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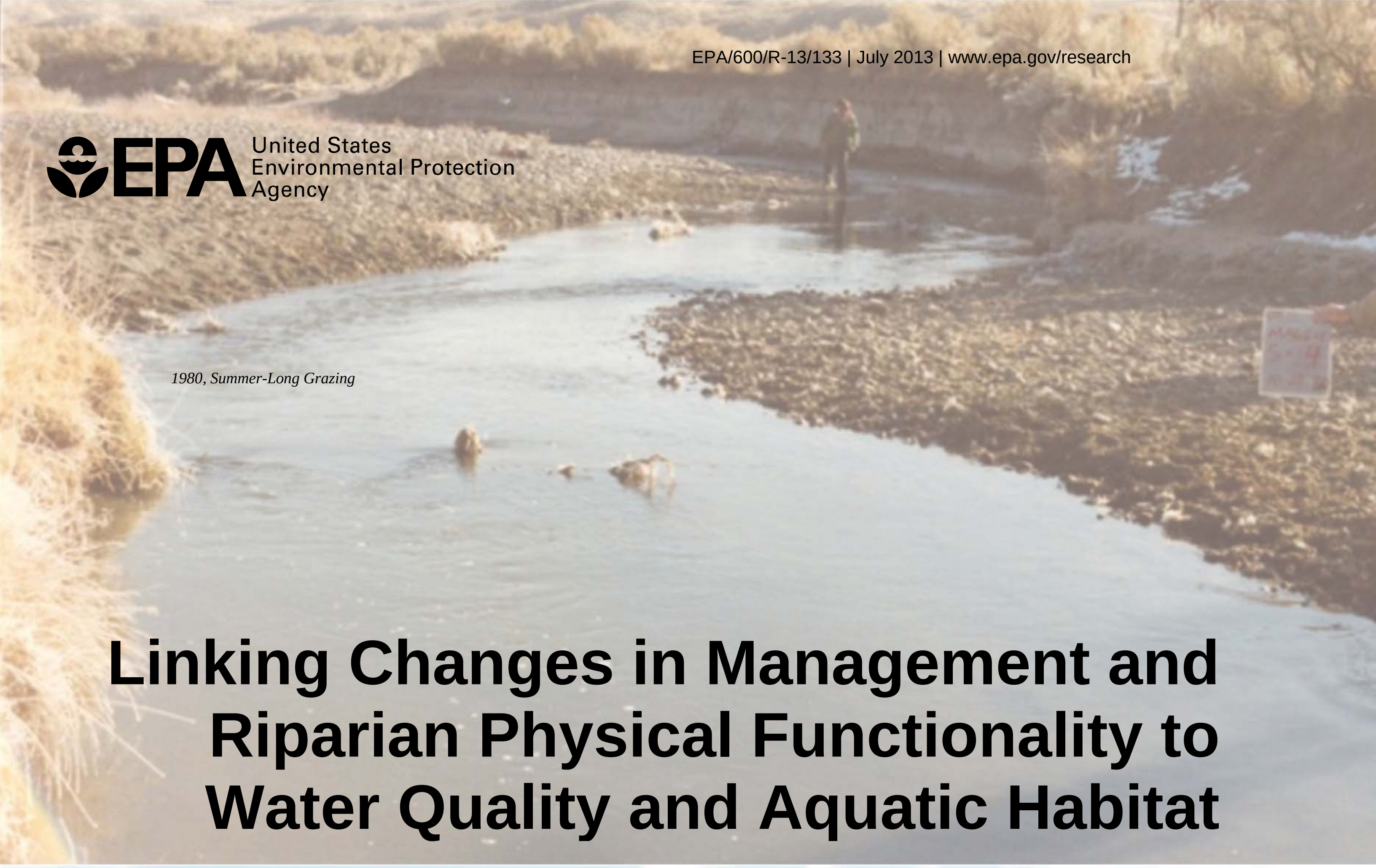
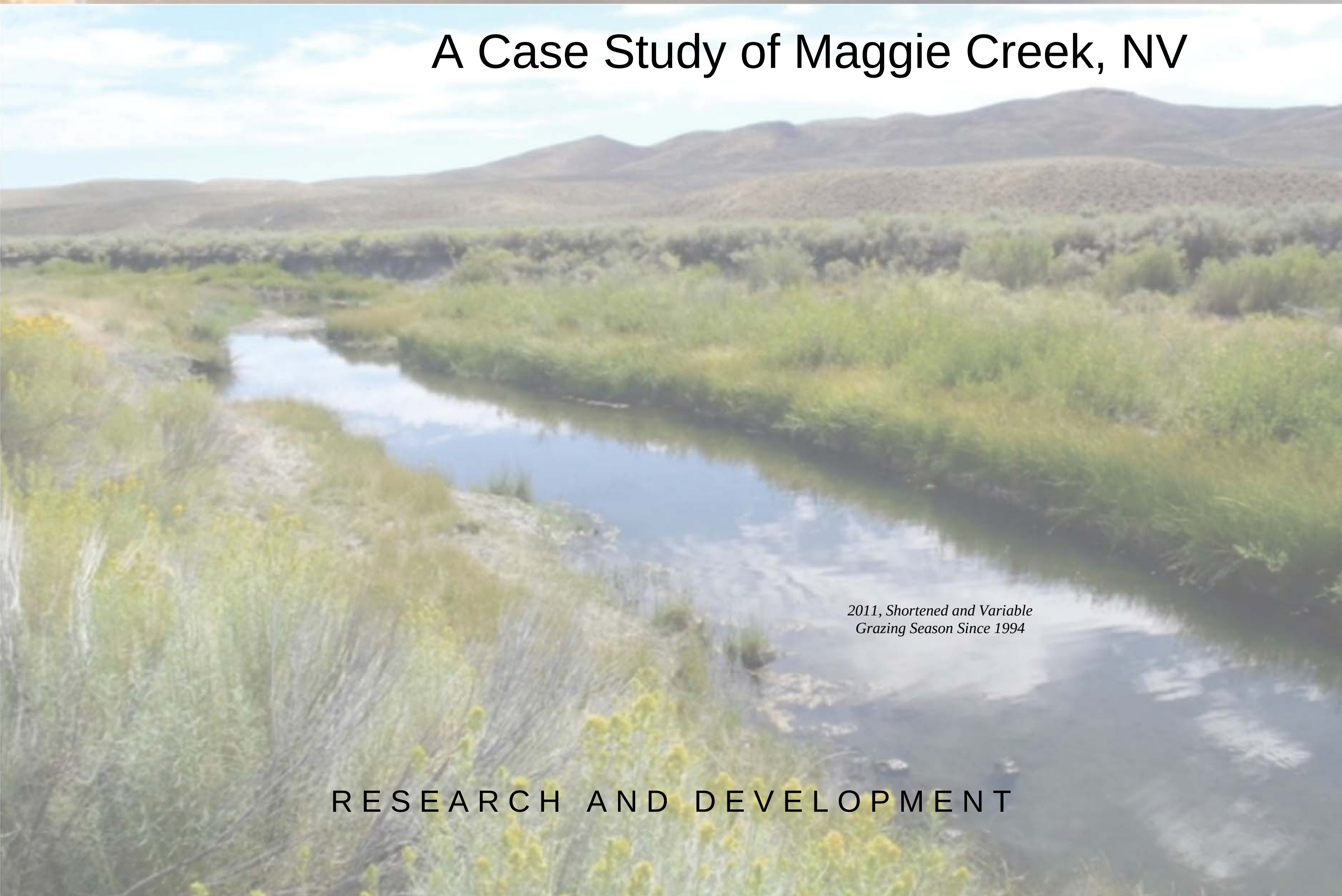


1980, Summer-Long Grazing

Linking Changes in Management and Riparian Physical Functionality to Water Quality and Aquatic Habitat

A Case Study of Maggie Creek, NV



2011, Shortened and Variable Grazing Season Since 1994

RESEARCH AND DEVELOPMENT

Linking Changes in Management and Riparian Physical Functionality to Water Quality and Aquatic Habitat:

A Case Study of Maggie Creek, NV

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Acronyms and Abbreviations

AMD	Acid Mine Discharge
BLM	Bureau of Land Management
B&W	Black and White
C	Celsius
CIR	Color Infrared
DO	Dissolved Oxygen
DOQQs	Digital Orthophoto Quarter-Quadrangles
DP	Dissolved Phosphorus
EPA	Environmental Protection Agency
FAR	Functional At Risk
GIS	Geographic Information System
GPS	Global Positioning System
ID	Interdisciplinary Team
LCT	Lahontan Cutthroat Trout
MCWRP	Maggie Creek Watershed Restoration Project
N	Nitrogen
NAIP	National Agriculture Imagery Program
NaOH-P	Sodium Hydroxide Extractable Phosphorus
NDEP	Nevada Department of Environmental Protection
NHD	National Hydrologic Dataset
NH4-N	Ammonia Nitrate
NOAA	National Oceanic and Atmospheric Administration
NO3-N	Nitrate Nitrogen

Acronyms and Abbreviations (cont.)

NOx	Nitrate and Nitrite
NWIS	National Water Information System
OP	Ortho-Phosphate
OP-P	Orthophosphate Phosphorus
P	Phosphorus
pH	Hydrogen Ion Concentration
PFC	Proper Functioning Condition
PP	Particulate Phosphorus
Q	Stream Flow
SOAP	South Operations Area Project
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey
VLSA	Very Large Scale Aerial
WQ&AH	Water Quality and Aquatic Habitat

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Abstract

The total maximum daily load (TMDL) process is ineffective and inappropriate for improving stream water quality in the rural areas of the northern Great Basin, and likely in many areas throughout the country. Important pollutants (e.g., sediment and nutrients) often come from the stream systems rather than external point or nonpoint sources where TMDL focuses. Water quality indicators lag behind ecosystem functions, and monitoring water quality fails to identify causes of, or recovery from, degraded water quality and loss of fish habitat, the most sensitive beneficial use. Ambient monitoring programs should identify risk and recovery, focusing resources toward effective land and water management strategies. To illustrate, we elucidate the connections between various water quality attributes and the seventeen items of the interagency riparian proper functioning condition (PFC) assessment for lotic (running water) riparian systems. We conducted PFC assessment for relevant parts of the Maggie Creek Watershed, and developed hypotheses of improved water quality from improved management and riparian conditions. We then tested these hypotheses using a far more intensive water quality monitoring data set than is generally available to rangeland, rural land, or water quality managers. The Maggie Creek, NV, case study demonstrates that changes in grazing management (timing and duration) resulted in improved stream functionality, leading to reduced sediment and phosphate, increased dissolved oxygen, and improved aquatic habitat. It also demonstrates that monitoring for water quality by monitoring water chemistry requires unaffordable frequency and generates highly variable data that obscures relevant issues while it fails to monitor drivers of system collapse or recovery. Thus water chemistry monitoring fails to timely inform management of impairment risk or the trend from management actions. We suggest that published protocols for monitoring multiple indicators of riparian functions are more relevant, timely, and less expensive.

Introduction

Streams differ in their potential to produce habitats, biota, and water quality for beneficial uses. Stream differences are often discussed or classified using stream order (Strahler 1964), valley confinement and landform setting, gradient, substrate, entrenchment, width/depth ratio, sinuosity, and bed form (e.g., Rosgen 1996, 2006, Knighton1998). Differences are caused by climate and geologic parent material, as well as historic and prehistoric human modifications (Dunne and Leopold 1978, Mann 2005). Riparian vegetation exerts strong influences on channel form and ecological processes (Prichard et al. 1998, Corenblit et al. 2007, 2009, and 2011). The importance of riparian vegetation and its differing roles in various geomorphic and ecological settings has led to numerous riparian vegetation classifications (e.g., Manning and Padgett 1995) and scorecards (e.g., Weixelman et al. 1996).

Maintaining healthy aquatic and riparian habitats depends on management that allows or facilitates natural recovery of riparian functions after natural or anthropogenic disturbance. These functions include dissipating flood energy and slowing travel rates of materials out of their watershed positions; erosion and deposition of sediment to maintain floodplain access and channel pattern, profile, and dimension appropriate for the landform setting; hydrologic processes of aquifer recharge and hyporheic interchange; and growth and reproduction of stabilizing plant communities. Maintaining these dynamic functions provides riparian floodplain and aquatic capital that create extremely productive fish and wildlife habitats and soils, high water quality, high biodiversity, and other ecosystem services. Impairment of riparian functions changes hydrologic, vegetative, and geomorphic interrelationships and may trigger cascading effects.

When management goes awry with nature or up- or down-stream neighbors exceed boundaries of dynamic equilibrium with too much or too little sediment or water or by changing vegetation or base level, it is not uncommon for streams to incise. This sets in motion a long-term chain reaction of geomorphic adjustment that leads to significant changes in water quality and aquatic habitats. Anthropogenically altered water cycles often lead to hydrologic alterations such as increased/decreased volume and velocity of runoff and size and frequency of floods, altered groundwater discharge, and changes in runoff storage capacity in wetlands, soil, and aquifers. Alterations frequently create additional environmental stressors via erosional/depositional processes such as changes in sediment and chemical concentrations (often considered pollutants) in the water. These changes modify habitats and affect other beneficial uses of water or water bodies. To address the aquatic impacts from environmental stressors, it is important to understand the interconnectivities of a system and recognize the fundamental changes to riparian ecosystem services coming from changes in hydrology, vegetation, and soil erosion/deposition within a geomorphologic context.

Properly functioning streams and riparian systems provide a steadying influence on various water quality and aquatic habitat attributes. Riparian proper functioning condition assessment connects to water quality and aquatic habitat by assessing the degree of functionality and the risk of losing this functionality. The job of a stream is to transport water and sediment; the key question is always the rate of that transport. Functioning streams dissipate the energy of flowing water. Stream potential energy, represented by higher elevation water influenced by gravity, has the power to exceed the critical shear stress of soil, banks, bed, or floodplains as it changes to kinetic energy. Dissipated energy is less likely, at any one spot, to exceed the critical shear stress of that material and cause erosion. Similarly, when water slows, it may no longer provide the velocity and turbulence to keep particles suspended or moving, leading to deposition.

Sediment is a major pollutant across the nation (USEPA 2009). Reducing erosion, or inducing sedimentation, has direct water quality implications. Sediment is the primary medium for transporting organic/inorganic chemicals that impact aquatic biota and beneficial uses (e.g., recreation and wildlife). Pathogens and nutrients are the most common biological and chemical stressors to wildland streams and lentic wetlands. Excess nutrients cause eutrophication. Ideally, the rate of nutrient availability should remain reasonably steady at an appropriate level for the community of organisms of the system to function. The appropriate level and variability differs widely among locations and stream reaches.

Temperature and other environmental variables fluctuate through time and space in relation to diurnal and annual cycles. Aquatic organisms alter their individual physiology and community structure to adapt to the respective systems' normal range of variation (Barnes and Minshall 1983). Properly functioning streams vary the magnitude of the fluctuations within a narrower range. Thus, temperature dependent biological and chemical processes operate with lower variation. Well vegetated and functioning stream and wetland systems typically decrease aquatic insolation and reduce heat exchange through radiation. They ameliorate fluctuations of water volume (downstream low flows and floods) through underground storage with aquifer recharge and hyporheic interchange. Thus, winter low temperatures remain higher and summer high temperatures remain lower.

Riparian Proper Functioning Condition (PFC) assessment (Prichard et al.1998) connects to water quality through system attributes that collectively lead managers to grasp the story of individual reaches and the overall watershed. This study assesses changes in riparian physical functionality and biophysical alterations due to changes in land management strategies. Understanding the resulting changes in water quality and aquatic habitat at a local scale empowers resource managers for adaptive management alternatives using the PFC protocol.

PFC

PFC is an interagency assessment protocol focusing on physical structure and functioning in relation to on-site potential. Although qualitative, it is based upon quantitative science (e.g. Prichard et al. 1998 (from Leonard et al. 1992) and incorporates the important attributes that numerically based surveys commonly address. An interdisciplinary team conducting PFC assessment in the field uses all relevant field observations, science, and life experience to inform understanding of local potential, what is locally possible, and what is needed for the system to maintain functions in large flow events. This replaces a similar qualitative process of interpretation of quantitative survey data in the office based on standard expectations or classifications that only partially capture inherent spatial variability in potential and attributes needed for ecosystem functions. A PFC rating relates how well the physical stream processes are functioning. To be properly functioning, a riparian system will: "Dissipate stream energy associated with high water flows, thereby reducing erosion and improving water quality; filter sediment, capture bedload, and aid floodplain development; improve floodwater retention and groundwater recharge; develop root masses that stabilize streambanks against cutting action; develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses, and; support greater biodiversity."

To determine how well a riparian area functions to achieve these criteria, an interdisciplinary team of experienced professionals uses a checklist of seventeen attributes in three categories: hydrology, vegetation, and erosion/deposition. The functional attributes in the PFC checklist provide important foci for this study's research. The rationale for the PFC assessment, including all seventeen attributes, has been summarized in technical references (Prichard et al. 1993 (revised and elaborated by Prichard et al. 1998).

When the stream and riparian system functions properly, meeting the previously mentioned criteria, it will be stable and resilient to major hydrologic events, even those with recurrence intervals of at least 25-30 years (Prichard et al. 1998). Stream stability requires that a stream be self-sustaining, retain the same general geometry over time (decades), and balance the import and export of sediment (Ward and Trimble 2004). These generalizations come from studies of a multitude of streams in various locales. Miller et al. (2004) describe a Great Basin morphologic setting influenced by climate changes that implies some riparian systems in this region may be more sensitive to disturbance and incision than "typical" streams. The hydrologic/stability interval expressed by Prichard et al. (1998) suggests possible instability at lower probability/higher magnitude events. Yet PFC streams may buffer the hydrologic and geomorphic stresses of even dam-break events analogous to extremely rare precipitation events. Prichard et al. (1993 and 1998) also describe mechanisms of natural recovery toward a renewed stability with restored functionality borrowing from Jenson et al. (1989) and many others.

If a riparian area does not function properly, it may not retain the same general geometry over time and may be out of balance regarding sediment transport. If the riparian zone is functioning but stressed or "at risk" because one or more attributes makes it susceptible to degradation, it may be prone to excess channel changes during major disturbances such as flooding or fire. These alter water levels and plant growing conditions, degrade nutrient uptake, and accelerate erosion. Undissipated hydraulic energy detaches particles ineffectively bound by roots. Kozlowski (2007) modeled changes in several stream channel attributes of burned northern Nevada riparian zones using PFC attributes, functional ratings, precipitation, and upland and riparian burn severity.

PFC Attributes and Water Quality

Each item of the PFC assessment addresses a specific and important attribute or process necessary to maintain a functioning riparian system. Similarly, each plays a role in maintaining good water quality, especially for those parameters of most concern in the rural streams of the northern Great Basin: baseflow, sediment, nutrients, dissolved oxygen, and water temperature. These important attributes commonly focus water quality managers for wildland streams wherever rangeland, forestry, or recreation management predominates. Furthermore, this conceptual foundation supports water quality management for management settings where pollution inputs outside of riparian areas dominate.

A) Hydrologic Attributes

1 - Floodplain Above Bankfull is Inundated in "Relatively Frequent" Events (1-3 Years).

The active floodplain (Gebhardt et al. 1989) is the area next to the stream where inundation occurs when bankfull discharge is exceeded, which occurs on average about two out of three years (Leopold 1994). Where a stream has frequent access to its floodplain, the energy associated with flood flows can be dissipated in shallow water across a wide surface and by the friction provided by riparian/floodplain vegetation with multiple stems. Shallow depth and roughness slows the velocity, allowing excess sediment to deposit rather than move downstream where it could damage economies and aquatic species habitats from algae to fish (Bilotta and Brazier 2008). Spreading and infiltrating water across a broad surface recharges aquifers. Saturation and availability of soil moisture then interacts with soils, climate, and management to control the distribution of plant communities. Species associations, their niche within the floodplain, and the internal structure of riparian communities are closely linked to flood duration, frequency, and stream energy. An important edaphic and climatic variable, soil moisture is a major determining factor in the establishment and survival of herbaceous and woody plants (Girel and Pautou 1997). Infiltrated water and the sediment deposited on the floodplain may be laden with pollutants or nutrients which can then be taken up in plants and incorporated into a food web, slowing their downstream spiral. Water infiltrated and percolated down to the water table recharges aquifers and extends baseflow into dry seasons or years. Ground water discharge helps stabilize flow and moderate the water temperature of streams (Caissie 1991; Blackport et al. 1995). Baseflow is often the result of ground water discharge into streams (Freeze and Cherry 1979; Blackport et al. 1995). Cooler water in discharge zones during summer allows for higher dissolved oxygen (Caissie 1991; Power et al. 1999), while relatively warmer water temperatures from discharge zones during the winter often keep water from freezing into the bed (anchor ice) and occupying refugia habitats (Cunjak and Power 1986; Power et al. 1999). Internal structure of riparian plant communities is linked to topography and flooding frequency, resulting in biodiversity changing along a gradient of elevation (Girel and Pautou 1997; Bush and Van Auken 1984; Hupp and Osterkamp 1985). Frequent flooding and the associated anoxic soil conditions are often needed to sustain riparian vegetation (Girel and Pautou 1997; Kozlowski 1984), especially the stabilizing wetland plants needed for channel stability (see items 8 and 9). The roughness encountered during energy dissipation coupled with the increase in water surface area may lead to increases in dissolved oxygen during flood events. Energy dissipation during floods allows streambank vegetation to withstand flood forces and then to narrow and shade channels, decrease insolation and summer temperatures, and increase dissolved oxygen.

Denitrification and sediment phosphorous adsorption are strongly influenced by water residence duration and accumulation of fine textured organic rich sediment. Management activities that maintain flooding and increase these processes increase the buffering capacity for nitrogen and phosphorous (Hill 1997). Spatial and temporal retention of nutrients are linked to geomorphology of catchments and channels (Marti and Sabater 1996). Reducing conditions that change pH values and mobilize minerals such as phosphorous, nitrogen, and magnesium occur during periods of anoxia. Repeated flooding and draining favors denitrification (Girel and Pautou 1997). Van Vliet and Zwolsman (2008) found that decreases in discharge due to drought brought on increased water temperatures, nutrient loads, and algal blooms. Kaushal et al. (2008) demonstrated increased geomorphic stability and increased denitrification by restoring and reconnecting an urban floodplain. Where or when a stream incises, it loses the important function of floodplain inundation and the water quality benefits associated with it. Streambanks then accelerate erosion and become pollution sources.

2 – Where Beaver Dams are Present they are Active and Stable.

Where dams are present, many implications for water quality depend on whether they are active and stable. If a dam is not being maintained or cannot be maintained long-term due to limitations of beaver forage or woody building material, it is inactive or unstable. Loss of a dam means potential degradation and adjustment that can include stream incision, loss of floodplain access, riparian dehydration, channel widening, and lateral migration. A dam’s ability to hold up against storm flows depends on the dam’s condition, which is controlled by factors such as beaver food availability, predation on beaver, abandonment, or the tunneling of other animals into and around the dam. Catastrophic failure of a dam can lead to rapid downcutting through accumulated sediment. Implications to water quality are then similar to those addressed in attribute 3.

Demmer and Beschta (2008) found that beavers facilitate riparian recovery. With increased beaver activity, dams/ponds accumulated sediment, improved conditions for establishment and growth of riparian plants, and altered channels, making them more complex from the formation of new meanders, pools, and riffles. Accumulated sediments provided fresh seedbeds for regeneration of various riparian plants where breaches occurred. Altered wetness further adjusted plant communities. Where beavers abandoned reaches due to heavy utilization of riparian vegetation, eventually woody vegetation occupied a larger portion of the floodplain. Wright et al. (2002) show that by increasing habitat heterogeneity via beaver dams, the number of herbaceous plant species increased by 33%, thereby increasing species richness on a landscape scale. This links directly to the importance of diverse composition of vegetation needed for channel maintenance and recovery (attribute 7, Table 1).

Klotz (2010), summarizing literature and using empirical data, found a 35.5% reduction of nitrate levels of water passing through beaver ponds. Reduction was greater during warmer periods, suggesting biological processes were responsible. Nitrates may have been transformed with microbial denitrification enhanced by anoxic substrates, ample organic matter, and increased residence times. Burchsted et al. (2010) describe increased area of combined surface water and elevated groundwater table across beaver impoundments. Longitudinal sediment transport is discontinuous as impoundments store fine grained and organic sediment. Deposition creates riparian landforms that can persist for centuries to millennia, created by a net balance of sediment accumulation and typically leading to a reducing environment and denitrification. Oxygen is depleted within the impoundment water column and sediments due to slow water and high productivity. Anoxic conditions create a net storage of organic nitrogen. Relatively higher levels of nitrogen may come out of an impoundment if levels were low going in due to increased microbial activity and beaver's addition of organic matter. However, if levels are high going in there can be a net decrease in transport out. Maret et al. (1987) found that during high flows (spring runoff), total suspended solids (TSS), total phosphorus (TP), sodium hydroxide extractable phosphorus (NaOH-P), and total kjeldahl nitrogen (TKN) were reduced when flowing through a series of beaver ponds. During low flow the ponds had less of an effect. Nitrate nitrogen (NO3-N) was reduced in both high and low flows. Ortho-Phosphate (OP) did not appear to be affected by the ponds. Ammonia nitrate (NH4-N) was always quite low.

The primary source of NaOH-P was from the TSS. TSS explained a large portion of TP and TKN. TP and OP were often significantly correlated. Bank and channel erosion appear to be contributing sources, and export of nutrients from banks within beaver dam areas was calculated to be less than from above or below the ponds. There was a 50-75% reduction in TSS, 20-65% reduction in TP and TKN, and 20-25% reduction in NO3-N within complexes as opposed to above or below them. Maret et al. (1987), Correll et al. (2000) found beaver ponds reduced annual discharge of water (8%), TN (18%), TP (21%), and TSS (27%). Prior to pond building all were highly significantly correlated w/discharge, but had no relationship after six years. Nitrate and ammonium were correlated with discharge at both times.

Margolis et al. (2001) measured stream water chemistry above and below two Appalachian stream beaver ponds and found that significant differences in chemistry were generally confined to summer. Both impoundments increased acid neutralizing capacity and pH by acting as sinks for nitrate and ammonium. Naiman et al. (1994) found that in beaver impoundments only a portion of nutrient and other stocks go downstream or to the atmosphere. Much of the nutrient load is retained in the organic soil horizons that make up the ponds. These remain available to plant communities long (decades to centuries) after beaver meadows have been abandoned. Ultimately they help determine what communities will establish.

Ponds usually have higher summer water temperatures, but are typically found to improve cool-water fisheries at the network scale. An increase in cool groundwater return to the channel can also help to mitigate the higher temperatures. Due to surface water storage and ground water recharge, baseflows generally increase, drought duration and frequency is reduced, and the duration but not the magnitude of high flows increase. However, evapotranspiration may be important enough in some systems to reduce baseflows.

3 – Sinuosity, Width/Depth Ratio, and Gradient are in Balance with the Landscape Setting (i.e., Landform, Geology, and Bioclimatic Region.

Streams in different locations differ in their gradient and form depending on their landscape setting. Steep headwater reaches tend to be sources of water and sediment. Below these, transport reaches with lower gradient and gently sloping margins move sediment to response reaches, where the valley widens and where the swinging and sweeping of meanders builds a floodplain. Floodplains act in concert with the channel form to keep hydraulic stresses within an acceptable range that allows channel migration. Point bars slowly build into replacement floodplain, storing sediment and nutrients, as the channel migrates. Alluvial aquifers store water rapidly during floodplain flooding.

Erosion from focused hydraulic stress (see attributes 1 and 13, Table 1) or an imbalance of sediment and water (see attribute 17, Table 1) may exceed a geomorphic threshold, causing incision and a long process of incised channel evolution. This vastly increases the rate of bank erosion with channel widening, especially through floodplain stored alluvium. Eventually, after large volumes of soil have washed downstream, the incision becomes wide enough to distribute stream power and begin capturing sediment at a lower level. Deposition and recovery processes can eventually bring back balance to the stream (Leopold et al. 1964; Schuum 1979, Schumm et al. 1984; Gebhardt et al. (1990); Rosgen 1996, 2006; Prichard et al. 1998.

Bank erosion and sediment issues may lead to other water quality problems associated with nutrients from freshly eroded sediment or the physical effects of sediment. Higher width/depth ratios can increase insolation and radiation, leading to greater fluctuation in water temperatures and possibly dissolved oxygen depletion or anchor ice. Greater width and/or increased sediment may allow deposition of fine sediments in stream substrate. Sometimes this embeddedness limits spawning-gravel dissolved oxygen and hyporheic groundwater/surface water interactions with implications for temperature moderation. Channel incision and embeddedness decrease riparian plant growth and nutrient uptake. Too much sediment is an obvious water quality problem, but so is too little. A lack of sediment (such as below impoundments) can degrade habitat for sediment dependent organisms and change channel form due to excess bottom scour (see attribute 17, Table 1). Stream incision generally decreases riparian amelioration of water quality. Where stream pattern, profile, and dimension conform more closely to what is appropriate in a given geomorphic position within a balanced system, the more natural configuration tends to process pollutants better (Sweeney et al. 2004) at more appropriate rates and times.

4 – Riparian-wetland Area is Widening or has Achieved Potential Extent.

The width of stream riparian vegetation depends on the overall width of watershed supplied water within the root zone. A riparian zone achieves its potential aerial extent in two ways. First, there is a limit to the amount of overall width of the zone, which is usually determined by topography, hydrology, and water table elevation. Riparian vegetation can established itself to these outer limits. Second, riparian vegetation can establish itself on soils deposited along the stream banks, essentially narrowing the stream, helping it achieve equilibrium width to depth ratio. When this potential extent is achieved, the riparian zone is at its maximum potential width to filter or buffer against various waterborne pollutants, etc. Where this occurs there would be no expected potential for future water quality improvement due to this physical condition. However, riparian vegetation amelioration of water quality diminishes in degraded stream systems. In a riparian zone recovering from a degraded condition, the riparian zone may have the opportunity to widen and improve water quality.

Mayer et al. (2005) found wider riparian buffers were generally better at removing nitrogen from surface waters and narrow buffers at times increase nitrogen delivery, but width or vegetation type was not important to subsurface removal, which is generally efficient. Infiltration is one of the most significant pollutant removal mechanisms. It allows for finer sediment particles (clays) to be incorporated into the soil profile and for deposition of silt-sized and greater particles. Vegetation helps filter larger sized particles, reduces surface runoff and thus sediment transport capacity (Dillaha and Inamdar 1997). Widening is generally associated with increased water elevation or with building a floodplain through channel narrowing (analogous to 1, 2 and 3 above).

As described by Cooper et al. 1987, riparian buffer zones removed 84-90% of sediment eroded from cropland. Much longer lengths of buffer are needed to filter incrementally more sediment (Castelle et al. 1994) e.g., doubling of buffer width is necessary to reduce sediment from 90 to 95% on 2% slopes. Buffer strips are the most important factor in reducing sediment loads to receiving waters, with efficiencies to 90% commonly reported in forested coastal plains (Gilliam 1994; Lowrance et al. 1995). Buffer zones are particularly effective in low order streams, but this is reduced as stream order increases (Lowrance et al. 1995).

Jordan et al. (1993) found that buffer zones can be sediment sources. The sink can be so great as to "starve" the stream, creating more stream energy that works on the banks and bottom, releasing through bank erosion wetland and/or channel soils with higher nutrient and organic content.

5 – Upland Watershed is not Contributing to Riparian-Wetland Degradation.

This attribute addresses whether unnatural disturbances or changes in the upland parts of the watershed contribute to degradation of the riparian reach being assessed. Excessive sediment delivery to the stream channel, a lack of sediment, or too much or too little water can lead to changes in the floodplain access, sinuosity, width/depth ratio, and gradient, all stream properties and implications addressed in attribute 3, Table 1. Implications addressed for that attribute can be expected here as well.

The main direct implication to water quality within this context is an increase in sediment load and the associated pollutants that come along with it. These pollutants can include nearly anything, depending on what is occurring within the watershed. Based on the nature of the sediment and the rate of its delivery, the introduction of sediment could lead to a total loss of physical functionality of the stream reach and thus the water quality implications of other attributes. A well-functioning riparian zone tends to be resilient, handling some increases and decreases of sediment without exceeding a threshold of stability. Therefore the issue is not simply whether the watershed has changed its delivery of water or sediment, but rather a watershed change contributing to riparian degradation and loss of functions.

B) Vegetation Attributes

6 – There is Diverse Age-Class Distribution of Riparian-wetland Vegetation (Recruitment for Maintenance/Recovery).

A diverse age-class of riparian wetland plants, particularly woody species, is an indicator of stable populations and is necessary for the long term maintenance of the plant community. Where age-classes are not diverse, it is important to determine whether the populations are expanding or diminishing (Kormondy 1969). Well established older mature plants have developed root masses capable of holding the soil in place, and usually assure water can be obtained even in drought years. They also represent a considerable carbon and nutrient sink. However, older communities will eventually become decadent, more prone to disease, and in some cases create stores of dead wood that can fuel wildfires. Middle-aged plants are necessary to take the place of older ones when they eventually die. They also lend some resiliency to communities by being less susceptible to disease and fire while still being able to reach water tables during drought periods. Young plants are needed to assure recruitment into the community to perpetuate it.

Young and middle aged plants are important for recovery and maintenance of the community (Prichard 1998). Because of the increased growth rate of younger plants, they may be more efficient at assimilating nutrients, but are more susceptible to die-off in drought situations because their root systems may not have grown deep enough to reach water tables. However, the root systems often help stabilize soils in shallower depth to water table zones at the streambank edge and point bars. The root systems help to maintain riparian width and thus are important to pollutant issues associated with attribute 4, Table 1. Recruitment in and near the stream allows for increased shading and evapotranspiration, which can lead to decreases in water temperature while increasing (DO) due to decreasing temperature and direct contribution of oxygen by the young plants' roots. Shading may be an effective tool for the management of algal growth (Ghermandi et al. 2009). The differing stem diameters and clustering of the different age classes (Myers 1989) may help in trapping different size sediment particles during flood events. Missing age classes, especially young ones, suggest altered hydrology, channel form, or management with implications for other attributes.

7 – There is Diverse Composition of Riparian-wetland Vegetation (for Maintenance/Recovery).

From a functionality standpoint, diverse composition of vegetation reduces the risk that an environmental stressor for one species will diminish stability from vegetation needed when catastrophic events occur. Diverse composition assures there will be some species more resilient to a stressor than others. Stabilizing vegetation will help hold the stream banks and floodplain together and begin recovery.

The implication to water quality is that accelerated erosion will be held in check, reducing sediment and its associated pollutants. Plants will be available to help mitigate nutrient loads, provide shade for cooling, and deliver (DO) to the water. Riparian composition is affected by mechanical injury, fine sediment deposition, inundation during flood events (Girel and Pautou 1997: Broadfoot and Williston 1973), fire, plant diseases and parasites, shading, nutrient availability, and plant succession.

Benefits outside the context of catastrophic events are numerous. Different plants have different abilities to uptake/process nutrients, mitigate pollutants, bind soil to reduce erosion, and trap sediment. Riparian vegetation trapping sediment and associated nutrient content from both overland flow to the stream and stream water overflow to the floodplain has been well documented (Correll 1997). The stems, leaves, and leaf litter of plants create the friction necessary to reduce water velocities and allow particulates to fall out. In surface runoff, most N is in the form of organic nitrogen associated with suspended solids. Grass is more effective at trapping particulates from overland flow (Parsons et al. 1994; Osborne and Kovacic 1993). Vegetation structure is influenced by the quality and quantity of litter from high primary productivity within the riparian buffer (Girel and Pautou 1997). The microbes on plants and soil as well as plant roots near the surface are able to assimilate dissolved nutrients in the water (Peterjohn and Correll 1984).

Although poplar (Populus spp) forests may be more effective than grass in the winter (Haycock and Pinay 1993), both herbaceous and woody vegetation can be very effective at removing nitrate from groundwater (Haycock and Burt 1993). Some forests may be more effective than grass at nitrate removal (Gilliam et al. 1997) but less effective at phosphate removal from groundwater (Osborne and Kovacic 1993). Other studies found similar nitrate removal efficiencies between the two (Correll et al. 1996). Denitrification potential is higher in grassed soils than forested (Groffman et al. 1991), while a combination of grass and trees may be best (Welsch 1991). Riparian vegetation is necessary to provide organic matter to soils necessary for denitrification (Correll 1997) and food web processes. Grass is very effective at removing it (more effective than forests), but less effective at removing soluble inorganic nitrogen (N). Trees are more effective at removing nitrate in groundwater.

Phosphorus (P) assimilation varies by plant species. Uusi-Kamppa et al. (1997) found dense, native vegetation of high species diversity and deep-rooted plants promotes trapping of P in plants. Trees are important sinks (Peterjohn and Correll 1984), and native herbs take up more P than grass (Uusi-Kamppa and Ylaranta 1996). Vegetation can be a source or sink, depending on decay or growth. Vegetation removes particulate phosphorous (PP) via deposition of suspended particles, dissolved phosphorous (DP) through sorption by soil components, and biological (microbes, plants) uptake. Release of DP may occur during runoff due to release by decaying material. Rooted macrophytes pump P from sediment and release in dissolved form (Uusi-Kamppa et al. 1997). Efficiency of riparian vegetation strips at removing P depends on amounts of P already there, residence/contact time, kinetic factors, and temperature. Sorption depends on aluminum and iron oxides, organic matter, and calcium carbonate, while desorption depends on P saturation on oxide surfaces (Uusi-Kamppa et al. 1997). Riparian buffers retain more PP than DP (Uusi-Kamppa et al. 1997). P is usually more mobile in surface runoff than subsurface flows. Alder and willow bushes are most effective at P removal (e.g., a ten meter wide strip can mitigate nearly 100% of incoming P (Mander et al. 1991)). Retention of DP is often low, especially when the system becomes saturated with P. Wetlands may convert PP to OP due to leaching of decaying vegetation and high water levels, inducing anaerobic conditions and increasing solubility of phosphate (Uusi-Kamppa et al. 1997).

8 – Species Present Indicate Maintenance of Riparian-wetland Soil Moisture Characteristics.

The presence of obligate or facultative wetland species (Reed 1988) usually indicates the water table is high enough to maintain a riparian-wetland community, especially where herbaceous and/or young woody species occur. Most of these species have root masses that effectively bind soil (see attribute 9, Table 1) and have roles in denitrification and other nutrient cycling. By definition, these plants (hydrophytes) grow in wet places where other plants usually cannot, including streambanks, point bars, mid-channel bars, and sometimes stream channel bottoms, thus making hydrophytic plants the most important species for stream stabilization and maintenance of riparian width. They are also essential for helping to provide shade for cooling water temperature and adding oxygen to water. Riparian vegetation reduces solar heating through shading in low order streams (Brown and Krygier 1970) and cooling via evapotranspiration (Beschta 1984; Theuer et al. 1984; Sinokrot and Stefan 1993). Evapotranspiration cooling is greatest in forest environments due to high leaf area index that leads to higher evapotranspiration rates (Peterjohn and Correll 1986).

Obligate or facultative wetland species typically have more root length and mass than other upland species (Manning et al. 1989). Vegetation channel stability ratings for riparian community types have been expressed by Winward (2000) and for riparian species by Burton et al. (2011) and at http://rmsmim.com/. As Winward (2000) pointed out, the "latter successional" community types are the ones expected in wetter conditions on the greenline, and these have higher stability ratings. Presence of riparian buffers is the most important factor controlling entry of non-point source nitrate in surface water (Lowrance et al. 1995).

9 – Streambank Vegetation is Comprised of those Plants or Plant Communities that have Root Masses Capable of Withstanding High Streamflow Events.

An important distinction for this attribute is that streambank (the area between bankfull depth and stream bottom) vegetation has to be comprised of obligate or facultative wetland species of a stabilizing nature. In dry climates, the upper banks of incised channels rarely stabilize with strongly rooted hydrophyllic vegetation unless watered from groundwater. Erosion of high banks (above frequent flows) then allows formation of new floodplains that enable and grow from active channel streambank revegetation. Most later successional hydrophilic plants have root masses capable of withstanding high streamflow events (Prichard et al. 1998; Winward 2000; Burton et al., 2011). The streambank is where most erosive, high velocity flows contact material that is easily eroded if not stabilized, especially in the upper strata of the water column where plant roots are strongest and most dense. Where these plants minimize bank erosion they reduce sediment and nutrient delivery. Where weakly rooted streambank vegetation or bare banks allow erosion, most or all sediment is delivered directly into the stream, resulting in a sediment delivery ratio much greater than from upland erosion. Streambank plants also take up other in-stream nutrients, support oxygen in the water, and cool the water by maintaining a narrow and deep channel and/or by providing shade. Where these plants do not dominate, streambanks more often undercut and collapse during high flows. This can change the geometry of the stream (e.g., broad and shallow), leading to problems associated with attribute 3, Table 1. Riparian plant communities of Nevada were classified by Weixelman et al. (1996), Manning and Padget (1995), and the United States Forest Service (USFS 1992). Winward (2000) evaluated rooting depth, density, and toughness of named riparian plant communities on a 1-10 rating scale. Individual species were similarly rated for their bank stabilizing effects by Burton et al. (2011). When wetland plants have the additional benefit of growing on an accessible floodplain, the combination of floodplain energy dissipation and floodplain aquifer recharge to support hydrophilic plants make streambanks especially stable. Whereas loss of floodplain functions (see attribute 1) tends to diminish attributes 8, 9, and 10, Table 1.

10 – Riparian-wetland Plants Exhibit High Vigor.

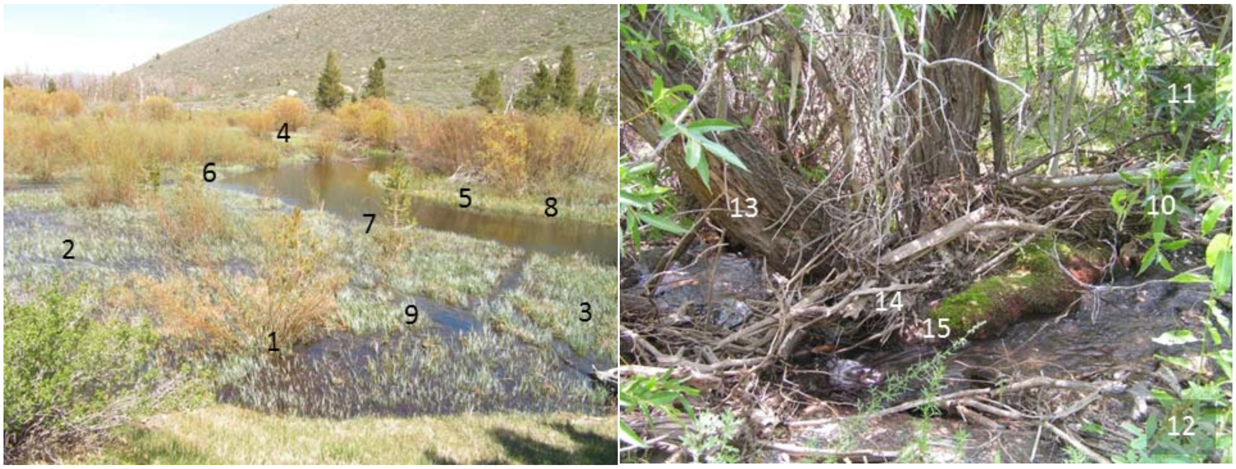
Plants exhibiting high vigor indicate good health with strong reproduction and rooting systems that bind soil and reduce erosion. New propagules are available to colonize new sediment deposits and areas bared by floods. Leaves and stems are larger and more effective at trapping particulates as flood waters flow across them and also provide for more shading and ameliorated water temperatures. Two major processes responsible for nitrate removal are plant uptake and denitrification (Gilliam et al., 1997). Numerous studies relate the removal of nitrate to riparian buffers (Hill 1997) (see attribute 7, Table 1). Rapidly growing plants process more nutrients. Also, vigorous riparian plants may indicate that nutrients are effectively being removed. Measures of plant vigor often focus on root systems.

11 – Adequate Riparian-wetland Vegetative Cover is Present to Protect Banks and Dissipate Energy During High Flows.

Where vegetation is of the stabilizing wetland species, more is better. Winward (2000) notes, depending on stream type, at least 80% to 98% of stream banks should be covered with stabilizing vegetation or anchored rocks/logs in order for them to function properly and help maintain channel pattern, profile, and dimension (see attribute 3 Table 1). The water quality benefits realized by attributes 6-10, Table 1, are only magnified as more of these species/communities grow or expand. Growing enough to protect banks and dissipate energy will keep banks from eroding, thus keeping sediment out of the water. Even more will increase nutrient uptake, maintain channel form and habitat quality, promote more shade and oxygen, and better filter sediment coming from overland flows.

Riparian buffers prevent nonpoint source pollution from entering low order steams and enhance instream processing of pollutants. Tabacchi et al. (2000) provide a review on the control of runoff by riparian vegetation, illustrating some of the physical effects of vegetation on water (Figure 1). Sweeny et al. (2004) found riparian deforestation caused stream narrowing (presumably due to incision) leading to losses in stream habitat and compromising in-stream pollutant processing. Conversely, streams may also narrow as they pass from forest to meadow due to dense meadow vegetation Zimmerman et al. (1967) and Davies-Colley (1997). Whether aquatic habitat deteriorates or improves with narrowing depends on whether it coincides with incision and on the vertebrate species and their habitat needs and limiting factors.

Figure 1. Some Physical Effects of Riparian Vegetation on Water Movement and Cycling



1. Slowing and modifying over-bank flow with roughness and turbulence from stems, branches, and leaves;
2. Increasing overbank flow or floodplain access, which increase the wetted surface area and residence time for infiltration and aquifer recharge.
3. Changing infiltration rate by organic structures and chemistry;
4. Increasing the capillary fringe and soil water storage capacity with fine roots and soil organic matter;
5. Enhancing vegetation growth into the channel to slow water at the margins of wide channels, thus inducing bank formation;
6. Stabilizing banks to enable meanders to persist and sinuosity to become high, which decreases gradient and velocity;
7. Narrowing channels so they become and stay coarser (less embeddedness) to enable hyporheic interchange;
8. Decreasing temperature extremes and summer evaporation by narrowing the channel, which decreases insolation and radiation, and increases hyporheic interchange with more constant temperature groundwater, and by increasing aquifer discharge and providing shade;
9. Increasing floodplain substrate macroporosity by roots and partitioning by particle size in deposition and transport;
10. Transpiration;
11. Condensation of atmospheric water and interception of rain, snow, and dew by leaves, etc.
12. Evaporation of intercepted water;
13. Increasing stem flow (the concentration of rainfall by leaves, branches and stems);
14. Permitting flow diversion and sediment storage by log jams; and
15. Increasing turbulence in channel from root exposure and complex channel form.

12 – Plant Communities are an Adequate Source of Coarse and/or Large Woody Debris (for Maintenance/Recovery).

Many rangeland settings in Nevada do not have communities of cottonwood or aspen (Populus spp.) and are dominated by willows (Salix spp.) or herbaceous vegetation. In these riparian areas, coarse and/or large woody debris are not needed as hydrologic controls, yet sticks and smaller wood provides function where it can span channel width. Riparian areas that rely on downed wood need it to slow channel and floodplain flows and dissipate energy. This allows particulate matter to fall out and further build the floodplain or reduce channel incision and sediment transport. These communities often have good overstory cover that provides shade and an evapotranspiration effect, keeping air and water temperatures cooler. Diverse channel morphology and aquatic habitat (e.g., cover) is created by the large debris, and water can be oxygenated by plunging over debris. Plant communities that do not provide enough woody material weaken riparian functions and make channels susceptible to erosive forces and incision as existing wood decays and fails. This can lead to increases in sediment transport (see item 13) and associated soil nutrient release, changes in channel geometry, and the associated loss of water quality parameters discussed in attribute 3, Table 1.

For systems where wood or riparian woodlands have an impact on water thermal regimes, their presence reduces diel variation and temperature extremes (Malcolm et al. 2004). As wood decays, nutrients are slowly released back into the riparian system to be used by other plants for growth. If decay outpaces growth, however, an increase of nutrients in the water might be expected. In the 1970s, forest practice rules allowed harvesting trees relatively close to streams but forbade slash in streams to avoid excess biological oxygen demand. Later, the rules changed to requiring riparian non-harvest zones as the importance of wood became understood.

C) Erosion/Deposition Attributes

13 – Floodplain and Channel Characteristics (i.e., Rocks, Overflow Channels, Coarse and/or Large Woody Debris) are Adequate to Dissipate Energy.

To some extent these features have already been addressed (i.e., floodplain in attribute 1, coarse and/or large woody debris in attribute 12, Table 1). The key question for physical functionality is related to their adequacy, enough of the right features to create friction and dissipate energy for the geomorphic setting. Attribute 1, Table 1 relates to floodplain accessibility. This attribute relates to its size and energy dissipating characteristics, especially important as the abandoned floodplain's role is replaced by an emerging floodable area after incision. The implication to water quality is related to slowing the erosive powers that release and transport sediment and nutrients/pollutants or not. This slowing not only decreases sediment transport by encouraging deposition, it also increases water residence time so plants can process nutrients/pollutants. With more surface area over a wide floodplain, overflow channels and friction with roughness elements (e.g., vegetation, rocks, debris), water velocity decreases. Interaction with the air across a wide or turbulent surface increases oxygen in the water.

Adequate vegetation on the banks is discussed under attribute 11, Table 1, but also important is adequate vegetation on the floodplain to add to the roughness elements. There must be enough roughness to handle high flow events without degrading the channel, changing channel geometry characteristics addressed in attribute 3, Table 1. Vegetation favors the deposition of sediment by increasing roughness and reducing flow velocity. Reduced velocity increases stage or flood depth and opportunities for hydrating floodplain soils and aquifers and thus growing appropriate plant communities to provide the roughness. Sedimentation rates increase where riparian vegetation is present (Girel and Pautou 1997).

14 – Point Bars are Revegetating with Riparian-Wetland Vegetation.

This attribute is addressed by a combination of attributes 4, 7 and 9, Table 1. Point bars are formed through deposition of bedload and later finer sediment. With growing vegetation on this coarse material, the stability and roughness decreases flow velocities, increasing deposition of finer suspended sediment. The fine particulate suspended sediments and organic matter is the size fraction most likely to contain higher concentrations of nutrients and hold or elevate capillary water which the plants use to grow. Alluvial soils are nutrient rich due to clay and high organic matter content that retains phosphorus and nitrogen. Streams with point bars meander through bank erosion where shear stress is higher on the outside of curves. Vegetation stabilizing deposited sediments and forming banks is important to maintaining channel width/depth relationships and meander form and sinuosity. Without this stabilizing vegetation, water quality implications related to attribute 3, Table 1, can arise as channel geometry adjusts to establish a new equilibrium during high flow events.

15 – Lateral Stream Movement is Associated with Natural Sinuosity.

Lateral stream movement, or bank erosion rate, is a natural process for meandering streams. However, continued functionality demands the movement must be due to the natural processes involved with the establishment of dynamic equilibrium and not accelerated. Because the appropriate rate relates to the landscape setting, and therefore to stream geometry, this attribute is strongly tied to attribute 3, Table 1 and its water quality implications. It is also related to bank erosion processes addressed by attributes 9, 11, and 14, Table 1. Accelerated bank erosion can lead to: channel widening, stage lowering and floodplain dehydration, removal or weakening of riparian vegetation, rapid sediment deposition with point and mid-channel bar growth, development of multi-thread channels, sediment-filled pools, and embedded stream bottoms. Mid-channel bars add to bank shear and erosion. Accelerated channel migration or evulsion can also lead to cut-off meanders and over steepen a stream, causing accelerated bed shear stress, erosion, and incision with, multiple implications for accelerated lateral movement (see attribute 3, Table 1). Water quality implications associated with these outcomes include direct effects of erosion adding sediment and nutrients to the stream. Indirect effects from altered channel pattern, profile and dimension include changes to water temperatures due to increased insolation in wider channels, less shading from bank plants, and limited ground water exchange due to fining of streambed substrate and diminished floodplain flooding. Vascular plants process nutrients less while more algae grow, and then respire and eventually die, increasing biological oxygen demand.

16 – System is Vertically Stable.

A vertically stable system is not down-cutting beyond natural rates (generally detectable on the order of centuries or more), therefore exhibiting normal rates of erosion, which deliver appropriate amounts of sediment. If erosion accelerates beyond natural rates, processes discussed in 15 can lead to headcuts, knick points or knick zones which often quickly cut headward (on the order of feet per year or per storm), incising up through the wetland. The lowered water table reduces base flows and dries out riparian vegetation (attributes 6-12, Table 1). The stream bottom erodes away and exposes eroding banks that often represent centuries of accumulated sediment and associated nutrients, which are then delivered downstream, especially in high flow events. Water quality degradation often persists for decades or longer until channel equilibrium geometry and riparian functions re-establish. The incision leads to an inaccessible floodplain (see attributes 1 and 15, Table 1), thus limiting plants' ability to process nutrients and the floodplain's ability to dissipate flood energy and recharge the aquifer.

17 – Stream is in Balance with the Water and Sediment being Supplied by the Watershed (i.e., No Excessive Erosion or Deposition).

When the stream is in balance with the water and sediment of the watershed, the stream will either be at or getting closer to its equilibrium geometry and the upland watershed will not be contributing to riparian-wetland degradation (attribute 5, Table 1). . An imbalance causes aggradation or degradation (Lane 1955), causing channels to change form. If it is not in balance, this attribute is highly related to attributes 3, 13, 15 and 16, Table 1 and the water quality implications associated with them Perhaps the most common imbalances are caused by upstream functionality issues (e g., items 15 & 16) or from reservoirs that trap sediment, especially bedload sediment. Because channels maintain floodplain access by replacing eroded bed material with newly deposited bedload, trapping bedload in a reservoir usually causes downstream incision. Often called the hungry water problem (Kondolf 1997), it has accelerated bank erosion and severely altered riparian capability and riparian and aquatic habitats (Braatne et al.2008) in many locations. Presumably former riparian structure and function will not be restored until long after the reservoir fills with sediment, spawning gravels are replaced (Pasternack et al. 2010) artificially and flows regulated to manage sediment input from downstream tributaries (Andrews 1986).

Functional Rating

The assessed attributes lead an interdisciplinary team (ID) team to an overall determination of whether the reach is nonfunctional, functional-at-risk (with an associated trend), or properly functioning. A properly functioning reach will be resilient to high flow events and often improve habitats during 5, 10, 20, or 25-year recurrence interval floods. They provide a variety of riparian and aquatic habitats appropriate to the location and will be the most effective at sequestering and/or mitigating pollutants that enter the riparian system while minimizing the stream's own contribution to those pollutants. A properly functioning condition yields good water quality, water availability, and aquatic habitat in relation to its potential (Prichard et al. 1998). A nonfunctional reach will be just the opposite, not only less effective at storing upland pollution contributions but also contributing pollutants that were previously sequestered for long periods. Just how effective at pollution mitigation/contribution a functional-at-risk reach will be depends upon which attributes are deficient. Ideally, the combined reaches in a riparian system ought to all function properly for maintaining habitats and water quality. Ultimately the pollution processing effectiveness for the entire system depends on the collective interacting functionality and dynamics of individual reaches. Such interactions are highly complex and worthy of future study.

Implications to Water Quality: Sediment, Nutrients, Temperature, and Dissolved Oxygen (DO).

All attributes of the PFC assessment are expected to affect sediment levels (i.e., inputs, storage, and environment) and therefore affect nutrients. Many affect temperature and dissolved oxygen (DO). Table 1 summarizes expected benefits ("Yes" responses) or detriments ("No" responses) for each of the PFC attributes. Note that the checklist items in hydrology, vegetation, and erosion/deposition groups are intended to aid an interdisciplinary team in observing indicators of opportunities for improved management to restore or maintain PFC. PFC is the condition sustaining the many water quality benefits. Yet the individual items also suggest direct and indirect relationships to water quality. An increase in a relevant PFC attribute generally contributes to a decrease in sediment movement, an increase in nutrient sequestration, a moderation of temperature extremes, and stabilization in DO. A decrease in functionality contributes to declining water quality.

Table 1. Summary of Water Quality Implications of Checklist Item Responses in PFC Assessment.

Water Quality and Aquatic Habitat Responses to PFC Attribute Condition			
#	**PFC Attribute**	**Yes**	**No**
1	**Floodplain above bankfull is inundated in "relatively frequent" events.**	**Capture and store water, nutrients, and sediment; dissipate flood energy and decrease erosion, TP and TN; diminish magnitude of downstream floods by increasing detention time and facilitating riparian vegetation.**	**Increased sediment, TN, TP, and turbidity. Less discharge in base flow and shorter higher peak flows, putting more stress on banks.**
2	**Where beaver dams are present are they active and stable?**	**Better aquifer recharge and pond storage to sustain riparian vegetation and base-flow conditions; increased sediment deposition and valley bottom widening; increase in fish refuge – cooler water on pond bottoms and in water returning to the stream from the aquifer; nutrient sequestration and denitrification; increase in fecal coliforms; decrease in trace metals**	**If beaver dam blows out, short-term burst of water and long-term increase in sediment, nutrients, microbiota, and other stored materials delivered to the stream due to increased risk of channel incision; loss of pond habitats.**

3	**Sinuosity, width/depth ratio, and gradient are in balance with the landscape setting (i.e., landform, geology, and bioclimatic region).**	**No accelerated erosion or release of chemicals sequestered in riparian sediments; stable water temperature and flow of water and sediments.**	**Accelerated erosion of soil and chemicals stored in riparian alluvium; altered aquatic habitat; floodplain access often diminished and flow variation increased if channel steepened; increased temperature fluctuations if channels are widened; aquatic habitats degraded.**
4	**Riparian-wetland area is widening or has achieved potential extent.**	**More area of vegetation uptake of nutrients; increased sediment and trace metals capture; decrease in temperature fluctuationwith increased shade or narrower channel and hyporheic exchange.**	**Missed opportunities for riparian vegetation induced sediment deposition and nutrient sequestration, and often a downward trend toward increased risk of incision.**
5	**Upland watershed is not contributing to riparian-wetland degradation.**	**No unnatural rate of sediment or water supply sufficient to destabilize the riparian system by exceeding its resilience; riparian functions continue.**	**Accelerated erosion and supply of fine sediment contributes pollution. Increased or decreased bedload or peak flows alter channel pattern, profile, and dimension. This can release stored riparian sediment, nutrients, and other materials, especially if alteration causes incision. Evapotranspiration from excess woody vegetation may diminish base flow and habitats and stress or reduce riparian vegetation.**
6	**Diverse age-class distribution of riparian-wetland vegetation (recruitment for maintenance/recovery).**	**Recruitment and survival of various age classes ensures that plants continue their roles in riparian functions (e.g., nutrient or pollutant uptake, slowing flows, and stabilizing banks to restore or maintain form) without future excess risk.**	**Missing age classes are missed opportunities and are often diminished functions (uptake, roughness, and soil binding). Missing recruitment leads to future risk.**
7	**Diverse composition of riparian-wetland vegetation (for maintenance/recovery). [species present]**	**Diversity of plants taking up diversity of nutrients at various times, trapping sediment of various sizes in slowed water on various geomorphic surfaces; stabilizing banks with roots throughout the soil profile. All with continuity and backup.**	**Risk of monoculture type failure and increased likelihood that important functions (uptake, roughness, and soil binding) will not be performed by missing species or functional groups if disease removes a monoculture.**
8	**Species present indicate maintenance of riparian-wetland soil moisture characteristics.**	**Riparian root abundance and depth much greater in moist or saturated soil; this stabilizes streambanks and fuels denitrification in the zone between aerobic and anaerobic conditions.**	**Drier plants lead to weakened roots and increased bank erosion, risking conversion to much less stable channel forms.**
9	**Streambank vegetation is comprised of those plants or plant communities that have root masses capable of withstanding high streamflow events. [community types present]**	**Dense root systems stabilize undercut banks, creating fish refuge and decreases in temperature from shading. Roots and stable banks dampen volatility by maintaining roughness, channel form, and pattern. This diminishes pollution from erosion. Vegetation well anchored against high flows persists to continue functions (e.g., uptake and shade).**	**Weak roots allow accelerated bank erosion and alteration of channel pattern, profile, and dimension. This unleashes stored materials that cause sedimentation and eutrophication, while increasing insolation, radiation and water temperature extremes and degrading habitat.**
10	**Riparian-wetland plants exhibit high vigor.**	**More uptake of nutrients slows the nutrient spiral and decreases eutrophication. More vigor leads to more reproduction for maintenance and recovery.**	**Weak plants fail to function optimally, leaving bare areas, faster export of riparian materials, and greater risk of collapse.**

11	**Adequate riparian-wetland vegetation cover present to protect banks and dissipate energy during high flows [enough?]**	**Adequate vegetation performs vegetation roles discussed above sufficiently well to maintain channel pattern, profile, and dimension and riparian functions through large flow events (20-25 year flows).**	**Inadequate stabilizing vegetation poorly performs riparian functions and risks major channel alterations in high flows**
12	**Plant communities are an adequate source of coarse and/or large woody material (for maintenance/recovery).**	**Wood stabilizes banks and bed sedoiments to form plunge pools that dissipate energy. It provides habitat diversity and stores water, sediment, and nutrients/pollutants. The woody plant communities provide shade-ameliorating water temperature and roots to reinforce channel form.**	**Loss of wood and woody plant community increases risk of losing structural reinforcement needed to maintain channel form and retain stored materials.**
13	**Floodplain and channel characteristics (i.e., rocks, overflow channels, coarse and/or large woody material) adequate to dissipate energy.**	**Dissipation of flood energy allows riparian functions to protect and restore habitats and water quality against the destabilizing effects of exponentially increased stream power.**	**Undissipated stream power can fundamentally alter channel and riparian form and function causing sequestered sediment, nutrients, and organic and other materials to be rapidly exported. Loss of form and function then continues this export with habitat degradation.**
14	**Point bars are revegetating with riparian-wetland vegetation.**	**While point bars are natural locations for bedload deposition, riparian vegetation helps build the veneer of fine sediment that converts a point bar into a floodplain with stable banks. Thus, pointbar riparian vegetation decreases sediment and nutrient transport by inducing deposition, rebuilds or maintains a stable meander pattern with a low width/depth ratio channel between stable banks, and this aids denitrification and uptake and as hyporheic water flows under riparian vegetation on point bars.**	**Absence of riparian vegetation misses opportunities for slowing flows, inducing sediment and organic matter deposition, nutrient uptake, and riparian habitat restoration. If point bars fail to build into floodplains with stable banks, an over-wide channel increases insolation, radiation, and temperature extremes and increases risk of avulsion and incision.**
15	**Lateral stream movement is associated with natural sinuosity.**	**Erosion at a natural rate allows maintenance of channel pattern, profile and dimension, and floodplain access with its functions of flood energy dissipation; floodwater capture to support riparian vegetation and base flows; and regulation of sediment and nutrient fluxes.**	**Accelerated lateral movement through excess bank erosion or channel evulsion risks channel incision with greatly accelerated input of sediment and nutrients, often indicated by unstable mid-channel bars and only reduced short-term sequestration.**
16	**System is vertically stable. (i.e., not downcutting)**	**Stability decreases risk of incision and rapid input of stored materials. Vertical stability facilitates riparian functions, uptake, energy dissipation, and soil binding.**	**A headcut or an over-steepened reach is likely to erode headward, causing channel incision. Erosion and export of stored riparian materials then pollutes water, degrades habitats, and diminishes function for many years, even decades.**

17	**Stream is in balance with the water and sediment being supplied by the watershed (i.e., no excessive erosion or deposition).**	**With the stream having the pattern, profile and dimension needed to transport the water and sediment being supplied by the watershed, riparian functions can continue to dissipate energies, stabilize banks, slow the nutrient spiral, and maintain or improve water quality and habitats. Gradual changes allow systems to adjust form to match function.**	**Excessive sediment supply, a channel too wide, or insufficient water to transport sediment load can lead to aggradation which damages aquatic habitat by filling pools, and it can lead to grossly altered form. Insufficient sediment (e.g., hungry water below a reservoir), or too much water can incise a channel and accelerate erosion of fine, nutrient-rich bank materials. Rapid or excessive changes overwhelm internal adjustment processes.**

Justification

The current system of water quality regulation focuses on the total maximum daily load (TMDL) process. Water quality monitoring is often implemented to ascertain pollutant levels. Across the U.S., hundreds of millions of dollars are spent each year by private enterprise, education and research facilities, government agencies, and others to monitor water quality in streams and rivers; although an accurate estimate has not been found, the USGS (2012) alone has budgeted some 62 million dollars to its National Water Quality Assessment program for 2013, and the USEPA (2012) has budgeted 3.8 billion dollars toward its Protecting America's Water goal. Acceptable levels of pollutants are set by comparing the beneficial uses for which each water is used to standards established for each use. Waters not meeting standards for their designated beneficial uses go on the states' list of impaired water bodies (the 303(d) (section of the Clean Water Act) list). This initiates the TMDL process. A TMDL is set for each listing, usually based on modeling predictions that consider, among other things, sources, flows, estimates of pollutant concentrations, and waterbody assimilative capacity. The TMDL is then allocated among the landowners and potential sources of pollution in the watershed. Education/funding toward best management practices to keep pollutants from entering the waterway are usually the first efforts made to protect the system.

Unfortunately, allocation of loads does not necessarily reflect opportunity to reduce pollution. Many streams (and other types of water bodies) are themselves the source of sediment, or nutrients, due to their failure to function properly. These often have extreme temperatures and sediment/nutrient loads, low DO, and poor habitat for aquatic organisms. In these cases, reducing an external load is not the solution. Rather, riparian functions must be restored to reduce pollution-releasing processes like erosion and engage assimilation processes that slow the nutrient spiral with flooding, uptake, and complex niches and food webs.

This system of water quality regulation is fraught with complications that can make the TMDL system all but ineffectual at reducing pollution levels. One problem is the assumption that the landowners, users, and managers have control of the pollutants and are the sole sources. The source of pollution addressed by this study is the stream and riparian area due to its nonfunctional or functional at risk physical condition. In 2000, the BLM reported that in Nevada only 30% of riparian miles and 26% of wetland acres were functioning properly (BLM 2001). This clearly limited the ability of the TMDL process to make any progress toward meaningful water quality improvement in these areas, because the waterway *is* the pollution source. Water quality and aquatic habitat, particularly in rural areas, can be improved by returning riparian/wetland systems to a functional condition. Once in a functional condition, riparian areas can act as pollutant processors helping to mitigate water quality before it enters the waterway. Only by including the functionality of the riparian system can the TMDL process effectively address water quality issues. Furthermore, water quality also embraces the physical and biological, not just the chemical, aspects of habitat, and properly functioning riparian areas provide far more complex and biologically productive aquatic habitat.

Objective

The primary objective of this study is to document changes in riparian land management to effect physically functional riparian condition of streams and test hypotheses related to changes in water quality. Maggie Creek in north-central Nevada serves as a case study location. It was chosen for its relatively rich water quality data sets and dramatic change in riparian land management leading to significant improvements in riparian zone physical functionality in small parts of the watershed having most of the important perennial stream habitat,

Conditions Affecting Hypotheses Development:

- Water quality datasets, spanning the entire time of this study, are only available at:
  - MAG2 (site established in middle section of Maggie Creek by Newmont Mining Corporation, hereafter referred to as the "upper station").
  - Simon Creek (site established on Simon Creek near confluence with Maggie Creek by Newmont).
  - MAG1 & HS14 (sites established on Maggie Creek closer to the Humboldt River confluence by Newmont (MAG1) and the Nevada Department of Environmental Protection (HS14), hereafter referred to as the "lower station").
- Water quality parameters collected differ slightly among the stations.
- Results of PFC assessments given in full detail.

Hypotheses

1. Because of the improved functional attributes and condition above the upper station, all water quality parameters addressed by this study will generally trend toward improvement through time, that is:
   - Improved base flows (higher flows, increased duration)
   - Decreased TSS
   - Decreased nutrients (TN, TKN, and/or NOx; OP)
   - Increased summer DO
   - Decreased summer water temperature
2. For the same reason, aquatic habitat features will also show improvement through time:
   - Increased riparian condition class
   - Decreased width to depth ratio
   - Increased riparian zone width
   - Increased shorewater depth
   - Increased woody riparian vegetation overhang (shading)
   - Increased pool quality

3. Because of the minimal improvement of functional attributes and condition of stream reaches between the upper and lower station, the lower station will demonstrate the residual effects of water quality improvement of trend from above, but to a lesser degree.

Site Description

The Maggie Creek Watershed is in northeastern Nevada within the northern Great Basin (a temperate desert with cold snowy winters and hot dry summers) and drains to the Humboldt River basin (Figure 2). Maggie Creek Watershed is bounded by the Tuscarora Mountains on the west and the Independence Mountains to the north and east. The National Hydrologic Dataset (NHD) indicates the Maggie Creek Watershed has 1,094 stream miles, predominantly intermittent or ephemeral, with 224 miles of perennial reaches (Figure 3). Elevation ranges from about 1435 to 2700m. The Maggie Creek Watershed covers 254,150 acres, of which BLM administers 42% and manages eight smaller and three large grazing allotments (Figure 4), 55% is privately owned and 3% is owned by the state of Nevada (Figure 5).

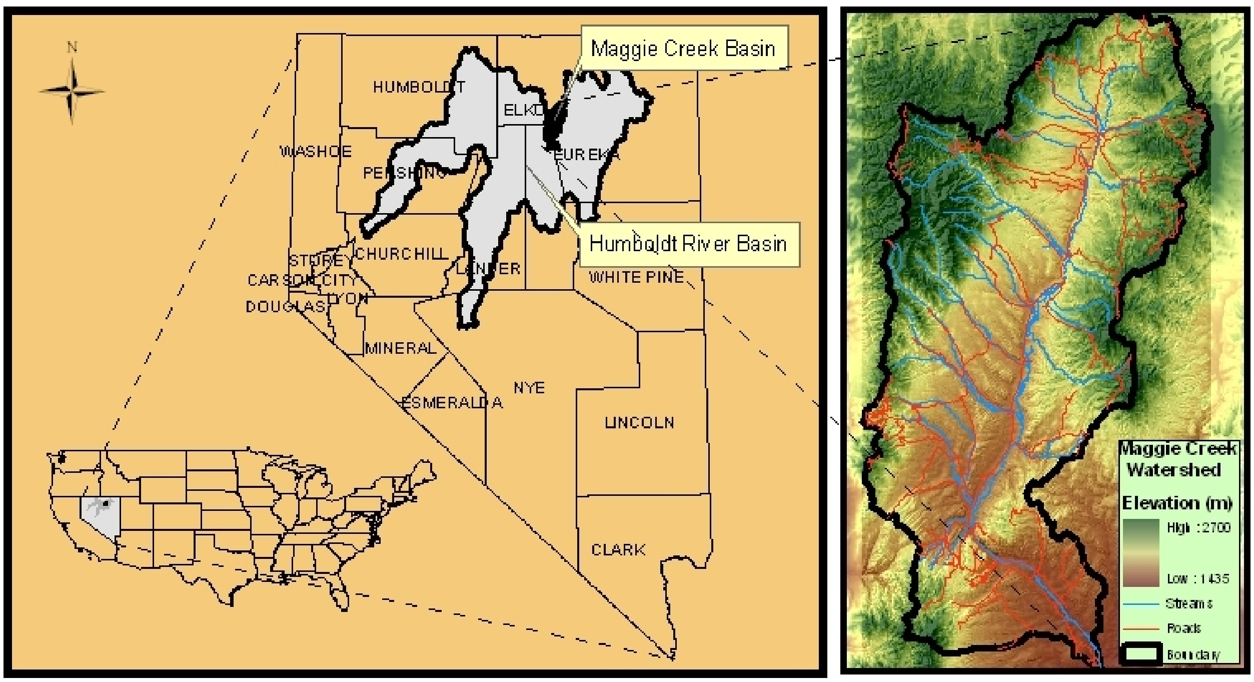


Figure 2. Study Area, Maggie Creek, NV.

Most of the watershed is in the Upper Humboldt Plains level 4 ecoregion (Bryce et al. 2003) except for the Semiarid Uplands of the Tuscarora Mountains on the basin's west side (Figure 6). The Tuscarora Mountains supply most of the runoff for Maggie Creek. Most precipitation is deposited as snow, especially at higher elevations. Snowmelt and spring flow is the major source of water feeding the streams in this study. The thirty year average (1970-2000) precipitation of the watersheds in the general area range from 284-830 mm (11.2-32.7 inches). Land cover is primarily shrub/scrub of short and mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *Vaseyana)* with Idaho fescue (*Festuca idahoensis* Elmer) and other grasses. Some juniper and aspen forests occupy headwater areas of tributaries. Riparian vegetation consists primarily of willow communities. There are smaller meadow areas of hay/pasture production located mostly along waterways (Figure 7). The primary land uses include ranching, hay production requiring diversions of stream water, and mining. As described, Maggie Creek is a microcosm representative of the northern Great Basin.

During the period of this study, the 2001 Coyote Fire burned 11,637 acres primarily in the Beaver Creek sub-basin. In the same year, the Maggie Creek Fire burned approximately a 2,550 acre portion on the east side of the lower portion of the watershed. The Basco Fire, in 2006, burned approximately 11,750 acres within the watershed on the east side in the upper portion of the watershed (Figure 8). Collectively, 9.8% of the watershed burned during this study. However, only the Red house Fire was adjacent to perennially flowing water connected to Maggie Creek.

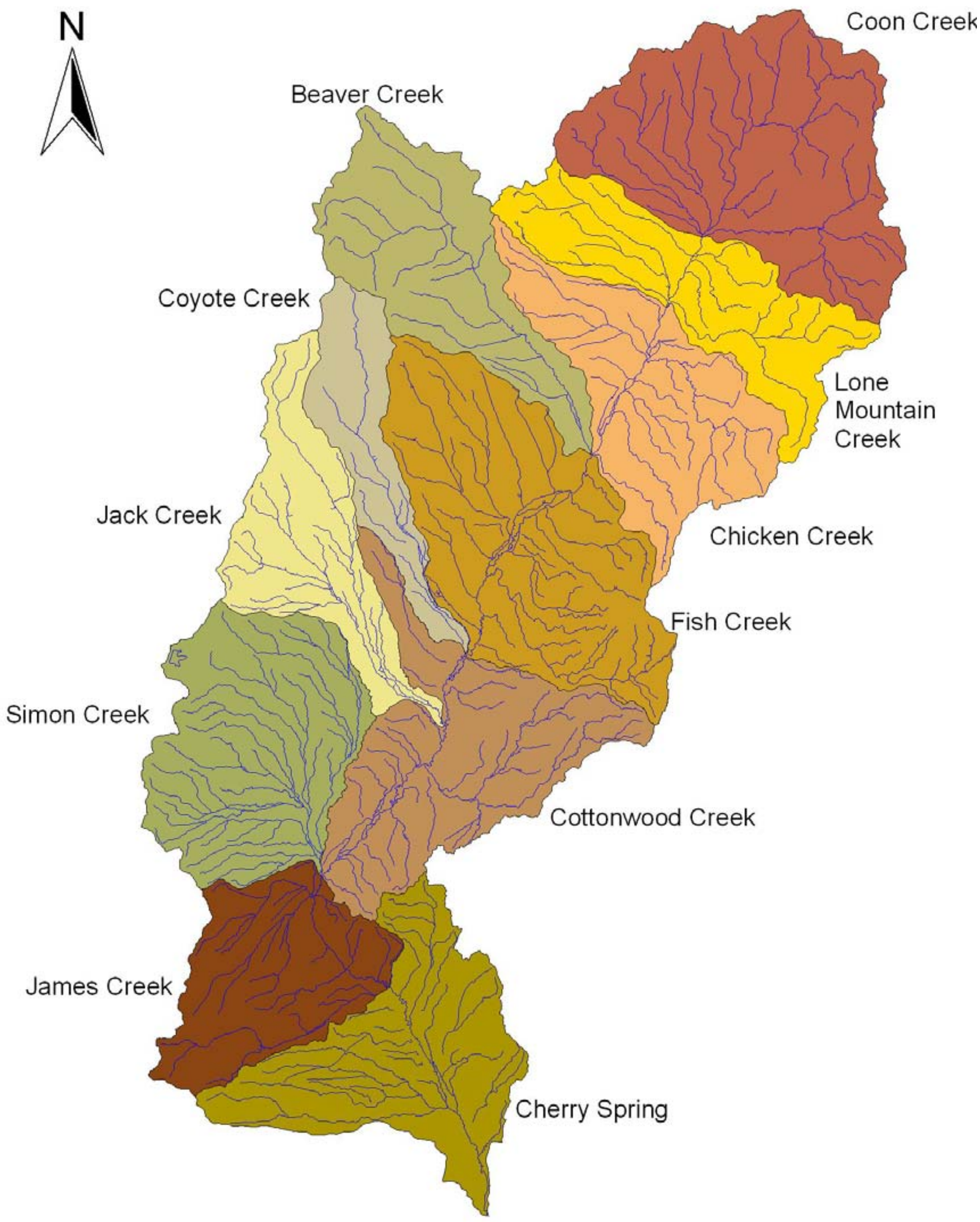


Figure 3. Maggie Creek, NV, River Reach and 12-Digit Hydrologic Units.

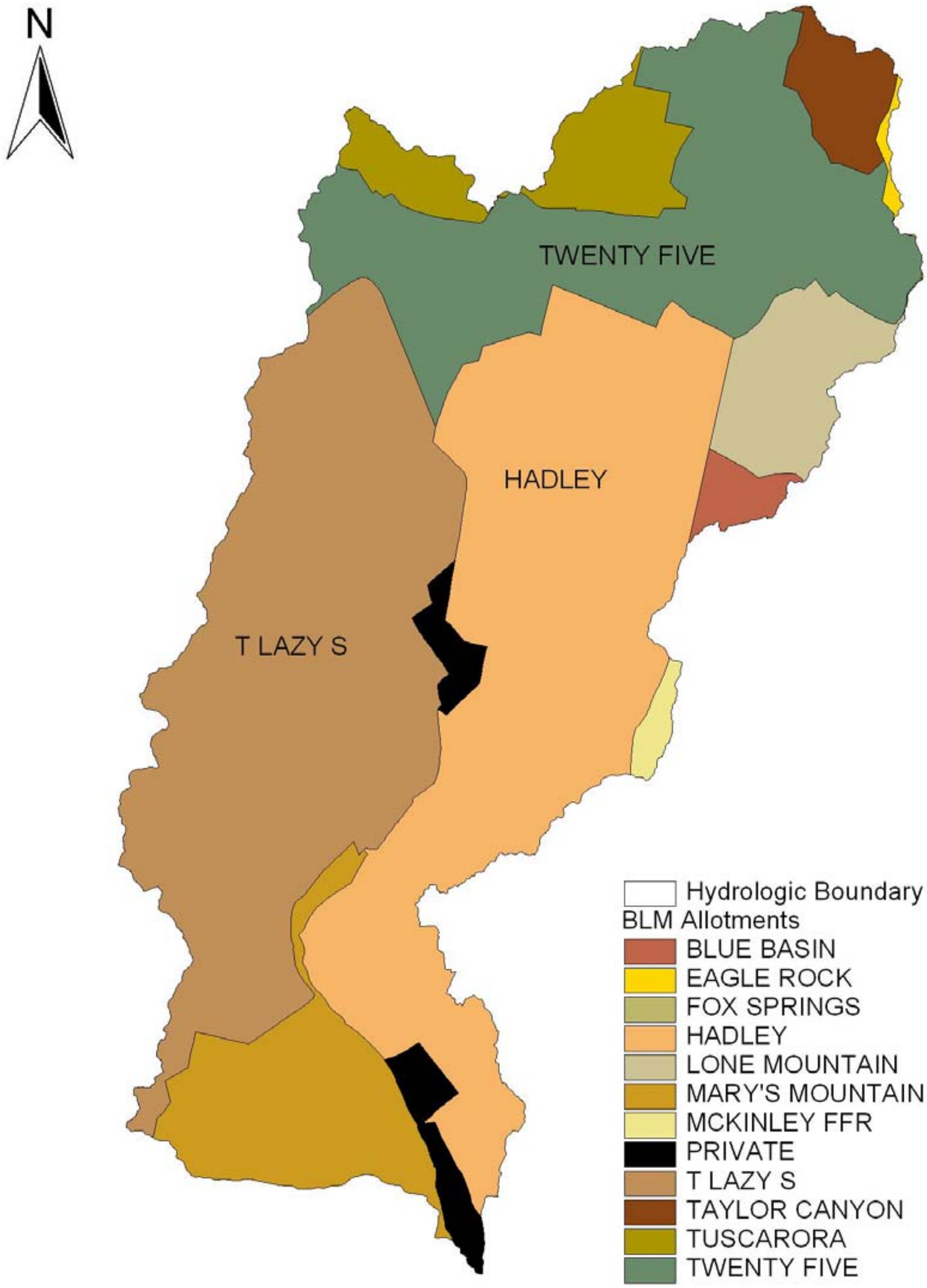


Figure 4. Maggie Creek, NV, BLM Grazing Allotments and largest ranches.

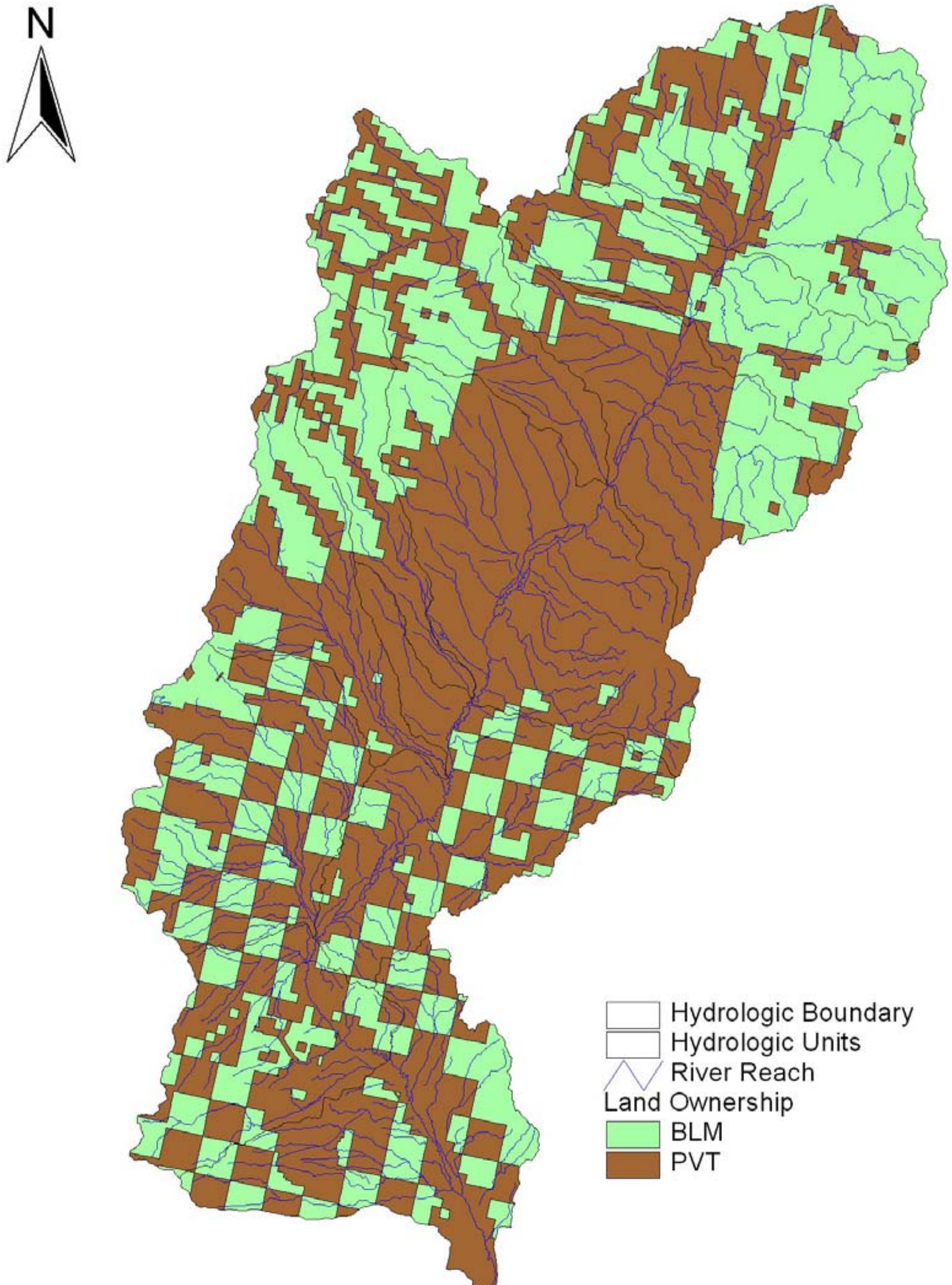


Figure 5. Maggie Creek, NV, Land Ownership.

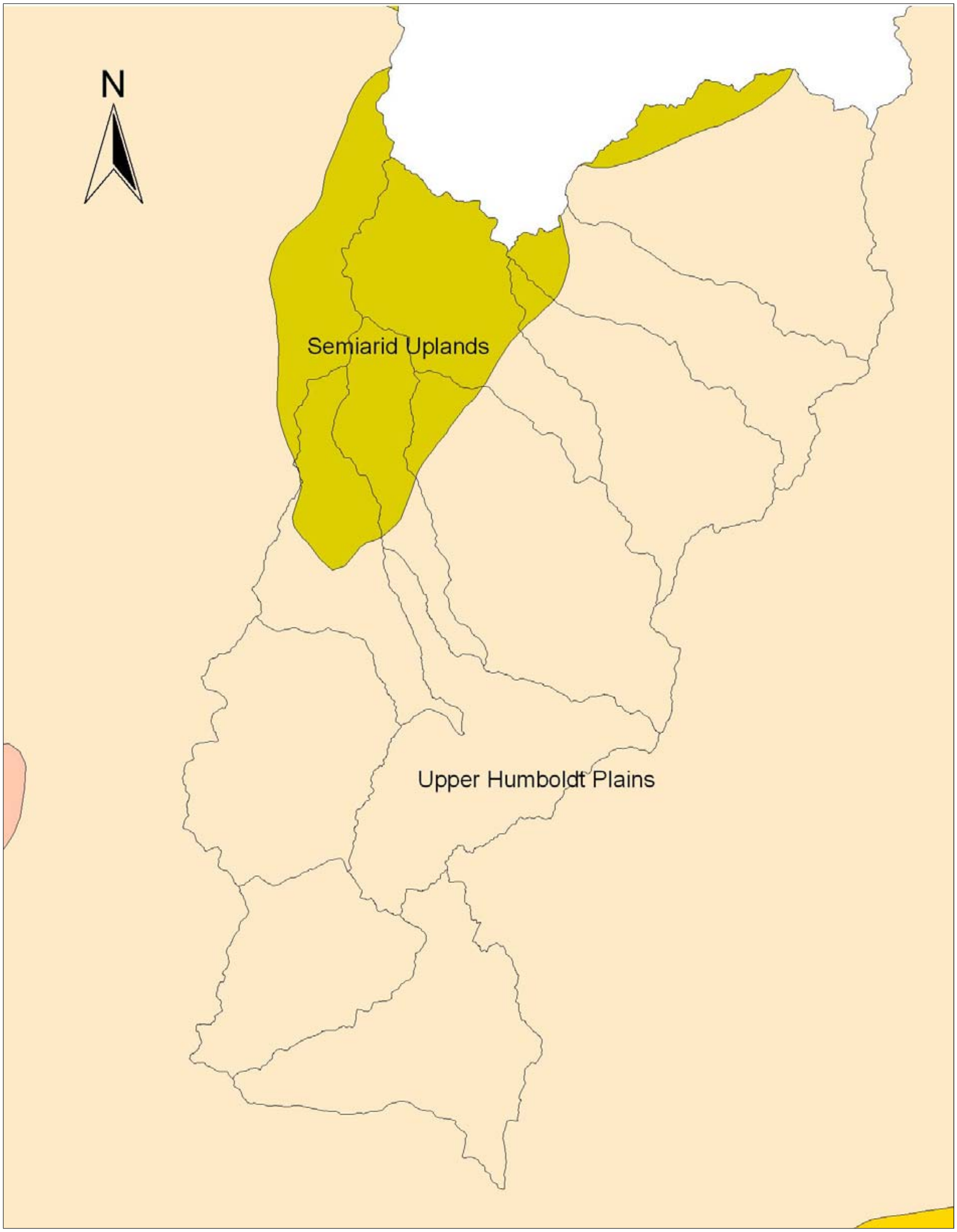


Figure 6. Maggie Creek, NV, Ecoregions.

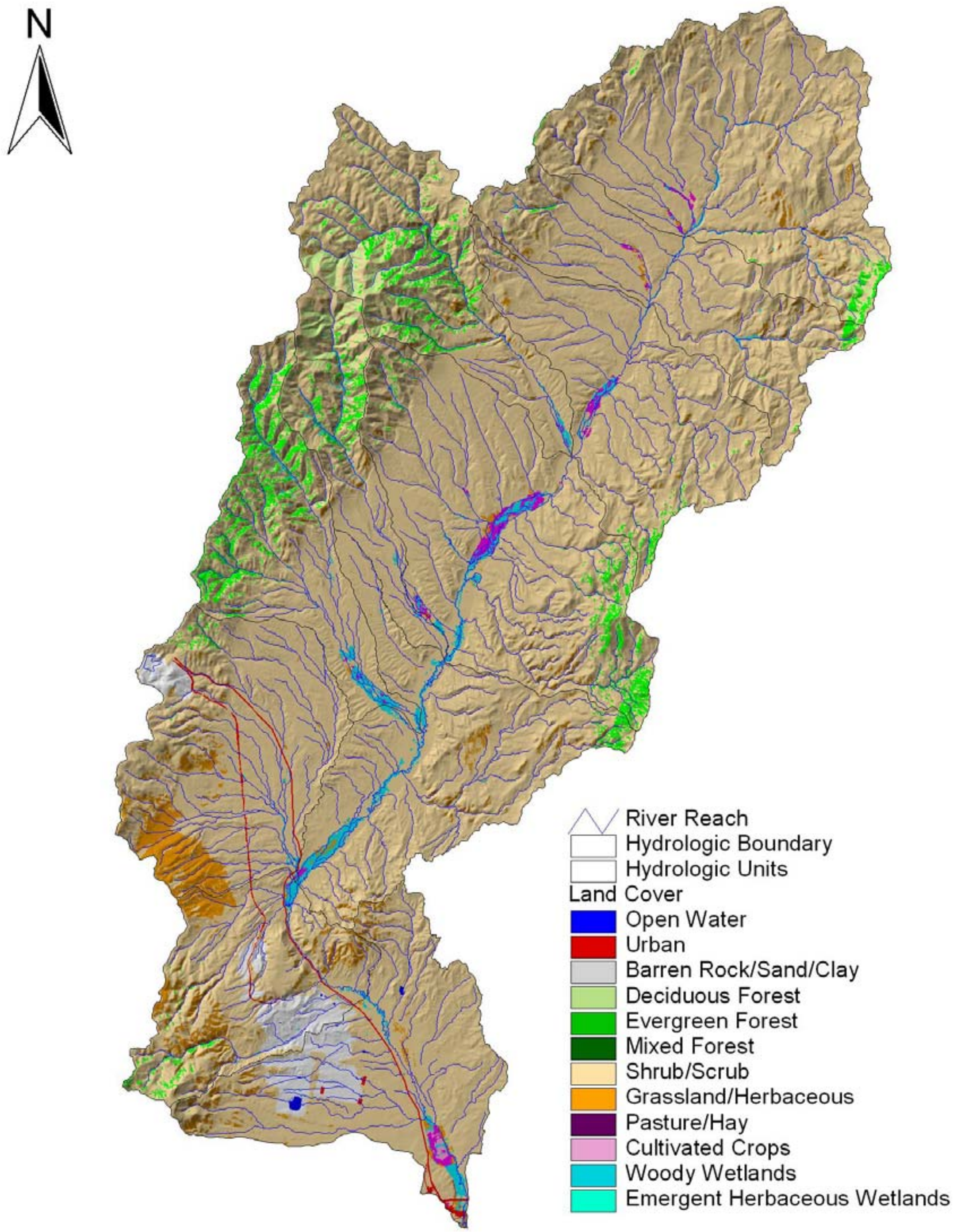


Figure 7. Maggie Creek, NV, National Land Cover Database Homer et al. (2007).

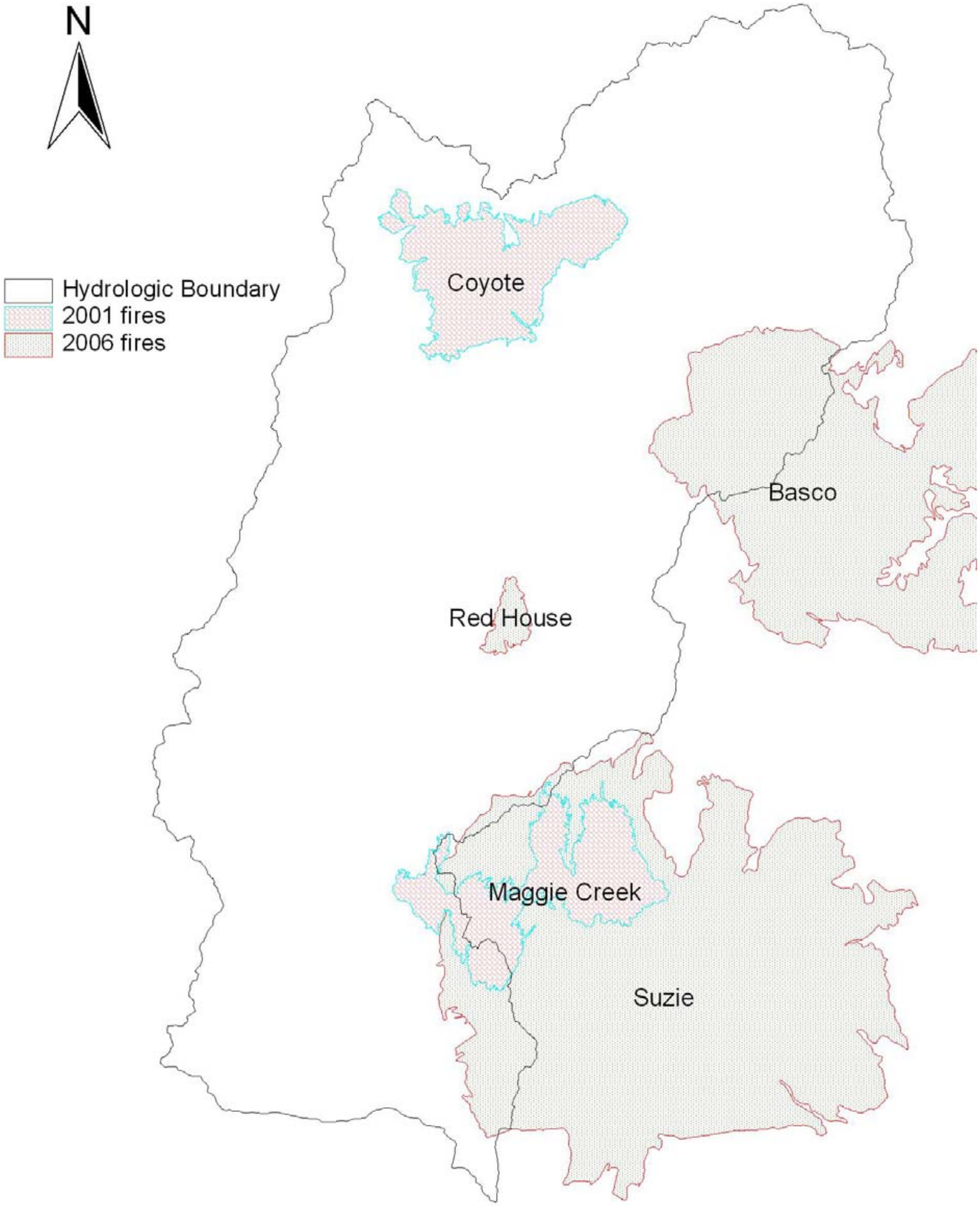


Figure 8. Maggie Creek, NV, Fire Event Areas.

History

Commercial ranching probably started in the watershed in the late 1870's around the time the T Lazy S Ranch was amassing vast acreages via homesteading and railroad land acquisitions. Land use then consisted of open range grazing and developing irrigated hay production, particularly in the Rock Creek and Humboldt drainages. The T Lazy S Ranch has since been renamed the TS Ranch, which today has private holdings and grazing allotments within the Maggie Creek Watershed. The Maggie Creek and Twenty-Five ranches also operate within the watershed. The TS Ranch is managed by the Elko Land & Livestock Company, a subsidiary of current owner Newmont Mining Corporation (Newmont), which purchased the ranch in 1986 to gain mineral rights, water rights, and transportation access.

The Carlin Trend, a 50-mile long, 5-mile wide belt of faulted terrain runs northwest to southeast from the town of Carlin, Nevada, through the Maggie Creek Watershed. The Carlin Trend has been called the most prolific goldfield in the Western Hemisphere. Newmont started open pit production on the Carlin Mine (within the lower portion of Maggie Creek Watershed) in 1965. With the discovery of higher grade gold at depth, underground mining began in 1994, necessitating mine water extraction and mitigation (BLM 1993).

Prior to 1993, the majority of Maggie Creek was grazed by cattle throughout the growing season, resulting in impacts to riparian vegetation and degraded stream conditions. Decades of intensive grazing, water development, and road construction degraded aquatic and riparian habitats. By the early 1990's, miles of stream were characterized by unstable banks, channel incision, riparian vegetation loss, wide shallow channels, excessive erosion and deposition, reduced stream flows, and increased water temperatures. This left degraded reaches in physically nonfunctional or functional-at-risk condition (Prichard et al. 1998) and fragmented critical habitat for the Lahontan Cutthroat Trout (LCT), causing their populations to decline.

The LCT, Nevada's state fish, was listed as threatened under the Endangered Species Act in 1975 and remains so today. The Maggie Creek drainage was historically renowned for its fishery and now supports multiple remnant LCT populations. Maggie Creek basin is considered one of only a few watersheds in northeastern Nevada that could support LCT metapopulations (multiple populations within an area in which interbreeding could occur), but does not due to geographic barriers.

As mitigation for their 1993 South Operations Area Project (SOAP, mine dewatering), Newmont, in cooperation with the Elko District Bureau of Land Management (BLM) and the Elko Land and Livestock Company, developed the Maggie Creek Watershed Restoration Project (MCWRP) to improve streams, riparian habitats, and watershed conditions within the Maggie Creek Basin (BLM 1993). The project was developed to enhance 82 miles of stream, 2,000 acres of riparian habitat and 40,000 acres of upland watershed primarily through prescriptive livestock management.

Beginning in 1994, grazing systems were implemented for portions of the perennial/intermittent streams and the twenty-five ranch allotments in the Maggie Creek Watershed (specifics found in Evans 2009). This greatly reduced the frequency and duration of hot season grazing on Maggie Creek and its tributaries. The area is divided into three zones including exclusion zones, a restoration zone, and a controlled grazing zone (Figure 9). The exclusion zone is closed to grazing while livestock use of the restoration zone is contingent on meeting and maintaining biological standards. The controlled grazing zone provides for rotational and deferred grazing practices. The extent of restoration accomplished by focused riparian grazing management is illustrated by the front cover of this publication. Both the exclusion and restoration zones support LCT habitat. Other measures, including construction of water developments, tree plantings, prescribed burning, and development of a conservation easement were also part of the restoration effort.

The primary focus of the plan was to improve LCT habitat. Other efforts to improve fish populations included replacing culverts and irrigation diversions that bar migration, and placement of barriers at the bottom of the watershed to keep out non-native fish species. Trout Unlimited and partners are working within the watershed to monitor fish population response due to habitat improvement and barrier removal.

Land uses that most significantly affect water quality and aquatic habitat issues elsewhere in the Humboldt basin include grazing, irrigation agriculture, and mining. Changing the land management of grazing and agricultural uses leads to changes in riparian functionality, which affects water quality and aquatic habitat variables. Changes in active mining management, in its current form, will likely not lead to changes in PFC. Exceptions would be accidental release of acid mine discharge (AMD), and deposition of excess sediment and/or flocculants (e.g., iron precipitates). Changes in PFC are not expected to significantly change water quality issues associated with mining (i.e., heavy metals, soluble metals, mineralization, and low pH). However, increased organic matter will provide binding sites for suspended and dissolved trace metals. There is also an ancillary effect via the absorption of soluble trace metals by riparian wetland plants, and deposition due to slowing of stream flows. Mine dewatering can lead to lowering water tables and reduced or augmented flow in stream channels, which is occurring in areas of Maggie Creek below where grazing management has changed.

Impacts to PFC are far more prevalent from grazing, agricultural use, and roads than from mining in the Humboldt Basin, including Maggie Creek. Water quality variables that most closely respond to changes in land use/management in the Humboldt Basin include sediment (turbidity, total suspended solids), flow alteration (quantity, timing), nutrients, temperature, dissolved oxygen, pathogens and trace metals. Important aquatic habitat variables include riffle/pool ratios, bankfull width/depth ratios, embeddedness, and bank stability.

Water Quality Stations

Four sample collection stations have water quality data spanning the entire period of this study. Other stations have data from much shorter periods, and are of limited or no use. Stations MAG1 (Newmont), HS14 (Nevada Department of Environmental Protection (NDEP)), and 1032200 (USGS) are within a quarter mile of each other (the “lower station”). Station HUM82 (EMAP, with a single sample date, July 1998) is about two and a half miles upstream of these stations. All are at the bottom of the watershed near the confluence to the Humboldt River. The “lower station” therefore represents water quality resulting from traveling through a physically poor or non-functional series of reaches with numerous water diversions for hay field irrigation. Station MAG2 (the “upper station”) is about 6.5 miles upstream of the lower stations, just above the mine reservoir flow augmentations, and below the Maggie Canyon narrows about 4.5 miles below the first pasture with a change in management. Station locations are shown in Figure 9.

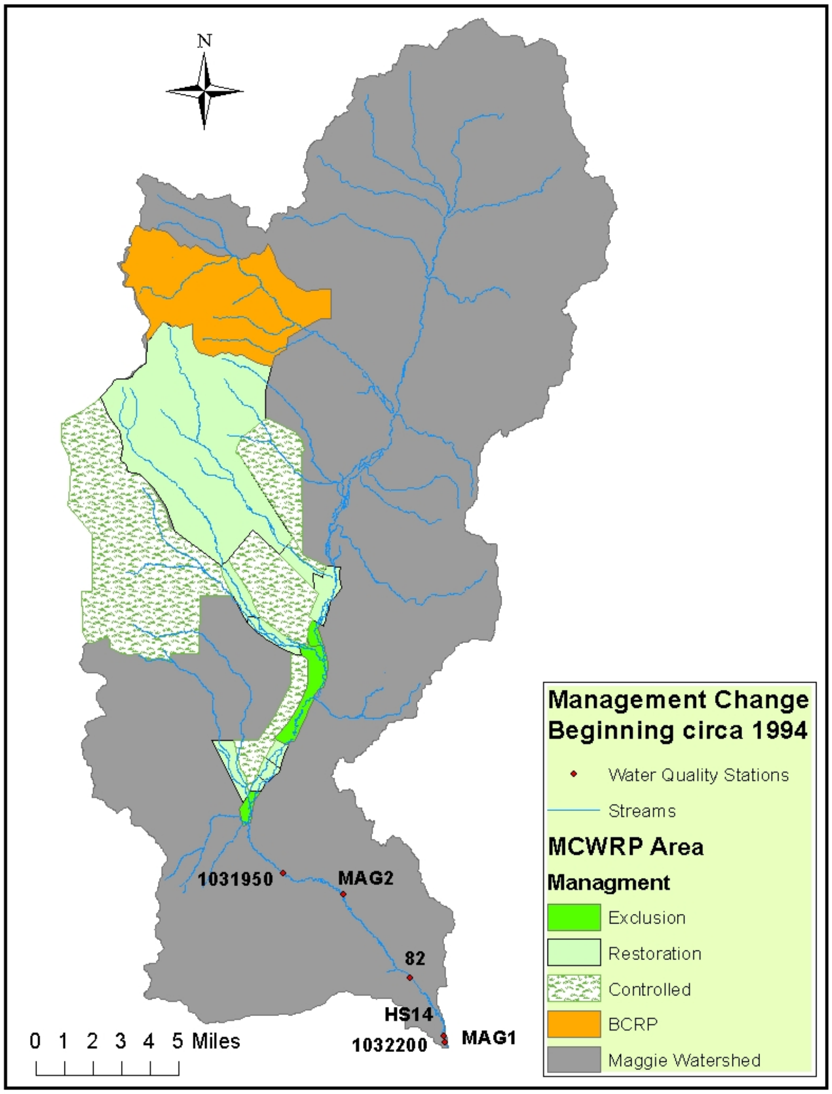


Figure 9. Management Change and Water Quality Stations in the Maggie Creek Watershed Restoration Project (MCWRP) and the Beaver Creek Riparian Pasture (BCRP), NV.

Water Quality Data Available

Sources of water quality data within Maggie basin include Newmont, NDEP, USGS, and the EPA. The dates of data collection are displayed on the hydrograph in Figure 10, which demonstrates good representation of data across many flow discharges. Noted also is the increased occurrence of data collected during periods of no flow starting in 2001, corresponding to a loss of continuous base flows discussed in Results. The parameters collected at any particular time are highly variable. Water quality data collected above the influence of mining activity and associated with flows as recorded at station 10321950 come exclusively from Newmont's data collection at station MAG2, which is approximately two and a half miles downstream of the USGS station 1031950 and just upstream of where reservoir water is discharged to Maggie. Both NDEP's station HS14 and Newmont's MAG1 station are within a quarter mile upstream of the USGS station 10322000. The EPA's station HUM82 is about 2.8 miles upstream of the USGS gage.

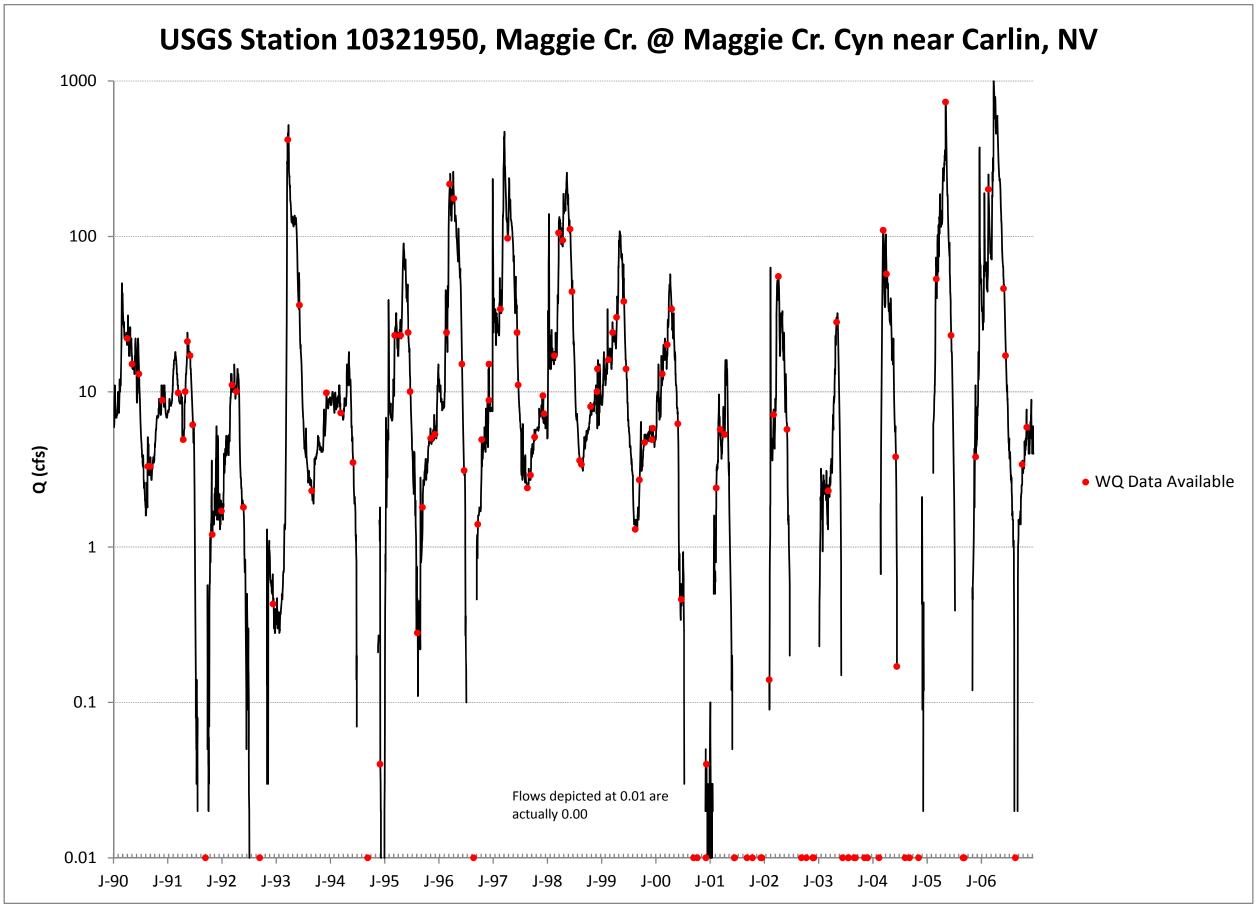


Figure 10. Water Quality Data Available at USGS Gage Station 10321950 on Hydrograph, Maggie Creek, NV..

Methods

Assessing Stream Functional Condition

Stream functional condition was assessed using the methods of Clemmer (1994) and Prichard et al. (1998). Evaluations were performed by an interdisciplinary team composed of a hydrologist, geomorphologist, and ecologist for the years 1994 and 2006 because of the availability of imagery. The year 1994 is important because it preceded management changes, and 2006 reflects recent conditions within the period of water quality data. Much of this assessment was done through remote sensing data in ArcGIS. 2006 Color Infrared (CIR) and National Agriculture Imagery Program (NAIP) 1-meter resolution imagery was used (with other ancillary data) to assess PFC condition for 2006. 1994 black-and-white (B&W) Digital Orthophoto Quarter-Quadrangles (DOQQs) and CIR 1-meter imagery (with other ancillary data) were used to assess PFC for 1994. 1994 CIR imagery (obtained from the BLM) is not complete for the entire Maggie Creek Watershed. It covers the major tributaries of Simon Creek, Jack Creek, Coyote Creek, and Spring Creek as well as Maggie Creek proper upstream nearly to Beaver Creek. Beaver Creek and the main channel and tributaries to the north were evaluated with B&W only. While some interpretations about vegetation status can be made using B&W photography, use of these images limits what interpretations can be made in the vegetation category of PFC assessments. For both years, some on-the-ground photography was available from stream surveys performed by the BLM. Very Large Scale Aerial (VLSA) imagery was flown by Open Range Consulting in 2006 (provided by the BLM) for some portions of Maggie Creek, Coyote Creek, and Beaver Creek. Where available, all these images were used to help assess PFC condition.

Ancillary data used for PFC assessments include: the USGS NHD showing springs, water bodies, and perennial and intermittent streams; landowner polygons from the BLM; landcover rasters from the USGS National Land Cover Database 2001; USGS topographic maps; pasture polygons from the BLM; and stream survey locations from the BLM. Several other layers have helped to a lesser degree.

Assessing PFC over hundreds of miles is a large task even when using aerial photography. However, investigations indicate many of the perennial stretches of stream in the upper watershed fail to connect to Maggie Creek in any but the more significantly large hydrologic events. In most cases, the larger tributaries of Jack's, Coyote, and Beaver creeks go sub-surface as they flow into the alluvial deposits at the base of the Tuscarora Mountains, except perhaps briefly in the early spring during the snowmelt runoff of a good snow year. In most years, surface water contributions from tributaries to water quality in Maggie Creek are negligible. Therefore, it is not relevant to downstream water quality to evaluate the PFC of the upper reaches. Similarly, downstream water quality measurements cannot be used to understand water quality or habitats in these headwater reaches. However, in the lower portion of the larger tributaries, springs return sub-surface flow to lentic and lotic systems that remain perennial or at least intermittent. These springs and seeps, as well as occasional surface waters and riparian conditions, likely influence water quality of Maggie Creek.

"Reach rules" were developed to help determine which segments (reaches) of streams were likely to significantly influence water quality and therefore, which reaches we would complete a PFC assessment for in both years.

Used reach rules:

1. There must be perennial flow on the stream (Maggie Creek proper) or primary, secondary, or tertiary tributary (unless tertiary is insignificant).
2. Tributaries must have at least an intermittent connection to Maggie Creek.
3. Ephemeral reaches above uppermost perennial sections are not included.
4. Secondary and tertiary tributaries less than 0.5 miles are not considered.
5. Delineated reaches will be homogeneous in their potential, based on geomorphology and plant community complex (Winward and Padgett 1987 and Burton et al. 2011) and apparently in their management, and generally no shorter than 0.25 miles.
6. Where there is no indication of riparian vegetation, a reach will be assumed to be ephemeral, and thus any perennial or intermittent reaches above this will be ignored.

To ground truth and validate observations made via remote sensing images, a field visit to Maggie Creek was made on April 9 & 10, 2010. A laptop with the geographic information system (GIS) project coupled with an interactive global positioning system (GPS) was used to help verify location in the field and find points of interest with relative ease.

Precipitation and Discharge

Data for precipitation were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html) for the Elko airport, the closest available data source that spans the time of the study. Stream flow data were obtained from the USGS National Water Information System (NWIS, http://waterdata.usgs.gov/nwis) for the stations 1031950 and 1032200 within the Maggie Creek Basin. Station 1032200 does not have data for 1990-1992. The 1993 data from the two stations was used to create a predictive regression model to fill in relatively dry 1990-1992 data gaps.

Water Quality and Aquatic Habitat Data

Water quality data for the stations HUM82, HS14, 1032200, and MAG1 (Figure 9) were combined to represent the "lower station" as the one lowest in the watershed location and associated with flow data from station 1032200. MAG2 (upper station) water quality data were associated with flow data from station 1031950, representing a location further up in the watershed. There were no flow data available to associate with the Simon Station, which represents a tributary location of static or slightly degrading physical functionality.

In order to prevent bias of predictions, this study did not analyze water quality data until PFC-based hypotheses were developed. However, the general natures of data sets were examined to select variables for testable hypotheses.

Analyses included trend of each water quality parameter. Students T-tests compared early to late study period data means and F-tests compared variances. In some instances medians were tested as data were skewed. The length of early or late period data depended on data availability, but generally focused on data from 1990-1993 (pre-management change period) compared to 2003-2006. Four years of data including at least one high flow event represent each period.

Total Suspended Solids (TSS)

TSS is known to be related to discharge. Therefore, in addition to the above mentioned general analyses of the parameters, sediment rating curves were developed to examine trends between sites. Having sufficient data necessitated using longer early (1990 to 1996, upper station; 1993 to 1999, lower station) and late (2000 to 2006, upper station; 2002 to 2008, lower station) periods.

Orthophosphate Phosphorous (OP-P)

Of four different types of phosphorus parameters collected, none span the entire range of dates for either the upper or lower station. OP-P has more coverage than most, with considerable overlap with other phosphorous parameters, especially at the lower station. Where overlaps occur, regression analysis is used to establish relationship models with TSS concentrations (R^2 = 0.934 to 0.986) to estimate OP-P values where gaps existed. Phosphate transport is associated with sediment transport (and therefore discharge), so phosphate rating curves were developed to examine trends between sites. As with TSS analysis, this necessitated using longer early and late periods.

Nitrogen (Total Nitrogen (TN), Total Kjeldahl Nitrogen (TKN) and Nitrate/Nitrite (NOx))

The upper station has very limited nitrogen data. TN is the sum of TKN (nitrogen bound by organics) and NOx (inorganic nitrogen sources). The lower station has better data coverage for TKN, but is missing some TN (14% of those with any data) and almost all NOx. Regression analysis is used to establish a relationship between TN and TKN (R^2 = 0.784), and the model used to fill in TN data gaps where they existed. NOx gaps were filled in by subtracting TKN from TN.

Dissolved Oxygen (DO)

DO concentration (mg/L) data were used in this analysis. Data are more limited at the upper station. Concentrations between 6 and 9 mg/L are generally desired for maintenance of aquatic health in cold freshwater fish habitat (EPA 1988).

Water Temperature

Air temperature data obtained from the NOAA National Climatic Data Center, Elko airport, are used to compare water temperature trends at the two Maggie Creek locations.

Results

Stream Functional Condition

Approximately 53 stream miles were assessed as 98 reaches (Figure 11) as defined by the reach rules described in Methods. Comparison of Figures 9 and 11 reveals that most of the restoration and controlled grazing zones and all of the Beaver Creek Riparian Pasture are outside of the accessed reaches. The perennial upstream reaches valued for fish and riparian habitat were isolated from downstream reaches and were not expected to influence water quality at sampling stations except during unusually high flow conditions. Downstream exclosure, restoration, and controlled grazing pastures comprised 14 of the 53 miles assumed to most directly affect water quality.

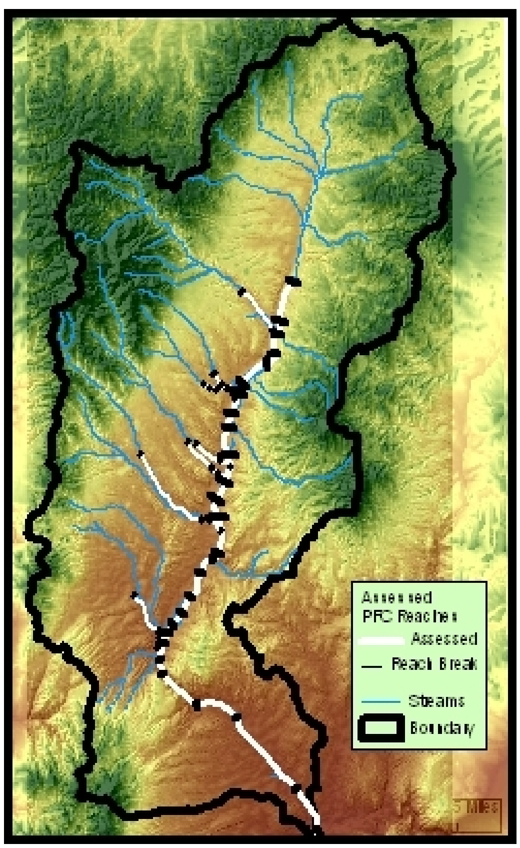


Figure 11. PFC Stream Reaches Assessed Along Maggie Creek, NV.

PFC assessments found no instances where upland watershed is contributing to riparian degradation (attribute 5). As mentioned previously, open pit mining is prevalent in this watershed, but aerial images revealed no evidence that tailings or sediment from erosion was making its way into any of the studied stream reaches. Furthermore, no evidence of natural mass wasting or excessive erosive forces that would contribute to stream degradation was found. One example of mass wasting was high in the Coyote Creek tributary. It occurred above miles of ephemeral channel and was therefore disregarded as per reach rules. This indicates that sediment pollution issues are likely to originate from erosional processes within the stream channel itself.

Determining riparian plant vigor (attribute 10) from the aerial photos was difficult. The influence of vigor on long-term water quality is also assessed by other PFC variables. Stream stability within assessed reaches is not dependent upon coarse and/or large woody debris (attribute 12). Where sticks provide a similar role along small brushy streams, that role is well addressed by items 6 and especially 11 and 13. Therefore, PFC attributes 10 and 12 are not addressed further.

Table 2 shows the percent change of assessed stream miles for PFC attributes and PFC rating on Maggie Creek and its tributaries. Note attributes 2, 4, 6, 7, 9, 11, 13, 14, and the functional rating all had more than 10% change on either Maggie or the total miles assessed. While arbitrary, it was decided 10% or greater represented a robust enough change for attribute or rating‘s role to be further evaluated as a driver of water quality change. While other tributaries had greater percentages of change, the relative length of stream miles to the whole was small (collectively only 3%).

The functional rating of Maggie Creek improved on 13% of the stream miles assessed and constitutes the largest portion of the 13.2% increase in functionality of the system overall. The largest contributors to this increase include an increase in active/stable beaver dams, an increase in the diverse age classes, composition, and amount of adequate well-rooted riparian plant communities, and an improvement of floodplain/channel energy dissipation characteristics.

Table 2. Percentage of Stream Miles that Changed According to Attribute, Maggie Creek, NV

			Hydrologic Attributes				Vegetative Attributes					Soils, Erosion/Deposition Attributes					
Creek	Stream Miles Assessed	% of Total	1	2*	3	4*	6*	7*	8	9*	11*	13*	14*	15	16	17	Functional Rating*
Maggie	33.8	64%	3.5%	28.6%	6.7%	8.9%	12.3%	10.5%	2.3%	17.4%	20.6%	11.8%	7.5%	-1.0%	6.7%	-2.5%	13.0%
Maggie in the MCWRP	14.2	27%	0.0%	56.7%	13.5%	0.0%	23.7%	19.1%	0.0%	28.9%	39.9%	19.9%	3.7%	0.0%	8.5%	-5.9%	26.8%
Simon	2.7	5%	0.0%	0.0%	13.1%	2.6%	-3.0%	-3.0%	-3.0%	-0.2%	10.0%	5.5%	-0.2%	0.0%	0.0%	-3.0%	2.8%
Haskell	3.0	6%	0.0%	20.3%	-8.1%	-22.3%	-36.8%	-26.4%	-11.5%	-21.1%	-31.9%	-29.4%	-15.0%	0.0%	0.0%	-6.1%	-15.2%
Coyote	2.7	5%	0.0%	0.0%	0.0%	52.6%	31.4%	62.7%	31.4%	0.0%	0.0%	0.0%	31.4%	0.0%	0.0%	-17.0%	0.0%
Beaver	2.3	4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Spring	2.1	4%	35.7%	0.0%	0.0%	35.7%	0.0%	35.7%	35.7%	35.7%	35.7%	35.7%	71.4%	71.4%	71.4%	0.0%	35.7%
Jack	6.0	11%	35.8%	0.0%	35.8%	52.4%	0.0%	0.0%	35.8%	35.8%	71.5%	35.8%	46.3%	-7.3%	-35.8%	-35.8%	35.8%
Total Miles Assessed	52.6	% Total Miles Changed	7.8%	19.5%	8.6%	14.7%	7.3%	9.8%	7.8%	15.5%	21.6%	11.7%	13.7%	1.3%	3.1%	-7.1%	13.2%

Positive values represent overall improvement w hile negative values represent overall degradation. *Values on either Maggie Cr. or the entire assessed system greater than 10% w e consider a robust measure of change for further evaluation. Attribute: 1) Floodplain inundated in relatively frequent events (1-3 years); 2) Active/stable beaver dams; 3) Sinuosity, w idth/depth ratio, and gradient are in balance w ith the landscape setting (i.e., landform, geology, and bioclimatic region); 4) Riparian zone is w idening or has achieved potential extent; 6) Diverse age-class distribution (recruitment for maintenance/recovery); 7) Diverse compositon of vegetation (for maintenance/recovery); 8) Species present indicate maintenance of riparian soil moisture characteristics; 9)Streambank vegetation is comprised of those plants or plant communities that have root masses capable of w ithstanding high streamflow events; 11) Adequate vegetative cover present to protect banks and dissipate energy during high flow s; 13) Floodplain and channel characteristics (i.e. rocks, overflow channels, coarse and/or large w oody debris) adequate to dissipate energy; 14) Point bars are revegetating; 15) Lateral stream movement is associated with natural sinuosity; 16) System is vertically stable; 17) Stream is in balance with the water and sediment being supplied by the watershed (i.e., no excessive erosion or deposition) ; Functional Rating) PFC, FAR w /trend, or Nonfunctional.

FAR – Functional At Risk

PFC – Proper Functioning Condition

Precipitation and Discharge

Figure 12 shows yearly precipitation for the period of study. Six years had below average precipitation while eight where above average. Four of the six below average years are clustered together in the middle of the study period from 1999 through 2002. This precipitation pattern is generally reflected in the hydrograph displayed in Figure 7. It should be noted, while Elko had below average precipitation in 1993, there was considerable spring runoff recorded at Maggie Creek (Figure 13).

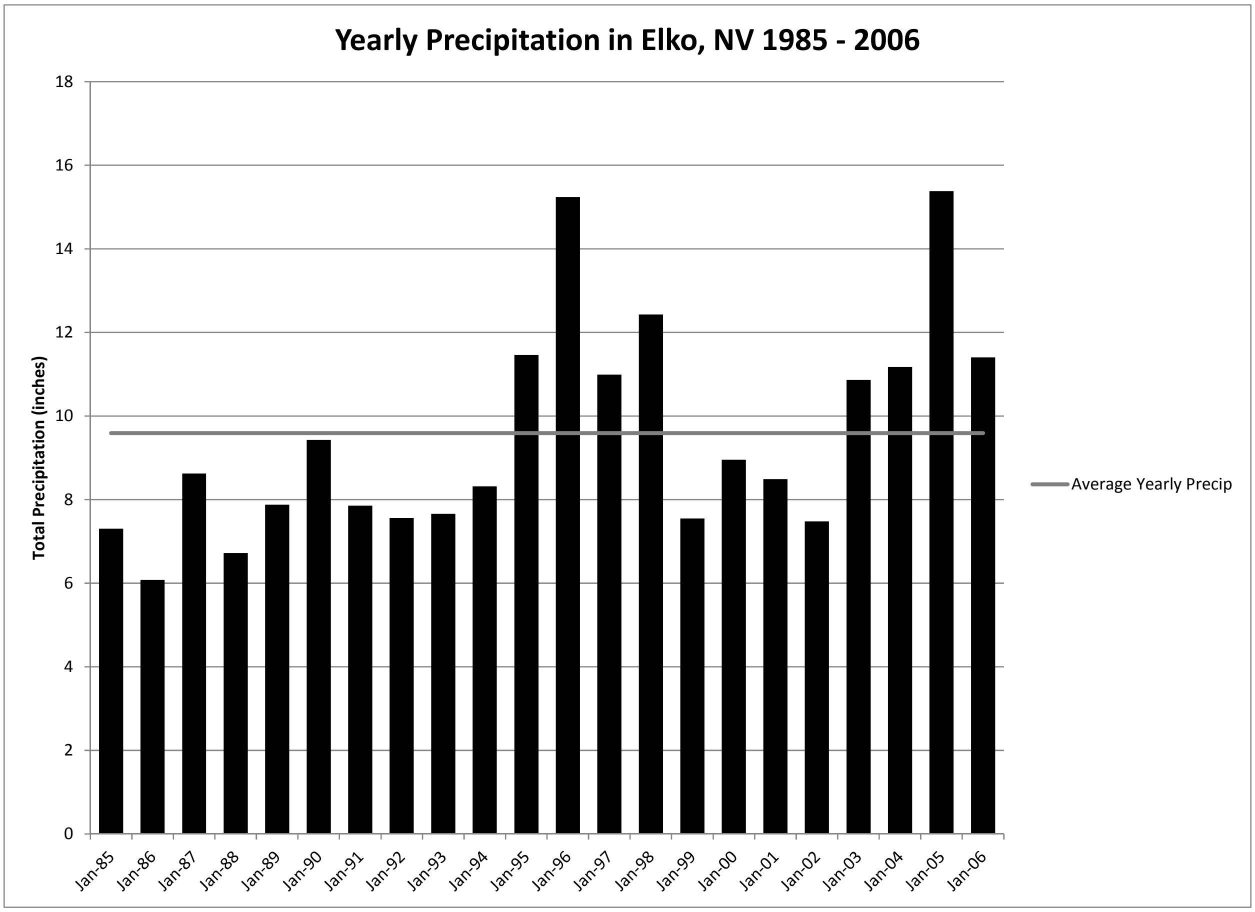


Figure 12. Yearly Precipitation in Elko, NV.

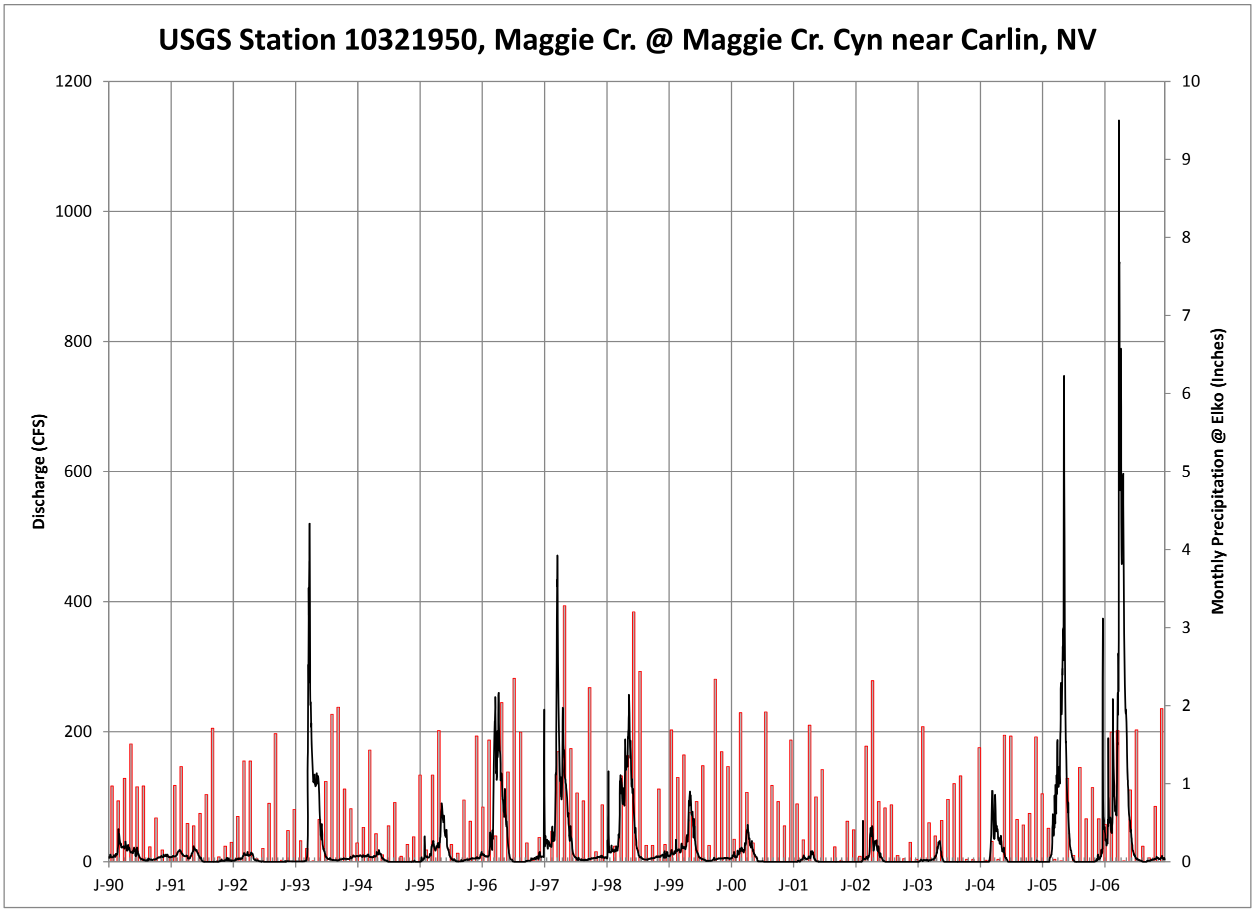


Figure 13. Monthly Precipitation at Elko, NV vs. Daily Hydrograph of Maggie Creek, NV.

Two USGS stations have discharge data available for the period of study (1994 – 2006) on Maggie Creek (Figure 14). Station 10322000 is about nine miles downstream of station 10321950 and is near the confluence to the Humboldt River. Discharge at 1032200 is influenced by additions from a reservoir built about seven miles upstream near the time of the beginning of this study to hold water from mine dewatering activities. As seen in Figure 14, flows prior to the middle of 1994 were generally lower than the above station. After 1994, flows were higher, marking the beginning of the reservoirs influence. Yearly peak discharges are similar at the two stations. Above average precipitation is recorded at Elko from 2003 through 2006 (Figure 12). This is evidenced by higher spring discharges (Figure 13) during the same time period. There does not appear to be a return of continuous base flows at station 10321950 as there was prior to July of 2000.

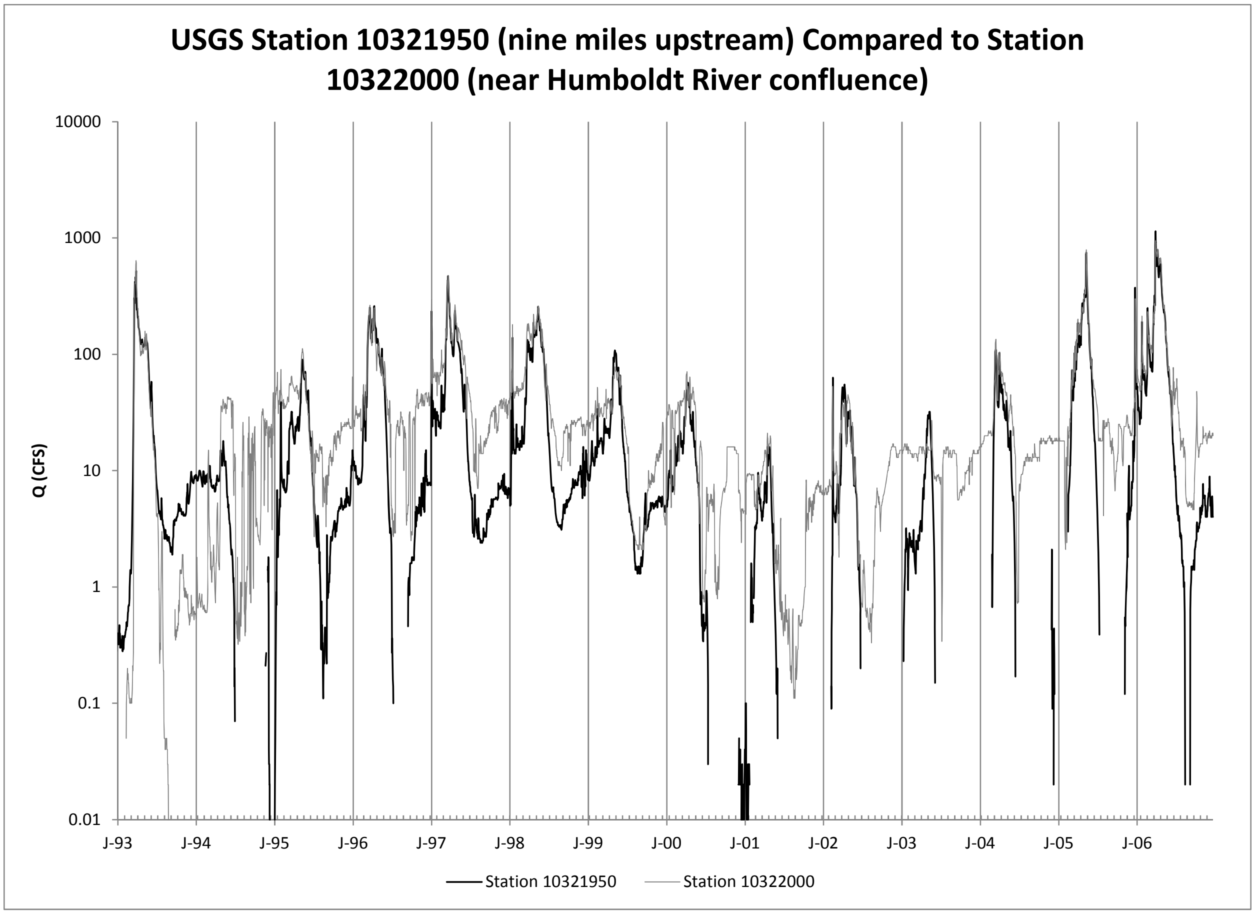


Figure 14. Comparison of Upstream (Bold Line) and Downstream (Light Line) Gage Stations on Maggie Creek, NV.

The cumulative frequency distribution of discharge at station 10321950 (Figure 15) shows that 90% of all flows are below approximately 55 cfs (bankfull discharge) and 70% are below 10 cfs. No flow is recorded about 27% of the time. The average flow at this station is about 24 cfs, the median is 4.5 cfs, and the mode is 0 cfs.

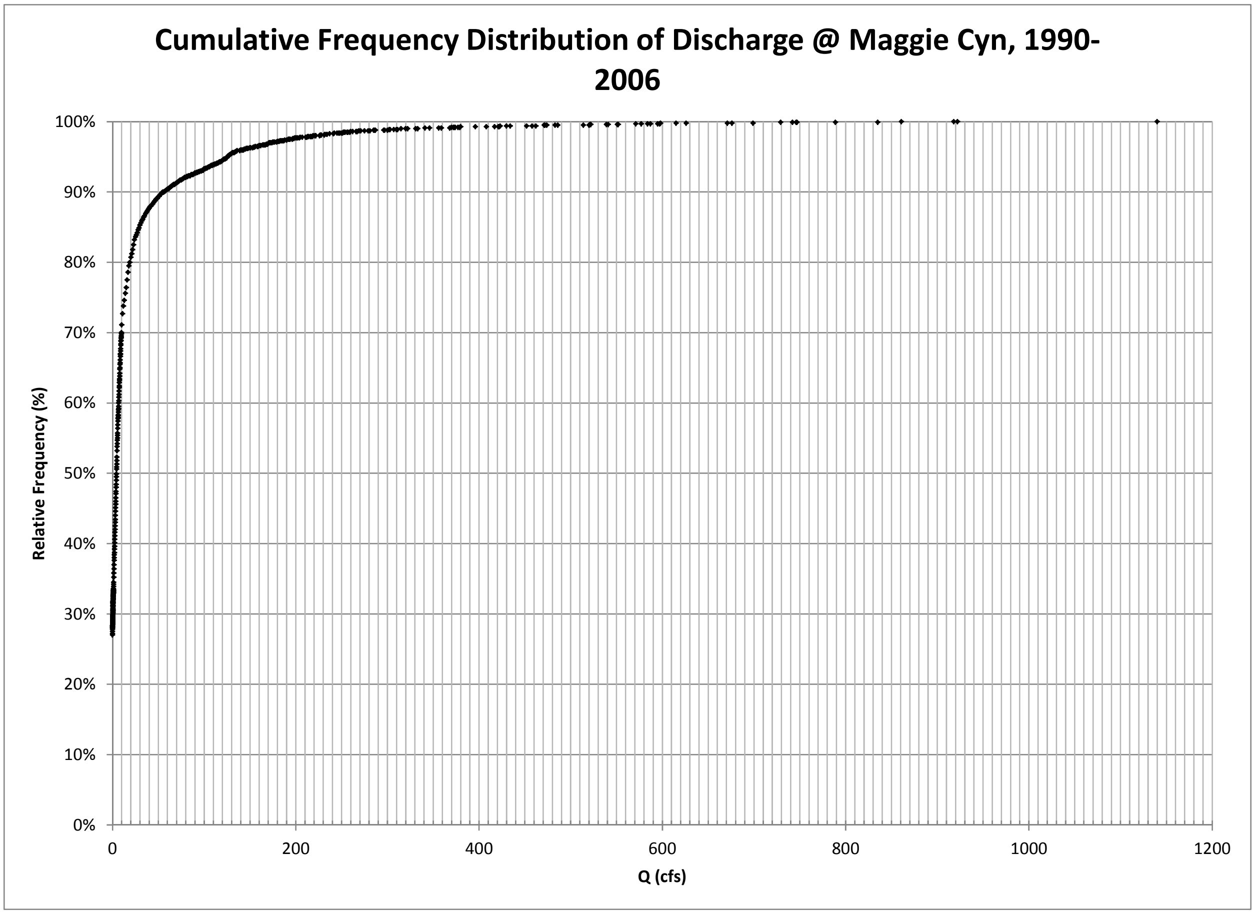


Figure 15. Cumulative Frequency Distribution of Discharge at Maggie Creek, NV, 1990 - 2006.

Total Suspended Solids (TSS)

TSS data collected at the four stations ranged from 0 (non-detectable or ND) to 1100 mg/L. The average value was approximately 51 mg/L, the median was 12 mg/L, and the mode was 10 mg/L.

Prior to management change, the trend in TSS at the upper station (Figure 16) was highly influenced by the March, 1993 runoff event. After the change in grazing management in 1994, TSS tended to decrease, though slightly (R^2 = 0.005). Figure 16 demonstrates the need for a sediment rating curve to help interpret high TSS anomalies.

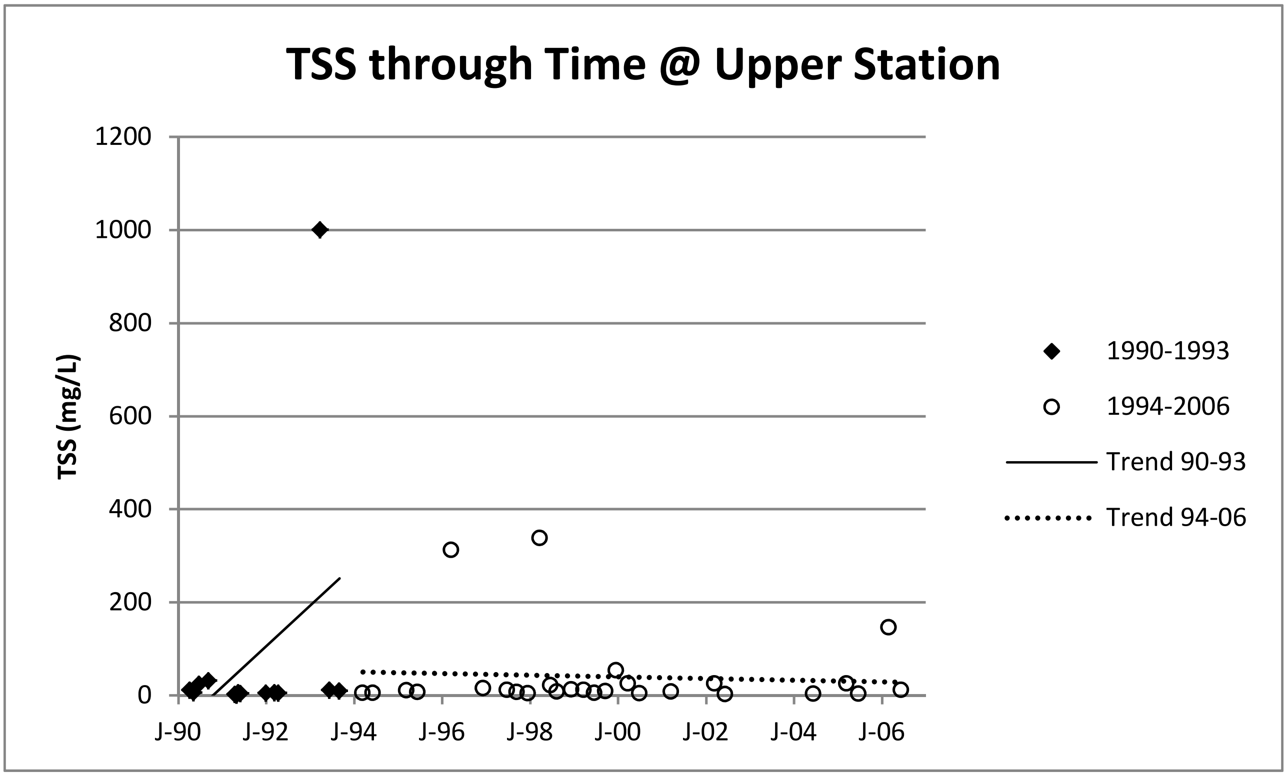


Figure 16. TSS Trend at Upper Station, Maggie Creek, NV, Pre- and Post-Management Change.

Figure 17 displays the suspended solids rating curves at the upper station established for the beginning and ending periods of this study. A downward shift of the TSS rating curves indicates TSS became less concentrated at higher flows after a change in management. At a discharge of 200 cfs, there was a modeled 46% reduction in TSS concentrations between before and after. While flows greater than 200 cfs did occur during the later period, no TSS data where obtained during those times. Data for flows at or below bankfull suggests no significant TSS or temporal difference in TSS.

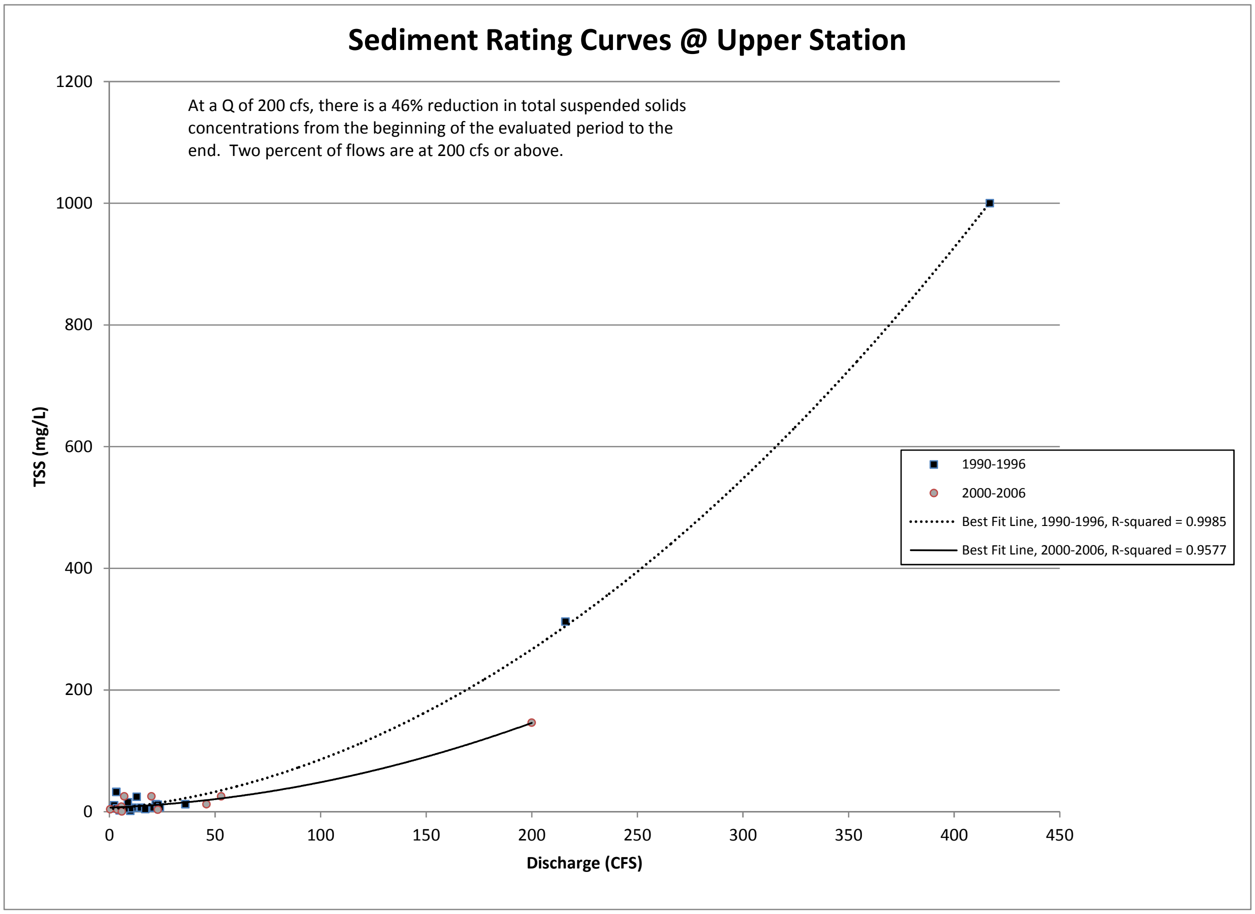


Figure 17. Sediment Rating Curves at Upper Station, Maggie Creek, NV.

Prior to management change the TSS trend in 1994 was increasing but again was influenced by the March, 1993 runoff event (Figure 18). TSS tended to slightly increase at the lower station after the change in grazing management. However this may be largely flow related.

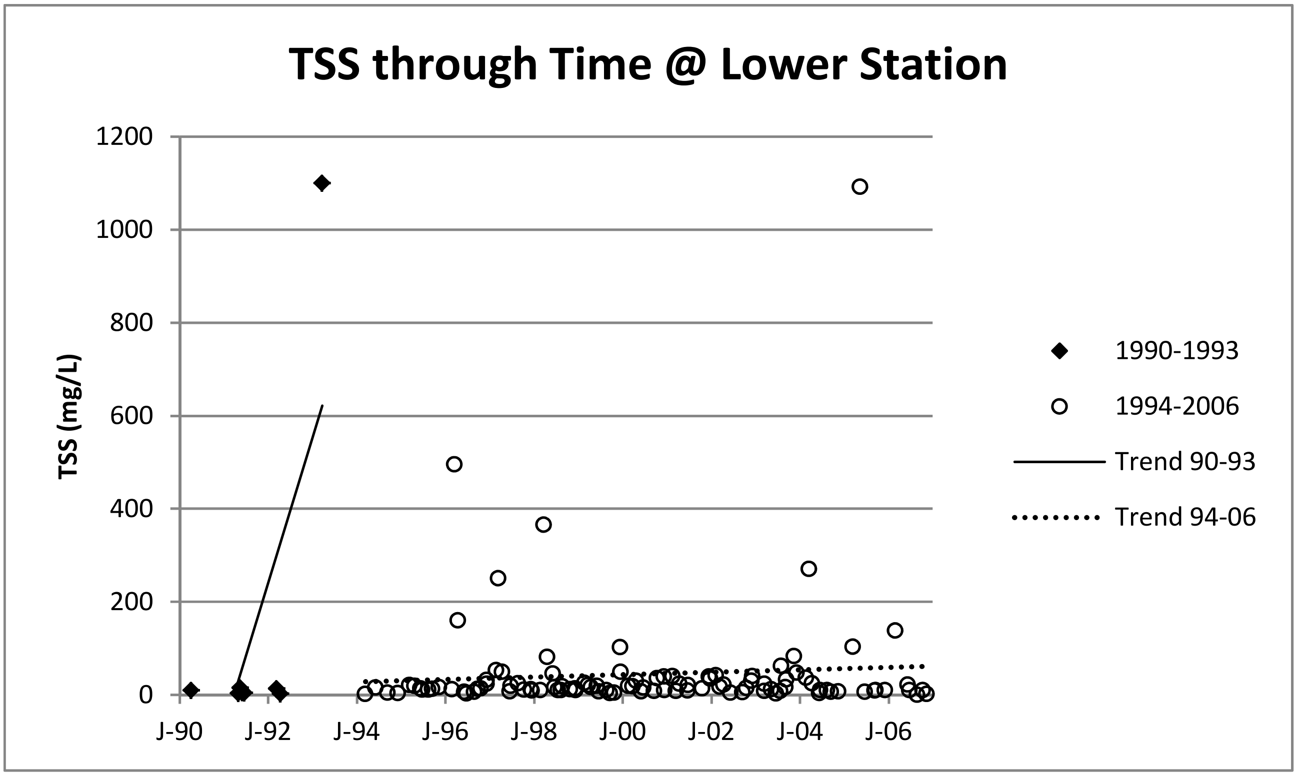


Figure 18. TSS at Lower Station, Maggie Creek, NV, Pre- and Post-Management Change.

Figure 19 demonstrates the same downward model shift at the lower station as the upper station (Figure 17). Again, a comparison of TSS concentrations at a flow of 200 cfs shows (Figure 19) a reduction of about 47% over the time periods, which is similar to what was modeled at the upper station. Note also what appears to be a threshold response around 125 cfs in the 1993-1999 point data, where small increases in discharge seem to bring about large increases in TSS concentrations. This may be a signature of the release of reservoir water into lower Maggie Creek, or of incision and discharge large enough to contact gully banks above hydrophilic riparian vegetation. Below 50 cfs (approximately 90% of all flows), there is little to no relationship between TSS and stream flow Q.

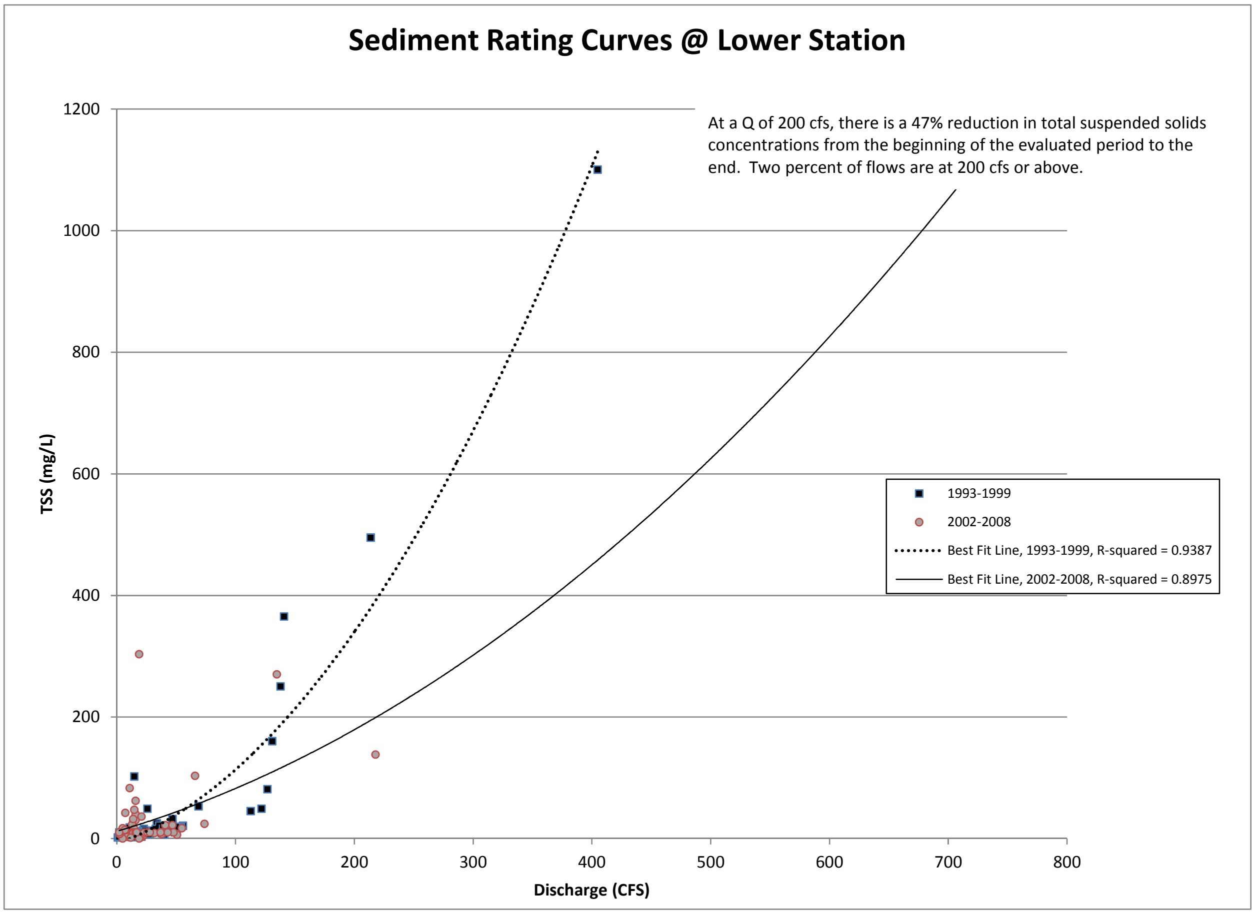


Figure 19. Sediment Rating Curves at Lower Station, Maggie Creek, NV.

The rating curves developed in Figures 17 and 19 used the limited data available to this study. Figure 20 depicts rating curves established using a substantially larger data set collected by Newmont. The figure illustrates the need for large data sets to make simple, more accurate yearly comparisons. Note that the 2005 curve is highly influenced by only a couple of data points representing higher flows.

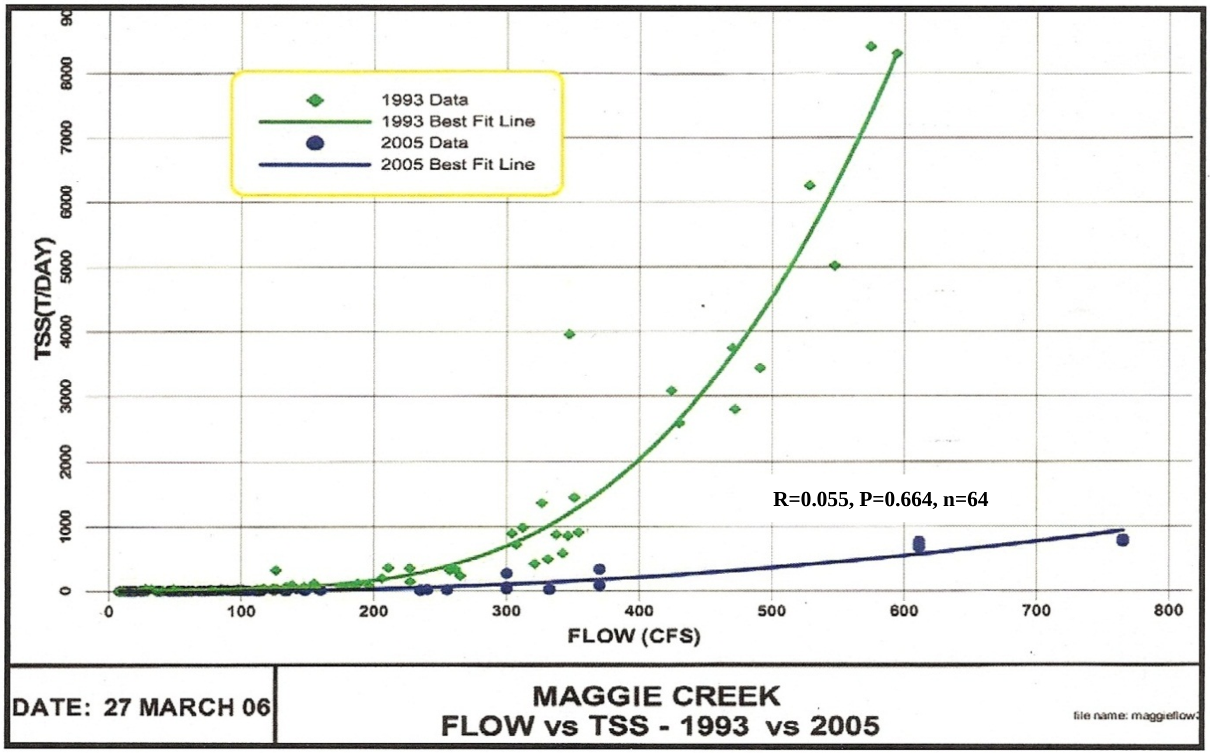


Figure 20. Rating Curves Developed by Newmont to Illustrate TSS Reductions through Time (from Simons et. al. 2009), Maggie Creek, NV.

Orthophosphate Phosphorus (OP-P)

Dissolved OP-P values for all stations ranged from 0 to 1.6 mg/L with an average value of 0.13 mg/L (Figure 21). The median value was 0.1 mg/L and the mode was 0 mg/L. The recommended maximum level for rivers and streams is 0.1 mg/L (USEPA, 1986). Prior to management change, the trend in OP-P concentration was influenced by the March, 1993 runoff event (Figure 21). After the change in grazing management, OP-P tended to decrease (R^2 = 0.30). No data were available at the upper station beyond 1999.

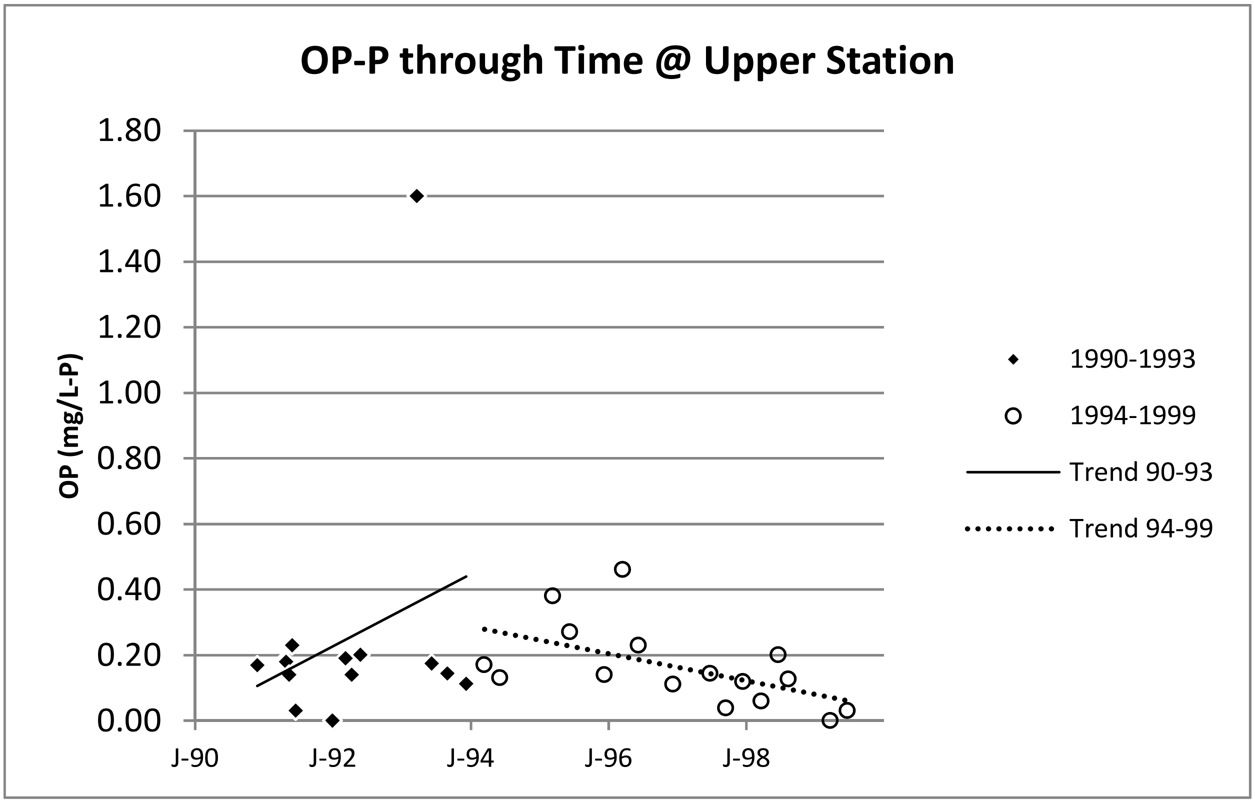


Figure 21. OP-P Trend at Upper Station, Maggie Creek, NV, Pre- and Post-Management Change.

The average value of OP-P (mg/L) from 1990-1993 was 0.25 compared to 0.14 from 1996-1999, a 44% reduction in concentrations (p = 0.18). The median value of OP-P during those same periods were 0.17 and 0.12 mg/L respectively, a 31% reduction (p = 0.14).

OP-P has a relationship with TSS and discharge (Q), as seen in Figure 22. TSS and Q were strongly related (Figure 17), especially at higher flows. Therefore, an OP-P discharge rating curve (Figure 23) was developed using beginning and middle periods of the study (OP-P data from the upper station are not available after 1999). There was a downward shift of the models, indicating OP-P becoming less concentrated at higher flows between the two time periods. At a discharge of 200 cfs, there is a modeled 66% reduction in OP-P concentrations between the two periods. Flows greater than 216 cfs did not occur during the middle time period.

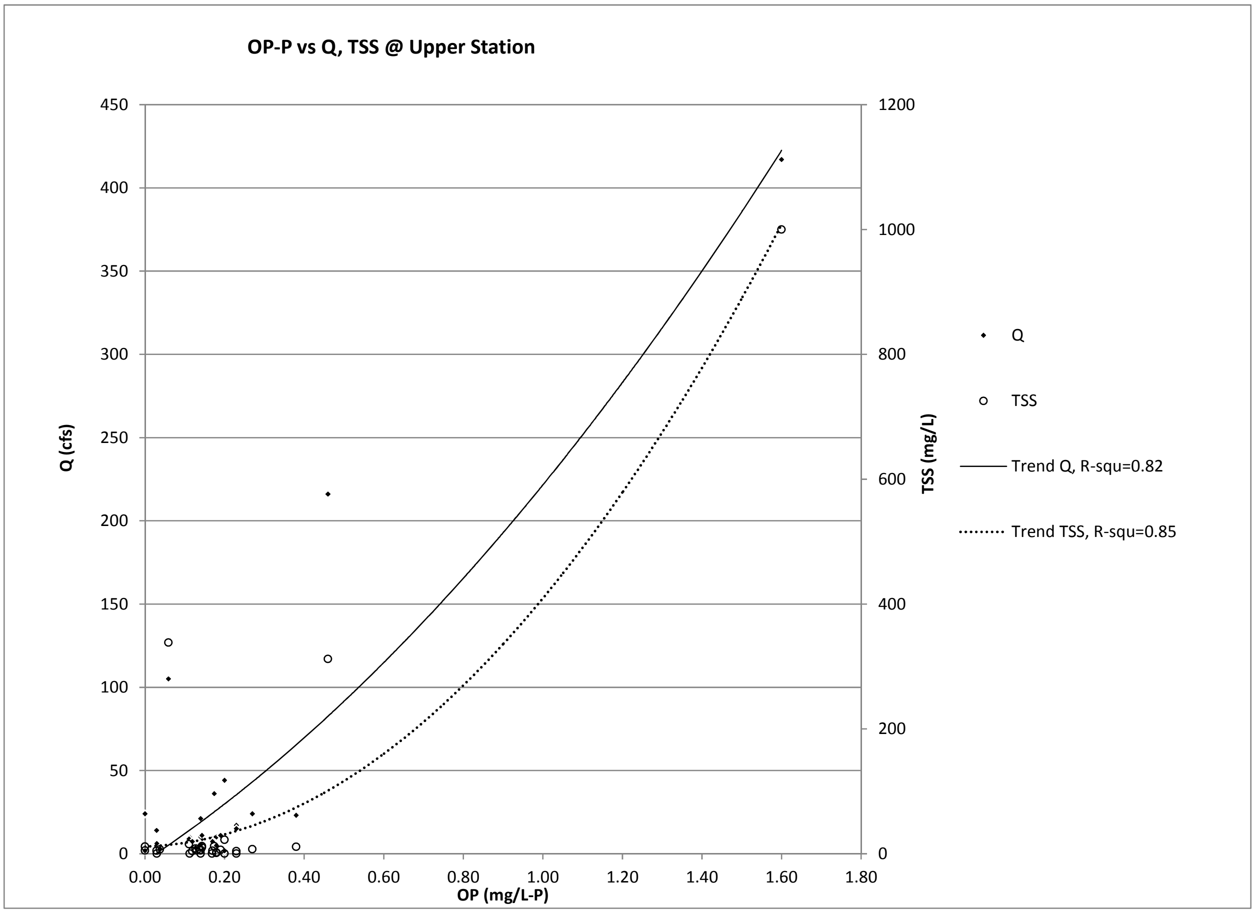


Figure 22. OP-P vs. Discharge and TSS at Upper Station, Maggie Creek, NV.

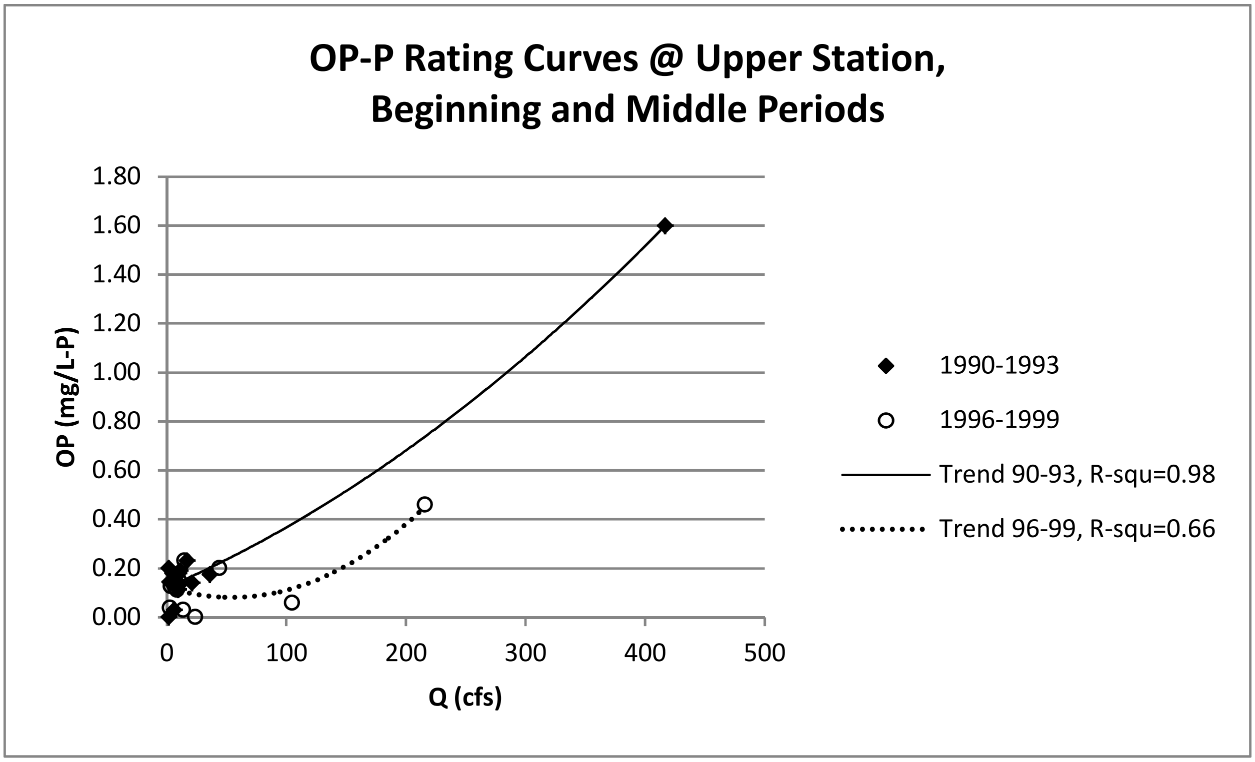


Figure 23. OP-P Rating Curves at Upper Station, Maggie Creek, NV, for Beginning and Middle Periods of the Study.

Both pre- and post-management change time periods exhibit declining trends in OP-P concentrations and are not appreciably different (Figure 24). OP-P concentrations for beginning (1990-1993, R^2 = 0.011) and ending (2003-2006, R^2 = 0.005) time periods were compared. At the lower stations, the mean value of 0.147 for the earlier time period was significantly higher than the later period value of 0.055 ($p = 0.009$), indicating this location experienced a 63% reduction in mean phosphorus concentrations over time. Comparison of median concentration values demonstrates a 93% reduction ($p = 0.002$). This could be related to dilution from groundwater/reservoir additions.

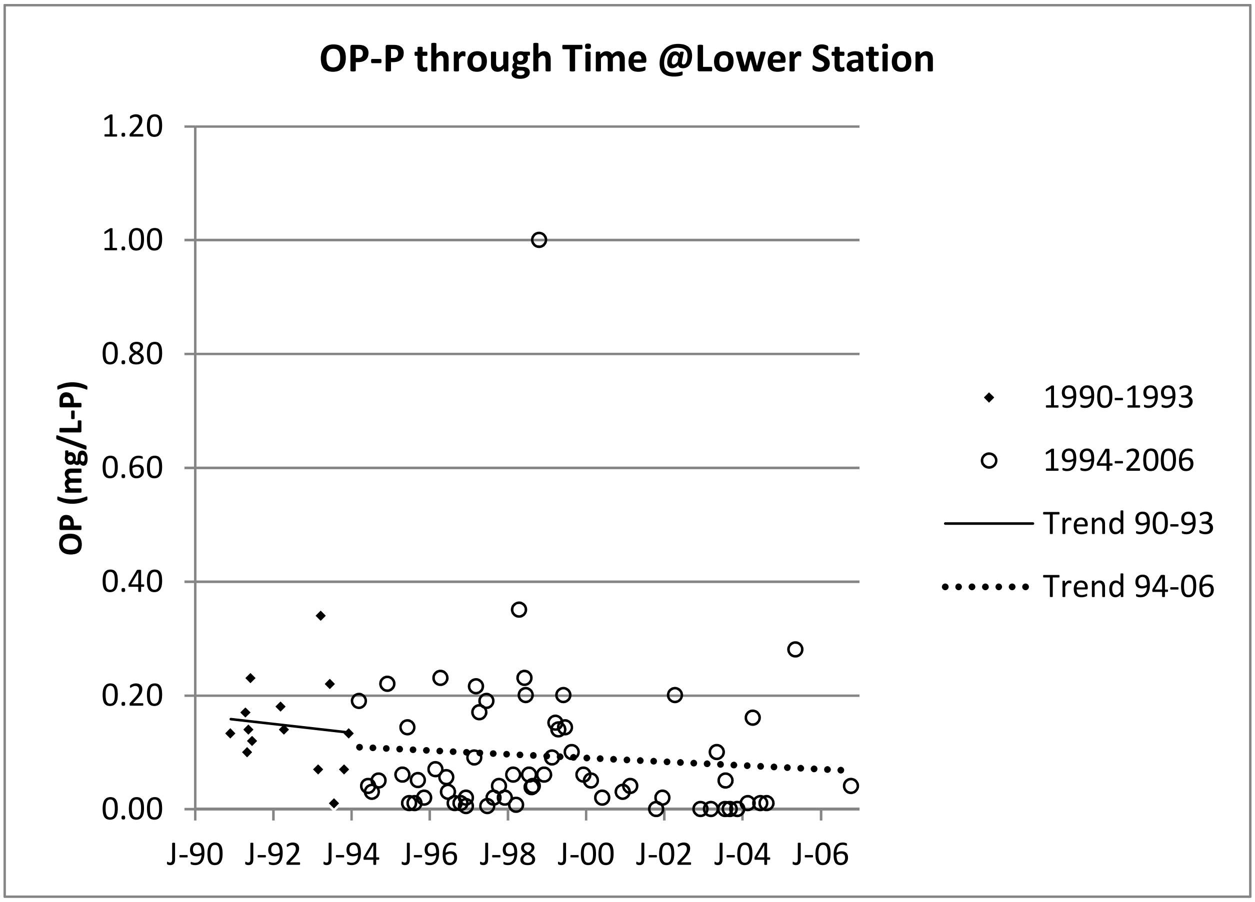


Figure 24. OP-P Concentration Trends for Two Periods at the Lower Station, Maggie Creek, NV.

A downward shift of the OP-P rating curve models for the lower station (Figure 25) indicates OP-P becoming less concentrated at higher flows between the two time periods. At a discharge of 200 cfs, there is a modeled 45% reduction in OP-P concentrations between the two periods. However, both models are heavily influenced by one large event. In the early time period (1990-1993), prior to flow augmentations from the reservoir, the upper station had 1.26 times the median phosphorus concentrations of the lower station ($p = 0.179$). After this period (1994-1999), the upper station had about 2.25 times the median OP-P concentration ($p = 0.034$), suggesting augmentation from reservoir releases may have been diluting phosphorous concentrations by almost 80% during that time period.

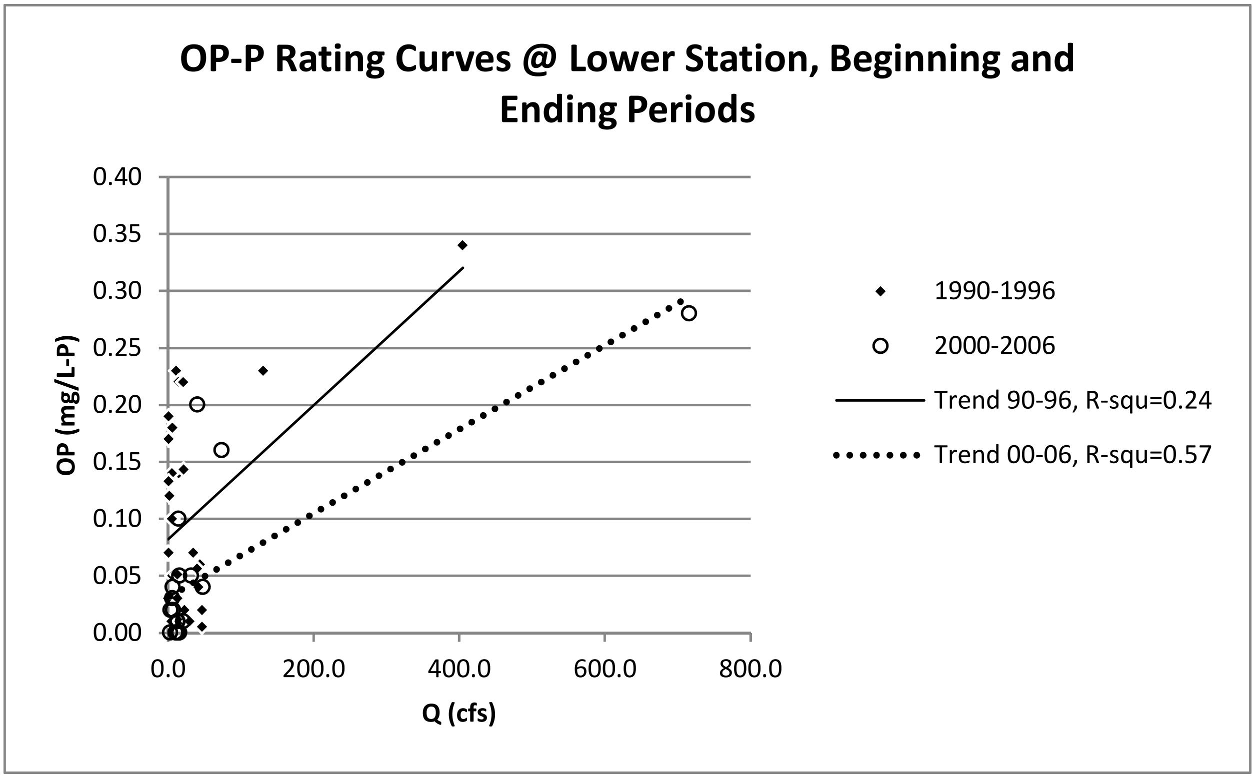


Figure 25. OP-P Rating Curves Displaying Lowering Trends at the Lower Station, Maggie Creek, NV.

Over two year time intervals, there was a steady decline in OP-P concentrations at the upper station and a general decline at the lower station with the exception of a spike in 1998/99 (Figure 26). This spike is not exhibited at the upper station. OP-P concentrations are generally declining at both locations while discharge is generally increasing (more obvious at the upper station), despite the positive relationship between discharge and OP demonstrated in Figure 22. The variance of OP-P values between the 1990-93 and the 2003-06 periods are the same.

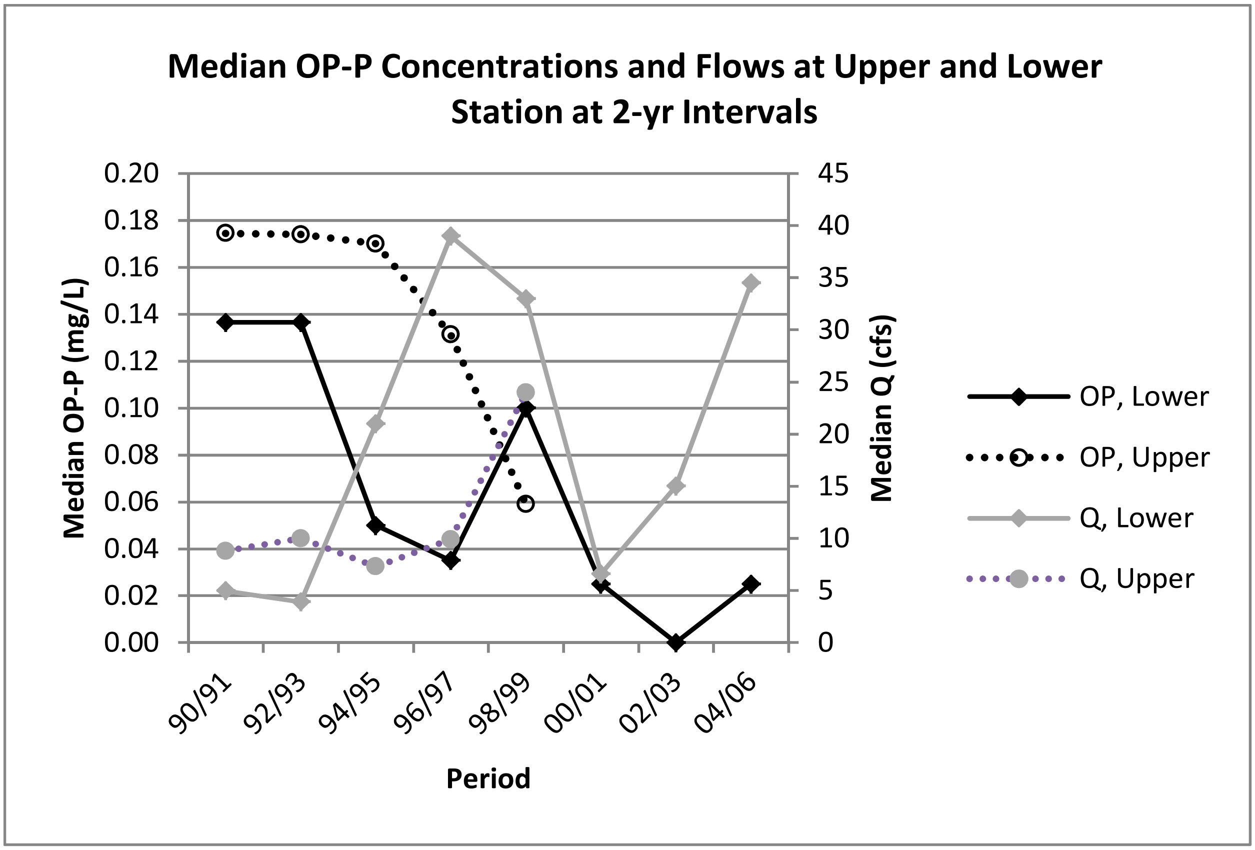


Figure 26. Median OP-P Concentrations and Flows at Upper and Lower Stations, Maggie Creek, NV, Based on Two-year Intervals.

Nitrogen: Total (TN), Total Kjeldahl (TKN), and Nitrate + Nitrite (NOx)

Prior to 1994, the trend of both TN and NOx was sharply increasing at the lower station (R^2 = 0.31 and 0.28, respectively) (Figure 27), representing a drought period that preceded a wet 1993. TKN is increased (R^2 = 0.01) at a slower rate. After grazing management changes in 1994, all nitrogen levels continued to increase, but all at moderate to slower rates. During the post-management change, NOx was a much smaller component of TN than before. Through time TKN contributes less, but still made up the majority of TN throughout the entire post-management change period. The average value of NOx-N prior to management change (1990-1993) was 0.25 mg/L, nearly 6.5 times the average between the years 2003-2006 (p = 0.067).

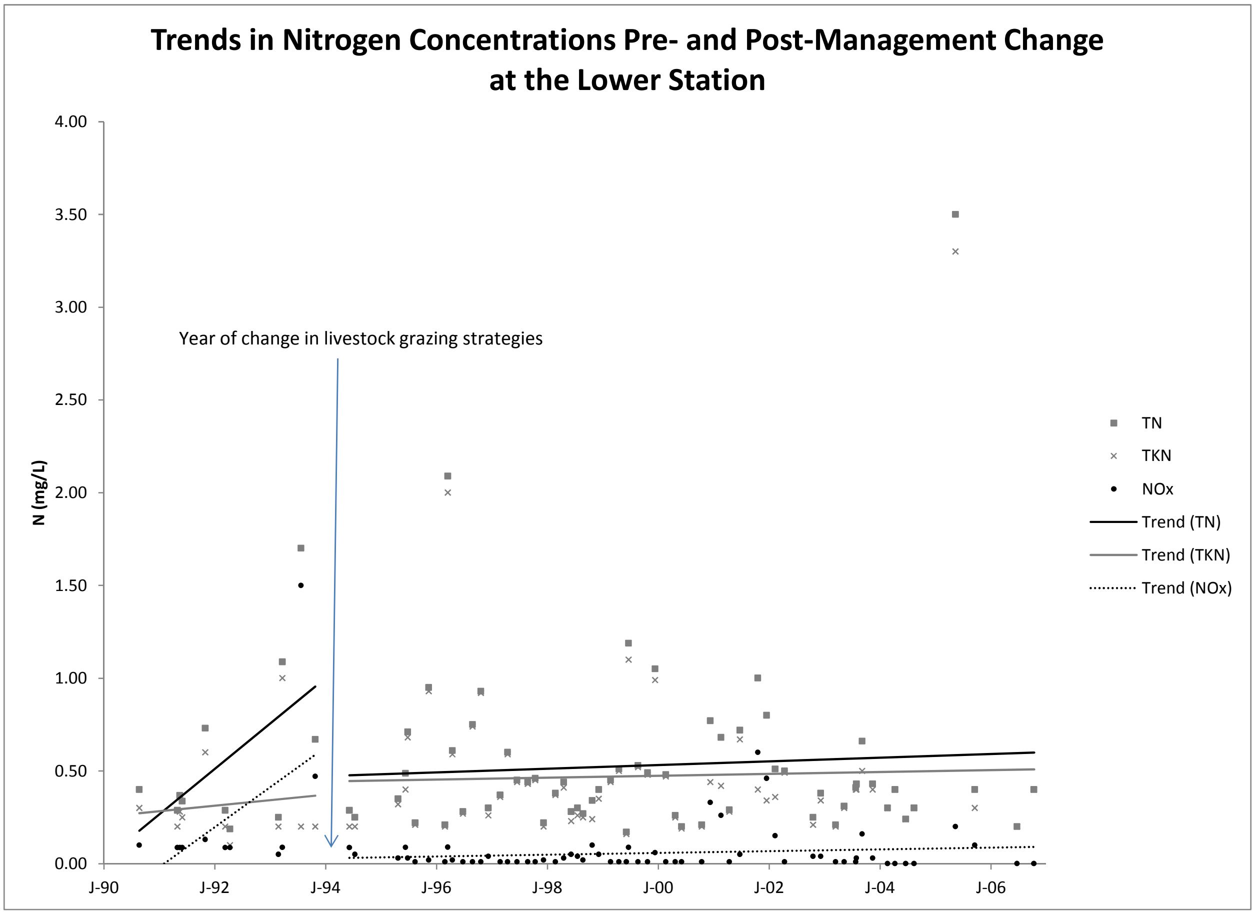


Figure 27. Nitrogen Concentration Trends at the Lower Station, Maggie Creek, NV.

Nitrogen data for the upper station is limited, consisting primarily of TKN data from 1991 through 1997 (n = 8, all $R^2 < 0.11$). Figure 28 shows these data compared to the lower stations for the same period and shows the upper station had slightly lower TKN concentrations compared to the lower station prior to management change ($p = 0.02$), but had higher concentrations post-change ($p = 0.19$). The figure also demonstrates the continued increasing trend in concentrations as seen at the lower station.

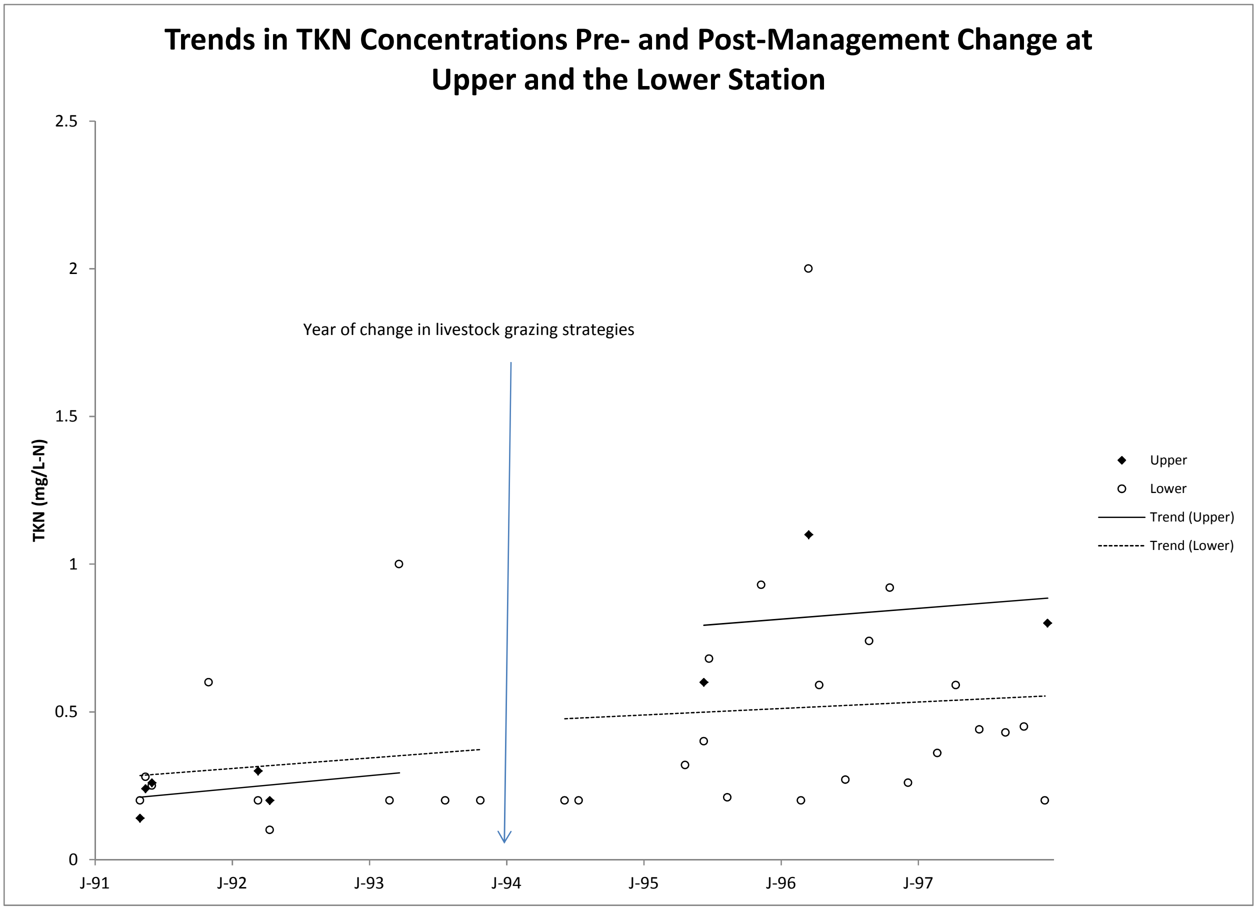


Figure 28. TKN Concentration Trends at Upper and Lower Stations, Maggie Creek, NV.

Dissolved Oxygen (DO)

The concentration of DO over time at the lower station (Figure 29) shows an increasing trend pre-management change ($R^2 = 0.32$) and a slightly declining trend post management ($R^2 = 0.00$). However, the increase in the pre-management change period was primarily caused by low levels in the dry summer of 1991. The average value for the years 1990-1993 was 8.5 while the average value for 2003-2006 was 9.5, indicating an insignificant ($p = 0.152$) increase of DO levels through the study period.

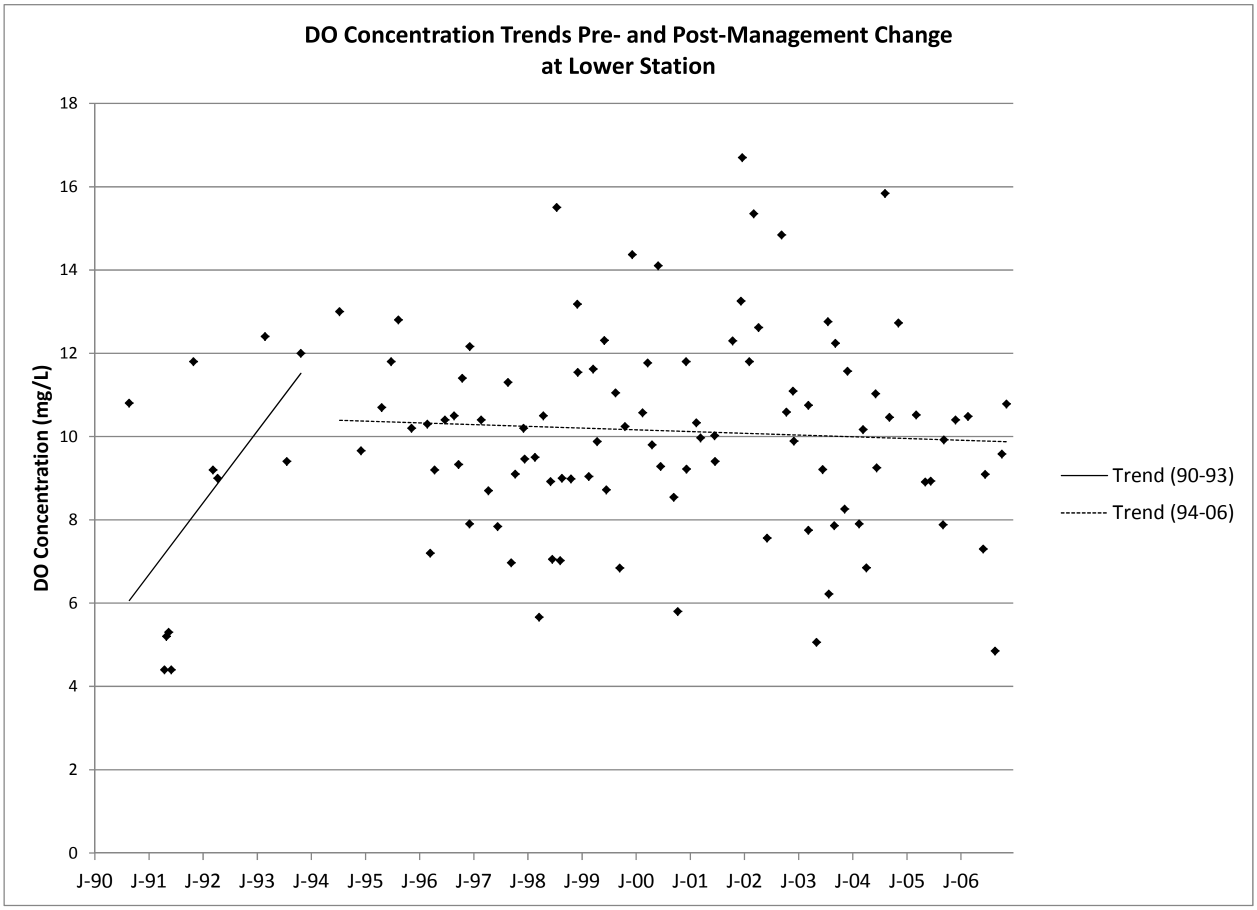


Figure 29. DO Concentration Trend at Lower Station, Maggie Creek, NV, Pre- and Post-Management Change.

The DO concentration over time at the upper station (Figure 30) increased during both pre- and post-management change. However the increase in the pre-management change period was primarily caused by low levels in the dry summer of 1991. The average value for the years 1990-1993 was 6.9 mg/L while the average value for 2003-2006 was significantly higher (p = 0.030) at 9.7 mg/L.

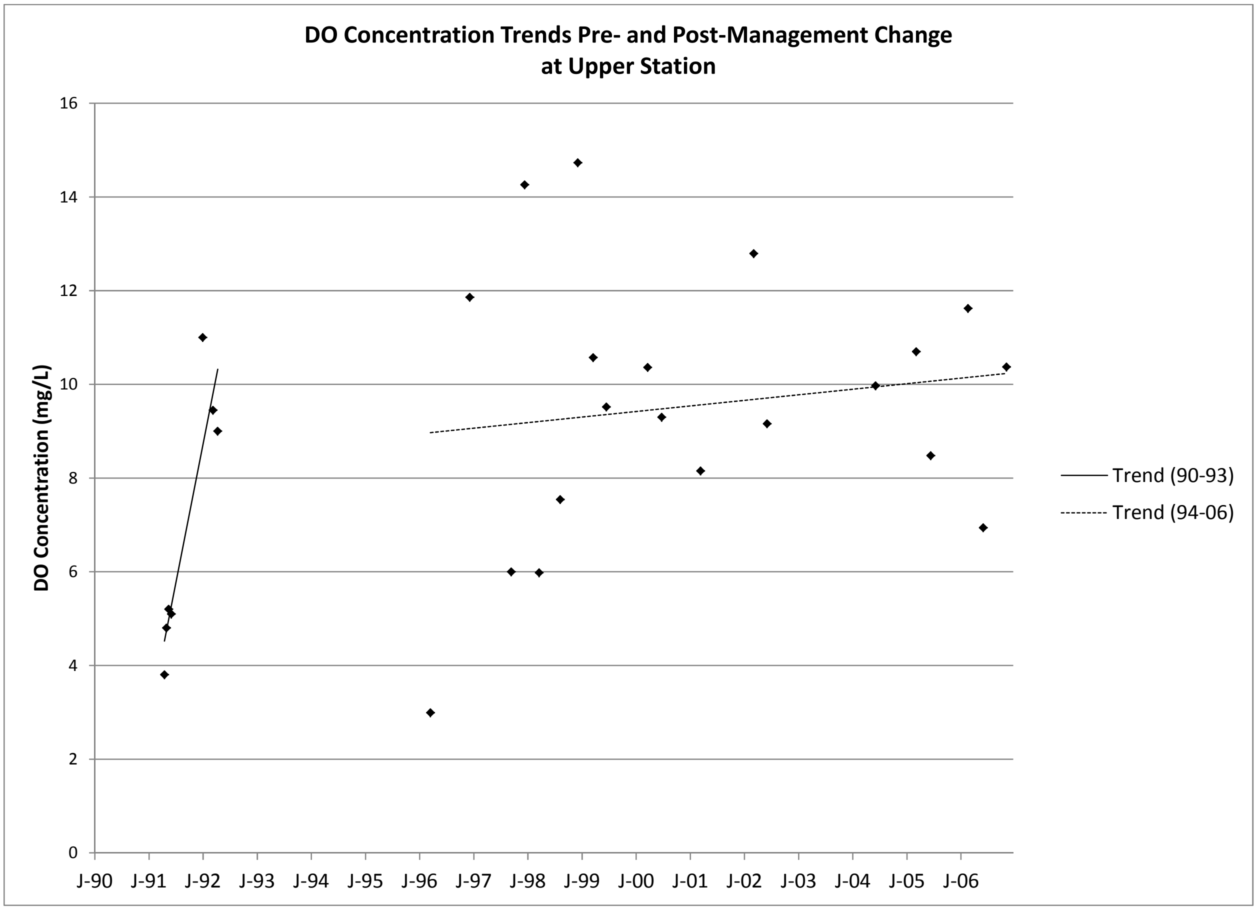


Figure 30. DO Concentration Trend at the Upper Station, Maggie Creek, NV, Pre- and Post-Management Change.

Water Temperature

The yearly average air temperature recorded at Elko, NV for the period of study displays a trend of increasing temperature ($R^2 = 0.27$) that appears to be heavily influenced by one early low (1993) and three later high readings in 2001, 2003, and 2006 (Figure 31).

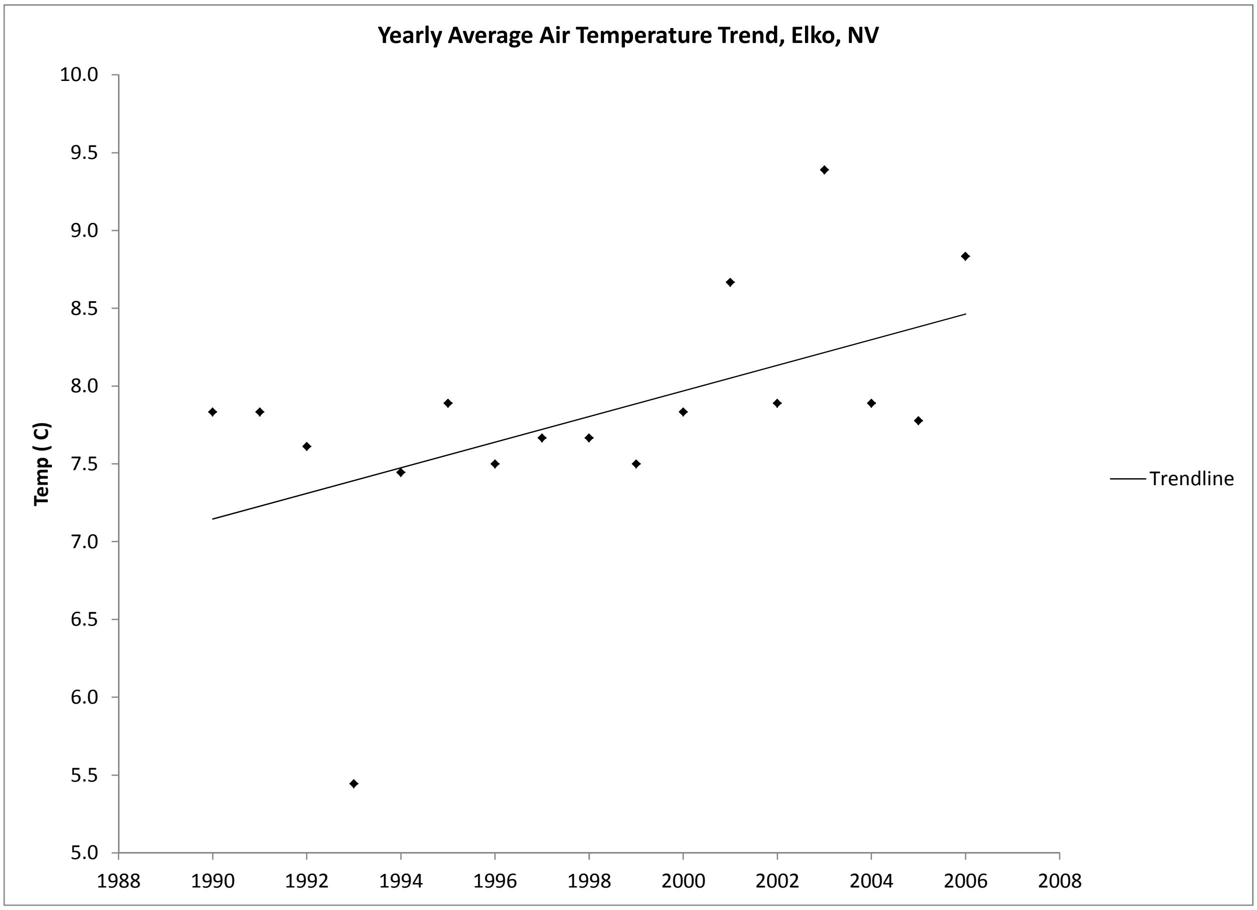


Figure 31. Yearly Average Air Temperature Trend at Elko, NV, 1990 - 2006.

Water temperature measurement at the upper station was very limited. In some cases the yearly average was based on one or two measurements. At the lower station, increasing water temperature (R^2 = 0.02) (Figure 32) reflects increasing air temperatures at Elko, while the upper station temperature increased more quickly (R^2 = 0.12). The average water temperature at the lower station averaged about 2.2° C higher than at the upper station for all data collected during the study period (p = 0.053).

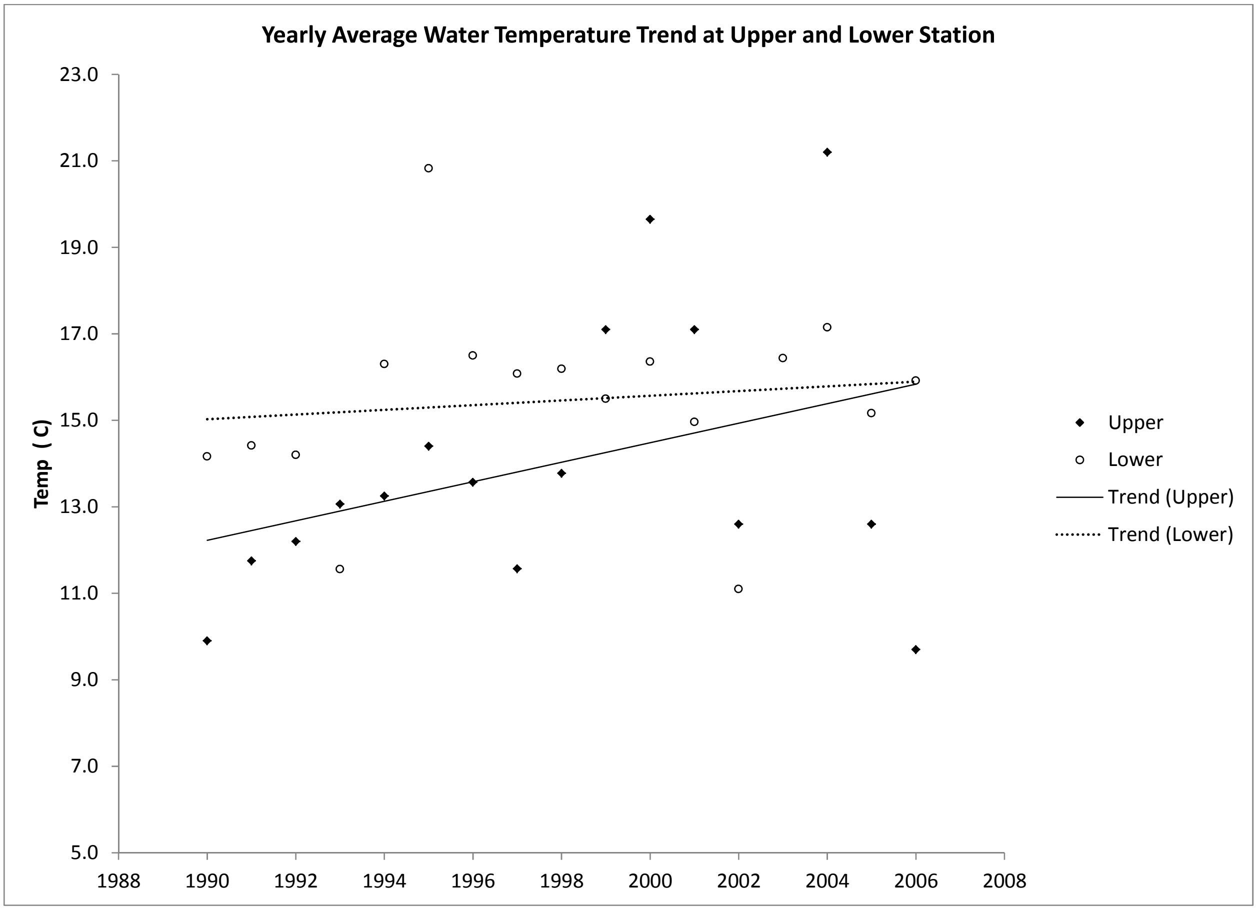


Figure 32. Yearly Average Water Temperature Trend at Upper and Lower Stations, Maggie Creek, NV.

Discussion

Figure 16 does not show a water quality issue related to TSS, yet occasionally TSS is high presumably during very high flow events. These events may indicate the ability of the stream to handle big events and maintain its functions. The water quality standards approach is not likely to address the more important question of whether TSS or sediment in general is related to what motivates water quality standards. For fish habitat, for example, spawning gravels can become clogged and the complexity of the aquatic food web can be diminished if habitat becomes less diverse and complex due to the force of big events when not dissipated and to the physical effects of sediment in altering habitats.

With no negative answers for “upland watershed contributing to riparian degradation” (attribute 5), it is clear that sources of sediment and pollutants are primarily the riparian ecosystem itself rather than external sources. Of the functional groups of attributes (hydrologic, vegetation, and soils) evaluated in a PFC assessment, the vegetation group responds most quickly to and is most immediately affected by management change. While each functional group is intertwined with the others (a functionality triangle or the "three-legged stool concept"), a functional vegetation community is crucial for riparian repair and maintenance. The vegetation response due to the change in grazing strategy on Maggie Creek during the time of this study has been addressed by Simonds et al. (2009). Some of their key findings include:

- Substantial recovery of riparian vegetation as a consequence of changes in livestock management.
- 138% increase in riparian vegetation acreage within all prescribed grazing pastures, 1994 vs. 2006 via (CIR) analysis.
- 114% increase in riparian vegetation acreage of Maggie Creek Watershed Restoration Project (MCWRP) reaches, 1994 vs. 2006 (CIR).
- Riparian recovery leading to elevated and more stable water tables.
- Well data in relation to precipitation, elevation, stream order, grazing use, and changes in riparian vegetation data suggest increased well elevations are correlated with increased vegetation beyond ambient influences.
- Percent of riparian vegetation in relation to the potential riparian area on Beaver Creek riparian pasture increased from 34% in 2001 to 85% in 2006 (Landsat analysis).

Other geomorphic features related to PFC and aquatic habitats have been measured/evaluated by Simonds et al. (2009) and Evans (2009) including:

- 54% decrease in water acreage of MCWRP reaches, 1994 vs. 2006, CIR analysis (indication of narrowing channels, especially in light of the following…).
- 7% increase in stream length of MCWRP reaches, 1994 vs. 2006, CIR analysis (indication of increased sinuosity, which aids in energy dissipation and increased water storage capacity).
- 54% decrease in gravel acreage of MCWRP reaches, 1994 vs. 2006, CIR analysis.
- Stream width to depth ratios decreased in all important LCT reaches monitored (1994 or 1996 to 2006).
- Woody riparian vegetation overhang generally tends toward increasing over time, but 2006 shows a decline likely due to the smothering by gravels from the 2006 flooding.
- Average number of quality pools has increased, with data starting from 1996. Quality pools are deeper and have more fish hiding cover.
- Limited hydrophytic plant cover data collected in 2006 by BLM and photos appear to support a wetter system than before.
- Streams generally show an improvement in PFC with the exception of the Lower Simon Creek Parcel (grazing practices questioned) and areas impacted by 2006 flooding.
- While 2006 flooding may have reduced the functionality ratings, riparian characteristics were effective at dissipating energy and capturing sediment, indicating that the riparian zone was functioning during a high flow event to maintain functions.
- Comparisons to survey data prior to 1994 indicate that riparian conditions have increased dramatically, with a substantial increase in riparian condition class, decrease in width to depth ratios, and increase in percent pool quality.

- Beaver activity has increased substantially, creating high quality pool habitat, especially in Maggie Creek.

These findings are consistent with and expected by the PFC assessments of this study. Two hydrologic, four vegetation, and two soil PFC attributes were found to have improved in over 10% of stream miles assessed, contributing to an overall improvement in the functional ratings of the reaches. These improvements lead to the general hypothesis that all water quality parameters examined would show an improving trend, especially at the upper station. The only attribute that declined over total stream miles (by less than 10%) was attribute 17 (stream is in balance with the water and sediment being supplied by the watershed). This was due to the excessive gravel loads that were moved during the 2006 floods. These gravels suggest that all reaches in the watershed and item 5 (upland watershed contributing to riparian degradation) may be relevant to functionality, even if reaches isolated by downstream ephemeral reaches are not relevant to water quality at monitoring stations.

Improved base flows (i.e., higher flows, increased duration) were predicted. Improvement was the case for the lower station, but may not have been for the upper station. As mentioned in the results, this may be due to mine dewatering activities that were in proximity to the upper station that discharged mine water back into Maggie Creek between the two stations. Baseflow is also influenced by the cycle of above average and below average precipitation, which occurred during the time period of this study. Furthermore, various water diversions in both the mid and lower watershed confound flow and groundwater recharge dynamics, making it difficult to determine if improvements were realized even without mine dewatering. A more detailed hydrologic study focused on the mid-basin where land management changes were implemented is needed to answer base flow questions; however, Simonds et al. (2009) did find evidence of increased well water elevations which, if sufficient, might help enhance future base-flow conditions.

Reductions in TSS were predicted and realized. Sediment rating curves for both stations indicated similar reductions in sediment transport, while it was hypothesized the lower stations should have less reduction. Simonds et al. (2009) cite a 2005 Newmont report that used an independent data set to determine a 10-fold decrease in sediment loads on Maggie Creek between 1993 and 2005 (Figure 20), although the specific location of data collection is unclear in the Newmont report. Other water quality issues are related to sediment (e.g., nutrients), and sediment is itself a chief pollutant of concern. There were no known upland land management changes which would have changed sediment delivery to the stream system. In fact, three fires occurred within the watershed during the period of this study. Bare, unstable banks persisted prior to the study. They became vegetated with enough of the appropriate riparian plant communities to not only reduce sediment delivery from bank erosion, but to effectively filter any fire induced sediment. This is a strong case for managing toward proper functioning condition.

Reductions in nutrients (P and N) were predicted. The results for this hypothesis were somewhat mixed, which is not surprising given the complex dynamics of nutrient cycling. It is expected that as plant communities expanded, nutrients would be taken up to meet growth needs and be filtered/processed by the expanded riparian width. It is also anticipated that litter material would become a source of nutrients eventually. However, it is thought the pace of uptake will be high enough to offset decomposition during this period of increasing riparian biomass and complexity.

Phosphorus, being highly associated with sediment, was expected to decline. This was the case for OP-P at both stations. Reductions in concentrations were found to be greater at the lower stations. Flow augmentations from the reservoir were likely diluting OP-P concentrations at the lower station, confounding hypothesis testing. Phosphorus release is expected during reducing conditions, which the majority of this system was clearly not experiencing during this time. Increased water oxygen levels coupled with increasing nitrate levels (addressed below) supports the assumption that Maggie Creek system was not dominated by a reducing environment. As the riparian systems continue to expand, a more reducing environment may eventually dominate. However, such an environment engages more effective sediment deposition on floodplains and more plant growth with nutrient uptake.

Phosphorus appeared to be effectively trapped and taken up by the riparian community during the time of this study. Total phosphorus is a nutrient of concern on Maggie Creek, being listed on the 2006 303(d) list as having a low TMDL priority. Continued decline in phosphorus could lead to delisting due to improved riparian functionality.

Nitrogen data are limited at the upper station, with only a few TKN values over a short time span to compare to the lower station. These data demonstrate comparably lower TKN concentrations prior to management change with indication of increasing trends. Post-management change saw continued increasing trends, but a considerable increase in concentration at the upper station. This is likely the result of increased organic litter accumulation due to increased riparian plant communities just upstream from the upper station.

The lower station had more nitrogen data than the upper station. Prior to management changes, TN was on a sharply increasing trend, driven mostly by increases in NOx in 1993. NOx may accumulate during drought and then be flushed in high water flows, especially if the flows come from uplands and precede the growing season. TKN is relatively low and barely exhibits an increasing trend. This indicates possible nitrogen sources other than vegetation. After management change, trend of all nitrogen forms leveled to slightly increasing, with the bulk of TN made up of TKN at the beginning. As the trend continues, TKN still makes the majority of TN, but progressively gives way to greater concentrations of NOx. This suggests that plant matter became the primary source of nitrogen in the system, perhaps from beaver feeding and their waste products along with accumulating organic nitrogen from leaf litter was gradually starting to convert to nitrate/nitrite especially in more oxygenated conditions upstream. If functionality increases and anoxic conditions prevail, nitrogen will be sequestered in the riparian zone. A fluctuating high water table with available organic material (e.g., from roots) facilitates denitrification.

Dissolved Oxygen (DO) was predicted to increase. This was the case for the overall data and upper station. At both the upper and lower stations, pre-management change trends were rapidly increasing due to very low DO levels recorded in 1991. The post-management period demonstrated an increasing trend at the upper station, a decreasing trend for the lower station, though both rates are much less radical than pre-management. That the lower station was trending down is not surprising. Any oxygen gains realized in the upper reaches would surely be diminished by the poorly functioning lower riparian reaches coupled with the augmentation of warm, relatively oxygen-poor reservoir water.

Water temperature was predicted to decrease. Water temperature is highly variable in general, fluctuating on a diel and seasonal basis, as well as being affected by variations in local shading, channel morphology, and ground water-surface water or hyporheic interactions. It is therefore unrealistic to expect meaningful trends in water temperature data collected at most once every four months (the upper station was not collected nearly as often) at a location that is outside the influence of management change. The results of yearly average air and water temperature comparisons shows the lower station exhibited an increasing water temperature trend not too unlike that of the air with just a slightly lower slope. This would be expected as water from the reservoir is fully exposed to the atmosphere (Smith and Lavis (1975). Crisp and Howson (1982) and Mackey and Berrie (1991) showed that surface water temperature is closely related to air temperatures across a range of catchment types and sizes, but water has a higher thermal capacity. Trend for the upper station demonstrated a markedly increased trend toward warmer temperatures, but variance between the later years was high due to missing quarterly data. In summary, little can be determined about the water temperature trend within the managed area with the data available.

Conclusion

Rather than implement a sampling design tailored to address the specific hypotheses (realized to be an excessively expensive approach), this retrospective study was based on currently available data, which limited the ability to sufficiently address hypothesis questions. To address this challenge, we sought and used a watershed with (relatively) extensive and intensive data, far more than generally available to managers of land and water quality.

Even though water quality data for this watershed were dense in comparison to other watersheds for which the study questions could be asked, they were inadequate. The sediment rating curves suggested a difference between before and after the change in management, but the change in slope was based on four points. One point was near the origin of the graph and represented base flow conditions. The other three points represented higher flows that were great enough to transport sediment (two before and one after). Many other graphs and statistical relationships (e.g., nitrogen and phosphorous especially, Figs. 21-28) appeared to be driven by special data points representing high or low flows. Because the Nevada Division of Environmental Protection protocol states that data from floods and droughts should not be used to evaluate whether water quality standards are being met these special conditions are deemed inappropriate for basing impairment decisions. Therefore, one is left to use average flow data even though these conditions may not be critical for the beneficial use. It is during drought and seasonal low flows when fish populations generally suffer.

Interestingly, during dry periods riparian vegetation can help a stream recover by growing toward the remaining water. Subsequently, in wetter periods, vegetation is available to capture sediment, build banks, and narrow the channel width. Much stream habitat rebuilding occurs during floods if a stream has floodplain accessibility for energy dissipation and vegetation in place for stabilizing banks and providing resistance to scouring flows.

In the Maggie Creek Watershed, the stream flows through three or four sequences of channel incision and recovery through gully widening. This is probably the major source of sediment (and nutrients or pollutants) in a watershed without upland watershed conditions that lead to riparian degradation. Thus, TSS data do not provide useful information to address the very reasons why monitoring data are collected and used to manage water quality. Furthermore, these data are so expensive ($300-500 for lab fees plus labor and travel expenses to collect the sample per sampling event at one location), that they can be collected only at infrequent locations that represent large watersheds. This watershed contained almost one hundred reaches that were presumed to be relevant to these water quality data and hundreds more where water quality and aquatic habitats are important to organisms and important to people. Lahontan Cutthroat Trout (LCT) live in some of the tributary streams that were not addressed by this study because the intervening reaches were ephemeral. Yet this large watershed had water quality data from only two locations and only quarterly.

A far better approach to monitoring for water quality management is to monitor the drivers (leading indicators) rather than the lagging response indicator of water quality. The driving functions provide insight to the variables that should be the focus for monitoring and management. For water quality in rangeland or most other wildland aquatic habitats, riparian PFC focuses attention on those attributes useful for quantitative monitoring (see introduction). An example of using these functions for focused monitoring is packaged in the Multiple Indicator Monitoring protocol (Burton et al. 2011). This was developed to quantitatively monitor fish habitat and focuses most attention on the conditions of riparian vegetation as it relates to bank stability. To apply Multiple Indicator Monitoring or any other quantitative monitoring method, it is first important to identify functional-at-risk static or downward trending reaches where a management change is needed or has recently been implemented. The PFC items discussed above provide insight to needed changes and help set good objectives. Good objectives should be specific, measureable, achievable, related to management and riparian functions, and valued by stakeholders. Since riparian conditions often depend on vegetation and the riparian management that drives these changes, riparian and water quality concerns should often focus on measuring vegetation change (e.g., Winward 2000 or Burton et al. 2011).

References

Addiscott, T. 1997. *A critical review of the value of buffer zone environments as a pollution control tool*. In: Haycock, N., Burt, T., Goulding, K., and Pinay, G. (eds.). Buffer zones: their processes and potential in water protection. The Proceedings of the International Conference on Buffer zones, September 1996. Electronic version, Haycock Associated Limited, St. Albans, Hertfordshire, UK. 326 pp.

Andrews E. D. 1986. Downstream effects of Flaming Gorge Reservoir on the Green River, Colorado and Utah. Geological Society of America Bulletin 97:1012–1023

Barnes, J.R., and Minshall, G.W. [Eds.]. 1983. *Stream ecology: application and testing of general ecological theory*. Plenum Press, New York and London. 399 p.

Beschta, R.L. 1984. *TEIMP-85; A computer model for predicting stream temperatures resulting from the management of stream-side vegetation*. USDA Forest Service, Watershed Systems Development Group, Ft. Collins, Colorado. WSDG-AD-00009, 76 pp.

Bilotta, G. and Brazier, R. 2008. *Understanding the influence of suspended solids on water quality and aquatic biota*. Water Research, 42, 2849-2861.

Blackport, R., MacGregor, R., and Imhof, J. 1995. *An approach to the management of groundwater resources to protect and enhance fish habitat*. Canadian Manuscript Report of Fisheries and Aquatic Sciences, no. 2284.

BLM (Bureau of Land Management). 1993. *Final Environmental Impact Statement, Newmont Gold Company's South Operations Area Project.* Elko District, Elko, Nevada.   Internal report, including Appendix A, Mitigation Plan.

BLM (Bureau of Land Management). 2001. *Public land statistics 2000. Volume 185, BLM/BC/ST-01/001+1165.* (http://www.blm.gov/natacq/pls00/). Accessed April, 2011.

Braatne, J. H., S.B. Rood, L. A. Goater, and C. L. Blair. 2008. analyzing the impacts of dams on riparian ecosystems: a review of research strategies and their relevance to the snake river through Hells Canyon. Environmental Management 41:267–281

Broadfoot, W. and Williston, H. 1973. *Flooding effects on southern forests.* Journal of Forestry, 71, 584-587.

Brown, G. and Krygier, J. 1970. *Effects of clear-cutting on stream temperature.* Water Resources Research 6, 1133-1139.

Bryce, S.A., Woods, A.J., Morefield, J.D., Omernik, J.M., McKay, T.R., Bracklry, G.K., Hall, R.K., Higgins, D.K., McMorran, D.C., Vargas, K.E., Petersen, E.B., Zamudio, D.C., and Comstock, J.A. 2003. *Ecoregions of Nevada (color poster with map, descriptive text, summary tables, and photographs): Reston, VA.* US Geological Survey (map scale 1:1,350,000).

Burchsted, D., Daniels, M., Thorson, R., and Vokoun, J. 2010. *The river discontinuum: applying beaver modifications to baseline conditions for restoration for forested headwaters.* BiosScience, 60 (11), 908-922.

Burton, T., Smith, S., and Crowley, E. 2011. *Multiple indicator monitoring (MIM) of stream channels and streamside vegetation.* Bureau of Land Management, Technical Reference 1737-23. 155 pp.

Bush, J. and Van Auken, O. 1984. *Woody species composition of the upper San Antonio River gallery forest.* Texas Journal of Science, 36, 139-148.

Caissie, D. 1991. *The importance of groundwater to fish habitat: base flow characteristics for three Gulf Region Rivers.* Canadian Data Report of Fisheries and Aquatic Sciences, no. 814.

Castelle, A., Johnson, A., and Conolly, C. 1994. *Wetland and stream buffer size requirements.* Journal of Environmental Quality, 23(5), 878-882.

Clemmer, P. 1994 (Revised 2001). *Riparian area management: The use of aerial photography to manage riparian-wetland areas.* USDI BLM Technical Reference 1737-10, 55 pp.

Cooper, J., Gilliam, J., Daniels, R., and Robarge, W. 1987. *Riparian areas as filters for agricultural sediment.* Soil Science Society of America Journal, 51(2), 416-420.

Corenblit, D., A. C. W. Baas, G. Bornette, J. Darrozes, S. Delmotte, R. A. Francis, A. M. Gurnell, F. Julien, R. J. Naiman, and J. Steiger. 2011. Feedbacks between geomorphology and biota controlling Earth surface processes and landforms: A review of foundation concepts and current understandings. Earth-Science Reviews 106:307-331.

Corenblit, D., J. Steiger, A. M. Gurnell, E. Tabacchi, and L. Roques. 2009. Control of sediment dynamics by vegetation as a key function driving biogeomorphic succession within fluvial corridors. Earth Surface Processes and Landforms 34:1790-1810.

Corenblit, D., E. Tabacchi, J. Steiger, and A. M. Gurnell. 2007. Reciprocal interactions and adjustments between fluvial landforms and vegetation dynamics in river corridors: A review of complementary approaches. Earth-Science Reviews 84:56-86.

Correll, D., Jordan, T., and Weller, D. 1996. *Failure of agricultural riparian buffers to protect surface waters from groundwater contamination.* In: Gilbert, J. (Ed.) Groundwater-Surface Water Ecotones. Cambridge Univ. Press, London.

Correll, D. 1997. *Buffer zones and water quality protection: general principles.* In: Haycock, N., Burt, T., Goulding, K., and Pinay, G. (eds.). Buffer zones: their processes and potential in water protection. The Proceedings of the International Conference on Buffer zones, September 1996. Electronic version, Haycock Associated Limited, St. Albans, Hertfordshire, UK. 326 pp.

Correll, D., Jordan, T., and Weller, D. 2000. *Beaver pond biogeochemical effects in the Maryland coastal plain.* Biogeochemistry, 49(3), 217-239.

Crisp, D. and Howson, G. 1982. *Effect of air temperature upon mean water temperature in streams in the north Pennines and English Lake District.* Freshwater Biology, 12, 359-367.

Cunjak, R. and Power, G. 1986. *Winter habitat utilization by stream resident brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta).* Canadian Journal of Fisheries and Aquatic Sciences 43, 1970-1981.

Davies-Colley, R.J. 1997. *Stream channels are narrower in pasture than in forest, New Zealand Journal of Marine and Freshwater Research*, 31:5, 599-608.

Demmer, R. and Beschta, R. 2008. *Recent history (1988-2004) of beaver dams along Bridge Creek in central Oregon.* Northwest Science, 82:4, 309-318.

Dillaha III, T., and Inamdar, S. 1997. *Buffer zones as sediment traps or sources.* In: Haycock, N., Burt, T., Goulding, K., and Pinay, G. (eds.). *Buffer zones: their processes and potential in water protection. The Proceedings of the International Conference on Buffer zones,* September 1996. Electronic version, Haycock Associated Limited, St. Albans, Hertfordshire, UK. 326 pp.

Dunne, T. and Leopold, L.B. 1978. *Water in Environmental Planning.* Freeman, New York. 818 pp.

Evans, C. 2009. *Maggie Creek watershed restoration project 1993 south operations area project mitigation plan: 2006 monitoring summary and evaluation of biological standards.* Elko District, Bureau of Land Management. Internal report.

Freeze, R. and Cherry, J. 1979. *Groundwater.* Englewood Cliffs, New Jersey: Prentice-hall.

Gebhardt, K., Gohn, C., Jensen, S., and Platts, W.S. 1989. *Use of hydrology in riparian classification. In Practical Approaches to Riparian resource Management-An Educational Workshop.* Bureau of Land Management. Billings, MT. pp. 53-59.

Gebhardt, K., Leonard, S., Staidl, G., and Prichard, D. 1990. *Riparian area management: riparian and wetland classification review.* USDI BLM TR 1737-5. 56 pp.

Gilliam, J. 1994. *Riparian wetlands and water quality.* Journal of Environmental Quality, 23(5), 896-900.

Gilliam, J., Parsons, J., and Mikkelsen, R. 1997. *Nitrogen dynamics in buffer zones.* In: Haycock, N., Burt, T., Goulding, K., and Pinay, G. (eds.). *Buffer zones: their processes and potential in water protection. The Proceedings of the International Conference on Buffer zones,* September 1996. Electronic version, Haycock Associated Limited, St. Albans, Hertfordshire, UK. 326 pp.

Ghermandi, A., Vandenberghe, V., Benedetti, L., Bauwens, W., and Vanrolleghem, P. 2009. *Model-based assessment of shading effect by riparian vegetation on river water quality.* Ecological Engineering, 35, 92-104.

Girel, J. and Pautou, G. 1997. *The influence of sedimentation on vegetation structure.* In: Haycock, N., Burt, T., Goulding, K., and Pinay G. (eds.). *Buffer zones: their processes and potential in water protection. The Proceedings of the International Conference on Buffer zones, September 1996.* Electronic version, Haycock Associated Limited, St. Albans, Hertfordshire, UK. 326 pp.

Groffman, P., Axelrod, E., Lemunyon, J., and Sullivan, W. 1991. *Denitrification in grass and forest vegetated filter strips.* Journal of Environmental Quality, 20, 671-674.

Hare, L., Heggem D., Hall R., and Husby P. An Ecological Characterization and Landscape Assessment of the Humboldt River Basin. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-13/006, January, 2013.

Hare, L., Heggem D., Hall R., and Husby P. Ecological Condition of Streams in Northern Nevada EPA R-MAP Humboldt Basin Project. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-12/605, August, 2012.

Hall, R., Watkins, R., Heggem, D., Jones, B., Kaufmann, P., Moore, S., and Gregory, S., *Quantifying Structural Physical Habitat Attributes Using Lidar and Hyperspectral Imagery; Journal of Environmental Monitoring and Assessment*. Journal of Environmental Monitoring and Assessment, published online, January, 2009.

Haycock, N. and Burt, T. 1993. *Role of floodplain sediments in reducing the nitrate concentration of subsurface runoff: a case study in the Cotswolds, UK.* Hydrological Processes, 7, 287-295.

Haycock, N. and Pinay, G. 1993. *Groundwater nitrate dynamics in grass and poplar vegetated riparian buffer strips during the winter.* Journal of Environmental Quality, 22, 273-278.

Hill, A. 1997. *The potential role of riparian forests as buffer zones.* In: Haycock, N., Burt, T., Goulding, K., and Pinay, G. (eds.). *Buffer zones: their processes and potential in water protection. The Proceedings of the International Conference on Buffer Zones, September 1996.* Electronic version, Haycock Associated Limited, St. Albans, Hertfordshire, UK. 326 pp.

Homer, C., Dewitz, J., Coan, M., Hossain, N., Larson, C., Herold, N., McKerrow, A., VanDriel, J.N., and Wickham, J. (2007). *Completion of the 2001 National Land Cover Database for the Conterminous United States. Photogrammetric Engineering and Remote Sensing, Vol. 73, No. 4, pp 337-341.*

Hupp, C. and Osterkamp, W. 1985. *Bottomland vegetation distribution along Passage Creek, Virginia in relation to fluvial landforms*. Ecology, 66, 670-681.

Jensen, S., Ryel, R., and Platts, W. 1989. *Classification of riverine/riparian habitat and assessment of nonpoint source impacts, North Fork Humboldt River Nevada.* Report to USDA Forest Service, Intermountain Research Station. White Horse Associates, Smithfield, UT. 165 pp.

Jordan, T., Correll, D., and Weller, D. 1993. *Nutrient interception by a riparian forest receiving inputs from adjacent cropland.* Journal of Environmental Quality, 22:3, 467-473.

Kaushal, S., Groffman, P., Mayer, P., Striz, E., and Gold, A. 2008. *Effects of stream restoration on denitrification in an urbanizing watershed.* Ecological Applications, 18: 789–804.

Klotz, R. 2010. *Reduction of high nitrate concentrations in a central New York state stream impounded by beaver.* Northeastern Naturalist, 17:3, 349-356.

Kondolf, G.M. (1997) Hungry water: effects of dams and gravel mining on river channels. Environmental Management 21:533–551

Kormondy, E. 1969. *Concepts of ecology*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 209 pp.

Kozlowski, D. 2007. *Pre-fire functional condition and post-fire channel changes in northern Nevada streams: the 1999-2001 fires* [thesis]. Reno, NV, USA: University of Nevada. 180 pp.

Kozlowski, T. 1984. *Responses of woody plants to flooding. In: Kozlowski, T. (Ed.) Flooding and plant Growth.* Orlando, Academic Press. pp 129-163.

Lane, E. W. 1955. *The importance of fluvial morphology in hydraulic engineering.* American Society of Civil Engineering, Proceedings, 81, paper 745:1-17.

Leonard, S., Staidl, G., Fogg, J., Gebhardt, K., Hagenbuck, W., and Prichard, D. 1992. *Procedures for ecological site inventory – with special reference to riparian-wetland sites.* U.S. Department of the Interior Bureau of Land Management, Technical Reference 1737-7.

Leopold, L.B. 1994*. A view of the river. Harvard University Press, Cambridge, Massachusetts.* 298 pp.

Leopold, L. B., Wolman, M.G., and Miller, J. P., 1964. *Fluvial processes in geomorphology*. Freeman Co., San Francisco, California, 522 pp.

Lowrance et al. 1995. *Water quality functions of riparian forest buffer systems in the Chesapeake Bay watershed.* Report No. EPA 903-R-95-004. U.S. Environmental Protection Agency, Washington, D.C.

Mackey A. and Berrie, A. 1991. *The prediction of water temperatures in chalk streams from air temperatures*. Hydrobiologia, 210, 183-189.

Malcolm, I., Hannah, D., Donaghy, M., Soulsby, C., and Youngson, A. 2004. *The influence of riparian woodland on the spatial and temporal variability of stream water temperatures in an upland salmon stream.* Hydrology and Earth System Sciences, 8(3), 449-459.

Mander, U., Matt, O., and Nugin, U. 1991. *Perspectives on vegetated shoals, ponds and ditches as extensive outdoor systems of wastewater treatment in Estonia*. In: Etnier, C. and B. Guterstam (Eds.) Ecological engineering for wastewater treatment. Proceedings of the International Conference at Stensund Folk College, Sweden. pp. 271-282.

Mann, C.C. 2005. 1491 - *New Revelations of the Americas before Columbus*. Vintage Books of Random House, New York, 541 pp.

Manning, M., Swanson, S., Svejcar, T., and Trent, J. 1989. *Rooting characteristics of four intermountain meadow community types.* Journal of Range Management, 42(4), 309-312.

Manning, M.E. and Padgett, W.G. 1995. *Riparian community type classification for Humboldt and Toiyabe National Forests, Nevada, and Eastern California.* USDA Forest Service, Intermountain Region, R4-Ecol-95-01. 306 pp.

Maret, T., Parker, M., and Fannin, T. 1987. *The effect of beaver ponds on the nonpoint source water quality of a stream in southwestern Wyoming.* Water Resources, 21(3), 263-268.

Margolis, B., Castro, M., and Raesly, R. 2001. *The impact of beaver impoundments on the water chemistry of two Appalachian streams.* Canadian Journal of Fisheries and Aquatic Sciences, 58, 2271-2283.

Marti, E. and Sabater, F. 1996. *High varaiability in temporal and spatial nutrient retention in Mediterranean streams.* Ecology, 77(3), 854-869.

Mayer, P., Reynolds, S., McCutchen, M., and Canfield, T. 2005. *Riparian buffer width, vegetative cover, and nitrogen removal effectiveness: a review of current science and regulations.* Washington, DC: US Environmental Protection Agency. EPA/600/R-05/118.

Meador, M. and Goldstein, R. 2003. *Assessing water quality at large geographic scales: relations among land use, water physicochemistry, riparian condition, and fish community structure.* Environment Management, 31(4), 504-517.

Miller, J.R., House, K., Germanoski, D., Tausch, R.J., and Chambers, J.C. 2004. *Fluvial geomorphic responses to Holocene climate change.* In: Chambers, J.C. and J.R. Miller (Eds.), Great Basin riparian ecosystems: ecology, management, and restoration. Island Press, 1718 Connecticut Ave. NW, Suite 300, Washington, D.C., 20009, pp.49-87.

Montgomery, D. and Buffington, J.M., 1993. *Channel classification, prediction of response and assessment of channel condition.* Washington State Timber, Fish, and Wildlife TFW-SH10-93-002, 104 pp.

Myers, L. 1989. *Riparian area management: inventory and monitoring of riparian areas.* TR 1737-3. Bureau of Land Management, BLM/YA/PT-89/022+1737, Service Center, CO. 89 pp.

Naiman, R., Pinay, G., Johnston, C., and Pastor, J. 1994. *Beaver influences on the long-term biogeochemical characteristics of boreal forest drainage networks.* Ecology, 75(4), 905-921.

Osbourne, L. and Kovacic, D. 1993. *Riparian vegetated buffer strips in water quality restorations and stream management.* Freshwater Biology, 29, 243-258.

Parsons, J., Daniels, R., Gilliam, J., and Dillaha, T. 1994. *Reduction in sediment and chemical load in agricultural field runoff by vegetative filter strips.* Report No. UNC-WWRI-94-286, Water Resources Res. Inst., Raleigh, NC, 45 pp.

Pasternack, G., A. A. Fulton, and S. L. Morford. 2010. Yuba River analysis aims to aid spring-run chinook salmon habitat rehabilitation. California Agriculture April-June P. 69-77.

Peterjohn, W. and Correll, D. 1984. *Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest.* Ecology, 65, 1466-1475.

Peterjohn, W. and Correll, D. 1986. *The effect of riparian forest on the volume and chemical composition of baseflow in an agricultural watershed*. In: Correll, D. (Ed.), Watershed Research Perspectives, Smithsonian Press, Washington, D.C. pp. 244-262.

Power, G., Brown, R., and Imhof, J. 1999. *Groundwater and fish: insights from northern North America. Hydrological Processes,* 13, 401-422.

Prichard, D., Anderson, J., Correll, C., Fogg, J., Gebhardt, K., Krapf, R., Leonard, S., Mitchell, B., and Staats, J. 1998. *Riparian Area Management: A User Guide to Assessing Proper Functioning Condition and Supporting Science for Lotic Areas*. USDI BLM, USDA FS and NRCS Technical Reference 1737-15, 126 pp.

Prichard, D., Barrett, H., Cagney, J., Clark, R., Fogg, J., Gebhardt, K., Hansen, P.L., Mitchell, B., and Tippy, D. 1993 (and 1995*). Riparian Area Management: Process for Assessing Proper Functioning Condition.* USDI BLM, USDA FS and NRCS Technical Reference 1737-9, 52 pp.

Reed, P., Jr. 1988. *National list of plant species that occur in wetlands: intermountain (region 8).* Biological Report 88(26.8), USDI Fish and Wildlife Service, Fort Collins, CO. 76 pp.

Rosgen, D. 1996. *Applied River Morphology.* Wildland Hydrology, Pagosa Spings, CO.

Rosgen, D. 2006. *Watershed Assessment of River Stability and Sediment Supply (WARSSS).* Wildland hydrology, Ft. Collins, CO.

Schumm, S.A. 1979. *Geomorphic thresholds: the concept and its applications.* Transactions of the Institute of British Geographers, 4(4):485-515.

Schumm, S.A., Harvey, M.D., and Watson, C.C. 1984. *Incised channels: Morphology, dynamics and control.* Water Resources Publications, Littleton, CO.

Simonds, G., Ritchie, M., and Sant, E. 2009. *Evaluating riparian condition and trend in three large watersheds.* Open Range Consulting, http://www.openrangeconsulting.com/watershed/watershed_report.pdf. Accessed April, 2011.

Strahler, A.N. 1964. Geology Part II. *Quantitative Geomorphology of Drainage Basins and Channel Networks*. Section 4-II In: Chow (Ed in Chief), Handbook of Applied Hydrology McGraw-Hill, New York 4-39 to 4-76.

Sinokrot, B. and Stefan, H. 1993. *Stream temperature dynamics: measurements and modeling.* Water Resources Research, 29(7), 2299-2312.

Smith, C. 1989. *Riparian pasture retirement effects on sediment, phosphorus and nitrogen in channelized surface runoff from pastures.* New Zealand Journal of Marine and Freshwater Resources, 23, 139-146.

Smith, K. and Lavis, M. 1975. *Environmental influences on the temperature of a small upland stream*. Oikos, 26, 228-236.

State of Nevada. 2011. *Directory of Nevada Mine Operations, January-December, 2010.* Department of Business & Industry, Division of Industrial Relations (http://dirweb.state.nv.us.) Accessed March 16, 2012.

Sweeney, B., Bott, T., Jackson, J., Kaplan, L., Newbold, J., Standley, L., Hession, W., and Horwitz, R. 2004. *Riparian deforestation, stream narrowing, and loss of stream ecosystem services.* Proceedings of the National Academy of Sciences, 101(39), 14132-14137.

Tabacchi, E., Lambs, L., Guilloy, H., Planty-Tabacchi, A., Muller, E., and Decamps, H. 2000. *Impacts of riparian vegetation on hydrological processes.* Hydrological Processes, 14, 2959-2976.

Theurer, F., Voos, K., and Miller, W. 1984. *Instream water temperature model.* Instream Flow Information Paper 16, U.S. Fish and Wildlife Service, Washington, D.C.

USEPA. 1986. *Quality Criteria for Water*. U.S. Environmental Protection Agency, EPA#440/5-86-001.

USEPA. 1988. Dissolved Oxygen Water Quality Standards Criteria Summaries: *A Compilation of State/Federal Criteria*. EPA # 440/5-88-024, September.

USEPA. 2009. The National Water Quality Inventory: *Report to Congress for the 2004 Reporting Cycle, Office of Water*, EPA 841-F-08-003, January.

USEPA. 2012. FY 2013 EPA Budget in Brief. U*nited States Environmental Protection Agency, Office of the Chief Financial Officer (2710A), Publication Number*: EPA-190-S-12-001. February 2012.

USFS. 1992. *Integrated riparian evaluation guide-Intermountain Region.* USDA Forest Service, Intermountain Region, Ogden, UT. 199 pp.

USGS. 2012. The United States Department of the Interior Budget Justification and Performance Information, FY 2013, U.S. Geological Society. http://www.usgs.gov/budget/2013/greenbook/FY_2013_USGS.pdf. Accessed April 5, 2012.

Uusi-Kamppa, J. and Ylaranta, T. 1996. *Effect of buffer strips on controlling soil erosion and nutrient losses in southern Finland.* In: Mulamoottil, G., B. Warner, and E. McBean (Eds.) Wetlands: environmental gradients, boundaries, and buffers. New York, CRC, Lewis Pubishers. pp. 221-235.

Uusi-Kamppa, J., Turtula, E., Hartikainen, H., and Ylaranta, T. 1997. *The interactions of buffer zones and phosphorus runoff.* In: Haycock, N., Burt, T., Goulding, K., and Pinay, G. (eds.). Buffer zones: their processes and potential in water protection. The Proceedings of the International Conference on Buffer zones, September 1996. Electronic version, Haycock Associated Limited, St. Albans, Hertfordshire, UK. 326 pp.

Van Vliet, M. and Zwolsman, J. 2008. *Impact of summer droughts on the water quality of the Meuse river.* Journal of Hydrology, 353, 1-17.

Vought, L., Dahl, J., Pedersen, C., and Lacoursiere, J. 1994. *Nutrient retention in riparian ecotones.* Ambio, 23, 342-348.

Ward, A.D., and Trimble, S.W. 2004. *Environmental hydrology, second edition.* CRC 122 Press LLC, 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431, 475 pp.

Weixelman, D., Zamudio, D., and Zamudio, K. 1996. *Central Nevada riparian field guide.* R4-ECOL-96-01. USDA Forest Service, Intermountain Region. 145 pp.

Welsch, D. 1991. *Riparian forest buffers- function and design for protection and enhancement of water resources.* USDA Forest Service Pub. NA-PR-07-91. 20 pp.

Winward, A. H. and Padgett, W.G. 1987. *Special considerations when classifying riparian areas.* Paper presented at the symposium, Land Classifications Based on Vegetation: Applications for Resource Management, Moscow, ID. Nov 17-19.

Winward, A. H. 2000. *Monitoring the vegetation resources in riparian areas*. Gen. Tech. Rep. RMRS-GTR-47. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Wright, J., Jones, C., and Flecker, A. 2002. *An ecosystem engineer, the beaver, increases species richness at the landscape scale.* Oecologia, 132(1), 96-101.

Zimmerman, R. C., Goodlet, J.C., and Comer, G.H. 1967. *The influence of vegetation on channel form of small streams.* International Association of Scientific Hydrology 75: 255-275.

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