Appendix 2 to Assessments 1 and 3
Aquatic and Semi-aquatic Ecological Drivers

For the Rio Grande National Forest
Land Management Plan Revision Rocky Mountain Region

Authors and Data/Geographic Analysts
David S. Winters *
Regional Aquatic Ecologist and Program Manager
Senior Author and Coordinator
Amarina Wuenschel *
Ecologist
Author and data analyst (Climate Change)
Joseph Gurrieri *
National Groundwater Expert
Senior Author – Glacial Valleys
Thomas Tenyah *
Regional GIS Specialist
Co-Author – Glaciated Valleys
GIS Specialist and data analyst
USDA Forest Service
Dennis Cleary *
Regional GIS Specialist
Geographer and GIS Analyst
Sarah Synowiec*
Regional Planning GIS
GIS Specialist
All-Points GIS **
Spatial Analysis and GIS Consulting
Spatial Management
GIS and Data Analysts
Data Management
Model Development
*- USDA Forest Service
Rocky Mountain Region
740-Simms Street
Golden, Colorado, 80403
** - All Points GIS
POB 12520
Denver, CO 80212

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Purpose and Need

The mission of the Forest Service is to sustain the health, diversity, and productivity of the Nation's Forests and Grasslands to meet the needs of present and future generations (Federal Register/Vol 77, No. 68, page 2116). Since the last revision of the Rio Grande National Forest land management plan in 1992, a considerable amount of knowledge has been gained through research, monitoring and management on numerous aspects of conducting assessments. Significant advances in modelling, genetic science, climate change, etc., now give us an opportunity to provide more defensible and more importantly more knowledge of ecosystem form and function of ecosystems and biology.

On April 8, 2012 the U.S. Department of Agriculture submitted to the Federal Register its final adoption of a new National Forest System land management planning rule (Federal Register/Vol. 77, No. 68 page 2116). The new planning rule guides the revision of land management plans, utilizing current information. The framework includes three phases: assessment, plan development/amendment/revision and monitoring.

The ultimate purpose of this assessment is to apply ecological information now available to facilitate sound management direction and decisions for current and future generations. The assessment will be focused on understanding the factors influencing aquatic habitat and populations, quantitatively evaluate the abundance, and identifying rare and/or unique areas where possible that may in turn harbor rare species of plants and animals.

Introduction

Identifying major ecological settings and their influence on aquatic habitats is critical for determining the distribution and function of these valuable resources across the landscape. We use the term "ecological drivers" as the environmental factors that exert a major influence on ecosystems and ultimately on the fitness of habitats, individuals and species. Drivers provide the "ecological template" of an ecosystem (Poff and Ward 1990) and thereby its community structure and species (Poff 1997, Pyne et al. 2007). Ecological drivers that define aquatic ecosystems are the basis for the analysis described in this document. Characterizing the dominant drivers at appropriate scales across the Rio Grande National Forest and surrounding ecosystem provides a foundation for understanding the landscape setting, as well as providing information for developing management direction, ecosystem abundance and health across the management Unit.

When human activities modify certain drivers, ecological communities and habitats respond. Aquatic productivity, populations, life-history strategies, vegetation community structure, etc. are not only influenced by watershed-level impacts, but also by site/reach-level components, such as specific habitats, temporal and spatial scales and anthropogenic activities. These influences can be inferred from assessments at different scales. However, it is important to note that quantifying the extent of activities may need further quantitative analysis at the site/reach level to fully understand the "degree" of impacts. In terms of Forest Plan revisions, one can think of "guidelines" as broader temporal and spatial direction while "standards" are very habitat specific and depend on defensible measurements and conclusions from monitoring and or implementation.

Scientific literature that describes the influence of various factors on the structure and function of aquatic, riparian, and wetland ecosystems is extensive (Winters et al. 2003a). From this literature, a team of hydrologists, ecologists, biologists, and other specialists familiar with assessment processes and limitations have been able to identify a set of ecological drivers that describe the spatial distribution and

function of aquatic, riparian, and wetland ecosystems in the Rocky Mountain Region landscape (Wohl, et al, 2012). The resulting analysis can help managers to understand the environmental sensitivity to management activities and the abundance or rarity of aquatic, riparian and wetland ecosystems (Cooper and Merritt, 2012). In addition, they are critical for developing the information necessary for this plan revision.

Relationship to Program and Project Development

The ecological driver assessment presented here may facilitate questions of past and current forest activities. Creation of a multi-scale approach that directly assists with prioritization of ecological land units including watersheds, vegetative communities, and geomorphic settings can aid in the distribution of future activities.

Aquatic, riparian, and wetland assessments can:

- Identify the highest priority watersheds for restoration and reintroduction of native species.
- Identify reference watersheds and conditions to support monitoring.
- Characterize relative impacts to important resource values.
- Assist in the development of funding requirements at appropriate scales.
- Identify subwatersheds at risk and sensitive areas suitable for program level planning, protection and management. More specific management direction at a fine scale can then be developed.

Brief Discussion of Geology

The geology of the Rio Grande study area deserves mention as it has a major influence on the conditions of aquatic ecosystems today. Ancient rocks formed the geology of the Rio Grande valley and surrounding peaks almost 2 billion years ago. During the cretaceous period (approximately 145 to 60 million years ago) a shallow ocean (termed the Western Interior Seaway) dominated the Colorado landscape and formed thick layers of sedimentary rock, some being calcareous in nature (e.g. limestone). During the mid-Cenozoic period a large change happened in the San Luis valley area, resulting in what is now called the Rio Grande Rift. The rift was a separation and stretching of the crust in the valley, pushing the Sangre de Cristo Mountains upward on the east and to a lesser extent the San Juan Mountains on the west. Violent volcanic activity occurred as a result of the “stretching and thinning” of the earth’s crust, with numerous calderas and other volcanic activity having a significant influence on the San Juan Mountains. What remained was a landscape with considerable volcanic influence on the western side of the valley, and eventually the Rio Grande River and tributaries as well. On the east side of the valley, where it was lower in elevation, erosion from tributaries flowing down the steep Sangre de Cristo Mountains began filling in the rift as well as a large, residual shallow lake (Lake Alamosa) in the valley. Further glaciation during the Pleistocene period filled in much of the lake with gravels and sands flowing from the mountains to the basin bottom. According to Dethier (2001), the high plains and mountains experienced stream incision rates of 10-15 cm per 1000 years during the past 600,000 years. Many streams incised over 9 feet during this period.

The Rio Grande valley floor is thousands of feet deep with volcanic and igneous sediment eroded over the eons from the surrounding area. The parent geology is so deep it is actually miles below the current surface elevation of the valley. The north east portion of the Rio Grande valley is termed a “closed basin”, as most of the streams coming off the Sangre’s sink into the alluvium at its base. Some water

resurfaces on the valley floor in the form of marshes, other wetlands and shallow ponds. Some "sub surface water flow" eventually connects to the Rio Grande River on the west side of the valley.

Methods

Discussion of Scale

The Rio Grande National Forest lies within the Rio Grande River basin. River basins are landscapes that are drained into a single large river, until it enters an ocean or other larger river (e.g. Mississippi River in the United States). River basin can drain hundreds and even thousands of square miles and ecologically have species and communities of plants and animals that have developed unique taxa and in some cases are ecologically unique to their boundaries (Winters et al, 2003). The Rio Grande National Forest lies exclusively in the Rio Grande River basin, and does indeed contain taxa of aquatic plants and animals (e.g. Rio Grande cutthroat trout).

The primary scale for this assessment is based on 6th level sub-watersheds or HUCs (Maxwell et al, 1995) that are only within the Rio Grande basin. The "management scale" area is defined by the collection of 6th level subwatersheds that fall entirely within, or have a portion of their area intersecting the National Forest boundary. This scale has been identified as large enough to incorporate species management at the population level, while being appropriate for management considerations of cost and complexity by management agencies.

This scale constitutes the appropriate area for addressing the relationship of ecological drivers at a "management" size as well as quantifying the distribution of anthropogenic activities related to human management activities. Preliminary assessments of risk, sensitivity and abundance related to ecological conditions are also most appropriate at this scale. Other ecological drivers, such as historic glacial activity and climate change are added to measures of climate, stream gradient and geology drivers to extend the analysis, and additional data are integrated to better understand the following:

- Distribution of high-value aquatic, riparian, and wetland ecosystems such as major wetland complexes;
- Sensitivity of subwatersheds and their aquatic, riparian, and wetland ecosystems to disturbances;
- Extent of natural and human disturbances and their effects on aquatic, riparian, and wetland ecosystems;
- Historic and current conditions of aquatic, riparian, and wetland ecosystems; and
- Physical and biological restoration priorities for degraded aquatic, riparian, and wetland ecosystems;
- Potential influences from modelled climate change analysis;
- Areas warranting protection and restoration

Reach/Site Scale

Because of the intensive effort needed to collect and synthesize data, this assessment does not include analyses at the reach/site scale. However, the conditions identified at the management scale set the "context" for stratifying reach/site analysis. The identification of clusters of similar 6th level watersheds should provide the basis for stratification of inventory and monitoring programs at the reach/site level. The identification of the range of anthropogenic influences within a given group of ecological drivers, both independently and cumulatively should also help focus efforts in determining the reach/site effects

on natural resources. This assessment provides specific questions that should be considered when addressing site/reach level analysis in the context of the larger scales.

Ecological Drivers

Identification of Ecological Drivers

Identifying the major ecological drivers important for studying aquatic, riparian, and wetland resources within a geographic area forms the basis for the protocol described in this document. There is an extensive scientific literature that describes the influence of various factors on the structure and function of ecosystems. From this literature, a team of hydrologists, ecologists, and biologists familiar with the region identified a set of ecological drivers that determine the spatial distribution and levels of productivity for aquatic, riparian, and wetland ecosystems in the management area of interest.

For this analysis, five ecological drivers were chosen to describe the setting for aquatic, riparian and wetland resources on the Rio Grande National Forest (Wohl et al, 1981):

1. geochemistry (calcareous, non-calcareous, or salt bearing)
2. sediment production based on geology (fine, moderate, or coarse)
3. dominant hydroclimatic regime (rain and snow, or snowfall)
4. stream gradient (high, medium, or low)
5. glaciation (glaciated, or non-glaciated).

In addition, “outside of” our analysis process, we have identified climate change and influence of glaciation as ecological drivers that will be analyzed and described in the attached Appendix.

Below is a description of each ecological driver and its importance as a “landscape level” predictor of finer scale influences on physical and chemical form and function of the Rio Grande National Forests aquatic ecosystems

1) Geochemistry

The geochemistry composition of the geology within a subwatershed (6th level HUC) can significantly influence its aquatic, riparian, and wetland ecology. For example, bedrock influences the chemical content of water, which can vary from slightly acidic in areas with granite and hard metamorphic rocks, to basic in areas with limestone, dolomite, and marine shale. Bedrock type can also influence salt concentrations in ground and surface water. For the Rio Grande National Forest assessment, three different “groups” geologies were identified: calcareous (Ca), non-calcareous (Co), and salt-bearing (Cs) were chosen (Winters et al, 2003. Classification of these groups that are identified on the Rio Grande National Forest study area were determined from the Colorado State Geologic maps, provided by the Colorado Geological Society (http://coloradogeologicalsurvey.org).

Figure 1. Trout Creek, a spring Creek derived from Calcareous Geology. Constant temperatures, elevated Ph and CaCO3 ions increase stream productivity.

Calcareous geology contains calcium carbonate (CaCO3) and includes sedimentary rocks such as limestone, which dissolves to form ions that influence aquatic productivity. Dolomite and limestone, as well as some metamorphic rocks, such as marble, are derived from calcareous sedimentary rocks. Calcareous rocks weather by dissolution when weakly acidic precipitation is present reacting with the CaCO3. Due to the reactions between the CaCO3 and hydrogen ions in the water, the chemistry of the resulting solutes differs from that of the initial rain, snowmelt, or groundwater. Dissolved constituents move through surface and groundwater, are introduced into aquatic, riparian, and wetland habitats, often increasing production (Figure 1). By raising the pH of the ambient water and by producing carbon dioxide for photosynthesis and stabilizing temperatures, rare taxa and taxa outside their normal ranges are often present. (Hynes, 1970). These changes may dramatically affect production of plants, benthic macroinvertebrates and fish as well. Given the inherent solubility of calcareous bedrock, its porous nature is often associated with springs, creating areas of unique wetland habitats. The Rocky Mountains have a limited amount of calcareous geology, making its presence very important for aquatic, riparian and wetland ecosystems. Historic populations of native Rio Grande chub and sucker thrive in the north eastern portion of the Rio Grande valley. The streams they inhabit are directly influenced by groundwater fed streams (John Alves, Senior Fishery Biologist, Colorado Parks and Wildlife, presentation given at the Winter 2016 Rio Grande sucker and chub Recovery Team meeting, Taos, New Mexico).

Non-calcareous geologies do not contain significant amounts of calcium carbonate. They include igneous rocks; sedimentary rocks, such as shale, sandstones, mudstones, and siltstones and metamorphic rocks derived from non-calcareous parent rocks, such as gneiss, schists, and quartzites. These geologies do not have properties that increase aquatic productivity by themselves, and are the most abundant type of geology in the Rocky Mountains. Through the chemical actions with other compounds, igneous geology can result naturally in slightly too highly acidic waters.

Figure 2. The White River near Rangeley Colorado flowing through salt bearing Mancos shale. Note the fine sediment and lack of vegetation

Bedrock type also influences salt concentrations in ground and surface water, which can have negative influences on aquatic biota. Sedimentary salt-bearing rocks, such as shale's, weather to produce significant amounts of compounds that may accumulate in salt flats, marshes, and wet meadows, consequently influencing the soil geochemistry and limiting the diversity of plant and species composition and community production. While there are many areas in the southwest that are influenced by salt-bearing geology, western Colorado has the highest abundance of this material (Figure 2).

2) Sediment Production

Aquatic, riparian, and wetland ecosystems have evolved with a sediment transport regime relative to the amount of material being produced upstream and upslope of them. Consequently, many organisms in these ecosystems are sensitive to increased yields of sediment. Since wetlands form in places where the depth of the water table creates seasonally or perennially saturated soils, whole wetlands can be eliminated when elevated sediment levels alter saturated conditions. Marshes typically are terminal basins, and sediment coming in can become long-term deposits. Salt flats and wet meadows typically have low sediment inputs and are either fed by ground water or very small drainage areas. Fens always have very low mineral sediment inputs. Peat accumulation in Rocky Mountain fens averages approximately 20 cm (8 inches) per thousand years, and if the rate of mineral sediment input exceeds this rate, the soils will be mineral, not peat. Considerable research indicates that fens and most other wetland types are easily impacted by changes in the natural sediment and water regime.

Sediment can be characterized in terms of the relative abundance and grain sizes of material produced by bedrock weathering. For the Rio Grande National Forest assessment, the geology was subdivided into categories that produce predominantly silt and clay (Sf), sand and gravel (Sm), or rocks that weather to cobbles and boulders. The movement of different sized sediment particles is directly related to the amount of energy applied to it by moving water. Changes in sediment input may affect 6th level HUCs dominated by geology that weather to silt and clay. These fine sediments may accumulate when the transport capacity of a stream declines, as a result of decreases in flow or in localized areas with lower velocities, such as pools (Sable and Wohl 2006). Increased levels of silt and clay can also infiltrate coarser stream bed sediments, altering exchange between groundwater and surface water, periphyton and macroinvertebrate communities, and spawning habitat. Riparian plants, such as willow and alder, establish on bare mineral sediment, and so the deposition of fine sediments can facilitate colonization of these plants on flood prone areas. However, excessive small sized sediment deposition can destabilize riparian areas by burying plants and potentially killing more shallow-rooted herbaceous species. If the stream system is not "overwhelmed" by unnaturally high volumes of fine sediment, periodic flooding can move these particles relatively easily onto adjacent floodplains, and downstream.

Drainages that developed in geologies that naturally produce greater amounts of unstable sediments (such as most of the foothills in eastern Colorado) can be sensitive to natural disturbances such as wildfire or anthropogenic disturbances. Either type of disturbance is likely to produce massive loads to drainage networks over a period of several years following the disturbance. These unnaturally high levels of sediment input over decades of instability can result in shallow, wide stream channels with little aquatic habitat and elevated in-stream temperatures. However, systems with naturally high sediment yields, as in some naturally braided streams, and the species associated with them, may be more tolerant of periodic excessive sediment loading.

Figure 3. Stream Channel filled with coarse sediment from igneous hillside

An increase in large sediment can alter stream morphology and stability considerably, although these materials are less likely to substantially affect streams at low flows, as the stream energy is not sufficient to move it (Figure 3). However during rain events, snowmelt runoff or flooding soils and other physical particles can be delivered in large quantities to wetlands, riparian areas and streams. The alteration and timing of sediment can overwhelm the system's ability to transport that material to important ecosystems.

Typically impacts are long-term, reducing biological diversity and abundance. Flow regime is ecologically important because it partially controls sediment transport and channel stability, as well as available habitat and characteristics such as water temperature and chemistry that drive life cycles of aquatic and riparian organisms (Poff eta, 1997).

3) Hydroclimatic Regime

Local climate in large part controls the hydrologic regime of streams, riparian areas and wetlands, making it a major ecological driver for aquatic/semiaquatic ecosystems.

Three moisture input patterns, snowfall (Ps) and rain and snow (Prs) and rain (R) dominate the precipitation zones in the Rocky Mountains in Region 2 (Wohl et al, 2007).

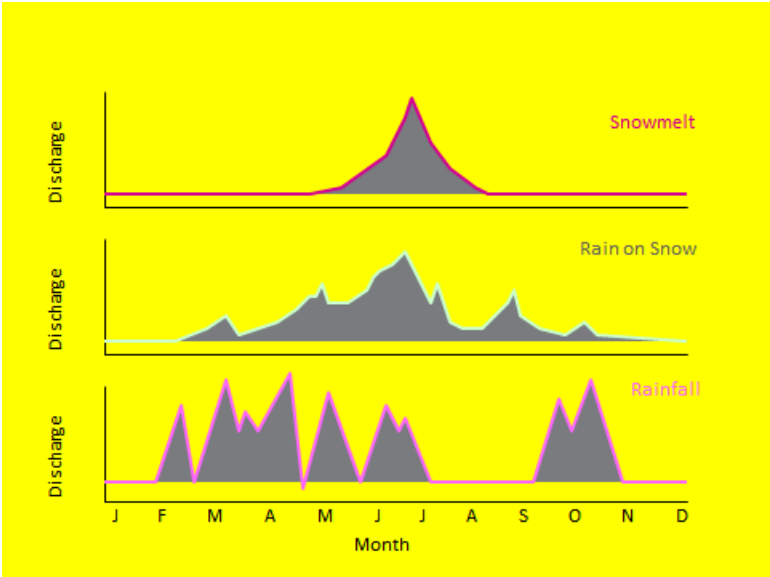


Figure 4. Precipitation zones in the Rocky Mtns. Changes In the discharge patterns are correlated with elevation, pattern of snowmelt accumulation and melt, and rain events.

The higher elevation mountains and valleys of the Rio Grande National Forest receive much greater amounts of precipitation than lower elevation areas, and most of this precipitation is in the form of snow. Streams in this elevation zone are influenced by snowmelt recharge of hill slope aquifers, which provide groundwater to support perennial stream flow during the summer. These streams typically have less interannual variability in flow and experience fewer floods compared to the rain- and snowfall- dominated areas (Figure 4). The more predictable hydrograph associated with snowfall-dominated hydroclimatic regimes recharges aquifers and wetlands on a nearly annual basis. A broader portion of the annual hydrograph of these streams is at or above baseflow. These streams have a relatively lower peaks and a longer duration than rainfall-dominated streams. The greater input of water via precipitation supports an abundance and variance of wetland types, because large groundwater-driven wetland complexes are found primarily in association with snowmelt-recharged aquifers. Generally, streams in the snow-melt zone generally exhibit lower temperatures and reduced productivity. Aquatic organisms have evolved life-history strategies to avoid the harsh conditions associated with the snowmelt runoff period (Hynes 1970).

The rain and snow climate zone is lower in elevation than the snow climate zone, and is characterized by a flow regime with a snowmelt peak during late spring or early summer, as well as rainfall from convective storms or from some dissipating tropical storms from mid-summer through the fall (Figure 1). These streams may have a rainfall-generated peak discharge that is greater than the snowmelt peak discharge at least once a decade. Based on the work of Jarrett (1990), these stream segments occur below 7550 ft. elevation on the Rio Grande National Forest, and may constitute a relatively harsher environment for aquatic biota than snowmelt-dominated streams, given similar habitat conditions. Lower elevation watersheds dominated by rain and snow hydrologic regimes tend to be flashier, with less predictability in timing and magnitude of the annual peak flow, and potentially higher peak floods relative to the mean annual flow. Because of the high variability in stream discharge throughout the year, stream productivity and biota population dynamics can also be quite variable. Localized effects of sudden flow changes can influence populations of algae, benthic macroinvertebrates, and fish. Fish biomass and diversity may be considerably higher in the rain and snow driven systems as temperatures are usually higher, habitat more complex and abundant. Low gradient stream reaches may contain the highest biodiversity and robust populations if not impacted by anthropogenic sources. Some of these lower elevation streams are intermittent and exhibit minimal riparian vegetation because perennial groundwater during the summer is not available to support riparian plants. Lower elevation watersheds that are dominated by rain and snow

hydrologic regimes also tend to support fewer wetlands, primarily due to considerably reduced precipitation and groundwater input.

Rain driven stream systems are highly variable and have numerous but inconsistent rain and subsequent flooding events. These events carve stream channels and flood plains in fine sediment prairie and grasslands streams. Fish and other biota have adapted unique abilities to survive and reproduce in these areas. We have found very few areas within this hydroclimatic regime associated with the Rio Grande National Forests and other National Forests in Region 2. However, where they are present, different biological communities exist than in the higher elevational areas, and may be refugia from more impacted areas downstream.

4) Stream Gradient

Stream gradient influences stream power, erosive capability, localized sediment sizes, aquatic and riparian productivity, water storage and floodplain characteristics. As a result, stream gradient dictates the habitat for specific flora and fauna. For the Rio Grande National Forest assessment, three categories of stream gradient were identified: high (> 4%), medium (2 - 4%), and low (<2%) (Montgomery and Buffington, 1997). It is important to note that streams represent a continuum of processes, longitudinally from mountains to lower elevation plains. Leaf litter and other organic input from aquatic and terrestrial plants entering the system are processed moving downstream by various organisms, primarily bacteria and benthic macroinvertebrates. Leaf litter from riparian shrubs represents a major food source for various trophic levels in Rocky Mountain streams.

Stream segments designated as high gradient are characterized by step-pool morphology and are fairly resistant to high flow events because of bedrock, or boulder and cobble characteristics. Floodplains are narrow or may be non-existent, and have coarse-textured soils that drain rapidly and are periodically eroded by high-energy floods or debris flows. Narrow valley bottoms promote high connectivity between the hill slope and valley bottom, with relatively frequent debris input and subsequent movement that introduce sediment, wood, and nutrients directly to the channel. Riparian areas support small communities of herbaceous vegetation, or woody plants that can tolerate periodic high-energy floods, as well as tree species, such as cottonwood and red osier dogwood, that sucker following flood disturbance. These channels typically have limited habitat for aquatic organisms, although the large substrate does provide habitat for fish and especially benthic macroinvertebrates and periphyton. Natural migration barriers for fish and other aquatic organisms, such as waterfalls, can limit upstream movement into upper stream reaches. Road crossings in these types of channels can also create barriers for animal migration and nutrient flow. High gradient streams have a relatively higher capacity to transport excessive sediment downstream to lower gradient reaches.

Medium stream gradients often correspond to channels that are transitional between step-pool and pool-riffle morphology. These stream segments are intermediate between high and low gradient streams in terms of streambed grain size, resistance to disturbance, and valley bottom width. Compared to high gradient streams, medium gradient streams have wider valley bottoms, where sediment originating from side slopes can be stored before reaching the channel. These stream reaches are relatively abundant in mountain streams, and provide a “transitional” zone between the low and high gradient systems. Stream habitat can be abundant, but typically depends on wood recruitment and large substrate. Stream reaches with moderate gradients, salt-bearing geology, and lithology that weathers to silt and clay are much more sensitive to changes in erosion and sediment input.

Figure 5. A low gradient section of the South Platte River. Note abundant sediment deposition on the inside meander, wildfire burned trees on the hillsides and green unburned riparian area.

Low stream gradient channels typically correspond to meandering pool-riffle morphology formed in relatively fine-grained sediments, with wider flood plains, supporting diverse plant and animal communities (Figure 5). Low gradient streams have wider valley bottoms and greater lateral mobility compared to stream segments in steeper, narrower valley bottoms. Lateral mobility depends on both flow characteristics and bank resistance; bank resistance depends on grain size, stratigraphy, and the presence and type of riparian vegetation. Sediment coming from adjacent hill slopes is less likely to reach low gradient channels directly during routine erosional processes, but it is more likely to be stored on the valley bottom for a period of years and then mobilized into the channel during lateral channel migration or flooding. These reaches can be very productive, especially in terms of fish and wildlife populations and woody riparian vegetation. Low gradient stream reaches with extensive shrub and tree riparian communities may also support beavers, ecosystem engineers that distribute water and sediment across the valley, increasing hydrologic and ecological complexity. Beavers contribute significantly to carbon storage through their construction of dams and trapping woody material moving downstream from upstream sources. Many species of birds, reptiles and mammals depend on the extensive wooded riparian areas associated with these channels. Low-gradient stream reaches are sensitive to excessive sediment deposition locally or upstream, channel widening, and pool filling. Pools are sensitive to sediment disturbance, as velocities and associated stream energy are less. As a result, low gradient streams are sometimes designated response reaches (Montgomery and Buffington 1997) because of their tendency to accumulate excess sediment preferentially in pools.

Because sediment tends to deposit in low-gradient reaches they are often the most impacted by anthropogenic activities, in terms of erosion and sediment deposition. Low-gradient reaches are more likely to accumulate sediment from decreases in water yield or increases in sediment yield, and also could undergo substantial erosion with increased water yield or decreased sediment yield. Those reaches with extensive shrub and tree riparian communities may also support beavers, ecosystem engineers that distribute water and sediment across the valley, increasing hydrologic and ecological complexity. Fish in mountainous areas of the Forest rely on low gradient reaches for food, spawning and high quality habitat for all life history stages. Water temperatures are generally very cold in higher elevation streams and can eliminate successful aquatic organism reproduction. Low gradient reaches allow direct solar radiation to increase water temperatures slightly and therefor increase productivity. However, removal of riparian vegetation for shade and increasing stream widths and reducing depths can result in too much of an increase in temperature and can be harmful to aquatic biota during warmer months. The relatively small amount of low-gradient stream reaches in the Rocky Mountains illustrates the importance of these sources of organic material for streams as well as habitat for other riparian species.

Aquatic macroinvertebrates are uniquely adapted to differences in stream gradient and substrate size. Those that live in steeper stream channels, with high shear stress, and larger substrate have adaptations that help them cling to the substrate, feed on attached algae, and are often dorso-ventrally flattened to reduce the effects of water currents (Hynes 1970). Other taxa take advantage of the current and build elaborate nets or hold appendages in the current to trap food that floats by. Benthic macroinvertebrates that live in lower gradient reaches with smaller substrate have adapted to these conditions by burrowing into the finer material and become more generalist feeders. As a result, there are typically considerable differences in the composition of community structure of benthic macroinvertebrates between high and low gradient stream channels with different substrate sizes. The high variability in responses to environmental change by communities and individuals of benthic macroinvertebrates often makes them the focus of monitoring aquatic conditions.

Fish also exhibit population differences across differing stream gradients. In high-gradient channels, large substrate and roughness create suitable habitat. However, high stream velocities can reduce habitat suitability, especially during high flow events. Generally, trout and other fish species found in the Rocky Mountains exhibit lower population levels in these areas. Intact Low-gradient stream reaches typically exhibit much higher habitat availability and larger fish populations because of increased stream depths and reduced velocities. Abundant overhanging riparian vegetation can supply considerable leaf litter and terrestrial food in these reaches. Substrate sorting within low gradient stream reaches typically produces areas of high reproduction for stream salmonids, usually at the downstream “tail” of pools. The moderate to low gradient reaches are expected to be important areas for salmonid reproduction and rearing.

5) Glaciation

Glaciation is the process where large snow and ice deposits accumulate during extended periods of cold climates. The ice masses tend to move extremely slowly, carving wide relatively flat valleys (Figure 6 and Figure 7). By scouring the valleys of high mountain landscapes and slowing runoff, glacial processes have made landscapes more suitable for wetland and riparian area development by gouging the surface and pushing sediment and boulders to act like dams. We conducted an analysis of the relationships between wetland abundance in glaciated valleys as part of this assessment later in this document. Wetlands and riparian areas in these areas provide important habitat for waterfowl, amphibians, aquatic invertebrates and many plant species. Due to their high elevation and small stream size, fish are often absent from these areas. Glaciers created landforms in high and middle elevation valleys that are conducive to the formation of wetlands on the Rio Grande National Forest. Therefore, glaciated areas and non-glaciated areas were considered as an ecological driver combination for this assessment. High elevation areas of the Rio Grande National Forest were repeatedly glaciated during the Pleistocene epoch, 2 million to 10 thousand years ago. The latest major period, termed the Pinedale Glaciation, covered some areas of most mountain ranges at higher elevations. Valley glaciers flowed from these high elevation areas where ice accumulated, and produced deltas and other landforms in lower elevations. The Pinedale glacial period ended approximately 14,000 years ago. Glaciers scoured cirques and valleys as the ice flowed downhill and pushed debris ahead of it, forming terminal moraines, and off to the sides of valleys, creating lateral moraines. In addition, the glaciers plucked rock and finer sediments from bedrock along its path, which was incorporated into the ice. Once these glaciers stagnated, they began to melt, and debris within the ice was deposited, forming “dead ice deposits,” that created kettles and ground moraines.

Figure 6. Glaciated valley on the Rio Grande National Forest. Note the wide riparian valley with heterogeneous vegetation types.

Figure 7. Glaciated landscape on the Rio Grande NF. Note the wide valley bottom, Willow community and intact stream channel.

Terminal moraines may have blocked the drainage of entire valleys, thus forming lakes, some of which persist today. Sediments from the melting glaciers filled lakes. Where moraines have persisted and the valleys behind them have filled with sediments, large, flat valleys were created, which are conducive to the formation of meandering streams, broad riparian areas, and wetlands. Lateral moraines on the sides of valleys are composed of thick masses of unconsolidated sediments. They hold large volumes of snowmelt-recharged groundwater that support localized flow systems that feed wetland complexes, including fens, wet meadows, and marshes at their base, and that stabilize flow and temperature regimes of connected streams. Kettle basins in dead ice moraines are depressions supporting ponds, marshes, and fens. Cirques and high elevation valleys have been scoured and as a result are also relatively wide and flat, compared to other valley types; they typically contain abundant wetlands. Terminal and lateral moraines are composed of unconsolidated deposits, and are critical recharge areas that supply groundwater to streams and wetlands.

Climate Change

Aquatic systems and water dependent taxa will be significantly affected if the trend for changing temporal and spatial scales in air temperature and patterns of precipitation continue (Bryson et al, 2008). Potential effects of climate change in the southern Rocky Mountains include: 1. Reduced precipitation, 2. Reduced period of snowmelt runoff, 3. Attenuated periods of base flows, 4. Increased water needs by the predicted

increase in Colorado's population, 5. Increased stream temperatures (Reiman and Isaak, 2010). There are several other indirect impacts, such as increases in non-native species (Rahel, 2010) and a reduction in overall adequate habitat for cold water species. Some scientists speculate that increased water temperatures in higher elevations will be advantageous for cold water native fish. However, instream habitats are more limited in the smaller streams found there, food animals such as benthic macroinvertebrates may not tolerate even a limited change in water temperature, and reduced precipitation and more sporadic precipitation events could lead to droughts.

We used a model recently developed by the USDA Rocky Mountain Research Station (http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml) that incorporates current and projected variables to estimate changes in mean annual discharge in the Rio Grande National Forest for the future (See appendix 2).

It is also the intent of this analysis to understand and potentially prepared for "short-term drought situations" that occur in the Southern Rocky Mountains (McKee, T. et al, 2000). While these events are measured in years, and followed by periods of "normal to high" discharge, the effects on aquatic ecosystems could mimic to a limited degree the effects of the long-term climate change in the future (Figure 8). The resiliency of aquatic ecosystems for the future may be to a limited degree be reflected in the effects of short-term drought conditions. If the components that affect the resiliency of aquatic ecosystems are not in place or at a much lower level of condition than would be expected, even short term droughts could have major impacts on aquatic systems. If we are able to increase resiliency substantially, the onset of climate change impacts may not be realized until later in the future, and the effects may not be as intense.

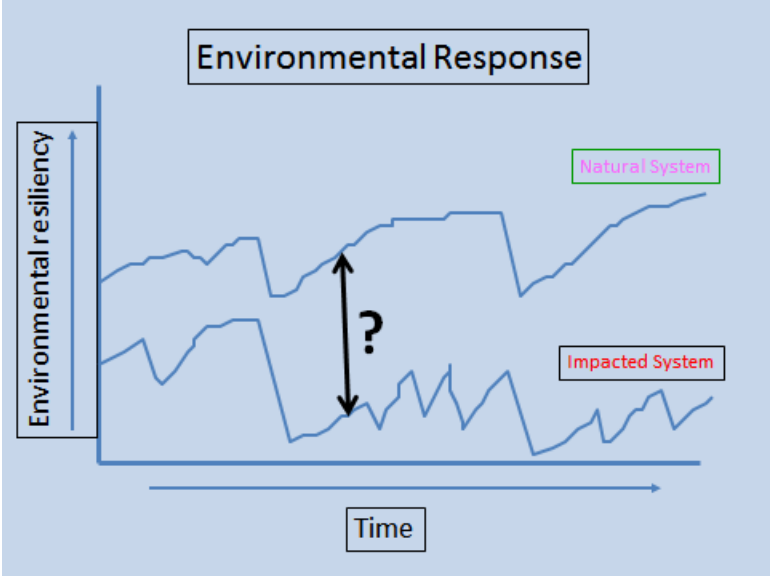


Figure 8. Theoretical relationship between resiliency of aquatic ecosystems in "natural" and "impacted" systems. Natural systems tend to 1. Withstand and recover more quickly, and 2. Are not impacted as severely by smaller stochastic or anthropogenic influences

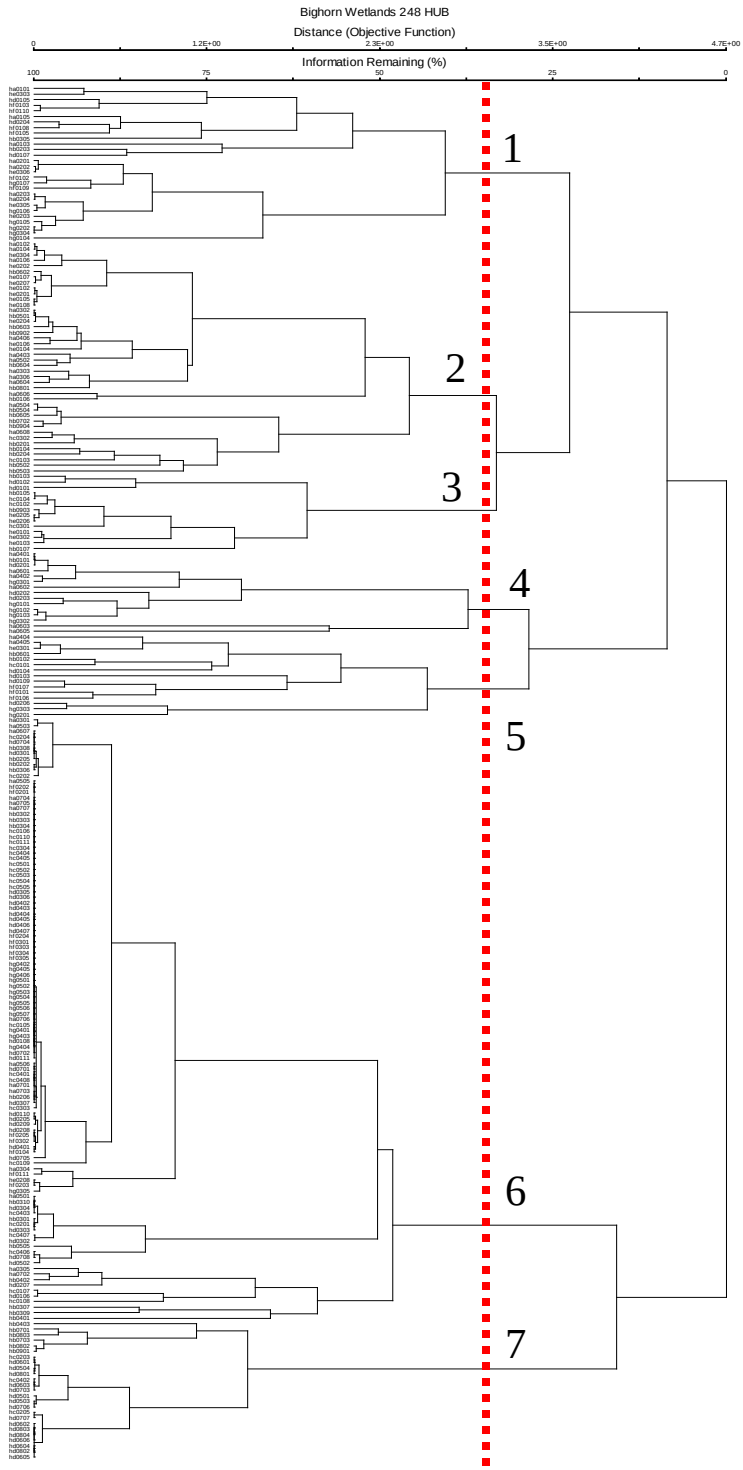


Figure 9. Dendogram of the similarity results for 160 subwatersheds on the Big Horn National Forest, The red line represents the level of similarity chosen, and the numbers represent the final clusters identified.

Methods: Ecological Driver Cluster Analysis for Stream/Riparian Areas

Step 1

After identifying the ecological drivers that will be used (as described above), the percentage of each ecological driver in each subwatershed are identified. For this analysis, hydroclimatology, stream gradient and geology (Erosional sediment size, geochemistry) were identified from Wohl et al. (2007). In addition, in a separate exercise the extent of historic glaciation was analyzed in relation to wetland abundance due to their influence, and the potential influence of climate change on stream discharge was also addressed at current and future estimates on mean annual discharge for each stream. It should be noted that all the summary information for each driver and each subwatershed will be provided for further analysis for this planning effort.

Step 2

Ward's cluster analysis (Batagelj, V., 1988) was used to identify groups of subwatersheds that have similar ecological characteristics for streams and riparian systems within the Forest (Figure 9). Ecological clusters are identified by number and color and summarized in the following sections. Several iterations of this analysis were conducted to identify the most logical number of clusters to characterize. This is an important step so differences between clusters can be explained. For example, a very high similarity of clusters may result in only 2 clusters. Explanation of the differences of these 2 clusters may not be meaningful for planning because they cover a broad range of conditions. Identifying too many clusters may mean they are so similar that differences cannot be made between similar clusters. Too few clusters identified and there are characteristics of all the ecological drivers in each cluster and no relationships are observable. The ecological characterization of 6th level subwatersheds through this process should allow for an understanding of the relative abundance, sensitivity, productivity and other management considerations of different ecological conditions on the Rio Grande National Forest. Clusters that are unique or sensitive to management may solicit special consideration when developing land management and/or project plans.

Step 3

This step involves explaining different characteristics of the clusters to be used in the appropriate planning exercise. Various graphics can also be developed to explain the location of particular subwatersheds in each Cluster (Figure 10). This effort illustrates the important ecological considerations for each cluster of similarly grouped subwatersheds without the influences of anthropogenic influences. For instance, we know that calcareous geology typically is an indicator of springs, increased productivity, rare species and potentially very good areas for native fish reintroduction. Conversely, clusters that are dominated by geology that produces large sediment, located in the rain and snow zone, and has steep stream gradients (also correlates with steep topography) is very indicative of sensitive landscapes to erosion, and high risk for natural and management activities that would potentially move sediment into streams and wetlands.

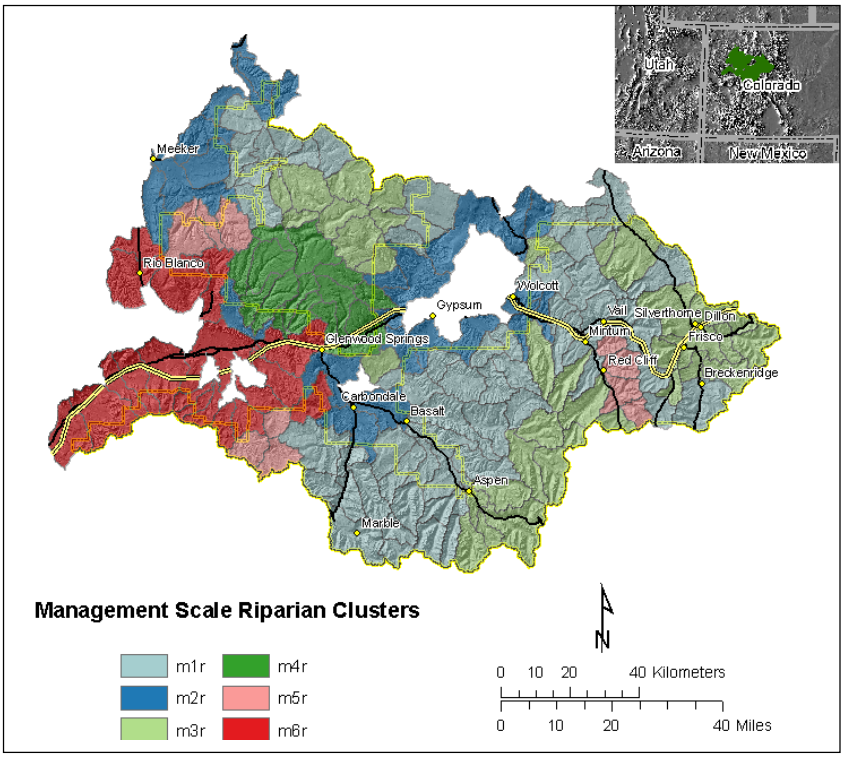


Figure 10. Results of cluster analysis for streams and riparian areas for the White River National Forest. There are 6 different groupings of subwatersheds with statistically similar ecological driver characteristics.

By using this process in the absence of anthropogenic factors we can deduce how streams within certain clusters should respond to sediment, chemical constituents, temperature and aquatic/riparian habitats and productivity over time.

Presented is a table of the riparian ecological drivers for the White River National Forest (Table 1). Differences between values can be used to illustrate ecological conditions and management importance within each "cluster". In addition, clusters with relatively low percentages of their area in the National Forest can be quantified. For example, 4 clusters exhibit over 80% of their area in the National Forest boundary. Are there species or ecosystems that we have the management ability to improve or maintain? Conversely, Cluster M6R comprises a much smaller percentage of the National Forest, and approximately 21% of this cluster is in the National Forest boundary. Managers may choose to investigate this cluster more closely to see if our ability to influence characteristics of this cluster are justified.

Table 1. Mean percentage of riparian ecological drivers for each cluster within the White River National Forest. Dominant values are colored to help discern differences between clusters

	Stream Gradient			Geochemistry			Sediment Production			Hydroclimatic Regime		Distribution of Clusters	
Management Riparian Cluster	H	M	L	Ca	Co	Cs	Sf	Sm	Sc	Prs	Ps	% in NF	% of NF
M1R (n=57)	68	13	19	13	74	13	55	18	27	6	94	82	43
M2R (n=22)	75	12	13	7	51	42	46	24	30	47	53	15	4
M3R (n=36)	72	12	16	6	91	3	7	11	82	1	99	95	31
M4R (n=14)	74	11	15	76	18	6	8	57	35	16	84	83	10
M5R (n=10)	75	11	14	81	18	1	85	8	7	4	96	91	7
M6R (n=19)	71	13	16	62	34	4	74	18	8	54	46	21	5

Results: Ecological Drivers

Geology - Geochemistry

Implications: Calcareous geology – abundant spring development increases aquatic productivity and biodiversity, more consistent water temperatures at and for some distance downstream, reduces natural sediment by dissolving, provides refugia for rare plants and animals. Often not dependent on current rainfall but "old" water from precipitation that infiltrated the earth's crust. Relatively rare in the Colorado Rocky Mountains. The aquatic systems associated with ground water and this geologic type could be considered extremely rare and important ecological types on National forest lands.

Non-Calcareous geology – limited nutrients, lower productivity (reduced ph), highly diel and seasonal water temperature and discharge changes, larger grain size and increased deposition in aquatic habitats. Generally the most abundant geologic type in the Rocky Mountains. Productivity is influenced from nutrients from terrestrial sources and productivity is influenced by solar warming and habitats that are more abundant at lower elevations.

Results - The results of the geochemistry driver results are presented in Figure 11. While the Rio Grande National Forest does not contain a significant amount of calcareous geology near the surface of the landscape (surficial), there are a few areas worth highlighting and considering for future analysis for rare taxa, springs and associated areas and streams for native trout restoration. The first area is along the northern and western portion of the Sangre de Cristo Mountains from approximately the Crestone Peak northward to the Hayden Pass area. The scale of surficial glaciation was relatively large for this exercise (1:500,000 Colorado State geology maps), and thus would not identify small outcrops that could be important for spring developments and rare taxa. Two smaller areas identified south of that area, were near Carbonate Mountain within the boundary of the Great Sand Dunes National Monument and California Peak. Again, there could be wetlands and springs in these areas fed by ground water input.

The other area of identified calcareous geology surrounds the town of Villa Grove. It is interesting that the one stream on National Forest land running through this geology is called "Soda Springs Creek", no doubt because of the unique characteristics of the groundwater from springs. Even on the Rio Grande National Forest visitor map numerous springs and hot springs are identified near this area. While spring areas on this side of the National Forest may have already been influenced significantly by past management there could be rare plants and animals still associated with them.

The calcareous geology identified is the result of the Rio Grift Rift moving laterally, pushing the Sangre de Cristo Mountains up. The igneous "basement" pushed through the sedimentary layer where most of it was fragmented and moved by glacial activity and/or eroded away over time into the San Juan valley below.

SPECIAL NOTE: While Calcareous geology is indeed a rare geologic formation in the upper Rio Grande valley, numerous important biodiversity and productivity possibilities exist. These remnants of prehistoric oceans could be important refugia for rare plants and animals as well as highly productive streams for rare taxa and for potentially recovering native fish, such as the Rio Grande cutthroat trout, chub and sucker. Other springs and habitats influenced by these relict sea bottoms could be identified in the Sangre De Cristo mountain range and assessed for rare taxa as well as important areas for restoration of native species...

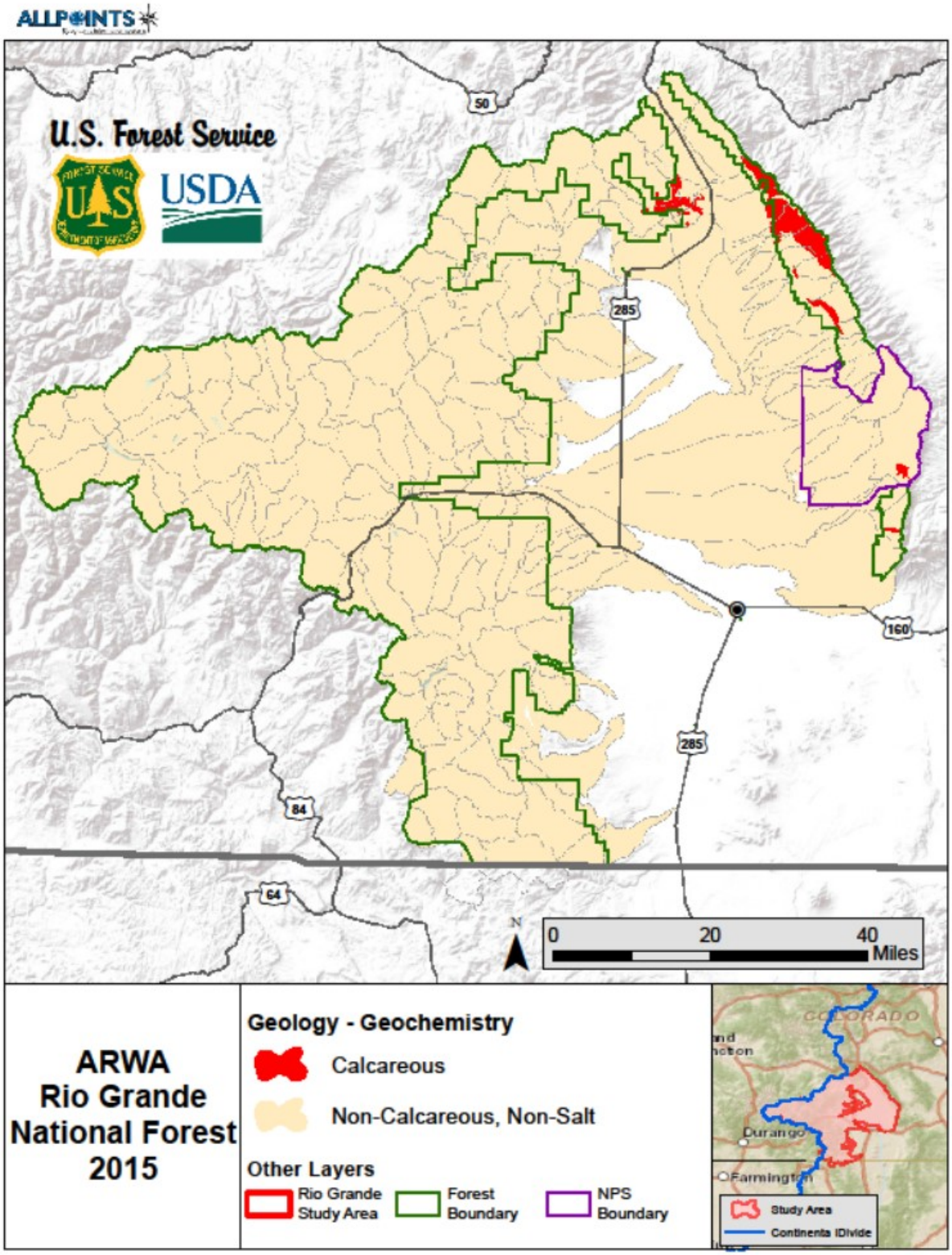


Figure 11. Geochemistry of the Rio Grande National Forest at the landscape scale. Similar to most areas of the Rocky Mountains, non-calcareous geology dominates this landscape. Calcareous geology is much less abundant than its neighboring National Forest to the north, the San Juan National Forest (Winters and Staley, 2005)

Geology - Sediment Production

Implications: Erosion and subsequent sediment movement and deposition are one of the leading pollutants in the world (http://www.fao.org/docrep/W2598E/w2598e05.htm). Sedimentation can directly influence aquatic ecosystems by filling of aquatic habitats for fish and other organisms, reducing reproduction success, scouring of substrate for benthic organisms and filling wetlands and riparian areas.

Indirect influences can include highly variable water temperature by changing stream geometry, water chemistry, reducing oxygen in the substrate (hyporheic), and establishing areas for invasive plant establishment. Sediment dynamics are generally in a state of dynamic equilibrium with its environment. While stochastic events may result in geologically short-term elevated levels of especially igneous sediment production and transport, anthropogenic disturbance can result in long-term, continuous degradation.

Results: The results of the sediment production analysis are presented in Figure 12. The Geology and related processes that have occurred on and around the Rio Grande National Forest are complicated and diverse, resulting in 2 distinctly different zones of sediment size (Figure 12). This distinct separation is due in large part to the “pulling apart” of the valley by the Rio Grande Rift, and abundant volcanic activity that occurred about 30 million years ago. This tremendous activity resulted in the development of the San Juan Mountains on the west side of the valley. The sediment produced by the volcanic activity is generally fine/medium in size and often turns red as the iron in the sediment is oxidized. Some volcanic areas can neutralize the ph of streams by forming CaCO3 when introduced to the atmosphere. Most of the streams in the southern Rocky Mountains are the result of igneous extrusions that can result is low ph water due to the chemical constituents of the bedrock. The areas on the San Juan side of the San Luis valley could contain water chemistry that is more conducive to aquatic productivity. However, there is a great deal of variability with volcanic rock, and further analysis of ph and carbonates would be an important step in finding streams that would be more conducive to native fish restoration or other activities where productivity is a an important component.

On the east side of the Rio Grande Valley the geology producing sediment is composed predominantly coarse igneous bedrock (Figure 13). The Blanca Massif is comprised of Precambrian rock, while most of the rest of the mountains south of the Rio Grande National Forest is composed of younger Permian-Pennsylvanian (about 250-million-year-old) rock, a mix of sedimentary and igneous intrusions. The fact that our analysis reveals coarse lithology on the valley floor is a result of erosional processes from the steep mountains adjacent to it. The limited sedimentary geology in this area of the Sangre’s originated as residual sea floor limestone eroded from the Ancestral Rocky Mountains.

The sand dunes associated with the flanks of the Sangre De Cristo started about 450,000 years ago as Lake Alamosa began to dry. The sediment on the bottom of the lake began to travel with the south west prevailing winds. However, winds from storms coming in a westerly direction over the Sangre’s made the prevailing winds swirl in the valley and the sand accumulated in “pockets” where they now remain. Due the vegetation that dominates the San Luis valley floor now, the dunes and surrounding area are not expected to grow significantly in at least the near future.

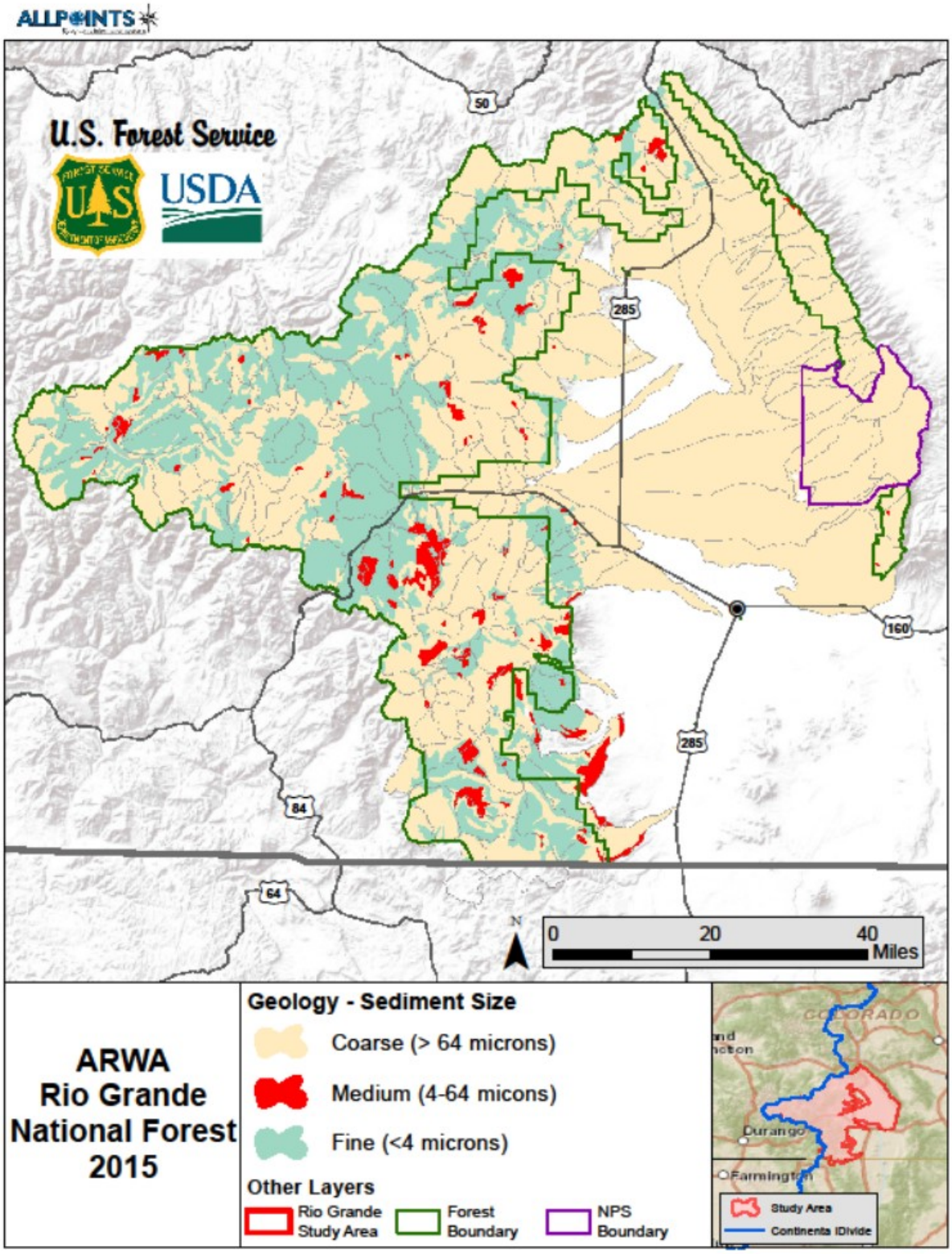


Figure 12. Map of different size sediment produced by underlying bedrock and erosion from the Rio Grande study area. Sediment produced from the west side of the Sangres is mostly coarse due to the igneous intrusion through ancient sedimentary layers. Sediments on the west side of the San Juan Valley is either fine/medium size from volcanic activity or coarse from granitic bedrock.

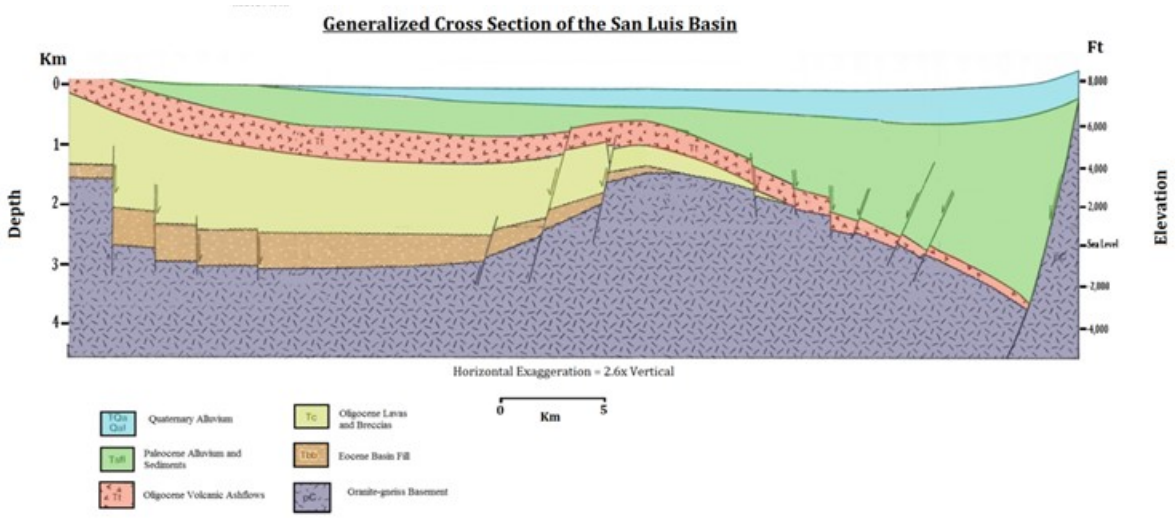


Figure 13. Cross section of the San Luis Valley geological structure. The steep igneous "lift" on the east side of the diagram continues up through the Sangre De Cristo mountains, while the volcanic west side rises more gradually through the volcanic slope to the San Juan mountains. The igneous sub "Rio Grande Rift San Luis basin". Licensed under Public Domain via Wikipedia - https://en.wikipedia.org/wiki/File:Riogranderift_sanluisbasin.png#/media/File:Riogranderift_sanluisbasin.png .

Special note: The granitic bedrock on the Rio Grande National Forest that produces coarse grained material is less likely to move with natural stream and overland water flow. However, when moved by anthropogenic erosional processes will settle in wetlands, pool habitats and riparian areas when energy is increased through flooding. Many of the potential sources of streams in aquatic ecosystems in the Rio Grande National Forest are probably from influences beginning in the mid 1880's (Wohl, 2001). Once excess sediment is deposited in these areas, it becomes extremely hard for energy in streams and wetlands to move it as it has settled into areas with lower stream power. The result is decreased aquatic habitat and filling in of wetlands and riparian areas. The sediment produced on the west side of the basin is somewhat easier to move because the average size produced is somewhat smaller. However, it still takes more energy to move out of low energy areas than off of hill slopes. In additions, many of the streams most likely do not have the wood and boulders available to sort sediment onto floodplains.

Monitoring watershed conditions in stream and riparian ecosystems from sediment intrusion is most successful in low gradient reaches, as they are the first areas in stream networks that exhibit changes in biota, temperature and stream channel morphology when excessive sediment is present. Low gradient stream channels comprise a small length of overall stream length in mountainous areas of the Rocky Mountains, requiring less effort and cost if planned correctly.

Wetlands are protected from impacts through the Clean Water Act, Executive Orders. As well as best management practices, and other national and regional policies. As such, existing laws, policies and best management practices should be implemented to protect individual wetlands from damage by excessive sediment accumulation.

Approximately 50% of wetlands have been lost in the state of Colorado (http://geochange.er.usgs.gov/sw/impacts/hydrology/wetlands/. While current protection of existing wetlands is extremely important, the restoration or creation of wetlands to replace historic wetlands could be considered and important action for the future.

Hydroclimatic Regime

Implications: Elevation has a major influence on aquatic ecosystems in the southern Rocky Mountains (Ward, 1986). Landscapes including the Rio Grande National Forest are dominated by annual snowmelt driven hydrographs, maintaining stream channels and greatly influencing the life-history of the organisms that live there (see review at (http://www.nature.com/scitable/knowledge/library/extreme-cold-hardiness-in-ectotherms-24286275). These plants and animals are well adapted to this environment but are not adapted to major changes. Plants and animals located lower in elevation are typically more resilient to changes in temperature and other environmental conditions because conditions are changing more often and to a higher degree (Hynes, 1970).

Major changes in the shape of the annual hydrograph including extended runoff, flooding events and drought can have major influences on aquatic and semi-aquatic biota, Taxa that persist in a warmer, lower elevation streams may be more tolerant and/or adaptable to changing conditions. However, plants and animals in cold water systems are typically less tolerant, unless inhabiting special environments (e.g. Ground water systems), connected habitats for large movements and reproduction adaptions Multiple life stages) allow them to survive. While large scale changes in climate may influence the hydroclimatology on a large scale, changes from human influence is typically smaller, with cumulative impacts having potentially severe influences on a system at any elevation. Management activities could be conducted to maintain the environmental “structure”, or restoring systems that have already gone outside expected conditions.

Results: Results of the Hydroclimatic regime are presented in Figure 14. Local climate controls the hydrologic regime of streams and wetlands, influencing ecosystems through the timing and magnitude of runoff and peak flows. Snowfall driven precipitation dominates the shape of the annual Rio Grande National Forest. (Figure 4). However, a rain and snow dominated hydrograph at the headwaters of subwatersheds that originate at the lowest elevations of the Forest may exist. These areas may contain plants and animals that are more representative of the valley floor. In addition, wetlands may also have different form and function if precipitation and resulting overland flow is modified. Given that the lower elevations of the valley receive little annual precipitation (approximately 8 inches per year), stream channels would be expected to be ephemeral or intermittent depending on the presence of groundwater. Wetlands would also be dependent on groundwater reaching the surface where rooting would allow wetland plants to exist. Aquatic dependent animals would most likely have to aestivate during dry periods or migrate to wetter areas.

With the valley floor reaching a an elevation of approximately 8000 feet, the majority of the entire study area is within the “snowmelt” driven precipitation zone, while the rain and snow elevation limit is below the National Forest boundary. The relatively high elevation and small stream size associated with the Rio Grande National Forest in the mountainous area can be interpreted as a fairly “unproductive” area for fish and other aquatic plants and animals. Growing seasons are relatively short, due to the limited size of the tributary streams. While groundwater fed systems most likely maintain warmer water temperatures than other systems, based on the extremely limited calcareous geology and findings from other assessments, they are very rare. Stream segments with low stream gradient and meandering character are often considered heat “sinks”, and as long as there are no mitigating circumstances can help increase water temperature during longer periods of time. (Poole and Berman, 2000).

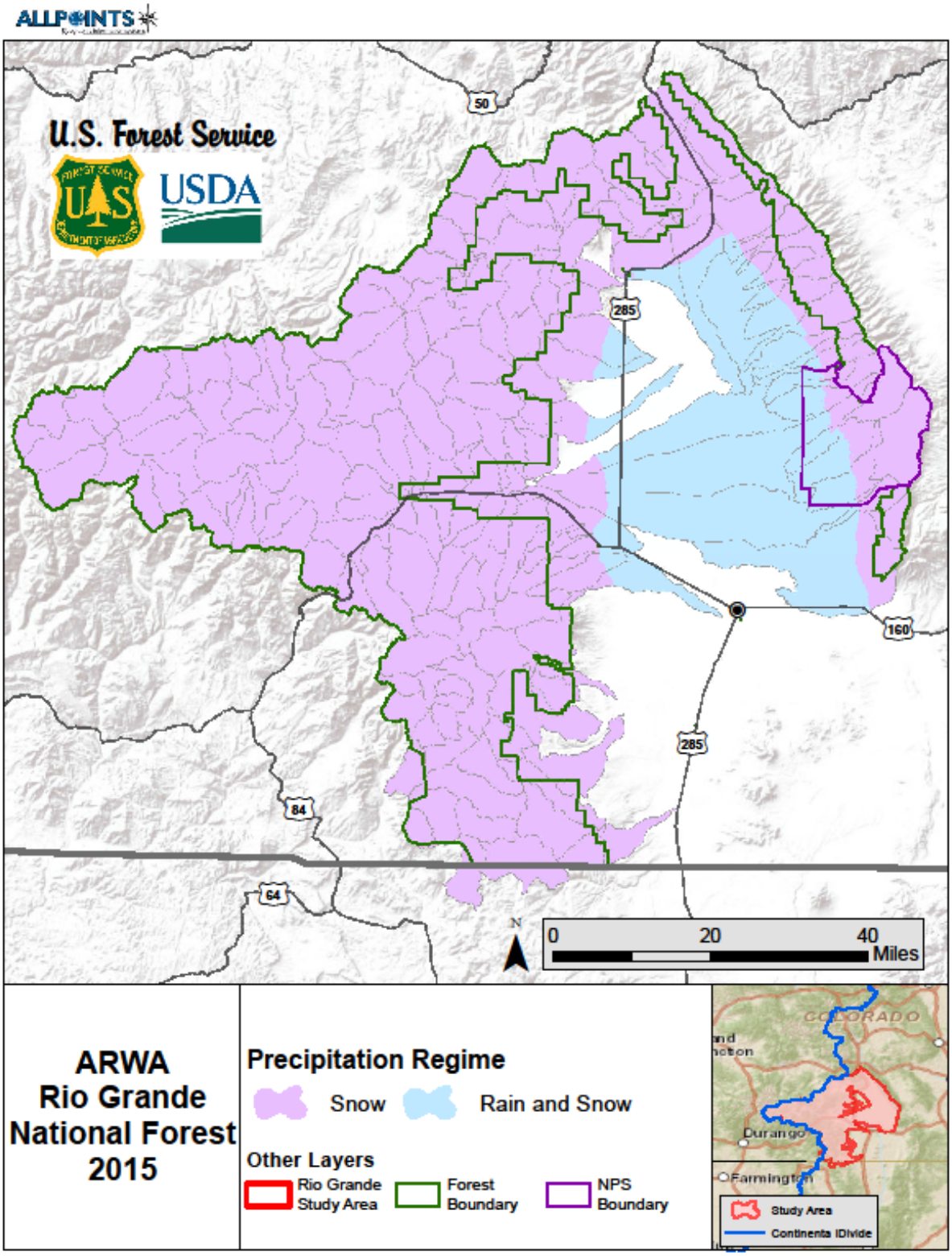


Figure 14. Hydroclimatic regime for the Rio Grande National Forest and surrounding landscape. Due to the relatively high elevation of the Forest, most this part of the landscape is in the snow driven hydroclimatic zone. Driven by high discharge during the summer months, channel maintenance discharge occurs during that time.

While it may seem intuitive to remove shading on low gradient reaches of streams that are generally considered "cold", there are far more negative impacts from this action than positive. Erosion, loss of food, aquatic and semi-aquatic organisms, etc. are much more impacted than the benefit it might have to increase temperature. In addition, depending on the position, and condition of the stream in relationship to the sun, lethal limits of water temperature can occur, even at higher elevations.

Special Note: The majority of the Rio Grande National Forest is located in the snow driven elevation zone. Aquatic productivity is relatively low at these high elevations, although aquatic species of plants can thrive if food, habitat and other limiting factors are not reduced significantly. Relatively short growing seasons and low temperatures related to reproduction can result in unsuccessful spawning efforts from fish. Connectivity, adequate water and discharge timing, habitat and temperature can be major limiting factors for aquatic and semi-aquatic taxa. Ensuring that important natural conditions of ecosystem elements maintaining the conditions for these taxa are very critical for the continued survival of water dependent species and ecosystem services such as angling. Areas at the lower elevational limits of the National Forest may be important areas for improved productivity in granitic dominated watersheds, due to increased water temperatures.

Stream Gradient

Due to the limited length of low gradient stream gradients on the Rio Grande National Forest, map scale was too large to graphically portray the different classifications.

Implications: Stream gradient influences stream power, aquatic productivity, erosive capability, localized sediment sizes, and floodplain characteristics. As a result, stream gradient dictates the habitat for specific flora and fauna. Steep gradient stream reaches are often called "erosional" reaches while low gradient reaches are called "depositional" zones. The sediment that is produced in the erosional zones will be deposited in the depositional zones, which thus can be indicators of upstream erosion. Indeed, steep stream channels have narrow floodplains and banks that are 'armored' with large rocks and boulders. They are very resistant to change, but move sediment through tem generally and are corridors for migration for aquatic species.

The medium gradient streams can be considered "transitional" reaches and have some of the characteristics of the steep and low gradient reaches. Low gradient reaches are very susceptible to upstream activities as well as local change. As a result, they are typically the reach that exhibits changes in channel morphology, temperature, and habitat and sediment accumulation. There banks are comprised of typically small alluvium from upstream and are extremely susceptible to erosion if the deep rooting riparian vegetation is removed or damaged. Low gradient reaches can act as "reservoirs" for storing water in the valley bottom, especially if beavers have colonized there. Terrestrial and aquatic animals are often much more abundant in low gradient valleys as habitat is diverse and abundant. Consequently, activities in the subwatershed where low gradient valleys reside that produce excess sediment, reduce woody material and change discharge dynamics can have a dramatic impact on these areas. In addition, local impacts that remove woody vegetation, compact riparian soils and damage stream banks can have a profound impact on these important areas.

Results: Only one cluster group out of 7 was dominated by low gradient stream reaches. A total of only 8 subwatersheds were in this cluster out of a total of 163 subwatersheds. This is not unusual for the southern Rocky Mountains considering the steep topography and erosional process occurring throughout its length. The White River National Forest to the Northwest of the Rio Grande had far fewer low gradient reaches and were smaller in length. None of the clusters identified in the White River assessment were dominated by low gradient reaches out of 435 subwatersheds. Further description of this driver will be explained in the Ecological Cluster results with subwatersheds and locations identified.

Special Note: The role of stream gradient reaches and their importance could be a valuable tool for future monitoring. As identified previously, low gradient reaches are sensitive to change, as are the plants and animals that inhabit them. By focusing monitoring on these important reaches, species and physical characteristics could be identified and utilized as tools for observing change. In addition, strategies to subsample and identify sampling ability could be developed to meet budgetary constraints as well as time limitations. A similar process is being conducted in the Pacfish/Infish Monitoring Plan (https://www.monitoringresources.org/).

Results: Aquatic and Riparian Clusters

There were a total of 7 statistically similar clusters identified for the Rio Grande National Forest with discernibly different ecological characteristics. (Table 2). Each of these clusters of subwatersheds revealed characteristics that can be translated in terms of aquatic productivity, sensitivity to management, temperature, aquatic and riparian habitat and stream discharge characteristics. The subwatersheds in each cluster are identified in a map of the Rio Grande National Forest and surrounding landscape to show geographic relationships and for identification (Figure 15).

Table 2. Results of the Ecological Cluster analysis. Each of the identified clusters contain average percentages of the ecological drivers identified within a particular subwatershed. The dominant driver within each cluster is highlighted in Red, while a "non-dominate" driver exhibiting a value that COULD BE important for management are highlighted in blue.

		Stream Gradient			Calcareous Geology		Sediment Size			Precipitation Regime	
Cluster ID	#HUCs	% Low	% Mod	% High	% Non-Calcareous	% Calcareous	% Fine Grained	% Med. Grained	% Coarse Grained	% Rain & Snow	% Snow
R1	2	9.3	18.3	72.4	37.4	62.6	0	2.7	97.3	4.1	95.9
R2	12	8.6	7.3	84.1	100	0	88.5	1.9	9.6	0	100
R3	52	5.3	8.8	85.9	99.3	0.6	11.2	2.2	86.5	0.2	99.8
R4	53	14.3	10.8	74.8	99.5	0	53.3	5.3	40.9	0	100
R5	20	29.4	23.7	46.8	95.1	3.8	12.6	2.4	83.9	1.3	98.7
R6	14	28.1	12.2	59.7	97.8	2.1	0.9	0.1	98.8	37.6	62.4
R7	10	79.8	6.5	13.7	99.5	0	2.2	0.5	96.8	72.1	27.9

The cluster ID and number of subwatersheds within each cluster are in the first column. A total of 6 of the 7 clusters were dominated by high gradient stream channels, which are closely correlated to steep topography, limited floodplains, aquatic and riparian habitats and ability for water storage in valley bottoms. Three of the clusters however exhibited more than 20% of their length in low gradient channels, indicating there could be areas that are quite influential on aquatic and production throughout the streams and riparian areas in each of the clusters, such as instream habitat and the size of riparian communities. These low gradient areas if functioning properly would be areas of groundwater storage in the alluvium in the valley floor.

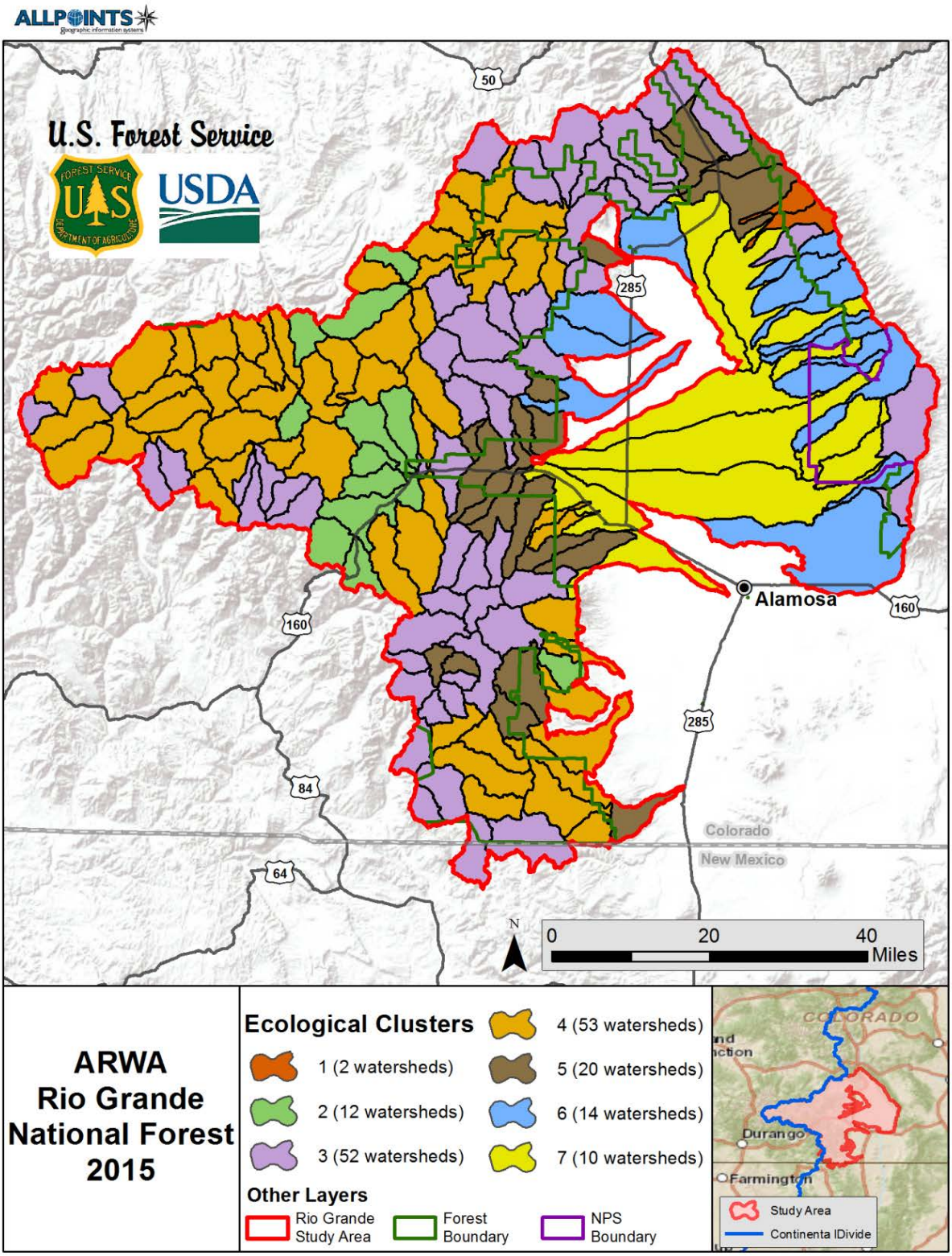


Figure 15. Results of the Aquatic/Riparian Cluster showing the location of subwatersheds within each cluster. Cluster numbers and the number of subwatersheds are also listed.

Only 1 cluster (R1) was dominated by calcareous geology, and as identified previously may be extremely important for harboring rare plants, animals and habitats such as springs and fens. As mentioned previously, this geology tends to be quite soluble and allows groundwater to surface where it is present. Downstream habitat for native fish could be important especially as habitat conditions may be more conducive to these fish.

A total of 5 of the 7 clusters were comprised of coarse grained sediment, primarily the result of the igneous, granitic bedrock dominating the Forest landscape. The 2 clusters dominated by fine sediment were primarily the result of weathering of volcanic basalts. These subwatersheds could also be quite productive if Calcium carbonate is released from the dissolved bedrock.

Coarse grained geology has dominated the clusters in all of the analysis areas on National Forests to date (including the San Juan, GMUG, White River, Arapahoe Roosevelt, Pike and San Isabel, Medicine Bow Routt and Bighorn). These results can be attributed to the overwhelming amount of coarse grained producing bedrock in the southern Rocky Mountains.

Because most of the National Forest is above 8000 in elevation, all of the clusters are located in the snow melt hydroclimatic zone. Only portions of 28 subwatersheds were associated with any rain and snow hydroclimatology at lower elevations. These subwatersheds however are fairly unique for the study area and could be important for taxa and habitats that are restricted to this precipitation regime. Wetlands would be expected to be of different character than colder, high elevation wetlands due to the flatter topography. In addition, plant and animal taxa associated with these wetlands could be quite different than the higher elevation wetlands.

Aquatic/Riparian Cluster 1R

Management Scale Aquatic and RIPARIAN Cluster 1R

- Stream gradient – High
- Geochemistry – Calcareous
- Sediment production – Coarse
- Hydroclimatic regime – Snow

The 2 subwatersheds in the 1R cluster are at mostly high elevations along the North East side of the Sangre de Cristo Mountains, and comprise only 1% of the number of subwatersheds on the study area (Figure 15). Limestone and sandstone is relatively abundant as remnants of an ancient ocean bed. Springs would be expected in these subwatersheds, helping stabilize stream temperatures and increasing ph levels. Streams and wetlands in these HUCs could be quite productive and if instream habitat is adequate, fish and benthic macroinvertebrates densities and biomass could be considerably higher than surrounding streams. Approximately 40% of the geology is comprised of the granitic bedrock protrusion that occurred from the uplifting of the Rio Grande Rift. While the calcareous geology “dissolves” in water over time, the coarse granitic sediment would tend to stay intact on the hillsides and mixed in stream channels.

Tall willows, river birch, and alder are expected along perennial streams, and willows would be the dominate vegetation along intermittent streams. The abundance of calcareous geology that could create opportunities for perennial springs, which would also support well developed riparian vegetation and provide habitats for unique species or riparian communities.

Stream gradients are typically high, but these HUCs average about 18% or more low-gradient channels. If streams are large enough, native fish could thrive in this area. Given the topography, disturbance of coarse soils could result in aggradation in stream channels, and filling of aquatic habitat. The

combinations of gradient, geology, and moderate sediment producing geology would foster a relatively high level of aquatic and riparian productivity compared to other clusters if precipitation is adequate and stream size is large enough.

Conclusions for Cluster 1R

Although this cluster occupies a limited area of the Rio Grande National Forest, it could represent an extremely important area from a biodiversity standpoint. Caves and springs are known in the area and trout are quite abundant in the stream system on the east side of this area (personal observation), even though the stream gradient is high. Ground water input through springs could harbor relict plants and animals for thousands of years due to the consistent water quality and quantity. In addition, if stream conditions, including habitat are adequate, the streams within this cluster should be very productive, and could be a high priority for the reestablishment of native fish.

Aquatic/Riparian Cluster 2R

Management Scale Aquatic and RIPARIAN Cluster 2R

- Stream gradient – High
- Geochemistry – Non-Calcareous
- Sediment production – fine
- Hydroclimatic regime – Snow

This cluster occupies 12(7%) of the 162 HUCS in the study area and is located in relatively steep topography and steep streams. They are all located on the west side of the Rio Grande Rift, associated with the San Juan Mountains. (Figure 15). The major feature separating it from the other clusters is the high abundance of volcanic soils. While volcanic rock can erode into different sizes and compositions, the basaltic base of this area produces fine sediment that also forms fine grained soils. There are also granitic rock found in this area, however, the volcanic rocks appear to be quite erodible. This fine sediment erodes easily when rain washes it from the hillsides, especially where vegetation and debris has been removed and ground disturbing activities have left the soils vulnerable.

Depending on the chemical composition of the soils produced, they can be quite fertile as minerals are released as the volcanic sediment dissolves. Indeed, some volcanic soils are considered the most productive of any soil type. Wetland and riparian vegetation in these clusters should also be fast growing and healthy.

Due to its “fine texture”, erosion in this cluster can be high during rainstorms and snowmelt runoff. Under natural conditions it would be expected that these fine grain sediments would be transported quite easily downstream and be deposited in only the lowest discharge areas, either on point bars, floodplains or the inside of meanders on low gradient reaches. However, if new sources of sediment have accumulated due to anthropogenic influences, they could overwhelm the energy in the system and be deposited within stream channels and have a major influence on low gradient reaches.

This cluster contains a relatively little low gradient reaches (<10% of total stream length). However, streams in this cluster could be more productive than those with igneous geology for native fish restoration, if all other attributes are the same. Measurements of ph and conductivity could easily tell if the volcanic geology is influencing water quality properties.

Conclusions for Cluster 2R

Subwatersheds in this Cluster are characterized by steep stream channels and topography (<84% of stream length in high gradient). While some reaches exhibit lower gradient slopes, this cluster is also dominated by small size volcanic sediment. These sediments should produce productive riparian areas, and the small sediment size could dissolve and improve water chemistry and productivity. Erosion could be high if considerable anthropogenic activities have occurred that expose soils. These fine grained sediments has the potential to reduce riparian and especially stream habitat if they overwhelm the systems. Low gradient reaches that show significant sedimentation and stress are most likely a result of upstream activities. Wide, shallow and exposed low gradient stream reaches could result in poor habitat conditions and especially elevated stream temperatures.

Aquatic and Riparian Cluster 3R

- Stream gradient – High
- Geochemistry – Non-calcareous
- Sediment production – Coarse
- Hydroclimatic regime – Snowfall

There are a total of 52 (32% of the total subwatersheds) in this Cluster. This is the second most dominant cluster in the study area and would be expected with the overall high elevation, igneous geology dominating the area, and relatively steep topography. The subwatersheds are distributed throughout the study area, but are most pronounced in a north/south direction on the west side of the San Luis Valley flanks and mountains and into the high elevations to the north (Figure 15).

The dominant ecological driver characteristics indicate most streams in this cluster are not particularly sensitive to changes in either water or sediment input (Table 2). Igneous, granitic bedrock dominates the entire San Luis valley, accept where there has been volcanic activity. Stream channels would tend to be fairly stable because of the coarse-grained soils and stream banks that under normal conditions would be fairly embedded. However, in the relatively few areas where there are low gradient stream channels with increased habitat, deposition could be influenced by the erosional properties upstream. If riparian vegetation is stabilizing stream banks in these areas should result in increased stream depths on the outside of menders, where velocities are highest. However, increased erosion, discharge, soil exposure and loss of woody riparian vegetation rooting from past and current anthropogenic activities could have extensive impacts on habitats in this cluster because the overall stream energy is very high. Streams that carry additional sediment will have a considerable amounts deposited in the stream channel, where further movement would be very difficult. Midstream gravel bars could form in areas of reduced velocities, forcing streams to move laterally into the banks, causing more erosion and increasing the width depth ratio of the channel. These conditions are extremely difficult for the stream energy to change, and physical alterations might be necessary to reverse the process.

Groundwater input to the surface would be expected to be limited to isolated wetlands with groundwater characteristics (e.g. springs and fens) that are not interconnected. High elevation valleys would contain an abundance of wetlands due to the variable topography, high precipitation and terrain developed by glacial movement. Surface water driven wetlands would also be widely distributed in concave depressions and conducive to collecting surface runoff.

The abundant gravel and cobble is associated with relatively stable stream channels and banks. Riparian vegetation would be abundant along small and larger streams, willow-dominated vegetation at higher elevations, and taller willows, cottonwoods, and alder at lower elevations. It would be expected that some

of the larger stream channels are found in this cluster, providing additional habitat for native trout and other fish. The potential for "high quality" recreational fishing opportunities are most likely found in this cluster. There should be abundant habitat in these areas due to larger channels, which would improve longevity and growth of sport fish. There would appear to be limited opportunity for larger tributaries to the Rio Grande River on most of the Rio Grande National Forest, and maximizing stream habitat conditions would be a major goal to keep the high quality experience.

Instream productivity would in large part be dependent on food sources and detritus from outside the stream system (allochthonous), with energy in the form of sunlight and nutrients from riparian detritus being more important seasonally. Trout and riparian food from terrestrial invertebrates typically dominates food for fish especially during the snowmelt runoff period and fall. To sustain adult fish and riparian taxa, riparian areas would need to be healthy, with woody vegetation being abundant and at a mid to late seral stage for shading purposes and sources of terrestrial food and detritus. High elevation, small streams would especially be unproductive as ph would probably be less than neutral, temperature and habitat would also be limited. While native trout would no doubt be present where habitat is acceptable, their populations could be limited by a number of factors.

Conclusions: In a natural state, the aquatic systems in this cluster would be expected to be quite resistant to sediment movement, albeit stochastic influences such as wild fire could cause short term inputs the steep topography. The resiliency of these areas would be quite high following natural events and recover quickly much quicker than impacted systems.

However, if anthropogenic influences reduced resiliency, large amounts of coarse sediment could enter stream areas and wetlands, depositing in important habitats. Moving unnaturally elevated material with normal flow regimes would be extremely difficult, leaving wide, shallow and homogenous stream channels with little productivity. Smaller order stream reaches receive less sediment due to their limited watershed area. Larger streams that have been impacted over decades can be restored with care, to focus restoration efforts where impacts, risk and opportunity are greatest.

The limited low gradient reaches would be important for monitoring subwatershed conditions, due to their sensitivity. Stream temperature, sediment deposition, riparian development, biota and morphology are variables that can be quantified in these areas.

Aquatic and Riparian Cluster 4R

Management Scale Aquatic and Riparian Cluster 4R

- Stream gradient – High
- Geochemistry – Non-calcareous
- Sediment production – Fine
- Hydroclimatic regime – Snow melt

Subwatersheds in cluster 4R are primarily at high elevations, dominated by high gradient stream channels. There are a total of 53 subwatersheds (33% of the total) in this cluster that has the highest percentage of fine grained sediment producing geology of all the clusters. Fine grained sediment producing geology accounts for the second highest percentage with 53% (Table 2). These subwatersheds are all located in the western portion of the Forest, from the north to the southern boundaries (Figure 15). The high proportion of both coarse and fine sediment producing geology in this portion of the landscape is a direct result of the igneous and volcanic bedrock underlying the entire Cluster. The process that caused this geologic change is explained in Figure 13. The combination of these geologies can influence the aquatic systems

typical of that explained for Cluster r4, where coarse grain sediment dominated and Cluster r3 that was dominated by fine grained sediment.

The location of each of these 2 geologies and amount exposed would predict which would have the most influence on aquatic and riparian systems. For instance, a subwatershed that is primarily comprised of igneous bedrock in all but the lowest elevation would be expected to be relatively stable with larger substrate and reduced erosion unless disturbed. Groundwater could be exposed through fissures and faults that reach the ground surface. The lower section could have significantly more unstable soils but more productive. Of course, combinations of the 2 would be found in many subwatersheds. Wetlands could be formed by the "cementing" of fine grained material to form impervious depressions on the landscape and runoff from the surrounding landscape. Groundwater surfacing from volcanic sediments could form underground water pressure moving upward through the unconsolidated fine grained sediment, as well as gradual solution of the basaltic geology. Riparian and wetland soils would be expected to be deeper and more productive in the areas with finer sediment.

Where the fine and coarse sediment have "mixed", natural rain events could destabilize the sediment by moving the fine material easily, dislodging the coarser material as well. Once the sediment has entered the stream channel, sorting would most likely occur, with fine grained material moving further downstream and the igneous sediment settling more rapidly. Again, the volcanic fine sediment could influence and raise ph levels slightly, accounting for higher productivity. Groundwater would be greatly influenced by the permeability of the combination of each of the geologic types, depending on the dominant geology.

Conclusion: This large, mixed geology cluster has the most heterogeneous characteristics of any of the clusters. Several ecological drivers are similar to Cluster 2: 1. Both are dominated by high stream gradient and topography, with R4, less so, 2. Both are in high elevation, snowmelt driven systems, 3. R4 contains significantly higher amounts of fine sized sediment that will produce more productive and deeper soils for riparian and wetlands. The increased amount of low gradient stream channels in R4 and potentially higher productivity could be a reason to address riparian condition and stream habitat in relationship for native and desired non-native fish and riparian vegetation management. From that standpoint, some subwatersheds in may have similar riparian and stream habitat potential.

Aquatic and Riparian Cluster 5R

Management Scale Aquatic and Riparian Cluster 5R

- Stream gradient – High
- Geochemistry – Non-calcareous
- Sediment production – coarse
- Hydroclimatic regime – snow melt

There are 20 (12%) subwatersheds in this cluster. Most are located in the western and southern part of the Forest, although there are 4 located in the extreme northern portion of the Forest (Figure 15). Of particular importance is that a considerable portion of the streams that are in low and medium gradient stream channels (Table 2). This cluster exhibits the second highest percentage of medium and low gradient stream gradient (Cluster 7 being the highest) of any Clusters.

Although the geology produces predominately large sediment, the terrain exhibits lower slopes than other clusters, resulting in reduced natural erosion, and wide riparian valleys to buffer some stream channels. Anthropogenic activities that reduce riparian and wetland cover and expose sediment could result in

considerable damage in the low gradient reaches. These habitats would be valuable for plant and animal diversity due to the abundance of surface and ground water and associated riparian vegetation. In addition, there should also be an abundance of low gradient meandering stream channels with considerable instream habitat (e.g. water depth) for fish, beaver and other aquatic and semi-aquatic species. Surface fed wetlands would also be expected to be more numerous in this Cluster.

Groundwater storage in low gradient stream channels could also be abundant if stream channels have not degraded significantly, and riparian vegetation is maintaining soils. The coarse sediment that is abundant in this cluster maintains interstitial spaces large enough to store considerable water in the floodplains that could be released slowly in drought years, maintaining downstream flows. In addition, artesian springs and associated wetlands would be present in the wide valley bottoms if storage capacity is maintained.

Wetlands would be quite variable in terms of characteristics due to the highly variable landscape. While the geology appears to be granitic, fissures could result in ground water surfacing, while lower slope landscapes could capture water in depressions and small catchments.

Conclusions: This cluster has a diversity of stream gradients, valley types and topography. Instream and riparian habitat in particular are diverse, and have the potential for good instream and riparian habitat that are not abundant throughout the Forest. Riparian and stream restoration where necessary could be a priority for these subwatersheds. The variety of topography could result in different forms and abundance of wetlands. Fishery resources could also be a priority as low gradient channels are important for native and non-native recreational fisheries. The potential for large riparian areas would also be important for wildlife and riparian restricted plants

Aquatic and Riparian Cluster R6

Management Scale Aquatic and Riparian Cluster R6

- Stream gradient – High
- Geochemistry – Non-calcareous
- Sediment production – coarse
- Hydroclimatic regime – rain and snow (72%)/ snow (30%)

There are 14 (8%) subwatersheds in this cluster (Table 2) that are located partially within the Sangre de Cristo Mountains (Figure 15) and exhibits the second highest area within the rain and snow driven hydroclimatology of any Cluster. These characteristics could have a major influence on flora and fauna, as they are mostly at lower elevations, and represent a transition between the valley floor and mountains (figure 9). It should be noted however that a high percentage of the Rio Grande National Forest boundary is in the Snow melt driven zone but have influences from both precipitation zones. A portion of this Cluster is also within the Great Sand Dunes National Monument. As mentioned previously, aquatic taxa have evolved their life history strategies to coincide with the most beneficial times of the year, especially considering temperature and annual hydrograph characteristics. There could be changes in taxa and population structures of fish, benthic macroinvertebrates and plants as a result of the warming in some portions of these subwatersheds if they exhibit different characteristics. One important characteristic of the subwatersheds in this Cluster along the Sangre de Cristo Mountains is that they enter the alluvium at the foot of the mountains and flow underground. Some of the water surfaces further out into the valley, creating wetlands and streams. These conditions, along with the influence of some limestone geology produce unique characteristics within their boundaries for plants and animals.

Subwatersheds located on the west side of the valley in these clusters are also relatively low in elevation, with a relatively low percentage of their area within the National Forest boundary. However, due to the variable conditions there they could also be investigated for unique ecosystems and/or taxa.

The high variability in the hydroclimatology in most of this cluster is due to more rain events in the spring-fall as well as the snow melt influence. This variability plus influences of management could cause considerable erosion and sediment movement during rain events. The coarse material entering the stream channels and wetlands would be difficult to move onto floodplains and out of surface water driven wetlands. In addition, surface water dependent wetlands, such as marshes would be expected in the lower elevations, resulting from flatter topography and increased surface water runoff throughout most of the year (Wohl et al, 2007). The diversity of aquatic and semi aquatic wetland dependent animals such as southern leopard frogs (Rana sphenocephala) and many different species of birds would be expected in these habitats.

Conclusions: This cluster has characteristics of both the higher elevation and mid-elevation hydroclimatology. While these boundaries represent a “shift” in ecological drivers, they are not precise. There still could be characteristics of both zones however, with variability in wetlands, precipitation and taxa of plants and animals. Due to these factors, the elevation portion of these subwatersheds in cluster R6 that are at lower elevations may have a much different plant, animal and aquatic habitat type than the upper elevations. With streams flowing subsurface for a distance once they reach the valley floor, very unique conditions persist in this Cluster both inside and outside the Forest boundary. Much of the valley floor has been managed quite intensively for agriculture and may not have the unique characteristics of the Forest Service. Closer examination of these areas could result in finding unique taxa and habitats, or the opportunity for restoration efforts. The streams upstream from the valley floor may be important for native trout or other taxa restoration as a “natural” barrier exists for many streams. Along with the National Park Service, public land is abundant and dominates several of these subwatersheds, Restoration of native fish could be administratively more efficient where federal land ownership occurs.

Aquatic and Riparian Cluster R7

Management Scale Aquatic and Riparian Cluster R7

- Stream gradient – Low
- Geochemistry – Non-calcareous
- Sediment production – coarse

Hydroclimatic regime – snow (72%)/ rain and snow (28%)

Results: There are 10 subwatersheds (13%) in this cluster (Table 2). The subwatersheds occupy a very small portion of the National Forest, with the majority being located on the valley floor and at the foot of the Sangre de Cristo Mountains, including the Great Sand Dunes National Monument (Figure 15). The very small portion of this cluster on the National Forest lands are located at high elevations and may be mostly in the alpine or sub-alpine ecosystem. This area would be expected to have high snow accumulation and considerable soil saturation, being conducive to wetland development. The lower elevation of the cluster occupies a significant portion of the National Monument, as well as some of the toe slope of the mountain range where erosion from glacial activity and runoff deposited coarse material. Stream gradient on the National Forest would be expected to be mostly steep, although some calcareous geology may persist with groundwater fed springs being present, similar to Cluster r6. While active management appears to be relatively limited (see Assessment 1), there could be rare flora and fauna in these high elevation, potentially spring fed systems.

Conclusions: This cluster is predominately characteristic of the valley floor and toe of the Sangre de Cristo Mountains. There is little representation on the Forest of this cluster that could be considered a different ecosystem type than R6. The overwhelming percentage of this cluster in the valley floor dominates the ecological drivers in the entire cluster. As such, the portion of this cluster found on the National Forest is most likely similar to R6. The Sangre de Cristo Mountain range with this Cluster type could have rare and/or important flora and fauna that are associated with high elevation groundwater fed wetlands.

Appendix - Ecological Drivers Not Included In The ARWA Process, But Pertinent To Assessment 3 For The Rio Grande National Forest Plan Revision

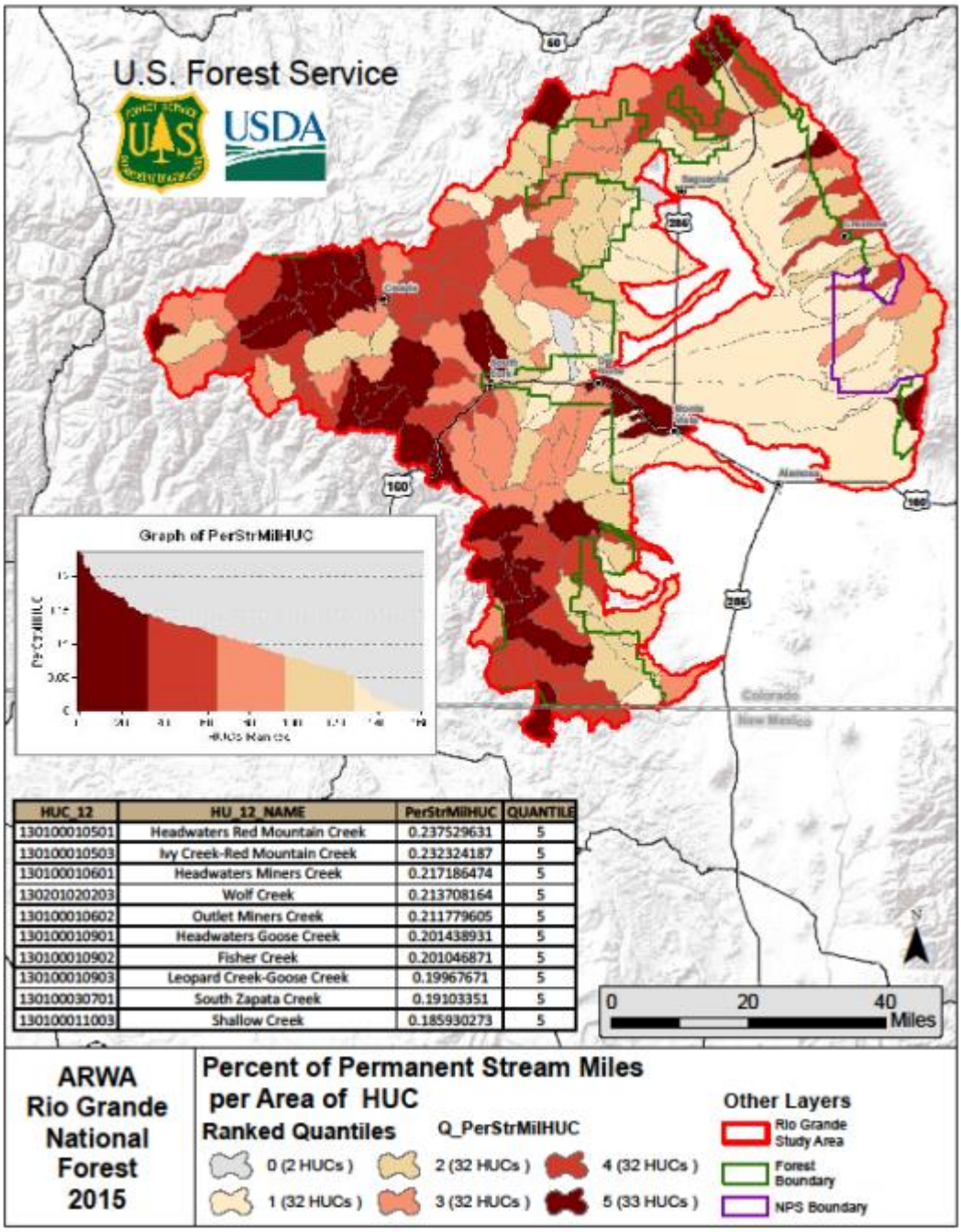
Stream Density As A Driver For Riparian And Aquatic Habitat Considerations

Dave winters and Thomas Tanyae
USDA Forest Service
Rocky Mountain Region

Numerous habitat requirements have been shown to influence salmonid and other aquatic organism's success in stream environments (Bjorn and Reiser, 1991). In addition, riparian habitats require the ecological form and function of riverine systems and resulting floodplains for their existence. It is not the purpose of this document to identify stream length or density within the subwatershed scale as "overriding" other habitat considerations, there are numerous other environmental and anthropogenic factors that are important individually or cumulatively that have major influences on plant and animal populations. However, in the arid and semi-arid Rocky Mountains, water is an extremely valuable commodity for increasing human populations, and the impacts from past management activities have either depleted water or influenced the form and function of streams and riparian areas (Wohl, 2001). The density of permanent stream networks is a "tool" that we can measure remotely that may identify needs to evaluate these systems at a finer scale. Fine scale influences, such as human caused fragmentation, habitat reduction, increased fire, vegetation removal and pollutants as well as predicted influences from a changing climate indicate that identifying the largest "patch size" for restoration and maintenance of aquatic, wetland and riparian ecosystems and taxa may be a consideration for management (Isaak, et al. 2012).

The purpose of this analysis was to identify the densities of permanent stream channels in the study area, assisting managers identify priorities and develop plans for restoration and protection as well as provide high value recreational fishing opportunities. Abundant riparian and wetland ecosystems would also be expected to persist in these areas, with increased plant and animal biodiversity more abundant and potentially more stable.

Results of this analysis are provided in Figure 16. There are 23 subwatersheds within the Rio Grande National Forest that are in the highest quantile for stream density, ranging from 0.3 to 0.2 miles of stream per acre for the 10 highest density subwatersheds. There appears to be a high correlation between elevation and these high density subwatersheds that is not surprising given that precipitation generally increases, and temperature decreases with elevation in the Rocky Mountains. Based on these results, the San Juan and Weminuche Wilderness areas may be "strongholds" for native taxa in the future. In addition, these subwatersheds are less "actively" managed and could continue to provide colder and less impacted water to lower elevations, especially if the effects of climate change will increase water temperatures at lower elevations. Stream size is also generally considered a good predictor of potential habitat and population size of aquatic species in the Rocky Mountains. There are several subwatersheds that exhibit relatively stream density (quantile 2-3) that would also be expected to have somewhat higher stream temperatures, and increased stream and riparian habitat complexity. Maximizing recreational fishing opportunities for non-native sport fish may be important in these areas where the public can easily access them, which benefits the local economy as well.



HUC_12	HU_12_NAME	PerStrMilHUC	QUANTILE
130100010501	Headwaters Red Mountain Creek	0.237529631	5
130100010503	Ivy Creek-Red Mountain Creek	0.232324187	5
130100010601	Headwaters Miners Creek	0.217186474	5
130201020203	Wolf Creek	0.213708164	5
130100010602	Outlet Miners Creek	0.211779605	5
130100010901	Headwaters Goose Creek	0.201438931	5
130100010902	Fisher Creek	0.201046871	5
130100010903	Leopard Creek-Goose Creek	0.19967671	5
130100030701	South Zapata Creek	0.19103351	5
130100011003	Shallow Creek	0.185930273	5

Figure 16. Stream Density results (miles of permanent stream/ acre/6th level HUC) for the Rio Grande National Forest and surrounding landscape. Most of the highest density subwatersheds are located on the northern and western portion of the basin at high elevations.

Management Considerations

Stratifying the study area by stream density presents several important management considerations and options. First, areas with high density and quality could be considered the highest priority for stream and

riparian related management. The relatively high number of these subwatersheds in the western portion of the national forest may be more productive, due to the potential for volcanic soils releasing important micro nutrients. However, in the Sangre de Cristo mountain range, the presence of calcareous geology may provide very high habitat conditions as well, given lower stream densities. Special consideration of subwatersheds located in the Sangre's where stream density and productivity is high could be very important for restoration consideration. The highest density subwatersheds identified in Wilderness designated landscapes could be considered as being important "strongholds" for aquatic, riparian and wetland species if water temperatures and associated influences, such as modified hydrology and invasive species establishment occur at lower elevations. They could also be considered for the reestablishment of native Rio Grande cutthroat trout that may be at risk from climate change at lower elevations in the future.

Wetlands in Glaciated Areas of the Rio Grande National Forest: Supplemental Information for Forest Planning

Joe Gurrieri, Dave Winters, Dennis Cleary, Thomas Tenyah

Introduction

The Rio Grande National Forest (RGNF) contains thousands of acres of high quality wetlands and other groundwater dependent ecosystems that provide essential services to the Forest and lands downstream. A disproportionately large number of wetlands occur in the glaciated areas of the forest. Understanding of wetland occurrence in relation to the geomorphology of the forest can help guide forest planning and management decisions pertaining to aquatic ecosystem sustainability, restoration, and climate change resilience (FSM 2881, FSH 1909.12 - Chapters 10, 20, and 30). For detailed information on incorporating groundwater dependent ecosystems into forest planning see Forest Service, National Groundwater Program, and Working Guide: Evaluating Groundwater Resources for Forest Planning, Release 1 – October 20 2015.

Geomorphology and Wetland Development

The most significant natural force in wetland creation in the northern hemisphere has been glaciation (Hammer 1996) and glaciation was a major factor in creating the wide variety of wetland habitats in the Rocky Mountains (McKinstry et al. 2010). Mountain valleys in the Southern Rocky Mountains are relatively young topographical forms created by the erosional and depositional effects of streams and glaciers (Windell et al. 1986). Glaciation has had a large influence on landforms at high elevations through large-scale erosional and depositional processes and has a large influence on the presence and distribution of wetlands (Rocchio 2006). Glacial features such as moraines and kettle ponds often result in a landscape conducive for fen formation. Terminal or lateral moraines often create a confined basin where impounded subsurface and/or surface water allow for peat accumulation (Windell et al. 1996; Cooper 1990; and Cooper 2005) whereas kettle ponds promote fen formation along the fringes. In addition, glaciation has created wide, relatively level mountain valleys where large wetland complexes tend to form (Rocchio 2006). Fens often form in these valleys due to the presence of permeable unconsolidated aquifers and springs supplied by snowmelt from adjacent hillsides (Cooper 1990).

High mountain wetlands in glaciated areas are fundamentally different than wetlands occurring at lower elevations that were never glaciated (Cooper and Lee 1987). Glacial moraines deposited during the Pleistocene have modified surface runoff and groundwater storage, roughening the topography and impeding drainage. Wetlands within the zone of glaciation have cold soils, often accumulate peat, and are greatly influenced by snowmelt water in early summer (Cooper 1990). Wetlands often form in the depressions in such landscapes if the water table is close to land surface. Most of the depressions do not have streams entering or leaving them; therefore, streamflow generally is not a major source of water to the wetlands. Wetlands in these areas receive their water supply from precipitation and groundwater discharge.

Many types of wetlands occur in the Rocky Mountains with palustrine emergent wetlands being an ecologically important type. Some palustrine emergent wetlands are classified as fens. Fens in Colorado belong to the Rocky Mountain Subalpine-Montane Fen Ecological System (Nature serve, http://explorer.natureserve.org/servlet/NatureServe?searchSystemUid=ELEMENT_GLOBAL.2.722842). Fens are confined to specific environments defined by groundwater discharge, soil chemistry, and peat

accumulation of at least 40 cm. Most fens in the Rocky Mountains are considered Intermediate to rich fens, however this system includes extreme rich and iron fens, both being quite rare (Rocchio 2006). Fens form at low points in the landscape or near slopes where groundwater intercepts the soil surface. Groundwater inflows maintain a fairly constant water level year-round, with water at or near the surface most of the time. Constant high water levels lead to accumulation of organic material. In addition to peat accumulation and perennially saturated soils, the extreme rich and iron fens have distinct soil and water chemistry, with high levels of one or more minerals such as calcium, magnesium, or iron (Rocchio 2006).

Rich and extremely rich fens are found in areas underlain by limestone. Water chemistry ranges from neutral to alkaline and is usually distinctly calcareous. Marl deposits (precipitated calcium carbonates) are common in these systems. Tufa deposits or terraces can be seen in some rich fens and are composed of virtually pure calcium carbonate at the soil surface, formed by continuous discharge and evaporation of calcite saturated groundwater. Calcareous rock units on the RGNF are confined to the Sangre de Christo Range (Figure 13). Volcanic rocks in the western part of the forest are not typically considered calcareous however pH values can be alkaline. The median pH values for groundwater wells sampled by the USGS in Park County, Colorado were 7.6 standard units for the volcanic-rock aquifers and the predominant cation and anion were calcium and bicarbonate (Ortiz 2004). It may be possible for groundwater of this chemistry to produce rich fens and diverse spring habitats. Rich fens and other diverse springs can also be found on glacial sediments derived from calcareous bedrock and moved downslope.

Digitized NWI mapping by Lemly (2012) provides an estimate of 38,174 acres of wetlands and 4,687 acres of lakes, rivers, and streams on the RGNF. This estimate represents approximately 2% of the land area within the Forest, a proportion that is similar to coarse estimates calculated for the entire state of Colorado (Dahl 1990). An independent analysis using NWI mapping was conducted by the Region 2 staff. Our analysis shows that 50% of palustrine wetlands within the forest boundary are in glaciated zones, yet glaciated zones comprise only 30% of the RGNF (Figure 17). These results show a disproportionate amount of wetlands in glaciated areas. These areas are extremely important for their biodiversity as well as functioning as natural “reservoirs”, which release water slowly to downstream reaches.

Climatic variables influence hydrological processes, so any change in precipitation, evapotranspiration, snow accumulation and snow melt will influence recharge to groundwater systems. Future climate change will affect recharge rates and, in turn, groundwater levels and the amount of groundwater available to support springs and wetlands (Ludwig and Moench 2009). Land use changes can also alter watershed conditions and generate responses in biological communities and processes. Land use changes may even override hydrologic modifications caused by large-scale climate shifts.

Lemly reports that 65% of all NWI mapped acres occur in the subalpine ecoregions, and another 29% of NWI acres occur in the alpine zone. These ecoregions also correspond to the areas that have been glaciated. Lower elevation zones represent very few wetland acres.

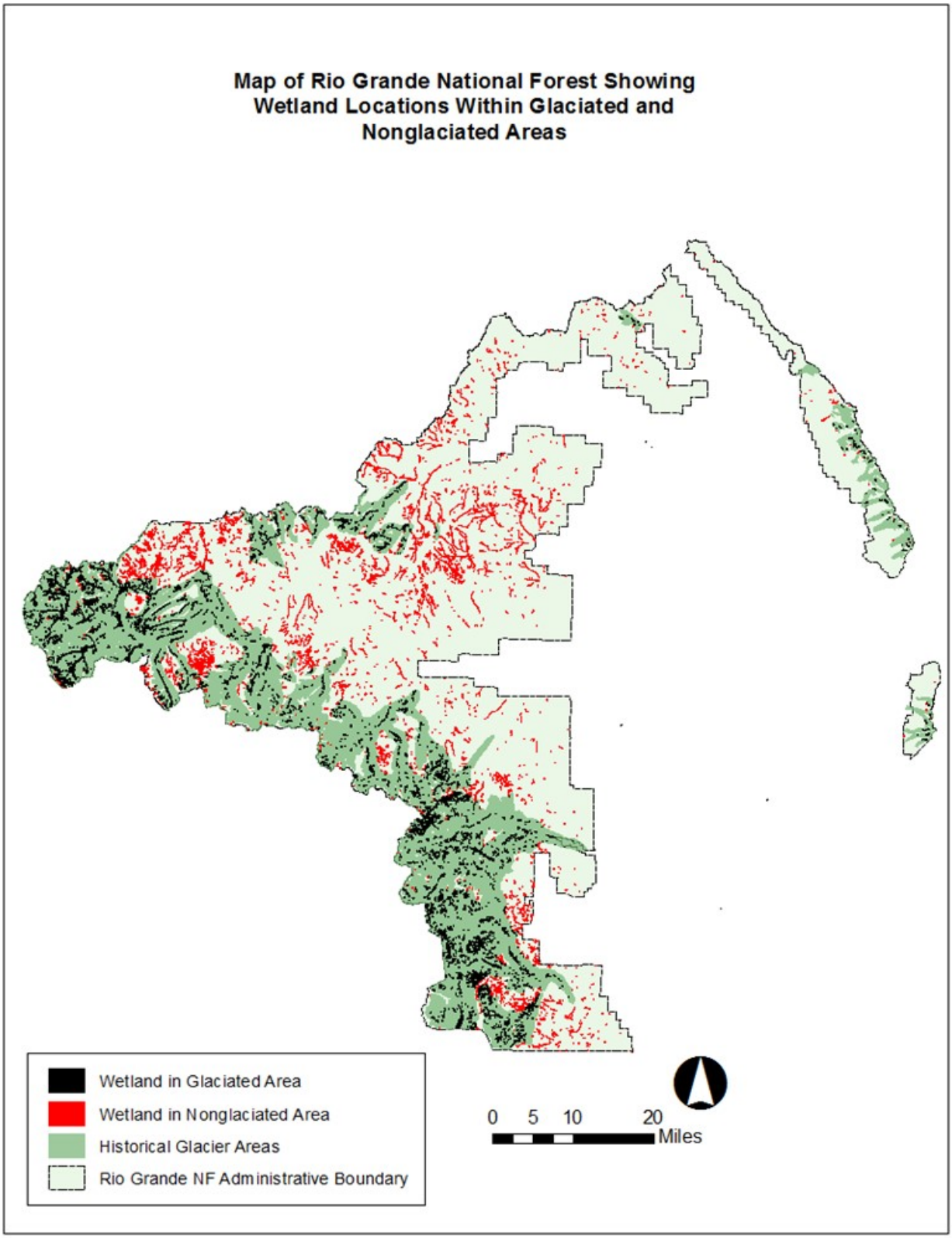


Figure 17. Distribution of wetlands in comparison to the extent of glaciation on the Rio Grande landscape. A total of 50% of the current wetlands on the Rio Grande National Forest are located within Glaciated areas.

In the western United States, winter and spring air temperatures have increased (Folland et al. 2001), the onset of snowmelt is earlier, and the snow water equivalent of snowpack has decreased. These and other indicators are especially important for groundwater dependent ecosystems, and have implications for groundwater recharge, which maintains springs, wetlands, soil moisture, and stream baseflows. In mountainous terrain, snowpack is the main source of groundwater recharge (Winograd et al. 1998). Higher minimum temperature can reduce the longevity of the snowpack, and decrease the length of time aquifer recharge can occur in various lithology's, potentially leading to faster runoff and less groundwater recharge. Decreased groundwater recharge can negatively affect aquatic biota and reduce wetland habitat. Unfortunately, the lack of comprehensive data on groundwater-surface water interactions precludes modeling efforts to determine current groundwater resources and predict changes due to climate (Drexler et al. 2013).

The hydrogeologic setting is important to consider when assessing the climate induced changes to groundwater systems. Geologic units will respond differently to changes in precipitation due to their hydrogeologic properties (hydraulic conductivity, primary vs secondary porosity, fractures vs porous media, etc.). On the RGNF several different hydrogeologic settings can be delineated (igneous/metamorphic, volcanic aquifers, and unconsolidated glacial/alluvial aquifers).

The properties of aquifers are essential to consider; small, shallow unconfined aquifers respond more rapidly to climate change, whereas larger and confined systems have a slower response. Alpine glacial deposits generally support small, unconfined and shallow aquifers. These are more likely to have renewable groundwater on shorter time scales and will be particularly sensitive to changes in climate (Winter 1999; Sophocleous 2002).

The recharge characteristics of different hydrogeologic settings also influence vulnerability to climate change. For example, igneous and metamorphic rocks that exhibit low permeability and porosity, low volume groundwater discharges to groundwater dependent ecosystems, and are recharged only during large infrequent precipitation or snowmelt events, may be less influenced by climate change than unconsolidated or basalt aquifers that have high permeability and porosity, larger volume discharges to groundwater dependent ecosystems, and are recharged more frequently.

The effects of climate change on groundwater dependent ecosystems will differ as a function of local geology and specific climatic variables. In a study that combined examination of aerial photography (over 50-80 years) and climate analysis, Drexler et al. (2013) showed that five fens in the Sierra Nevada (California) decreased 10 to 16 percent in area. This decrease in area occurred over decades with increased annual mean minimum air temperature and decreased snow water equivalent and snowpack longevity. However, two fens in the southern Cascade Range, underlain by different geology than the Sierra Nevada, did not change in area. The volcanic lithology's of the Cascade sites, with high groundwater storage capacity, likely affected recharge of groundwater.

Changes to groundwater levels can alter the interaction between groundwater and surface water (Hanson et al. 2012). Groundwater storage acts as a moderator of surface water response (Maxwell and Kollet 2008). Climate-induced changes in groundwater/surface water interactions will directly affect stream baseflows and associated springs and wetlands (Earman and Dettinger 2011; Kløve et al. 2012; Candela et al. 2012; Tujchneider et al. 2012). Changes in groundwater can change wetland water balances, leading to lowered water level and reduced groundwater inflow. For terrestrial and riparian vegetation, a shift in location, as well as in species composition, can occur.

A reduction in average groundwater level tends to promote soil aeration and organic matter oxidation. The generation and maintenance of peat soils over time depend on stable hydrological conditions, and in recent studies of peatlands exposed to groundwater lowering, soil cracking, peat subsidence and

secondary changes in water flow and storage patterns have been observed (Kværner and Snilsberg 2008, 2011).

Freshwater springs are dependent on a continuous discharge of groundwater and form subsurface–surface water and aquatic–terrestrial ecotones, which are important components of aquatic biodiversity (Ward and Tockner 2001). Springs and spring brooks are physically stable environments that support stable biological communities (Barquin and Death 2006). Biota with low dispersal abilities and long generation times are more common in permanently flowing springs, whereas biota with strong dispersal ability will be favored in non-permanent habitats (e.g. Erman and Erman, 1995; Smith and Wood, 2002). Climate change induced modifications of recharge may have a profound impact on spring communities. Such changes may be reflected in decreased summertime flows with possible drying, but also increased winter flow and associated flooding that can affect biological communities (Green et al. 2011).

Management Considerations

Management of aquatic systems begins with inventory of the types and condition of existing resources. The Forest Service has published several guides to inventory of aquatic systems including the Groundwater Dependent Ecosystem Inventory Field Guides (USDA Forest Service 2012). These field guides provide protocols for inventorying palustrine wetlands and springs.

Land uses surrounding palustrine wetlands and springs can potentially alter the hydrology and nutrient inputs of these systems, thus changing their underlying processes. Draining, water developments, heavy cattle use, ORV use and irrigation practices can alter hydrology and result in the loss of species diversity. Increased land use within 100 meters has been found to be correlated with increased nutrient levels in peatlands, suggesting that setbacks should be 100 meters or more for adequate protection (Jones 2003).

Heavy cattle use in palustrine systems can alter the hydrology by damaging soils. Soil compaction and pugging within the peat layer will change surface water flow. Heavy cattle use can also alter the successional processes within the sedge- dominated area of a fen. Cattle hoof action can lead to pugging and hummocking, creating microsites where shrubs can become established, changing the sedge-dominated meadow to Carr shrubland.

Projected Future Change in Mean Annual Flow for Streams within the Rio Grande National Forest and surrounding ecosystem: Focus on Climate Change

Amarina Wuenschel and David Winters
USDA Forest Service
Rocky Mountain Region

Current climate change efforts have predicted future changes in influence streamflow through altered temperatures, precipitation patterns and frequency of catastrophic weather events and this will in turn impact physical processes and organisms not only within these streams but throughout the ecosystems these streams feed (Reiman and Isaak, 2010). Fish and other aquatic organisms are likely to be most directly and dramatically affected by changing hydrologic flows, particularly those species adapted to specific flow regimes (Wenger et al. 2010). To estimate future change in flow metrics for the Rio Grande National Forest, we used modeled mean annual flow metric data (Wenger et al. 2010) which predict flows in 2040 and 2080 (Figure 18 and Figure 19). By predicting where flows will change most dramatically across the Rio Grande National Forest due to climate change, the Forest can identify potential areas to focus management efforts on.

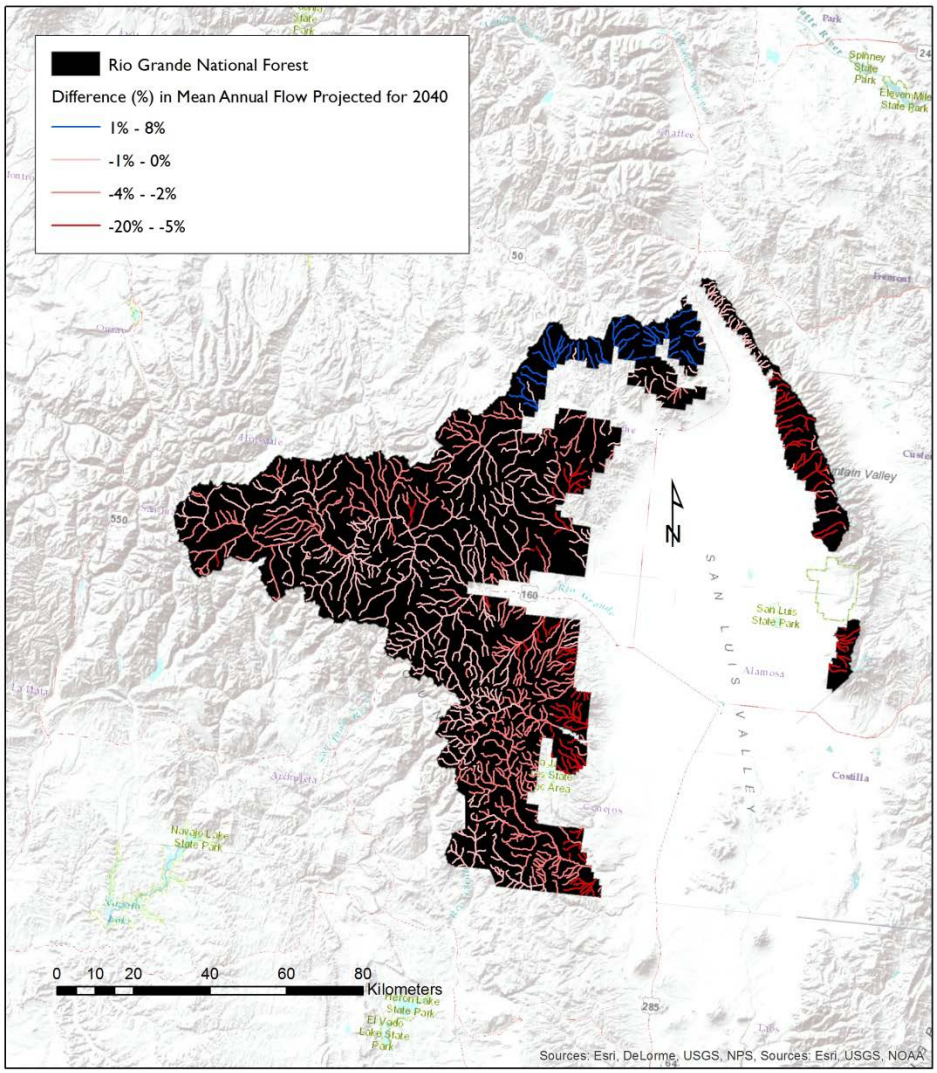


Figure 18. Percent difference in historic mean annual flows relative to flows projected for 2040 on the Rio Grande National Forest. The southern Sangre de Cristo mountain range and streams at the lower elevations are predicted to have the largest change under unregulated conditions.

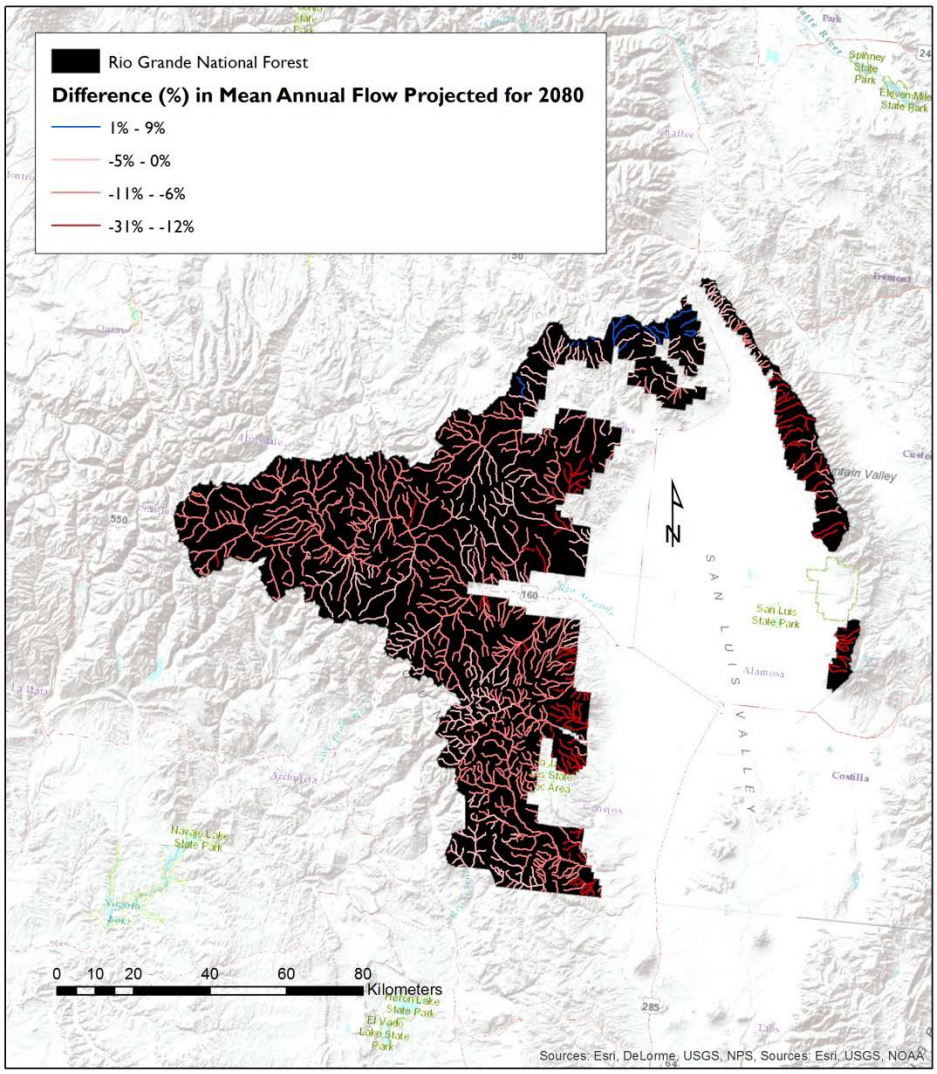


Figure 19. Percent difference in historic mean annual flows relative to flows projected for 2080 on the Rio Grande National Forest. Mean annual discharge will decline for all; most streams are expected to be reduced by more than 5% in 2080.

The most dramatic reduction in projected flows is forecasted for the Sangre de Cristo Mountains (Figure 18, Figure 19, and Figure 20) and the portions of the Forest adjacent to the San Luis Valley (Figure 18 and Figure 19). These patterns are consistent between the 2040 and 2080 projections with relatively greater decrease estimated for 2080. At the extreme of the predictions, we estimate as much as a 20% decline in flow levels for some streams in 2040 and as much as a 30% decrease by 2080. Conversely, increases in flows are forecasted for the Cochetopa Hills in 2040 and 2080 (Figure 18, Figure 19, and Figure 21) but with flows on some streams predicted to be declining by 2080. The central portion (moving from south to north) of the Rio Grande National Forest is expected to experience more variability and relative larger declines in mean annual flows (Figure 21). Lower elevation streams are expected to have more variability in discharge and larger declines in flows relative to historic levels (Figure 22), and more pronounced reductions and variability in flows expected in 2080 than 2040. Relative to original, historic flow levels, we expect larger relative declines and more variability in streams with lower overall flows (Figure 23).

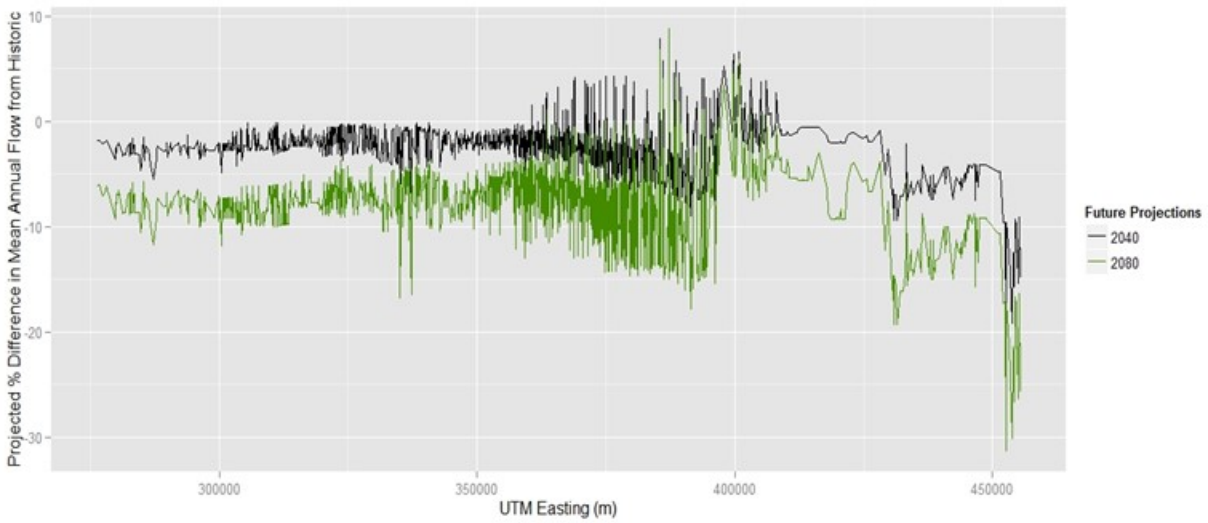


Figure 20. Changes in predicted difference in mean annual flow (for 2040 and 2080) shown from west to east (top) across the Rio Grande National Forest. The relatively high percentage change in the east boundary can be explained by the influence of the Sangre de Cristo mountain range where mean annual flows are expected to be reduced as much as 30% in some years by 2080.

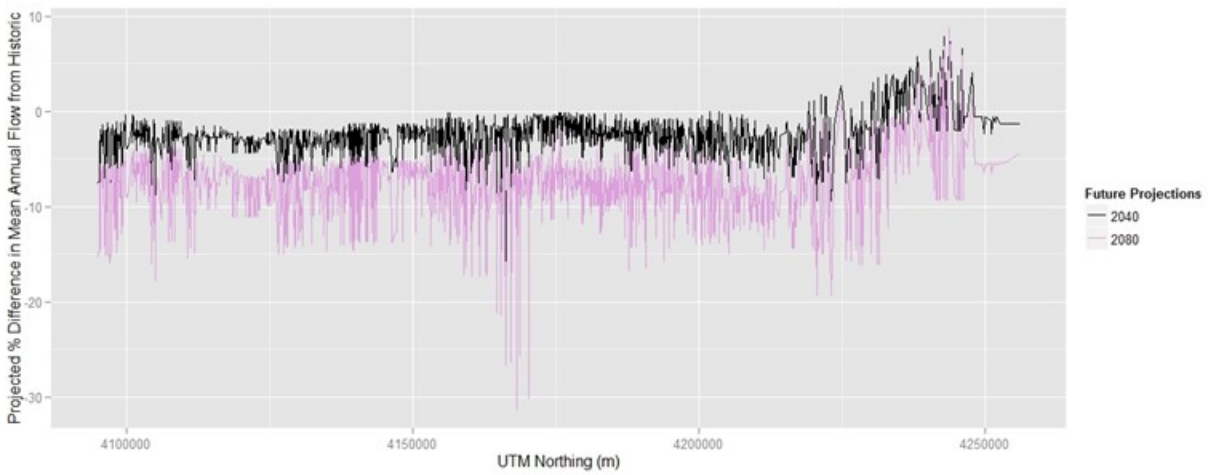


Figure 21. Changes in predicted difference in mean annual flow (for 2040 and 2080) shown from south to north (bottom) across the Rio Grande National Forest. The estimated increase in mean annual flows in the north (bottom) can be explained by the high elevation Continental Divide.

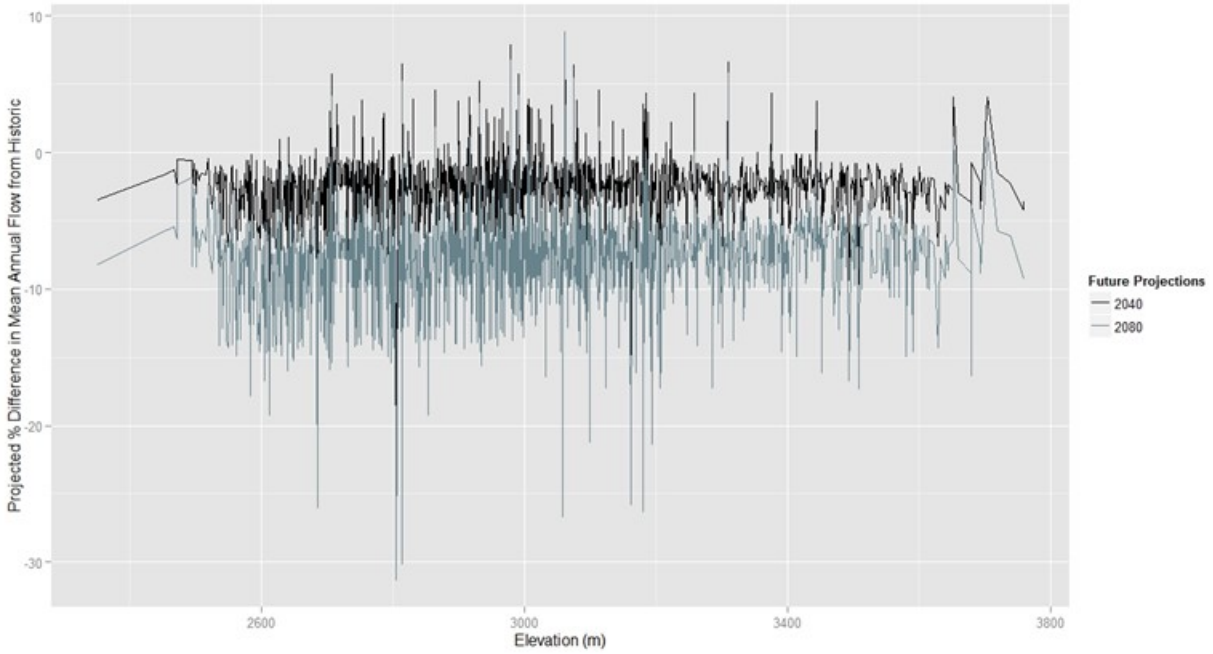


Figure 22. Percent difference in mean annual flows in 2040 and 2080 relative to elevation of stream reach midpoint.

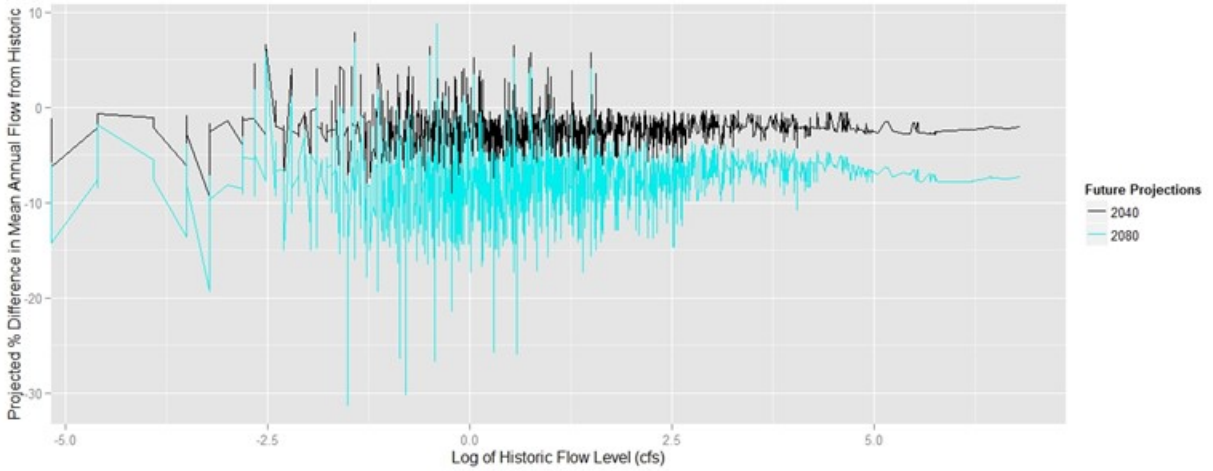


Figure 23. Percent difference in mean annual flows in 2040 and 2080 relative to historic flow levels on the Rio Grande National Forest.

Conclusions

The influence of long-term stream flow modification from climate change research are limited (Reiman and Isaak, 2010). However, available information indicates that lower elevation streams and those with limited base flows should be management priorities as they will most likely be influenced in the future. The analysis we conducted showed that discharge could be significantly reduced, variability could be much higher, and declines in fish and other aquatic biota on the Rio Grande National Forest would be expected if these conditions occurred (Wenger, et al., 2011). To mitigate the impacts of projected reductions in flows, management could focus on maintaining stream structure and surrounding vegetation within their perceived natural range of variation particularly at streams, wetlands and riparian areas thought to be more vulnerable to climate change (Dawson, 2011). Keystone species such as beaver that

act to restore streams to more natural flow rates and water table levels could be managed to maintain stream function and store water naturally on the landscape. Activities that have/are influencing the natural hydrology, physico/chemical parameters and habitat of these water dependent ecosystems (see in large part Meehan, 1991) could be a focus of discussion when project NEPA is being conducted. While it is important to understand that there is variability in this modelling effort, monitoring data on stream flow rates and temperatures should be collected and reviewed periodically where on the Rio Grande National Forest streams and their associated ecosystems are threatened by climate change.

References Cited

Barquin, J., Death, R.G., 2006. Spatial patterns of diversity in New Zealand springs and rhithral streams. J. North Am. Benthol. Soc. 25, 768–786.

Batagelj, V., 1988. Generalized Ward and related clustering problems,

In. H.H. Bock, ed., Classification and Related Methods of Data Analysis,

North-Holland, pp. 67-74

Bjorn, T.C. and D.W. Reiser. 1991. Habitat requirements of salmonids in streams.

IN. Meehan, W. Ed. Influences of Forest and Rangeland Management on salmonid fishes and stream habitat. Amer. Fish. Soc. Special Publication 19:83-138

Candela, L., von Igel, W., Elorza, F.J., Jimenez-Martinez, J., 2012. Impact assessment of combined climate and management scenarios on groundwater resources, pp. 191–204. In: Treidel, H., Martin-Bordes, J.J., Gurdak, J.J. (Eds.), Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations. International Association of Hydrogeologists (IAH) – International Contributions to Hydrogeology, Taylor & Francis Publishing, 414p.

Chadde, S.W., J.S. Shelly, R.J. Bursick, R.K. Moseley, A.G. Evenden, M. Mantas, F. Rabe, B. Heidel. 1998. Peatlands on National Forests of the Northern Rocky Mountains: Ecology and Conservation. Gen. Tech. Rep. RMRS-GTR-11. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 75 p.

Cooper, D.J. 1986. Community structure and classification of Rocky Mountain wetland ecosystems. In: An ecological characterization of Rocky Mountain montane and subalpine wetlands. Edited by: J.T. Windell et al. U.S.D.I. Fish and Wildlife Service, Biological Report 86(11). Washington, DC.

Cooper, D. J., and L. C. Lee. 1987. Rocky Mountain wetlands: ecosystems in transition. National Wetlands Newsletter 9(3): 2-6.

Cooper, D.J. 1990. Ecology of Wetlands in Big Meadows, Rocky Mountain National Park, Colorado. U.S. Fish and Wildlife Service, Biological Report 90(15).

Cooper, D.J. and R. Andrus. 1995. Peatlands of the west-central Wind River Range, Wyoming: Vegetation, flora and water chemistry. Canadian Journal of Botany 72:1586-1597.

Cooper, D.J. 2005. Analysis of the Strawberry Lake fen complex, Arapaho National Forest, Colorado. Unpublished Report prepared for the U.S. Forest Service, Fort Collins, CO. Dept. of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO.

Cooper, D.J and.D. M. Merritt. 2012. Assessing the Water Needs of Riparian and Wetland Vegetation in the Western United States. General Technical Report. RMRS_GTR_282. Fort Collins, Colorado 125 p.

Dahl, T. E., 1990. Wetlands losses in the United States 1780s to 1980s. U.S. Fish and Wildlife Service, Washington DC.

Dethier, D.P. 2001. Pleistocene incision rates in the western United States calibrated using Lava Creek B tephra. Geology 29, p. 783-786.

Drexler, J.A., Knifong, D.; Tuil, J. [et al.]. 2013. Fens as whole-ecosystem gauges of groundwater recharge under climate change. Journal of Hydrology. 481: 22–34.

Earman, S., Dettinger, M., 2011. Potential impacts of climate change on groundwater resources – a global review. J. Water Clim. Change 2 (4), 213–229.

Erman, N.A., Erman, D.C., 1995. Spring permanence, Trichoptera species richness, and the role of drought. J. Kansas Entomol. Soc. 68 (2), 50–64.

Folland, C.K., Rayner, N.A.; Brown, S.J. [et al.]. 2001. Global temperature change and its uncertainties since 1861. Geophysical Research Letters. 28: 2621–2624.

Green, T.R., Taniguchi, M., Kooi, H., Gurdak, J.J., Allen, D.M., Hiscock, K.M., Treidel, H., Aureli, A., 2011. Beneath the surface: impacts of climate change on groundwater. J. Hydrol. 405, 532–560.

Hammer D. A., 1996, Creating Freshwater Wetlands, Second Edition, CRC Press, Technology & Engineering, 448 pp.

Hanson, R.T., Flint, L.E., Flint, A.L., Dettinger, M.D., Faunt, C.C., Cayan, D., Schmid, W., 2012. A method for physically based model analysis of conjunctive use in response to potential climate changes. Water Resour. Res. 48, W00L08.

Hynes, H.B.N. 1970. The Ecology of Running Waters. University of Toronto Press, Toronto, ON.

Isaak, D.J., C.C. Muhlfield, A.S. Todd, R. Al-Chohachy, J.J. Roberts, J.L. Kerschner, K.D. Fausch, S.W. Hostetler. 2012. The past as a prelude to the future for understanding 21st century climate effects on Rocky Mountain Trout. Fisheries 37:542-556.

Jones, W.M. 2003. Kootenai National Forest Peatlands: Description and Effects of Forest Management. Unpublished report prepared for the Kootenai National Forest. Montana Natural Heritage Program, Natural Resources Information System, Montana State Library, Helena, MT.

Kløve, B., Ala-aho, P., Okkonen, J., Rossi, P. 2012. Possible Effects of Climate Change on Hydrogeological Systems: Results From Research on Esker Aquifers in Northern Finland, pp. 305–322. In: Treidel, H., Martin-Bordes, J.J., Gurdak, J.J., (Eds.), Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations. International Association of Hydrogeologists (IAH) – International Contributions to Hydrogeology. Taylor & Francis Publishing, 414pp.

Kværner, J., Snilsberg, P., 2008. Romeriksporten railway tunnel—drainage effects on peatlands in the Lake Northern Puttjern area. Eng. Geol. 101, 75–88.

Kværner, J., Snilsberg, P., 2011. Groundwater hydrology of boreal peatlands above a bedrock tunnel – drainage impacts and surface water groundwater interactions. J. Hydrol. 403, 278–291.

Lemly, Joanna, 2012, Assessment of Wetland Condition on the Rio Grande National Forest Colorado Natural Heritage Program, Warner College of Natural Resources, Colorado State University.

Ludwig, F., Moench, M., 2009. The impacts of climate change on water. In: Ludwig, F., Kabat, P., Schaik, H.V., van der Valk, M. (Eds.), Climate Change Adaptation in the Water Sector. Earthscan Publishing, London, pp. 35–50.

Maxwell, J.R., C.J. Edwards, M.E. Jensen, S.J. Paustian, H. Parrot, and D. M. Hill. 1995. A hierarchical framework of aquatic ecological units in North America (nearctic zone). Gen. Tech. Rep. NC-176. St. Paul, MN, USDA, Forest Service, North Central Forest Experiment Station.

Maxwell, R.M., Kollet, S.J., 2008. Interdependence of groundwater dynamics and land-energy feedbacks under climate change. Nature Geoscience 1, 665–669.

Meehan, W. 1991. Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats. American Fisheries Society. Publication 19. Evans City, Pennsylvania.

Montgomery, D.R. and J.M. Buffington. 1997. Channel reach morphology in mountain drainage basins. Geology Society of America Bulletin 109:596-611.

McKinstry, M.C., Hubert, W. A., Anderson, S.H., 2010, Wetland and Riparian Areas of the Intermountain West: Ecology and Management, University of Texas Press.

Montgomery, D.R. and J.M. Buffington. 1997. Channel reach morphology in mountain drainage basins. Geology Society of America Bulletin 109:596-611.

Ortiz, R.F., 2004, Ground-Water Quality of Granitic- and Volcanic-Rock Aquifers in Southeastern Park County, Colorado, July-August 2003. U.S. Geological Survey, Fact Sheet 2004–3066.

Poff, N.L. 1997. Landscape filters and species traits: Towards mechanistic understanding and prediction in stream ecology. Journal North American Benthological Society 16:391-408.

Poff, N.L. and J.V. Ward. 1990. Physical habitat template of lotic systems: Recovery in the context of historical pattern of spatiotemporal heterogeneity. Environmental Management 14:629-645.

Pyne, M.I., R.B. Rader, and W.F. Christensen. 2007. Predicting local biological characteristics in streams: a comparison of landscape classifications. Freshwater Biology 52(7):1302–1321.

Rahel, F.J., 2010. Homogenization, Differentiation, and the Widespread

Alteration of Fish Faunas. American Fisheries Society Symposium 73:311–326, 2010

Reiman, Bruce E.; Isaak, Daniel J. 2010. Climate change, aquatic ecosystems, and fishes in the Rocky Mountain West: implications and alternatives for management. Gen. Tech. Rep. RMRS-GTR-250. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 46 p.

Rocchio, J., 2006, Rocky Mountain Subalpine-Montane Fen Ecological System, Ecological Integrity Assessment, Colorado Natural Heritage Program.

Sable, K.A. and E.E. Wohl. 2006. The Relationship of lithology and watershed characteristics to fine sediment deposition in streams of the Oregon Coast Range. Environmental Management 37(5):659-670.

Sjors, H. 1950. Regional studies on North Swedish mire vegetation. Bot. Not. Hafte 2:173-222.

Smith, H., Wood, P.J., 2002. Flow permanence and macroinvertebrate community variability in limestone spring systems. Hydrobiologia 487, 45–58.

Sophocleous, M., 2002. Interaction between groundwater and surface water: the state of the science. Hydrogeol. J. 10, 52–67.

Tujchneider, O., Paris, M., Perez, M., D'Elia, M., 2012. Possible Effects of Climate Change on Groundwater Resources in the Central Region of Santa Fe Province, Argentina, pp. 265–280. In: Treidel, H., Martin-Bordes, J.J., Gurdak, J.J. (Eds.),

USDA Forest Service. 2012. Groundwater-dependent ecosystems: level I and II inventory field guides. Gen. Tech. Rep. WO-86a and b. Washington, DC: U.S. Department of Agriculture, Forest Service. http://www.fs.fed.us/geology/groundwater.html. (15 September 2014).

Ward, J.V., Tockner, K., 2001. Biodiversity: towards a unifying theme for river ecology. Freshw. Biol. 46, 807–819.

Ward, J.H. 1963. Hierarchical grouping to optimize an objective function. Journal of the American Statistical Association 58:236-244.

Windell, J.T., B.E. Willard, and S.Q. Foster. 1986. Introduction to Rocky Mountain wetlands. Pages 1-41 in J.T. Windell, B.E. Willard, D.J. Cooper, S.Q. Foster, C.F. Knud-Hansen, L.P. Rink, and G.N. Kiladis, editors. An ecological characterization of Rocky Mountain montane and subalpine wetlands. U.S. Fish and Wildlife Service, Biological Report 86.

Winter, T.C., 1999. Relation of streams, lakes, and wetlands to groundwater flow systems. Hydrogeol. J. 7, 28–45.

Winters, D.S., M. Welker, B.A. Bohn, D. Cooper, J. Hamerlinck, N. Lee, J. Maxwell, D. Peterson, D. Plume, N.L. Poff, C. Quimby, F.J. Rahel, D.M. Staley, and E.E. Wohl. 2003. Aquatic, Riparian and Wetland Ecosystem Assessment, Bighorn National Forest, Wyoming. Report for the Rocky Mountain Region of the USDA Forest Service.

Winograd, I.J; Riggs, A.C.; Coplen, T.B. 1998. The relative contributions of summer and cool-season precipitation to groundwater recharge, Spring Mountains, Nevada. Hydrogeology Journal. 6: 77–93.

Wohl, E. 2000. Mountain Rivers. American Geophysical Union Press, Washington, DC.

Wohl, E. 2001. Virtual rivers: Lessons from the mountain rivers of the Colorado Front Range. Yale University, New Haven, CT.

Wohl, E., D. Cooper, L. Poff, F. Rahel, D. Staley, and D. Winters. 2007. Assessment of stream ecosystem function and sensitivity in the Bighorn National Forest, Wyoming. Environmental Management 40:284–302.