Upper Feather River Basin Fisheries Assessment and Restoration Strategy

A Cooperative Project:

Sierra Institute for Community and Environment

Feather River Chapter, Trout Unlimited

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Executive Summary

An assessment of Rainbow Trout distribution and habitat condition was conducted for the Feather River watershed upstream of Lake Oroville. Physical and biological attributes were used to rate the relative condition of 121 sub-watersheds and 64 reaches. Ultimately, the assessment was driven by projections of future conditions for native trout, based on climate change models used to estimate thermal and hydrologic factors. This analysis produced ratings of exposure applied to each subwatershed. Estimates of exposure and condition were combined to produce priorities for restoration based on relative resilience of subwatersheds and associated stream reaches. Trout habitat was rated based on stream temperature, habitat connectivity, biological indicators and watershed condition. Biological indicators included distribution of rainbow, brook and Brown Trout; presence of two pathogens with a history of debilitating impacts on trout in the basin; and presence of three invasive gastropods. Watershed condition was rated using indicators of road impacts (near stream road density and frequency of road crossing), wildfire, number of water diversions, estimates of baseflow diversion and low gradient channel condition.

Review of survey records, monitoring, published reports and literature were used to determine distribution of Rainbow Trout (*Oncorhynchus mykiss*), Brown Trout (*Salmo trutta*) and Eastern Brook Trout *Salvelinus fontinalis*. Use of survey records for these species was supplemented by sampling for environmental DNA from 68 stream and river sites. In addition to fish, eDNA was used to detect presence of New Zealand Mudsnails *(Potamopyrgus antipodarum)*, Zebra Mussels *(Dreissena polymorpha)* and Quagga Mussels *(Dreissena bugensis*). These invasive species have been found in waters relatively close to the basin. eDNA analyses for the pathogens *Myxobolus cerebralis* and *Ceratanova shasta* was also performed. Results found no positive tests for invasive snails. Positive eDNA results for whirling disease and Ceratanova shasta were found at sites where previous studies confirmed presence of the pathogens. Results for trout species showed strong correlations between eDNA results and presence based on survey and monitoring records.

Examination of historic climatological data found trends of warmer temperatures, less snow and lower streamflow in the basin. The impact of continued warming on future habitat conditions was assessed using the Basin Characterization Model. Projections from two climate scenarios were used to estimate future air temperatures, runoff and snowpack across the basin. The NorWeST stream temperature model was used to estimate historic and future stream temperatures. Ranges for thermally suitable and optimum conditions for the three trout species were developed and compared. A combined rating of likely future conditions for trout was conducted using projected runoff (representing available habitat), snowpack (maintaining baseflows), and stream temperature. This assessment was used to place sub-watersheds into four exposure classes (Figure i).

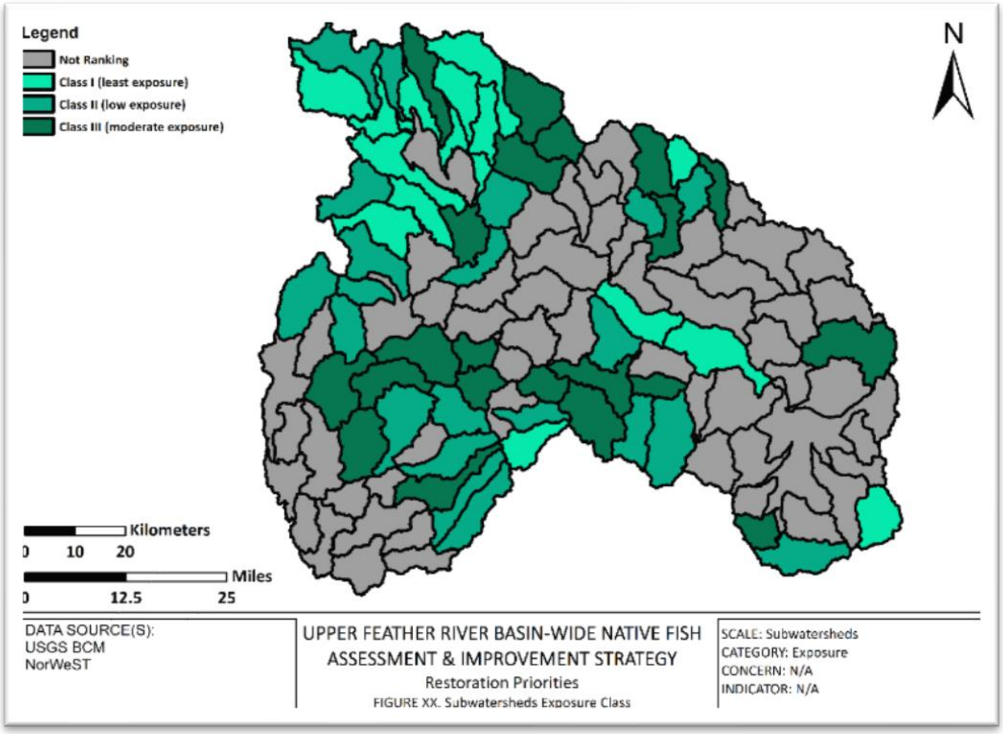

Figure i. Subwatersheds grouped into three Exposure Classes

Indicator information was aggregated to provide relative ratings of condition for each sub-watershed. Condition indicators used in the rating were the densities of stream channel road crossings and roads within 30m of a channel, the number of diversions and amount of streamflow diverted, the condition of low gradient stream channels and the connectivity of stream habitats (presence or lack of barriers to fish movement). Available stream monitoring data was used to explore the relationship between the condition factors and habitat conditions and provided justification for their use.

Results revealed a range of conditions within sub-watersheds. The few watersheds with no or very few roads and no stream diversions were rated in the best condition. Typically, watersheds in the higher elevations (usually with steeper terrain) had less roads and fewer diversions. Presence of whirling disease, and presence of high severity wildfire (in past 15 years) were deemed to be important condition indicators. They occurred in relatively few locations, so were not included in the basin-wide rating. Rather they are noted where present in watersheds ultimately rated as priority for restoration. Rainbow Trout were found in every sub-watershed and reach, and brook and Brown Trout in most areas. Only 4 sub-watersheds are thought to support only Rainbow Trout.

Stream reaches were generally found to be in poor condition. Reaches in the headwaters are strongly influenced by roads and had highest densities of channel crossings and near stream roads. Mid-elevation reaches located primarily in the large meadows of the basin are the site of considerable diversion of baseflow for agricultural use and displayed warm stream temperatures. Farther downstream, water temperatures in reaches were typically too high to provide highest quality habitat for Rainbow Trout.

The assessment was used to identify priority areas for habitat protection and restoration. Concepts from the Trout Unlimited and FEMAT strategies for protection and recovery of aquatic species were employed. Both approaches emphasize protection of areas in the best condition, and reconnection and restoration actions targeted at priority habitats. Geographic restoration priorities were based on the relative resilience of sub-watersheds. Resilience was assessed by combining ratings of exposure and condition. Highest priority for protection and improvement was given to areas that possess the lowest exposure (best streamflow, snowmelt and thermal) characteristics; and the least disturbance (best connectivity, fewest diversions, fewest roads). In all, 48 sub-watersheds were classed as priority, with 5 receiving a rating of very high resilience, 21 with high resilience and 23 with moderate resilience (Figure ii). These areas were typically sub-watersheds at high elevation where projected changes to snowpack and stream temperature would be moderated. As a result, sub-watersheds with highest resilience tended to be clustered. Reaches that provide connection between sub-watersheds within the resulting clusters, and between clusters, were rated as highest priority for protection and restoration. Actions that could be applied to maintain or improve resilience of priority areas are recommended and discussed.

Results from eDNA surveys for whirling disease confirmed the presence of the pathogen at several locations in the basin. This disease has had devastating impacts on fish populations in the basin, and elsewhere in the western United States. Currently, there are no efforts or actions by any agency or party to contain or manage whirling disease in the Feather River. Development of a plan or strategy for containment of the disease is identified as a top priority for restoration in the basin.

The condition ratings provide a starting point for identifying other actions most likely to maintain or improve resilience in the priority areas. Subwatersheds in the highest priority class are targets for protection as investments in restoration actions are not needed to maintain their resilience. Subwatersheds with low road condition ratings could be improved with treatments aimed at disconnecting road-channel delivery of fine sediment and runoff; work with water users on fish screens and instream flows are of high priority in areas with diversions. Improving connectivity by providing for fish passage at key man-caused barriers (typically road crossings with culverts) is priority in areas with low connectivity and appears to be the most practical way to improve resilience in the short term.

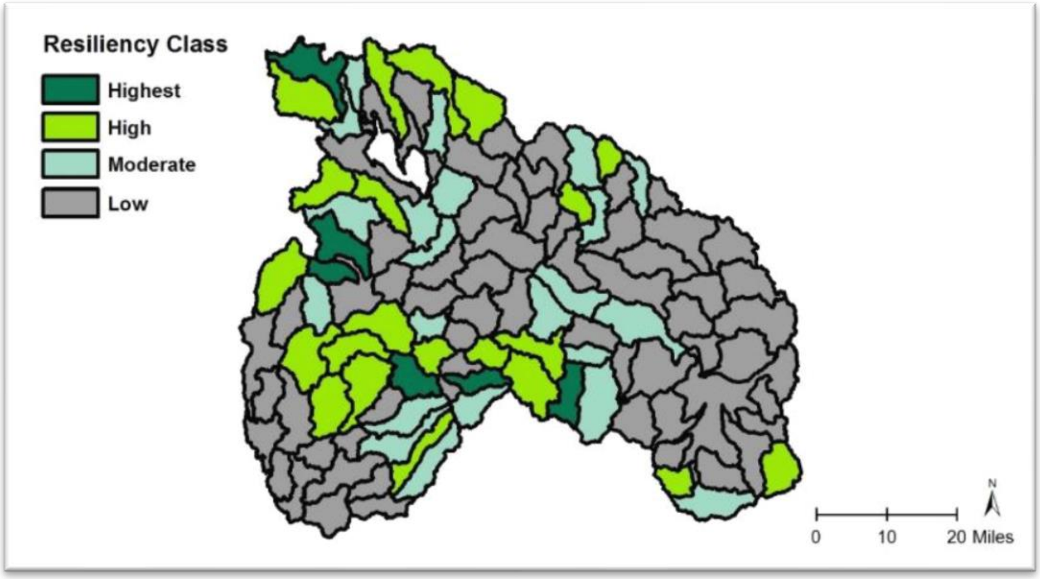

Figure ii. Priority subwatersheds for restoration, by resiliency (priority) class.

Acknowledgments

This assessment and restoration plan resulted from the assistance of many individuals and groups. The assistance and encouragement of Matthew Johnson of the Plumas National Forest was instrumental in beginning the project and gaining support. His contributions as a member of the Technical Advisory Committee were important in formulating many aspects of the assessment, as was the input of the other members of this Committee including Mike Berry, Joe Hoffman, Chris Mayes, Debra Urich and Amber Rossi. Support from Melanie McFarland of the Lassen National Forest was also critical.

Members of the Stream Condition Expert Opinion sub-group were responsible for that part of the assessment. Members of that group not named above included Terry Benoit, Ken Cawley, Antonio Duenas, Kelby Gardiner, Kurt Sable and Bob Schultz. Ralph Martinez of the Plumas National Forest played a key role in capturing Climate Change Projection data and served as a source of support for GIS questions.

Dr. Caren Goldberg supplied technical advice and counsel about eDNA sampling, storage and approach. We are indebted to Dr. Chris Jerde for his advice and support in formulating our approach to eDNA sampling, and to Mike Caltagirone for suggesting to include eDNA in the assessment. We thank Gary Rotta, Wayne Cartwright, Chris Mayes, Laurie Early, Brooke Huffman and Camille Sweezy for assistance in field sampling.

We also want to thank the organizations who funded the project, including the Sierra Nevada Brewery, New Belgium Brewery, Patagonia Wild Trout Initiative, The Bella Vista Foundation, The Rose Foundation, the Plumas County Fish and Wildlife Commission, Trout Unlimited Feather River Chapter and the Plumas and Lassen National Forests.

Finally, we acknowledge the work of Courtney Gomula of the Sierra Institute who handled all administrative matters related to the project.

Plan Purpose

The Feather River watershed above Oroville Dam (Upper Feather River Watershed, hereafter referred to as the Basin) (Figure 1) once supported diverse and productive fish communities. A combination of anthropogenic activities has functionally removed over 150 miles of anadromous fish stream habitat from the Basin and degraded hundreds of miles of native freshwater fish habitat.

Poor watershed conditions in the Basin are recognized by the public and resource managers (Buer, 2004, USSCS, 1989, USSCS, 1991). Considerable resources have been invested to improve wetland, stream and watershed conditions but broad-scale improvements to fish habitat from prior restoration efforts have been limited, primarily because a basin-wide assessment and restoration strategy for native fisheries has been lacking. One reason is that though resource managers have collected fisheries and habitat information throughout the Basin, the information has never been synthesized or evaluated at the landscape scale; rather, projects have assessed fisheries and habitat needs at the site scale. As a result, basic basin-wide understandings of fish distribution and habitat condition are lacking.

The aim of this project is to gather and consolidate information on the fisheries of the Upper Feather River watershed to enable a basin-wide native fish condition assessment and, based on this work, a landscape-level fisheries restoration strategy. The assessment provides context necessary to evaluate the relative potential benefits of proposed watershed restoration projects to native fisheries and habitat and will also help to set priorities for restoration to increase the effectiveness, rate and scale of native fish habitat restoration in the watershed. Protection and restoration would also benefit the wide range of aquatic communities and species that depend on lotic habitats, including benthic invertebrates and amphibians.

The bulk of the assessment was prepared by the lead authors- the Sierra Fellow and two Trout Unlimited advisors, assisted by a Core group as well as a larger Technical Advisory Committee (TAC). Both the Core group and TAC were comprised of biological and earth scientists, representative of the multiple agencies with management responsibilities that affect Basin fisheries, and each member, like the two primary advisors, holds extensive past or current experience with watershed and aquatic resources of the Basin.

The project also included public participation. Public participation was derived through two primary avenues: 1) long-time anglers familiar with the Basin were interviewed to gather anecdotal long-term information on fish distribution and condition and 2) town-hall meetings conducted in the communities of Chester, Greenville, Quincy and Sierraville to solicit public comment on fisheries conditions and restoration needs. By involving local anglers and incorporating community review and comment the project aims to build greater advocacy for fish conservation throughout the Basin.

This assessment and strategy is local in focus and meant to improve understanding of the condition, restoration needs, and management concerns for fisheries within the Basin. The Feather River Chapter of Trout Unlimited has developed and will apply this assessment through Trout Unlimited's approach of conserving cold-water fisheries through protection, reconnection and restoration. Additionally, this information will aid and assist the U.S. Forest Service, California Department of Fish and Wildlife, private landowners and other stakeholders in with developing adaptive management that maintains and improves fisheries habitat.

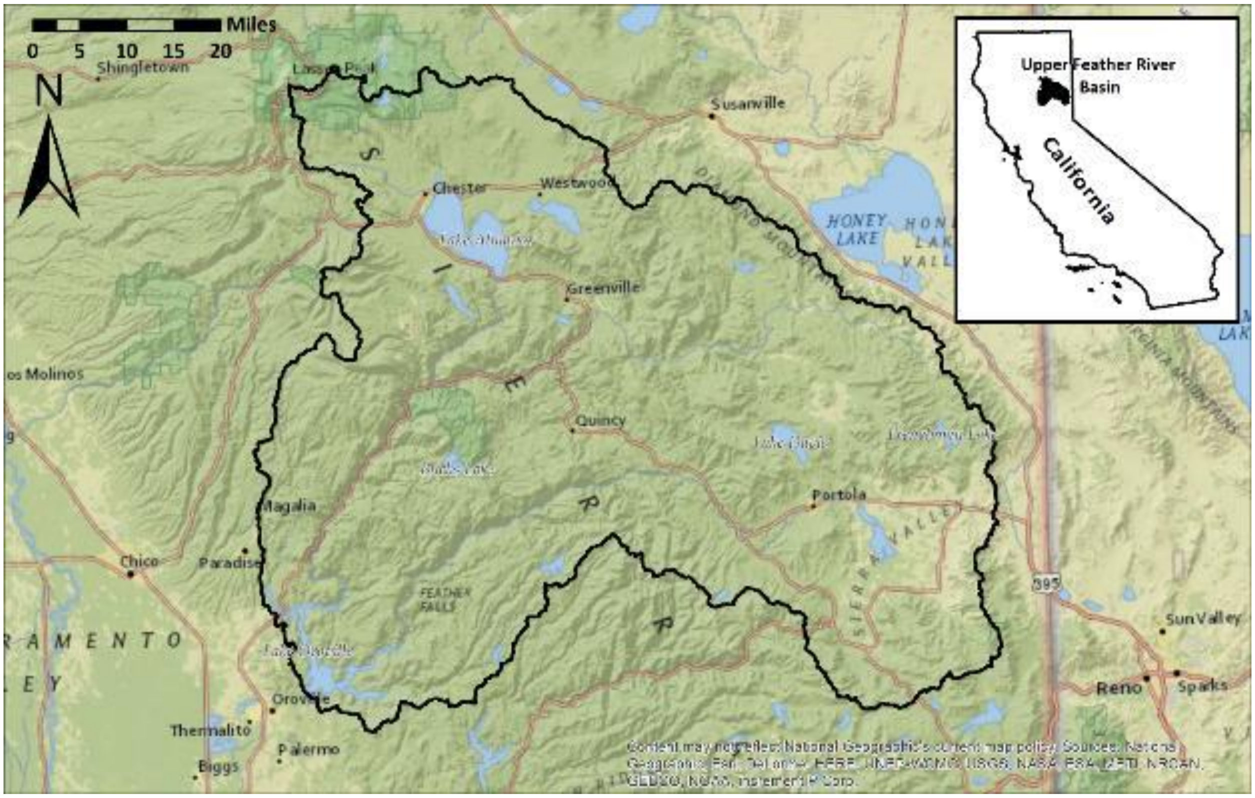

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Figure 1. The Upper Feather River Basin is located above Lake Oroville in Northeastern California. It extends from Lake Oroville north to Mt. Lassen, east to the divide with the Great Basin and southeast to Sierra Valley. The Basin is predominantly publicly owned, with the majority of ownership comprised of the Plumas, Lassen and Tahoe National Forests. The Basin along with Lake Oroville, its largest reservoir is a significant source of water for California cities, towns, agriculture and ecosystems.

Part 1. Assessment Approach & Framework

1.1 Background

Over two years ago, the Feather River Chapter of Trout Unlimited was asked to participate in the Integrated Watershed Management Planning effort for Plumas County. Soon after agreeing to participate, TU was asked for a list of priority projects. Feather River TU felt a basin-wide native fish condition assessment would provide the information needed for deciding where, and what the priorities for a restoration project should be. In absence of such planning, members were concerned that time and investments in site specific projects might not be effective. Thus, began our effort to provide such a plan, with the objective of assessing and rating factors affecting fish communities throughout the entire Feather River Watershed above Lake Oroville.

1.2 Analytical Scales

Two analytical scales were used in the analysis.

Subwatersheds

A physical watershed reporting unit made sense for a variety of reasons. Watersheds have unambiguous physical meaning. They do not change with climate, fires, or current thinking. Watersheds are widely understood by land management partners and key publics. Many collaborative resource management efforts are organized around watersheds. Watersheds are more durable and precise than abstract and *ad hoc* definitions of "landscapes" or units that are based on vegetation associations. Watersheds are not agency or ownership specific and provide a way to transcend administrative and political boundaries.

Sub-watersheds (HUC 12) (Figure 2) were selected as the most useful analytical scale. Watershed units of this size provided a workable population sufficient to characterized differences across the Basin. A map index and complete list of Sub-watersheds in the Basin is provided in Appendix A.

The HUC12 delineation is widely used in assessment and analysis of the sort contained herein. Recent work by the United States Forest Service (USFS) on assessing watershed vulnerability to climate change point to this scale as useful for analysis (Furniss, et al, 2013). Sub-watersheds are also the reporting unit utilized for Watershed Condition Framework now being implemented across all Forest Service units. Subwatersheds can be expected to be a central unit for many kinds of assessments and resource tracking in the coming decades. With the goal in mind of identifying landscapes important to sustaining or improving fisheries, the HUC12 possesses the additional attribute of being the appropriate size where such actions can be planned and implemented.

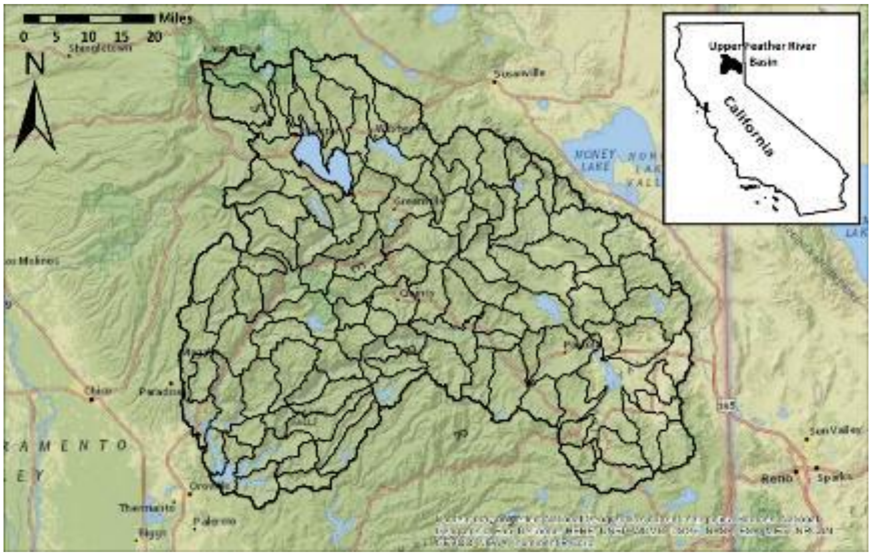

Figure 2. The Upper Feather River Basin with subwatershed (HUC12) hydrologic units delineated.

Reaches

We recognized that conditions in river and stream habitats not contained within sub-watersheds were important components of overall basin conditions. As a result, we included a “reach” scale to assess condition of larger-order streams and rivers that traverse multiple subwatersheds. Reaches were delineated for streams and rivers that traverse two or more subwatersheds. Upstream and downstream reach boundaries were delineated using a combination of subwatershed boundaries, channel gradient and hydroelectric development structures. Reaches were at least 1 mile in length, and typically began or

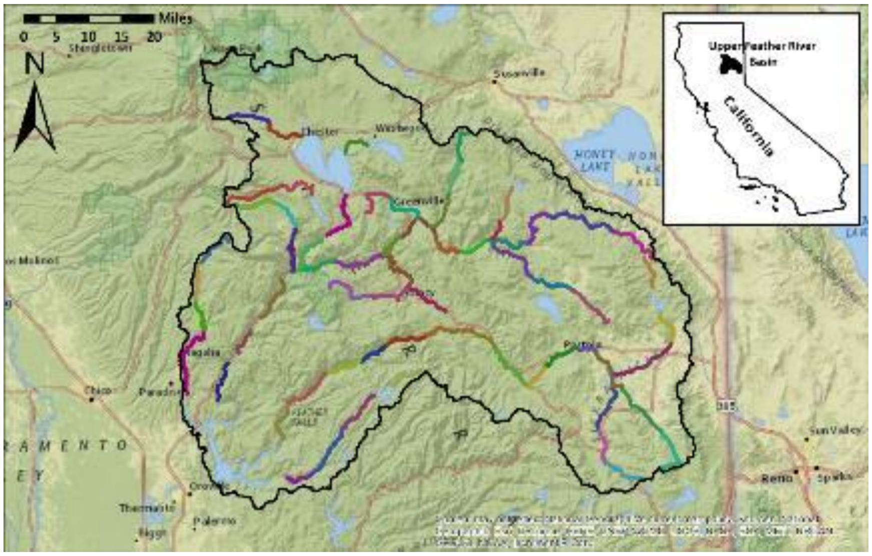

Figure 3. Location of UFRBWA Reaches (delineated by color breaks)

ended at the confluences of sub-watersheds. Reaches are illustrated in Figure 3. A map index and complete list of Sub-watersheds in the Basin is provided in Appendix B.

1.3 Approach

Our goal in assessing restoration was to identify those areas in the watershed most likely to sustain quality Rainbow Trout habitat in the long term. To this end, we employed projections of future climatic condition, including changes to hydrologic characteristics we considered important to maintaining habitat. We also employed projections of future water temperatures. We used these projections to assess the relative exposure of basin subwatersheds to future change. We also assumed that areas with the greatest resilience would have the greatest potential to maintain habitat. Our approach assumed resilience was a product of exposure and condition (Figure 4). That is, areas with the least exposure and in the best condition had the greatest resilience, or potential to sustain ecosystem function and products. In contrast, our working assumption is that areas with the greatest exposure and in the poorest condition will prove to be least resilient and are least likely to retain good habitat for native trout. As a result, our approach combined two primary elements: exposure to future climate, and condition of sub-watersheds and reaches.

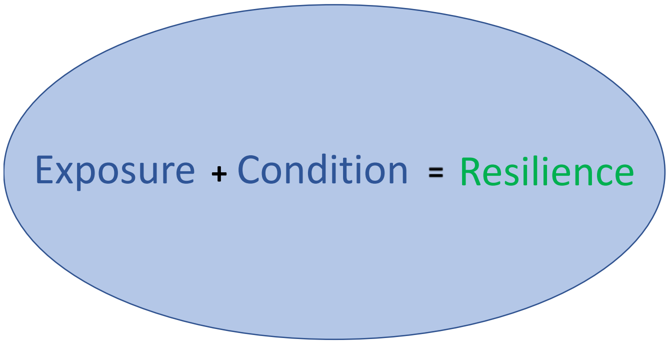

Figure 4. Conceptual relationship of resilience as product of exposure to hydrologic changes from warming and condition of watersheds and habitat

Part 2: Assessing Climate Change Exposure

2.1 Introduction

The primary goal of this assessment is to identify geographical priorities for Rainbow Trout protection and habitat restoration. Though the focus of the assessment in on native trout, maintenance, protection or improvement of their habitat would also benefit all lotic habitat dependent species. If reached, this goal would aid resource managers in effectively focusing limited resources to maintain and where necessary, improve watershed and habitat conditions. In this section, we consider the influence of changing hydrologic conditions on trout habitat and assess how such factors can be integrated into assessing protection and restoration priorities such that habitat and populations can be sustained in the future.

Our primary concern is how projected changes to temperatures and hydrologic processes might impact fish habitat quality and fish distribution. We considered potential changes to the following ecological elements and processes:

- Snowpack
- Stream temperatures
- Streamflow
- Wildfire
- Storm intensity (higher peak flows)
- Riparian Communities
- Species Distribution
- Near stream Roads and Road Crossings

Our analysis was ultimately based on the criteria listed in Table 1. In this section of the assessment, we begin with a review recent and historic trends in important climate characteristics. We then discuss some practical impacts of those changes on watershed processes and native fish ecology and habitat. Modeling of potential future climate scenarios are described and findings of those analyses summarized. The results are used to rate relative exposure of subwatersheds to hydrologic change detrimental to native fishes.

CONCERN	INDICATOR	METRIC	DATA SOURCE
Flow	Snowpack	Near-future projected April 1 Snow-Water Equivalent (SWE) remaining	USGS BCM
Flow	Annual Runoff	Near-future projected annual runoff remaining	USGS BCM
Temperature	Stream Temperature	Miles of thermally optimal/suitable stream miles	NorWeST
Sediment	Fire Risk*	% watershed in high vulnerability fire class	USFS[1]/CalFire[2]

*Table 1. Indicators used to describe future hydrologic and habitat condition. *not carried forward as exposure criterion*

[1] Fire Return Interval Departure (FRID). USDA Forest Service, Pacific Southwest Region. 2011.

[2] Fire Regime and Condition Class (FRCC). CalFire. 2015.

2.2 Climatic Trends in the Feather River Basin

This discussion draws heavily from the work of Merriam, Stafford and Sawyer (Merriam, et al, 2013) who undertook an intensive review of climatological data from the Sierra Cascade Province. Their review of climatological records reveals trends important to the hydrology of the basin.

Temperature

Merriam, et al (2013) found significant increases in minimum, mean, and maximum temperatures since 1895 (Figure 5) and reported an increase of 1.7 degrees Fahrenheit (° F) in the Sierra climate region (values based on regression equations). This trend is driven primarily by significant increases in mean minimum (i.e., nighttime) temperatures, which have risen by 2.5° F since 1895. The authors also found an increase in monthly minimum temperatures (Figure 6). This trend was reported at Canyon Dam near Lake Almanor (Freeman, 2010).

Precipitation

Merriam et al (2013) reported precipitation trends across California ranged from negative to positive with trends at nearby stations varying widely. Data from the Sierra regions show no significant change in precipitation over the past century. The Sierra currently receives almost five inches more annual precipitation than in 1931, according to PRISM data. Most of the weather stations across the Province showed no significant change in precipitation over their period of record (between 62 and 115 years). The Susanville station was the only station to show a significant trend in precipitation. Total annual rainfall at the Susanville station has decreased by almost eight inches since 1893. Additionally, variation in annual precipitation has significantly increased since 1895.

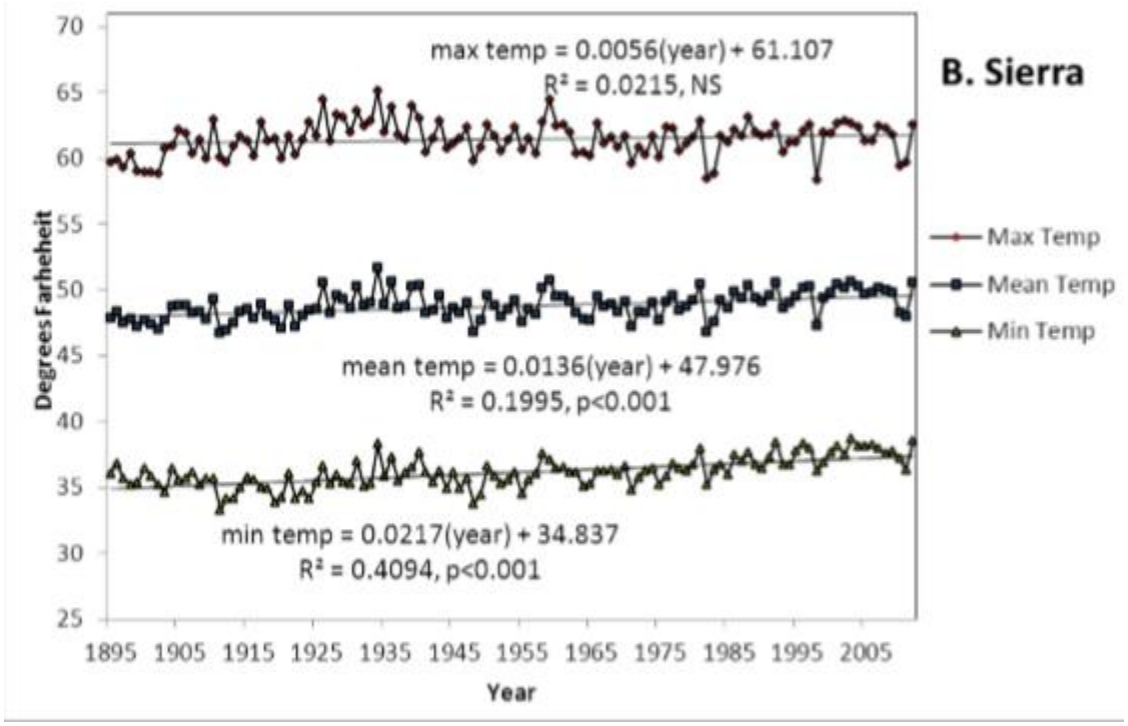

Figure 5. Trends in maximum, mean and minimum temperatures recorded at weather stations across the Sierra region between 1895 and 2010. Trend lines fit with simple linear regression. Data from WRCC (2010). Modified after Merriam, et al (2013)

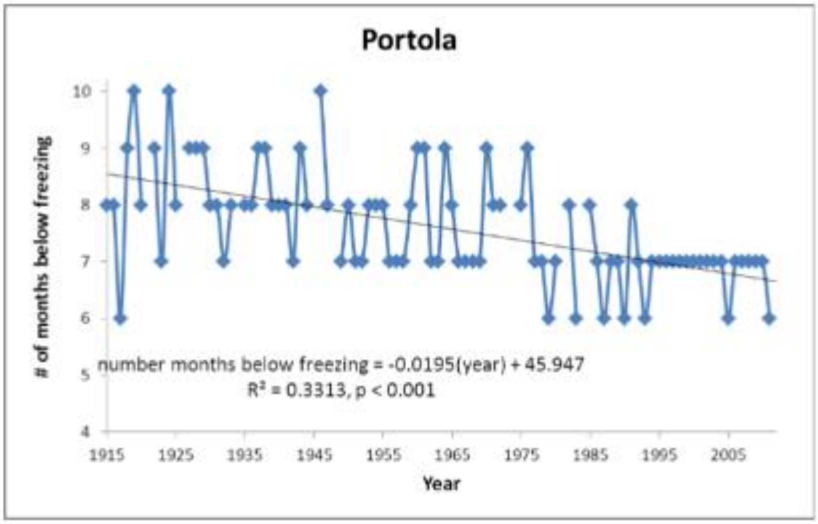

Figure 6. Number of months with average monthly minimum temperatures remaining below freezing at Portola (1915-2011). Data from WRCC (2012). Modified after Merriam, et al (2013)

Snow

In general, April 1 snow-water equivalent (SWE, the amount of water in snow as measured on April 1) has been declining throughout the region since the late-1940s. Declines in snowpack have resulted from changes in both temperature and precipitation over this period. Changes in April 1 SWE reflect both snow residence time (length of time snow sits in the snowpack), and timing of maximum snowpack which are sensitive to both temperature and precipitation variations. Merriam, et al (2013) reported that four of the nine stations in the northern Sierra-southern Cascades experienced significant declines in snowfall over the past century and two additional stations exhibited near significant declining trends. For example, total annual snowfall at the Susanville Station has declined from about 40 inches in 1933 to eighteen inches in 1989. Limited data since 1989 suggest even larger declines to about eight inches in 2010. There is also evidence of decreases in early spring (April 1) snowpack and snow-water equivalents between 1950 and 1997 for most of northeastern California.

Runoff

Across the western United States, widespread changes in surface hydrology have been observed since the mid-1900s. These shifts include: earlier snow melt and spring runoff (0.3 to 1.7 days per decade); decline in total runoff occurring in the spring, rising river temperatures and increased variability in streamflow. Over the last half-century, peak runoff/streamflow (measured as the center of mass annual flow) has shifted earlier in the year for many Sierra Nevada watersheds. Stewart et al. (2005) showed that the onset of spring thaw in most major streams on the western slopes of the southern Sierra Nevada occurred 5-20 days earlier in 2002 compared to 1948, and peak streamflow occurred 0-15 days earlier. Moser et al. (2009) reported that over the past 100 years, the fraction of annual runoff that occurs during April– July has decreased by 23% in the Sacramento basin and by 19% in the San Joaquin basin in California. March flows during the last 100 years in Sierra Nevada streams have increased by 3-10%, whereas June flows were mostly lower, and overall spring and early summer streamflow has decreased in most studied streams (Stewart et al. 2005). In addition to temporal shifts, California streams also have exhibited increased variability in streamflow during the last 100 years. Beneath these general trends, there is much variation in the range of hydrologic response to climate change in the

Sierra Nevada, but watersheds in the northern Sierra Nevada exhibited the greatest reductions in mean annual flow (Merriam, et al 2013).

The Feather River Basin has exhibited some of the largest changes in timing of runoff and loss of low elevation snowpack observed in California (Freeman 2008, 2009). For example, on the East Branch of the North Fork Feather River, April 1 snowpack has decreased by 37% since 1949, and April-June runoff has declined by 27%. In contrast, March runoff has increased by 39% (Freeman 2010).

Streams in the basin with portions of their watersheds above 5000-foot elevation depend on snowmelt for runoff, with changes in snowpack resulting in subsequent strong responses in streamflow. Effects can be categorized by seasonality and water yield effects. Precipitation in the basin is variable, with large flow events most often the result of warm rain on snow (ROS) events. In other years, annual peaks are the result of snowmelt.

Projections regarding precipitation and streamflow are more variable than those for snow and snowmelt. It is expected that declines in precipitation will be less pronounced and increased precipitation is possible. Earlier streamflow center of timing of two to three weeks (Stewart, et al, 2005) is expected over much of the basin, and summer low flows are expected to decline. Total yields are expected to decrease due to increased evapotranspiration. Decreasing precipitation could substantially exacerbate annual water yields and low flow declines.

Flooding is expected to become more common in places where it now occurs and to occur in more locations (Furniss, et al, 2010). Because ROS-driven flood peaks tend to be much higher, the height of floods are expected to increase in those locations as well (ibid).

In summary, the following potential trends appear to be most applicable to the Feather River Basin.

- Warming Air Temperatures
- Decrease in number of months with freezing temperatures
- Higher Variability in annual Precipitation
- Less snow
- Lower base streamflow

2.3 Potential Effects of Hydrologic Change

Fish Distribution

Projected changes to air temperature and stream flow will result in warmer water temperatures, a significant factor affecting distribution of fishes. Warming temperatures are expected to shift thermally suitable habitats for Rainbow Trout upstream. Reductions in snowpack and earlier runoff would lead to decreased summer flows. Declines in summer flows will reduce habitat volume in perennial channels and the largest natal habitat patches will continue to decline in size and may fragment into smaller patches. Brown Trout, which are more tolerant of warmer temperatures will expand their distributions upstream and further constrain or replace native trout in some stream reaches. Brook Trout are capable of persisting in the coldest headwater streams (e.g., <52 °F mean August temperatures) so habitat for the species may be reduced, providing a competitive advantage for Rainbow Trout in these areas.

More wildfires (discussion below) may result in more extensive disturbances including debris flows, especially in the steepest channels at the upstream extent of the network. Less water, hostile environments, and declining fluvial connectivity (e.g., from water development or interactions with road culverts) would favor resident life histories, as would greater separation between spawning and adult growth habitats. Smaller habitats and populations will be more susceptible to extirpation from local environmental disturbances (such as debris torrents following fire, or larger and more frequent floods).

Wildfire

Decades of fire exclusion have impeded the ecological benefits that historically resulted from fire in most of the basin. Changes in fire regime has resulted in changes to vegetation composition and density and changes in density of fuel accumulations in these systems as they shifted from the frequent occurrence of typically low severity fire to that of infrequent high severity fires in the present.

Climate is a strong driver of wildfires, and its influence on fire regimes varies by forest type. Increases in area burned are likely in a warming climate, but fire activity will ultimately be limited by the availability of fuels. Less snow, earlier onset of snowmelt and higher temperatures that reduce fuel moisture will make a larger portion of the landscape flammable for longer periods of time.

Post-fire regeneration of forests may be slowed (e.g., decades to centuries) because of the time required for seed dispersal over large burned areal extents. In addition, the droughty, high temperature conditions associated with anthropogenic climate changes may inhibit seedling establishment and survival.

Near stream Roads and Crossings

Roads effects on aquatic communities are described in Section 2.1.3. If storms of greater magnitude occur, road related impacts are likely to be greater. Because rain on snow (ROS) driven flood peaks tend to be high relative to rain and snowmelt generated runoff, flood magnitudes are expected to increase in the ROS zone. Flooding is expected to become more common in places where it now occurs and to occur in more locations. Roads in near-stream environments are periodically exposed to high flows. Increased peak flow makes infrastructure more vulnerable to effects ranging from minor washout to complete loss of road prisms, with effects on public safety and access for resource management and impacts to stream habitats. Damage to roads near streams often has ecological effects on stream water quality and aquatic habitats. Water use infrastructure (e.g., head gates) may also see an increase in storm damage and maintenance needs/cost due to the increase in high streamflow events, particularly in those areas where the likelihood of ROS events are projected to increase.

There are many roads near streams in the basin. On federal lands, there is decreased capacity to maintain these roads, and there is a backlog of deferred maintenance.

Riparian Communities

Most riparian and wetland systems in the basin have been altered from historical conditions, resulting in changes in stream geomorphic and hydrologic processes, including stream-downcutting and channel straightening. These changes, in turn have altered water availability to riparian ecosystems. Along the

North Fork stream discharge has been greatly manipulated as a result of the construction of hydroelectric facilities. Most of the large, historic wetlands in the basin have been significantly altered, by inundation (e.g. Big Meadows, Antelope Valley) or by water manipulation and diversion dams and water diversions (e.g. Indian Valley, American Valley). These systems have also been affected by domestic livestock use, road construction, and non-native invasive species.

Water availability will be reduced in a warming climate because of earlier snowmelt and runoff, reduced summer stream flows, and increased drought. Riparian community composition and structure will be affected by increased water stress, and drought-tolerant species are likely to replace those riparian and wetland species more dependent on water. Many riparian species are dependent on flooding to transport and deposit sediments and provide bare, moist substrates necessary for seed germination and establishment. Thus, riparian and wetland species will likely be sensitive to any shifts in the timing and magnitude of flooding with climate change.

2.4 Projected Hydrologic Changes

Approach

Climate

We employed two future climate projections to assess changes to the hydrologic attributes. These were the CCSM4_rcp85 and GFDL_A2 models. Because the amount and timing of runoff was one of our primary concerns, the CCSM4 projection was selected because it produces what appeared to be the median projection for Feather River runoff (Figure 7). GFDL_A2 was selected because Basin Characterization Model documentation suggested it was closest to the ensemble mean for projected air temperature increases.

We projected changes for August 1 air temperature, April 1st snowpack and annual runoff. Projections for these attributes were derived for two time periods, 2010-2039 and 2040-2069. The future scenarios were compared to estimates of historic condition for the same attributes.

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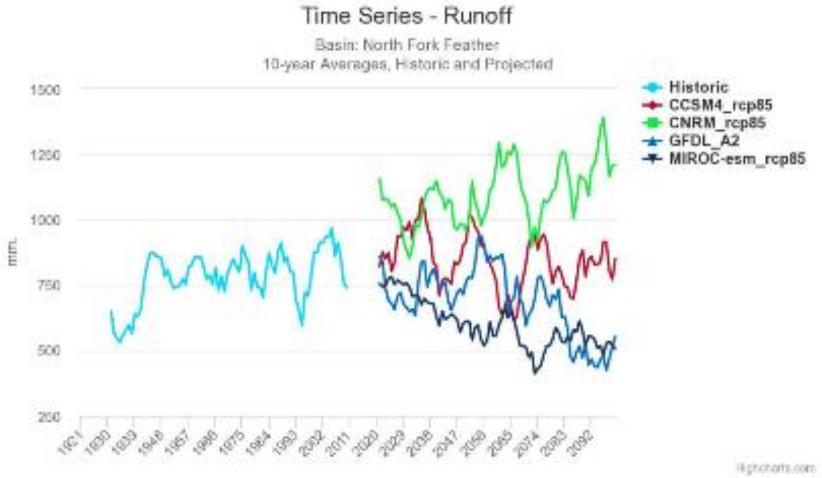


Figure 7. Historic and modeled runoff for the North Fork Feather River, using four climate change models (from Flint, et al 2013)

The Basin Characterization Model (BCM) (Flint and others, 2013) was used to estimate runoff and hydrologic changes associated with climate change. The BCM was used to calculate a monthly water balance for the California hydrologic region which includes all basins in the state. The model was developed at a 270-m spatial resolution, using monthly data, and has been supported by numerous federal, state, local agencies, and international organizations. The BCM uses historical climate data from 1896-2010, and an ensemble of 18 future climate projections to develop hydrologic output such as snowpack, recharge, runoff, and climatic water deficit. To produce this dataset, digital maps of soils and geology for the California hydrologic region were integrated with monthly maps of climate and hydrology, to generate average water year and 30-year water year maps for the historical record (1951-1980 and 1981-2010) and future projections (2010-2039, 2040-2069, and 2070-2099).

Figure 8 displays the hydrologic model employed by BCM. Potential evapotranspiration is calculated from solar radiation with topographic shading and cloudiness, snow is accumulated, sublimated, and melted (sublimation, snowfall, snowpack, snowmelt), and excess water moves through the soil profile, changing the soil water storage. Changes in soil water are used to estimate evapotranspiration, and when subtracted from potential evapotranspiration calculate climatic water deficit. Depending on soil properties and the permeability of underlying bedrock, water may become recharge or runoff. Routing is done via post-processing to estimate baseflow, streamflow, and groundwater recharge. Monthly downscaled climate inputs and hydrologic output variables can be examined for any size polygon representing regions or watersheds, or the distribution across the landscape.

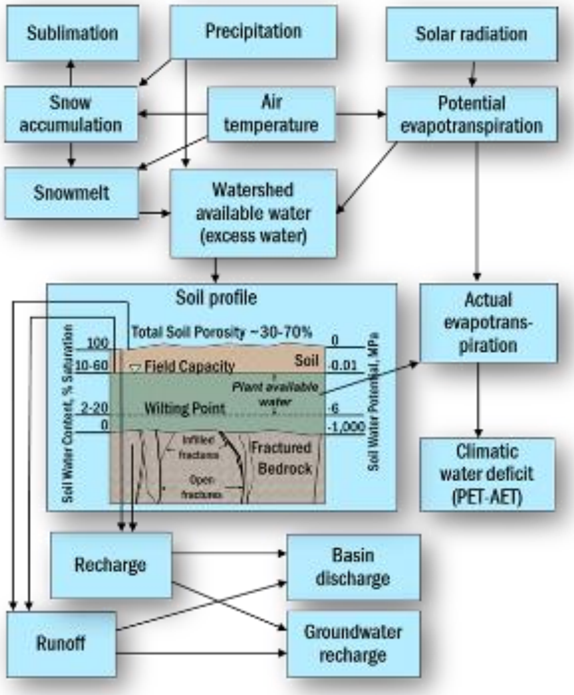


Figure 8. Schematic illustrating relationship of components of the Basin Characterization Model (from Thorne, et al, 2012)

Water Temperature

The NorWeST Stream Temperature Modeling Procedure Issak, et al 2016) (http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html) was used to estimate historic, current and future temperatures. The following description is taken from that site.

“The model employs ten predictor variables with strong influences on August stream temperatures. Air temperature and stream discharge were used to represent temporal change in climate. The remining indicators reflected physical factors affecting within-basin differences in stream temperature. These factors were elevation, latitude, canopy cover (derived from 2001 version of the National Land Cover Database), drainage areas, stream slope, mean annual precipitation, base flow index and tailwater influence.

Stream temperature observations that drove the model came from thermograph data supplied by multiple partners from thousands of unique stream sites across the region. August mean stream temperature was the metric selected to be modeled because this metric allowed the largest proportion of data to be used.

After the spatial statistical models were fit to the temperature database within a river basin, the model was used to make predictions representing climate scenarios at one kilometer intervals throughout the NHDPlus 1: 100,000 scale river network. The NorWeST model produced estimates of historical conditions by setting mean August air temperature and stream discharge values to match those observed for a historical period, whether it was an individual year or a composite of multiple years (e.g., 1993-2011).

Future scenarios were developed by adding predicted future stream temperature changes to the historic estimates (composite of years from 1993-2011). Projections of August air temperature changes were based on an ensemble mean of the 10 IPCC climate models that showed the lowest bias in observed climate across the Northwest U.S. (Hamlet et al. 2013). The same global climate model projections were used with the Variable Infiltration Capacity (VIC) model to generate hydrographs, from which August mean flows were extracted at the USGS gage locations used in stream temperature model development.

Differential sensitivity of streams to climate (i.e., some streams warming more than others) was incorporated by scaling future stream temperature increases relative to the average historical stream temperatures. Basin-specific sensitivity parameters were developed by regressing the observed stream temperatures for each year against predictions at the same site. The analysis described the sensitivity of the temperature gradient across a river network relative to inter-annual variation in stream temperatures. That relationship consistently indicated that cold streams were less sensitive than warmer streams as described in Luce et al. 2014. Incorporating differential stream sensitivity created future scenarios in which the coldest streams warmed 40% - 60% less than the warmest streams."

Thermal Regimes for Trout Species

Drawing from multiple sources, we applied the temperature tolerances for rainbow, brown and Brook Trout shown in Table 2 to the analysis. Basically, these values show Eastern Brook Trout to have the narrowest and coldest water temperature needs and German Brown Trout the widest and warmest range. The suitable range represents the temperature extremes between which the species will feed, grow and remain unstressed by thermal conditions. The optimum range represents the preferred temperatures for the species, where needs for growth, feeding and other activities and processes are best balanced.

Species	Suitable		Optimal	
	Lower	Upper	Lower	Upper
Brook Trout	6	15	9	12
Rainbow Trout	9	18	11	15
Brown Trout	10	19	12	16

Table 2. Thermal tolerances for trout species used in the Assessment. Values are degrees Celsius

Application

The NorWest model results for current and near future condition were described in terms of miles of thermally suitable and thermally optimum habitat. These values were also compared to estimates of the amount of perennial stream habitat within each watershed to describe results in terms of percentages of suitable and optimal habitat.

Results

Air Temperature

The two climate scenarios produced similar projections for temperature increases. August 1 temperatures were predicted to rise for all sub-watersheds between about 3 and 6% by 2039, or about

1 to 1.5 degrees C (2 to 3 degrees F) (Figure 9). This trend continues for 2069 projections with temperatures rising between 8-14% from present conditions, or about 2-3 degrees C (5 to 8 degrees F).

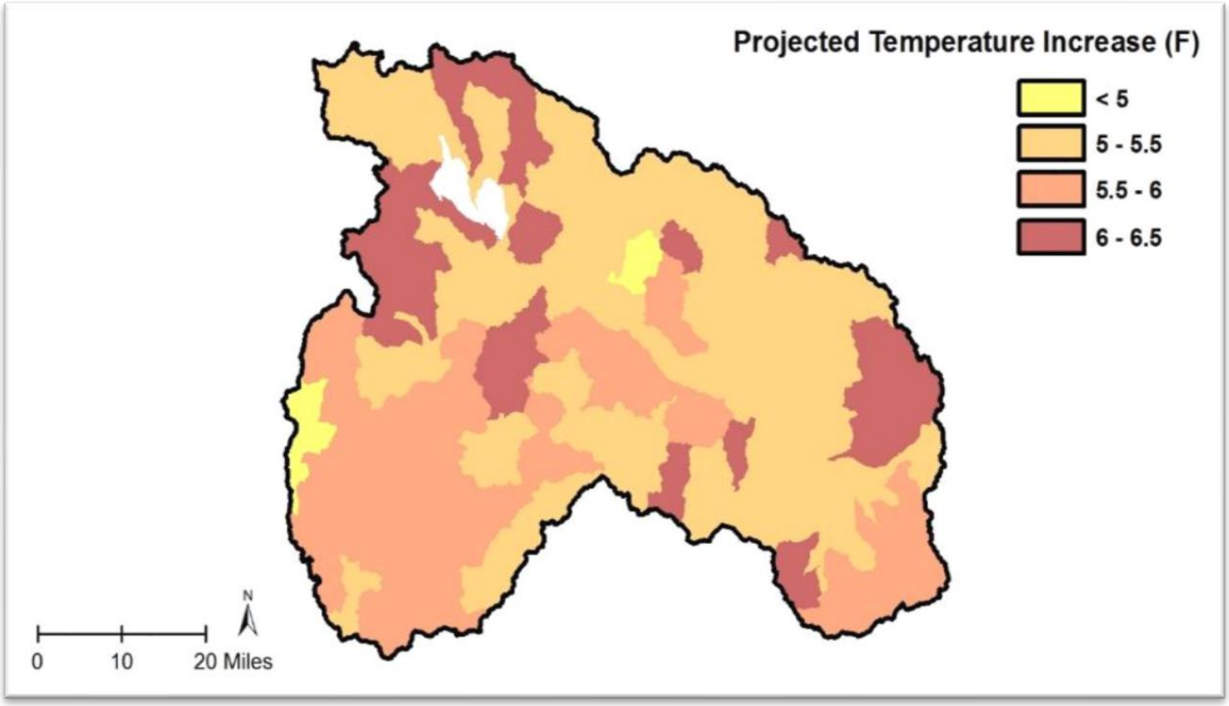


Figure 9. Projected changes in August air temperatures (Daily maximum) (2069, ccsm model)

Precipitation

Both scenarios predict reduced precipitation in 2039 across the basin, with about a 15% decrease for most sub-watersheds under the ccsm model. The gdlf projection is for reduction in sub-watersheds to range from about 1 % to about 14%. The ccsm model projects a slight increase in precipitation between 2039 in 2069, whereas the gdlf projects a slight, continued decrease in precipitation over the same period.

Snowpack (April 1)

Both models project significant reduction in April 1 snowpack for both time periods across the entire basin. Figure 10 displays the amount of snowpack projected to remain in 2039 (ccsm model) by sub-watershed. The westernmost portions of the basin are projected to have no April 1 snowpack. The greatest snowpack retained are in high elevation sub-watersheds including those tributary to Lake Almanor and around Mount Ingalls.

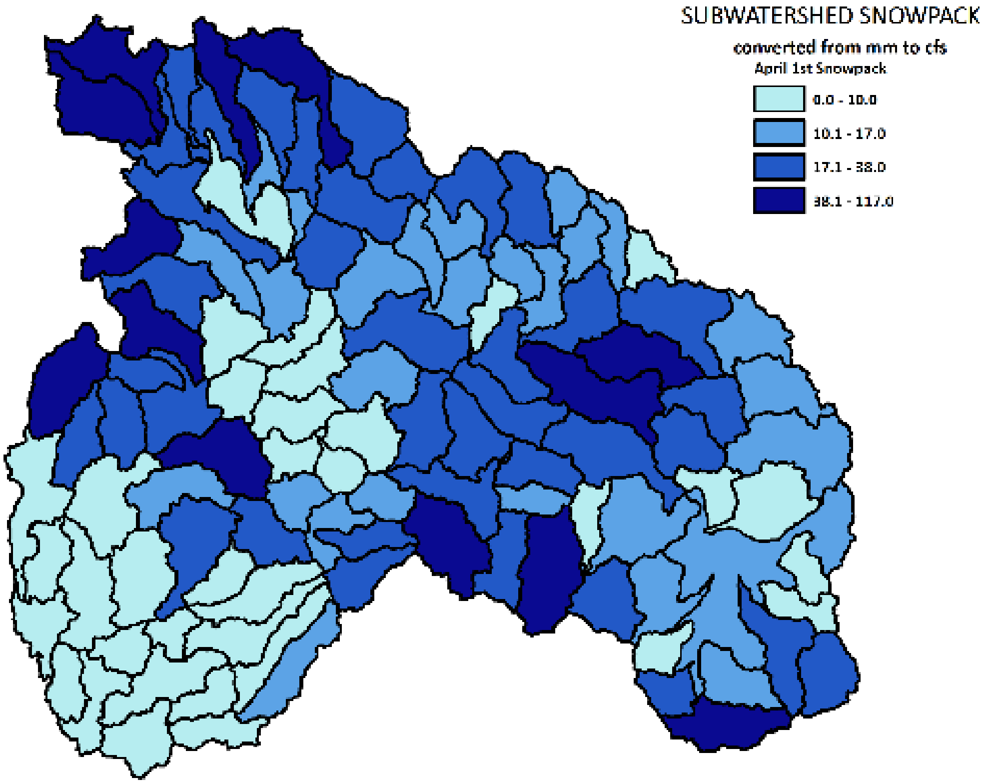


Figure 10. Projected remaining snowpack, by subwatershed (2039, ccsm model)

Streamflow

Variations in projected precipitation and snowpack contribute to a range of projected runoff conditions in basin sub-watersheds (Figure 11). Eight sub-watersheds, those at the highest elevations, show a slight increase in flow. The remaining sub-watersheds are projected to see reduced flow, with reductions ranging from 1% to more than 20%. Sub-watersheds at relatively low elevations are projected to experience the greatest reductions. Estimates of runoff are influenced by changes in both precipitation and evaporation. Increases in evapotranspiration associated with increased air temperatures and longer growing seasons are strong influences on runoff, especially in the western portions of the basin.

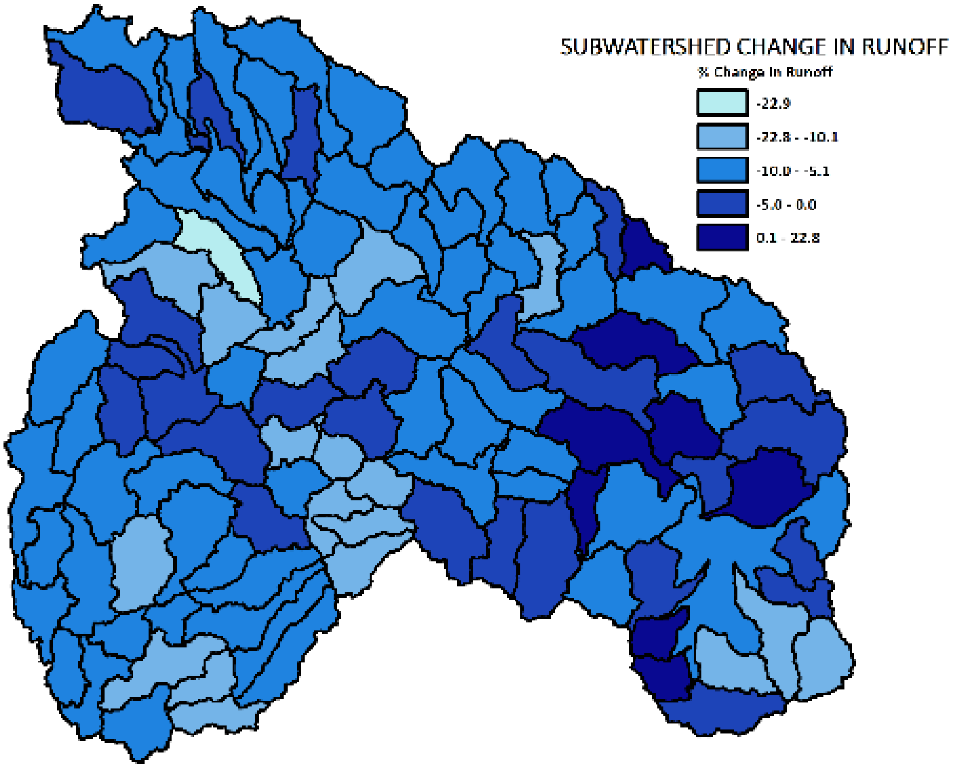


Figure 11. Projected change in runoff, by sub-watershed. 2039, ccsm model

Water Temperature

As described in section 2.1.5, future water temperatures were derived from the NorWeST model. Predictions of changes to stream temperature were described in terms of changes in the amount of suitable and optimum thermal habitat for Rainbow Trout.

Suitable Habitat

Warming temperatures result in a slight gain (0.1-4%) in suitable habitat in 6 sub-watersheds. These sub-watersheds are all high elevation where the model shows current temperatures to be slightly too low to provide suitable habitat for Rainbow Trout. All these watersheds (Lower Yellow, Mill, Milk Ranch, Rock, Warner, Willow) are tributaries to the North Fork. Losses in suitable habitat are projected for the remaining sub-watersheds. The greatest losses would occur in low elevation western portions of the basin and in Indian Valley and its tributary streams.

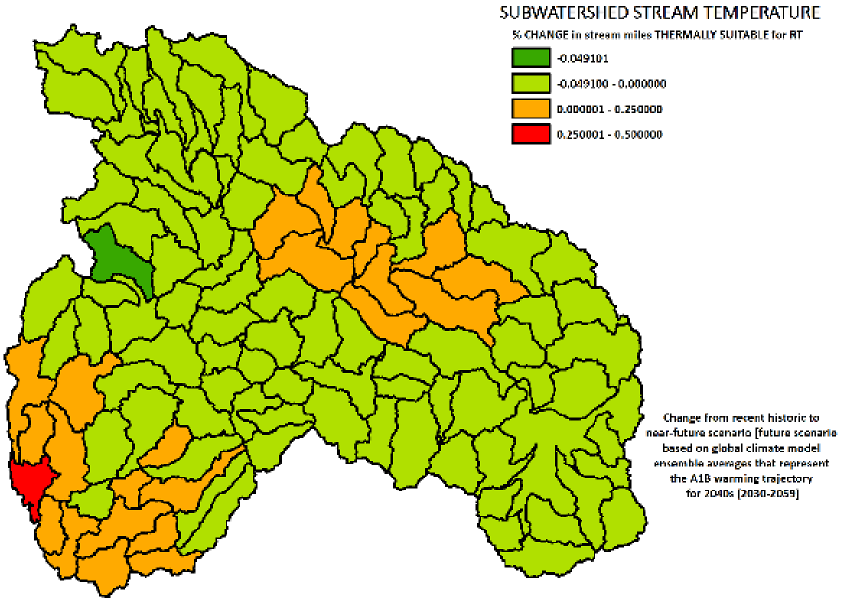
Characteristic	Suitable	Optimal
range	43-100	0-100
Number with <90%	26	89
Number with 100%	85	8
Number with 0%	0	4

Table 3. Summary of predicted suitable and optimal thermal habitat for Rainbow Trout, by sub-watershed

Characteristic	Suitable	Optimal
Number with habitat gain	4	2
Number with habitat loss	18	50
Largest Gain (%)	4	29
Largest Loss (%)	86	100

Table 4. Summary of changes to suitable and optimal thermal habitat for Rainbow Trout, by reach

7 sub-watersheds project decreases in suitable habitat of more than 10%. 4 of these watersheds (Chino, Concow, Dark Canyon, E Fork Canyon) are located in the low-elevation, western portion of the basin. The other 3 sub-watersheds are tributaries to Indian Creek in Indian and Genesee Valleys (Hough, Lower Lights, Ward). The changes in suitable habitat condition, by sub-watershed, are shown in Figure 12.



Change from recent historic to near-future scenario [future scenario based on global climate model ensemble averages that represent the A1B warming trajectory for 2040s [2030-2059]

Figure 12. Change in percentage of perennial stream with suitable thermal conditions for Rainbow Trout, by sub-watershed. Losses are in orange and red, gains in green

Since the range of suitable temperatures is wider than that for optimal temperatures, it would be expected that there would be less loss of suitable than optimal habitat. This assumption mirrors the results, summarized in Tables 3 and 4.

Optimal Habitat

We defined optimal habitat ranges for rainbow, brown and Brook Trout (section 2.5). These temperatures are best for each species in terms of feeding, growth and survival. Gains in optimal habitat are the result of increased temperatures in streams in the highest elevation watersheds. Those with the largest gains (10%) were all tributaries to the North Fork (Bailey, Bucks, Soldier). Twenty-five watersheds (listed in Table 5) are predicted to lose at least 10% of their current optimal habitat due to warming. These watersheds are predominantly of two types. They are either located in the low elevation, western portion of the watershed (i.e. Berry Creek, Sucker Run), or are in mid-elevation sub-watersheds with large, low gradient streams (i.e. Lone Rock, Middle Lights, Goodrich). Stream gradient is a key predictive factor in the NorWest model, with steeper streams less susceptible to warming.

Waterbody
Berry Creek
Ferris Creek
Tollgate Creek-Spanish Creek
Mountain Meadows Reservoir
Upper Red Clover Creek
Middle Lights Creek
Carman Creek
Upper Lights Creek
Dixie Creek
Goodrich Creek
Lower Red Clover Creek
Mapes Canyon
Squaw Queen Creek
Little West Fork West Branch Feather River
Chino Creek
Lone Rock Creek
Sucker Run
Mountain Meadows Creek
Poison Creek
Rock Creek (Spanish)
Willow Creek (Last Chance)
Humbug Creek (Middle Fork)
Oroleve Creek

Table 5. Sub-watersheds projected to have losses of >10% thermally optimal habitat for Rainbow Trout.

2.5 Rating Sub-Watershed Exposure (Attributes combined)

We used available projections of future climate, and modeling of how those changes might affect hydrologic processes critical to fish habitat, most importantly, the availability of water. These results were coupled with projections of future stream temperatures to identify those areas with the greatest potential to support trout should warming continue to occur. We term the risk of potential changes as exposure to climate change. Areas with highest exposure are likely to see the largest decreases in flow and baseflow and greatest increases in stream temperature.

Our judgement was that areas predicted to have the least reduction (or increases) changes in streamflow and water temperature would provide the best chance for sustainability of trout habitat. To assess the relative exposure of sub-watersheds to warming water temperatures and changes in runoff, we combined the results from the runoff, snowpack and water temperature projections. Results (Figure 13) indicate which sub-watersheds have the greatest likelihood of providing the best flow and water temperature conditions for Rainbow Trout in the future.

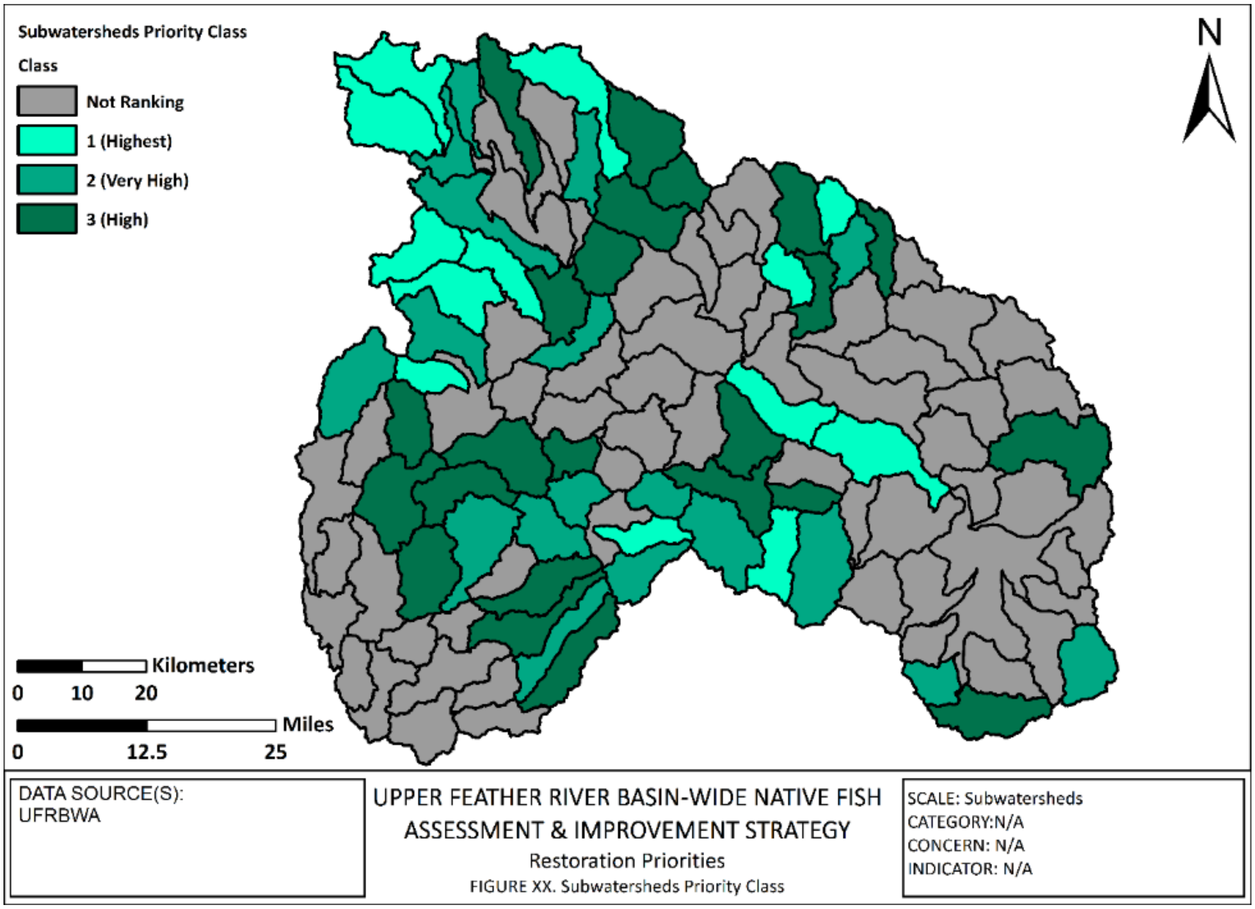


Figure 13. Sub-watersheds with lowest exposure (highest projected flow, snowpack and optimal stream temperatures

We rated exposure for each sub-watershed by combining results from the runoff, snowpack and stream temperature projections, applying the criteria shown in Table 6. Criteria levels were set using quartiles, adjusted slightly to conform to a break in the unit of measure (e.g. 1.5 cfs). 89 of the 121 sub-watersheds were projected to support at least one of the conditions (0.3 cfs runoff from snow, 0.75 cfs runoff, 80% perennial stream habitat with optimum temperature for Rainbow Trout). The fourth criterion was an increase in the amount of optimal habitat for Rainbow Trout. We felt subwatersheds with an upward trend were more likely to sustain habitat for Rainbow Trout than other areas.

Criteria #	Criteria	Level 1	Level 2
1	Snow remaining	0.5 cfs (23 of 112)	0.3 cfs (55 of 112)
2	Runoff Remaining	1.5 cfs (25/112)	0.75 cfs (51/112)
3	Percent Habitat Opt Temp for RBT	90% (23/112)	80% (45/112)
4	Upward Trend in Opt Temp for RBT	Yes (24/112)	NA

Table 6. Scheme applied to watersheds to rate exposure.

We classified subwatersheds (Figure 14) into three exposure groups using the following rule set:

> **Exposure Class I (least exposure):** *Meets criteria 1-3 at either level, and at least one at Level 1.*
>
> **Exposure Class II (low exposure):** *Meets criteria 1-3 in Level 2, or; Meets two criteria, one at Level 1.*
>
> **Exposure Class III (moderate exposure):** *Meets 2 criteria, but none at upper level, or; Meets one criteria, at either level, and has projected increase in Opt RT Temp*

The rule set reflects our logic that the combination of sustaining flow (runoff projection), baseflow (snow runoff projection) and stream temperature optimum for Rainbow Trout represent areas with the highest likelihood of providing good habitat in the future. Applying the rule set to the 89 sub-watersheds that met at least one exposure criteria identified 56 sub-watersheds in at least one of the priority classes.

Subwatersheds with the least exposure are located at the highest elevations in the basin. Most (10 of 15) of these subwatersheds are tributary to Lake Almanor or the North Fork Feather River. The remaining five sub-watersheds are not clustered but drain some the highest points in the basin (Mt Ingalls, Bald Mt, Thompson Peak) and the ridge east of Sierra Valley.

Retention of flow, baseflow and lower water temperatures were viewed as key components of future habitat condition for native fishes. Volcanic geology can result in more infiltration and higher baseflows (Tague and Grant, 2004). We considered employing a measure of volcanic geology that would contribute to hydrologic resilience but were unable to identify a useable indicator. We note however that volcanic geology dominates certain portions of the basin (Koczot, et al, 2005). The largest contiguous volcanic geology is located roughly in the northeastern portion of the basin, in what is considered the Cascade Range. This area, due to its elevation, rates as having high resilience using the hydrologic projections. Other areas of with volcanic rock lie at the headwaters of Red Clover and Last Chance Creeks, and tributaries draining to Sierra Valley from the east. These areas might be considered as being more resilient as a result of their volcanic geology.

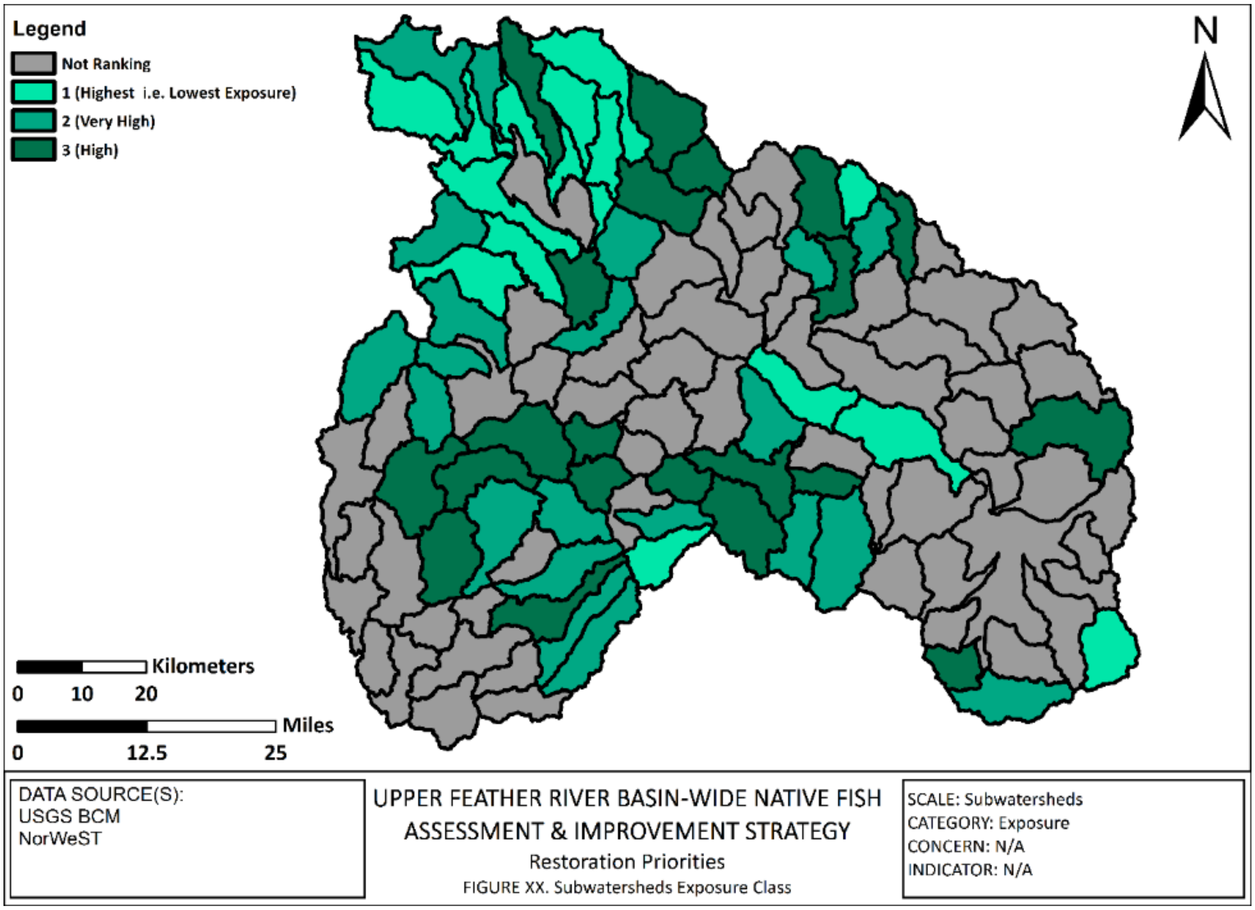


Figure 14. Sub-watersheds grouped into three Exposure Classes

Note also that assessment of exposure is confined to analysis of Subwatersheds, as applicability to the scale of an individual reach is presumably limited. Nonetheless, inferences could be made regarding the resilience of reaches lying within clusters of resilient Subwatersheds.

Part 3: Existing Condition Assessment

Introduction

Early on in development of the assessment, the TAC met to discuss which indicators might be useful in describing watershed and fish habitat conditions. The result of this discussion was the extensive list of potential indicators listed in Table 7.

- Temperature (stream temp, air temp)
- Pathogens (fish health)
- Fish community (native salmonids, non-native salmonids and other fishes)
- Stocking practices
- Amphibians (presence)
- Aqua (mussels and vegetation)
- Beavers (habitat engineers)
- Otters (indicator, stressor)
- Benthic Macroinvertebrate (BMI) communities (productivity)
- Outdated catch regulations
- Riparian vegetation (type, density, condition)
- Barriers (dams, crossings, projects)
- Diversions (number, flow, stranding)
- Sediment (roads, crossings, burn, slope, soils)
- Habitat Complexity (wood, type ratio, floodplain connectivity)
- Water quality (mines, 303d)

Table 7 List of potential or proposed indicators discussed by the TAC and/or community members.

Each of the indicators listed in Table 7 were reviewed against three criteria:

- a close relationship to fishery and/or habitat condition (*research documents a connection between the indicator and fisheries habitat)*
- available (or easily assembled) data source of reasonably reliable quality
- basin-wide coverage (i.e. *data available for the entire watershed*)

Four primary fish habitat concerns were identified: sediment, flow, temperature and channel condition. Concerns. Our goal was to include indicators that met the criteria above for else of the habitat concerns. The indicators ultimately selected represented three primary elements: biological characteristics, physical characteristics and habitat connectivity. For each element, we identified major fish population and habitat concerns, indicators that were reflective of each concern, and metrics that would be used to quantify each indicator. An example of this logic path (for the assessment of Physical Condition) is shown in Figure 15.

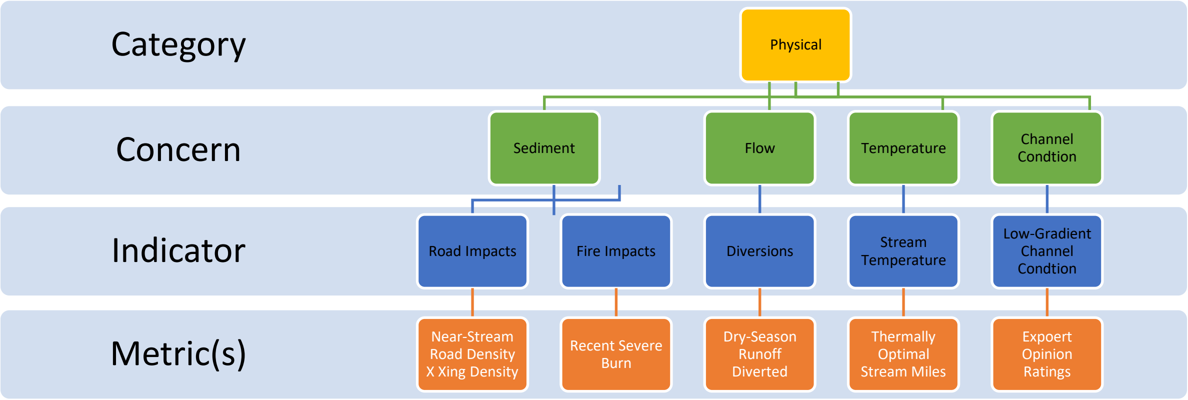


Figure 15. UFRBWA Framework- aspects of condition were placed into a hierarchy of general Categories, fishery condition-specific Concerns, applicable Indicators and appropriate Metrics. The example provided here describes assessment of physical (abiotic) condition.

the concerns were identified for each of the three elements (physical, biological, connectivity) are shown in Table 8. Also listed in Table 8 are the indicators and metrics used to describe condition for each concern.

CATEGORY	CONCERN	INDICATOR		METRIC	DATA SOURCE
Physical	**Sediment**	**Road**	Near-stream road density (30m buffer)	length of road/near-stream buffer area (mi./sq. mi.)	USFS[1]/US Census[2]
			Road-stream crossings	# of crossings/total channel length (x-ings/mi.)	USFS/US Census
		Soil Stability		watershed area with 'Very Severe' Erosion Hazard Rating (%)	NRCS[3]
		Fire Impacts	High Severity Burn in the 10-year period 2000 to 2009	watershed area burned at high severity (%)	MTBS[4]
			High Severity Burn in the 5-year period 2010 to 2014	watershed area burned at high severity (%)	MTBS
	Temperature	Stream Temperature		miles of thermally optimal/suitable stream miles	NorWeST[5]
	Flow	Annual runoff diverted		dry season runoff less sum of active diversions	USGS BCM[6]/CA SWRCB[7]/UFRBWA[8]
	Channel Condition	Low-Gradient Channel Condition for Contained Reaches		expert opinion ratings	UFRBWA
Biological	**Fish Community**	Native Fish Presence		native fish presence	UFRBWA
		Non-native Fish Presence		non-native fish presence	UFRBWA
	Fish Health	Pathogen Presence		pathogen presence	UFRBWA
	Invasive Mollusks	Presence of Quagga, New Zealand mudsnails, Zebra Mussels		Species presence	UFRBWA
Connectivity	**Habitat Connectivity**	% contributing stream connected		proportion of total channel length <20% gradient below barriers	USFS/US Census/UFRBWA/CDFW-CalFish CPAD[9]/ CalTrans[10]
	Entrainment Risk	Diversions		# of diversions/total channel length	CA SWRCB/UFRBWA

*Table 7. Indicators used to describe physical and biological condition, and connectivity in the assessment. * Indicators applied to HUC12 only.*

[1] USDA Forest Service. Forest Service Roads. 2016.

[2] US Census Tiger Roads. Processed TIGER 2010 Primary and Secondary Roads. U.S. Census Bureau, Geography Division. 2010.

[3] NRCS SMS Soil Data Mart ArcGIS tool. United States Department of Agriculture, Natural Resources Conservation Service. 2016.

[4] Monitoring Trends in Burn Severity (MTBS)- Eidenshink, J. et al. 2007. A project for monitoring trends in burn severity. Fire Ecology 3(1): 3-21

[5] Isaak, D.J. et al. 2016. NorWeST modeled summer stream temperature scenarios for the western U.S. Fort Collins, CO: Forest Service Research Data Archive.

[6] Flint, L.E. and Flint, A.L., 2014, California Basin Characterization Model: A Dataset of Historical and Future Hydrologic Response to Climate Change, U.S. Geological Survey Data Release, doi:10.5066/F76T0JPB

[7] State of California, Water Resources Control Board, Electronic Water Rights Information Management System (eWRIMS). 2016.

[8] Data compiled by UFRBWA authors during the course of the project.

[9] California Fish Passage Assessment Database. Pacific States Marine Fisheries Commission. GIS shapefile (Via CDFW BIOS). 2017.

[10] Bridges in California. CalTrans. GIS shapefile. 2015.

Community Engagement Meetings

We supplemented our research and discussions with the TAC with community engagement sessions. This effort was intended to inform local communities about the assessment and also to gather information on issues of concern that might be used to adjust or include indicators as well as gather first hand information useful in describing fish distribution and habitat condition. Four public meetings were held in December, 2016 and January, 2017 to discuss the project and gather information from the public that might be useful in preparing the assessment and improvement plan. Meetings were advertised in local print and radio media, and held in the evening in Sierraville, Greenville, Quincy and Chester. Generally, the meetings were not well attended but nonetheless provided some local insights and knowledge. There were many suggestions and concerns raised by attendees, both in terms of specific locations as well as resource concerns or management practices.

Residents in attendance at the Chester-Lake Almanor installment highlighted the importance of Lake Almanor tributaries (Benner Creek, Last Chance Creek, Bailey Creek, Mud Creek and the many ephemeral streams) for wild fish reproduction. They also voiced concern about the functionality of the fish ladder on the North Feather River and the flood control diversion structure upstream of the town of Chester. Many area anglers feel the structure does not allow passage for Rainbow Trout during the high flows sometimes associated with the spring spawning period. They and also noted the illegal fishing effort that often takes place in the pool immediately below the ladder during that time. Attendees also expressed concern about the management of the Hamilton Branch hydroelectric complex in response to the then recent total drawdown of Mountain Meadows Reservoir, which resulted in significant fish mortality and water-quality concerns in the drainage.

At the Quincy meeting specific areas cited for possible restoration or protection included Spanish Creek, the Middle Fork Feather River and upper Last Chance Creek and their tributaries. The single most useful suggestion was to consider the Upper Last Chance Creek drainage as an area for protection and improvement, due to its relatively low amount of water diversions, good connectivity between tributaries and the main stem, and presence of healthy Rainbow Trout populations in most tributaries.

Each group expressed some common resource and management practice concerns. One practice highlighted was changing stocking practices. Concerns were expressed about scaling back of stocking in general, and scaling back of stocking of non-native species (especially brown trout, which are thought to have a certain allure for tourists, particularly in the Almanor area). Some also expressed concern about the practice of stocking triploid fishes, which some attendees perceived to be less catchable. Other management issues cited included the disparity of fishing regulations to changing stocking practices. The concern was that more stringent regulations might be needed in response to decreasing and changing stocking practices that could cause greater stress on wild-reproducing populations. Another concern expressed at two meetings was the impact of rebounding river otter populations on wild trout populations. A family of otters can find an easy meal, for example, in the Hamilton Branch where fish seek thermal refugia from the warm waters of Lake Almanor.

Many of the locations, resource and practice concerns expressed during the public meeetings were echoed in angler interviews. Some overlap existed as well with the opinions and perceptions of the Technical Advisory Teams.

3.1 Biological Indicators

The purpose of this assessment is to identify current condition and assess future condition for native fish communities, with an emphasis on Rainbow Trout. We assembled data to address the following primary questions:

- Where are native trout present?
- Where are non-native trout present?
- Where are fish pathogens, namely *Ceratanova shasta* and Whirling Disease (*Myxobolus cerebralis*), present?
- Where are three extremely problematic invasive mollusks (Quagga, zebra mussels and New Zealand mudsnails) present?
- What areas might support Rainbow Trout populations least impacted by hatchery fish (genetic introgression)

Fishes

Historic Fish Distribution

The assemblage and distribution of fish species in the Upper Feather River Basin is extensively altered. The most significant change to the fish assemblage and distribution in the basin is the extirpation of anadromous fishes. The second most significant alteration is the extensive stocking of both non-native and native fishes. These actions resulted in the establishment of populations of non-native fishes and genetic introgression of the hatchery stock Rainbow Trout into the native Rainbow Trout gene pool. A third consideration is the alteration of habitat that has created conditions that favor non-native fish assemblages.

Historic Anadromy

Chinook Salmon

The Feather River Basin is assumed to have once supported substantial runs of all four runs (winter, spring, fall, late-fall) of Central Valley chinook salmon, as well as Central Valley steelhead. However, going back in time, the record for historic abundance of Central Valley chinook is sparse and accounts of steelhead are fewer yet. Accounts began circa mid-to-late 19th century, at which time those concerned were already documenting significant declines, largely due to the habitat alteration and blockage caused by the widespread mining operations occurring across the Sierra Nevada. Accurate scientific accounts began much later, circa 1920.

The extent of chinook migration within the Feather River Basin was greatest in the North Fork of the Feather River. Under a favorable water year and with proper channel morphology Spring-run Chinook salmon could surmount Salmon Falls, located a few miles below Canyon Dam, and ascend past Big Meadows (now Lake Almanor) several miles to headwaters on the southeastern face of Mt. Lassen. Chinook probably also ascended a few miles of Hamilton Branch. Chinook likely ascended the West Branch of the Feather River to within the vicinity of Sterling City.

In the East Branch of the North Fork Feather River system, Indian Falls, located on Indian Creek approximately midway between Indian Valley and its confluence with Spanish Creek, similar to Salmon

Falls on the North Fork, probably posed as a long-interval temporal barrier, passable only under favorable conditions. Spanish Creek, along with Yellow Creek, probably also held a few miles of the spawning habitat accessible in the East Branch system. The extent of migration in the Middle Fork Feather River system reached to Bald Rock-Curtain Falls on the main stem, Feather Falls on Fall River and to the proximity of Forbestown on the South Fork of the Feather River (Yoshiyama et. al. 2000). The fall run, which spawned primarily in the main stem North Fork Feather River, was most abundant.

Precise numbers for the historic abundance of chinook salmon runs in an unblocked, undisturbed Upper Feather River Basin are not known. From the mid-19th century, salmon numbers were already in decline, based on naturalist and fish culturist accounts and commercial harvest records.

Early designations of the spring and fall runs of chinook in the Central Valley drainages were made on the basis of peak run-timing observed by commercial fishermen. The fall run historically included the fall, late-fall and winter runs because seasonal peaks in run-timing were not observed until much later. Early fall-run accounts indicate that late-fall and winter run fish were less abundant (Yoshiyama et. al. 1998). The historic record indicates that no appreciable winter-run of Chinook occurred in the Feather River system (Yoshiyama et al. 2001).

Central Valley Steelhead (Rainbow Trout)

There is greater uncertainty regarding historic distribution and abundance of the anadromous life-history form of Rainbow Trout within the Basin. It is assumed that steelhead were more widely distributed than salmon, based on observations that steelhead typically spawn in smaller tributaries than chinook salmon. Further complicating the story is that steelhead breed with resident life-history forms of Rainbow Trout. Resident populations may have existed above anadromous migration limits. Schick et al. (2005) using the synopsis on chinook salmon prepared by Yoshiyama, mapped steelhead distribution as being essentially the same as that of chinook, but with limited confidence based on the above caveats. Lindley et al. (2006) modeled potential historic steelhead habitat based on discharge, gradient and air temperature. Their results found most of the Upper Feather River Basin suitable for O. mykiss, but may be liberal, as only one natural barrier (Feather Falls) appears to be acknowledged. A more accurate extent of historic habitat-use by anadromous life-history forms of Rainbow Trout within the Basin, likely lies somewhere in between.

Aside from altered fish assemblages resulting from the extirpation of anadromous fishes, the importance of anadromous fishes, and salmon in particular, to wider ecosystem function and process is increasingly studied. The nutrient subsidy carried by anadromous fishes to terrestrial-aquatic ecosystems is substantial and has implications for function and process through many ecological pathways and trophic levels (Gende et al.2002, Helfield & Naiman 2001, Hocking and Reimchen 2006, Moore et al. 2007). Broad scale estimates of the nutrient deficit caused by the extirpation of anadromous fishes has been shown to be significant (Gresh et al. 2000).

Inland Fisheries

Prior to the extensive habitat alteration and introduction of non-native fishes to the Basin, assemblage of non-anadromous, native fishes probably very closely approximated, if not matched, the distribution continuum for Central Valley Streams described Dr. Peter Moyle in Inland Fishes of California (2002).

From the headwaters to the mouth at the Sacramento River one would have found the Rainbow Trout, Pikeminnow-hardhead-sucker and deep-bodied fish assemblages, respectively, with the California roach assemblage scattered throughout small tributaries at the lower elevations. At higher elevations, the Rainbow Trout assemblage would have been present, consisting of both anadromous and freshwater Rainbow Trout and riffle sculpin, with Sacramento sucker present at elevations below about 600 m. Between any two given assemblages, boundaries would have shifted seasonally.

Anthropogenic habitat alteration, namely the creation of reservoirs and/or reductions in flow, has favored assemblages comprised of native species with tolerance for warmer temperatures (the pikeminnow-hardhead-sucker assemblage predominates the reservoirs associated with hydroelectric development on the North Fork Feather River). Altered habitats now host a variety of introduced non-native fishes (black bass species are established in nearly every major reservoir in the Basin). A variety of alien cyprinids (common carp) and forage fish (Wagasaki, golden shiner, and others) are also established in many areas of the Basin.

Fish stocking, by both management agencies and individuals has significantly affected native fish communities. The history of stocking in the Basin is complex. Planting Rainbow Trout raised outside the Basin has been a part of CDFW stocking operations from very early stages. Early stocking efforts likely utilized fish of wild origins, from within and without the Basin, to establish populations in fishless areas. Stocking trout in the NFFR began after the completion of the Western Pacific Railroad in 1909. Records show planting sack-fry and fingerling trout began as early as 1910. While the survival of hatchery-reared fish is thought to be generally low, survival of native transplants may have been greater than hatchery fish utilized later.

Recent studies that included two sites within the Basin, both in locations subject to heavy stocking efforts, indicated that hatchery introgression was limited (Pearse and Garza, 2015). More recently CDFW has shifted to planting only reproductively-sterile, native species. While precise information regarding the distribution of all alien fishes would be desirable, our analysis included only salmonids. We assumed that non-native salmonids pose the most immediate concern to existing Rainbow Trout habitat. Brown Trout and Brook Trout are the two most common stocked non-natives and are well distributed and well established in the basin. In many locations they are the dominant fish species. There is some evidence that when stocking of Brown Trout is terminated, Rainbow Trout may return to dominance where habitat favors them. Current CDFW stocking philosophies favor native species.

Fish Pathogens

Whirling Disease

This pathogen is an important disease of salmonids. It is caused by the myxozoan parasite, *Myxobolus cerebralis*. The parasite has a two-host life cycle, involving a salmonid fish and an aquatic oligochaete host (*Tubifex tubifex*). The fish host produces the myxospore stage of the parasite, which is infectious for the benthic filter-feeding worm; in turn, the worm produces the triactinomyxon stage, which is released into the water to infect fish (Wolf and Markiw 1984).

The disease can result in mass mortalities to fry. Infected fish exhibit convulsive movements, increased rate of breathing and jerking backwards movements. The name of the disease comes from the behavior of infected fish, which tend to swim in a whirling motion (tail chasing) and show erratic and darting movements.

First described in Germany, *M. cerebralis* was carried to the United States in infected trout. It was first recorded in North America in 1956 in Pennsylvania and has spread steadily south and westwards

Bergersen and Anderson (1997). The pathogen has become most broadly established in waters of the Rocky Mountain states where it is causing heavy mortalities in several sportfishing rivers. Some streams in the western United States have lost 90% of their trout (Tennyson, et al, 1997). In the Feather River Basin, Whirling Disease has had devastating impacts on trout populations in Yellow Creek and has also been reported in Goodrich Creek and Indian Creek below Antelope Dam (Kossow, personal comment). Surveys in the Moonlight Fire area found additional infections in Indian Creek above Antelope Lake and in Lights Creek (Richey, et al, 2016).

Ceratanova

Ceratanova shasta is a parasite that causes losses in hatchery reared and wild juvenile salmonids. It also contributes significantly to pre-spawning mortality in adults. Better known by its old name, Ceratomyxa shasta, this microscopic parasite causes hemorrhaging and necrosis of the intestine of salmon and trout.

This myxozan parasite (formerly Ceratomyxa shasta) causes enteronecrosis “gut rot” in salmon and trout. *C. shasta* infects a freshwater polychaete worm. Actinospores are released from the worm, and infect fish, on contact, in the water column. Once infected juvenile rainbow trout become anorexic, lethargic, and darken. Infected fish become emaciated and later sometimes develop large fluid filled blebs and kidney pustules. Internally, the entire digestive tract, the liver, gall bladder, spleen, gonads, kidney, heart, gills, and skeletal muscle may become diseased, hemorrhaged, and necrotic. Light infections can be cleared by some fish species, whereas larger doses result in mortality, especially in combination with high water temperatures (Bartholomew et al., 1997).

The disease was first observed in 1948 in fall spawning rainbow trout (*Salmo gairdneri*) from Crystal Lake Hatchery, Shasta County, California It was first observed at the Crystal Lake Hatchery, Shasta County. The parasite was most likely introduced to the North Fork Feather River via hatchery fish in the 1950s. It appears that juvenile salmonids originating from waters containing the infective stage of the parasite are more resistant than strains from areas free of the infective stage (Bartholomew 1998).

At the present time the only section of the lower NFFR (below Almanor) that receives fish plants is the Belden Section of the NFFR from Gansner Bar to the Queen Lilly Campground. This reach of river receives 10,000 lbs./year as required by Pacific Gas & Electric (PG&E) Company’s FERC Belden Project Agreement. The agreement does not require planting C. shasta resistant stock. It is believed spores released back into the water column following salmonid mortality and elevated stream temperatures in the Belden Section below Belden Dam help enhance/perpetuate C. shasta in that section of the NFFR.

White Spot Disease

Ichthyopthirius multifili (Ich) is a fish pathogen caused by a ciliated protozoan parasite. The pathogen is worldwide in distribution and most freshwater fishes are susceptible. Ich’s life cycle has both host and environmental life stages. The Ich trophont feeds within the epithelium fin, skin, and/or gills of the host fish. After feeding, Ich breaks through the epithelium, falls off the host, and forms a reproductive cyst. The disease can infect crustaceans as well as most fishes.

The protozoa damages the gills and skin as it enters the tissues, leading to ulceration and loss of skin. Severe infections rapidly lead to loss of condition and death. Damage to the gills reduces the respiratory efficiency of the fish, reducing its oxygen intake from the water. Considerable acquired immunity is present in fish that recover from infections.

A recent report (Soto, 2018) reported the presence of White Spot in the NF Feather River, during eDNA sampling conducted in summer and fall of 2017 and February and May of 2018. The pathogen was identified as far upstream as Butt Creek and Butt Lake on the North Fork and just below the confluence of Spanish and Indian Creeks on the East Branch NF; and as far downstream as Shady Rest.

We did not sample for White Spot Disease, but its presence in the NF is worthy of documentation.

Invasive Mollusks

Quagga Mussels

Dreissena rostriformis bugensis is indigenous to the Dneiper River drainage of Ukraine and the Ponto-Caspian Sea. It was discovered in the Bug River in 1890 by Andrusov, who named the species in 1897. The first discovery of Quagga mussels west of the Continental Divide was at Lake Mead in Nevada in 2007. Subsequent surveys found smaller numbers of Quagga mussels in Lakes Mohave and Havasu in the Colorado River Basin and in the Colorado River Aqueduct System which serves Southern California. The mussel has been identified at several locations in southern California through October of this year. The mussel was also found in two locations in Nevada, Pyramid Lake and Rye Patch Reservoir, in 2011 raising concerns that it may have been transported into the Feather River basin.

Quagga mussels accumulate organic pollutants within their tissues to levels more than 300,000 times greater than typical concentrations in the environment. The mussels generate toxic byproducts that significantly oxygen levels and lower pH to an acidic level. The mussels have been associated with outbreaks of botulism poisoning in wild birds.

Quaggas colonize both hard and soft substrates. The mussels clog water intake structures, such as pipelines and screens, reducing pumping capabilities for power and water treatment facilities. Recreation-based industries and activities are also affected by the mussels which take up residence on docks, breakwalls, buoys, boats and beaches.

New Zealand mudsnails

Potamopyrgus antipodarum is a species of small aquatic snails that reach, on average 4-6 mm in the western United States. This species is ovoviviparous and parthenogenic, meaning they are live-bearers, which release live young rather than eggs, and those offspring are clonal (genetically identical) females that are asexually reproduced. When born, offspring already contain developing embryos within their reproductive system. Upon reaching maturity at 3 mm, females can produce 230 new females per year. Estimates indicate that one snail and its offspring can result in over 2.7 billion snails within 4 years. Though sexually reproductive males (<5% of the population) and females do exist in their native range, the populations in the western U.S. are believed to contain only clonal females.

The mudsnail can become the dominant macroinvertebrate by displacing and outcompeting native species; some North American streams have reached densities over ¾ million individuals/m2. They may consume up to half of the food resources in a stream and have been linked to reduced populations of aquatic insects, including mayflies, caddisflies, chironomids, and other insects important to trout and salmon. High density New Zealand mudsnails (NZMS) populations are likely to cause substantial negative impacts on fisheries by replacing preferred, nutritious foods. Vinson and Baker (2008) showed that (Green River, Utah) trout with NZMS in their guts had significantly poorer body conditions than those without. In feeding trials, Rainbow Trout fed an exclusive diet of unlimited NZMS passed 54% of mudsnails through the digestive tract alive, and subsequently lost up to 0.48% of their initial body weight each day, nearly equal to the impact of starvation.

These mudsnails are native to the rivers and lakes of New Zealand. In 1987, NZMS were first discovered in North America in the Snake River, Idaho. In 2000, they were found in the Owens River, California. It is believed that mudsnails were introduced to western rivers through shipments of live sportfish, but subsequent spread is likely due to recreational activities. Mudsnails easily attach to boots, waders, clothing, shoelaces, watercraft, aquatic vegetation, and gear, and can go unnoticed due to their very small size. As a result, they are commonly transported by unsuspecting anglers, boaters, other water recreationists, or even wildlife, including harvested fish. Mudsnails also disperse through floating freely or on algal mats, or by surviving passage through fish guts. In the U.S., they have been found in all western states, except New Mexico. In California, they are found in many lakes and river systems, including, but not limited to, the Owens, Klamath, Russian, Lower American, Stanislaus, Merced, San Joaquin, and Sacramento rivers, and many of their tributaries.

In February 2016, NZMS were discovered in the lower Yuba and lower Feather rivers. NZMS were found at two locations below Oroville dam, at the crossing of State Highway 70 and at the Oroville Boat ramp. The snails were also found in the Truckee River in Reno, Nevada in 2012.

Zebra Mussels (Dreissena polymorpha)

The zebra mussel is a small shellfish named for the striped pattern of its shell. The zebra mussel is native to the Black, Caspian, and Azov Seas. The species was introduced into the United States in the late 1980s with populations documented in several midwestern and eastern states. Zebra mussels represent one of the most important biological invasions into North America, with rapid dispersal throughout the Great Lakes and major river systems due to the passive drifting of the larval stage and its ability to attach to boats navigating lakes and rivers. They were first found in California at San Justo Reservoir in 2008.

Zebra mussels are filter feeders and are capable of filtering about one liter of water per day, feeding primarily on algae. The settling stage attaches to a substrate via threads secreted from the byssal gland. The vast majority of veliger mortality (99%) occurs at this stage due to settlement onto unsuitable substrates. Sensitivity to changes in temperature and oxygen are also greatest at this stage. Once attached, the life span of *D. polymorpha* is variable, but can range from 3–9 years. Maximum growth rates can reach 0.5 mm/day and 1.5–2.0 cm/year. Adults are sexually mature at 8–9 mm in shell length (i.e. within one year).

Zebra mussels attach to any stable substrate in the water column or benthos: rock, macrophytes, artificial surfaces (cement, steel, rope, etc.), crayfish, unionid clams, and each other, forming dense colonies called druses. Long-term stability of substrate affects population density and age distributions on those substrates.

Methods (fish, pathogens and invasive mollusks)

Because of the complexities and incomplete knowledge surrounding precise pre-settlement historic distribution of native Rainbow Trout this assessment is constrained to the recent-historic monitoring record in defining the presence of Rainbow Trout, as well as the non-native salmonids. Furthermore, the assessment includes positive observations only. Therefore, the non-presence of a species as determined by this assessment is not conclusive; presumed absence should be confirmed prior to taking restoration actions.

The extent of pathogen distribution is fundamentally lacking. The same methodology applied in the description of the methods for assigning fish presence was utilized in the assignment of pathogen presence except that information regarding pathogens came primarily from the scientific literature. Agency reports were the other primary source of information. Data sources used in determining pathogen presence are listed in the References.

In addition to looking at fish survey information for notes on New Zealand Mudsnails, Zebra Mussels and Quagga Mussels, we relied on information on statewide status of invasive snails maintained by the State Department of Fish and Wildlife and the US Geological Survey. These data sources include documented sightings of the two species, updated as recently as October 17, 2017.

While initial efforts towards developing better understanding of fish distribution included the digitization of the extensive monitoring record into detailed maps and GIS data, time constraints precipitated by other necessary components of the assessment interrupted the completion of this aspect of the project. Thus, for the final purposes of this assessment, distribution is only defined by species presence at the level of the reporting unit (i.e. a sub-watershed or a reach).

For all but a few sub-watersheds, records for more than one stream, river or lake location were used to assign or preclude species presence. For example, for the four sub-watersheds for which no Rainbow Trout are listed as present, this assignment was based on having no documented record of survey on-hand and no local knowledge of presence. Every survey record on-hand for a given sub-watershed was reviewed to preclude overlooking the possible positive observation of species. This was often necessary for precluding presence of Brook Trout populations if there were streams or waterbodies at high elevations in the unit.

To ascribe species presence at the reach scale, presence was assigned from the Sub-watersheds intersected by a given reach. Subsequently, Brook Trout presence was precluded from lower elevation reaches using professional judgement.

Data Sources used in determining fish species presence included:

- USFS Stream Files
- USFS Fishery Habitat Inventory (FISHHAB) data ca. 1990s
- Plumas Corporation fishery monitoring data
- CDFW Stream Files
- CDFW High Mountain Lakes Project
- CDFW Heritage and Wild Trout Program
- CDFW Plumas-Sierra District Fisheries Monitoring
- CDFW Lake Davis Northern Pike Eradication Project Monitoring
- DWR Standing Stock of Fishes Reporting
- DWR Recreational Use Reporting
- Local Angler Interviews

Local Angler Interviews

Local anglers, from communities across the Basin, were interviewed regarding 1) their knowledge of historic/current fish distribution and 2) their concerns for fishery quality, condition and their thoughts on the drivers thereof. Anglers were prompted with a list of questions and asked to assist with tracing species distribution on maps. Additionally, conversations were recorded and subsequently transcribed to ensure information was captured accurately. Much of the information provided by anglers was corroborated by agency survey records and anglers expressed much of the same concerns regarding fishery declines and knowledge of drivers as compared to those of the TAT. Interview prompts and an example transcript are provided in Appendix C.

eDNA

We incorporated testing for environmental DNA (eDNA) to provide information about the distribution of our species of concern. The use of eDNA (environmental DNA) is a relatively new technique utilized to identify the presence or absence of specific species. The most well-known use of eDNA is in identifying and combating movement of Asian carp in the Mississippi River. The eDNA method extracts free DNA or spore bodies from water samples and uses molecular techniques to match genetic markers for specific organisms from these extractions. More info on eDNA is available here: http://www.fs.fed.us/research/genomics-center/edna/

Water samples were collected from 68 streams and river and stream reaches and four reservoirs. Samples were analyzed for presence of Rainbow Trout, Brown Trout and Brook Trout, as well as the invasive mollusk species (New Zealand Mudsnails *(Potamopyrgus antipodarum),* Zebra Mussels *(Dreissena polymorpha)* and Quagga Mussels *(Dreissena bugensis)* and two fish pathogens of major concern: *Myxobolus cerebralis* (whirling disease) and *Ceratanova shasta.* Samples were replicated to provide confidence in both positive and negative results.

Results

To our knowledge, this assessment is the first to employ eDNA as a tool at a large geographic scale in the Sierra Nevada. eDNA has been used in the Feather River basin at several locations in conjunction with studies of both whirling disease and amphibian populations (Richey, et al, 2016). The method has also been used elsewhere to assess distribution of fish species at basin scales (Young, et al, 2017). We found the sampling procedure to be straightforward and far less time intensive than alternative techniques for obtaining information on species at sites. In retrospect, our sample design could have been improved. The design we employed emphasized large rivers and streams at the expense (given available funding) of smaller streams. This led to difficulty in matching results from eDNA with the watershed characterization (subwatershed scale). It would have been wiser to take more samples, with different sampling strategies for different species (e.g. brook trout) with lab analysis focused on specific species rather than looking for all species in all samples.

We could have strengthened confidence in the invasive gastropod results by adding sites outside the basin where the species were known to exist.

That said, we think the results demonstrate the utility of the method for broadscale assessments. Additional application of the methodology should better define the best times to sample for specific species, the expected length of downstream signals and other relationships to increase the utility of eDNA survey for broad and site-specific applications.

Trout

Rainbow Trout presence

Records exist for confirmed Rainbow Trout presence in at least one waterway or waterbody in almost every subwatershed in the Basin (Figure 16). Only two eDNA sample locations were negative for Rainbow Trout. These were Goodrich Creek, where RBT are known to be present, and Little Grizzly Creek, where the samples were mistakenly taken very high in the watershed, possibly upstream of RBT presence. There was consistency between eDNA and survey records review at all other eDNA sample locations.

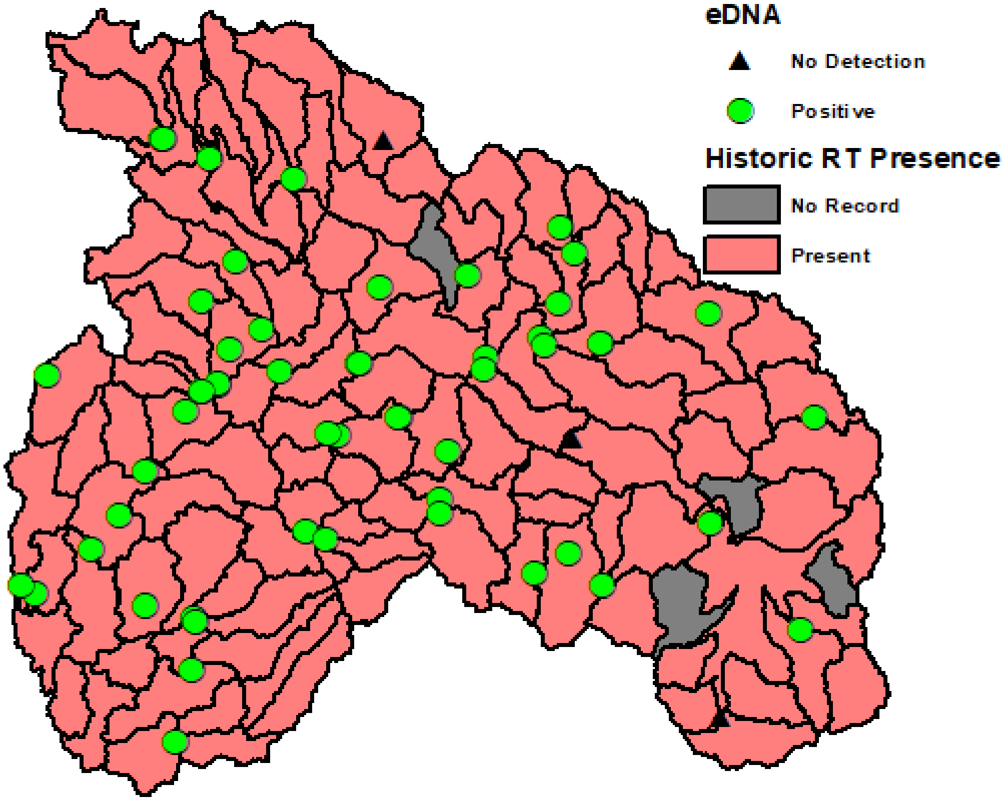


Figure 16. Distribution of Rainbow Trout. Colored subwatersheds depict presence from historic records, points indicate eDNA sample results.

Brown Trout presence

Our results found Brown Trout exist in 75% of basin subwatersheds and 89% of the study reaches (Figure 17). As with the Rainbow Trout populations, abundance is uncertain in areas where condition is marginal, even though Brown Trout exhibit greater temperature tolerance and different habitat preferences. Brown Trout dominate fish communities in some of the more well-studied locations in the basin, such as Indian Creek below Lake Antelope. Project changes in condition relative to changing climate, however, may favor the expansion of Brown Trout distribution.

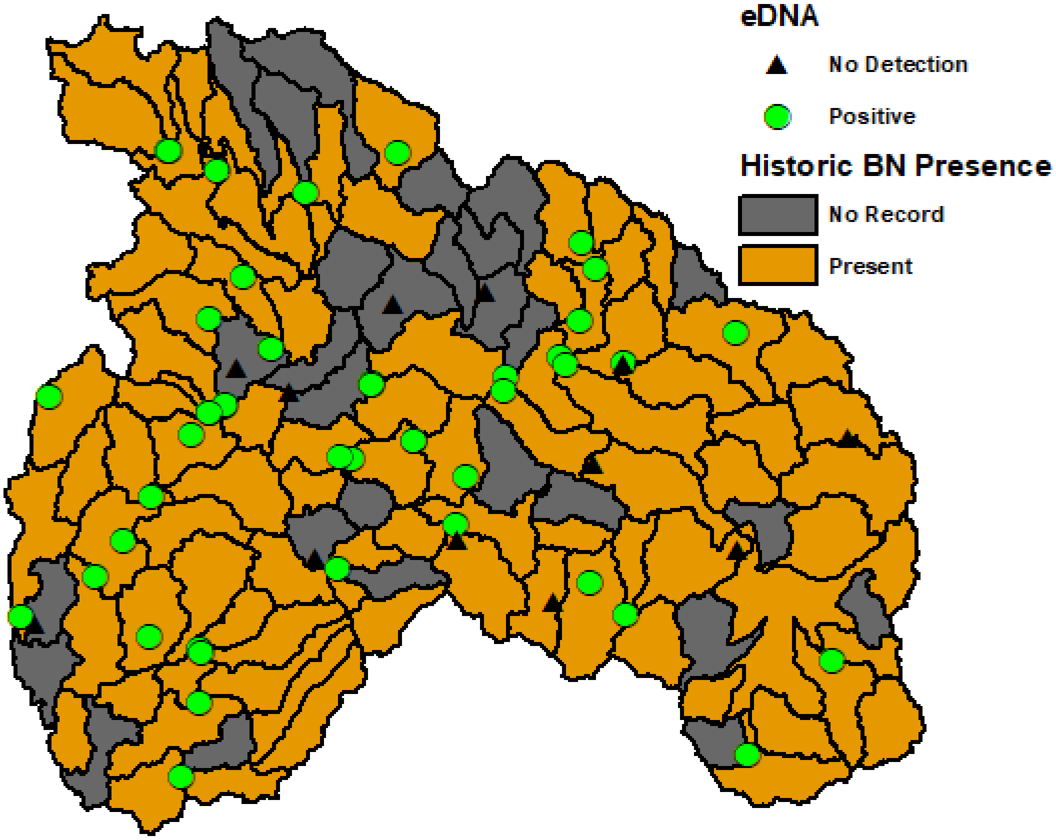


Figure 17. Brown Trout Distribution. Colored subwatersheds depict presence from historic records, points indicate eDNA sample results.

Brook Trout presence

Brook Trout occur in 36% of subwatersheds (Figure 18) and 15% of Reaches. In both the subwatersheds and reaches Brook Trout are confined to lakes and headwater reaches at the highest elevations or other limited areas where groundwater discharge satisfies temperature requirements.

The projected changes in stream temperature (Sec 3.3, pg 89) are not favorable to sustaining Brook Trout populations and their distribution is expected to further contract. While many of the established Brook Trout populations were probably the result of stocking efforts, as with Brown Trout, similar trends of decline may be observed as result shifting fish stocking priorities.

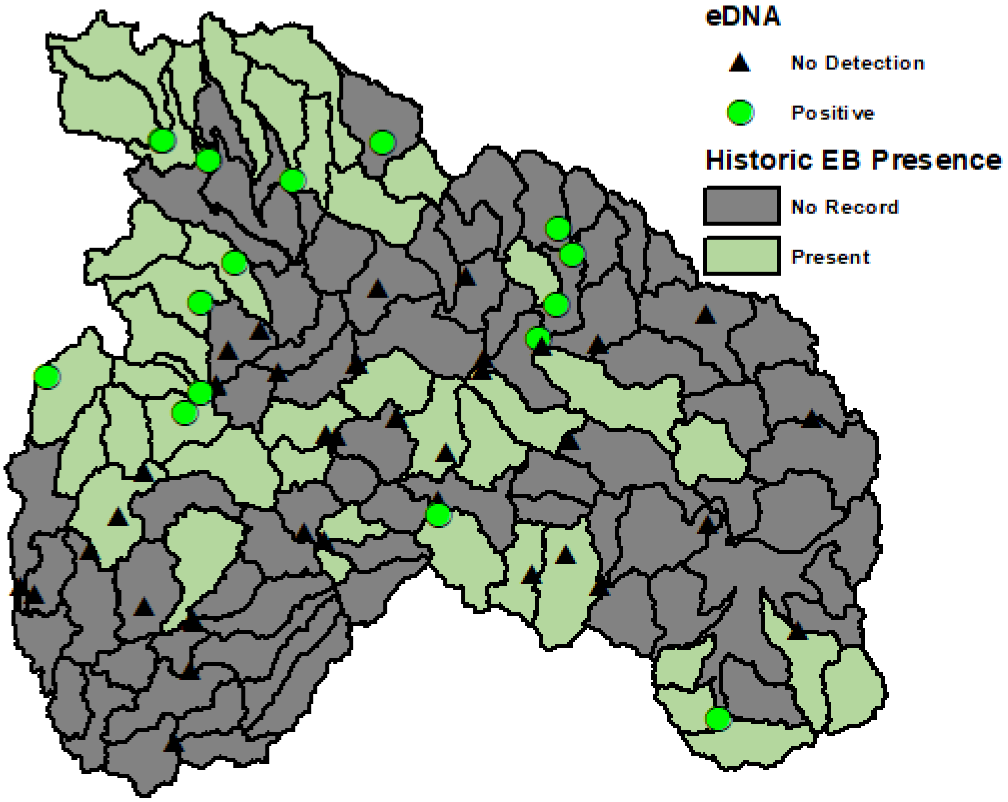


Figure 18. Eastern Brook Trout Distribution. Colored subwatersheds depict presence from historic records, points indicate eDNA sample results.

eDNA

Rainbow Trout were detected at all sites except Goodrich Creek, the Middle Fork at Sierra Valley and Bonta Creek (Figure 16). They were also detected in samples from Butt Lake and Lake Almanor.

Brown Trout were not as prevalent as Rainbow Trout, but far more widely distributed than Brook Trout (Figure 17). They were found in all stream samples except those from Butt Creek, Concow Creek, Jamison Creek, Lights Creek, Mosquito Creek, Nelson Creek, Squaw Queen Creek, Wolf Creek and the Upper Red Clover Creek site.

Samples were positive for Brook Trout at seventeen river-stream sites, and from Butt Lake (Figure 18). As expected, Brook Trout were largely limited to headwater streams that provide cold water year-round, such as Bonta and Nelson and Warner Creeks. A few mainstem river and creek sites (e.g. North Fork below Rock Creek dam and Indian Creek at Red Clover confluence) were positive for Brook Trout. We suspect that cold tributaries to these streams (such as Chipps Creek for the North Fork site) support Brook Trout and are the source of eDNA collected downstream.

Comparisons between eDNA sampling and information from survey data are made difficult because while information form survey data was summarized at the sub-watershed scale, many of the eDNA samples were taken at main stem river sites. Simple comparisons between eDNA sample sites representative of sub-watersheds shows considerable overlap with the survey data. Of 14 sites where eDNA results were positive at sub-watershed scale sites for Brook Trout, 13 of those subwatersheds had survey records indicating they were present. For subwatershed scale eDNA samples with results positive for Brown Trout, all 27 correlated with survey records documenting Brown Trout. Likewise, there good consistency between historic records and eDNA sampling for Rainbow Trout. Two samples (Goodrich Creek, Bonta Creek) were negative for Rainbow Trout, but historical survey data indicated they were present. In no case did survey records indicate presence of one of the trout species when an eDNA result was positive. In one case (Goodrich Creek) eDNA results were positive (for Brook Trout) and no survey record had been found documented species presence.

Most Likely Sites of Trout with little Hatchery Influence

The extent of genetic introgression from extensive historic stocking is not adequately understood and remains a key knowledge gap. However, a few inferences can be made regarding general locations where extensive introgression of non-native genetics is less likely. Populations at these locations are repeatedly cited as of interest for genetic inquiry.

Areas farthest from population centers, main thoroughfares, man-made reservoirs and natural lakes, all locations that have historically been the focus of extensive stocking effort, are the most likely to have less influence of non-native genes. Undisturbed areas of the Basin where natural dynamics and habitats are best preserved could be presumed to favor native genetics. Areas of the Basin that most applicably fit this description are the drainages in the upper portions of the East Branch (e.g. Red Clover, Last Chance, Squaw Queen, their tributaries and, in particular, headwaters) as well as the Wild and Scenic portions of the Middle Fork Feather River and its tributaries. Specific drainages/populations cited during the course of this work as possibly or probably having high genetic integrity include:

- Fant Creek, tributary to East Branch Lights Creek
- Nye Creek, tributary to Ward Creek
- Bellas Creek, headwaters of North Canyon Creek /tributary to Round Valley Reservoir
- Red Clover Creek, between Notson and Drum bridges
- Crocker Creek, headwaters of Red Clover Creek
- Ferris Creek, headwaters to Little Last Chance Creek
- Siegfried Canyon, headwaters to Squaw Queen Creek

Not all of the populations cited above equally meet the criteria preceding the list. Brook and Brown Trout are found in some of these areas, so some planting has occurred and likely have hatchery-introduced genetics.

Pathogens

Records Review

Myxobolus cerebralis, the agent of whirling disease, has been positively detected in locations within nine sub-watersheds (Figure 19). *Ceratanova shasta* (formerly *Ceratomyxa*) has been positively detected in locations within 5 Sub-watersheds (Figure 19).

eDNA

Myxobolus cerebralis eDNA was found at two sites: Lower Indian Creek and Yellow Creek. These results indicate that whirling disease may be confined to locations where it has already been observed. eDNA results were negative in Goodrich Creek, where whirling disease was reported to be present (California Fish and Wildlife, personal comment).

Survey of streams located within the Moonlight Fire detected presence of Whirling Disease in Lights Creek, Hungry Creek and Upper Indian Creek (Richey, et al, 2016). Our samples were negative for these streams. Two of our sample locations (Lights and Indian Creek) were located several miles downstream of the Richey study sites. Samples located similar distances downstream of sites where *Myxobolus cerebralis* was detected (Indian Creek and Yellow Creek) were negative for the pathogen, indicating a dilution effect. We have no explanation for the negative result of sampling in Hungry Creek.

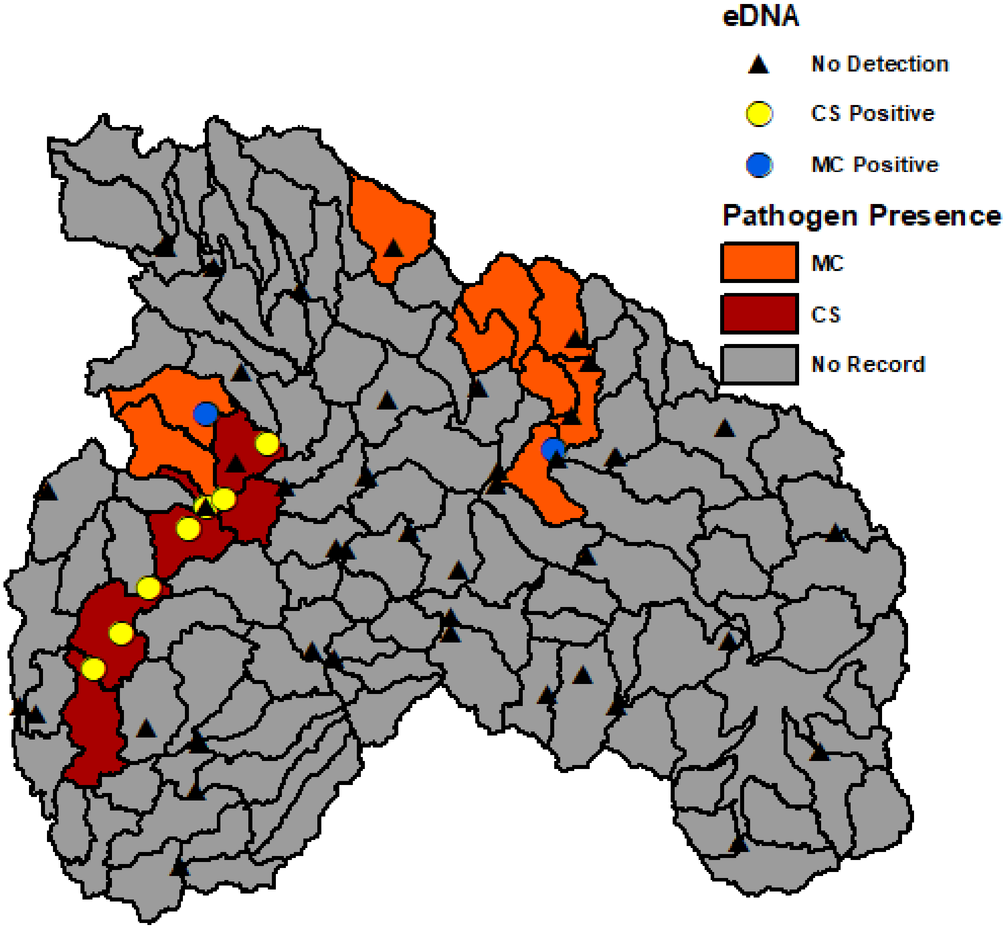


Figure 19. Presence of pathogens Ceratanova shasta (CS) and Myxobolus cerebralis (MS) as indicated from search of literature, monitoring and survey records (by subwatershed); and from analysis for eDNA (points).

Ceratanova shasta was detected at seven sample sites, all in the North Fork system (Figure 19) and consistent with findings of the records review. The pathogen was detected furthest upstream above the Caribou Powerhouses and downstream as far as the Shady Rest between the Cresta and Poe Dams. Soto (2018) reported the pathogen was present in the North Fork downstream of Rush Creek in eDNA sampling conducted in Fall of 2017 (Soto, 2018).

Invasive Snails

Record Review

No survey or collection records were found for species in the Feather River above Lake Oroville. Locations of nearby documented populations were described earlier.

eDNA

No positive results were found for either New Zealand Mudsnails, Zebra Mussels or Quagga Mussels. While the interpretation of eDNA results is in its infancy, in terms of extension of point sampling to upstream conditions, variation with flow and other temporally sensitive influences and longevity of eDNA in aquatic systems, finding no positive results for either invasive snail is encouraging.

3.2 Physical Indicators

Introduction

Sediment, flow, low gradient channel condition and temperature were the concerns identified related to physical influences on fish populations and habitat.

To determine which watershed indicators would be most useful in describing condition of stream habitat, we compared them with existing channel condition information from the basin. Research has documented adverse effects to streams from roads located near channels (McGurk and Fong 1995, Luce and Wemple, 2001) we explored and eventually selected near stream road density as an indicator of condition. These analyses are presented in Appendix D. In brief, we calculated values for potential indicators (e.g. road density) and compared them with stream habitat information from subwatersheds in the basin. We found weak, positive correlations between metrics and stream attributes that justified use of the selected indicators.

Sediment

Most (>70%) of the Feather River watershed upstream of Lake Oroville are public lands, managed primarily by the US Forest Service. A considerable percentage of the remaining land base are forested lands managed by private timber companies; and valleys and meadows managed as rangelands, also in private ownership. Very little of the watershed could be considered urbanized, the exceptions being the towns of Chester, Greenville, Westwood, Portola, Sierraville, Loyalton, Taylorsville, Quincy, as well as residential developments in the Lake Almanor and Graeagle-Blairsden areas.

As a result, disturbances to watersheds from land management activities and wildfire are the primary influences on watershed condition. Existing condition in some watersheds is still influenced by past management activities, including timber and range management, as well as mining (FERC, 2007). Water diversions, and infrastructure associated with water development have also had significant impact on fisheries habitat (ibid).

Past and present management activities can impact fisheries habitat in several ways. The most widespread impact is an increase in erosion, with subsequent increased delivery of sediment to stream channels and other habitats. In the channel, increased sediment increases mortality of trout fry and alevins when it is deposited on redds (Jensen, et al, 2009) and is detrimental to the food supply of young fish.

Roads

Background

Roads affect watershed function and fish ecology through numerous mechanisms, such as water flow, sediment delivery and transport, stream connectivity, and stream temperature (Jones *et al.,* 2000; Luce and Wemple, 2001). Research (Luce and Black, 2001) has consistently found roads to be the primary source of accelerated erosion in wildland watersheds. Surface erosion from forest roads increases sediment production and may impose a chronic condition of sediment inputs to streams, directly affecting the stream substrate and the health of aquatic life. This sediment is delivered to streams mainly at stream crossings (Case et al. 1994).

Roads and road crossings redirect surface flows and groundwater to channels. Some evidence exists that roads increase peak flows of floods, especially floods high frequency (Thomas and Megahan, 1998). Interception of subsurface flow by forest roads has been suggested as a mechanism for increased peak flows in roaded basins. Subsurface flow interception may also alter the timing of runoff within a season, reducing baseflows.

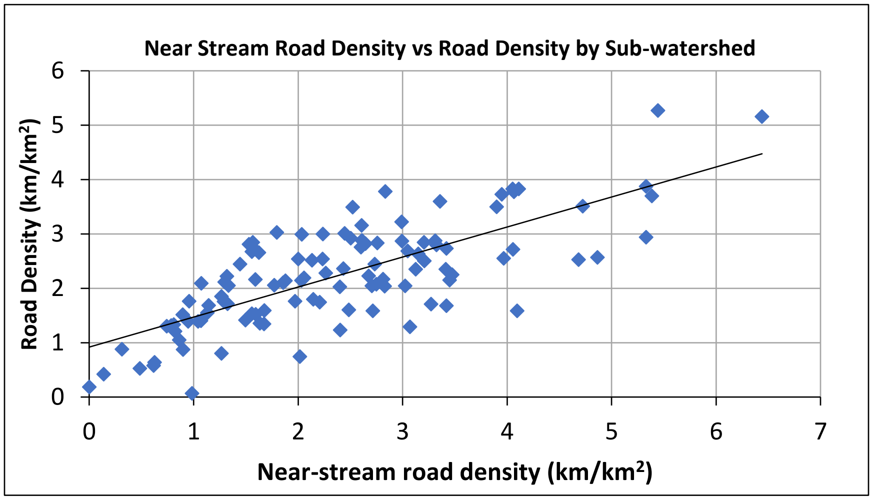


Figure 20. Relationship between road density and near stream road density for sub-watersheds in the Feather River watershed.

Sediment delivery from roads to streams is influenced by both road and landscape characteristics. Numerous studies have illustrated the importance of roads in proximity to stream channels. A recent detailed study (Cabrerra, et al, 2015) of road impacts conducted in areas of the Basin impacted by fire showed that near-stream roads and road-stream crossings are the most significant features in the road network in terms of road-stream hydrologic connectivity and concomitant sediment delivery, both within and outside burned areas.

Large volumes of sediment can be delivered to streams when road crossings fail and streamflow is diverted down roadways. Such stream diversions typically occur when a crossing inlet is plugged, or designed capacity is exceeded. Storm water then climbs to the crossing surface, and rather than flowing across the crossing and back to the channel, it is diverted along the road until natural or designed drainage forces the flow off the roadway. Such an incident can cause gullying in the roadway and to slopes between the road and where the water eventually returns to a channel.

Road characteristics (slope, surface material, surface material source, etc.) influence sediment produced by roads. Landscape attributes such as soil erosivity and infiltration, slope and topography and vegetation cover also affect sediment production. Spatial scale and data quality and availability limited roads analyses in this assessment to considerations of densities only.

To evaluate the relative potential for roads to impact fisheries habitat, we applied two road related indicators: density of near stream roads and the density (or frequency) of road stream channel crossings. Road density was also considered as a sediment indicator. It was not included because it proved to be correlated (r >.75) (Figure 20) with near stream road density. Near stream road density was selected (over road density) because we felt the literature (McGurk and Fong, 1995) linking near stream disturbance to fish habitat was stronger than that for road density.

Roads Density

Methods

Road impacts were derived using a composite of road network datasets. Three datasets were used: 1) the US Census Bureau 2016 Tiger/Line Shapefiles for transportation 2) USDA USFS National Forest System Roads and 3) USDA USFS Forest Service Topo Railroads.

The composite dataset used in the assessment was based on predominant reporting unit ownership. For predominantly USFS ownership (3rd quartile or ~90 percent Forest-owned) the USFS dataset was used. For reporting units less than this threshold, the US Census dataset was used. An exception was made for railroads. The USFS railroads dataset was used for both reporting unit subsets as upon inspection it more accurately represented railroad networks in the Basin.

There are some inconsistencies between the results based on the composite of datasets used in the assessment and on-the-ground road networks. and the limitations described by the publisher of each dataset must be acknowledged. A ground-based quality assurance analysis of the roads datasets was prohibitive, but the approach used here is considered best available.

For near-stream road density two relatively narrow widths (10m and 30m) were correlated with stream data (detailed in Appendix D) and based on this analysis, the 30m width selected. This distance was determined to be adequately wide enough to capture significant near-stream portions of the road network and narrow enough to prevent dilution of results caused by diminishing ratios of road miles to square miles in the near-stream area. Near-stream road density values are calculated by dividing miles of road located in the 30m wide stream corridor by the area within the corridor, expressed in square miles.

Results

Sub-watersheds

As most of the Basin is roaded, it follows that most sub-watersheds and reaches would contain near-stream roads. Chipps Creek is the only watershed with no near stream roads. As shown in Table 9, sub-watersheds averaged just over 2.4 miles of road per square mile of near stream (within 30m of channel) road area.

Areas with the highest near stream road density were sub-watersheds that contain urbanized areas, including the Chester-Lake Almanor area and the towns of Quincy, Portola and Loyalton.

Intermediate levels of near stream roads tended to be located in the mid-elevation zone between the west and eastern portions of the watershed that have historically supported timber harvest.

Sub-watersheds with the lowest near stream road density include those with special land management designations that have precluded typical forest management activities. These include the sub-watersheds adjacent to Lassen NVP and in and downstream of the Bucks Lake Wilderness. Major portions of the Wild and Scenic MFFR with limited access also have low levels of near stream road disturbance (Figure 21).

Reaches

Near Stream road densities were higher for some reaches than for sub-watersheds (Table 9) (Figures 22 and 23) the result of highways and major roads that parallel rivers and streams within the watershed. Examples are Indian Creek below Antelope Lake and Highway 70 along the North Fork Feather River.

Road Crossings

Methods

Road crossings were evaluated by intersecting the NHD Flowlines with the ownership-based roads composite as described above. Density was calculated as the count of crossings per stream mile within the reporting unit.

Results

Crossings show much the same pattern as the near stream road density though the frequency of road crossings is typically lower in reaches than sub-watersheds, and 15 reaches have no channel crossings. Values summarized in Table 9 and displayed in Figures 24 and 25.

Attribute	Sub-watersheds		Reaches	
	range	mean	range	mean
Near Stream Road Density (mi/mi^2)	0-6.44	2.41	0-10.75	2.53
Road Crossing Density (crossings/km perennial stream)	0-4.08	1.5	0-1.1	0.35

Table 8. Summary statistics for two sub-watershed sediment indicators

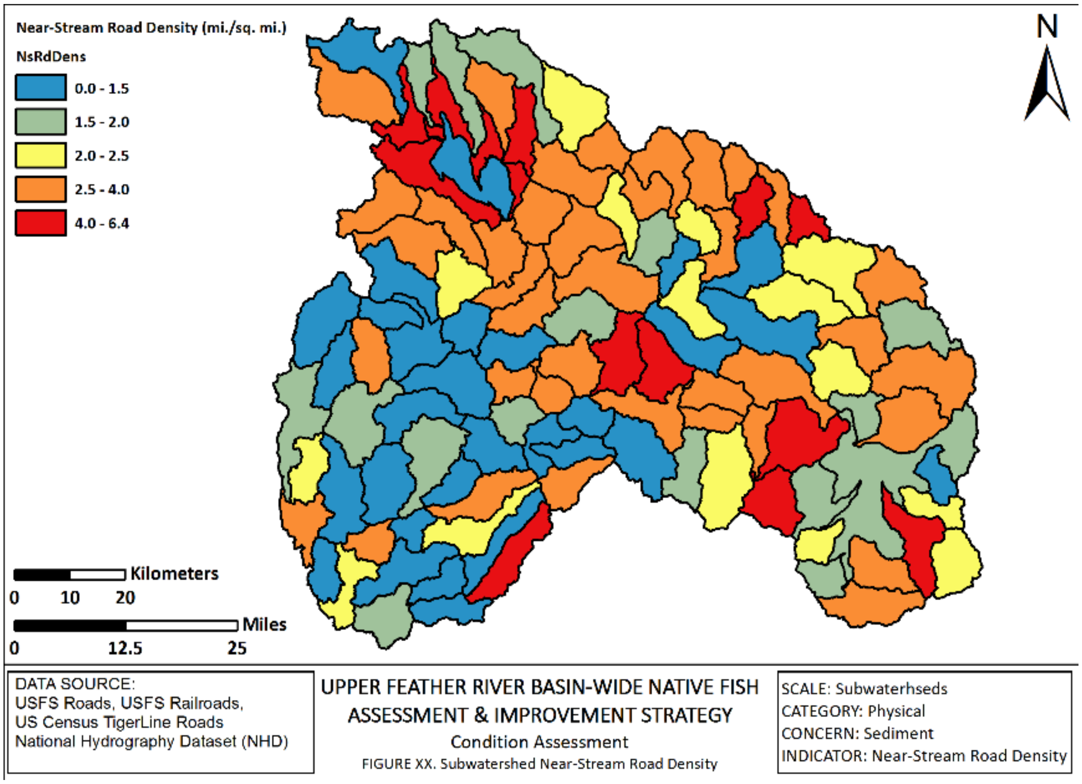


Figure 21. Near stream road densities by subwatershed

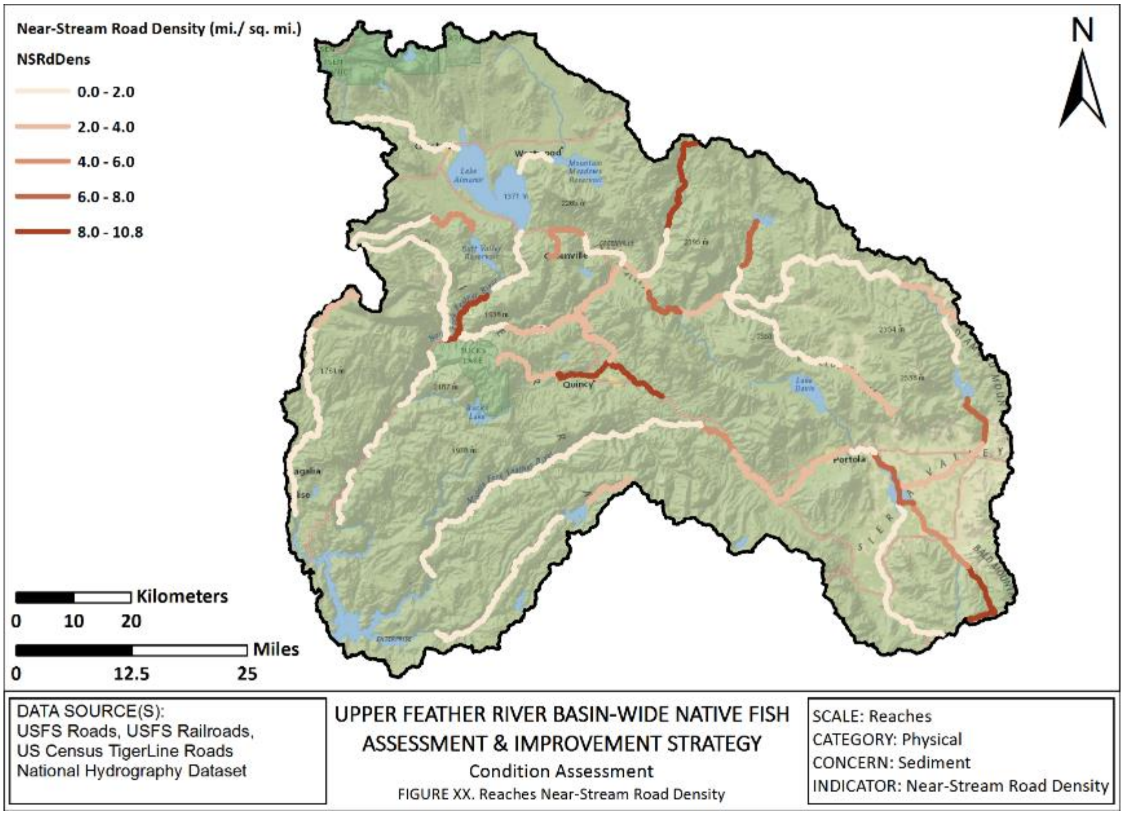


Figure 22. Near stream road density by reach

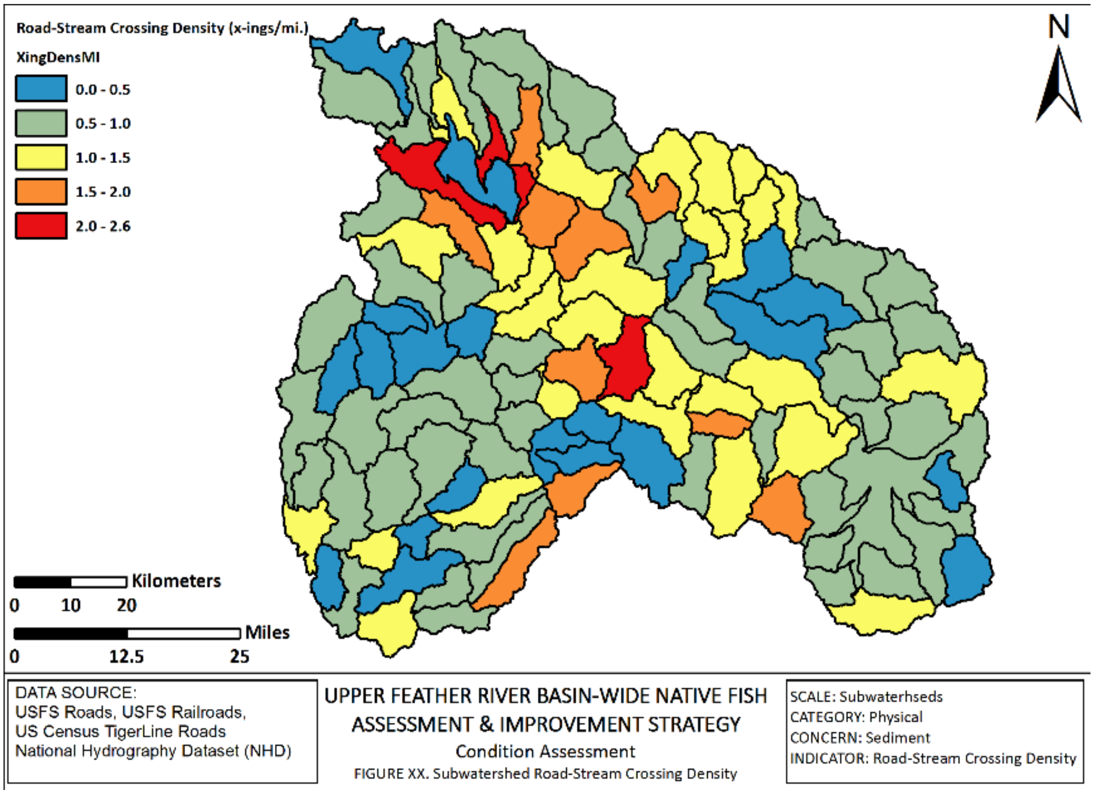


Figure 23. Subwatershed Road Stream Crossing Density

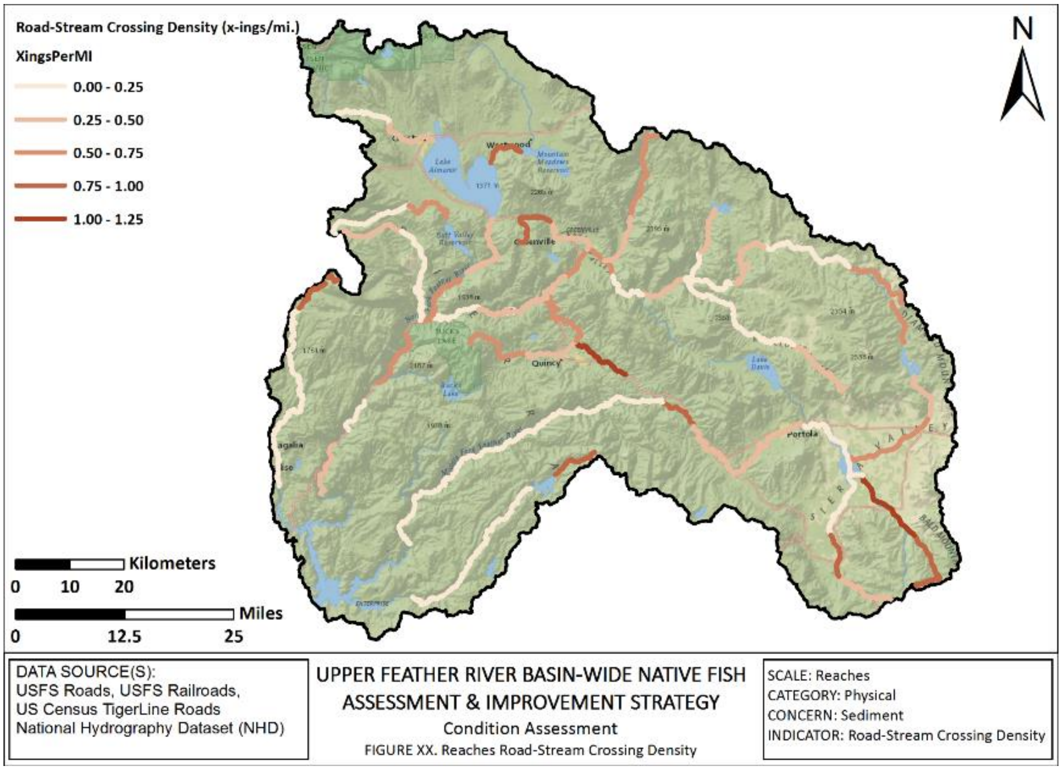


Figure 24. Reach Road Stream Crossing Density

Combining Measures of Road Disturbance

Ultimately, all condition data was used in rating the resilience of subwatersheds (Part 4). This rating combined results from water diversions, low gradient channel condition, connectivity and roads to produce a single rating for each subwatershed. We feared overstating the influence of roads in this rating scheme, so we decided to combine results from the road crossing and near stream road indicators into a single road rating.

Environmental Evaluation Modeling System (EEMS)

We used the Environmental Evaluation Modeling System (Conservation Biology Institute, 2013) to integrate and combine near-stream road density and road-stream crossing density results to produce the single road impacts measure for each subwatershed. The system was also used to combine indicator data to rate stream reach condition. EEMS is a tree-based, fuzzy logic modeling system that allows data from different sources and with different domains to be rapidly synthesized.

EEMS employs a tree-based logic model in which the leaf nodes represent initial data inputs. Data are converted into fuzzy values (each input value is represented by value ranging from -1 for fully false to +1 for fully true). Fuzzy logic operations (analogous to basic logic operations such as “and” and “or”) are combined to produce a composite response (e.g. “What is the relative road condition in sub-watersheds across our study area?”) (CBI, 2016). The EEMS logic for road impacts is shown in Figures 25 and 26.

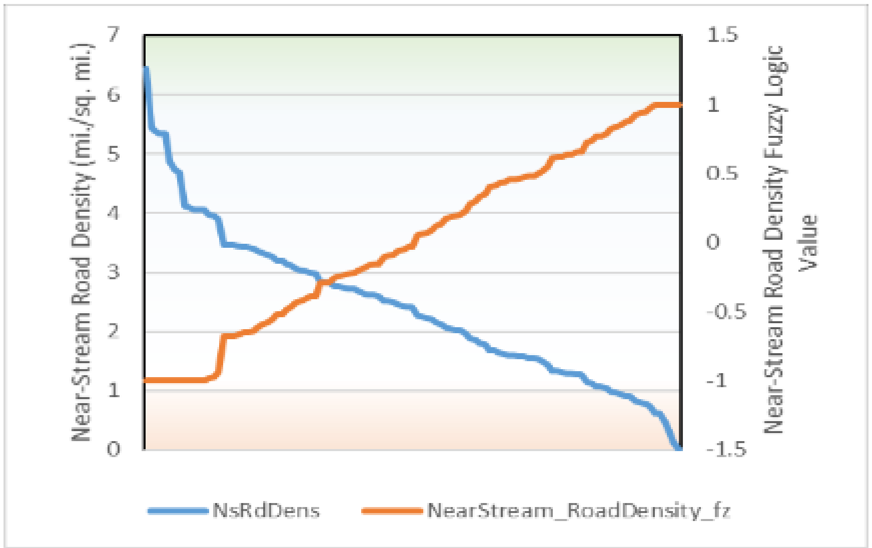


Figure 25. Conversion of the Near-Stream Road Density values into fuzzy space. Based on evaluation of results it was determined that Subwatersheds in the Basin with values below 0.4 mi./sq. mi. were the least-impacted and were thus given a value of 1 (fully true)

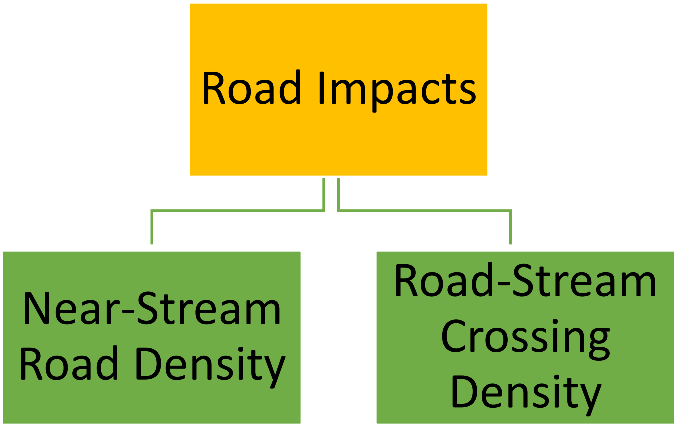


Figure 26. EEMS logic for evaluating the cumulative impacts of road; near-stream roads and road-stream crossings are the primary components of a road network that significantly alter flow and sediment regimes.

Combined Road Ratings

Results of the combination of road crossing and near stream road data is displayed in Figure 27. As expected, the results follow patterns similar to the crossing and near stream roads results. Areas with low road impact are limited to areas under special management, including the Bucks Lake Wilderness and areas tributary to the North and Middle Forks that are steep and largely roadless. 19 subwatersheds have ratings of very high disturbance, 16 are characterized by high disturbance and another 20 rated as moderately high. The combined road rating undoubtedly has strong connection to sediment production and runoff, the rating is also a surrogate for overall watershed disturbance. This is because a road network is necessary to support timber harvest, range management, mining and other activities that have contributed to watershed disturbance.

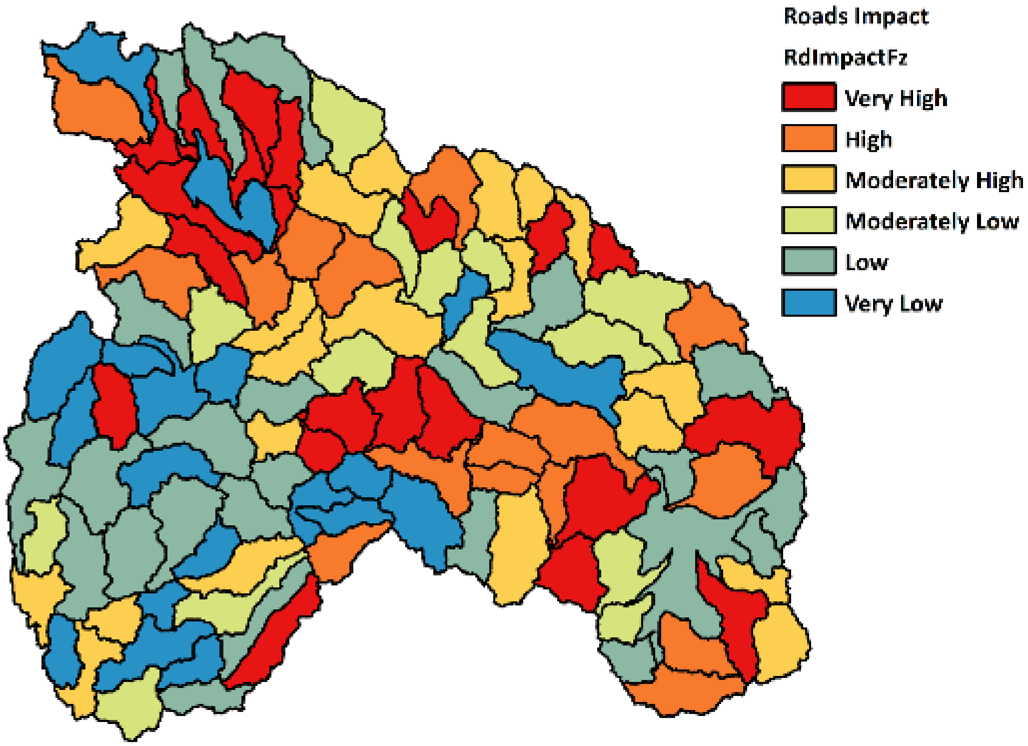


Figure 27. Relative impact from road crossing frequency and density of near stream roads by sub-watershed.

Wildfire

Background

Wildfires that burn large acreages at high intensity are a major source of disturbance (and sediment) in the basin. Large-scale, severe fires have been shown to increase sediment production by reducing infiltration, increasing runoff and increasing surface erosion. High severity fires can also increase the probability of slope failure and debris flows. Negative effects are compounded by the size and location of high severity burn (Ice et al, 2004). A comparison of monitoring data from streams in relatively undisturbed watersheds, streams with watersheds managed for timber production and from streams in watersheds burned by high intensity wildfire showed higher levels of sediment, and greater impacts to benthic invertebrate communities in the burned watersheds (Roby and Mayes, 2013) (Figures 28-29). Note also that these results support the contention that subwatersheds that are the site of timber harvest activities have increased sediment production relative to watersheds with less disturbance (including fewer road crossings and near stream roads).

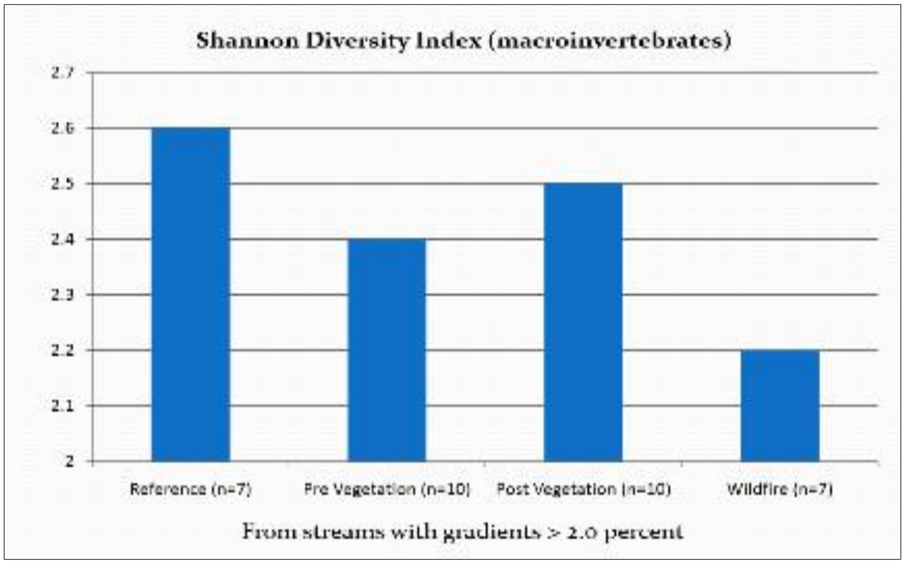


Figure 28. Relationship between percentage of pool tails fines and channel gradient for streams with little disturbance, those with forest thinning activities and those burned by wildfire from the HFQLG project area.

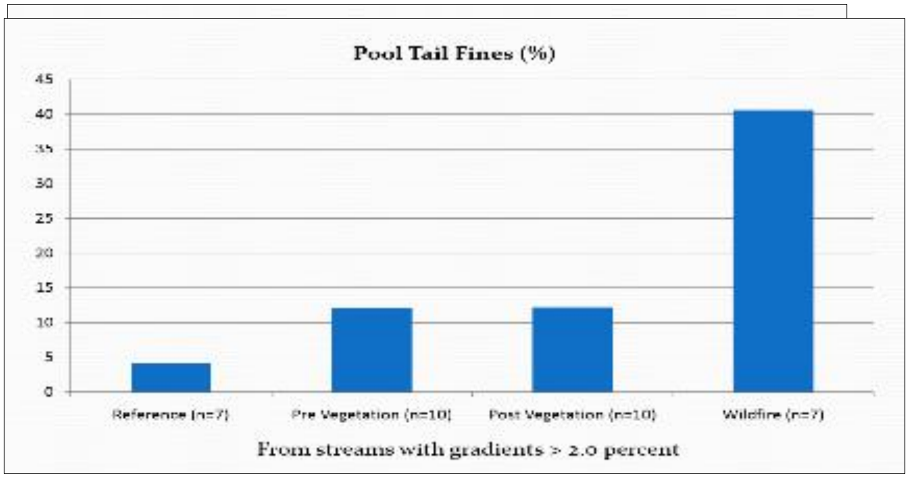


Figure 29. Comparison between Shannon Diversity values from benthic macroinvertebrate samples from percentage streams with little disturbance, those with forest thinning activities and those burned by wildfire from the HFQLG project area.

Post-fire increases in sediment have a negative impact on salmonids, particularly for juvenile life-stages. However, in some instances sediment and debris released by fire contributes to habitat-favorable channel morphology (Miller and Benda, 2000). Recently, areas of the Basin that are sediment-starved due to trapping of bedload by hydroelectric dams have seen deliveries of sediment yield from wildfire increased the availability of spawning gravels. Use of this habitat use was almost immediate (Kossow, Pers. Comm. 2016).

Results of a study of Williams Creek in the Wolf Creek subwatershed showed recovery (sediment and macroinvertebrate community diversity) to be incomplete 15 years-post-fire (Roby & Azuma, 1995). Post fire monitoring within the Moonlight Fire on the Plumas National Forest found significant reductions in stream shade and high levels of pool tail fines (Mayes and Roby, 2013). Additionally, large-scale debris flows initiated in the first year immediately following a large, severe fire have been observed to reactivate in subsequent high intensity precipitation events, even following periods of significant drought (Kossow & Roby, Pers. Comm. 2017). These findings imply that stream habitats within watersheds with high concentrations of high intensity wildfire would provide sub-optimal conditions for Rainbow Trout. For the purpose of this assessment sediment-regime disturbance caused by severe fire is considered to be negative.

Methods

The amount of wildfire occurring in each sub-watershed was calculated for two time periods. A shorter (later) interval (2010-2014) was selected based on literature results (Norris and Webb, 1989; Reiman, et al 2012) and monitoring in the Feather River watershed (Mayes and Roby, 2013) indicating the greatest impacts from wildfire on sediment and water occur within five years. A longer (earlier) time frame (2000-2009) was also employed because results from monitoring a fire in the Lower Wolf Creek sub-watershed (Roby and Azuma, 1995) found elevated sediment in Williams Creek 15 years after a wildfire of high intensity.

To identify and assess areas affected by wildfire we utilized geospatial products compiled by the Monitoring Trends in Burn Severity (MTBS) project. MTBS develops consistent maps of burn severity and fire perimeters at a high resolution to support land managers and monitor trends over time (Eidenshink et. al. 2007). The MTBS definition of Burn Severity is “the degree to which a site has been altered or disrupted by fire; loosely, a product of fire intensity and residence time” (NWCG, 2005).

MTBS classifies burn severity on an ordinal scale. We determined the proportion of each reporting unit in MTBS’ highest severity class. This class represents the greatest impact and longest recovery time. The use of MTBS in this assessment is imprecise. Similar to other indicator data sources it was considered best-available for the geographic scale and scope of the project.

Sub-watersheds were evaluated for the proportion of total watershed area burned. Reaches were assessed for the proportion of near-stream area burned at high severity.

Results

The majority of the Basin, and thus, the reporting units at both scales were not burned at high severity for the recent 5-year period (Figures 30, 31). The majority of severe burns occurred in the more distant 6-15-year period (Table 10). Burned areas were the result of the Storrie, Chips and Moonlight fires, which burned during these time periods.

Time Period	Sub-watersheds with High Intensity Wildfire		
	Number	Percent Burned	
		range	average
burned 2010-2014	9	0.5-29.4	8.6
burned 2000-2009	43	2-49	9.1

Table 9. Sub-watersheds burned by wildfire

More intensive surveys of road conditions and barriers to fish passage were conducted in several subwatersheds identified as high priority for restoration in this plan. Those surveys found impacts of wildfire persisting well after the 15-year time period used in the assessment. Lack of ground cover was evident in these burned areas, which undoubtedly translates to increased sediment delivery and changes to runoff.

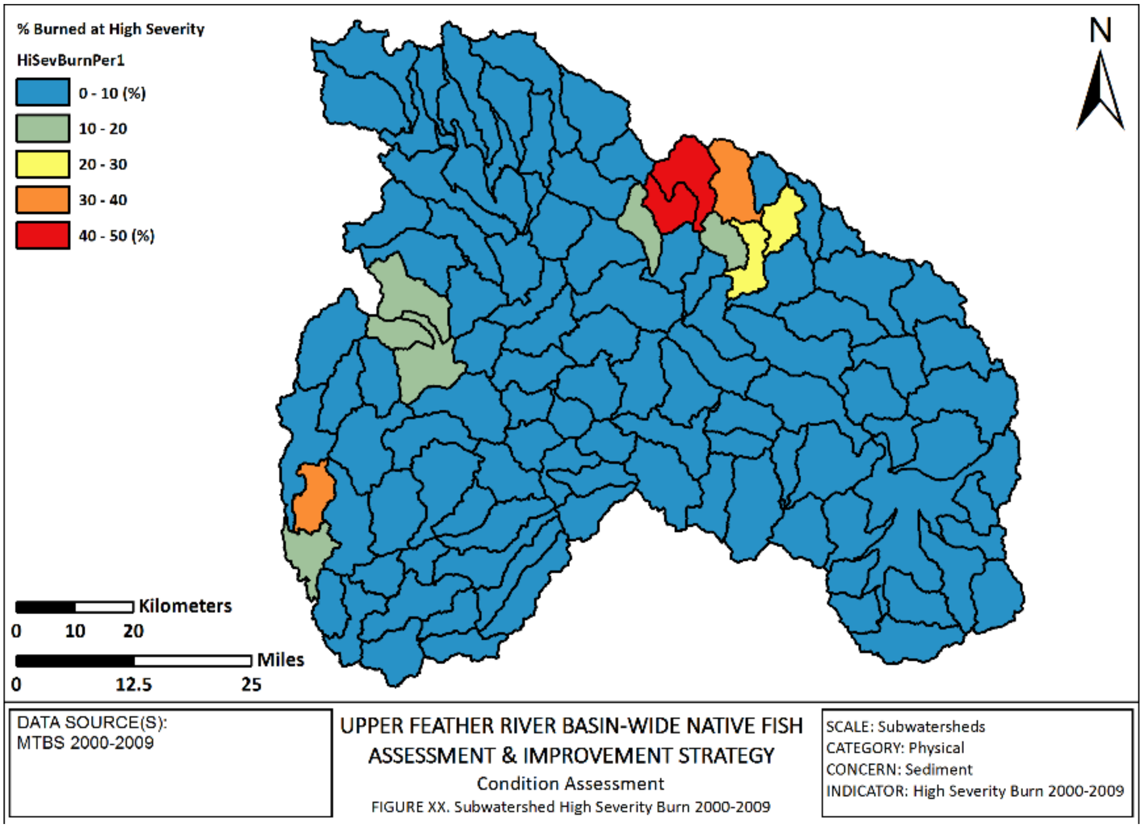


Figure 30. High Severity burn 2000-2009

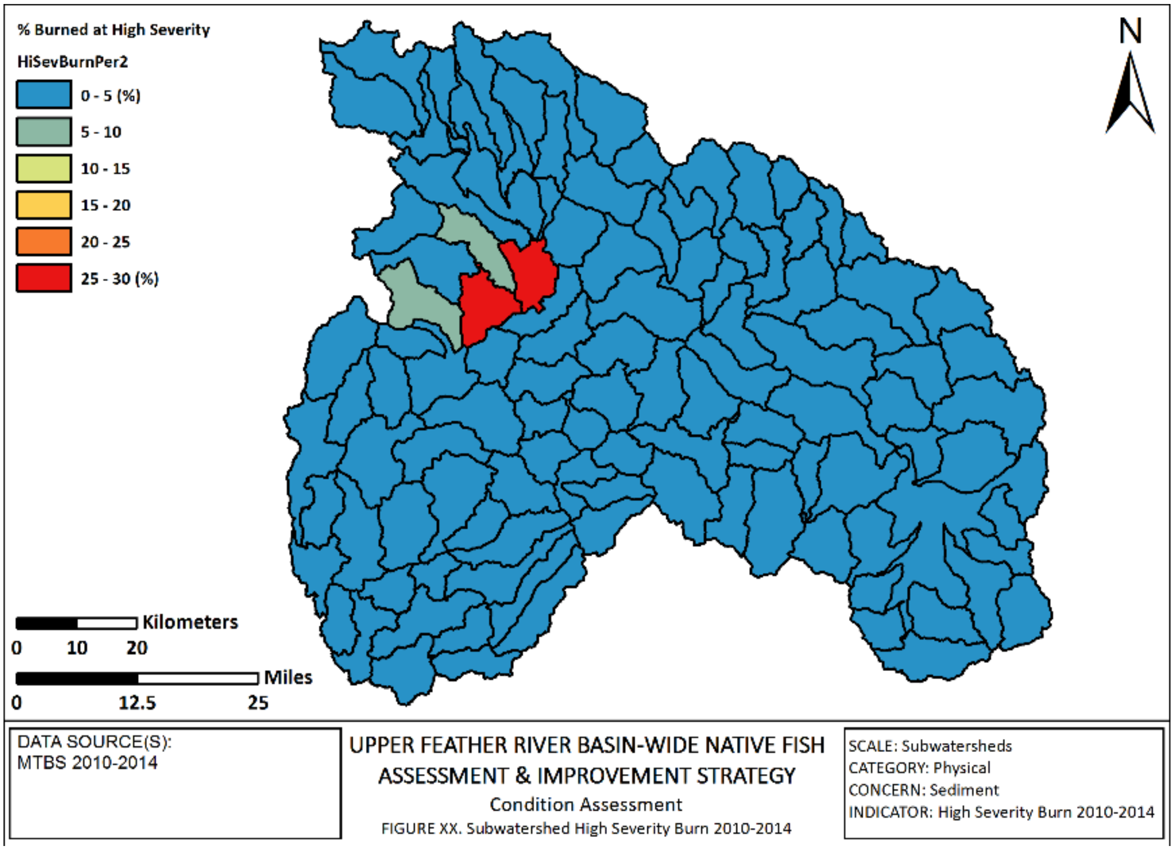


Figure 31. High Severity burn, 2000-2014

Vegetation

The current condition class of vegetation (related to fire risk) were assessed. Results (Appendix E) showed that most of the basin were in high risk classes. Our working threshold for poor condition was 50% of vegetation in high risk class. Applying this standard, all but 13 subwatersheds were rated in poor condition, so we deemed fire risk class a poor discriminator. As a result, this attribute was not used to inform recommendations on geographic priorities. There is no doubt that reintroduction of fire into the basin's forests is a key ecosystem need. Based on our findings, this is true almost everywhere in the basin. We have included our limited evaluation in Appendix E. We hope this information may be valuable when looking at restoration needs in specific subwatersheds.

3.3 Stream Temperature

Methods

The NorWeST stream temperature model was employed to estimate current, historic and future stream temperatures. The method was described earlier in Section 2.4.

Results

Current Temperatures

Modeling of 2011 temperatures were taken to represent the current condition. Results (Tables 11-12) found a range of August stream temperatures from less than 7C to greater than 17C. As shown in Figures 32-36, there are notable patterns to the distribution of temperatures. The highest temperatures are found in low elevation, western portions of the watershed. Streams flowing through the large valleys of the watershed (American, Indian, Red Clover) all have relatively high temperatures, with the exception of Sierra Valley. Our expectation is that stream temperature prediction in Sierra Valley was confused by the multiple channels there, and most likely stream temperatures are higher than predicted by the model. The lowest temperatures, as would be expected, are at high elevations, including upstream of Lake Almanor and streams tributary to the North Fork, Feather River.

Characteristic	Suitable	Optimal
range	45-100	0-100
Number with <90%	5	81
Number with 100%	93	8
Number with 0%	0	4

Table 10. Percentage of perennial streams within sub-watersheds with suitable and optimal thermal Rainbow Trout habitat (current:2011). Results from NorWeST Model.

Characteristic	Suitable	Optimal
range	34-100	0-100
Number with <90%	8	49
Number with 100%	45	12
Number with 0%	0	19

Table 11. Percentage of reaches with suitable and optimal thermal Rainbow Trout habitat (current:2011). Results from NorWeST Model.

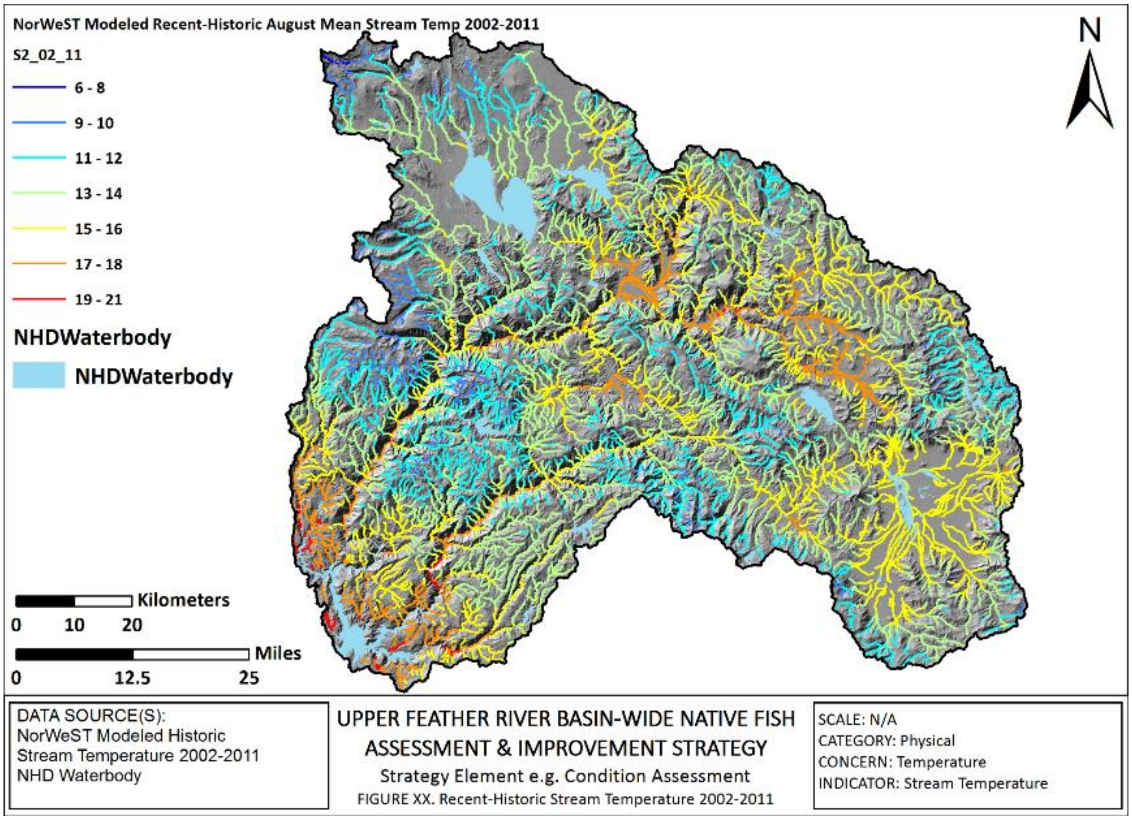


Figure 32. Modeled stream temperatures (current)

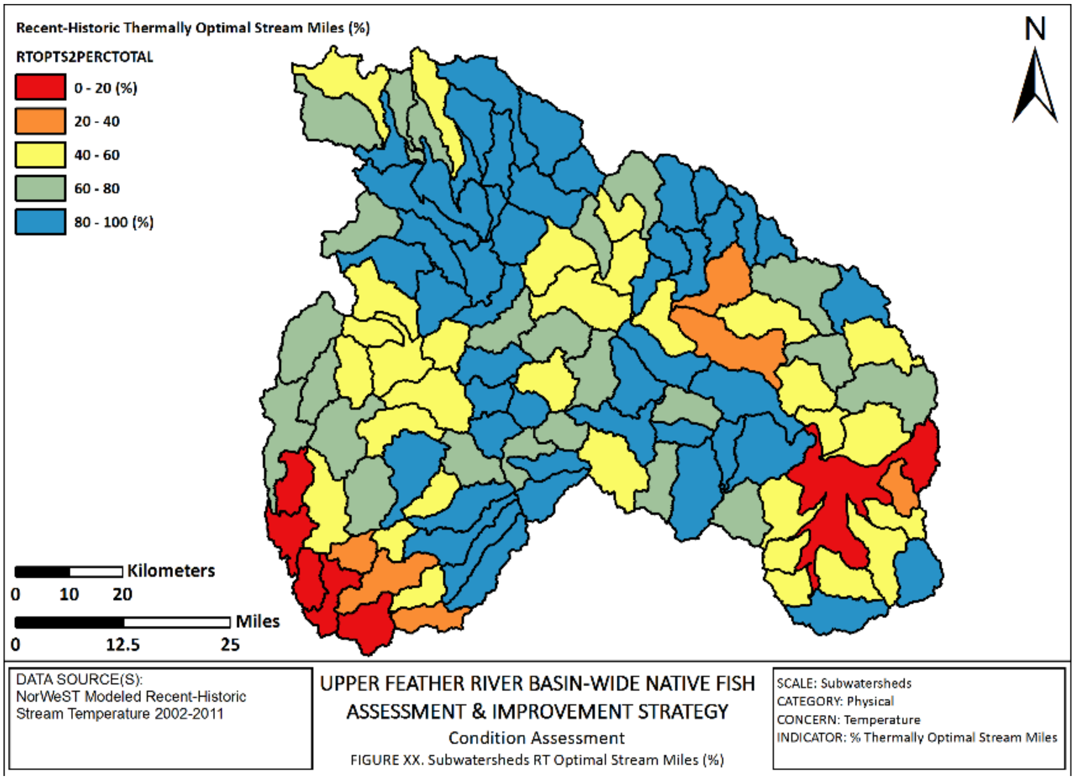


Figure 33. Percent perennial stream with optimum temperatures for Rainbow Trout, by subwatershed

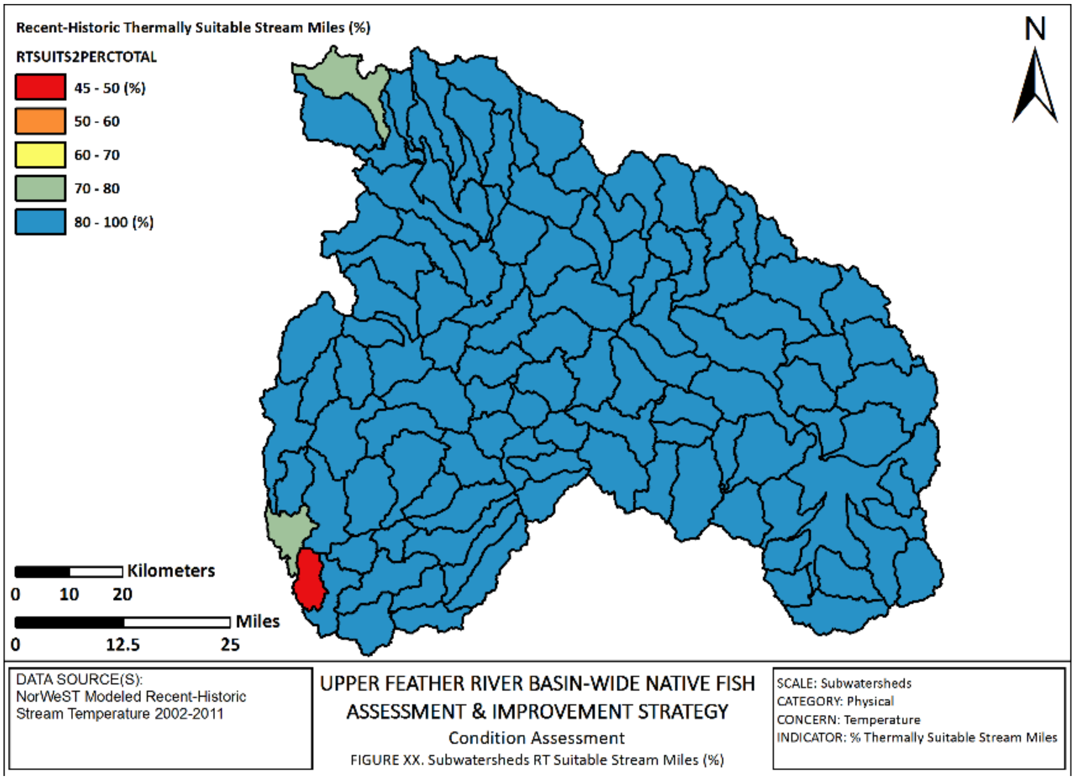


Figure 34. Percent perennial stream with suitable temperatures for Rainbow Trout, by subwatershed

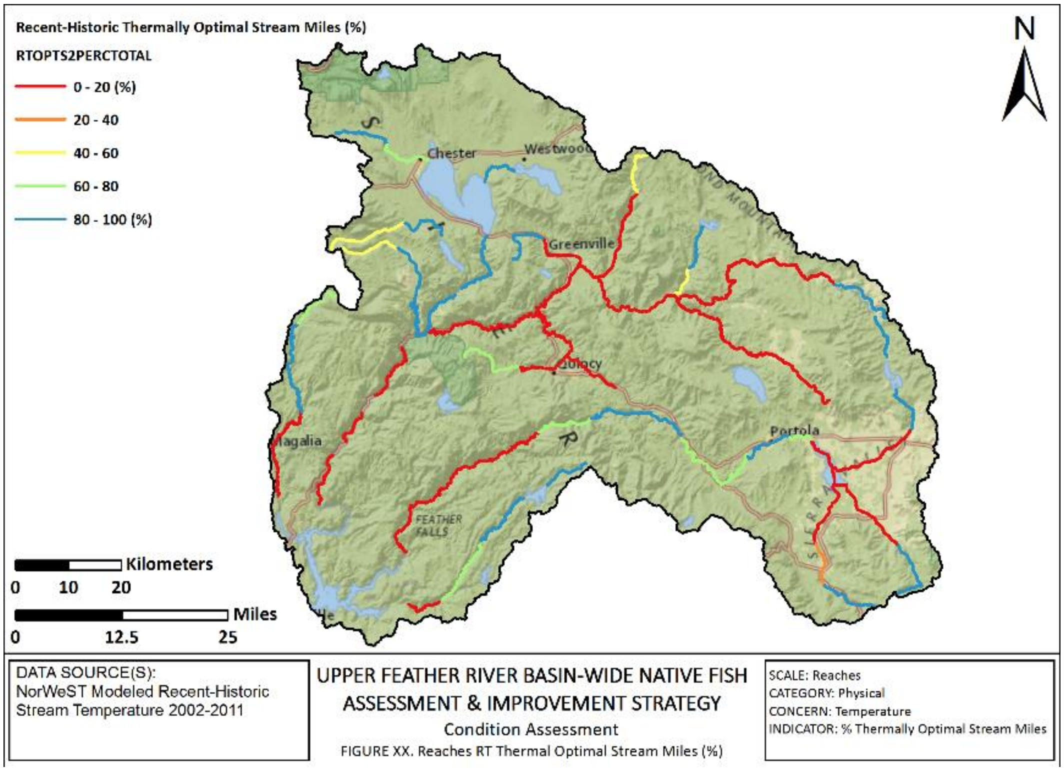


Figure 35. Percent perennial stream with optimum temperatures for Rainbow Trout, by reach

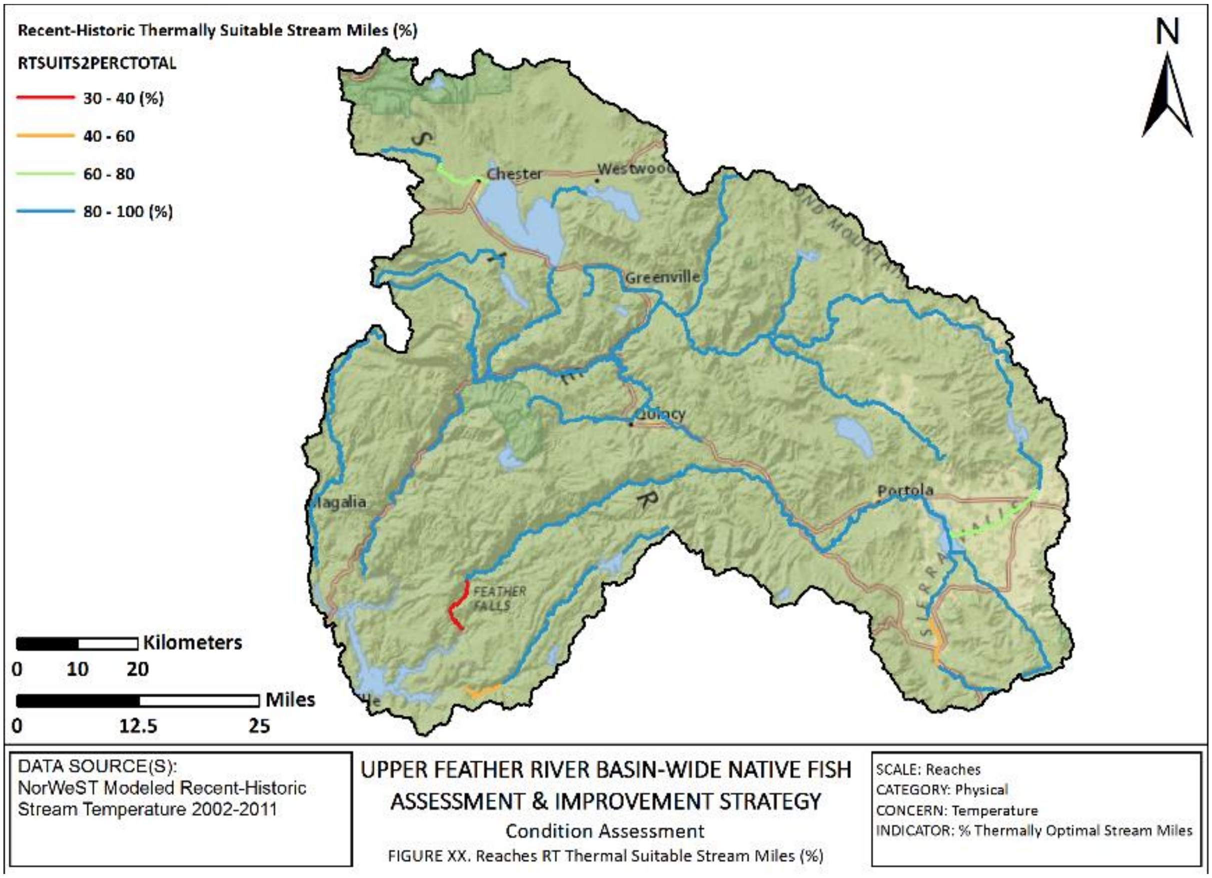


Figure 36. Percent perennial stream with suitable temperatures for Rainbow Trout, by reach

3.4 Runoff and Diversions

Background

In the large valleys of the basin, and many "river" reaches, it is common practice to divert water for irrigation for forage and crop production or hydroelectric production. Most diversions in the basin have been in place for decades. Most agricultural diversions divert streamflow on a seasonal basis. In addition to decreasing instream flows, water diversion structures can block fish migration. When water is diverted from streams into irrigation ditches, trout often follow the flow and are trapped or stranded.

Young of the year rainbow (RTYOY) trout are extremely susceptible to irrigation diversions. YOY leaving their redds disperse and travel downstream, tail first, on the stream edges to avoid high water velocities. They seek areas with cover and access to food and are in constant competition other RTYOY. Most irrigation diversion structures are situated on stream edges and often divert more than 10% of the streamflow.

A long-standing premise employed by California Department of Fish and Wildlife is that if a water diversion diverts 10% of the flow, 10% of the fish population is entrained. It follows then that entrainment from diversions is correlated to the percentage of streamflow diverted and therefore is substantial. That said, all diversions differ, year-long hydropower diversions are not comparable to seasonal irrigation diversions. Though entrainment from agricultural diversions is substantial, impacts at hydropower diversions are greater, entraining all species and all year classes year around.

While the CDFW convention surrounding one-to-one loss for percentage of water and fish diverted is acknowledged, this assessment rated entrainment risk based on the gross metric of frequency of diversion points per stream mile. Amount of water diverted was used as the "Flow" indicator for current condition.

Streamflow alterations also have physical consequences. They affect water depth and velocity, stream temperature, and sediment deposition (Harvey, et al, 2014). Most attention on stream diversions has been focused on direct impacts to fish but they also impact benthic invertebrate communities, which in turn affect fish foraging and productivity. In-channel conditions resulting from diversions may also promote habitat conditions more suitable to invasive species. Lower flows decrease water velocities and decreased water velocities increase the amount of time an un-shaded stream is exposed to solar input and higher water temperature. Additionally, highly-altered channels limit fish movement (Clothier, 1954, Wenger, et al, 2011).

Methods

Our objective in assessing flows was to develop a method that would provide relative comparisons between reaches in terms of the portion of water diverted and number of diversions. Our assumption was that the more flow diverted, the greater risk of entrainment and stranding, and the greater the impact on habitat in the channel from which flow is diverted. Our method was based on rough estimates of baseflow and rough estimates of water diverted from all reaches in the basin. Both attributes are highly variable. Streamflow (and baseflow) varies, primarily with annual precipitation. Flow diverted increases as more streamflow is available and decreases as less flow is available.

Annual runoff for each sub-watershed was estimated using the Basin Characterization Model (BCM) described in the Climate Change section. Flows for reaches were calculated by summing runoff all sub-watersheds upstream of the reach. We used the findings of Rantz (1972) to apply a coefficient of .35 to the annual runoff (acre/ft year) values to produce an estimate of runoff during the May-October period, which we took to roughly correspond with timing of diversion for agricultural uses.

Estimates of water diverted was derived from water rights information available from the California Department of Water Resources. The amount of water authorized was used as the value for each diversion. Diversions were mapped. If reaches contained more than a single diversion, amounts from all diversions within the reaches were added together.

Diversions with authorized use of greater than 0.4 cfs were assumed to have a diversion structure large enough to pose at least a partial barrier to fish passage. Aerial photography was used to confirm infrastructure at these sites was present that might hinder fish movement at some time. Where confirmation was not possible, the sites of diversions >0.4 cfs were assumed to be barriers.

We then divided the estimate of runoff by the summed authorized use amounts to produce a value that represents the relative percentage of water potentially diverted from each reach. Our feeling is that both runoff and amount of water diverted are over estimated, but comparisons between reaches on a relative basis are sound.

Results

Diversions

Reaches and subwatersheds explained

The two scales of analysis employed in this assessment both contain stream channels. We have termed one of these scales the "reach scale" which are large streams and rivers not fully contained within any single subwatershed. They typically flow through several sub-watersheds. For the purposes of the assessment, we termed channels that did not fit the definition for reaches as "reaches within sub-watersheds". These channels are typically smaller than those defined as reaches. The key distinction is that they are contained entirely within a "headwater" subwatershed.

Reaches within Sub-watersheds

All but 17 sub-watersheds were found to have at least one recorded water right. While flow from all diversions from creeks were considered in the flow calculations, we tracked only diversions of >0.4 cfs in terms of their potential to pose barriers to fish passage. We assumed a diversion of this amount would likely require permanent diversion infrastructure. Only 27 reaches within sub-watersheds included diversions of >0.4 cfs (Table 13). Most of these diversions are located in streams tributary to the large meadow streams in the watershed, such as Mill and Estray Creeks (tributaries to Spanish Creek) and Ward and Cooks Creek (tributaries to Indian and Lights Creeks).

Frequency of Diversions >0.4cfs	Reaches Within Sub-watersheds	Reaches
1	12	7
2	7	0
3	4	3
4	3	4
5	1	1
8	0	1
>10	0	1

Table 12. Number of diversions >0.4cfs by sub-watershed and reach

Reaches

Seventeen reaches had diversions of at least 0.4 cfs. Three had a single diversion (Table 13), though areas with significant agricultural use (American Valley, Indian Valley). Sierra Valley has hundreds of diversions.

Diverted Flow, Reaches

Figures 37 and 40 display the frequency of estimated diverted flow percentages, by reach. More than half of reaches have no diverted flow. As would be expected, reaches with the greatest amount of flow diverted are associated with hydroelectric development along the North Fork Feather River, and in valley systems with the greatest amount of historic and current agricultural (range) production. Among the latter group of streams are numerous channels in Sierra Valley, Indian Creek and Lights Creek in Indian Valley and Spanish and Greenhorn Creeks in American Valley.

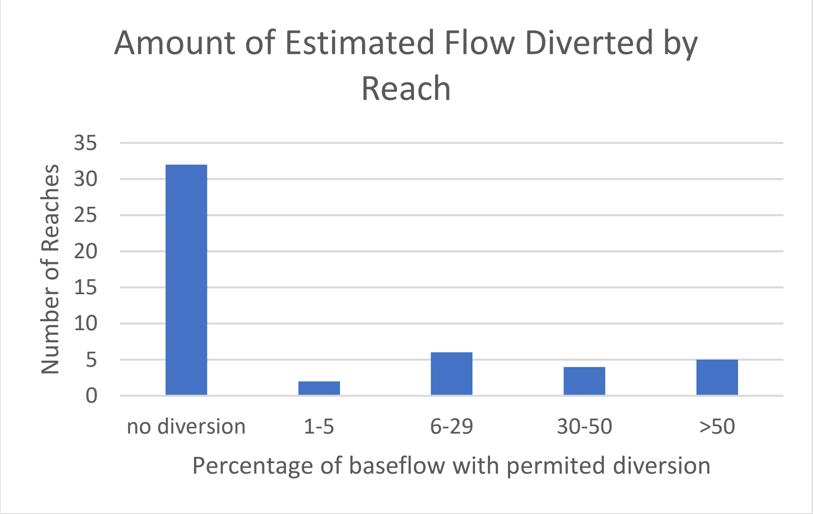


Figure 37. Frequency of estimated diverted flows (percentage of estimated baseflow diverted) from reaches

Diverted Flow, Reaches within Sub-Watersheds

Figures 38 and 39 display the frequency of potential percentage of flow diverted within stream reaches contained within sub-watersheds. Because these are generally smaller channels (and have less flow) than those described by the reach scale, few of these diversions are for hydroelectric production (Ward Crk is a notable exception). Instead, most diversions are for agriculture (Ward Creek has both). Nearly all these diversions are liked to other nearby, downstream agricultural diversions. For example, diversions on Little Grizzly and Mill Creek are associated with irrigation diversions on Indian and Spanish Crks, respectively. The streams with the greatest percentages of estimated diverted flow are Sulphur Crk, Taylor Crk (Greenhorn), Mill Crk (Spanish), Dixie Crk, Long Valley Crk and Meadow Valley Crk.

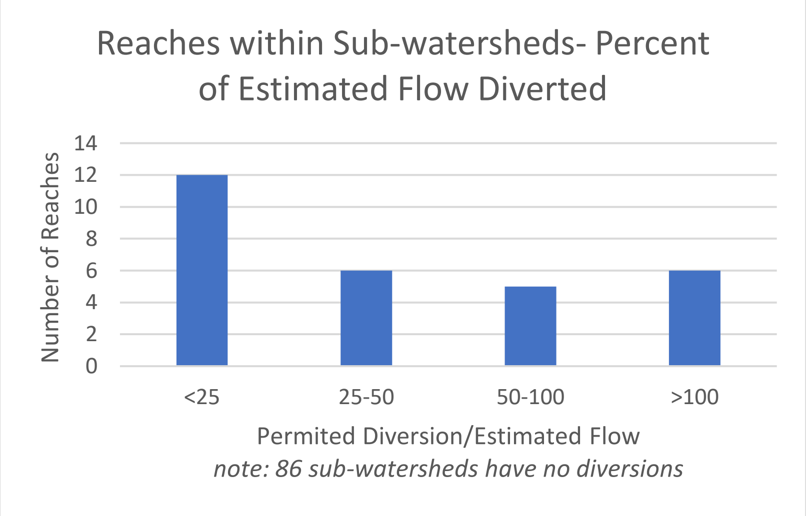


Figure 38. Frequency of estimated diverted flows (percentage of estimated baseflow diverted) from streams within sub-watersheds

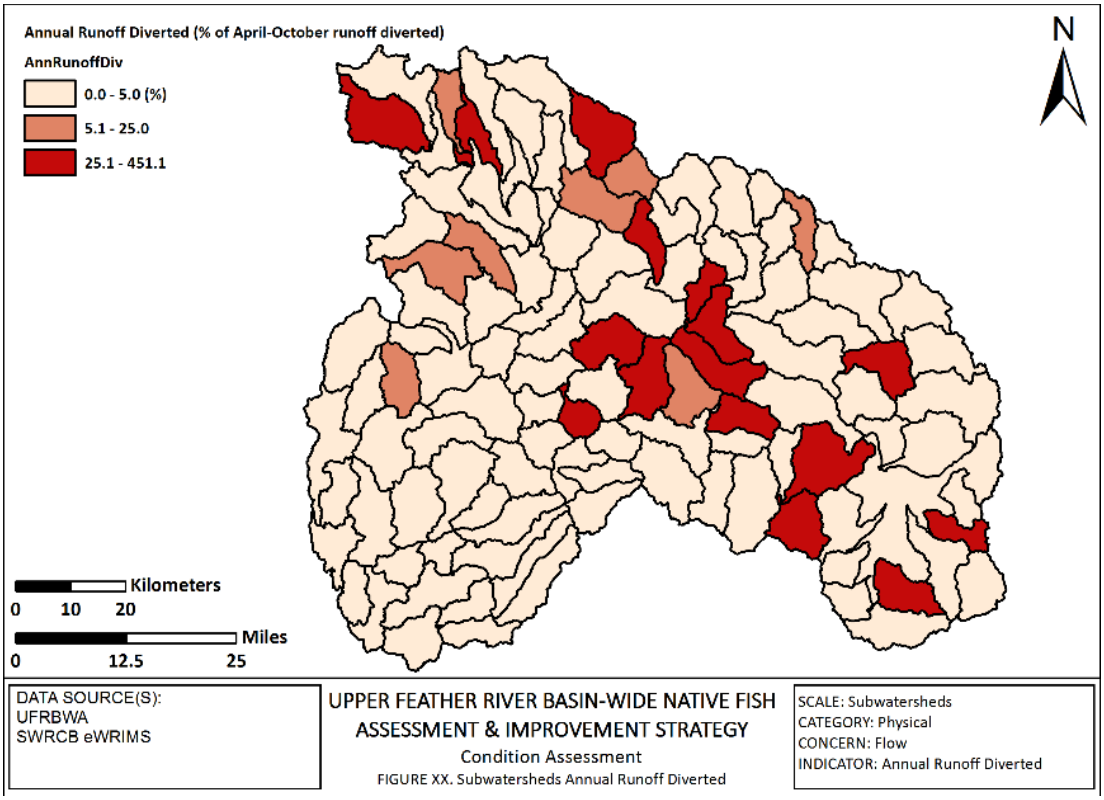


Figure 39. Estimated diverted flows (percentage of baseflow diverted) from streams within sub-watersheds

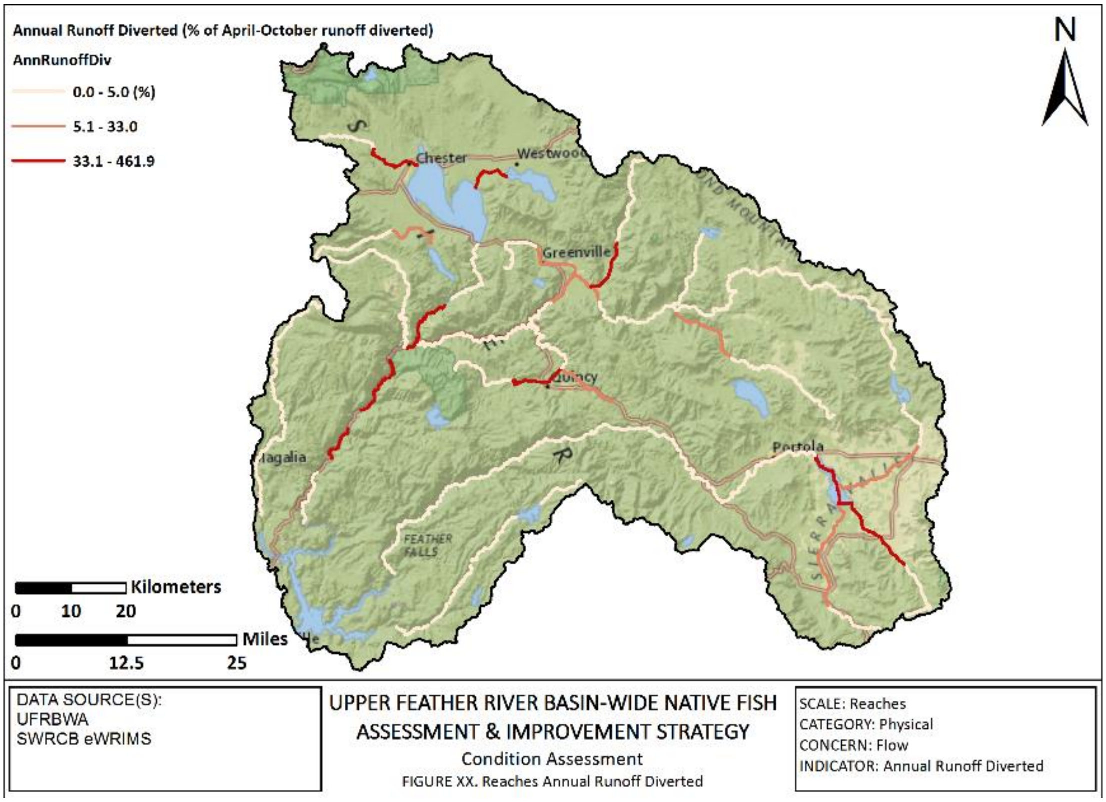


Figure 40. Estimated diverted flows (percent of estimated baseflow diverted) from reaches

3.5 Low Gradient Channel Condition

Background

During discussion about what indicators to use to characterize watershed and reach condition, the TAC felt strongly that the condition of low gradient reaches (also termed response channels, Montgomery and Buffington 1997) was an important indicator of both fisheries habitat and watershed condition. Because we employed measures that could be applied basin-wide and data was available on only a small percentage of low gradient stream reaches throughout the basin, we elected to convene an expert panel to rate reach condition.

The panel provided ratings for 36 stream reaches. These reaches had been identified through a GIS mapping exercise applied to all channels throughout the basin that had gradients less than 1% and were at least 1000 m in length. These streams were reviewed and stream reaches with bedrock morphology were not rated, but rather assumed to be stable.

The panel consisted of 10 members. The panel included hydrologists and fisheries biologists currently working on the Plumas or Lassen National Forests, and retired hydrologists from both forests. Collectively, the group had observed all but two of the stream reaches (these were not rated). Recollection of observations was assisted by viewing Google Earth during the collective rating exercise.

Rating criteria for four attributes (floodplain connectivity, channel form, fisheries habitat and riparian vegetation community) were developed. They are listed below.

A- Floodplain Connectivity

1- Riparian-wetland area is almost never saturated at or near the surface or inundated by flows, other than at constrictions or at extremely high flows.

2- Riparian-wetland area is saturated at or near the surface or inundated in by flows >2 yr and other than at constrictions.

3- Riparian-wetland area is saturated at or near the surface or inundated in by 2 yr flow

B- Channel Form

1- Channel displays lateral and/or vertical cutting greater than would be expected.

2- Channel is laterally and vertically stable, but at an elevation below the historic floodplain.

3- Channel is laterally and vertical stable, at “natural” elevation

C- Fish Habitat (pools, riffles, etc.)

1- Very few pools or riffles. Low water habitat characterized by nearly continuous flatwater.

2- Reach has a pool-riffle sequence evident, but pools are shallow and long, riffles are shorter than would be expected for a stream of this size and type.

3- Reach has pools and riffles with frequency and size (depth) expected in a stream of this size and type.

D- Riparian Vegetation Community (at the Greenline and above)

1- Riparian Vegetation Sparse, not near potential, regeneration not evident or successful.

2- Where herbaceous vegetation present, diverse age classes but sparse, regeneration at risk. Mature trees/plants decadent. When dense, diverse age assemblage absent.

3- Riparian community composed of diverse assemblage of sprouts, young, mature, dead, decadent trees. Or grasses and forbs representing climax community. Vegetation is dense.

Results

Ratings derived from the panel are summarizes in Table 14 and illustrated in Figure 41. Of the 35 reaches evaluated, 12 were rated in good condition, 14 were rated in poor condition. Riparian condition was the criteria most often rated in the poorest category, with condition often ascribed to impacts from range management.

Stream Reach	Consensus Rating					Summary Rating
	Floodplain Connectivity	Channel Form	Fish Habitat	Riparian Vegetation	total	
Lemon Canyon-Perry Creek					0	nr
Little West Fork West Branch Feather River-West Branch Feather River					0	nr
Dixie Creek	1	1	1	1	4	Poor
Dry Creek-Hamilton Branch	1	1	1	1	4	Poor
Cooks Creek	2	1	1	1	5	Poor
Cottonwood Creek	2	1	1	1	5	Poor
Hough Creek-Indian Creek	2	1	1	1	5	Poor
Mill Creek-Spanish Creek	2	1	1	1	5	Poor
Squaw Queen	2	1	1	1	5	Poor
Sulphur Creek	1	1	2	1	5	Poor
French Creek	2	2	1	1	6	Poor
Frenchman Lake-Little Last Chance Creek	2	2	1	1	6	Poor
Hamlin Creek (Sierra Valley)	3	1	1	1	6	Poor
Little Grass Valley Reservoir-South Fork Feather River	2	1	2	1	6	Poor
Lookout Creek-Little Last Chance Creek	2	2	1	1	6	Poor
Mountain Meadows Creek-Frontal Mountain Meadows Reservoir	2	2	1	1	6	Poor
Willow Creek (MF Trib nr Clio)	3	2	1	1	7	Fair
Big Grizzly Creek	2	2	2	2	8	Fair
Clarks Creek	2	2	2	2	8	Fair
Ferris Creek-Last Chance Creek	2	2	2	2	8	Fair
Lone Rock Creek-Indian Creek	2	2	2	2	8	Fair
Meadow Valley Creek	2	2	2	2	8	Fair
Robbers Creek	3	2	2	1	8	Fair
Bailey Creek	3	2	1	2	8	Fair
Bear Valley Creek-Smithneck Creek	2	2	2	2	8	Fair
Antelope Creek	3	2	2	2	9	Good
Little Grizzly Creek	2	2	3	2	9	Good
Carman Creek	2	2	3	3	10	Good
Humbug Creek-Middle Fork Feather River	3	2	2	3	10	Good
Hungry Creek	3	2	3	2	10	Good
Jamison Creek	3	2	2	3	10	Good
Poplar Creek-Middle Fork Feather River	3	2	2	3	10	Good
Rock Creek (Almanor)	3	2	2	3	10	Good
Rush Creek	3	2	2	3	10	Good
Willow Creek-North Fork Feather River	2	2	3	3	10	Good
Boulder Creek	3	3	2	3	11	Good
Willow Creek-Last Chance Creek	3	3	2	3	11	Good

Table 13. Expert Panel Stream Reach Rating

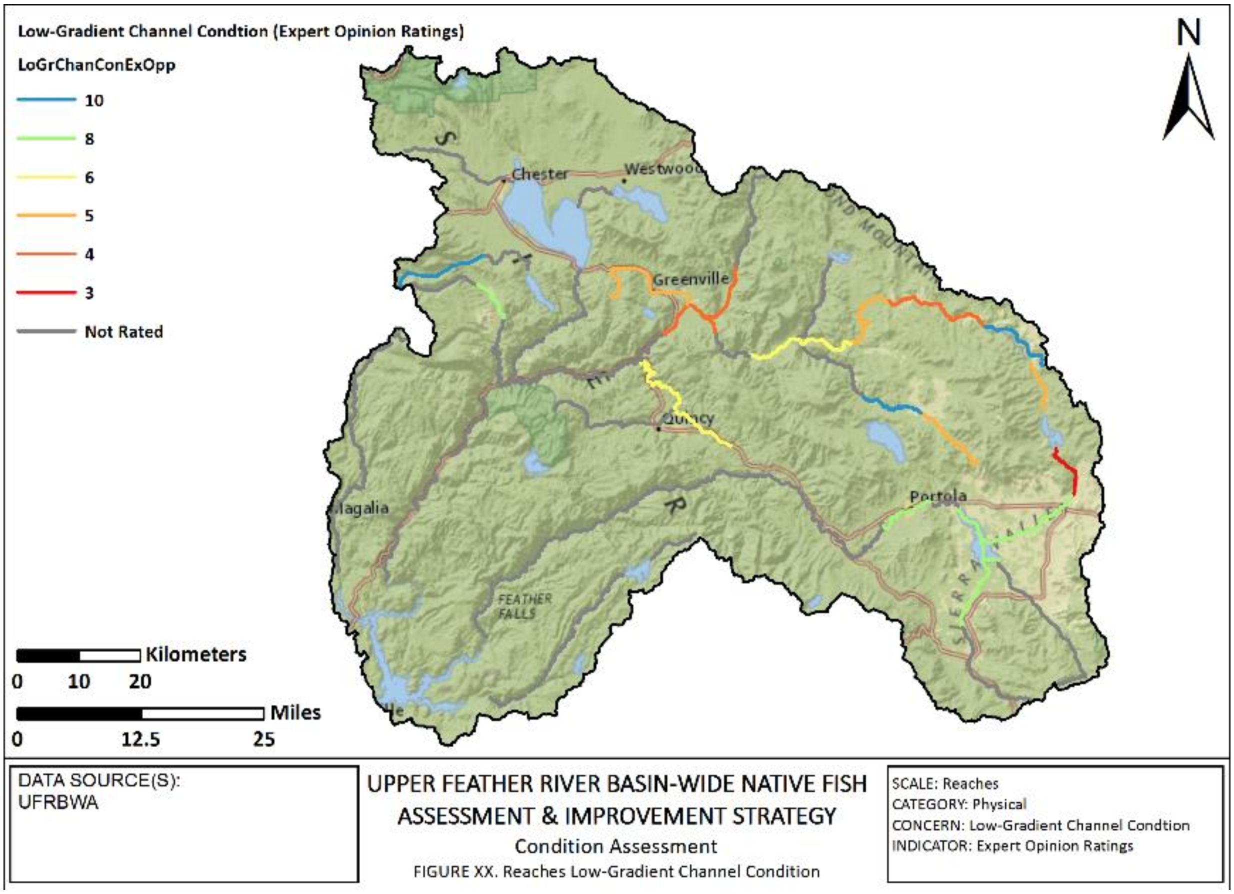


Figure 41. Low gradient channel reach condition

3.6 Connectivity

Background

Analysis of habitat connectivity estimated and rated the ability of native fishes to migrate within and throughout the stream network. More specifically, the analysis was meant to identify where habitats had been fragmented by road crossings, diversion structures and other structures constructed or placed in stream channels.

Habitat connectivity is important to native fishes for many reasons. In areas where all the needs of a population are met in close proximity, migration is less likely to be a significant part of life-history strategy. This is true in areas of the Basin where natural habitat connectivity is low because of high channel gradient or frequent impassable falls and cascades. However, in most areas, connectivity was naturally high and some population needs and migration was likely a significant part of populations' (versus individual's) life-history strategy. Migration is important in providing genetic interchange between populations, and for repopulation of habitats following events such as wildfire and debris flows. It follows that connectivity may be more important to sustain populations in the long (versus short) term. Improving connectivity in areas where it was naturally high is thus a greater priority that improving connectivity in areas where it was low.

Among others, habitat connectivity is important to Rainbow Trout to provide:

- Access to spawning and rearing habitat (i.e. tributaries to the large-order streams throughout the Basin)
- Access to late-summer thermal refugia (e.g. tributaries to the main stem North Fork Feather River and reaches in large valleys)
- Access to productive food sources
- Refugia (i.e. tributaries with lower flow and higher water quality during high-flow events)
- Genetic exchange
- Restocking of habitats following catastrophic events
- Nursery sites for young

For many of the populations in the Basin habitat connectivity is important for at least one of these reasons. While our focus is on fish, and specifically trout, habitat connectivity is also important to other aquatic organisms, including amphibians.

For the purposes of this assessment habitat connectivity is considered a benefit to populations. We acknowledge greater value for fish populations with connection dependent life-history strategies in different portions of the Basin. There is some thought (though little evidence) that barriers to fish movement may be beneficial to amphibian species by reducing frog (and especially tadpole)-fish interactions. Fragmentation is extensive throughout the Basin (due primarily to the large number of road-stream crossings), it is generally greater in areas with moderate topography, as these were the sites of the first road and timber access. Steeper areas generally were not roaded. The large valleys of the basin, and many of the “river” reaches are the site of numerous water diversion structure and dams for hydropower development.

Methods

We investigated habitat connectivity at the subwatershed scale using and index of three measures: internal, external and baseline. The estimate of external connectivity, that is, the amount of habitat in the subwatershed that is connected to habitat outside the subbasin (in larger streams at the subwatershed confluence and up and downstream of the confluence) was estimated by calculating the length of habitat (perennial-intermittent stream miles) between the mouth of a unit and the first upstream barrier. The internal calculation represents the longest total length of habitat *within* each Subwatershed. In some subwatersheds, the internal and external values were based on the same stream lengths and were equal. Baseline connectivity was defined as the length of stream network with less than a 20% channel gradient. We applied this factor to represent the portion of the stream network that trout could reasonably expect to negotiate, used as a coarsely characterization of each subwatershed in an unimpeded state. 20% channel gradient is no doubt too steep for trout. Initial work indicated that mapped gradient values were considerably steeper than actual gradients, 20% was selected to represent a lower (in the range of 7%) actual stream gradient. As applied, the 20% threshold serves to highlight those watersheds with steeper gradients and provides a relative estimate of naturally accessible habitat.

The barrier dataset used in this assessment was developed by combining multiple datasets cross-referenced by a proximity analysis to eliminate redundancies or false barriers. Road networks were intersected with the NHD to identify road-stream crossings. These features were then cross-referenced with CalTrans data on location of bridges. Aerial imagery was used to verify the sites were bridges, which were assumed to be passable by fish. Another source of barriers are railroad crossings of streams. Almost all are barriers to passage of aquatic organisms. These crossings were mapped and included in the analysis.

We used aerial imagery and local knowledge to review large streams and rivers for crossings. This review added crossings not included in the other layers, and to determine if crossings were bridges or culverts. These crossings were combined with the CalFish CPAD dataset, the SWRCB diversion points, and available data for known waterfall barriers. Attributes in the CPAD dataset were examined to eliminate redundancy or false barriers in that dataset. The SCWRCB diversion point dataset was examined with the aid of aerial photos to identify large, concrete diversion structures.

Natural barriers included were derived from CPAD supplemented by a few additional natural barriers identified during the course of initial fish distribution mapping efforts. While a limited number of known important natural barriers (impassable falls) were included, a comprehensive inventory fell outside the scope of the project (hence the need for the “base” estimate.

Combined Connectivity Rating

We combined the base, internal and external connectivity estimates in a single rating to more easily display the results. We felt the degree to which subwatersheds afforded habitat connection to rivers, major streams and other subwatersheds was important ecologically, specifically long-term population sustainability, gene-flow and access to thermal refugia. This is reflected in doubling the weight of the external connection relative to internal connectivity in the following equation used to derive the summary ratings:

$$((\text{External connectivity} \times 2) + \text{Internal Connectivity}) \times \text{Base Connectivity})/\ 3$$

We multiplied the sum of the weighted connectivity and internal connectivity by the base connectivity because we felt both estimates were high as they did not accurately reflect the presence of cascades and other natural barriers. Note this results in relative estimates, rather than precise measures of connectivity. The theoretical range of the estimates from the equation range from 0 to 3. We therefore normalized the product of the three connectivity values by dividing by three. This changes the potential range of results from 0 to 1.0.

Results

Sub-watersheds

A summary of subwatershed connectivity ratings are presented in Table 14. Connectivity ratings ranged from 0% (11 sub-watersheds) to 100% (Chipps Creek). Two other watersheds (Onion Creek, Washington Creek) had connectivity estimated at 90% or higher, while another 34 had connectivity of 10% or less. Mean sub-watershed connectivity was 24%. Connectivity ratings by subwatershed are displayed in Figure 42.

	Subwatershed Connectivity			
	Base (%)	Internal (%)	External (%)	Rating
min	24	0	0	0
max	100	100	100	59.6
average	74	29.4	26.7	19.7
	10 ten subwatersheds (with values)			
	Robbers (100)	Chipps (100)	Chipps (100)	Lower Red Clover (59)
	Rock-Hamilton Br (100)	Washington (98.5)	Washington (98)	Warner (59)
	Bailey (99)	Onion Valley (93.1)	Onion Valley (93)	Potter Ravine NF (59)
	Ferris Creek (98)	Dogwood (83.4)	Dogwood MF (83)	Squaw Queen (58)
	Cottonwood (98)	Potter Ravine NF (74.2)	Potter Ravine NF (74)	Carman (51)
	Benner (98)	Lower Red Clover (70.8)	Lower Red Clover (71)	Mountain Meadows (47)
	Willow Last Chance (97)	Hosselkus (68.3)	Hosselkus (68)	North Channel LL Chance (46)
	Goodrich (97)	Warner (68.2)	Warner (68)	Mapes (46)
	Squaw Queen (97)	Brush MF (66.5)	Willow MF (64)	Goodrich Creek (42)
	Carman (97)	Willow MF (64.1)	Lower Yellow (59)	Onion Valley (41)

Table 14. Summary of subwatershed connectivity ratings. Ratings are a combination of within subwatershed, outer watershed and base connectivity estimates. 10 subwatersheds with highest values are listed for each attribute

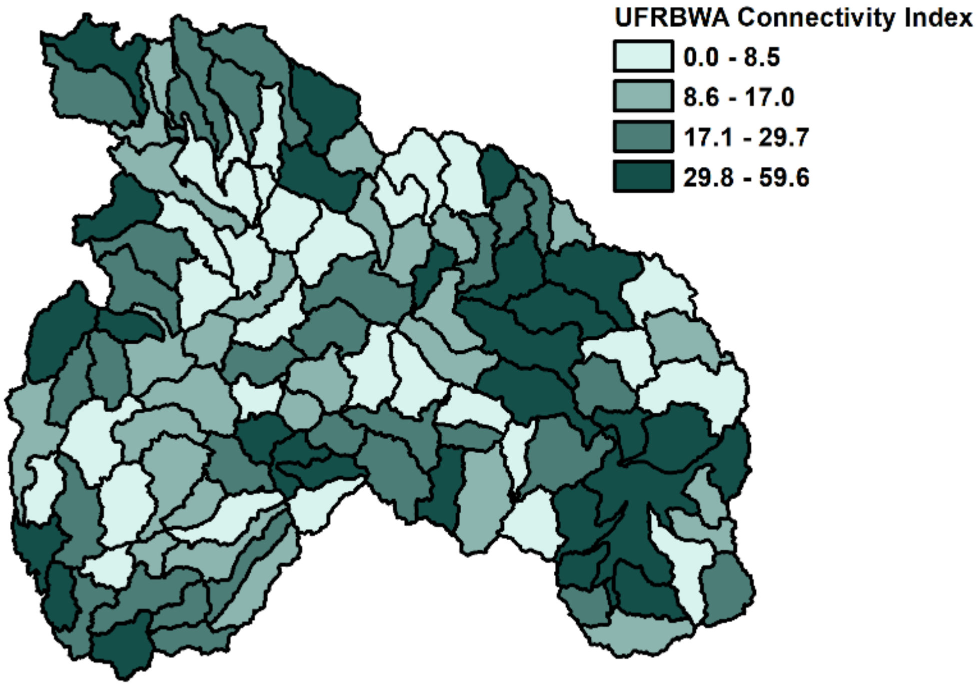


Figure 42. Connectivity ratings, by subwatershed

Reach Scale

The presence of dams associated with hydroelectricity production and the State Water Plan have significant impacts on broad scale connectivity of trout habitat. Historically, there were few (e.g. Feather

Falls, Curtain Falls) natural barriers on the main stems of the forks of the Feather River. Currently, there are numerous impassable man-made barriers on several large tributaries and notably, the North Fork. Our estimates of resulting connectivity are summarized in Table 16 and displayed in Figure 43.

The undeveloped nature of the Middle Fork results in the second longest connected habitat in the basin, with tributaries and main stem habitat contributing over 200 miles of estimated habitat. We assumed that trout could pass Indian Falls (Indian Creek upstream of the confluence with Spanish Creek) during high flows. Habitat in Indian Creek extends far to the eastern portion of the basin, including both Red Clover and Last Chance Creek an on Indian Creek as far as Antelope Dam. This connected reach also extends from Rock Creek Reservoir to the South, including Spanish Creek and its tributaries.

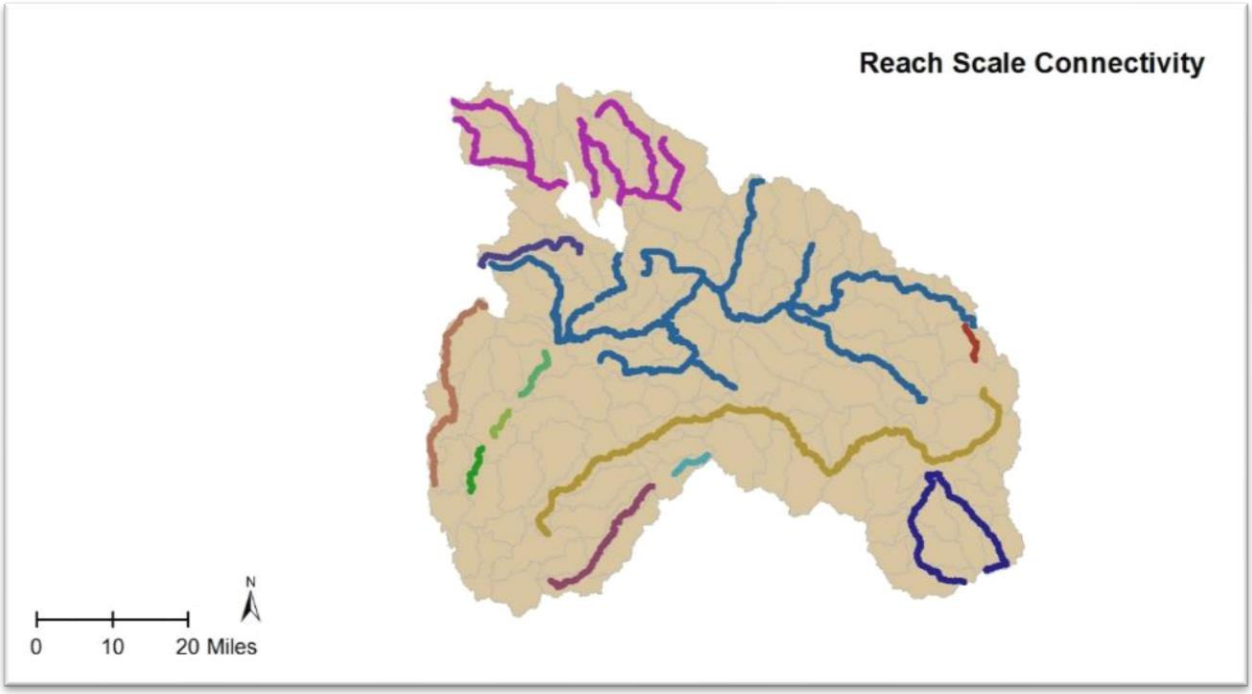


Figure 43. Connectivity of Reaches, Feather River Watershed (note only reaches, and not tributaries contributing to total connected length estimates in Table XX are shown)

Note that we assumed that there was connectivity (though no doubt less than historic) between streams tributary to Lake Almanor. In contrast, we did not assume there was connectivity between the Middle Fork Feather River and tributaries to Sierra Valley, due to the large number of irrigation diversion structures. Assessment of connectivity of these structures would provide a clear picture of connectivity in Sierra Valley as well as identify improvement opportunities.

Reach	Connected Habitat (miles)
North Fork above Rock Creek Reservoir	411.3
Middle Fork: Curtain Falls to Sierra Valley	224.8
North Fork Above Lake Almanor	105.3
North Fork: Cresta to Poe	67.2
North Fork: Rock Creek Dam to Cresta	61.5
North Fork: Poe to Oroville	38.0
Grizzly Creek Above Lake Davis	32.4
South Fork Ponderosa to Forbestown	27.6
Upper West Branch	23.5
Indian Creek Above Antelope Lake	14.7
Butt Creek Above Butt Valley Reservoir	13.1
South Fork: SF Diversion to Forbestown	12.2
Headwaters Coldstream Creek	8.7
Little Last Chance Above Frenchman	7.3
Lower West Branch	6.6
Headwaters South Fork	6.3
South Fork Below Little Grass Valley Reservoir	1.4
Sierra Valley	219.0

Table 15. Estimated connectivity of fish habitat by reach, Feather River Watershed

Wildfire

As previously discussed, wildfires of high severity have negative impacts on watersheds and fish habitat. We did not include wildfire as an indicator of sub-watershed condition for several reasons. First, while significant at the sub-watershed scale, relatively few sub-watersheds (twelve) have been burned by high severity fire in the past 15 years (Figure 44). Note this is in context of a basin wide assessment, and not intended to minimize the impacts of the Moonlight, Chips and Storrie Fires (which are evident in Figure 45).

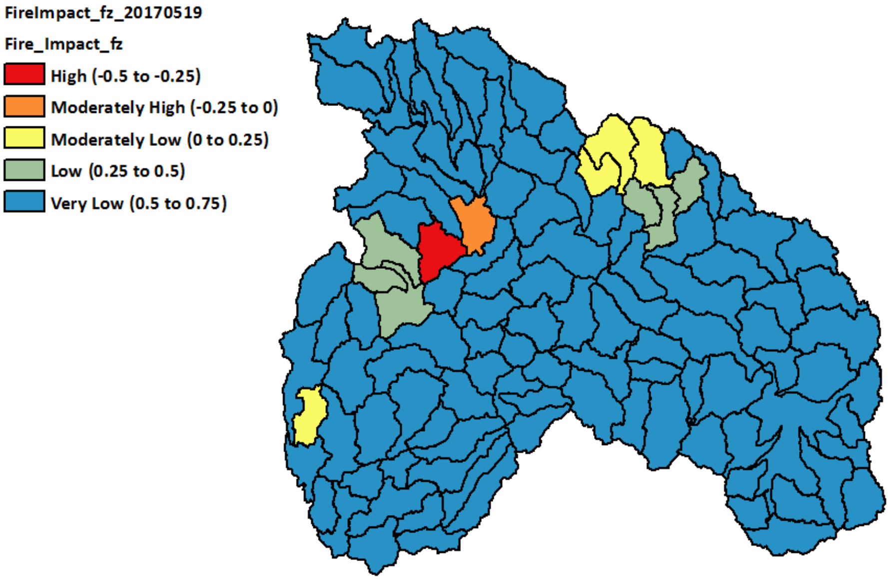


Figure 44. Percentage of subwatershed burned by high severity wildfire 2000-2014.

A final wildfire consideration was applied when priorities for treatment were developed. As explained in Part 4 of the assessment, some of the burned watersheds rated high in factors influencing resilience (i.e. low exposure, high connectivity). As the recommendations for treatment are aimed at long term sustainability, we decided not to "downgrade" areas based on past wildfire. Rather, it is assumed that sub-watersheds with high resilience ratings and wildfires would have restoration activities that reflect both relatively short-term fire recovery objectives and long-term watershed and habitat needs.

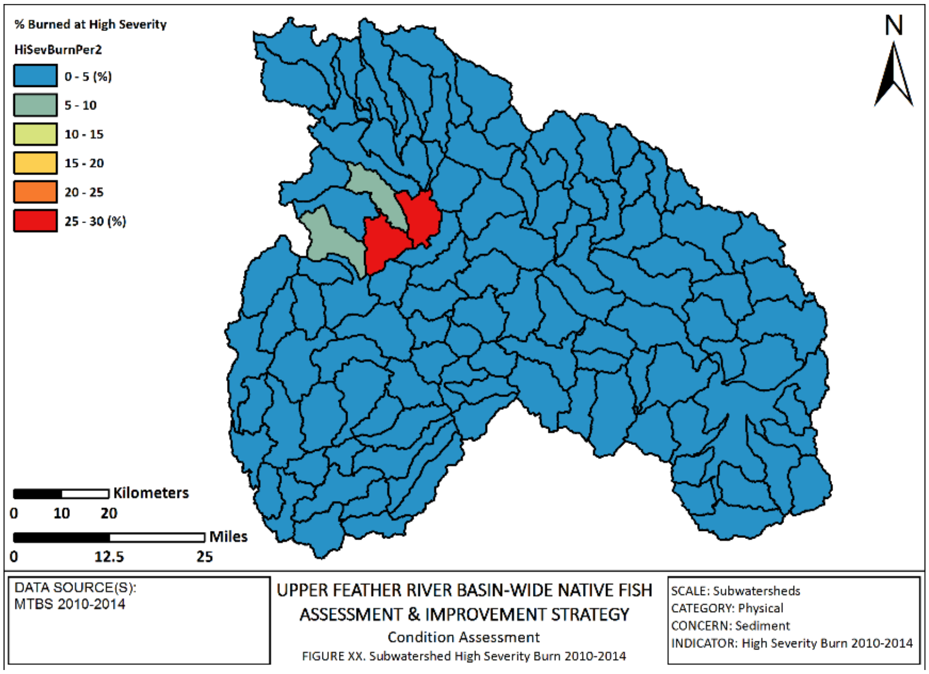


Figure 45. High Severity burn, 2000-2014

Reaches

Results from the combined reach condition ratings are shown in Figure 46. The EEMC model was used to combine results from road crossing density, near stream road density, diverted flow and optimal RT stream temperature. The results show most reaches in the basin are in poor condition for a variety of factors, depending primarily on the location of the reach. Reaches located relatively high in watersheds are strongly influenced by roading, with relatively high densities of channel crossings and near stream roads adversely affecting condition. From a practical standpoint, this means that intervention (road work) could improve condition in these headwater streams. Mid-elevation reaches are located primarily in the large meadows of the basin (e.g. American and Indian Valleys). Such reaches are the site of considerable diversion of baseflow for agricultural use and elevated stream temperature also influences condition in these reaches. Farther downstream, water temperatures are typically too high to provide optimum quality habitat for Rainbow Trout. In the North Fork and West Branch, hydroelectric facilities with associated diversions negatively impact habitat. The reaches in the best condition all lie upstream of areas where water diversions are prevalent and have topography too steep to have provided easy access for timber management and road construction.

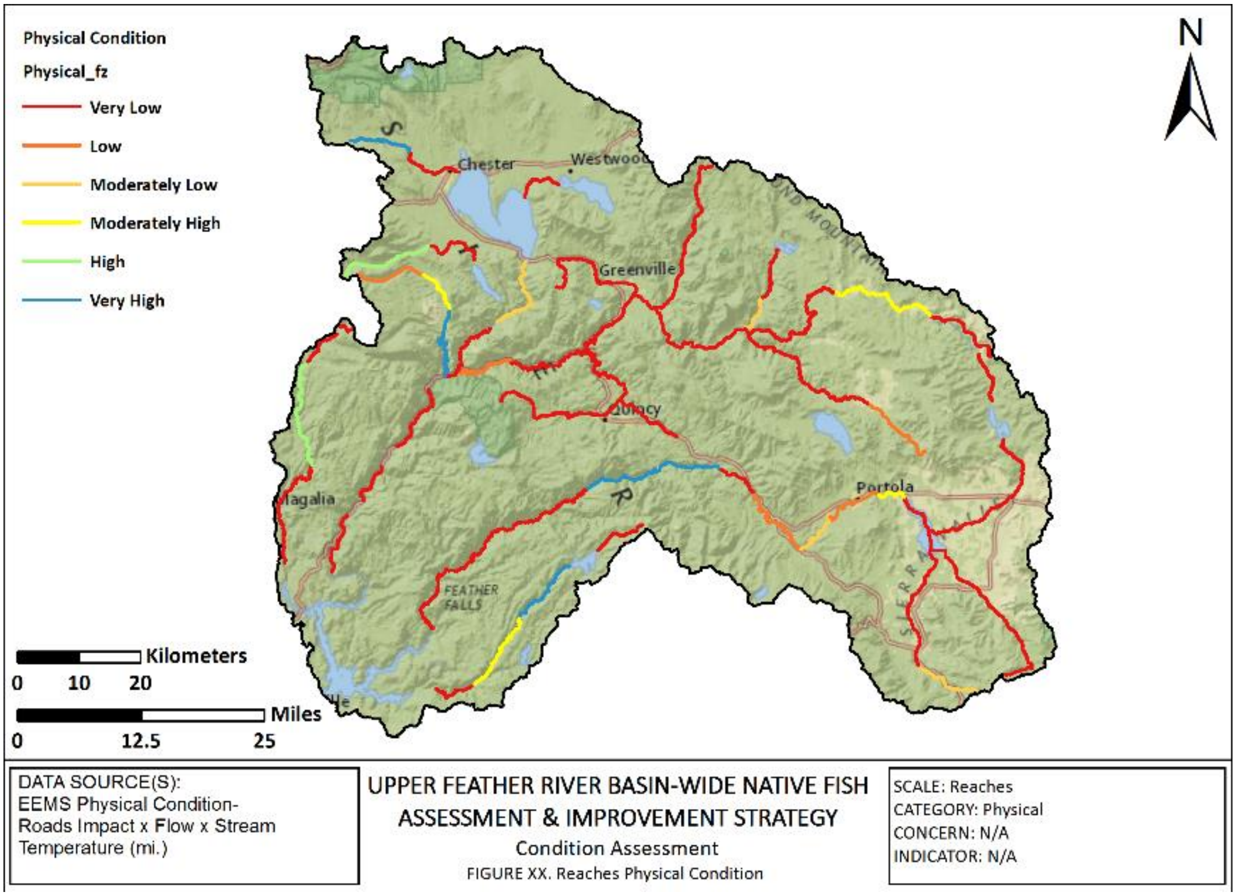


Figure 46. Reach condition ratings. Rating based on road xing density, near stream road density, diverted flow and optimal RT stream temperature

Part 4. Restoration Priorities-Identifying Adaptive Management Responses

Introduction

The framework for this restoration plan is based on the Trout Unlimited National Conservation Approach. This approach contains three primary elements: protection, reconnection and restoration. The assessment identified a range of fish habitat conditions throughout the watershed with reaches and sub-watersheds with little disturbance and habitat fragmentation to high levels of disturbance and significant loss of connectivity.

Areas in the watershed highlighted for protection (Figure 48) are those that currently support Rainbow Trout and appear to be the most resilient to likely climate change effects of increased water temperature and loss of flow. TU will explore special designation of some of these waters with the California Department of Fish and Game, but the primary thrust of protection is for land managers to recognize the importance of these areas to native fishes and incorporate appropriate conservation measures during implementation of management activities. Such measures include protection of riparian zones, road decommissioning and appropriate upgrades of roads and road channel crossings. The priority subwatersheds should also be considered as high priority for actions aimed at mimicking historic fire return frequencies. The assessment focused on native trout, but at its crux, the priority areas are those that promise to maintain the best lotic habitat, in terms of flow and water temperature. Other aquatic species, including native fish, benthic invertebrates and amphibians dependent on these habitats will also benefit from protection and restoration.

The assessment found substantial fragmentation of fish habitats across the basin at every scale. With the exception of the Middle Fork, hydropower facilities in main stems block upstream movement of fish. Several dams block upstream movement higher in the watershed. In most of the basin's low gradient "meadow" streams, infrastructure for diversion of water for agricultural use is a barrier to fish movement during at least part of the year. Finally, in the headwaters of many sub-watersheds, large numbers of road crossings block the upstream movement of aquatic organisms during at least some flows. The restoration plan identifies where opportunities to improve habitat connectivity best parallels objectives of improving resiliency and habitat condition.

The assessment documented that there are very few areas in the basin in pristine condition (Figures 39-44). The basin has been the site of extensive mineral extraction historically and agricultural and forestry production both historically and currently. In addition, a century of fire suppression has produced conditions more conducive to high intensity wildfires than existed historically across nearly the entire basin. Opportunities to improve conditions are present in nearly every sub-watershed and reach evaluated in the assessment. The Restoration Plan identifies those areas where the greatest benefit, in terms of sustaining resilience and improving condition and connectivity might be realized with investments in restoration.

Approach

In discussion with the TAC, it was agreed that the basic concept applied by the Forest Ecosystem Management Plan (FEMAT, 1993; Reeves, et al, 2006) Aquatic Conservation Strategy of: "Protect the best, restore the rest", should be applied to the current strategy. The reasoning is that by identifying areas currently in good condition, relatively low investments can be made to maintain condition, relative to considerable investments that might be necessary to improve condition of watersheds/habitats presently in poorer condition.

Since FEMAT, the likely impacts of climate change on hydrologic processes important to aquatic systems has become much better understood. It is now important to consider not only existing condition of watersheds and habitats, but also the exposure of systems to potential risks. Together, watershed (and habitat) condition and exposure define the relative resilience of sub-watersheds and reaches, that is, their ability be sustained over time.

Our recommendation is that management actions, including restoration, should focus on maintaining or improving watershed resilience. Resilience is the capacity of an ecosystem to respond to a perturbation or disturbance by resisting damage and recovering quickly (Holling 1973). By definition, resilient watersheds are better able to continue delivery of ecosystem services when subjected to ecological change, including changes that might result from a warming climate. Our assumption is that watersheds that combine low exposure with good condition are those most likely to maintain display resilience and maintain habitat for native fishes and other aquatic species.

4.1 Geographic Priorities (sub-watersheds with greatest resilience)

It follows then, that priorities for restoration are based on identifying areas with the greatest resilience, and those that have potential for improving resilience while providing quality lotic habitat in the long term. To that end, we identified three priority classes of sub-watersheds for restoration activities in the basin. Priorities for reaches are based on their condition and proximity to priority sub-watersheds. The analysis (Figure 47, Table 18) combined results from the ratings of sub-watershed exposure, condition and connectivity. Pathogens were also considered, but did not factor into the ratings, as they are known to exist in only two (Upper Yellow Creek, Cold Stream-Indian Creek) of the watersheds rated as priority for restoration.

Priority areas for restoration are subwatersheds with the least exposure to expected hydrologic changes. The subwatersheds placed in Exposure Classes I, II and III are those expected to retain the best habitat for rainbow trout in terms of flow, baseflow and stream temperature. We first reviewed the streams within Exposure Class I-III watersheds to confirm they provided enough trout habitat to merit a priority rating. The review was based on historic fish survey records and our personal knowledge and experience. Based on this review, six subwatersheds in the three low exposure classes were deemed low priority. These subwatersheds are: Antelope Creek, Camp Creek, Marian Creek (Frontal Lake Almanor), Frenchman Lake-Little Last Chance Creek, Mountain Meadows Creek (Frontal Mountain Meadows Reservoir) and Mountain Meadows Reservoir. These subwatersheds are high elevation relative to most of the Basin, and as such are projected to retain relatively high amounts of snow (our proxy for baseflow) and flow. As such, they remain important in delivering water, and cold water downstream. We do not feel these areas possess enough habitat for rainbow trout to warrant direction limited improvement and protection efforts to them.

We applied results from the evaluation of condition indicators using a simple approach. The rating included results from the combined road disturbance rating, with ratings of low or very low disturbance used as the criteria for watersheds with greatest resilience. Flow diversions obviously impact a stream resilience in supporting aquatic biota. Most sub-watersheds have no water diversions, but some (most tributary to large meadow systems) have a considerable portion of their baseflow affected. We used a guideline of at least 1.0 cfs of diverted flow to rate a sub-watershed as negatively impacted by diversions. We applied the rating of habitat connectivity developed for the assessment that considers both the amount of habitat available to fish within the watershed, and the amount of connection to habitat outside the subwatershed. Ratings of “good” for low gradient channel condition were considered to be representative of resilient stream systems (and subwatersheds).

We applied a simple rule set to classify the resilience of the remaining sub-watersheds in Exposure Classes I-III. Three condition attributes were employed: road disturbance, amount of water diverted and connectivity. The criteria applied to the indicators are listed in Table 17.

Attribute	Standard
Roads (crossings and near stream combined)	Rating of Low or Very Low
Diverted Flow	< 1.0 cfs
Connectivity	Rating of .30
Low Gradient Channel Condition	Good or Better (when present)

Table 16. Indicators and standards used to rate sub-watersheds condition

Where applicable, ratings of channel condition were also applied. Note that wildfire did not impact the resilience rating. Our reasoning is that in the long term, post-fire recovery, areas with relatively low exposure to hydrologic change would continue to serve as anchors for trout populations, even if they have been the site of recent, high intensity wildfire.

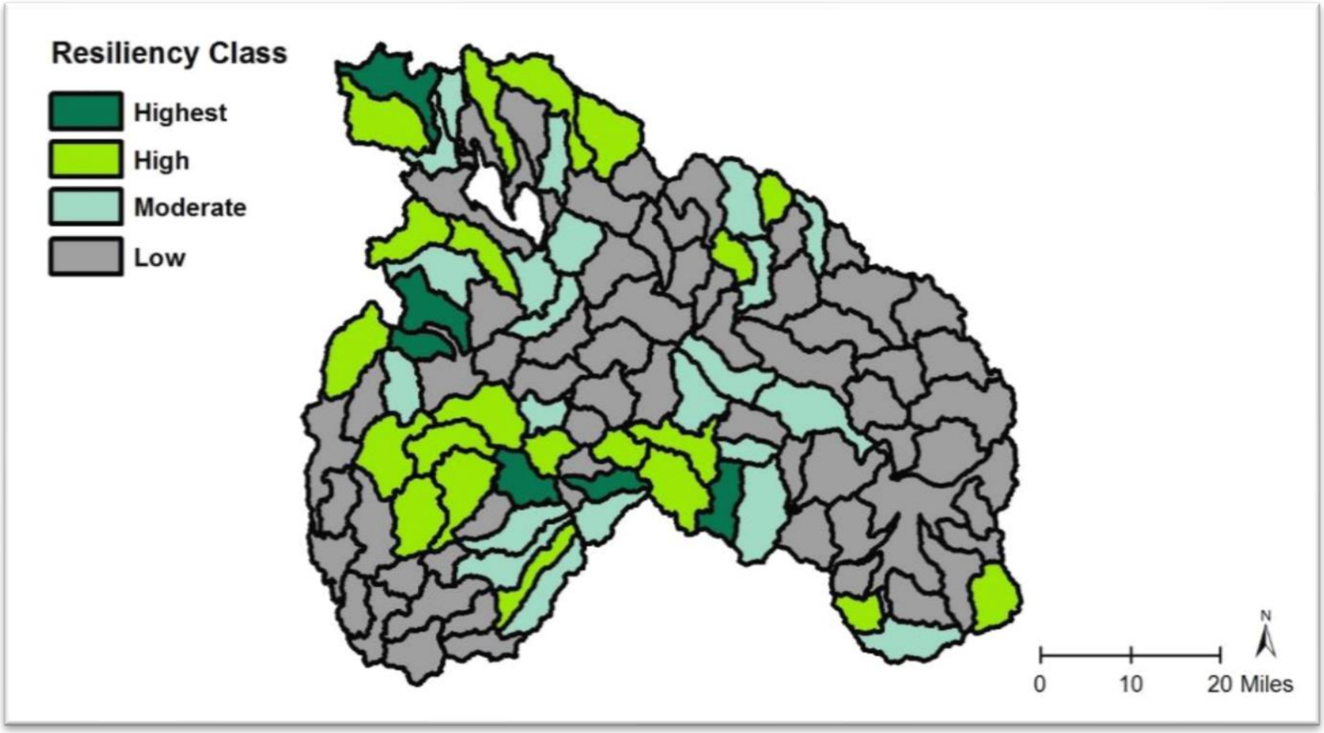


Figure 47. Priority sub-watersheds for restoration, by priority class

Highest Priority (6 of 121 Subwatersheds)

Subwatersheds in this category are those with the lowest exposure, are currently in good condition, and have relatively good habitat connectivity. These were watersheds in Exposure Class I or II that met all three condition criteria or met two criteria and also had good or excellent low gradient channel condition.

Emphasis: Very few of these areas are pristine. While consideration should be given to special management designations (Fish and Wildlife designations and land management considerations), land management activities should reflect the importance of these areas to trout and other lotic species and incorporate appropriate protective and restoration measures.

From a restoration standpoint, emphasis should be on improving connectivity, and addressing other condition factors that might include resilience, including roads and fire management.

High Priority (21 of 121 Subwatersheds)

This group of watersheds includes the Exposure Class I watersheds not included in the Highest Priority Category, along with Exposure Class II sub-watersheds meeting two of the condition criteria, or meeting one criteria and having good or excellent low gradient channel condition. Also included are Exposure

Class III subwatersheds meeting all three condition criteria and those that meet two criteria and have low gradient channels rated as good or excellent.

Emphasis: Highest priority areas in this group are those adjacent to Highest Priority and other High Priority subwatersheds.

Management actions should be aimed at improving condition and connectivity.

Moderate Priority (23 of 121 Subwatersheds)

This group of areas includes Exposure Class II and III sub-watersheds not included in the previous category.

Emphasis: Highest priority areas in this group are those adjacent to High Priority and Highest Priority subwatersheds.

Management actions should be aimed at improving condition and connectivity.

Low Priority (72 of 121 Subwatersheds)

Sub-watersheds and reaches with greater exposure, regardless of condition.

Emphasis: Given the large number of areas in other priority classes, it is unlikely that significant restoration investments would be made in these areas. If activities are planned, they should be implemented only when the likely outcome are improvements in condition sufficient to move the area into a higher condition class. Consideration should also be given to locating activities in subwatersheds and reaches adjacent to areas with higher resilience.

Watershed Resilience Category		
Very High	High	Moderate
Chipps Crk*	Badendaugh Can-Smithneck Crk	Benner Crk
Jamison Crk	Bailey Crk	Big Grizzly Crk****
Lower Yellow Crk***	Bear Crk**	Bonta Crk-Cold Stream
Onion Valley Crk**	Boulder Crk	Clarks Crk
Warner Crk	Bucks Crk****	Clear Crk-N F Feather R****
Willow Crk-M F Feather	Butt Crk	Cold Stream-Indian Crk****
	Camp Crk-N F Feather R	Estray Crk-Greenhorn Crk
	French Crk	Fall R
	Goodrich Crk	Frazier Crk-M F Feather R
	Grizzly Crk	French Crk
	Hamlin Crk	Hamilton Branch
	Hungry Crk	Jackson Crk-M F Feather R
	Last Chance Crk-W B Feather R	Little Grass Val Res, SF Feather ****
	Little N F of M F Feather	Little Grizzly Crk
	Nelson Crk	Lone Rock Crk-Indian Crk
	Poplar Crk-M F Feather R	Lost Crk
	Robbers Crk	Louse Crk
	Rock Crk- N F Feather R	Meadow Valley Crk
	Soldier Crk	Rock Crk-S F Feather
	Washington Crk-M F Feather	Rush Crk**
	Willow Crk- N Fk	South Branch M F Feather R
		Up Yellow Crk***
		Upper Wolf Crk**

*Table 17. Priority Sub-watersheds for protection and restoration. Sub-watersheds with more than minimal recent, high severity wildfire are identified with an *. ** sub-watersheds are those that support only Rainbow Trout populations. *** sub-watershed with whirling disease. **** sub-watersheds with reaches directly downstream of reservoirs.*

Priority sub-watersheds without non-native trout species

We intended to apply the absence of non-native salmonids as a large scale biological condition indicator, but the results found only three sub-watersheds in the moderate and high priority classes where Rainbow Trout were the only salmonid. Streams in the Bear, Onion Valley, Rush Creek and Upper Wolf Creek sub-watersheds might be considered higher priority for that reason.

4.2 Watershed groupings and consideration of Connectivity in setting priorities

Because sustained runoff, snowpack and desirable temperature regimes were used to assess exposure, and these attributes are all strongly influenced by elevation, it is not surprising that priority areas resulting from the analysis tend to be grouped in higher elevation areas of the watershed. As shown in Figure 48, there are seven such groupings (clusters).

One cluster is located above Lake Almanor. Some sub-watersheds in this cluster have modeled stream temperatures colder than the optimum for Rainbow Trout and would have rated higher if a longer exposure period had been employed. Bailey Creek was rated in Exposure Class III primarily because most channels are seasonally flowing, providing a relatively low amount of optimum trout habitat.

A second, large cluster drains sub-watersheds tributary to the North Fork Feather River downstream of Lake Almanor. This cluster includes sub-watersheds in the Yellow Creek drainage, and those draining to the East Branch North Fork and North Fork Feather River above Rock Creek Dam. A third cluster is located above Antelope Lake and includes sub-watersheds that climb the eastern escarpment of the Sierra Nevada. A fourth cluster drains relatively high elevation sub-watersheds along the Middle Fork between Portola and Quincy.

Three clusters include sub-watersheds lying along a band of high precipitation that runs roughly SE from Snow Mountain (7015’) through Table Mountain (6038’) to Bald Mountain (5534’). This area currently receives from 65 to over 100 inches of precipitation annually (Koczat, et al, 2004) and is projected to maintain substantial stream flows. The higher elevation streams in these subwatersheds are also projected to provide optimum stream temperatures for Rainbow Trout. Subwatersheds in the cluster drain to North Fork, Middle Fork and South Fork and are grouped on this basis.

Consideration was given to sub-watersheds and stream reaches downstream of reservoirs. These reaches are likely to provide cool water and maintain flows in the future, because reservoir releases are likely to consider cold water fish habitat. All sub-watersheds containing below reservoir reaches were included in one of the three priority Resilience Classes. Special consideration might be given to reaches below Little Grass Valley, Almanor, Antelope and Bucks Lake. These were rated in Resilience Classes II (Little Grass Valley) and III, but conditions for flow and temperature could be further moderated by cold water releases. The reach below Lake Davis is located in sub-watersheds rated in Class I.

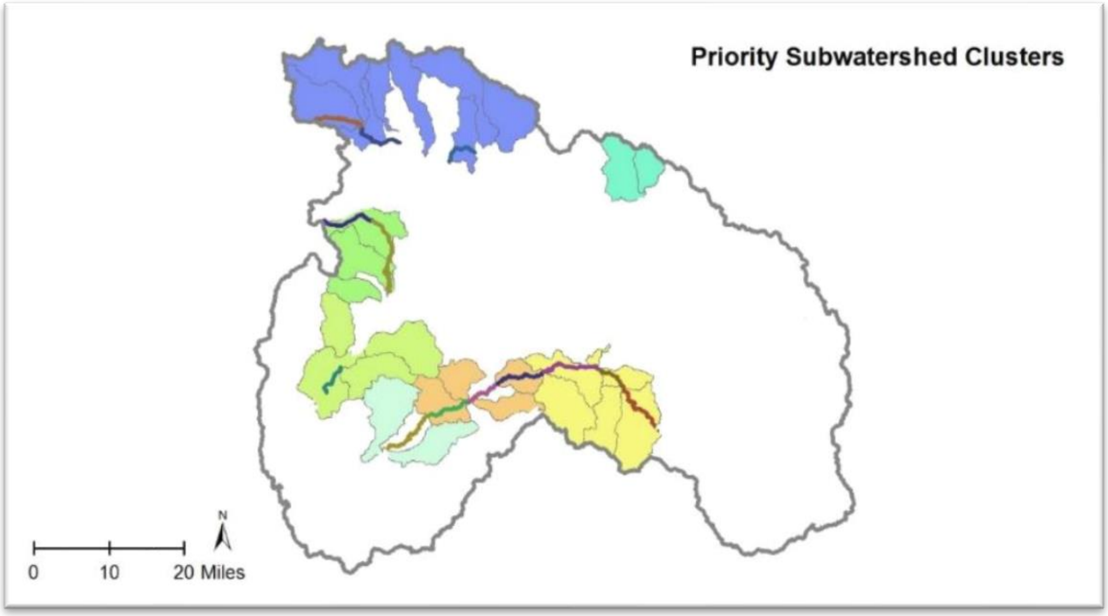


Figure 48. Clusters of resilient subwatersheds with adjacent stream reaches.

Most of the clusters are connected hydrologically, that is they contribute flow to the same stream or river reaches. A few, drain different aspects of high elevation lands, and are isolated hydrologically. The TAC felt that the larger the size of areas with greatest resilience, the more benefit they would provide to fish and other aquatic species. Areas of larger size would likely provide for genetic transfer between populations as well as provide habitat refugia when some portion of the area is disturbed by intense wildfire, debris flows and other natural or anthropogenic disturbance. This probably affords greater potential for sustaining populations than afforded by smaller, isolated areas. Our recommendation is that sub-watershed clusters be considered more important to protection and restoration than the isolated priority subwatersheds. This reasoning also drives setting priorities for reaches.

Sub-watersheds in the highest resilience categories have relatively high connectivity, due to the relative low density of roads and crossings. Therefore, improving connectivity within clusters, and in reaches associated with clusters where there is the highest need may provide the best approach to setting priorities for connectivity.

4.3 Reach Priorities

Setting priorities for protection and restoration of reaches is not as straight forward as the process used to identify priority sub-watersheds. We did not develop a numeric rating or rubric to rate for reach resilience. While such an exercise might have been useful for reaches fed by relatively few sub-watersheds, it would be difficult to apply to reaches further downstream. The general findings of sub-watershed exposure apply to reaches, as well. That is, reaches in high elevation portions of the watershed are likely to be less susceptible to reduced flows and increased water temperatures than reaches in the western, low elevation of the basin and reaches in mid-elevation, large meadow systems.

Following the reasoning outlined above, regarding assigning priority to sub-watersheds due to their membership in a cluster, it follows that reaches that provide connectivity between watersheds in or between those clusters should be deemed as high priority. In addition to providing connectivity for movement, reaches that provide high quality habitat will likely provide support of life stage needs for native fish, including trout. For instance, downstream reaches could provide low gradient rearing habitat for young fish hatched in tributary streams. Providing connectivity objective is not practical in reaches in clusters where dams are located. These include reaches downstream and upstream of Rock Creek Dam on the NF Feather River, and between the sub-watersheds located above and below Lake Almanor, Antelope Reservoir and Little Grass Valley Reservoir. On the basis of proximity to priority sub-watershed clusters, the following reaches (Table 19) are priority.

Sub-Watershed Cluster	High Priority Reaches	Condition*
Upstream of Lake Almanor	Headwaters NF Feather River	Very High
	NF Warner to Almanor	Very Low
	Hamilton Branch	Very Low
NF Feather River Upstream of Rock Creek Dam	Upper Yellow Creek	Low
	Yellow Creek Humbug Valley	Mod High
	Lower Yellow Creek	Very High
	North Fork, Rock Crk Reservoir to East Branch	Not Rated
	Lower East Branch NF FR	Very Low
NF Feather Below Rock Creek Reservoir	NF Rock Crk Reservoir to Cresta	Very Low
	Cresta Reach	Very Low
Middle Fork	MF Frazier Creek Reach	Low
	MF Jackson Reach	Very Low
	MF Poplar Creek Reach	Very High
	MF Washington Creek Reach	Very High
Lower Middle Fork	MF Brush Creek Reach	Very Low
	MF Willow Creek Reach	Very Low
	MF Milsap Bar-Willow Creek	Very Low
	MF Below Milsap Bar	Very Low
Sierra Valley Headwaters	Lower Cold Stream	Mod Low
	Cold Steam in Sierra Valley	Very Low
SF Feather River	SF Below Little Grass Valley Reservoir	Very High
	SF Diversion Dam to Lost Creek	Mod High
Antelope Lake	Indian Creek below Antelope	Very Low
	Cold Stream- Indian Creek	Mod High

*Table 18. Reaches selected as highest priority for protection and restoration (*from composite reach condition rating)*

Because most of the priority reaches are in poor condition basin wide, restoration priorities will most likely focus on improving connectivity between sub-watersheds. This may involve addressing passage at existing barriers but might also involve trying to secure greater volumes of instream flow, to reduce stranding and entrainment.

In reaches located relatively high in their watersheds, opportunities to improve condition of near stream roads and road crossings may be present. Reaches in this category include NF Warner, Red Clover Canyon and Lower Cold Stream.

Improved channel condition, which would reduce water temperature and habitat, could be an objective in the low gradient reaches located in valley landforms. These include Indian Creek in Genesee Valley, and the two upstream Red Clover reaches.

4.4 Other Restoration Priorities

Pathogens

Over the past decade, whirling disease has been found in the basin. This pathogen decimated Rainbow Trout populations in Yellow Creek, and recent studies have detected infected fish in Indian Creek above and below Antelope Lake, Hungry Creek (a tributary to Indian Creek) and Lights Creek. Whirling disease has also been reported in Goodrich Creek. These findings are alarming. Presence of the pathogen raises questions as to the value of investing resources to maintain or improve habitat. Fortunately, whirling disease has been found in only one priority sub-watersheds (Yellow Creek). Also encouraging is that no additional contamination downstream of the Yellow Creek infection has been detected, and that no additional locations of the pathogen were detected by the eDNA sampling.

Given the severity of impacts to Rainbow Trout and apparent increase in distribution of the pathogen, long term sustainability of Rainbow Trout must include consideration of whirling disease. No effective treatments have been developed, though many have been tried in response to substantial impacts to trout populations throughout the Western United States. In several locations, including Yellowstone National Park, the Province of Alberta and the state of Montana, public information programs have been established to inform anglers and other recreationists about the pathogen and the rule of humans in spreading the disease. Research and monitoring in these areas has documented severe declines in trout populations, but also apparent genetic resistance in some portions of the population. We believe that the threat of Whirling Disease is serious enough that action should be taken in the Basin. We recommend that a public-private task group be organized to coordinate monitoring, research and control strategies.

The continued presence of *Ceratomyxa shasta* in the North Fork, Feather River is also of concern. We believe partners (including FRTU) should work with CDF&W to develop a C. shasta resistant brood stock for areas where C. shasta is present and fish stocking is required by FERC or other agreements. To this end, we believe CDF&W should explore a partnership with Feather River College (FRC)to develop *Ceratomyxa shasta* resistant stock. The FRC Fish Hatchery could use NFFR eggs from resistant brood stock to raise fish resistant to *Ceratomyxa shasta* for planting the Belden Section of the NFFR. Currently, PG&E pays CDF&W to raise 10,000lbs./year as required by FERC Hydro license conditions. PG&E acquire fish from anyone that has a stocking permit with CDF&W.

4.5 Actions to Increase Resilience and Improve Habitat Conditions

One objective of the assessment was to provide managers with information necessary to identify priority areas to undertake management actions. A critical next question is what actions should be considered in these areas. The condition of sub-watersheds and reaches in the basin is determined by both inherent and management-related factors. Managers have no control over the inherent factors, so to improve resilience, efforts must be directed at anthropogenic influences such as instream flows, diversions, roads, crossings, rangeland, and vegetation management. The indicators used to describe condition in the assessment provide an organizational framework to consider potential restoration actions.

Roads

Background

Due to the significant impact of roads on aquatic systems and the fact that improvements are practical and proven, road improvements have been identified as a key action to improve condition and resilience of watersheds (Furniss, et al, 2013). In addition to treatments that reduce erosion, road improvements can reduce the delivery of runoff from road segments to channels, prevent diversion of flow during large events, and restore aquatic habitat connectivity by providing for passage of organisms.

An analysis on the Ouachita NF (Furniss, et al, 2013) demonstrated that implementation of road management activities would increase resilience of sub-watersheds where road improvement work was implemented by reducing sediment production and impacts to aquatic organisms. Analysis of road improvements associated with the USFS Legacy Roads Program on the Payette and Umatilla National Forests found reductions in fine sediment delivery, channel connectivity and sites with diversion potential (Nelson, et al 2011, Nelson, et al 2012). Similar road work on the Lassen National Forest designed to reduce road-stream connections and reduce risk of diversion potential in the Battle Creek watershed found reductions in connected road length, road related rills and gullies and sites with diversion potential (BCWC, 2008).

We treated railroads as roads in the assessment. In most locations in the basin, where these routes cross channels, they, like roads, may present barriers to aquatic passage. This is particularly along the railroad's path up the North Fork Feather River, where it is believed all crossings, with the exception of trestles are barriers. These locations present opportunities to improve passage.

Actions

Many of the adverse impacts of roads on fish habitat can be reduced by implementing designs that:

- disconnect the delivery of sediment and flow from road surfaces to channel
- reduce risk of stream diversion
- provide for passage of fish and other aquatic organisms
- treat and drain road surfaces to reduce sediment delivery

Relocation of roads away from channels, or decommissioning unneeded roads are additional, effective, management tools.

Channel Condition (low gradient) and Associated Riparian Communities

Background

The importance of the low gradient reaches to overall basin fisheries productivity, health and distribution is not known. At the very least, these reaches provide for connectivity between sub-watersheds and watersheds in the basin. Apart from connectivity, the low gradient reaches (when in suitable condition) provide habitats not available in steeper, smaller systems. These features include higher proportions of riparian plant species and the allochthonus productivity they provide, deep pools and undercut banks. Low gradient streams that retain floodplain connectivity also provide important habitat for young and juvenile life stages of trout.

The assessment found that most of the longest low-gradient channels in the basin have been altered from historical conditions, resulting in changes in stream geomorphic and hydrologic processes, including stream-downcutting and channel straightening. Historical evidence indicates that prior to approximately 1930, most Sierra Nevada meadows were not incised and had perennial surface flows. Meadow erosion probably started in the late 1800's and continues to the present, but most of the erosion apparently occurred between 1930 and 1960.

Many low gradient reaches in the watershed are the site of infrastructure to provide for agricultural and range management. These include diversions that provide for consumptive water use. In some of these areas, the combination of water diversion and stranding, if not improved, would reduce the effectiveness of restoration efforts intended only to address channel form and riparian condition.

Actions

Efforts to improve channel condition can take either passive or active approaches. Both approaches have proved to be effective in improving channel conditions in the basin when properly designed and implemented. The passive approach is typically directed at revising range management such that factors affecting channel condition, usually vegetation are improved. In the long term under revised management, channel conditions can improve. In some cases, fencing is used to exclude cattle from channel banks and the most sensitive riparian areas.

Active management involves physical intervention to make structural changes to channels to replicate a more desirable channel form. Given that priority reaches provide connectivity between sub-watersheds, restoration designs should include features that maintain or improve conditions for trout passage. It should be noted that the impact of recent pond and plug interventions on trout movement is currently under study but appear to restrict fish movement under some flow conditions.

Flow

Background

Reduced runoff and changes to the timing of runoff raise concerns at both assessment scales. At the reach scale, reduced flow, especially base flow, will further tax systems where water is diverted. At the sub-watershed scale, loss of flow will result in loss of habitat as headwater areas that are not spring fed may be lost. Additionally, lower flows will result in relatively higher water temperatures.

The relationship between forest stand density and water yield is the subject of considerable debate. Podolak, et al (2016) projected that 6% increases in runoff could be realized if about 30% of a watershed were thinned. Troendle (2007) estimated water yield increases of 1-2% at a sub-watershed scale under thinning guidelines and amounts associated with the Herger-Feinstein Forest Act. This estimate is probably closer to what could be expected, given capabilities of Forest Service and private landowners to plan and implement vegetation management projects within time frames where increases could be realized. Some observers doubt any flow increases could be measured following thinning activities. We believe that given the uncertainty over flow responses from thinning and activities implemented to manage for wildfire, actions should be planned where other results (stand condition, fuel loading, etc.) drive these treatments, rather than as an objective for increased flow.

Actions

Reaches: Work with willing landowners to improve efficiency of water use that includes objective of increasing in channel flows.
Pursue water rights for in channel uses.

Sub-watersheds
Implement road disconnection to reduce storm flows and increase base flow

Diversions

Background

No studies on impacts of diversions on entrainment and stranding of trout are known in the basin. There is no reason to believe that impacts would differ from the serious impacts documented elsewhere. Technical advances have improved implementation of practices related to fish ladders, fish screens and irrigation diversions. Only one effective screen is known to exist on a diversion in the basin, though monitoring of fish screens elsewhere has shown them to be very effective, with the general consensus that an effective screen reduces entrainment significantly (Gale, et al 2008); Simpson and Ostrand, 2011). There are opportunities to improve irrigation diversion structures to make them more fish-friendly or enable them to divert only the amount of water actually needed for irrigation. Such projects are generally technically straightforward legally, with obvious benefits to fisheries and water quality. The primary issues are landowner interest and cooperation and funding.

Recently, attention has been given to reducing fish loss by implementing staged flow reductions. Clothier (1954) demonstrated that abrupt flow reductions (as opposed to instantaneous flow termination) at the end of the irrigation season prompted fish to migrate back to host streams. Finnegan (1978) noted the same response to a rapid drop in flow. These studies have prompted several states to promote staged flow reductions for a period of three days prior to canal closure in conjunction with habitat removal. The method is relatively time and labor intensive because head gate manipulation and canal maintenance are required. The procedure may also be impractical in canals that have: 1) drop structures which prohibit movement beyond certain points; 2) head gate velocities that prevent exit back to the host stream; and 3) lateral canals that deter passage to the main canal. To our knowledge, this technique has not been tested in the basin.

Finally, irrigation efficiency improvements, such conversion of conveyance from ditches to pipelines can provide fish-related benefits if water saved by the improvements is left in the channel. Obviously, financial or other incentives would need to be provided to willing landowners to make such improvements worthwhile.

Actions

Work with willing landowners to implement fish friendly diversions.

Work with partners to share available technology with diverters.

Work with partners to fund fish friendly diversions.

Work with willing landowners and or agricultural water diverters to manage timing and ramping of diversions to reduce entrainment of trout.

Pathogens

Background

The impacts of Whirling disease were discussed in earlier and are major. To our knowledge no control measures have been implemented, not only in the basin, but in the state. To date, there are no known treatments for the disease. Given the devastating impact on Rainbow Trout, actions that could lead to control must be considered. Because so little has been done to manage for whirling disease, first steps will by nature be experimental, and may or may not prove effective. It is beyond the scope of this assessment to recommend a treatment strategy. But development of such a strategy is needed.

Ceratomyxa shasta is present in the North Fork, Feather River. Because planting of hatchery fish remains the primary vector of pathogen introduction, providing resistant brood stock for required fish plants is necessary.

Actions

Develop a Whirling Disease control strategy for the basin.

Form a public-private working group.

  Improve information dissemination to anglers and the public

  Is there a need for special regulations in infected waters?

Encourage additional research:

  Better define susceptible habitats

  Study Rainbow Trout resistance (are their resistant strains)

  Better understand transmission of the pathogen (downstream, etc.)

Work with Feather River College and California Department of Fish and Wildlife to develop hatchery stocks resistant to *Ceratomyxa shasta* for planting in North Fork Feather River.

Temperature

Background

Projections indicated increased in stream temperatures throughout the basin. In some areas, temperatures are increased from below optimal to optimal for Rainbow Trout, but the more common change is for temperatures to warm to sub-optimal levels. Apart from geographic influences, stream gradient strongly affects stream temperature. Summer stream temperatures in most low gradient reaches are high, and very few of these streams are well shaded.

This presents an opportunity for restoration. Numerous factors affect temperatures in a reach. Three of the most important are water surface area, flow and shade. To some degree, all three factors could be improved with management activities. Flow is addressed above. Channel improvements that reduced channel width would reduce surface area and should be considered in project design. As with fish passage, pond and plug designs may not be the best approach to improving temperature conditions. Revised range management that would provide for increased woody riparian species, that in turn could provide shade might be the most cost-effective approach to managing for stream temperatures.

Actions

Actions that improve baseflow will contribute to temperature improvements as well.
Manage rangelands to increase shade where potential for woody riparian species exists.
Restore channels to natural dimensions such that stream surface area is reduced.
Implement road disconnection to reduce storm flows and increase base flows

Vegetation and Wildfire

Background

Decades of fire exclusion have impeded the ecological benefits that result from fire in most of the basin. These changes have resulted in vegetation composition, density and fuel accumulations in systems that historically burned with high frequency at low severity.

Climate is a strong driver of wildfires, and its influence on fire regimes varies by forest type and region. Increases in area burned are likely in a warming climate, but fire activity will ultimately be limited by the availability of fuels. Less snow, earlier onset of snowmelt and higher temperatures that reduce fuel moisture will make a larger portion of the landscape flammable for longer periods of time.

Actions

Public and private land managers in the basin have considerable experience in planning and implementing forest management prescriptions aimed at reducing the impacts of wildfire. Monitoring of these activities has shown them to be effective in moderating fire intensities and fire impacts (Murphy, et al, 2010). We recommend that actions shown to be effective, including thinning and broadcast burning be applied strategically in priority areas to reach the objective of returning fire to these forests.

4. 6 Administrative Considerations

Introduction

This assessment provides a basis to guide where to implement restoration activities and emphasize protection of trout habitat. It also provides basic guidance on actions that would be beneficial to maintaining or improving watershed resilience and by extension, trout habitat. Turning this guidance into action is the next challenge. Trout Unlimited, Feather River Chapter looks forward to working with its partners to undertake this work.

Processes for planning, environmental review, funding and implementation vary considerably on public and private lands.

Approach on public lands managed by the US Forest Service

The restoration plan identified geographical areas that are priorities for actions designed to maintain or improve watershed resilience, thereby sustaining fish habitat. On public lands managed by the Forest Service, priorities for restoration can be incorporated into the USFS Watershed Condition Framework (see Figure 49).

Presently, 9 sub-watersheds within the basin located on the Plumas National Forest have been designated as priority watersheds. These are the areas of current and near future emphasis for watershed restoration. These watersheds are listed below. Several (highlighted in bold) are identified as priority in this analysis. These offer the potential for planning and implementing restoration actions in the near term. No Lassen or Tahoe National Forest subwatersheds currently designated as priority are located in the Feather River Watershed.

Plumas National Forest Priority Watersheds

Big Grizzly

Carmen

Frazier

French

Nelson

Tollgate-Spanish Creek

Upper Wolf

Washington

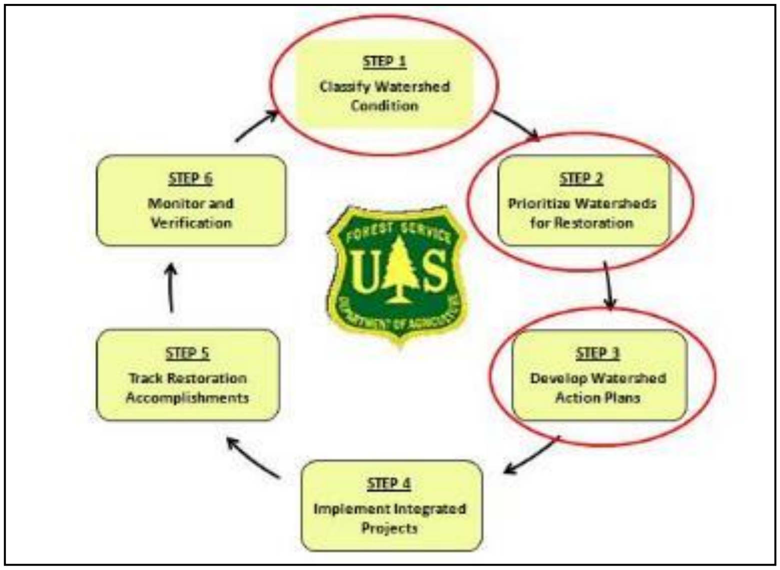


Figure 49. USFS Watershed Condition Framework. Steps 1-3 align directly with the Basin Assessment and plan.

FRTU will support and partner with the three National Forests to plan, fund and implement projects on their lands.

Approach on Private Lands

The Feather River CRM (Coordinated Resource Management) group served as mechanism for private and public partners to coordinate watershed restoration work on both public and private lands. The CRM ceased and to date has not been replaced by a similarly effective group. Several groups have been established to serve the same function, and Trout Unlimited looks forward to exploring the effectiveness of the groups to determine which might provide the best opportunity to facilitate implementation of restoration measures outlined in this plan. Groups that offer promise in this regard are the Feather River Round Table, the Plumas County Integrated Resource Management Planning group, and the Lake Almanor Watershed Group.

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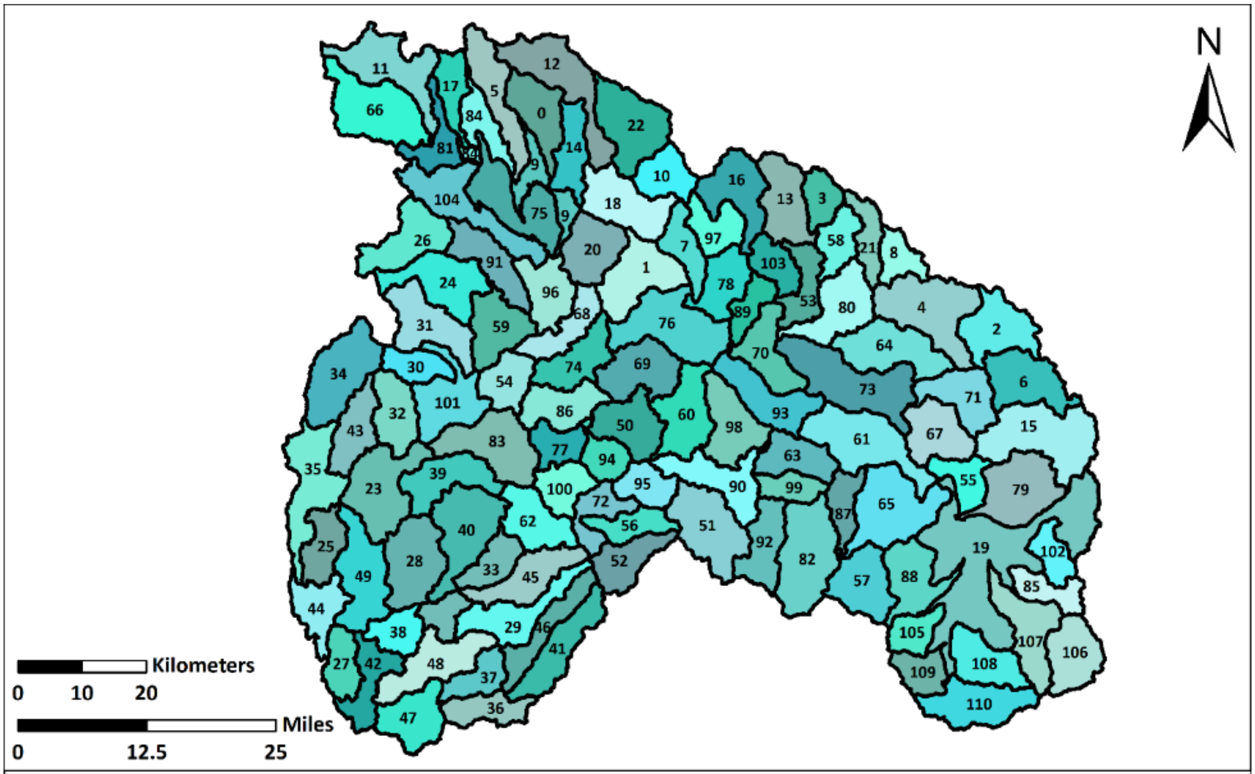
Appendix A: Subwatershed (HUC 12) Map and Listing



DATA SOURCE:
USGS Watershed Boundary Dataset (WBD)
Upper Feather River Basin Subwatersheds
12-digit, sixth-level Hydrologic Unit Code (HUC)
Via NRCS Geospatial Data Gateway
(https://gdg.sc.egov.usda.gov/)

UPPER FEATHER RIVER BASIN-WIDE NATIVE FISH
ASSESSMENT & IMPROVEMENT STRATEGY
Condition Assessment- Analytic Scales
FIGURE XX. Subwatersheds Index Key Map

SCALE: Subwatersheds
CATEGORY: N/A
CONCERN: N/A
INDICATOR: N/A

Figure 46. Feather River Basin subwatersheds. Numbers linked to subwatershed name and HUC on following list

Map ID	HUC12	NAME
0	180201210205	Rock Creek- Hamilton Branch
1	180201220502	Lower Wolf Creek
2	180201220201	Ferris Creek-Last Chance Creek
3	180201220301	Boulder Creek
4	180201220204	Willow Creek-Last Chance Creek
5	180201210402	Bailey Creek
6	180201230101	Lookout Creek-Little Last Chance Creek
7	180201220403	Cooks Creek
8	180201220202	Cottonwood Creek
9	180201210405	Almanor Peninsula-Frontal Lake Almanor
10	180201210201	Mountain Meadows Creek-Frontal Mountain Meadows Reservoir
11	180201210101	Warner Creek
12	180201210203	Robbers Creek
13	180201220303	Lone Rock Creek-Indian Creek
14	180201210206	Dry Creek-Hamilton Branch
15	180201230102	Frenchman Lake-Little Last Chance Creek
16	180201220401	Upper Lights Creek
17	180201210401	Benner Creek
18	180201210204	Mountain Meadows Reservoir
19	180201230310	Sierra Valley Channels
20	180201220501	Upper Wolf Creek
21	180201220203	Clarks Creek
22	180201210202	Goodrich Creek-Frontal Mountain Meadows Reservoir
23	180201210606	Camp Creek-North Fork Feather River
24	180201210501	Upper Yellow Creek
25	180201210703	Concow Creek
26	180201210301	Soldier Creek-Butt Creek
27	180201210804	Potter Ravine-North Fork Feather River
28	180201210801	French Creek
29	180201230704	Fall River
30	180201210601	Chips Creek
31	180201210502	Lower Yellow Creek
32	180201210604	Rock Creek- North Fork Feather River
33	180201230705	Brush Creek-Middle Fork Feather River
34	180201210701	Last Chance Creek-West Branch Feather River
35	180201210704	Little West Fork West Branch Feather River-West Branch Feather River
36	180201230604	Oroleve Creek-South Fork Feather River
37	180201230605	Sucker Run
38	180201210802	Berry Creek
39	180201210605	Grizzly Creek
40	180201230702	Little North Fork of Middle Fork Feather River
41	180201230602	Lost Creek

42	180201230707	East Fork Canyon Creek-Feather River
43	180201210702	Big Kimshew Creek
44	180201210705	Dark Canyon-West Branch Feather River
45	180201230703	South Branch Middle Fork Feather River
46	180201230603	Rock Creek-South Fork Feather River
47	180201230606	Oregon Gulch-South Fork Feather River
48	180201230706	Frey Creek-Middle Fork Feather River
49	180201210803	Chino Creek-North Fork Feather River
50	180201220804	Mill Creek-Spanish Creek
51	180201230503	Nelson Creek
52	180201230601	Little Grass Valley Reservoir-South Fork Feather River
53	180201220305	Cold Stream-Indian Creek
54	180201220903	Mill Creek-East Branch North Fork Feather River
55	180201230308	Mapes Canyon
56	180201230506	Onion Valley Creek
57	180201230403	Sulphur Creek
58	180201220302	Antelope Creek
59	180201210408	Mosquito Creek-North Fork Feather River
60	180201220702	Taylor Creek-Greenhorn Creek
61	180201230401	Big Grizzly Creek
62	180201230701	Willow Creek-Middle Fork Feather River
63	180201230501	Long Valley Creek
64	180201220205	Squaw Queen Creek
65	180201230404	Humbug Creek-Middle Fork Feather River
66	180201210102	Willow Creek-North Fork Feather River
67	180201220102	Upper Red Clover Creek
68	180201220901	Rush Creek
69	180201220805	Tollgate Creek-Spanish Creek
70	180201220603	Ward Creek-Indian Creek
71	180201220101	Dixie Creek
72	180201230508	Dogwood Creek-Middle Fork Feather River
73	180201220103	Lower Red Clover Creek
74	180201220902	Soda Creek-East Branch North Fork Feather River
75	180201210406	Lake Almanor
76	180201220604	Hough Creek-Indian Creek
77	180201220801	Meadow Valley Creek
78	180201220404	Lower Lights Creek
79	180201230309	North Channel Little Last Chance Creek
80	180201220206	Poison Creek-Last Chance Creek
81	180201210103	Louse Creek-North Fork Feather River
82	180201230406	Frazier Creek-Middle Fork Feather River
83	180201210602	Bucks Creek
84	180201210403	Mud Creek-Frontal Lake Almanor

85	180201230306	Town of Loyalton
86	180201220803	Silver Creek-Spanish Creek
87	180201230402	Willow Creek
88	180201230307	Carman Creek
89	180201220601	Hosselkus Creek
90	180201230504	Poplar Creek-Middle Fork Feather River
91	180201210302	Butt Valley Reservoir-Butt Creek
92	180201230405	Jamison Creek
93	180201220602	Little Grizzly Creek
94	180201220802	Rock Creek- Spanish Creek
95	180201230505	Washington Creek-Middle Fork Feather River
96	180201210407	Clear Creek-North Fork Feather River
97	180201220402	Middle Lights Creek
98	180201220701	Estray Creek-Greenhorn Creek
99	180201230502	Jackson Creek-Middle Fork Feather River
100	180201230507	Bear Creek
101	180201210603	Milk Ranch Creek-North Fork Feather River
102	180201230305	Correco Canyon
103	180201220304	Hungry Creek
104	180201210404	Marian Creek-Frontal Lake Almanor
105	180201230304	Turner Creek
106	180201230201	Badenaugh Canyon-Smithneck Creek
107	180201230202	Bear Valley Creek-Smithneck Creek
108	180201230303	Lemon Canyon-Perry Creek
109	180201230302	Hamlin Creek
110	180201230301	Bonta Creek-Cold Stream

Appendix B: Stream Reach Map and Index

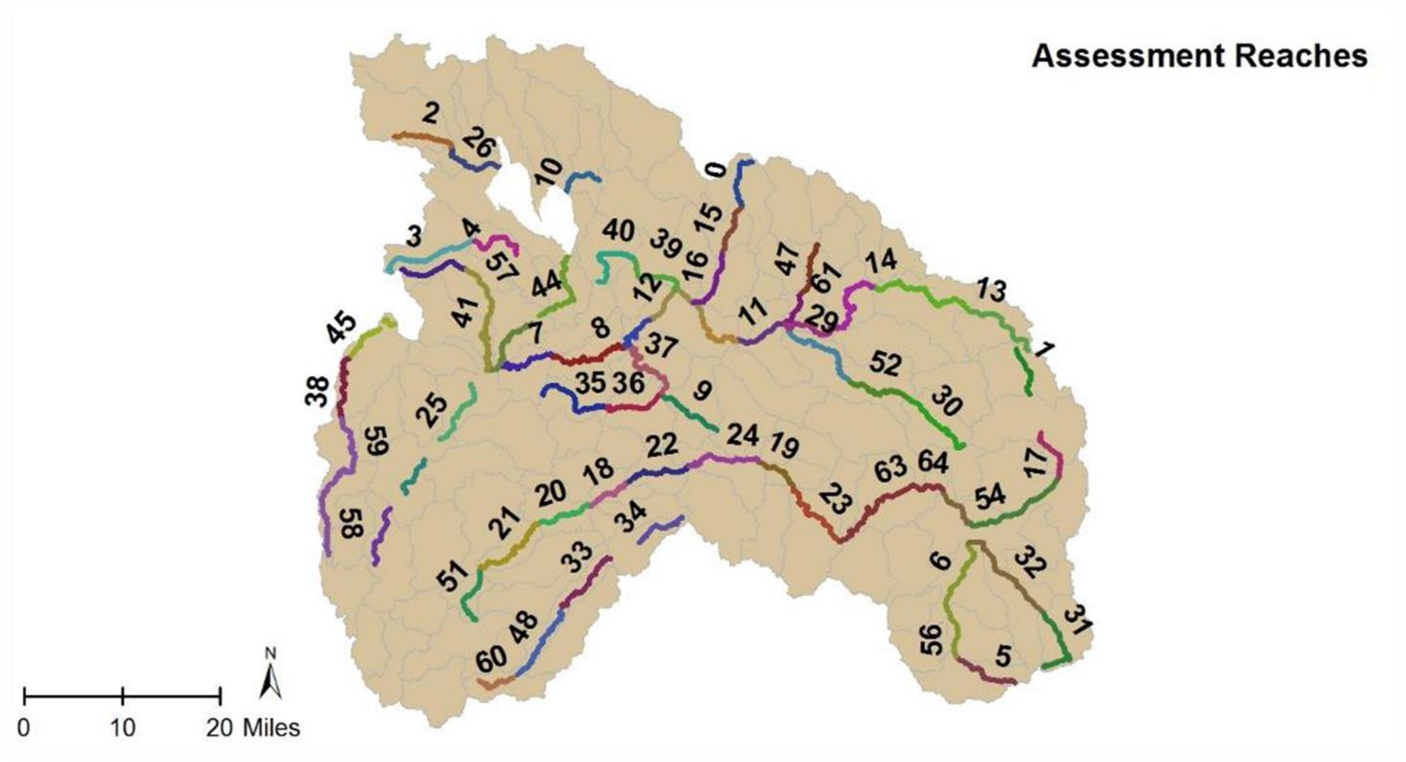


Figure 47. Assessment defined Stream Reaches. Numbers linked to reach names on following list

FID	Reach Name
0	Upper Lights Creek
1	Upper Little Last Chance Creek
2	Headwaters North Fork Feather River
3	Headwaters Butt Creek
4	Middle Butt Creek
5	Headwaters Cold Stream
6	Cold Stream in Sierra Valley
7	Lower East Branch North Fork Feather River
8	Upper East Branch North Fork Feather River
9	Lower Greenhorn Creek
10	Hamilton Branch
11	Indian Creek- Genesee Valley
12	Indian Creek- Indian Valley
13	Headwaters Last Chance Creek
14	Last Chance Creek-Within Willow Creek
15	Middle Lights Creek
16	Lower Lights Creek
17	Little Last Chance Below Frenchman Lake
18	Middle Fork- Dogwood Creek Reach
19	Middle Fork- Jackson Creek Reach
20	Middle Fork- Willow Creek Reach
21	Middle Fork- Milsap Bar to Willow Creek
22	Middle Fork- Washington Creek Reach
23	Middle Fork- Frazier Creek Reach
24	Middle Fork- Poplar Creek Reach
25	North Fork- Rock Creek Res. to Cresta Res.
26	North Fork- Warner Creek to Almanor
27	North Fork- Belden Forebay to Yellow Creek
28	North Fork- Cresta Reach
29	Red Clover Canyon
30	Headwaters Red Clover Creek
31	Headwaters Smithneck Creek- Badenaugh Canyon
32	Lower Smithneck Creek- Bear Valley
33	South Fork- Below Little Grass Valley Reservoir
34	Headwaters South Fork Feather River
35	Headwaters Spanish Creek
36	Middle Spanish Creek
37	Lower Spanish Creek
38	West Branch- Philbrook Creek to Last Chance Creek
39	Lower Wolf Creek
40	Upper Wolf Creek
41	Lower Yellow Creek
42	Headwaters Yellow Creek
43	North Fork- Poe Reach
44	North Fork- Almanor to Belden Forebay
45	Headwaters West Branch Feather River

46	Indian Creek- Last Chance to Hungry
47	Indian Creek- Antelope to Hungry Creek
48	South Fork- South Fork Diversion to Forbestown Dam
49	Lower Indian Canyon
50	Indian Creek- Indian Valley to Genesee
51	Middle Fork Feather River Below Milsap Bar
52	Lower Red Clover Valley
53	Last Chance Creek-Canyon Reach
54	Little Last Chance Creek in Sierra Valley
55	Headwaters Middle Fork Feather River
56	Lower Cold Stream
57	Yellow Creek- Humbug Valley
58	Lower West Branch
59	West Branch Feather River- Last Chance to Kimshew
60	South Fork- Forbestown Dam to Ponderosa Reservoir
61	Last Chance Creek-Poison Creek Reach
62	Middle Fork- Clio Reach
63	Middle Fork- Portola Reach
64	Middle Fork- Sierra Valley to Big Grizzly

Appendix C: Local Angler Interview Questionaire and Example Interview Summary

Angler Interview Questionnaire

1. How long have you been angling in the Feather River Basin?
2. Which areas of the Basin are you most familiar with?
3. Can you describe, generally, trends in the quality of the fisheries in the areas with which you are familiar, over time?
4. What species were present in the past? Has that changed in more recent years?
5. Do you remember a time in which stocking of fish began, occurred or ceased? What species were stocked? What effect did that have on the quality of the fishery?
6. What natural changes (wildfire, etc.) occurred to the landscape over time, if any? Did they seem to effect any change in the fishery?
7. What natural changes occurred on the river (flood scour, deposit, changes in vegetation, etc.) over time, if any?
8. What changes in management (grazing, tree harvest, tree thinning, prescribed burns, etc.) were made to the landscape over time, if any? Did they seem to effect any change in the fishery?
9. What changes in management were made for the river (reservoir construction, stream flow changes, etc.) over time, if any?
10. Are there specific areas or drainages in the Basin that you strongly feel should targeted for conservation or restoration?
11. Who else should I speak with about the areas with which you are familiar?
12. Who else should I speak with about other areas of the Basin?

ANGLER INTERVIEW SUMMARY

Date: May 4th, 2016

Angler: Tom Rahn, Indian Valley
5797 North Valley Road
Greenville, CA 95947

Interview Highlights:

Bellas Creek:

- Population of wild, probably native, rainbows (potentially redbands) persist in a short perennial segment of the creek.

Nye Creek:

- Populations of wild, probably native, rainbow trout are present.

Fant Creek:

- Populations of wild, probably native, rainbow are present.

Red Clover Creek:

- Populations of wild, probably native, rainbows plentiful in the Box Canyon area during the '50s and '60s persist today, but not in as great numbers or size.
- Brown trout were also present in the past, and also persist today, but likewise, in lesser numbers and smaller size. The upper reaches of Red Clover Valley were a particularly good brown trout fishery although good numbers and size could be found throughout.

Lights Creek:

- Stocked extensively with rainbows throughout the main stem.
- Native rainbows present in the headwaters.
- No recollection of ever catching brown trout.

North Fork Feather River (below Almanor):

- A tremendous fishery for large rainbow trout prior to the increased transfer of water from Lake Almanor to Butt Valley Reservoir.

Upper Hungry Creek (tributary to Indian Creek):

- Native rainbows in the headwaters.
- Possibly brook trout that drifted downstream from Taylor (Kettle Rock) Lake.

Long Valley Creek

- Similar to Hungry Creek, native rainbows in the head waters.

Boulder Creek (tributary to Antelope Lake):

- Native rainbows throughout, pure genetics upstream.

Soda Creek

- Historic stocking efforts included planting (Snake River fine-spotted) cutthroat trout, sustaining population rumored to exist.

Rush Creek

- Native rainbow trout persist in the headwaters.

Chips Creek

- Rainbows and browns in the headwaters ca. 1950s-1960s.

Chambers Creek

- Rainbows and browns in the headwaters ca. 1950s-1960s.

Appendix D: Fire Risk

Background

The current condition class of vegetation were assessed. In order to achieve complete coverage of the Basin the USFS Fire Return Interval Departure dataset (Safford, et al, 2014) was mosaiced with the CalFire FireThreat dataset (CDF-FRAP) and then the number of square miles of the most at-risk vegetation class was aggregated for each subwatershed.

Results

Current condition classes indicated that most subwatersheds in the basin were in high risk classes relative to vegetative condition. Our working threshold for poor condition was 50% of vegetation in high risk class. Applying this standard, all but 13 subwatersheds (see Figure C1) were rated in poor condition, so we deemed fire risk class a poor discriminator. As a result, this attribute was not used to inform recommendations on geographic priorities.

Reintroduction of fire into the basin's forests is a key ecosystem need. Based on our findings, this is true almost everywhere in the basin. We have included our limited evaluation in Appendix E. We hope this information may be valuable when looking at restoration needs in specific subwatersheds.

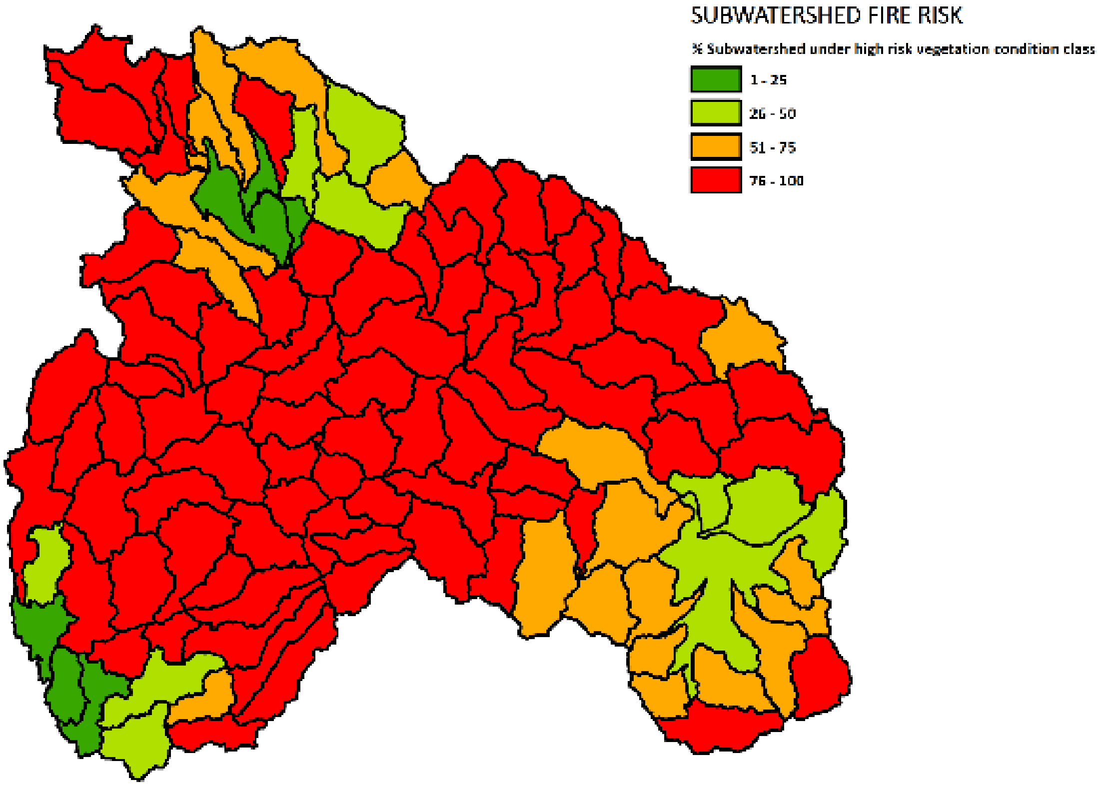


Figure 48. Percent area in high risk vegetation class, by subwatershed.

Data sets used in the analysis:

CalFire FireThreat Dataset

Title: fthrt05_1

Originators: CDF-FRAP

Publication date: 20040101

Edition: 05_1

Data type: raster digital data

Data location: http://frap.cdf.ca.gov/data/frapgisdata/select.aspx

USFS FRID Dataset

Safford, H.D., K. van de Water, and C. Clark. 2013. California Fire Return Interval Departure (FRID) map, 2012 version. USDA Forest Service, Pacific Southwest Region, Sacramento and Vallejo, CA. URL: http://www.fs.usda.gov/main/r5/landmanagement/gis

Appendix E: Comparison of Indicators with Stream Condition Data

To determine which watershed indicators would be most useful in describing condition of stream habitat, we compared them with existing channel condition information from the basin. We also assessed which of two widths (10m, 30m) would be the better to use as the near stream road width. Stream Condition Inventory (SCI) (USFS 2012) data collected over the past 20 years was available for 52 streams. All stream reaches were on public lands managed by the US Forest Service. SCI is a fairly intensive monitoring protocol used by the US Forest Service in the Pacific Southwest Region. It was designed to collect data on channel metrics shown by research to be affected by management, at an intensity that provides for statistical comparison of results over time, or between streams. Indicators of channel morphology including cross sections, bank angle, channel stability, gradient and pool depths are measured, as are indicators of channel substrate (particle counts and pool tail surface fines). SCI also includes protocols for collection of benthic macroinvertebrates as well as for channel shade and large, instream wood.

Some attributes measured by the protocol, such as residual pool depth, are strongly influenced by natural factors such as basin size. These attributes were not considered in the analysis. Attributes that were examined for all channel types were: bank full channel width to depth ratio, pool tail surface fines, percentage of particle count <2mm, percent shade and channel stability. Bank angle data from streams with gradients of 1% or less were also analyzed.

Macroinvertebrate data was available from 21 of the streams. “Observed over Expected” ratios (O/E) (Ode, et al (2008)) were correlated with the watershed condition indicators, as was a macroinvertebrate index developed for interpretation of HFQLG monitoring data (Mayes and Roby, 2013). O/E is a measure of the taxonomic completeness of the biological community observed at a site that compares the number of observed taxa (O), with the number of taxa expected to be collected (E). The taxa expected to be collected are based on collections from reference sites comparable to the monitoring site in terms of attributes such as elevation, basin size, annual precipitation and geology.

Road density (km road/km^2 watershed area), road density within the two stream buffers (km road/km^2 stream side area) and road crossings (crossings/km^2 watershed area and crossings/km channel length) were the disturbance indicators evaluated.

The percent of watershed area burned in 2000-2009 and 2010-2014, as well as the % of streamside areas (buffered to 30m) burned over these time periods were also used as indicators in the assessment, but not correlated with stream monitoring data. Previous stream monitoring results burned areas showed elevated surface fines and water temperatures following wildfire (Roby and Mayes, 2013).

Findings

We expected weak correlations between the watershed indicators and channel attributes for a number of reasons. First, the indicators were calculated for the entire watershed. The monitoring reaches rarely, if ever were located at the downstream extent of the watershed, so “large” watershed conditions were correlated with reaches influenced by only that portion of the watershed above the reach. Second, the SCI data was collected over a period of 15 years, the watershed indicators were derived from data sets that might or might not accurately reflect conditions at the time of stream sampling. Given these weaknesses, our hope was to see weak correlations reflecting the expected ecological result, such as increasing surface fines with increasing road density.

The results essentially followed this pattern. Weak “positive” correlations were found for most attributes. The clear exception were correlations with shade and the watershed indicators. Shade is arguably the instream attribute with the strongest link to on-site (vs contributing watershed) conditions, so this result could be expected. Correlation values are presented in tables D1 and D2.

Correlations between SCI attributes and near stream roads within 30m of channels was slightly stronger than the correlation with roads within 10m of channels, so the 30m buffer width was employed in the analysis. We suspect this is due to a greater number of roads in the 30m buffered area than within the 10m buffer.

The correlations between the stream attributes and the watershed indicators are sufficient in our opinion to support their use in rating relative condition of sub-watersheds in the basin. In other words, the correlations support use of the watershed parameters as indicators of fish habitat condition

A typical correlation is displayed in Figure D1, three of the strongest correlations are displayed in Figures D2-4.

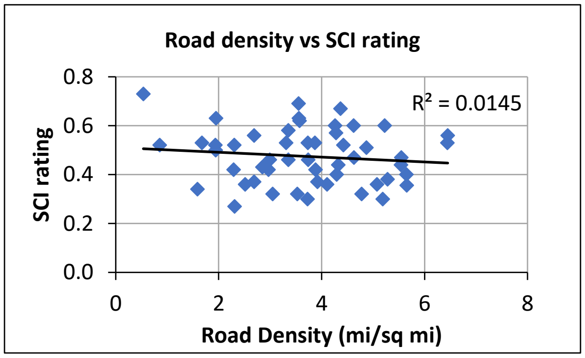


Figure D1 Relationship between Road Density and a rating from composited SCI attributes.

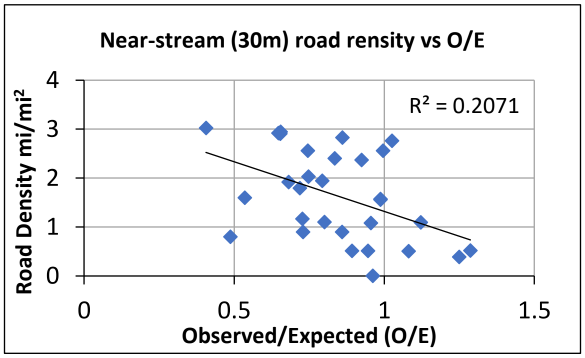


Figure D2 Relationship between Near Stream (30m) road density and O/E (observed taxa/expected taxa).

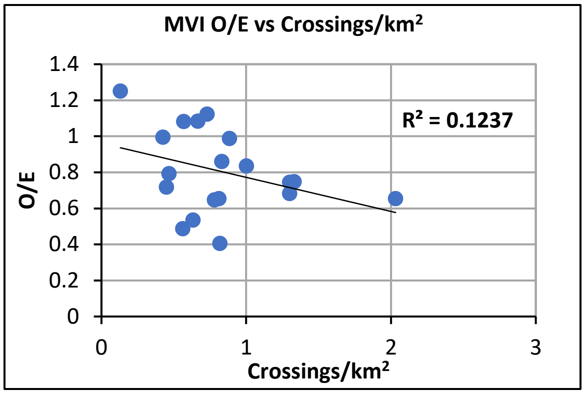


Figure D3 Relationship between Crossings per Square Kilometer and O/E (observed taxa/expected taxa)

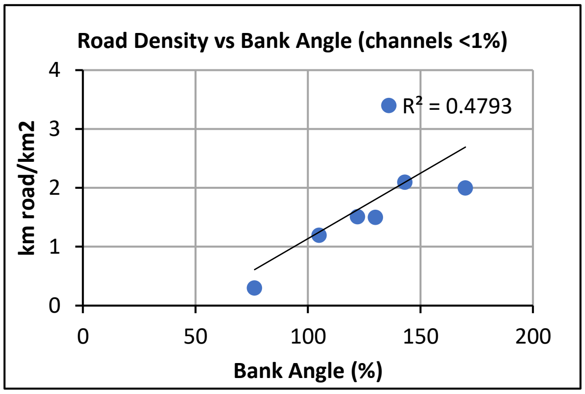


Figure D4 Relationship between average bank angle and road density, for streams with channel gradients of 1% or less

Stream Type	Watershed Indicator	W/D	particle count <2mm	stable banks	%fines	shade	O/E
All Streams	Road Density	0.22	0.14	-0.117	0.016	0.23	-0.15
	Near Stream RD (30m)	0.10	0.16	-0.02	0.016	0.123	-0.22
	Nr Stream RD (10m)	0.08	0.3	0.08	0.13	0.06	-0.04
Streams < 1.5% gradient	Road Density	0.34	0.1		0.03	0.3	-0.32
	Near Stream RD (30m)	0.17	0.14		0.075	0.21	-0.45
	Nr Stream RD (10m)	0.03	0.23		0.239	0.08	-0.35
1.5 to 2.5% channels	Road Density	0.44	0.98		0.48	-0.02	-0.15
	Near Stream RD (30m)	0.21	0.97		0.72	-0.89	-0.21
	Nr Stream RD (10m)	0.13	0.78		0.76	-0.43	-0.26

Table D1 Correlations between sub watershed road and near stream road density and SCI attributes from reaches within that watershed. Correlations in orange are inverse.

Stream Type	WD Ratio		% particle count <2m		stable banks		% surface fines		shade (%)		0/E	
	Crossings/KM	Crossings/KM^2	Crossings/KM	Crossings/KM^2	Crossings/KM	Crossings/KM^2	Crossings/KM	Crossings/KM^2	Crossings/KM	Crossings/KM^2	Crossings/KM	Crossings/KM^2
All	0.16	0.05	0.01	0.12	-0.05	-0.02	0.18	0.18	0.079	0.16	-0.02	-0.14
<1.5%	0.06	0.18	0.05	0.15	-0.34	-0.20	0.30	0.30	0.099	0.11	-0.35	-0.30
1.5-2.5%	0.77	0.28	-0.29	0.16	-0.10	-0.07	0.31	0.31	0.64	-0.09	-0.30	-0.01
>1.5%					-0.14	0.11	0.09	0.07	0.153	0.30	-0.18	-0.05
>2.5%	0.27	0.04	-0.10	-0.12			0.11	0.14	0.045	0.37	-0.21	-0.07

Table D2 Correlations between road crossings per km and road crossings km2 by sub-watershed and SCI attributes from reaches within that watershed. Correlations in orange are inverse.

Appendix E: Soil Erosion Hazard

The relative impact of management activities and wildfire on erosion and sediment production is influenced by soil erosion potential. Erosion rates are naturally higher, and rates of sediment production on disturbed lands generally higher on soils that are inherently less stable. Accordingly, an indicator to establish baseline soil stability was included to better inform the relative impact of indicators, such as road densities, across the landscape. Soils within the basin are diverse.

Major soil groupings by location are:

- adjacent to Lake Almanor, along the Plumas Trough to Mohawk Valley,
- granitic soils along the North Fork of the Feather River and the upper portion of Plumas County,
- the Middle Fork and the South Fork of the Feather River
- soils in the eastern part of the County
- granitic soils of the Frenchman area.
- Sierra Valley, a block-faulted part of the Sierra Nevada at the head of the Middle Fork of the Feather River

Methods

For the assessment, soil stability was assessed using Erosion Hazard Ratings (EHRs) derived from the Soil Data Viewer ArcMap extension produced by NRCS Soils (US NRCS).

The EHR used in the assessment are based on two factors 1) K factor (soil erodibility) and 2) slope.

To rate the relative soil stability throughout the Basin, each reporting unit was evaluated for the proportion under a "Very Severe" EHR. A Very Severe EHR "indicates that significant erosion is expected, loss of soil productivity and off-site damage are likely, and erosion-control measures are costly and generally impractical."

Results

The percentage of sub-watersheds with soils classified as Very Severe EHR (VSEHR) ranged from 0-63% (Figure 51). 10 (of 111) sub-watersheds had less than 10% of their area in the VSEHR. Most of these sub-watersheds were in the Cascades (or Cascades-Modoc) geologic province, upstream of Lake Almanor. Soils in these areas are of volcanic origin. Sub-Watersheds in Red Clover Creek and Squaw Queen Creek also had low percentages of VSEHR.

Areas with a high potential for erosion as indicated by higher percentages of VSEHR coincide with locations located at higher elevations in the basin. Most of these areas have soils derived from granitic parent materials.

Application

When we combined condition indicators to rate sub-watersheds, we could not decide how to apply the soil sensitivity information. Should subwatersheds rank high if they had high percentages of erosive soils, and could then be considered more sensitive? Of should they rank high if they had a low percentage of erosive soils, and could then be considered more resilient? Ultimately, we could not develop a rationale, and did not include soils in either ratings of condition or exposure.

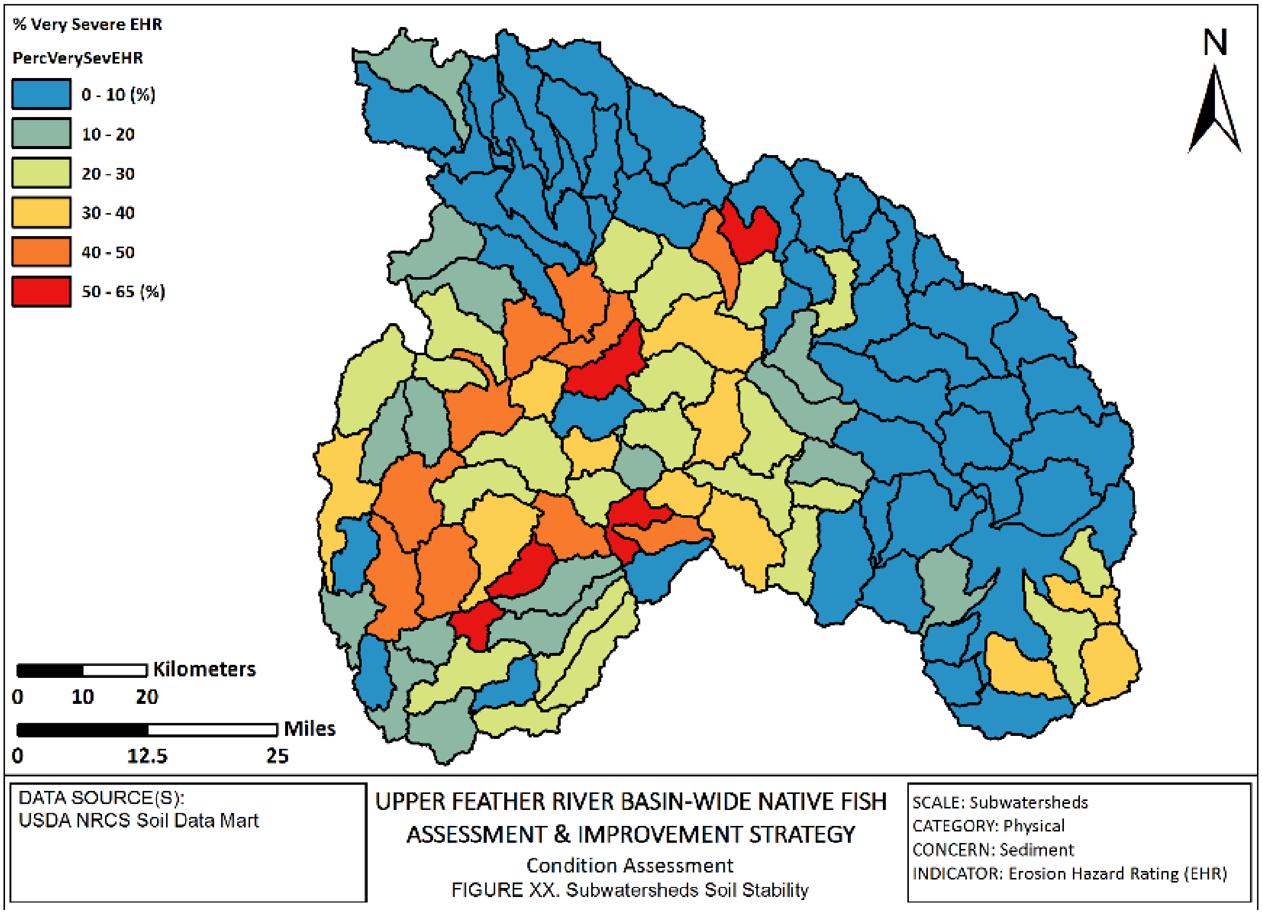


Figure 49. Soils with extreme Erosion Hazard Rating, by percentage of subwatershed