the second column, and 5-yr post-fire in the third column. Each bar represents one temporal band: the percent change between the pre-fire timeframe and post-fire timeframe. Therefore, the blue bar in the first boxplot on the top left shows the change in flow between the first year before the fire and after the fire, and so on. The percent changes for the burnt watersheds are shown in the first row, unburnt neighbouring watersheds (control by proximity) in the second row, and unburnt watersheds in the ecozone (control by ecozone) in the third row.

Overall, there is a wide range of change in all hydrological metrics (also seen by Saxe, Hogue, & Hay (2018)), though there is a noticeable difference between the fire (top row) and

control by ecozone groups (bottom row) for all hydrological metrics. The percent changes can be positive or negative; in all hydrological metrics, the lower ranges are negative values (meaning a decrease in flow). Fairly similar trends are observed for low, high, and peak flows; differences in runoff ratio percent changes are harder to distinguish. Overall, the highest extreme flow changes (represented by the outliers) are seen in the burnt watersheds, with the exception of ecozone 4, which show the highest change in low, high, and peak flows in the neighboring unburnt watersheds. The outliers for the control by ecozone group rarely reach over 500% change in low, high, and peak flows. Generally, the control by ecozone groups have smaller ranges compared to the fire & control by proximity groups (further discussed in Section 4.1.2). Compared to the three hydrological metrics, runoff ratio fire group has the widest ranges, particularly for ecozone 9 (reasons for which are described in Section 4.1.2).

Saxe, Hogue, & Hay (2018) and other studies have found streamflow response to be the greatest in the first year following a fire, which is not the case in the burnt watersheds studied here, even when using the same pre-fire timeframe that Saxe, Hogue & Hay used (10 yrs). While post-fire changes increase overall over the five years after a fire, the greatest changes are seen two years after a fire (seen in all pre-fire timeframes). Specifically, there is an average maximum increase of 300% in all hydrological metrics in the first year, which increases up to 588% in the second year and then slightly decreases in the fifth year. The specific observations for each hydrological metric are described in the following paragraphs.

Looking at low flow in Figure 7, both control groups for ecozone 4 have higher outliers compared to its fire group; the fire group barely show any extreme changes. Ecozones 9 and 12 remain fairly consistent across all temporal bands. For ecozones 13, the highest percent change is

seen in the fire group, though its neighboring unburnt watersheds also show extreme changes of similar magnitude.

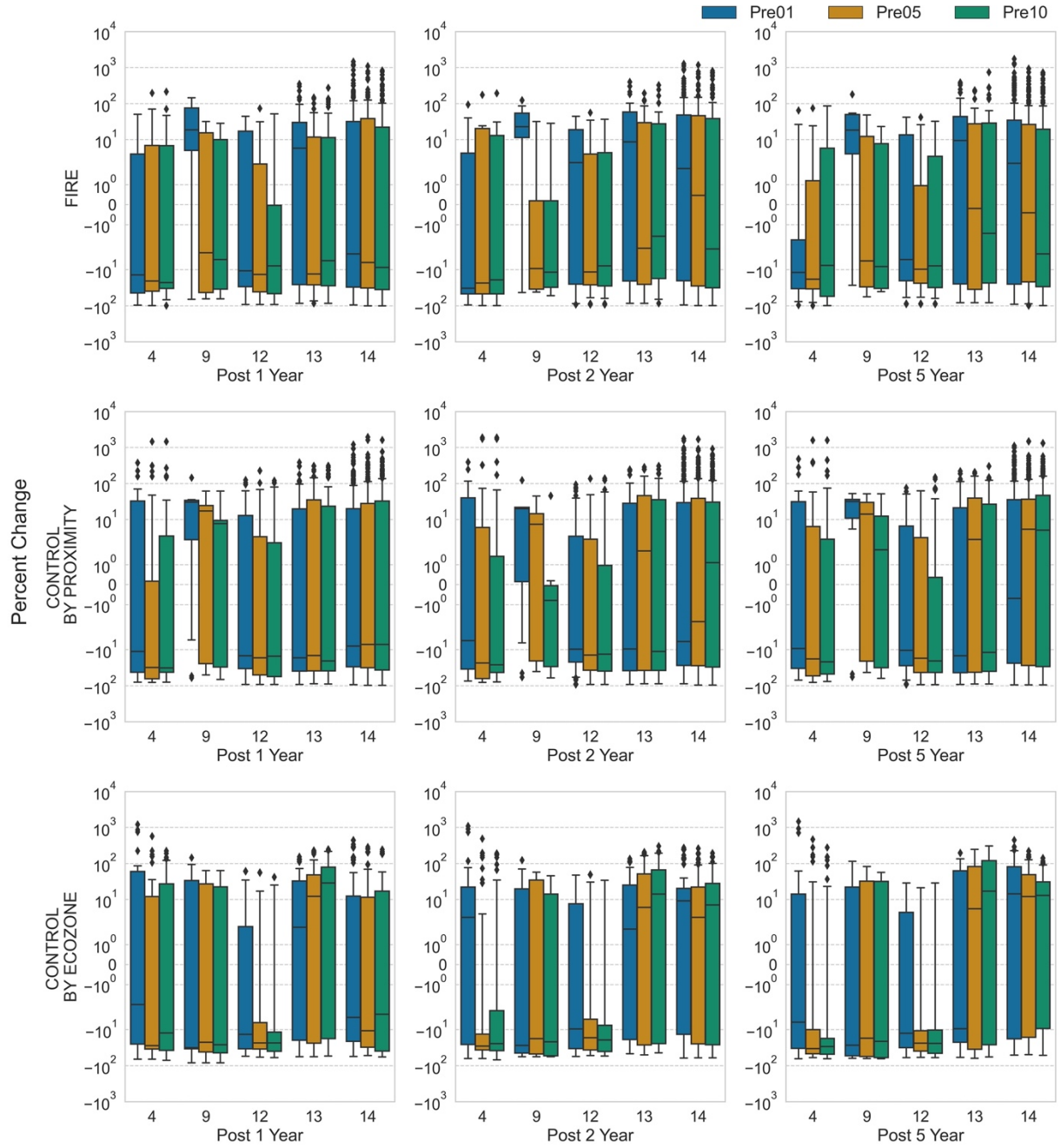


Figure 7: Boxplot of the percent changes in low flow (in symmetrical log scale) grouped by the three pre-fire time ranges and by ecozones; burnt watersheds on the top row, control on the bottom; 1-yr pre-fire shown in green, 5-yr pre-fire shown in yellow, and 10-yr pre-fire shown in purple. First column compares pre-fire to 1-yr post-fire; second column compares to 2-yr post-fire, and third column compares to 5-yr post-fire.

For ecozone 14, the highest percent change is in the unburnt neighboring watersheds (with the exception of the 5th year after the fire, where the highest percent change is seen in the burnt watershed). Unburnt watersheds in the whole ecozone show the lowest percent changes compared to the two groups, except in ecozone 4 (where the lowest is in the fire group). The low flow trends seen for each ecozone are consistent for each post-fire timeframes.

The magnitude of percent change for high flow, as shown in Figure 8, are similar to low flow percent changes. As in low flow, the highest percent change in ecozone 4 is seen in its neighboring unburnt watersheds and in the unburnt watersheds in the same ecozone. Again, ecozone 9 remains consistently in all groups, though a few outliers are seen in the unburnt watersheds in the same ecozone. For ecozone 12, the burnt and neighboring unburnt watersheds show similar percent changes, with extreme high flow changes reaching over 500%. Unburnt watersheds in the ecozone 12 have the least percent change. Burnt watersheds in ecozone 13 have the highest high flow percent change, decreasing in its unburnt neighboring watersheds, and decreasing further in the unburnt watersheds in the same ecozone. Similarly, for ecozone 14, the burnt watersheds show the highest percent change in high flow, decreasing in its unburnt neighboring watersheds, and further decreasing in the unburnt watersheds in the same ecozone. The high flow percent change trends in the burnt watersheds remain consistent for the five years post-fire. In the unburnt neighboring watersheds, the percent changes for ecozone 4 decreases over the five years, while the opposite is true for ecozone 14.

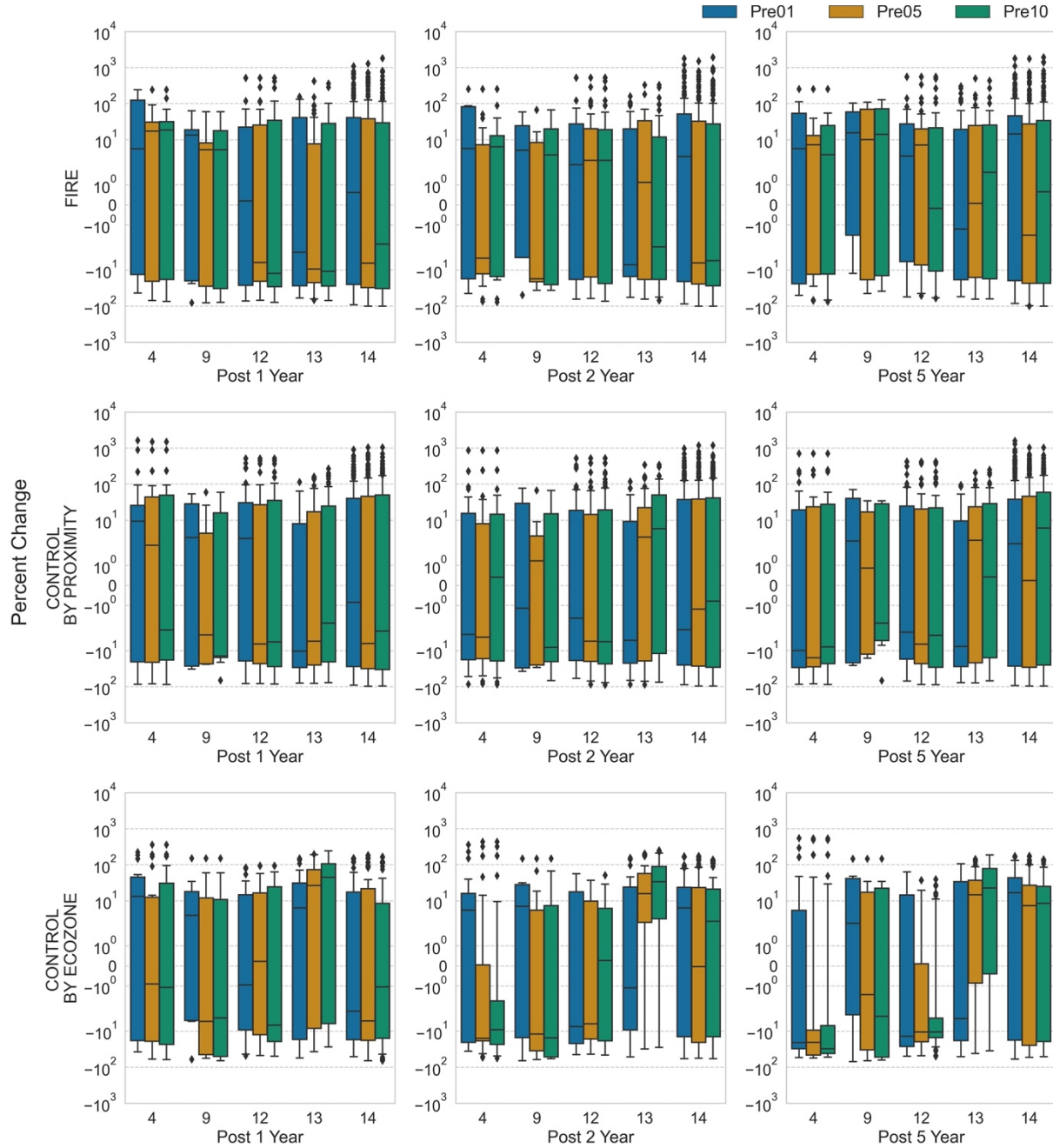


Figure 8: Boxplot of the percent changes in high flow (in symmetrical log scale) grouped by the three pre-fire time ranges and by ecozones; burnt watersheds on the top row, control on the bottom; 1-yr pre-fire shown in green, 5-yr pre-fire shown in yellow, and 10-yr pre-fire shown in purple. First column compares pre-fire to 1-yr post-fire; second column compares to 2-yr post-fire, and third column compares to 5-yr post-fire.

Peak flow percent changes are shown in Figure 9. The highest peak flow changes are seen in both burnt watersheds and unburnt neighboring watersheds. In the burnt watersheds, the 1-yr pre-fire show the widest range of percent changes, particularly in ecozone 4.

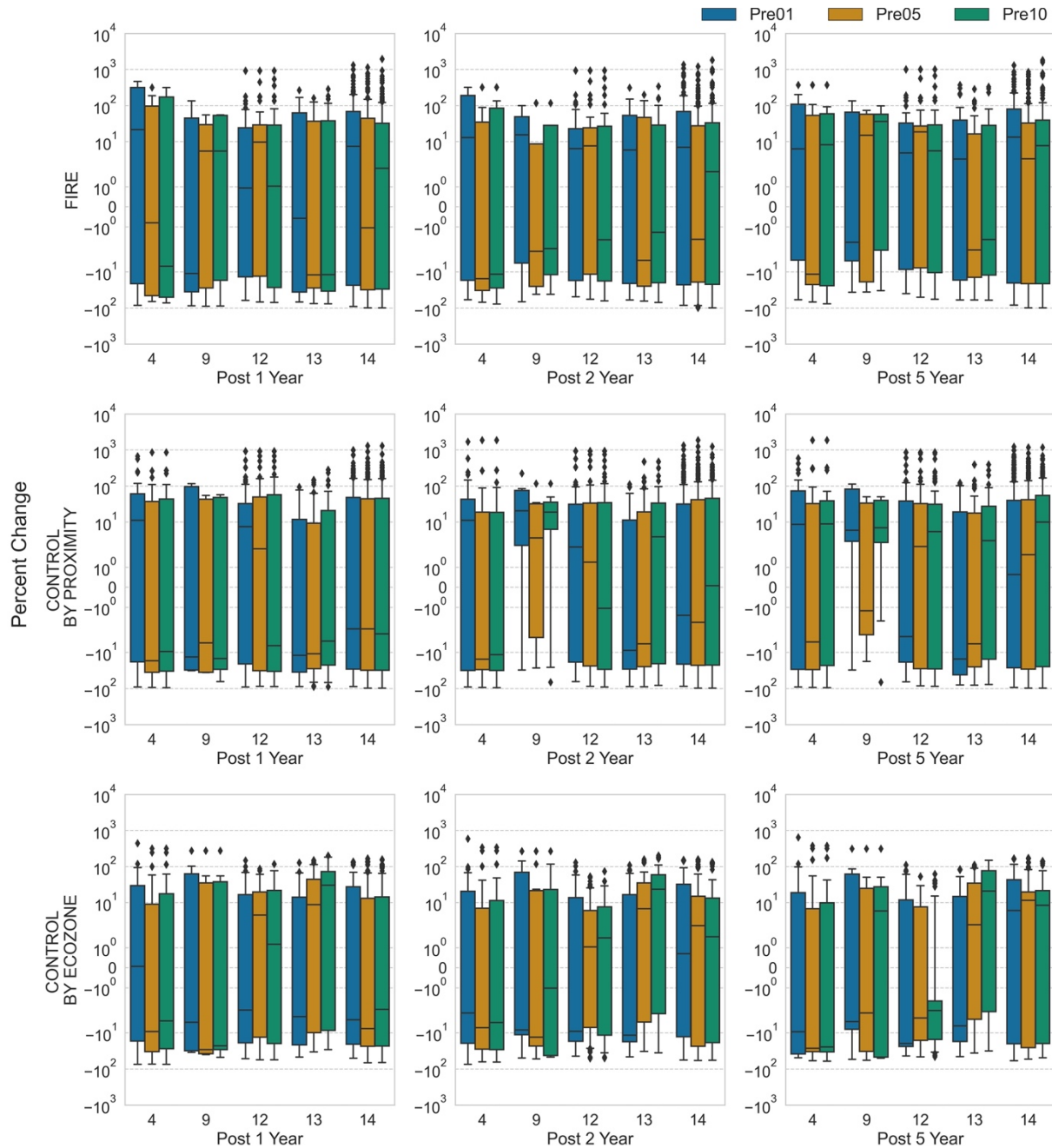


Figure 9: Boxplot of the percent changes in peak flow (in symmetrical log scale) grouped by the three pre-fire time ranges and by ecozones; burnt watersheds on the top row, control on the bottom; 1-yr pre-fire shown in green, 5-yr pre-fire shown in yellow, and 10-yr pre-fire shown in purple. First column compares pre-fire to 1-yr post-fire; second column compares to 2-yr post-fire, and third column compares to 5-yr post-fire.

The unburnt neighboring watersheds in ecozone 4 show the highest extreme change compared to the burnt and unburnt watersheds in ecozone 4. In the neighboring unburnt watersheds of ecozone 4, the percent changes increase over the five years post-fire. Similar to

low flow and high flow, ecozone 9 percent changes in peak flow remain consistently in all groups, though a few outliers are seen in the unburnt watersheds in the same ecozone. For ecozone 12, the burnt and neighboring unburnt watersheds show similar percent changes, with extreme peak flow changes reaching over 1000% (double the high flow percent change). Unburnt watersheds in the ecozone 12 have the lowest post-fire percent change. Burnt watersheds in ecozone 13 have the highest peak flow percent change, decreasing in its unburnt neighboring watersheds, and decreasing further in the unburnt watersheds in the same ecozone (just as in high flow). Similarly, for ecozone 14, the burnt watersheds show the highest percent change in peak flow, decreasing in its unburnt neighboring watersheds, and further decreasing in the unburnt watersheds in the same ecozone. The peak flow percent change trends in the burnt watersheds remain consistent for the five years post-fire. In the unburnt neighboring watersheds, the percent changes for ecozone 4 increases over the five years, while for ecozone 14, percent changes increase on the second year and reduces back to first year levels in the fifth year.

Runoff ratio percent changes in Figure 10 are also highly variable. For ecozone 4, the outliers are mostly seen in the unburnt watersheds in the ecozone. A similar pattern is seen in ecozone 9, though there are wider ranges of percent change in the burnt watersheds, particularly in the 5-yr and 10-yr pre-fire timeframes. For ecozone 12, the highest runoff ratio percent change is seen in the unburnt neighboring watersheds. For ecozone 13, the burnt watersheds show higher runoff ratio percent change in the second year post-fire reaching over 1000%, which is reduced in the fifth year post-fire. In ecozone 14, the neighboring unburnt watersheds have the highest runoff percent change compared to the burnt and unburnt watersheds in the ecozone. High runoff ratio percent changes are distributed in all three groups.

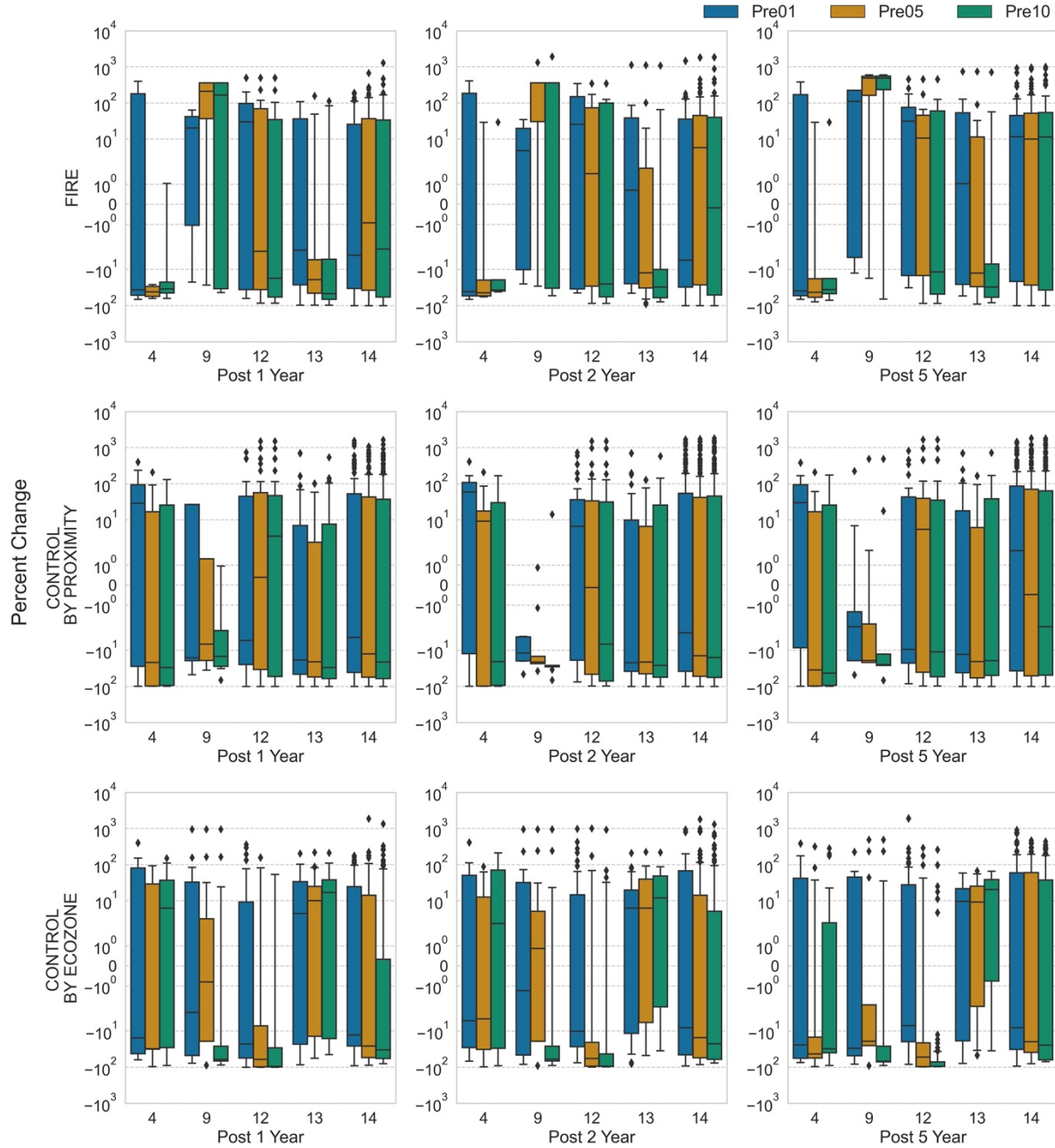


Figure 10: Boxplot of the percent changes in runoff ratio (in symmetrical log scale) grouped by the three pre-fire time ranges and by ecozones; burnt watersheds on the top row, control on the bottom; 1-yr pre-fire shown in green, 5-yr pre-fire shown in yellow, and 10-yr pre-fire shown in purple. First column compares pre-fire to 1-yr post-fire; second column compares to 2-yrs post-fire, and third column compares to 5-yr post-fire.

4.1.2 Discussion

This section describes the effect on the percent changes from: the ecozone, fire management centre, sample size, and the temporal band.

4.1.2.1 Ecozone and Fire Management Centre

By examining percent changes by ecozone, the expectation is that more accurate trends can be identified, compared to examining the provincial dataset as a whole. Overall, flow percent changes are highly variable throughout each ecozone. The wider ranges seen in larger ecozones can be easily attributed to the varying topographies within the ecozone, particularly ecozone 13 and 14. Likewise, the tighter ranges seen in the smaller ecozones, can be attributed to lower variability in topography, as well as the smaller dataset (described in the next section).

Additionally, though the province of BC can be grouped into five ecozones, the province is also managed by six different fire centres (which cross multiple ecozones), introducing an additional dimension that may affect post-fire hydrology. The six fire centres (Northwest, Prince George, Cariboo, Kamloops, Southeast and Coastal) are responsible for managing their area in relation to wildfire prevention and response. Just as the five BC ecozones are further divided into smaller ecoregions, the BC fire centres are further divided into fire zones. Effect of post-fire land management have been shown to create significant differences in the long-term recovery of catchments after a fire (Niemeyer, Bladon, & Woodsmith, 2020). In that study, post-fire management differences focused on salvage logging, aerial seeding, and fertilization. In the different BC fire centres, strategies vary from several types of wildfire suppression and rehabilitation, such as control lines, planned ignitions, fire retardants, and foam, contributing to different forest recovery patterns.

A summary of the ecozones and corresponding fire management centres are summarized in Table 1. The Prince George fire centre completely covers ecozones 4 and 9, and parts of ecozones 12, and 14, making it the largest fire centre of the province. The large, forested area contains sub-alpine fire, and interior cedar-hemlock.

Table 1: Summary of ecozones

Ecozone	Description	Fire Management Centres
4	Taiga Plains is one of smaller BC ecozones, dominated by lowlands and plateaus, and some river valleys as deep as 100 metres.	Prince George
9	Boreal Plains is the smallest BC ecozone, covered with fire-adapted plants resulting in forest patches at different stages of fire recovery. This ecozone also has higher agricultural use.	Prince George
12	Boreal Cordillera is the third largest BC ecozone, dominated by mountains, plateaus, and valleys. There are also permanent ice and snow fields.	Prince George, Northwest
13	Pacific Maritime is the warmest and wettest ecozone in Canada, dominated by mountains, fjords, glacial valleys with old forests and steep slopes. It is the most populated area in BC with six distinct microclimates.	Coastal
14	Montaine Cordillera covers the majority of the province, is fire-dominated and extremely diverse with mountain ranges, interior plains, and a desert.	Caribou, Kamloops, Southeast, Prince George, and Northwest

Ecozone 4 (Taiga Plains) contains 11 BC watersheds. The low, high, and peak flow patterns in both control groups are similar, which is expected since the ecozones included in both control groups could be the same watersheds. The higher percent changes in both control groups compared to the burnt watershed could suggest that the wildfire may provide a stabilizing effect on all four hydrological metrics.

Ecozone 9 is the Boreal Plains and contains 6 BC watersheds, making it the smallest BC ecozone. Though fires are common, the plants are fire-adapted and have resulted in forest patches at different stages of fire recovery (Natural Resources Canada, 2022). There is also a higher percentage of agricultural land use compared to the other ecozones which could explain the consistent percent changes for low, high, and peak flows seen in all groups for 5 years post-fire, with few outliers in unburnt watersheds in the same ecozone.

Ecozone 12 is the Boreal Cordillera and is the third largest ecozone in BC, dominated by mountains, plateaus, and valleys with forests consisting of pine, spruce, balsam, hemlock, and red cedar. There are also permanent ice & snow fields in the western part of the ecozone. It is managed by the Northwest fire centre and has had steady presence of fires that has increased in the last decade that is of the same magnitude as those in the 1950s (Figure 4). The low flow percent changes remain consistent in all burnt and unburnt watersheds throughout five year post-fire. The extreme high and peak flow changes were in burnt and unburnt neighboring watersheds (unburnt watersheds in the ecozone have lower changes). For runoff, extreme changes are seen in unburnt neighboring watersheds. Fires with the greatest percent burn took place in ecozone 12, which could account for the post-fire changes that are seen in both burnt and unburnt watersheds.

Ecozone 13 (Pacific Maritime) is the warmest & wettest ecozone in Canada, bordering the western edge of the province (and country). This ecozone is managed by the Coastal fire centre. Dominated by mountains, fjords, and glacial valleys, with old forests and steep slopes, it is also the most populated area in the province. There are long intervals between fires (low number of fires between 1970 to 2019 but increase this past decade) (see Figure 2). The six distinct microclimates in this region means significantly different fuel types (vegetation) and fire danger ratings, contributing to the highly variable post-fire changes seen in the previous section.

Ecozone 14 (Montane Cordillera) covers the majority of the province. It is extremely diverse containing mountain ranges, interior plains, and Canada's only desert (Natural Resources Canada, 2022). There are more than 11, 000 lakes (including the Fraser & Columbia rivers). It is a fire-dominated ecosystem (Figure 4), home to the Caribou, Kamloops, and Southeast fire centres, and some parts of the Prince George and Northwest fire centres. Unsurprisingly, this ecozone has the most varied patterns in low, high, and peak flow changes. Overall, it also has

highest low, high, and peak flow changes in the burnt watersheds, which extends to its unburnt neighboring watersheds. The runoff ratio percent changes are highest in the unburnt neighboring watersheds, followed by the burnt watersheds. The highly variable results in this ecozone can be attributed to its large area that contains a diverse topography, as well as the multiple fire centres within the ecozone.

The Cariboo fire centre has two climatic belts known as the western dry belt, and the eastern wet belt. In the west are thin grassy meadows, sagebrush, and coniferous trees. In the east are forests with cedar, hemlock, spruce, and balsam trees. Directly south of the Cariboo fire centre is the Kamloops fire centre, containing glaciers, plains, canyons, rainforests, and the desert mentioned above. Vegetation in this fire centre include spruce, balsam, sagebrush, Douglas fir, and ponderosa and jack pine. Finally, east of the Kamloops fire centre is the Southeast fire centre, which again, is diverse ranging from wet northern climate to dry southwestern climate. Vegetation in this fire centre includes Douglas fir, larch, pine, spruce, cottonwood, aspen, red cedar, and birch. The immense diversity of the vegetation in ecozone 14 contributes significant impacts to the post-fire changes in hydrological metrics in many ways, that include (but are not limited to) the vegetation recovery post-fire. The recovery rates of different North American vegetation types have been studied, with conifer-oak-chaparral types with the highest recovery rates, followed by mixed conifers, and tailed by ponderosa pine with the longest recovery rates (Bright, Hudak, Kennedy, Braaten, & Khalyani, 2019). These three vegetation types are all found in ecozone 14, along with many other vegetation types. The wide ranging of percent changes seen in this ecozone are expected, considering the extensive diversity of forest ecosystems present. Therefore, analysis of the percent changes per ecoregion (as

opposed to the larger ecozone) could provide further insight (recommendations are discussed in Chapter 5).

4.1.2.2 *Sample Size*

The size of the sample dataset affects how dispersed the data is in relation to the mean (also known as the standard deviation). Recall that the dataset of the hydrological metrics used here are taken as the sample from the population. Though the mean of the sample and the population are the same, the standard deviation of the sample depends on the sample size. As the sample size increases, the standard deviation decreases. In other words, the bigger the dataset, the less dispersed the data is in relation to the mean.

This effect is clearly seen in the calculated percent changes of high flow, peak flow and runoff ratio in Figure 10, particularly for ecozones 4 and 9, which were calculated from the lowest number of data points compared to the other ecozones. For all the 1-yr post-fire high flow changes, ecozones 4 and 9 were calculated from 17 and 11 data points, respectively, while ecozones 12, 13, and 14 were calculated from 77, 54, and 352 points, respectively. The lower data points in ecozones 4 and 9 contribute to the wider range of values compared to the other 3 ecozones. The lower number of data points are due to the lower area they occupy in the province, resulting in a lower number of watersheds, and consequently, lower number of flow gauge stations. This consequence is magnified in the runoff ratio (Figure 10) for ecozones 4 and 9 (where 2 and 5 data points are used, respectively), where the range of percent changes span nearly 400%, for all five years post-fire. The lower data points seen in low, high and peak flows are magnified in runoff ratio since runoff ratio is calculated from multiple variables, which were lacking in many stations: the total runoff depth per watershed area, and the total annual precipitation. Though the raw precipitation data included all stations in BC, making quite a large

dataset, precipitation data in the years following after a fire were missing for many of the fire dates included in the study. Indeed, the lack of precipitation data after the fire may be related to the fire's impact on the weather monitoring stations.

Furthermore, though there is a noticeable difference between the burnt watersheds and the unburnt watersheds in the ecozone (control by ecozone group), it may arise from the difference in sample sizes, resulting in the tighter ranges found in the control group. This effect is less pronounced in the control by proximity group (unburnt neighbouring watersheds), since this would include only the adjacent watersheds (2-5 watersheds at most).

Appendix VIII shows exact values of the sample size, minimum, maximum and mean for each temporal band, for the fire and control groups.

Though the sample size can affect the post-fire changes observed, hypothesis testing like the two-sample Kolmogorov-Smirnov test helps to distinguish between two sample distributions, while also accounting for the sample size; results are discussed in Section 4.2.

4.1.2.3 Pre-Fire Temporal Band

The boxplots of the percent changes shown in Figure 7– 10 show that different pre-fire timeframes over which pre-fire values are averaged change the percent change parameters (minimum, mean, and maximum) in all hydrological metrics. This effect is more pronounced in the smaller ecozones (4 and 9) with smaller datasets, where using a 1-yr pre-fire average resulted in a mean increase in low flow in burnt watersheds, versus using a 5-yr pre-fire resulted in a mean decrease in low flow.

The change in direction of effect (increase vs. decrease) was more often seen in low flow and high flow percent changes. This effect was not observed for peak flow, and runoff ratio percent changes. Though the parameters did still change from using different pre-fire

timeframes, the change was nearly always an increase (in some cases, there was an 80% increase in the mean runoff ratio percent change). With bigger datasets, as in ecozones 12, 13, and 14, the effect of the different pre-fire timeframes was less pronounced, though still significant (in some cases, a 20% difference); and this is to be expected since a larger sample size creates more variability, which in turn leads to less pronounced effects.

4.2 Hypothesis Testing Results

The following sections discuss the results of the two-sample Kolmogorov-Smirnov tests comparing the percent changes (plotted in Figure 11- 18) of the fire group to the control by proximity group, and the fire group to the control by ecozone group, followed by discussion. Hypothesis testing highlights distribution differences that are not easily discernible from the boxplots of the raw data of percent changes. Recall that the null hypothesis is that the two sample distributions are identical, meaning that there is not a statistical difference between the two distributions. The alternative hypothesis is that the two sample distributions are not identical, meaning there is a statistical difference between the two distributions. P-values can range between 0 to 1, and values less than 0.05 rejects the null hypothesis, meaning the fire and control group are *not* from identical distributions. In other words, p-values less than 0.05 support the alternative hypothesis that the two groups have a statistically significant difference.

4.2.1 Hypothesis Testing by Proximity

Hypothesis tests between the fire group and the control by proximity group show highly variable results for all hydrological metrics in all ecozones (Figure 11 – 14). Control temporal bands (including pre-fire ranges) are shown on the y-axis, and fire temporal bands shown on the x-axis. Temporal bands that show significant differences between burnt and unburnt watersheds are shown in dark blue, and those without a significant difference are shown in white. For

instance, the top right box shows the hypothesis test results comparing the 1-yr post of the control to the 5-yr post-fire, using the 1-yr pre-fire value. For that temporal band, there is a statistically significant difference between the burnt and unburnt neighboring watershed.

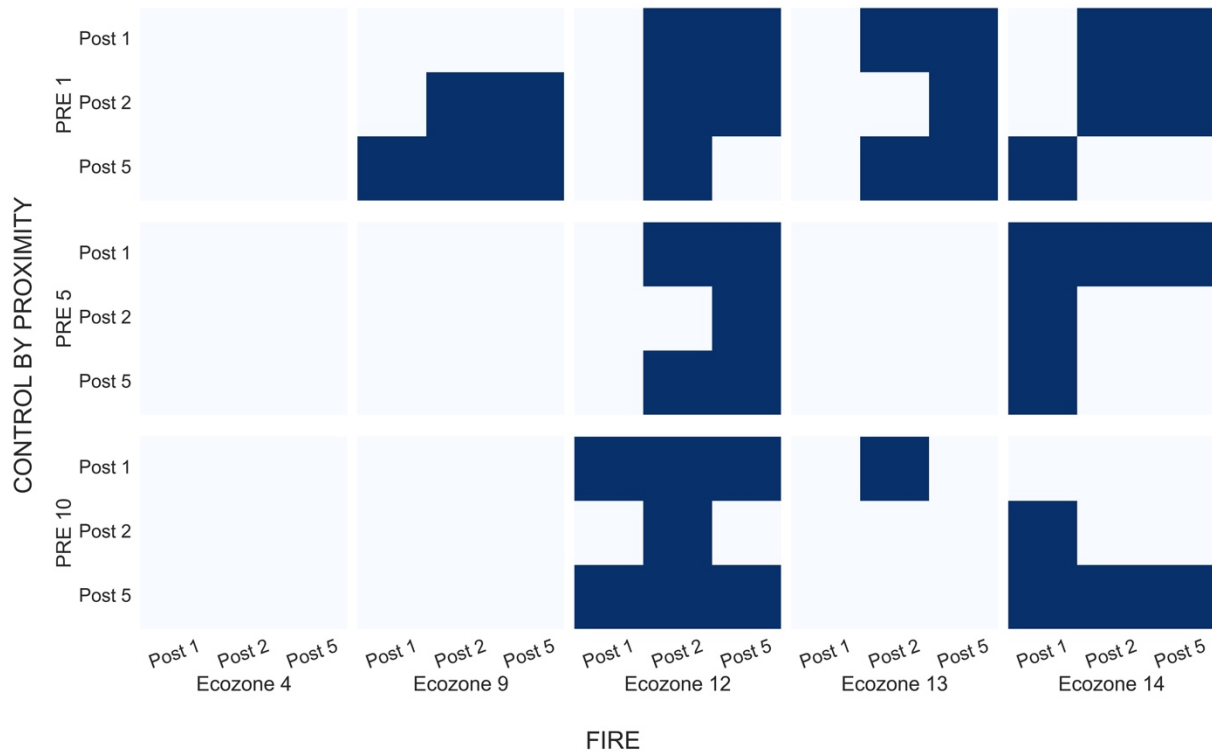


Figure 11: A heatmap of the results of the Kolmogorov-Smirnov hypothesis test for low flow, comparing the percent changes in burnt watersheds (fire) to the unburnt watersheds (control). Dark blue boxes support the alternative hypothesis: that the fire and control groups are not identical.

For all hydrological metrics in ecozones 4 and 9, most temporal bands resulted in p-values significantly greater than 0.05 for the majority of the temporal bands, suggesting that the percent changes in the burnt and unburnt neighboring watersheds have the same distribution. Ecozones 4 and 9 dominated the most p-values greater than 0.05, suggesting that there isn't a statistical difference between the distribution of hydrological metrics in the burnt and unburnt

watersheds. This observation was also seen in the previous figures (7-10) and sections discussing the boxplot of raw percent changes data.

The results for ecozones 12, 13, and 14 vary for each hydrological metric. Overall, the low flow percent changes for ecozones 12, 13, and 14 had p-values of less than 0.05 (meaning burnt & unburnt watersheds have a statistical difference), with a few exceptions. Therefore, in these larger ecozones, the low flow percent changes of the burnt and unburnt neighboring watersheds most likely come from a different distribution.

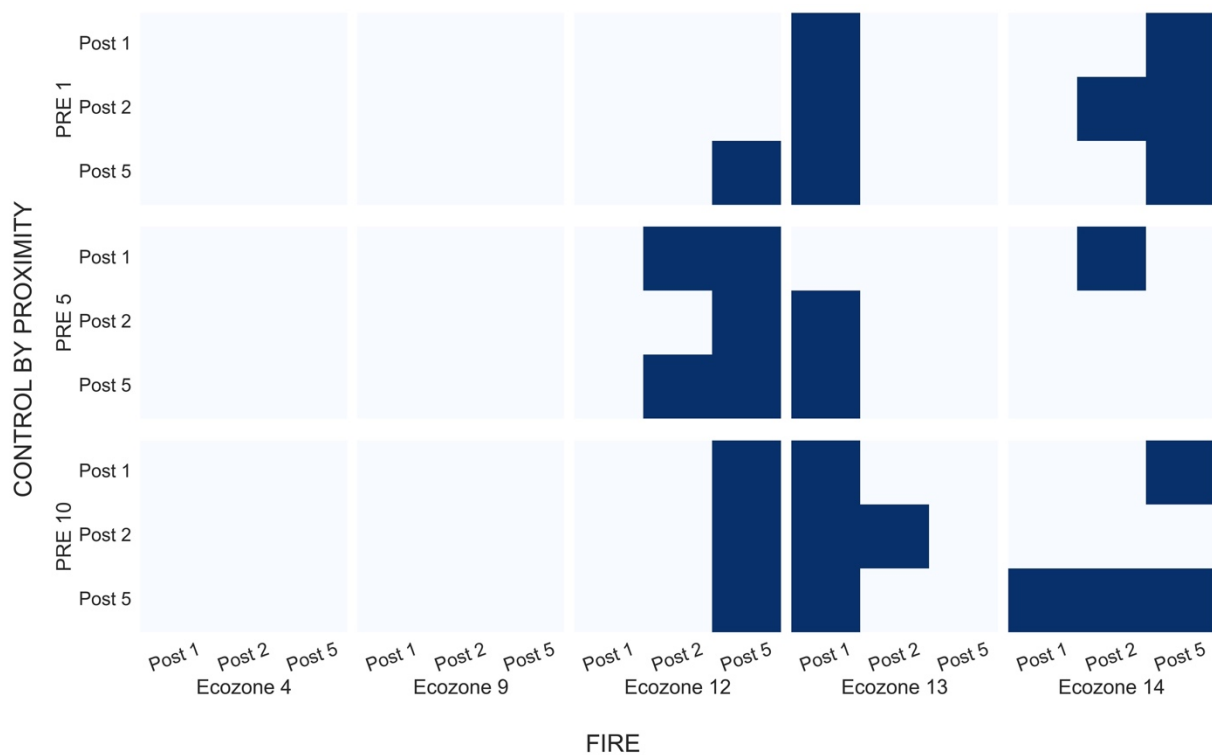


Figure 12: A heatmap of the results of the Kolmogorov-Smirnov hypothesis test for high flow, comparing the percent changes in burnt watersheds (fire) to the unburnt watersheds (control). Dark blue boxes support the alternative hypothesis: that the fire and control groups are not identical.

For high flow percent changes (Figure 12), all temporal bands for ecozones 4 and 9 did not show a statistically significant difference. For these smaller ecozones, there is not a significant difference between the burnt and neighboring unburnt watersheds. For the larger

ecozones, 12, 13, and 14, there are more variability, with some temporal bands showing significant difference, and others not.

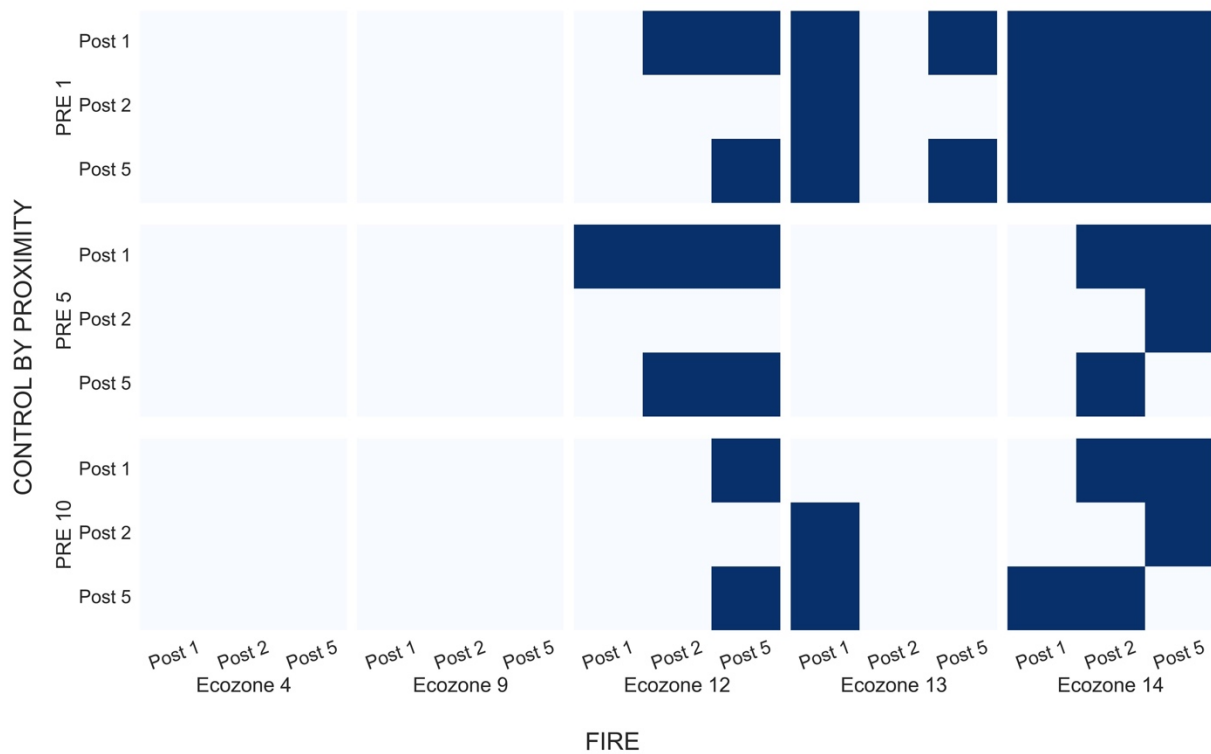


Figure 13: A heatmap of the results of the Kolmogorov-Smirnov hypothesis test for peak flow, comparing the percent changes in burnt watersheds (fire) to the unburnt watersheds (control). Dark blue boxes support the alternative hypothesis: that the fire and control groups are not identical.

Trends in peak flow (Figure 13) hypothesis testing were similar to the trends described for high flow percent changes. All temporal bands using 1-yr pre-fire for ecozone 14 showed consistent statistically significant differences. Runoff ratio (Figure 14) hypothesis testing resulted in variable results, as well. Runoff ratio for ecozones 4 and 12 showed no statistically significant difference between burnt and unburnt neighboring watersheds for all temporal bands.

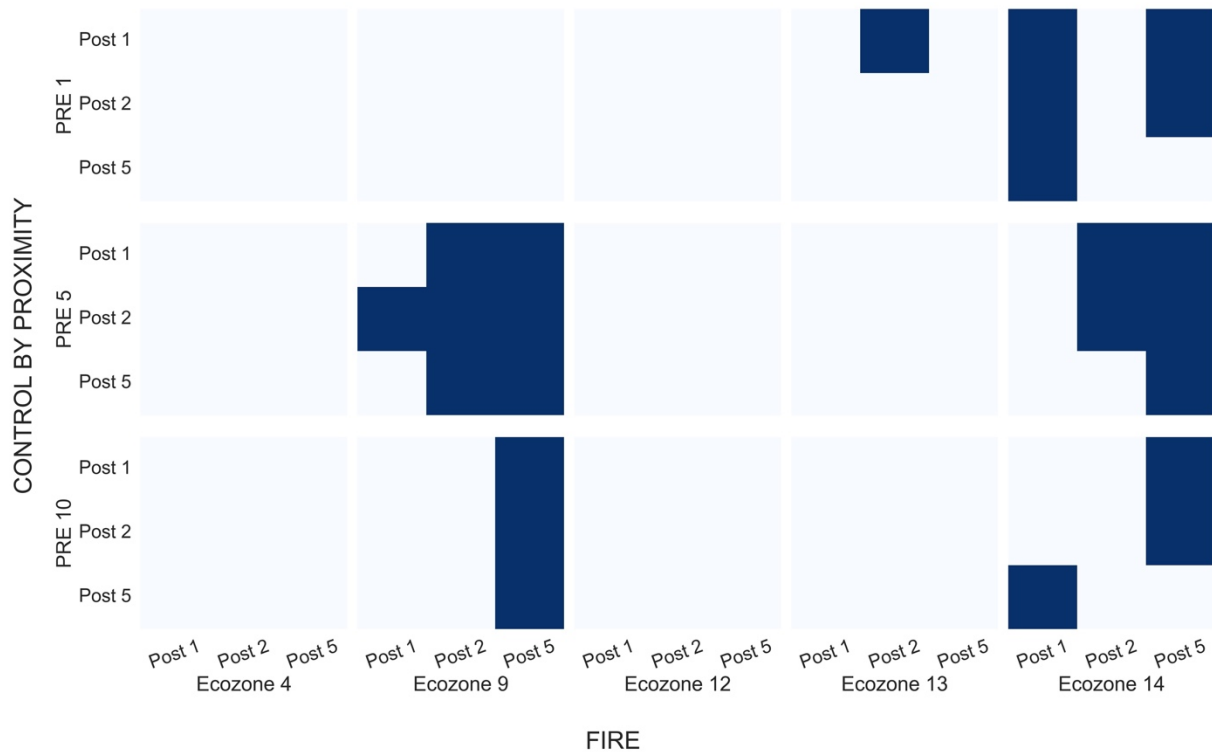


Figure 14: A heatmap of the results of the Kolmogorov-Smirnov hypothesis test for runoff ratio, comparing the percent changes in burnt watersheds (fire) to the unburnt watersheds (control). Dark blue boxes support the alternative hypothesis: that the fire and control groups are not identical.

4.2.2 Hypothesis Testing by Ecozone

Hypothesis tests between the fire group and the control by ecozone group show p-values that reject the null hypothesis for nearly all temporal bands in the larger ecozones 12, 13, and 14 (Figure 15 - 18), suggesting that the burnt watersheds are statistically different from the unburnt watersheds in the same ecozone. P-values that show support for the null hypothesis (shown in white boxes) in these 3 ecozones mostly belong to the temporal bands that use only 1 year of pre-fire averaging, suggesting that there is no statistical difference between the fire and control group. In other words, when compared to the previous year before the fire, post-fire fire changes are minimal throughout the five years after the fire, for larger ecozones (12, 13, and 14). Generally, the greater number of years used to average pre-fire values, the lower the number of p-values less than 0.05 (and therefore the bigger the difference between the two sample groups).

Within each pre-fire time range, the lower p-values are seen when pre-fire values are compared to 5 years and 10 years post-fire (shown in dark blue). Therefore, the hypothesis testing suggests that, for at least ecozones 12, 13, and 14, there is a statistically significant difference between burnt and unburnt watersheds in the same ecozone.

In ecozones 4 and 9, the hypothesis tests between the control by ecozone and fire groups resulted mostly in p-values of greater than 0.05 (in white), suggesting the null hypothesis cannot be rejected and that there is no statistically significant difference between the burnt and unburnt watersheds. In these two ecozones, the burnt and unburnt watersheds in the ecozone often come from the same distribution, which is the same observation found in the previous section comparing unburnt neighboring watersheds.

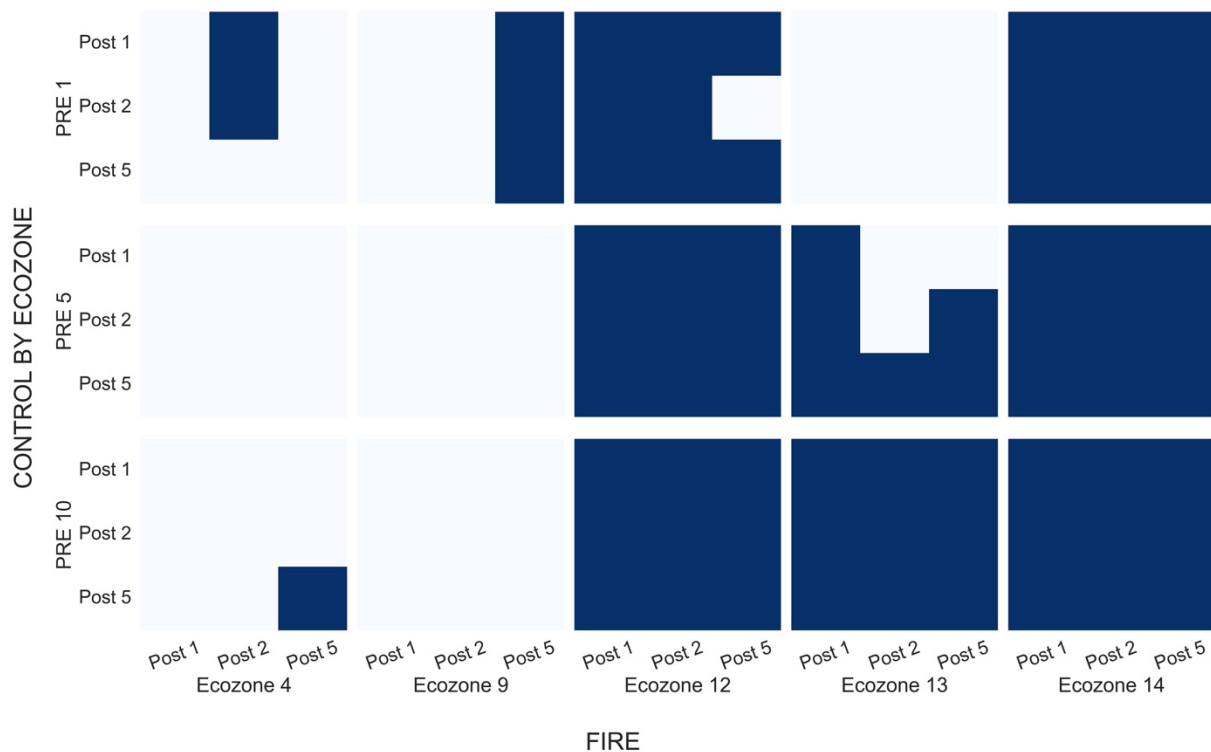


Figure 15: A heatmap of the results of the Kolmogorov-Smirnov hypothesis test for low flow, comparing the percent changes in burnt watersheds (fire) to the unburnt watersheds (control). Dark blue boxes support the alternative hypothesis: that the fire and control groups are not identical.

Ecozones 4 and 9 were dominated by All temporal bands for low flow in 14 all resulted in p-values of less than 0.05 (dark blue), suggesting significant differences between burnt and unburnt watersheds in the same ecozone. A similar pattern is seen for ecozone 12, where only one temporal band showed no statistically significant difference, while the rest are shown in dark blue. For ecozone 13, 1-yr pre-fire timeframes resulted in p-values greater than 0.05 (suggesting no statistical difference), while the rest had less than 0.05 (dark blue).

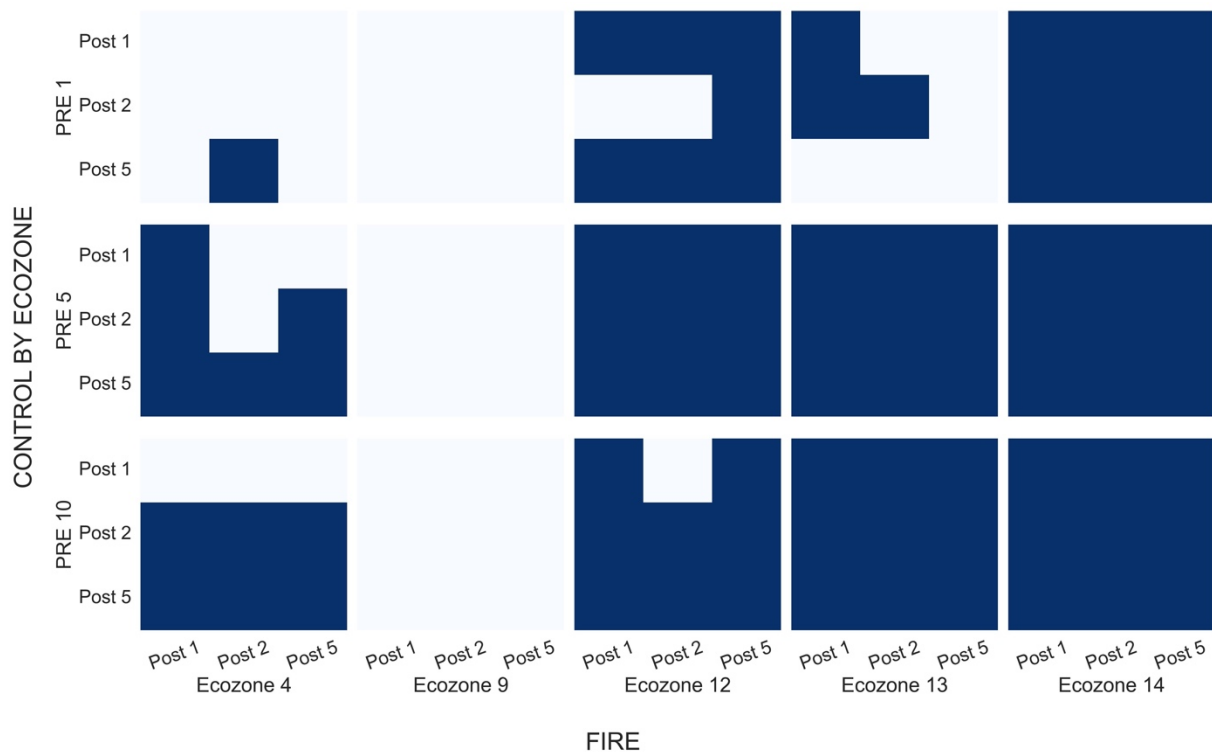


Figure 16: A heatmap of the results of the Kolmogorov-Smirnov hypothesis test for high flow, comparing the percent changes in burnt watersheds (fire) to the unburnt watersheds (control). Dark blue boxes support the alternative hypothesis: that the fire and control groups are not identical.

Similar to low flow, the high flow percent changes for ecozone 14 (Figure 16) show statistically significant differences for all temporal bands between burnt and unburnt watersheds in the same ecozone. The majority of the temporal bands for ecozones 12 and 13 also statistically significant differences, with a few exceptions. The opposite is seen for ecozone 9, where all

temporal bands resulted in p-values greater than 0.05, suggesting that the burnt and unburnt watersheds in the ecozone come from the same distribution (and therefore, no statistically significant difference). The trends seen in high flow are similarly seen in peak flow (Figure 17).

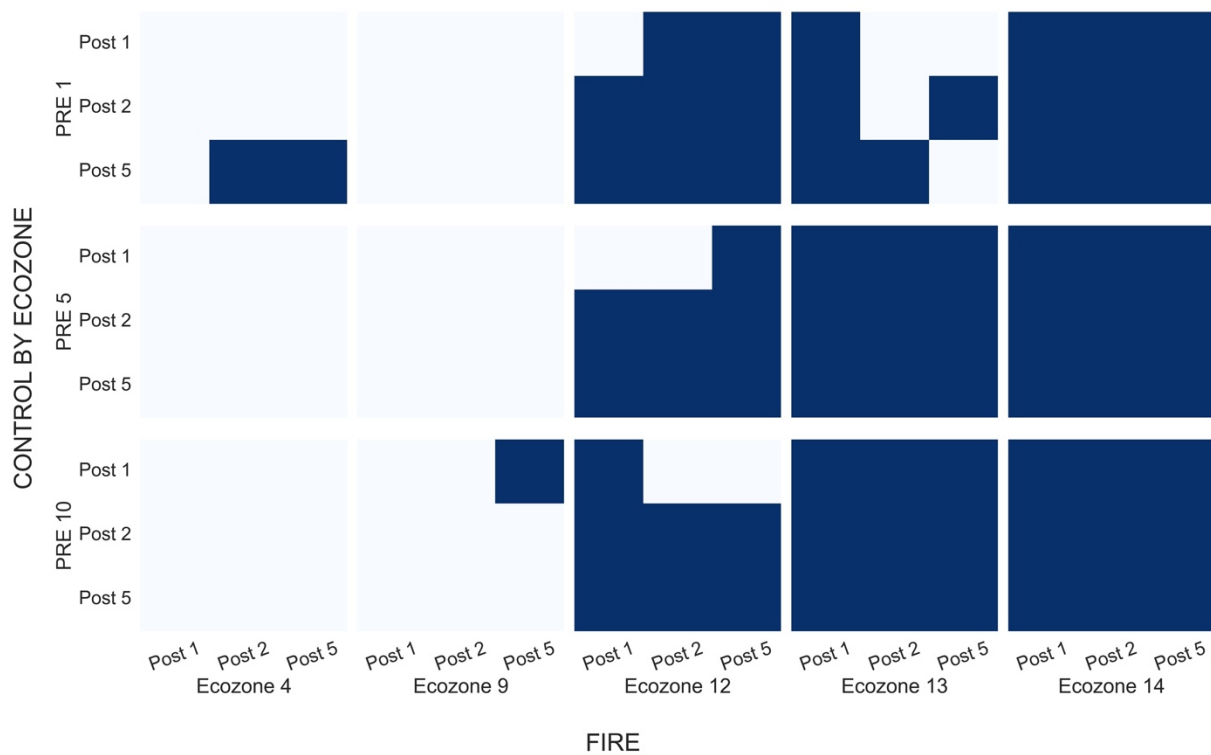


Figure 17: A heatmap of the results of the Kolmogorov-Smirnov hypothesis test for peak flow, comparing the percent changes in burnt watersheds (fire) to the unburnt watersheds (control). Dark blue boxes support the alternative hypothesis: that the fire and control groups are not identical.

The runoff ratio (Figure 18) for ecozones 12, 13, and 14 have the similar trends seen in high flow and peak flow. For runoff, all the temporal bands for ecozone 12 showed statistically significant differences between burnt and unburnt watersheds.

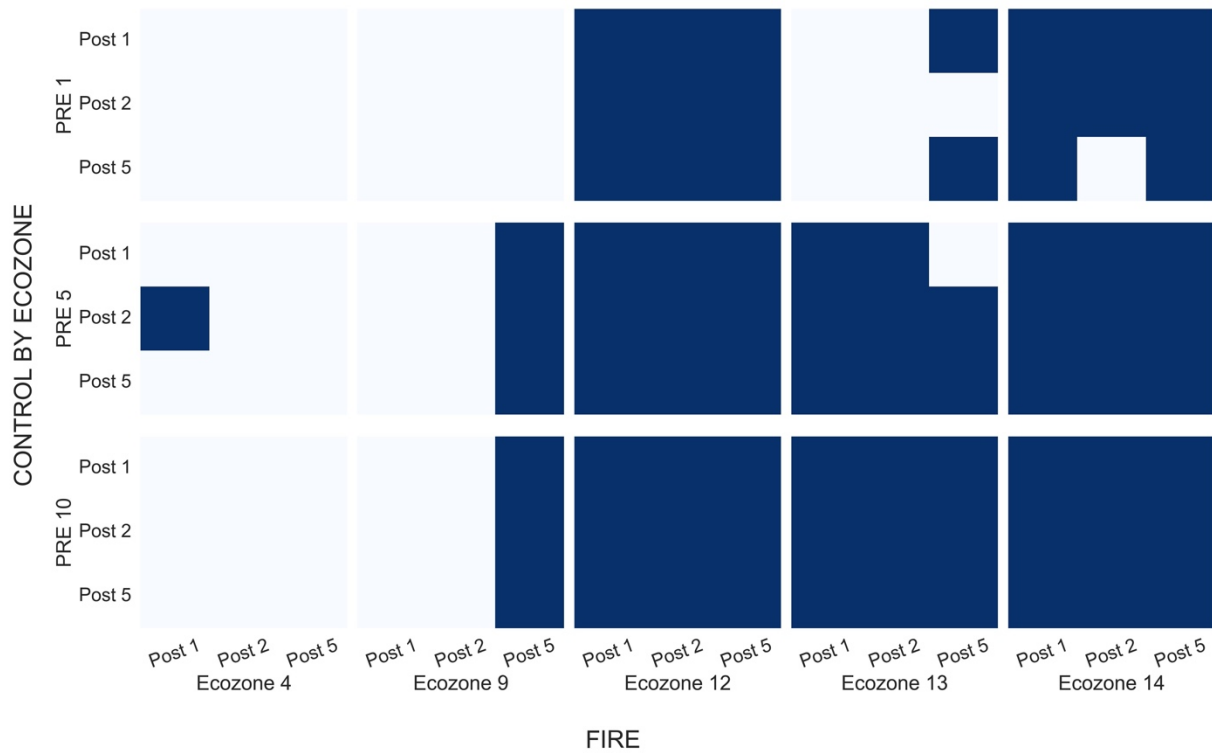


Figure 18: A heatmap of the results of the Kolmogorov-Smirnov hypothesis test for runoff ratio, comparing the percent changes in burnt watersheds (fire) to the unburnt watersheds (control). Dark blue boxes support the alternative hypothesis: that the fire and control groups are not identical.

4.2.3 Discussion

The two-sample Kolmogorov-Smirnov tests do not assume that the data from both groups are from a defined distribution. By comparing the empirical cumulative distribution functions of the fire and control groups, the KS test provided p-values that either supported or rejected the null hypothesis that the fire and control groups were from the same distribution. P-values lower than 0.05 rejected the null hypothesis, suggesting a statistically significant difference between the two sample distributions.

Observations from the hypothesis testing described in the latter and former sections confirm the visual observations described in Section 4.1. However, hypothesis testing also helps determine differences between the burnt and unburnt watersheds that are not easily observable by visual inspection of the raw data alone. Overall, in the smaller BC ecozones (4 and 9), hypothesis

testing supported the null hypothesis; that the burnt, unburnt neighboring watersheds, and unburnt watersheds in the same ecozone most likely come from the same distribution. This is unsurprising since the unburnt neighboring watersheds and unburnt watersheds in the same ecozone had a high probability of being the same watersheds due to the smaller land areas of ecozone 4 and 9. In other words, the unburnt neighboring watersheds adjacent to the burnt watershed could be the same as the unburnt watersheds in the ecozone.

In the larger BC ecozones (12, 13, and 14), there were higher variability in the hypothesis testing results. For high flow, peak flow, and runoff ratios, the burnt and unburnt neighboring watersheds were most likely from the same distribution, which may suggest that the wildfire's effect on the burnt watersheds may extend to their neighboring unburnt watersheds. For low flow percent changes, the burnt, unburnt neighboring watersheds, and unburnt watersheds in the same ecozone were most likely not from the same distribution, which may suggest that wildfires affect low flow only in burnt watersheds. The high variability seen in all ecozones may allude to what Wine, Cadol, & Makhnin (2018) refer to as the threshold effect where a percent burn of some magnitude is required to create hydrological impact. That threshold may be different for each ecozone.

To compare the results of the hypothesis testing between control by proximity and control by ecozone, Figures 19 – 22 show a summary of the results. Dark blue boxes represent temporal bands that showed statistically significant differences between the fire group, and both control groups. Light blue boxes represent temporal bands that showed statistically significant changes for only one control group. White boxes represent temporal bands that did not show statistically significant changes for any control group. The summary figures highlight the importance of ecozone grouping, use of control groups, and varying temporal bands.

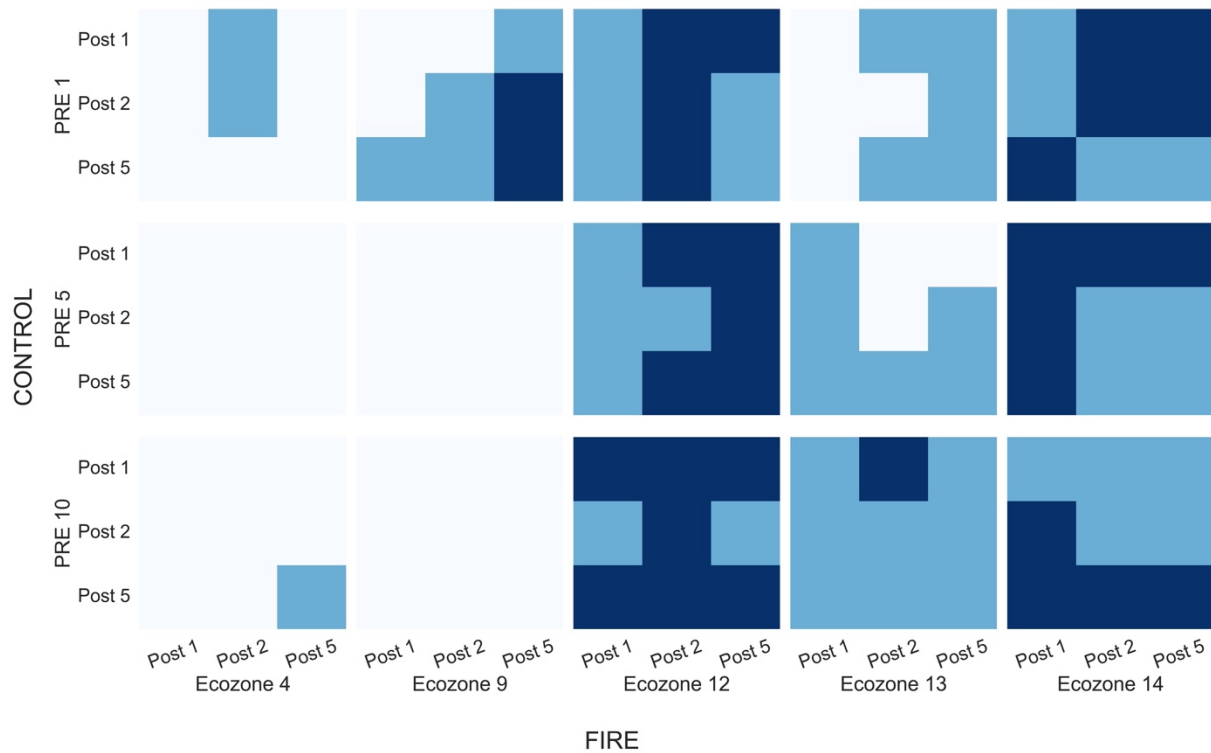


Figure 19: Low flow summary of p-values. Dark blue represents temporal bands that showed a significant different post-fire for both controls; light blue represents temporal bands had significant difference for one control, and white represents temporal bands without a significant difference post-fire.

The summary figures show that nearly none (except two) of the temporal bands for ecozones 4 and 9 resulted in statistically significant differences when compared to both control groups. Indeed, for some flows for ecozones 4 and 9, there was consistently no statistically significant difference when compared to either control group (particularly ecozone 9 for high flow).

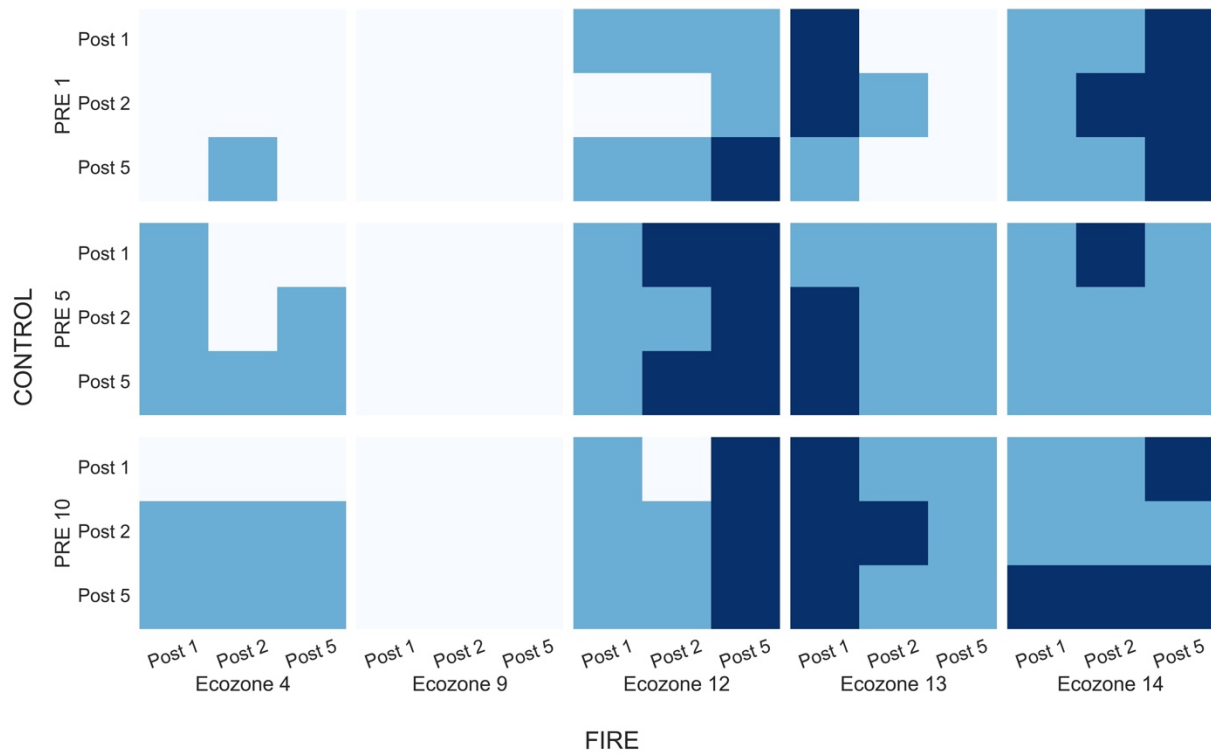


Figure 20: High flow summary of p-values. Dark blue represents temporal bands that showed a significant difference post-fire for both controls; light blue represents temporal bands that had a significant difference for one control, and white represents temporal bands without a significant difference post-fire.

Results for the larger ecozones 12, 13, and 14 show mixed results, highlighting the importance of how a control group is defined, as well as how a pre-fire value is defined. For a majority of the temporal bands for ecozones 12, 13, and 14, there is a disagreement in the findings between control by proximity and control by ecozone. Using one particular control group and pre-fire range over the other can result in contrasting findings, creating implications for the watershed, forestry and land managers that utilize research conclusions to make decisions that have social, economic, and environmental implications.

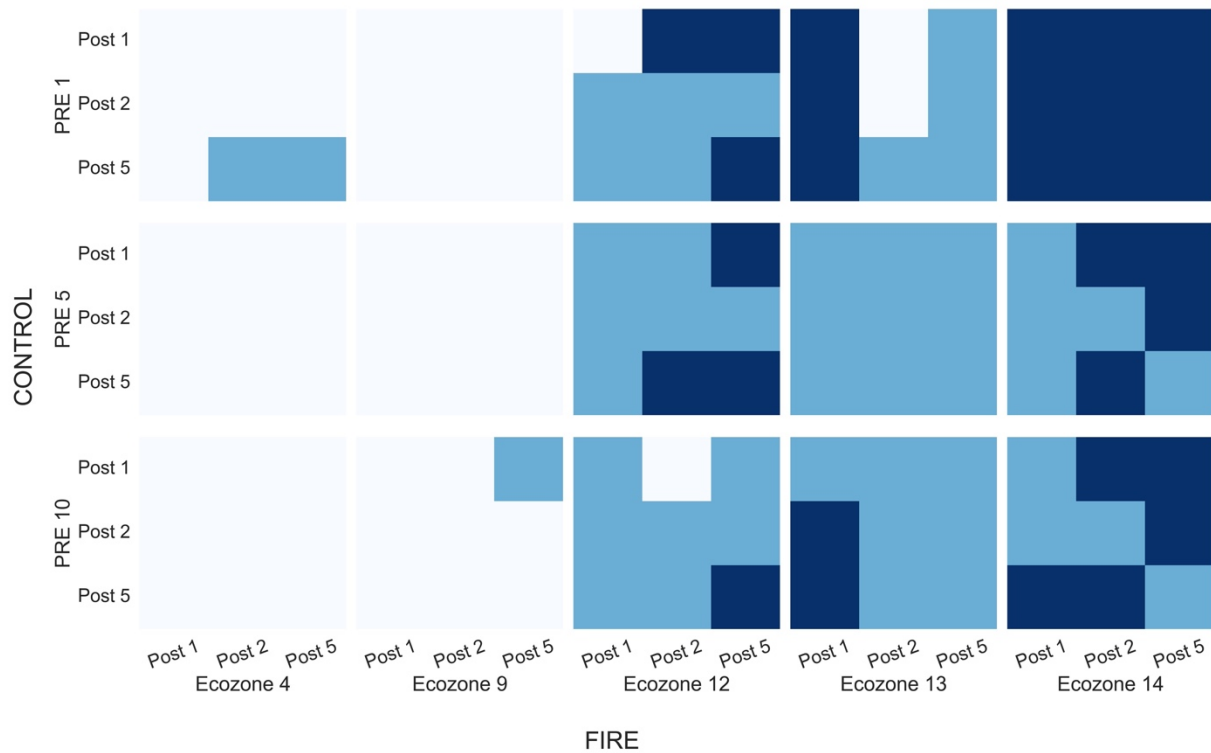


Figure 21: Peak flow summary of p-values. Dark blue represents temporal bands that showed a significant different post-fire for both controls; light blue represents temporal bands had significant difference for one control, and white represents temporal bands without a significant difference post-fire.

Further, the use of multiple control groups and pre-fire ranges create additional confirmation of positive results. Many temporal bands showed statistically significant differences for both control groups, and for multiple pre-fire ranges. For instance, all temporal bands using 1-yr pre-fire for ecozone 14 (Figure 21) had statistically significant differences when comparing the burnt watershed to both control groups. The 5-yr post-fire for ecozone 9 (Figure 22) showed statistically significant differences when using both 5-yr and 10-yr pre-fire ranges, for both control groups. In both these instances, the confirmation from both control groups, and multiple pre-fire ranges adds confidence to the statement that the distribution of the percent change of flow does change after a wildfire. The latter is especially important since many post-fire hydrology studies use only one pre-fire range (and that range often varies per study), and control groups are rarely used.

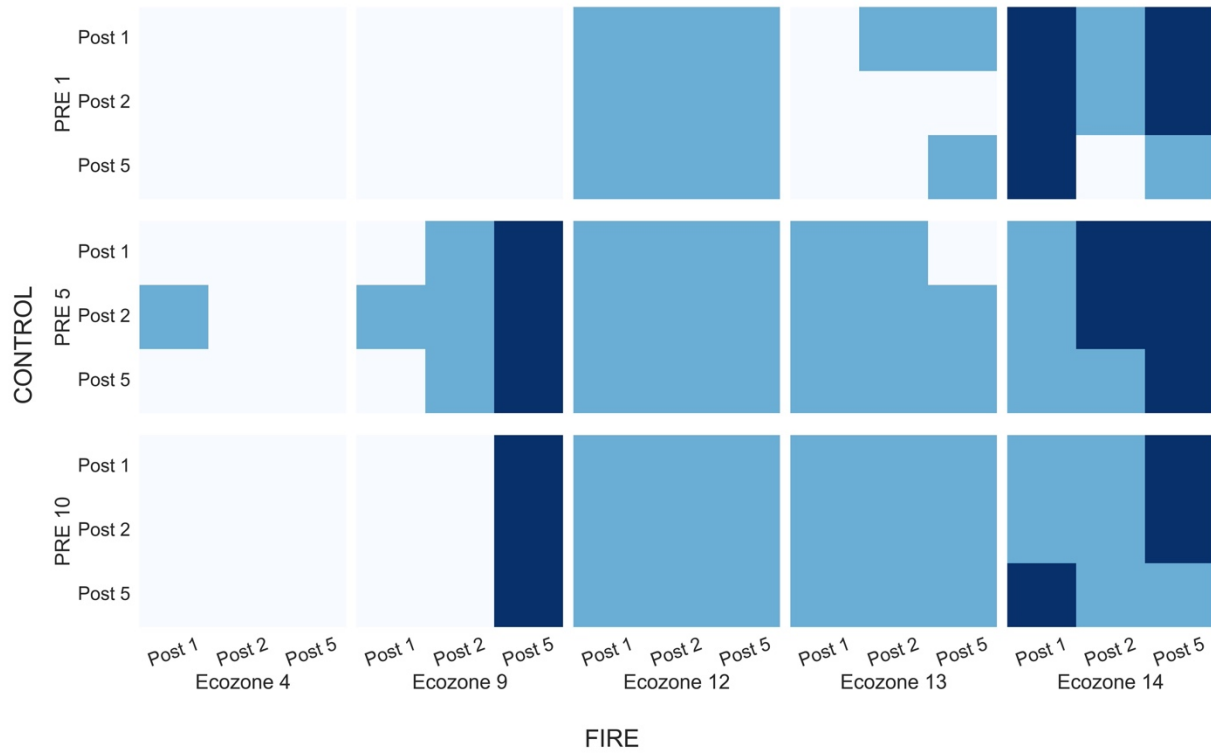


Figure 22: Runoff ratio summary of p-values. Dark blue represents temporal bands that showed a significant different post-fire for both controls; light blue represents temporal bands had significant difference for one control, and white represents temporal bands without a significant difference post-fire.

Lastly, distributions are affected by skewness (measure of symmetry), central tendency (measure of the centre, affected by mode, mean, and mean), and dispersion (measure of how spread the data is, i.e., standard deviation, variance). The KS test can determine a difference in distribution; however, it cannot determine the type of difference. The distributions of the post-fire hydrological metrics can be affected by various factors, which are explored in the next section.

4.3 Influence of Hydrometeorological Parameters on Response

4.3.1 Spearman Correlation

The scatterplots in Figure 23 show possible linear correlation relationships between the independent variables versus each of the hydrological metric percent changes. The different colors represent the different temporal bands (different combinations of pre-fire and post-fire

used for percent change calculations), along with best fit lines for each. Simple linear relationships between each independent variable and response variables are difficult to observe, however performing multiple linear regression (explained in the next section) allows for the combined use of all the independent variables to predict each hydrological metric percent change.

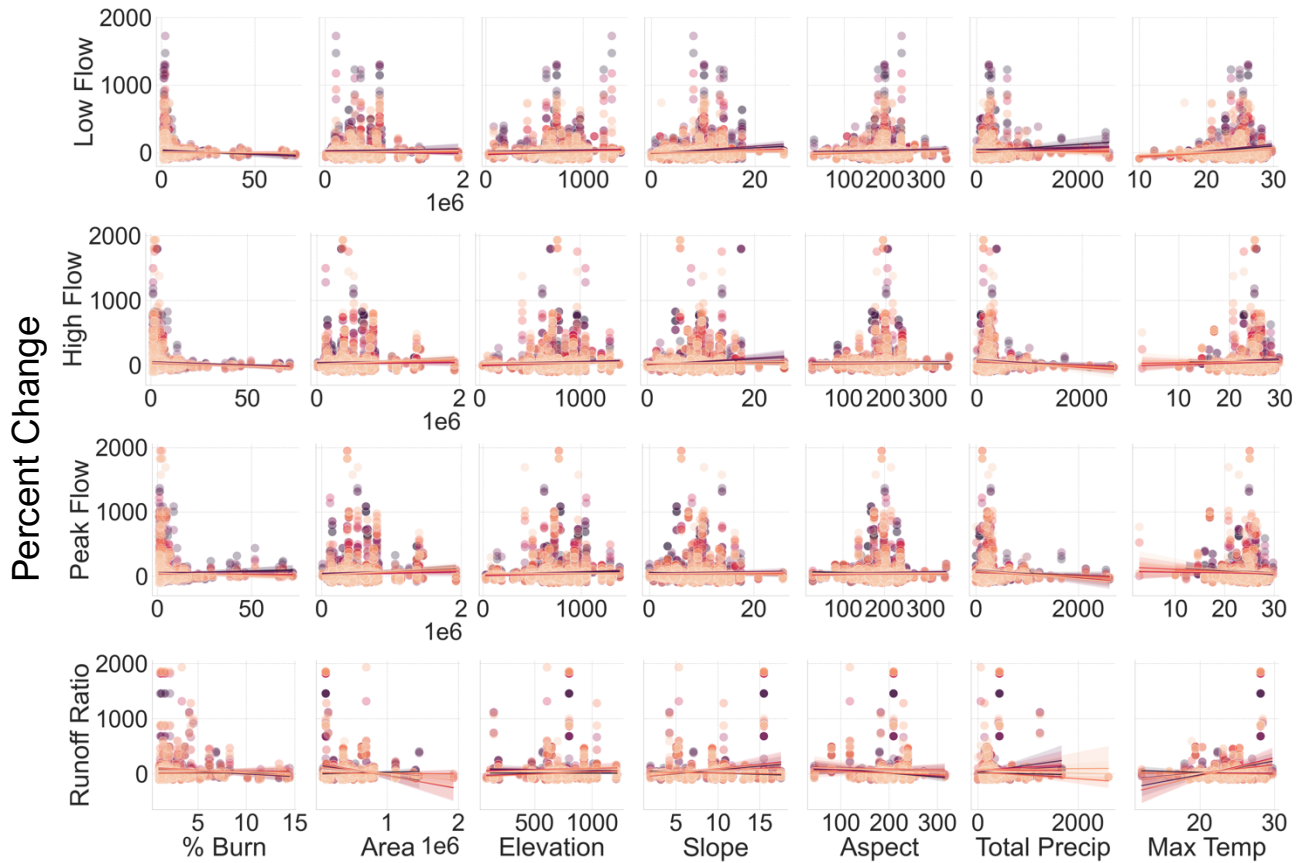


Figure 23: Scatterplots of independent variables (x-axis) versus the percent changes of flow (y-axis).

As was also done by Saxe, Hogue, & Hay (2018), Spearman correlation was done to further examine the individual correlation between the independent variables and the response flows (shown in Figure 24 – 22). Spearman correlation coefficients ($-1 \leq \rho \leq 1$): a value of -1 means a strong negative correlation (represented by blue), while a value of +1 means a strong positive correlation (represented by red) and a value of 0 means no correlation (represented by white).

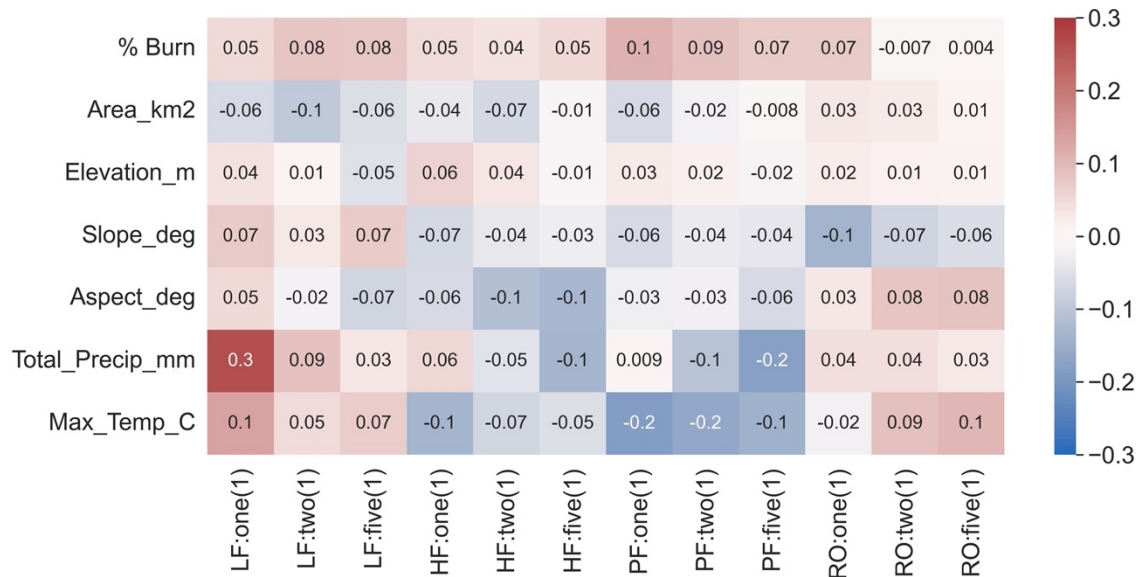


Figure 24: Heatmap of Spearman correlation coefficients of independent variables (on y-axis) versus the percent change of hydrological metrics (on the x-axis), using the 1-yr pre-fire.

Figure 24 – 26 show the Spearman correlation results the 1-yr pre-fire, 5-yr pre-fire, and 10-yr pre-fire, respectively. The hydrological metrics are shown on the bottom axis, with the post-fire timeframe, and pre-fire timeframe in brackets.

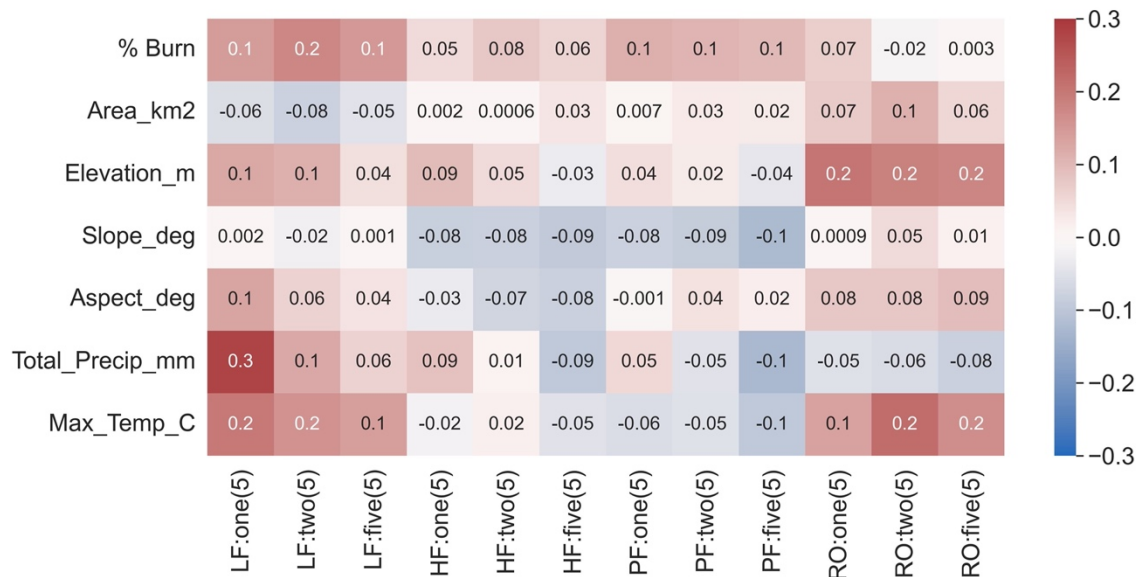


Figure 25: Heatmap of Spearman correlation coefficients of independent variables (on y-axis) versus the percent change of hydrological metrics (on the x-axis), using the 5-yr pre-fire.

The overall maximum correlation value for all temporal bands is 0.3, seen for total precipitation and low flow, 1-yr post-fire (for 1-yr pre-fire and 5-yr pre-fire: Figure 24 and Figure 25), with corresponding p-values that are greater than 0.05 (meaning that they are uncorrelated).

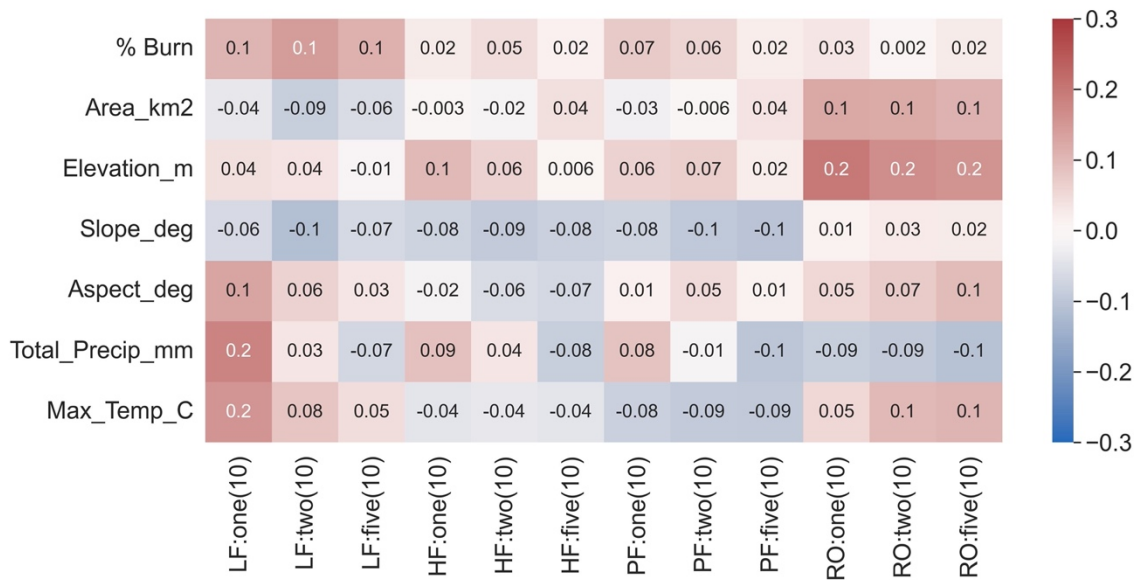


Figure 26: Heatmap of Spearman correlation coefficients of independent variables (on y-axis) versus the percent change of hydrological metrics (on the x-axis), using the 10-yr pre-fire.

Only 5%, 24%, and 15% of the Spearman correlation coefficients are greater than 0.10, for pre-fire years 1, 5, and 10, respectively. Additionally, only 18%, 19%, and 11% of the correlations had p-values of less than 0.05 (for pre-fire years 1, 5, and 10, respectively). These statistics mean that only a small percentage of hydrometeorological variables have statistically significant correlations with the post-fire changes hydrological metrics.

For all temporal bands, percent watershed area burned tend to have a weak positive correlation with post-fire flow changes, though the corresponding p-values are all greater than 0.05, confirming no single correlation between percent burn and each post-fire percent change of hydrological metric. Total annual precipitation did not result in any p-values less than 0.05, for

any hydrological metric for any temporal band, suggest no correlation between total annual precipitation and post-fire flow changes.

Correlations that resulted in p-values less than 0.05 vary per pre-fire timeframe, though the most frequent parameters that showed statistically significant correlations were slope, elevation, and maximum daily temperature. Slope (1-yr pre-fire), in particular, had statistically significant correlations for all post-fire low flow changes, for high flow changes in the second and fifth year post-fire, and runoff ratio in the first and second years post-fire. Maximum daily temperature had statistically significant correlations for all post-fire low flow changes in the 1-yr pre-fire. Elevation also had statistically significant correlations for all post-fire low flow changes, but in the 5-yr pre-fire timeframe. Overall, the majority of the correlations that result in p-values less than 0.05 were with post-fire low flow, suggesting that post-fire low flow changes have statistically significant correlations with maximum daily temperature, elevation, and slope. Discussion of these results are in Section 4.3.3.

4.3.2 Multiple Linear Regression

The linear regression models aimed to predict the post-fire percent changes of each hydrological metric using the multiple hydrometeorological parameters. The regression results in Figure 27 show R^2 values that are highly variable without any trends. R^2 values can range from 0 to 1, with R^2 values of 1 meaning the best performance, resulting in the most accurate predictions. Most models performed poorly, resulting in R^2 values of less than 0.1, suggesting that the hydrometeorological parameters alone cannot account for the post-fire changes (reasons for which are discussed in Section 4.3.3). The highest R^2 values are seen in low flow (ecozone 9), peak flow (ecozone 9), and runoff ratio (ecozone 4).

Low flow percent changes had the best predictions resulting in R^2 values of 0.021 to 0.47. Regression models for high flow percent changes did not produce R^2 values higher than 0.27. The worst performance was observed in ecozone 14, which also had the most data points.

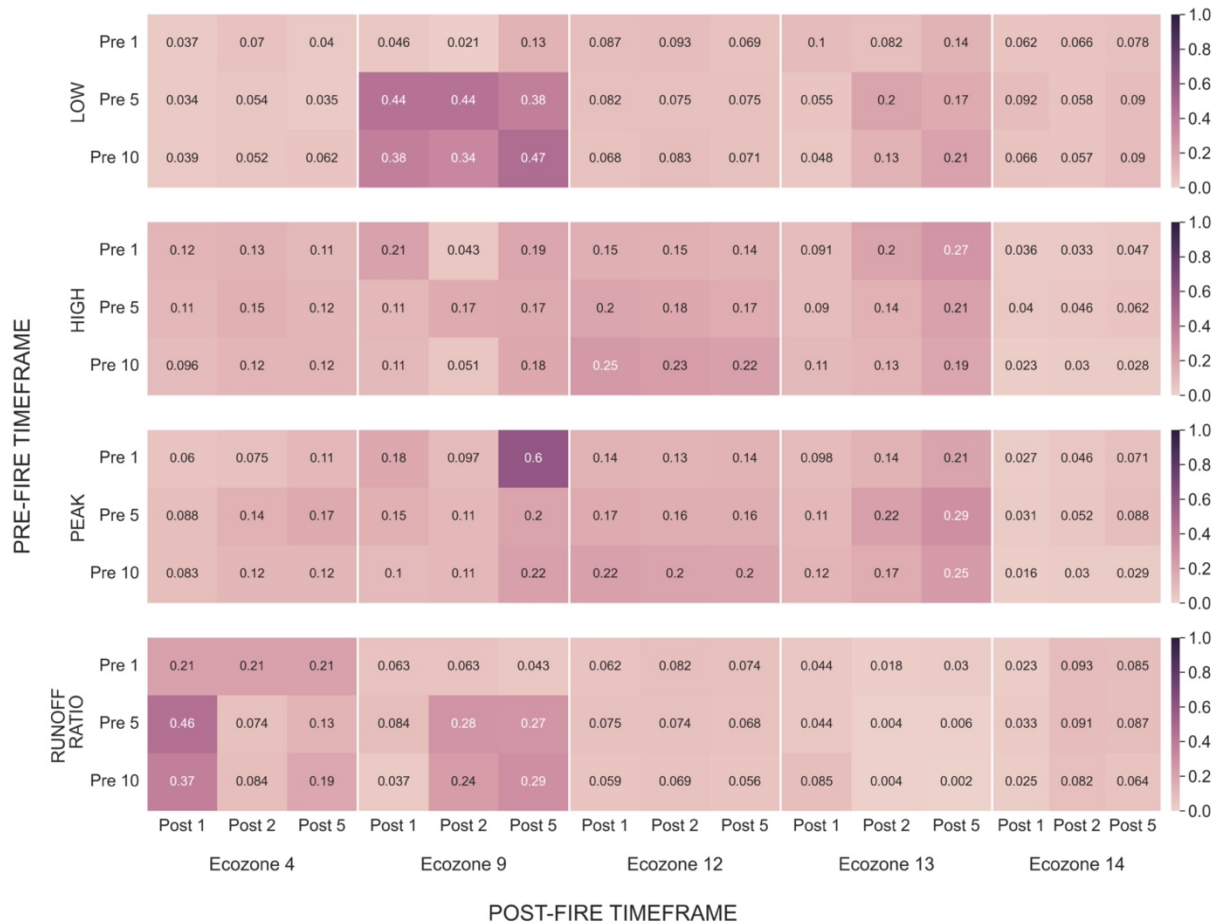


Figure 27: A heatmap of the regression analysis results showing the R^2 values for all hydrological metrics.

Compared to the high flow models, the regression models for peak flow percent changes overall performed slightly better. The best performing model ($R^2 = 0.6$) predicts the 1-yr pre-fire/5-yr post-fire peak flow percent change in ecozone 9, which has one of the least data points. Models predicting the runoff ratio percent changes mostly performed poorly; the best performing belong to ecozone 4 with $R^2 = 0.46$.

For each regression model performed, the resulting output includes the p-value of the t-test ($P > |t|$) for each independent variable, which represents the probability that the variable has

no effect on the dependent variable. P values of less than 0.05 mean that the variable is a statistically significant predictor of the hydrological metric. The frequency with which each independent variable resulted in a p-value less than 0.05 (and are therefore strong predictors of the hydrological metric) are shown in Figure 28 and Figure 29. Figure 28 shows the frequency grouped by ecozone, while Figure 29 shows the frequency grouped by hydrological metric.

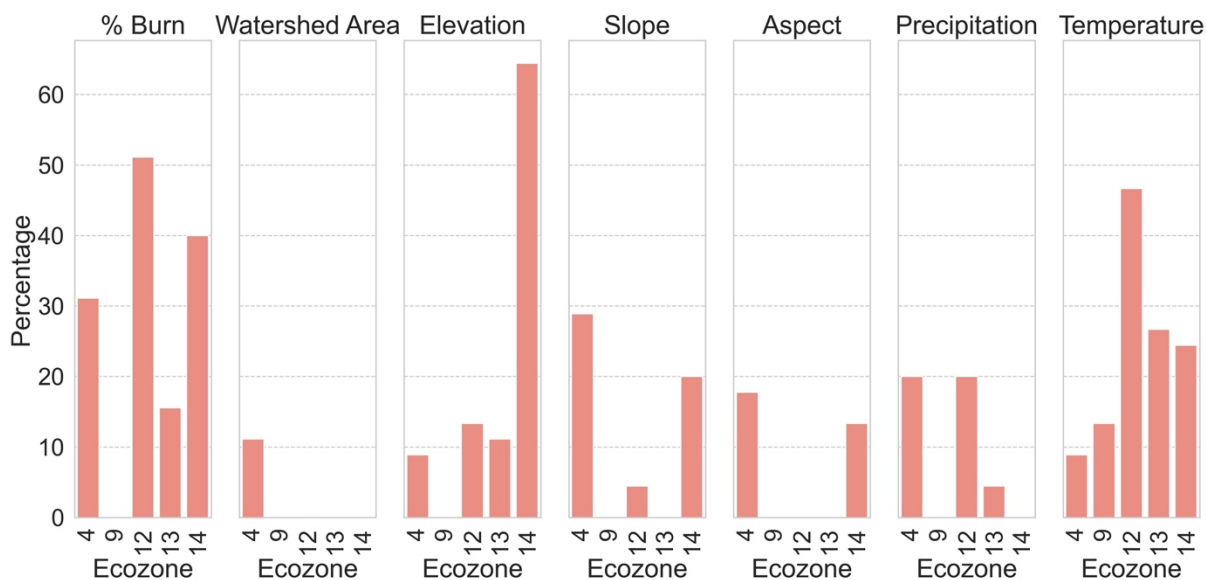


Figure 28: Bar graph showing the percentage of regression models per ecozone that each independent variable was found to be a statistically significant predictor ($p < 0.05$).

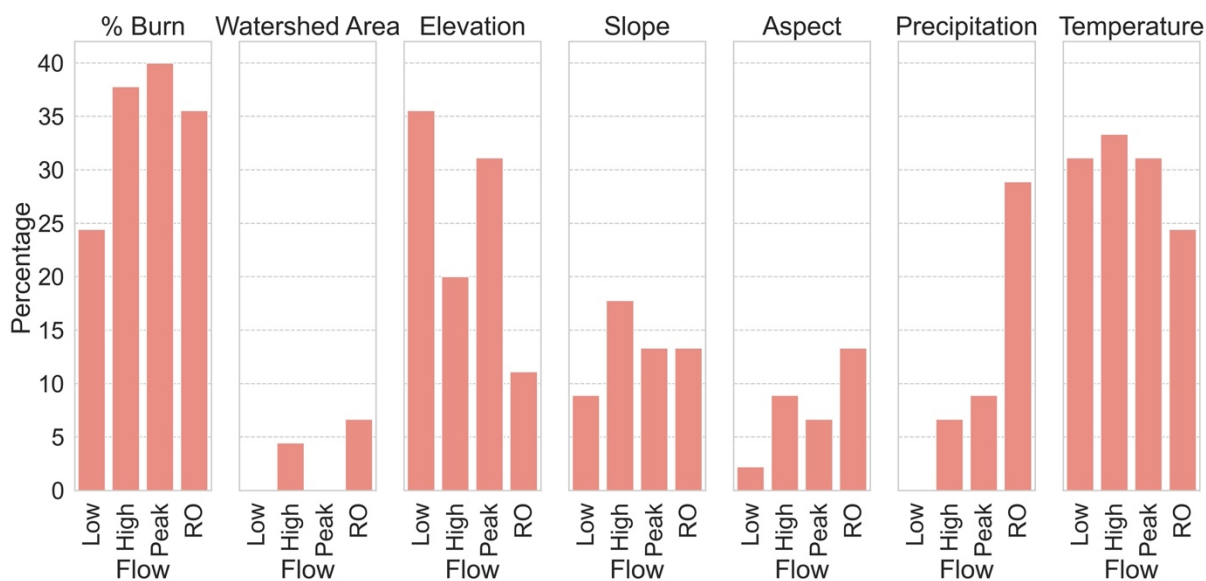


Figure 29: Bar graph showing the percentage of regression models per flow that each independent variable was found to be a statistically significant predictor ($p < 0.05$).

Overall, the variable with highest frequency of being a significant predictor are the maximum daily temperature, percent burn, and elevation. This is the case when grouped by ecozone or by hydrological metric. For ecozone 9, only maximum daily temperature proved to be significant predictor, and for less than 20% of the models. Watershed elevation was found as a significant predictor for 80% of the models for ecozone 14.

4.3.3 Discussion

In Spearman correlation coefficient testing, the individual correlation of each hydrometeorological parameter with the post-fire changes were examined. The Spearman correlation coefficients ranged between -0.2 and 0.3, which were the magnitudes similarly seen by Saxe, Hogue, & Hay (2018). The most frequent hydrometeorological parameters that showed statistically significant correlations were maximum daily temperature, slope and elevation, the majority of which were for low flow and runoff ratio percent changes. Slope was also found to be correlated with post-fire flow changes in Saxe, Hogue, & Hay (2018), however, they found a positive correlation, as opposed to the negatively correlations seen here. Percent burn and total annual precipitation did not result in p-values less than 0.05 for any temporal band and hydrological metric, suggesting no correlation with any of the post-fire flow changes, which is in contrast to many studies that found strong correlations between percent burn and post-fire flow changes (Belongia, Wagner, Seipp, & Ajami, 2023).

In multiple linear regression, the correlation of all hydrometeorological parameters together with the post-fire changes in hydrological metrics were examined. The most frequent hydrometeorological parameter that showed statistically significant influence on post-fire flows were maximum daily temperature, elevation, and percent burn, which were for all post-fire

hydrological metrics. Elevation was a particularly strong predictor in 80% of the models for ecozone 14, which also has the largest ranges of elevation (Figure 4), to be expected in a such a large and diverse ecozone. Percent watershed burn was a strong predictor in 60% of the models for ecozone 12, which is one of the ecozones that experienced the largest percent burn.

The Spearman correlation coefficient and multiple linear regression results both found maximum daily temperature and elevation as statistically significant parameters for prediction post-fire hydrological changes. Elevation was most often positively correlated with post-fire changes, though the correlations are very weak; this observation was also found by Saxe, Hogue, & Hay (2018). A possible explanation for this observed correlation of elevation could be that the dominant vegetation types varies at different elevations (Niemeyer, Bladon, & Woodsmith, 2020), which can affect fire resistance, post-fire vegetation recovery, and hydrological patterns (such as infiltration and evapotranspiration). Additionally, human access differs at different elevations, where lower elevations may have more human activity such as logging, which further affects post-fire hydrology changes through vegetation and land cover differences. The type of fire suppression patterns may also differ by elevation, again due to varying human access.

Maximum daily temperature was not included as a parameter by Saxe, Hogue, & Hay (2018); this parameter was found to be positively correlated to the post-fire low flow and runoff ratio changes, and negatively correlated to the post-fire high and peak flows. However, these correlations are also very weak ($\rho < 0.2$). Maximum daily temperature can affect wildfire risk (higher temperatures can lead to drier conditions that make wildfires more likely). Watershed area was found as a strong influence on post-fire impacts by Belongia, Wagner, Seipp, & Ajami, (2023), however, watershed area was not found as a statistically significant parameter in either Spearman correlation testing or multiple linear regression.

Additionally, both Spearman correlation coefficient testing and multiple linear regression are highly sensitive to the sample size; and as previously mentioned, many of the temporal bands were analyzed with small sample sizes (particularly ecozones 4 and 9). Effects of the sample sizes observed by Saxe, Hogue, & Hay, (2018) are echoed here as well. Determining accurate post-fire indicators at the ecozone level, with these sample sizes, do come with limitations (discussed in the next Chapter).

Finally, recall that unbiased linear regression results are dependent on assumptions being satisfied: linearity, independence of errors, and homoskedasticity. Appendix IX shows a sample plot of the regression results against each of the independent variables (regressor), showing the predicted values versus the regressor, and the residuals (error) versus the regressor.

The graphs in Appendix IX show four plots for each of the seven independent variables (from the top left clockwise): (1) fitted values versus independent variable (x), (2) residuals plot versus the x , (3) component-component plus residual (CCPR) plot, and (4) partial regression plot. The residuals plot can help detect heteroskedasticity (observations not having the same error variance). From the sample plots for one regression model, the residuals plot for all independent variables are not homoscedastic, meaning that they do not have the same error variance. The sample plots in Appendix IX are from ecozone 14, which is one of the biggest ecozones in BC, resulting a large range of observed values. Therefore, a multiple linear regression model may not be the appropriate model since OLS assumptions are not satisfied. Additionally, sample sizes of some ecozones (particularly ecozones 4 and 9) are small which may affect the regression model performances (a limitation also cited by Saxe, Hogue, & Hay (2018)).

Chapter 5 Conclusion and Recommendations

This research aimed to examine the changes in flow after a fire and to determine accurate indicators for post-fire hydrological responses. The various statistical methods performed yielded highly variable results across all temporal bands, and across all five ecozones for the four hydrological metrics analyzed.

Trends in post-fire flow changes were easier to observe in the smaller ecozones (4 and 9), with the caveat that these ecozones also contained the smallest amount of data points (particularly for runoff ratio percent changes). Therefore, major conclusions would be premature, since it is less likely that the sample dataset represents the data of the population. The larger ecozones 12, 13, and 14 (and therefore larger sample sizes) showed more extreme flow changes. Calculated percent changes were also altered significantly when using different pre-fire timeframes, in some cases, changing the direction of change entirely (from positive to negative). This highlights the importance of the temporal bands chosen, necessitating a standardized method for calculating percent changes; studies comparing pre-fire and post-fire values use a different number of years for calculating pre-fire values, making cross-study comparisons difficult.

Hypothesis testing methods like Kolmogorov-Smirnov tests can help distinguish between the distribution of two sample datasets, while considering the sample size of both groups, and should be one of the first steps in statistical analysis. The use of two different control groups yielded contrasting results, allowing conclusions to be made about unburnt neighboring watersheds, and unburnt watersheds in the same ecozone. In the smaller ecozones 4 and 9, unburnt neighboring watersheds had similar distributions as burnt watersheds, suggest that the wildfire impact extends outside of the burnt watershed. However, this was not observed in the

larger ecozones. The hypothesis testing illustrated the presence of post-fire impacts in burnt watersheds, while inclusion of two control groups illustrated the potential extent of wildfires in different ecozones.

The Spearman correlation testing and multiple linear regression yielded weak correlation and poor model performance for predicting post-fire flow changes, using the hydrometeorological parameters, suggesting that these parameters cannot explain post-fire flow changes on their own, raising the question of further parameters that could potentially explain the post-fire changes. Therefore, the attempt of determining accurate indicators for post-fire hydrological changes yielded inconclusive results. Potential indicators are maximum daily temperature, elevation, and percent watershed burn.

Post-fire hydrology literature has highly variable results, which were also observed in this research. The varying results from the multiple statistical analyses performed here highlight the importance of study design, specifically the temporal bands, and control groups. Studies comparing pre- and post-fire hydrological changes often use only one pre-fire range; some studies use 5 years to create the pre-fire value, while others use 10 years. This is important since the results of these same studies are compared to one another to further make conclusions about post-fire hydrology. Further, many studies do not include a control group, which reduces the confidence in any conclusion made that post-fire changes are due to wildfires, since these changes may also be present in unburnt watersheds. As has been presented in the results in Chapter 4, the use of different pre-fire ranges and different control groups show different and often contrasting findings, where the use of one pre-fire range or control group results in statistically significant post-fire changes, while others do not. It is unsurprising then, that post-fire hydrology studies, have such variable and contrasting results. The use of multiple pre-fire

ranges, and multiple control groups also provided the additional confirmation of results, when similar findings were observed for multiple pre-fire ranges and both control groups. Without a standardized method for calculating percent changes after a wildfire, using multiple pre-fire ranges and control groups may offer more confidence in the conclusions made from the results.

5.1 Limitations

The literature has called for studies with larger spatial and temporal scales, since few studies of this scale exist. Saxe, Hogue, & Hay (2018) is one of the few that analyze a large spatial area, of the western United States of America. Saxe, Hogue & Hay also found variable results, which is unsurprising, as has been observed in this research.

A study across such large spatial and temporal scale are difficult due to the inherent noise, giving rise to many limitations. The five ecozones had a wide ranging number of watersheds, which consequently influenced the number of flow gauge stations used, further influencing the sample size of each ecozone. Ecozone 14 had over 100 watersheds and therefore, analysis at this broader level may be unreasonable; however, there is a balancing act between the size of the dataset grouping and the sample size. Smaller groupings of watersheds may result in more representative observations, but it is quickly overtaken by the unreliability of small datasets. Sample size was heavily impacted by the lack of data. For instance, the lack of corresponding precipitation and temperature data also contributed to the reduced number of data points for runoff ratio. Additionally, covering 100 years presents many concerns to the data collection methods that have evolved in the long study period. There are also other factors that were not accounted for, such as burn severity and intensity, soil data which could account for soil erodibility, complex feedback mechanisms associated with post-fire changes to stream channels and wildfire management units (accounting for differences in fire suppression efforts).

5.2 Recommendations

Future work may consider the use of smaller grouping found in ecoregions, especially for the larger ecozones 12, 13, and 14. A focus on ecozone 14 may be the most fruitful since most of the fire that have occurred in the past decade have occurred here (Figure 2 (b)), and since it is the largest and most diverse ecozone, with multiple fire centres. A focus on ecozones 12 and 13 also would be beneficial, since these ecozones have experienced the largest wildfires (when fires are divided by watershed boundaries). Ecozone 13 also has the largest population of residents. Extensive analysis on a single region would be best, however, data availability limits this type of extensive analysis; expanding the spatial scale helps solve this problem, but interpretation becomes difficult when the region encompasses such different types of landscapes. A similar analysis done with inclusion of fire management strategy data into the analysis could provide new insight. Nonlinear regression methods and machine learning methods may result in better performing models.

Finally, as mentioned in the previous sections, and in previous literature, post-fire hydrology is important for maintaining hydrologic ecosystem services that benefit humans. Identification of accurate post-fire indicators are especially important for land managers, allowing the proper allocation of resources, such as flood and fire suppression efforts that cost billions per year. With accurate post-fire indicators, the most appropriate actions can be taken which help reduce socio-economic costs by avoiding unnecessary preventative measures in areas that aren't likely to experience post-fire flood (saving financial costs) and providing necessary disaster management efforts to areas that are, saving lives and property that would have otherwise been lost or damaged.

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Appendix

Appendix I: Post-fire calculation for control by proximity code

```

post1low = []
post2low = []
post5low = []

for idx, col in enumerate(post_nofire['Fire_Date']):
    firedate = post_nofire['Fire_Date'][idx].strftime("%Y")
    post1 = post_nofire['Post01Yr'][idx].strftime("%Y") # year to check
    post2 = post_nofire['Post02Yr'][idx].strftime("%Y")
    post5 = post_nofire['Post05Yr'][idx].strftime("%Y")
    wshed = post_nofire['Watershed'][idx] # watershed to check
    ecoz = post_nofire['Ecozone'][idx] # ecozone to check
    neighbors = gdf[gdf['Name'] == wshed]
    u = neighbors['NEIGHBORS'].astype(str).str.cat(sep=',')
    u = u.split(',')

    # check which neighbours have fire on same day
    f = pd.DataFrame(post_nofire.loc[(post_nofire['Watershed'].isin(u))
                                     & (post_nofire['Fire_Date'] == post_nofire['Fire_Date'][idx])])
    neigh_wfire = f['Watershed'].astype(str)

    if len(f) == 0:
        new_u = u
    else:
        new_u = list(set(u).difference(neigh_wfire))

    # LOW FLOW
    x = pd.DataFrame(low.loc[(low['Date'] <= post1) # date post-fire
                             & (low['Date'] > firedate) # fire date
                             & ~(low['Watershed'] == wshed) # not fire watershed
                             & (low['Watershed'].isin(new_u))]) # neighbouring watersheds without fire only

    y = pd.DataFrame(low.loc[(low['Date'] <= post2)
                             & (low['Date'] > firedate)
                             & ~(low['Watershed'] == wshed)
                             & (low['Watershed'].isin(new_u))])

    z = pd.DataFrame(low.loc[(low['Date'] <= post5)
                             & (low['Date'] > firedate)
                             & ~(low['Watershed'] == wshed)
                             & (low['Watershed'].isin(new_u))])

    if len(x) == 0:
    if len(y) == 0:
        post2val_low = np.nan
    else:
        y = pd.DataFrame(y.groupby(['Watershed'])['Value'].mean())
        post2val_low = y['Value'].mean()

    if len(z) == 0:
        post5val_low = np.nan
    else:
        z = pd.DataFrame(z.groupby(['Watershed'])['Value'].mean())
        post5val_low = z['Value'].mean()

    post1low.append(post1val_low)
    post2low.append(post2val_low)
    post5low.append(post5val_low)

post_nofire['Post01Val_Low'] = post1low
post_nofire['Post02Val_Low'] = post2low
post_nofire['Post05Val_Low'] = post5low

```

Appendix II: Percent change calculation sample code

```
# Fire: pre.csv and post.csv
column_low = [29,30,31]
column_high = [32,33,34]
column_peak = [35,36,37]
column_ro = [38,39,40]

column = [column_low, column_high, column_peak, column_ro]
pc_low = pre.drop(pre.iloc[:,29:41], axis = 1)
pc_high = pre.drop(pre.iloc[:,29:41], axis = 1)
pc_peak = pre.drop(pre.iloc[:,29:41], axis = 1)
pc_ro = pre.drop(pre.iloc[:,29:41], axis = 1)
df = [pc_low, pc_high, pc_peak, pc_ro]

for i, col_type in enumerate(column):

    for ii, col_element in enumerate(column[i]):
        pre_col = pre.columns.values[column[i][ii]]

        for iii, col_element in enumerate(column[i][ii]):

            post_col = post.columns.values[column[i][iii]]
            pc = []

            for idx, fire in enumerate(pre['Fire_Date']):
                pre_val = pre.iloc[idx][column[i][ii]]
                post_val = post.iloc[idx][column[i][iii]]

                if np.isnan(pre_val) or np.isnan(post_val):
                    percentchange = np.nan
                else:
                    percentchange = float(((post_val - pre_val) / pre_val) * 100)

            pc.append(percentchange)

            if column[i][ii] in column_low:
                pc_low[str(pre_col) + ' v ' + str(post_col)] = pc
            if column[i][ii] in column_high:
                pc_high[str(pre_col) + ' v ' + str(post_col)] = pc

            if column[i][ii] in column_peak:
                pc_peak[str(pre_col) + ' v ' + str(post_col)] = pc
            if column[i][ii] in column_ro:
                pc_ro[str(pre_col) + ' v ' + str(post_col)] = pc

pc_low = pc_low.replace([np.inf, -np.inf], np.nan)
pc_high = pc_high.replace([np.inf, -np.inf], np.nan)
pc_peak = pc_peak.replace([np.inf, -np.inf], np.nan)
pc_ro = pc_ro.replace([np.inf, -np.inf], np.nan)

pc_low.to_csv('f_pc_low_1012.csv', index=False)
pc_high.to_csv('f_pc_high_1012.csv', index=False)
pc_peak.to_csv('f_pc_peak_1012.csv', index=False)
pc_ro.to_csv('f_pc_ro_1012.csv', index=False)
pc_low.describe()
```

Appendix III: Neighboring watersheds code

```
file = "/Users/karenabogadil/Documents/Masters/DRAINAGE_BASIN_neighbours.shp"
gdf = gpd.read_file(file)
```

Appendix IV: Post-fire calculation code for control by ecozone

```

for idx, col in enumerate(post_nofire['Fire_Date']):
    firedate = post_nofire['Fire_Date'][idx].strftime("%Y")
    post1 = post_nofire['Post01Yr'][idx].strftime("%Y") # year to check
    post2 = post_nofire['Post02Yr'][idx].strftime("%Y")
    post5 = post_nofire['Post05Yr'][idx].strftime("%Y")
    wshed = post_nofire['Watershed'][idx] # watershed to check
    ecoz = post_nofire['Ecozone'][idx] # ecozone to check

# LOW FLOW
x = pd.DataFrame(low.loc[(low['Date'] <= post1)
                        & (low['Date'] > firedate)
                        & (low['Ecozone'] == ecoz)
                        & ~(low['Watershed'] == wshed)])
y = pd.DataFrame(low.loc[(low['Date'] <= post2)
                        & (low['Date'] > firedate)
                        & (low['Ecozone'] == ecoz)
                        & ~(low['Watershed'] == wshed)])
z = pd.DataFrame(low.loc[(low['Date'] <= post5)
                        & (low['Date'] > firedate)
                        & (low['Ecozone'] == ecoz)
                        & ~(low['Watershed'] == wshed)])

if len(x) == 0:
    post1val_low = np.nan
else:
    x = pd.DataFrame(x.groupby(['Watershed'])['Value'].mean())
    post1val_low = x['Value'].mean()

if len(y) == 0:
    post2val_low = np.nan
else:
    y = pd.DataFrame(y.groupby(['Watershed'])['Value'].mean())
    post2val_low = y['Value'].mean()

if len(z) == 0:
    post5val_low = np.nan
else:
    z = pd.DataFrame(z.groupby(['Watershed'])['Value'].mean())
    post5val_low = z['Value'].mean()

post1low.append(post1val_low)
post2low.append(post2val_low)
post5low.append(post5val_low)

```

Appendix V: Kolmogorov-Smirnov hypothesis testing code

```

for idx, col in enumerate(post_nofire['Fire_Date']):
    firedate = post_nofire['Fire_Date'][idx].strftime("%Y")
    post1 = post_nofire['Post01Yr'][idx].strftime("%Y") # year to check
    post2 = post_nofire['Post02Yr'][idx].strftime("%Y")
    post5 = post_nofire['Post05Yr'][idx].strftime("%Y")
    wshed = post_nofire['Watershed'][idx] # watershed to check
    ecoz = post_nofire['Ecozone'][idx] # ecozone to check

    # LOW FLOW
    x = pd.DataFrame(low.loc[(low['Date'] <= post1)
                            & (low['Date'] > firedate)
                            & (low['Ecozone'] == ecoz)
                            & ~(low['Watershed'] == wshed)])
    y = pd.DataFrame(low.loc[(low['Date'] <= post2)
                            & (low['Date'] > firedate)
                            & (low['Ecozone'] == ecoz)
                            & ~(low['Watershed'] == wshed)])
    z = pd.DataFrame(low.loc[(low['Date'] <= post5)
                            & (low['Date'] > firedate)
                            & (low['Ecozone'] == ecoz)
                            & ~(low['Watershed'] == wshed)])

    if len(x) == 0:
        post1val_low = np.nan
    else:
        x = pd.DataFrame(x.groupby(['Watershed'])['Value'].mean())
        post1val_low = x['Value'].mean()

    if len(y) == 0:
        post2val_low = np.nan
    else:
        y = pd.DataFrame(y.groupby(['Watershed'])['Value'].mean())
        post2val_low = y['Value'].mean()

    if len(z) == 0:
        post5val_low = np.nan
    else:
        z = pd.DataFrame(z.groupby(['Watershed'])['Value'].mean())
        post5val_low = z['Value'].mean()

    post1low.append(post1val_low)
    post2low.append(post2val_low)
    post5low.append(post5val_low)

```

Appendix VI: Spearman correlation code

```
#### PRE 1

y = pc_low.iloc[:, 29:32]
x = independent.iloc[:, 4:11]
df1 = pd.concat([x, y], axis=1)

y = pc_high.iloc[:, 29:32]
df1 = pd.concat([df1, y], axis=1)
y = pc_peak.iloc[:, 29:32]
df1 = pd.concat([df1, y], axis=1)
y = pc_ro.iloc[:, 29:32]
df1 = pd.concat([df1, y], axis=1)

df1.rename(columns={'Pre01Val_Low v Post01Val_Low': 'LF:one(1)',
                    'Pre01Val_Low v Post02Val_Low': 'LF:two(1)',
                    'Pre01Val_Low v Post05Val_Low': 'LF:five(1)',
                    'Pre01Val_High v Post01Val_High': 'HF:one(1)',
                    'Pre01Val_High v Post02Val_High': 'HF:two(1)',
                    'Pre01Val_High v Post05Val_High': 'HF:five(1)',
                    'Pre01Val_Peak v Post01Val_Peak': 'PF:one(1)',
                    'Pre01Val_Peak v Post02Val_Peak': 'PF:two(1)',
                    'Pre01Val_Peak v Post05Val_Peak': 'PF:five(1)',
                    'Pre01Val_R0 v Post01Val_R0': 'R0:one(1)',
                    'Pre01Val_R0 v Post02Val_R0': 'R0:two(1)',
                    'Pre01Val_R0 v Post05Val_R0': 'R0:five(1)',
                    }, inplace=True)

df1

spearman1 = df1.corr(method = 'spearman')
spearman1 = spearman1.iloc[0:7,7:19]

fig = plt.figure(figsize=(14,7))
sns.set(font_scale = 1.75)
heatmap = sns.heatmap(spearman1, annot=True, cmap="vlag", vmin=-.3, vmax=0.30,
                      fmt='.1g', annot_kws={'size': 15})

fig.tight_layout()
fig.subplots_adjust(wspace = 0.05)
plt.show()

fig.savefig('spearman_pre1_1219.jpg', dpi=300)
```

Appendix VII: Multiple linear regression code

```

for eco in ecos:

    ind_eco = pd.DataFrame(independent.loc[independent['Ecozone'] ==eco])
    x = ind_eco[['% Burn','Area_km2', 'Elevation_m', 'Slope_deg', 'Aspect_deg', 'Total_Precip_mm', 'Max_Temp_C']]

    imputer = SimpleImputer(strategy = 'median')
    imputer.fit(x)
    X = imputer.transform(x)
    X = pd.DataFrame(X, columns = x.columns, index=x.index)

    flow = pc_low, pc_high, pc_peak, pc_ro
    for ii, res in enumerate(flow): # for every flow: y = low, high, peak
        a = flow[ii].iloc[:,0:38]
        b = pd.DataFrame(a.loc[a['Ecozone'] ==eco])
        b = b.iloc[:,29:38]
        imputer.fit(b) # impute y
        y = imputer.transform(b)
        y = pd.DataFrame(y, columns = b.columns, index=b.index)

        for i, col in enumerate(y): ### for every column i (percent change: pre1,5,10, v post1,2,5)
            eco_no = eco
            X = add_constant(X)
            Y = y.iloc[:,i]
            model = sm.OLS(Y, X, missing='drop')
            results = model.fit()
            # results.params
            z = results.summary()

            z_html = z.tables[0].as_html()
            a = pd.read_html(z_html, header=0, index_col=0)[0]
            r2 = a.columns.values[2]
            name = a.columns.values[0]

            v_html = z.tables[1].as_html()
            c = pd.read_html(v_html, header=0, index_col=0)[0]

            ecozone_ = eco_no
            P_t_burn = c.iloc[0,3]
            t_burn = c.iloc[0,2]
            P_t_area = c.iloc[1,3]
            t_area = c.iloc[1, 2]
            P_t_elev = c.iloc[2, 3]
            t_elev = c.iloc[2, 2]
            P_t_slope = c.iloc[3,3]
            t_slope = c.iloc[3,2]
            P_t_aspect = c.iloc[4, 3]
            t_aspect = c.iloc[4,2]
            P_t_precip = c.iloc[5,3]
            t_precip = c.iloc[5,2]
            P_t_temp = c.iloc[6, 3]
            t_temp = c.iloc[6,2]

```

Appendix VIII: Detailed summary of percent changes between pre-fire and post-fire Flows

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
4	Pre01	Post01	Low	Fire	17	-96.47	50.31	-14.34
4	Pre01	Post02	Low	Fire	17	-94.41	93.56	-17.78
4	Pre01	Post05	Low	Fire	17	-95.92	64.40	-20.43
4	Pre05	Post01	Low	Fire	17	-99.46	194.85	-7.06
4	Pre05	Post02	Low	Fire	17	-99.15	174.73	-13.30
4	Pre05	Post05	Low	Fire	17	-99.38	74.44	-18.04
4	Pre10	Post01	Low	Fire	17	-99.46	214.30	-2.73
4	Pre10	Post02	Low	Fire	17	-99.15	192.84	-9.85
4	Pre10	Post05	Low	Fire	17	-99.38	85.95	-14.90
4	Pre01	Post01	High	Fire	17	-43.72	243.82	40.84
4	Pre01	Post02	High	Fire	17	-44.69	255.17	26.22
4	Pre01	Post05	High	Fire	17	-50.02	253.68	30.85
4	Pre05	Post01	High	Fire	17	-69.97	243.82	19.54
4	Pre05	Post02	High	Fire	17	-74.40	255.17	9.32
4	Pre05	Post05	High	Fire	17	-70.85	253.68	10.94
4	Pre10	Post01	High	Fire	17	-74.01	243.82	26.38
4	Pre10	Post02	High	Fire	17	-77.85	255.17	14.25
4	Pre10	Post05	High	Fire	17	-74.78	253.68	15.79
4	Pre01	Post01	Peak	Fire	17	-84.24	467.75	117.26
4	Pre01	Post02	Peak	Fire	17	-58.76	322.58	73.70
4	Pre01	Post05	Peak	Fire	17	-58.76	368.23	65.12
4	Pre05	Post01	Peak	Fire	17	-66.34	317.74	42.90
4	Pre05	Post02	Peak	Fire	17	-69.35	322.58	20.76
4	Pre05	Post05	Peak	Fire	17	-67.72	368.23	20.80
4	Pre10	Post01	Peak	Fire	17	-72.01	317.74	58.67
4	Pre10	Post02	Peak	Fire	17	-77.84	322.58	31.69
4	Pre10	Post05	Peak	Fire	17	-76.67	368.23	28.83
4	Pre01	Post01	RO	Fire	3	-67.53	396.96	97.65
4	Pre01	Post02	RO	Fire	3	-67.53	409.64	100.31
4	Pre01	Post05	RO	Fire	3	-67.53	379.68	90.92
4	Pre05	Post01	RO	Fire	4	-63.80	-26.29	-43.27
4	Pre05	Post02	RO	Fire	4	-57.43	28.99	-29.15
4	Pre05	Post05	RO	Fire	4	-79.08	28.99	-34.07
4	Pre10	Post01	RO	Fire	4	-63.80	1.04	-32.94
4	Pre10	Post02	RO	Fire	4	-41.65	28.99	-21.70
4	Pre10	Post05	RO	Fire	4	-71.32	28.99	-28.63

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
4	Pre01	Post01	Low	Control by Proximity	43	-80.14	375.71	14.37
4	Pre01	Post02	Low	Control by Proximity	43	-74.83	393.06	18.20
4	Pre01	Post05	Low	Control by Proximity	43	-70.46	480.95	27.08
4	Pre05	Post01	Low	Control by Proximity	44	-80.50	1464.12	26.72
4	Pre05	Post02	Low	Control by Proximity	45	-81.01	1907.98	77.17
4	Pre05	Post05	Low	Control by Proximity	44	-80.60	1601.45	39.27
4	Pre10	Post01	Low	Control by Proximity	44	-80.14	1464.12	22.99
4	Pre10	Post02	Low	Control by Proximity	45	-78.94	1907.98	73.50
4	Pre10	Post05	Low	Control by Proximity	44	-77.05	1601.45	37.82
4	Pre01	Post01	High	Control by Proximity	44	-85.67	1632.49	67.88
4	Pre01	Post02	High	Control by Proximity	43	-85.67	872.32	27.09
4	Pre01	Post05	High	Control by Proximity	43	-85.67	704.75	24.10
4	Pre05	Post01	High	Control by Proximity	44	-83.51	1509.85	63.85
4	Pre05	Post02	High	Control by Proximity	43	-83.51	872.32	24.15
4	Pre05	Post05	High	Control by Proximity	43	-83.51	704.75	21.35
4	Pre10	Post01	High	Control by Proximity	44	-86.77	1509.85	67.53
4	Pre10	Post02	High	Control by Proximity	43	-86.77	872.32	26.29
4	Pre10	Post05	High	Control by Proximity	43	-86.77	704.75	24.76
4	Pre01	Post01	Peak	Control by Proximity	44	-91.31	673.27	49.89
4	Pre01	Post02	Peak	Control by Proximity	44	-91.31	1697.46	70.68
4	Pre01	Post05	Peak	Control by Proximity	43	-91.31	586.20	51.26
4	Pre05	Post01	Peak	Control by Proximity	43	-94.04	861.59	29.24

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
4	Pre05	Post02	Peak	Control by Proximity	43	-94.04	1870.11	46.32
4	Pre05	Post05	Peak	Control by Proximity	43	-94.04	1882.10	61.12
4	Pre10	Post01	Peak	Control by Proximity	43	-95.66	861.59	33.03
4	Pre10	Post02	Peak	Control by Proximity	43	-95.66	1870.11	49.62
4	Pre10	Post05	Peak	Control by Proximity	43	-95.66	1882.10	64.62
4	Pre01	Post01	RO	Control by Proximity	22	-99.75	396.96	67.76
4	Pre01	Post02	RO	Control by Proximity	22	-99.75	409.64	75.67
4	Pre01	Post05	RO	Control by Proximity	22	-99.75	379.68	65.57
4	Pre05	Post01	RO	Control by Proximity	20	-99.94	207.10	-20.79
4	Pre05	Post02	RO	Control by Proximity	20	-99.93	207.10	-12.55
4	Pre05	Post05	RO	Control by Proximity	20	-99.91	207.10	-21.70
4	Pre10	Post01	RO	Control by Proximity	20	-99.76	129.98	-20.39
4	Pre10	Post02	RO	Control by Proximity	20	-99.73	166.57	-9.34
4	Pre10	Post05	RO	Control by Proximity	20	-99.73	174.54	-19.98
4	Pre01	Post01	Low	Control by Ecozone	55	-66.49	1216.15	59.88
4	Pre01	Post02	Low	Control by Ecozone	55	-63.81	1100.90	48.28
4	Pre01	Post05	Low	Control by Ecozone	55	-64.28	1455.39	44.84
4	Pre05	Post01	Low	Control by Ecozone	55	-66.43	569.55	8.66
4	Pre05	Post02	Low	Control by Ecozone	55	-63.75	485.13	0.35
4	Pre05	Post05	Low	Control by Ecozone	55	-60.20	465.34	-6.57
4	Pre10	Post01	Low	Control by Ecozone	55	-71.18	222.65	1.19
4	Pre10	Post02	Low	Control by Ecozone	55	-68.87	191.03	-6.67

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
4	Pre10	Post05	Low	Control by Ecozone	55	-64.61	276.93	-14.24
4	Pre01	Post01	High	Control by Ecozone	55	-37.37	222.22	21.88
4	Pre01	Post02	High	Control by Ecozone	55	-35.80	361.74	16.46
4	Pre01	Post05	High	Control by Ecozone	55	-53.71	550.55	9.49
4	Pre05	Post01	High	Control by Ecozone	55	-59.54	360.62	13.84
4	Pre05	Post02	High	Control by Ecozone	55	-53.99	434.09	10.25
4	Pre05	Post05	High	Control by Ecozone	55	-55.14	537.44	5.61
4	Pre10	Post01	High	Control by Ecozone	55	-61.55	360.62	15.10
4	Pre10	Post02	High	Control by Ecozone	55	-56.29	434.09	10.27
4	Pre10	Post05	High	Control by Ecozone	55	-52.69	537.44	4.79
4	Pre01	Post01	Peak	Control by Ecozone	55	-74.32	440.53	13.04
4	Pre01	Post02	Peak	Control by Ecozone	55	-74.35	591.92	12.77
4	Pre01	Post05	Peak	Control by Ecozone	55	-48.74	644.45	9.31
4	Pre05	Post01	Peak	Control by Ecozone	55	-73.33	315.46	7.55
4	Pre05	Post02	Peak	Control by Ecozone	55	-63.27	340.46	4.91
4	Pre05	Post05	Peak	Control by Ecozone	55	-58.73	373.90	2.12
4	Pre10	Post01	Peak	Control by Ecozone	55	-74.36	315.46	9.79
4	Pre10	Post02	Peak	Control by Ecozone	55	-64.68	340.46	6.64
4	Pre10	Post05	Peak	Control by Ecozone	55	-60.32	373.90	3.27
4	Pre01	Post01	RO	Control by Ecozone	49	-62.62	396.96	34.05
4	Pre01	Post02	RO	Control by Ecozone	49	-67.75	409.64	35.97
4	Pre01	Post05	RO	Control by Ecozone	49	-74.50	379.68	12.21

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
4	Pre05	Post01	RO	Control by Ecozone	46	-97.03	92.23	-13.69
4	Pre05	Post02	RO	Control by Ecozone	46	-97.33	87.89	-9.69
4	Pre05	Post05	RO	Control by Ecozone	46	-97.05	317.27	-27.47
4	Pre10	Post01	RO	Control by Ecozone	46	-89.70	148.19	2.47
4	Pre10	Post02	RO	Control by Ecozone	46	-90.74	210.94	12.00
4	Pre10	Post05	RO	Control by Ecozone	46	-89.74	283.37	-14.43
9	Pre01	Post01	Low	Fire	11	-66.41	145.09	34.57
9	Pre01	Post02	Low	Fire	11	-42.84	123.15	32.34
9	Pre01	Post05	Low	Fire	11	-27.16	180.28	32.67
9	Pre05	Post01	Low	Fire	11	-64.31	31.95	-10.60
9	Pre05	Post02	Low	Fire	11	-41.83	31.79	-9.67
9	Pre05	Post05	Low	Fire	11	-56.15	47.98	-5.73
9	Pre10	Post01	Low	Fire	11	-64.31	28.23	-12.36
9	Pre10	Post02	Low	Fire	11	-52.81	28.08	-11.09
9	Pre10	Post05	Low	Fire	11	-40.66	23.02	-9.30
9	Pre01	Post01	High	Fire	11	-81.43	63.34	1.19
9	Pre01	Post02	High	Fire	11	-49.38	58.95	5.05
9	Pre01	Post05	High	Fire	11	-12.24	103.17	27.34
9	Pre05	Post01	High	Fire	11	-81.20	59.82	-3.17
9	Pre05	Post02	High	Fire	11	-36.69	67.25	-0.14
9	Pre05	Post05	High	Fire	11	-44.58	109.46	27.76
9	Pre10	Post01	High	Fire	11	-79.16	59.82	-0.01
9	Pre10	Post02	High	Fire	11	-36.69	67.25	3.82
9	Pre10	Post05	High	Fire	11	-38.79	128.10	31.91
9	Pre01	Post01	Peak	Fire	11	-86.52	135.07	6.73
9	Pre01	Post02	Peak	Fire	11	-66.80	99.64	14.88
9	Pre01	Post05	Peak	Fire	11	-36.55	133.98	24.92
9	Pre05	Post01	Peak	Fire	11	-90.03	54.91	1.03
9	Pre05	Post02	Peak	Fire	11	-41.75	117.22	9.54
9	Pre05	Post05	Peak	Fire	11	-36.21	73.16	21.68
9	Pre10	Post01	Peak	Fire	11	-88.59	54.91	8.22
9	Pre10	Post02	Peak	Fire	11	-41.75	117.22	18.53
9	Pre10	Post05	Peak	Fire	11	-32.93	98.08	31.58
9	Pre01	Post01	RO	Fire	2	-22.43	63.11	20.34

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
9	Pre01	Post02	RO	Fire	2	-24.94	34.42	4.74
9	Pre01	Post05	RO	Fire	4	-12.47	223.04	107.91
9	Pre05	Post01	RO	Fire	4	-26.87	362.57	189.08
9	Pre05	Post02	RO	Fire	5	-29.24	1320.72	409.37
9	Pre05	Post05	RO	Fire	7	-17.47	598.37	354.84
9	Pre10	Post01	RO	Fire	4	-43.45	362.57	162.66
9	Pre10	Post02	RO	Fire	5	-53.40	1933.95	514.48
9	Pre10	Post05	RO	Fire	7	-66.02	598.37	371.97
9	Pre01	Post01	Low	Control by Proximity	10	-60.70	145.09	21.43
9	Pre01	Post02	Low	Control by Proximity	10	-57.76	123.15	13.93
9	Pre01	Post05	Low	Control by Proximity	10	-57.67	52.49	16.56
9	Pre05	Post01	Low	Control by Proximity	10	-50.36	61.58	8.69
9	Pre05	Post02	Low	Control by Proximity	10	-40.24	45.16	2.59
9	Pre05	Post05	Low	Control by Proximity	10	-43.10	51.79	7.81
9	Pre10	Post01	Low	Control by Proximity	10	-67.62	61.91	-1.15
9	Pre10	Post02	Low	Control by Proximity	10	-61.01	45.46	-7.00
9	Pre10	Post05	Low	Control by Proximity	10	-62.88	52.10	-3.11
9	Pre01	Post01	High	Control by Proximity	10	-32.53	54.33	3.66
9	Pre01	Post02	High	Control by Proximity	10	-37.43	77.19	3.93
9	Pre01	Post05	High	Control by Proximity	10	-25.70	70.87	10.15
9	Pre05	Post01	High	Control by Proximity	10	-23.96	59.82	-0.53
9	Pre05	Post02	High	Control by Proximity	10	-29.48	67.25	-1.48
9	Pre05	Post05	High	Control by Proximity	10	-16.26	34.42	3.77
9	Pre10	Post01	High	Control by Proximity	10	-66.59	59.82	-2.06
9	Pre10	Post02	High	Control by Proximity	10	-67.70	67.25	-3.21

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
9	Pre10	Post05	High	Control by Proximity	10	-67.86	34.42	2.97
9	Pre01	Post01	Peak	Control by Proximity	10	-32.05	117.15	24.88
9	Pre01	Post02	Peak	Control by Proximity	10	-30.57	224.61	43.59
9	Pre01	Post05	Peak	Control by Proximity	10	-30.87	113.59	33.39
9	Pre05	Post01	Peak	Control by Proximity	10	-36.08	54.91	2.82
9	Pre05	Post02	Peak	Control by Proximity	10	-26.95	117.22	18.01
9	Pre05	Post05	Peak	Control by Proximity	10	-17.81	50.19	11.38
9	Pre10	Post01	Peak	Control by Proximity	10	-64.58	57.74	2.50
9	Pre10	Post02	Peak	Control by Proximity	10	-67.00	117.22	19.54
9	Pre10	Post05	Peak	Control by Proximity	10	-67.14	50.19	12.24
9	Pre01	Post01	RO	Control by Proximity	8	-47.27	26.54	-4.85
9	Pre01	Post02	RO	Control by Proximity	8	-46.38	-4.12	-15.28
9	Pre01	Post05	RO	Control by Proximity	9	-47.88	223.04	15.01
9	Pre05	Post01	RO	Control by Proximity	8	-35.44	1.31	-10.40
9	Pre05	Post02	RO	Control by Proximity	8	-37.80	0.87	-18.30
9	Pre05	Post05	RO	Control by Proximity	9	-21.70	489.76	41.03
9	Pre10	Post01	RO	Control by Proximity	8	-67.55	0.96	-20.01
9	Pre10	Post02	RO	Control by Proximity	8	-67.00	14.22	-27.46
9	Pre10	Post05	RO	Control by Proximity	9	-67.92	489.76	33.24
9	Pre01	Post01	Low	Control by Ecozone	14	-84.02	145.09	1.14
9	Pre01	Post02	Low	Control by Ecozone	14	-56.53	123.15	-2.18
9	Pre01	Post05	Low	Control by Ecozone	14	-62.94	115.72	-6.34

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
9	Pre05	Post01	Low	Control by Ecozone	14	-84.02	63.46	-5.25
9	Pre05	Post02	Low	Control by Ecozone	14	-56.53	57.28	-7.47
9	Pre05	Post05	Low	Control by Ecozone	14	-63.26	82.10	-9.05
9	Pre10	Post01	Low	Control by Ecozone	14	-84.02	63.67	-10.37
9	Pre10	Post02	Low	Control by Ecozone	14	-56.53	45.31	-12.79
9	Pre10	Post05	Low	Control by Ecozone	14	-64.64	56.71	-15.09
9	Pre01	Post01	High	Control by Ecozone	14	-60.61	150.65	5.73
9	Pre01	Post02	High	Control by Ecozone	14	-65.71	147.57	3.49
9	Pre01	Post05	High	Control by Ecozone	14	-69.66	146.64	8.10
9	Pre05	Post01	High	Control by Ecozone	14	-56.15	150.65	0.21
9	Pre05	Post02	High	Control by Ecozone	14	-61.53	147.57	-3.13
9	Pre05	Post05	High	Control by Ecozone	14	-65.96	146.64	-0.14
9	Pre10	Post01	High	Control by Ecozone	14	-65.76	150.65	-3.91
9	Pre10	Post02	High	Control by Ecozone	14	-58.11	147.57	-7.52
9	Pre10	Post05	High	Control by Ecozone	14	-62.94	146.64	-4.59
9	Pre01	Post01	Peak	Control by Ecozone	14	-34.62	274.10	27.75
9	Pre01	Post02	Peak	Control by Ecozone	14	-49.84	265.64	31.42
9	Pre01	Post05	Peak	Control by Ecozone	14	-54.33	312.99	31.26
9	Pre05	Post01	Peak	Control by Ecozone	14	-40.11	274.10	11.28
9	Pre05	Post02	Peak	Control by Ecozone	14	-52.81	265.64	14.40
9	Pre05	Post05	Peak	Control by Ecozone	14	-57.03	312.99	14.83
9	Pre10	Post01	Peak	Control by Ecozone	14	-47.36	274.10	11.35

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
9	Pre10	Post02	Peak	Control by Ecozone	14	-46.56	265.64	14.87
9	Pre10	Post05	Peak	Control by Ecozone	14	-50.44	312.99	15.36
9	Pre01	Post01	RO	Control by Ecozone	13	-77.46	946.81	68.47
9	Pre01	Post02	RO	Control by Ecozone	13	-82.95	946.81	72.65
9	Pre01	Post05	RO	Control by Ecozone	13	-82.58	223.33	10.15
9	Pre05	Post01	RO	Control by Ecozone	13	-87.94	946.81	64.78
9	Pre05	Post02	RO	Control by Ecozone	13	-90.87	946.81	70.20
9	Pre05	Post05	RO	Control by Ecozone	13	-90.68	489.76	27.94
9	Pre10	Post01	RO	Control by Ecozone	13	-86.82	946.81	41.53
9	Pre10	Post02	RO	Control by Ecozone	13	-90.03	946.81	46.65
9	Pre10	Post05	RO	Control by Ecozone	13	-89.82	489.76	8.90
12	Pre01	Post01	Low	Fire	76	-91.92	44.11	-12.83
12	Pre01	Post02	Low	Fire	78	-92.60	44.25	-7.21
12	Pre01	Post05	Low	Fire	78	-89.94	41.83	-7.73
12	Pre05	Post01	Low	Fire	77	-91.92	73.03	-19.22
12	Pre05	Post02	Low	Fire	79	-92.60	55.48	-14.50
12	Pre05	Post05	Low	Fire	79	-89.94	41.64	-15.23
12	Pre10	Post01	Low	Fire	77	-91.92	51.84	-19.37
12	Pre10	Post02	Low	Fire	79	-92.60	36.44	-14.93
12	Pre10	Post05	Low	Fire	79	-89.94	32.18	-15.46
12	Pre01	Post01	High	Fire	76	-71.71	516.47	20.01
12	Pre01	Post02	High	Fire	78	-63.93	524.45	24.38
12	Pre01	Post05	High	Fire	78	-55.27	551.41	31.43
12	Pre05	Post01	High	Fire	77	-69.45	516.47	25.64
12	Pre05	Post02	High	Fire	79	-61.64	524.45	28.39
12	Pre05	Post05	High	Fire	79	-51.68	551.41	36.13
12	Pre10	Post01	High	Fire	77	-78.32	516.47	28.66
12	Pre10	Post02	High	Fire	79	-72.85	524.45	30.63
12	Pre10	Post05	High	Fire	79	-60.68	551.41	38.01
12	Pre01	Post01	Peak	Fire	76	-61.22	916.56	46.61

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
12	Pre01	Post02	Peak	Fire	78	-48.53	941.85	44.83
12	Pre01	Post05	Peak	Fire	78	-39.94	1010.03	54.26
12	Pre05	Post01	Peak	Fire	77	-67.85	916.56	54.62
12	Pre05	Post02	Peak	Fire	79	-57.32	941.85	51.98
12	Pre05	Post05	Peak	Fire	79	-50.20	1010.03	62.98
12	Pre10	Post01	Peak	Fire	77	-70.35	916.56	56.83
12	Pre10	Post02	Peak	Fire	79	-63.78	941.85	52.96
12	Pre10	Post05	Peak	Fire	79	-57.10	1010.03	64.11
12	Pre01	Post01	RO	Fire	23	-63.69	493.12	83.10
12	Pre01	Post02	RO	Fire	23	-44.58	343.19	77.08
12	Pre01	Post05	RO	Fire	25	-32.16	457.19	88.90
12	Pre05	Post01	RO	Fire	24	-86.35	493.12	64.00
12	Pre05	Post02	RO	Fire	24	-86.77	343.19	49.53
12	Pre05	Post05	RO	Fire	26	-86.56	457.19	61.74
12	Pre10	Post01	RO	Fire	24	-86.35	493.12	48.75
12	Pre10	Post02	RO	Fire	24	-86.77	343.19	36.16
12	Pre10	Post05	RO	Fire	26	-86.56	457.19	48.54
12	Pre01	Post01	Low	Control by Proximity	148	-91.92	124.53	-14.17
12	Pre01	Post02	Low	Control by Proximity	150	-92.60	94.07	-10.24
12	Pre01	Post05	Low	Control by Proximity	150	-93.48	75.07	-12.03
12	Pre05	Post01	Low	Control by Proximity	148	-91.92	228.34	-21.20
12	Pre05	Post02	Low	Control by Proximity	150	-92.60	136.01	-17.95
12	Pre05	Post05	Low	Control by Proximity	150	-93.48	62.56	-19.70
12	Pre10	Post01	Low	Control by Proximity	148	-91.92	120.49	-20.88
12	Pre10	Post02	Low	Control by Proximity	150	-92.60	138.48	-17.01
12	Pre10	Post05	Low	Control by Proximity	150	-93.48	148.76	-18.12
12	Pre01	Post01	High	Control by Proximity	148	-82.19	516.47	17.53
12	Pre01	Post02	High	Control by Proximity	150	-59.22	524.45	16.00
12	Pre01	Post05	High	Control by Proximity	150	-70.44	421.27	14.57

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
12	Pre05	Post01	High	Control by Proximity	148	-82.52	516.47	16.60
12	Pre05	Post02	High	Control by Proximity	150	-87.31	524.45	14.28
12	Pre05	Post05	High	Control by Proximity	150	-86.77	421.27	12.02
12	Pre10	Post01	High	Control by Proximity	148	-84.96	516.47	19.05
12	Pre10	Post02	High	Control by Proximity	150	-89.08	524.45	16.17
12	Pre10	Post05	High	Control by Proximity	150	-88.61	421.27	13.67
12	Pre01	Post01	Peak	Control by Proximity	148	-90.48	916.56	36.38
12	Pre01	Post02	Peak	Control by Proximity	150	-64.43	941.85	34.67
12	Pre01	Post05	Peak	Control by Proximity	150	-65.57	861.86	31.84
12	Pre05	Post01	Peak	Control by Proximity	148	-87.29	916.56	37.42
12	Pre05	Post02	Peak	Control by Proximity	150	-87.70	941.85	35.27
12	Pre05	Post05	Peak	Control by Proximity	150	-84.18	861.86	31.81
12	Pre10	Post01	Peak	Control by Proximity	148	-88.69	916.56	39.00
12	Pre10	Post02	Peak	Control by Proximity	150	-90.42	941.85	36.93
12	Pre10	Post05	Peak	Control by Proximity	150	-87.68	861.86	33.22
12	Pre01	Post01	RO	Control by Proximity	64	- 100.00	740.12	54.33
12	Pre01	Post02	RO	Control by Proximity	71	-75.46	731.82	53.32
12	Pre01	Post05	RO	Control by Proximity	69	-84.37	817.32	59.58
12	Pre05	Post01	RO	Control by Proximity	66	- 100.00	1515.46	85.48
12	Pre05	Post02	RO	Control by Proximity	73	-97.76	1499.51	57.64
12	Pre05	Post05	RO	Control by Proximity	72	-97.76	1663.91	82.00
12	Pre10	Post01	RO	Control by Proximity	71	- 100.00	1515.46	66.93

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
12	Pre10	Post02	RO	Control by Proximity	78	-97.65	1499.51	43.96
12	Pre10	Post05	RO	Control by Proximity	78	-97.64	1663.91	66.98
12	Pre01	Post01	Low	Control by Ecozone	249	-54.54	61.04	-13.57
12	Pre01	Post02	Low	Control by Ecozone	249	-55.28	47.89	-10.18
12	Pre01	Post05	Low	Control by Ecozone	249	-59.90	28.78	-17.45
12	Pre05	Post01	Low	Control by Ecozone	249	-58.30	55.70	-19.87
12	Pre05	Post02	Low	Control by Ecozone	249	-52.67	49.22	-16.68
12	Pre05	Post05	Low	Control by Ecozone	249	-58.60	21.06	-23.90
12	Pre10	Post01	Low	Control by Ecozone	249	-59.69	41.70	-23.10
12	Pre10	Post02	Low	Control by Ecozone	249	-54.25	34.15	-20.29
12	Pre10	Post05	Low	Control by Ecozone	249	-59.98	28.81	-26.18
12	Pre01	Post01	High	Control by Ecozone	249	-48.36	83.88	0.94
12	Pre01	Post02	High	Control by Ecozone	249	-44.48	56.03	-2.12
12	Pre01	Post05	High	Control by Ecozone	249	-49.33	63.41	-7.43
12	Pre05	Post01	High	Control by Ecozone	249	-47.33	92.90	0.99
12	Pre05	Post02	High	Control by Ecozone	249	-43.37	36.92	-3.44
12	Pre05	Post05	High	Control by Ecozone	249	-48.32	36.92	-9.12
12	Pre10	Post01	High	Control by Ecozone	249	-49.56	92.90	2.15
12	Pre10	Post02	High	Control by Ecozone	249	-45.76	50.64	-2.80
12	Pre10	Post05	High	Control by Ecozone	249	-50.50	39.35	-9.08
12	Pre01	Post01	Peak	Control by Ecozone	249	-52.06	146.49	1.06
12	Pre01	Post02	Peak	Control by Ecozone	249	-43.96	128.15	-2.94

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
12	Pre01	Post05	Peak	Control by Ecozone	249	-43.25	109.56	-6.67
12	Pre05	Post01	Peak	Control by Ecozone	249	-55.37	85.68	4.88
12	Pre05	Post02	Peak	Control by Ecozone	249	-50.76	52.76	-0.62
12	Pre05	Post05	Peak	Control by Ecozone	249	-46.36	52.76	-4.97
12	Pre10	Post01	Peak	Control by Ecozone	249	-55.27	116.22	4.74
12	Pre10	Post02	Peak	Control by Ecozone	249	-50.66	73.18	-0.87
12	Pre10	Post05	Peak	Control by Ecozone	249	-46.24	61.42	-5.81
12	Pre01	Post01	RO	Control by Ecozone	211	-100.00	362.73	-7.04
12	Pre01	Post02	RO	Control by Ecozone	201	-75.23	976.22	9.05
12	Pre01	Post05	RO	Control by Ecozone	181	-83.67	1910.04	59.67
12	Pre05	Post01	RO	Control by Ecozone	211	-100.00	155.42	-44.76
12	Pre05	Post02	RO	Control by Ecozone	201	-99.06	1009.88	-42.13
12	Pre05	Post05	RO	Control by Ecozone	176	-97.79	289.70	-48.22
12	Pre10	Post01	RO	Control by Ecozone	211	-100.00	53.52	-65.01
12	Pre10	Post02	RO	Control by Ecozone	201	-98.08	922.38	-62.18
12	Pre10	Post05	RO	Control by Ecozone	176	-96.49	258.98	-72.65
13	Pre01	Post01	Low	Fire	54	-85.56	350.86	24.82
13	Pre01	Post02	Low	Fire	54	-85.61	398.28	34.17
13	Pre01	Post05	Low	Fire	54	-82.22	388.62	42.69
13	Pre05	Post01	Low	Fire	54	-85.56	146.74	-2.99
13	Pre05	Post02	Low	Fire	54	-85.61	193.38	6.34
13	Pre05	Post05	Low	Fire	54	-82.22	233.82	10.57
13	Pre10	Post01	Low	Fire	55	-85.56	272.51	3.42
13	Pre10	Post02	Low	Fire	55	-85.61	325.21	12.86
13	Pre10	Post05	Low	Fire	56	-82.22	742.81	28.55
13	Pre01	Post01	High	Fire	54	-59.93	154.32	9.44

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
13	Pre01	Post02	High	Fire	54	-57.05	160.13	12.09
13	Pre01	Post05	High	Fire	54	-54.99	302.38	22.95
13	Pre05	Post01	High	Fire	54	-67.66	419.13	7.89
13	Pre05	Post02	High	Fire	54	-64.34	328.41	10.30
13	Pre05	Post05	High	Fire	54	-63.77	497.86	17.08
13	Pre10	Post01	High	Fire	55	-69.60	361.57	10.68
13	Pre10	Post02	High	Fire	55	-70.33	330.53	13.63
13	Pre10	Post05	High	Fire	56	-63.04	431.57	17.54
13	Pre01	Post01	Peak	Fire	54	-67.87	266.19	22.38
13	Pre01	Post02	Peak	Fire	54	-60.01	311.39	20.53
13	Pre01	Post05	Peak	Fire	54	-60.01	371.01	28.05
13	Pre05	Post01	Peak	Fire	54	-75.76	161.20	10.74
13	Pre05	Post02	Peak	Fire	54	-64.53	199.03	9.28
13	Pre05	Post05	Peak	Fire	54	-59.45	285.07	14.03
13	Pre10	Post01	Peak	Fire	55	-76.31	284.17	17.30
13	Pre10	Post02	Peak	Fire	55	-69.67	339.81	15.17
13	Pre10	Post05	Peak	Fire	56	-60.36	328.92	21.10
13	Pre01	Post01	RO	Fire	22	-97.98	108.92	2.50
13	Pre01	Post02	RO	Fire	22	-45.19	1121.32	57.30
13	Pre01	Post05	RO	Fire	22	-54.18	745.75	46.28
13	Pre05	Post01	RO	Fire	26	-98.06	156.79	-20.63
13	Pre05	Post02	RO	Fire	26	-90.62	1112.77	24.76
13	Pre05	Post05	RO	Fire	26	-90.77	739.83	12.22
13	Pre10	Post01	RO	Fire	27	-97.75	111.31	-30.90
13	Pre10	Post02	RO	Fire	27	-79.00	1073.83	10.51
13	Pre10	Post05	RO	Fire	27	-83.22	712.87	-3.61
13	Pre01	Post01	Low	Control by Proximity	88	-92.04	385.23	7.70
13	Pre01	Post02	Low	Control by Proximity	88	-91.92	243.60	7.15
13	Pre01	Post05	Low	Control by Proximity	88	-92.48	220.87	-1.45
13	Pre05	Post01	Low	Control by Proximity	88	-88.51	305.70	13.83
13	Pre05	Post02	Low	Control by Proximity	91	-88.35	286.32	21.97
13	Pre05	Post05	Low	Control by Proximity	91	-89.15	207.77	7.65
13	Pre10	Post01	Low	Control by Proximity	92	-89.20	312.29	14.70

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
13	Pre10	Post02	Low	Control by Proximity	95	-89.05	305.73	21.23
13	Pre10	Post05	Low	Control by Proximity	95	-89.80	303.33	6.56
13	Pre01	Post01	High	Control by Proximity	88	-79.41	114.52	-8.95
13	Pre01	Post02	High	Control by Proximity	88	-87.06	118.67	-3.16
13	Pre01	Post05	High	Control by Proximity	88	-77.49	94.76	-7.68
13	Pre05	Post01	High	Control by Proximity	88	-80.64	160.95	3.37
13	Pre05	Post02	High	Control by Proximity	91	-87.83	342.64	20.05
13	Pre05	Post05	High	Control by Proximity	91	-78.84	207.93	8.57
13	Pre10	Post01	High	Control by Proximity	92	-78.03	268.36	15.16
13	Pre10	Post02	High	Control by Proximity	95	-75.48	342.64	30.96
13	Pre10	Post05	High	Control by Proximity	95	-69.00	251.77	15.86
13	Pre01	Post01	Peak	Control by Proximity	88	-88.97	93.36	-12.24
13	Pre01	Post02	Peak	Control by Proximity	88	-87.91	111.72	-7.88
13	Pre01	Post05	Peak	Control by Proximity	88	-80.46	122.01	-6.42
13	Pre05	Post01	Peak	Control by Proximity	88	-89.12	147.69	-2.62
13	Pre05	Post02	Peak	Control by Proximity	91	-89.15	476.22	18.33
13	Pre05	Post05	Peak	Control by Proximity	91	-80.68	392.31	13.77
13	Pre10	Post01	Peak	Control by Proximity	92	-89.22	279.87	6.93
13	Pre10	Post02	Peak	Control by Proximity	95	-82.04	476.22	26.82
13	Pre10	Post05	Peak	Control by Proximity	95	-77.93	392.31	20.47
13	Pre01	Post01	RO	Control by Proximity	68	- 100.00	701.14	16.10
13	Pre01	Post02	RO	Control by Proximity	68	- 100.00	701.14	22.44

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
13	Pre01	Post05	RO	Control by Proximity	68	-100.00	701.14	24.93
13	Pre05	Post01	RO	Control by Proximity	68	-100.00	101.23	-22.65
13	Pre05	Post02	RO	Control by Proximity	68	-100.00	127.11	-16.46
13	Pre05	Post05	RO	Control by Proximity	68	-100.00	164.11	-14.41
13	Pre10	Post01	RO	Control by Proximity	73	-100.00	541.73	-12.77
13	Pre10	Post02	RO	Control by Proximity	73	-100.00	577.56	-5.91
13	Pre10	Post05	RO	Control by Proximity	73	-100.00	716.87	4.89
13	Pre01	Post01	Low	Control by Ecozone	106	-56.50	153.11	11.72
13	Pre01	Post02	Low	Control by Ecozone	106	-46.57	134.16	13.31
13	Pre01	Post05	Low	Control by Ecozone	106	-59.22	196.70	18.57
13	Pre05	Post01	Low	Control by Ecozone	106	-56.67	231.56	27.01
13	Pre05	Post02	Low	Control by Ecozone	106	-50.27	206.73	29.32
13	Pre05	Post05	Low	Control by Ecozone	106	-62.05	248.10	35.73
13	Pre10	Post01	Low	Control by Ecozone	106	-54.14	245.83	39.87
13	Pre10	Post02	Low	Control by Ecozone	106	-44.10	304.49	43.19
13	Pre10	Post05	Low	Control by Ecozone	106	-57.34	307.64	50.11
13	Pre01	Post01	High	Control by Ecozone	106	-55.80	149.32	20.62
13	Pre01	Post02	High	Control by Ecozone	106	-51.75	156.34	19.67
13	Pre01	Post05	High	Control by Ecozone	106	-51.19	107.09	11.23
13	Pre05	Post01	High	Control by Ecozone	106	-36.87	197.06	41.09
13	Pre05	Post02	High	Control by Ecozone	106	-31.08	205.42	39.44
13	Pre05	Post05	High	Control by Ecozone	106	-41.72	142.69	28.84

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
13	Pre10	Post01	High	Control by Ecozone	106	-27.24	243.12	61.37
13	Pre10	Post02	High	Control by Ecozone	106	-27.96	249.29	58.79
13	Pre10	Post05	High	Control by Ecozone	106	-34.73	186.87	46.35
13	Pre01	Post01	Peak	Control by Ecozone	106	-46.80	126.36	4.69
13	Pre01	Post02	Peak	Control by Ecozone	106	-46.01	108.67	5.64
13	Pre01	Post05	Peak	Control by Ecozone	106	-45.55	83.25	1.06
13	Pre05	Post01	Peak	Control by Ecozone	106	-33.51	148.98	26.50
13	Pre05	Post02	Peak	Control by Ecozone	106	-32.52	158.49	27.55
13	Pre05	Post05	Peak	Control by Ecozone	106	-36.13	111.92	21.59
13	Pre10	Post01	Peak	Control by Ecozone	106	-28.95	198.70	44.80
13	Pre10	Post02	Peak	Control by Ecozone	106	-35.61	202.70	45.49
13	Pre10	Post05	Peak	Control by Ecozone	106	-31.50	148.16	38.51
13	Pre01	Post01	RO	Control by Ecozone	87	-85.75	201.95	7.01
13	Pre01	Post02	RO	Control by Ecozone	87	-81.27	207.20	9.39
13	Pre01	Post05	RO	Control by Ecozone	87	-78.42	58.14	4.68
13	Pre05	Post01	RO	Control by Ecozone	87	-56.40	217.74	10.02
13	Pre05	Post02	RO	Control by Ecozone	87	-47.57	223.27	12.69
13	Pre05	Post05	RO	Control by Ecozone	87	-47.57	66.41	7.89
13	Pre10	Post01	RO	Control by Ecozone	87	-44.79	211.03	20.90
13	Pre10	Post02	RO	Control by Ecozone	87	-35.03	216.45	23.40
13	Pre10	Post05	RO	Control by Ecozone	87	-35.03	65.06	18.07
14	Pre01	Post01	Low	Fire	338	-94.80	1474.24	35.20
14	Pre01	Post02	Low	Fire	337	-95.08	1276.16	39.37

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
14	Pre01	Post05	Low	Fire	338	-91.50	1730.28	48.43
14	Pre05	Post01	Low	Fire	353	-100.00	1102.79	14.68
14	Pre05	Post02	Low	Fire	353	-99.70	1174.97	21.75
14	Pre05	Post05	Low	Fire	355	-99.84	936.26	22.64
14	Pre10	Post01	Low	Fire	356	-100.00	837.57	12.04
14	Pre10	Post02	Low	Fire	356	-99.85	814.98	19.10
14	Pre10	Post05	Low	Fire	359	-99.92	727.71	20.38
14	Pre01	Post01	High	Fire	351	-91.99	1097.91	43.44
14	Pre01	Post02	High	Fire	355	-86.97	1794.84	57.29
14	Pre01	Post05	High	Fire	354	-84.43	1796.41	62.48
14	Pre05	Post01	High	Fire	361	-99.91	1283.51	28.71
14	Pre05	Post02	High	Fire	364	-99.89	1497.40	30.17
14	Pre05	Post05	High	Fire	365	-99.91	1756.81	36.49
14	Pre10	Post01	High	Fire	363	-99.94	1810.09	32.97
14	Pre10	Post02	High	Fire	367	-99.93	1931.55	35.20
14	Pre10	Post05	High	Fire	370	-99.94	1931.55	45.72
14	Pre01	Post01	Peak	Fire	351	-90.39	1321.65	53.01
14	Pre01	Post02	Peak	Fire	353	-84.89	1369.04	60.74
14	Pre01	Post05	Peak	Fire	352	-83.34	1311.62	67.14
14	Pre05	Post01	Peak	Fire	361	-99.93	1138.53	30.92
14	Pre05	Post02	Peak	Fire	364	-99.88	1220.14	34.52
14	Pre05	Post05	Peak	Fire	364	-99.91	862.17	37.89
14	Pre10	Post01	Peak	Fire	363	-99.95	1950.37	36.02
14	Pre10	Post02	Peak	Fire	367	-99.92	1831.16	38.57
14	Pre10	Post05	Peak	Fire	370	-99.94	1831.16	50.63
14	Pre01	Post01	RO	Fire	146	-100.00	189.81	3.80
14	Pre01	Post02	RO	Fire	146	-100.00	1457.18	76.57
14	Pre01	Post05	RO	Fire	148	-100.00	916.50	57.22
14	Pre05	Post01	RO	Fire	151	-100.00	667.57	15.22
14	Pre05	Post02	RO	Fire	151	-100.00	1820.69	100.31
14	Pre05	Post05	RO	Fire	153	-100.00	965.17	72.37
14	Pre10	Post01	RO	Fire	159	-100.00	1281.63	14.77

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
14	Pre10	Post02	RO	Fire	159	- 100.00	1857.43	94.92
14	Pre10	Post05	RO	Fire	161	- 100.00	1005.41	66.81
14	Pre01	Post01	Low	Control by Proximity	492	-93.25	1210.59	16.11
14	Pre01	Post02	Low	Control by Proximity	494	-88.53	1755.93	39.27
14	Pre01	Post05	Low	Control by Proximity	494	-94.58	1113.33	45.36
14	Pre05	Post01	Low	Control by Proximity	495	-97.69	1960.43	18.61
14	Pre05	Post02	Low	Control by Proximity	496	-96.95	1703.72	28.01
14	Pre05	Post05	Low	Control by Proximity	498	-95.20	1492.19	36.86
14	Pre10	Post01	Low	Control by Proximity	496	-97.69	1627.04	15.77
14	Pre10	Post02	Low	Control by Proximity	497	-97.09	921.18	22.79
14	Pre10	Post05	Low	Control by Proximity	505	-95.46	1326.81	32.72
14	Pre01	Post01	High	Control by Proximity	494	-90.26	903.13	23.77
14	Pre01	Post02	High	Control by Proximity	494	-88.44	978.00	26.36
14	Pre01	Post05	High	Control by Proximity	494	-93.85	1586.51	52.12
14	Pre05	Post01	High	Control by Proximity	495	-97.36	1054.28	24.48
14	Pre05	Post02	High	Control by Proximity	495	-96.81	1196.26	25.83
14	Pre05	Post05	High	Control by Proximity	498	-96.33	1034.40	40.04
14	Pre10	Post01	High	Control by Proximity	497	-96.51	1054.28	26.21
14	Pre10	Post02	High	Control by Proximity	497	-95.80	1196.26	26.57
14	Pre10	Post05	High	Control by Proximity	505	-95.79	1034.40	35.52
14	Pre01	Post01	Peak	Control by Proximity	494	-88.89	993.86	22.39
14	Pre01	Post02	Peak	Control by Proximity	495	-87.33	1348.98	28.21

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
14	Pre01	Post05	Peak	Control by Proximity	493	-93.34	1226.62	45.49
14	Pre05	Post01	Peak	Control by Proximity	495	-97.90	1312.80	23.65
14	Pre05	Post02	Peak	Control by Proximity	496	-97.77	1879.64	28.94
14	Pre05	Post05	Peak	Control by Proximity	498	-97.70	1171.33	38.22
14	Pre10	Post01	Peak	Control by Proximity	497	-97.59	1312.80	25.91
14	Pre10	Post02	Peak	Control by Proximity	497	-97.45	1256.66	26.75
14	Pre10	Post05	Peak	Control by Proximity	505	-97.38	1171.33	35.48
14	Pre01	Post01	RO	Control by Proximity	349	- 100.00	1553.04	36.59
14	Pre01	Post02	RO	Control by Proximity	348	- 100.00	1698.65	57.97
14	Pre01	Post05	RO	Control by Proximity	347	- 100.00	1472.75	69.17
14	Pre05	Post01	RO	Control by Proximity	366	- 100.00	1063.24	34.67
14	Pre05	Post02	RO	Control by Proximity	365	- 100.00	1730.00	54.09
14	Pre05	Post05	RO	Control by Proximity	363	- 100.00	1826.63	80.57
14	Pre10	Post01	RO	Control by Proximity	371	- 100.00	1643.15	21.07
14	Pre10	Post02	RO	Control by Proximity	376	- 100.00	1823.76	60.80
14	Pre10	Post05	RO	Control by Proximity	374	- 100.00	1788.48	76.78
14	Pre01	Post01	Low	Control by Ecozone	639	-55.37	440.07	13.34
14	Pre01	Post02	Low	Control by Ecozone	639	-61.72	275.28	21.85
14	Pre01	Post05	Low	Control by Ecozone	639	-50.73	445.20	34.44
14	Pre05	Post01	Low	Control by Ecozone	639	-52.21	284.03	2.47
14	Pre05	Post02	Low	Control by Ecozone	639	-60.74	262.23	10.38
14	Pre05	Post05	Low	Control by Ecozone	639	-49.47	221.01	20.97

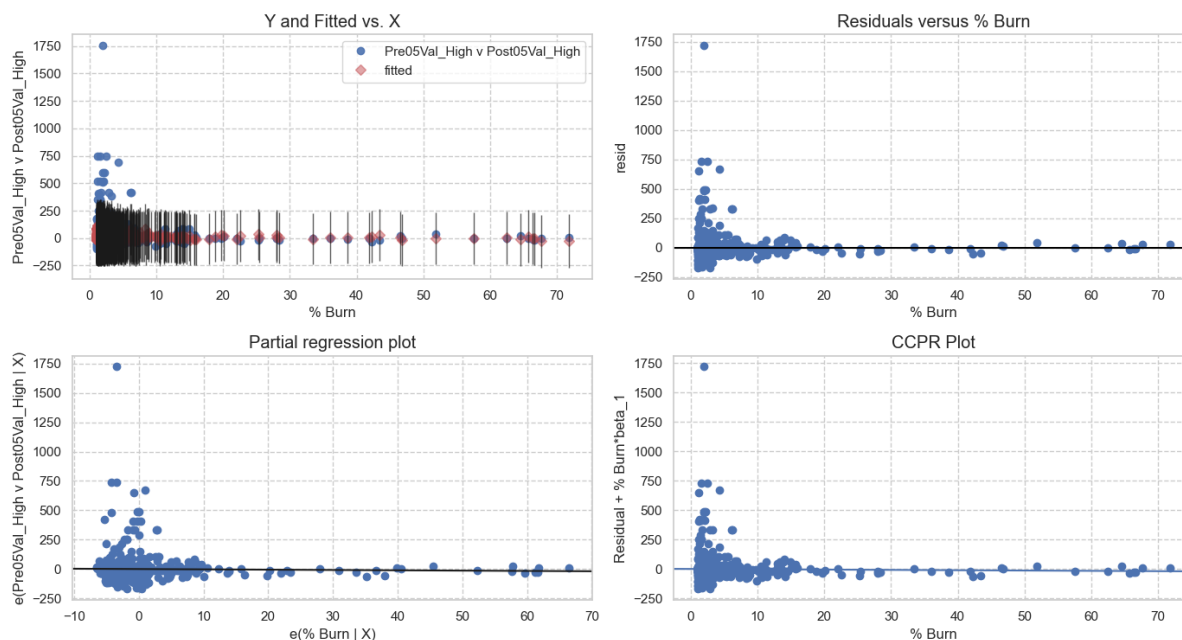
Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
14	Pre10	Post01	Low	Control by Ecozone	639	-56.95	242.11	0.76
14	Pre10	Post02	Low	Control by Ecozone	639	-60.92	192.95	8.03
14	Pre10	Post05	Low	Control by Ecozone	639	-51.97	141.65	15.78
14	Pre01	Post01	High	Control by Ecozone	639	-51.04	153.11	6.64
14	Pre01	Post02	High	Control by Ecozone	639	-57.65	171.49	12.16
14	Pre01	Post05	High	Control by Ecozone	639	-59.92	173.15	18.45
14	Pre05	Post01	High	Control by Ecozone	639	-65.70	183.68	6.36
14	Pre05	Post02	High	Control by Ecozone	639	-56.52	173.70	10.41
14	Pre05	Post05	High	Control by Ecozone	639	-53.52	175.37	13.90
14	Pre10	Post01	High	Control by Ecozone	639	-65.66	167.65	7.29
14	Pre10	Post02	High	Control by Ecozone	639	-57.84	137.61	10.80
14	Pre10	Post05	High	Control by Ecozone	639	-50.66	139.07	13.20
14	Pre01	Post01	Peak	Control by Ecozone	639	-50.32	136.97	5.07
14	Pre01	Post02	Peak	Control by Ecozone	639	-56.45	153.78	8.35
14	Pre01	Post05	Peak	Control by Ecozone	639	-58.98	168.39	15.01
14	Pre05	Post01	Peak	Control by Ecozone	639	-67.00	167.38	4.66
14	Pre05	Post02	Peak	Control by Ecozone	639	-57.72	158.29	8.10
14	Pre05	Post05	Peak	Control by Ecozone	639	-53.27	173.17	12.07
14	Pre10	Post01	Peak	Control by Ecozone	639	-66.55	156.84	5.98
14	Pre10	Post02	Peak	Control by Ecozone	639	-57.33	133.04	9.11
14	Pre10	Post05	Peak	Control by Ecozone	639	-49.16	141.17	11.72
14	Pre01	Post01	RO	Control by Ecozone	521	-90.81	175.78	-1.57

Ecozone	Pre-Year	Post Year	Flow Metric	C/ F	Count	Min	Max	Mean
14	Pre01	Post02	RO	Control by Ecozone	521	-92.97	937.76	33.86
14	Pre01	Post05	RO	Control by Ecozone	522	-94.03	903.49	68.75
14	Pre05	Post01	RO	Control by Ecozone	522	-87.82	1865.78	-9.18
14	Pre05	Post02	RO	Control by Ecozone	522	-84.88	1804.54	23.10
14	Pre05	Post05	RO	Control by Ecozone	522	-80.08	465.32	37.06
14	Pre10	Post01	RO	Control by Ecozone	522	-80.41	1348.56	-9.45
14	Pre10	Post02	RO	Control by Ecozone	522	-76.05	1303.43	16.96
14	Pre10	Post05	RO	Control by Ecozone	522	-70.51	433.11	32.36

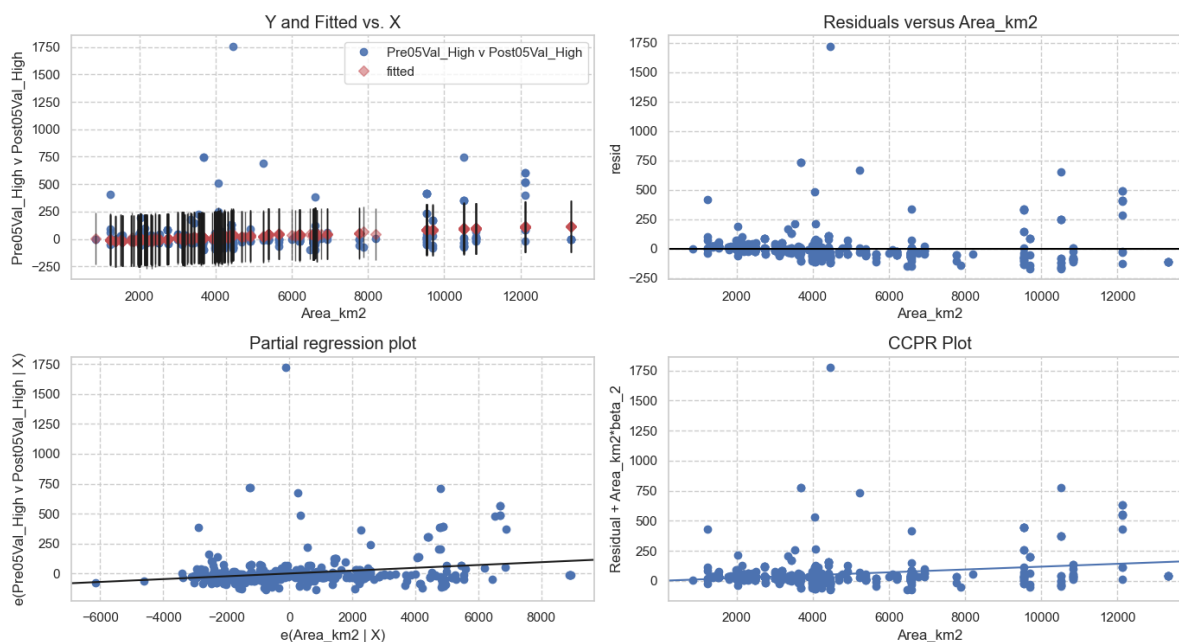
Appendix IX: Sample outputs for regression model, showing 4 plots of regression results for each regressor (independent variable): 'endog versus exog', 'residuals versus exog', 'fitted versus exog', and 'fitted plus residual versus exog'.

FIRE

Regression Plots for % Burn

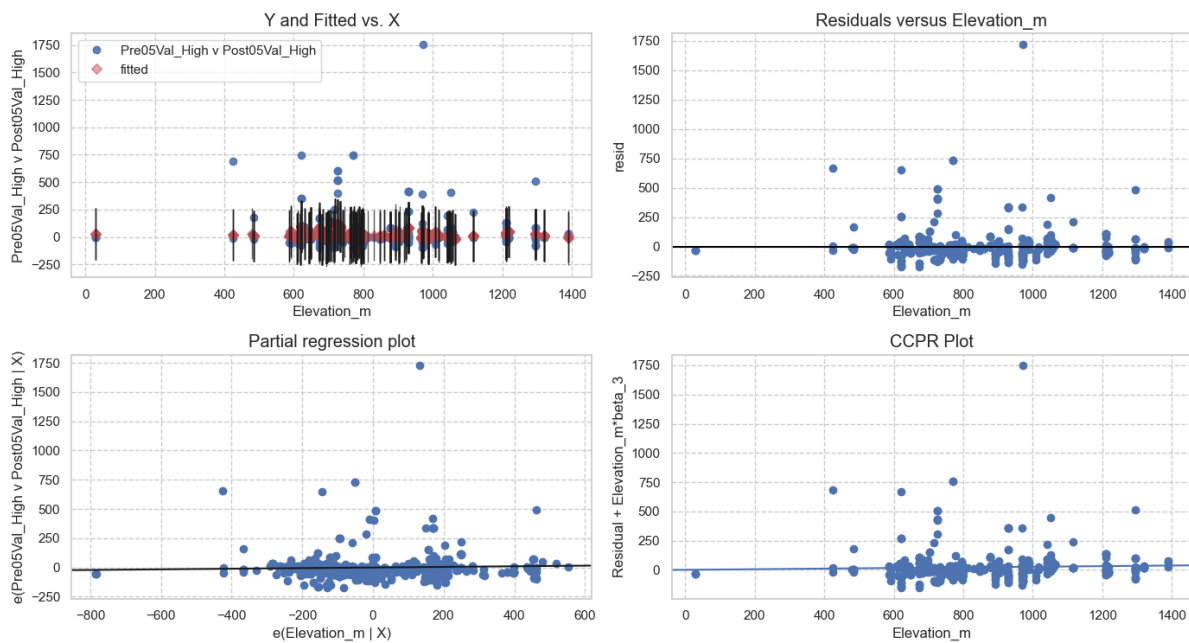


Regression Plots for Area_km2

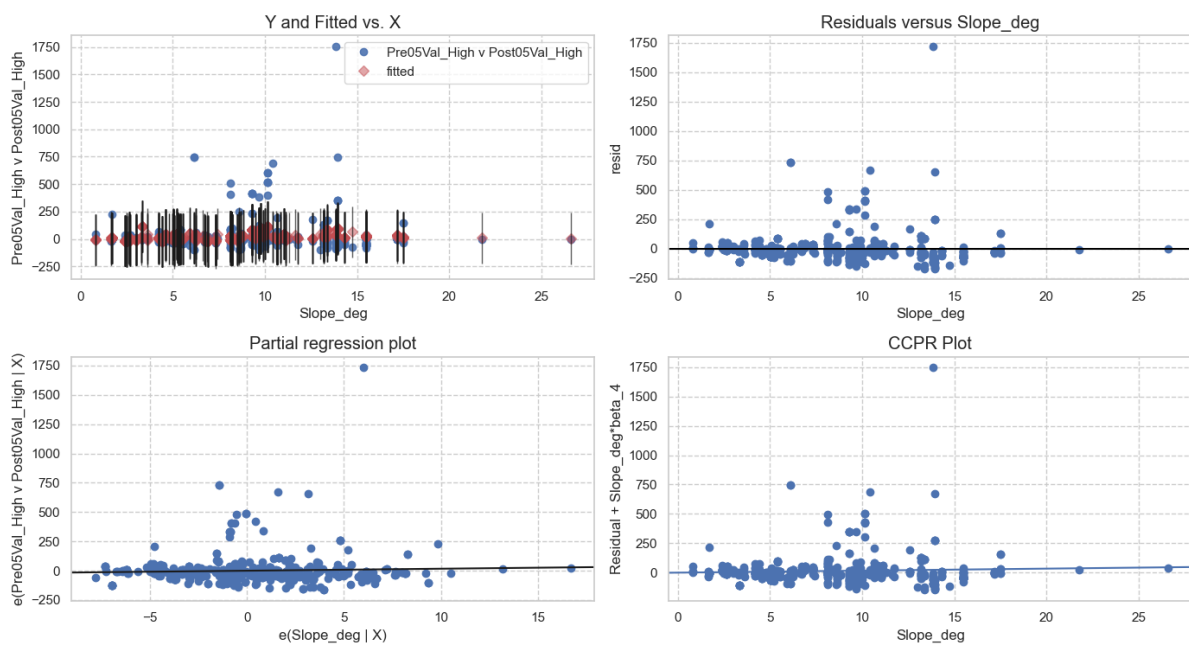


FIRE

Regression Plots for Elevation_m

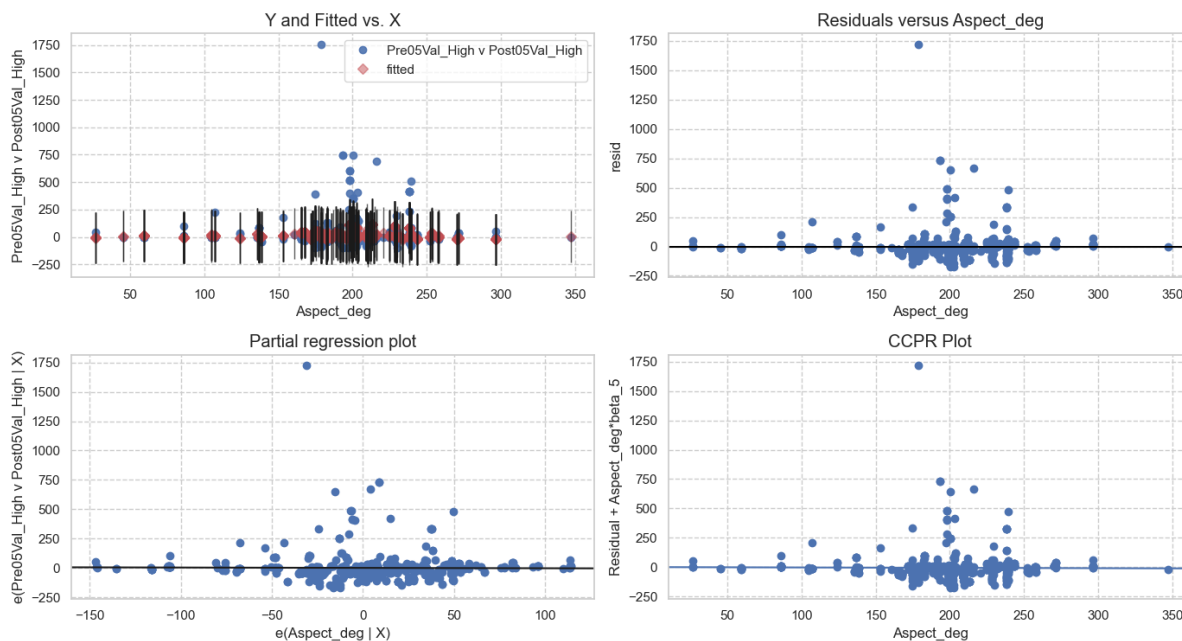


Regression Plots for Slope_deg

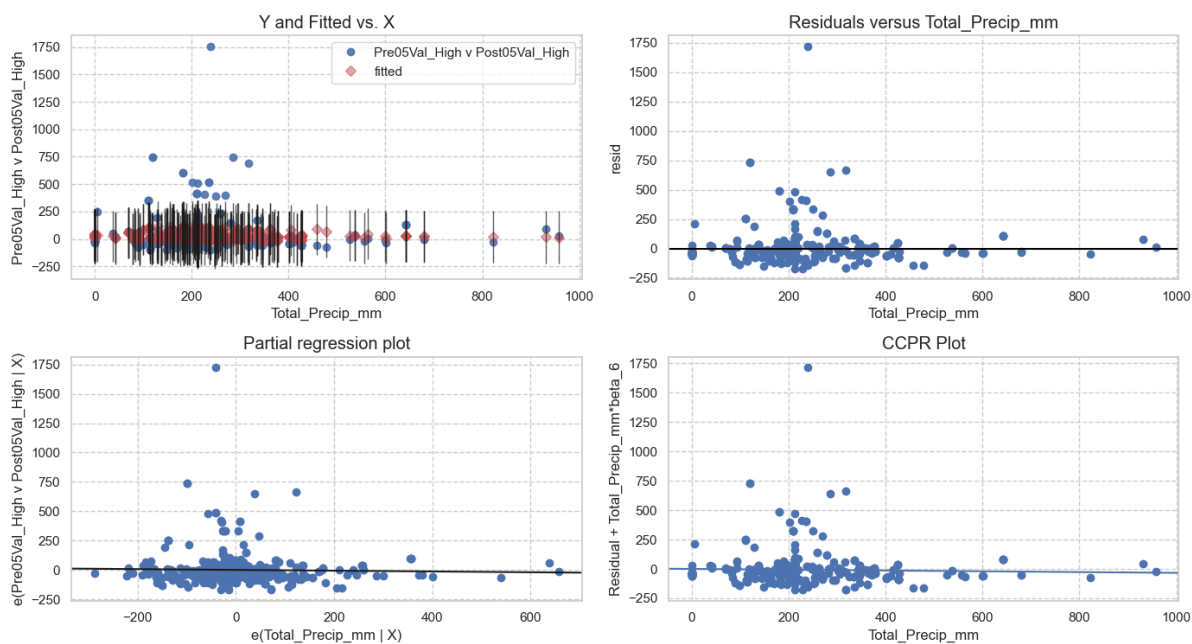


FIRE

Regression Plots for Aspect_deg



Regression Plots for Total_Precip_mm



FIRE

Regression Plots for Max_Temp_C

