Effects of Restoration on Water Quality in a Sierra Nevada Meadow

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In

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by

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San Francisco, California

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Certification of Approval

I certify that I have read Effects of Restoration on Water Quality in a Sierra Nevada Meadow by Nicholas David Fetherston, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requirement for the degree Master of Arts in Geography: Resource Management and Environmental Planning at San Francisco State University.

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2022

Sierra Nevada meadows have the capacity to improve water quality by filtering out non-point source (NPS) pollutants and releasing clean water downstream. Red Clover Valley (RCV) is a large Sierra Nevada meadow currently undergoing restoration along two creeks that flow through the meadow. Under current climate warming predictions, meadows will experience higher air temperatures and less seasonal snowpack, threatening water availability, which has implications for water quality, ecological function, and community resources. Restoration looks to promote water storage at higher elevations for longer periods of time, increasing late summer stream flows, improving water quality, and supporting aquatic habitats. This research investigated water quality along two creeks in RCV which used different restoration techniques. Water quality varied between Red Clover Creek, influenced by grade control structures (GCS), and Dixie Creek, influenced by beaver dam analogs (BDAs). Dixie Creek had cooler stream temperatures and disrupted nutrient transport downstream, whereas Red Clover Creek had higher stream temperatures and greater nutrient transport downstream. Upstream vegetation was highly correlated with lower stream temperatures later in the growing season. This supports core conceptual models for meadow hydrology where greater upstream riparian vegetation can limit daily maximum stream temperatures during low flow periods by promoting groundwater and providing riparian shade. Locations of potential groundwater sources, contributing to cooler stream temperatures, are highlighted, and supported by other water quality data. Diel cycles of pH, dissolved oxygen (DO), and inorganic carbon were also observed suggesting a strong influence of photosynthesis and respiration occurring in the water column. This temporal trend could indicate episodic acidification and should further be investigated. Continued monitoring of water quality in RCV will provide useful information for adaptive management and may serve as a tool for planners to understand how meadow restoration influences water quality.

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1. Introduction

1.1 Sierra Nevada Meadows

Sierra Nevada meadows are key watershed features because of their influence on hydrology (American Rivers, 2012; Vernon et al., 2019). Sierra Nevada meadows are low gradient alluvium filled basins located in an elevation belt between 1,220 and 2,440 meters (Purdy & Moyle, 2009). As water flows downstream and enters meadows, it has the potential to move both vertically down into the ground as well as laterally across the floodplain. This hydrologic movement allows water to be stored in meadows for extended periods of time before it is eventually released downstream. Storing water at higher elevations for longer periods of time reduces environmental risks in California by increasing water availability during the dry season and providing flood attenuation during the wet season (Davis et al., 2020; Ficklin et al., 2013; Null et al., 2013). Under healthy and non-degraded states, meadows can also improve water quality by reducing sediment loads and filtering out non-point source (NPS) pollutants such as excess nutrients and harmful pathogens (Derlet et al., 2010).

Other benefits provided by montane meadows include ecological services such as carbon sequestration, fire suppression, and unique habitats supporting high levels of biodiversity for native plant, animal, and fish species. When meadows are unhealthy, with degraded streams, these benefits are drastically decreased or eliminated, threatening ecosystems at various scales (individual organisms, populations, communities) (Burchsted et al., 2010; NFWF, 2010). Over the past one and a half centuries, common land use practices in the Sierra Nevada have transformed healthy meadows into degraded meadows. These land use practices include grazing, logging, and construction of railroads, roads, diversions, culverts, and ditches (Viers et al., 2013).

1.2 Healthy vs. Degraded Meadows

Healthy meadows can be distinguished from unhealthy meadows based on their landscape features. Healthy meadows have meandering creeks, riparian vegetation such as willows and alders, aquatic habitat conditions for native fish, lush wetland vegetation across the floodplain, and conditions contributing to a high water table through soil infiltration and groundwater recharge (The Sierra Fund, 2021). An unhealthy meadow has eroded stream channels with a low water table, drier vegetation communities, and limited habitat for biodiversity. Water availability directly influences vegetation communities which play a large role in the geomorphic and hydrologic cycles of the meadow. The relationships among vegetation, geomorphology, and hydrology, creates a dynamic feedback loop that can either increase or decrease the health of a meadow (American Rivers, 2012; Viers et al., 2013).

A healthy meadow has a hydrologic cycle that functions through a positive feedback loop (Figure 1). Rainfall and snowmelt are the inputs to the system. When water infiltrates into the soil more often than running off on the surface, groundwater levels increase and flooding of the meadow occurs more frequently during runoff events (Vernon et al., 2019). Flooding of the meadow in this manor allows for the growth and development of mesic and hydric vegetation which helps stabilize the stream channels. Increased stream bank stability allows for the initial process of flooding the meadow to continue and maintain the cycle (Viers et al., 2013). This hydrologic cycle is key to sustaining water availability and other benefits provided by meadows.

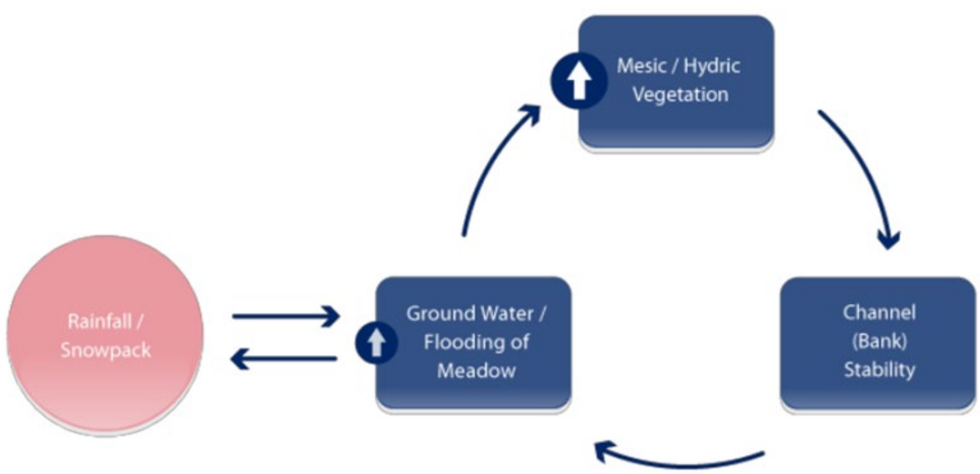

Figure 1: Hydrologic process and function in a healthy meadow (From: Viers et al., 2013).

Unhealthy meadows are driven by the incision cycle (Figure 2), which also functions in a feedback loop (NFWF, 2010, Viers et al., 2013). Incision is the downcutting of a stream bed and lowering of the water table and the effects can be further exaggerated under current climate warming predictions (Ficklin et al., 2013). Increases in air temperature leads to more rainfall and less snowpack, adding more water as surface runoff, resulting in less water for groundwater recharge. This decrease in groundwater decreases mesic and hydric vegetation which leads to higher susceptibility to streambank erosion. As this process continues it leads to more runoff and deeper incision of the channel, further dropping the water table and degrading the landscape (Viers et al., 2013).

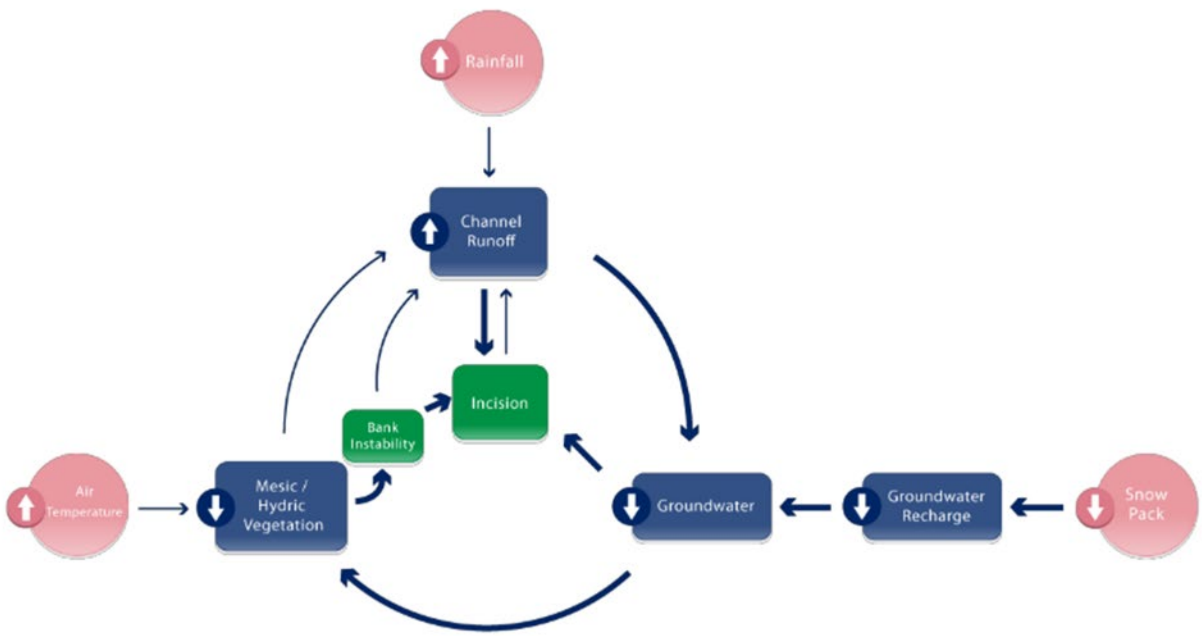

Figure 2: Accelerated incision cycle from degradation with predicted Sierra Nevada climate change considerations (From: Viers et al., 2013).

1.3 Water Quality of Montane Meadows

Sierra Nevada meadow water quality is critical to humans who depend on the watershed as well as ecosystems that have specific requirements for the physical, chemical, and biological parameters of that water. Meadows are commonly located at the headwaters of Sierra Nevada watersheds; therefore, if water is contaminated at the source, it can affect the whole system that communities and ecosystems depends on (Myers & Whited, 2012). With increasing risk of drought, it is critical to ensure the water that is available meets quality standards for beneficial uses of both humans and ecosystems downstream.

A variety of environmental factors can influence water quality including geology, soils, stream morphology, climate, water source, local biota, land use practices, and other basin characteristics (Nilsson, 2009; Vernon et al., 2019; Viers et al., 2013). Meadows have the potential to improve water quality by filtering out contaminants. One way this process occurs is through decreasing stream velocity, allowing sediment and nutrients to be deposited. Another process is through increases in groundwater inputs, allowing water to flow through the soil like a filter before it is released downstream. Alternatively, if the landscape has steep slopes with high stream velocity, more runoff will occur than infiltration, and erosion rates will increase leading to outputs with higher concentrations of sediment and associated nutrients and pathogens (Clow et al., 2018; Levine & Meyer, 2019; Lohse et al., 2009).

Riparian vegetation can also play a large role in meadow water quality. Compared to dry meadow plant species, wet meadow plant species have larger and stronger roots with the ability to take up excess nutrients (Blank et al., 2006). Strong roots also improve stream bank stability, further supporting the positive feedback loop that allows for greater groundwater input compared to surface runoff (see Figure 1). Another benefit from increased riparian vegetation is reduced solar exposure (Willis et al., 2012). During summer months, meadow streams can reach dangerously high temperatures, exceeding native fish survival thresholds (Table 1) (UC Davis, 2021a). Maintaining cover from solar radiation can ensure aquatic habitats are suitable year-round. High stream temperatures can also decrease dissolved oxygen (DO) levels, increase metabolic rates of aquatic organisms, alter nutrient cycling productivity, and increase chemical reaction rates (Null et al., 2013; Puttock et al., 2018; Williams et al., 2015).

Degraded meadows are typically associated with poor water quality (Drew et al., 2016; Hunt & Nylen, 2012; Vernon et al., 2019). Meadow restoration projects aim to reverse the incision cycle (see Figure 2) and return meadows to desired hydrologic conditions (see Figure 1) where geomorphology, hydrology, and vegetation work together in a self-sustaining manor (Davis et al., 2020; Viers et al., 2013). By reversing incision, the landscape can process water in a manner that releases higher quality water downstream (Hunt & Nylen, 2012; Vernon et al., 2019). Popular meadow restoration methods include pond-and-plug, grade control structures (GCS), beaver dam analogs (BDA), and cattle exclusion fencing. Many studies have been conducted on individual restoration techniques and have shown that they improve water quality for specific parameters of interest. However, since restoration projects may combine methods and other environmental factors may differ, comparing water quality between two different restoration techniques is difficult. To better understand how specific restoration techniques influence water quality, it would be useful to compare two different restoration techniques on two streams in one meadow. The streams would have more similar environmental influences on water quality and variation between stream water quality may be influenced by the type of restoration technique instead of local environmental factors.

1.4 Study Area

Red Clover Valley (RCV) is a large meadow in the Northern Sierra Nevada range and is part of the Plumas County National Forest (Figure 3). RCV is 1,670 meters above sea level and at the headwaters of the East Branch North Fork Feather River Watershed. Red Clover Creek's watershed is 31,568 hectares and flows to Lake Oroville before being released to the Sacramento River (Plumas Corporation, 2013b). RCV primarily receives water from two streams, draining from two different sub basins. Red Clover Creek flows west-northwest from Horton Ridge, through RCV, before meeting Last Chance Creek. Dixie Creek flows west-southwest from Dixie Mountain, through RCV, where it converges with Red Clover Creek, roughly 20 km upstream from Last Chance Creek.

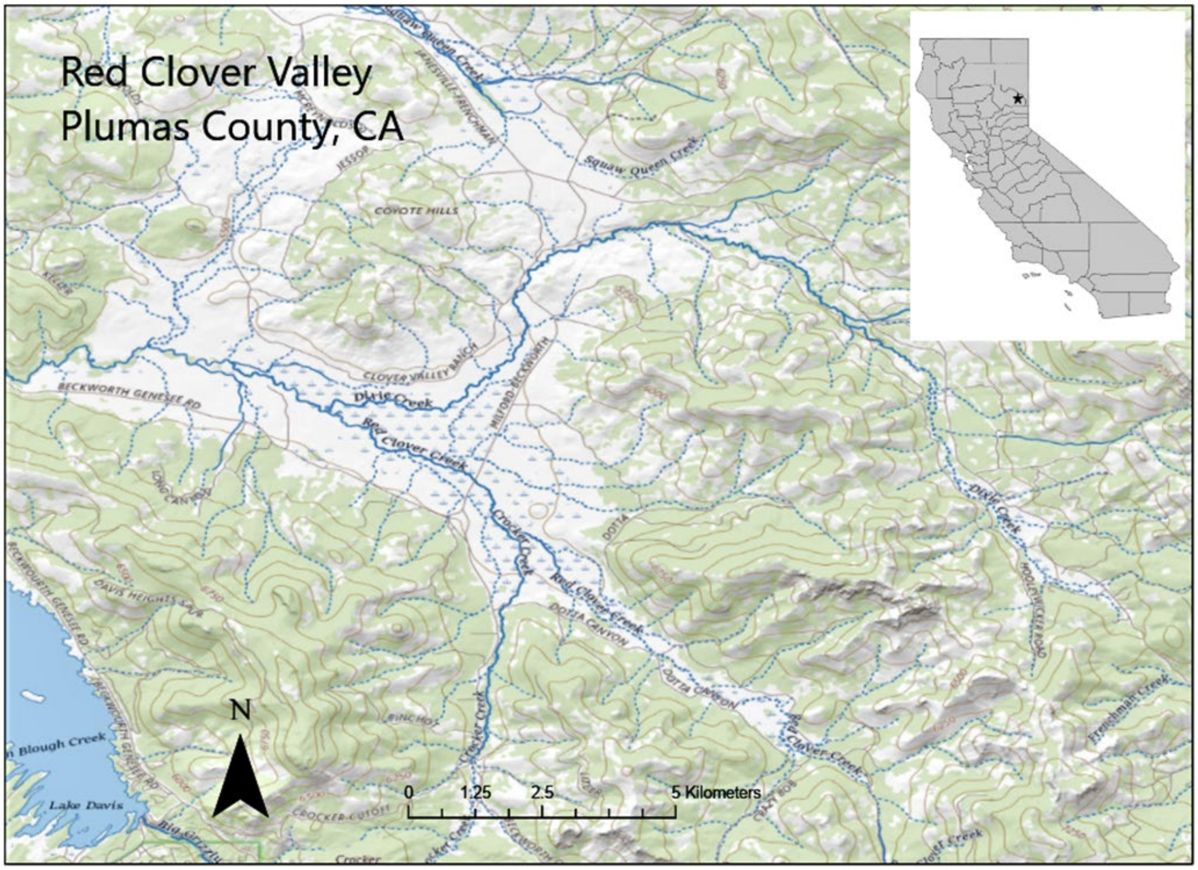

Figure 3: Red Clover Valley located in Plumas National Forest, Plumas County, CA.

Red Clover Valley's geology is Quaternary alluvium and marine deposits in the main valley section of the watershed. The surrounding mountains are composed of a variety of Miocene-Pliocene intrusive and volcanic rocks, mostly composed of andesite and basalt (US Geological Survey, 1992). Bedrock geology can play a large role in ionic composition of streams. Rost et al. (2011) measured ionic compositions of streams from various watersheds in the Sierra Nevada compared to bedrock geology. Sites studied in the Plumas region of the Northern Sierra Nevada had a similar geologic composition as Red Clover Valley. Anions in these sites were ranked bicarbonate (HCO_3^-) > chloride (Cl^-) > sulfate (SO_4^{2-}) > other anions. HCO_3^- heavily dominated the anion proportions, being greater than all other anions combined. Cations were more balanced in proportion with a ranking of calcium (Ca^{++}) > magnesium (Mg^{++}) > sodium (Na^+) > potassium (K^+) (Rost et al., 2011).

Soils can also influence water quality. RCV's soils are composed of a variety of mollisols, which are very dark, rich in organic matter, very fertile, and typically formed in temperate grasslands (Schafer & White, 1982). RCV soil types include loams, clays, and complexes. Soil characteristics such as organic matter, saturated hydraulic conductivity (ability of water to flow through soil), and soil texture have the greatest influence on water chemistry (Jutras et al., 2011; Leonardson et al., 1994; NFWF, 2010).

The US Forest Service conducted a fish survey for Red Clover Creek and its tributaries between 1973 and 1994. Native and non-native fish found during this survey that are within the study area of this research project are detailed in Table 1. Various water quality parameters can directly impact aquatic habitats. However, one of the most critical factors for fish survival is stream temperature. Table 1 (below) lists fish species found in Red Clover Valley and their specific thermal thresholds for desired conditions for optimal growth as well as maximum thermal thresholds where adult fish mortality can occur. Dissolved oxygen (DO) can also limit development of various life stages of salmonid species. Adult salmonids can survive in environments with DO less than 5 mg/L with some impairments to growth and production, however, acute mortality can occur when DO falls below 3 mg/L. Production of salmonid embryo and larval life stages are even more vulnerable to low DO concentrations, with acute mortality occurring when DO falls below 6 mg/L. Table 2 displays instream DO thresholds for various life stages of California salmonids (SWRCB, 2004).

Table 1: Red Clover Valley native and non-native fish species' desirable temperature ranges and maximum temperature thresholds for adult survivability (Plumas Corporation, 2013a; UC Davis, 2021a).

Species (native/non-native)	Desired Temperature Range (°C)	Maximum Temperature Thresholds (°C)
Cutthroat Trout (native)	9 - 12	23 - 27
Rainbow Trout (native)	15 - 18	24 - 27
Brook Trout (non-native)	14 - 19	26
Brown Trout (non-native)	12 - 20	28 - 29

Table 2: Dissolved oxygen thresholds for various life stages of California salmonids (SWRCB, 2004).

Embryo and Larval Stages	Instream DO (mg/L)	Other Life Stages	Instream DO (mg/L)
No production impairment	>11	No production impairment	>8
Slight production impairment	< 9	Slight production impairment	< 6
Moderate production impairment	< 8	Moderate production impairment	< 5
Severe production impairment	< 7	Severe production impairment	< 4
Limit to avoid acute mortality	< 6	Limit to avoid acute mortality	< 3

The Clover Valley Project uses three different types of restoration techniques in RCV. Exclusion fencing is used on both Red Clover Creek as well as Dixie Creek to keep cattle away from the riparian zones. Cattle grazing and trampling in riparian zones can directly influence stream hydrology. By decreasing mesic/hydric vegetation and reducing stream bank stability (see Figure 1), healthy functioning meadows can transition to unhealthy meadows via the incision cycle (see Figure 2).

Grade Control Structures (GCS) were installed along Red Clover Creek in 2019. The Clover Valley Project used earthen grade control structures composed of various sizes of rocks which were placed strategically along the streambed (The Sierra Fund, 2021). GCSs are effective at slowing the flow of water, promoting sediment deposition, and redirecting streams to interact with the floodplain (Adduce et al., 2004; USDA Forest Service, 2010). Figure 4 shows a stretch along Red Clover Creek before and after installation of GCSs.

Beaver Dam Analogs (BDA) were installed along Dixie Creek in June 2018 (The Sierra Fund, 2021). BDAs are constructed using wooden posts weaved with willow branches which mimic beaver dams and are effective at slowing and or storing water upstream as well as promoting sediment deposition (Burchsted et al., 2010; Weber et al., 2017). Figure 5 shows a stretch along Dixie Creek before and after installation of BDAs.

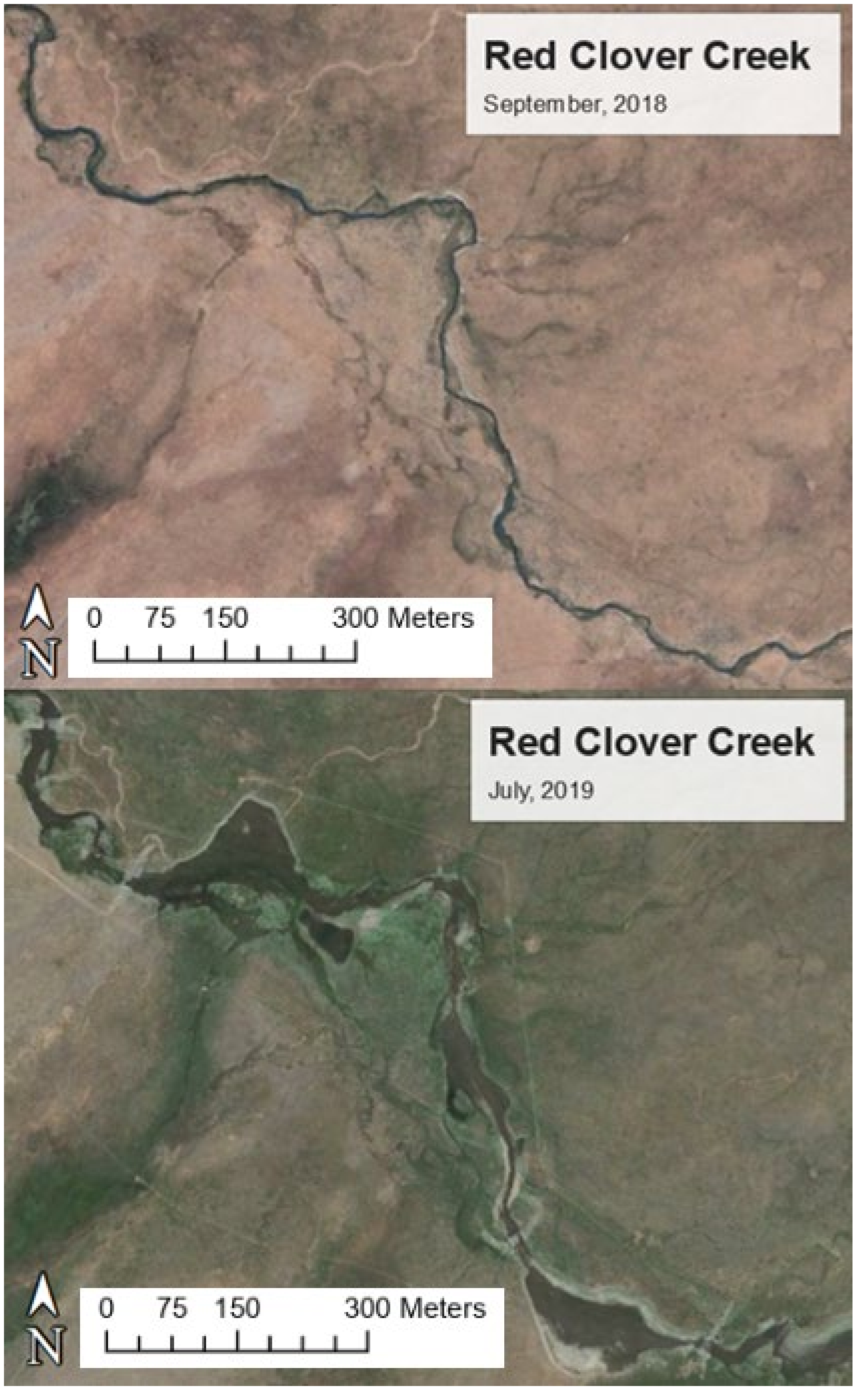

Figure 4: Middle Red Clover Creek before installation of GCSs (top), compared to the same location after installation of GCSs (bottom).

Figure 5: Upper Dixie Creek before installation of BDAs (top), compared to the same location after installation of BDAs (bottom).

2. Background & Literature

2.1 History of Red Clover Valley

Red Clover Valley's meadows have been inhabited and stewarded for thousands of years by the Mountain Maidu, a Native American tribe (The Sierra Fund, 2021). Prior to the 1880s, Red Clover Valley was known for having a productive trout fishery that had well developed riparian zones (Wilcox, 2012). The arrival of European settlers during the Gold Rush led to the Mountain Maidu being displaced from Red Clover Valley (The Sierra Fund, 2021). Degradation of the landscape ensued with excessive cattle and sheep grazing as well as the development of roads and railroad grades contributing to increases in erosion and sedimentation in the streams (Plumas Corporation, 2013b). In the 1950's this landscape was further altered by a beaver eradication effort along with the introduction of a federal program to eliminate willows using aerial herbicide spraying (FRCRM, 2008; Ponce, 2007).

Restoration efforts in Sierra Nevada meadows began in the 1930s, but the first restoration project conducted in Red Clover Valley was in 1985 (American Rivers, 2012; Plumas Corporation, 2013b). Red Clover Creek's channel had eroded up to 3 meters high and 15-18 meters wide and was reported as the third highest sediment producing sub-watershed in the East Branch North Fork Feather River watershed (FRCRM, 2008; Wilcox, 2012). In 1985, a series of check dams were installed by the Feather River Coordinated Resource Management group (FRCRM) as a demonstration project to raise the water level to access the floodplain. In 2006 and 2011, two more restoration projects were implemented in the Red Clover watershed using the Pond and Plug technique (Plumas Corporation, 2013b). In 2017, The Sierra Fund (TSF) launched the Clover Valley Project (CVP). This restoration project involves engagement with the ranching community, the scientific community (including Universities and Federal Agencies), and the Maidu Summit Consortium (The Sierra Fund, 2021). Construction of BDAs and GCSs in RCV began in 2018.

2.2 Sierra Nevada Meadow Water Quality

Water quality in Sierra Nevada meadows can be influenced by various factors such as climate, land use practices, and basin characteristics. Most previous meadow water quality research has primarily focused on stream temperature, DO, nutrients, and pathogens. These parameters have immediate implications for human health as well as aquatic habitats for native flora and fauna. Other water quality parameters of interest include dissolved organic carbon, specific conductance, pH, and other major anions and cations. Many parameters are coupled though biogeochemical cycling. Therefore, it is important to understand how environmental change, such as climate change or variability in land use practices, will influence biogeochemical cycles that may impact ecosystem processes on multiple spatial and temporal scales (Williams et al., 2015).

2.2.1 Climate Impacts

The Sierra Nevada is already experiencing the effects of climate change, most notably declining snowpack and earlier snowmelt (Vernon et al., 2019). The Sierra Meadows Partnership (SMP) projected an air temperature warming of up to 2.2 °C by the midcentury (2041-2060). These projections will have a direct impact on the water quality of mountain meadow systems due to reduced cold-water input from snowmelt. Aquatic habitats are highly vulnerable to projected increases in air temperature and declining snowpack. To understand the relationship between air temperature and stream temperature, Null et al. (2013) explored stream temperature modeling at the mesoscale for west-slope Sierra Nevada watersheds. They estimated an increase in stream temperature of 1.6 °C with each 2 °C increase in air temperature. The findings suggest that high elevation cold water fish would be vulnerable to changes in stream temperature resulting from projected Sierra climate change.

Ficklin et al. (2013) modeled stream flow and water quality through the 21st century using SWAT (soil and water assessment tool). Their model results suggest there will be substantial changes in temperature and DO in water limited basins with less seasonal snowpack. Results projected summer stream temperatures to increase by up to 3.4 °C by mid-century and 5.5 °C by late-century. Increased stream temperature correlates with decreased DO concentration. The projected decrease in summer stream DO was 1.6 mg/L by late-century due to increased stream temperature. The study also suggests sediment concentrations will decrease due to increases in terrestrial biomass and decreases in stream flow. However, basin characteristics, snowpack availability, amount and timing of precipitation, land use practices, and severity of degradation also play a large role in determining erosion rates (American Rivers, 2012; Hunt & Nylen, 2012; Nilsson, 2009; Thiptara, 2011; Viers et al., 2013).

2.2.2 Effects of Grazing

Summer cattle grazing is the most common land use practice that leads to water quality degradation in Sierra Nevada meadows (Thiptara, 2011). Cattle impact water quality by depositing large quantities of nutrients from urine and feces directly into streams or indirectly into groundwater through infiltration. High concentrations of nutrients such as nitrogen and phosphorus can lead to eutrophication of mountain lakes and streams (Belsky et al., 1999). Negative effects of excess nutrients can include high concentrations of bacteria, non-favorable microorganisms, frequent algal blooms, macrophyte outgrowths, depletion of DO, and inhabitable conditions for native fish (Agouridis et al., 2005; Blank et al., 2006; Derlet et al., 2012).

Cattle can also indirectly influence water quality by causing alterations to the landscape that either change the flow of water, or the ability of a meadow to filter pollutants (Myers et al., 2012). These alterations include soil compaction, streambank erosion, and loss of vegetation (Willis et al., 2012). Under these landscape conditions, aquatic habitat conditions can deteriorate and become unfavorable for native fish species. These conditions include high stream temperatures, low DO, and high concentrations of suspended sediment (Matthews, 2010; Nusslé et al., 2015).

To identify threats to water quality and hydrology from cattle grazing in montane meadows, a literature review was conducted and synthesized into Table 3. This synthesis represents literature published between 2000-2020 and identifies the impacts of cattle grazing on multiple water quality parameters (Table 3).

Table 3: Effects of cattle grazing in montane meadows on stream hydrology and water quality: Table includes the water quality parameter that is being influenced, the response of that parameter, the external processes causing that response, and further impacts.

Parameter	Response	External Influence on WQ Parameter	Impacts	References
Water Table	Lowered	Increased runoff, decreased infiltration, decreased bank stability, channel incision	Dry veg species replace wet veg, continued incision cycle, less capacity for GW storage	Agouridis al., 2005; American Rivers, 2010; Viers et al., 2013
Seasonal Flow	Altered	Decreased aquifer storage, increased runoff	Increased flood risk, lower summer flows, decreased fish habitat	American Rivers, 2010; Myers & Whited, 2012; Willis et al., 2012;
Dissolved Solids	Increase	Erosion from bank instability, higher runoff from soil compaction	Aquatic habitat, decreased water clarity, increased conductance	Agouridis al., 2005; USDA FS 2010; Kauffman et al., 2016
Temperature	Increase	Solar exposure from widening of channel and less riparian veg, less groundwater contribution	Decreased DO, threat to cold water fish habitat, increased microorganism productivity & algae growth	Nussle et al., 2015, Weber et al., 2017, Willis et al., 2008
Nutrients	Increase	Increased sediment from erosion, cattle feces and urine, decreased infiltration	Human health, algae growth, aquatic habitat, DO, lake eutrophication	Agouridis al., 2005; Blank et al., 2006; Derlet et al., 2010; Roche et al., 2013
Bacteria & Pathogens	Increase	Direct feces and urine in water, indirectly through groundwater	Human and wildlife health	Derlet et al., 2012 ; Myers et al., 2012; Roche et al., 2013; Thiptara, 2011
Dissolved Oxygen	Altered	Increased temp decreases solubility, temporal variation from photosynthesis & BOD from algal blooms	Fish survival rates, eutrophic conditions	Derlet et al., 2012; Myers & Whited, 2012; Nilsson, 2009; Willis et al., 2008
Fish	Decrease	Corridors fragmented, increased drought frequency, higher temperatures, lower DO	Altered ecosystem food-web, social and economic significance of fish	Agouridis al., 2005; Vernon et al., 2019; Viers et al., 2013

2.3 Meadow Management & Restoration

Meadow restoration aims to transition a degraded meadow into a healthy meadow. The key to this transition lies within the connection between geomorphology, hydrology, and vegetation (Davis et al., 2020). Degraded meadows experience a cycle of incision and erosion which can lead to lowering the water table, increasing runoff rates, and decreasing plant biomass (Viers et al., 2013). To reverse this cycle, most restoration techniques attempt to store more water in the meadow, raising the water table, increasing wet plant communities, depositing sediment, and stabilizing channel banks (USDA Forest Service, 2010). Given that water quality is the output of all processes occurring in a watershed, it can be a key indicator for restoration success. (NFWF, 2010).

2.3.1 Exclusion Fencing

Exclusion fencing is a restoration technique used to restore riparian habitat and improve water quantity and quality by eliminating cattle access to floodplains and riparian zones (Hunt et al., 2012). Cattle prefer grazing in or near the stream channel during dry months of the year when vegetation options are not as abundant (Blank et al., 2006). Grazing and trampling causes erosion, widening the stream channel, and increases in sediment loads downstream (Vernon et al., 2019). These activities also reduce riparian buffer services like stream bank stabilization, filtration capacity for excess nutrients, enhanced habitat in the stream and riparian zone, and decreased runoff (Agouridis et al., 2005).

Exclusion fencing is becoming a more common technique to restore grazed areas (Hunt et al., 2012). According to the National Fish and Wildlife Foundation, exclusion fencing is the cheapest restoration method for degraded meadows. Complete cattle removal is noted to be the most effective route towards restoration but grazing in Sierra Nevada meadows is too important to ranching enterprises and local economies (Roche et al., 2013). This method provides an opportunity for ranching communities to continue to survive and for ecosystems to begin to repair themselves.

2.3.2 Beaver Dam Analogs

Prior to anthropogenic alterations to meadow landscapes, beavers inhabited mountain meadows and acted as ecosystem engineers (Puttock et al., 2018). Beaver foraging and dam building has a direct influence on stream dynamics which leads to disruptions and discontinuities in waterways. Obstructions to streams allows for flooding of meadows which can provide diverse habitats, water storage, reduced erosion, and can result in improved water quality (Burchsted et al., 2010). Given the benefits that beaver, and their activities have on a landscape, environmental managers attempt to recreate this process using artificial beaver dam analogs (BDAs). BDAs are effective at reversing the hydrologic process that can lead to erosion, lowing of the water table, and declining water quality such as high stream temperatures, low DO, and nutrient loading (Puttock et al., 2018; Viers et al., 2013; Weber et al., 2017).

Beaver dams and BDAs can improve water quality in numerous ways. BDAs dam stream channels and can create ponds upstream. Slowing the flow of water allows for ponds to act as deposits for sediment and their associated nutrients where they are retained and eventually used by vegetation (Puttock et al., 2018). This process helps to avoid excess nutrient transport, which could be harmful to communities and ecosystems downstream. Beaver dams also increase dissolved organic matter which alters the carbon cycle in ways that beneficially affect pollutant turnover, food web structure, and biodiversity patterns (Catalan et al., 2017). Additionally, BDAs can transition deep incised stream channels to a wide stream with a connected floodplain. Dams can induce meandering, causing a widening of the channel and development of an inset floodplain. As the channel widens, stream power is decreased causing greater sediment deposition which establishes a good environment for riparian development (Pollock et al., 2014).

Studies of beaver dams agree that they can play a significant role in influencing hydrologic flow paths, however, impacts on stream temperature are more contended. Majerova et al. (2015) studied flow and temperature regimes and found beaver dam sites raised the water table and increased discharge. Typically, greater groundwater inputs from a high water table would correlate with lower water temperatures (Vernon et al., 2019; Viers et al., 2013), but in this complex system, temperature increased over time due to an increase in stream surface area and residence time. Other studies (Kemp et al., 2012; Margolis et al., 2001) also suggest degradation of thermal habitat for fish with sensitive thermal thresholds. However, Weber et al. (2017) refutes the claim that beaver dams increase temperature in their study of beaver dams and BDAs influence on stream temperature. Their reach scale study showed a lower maximum daily temperature and higher minimum daily temperature, likely caused by an increase in the height of the water table allowing for more groundwater upwelling into the stream, exerting a more consistent temperature profile (Weber et al., 2017). Differences between studies could be caused by various environmental factors such as hydrology and channel morphology.

2.3.3 Grade Control Structures

Grade control structures (GCS) are used to reverse the incision cycle by promoting sediment deposition and raising the streambed (Maestas et al., 2018). Earthen grade control structures are composed of various sized rocks and boulders which are placed along the streambed. By adding bed roughness, stream power decreases, and aggradation is favored over erosion (USDA Forest Service, 2010). As water reaches the structures, sediment is either trapped in the structure or deposited behind the structure. This process also allows water to reconnect to the floodplain and form new channels as it is redirected around the GCS (Adduce et al., 2004; USDA Forest Service, 2010). Specifically, in incised streams, GCSs can induce meandering, similar to BDAs (above), and develop new inset floodplains via channel widening and sediment deposition (Zeedyk & Clothier 2014). Although implementing GCSs is a more expensive way to restore a meadow, it can be fast and effective (The Sierra Fund, 2021).

2.4 Knowledge Gaps

Meadow research is becoming more abundant due to the increase in number of restoration projects taking place in Sierra meadows. Because these projects are more recent, long-term monitoring of water quality is not as available. Older restoration projects such as the RCV check dam restoration of 1985 discontinued monitoring after the project was completed. Continued monitoring and assessment would have provided useful information for current and future restoration. Current restoration projects should plan for continued monitoring to ensure future projects have the best available data to base management decisions around.

For the studies that are available, results could vary because water quality can be influenced by many different environmental factors. Methods also differ between studies due to different restoration goals and restoration techniques used. Diverse basin characteristics and environmental settings of meadows also play a role in water quality as different climates and landscapes can significantly influence water quality. However, Sierra meadows have similar enough characteristics to where long-term monitoring of some meadows could prove beneficial for future meadow restoration work in similar environments.

One of the goals of the Clover Valley Project is to improve water quality. Historically, this area has experienced issues of channel incision and sedimentation. Water quality impairments associated with sedimentation include stream temperature, dissolved oxygen, turbidity, and loss of aquatic habitat. However, there is limited information on which specific water quality parameters are impaired in Red Clover Valley. This information could help to improve planning and adaptive management for the remainder of the Clover Valley Project. Another gap in knowledge is the effectiveness of the specific restoration technique to improve water quality. Applying BDAs and GCSs in the same meadow on two different streams could provide direct information on how the two techniques affect water quality.

2.5 Research Questions

This research project conducts a water quality analysis in Red Clover Valley. It investigates how specific restoration techniques as well as other environmental factors influence water quality parameters. Parameters of particular interest include stream temperature, dissolved oxygen (DO), pH, nutrients, specific conductance (SpC), and dissolved organic carbon (DOC). This study was conducted to address the following questions:

1.) How do different restoration techniques impact water quality in a montane meadow?
   a. How do beaver dam analogs impact water quality?
   b. How do grade control structures impact water quality?
2.) How does water quality vary in Red Clover Valley?
   a. How do different basin characteristics influence variation in water quality?
   b. Is either Red Clover Creek or Dixie Creek impaired for any water quality parameters during the growing season?
   c. Does Red Clover Valley act as a sink, source, or neither, for nutrients or other water quality parameters of concern?
   d. How does water quality vary temporally?

3. Methods

3.1. Study Area

Water quality samples were taken from Red Clover Creek, Dixie Creek, and a local undisturbed spring (Spring) (Figure 6). Dixie Creek's sampling reach stretches about 5,800 kilometers (km) and has numerous beaver dam analogs located between Dixie2 and Dixie7. Dixie1 is located above a bridge where Milford Beckwourth Road crosses the creek. A dirt road runs along the hillslope north of Dixie Creek. Red Clover Creek's sampling reach stretches about 5,600 km with various sized grade control structures along the creek. The causeway intersects Red Clover Creek between Clover 2 and Clover3 and Beckwourth Genessee Road, a mostly dirt and gravel road, runs along the hillslope south of Red Clover Creek. Dixie Creek feeds into Red Clover Creek between Clover6 and Clover7, and the most downstream site, Clover8, is located at a Department of Water Resources stream gage station.

16 sampling sites were selected throughout the meadow for this analysis. Initial sites (Dixie1, Dixie7, Clover6, Clover8) were selected based on previous water quality sampling locations as well as the existence of two stream gauges. Additional sites were selected along Red Clover Creek and Dixie Creek to analyze spatial variation of water quality based on restoration type and potential environmental influences including vegetation density, channel morphology, stream discharge, and cattle presence. Samples were taken above, within, and below restoration features along both creeks. A final sampling site was from an undisturbed spring, likely influenced by the contribution of groundwater. The spring site is located southwest of the main valley area, above Beckwourth Genessee Road, and has not been influenced by land use practices that are known to cause degradation.

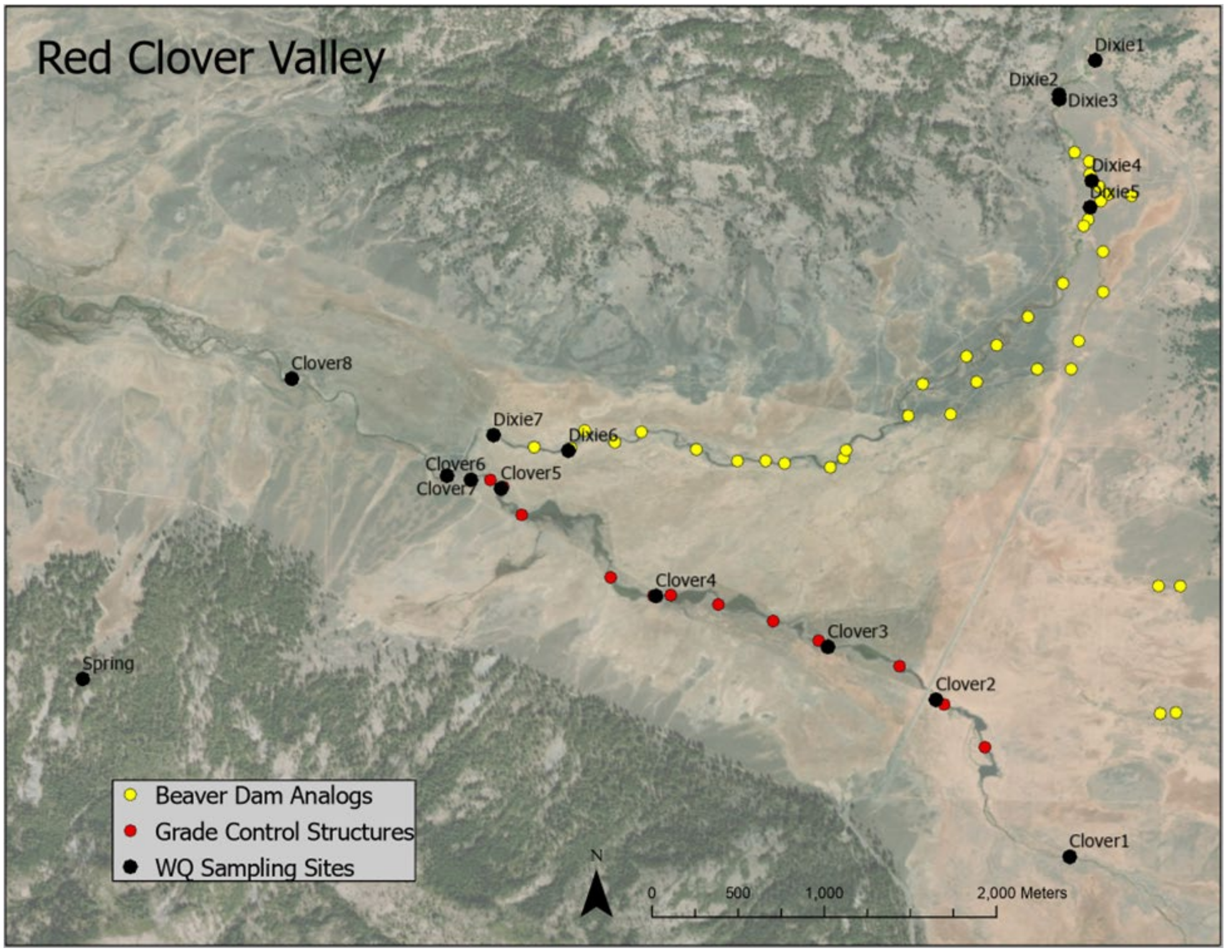

Figure 6: Map of Red Clover Valley with water quality sampling sites (n = 16) and restoration structure locations, including beaver dam analogs and grade control structures.

3.2 Surface Water Sampling

3.2.1 Sampling Time Period

Initial water quality sampling was conducted on August 4th, 2020 (Table 4). Local air temperature on August 4th, 2020, ranged from 6.6 °C to 31.1 °C (Portola weather station, 22 km southwest and 153 meters lower in elevation). 2021 sampling was conducted on June 28th, August 3rd, and August 4th. June 28th, 2021 air temperatures ranged from 11.7 °C to 36.6 °C. August 3rd and 4th, 2021 air temperatures ranged from 6.1 °C to 35.6 °C. To examine diel effects on stream temperature and dissolved oxygen, August 3, 2021, was sampled during the afternoon (12:50pm – 5:31pm) and August 4, 2021, was sampled during the morning (7:22am – 11:22am).

Selecting a sampling period in late summer allows us to evaluate the effects of the growing season on water quality parameters including temperature, dissolved oxygen, and nutrients. This season is associated with low stream flow when water bodies are more susceptible to high temperatures, low dissolved oxygen, and high concentrations of pollutants when grazing is occurring (Derlet et al., 2010; Nilsson, 2009). The selected sampling dates provided information on variation over one year (August 4, 2020 to August 4, 2021) as well as changes over the summer of 2021 (June to August) as discharge decreased into the later part of the growing season.

3.2.2 Water Quality Parameters and Equipment

Water quality parameters analyzed at each site varied based on the sampling method. The YSI Pro DSS multiparameter water quality meter (YSI MPI) was used to measure in-situ stream temperature, dissolved oxygen (DO), specific conductance (SpC), pH, and nitrate (NO_3^-) for all sampling dates. Ammonium (NH_4^+) and chloride (Cl^-) YSI measurements were only collected in August 2021. Grab samples were taken from nine surface water sites and analyzed at the UC Davis Analytical Lab for nutrients, major anions, major cations, and dissolved organic carbon (DOC) (n=6). Sampling methods for specific sites is displayed in Table 4.

Table 4: Water Quality Sampling Site Information.

Site	Sample Dates	Latitude	Longitude	Description & Sample Method
Dixie1	8/4/2020, 6/28/2021, 8/3/2021, 8/4/2021	39.97304539	-120.412121	Upper Dixie Creek above bridge – YSI & Grab + DOC
Dixie2	8/4/2020, 6/28/2021, 8/3/2021, 8/4/2021	39.97123101	-120.413964	Upper Dixie Creek above beaver dam – YSI
Dixie3	8/4/2020, 6/28/2021, 8/3/2021, 8/4/2021	39.97103962	-120.413949	Upper Dixie Creek below beaver dam – YSI & Grab +DOC
Dixie4	8/4/2020, 6/28/2021, 8/3/2021, 8/4/2021	39.96672134	-120.412340	Middle Dixie Creek above tributary – YSI
Dixie5	8/4/2020, 6/28/2021, 8/3/2021, 8/4/2021	39.96538023	-120.412460	Middle Dixie Creek below tributary – YSI & Grab
Dixie6	6/28/2021, 8/3/2021, 8/4/2021	39.95270442	-120.439587	Lower Dixie Creek, between BDAs – YSI
Dixie7	8/4/2020, 6/28/2021, 8/3/2021, 8/4/2021	39.9534858	-120.443491	Lower Dixie Creek, before confluence – YSI & Grab +DOC
Clover1	8/4/2020, 6/28/2021, 8/3/2021, 8/4/2021	39.93152026	-120.413462	Upper RC Creek past property line – YSI & Grab
Clover2	8/4/2020, 6/28/2021, 8/3/2021, 8/4/2021	39.93981155	-120.420369	Upper RC Creek above causeway – YSI & Grab
Clover3	6/28/2021, 8/3/2021, 8/4/2021	39.94248451	-120.426057	Middle RC Creek below causeway – YSI
Clover4	6/28/2021, 8/3/2021, 8/4/2021	39.94500868	-120.435094	Middle RC Creek between GCS structures – YSI
Clover5	6/28/2021, 8/3/2021, 8/4/2021	39.950729	-120.443100	Middle RC Creek between GCS structures – YSI
Clover6	8/4/2020, 6/28/2021, 8/3/2021, 8/4/2021	39.9511837	-120.444668	Lower RC Creek before confluence – YSI & Grab +DOC
Clover7	8/4/2020, 6/28/2021, 8/3/2021, 8/4/2021	39.95131513	-120.445942	Lower RC Creek past confluence – YSI
Clover8	8/4/2020, 6/28/2021, 8/3/2021, 8/4/2021	39.95649827	-120.453973	Downstream RC Creek at gauge site – YSI & Grab +DOC
Spring	8/4/2020, 6/28/2021, 8/4/2021	39.94080836	-120.464905	Southwest meadow, natural spring – YSI & Grab +DOC

3.2.3 Field Sampling Protocol

On August 3rd, 2020, the day before sampling, a reconnaissance survey was conducted in Red Clover Valley (RCV). The area was explored to identify the sampling locations in the sampling plan. This process involved identifying accessibility of all sites, adding extra sites of interest, and recording site descriptions in the field notebook. For each site, the following were recorded in the site description: notable features in area, channel shape, substrate of channel, description of discharge, water clarity, algae presence, vegetation type and abundance, cattle presence, cattle feces presence, and GPS coordinates in decimal degrees. Sites were entered into Avenza Maps with GPS coordinates and pictures of sampling location. Once all sites were identified, they were arranged into a sampling order to ensure maximum efficiency of time.

Upon arrival at the first site on the days of sampling, the YSI instrument was calibrated with four probes. The specific conductance probe includes a metal rod that acts as a thermistor to read temperature. This probe was calibrated using a 1000 microsiemens per centimeter standard. pH was calibrated using a three-point calibration with pH10, pH7, and pH4 buffers. Nitrate was calibrated using a two-point calibration with a low standard of 1 mg/L and a high standard of 10 mg/L. 2021 sampling included chloride and ammonium probes. The chloride probe was calibrated using a 100 mg/L standard. The ammonium was calibrated with 1 mg/L and 100 mg/L standards. Calibration, maintenance, and storage protocol followed the ProDIGITAL User Manual (YSI, 2020).

In-situ measurements were recorded at all sites ($n = 16$) along Red Clover Creek, Dixie Creek, and the Spring site. The YSI MPI was completely submerged toward the center of the stream until the reading stabilized. Probes were always pointed in the direction of flow and placed upstream of any potential factor that could influence water quality. Other considerations included avoiding disturbing the substrate as well as releasing any air bubbles attached to the probes. Once the readings were stabilized, the data was recorded into a field notebook. During August 2020 and August 2021 sampling, the Spring site was not sampled with the YSI instrument due to low flow and risk of damaging the probes. On June 28th, 2021, baseflow at this site was high enough to submerge the instrument and not damage the probes.

Grab samples were taken from nine sites using 500 mL bottles. Before collecting the samples, each bottle was triple rinsed with stream water from the site. After collection, the bottles were stored in a cooler with ice. At the end of the field day, all grab samples were filtered using a 0.45 μm capsule filter from Geotech to remove microorganisms and suspended material that could interfere with lab analysis. Using a Geotech Geopump, samples were transferred from clear bottles, through disposable filters, and into amber sample bottles. Operation protocol followed the Geotech Geopump Peristaltic Pump Installation and Operation Manual (Geotech, 2017). Samples were then frozen until they were submitted to the UC Davis lab for analysis (UC Davis Analytical Lab, 2021).

3.3 Computations of Collected and Supplemental Data

Collected data from the YSI MPI and UC Davis Lab analysis were manually entered into Microsoft Excel. Next, longitude and latitude data were used to import sampling sites with their associated water quality data into ArcGIS Pro (2.5.0). The Excel spreadsheet was also read into RStudio (4.0.5) where a statistical analysis was conducted on various water quality parameters.

Supplemental data were downloaded from publicly accessible sources shown in Table 5. Other supplemental data were created or processed using ArcGIS Pro, as well as R (i386 4.0.5) and RStudio (4.0.5). RStudio packages used for this analysis include tidyverse, ggplot2, tibble, tidyr, readxl, dplyr, plotly, raster, psych, and PerformanceAnalytics.

Table 5: Summary of supplemental data.

Data Files	Publisher	Publication Date	Accessed From	Date Accessed
World Imagery	ESRI	12/12/2009	Arcgis.com	2/20/2021
USA Soils Map Units	ESRI	4/4/2019	ESRI Living Atlas	1/15/2021
Sentinel-2 Imagery	Copernicus	8/2/2020, 6/28/2021, 8/2/2021	Copernicus Open Access Hub	1/15/2021, 7/20/2021,

3.3.1 NDVI Wedge

To analyze local upstream vegetation relationships with water quality, a normalized difference vegetation index (NDVI) wedge was calculated through RStudio and ArcGIS Pro. NDVI represents density of greenness reflected in imagery and has been found to be highly correlated with field observations of plant phenology in meadows (Richardson et al., 2021). Specifically, NDVI from Sentinal-2 imagery at 10-meter resolution has shown considerable promise for interpreting grasslands and can be used as a signal for meadow restoration efforts (Davis et al., 2020). The concept for creating an NDVI wedge followed the approach detailed in a USGS Scientific Investigation Report (Gurdak and Qi, 2004) that uses an upgradient 90-degree sector slice from a 300-meter diameter circular buffer around the sampling location. Based on the significance of vegetation in the meadow feedback loop detailed in Figure 1, upstream NDVI could represent areas with a higher water table and greater groundwater contributions. Upstream NDVI could also indicate site specific shade potential from riparian vegetation.

To process NDVI data, 10-meter Sentinel-2 imagery (with atmospheric correction) of RCV was downloaded through Copernicus Open Access Hub. The satellite collected imagery on August 2nd, 2020, June 28th, 2021, and August 2nd, 2021. If imagery was not available on the day of sampling, the next closest day of available data was selected. Red (R) and near infrared (NIR) bands were processed in RStudio and cropped to the extent of the water quality sampling locations. An NDVI raster was calculated with the following equation: (NIR – R)/(NIR+R). The NDVI raster was written to a .Tif file and imported into Arc GIS Pro.

In ArcGIS, circular buffer polygons with 300-meter diameters were created around each sampling site. These polygons were edited using the ‘Replace Geometry’ function with the ‘Right Angle’ function to create a 90-degree angle at the center of the polygon and removing three quarters of the feature. The direction of each wedge was then angled upstream to capture 150 meters of riparian vegetation above the sampling sites. The ‘Extract by Mask’ tool extracted the NDVI raster data that overlapped with the wedge buffer. Next, ‘Raster to Point’ was used to convert the new raster dataset to point features. This allows the ‘Spatial Join’ function to join the attributes from the NDVI point features to the original points that contain water quality data. Mean NDVI values were derived from the grid code of each buffer and added to the primary datasheet for further analysis.

3.3.2 Other Supplemental Data

Restoration classification was assigned to each sampling site based on whether water flows to, flows through, or flows from a restoration structure (BDA or GCS). This classification was based on field observations, satellite imagery, and GIS shapefile data. The undisturbed spring site was given the restoration classification of “Spring.” To analyze spatial trends in water quality, specific reach location classifications were also assigned to sampling points. Reach classifications include Upper Clover (Clover1-2), Mid Clover (Clover3-5), Lower Clover (Clover6), Upper Dixie (Dixie1-5), Lower Dixie (Dixie6-7), Confluence (Clover7-8) and Spring.

Grade control structures (GCSs) and beaver dam analogs (BDAs) were digitized using satellite imagery and field notes. Using Google Earth Pro, historical satellite imagery from before installation of restoration features were compared to the current World Imagery GIS layer. The Create Features pane in ArcGIS Pro allowed for creating new point features to represent location of GCSs and BDAs.

A primary soil type was attributed to each sampling location. The wedge buffer process detailed in section 3.3.1 was used to create upstream wedge-shaped polygons above sample sites.

Whichever soil type from the USA Soils Map Units layer covered the majority percent of the upstream wedge was identified as a potential influence on surface water quality. Soil profile data including hydraulic conductivity (Ksat (mm/Hr)) and K Factor (erodibility) were also added as supplementary data for primary soil types. This data was provided by SoilWeb, an NRCS web soil resource (UC Davis, 2021b).

3.4 Analysis of Collected and Supplemental Data

3.4.1 Spatial Analysis

Simple feature layers in ArcGIS Pro were created for each of the 4 sampling dates. To visualize spatial variability of various water quality parameters, maps were created in ArcGIS Pro using graduated colors with breaks at equal intervals of meaningful values for the symbology. Statistical analysis tools were also used to explore and extract additional information.

3.4.2 Statistical Analysis

Collected and supplemental data were compiled into one Excel sheet which was uploaded to RStudio (4.0.5) for statistical analysis in R (i386 4.0.5). This analysis uses Pearson's correlation coefficients (r) to quantify the strength of relationship between variables. An r value of 1 represents a perfect positive correlation, an r value of 0 represents no correlation, and an r value of -1 represents a perfect inverse correlation. Statistical significance levels are also provided, representing the p-value (0.001***, 0.01**, 0.05*).

Correlation matrixes were created using the chart.Correlation() function in the PerformanceAnalytics package to identify variables with high correlation coefficients. Parameters for this analysis were selected based on whether they may have physical, chemical, or biological relationships to other parameters. Next, linear models were created, and ANOVA tests were conducted on variables that could be influencing each other. These tests provide information on the strength of the linear relationship between multiple parameters is as well as whether or not that relationship is statistically significant. For data categorized into different groups, two-way t-tests were run to analyze whether groups were statistically significantly different from each other. Data visualization was also conducted in RStudio and produced various figures including box and whisker plots, time series, and scatter plots with trendlines.

Various groups of data were investigated to answer the research questions outline for this study. Data was grouped and analyzed by specific water quality parameter, sampling day, time of day, location, soil type, and restoration technique. By grouping data this way, statistical analysis could provide insight to which basin characteristic or restoration technique has the greatest influence in variability of specific water quality parameters.

4. Results

4.1 Water Quality Data

4.1.1 Temperature and Dissolved Oxygen

In situ measurements for stream temperature and dissolved oxygen (DO) were taken at multiple sites in 2020 and 2021 towards the beginning of the growing season in June (6/28/2021) and towards the end of the growing season in August 2020 (8/04/2020) and August 2021 (8/03/2021, 08/04/2021) (Table 6). Two sets of samples from consecutive days were collected in August 2021 because previous data suggested a large variation between temperature, DO, and time of day. Stream temperatures greater than 24 °C indicate potential for mortality of adult native fish, such as Cutthroat Trout and Rainbow Trout (see Table 1). Twenty-seven percent of observations in August 2020 exceeded maximum thermal thresholds for native trout and 53% of observations from June and August 2021 exceeded maximum thermal thresholds for native fish (Table 6) (Plumas Corporation, 2013a; UC Davis, 2021a). Zero observations from early morning sampling on August 4th, 2021, exceeded temperature thresholds for native fish (Table 6).

Stream temperature data from June 28th, 2021, and August 3rd, 2021, are shown in Figure 7. The lowest temperature values (< 18 °C) represent a common desirable temperature range for fish native to Red Clover Valley (see Table 1) (Plumas Corporation, 2013a; UC Davis, 2021a). The highest value class represents a common maximum temperature threshold for native fish (Plumas Corporation, 2013; UC Davis, 2021a). Upper Dixie Creek experienced large temperature increases from June to August, transitioning from desirable temperature ranges to maximum temperature ranges. However, sites along this reach that were below dam structures never crossed maximum thermal thresholds. Red Clover Creek had consistently high temperatures on all dates, specifically along the middle reaches of the creek. However, stream temperatures decreased downstream below the confluence of Dixie Creek and Red Clover Creek on all sampling dates. Clover8, the most downstream sampling site in the study area (Figure 7), also had higher temperatures in August compared to June.

DO values varied spatially between June 28th, 2021, and August 3rd, 2021 (Figure 7). DO below 3 mg/L can indicate eutrophic conditions where fish and other aquatic organisms cannot survive (Belsky et al., 1999; Nagisetty et al., 2019; Nilsson, 2009). No values reached this threshold, however, various sites surpassed DO thresholds for severe production impairment (< 7 mg/L) or acute mortality (< 6 mg/L) of salmonids in the embryo and larval life stages (SWRCB, 2004). There was large variation between creeks, however, Clover8, the most downstream site, remained constant over all sampling days ranging from 10.69 to 12.44 mg/L, and never falling below thresholds of impairment for any life stage of salmonids (Figure 7). Upper Dixie Creek recorded much lower DO in June compared to August, while Lower Dixie Creek had consistently higher DO. Middle and upper Red Clover Creek were consistently lower in DO compared to other sites. August 3rd, 2021, experienced the greatest concentrations of DO ranging from 8.14 to 19.23 mg/L. When comparing the two sets of samples collected in August 2021, morning samples (8/4/21; 7:22am – 11:22am) were notably lower than afternoon samples (8/3/21; 12:50 – 5:31).

Table 6: Temperature and dissolved oxygen data across all sampling dates. Values highlighted in red identify temperatures greater than 24 °C. Grey cells indicate that sites were not sampled on that day.

	August 4th 2020		June 28th 2021		August 3rd 2021 (PM)		August 4th 2021 (AM)	
Site	Temp (°C)	DO (mg/L)	Temp (°C)	DO (mg/L)	Temp (°C)	DO (mg/L)	Temp (°C)	DO (mg/L)
Dixie1	18.2	10.75	17.8	7.9	25.3	16.51	19.5	13.01
Dixie2	19.2	7.5	21.5	7.1	24.2	16.72	19.9	14.3
Dixie3	17.8	5.5	19.7	5.1	20.4	12.18	17.5	6.45
Dixie4	18.2	7.12	17.3	5.26	22.4	9.33	18.4	7.3
Dixie5	20.7	7.65	20.7	7.26	21.5	19.23	16.5	9.8
Dixie6			24	9.12	25.3	11.05	14.1	6.95
Dixie7	25.5	13.5	26.5	14.8	24.6	17.8	13.2	8.03
Clover1	23.7	9.12	27.2	9.49	23.3	9.52	12.6	9.2
Clover2	27.1	11.7	28.2	6.99	23.6	8.14	13.2	6.83
Clover3			24.6	7.55	25.2	11.72	14.8	7.52
Clover4			28.3	12.25	24.6	9.75	14.7	5.9
Clover5			27.3	14.3	25.5	9.1	15.7	5.25
Clover6	26.6	9.95	28	9.5	20.4	13.52	12.8	9.07
Clover7	21.9	10.65	20.4	12.39	17.4	15.1	11.3	9.5
Clover8	23.1	12.7	20.9	11.12	24.7	12.44	13.9	10.69
Spring			14.6	7.45				

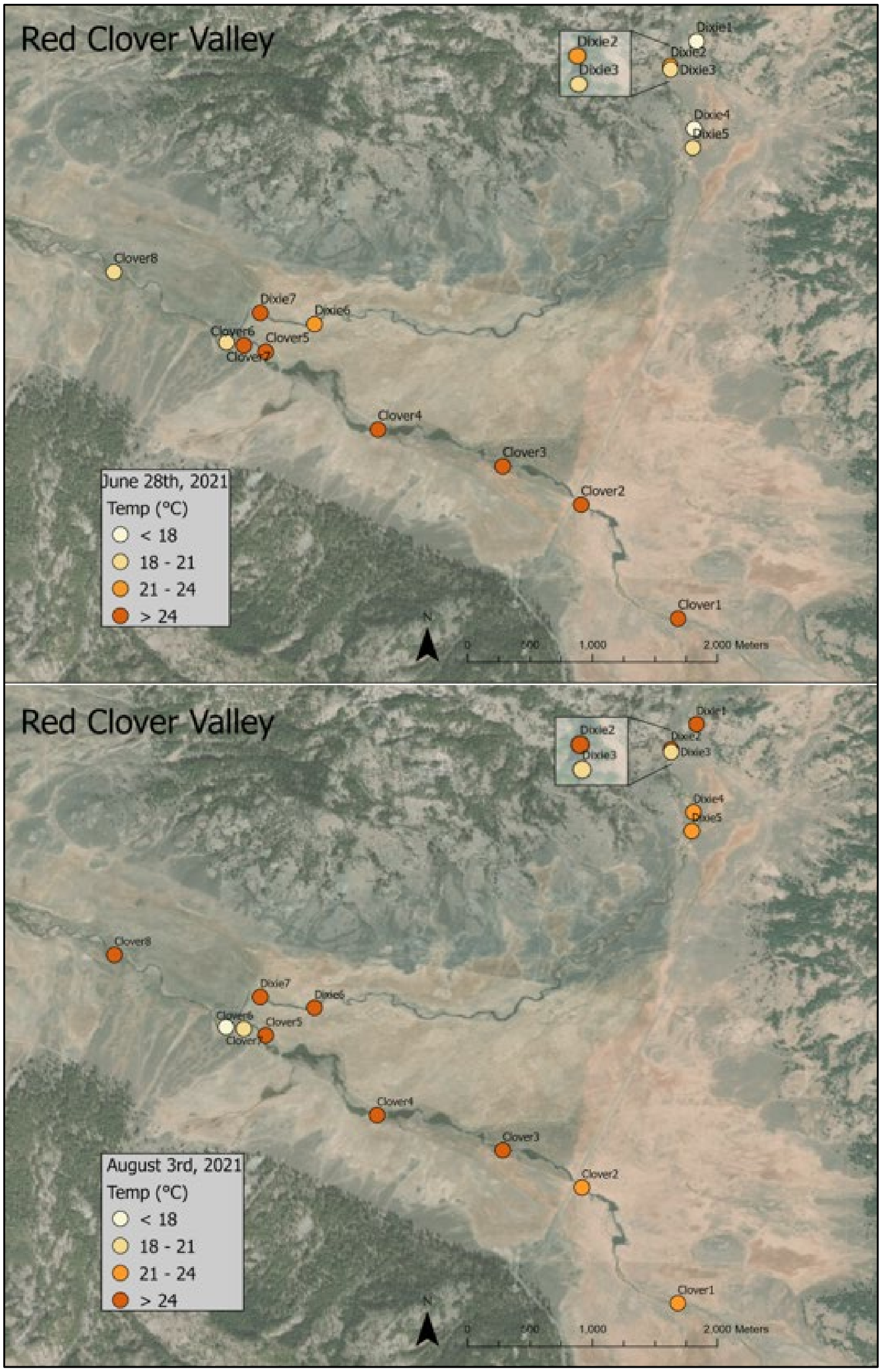

Figure 7: Stream temperature across all sampling sites from June 28th, 2021, and August 3rd, 2021.

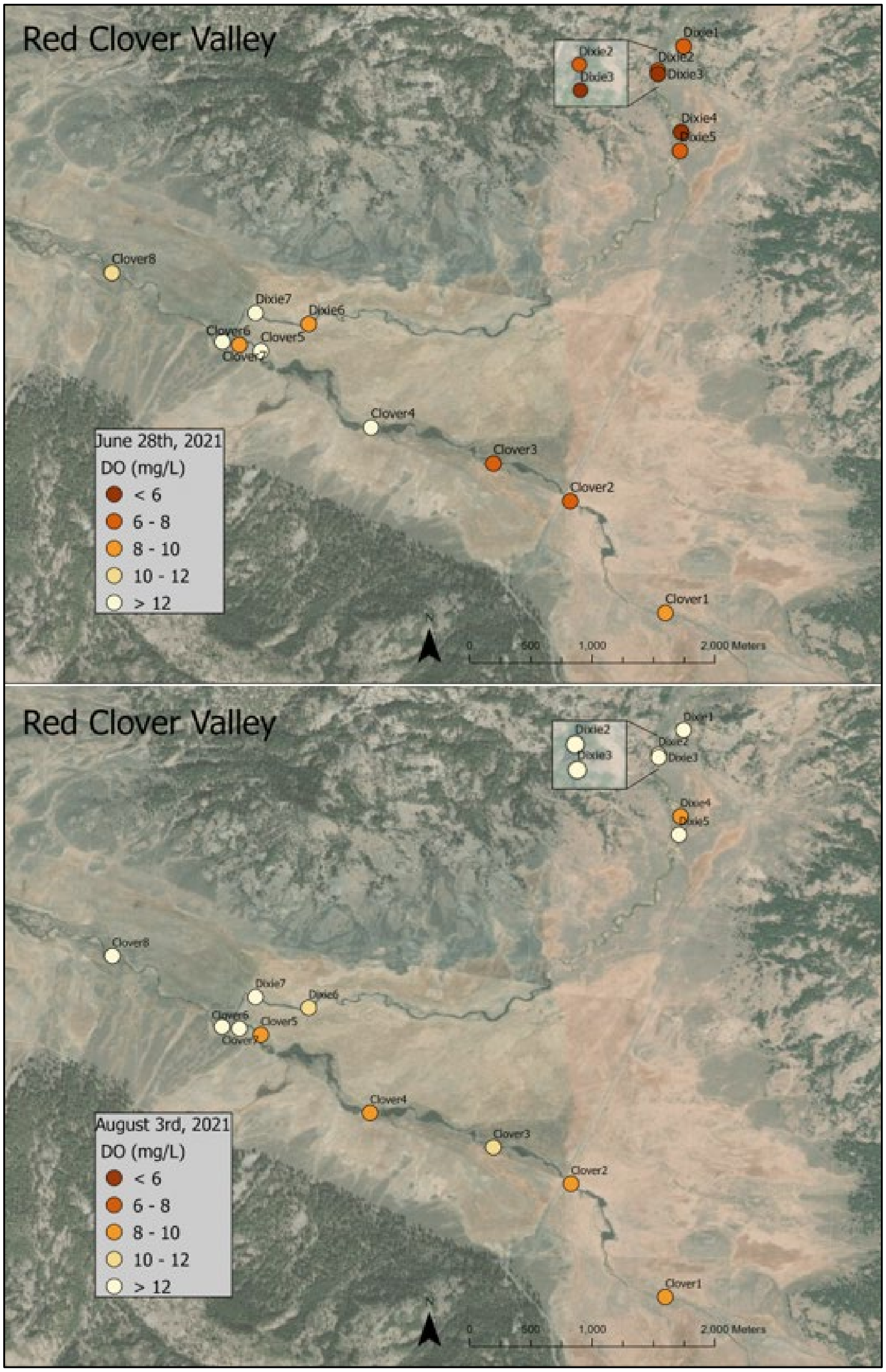

Figure 8: Dissolved oxygen (DO) across all sampling points from June 28th, 2021, and August 3rd, 2021.

4.1.2 Inorganic Nitrogen

YSI data for nitrate (NO_3^-) were collected on all sampling days, and ammonium (NH_4^+) was collected once at all sites in August 2021. Grab samples were analyzed by UC Davis Analytical Lab for nitrate as well as ammonium, however, the results of all samples for all sampling dates were below the lab's detection limit.

Background NO_3^- for the Sierra Nevada EPA Level III sub-ecoregion ranges from 0.02 to 0.18 mg/L (Roche et al., 2013). Table 7 provides all original YSI data collected for NO_3^- and NH_4^+. NO_3^- observations that fell into the natural background range (< 0.18 mg/L) are highlighted. The Spring site had a NO_3^- concentration of 0.26 mg/L, which is above natural background concentrations. Maximum concentration of NO_3^- (0.66 mg/L) was less than half the potential eutrophication concentration as suggested by Roche et al. (2013). Median concentration of NO_3^- in June 2021 (0.34 mg/L) was higher than median concentrations for both August 2020 (0.29 mg/L) and August 2021 (0.27 mg/L).

Figure 9 displays spatial variation of NO_3^- from June to August 2021. Upper Dixie Creek experienced a decreasing trend in NO_3^- from upstream to downstream on all sampling days. On all sampling days, NO_3^- was higher above the active beaver dam site at Dixie2 than below at Dixie3, most notably in August 2021 (0.66 mg/L above beaver dam, 0.18 mg/L below beaver dam). Red Clover Creek was relatively consistent between the two time periods with lower values in the upper reach and higher values in the lower reach before the confluence. Clover8 had consistent NO_3^- concentrations over time ranging from 0.22 to 0.28 mg/L, which were similar to the Spring site (0.26 mg/L) but greater than background concentrations.

Ammonium (NH_4^+) concentrations varied spatially across both Red Clover Creek and Dixie Creek (Figure 10). Median NH_4^+ across all sites was 0.9 mg/L. Spatially, concentrations increased from Dixie1 (0.4 mg/L) to Dixie5 (1.51 mg/L), then decreased downstream at Dixie6 (0.62 mg/L). Red Clover Creek NH_4^+ concentrations started higher at Clover1 (1.95 mg/L) then gradually decreased downstream at Clover5 (0.85 mg/L). After Clover5 there was a notable increased in concentration near the confluence at Clover6 (7.82 mg/L) and Clover7 (5.45 mg/L).

At the most downstream site, NH_4^+ concentration dropped back to 0.75 mg/L. High concentrations of NH_4^+ at Clover6 and Clover7 were independent of NO_3^- which did not have notable variation at these sites.

Table 7: YSI Nitrate and Ammonium concentrations across all sampling dates. Blue cells indicate Nitrate concentrations within the natural background range (Roche et al., 2013). Grey cells indicate that samples were not collected.

	NO_3^- (mg/L)			NH_4^+ (mg/L)
Site	August 4th 2020	June 28th 2021	August 4th 2021	August 3rd 2021
Dixie1	0.46	0.6	0.34	0.4
Dixie2	0.34	0.34	0.66	0.59
Dixie3	0.31	0.26	0.18	1.44
Dixie4	0.26	0.15	0.29	1.51
Dixie5	0.29	0.22	0.41	0.77
Dixie6		0.34	0.22	0.62
Dixie7	0.32	0.43	0.23	0.71
Clover1	0.15	0.23	0.1	1.95
Clover2	0.2	0.24	0.18	1.47
Clover3		0.25	0.24	1.06
Clover4		0.37	0.27	0.9
Clover5		0.58	0.32	0.85
Clover6	0.43	0.44	0.44	7.82
Clover7	0.23	0.47	0.21	5.45
Clover8	0.22	0.25	0.28	0.75
Spring		0.26		

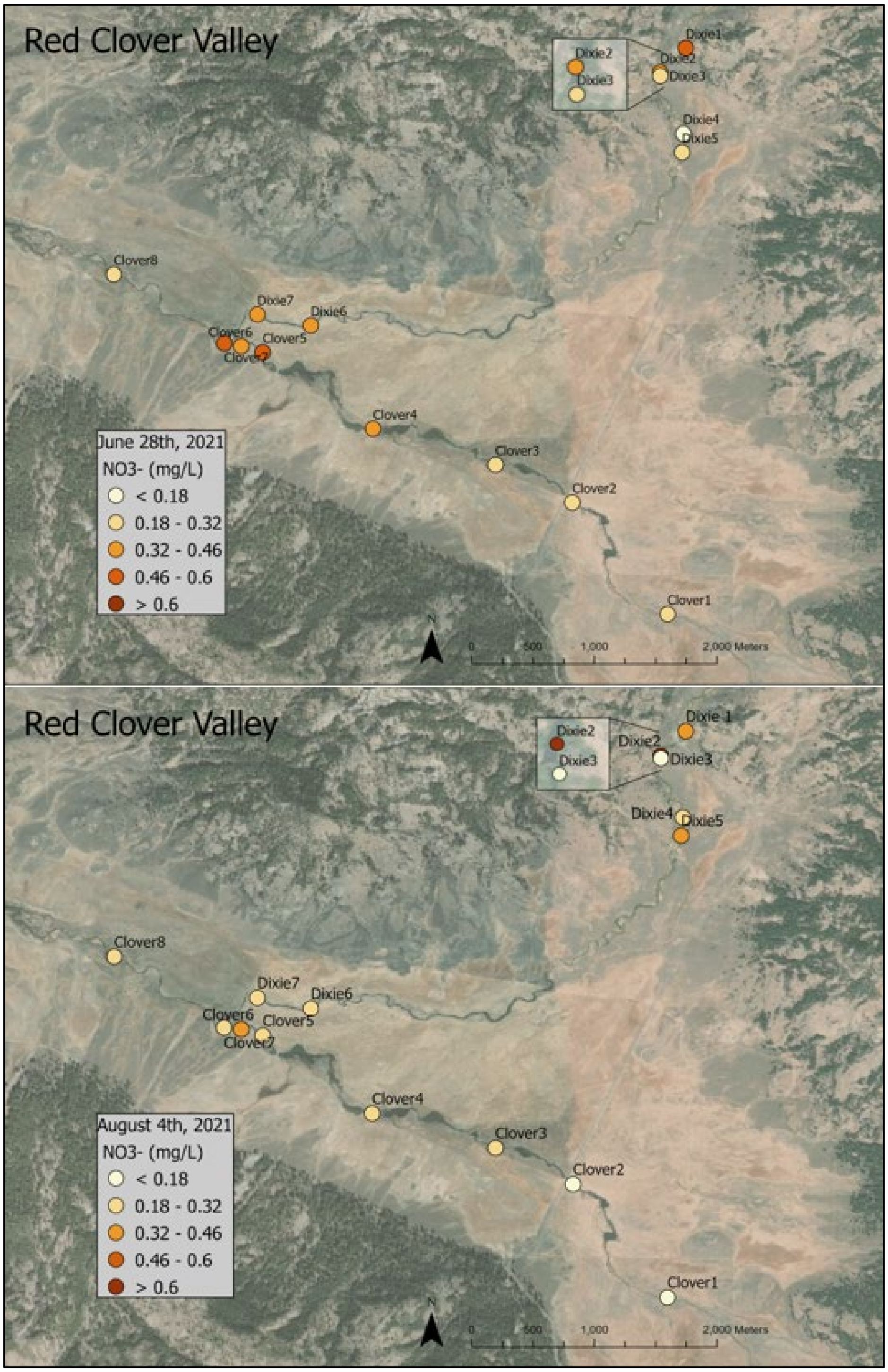

Figure 9: Nitrate across all sampling points from June 28th, 2021, and August 4th, 2021.

Figure 10: Ammonium across all sampling points on August 3rd, 2021.

4.1.3 Dissolved Organic Carbon

Dissolved organic carbon (DOC) data was analyzed by UC Davis Analytical Lab for samples collected on August 4th, 2020, and August 4th, 2021 (Table 8). Six sites were selected for this analysis based on features of interest in the meadow. Lowest DOC concentrations were found at the Spring site and highest concentrations were found on Red Clover Creek before the confluence at Clover6, on both sampling days (Figure 11). Dixie1 and Dixie3 were selected in 2020 to evaluate the variation in DOC above and below the active beaver dam site. DOC above the dam site was 2.2 mg/L and DOC below the dam site was 2.3 mg/L. DOC was higher in 2020 than it was in 2021 at all sites, except Clover6. The greatest differences (2021 minus 2020) (Table 8) was found at Dixie7 (-1.3 mg/L) and Clover8 (-1.4 mg/L). In both years, DOC at Clover6 was significantly higher than other sites. This site was also noted to have high concentrations of NH_4^+ which is typically associated with microbial decomposition of organic matter (Nilsson, 2009). Clover8, downstream of Clover6, had much lower concentrations of DOC in both years, suggesting that high concentrations of DOC are processed within the meadow and not released downstream.

Table 8: Dissolved Organic Carbon for select sampling locations.

Dissolved Organic Carbon (mg/L)			
Site	8/4/2020	8/4/2021	2021 - 2020
Dixie1	2.2	1.5	-0.7
Dixie3	2.3		
Dixie7	2.5	1.2	-1.3
Clover6	4.2	4.9	0.7
Clover8	2.4	1	-1.4
Spring	1.9	0.9	-1

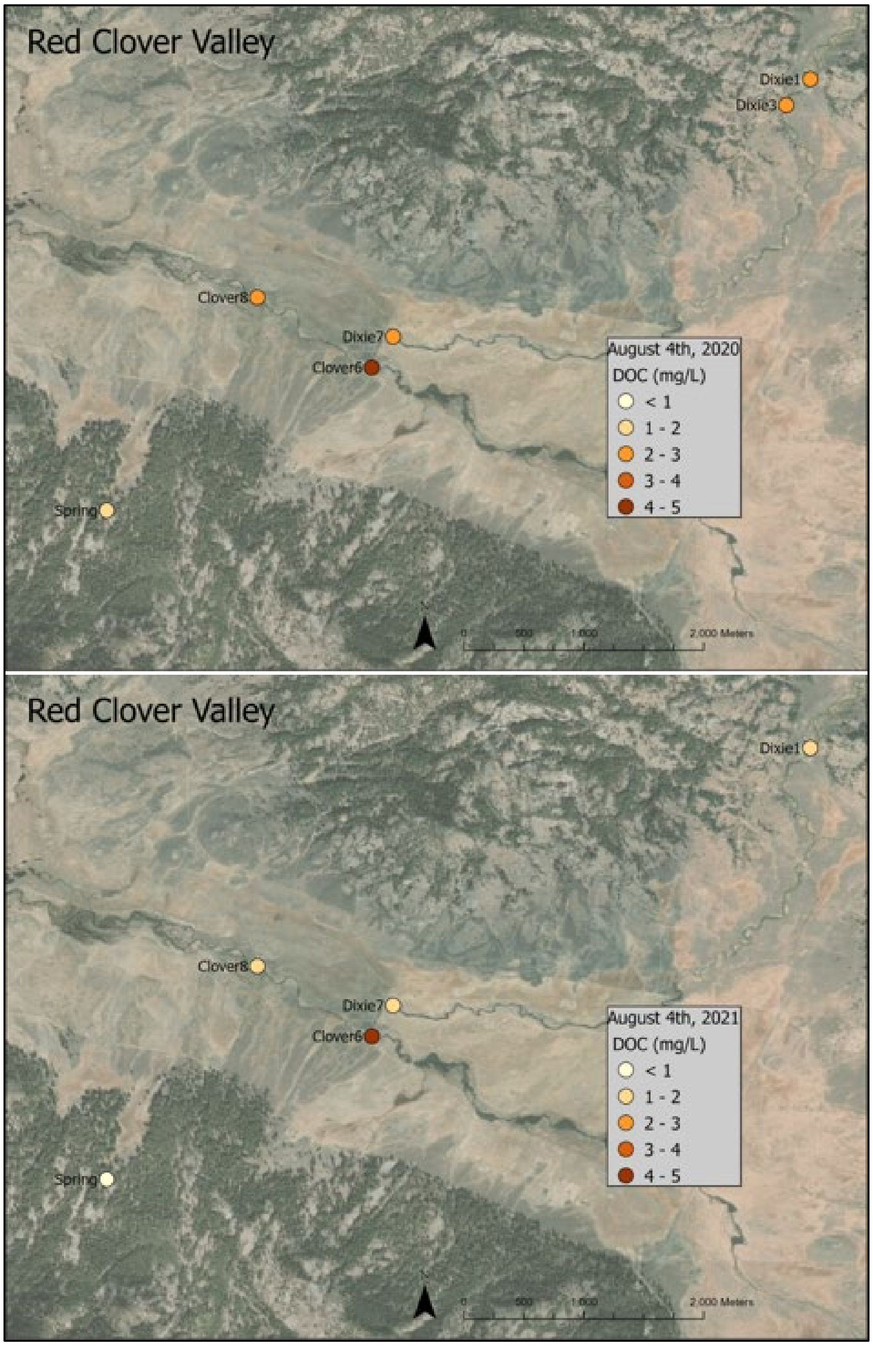

Figure 11: DOC across select sampling sites from August 4th, 2020, and August 4th, 2021.

4.1.4 Other Water Quality Parameters

Major anions and cations were analyzed by UC Davis Analytical Lab. Major anion and cation proportions were consistent with other studies in this region of the Sierra Nevada (Rost et al., 2011). Anions were consistently dominated by bicarbonate (HCO_3^-), ranging from 1.1 to 3 meq/L (Table 9). Chloride (Cl^-) was below detection limits (< 0.1 meq/L) in all samples. Nitrate as Nitrogen (NO_3^-N) was also below lab detection limits (< 0.01 meq/L). Sulfate (SO_4^{2-}) ranged from 0.002 to 0.04 meq/L SO_4-S. SO_4^{2-} concentrations were always highest at Dixie1, then decreased down Dixie Creek. SO_4^{2-} was lowest at the top of Red Clover Creek then increased moving downstream. These anions had little temporal variation, except for Clover6 having a spike in HCO_3^- on August 4th, 2021. Specific conductance as well as cation data at this location corroborate this increase in anion concentration. The Spring location had no variation in HCO_3^- and a slight increase in SO_4^{2-} on August 4th, 2021.

Table 9: Anion concentrations from all grab sample locations across all sampling dates (UC Davis Analytical Lab).

	Aug. 4th 2020	Aug. 4th 2020	Aug. 4th 2020	Aug. 4th 2020	June 28th 2021	June 28th 2021	June 28th 2021	June 28th 2021	Aug. 4th 2021	Aug. 4th 2021	Aug. 4th 2021	Aug. 4th 2021
Site	HCO_3^- meq/L	Cl^- meq/L	NO_3^- N meq/L	SO_4^{2-} meq/L	HCO_3^- meq/L	Cl^- meq/L	NO_3^- N meq/L	SO_4^{2-} meq/L	HCO_3^- meq/L	Cl^- meq/L	NO_3^- N meq/L	SO_4^{2-} meq/L
Dixie1	1.4	<0.1	<0.01	0.04	1.6	<0.1	<0.01	0.033	1.4	<0.1	<0.01	0.04
Dixie3	1.7	<0.1	<0.01	0.004								
Dixie5	1.4	<0.1	<0.01	0.01	1.6	<0.1	<0.01	0.01				
Dixie7	1.2	<0.1	<0.01	0.01	1.7	<0.1	<0.01	0.01	1.8	<0.1	<0.01	0.01
Clover1	1.6	<0.1	<0.01	0.002	1.4	<0.1	<0.01	0.002	1.8	<0.1	<0.01	0.002
Clover2	1.1	<0.1	<0.01	0.002								
Clover6	1.9	<0.1	<0.01	0.002	1.8	<0.1	<0.01	0.002	3	<0.1	<0.01	0.006
Clover8	1.4	<0.1	<0.01	0.006	1.7	<0.1	<0.01	0.008	1.5	<0.1	<0.01	0.008
Spring	1.6	<0.1	<0.01	0.002	1.6	<0.1	<0.01	0.002	1.7	<0.1	<0.01	0.004

Calcium (Ca^{++}) and magnesium (Mg^{++}) were the dominant species of cations, followed by sodium (Na^{+}) then potassium (K^{+}) (Table 10). Ca^{++} ranged from 0.45 to 1.3 meq/L, Mg^{++} ranged from 0.48 to 1.2 meq/L, Na^{+} ranged from 0.28 to 0.7 meq/L, and K^{+} ranged from 0.027 to 0.114 meq/L. Cations varied spatially and temporally along Red Clover Creek and Dixie Creek. Most notably, Ca^{++} and Mg^{++} had an increase in concentration in August. This increase in concentration is also seen in specific conductance data. Little to no variation in cation concentration was observed at the Spring location from June to August.

Table 10: Cation concentrations from all grab sample locations across all sampling dates.

	Aug. 4th 2020	Aug. 4th 2020	Aug. 4th 2020	Aug. 4th 2020	June 28th 2021	June 28th 2021	June 28th 2021	June 28th 2021	Aug. 4th 2021	Aug. 4th 2021	Aug. 4th 2021	Aug. 4th 2021
Site	K^{+} meq/L	Ca^{++} meq/L	Mg^{++} meq/L	Na^{+} meq/L	K^{+} meq/L	Ca^{++} meq/L	Mg^{++} meq/L	Na^{+} meq/L	K^{+} meq/L	Ca^{++} meq/L	Mg^{++} meq/L	Na^{+} meq/L
Dixie1	0.037	0.79	0.48	0.32	0.037	0.92	0.5	0.35	0.027	0.77	0.51	0.36
Dixie3	0.043	0.81	0.59	0.35								
Dixie5	0.037	0.8	0.49	0.33	0.042	0.87	0.52	0.35				
Dixie7	0.067	0.53	0.58	0.42	0.059	0.45	0.56	0.41	0.073	0.81	0.69	0.45
Clover1	0.066	0.81	0.56	0.29	0.075	0.56	0.59	0.31	0.088	0.91	0.66	0.33
Clover2	0.07	0.48	0.56	0.31								
Clover6	0.076	0.89	0.8	0.44	0.073	0.59	0.83	0.51	0.114	1.3	1.2	0.7
Clover8	0.07	0.62	0.59	0.34	0.073	0.77	0.64	0.37	0.074	0.68	0.62	0.36
Spring	0.076	0.75	0.65	0.28	0.08	0.82	0.63	0.28	0.079	0.82	0.64	0.28

pH values ranged from 6.8 to 9.04 (Table 11). Only four of the 42 observations had a pH lower than 7. The lowest values (< 7.25) were recorded along upper Dixie Creek in August 2020 and June 2021. Lower Dixie Creek and Red Clover Creek recorded higher pH values on the first two sampling regimes, frequently exceeding a pH of 8. August 2021 pH values were consistent across all sites except for at Dixie2 above the beaver dam (pH = 9.04). The Spring site had a slightly above neutral pH of 7.05.

Specific conductance (SpC) values ranged from 160 to 307.5 µS/cm (Table 11). The lowest SpC was recorded along upper Dixie Creek and the highest SpC values were recorded at lower Red Clover Creek. SpC increased at Clover5 and Clover6 in August 2021, the same time that high concentrations of anions and cations were observed. Both Red Clover Creek and Dixie Creek experienced increases and decreases in SpC spatially and temporally, but SpC at Clover8 was consistent over time ranging from 180.1 to 187.6 µS/cm. The Spring site SpC in June 2021 was 168.5 µS/cm.

Table 11: pH and specific conductance across all sampling dates.

	August 4th 2020		June 28th 2021		August 4th 2021	
Site	pH	SpC (µS/cm)	pH	SpC (µS/cm)	pH	SpC (µS/cm)
Dixie1	6.98	162.7	7.02	165.8	7.88	171.2
Dixie2	7.24	179.8	7.01	171.2	9.04	187.1
Dixie3	6.8	186	7.07	178.4	7.78	186.2
Dixie4	7.06	173.1	6.8	161.8	7.24	179.7
Dixie5	7.23	161	6.93	163.1	7.36	173.4
Dixie6			7.12	190.8	7.66	195.9
Dixie7	8.7	187.2	8.75	174.7	7.77	205.7
Clover1	8	176	7.93	175.6	7.52	195.1
Clover2	8.82	170.4	7.47	160	7.29	179.8
Clover3			7.17	176.9	7.28	203.7
Clover4			7.69	196.5	7.27	208.5
Clover5			8.45	205.3	7.32	280.8
Clover6	8.37	220	7.85	225.2	7.58	307.5
Clover7	8.16	198.6	7.92	185.6	7.38	193.2
Clover8	8.47	181.3	7.69	180.1	7.63	181.7
Spring			7.05	168.5		

4.2 Statistical Analysis

Correlation matrices which display the dependence between multiple variables are shown in Figures 12 and 13. The values above the diagonal list of parameters shows the Pearson's correlation coefficient (*r*) value between two sets of data. An *r* value of 1 represents a perfect positive correlation, an *r* value of 0 represents no correlation, and an *r* value of -1 represents a perfect inverse correlation. Statistical significance levels are also provided, representing the p-value (0.001***, 0.01**, 0.05*). Boxes below the diagonal list of parameters show the bivariate scatter plots with fitted lines. Figure 12 includes in situ data collected with the YSI MPI, as well as computed NDVI data. The results of anions and cations collected as grab samples (UC Davis Analytical Lab) as well as specific conductance from YSI data are included in Figure 13.

Significant correlations were found in 8 of the 15 pairs in Figure 12. The strongest correlations (p-values < 0.001) were found between pH and DO as well as pH and temperature. SpC, a measure of ionic concentration, had a positive significant correlation with all ions except for SO_4^{2-} (Figure 13). Significant correlations between specific anions and cations were also found. SO_4^{2-} and K^+ had a significant negative correlation (p-value < 0.001). HCO_3^-, the dominant anion, was significantly positively correlated with all cations, most notably with Mg^{++} (r = 0.89) and Ca^{++} (r = 0.83).

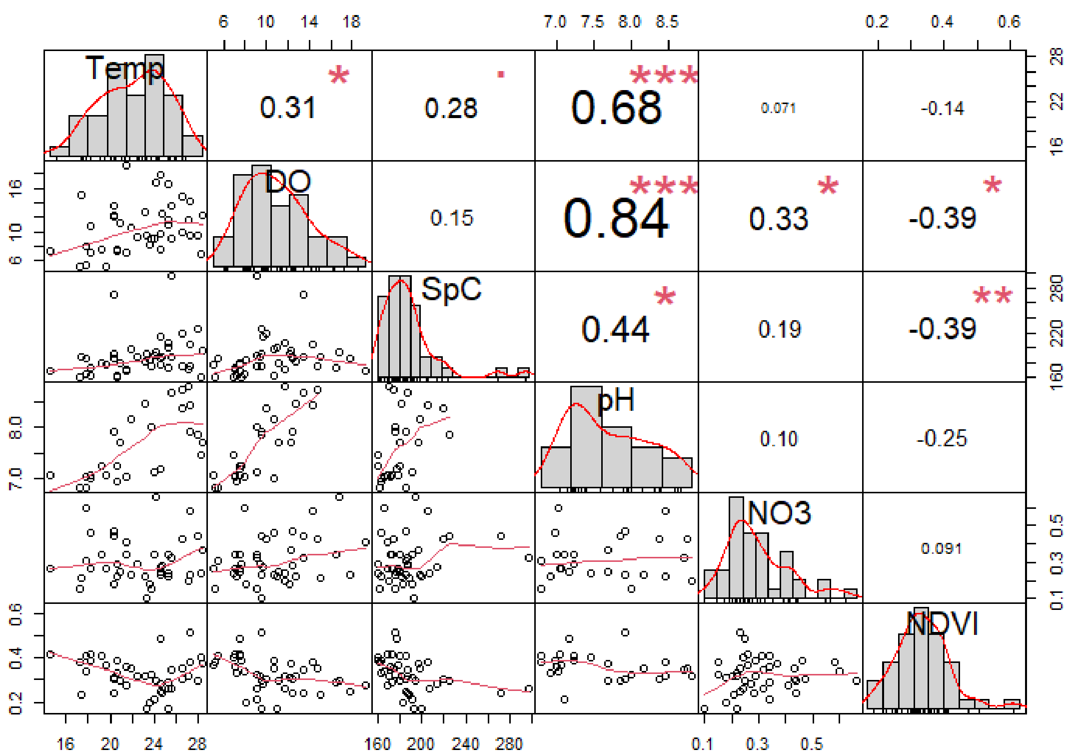

Figure 12: Correlation matrix for stream temperature (Temp), dissolved oxygen (DO), specific conductance (SpC), pH, nitrate (NO3), and NDVI values from all sampling dates.

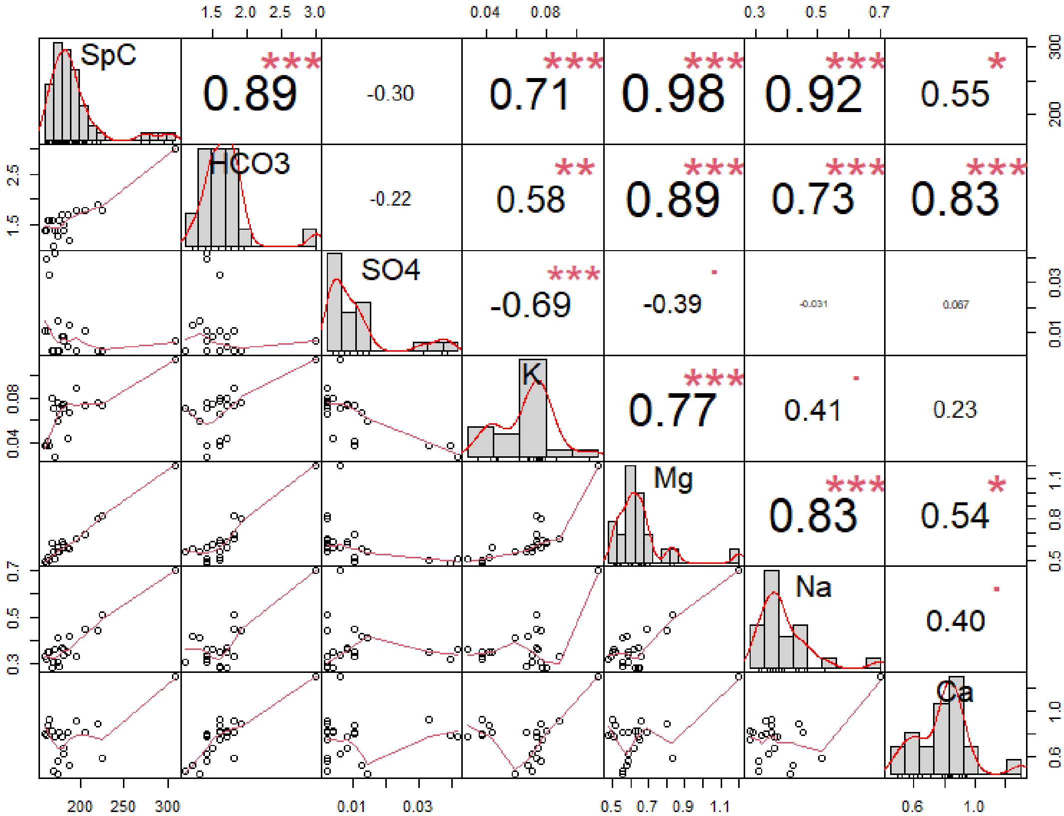

Figure 13: Correlation matrix for specific conductance (SpC) and detectable anions and cations.

4.3 Environmental Influences on Water Quality

4.3.1 NDVI Influence on Water Quality Parameters

Upstream mean NDVI values were calculated to evaluate the influence that riparian vegetation plays in water quality. NDVI is a site characteristic that varied spatially throughout the meadow. Figure 14 shows boxplots grouped by the specific reach where NDVI values were computed. The Upper Dixie reach had the highest median NDVI, and Lower Dixie had the lowest median NDVI. Wide ranges in values were found in the Upper Clover, Mid Clover, and Lower Dixie groups. Lower Clover, Confluence, and Upper Dixie had less variability between NDVI values.

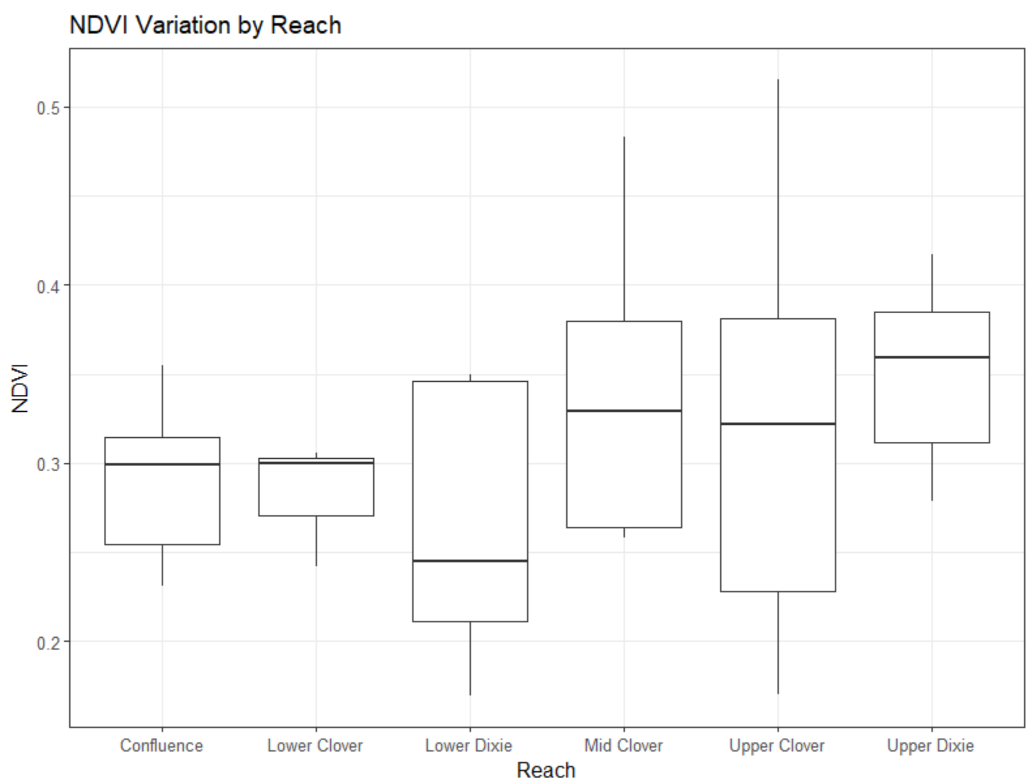

Figure 14: NDVI values grouped by reach classification for all sampling periods.

Figure 15 displays stream temperature compared to NDVI across all sampling sites in August 2020, June 2021, and August 2021, and the data points were symbolized to represent the location of the sampling point. These relationships were further investigated by analyzing data from Red Clover Creek, Dixie Creek, August samples, and June samples (Figure 16). August samples were inversely correlated, and the relationship was statistically significant (r = -0.45; $p < 0.05$), however, June sampling did not show a significant relationship ($p > 0.05$). Significant relationships were found when analyzing individual creeks. Dixie Creek samples were inversely correlated (r = -0.66; $p < 0.01$) and Red Clover Creek was positively correlated (r = 0.45; $p < 0.05$). Significant inverse correlations were found during August months and along Dixie Creek. To further evaluate these relationships, data from Dixie Creek in August were isolated and that produced a stronger inverse relationship at a higher significance level (r = -0.77; $p < 0.01$).

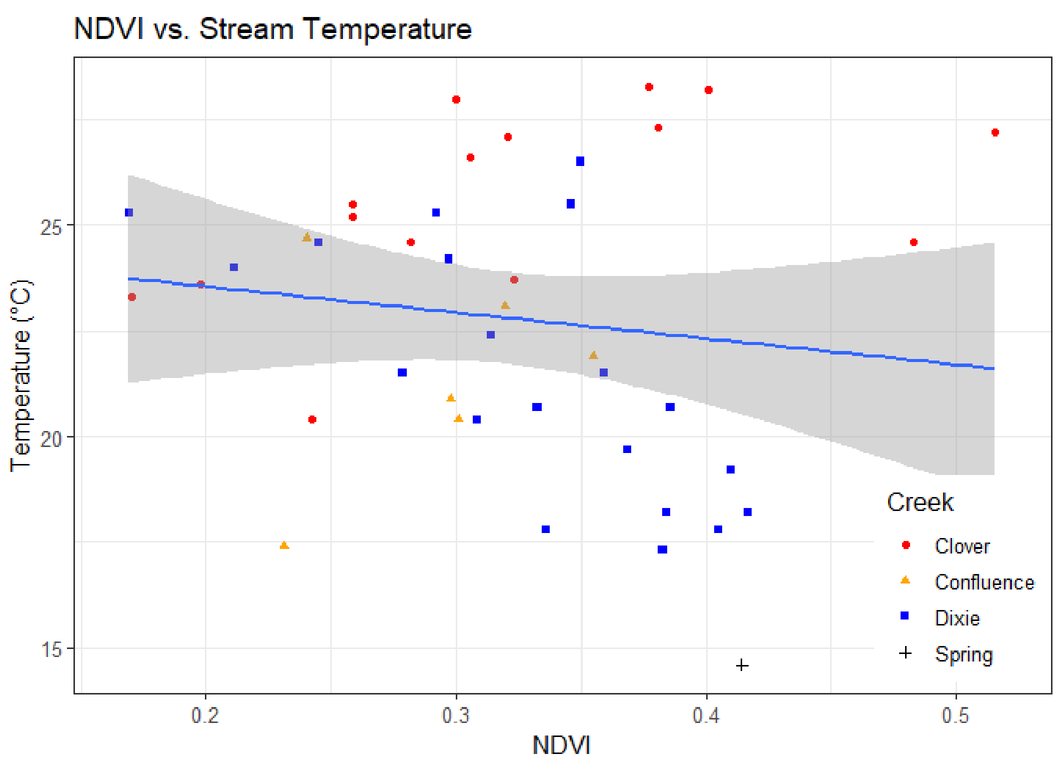

Figure 15: NDVI compared to stream temperature from August 4th, 2020, June 28th, 2021, and August 3rd, 2021, symbolized by location for Red Clover Creek (Clover), Dixie Creek (Dixie), sites below the confluence (Confluence) and the Spring site.

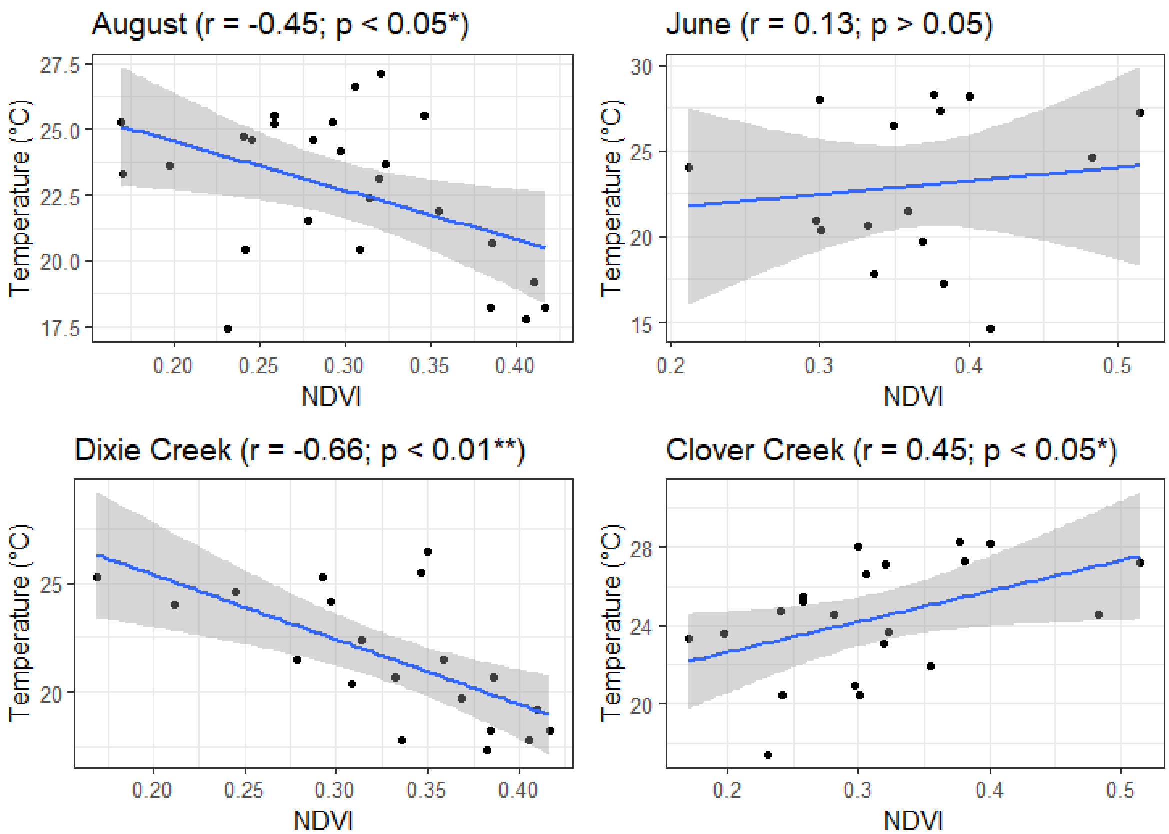

Figure 16: Plot grid displaying NDVI vs. stream temperature with specific spatial and temporal categories.

Specific conductance (SpC) was compared to NDVI to evaluate the influence of riparian vegetation on dissolved ion concentrations. Figure 17 shows that these variables were inversely related with an r value of -0.42 and the relationship was significant (p-value <0.01). This relationship was further investigated to identify spatial and temporal trends. NDVI and SpC from Dixie Creek had the strongest inverse relationship (r = -0.61, p-value < 0.001). Data from Red Clover Creek did now show a significant relationship (p-value > 0.05). Temporally, grouping data by month did not show a significant relationship for August data or June data (p-value > 0.05).

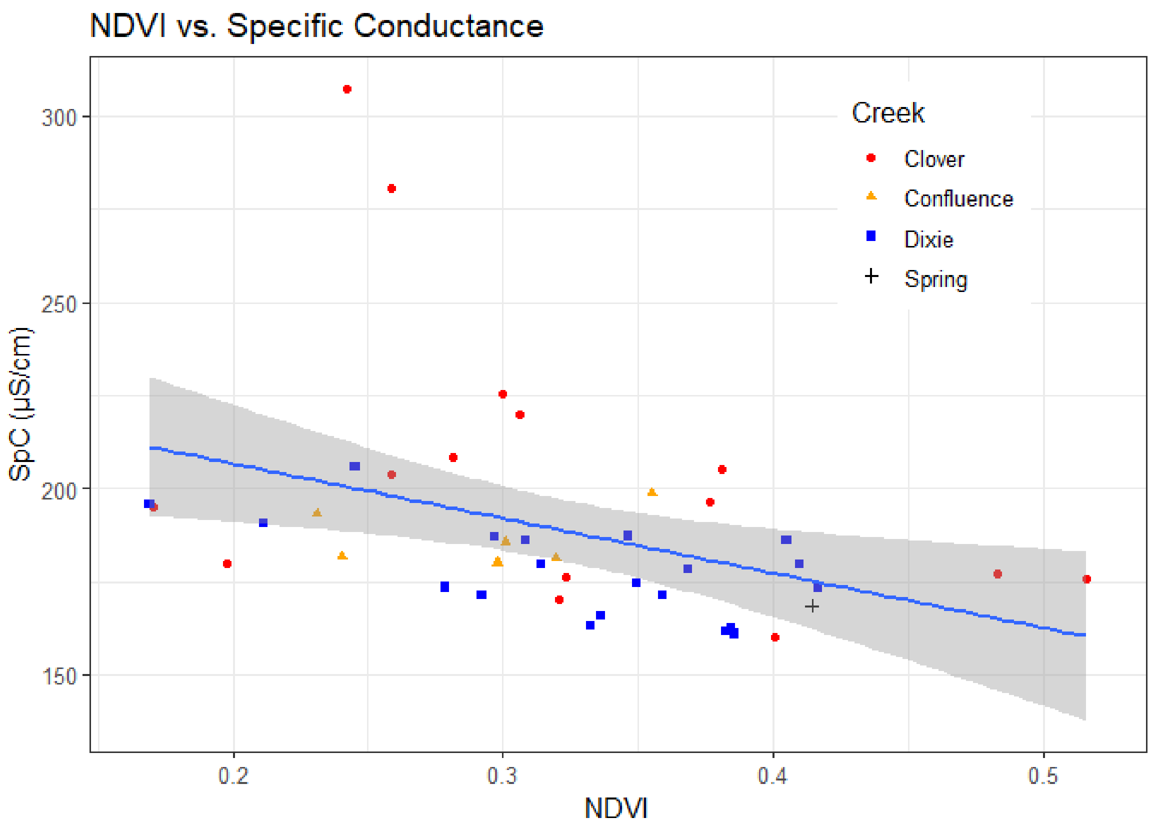

Figure 17: NDVI compared to specific conductance across all sampling dates, symbolized by location for Red Clover Creek (Clover), Dixie Creek (Dixie), sites below the confluence (Confluence) and the Spring site.

NO_3^- was compared to NDVI data to evaluate the influence that upstream riparian vegetation has on nutrients (Figure 18). When all data were analyzed, the relationship was not statistically significant (p-value > 0.05), therefore, these data were further investigated based on spatial and temporal factors. NDVI and NO_3^- data were grouped by individual stream as well as by the month that samples were collected (Figure 19). An inverse relationship was expected when comparing NDVI and nitrate, however, none of the analyses showed a significant relationship and all p-values from these tests were > 0.05. A greater number of samples may show different results for these two variables.

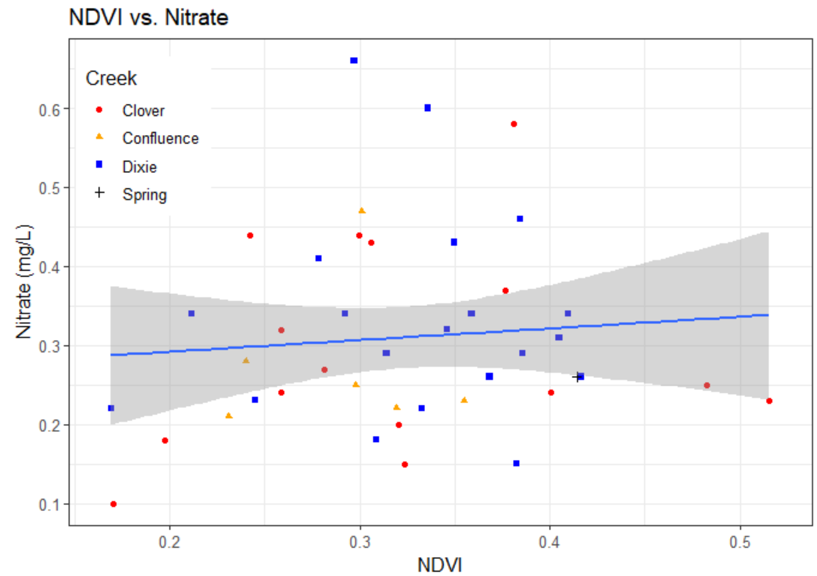

Figure 18: NDVI compared to nitrate across all sampling dates, symbolized by location for Red Clover Creek (Clover), Dixie Creek (Dixie), sites below the confluence (Confluence) and the Spring site.

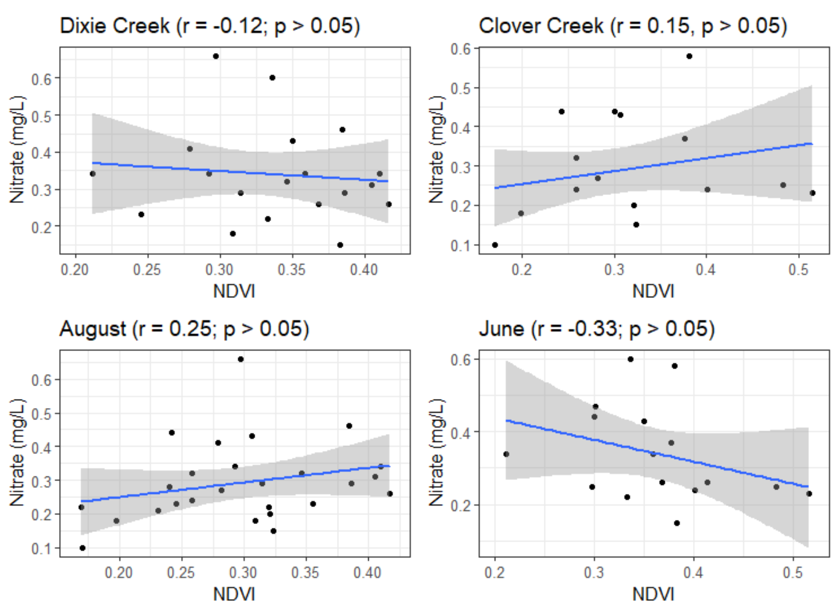

Figure 19: Plot grid displaying NDVI vs. nitrate with specific spatial and temporal categories.

4.3.2 Geology and Soil Influence on Water Quality

Soil classifications were assigned to each sampling site by identifying the dominant type in the upstream wedge buffer used to calculate NDVI data. Table 12 displays soil characteristics for four types of soils (Soil Series) found at the sampling sites, including supplemental data for each Soil Series (Ksat and K Factor) as well as collected water quality data (median SpC). Ksat values represent saturated hydraulic conductivity which is the rate that water moves through the saturated soil. K Factor values represent soil erodibility and are the most important measure of erodibility for many soil erosion models (Auerswald et al., 2014). Median SpC was highest with Keddie soils as the dominant soil type in the upstream wedge buffer, which also happens to have the highest Ksat value. The Trojan Family group of samples had the second highest median SpC and the second highest Ksat, and the Ramelli group of samples had the lowest median SpC and the lowest Ksat.

Table 12: Summary table of the dominant upstream soil series characteristics (UC Davis, 2021b) and median SpC from all sample dates.

Soil Series	Keddie	Trojan Family	Ramelli	Sattley Family
K Factor	.32	.37	.2	.32
Ksat (mm/Hr)	32.4	30	3.24	32.4
Median SpC (µS/cm)	196.2	175.9	171.2	168.5
n	20	12	9	1

The influence of upstream soils (Soil Type) on specific conductance (SpC), nitrate, and pH, is shown in Figure 20. Keddie Loam soils had the greatest median SpC. Two outliers were also found in this group which occurred in August 2021 on lower Red Clover Creek before the confluence. All other soil groups had similar median values between 168.5 and 179 µS/cm. Median nitrate between all groups ranged from 0.22 to 0.29 mg/L. With the exception of outliers in the Ramelli Clay and Trojan-Sattley groups, nitrate was greatest in the Keddie Loam group. Soil groups with the greatest pH were Keddie Loam (median = 7.69) and Ramelli Clay (median

= 7.52). Trojan-Sattley soil groups had the lowest pH with a median value of 7.15. Trojan-Sattley was also the only group to have any observations of pH below 7 (n=3).

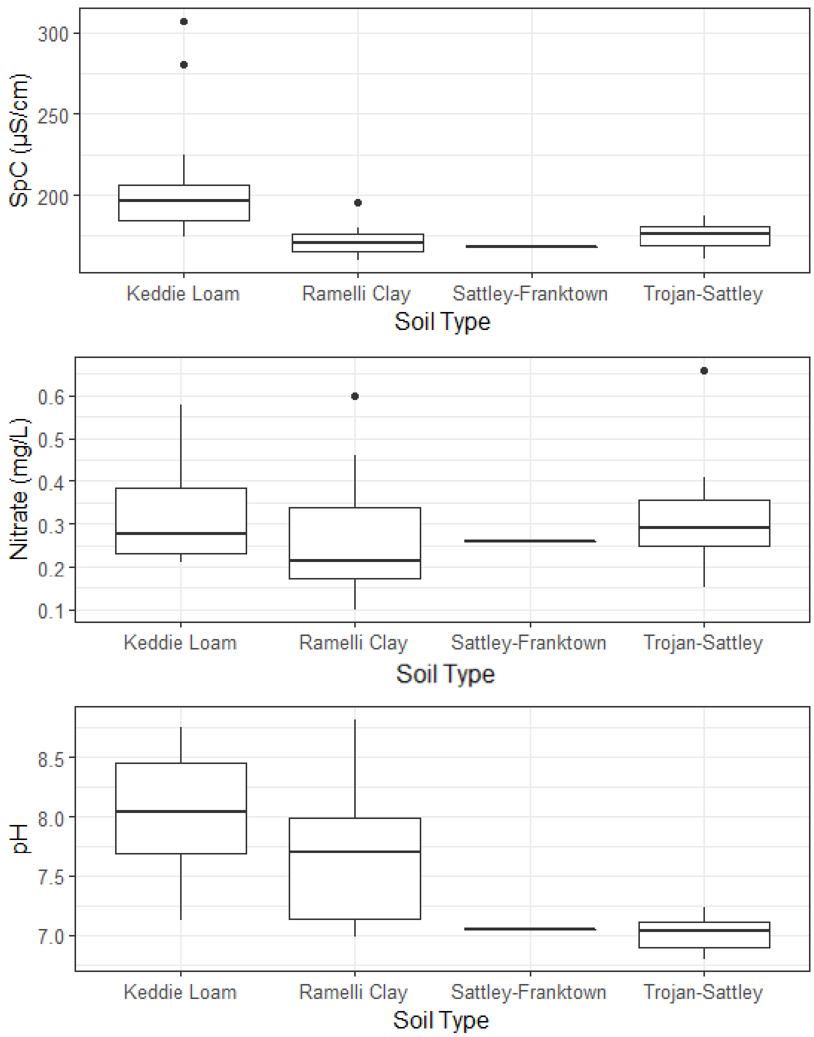

Figure 20: Box plots comparing pH, nitrate, and specific conductance to upstream soil types for all dates (n=42).

Catchment characteristics are highly correlated with solute concentrations and ionic compositions in high elevation montane environments (Clow et al., 2018). Mixing diagrams displaying the relationship between HCO_3^-/Na^+ and Ca^{++}/Na^+ can be used to differentiate between different types of weathering processes (Fan et al., 2014; Gaillardet et al., 1999). Figure 21 displays a mixing diagram of Red Clover Valley's streams ionic composition plotted in relation to carbonate, silicate, and evaporite end members. Site locations are symbolized based on specific reach of the creek to identify spatial trends in weathering processes. Samples taken from the Spring site were the closest to carbonate end members. Upper reaches of Red Clover Creek and Dixie Creek were closer to carbonate end members whereas the lower reaches of both creeks were closer to silicate end members. Sites below the confluence where waters are influenced by both creeks, were positioned most in the middle of all data.

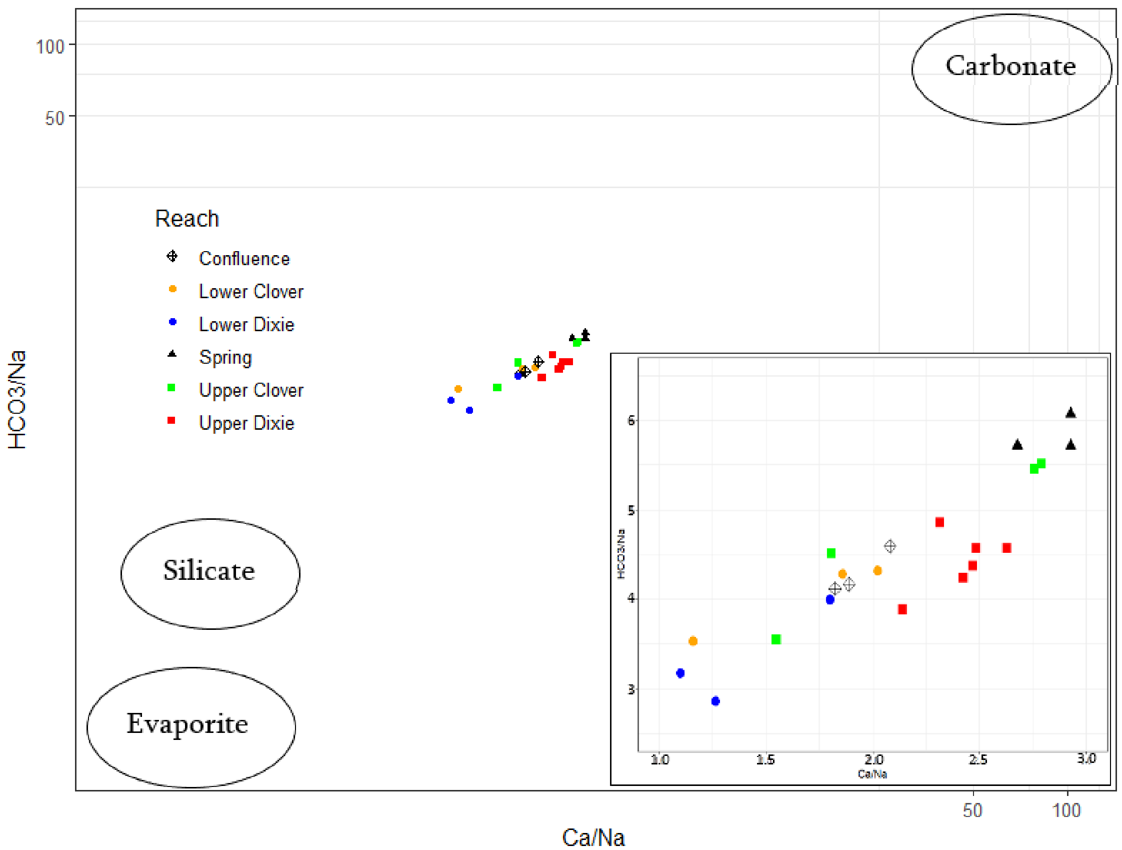

Figure 21: Mixing diagram of HCO3-/Na+ and Ca++/Na+ showing the chemical composition in relationship to end members of carbonate, silicate, and evaporite. X and Y axis are scaled to log10 to visualize end members. An inset plot is provided with a normal axis scale.

4.3.3 Temporal Variation of Water Quality

Early observations found correlations between time of day and water quality parameters, suggesting potential diel influences on water quality. To further investigate this, in August 2021, consecutive days were sampled during different parts of the day. Afternoon temperatures were collected on August 3rd, 2021, between 12:50pm and 5:31pm, after solar noon when the sun was most directly overhead of the meadow and solar radiation had the greatest ability to influence stream temperature. Early morning temperatures were collected on August 4th, 2021, between 7:22am and 11:22am, before solar noon when solar radiation would not have as significant of an influence on stream temperatures. Each afternoon sample was taken five and a half to six hours later in the day than the morning sample. Samples for this analysis could not be taken in the same day due to logistical constraints, however, the monitoring design represents a reliable time of day comparison.

The difference in stream temperatures from afternoon and morning (August 3rd temperature minus August 4th temperature) are shown in Figure 22. Higher values indicate a larger increase in temperature from morning to afternoon. Lower values indicate more stable temperatures throughout the day. Upper Dixie Creek had the least change in stream temperature (2.9-5.8 °C) and lower Dixie Creek had the greatest change (>11 °C). Red Clover Creek change in temperature ranged from 7 °C to 11 °C, except for Clover6 which only changed by 6.1 °C. To evaluate the influence of riparian vegetation on reducing diel stream temperature, upstream NDVI values were compared to the change in stream temperature between morning and afternoon sampling (Figure 23). These variables had a significant, negative trend (r = -0.73) with a p-value < 0.001.

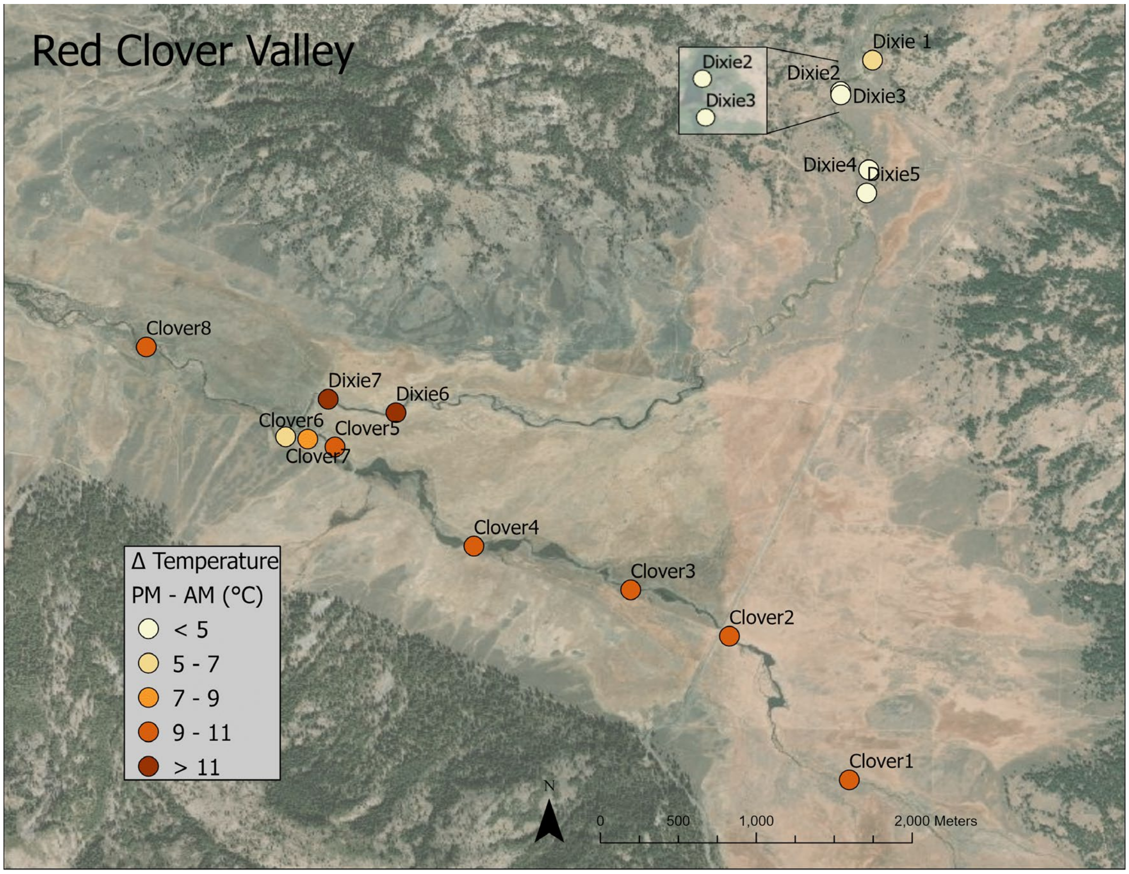

Figure 22: Difference between afternoon stream temperatures (August 3rd, 2021, 12:50 – 5:31pm) and early morning temperatures (August 4th, 2021, 7:22 – 11:22am) across all surface water sampling sites (n=15).

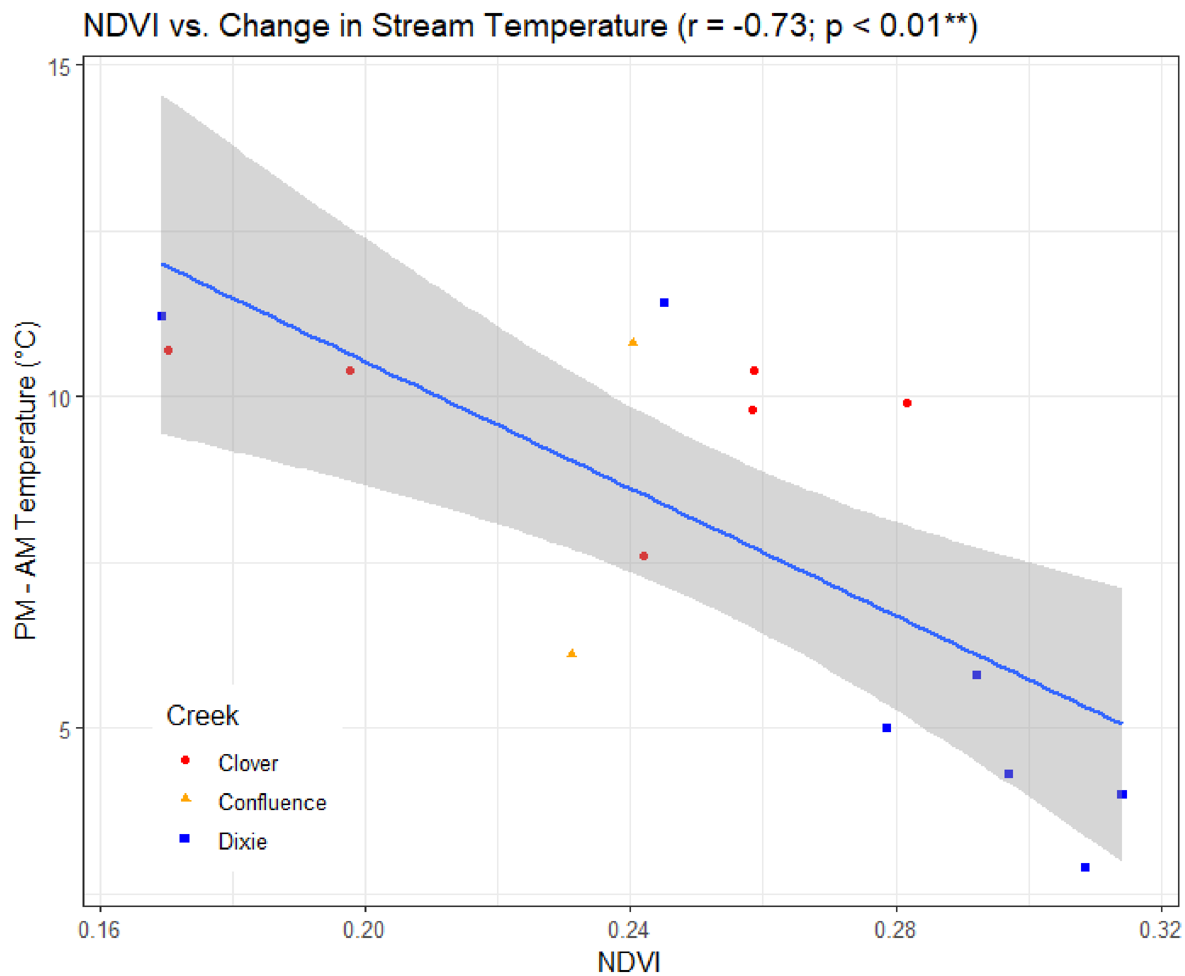

Figure 23: Upstream NDVI values compared to the difference between PM and AM stream temperatures in August 2021.

Dissolved Oxygen (DO) concentration ranged from 5.1 mg/L to 19.23 mg/L. DO was expected to be negatively correlated with temperature because the solubility of oxygen decreases as water temperature increases (Nilsson, 2009). However, a positive correlation between DO and temperature observed in this study (see Figure 12) suggests that other variables such as biologic activity may influence DO. To evaluate diel influences on DO, DO data was compared to the time of day that the sample was collected ($r = 0.56$) (Figure 24). An analysis of variance test was run with Time of Day as an independent variable and DO as the response variable yielded a significant relationship (p-value < 0.001).

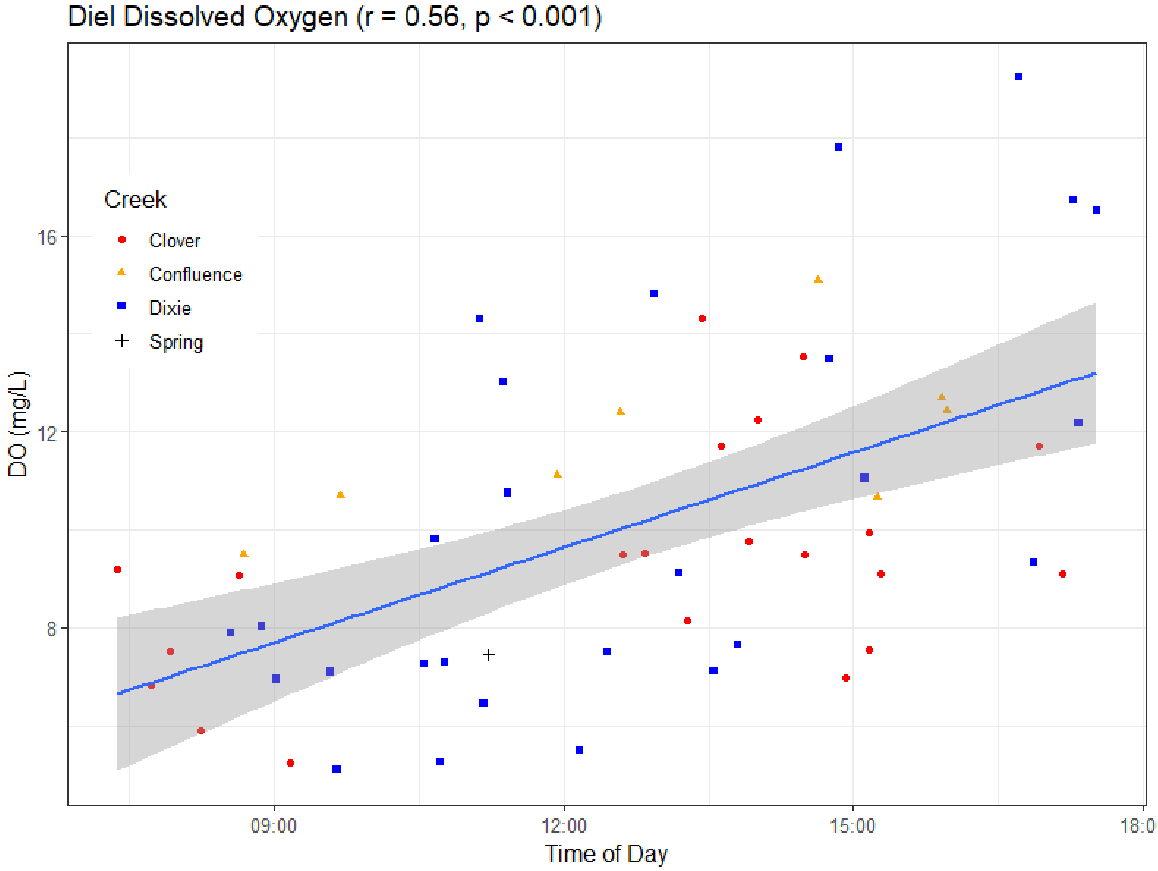

Figure 24: Dissolved oxygen (DO) concentrations over time of day for samples collected in August 2020, June 2021, and August 2021.

To analyze site specific diel DO, morning and afternoon data was collected in August 2021, and the difference between afternoon and morning concentrations were plotted in Figure 25. All sites showed increases from morning to afternoon. Longitudinal trends were not found, suggesting that significant differences in DO were site specific and could be indicative of rooted aquatic plants or buildups of algae behind flow impeding structures. Dixie5 and Dixie7 had the greatest difference in DO (> 8 mg/L) and sites with the lowest difference in DO include Clover1, Clover2, and Clover8.

Figure 25: Difference between afternoon and morning DO across all surface water sampling sites in August 2021.

To further evaluate diel influences on water quality, Figure 26 plots water quality parameters associated with biologic activity over the time of day that samples were collected. All variables were statistically significantly correlated with time. Stream temperature, DO, and pH were positively correlated with time of day and HCO_3^- was negatively correlated with time of day.

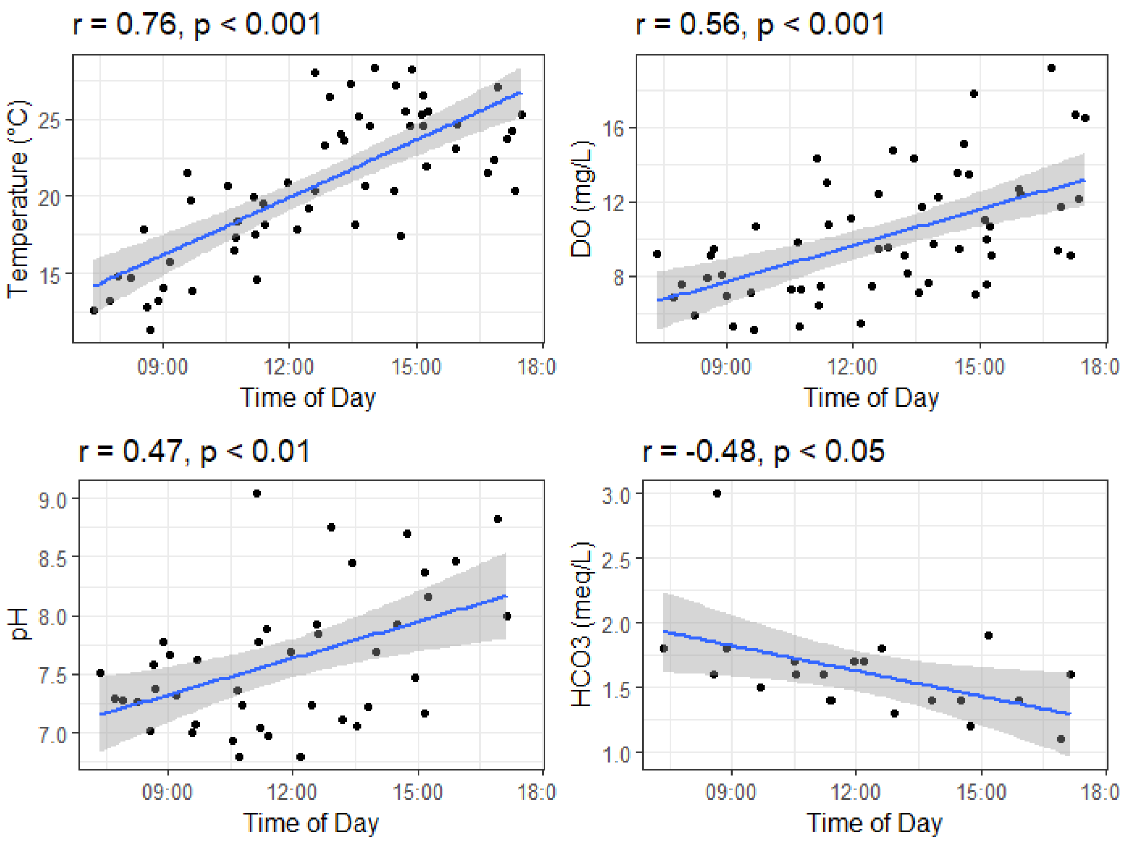

Figure 26: Grid plot of various water quality parameters over time of day and associated Pearson's r and p-value.

4.4 Influence of Management on Water Quality

Three different management categories were used to evaluate their influence on various water quality parameters. Variation in stream temperature influenced by different restoration techniques is shown in Figure 27. Grade control structures (GCS) temperatures had the highest max (28.3 °C), highest median (24.6 °C), and the largest range of values (17.4 °C to 28.3 °C). 57% of GCS temperatures were above maximum thermal thresholds for native fish species such as Cutthroat Trout and Rainbow Trout. Beaver dam analog (BDA) temperatures ranged from 17.3 °C to 26.5 °C with a median value of 21.1 °C (Figure 27). 35% of BDA temperatures were above maximum thermal thresholds for native fish species. Both GCS and BDA minimum values were greater than the Spring site temperature (14.6 °C).

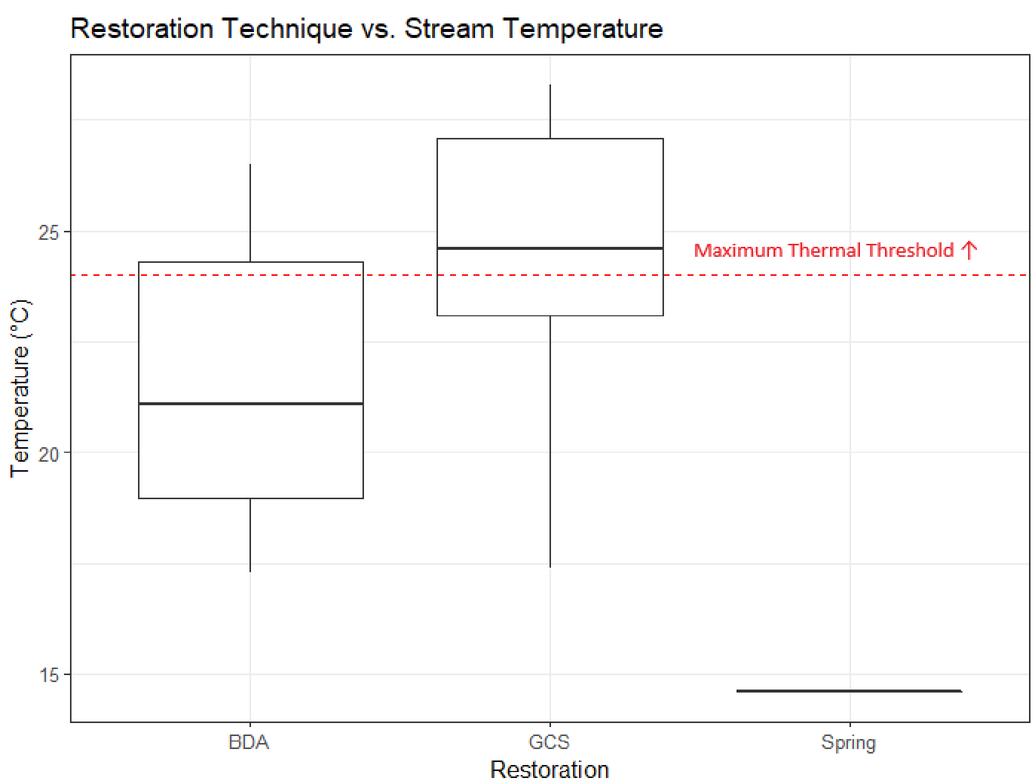

Figure 27: Surface water temperature variation between two different restoration types (BDA, n=20; GCS, n=21) and the Spring site (n=1), compared to the maximum thermal threshold for native fish (24°C).

Diel stream temperature was further analyzed by grouping data by restoration type (Figure 28). Both GCS and BDA data were statistically significantly correlated with time of day ($p < 0.001$), however, GCS sites had a higher *r* value (0.83) than BDA sites (0.69). Although both groups are strongly influenced by time, BDA sites being lower could indicate other covariates influencing this group of data. Potential covariates that could decrease stream temperature include discharge, groundwater inputs, and or riparian shade, potentially limiting the influence of increases in air temperature and solar radiation later in the day.

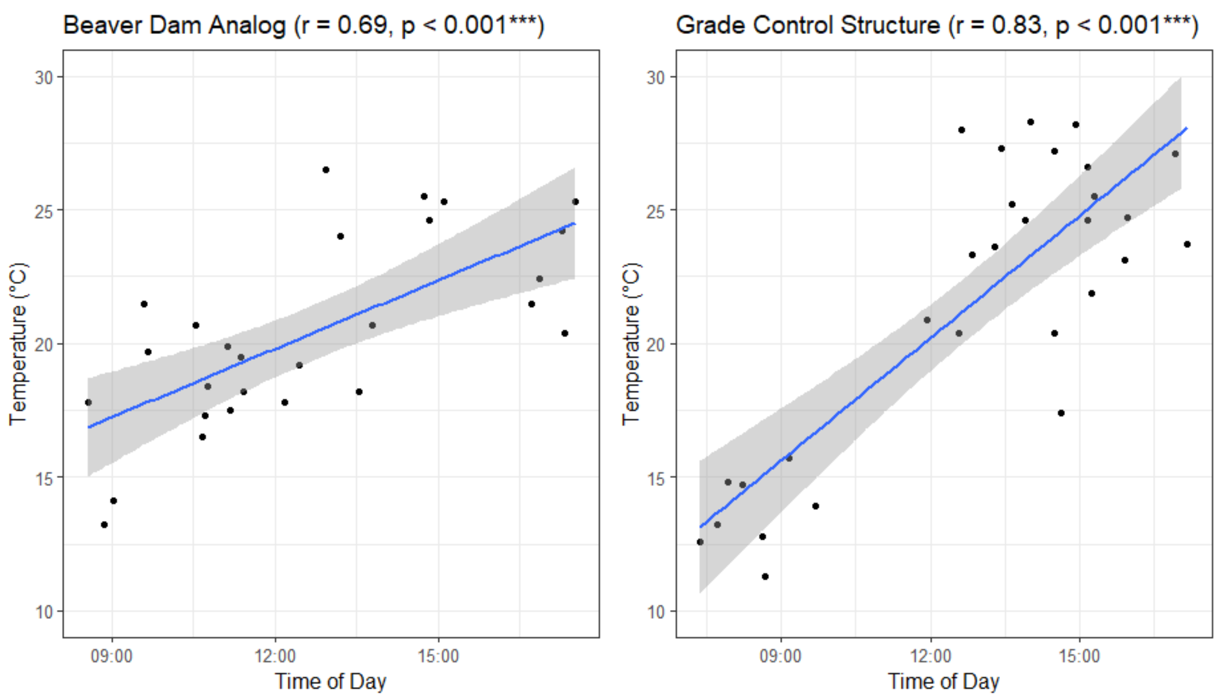

Figure 28: Diel influence on stream temperature between two restoration techniques.

DO variation compared to the different restoration techniques is shown in Figure 29. BDA site DO ranged from 5.1 mg/L to 19.2 mg/L, with a median DO of 9.22 mg/L (Figure 29). Compared to BDA sites, GCS sites had a lower range of values (6.99 mg/L – 15.1 mg/L) with a median DO of 10.65 mg/L (Figure 29). Both median values for BDA and GCS groups were slightly higher than the Spring site DO (7.45 mg/L).

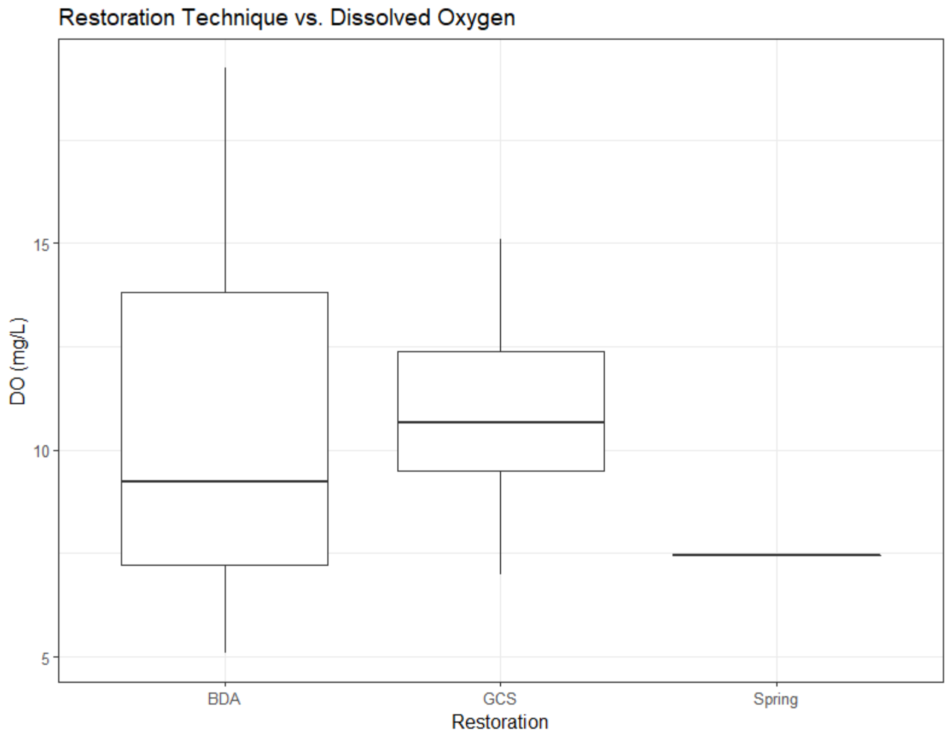

Figure 29: Dissolved oxygen (DO) variation between two different restoration types (BDA, n=20; GCS, n=21) and the Spring site (n=1).

Diel DO was also compared to restoration type (Figure 30). Both groups of data had p-values < 0.001, however, BDA sites had a higher *r* (0.66) compared to GCS sites ($r = 0.47$). The relationship between temperature and DO was also different between these two groups. BDA sites had a significant positive relationship between temperature and DO ($r = 0.62$; $p < 0.001$). However, GCS sites did not have a significant relationship between temperature and DO ($p > 0.05$). This analysis suggests that other covariates could influencing or limiting the diel response of DO throughout the day in GCS sites.

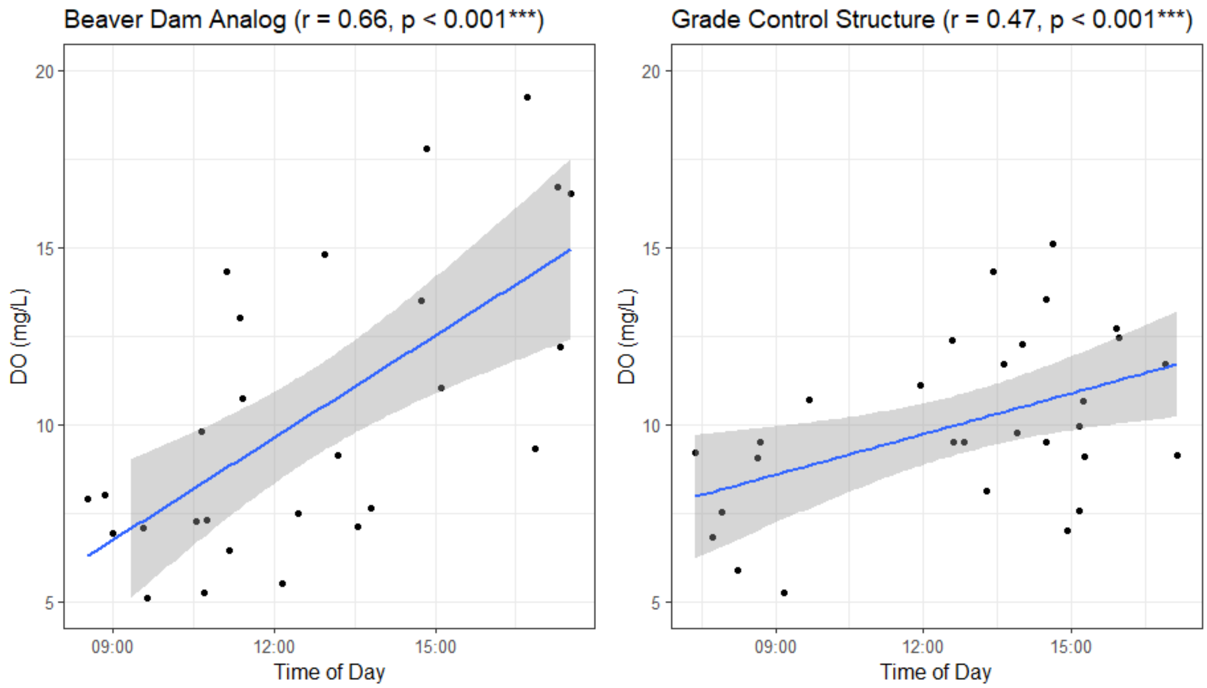

Figure 30: Diel influence on dissolved oxygen between two restoration techniques.

Nitrate variation based on different restoration techniques is shown in Figure 31. BDA sites had a greater range of values than GCS, however, the two highest values were identified as outliers (more than 3/2 times the upper quartile) (Figure 31). GCS nitrate ranged from 0.1 mg/L to 0.58 mg/L with a median nitrate of 0.25 mg/L (Figure 31). 86% of GCS nitrate observations were above the natural background range for the Sierra Nevada EPA Level III sub-ecoregion (Roche et al., 2013). BDA nitrate ranged from 0.15 mg/L to 0.66 mg/L with a median nitrate of 0.32 mg/L (Figure 31). 90% of BDA nitrate observations were above natural background range for the Sierra Nevada EPA Level III sub-ecoregion (Roche et al., 2013). Median nitrate values for GCS (0.25 mg/L) and BDA (0.32 mg/L) were similar to the Spring site nitrate observation (0.26 mg/L).

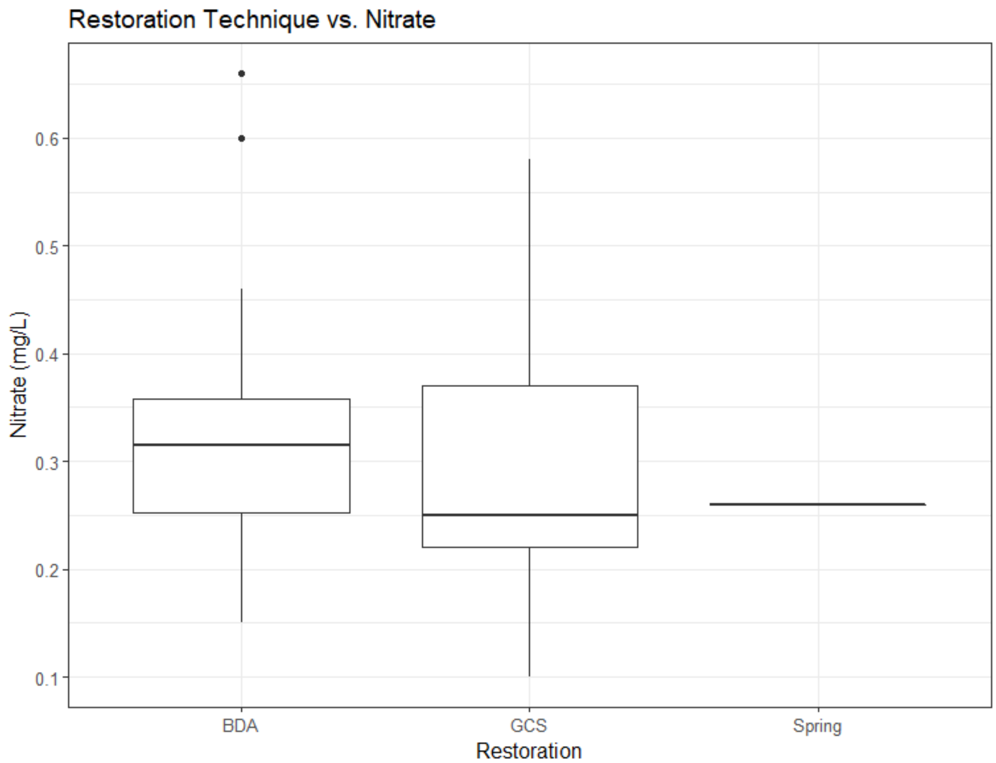

Figure 31: Nitrate variation between two different restoration types (BDA, n=20; GCS, n=21) and the Spring site (n=1).

5. Discussion

Water quality objectives have been established for the Clover Valley Project based on the primary goal of restoring and sustaining a healthy functioning meadow. Under healthy hydrologic conditions, meadows provide cool groundwater inputs and riparian shade to surface water during the dry season, promoting low summer stream temperatures (Viers et al., 2013). Meadows also filter out sediment and non-point source pollutants, improving downstream water quality (The Sierra Fund, 2021). Quantitative concentrations for individual water quality parameter have not yet been established for the Clover Valley Project and data on temporal variation in water quality is limited. However, exploratory analysis from this study provides baseline information for water quality conditions in the early stages of restoration. Future research can use this information to identify spatial and temporal variation as the meadow transitions through years of restoration.

5.1 Water Quality Data

5.1.1 Stream Temperature

Stream temperature plays a critical role in the health of aquatic ecosystems. Spatial and temporal differences in this study allows us to identify various factors that could be influencing stream temperature. For example, time of day was significantly correlated with stream temperature across all sites ($r = 0.76$; $p < 0.001$) suggesting a strong influence of solar radiation and air temperature on stream temperature. This is consistent with findings form other studies focused on climate warming impacts to Sierra Nevada streams (Ficklin et al., 2013, Morrill et al., 2005, Null et al., 2013, Vernon et al., 2019). High elevation mountain stream temperatures were found to be highly vulnerable to increases along with projected air temperature increases (Ficklin et al., 2013; Morrill et al., 2005; Null et al., 2013).

Studies have found that cooler temperatures can be attributed to greater contributions of groundwater (Ficklin et al., 2013; Marzadri et al., 2013; Null et al., 2013; Weber et al., 2017). One of the key objectives of meadow restoration is to raise the water table and increase groundwater contribution and baseflow (Hunt & Nylen, 2012). Groundwater sources, not geothermally influenced, provide cool and stable temperatures, whereas runoff sources are more susceptible to outside influences such as diel fluxes (Gordon et al., 2005). Other environmental factors in meadows such as physical and biological characteristics of the stream channel can influence a stream's ability to limit temperature fluxes (Weber et al., 2017; Willis et al., 2012). Along with increasing groundwater inputs, raising the water table also increases riparian vegetation, such as willows and alders, which reduces streambank erosion and provides shading from direct solar radiation.

Although it is difficult to determine which mechanism is most directly controlling water temperature, we can identify which sites have the greatest capacity to limit diel temperature extremes. Spatial variation in differences in stream temperature were evaluated by taking one set of in situ measurements from an afternoon (August 3rd, 2021) and subtracting those values from measurements taken from the following morning (August 4th, 2021). Sites with the lowest difference in temperature were found in the upper Dixie Creek area as well as below the confluence. Sites with the greatest increases in temperature were found at lower Dixie Creek as well as lower Red Clover Creek above the confluence (see Figure 22).

Cutthroat Trout and Rainbow Trout, native fish to Red Clover Valley, require specific thermal conditions to survive. A common maximum thermal threshold for native fish in the region is 24°C and desirable temperatures are below 18 °C (Plumas Corporation, 2013a; UC Davis, 2021a). Early morning temperatures measured on August 4th, 2021, were all within the desired temperature range. However, afternoon temperatures exceeded desirable temperature thresholds (> 18 °C) in 90% of observations and exceeded maximum temperature thresholds (> 24 °C) in 46% of observations. Temperature trends were spatially consistent across time with greatest temperatures at the lower Dixie Creek sites and the Red Clover Creek sites above the confluence. Lowest temperatures were always in the upper Dixie Creek reach and below the confluence. All afternoon stream temperatures at the most downstream site, Clover8, were higher than the desired temperature range for native fish species (18 °C); however, only one observation, in August 2021, exceeded maximum temperature thresholds (24 °C). Clover8 also had a difference of 10.8 °C between morning and afternoon observations in August 2021. This sampling period was noted to have the lowest flows which could have contributed to higher stream temperatures.

5.1.2 Dissolved Oxygen

Dissolved oxygen (DO) plays a significant role in the health of aquatic ecosystems and is a vital requirement for the survival of native fish. If DO were to drop below 2 mg/L, the system could enter a eutrophic state threatening the aquatic ecosystem (Belsky et al., 1999; Derlet et al., 2010). Too low DO concentrations also affect salmonid species at different life stages (see Table 2) (SWRCB, 2004). Nine percent of observations exceeded the limit to avoid acute mortality during the embryo or larval stages. However, for other life stages of salmonids, no observations exceeded moderate production impairment and only nine percent fell in the slight production impairment category. The data suggests there are certain locations along Red Clover Creek and Dixie Creek that may be harmful for salmonid development at early life stages, but most sites provide sufficient DO for all other life stages.

DO did not have a negative correlation with temperature (see Figure 12), which is typically a primary controlling factor on DO (Null et al., 2013; Puttock et al., 2018; Williams et al., 2015). DO cycles can also be influenced by biologic activity that can either increase or decrease rates based on photosynthesis and respiration (Nilsson, 2009; Rounds, 2011). DO data was compared to time of day (see Figure 24) and the two variables were positively correlated with a statistically significant relationship ($r = 0.56$, $p < 0.001$). Majority of sampling sites were noted to have large growths of unidentified species of macrophytes and algae (Figure 32). Red Clover Creek and Dixie Creek had limited shade cover in the main section of the meadow, and little to no flow velocity due to flow impeding structures; this allows for greater direct solar radiation to penetrate through the water column stimulating plants, and potentially plankton organisms, causing large fluxes of oxygen to be released later in the day.

DO results from this study were similar to Nagisetti et al. (2019) who investigated diel DO responses in eutrophic effluent-dominated macrophyte-rich headwater streams. All sites in their study had similar trends of DO, being low from midnight until 8am, then gradually increasing through the afternoon and reaching max DO around 4pm, then gradually decreasing into the evening. Diel DO trends in their data were similar to RCV data, where minimum DO in the morning were around 5 mg/L and maximum DO in the late afternoon exceeded 15 mg/L. Although Nagisetti et al. (2019) studied streams influenced by treated water, biologic processes influenced by the dominance of macrophytes resembled results from our study. Another study (Rounds, 2011) investigated various factors and processes influencing a stream's dissolved oxygen budget and also found a positive correlation between stream temperature and DO. Characteristics of sites that reached DO of greater than 20 mg/L included the following: stream temperatures greater than 12-15 °C, low turbidity, the presence of phytoplankton rather than periphyton, lack of riparian shading, and high macrophyte density. These are consistent with characteristics of many sites in Red Clover Valley. For example, low turbidity was noted at all sites due to restoration structures slowing the flow of water. Macrophyte descriptions were noted in the field notes and photos; all sites had some growth within seeing distance and many downstream streambeds were dominated by macrophytes (Figure 32). Phytoplankton measurements were not conducted for this study.

Figure 32: Examples of aquatic rooted macrophytes and algae presence in Red Clover Valley at Clover3(top left), Clover7(top right), Dixie7(bottom left), and Dixie1(bottom right).

5.1.3 Nutrients

The Clover Valley Project looks to promote a healthy meadow while continuing to allow cattle grazing on the landscape. Summer cattle grazing is the most common land use practice that leads to water quality degradation in the Sierras (Atwill et al., 2011; Derlet et al., 2012; Myers et al., 2012). Cattle influence the landscape by compacting and eroding soils as well as depositing high concentrations of nutrients into streams and groundwater (Agouridis et al., 2005; Blank et al., 2006; Derlet et al., 2012). Healthy meadows can help reduce nutrient concentrations in streams due to greater soil infiltration, lower runoff rates, higher water table, and a productive riparian zone with plant species that actively take up nutrients (Blank et al., 2006; Kauffman et al., 2016; Viers et al., 2013).

Nutrient data from in-situ YSI sampling includes nitrate (NO_3^-) and ammonium (NH_4^+) (Table 7). NO_3^- was above background concentrations for the Sierra Nevada EPA Level III sub-ecoregion (0.18 mg/L) (Roche et al., 2013) in 88% of observations in this study. Spatial variation of NO_3^- was observed due to various potential factors such as stream flow, vegetation presence and abundance, and cattle activity. Temporal variation in NO_3^- was also noticed, with NO_3^- decreasing from June to August in 2021. This is likely because it was later in the growing season and plant uptake of NO_3^- over time reduced surface water concentrations (Blank et al., 2006; KopciCek et al., 1995; Lohse et al., 2009; Nilsson, 2009). In situ NO_3^- data suggests that although cattle grazing was occurring during the field season, NO_3^- contamination was not a concern for eutrophication at any sampling site during the time of sampling.

Ammonium (NH_4^+) concentrations were sampled at all sites in August 2021. NH_4^+ is the product of ammonification, part of the nitrogen cycle, which occurs through microbial decomposition of plant and animal matter (Lohse et al., 2009; Nilsson, 2009). Figure 10 displays a large spatial variation of NH_4^+, with notably higher concentrations at Clover6 and Clover7 (up to 7.82 mg/L). High concentrations at these locations coincide with high concentrations of DOC (see Figure 11) that was found above the confluence, which could be caused by plant and animal matter decomposition. This site could also be higher in NH_4^+ due to a greater flushing of solutes and particles, as seen in the high specific conductance that occurs at this site on all sampling dates. One other possibility is direct deposition of ammonia (NH_3) in the stream or riparian area by cattle. When NH_3 dissolves in water, a portion of it converts to NH_4^+ ions ($NH_3 + H_2O = NH_4^+ + OH^-$). Due to NH_4^+ only being recorded on the last day sampling, it is difficult to come to conclusions on its role in the meadow's biogeochemical cycles. However, high concentrations found at lower Red Clover Creek should be further investigated to identify possible organic pollution sources.

Roche et al. (2013) collected data on NO_3^-, NH_4^+, and other pollutants in Northern California National Forest lands associated with cattle grazing. Sites with cattle present were primarily found in wet meadows. Where cattle were present (n = 462), mean NO_3^- was 0.08 mg/L and max NO_3^- was 0.98 mg/L. Mean NO_3^- in Red Clover Valley (0.31 mg/L) was greater than the mean in Roche et al. (2013), but max NO_3^- (0.66 mg/L) was lower. Mean NH_4^+ in Roche et al. (2013) was 0.01 mg/L and max NH_4^+ was 0.19 mg/L. NH_4^+ data from Red Clover Valley was greater for both the mean and max compared to Roche et al. (2013). The timing of the data collected should also be considered. Roche et al. (2013) collected data between June and November of 2011, and RCV data was collected only in June and August months. NO_3^- is typically lower during summer months in headwater streams due to instream uptake between Spring and Summer (KopciCek et al., 1995; Nilsson, 2009). Mean NO_3^- in RCV decreased from June 2021 (0.34 mg/L) to August 2021 (0.29 mg/L). It should be further investigated whether NO_3^- concentrations in RCV are higher and potentially surpassing eutrophication thresholds earlier in the year. One current indicator that this could be occurring is the overabundance of macrophyte and algae growth that was observed during sampling, which may have resulted from high nutrient levels earlier in the growing season (EPA, 2022; Ferreira et al., 2011; Smolders et al., 2006).

5.1.4 Other Water Quality Parameters

Other water quality parameters of interest showed spatial and temporal patterns. Specific conductance (SpC) had a very large range of values, ranging from 161 µS/cm to 307.5 µS/cm. Typically, high-elevation streams in the western U.S. have SpC lower than 20 µS/cm due to minimal interaction between precipitation and catchment soils (Clow et al., 2018). However, SpC data in this study were much higher with a minimum of 160 µS/cm. The Spring site, which is most likely majority groundwater, had an SpC of 168.5 µS/cm, which is lower than 83% of all SpC values along the creeks. Lower SpC was found in the more upstream sampling sites for both Red Clover Creek and Dixie Creek. Highest SpC was recorded downstream, most notably at Clover5 and Clover6. High downstream concentrations could be the product of restoration structures influencing stream flow, causing water to have greater interaction with soils. SpC could also be influenced by stream volume. Clover5 and Clover6 were noted to have lower flow volumes, which could lead to increased ionic concentrations as volume decreases. This can also be seen throughout the growing season, as streamflow decreases, the mean SpC of all sites increases from June 2021 (180 µS/cm) to August 2021 (203 µS/cm). Inversely, on all sampling days, SpC decreased downstream as stream volume increased below the confluence of Red Clover Creek and Dixie Creek at the Clover7 and Clover8 sites.

pH ranged from 6.8 to 9.04, which could be attributed to physical, chemical, and biological processes occurring in RCV. Due to the large presence of aquatic macrophytes and algae discussed in section 5.1.2, photosynthesis and respiration could have influences on specific water quality parameters, including pH and parameters that are influenced by changes in pH. pH was significantly correlated with DO (r = 0.84), and pH was inversely correlated with bicarbonate (HCO_3^-) (r = -0.28). Photosynthesis from macrophyte and algae releases oxygen and consumes carbon dioxide (CO_2) from the water column, which results in an increase in pH throughout the day (Andersen et al., 2017; Nagisetty et al., 2019; Nilsson, 2009). Both pH and DO data in this study showed significant temporal relationships (see Figure 26) with increased values in the afternoon which could indicate a diel cycle caused by photosynthesis and respiration in the streams.

HCO_3^- was inversely correlated with time of day (r = -0.48, $p < 0.05$) (see Figure 26). The DO and pH diel cycle detailed above could decrease HCO_3^- throughout the day through assimilation of CO_2 during photosynthesis, therefore releasing the oxygen and hydrogen ions into the water column ($HCO_3^- - CO_2 = OH^-$) (Nilsson, 2009; Zang et al., 2011). Andersen et al. (2017) studied similar diel cycles of DO, pH, and HCO_3^-, and found that diel decreases in HCO_3^- can occur through precipitation processes as well. One result is the formation of carbonate minerals (CO_3^{2-}) due to high pH in the water ($HCO_3^- + OH^- = CO_3^{2-} + H_2O$) (Andersen et al., 2017; Nilsson, 2009). Another potential result from diel pH and DO occurs in waters with available Ca^{++} and HCO_3^- leading to loss of CO_2 through simultaneous processes of photosynthesis and calcification ($Ca^{2+} + 2HCO_3^- = CaCO_3$ (precipitated) + CO_2 (assimilation) + H_2O). With RCV being dominated by Ca^{2+} and HCO_3^-, with significant diel trends in, and correlations between DO and pH, it is possible that formations of carbonate minerals could be resulting at later times in the day when pH is highest.

Dissolved Organic Carbon (DOC) has various sources and could indicate different processes occurring in the meadow. Typically, DOC is highly correlated with dissolved organic matter (DOM) (Lohse et al., 2009). Spatially, DOC was greatest at the site where other parameters associated with DOM are also greatest (Clover6). NH_4^+, which can occur through microbial decomposition of plant and animal matter, is also greatest at Clover6. This may indicate that this part of the meadow has greater upstream organic matter content. Another possibility is that this location experiences greater upstream surface water-soil interaction. Red Clover Valley is composed of a variety of mollisol soils, which are rich in organic matter. Therefore, streams that have greater interaction with mollisol topsoils, and the soluble organic carbon in their upper profiles, could discharge higher concentrations of DOC. Studies have also shown that DOM and DOC exhibit a temporal flushing response as flows increase (Lohse et al., 2009). Williams et al. (2015) supports this and adds that groundwater flow transports more minerals from rock weathering, compared to surface and subsurface (inter-soil) flows which can transport more DOC from leaching or desorption. If these are the processes occurring in Red Clover Valley, that could indicate greater surface and inter-soil flow is occurring on Red Clover Creek (higher DOC at Clover6) compared to Dixie Creek (lower DOC at Dixie7). Stream temperature data further supports this due to lower and more stable stream temperatures along Dixie Creek compared to Red Clover Creek, potentially attributed to a greater groundwater contribution.

5.2 Environmental Influences on Water Quality

One of the primary goals of meadow restoration is to increase mesic and hydric vegetation which helps promote the positive feedback loop detailed in Figure 1 (Viers et al., 2013). Under this scenario, healthy riparian zones help improve water quality by decreasing stream velocity and allowing sediment to be deposited. Mesic and hydric vegetation has longer and stronger roots that help stabilize stream banks and can take up excess nutrients (Blank et al., 2006). Riparian vegetation also plays a key role in providing shade to maintain low stream temperatures during the growing season when the Sierra Nevada experiences longer days and higher air temperatures (Nusslé et al., 2015). In healthy meadows, the relationship between vegetation, geomorphology, and hydrology, creates a dynamic feedback loop that promotes greater contributions of groundwater which promotes lower maximum daily temperatures (Null et al., 2013; Viers et al., 2013; Weber et al., 2017).

Upstream NDVI, representing amount of riparian vegetation, was compared to stream temperature, specific conductance (SpC), and nitrate (NO_3^-). Stream temperature was inversely correlated with NDVI across all data; however, seasonal differences were found when the data was grouped and analyzed by month. August data showed significant inverse correlations between NDVI and temperature (r = -0.45, $p < 0.05$). This could be due to available shade, vegetation influences on hydrology, or a combination of both, leading to decreased stream temperatures later in the growing season. June data did not show a significant relationship and may not be a strong indicator of the relationship due to it being earlier in the growing season when there is greater water availability and higher NDVI values. August data was a strong indicator of this relationship due to it being later in the growing season when sites with less groundwater inputs undergo senescence are more likely to have less green vegetation available.

To further investigate these results, Figure 23 compared NDVI to the difference in AM and PM temperatures in August 2021. This analysis produced an even stronger negative correlation ($r = -0.73$; $p < 0.01$) showing that not only does upstream NDVI contribute to lower afternoon stream temperatures, but it also influences the increase in temperature from morning to afternoon. This process plays a significant role in aquatic habitat suitability as stream temperatures frequently surpassed native fish thermal thresholds (24 °C) in the afternoon. Therefore, increasing riparian vegetation in those vulnerable locations could improve the overall fish habitat suitability of the meadow during late summer months.

NDVI was compared to other parameters to evaluate the influence of upstream vegetation on water quality. NDVI was significantly inversely correlated with SpC ($r = -0.42$, $p < 0.05$). Studies have shown that SpC strongly correlates with topography, geology, soils, and vegetation, and that increases in interaction between precipitation and the catchment tends to increase SpC (Clow et al., 2018). Riparian vegetation in meadows decreases runoff rates and promotes infiltration into the groundwater. Since the Spring site represents groundwater in this study, and SpC at this site (168.5 µS/cm) is lower than 83% of all observations, sites with lower SpC could be more likely to have greater groundwater contributions. Therefore, due to the strong negative correlation between NDVI and SpC, upstream NDVI could be contributing to a greater groundwater contribution. Inversely, sites with lower NDVI would have greater runoff rates, more surface interaction, and a higher SpC. It is also possible that the relationship between parameters is not dependent and locations with high NDVI coincided with low SpC due to other controlling factors. The highest concentrations of SpC were found in the downstream reaches likely due to longer resident time and a greater amount of the catchment interaction. Also, the upper quartile of NDVI observations was exclusively in the upper reaches of both creeks, potentially causing the relationship to appear significant.

NDVI was also compared to nitrate (NO_3^-) to evaluate the relationship between increased vegetation and available nutrients. It was expected that NO_3^- would decrease as upstream NDVI increased due to greater plant uptake capacity. NO_3^- was compared to NDVI (see Figure 18) but there was not an inverse correlation. To evaluate specific trends, the data was separated based on month and creek (see Figure 19). June data showed the strongest relationship between NDVI and

NO_3^- (r = -0.33), however, due to a small sample size, the relationship was not statistically significant. This inverse trend could be because it was earlier in the growing season before plant uptake of NO_3^-. NO_3^- data from this study supports this as mean NO_3^- from June (0.34 mg/L) was greater mean NO_3^- from August (0.29 mg/L). This analysis should be further investigated earlier in the growing season to understand the relationship between NO_3^- and upstream vegetation at a larger temporal scale.

Geology and soils can also have strong influences on water quality. Rost et al. (2011) studied other watersheds in this region of the Sierra Nevada and found similar geologic compositions as those found in Red Clover Valley. Anion and cation compositions were also similar, being heavily dominated by HCO_3^-, Ca^{++}, and Mg^{++}. In this study, sites were grouped by location and plotted on a mixing diagram to show their relation to different weathering processes (see Figure 21). Na^+ is primarily derived from silicate dissolution and HCO_3^- and Ca^{++} primarily indicate carbonate weathering (Fan et al., 2014; Gaillardet et al., 1999). All sites in Red Clover Valley showed a combination of silicate and carbonate weathering. However, data collected at the Spring site were the closest to carbonate end members. The Spring is not located in the main valley with all other sites and may be influenced by a greater contribution of groundwater. There was also a difference in whether samples were taken in the upper reaches compared to the lower reaches. Samples collected from the upper reaches were closer to carbonate end members and lower reaches were closer to silicate end members. It is possible that as water flows downstream through the meadow, different weathering processes are occurring compared to those at more upstream locations.

Analysis of soil influence on water quality did not show clear differences for many soil groups. Only the Keddie Loam soil group showed differences to all other groups, and only for SpC. All other groups and water quality parameters did not show strong enough differences to come to conclusions on their influence on water quality. This could be due to the high number and nonuniform distribution of soil clusters within Red Clover Valley, allowing for multiple soil types to influence stream water chemistry.

5.3 Influence of Management on Water Quality

One of the objectives of this research was to investigate how different restoration techniques impact water quality. Red Clover Valley uses two restoration techniques on two different creeks in the same meadow, thus minimizing environmental heterogeneity between water bodies and making variation in water quality data more likely to be due to differences between restoration techniques. Beaver dam analogs (BDA) and grade control structures (GCS) differ in the way that they influence the flow of water. BDAs dam a stream and either slow the flow of water that passes through it or creates a pond upstream of it (Burchsted et al., 2010; Puttock et al., 2018). GCSs slow the flow of water, trapping sediment, and redirecting flow to access the floodplain (Adduce et al., 2004; USDA Forest Service, 2010). One of the primary differences between the two processes is that GCSs can allow water to flow through the structures, creating turbulence and mixing, whereas BDAs have greater potential to dam the stream and not allow water to flow directly through them. BDAs are also a processed based restoration that is self-sustaining once dams are mature and inhabited by beaver. In general, both processes attempt to increase groundwater storage and reconnect streams to the floodplain. The undisturbed “Spring” site was used to act as a control in comparing restoration techniques. It should be noted that samples were collected during dry years and might not reflect the way that restoration structures would influence water quality during a wet year.

Sites along Red Clover Creek under the influence of GCSs had higher stream temperatures than sites along Dixie Creek under the influence of BDAs (see Figure 27). Time of day had a significant influence on stream temperature. Although both BDA and GCS sites were statistically significantly correlated with time of day ($p < 0.001$), BDA temperatures were less correlated with time of day ($r = 0.69$) than GCS temperatures ($r = 0.83$) (see Figure 28). This suggests that other covariates are contributing to cooler temperatures at BDA sites, compared to GCS sites which are more driven by increases in air temperature and solar radiation associated with the time-of-day variable. This could be due to the dynamics of the structures. GCSs only slow down the flow of water or redirect it. This could be problematic if there is not enough flow to redirect the stream to the floodplain. In that situation water would either pool up in the current channel or flow through the structure downstream. However, BDAs are effective at storing water behind the structure and can hold it for long periods of time before it is released downstream. This increase in residence time promotes surface to groundwater exchange, raising the local groundwater table (Burchsted et al., 2010; Davee et al., 2019; Puttock et al., 2018). However, both restoration techniques had much higher temperatures than the Spring site which is fed by groundwater.

When comparing restoration sites to change in temperature from AM to PM, sites along Dixie Creek under the influence of BDAs were effective at reducing increases in afternoon temperatures (see Figure 22). Weber et al. (2017) studied alterations of stream temperatures by natural and artificial beaver dams and found similar results. In their study, beaver dam structures buffered diel summer temperatures at the reach scale by increasing surface water storage, leading to cooler stream temperatures caused by enhanced groundwater surface water connectivity. One way to examine the influence of groundwater in meadows, is by measuring NDVI (Richardson, 2021). Figure 23 shows that upstream NDVI was significantly inversely correlated with diel temperatures ($r = -0.73$, $p < 0.01$), potentially due to site characteristics such as a higher water table. Other studies argue that beaver dam structures increase stream temperature due to increases in stream surface area (Kemp et al., 2012; Majerova et al., 2015; Margolis et al., 2001). Our results from Red Clover Valley more support Weber et al. (2017) in that BDAs are effective at minimizing diel temperature extremes. However, sites along Red Clover Creek under the influence of GCSs had much higher diel temperature extremes and could be influenced by increases in stream surface area as described in the other studies.

Restoration promotes healthy meadows which can help reduce nutrient concentrations in streams due to greater infiltration and lower runoff rates and by having a productive riparian zone with plant species that actively take up nutrients (Blank et al., 2006; Kauffman et al., 2016; Viers et al., 2013). Burchsted et al. (2010) suggests that beaver ponds may be higher in nitrogen compared to free-flowing streams. However, in catchments rich in nitrogen from anthropogenic activities, beaver ponds are much more effective at reducing nitrogen transport downstream. Puttock et al. (2018) found that beaver dams in high power streams are more susceptible to failure with potential to release stored sediment and nutrients downstream. However, low gradient streams, such as those found in meadows, supports stable construction of beaver dams and this discontinuity in the stream leads to nutrient retention in captured sediment. Plant colonization from these conditions can continue the process, capturing sediment and associated nutrients.

Both BDA and GCS sites had similar median NO_3^- concentrations as the Spring site. Longitudinal variation of NO_3^- shows differences between the two creeks (see Figure 8). As water entered upper Dixie Creek and moved through BDA structures, NO_3^- generally decreased. This supports studies that beaver dams could effectively store nutrients (Burchsted et al., 2010; Puttock et al., 2018). The highest concentration of NO_3^- in this study was found in August 2021 above the active beaver dam site at Dixie2 (0.66 mg/L). Below the beaver dam at Dixie3, NO_3^- was 0.18 mg/L. All other dates also had higher concentrations of NO_3^- above the dam, compared to below. This suggests that the dam was effectively disrupting nutrient transport during this study. Alternatively, on Red Clover Creek, NO_3^- increased downstream as water moved through GCSs. This was observed on all three sampling days and suggests that nutrients are more easily transported through GCSs than BDAs. Other factors could also have an influence on NO_3^-. Temporal variation of NO_3^- showed that NO_3^- noticeably decreased towards the end of the growing season. This could be due to plant uptake of nitrate over the growing season. It would be useful to understand how these restoration structures influence NO_3^- earlier in the year, under different hydrologic conditions.

Other parameters were also analyzed to evaluate the influence of management on water quality. DO concentrations varied between different restoration techniques. BDA sites had a greater range of DO values, however GCS sites had a higher median DO and both sites had higher median DO than the Spring site. Based on the analysis between DO and time of day ($p < 0.001$), it is more likely that temporal variability had a greater influence on DO compared to spatial variability in Red Clover Valley. The relationship between DO and time of day was stronger in BDA sites ($r = 0.66$) compared to GCS sites ($r = 0.47$). This suggests that either BDA sites are creating environments that promote photosynthetic processes, or GCS sites have other covariates reducing DO, such as higher temperatures, limiting the solubility of oxygen. GCSs also promote water mixing as streams cross structures, increasing turbulence and aerating the water, which could contribute to GCS sites having a higher median DO than BDA sites. pH was also compared between restoration techniques; however, the two groups were not statistically significantly different from each other ($p > 0.05$). Due to the strong correlation between DO and pH ($r = 0.84$, $p < 0.001$), pH is most likely more driven by factors that are driving DO.

Management is only one of the contributing variables that influence water quality and other variables may have stronger influences but are difficult to differentiate due to spatial characteristics of Red Clover Valley. All BDA sites are along Dixie Creek and all GCS sites are along Red Clover Creek, therefore other basin characteristics could be influencing the data. Continued monitoring throughout the Clover Valley Project over different seasons with different flows would provide more information to evaluate how restoration influences water quality. However, during the low flow years of this research, data suggests that BDA sites along Dixie Creek were more effective at reducing diel temperature extremes as well as disrupting nutrient transport downstream, compared to GCS sites along Red Clover Creek.

5.4 Limitations

This study faced a variety of limitations including data collection and uncertainties in GIS and data analysis. Original plans for data collection included multiple field days in 2020 and 2021. However, COVID-19 travel restrictions limited field work and the ability to collect greater temporal data over the growing seasons. Potential field errors could have come from equipment calibration as well as the storage and transportation of grab samples. Nutrients were detected with the YSI probe, at relatively high concentration in some instances, but were non-detect in the UC Davis lab analysis. This could be caused by YSI calibration error, denitrification during transportation, or lab errors. Another factor that could influence data accuracy is disturbances to the landscape or water in the stream caused by humans, cattle, or beaver.

Sample site selection should also be considered. 2020 sampling included a greater number of grab samples than 2021, but 2021 had a greater number of YSI collection sites than 2020. The Spring site was only sampled with the YSI one time when the stream flow was high enough to submerge the probes without damaging them. Stream temperature at the Spring site was also higher than expected and may be influenced by geothermal activity. Also, collecting only one sample per site could be misleading as slow-moving streams may have stratified and could produce different data at different depths. Another issue could be from data collected past the confluence of Red Clover Creek and Dixie Creek as there might not have been sufficient time for transverse mixing of the two creeks leading to the samples representing more of one creek than the other.

GIS data analysis could increase the uncertainty. Soil classifications were based on publicly available shapefiles and may not accurately represent basin characteristics. Additionally, the NDVI wedge used to create upstream buffers is not a perfect representation of upstream riparian vegetation, just the mean NDVI value of the raster cells within the buffer. NDVI values also do not distinguish native from non-native vegetation and is not a perfect representation of riparian health. Also, buffer processing required manually aiming the wedge in the general upstream direction, however, each stream reach had unique sinuosity and the upstream direction was based on visual inspection and best judgment. Therefore, NDVI data is more of a general representation of the upstream vegetation near that sampling site.

Statistical analysis is limited due to the number of samples available at each site. Water quality parameter correlations could be different if there were more temporal samples collected. Significance levels (p) between parameters may also be inflated due to spatial autocorrelation as sites along the same creek flow to one another. On the other hand, due to the large number of sampling locations with limited samples taken at each site, unique environmental variables at each site could influence correlations between parameters. Variables such as basin characteristics and management type also leave uncertainties as restoration techniques were specific to creeks. Dixie Creek only used BDAs and Red Clover Creek only used GCSs; therefore, data collected on each creek is influenced by all processes occurring within the individual watersheds as well as its respective restoration technique. Temporal variation was also a largely influencing factor, which could limit the ability to explain how basin characteristics and management practices influence water quality for parameters that have diel variation.

5.5 Considerations for Future Studies

Specific water quality objectives should play a role in developing the methodology for future monitoring efforts in Red Clover Valley. For example, if eutrophication is a concern, nitrogen as well as phosphorus data should both be collected at each creek as well as the downstream site. Also, a greater temporal range of temperature, DO, and pH data would provide more insight to the role of oxygen consumption during respiration by aquatic plants and whether hypoxic episodes are occurring in the streams. Aquatic vegetation sampling could also provide critical information on its role in biogeochemical cycling. Having quantitative data could provide insight on its relationship with specific water quality parameters that appear to be influenced by photosynthesis and respiration.

Multiple measurements at different depths in the water column could also provide useful information about aquatic habitats. Weber et al. (2017) noted temperature stratifications in streams with beaver dam analogs caused by enhanced groundwater-surface water connectivity, creating cool corridors for fish refugia during summer months. This could provide useful information on habitat site suitability for native fish during summer months. Also, different restoration techniques influence the flow of water differently and identifying whether mixing or stratification is occurring could provide more information on restoration hydrologic dynamics. Measuring DO and pH could also provide useful information on aerobic and anerobic conditions at various depths in the streams. Current temporal trends in pH suggests vulnerability to episodic acidification and should further be investigated.

Because erosion is one of the key issues with degraded meadows, long term monitoring of turbidity at the downstream site could provide statistically significant information based on how different processes in the meadow are influencing sediment transport downstream. Comparing turbidity to discharge would provide useful information on effectiveness of restoration structures to retain sediment during different flow stages. This could help track progress of restoration to identify successful trends of decreasing erosion or whether adaptive management strategies should be implemented. Other aquatic habitat trends data would also provide useful information on restoration progress. This includes streambed substrate (percent fines, D50), residual pool depth, pool spacing, and canopy cover data. Fish surveys between the two creeks would also provide useful information as to which creek has the greatest aquatic habitat site suitability.

Continued monitoring of key water quality parameters such as temperature, DO, and nutrients will provide evidence of whether current activities in Red Clover Valley are going to improve water quality in the long-term. Due to this study being conducted during relatively dry years, stream temperature data might be skewed and not be of concern when there is greater precipitation, lower air temperatures, and increased snowmelt. On the other hand, cattle grazing over a long dry period could have created a buildup of nutrients on the landscape and when there are sufficient flows, those nutrients could be flushed out at high concentrations. Influence of algae and macrophytes on DO and pH might also change when stream flows are greater and improve biostimulatory conditions.

6. Conclusion

This study investigated various water quality parameters and how they related to management practices and other environmental influences in Red Clover Valley, specifically during the summer months of low flow years. Literature from the past 20 years suggests that cattle grazing in montane meadows has significant impacts on water quality, hydrology, and aquatic ecology (see Table 2). Results from this study show significant spatial and temporal variation of water quality in Red Clover Valley. Impairments of specific water quality parameters were identified at specific locations or at specific times in the day.

Stream temperatures surpassing thermal thresholds for native fish were found at various locations, most notably during the later parts of the day. Diel analysis showed that sites along upper Dixie Creek had less temperature variation during the day compared to sites along Red Clover Creek. Lower diel temperature extremes can be attributed to increased groundwater inputs, increased flow, and increased riparian shade. This study supports the literature that suggests BDAs are effective at increasing groundwater inputs and limiting diel temperature extremes. However, sites along Red Clover Creek associated with GCSs had higher temperatures and were not as effective at limiting diel temperature extremes. BDA and GCS sites also varied in longitudinal profiles of nutrients. Nitrate was generally higher above the BDA sites and decreased downstream. However, nitrate concentrations increased downstream on Red Clover Creek through the GCSs. Ammonium, DOC, and SpC were also significantly higher at the lower Red Clover Creek sites compared to other sites in the meadow. Overall, sites associated with BDA were more effective at limiting temperature extremes and disrupting nutrient transport whereas sites associated with GCSs experienced greater temperature extremes and promoted nutrient transport downstream.

Local environmental factors influenced select water quality parameters, but not all. Most notably was the relationship between NDVI and stream temperature. Low stream temperatures later in the growing season were highly correlated with higher upstream NDVI values. This analysis supports conceptual models in that meadows with mesic and hydric vegetation are more likely to have cooler stream temperatures by increasing groundwater inputs as well as providing riparian shade (American Rivers, 2012; NFWF, 2010). NDVI was expected to show an inverse relationship with nitrate, however, these analyses did not show statistical significance. Future analyses of the relationship between riparian vegetation and nitrate concentrations in Spring or early Summer could improve our understanding of vegetation's role in nitrogen cycles in meadows throughout the growing season.

Diel trends in water quality parameters were found indicating a strong presence of in-stream aquatic vegetation influencing biogeochemical cycles. DO and pH were found to increase throughout the day, likely due to aquatic plant photosynthesis and respiration. Bicarbonate decreased throughout the day potentially due to this diel cycle and the influence that pH has on inorganic carbon. Diel DO and pH can indicate a large presence of aquatic biomass which may be indicator for eutrophication. However, nitrate data from this analysis was closer to background conditions and does not suggest eutrophication is occurring during the sampling period. A greater compilation of temporal data, as well as other biostimulatory water quality data, could provide further insight as to whether episodic acidification or eutrophication in Red Clover Valley is of concern and how conditions are influenced by different flow conditions throughout the restoration process.

This study evaluated whether Red Clover Valley acts as a sink, source, or neither, for water quality parameters of concern and found that this likely varies spatially and temporally. For example, Clover8, the most downstream site, consistently had lower nutrient concentrations, SpC, and DOC, compared to other sites in the meadow. Clover8 also did not show signs of diel fluxes in DO, suggesting that potentially harmful diel trends were not occurring at this location. DO at this site was also consistently high, even during early morning sampling when many other sites experienced low DO. Temperature was the only parameter of concern, however, temperature only exceeded native fish thresholds on one of the sampling days during low flows.

Overall, this study provided useful information on water quality during the early stages of meadow restoration in Red Clover Valley. During low flow summer months, which are expected to continue and potentially become even hotter and drier in the future, aquatic habitat for native fish is a concern and should continue to be monitored to evaluate potential impairment. Sites that may be influenced by a greater groundwater contribution showed more improved water quality. Biostimulatory indicators were also observed and should be further investigated under various flows scenarios to evaluate whether these are ongoing concerns or if they are only seasonal. Given the significance of hydrologic variability in meadows, using management practices that have the greatest capacity to increase residence time of water at higher elevations, will be imperative for ecosystem health moving forward with projected climate warming. Increased late summer flows augmented by restoration not only can improve water quality conditions but will also be critical to improving drought resiliency.

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