NORTH COAST RESOURCE PARTNERSHIP

Trinity County Forest Ecology and Watershed Hydrology

ASSESSMENT TO IMPROVE LATE SPRING/SUMMER STREAM FLOWS, REDUCE FIRE INTENSITY AND FIRE RELATED CARBON EMISSIONS IN THE TRINITY RIVER WATERSHED

Northwest California Resource Conservation & Development Council's
Five Counties Salmonid Conservation Program (5C)

31 March 2017

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SUMMARY

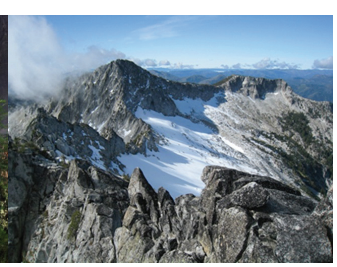
This assessment examines watershed level GIS fire history, forest stand data, aerial photography, topography, elevation, climatic patterns, and stand management factors of the Trinity River Watershed within Trinity County to develop recommendations to improve late spring/summer stream flows, reduce fire intensity and fire related carbon emissions. Strategic forest stand thinning can reduce sublimation, open canopies to extend the length of the spring/summer snowmelt and modify forest fuels to reduce fire intensity without triggering adverse watershed effects due to past fire activity.

Declining snow packs, unreliable precipitation patterns, and climatic changes over the past 50+ years have impacted water reliability for communities and habitat for endangered species. Additionally, the explosive growth of wildfire since 1987 has caused concerns and opportunities for forest management that must be considered in any effort to influence water yield. Between 2006 and 2015, wildfires burned 468,467 acres subsequently changing conifer forest stand composition.

Based on selective criteria a total of 118,278 acres which have not burned in the past decade and which are outside of Wilderness areas or Sierra Pacific Industries ownership were identified as conceptually suitable for thinning to meet water yield, fire reduction and carbon storage objectives. A 10,715 acre subset of these stands was then selected to estimate the water yield changes from a hypothetical thinning.

Under two sets of assumptions on water yields this subsample area would yield an additional 1,086 to 3,019 acre feet of runoff from thinning 2,280 acres. Expanding that analysis to all 118,278 acres of potentially treatable lands would result in a theoretical maximum increase of approximately 18,000 acre feet to 36,000 acre feet while increasing snow water equivalent and snow melt in late spring and summer.

Assuming a simplistic linear relationship between carbon release estimated in a series of forest fires in 2015 in stands structurally similar to stand assessed here, suggests that thinning 2,280 acres would retain approximately 15 tonnes of stored CO2e per acre (12,500 tonnes total) that could otherwise be released when fire burns through the stands.



Weaver Bally and Monument Peak Mountain Range's snow pack provides the community of Weaverville with its water supply

1. INTRODUCTION

This paper examines forest management (including wildland fire) changes that could affect summer water yields within Trinity County. It is the third in a series of papers prepared for the North Coast Resource Partnership (NCRP) that looks at water management within the Trinity River watershed. This paper is the outgrowth of significant climatic and cultural shifts that have disrupted traditional water systems, laws, politics and thinking. The first two assessed water demand and impacts on beneficial uses under assumed and actual development scenarios. In both cases the studies indicated that beneficial uses of water in some watersheds could be impacted in summer months as a result of nearly any growth in water demand.

This assessment is the outgrowth of discussions emanating from various interest groups (County government, Trinity Collaborative, and others) that have expressed desires to assess the potential to "tap" water in the soil mantle to either increase flows in the basin to benefit humans and fisheries or to allow greater export from Trinity Reservoir to the Central Valley Water Project (CVP).

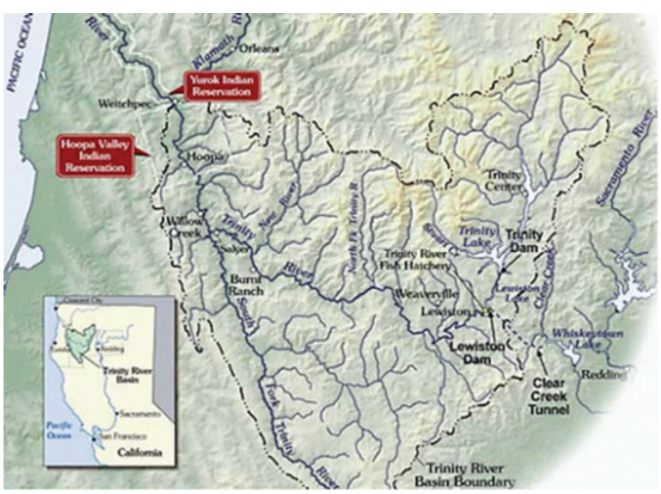
Within Trinity County there is typically an abundance of water for people, fisheries, and other needs for approximately nine months of the year (November-July) and shortages between August and October. Ironically, Trinity County's most valuable economic commodity is water exports which benefit the state as whole far more than the County residents. The lack of water in summer is a significant constraint on economic growth, community water security, firefighting resources and environmental impacts. Residents often lack adequate water in summer when streams dry up pitting human needs against other beneficial uses of those waters, especially endangered fisheries.

As weather patterns have shifted, winter temperatures have risen and snow packs have declined (Mote 2003). The effects of less summer flows has resulted in calls for policy shifts as well as stepped up enforcement of illegal water diversions by state agencies. The declining snow packs and increasing rate of wildfire also suggest that any efforts to address water yield must consider fire and climate adaptation strategies for the long term.

One of the best understood and effective ways to increase summer water yield is to increase the snow pack depth by reducing interception rates of snow fall in vegetation (referred to as sublimation
). All actions must be considered in the context of wildland fire, which has become the dominant forest management activity of the past four decades (Refer to Figure 10) and this in turn must be considered in relation to climatic change.

There are exhaustive numbers of studies published that can be referenced to assist in estimating effects on water yields from forest management and even to anticipate effects of climate variation. Not surprisingly there are also disagreements in these studies regarding the amount or effect of forest stand management on water yields.

2. OVERVIEW OF THE TRINITY RIVER WATERSHED



The Trinity River is one of the most economically and environmentally valuable river systems in California. The 2,853 mi^2 (1.83 million acre) watershed encompasses five rivers (Main Stem, Stuarts Fork, North Fork, New River and South Fork). Downstream of the South Fork numerous large streams drain the west side of the Trinity Alps or the east side of the Coast Range (e.g. Willow, Supply, Horse Linto, Tish Tang a Tang, Pine, and Mill Creeks).

Figure 1. The east side of the Mount Eddy Mountain Range showing spring snow pack

Approximately 89% of the Trinity River watershed lies within Trinity County (1.63 million acres) and 43% of that area is above 4000' elevation, high enough in elevation to receive and store snow in the winter.

The Main Stem Trinity River begins on 9,026' Mt Eddy (Figure 1), while the North Fork and Stuart's Fork originate on 9,002' Thompson Peak (Figure 2.2). The New River begins on 6,956' Salmon Mountain and North Yolla Bolly Peak (7,868') defines the headwaters of the South Fork Trinity River (Figure 2). All of these streams coalesce to flow into the Klamath River at Weitchpec, Humboldt County (elevation of ~200').

The Trinity River watershed is so large that one driving on Interstate 5 would first notice it in Red Bluff when looking west at the Yolla Bolly Mountains. The interstate then parallels the watershed until reaching Mt Shasta City, where Mt. Eddy marks its northern extent. The watershed is renowned for tall peaks, lush forests, cold, clear waters, and cascading streams and rivers.

The mountain ranges that define the Trinity River watershed are steep, uplifted, ancient coastal mountains pushed east and are compressed, sheared and folded. These mountains rise to slightly over 5000 feet in elevation and are covered with conifer and hardwood forests and are referred to as the "Green Trinities".

Into these mountains an arc of younger granitic bedrock pushed upward several thousand feet through the

Green Trinities forming the taller and much more sparsely forested "White Trinities" and Mt Eddy.

While the White Trinities can be snowcapped, their glaciers and snow fields have gradually retreated, leaving only one permanent snow field on the north side of Thompson's Peak (Figure2). Even with the loss of glaciers and permanent snowfields, annual snow melt remains a critical source of water. But the reliability of snow melt has begun to falter over the past 50 years as climatic changes have reduced the snowpack by 30% (Mote, 2003).

Figure 2. At 9002' tall Thompson Peak and permanent snow field defines the "White Trinities"

Figure 3. North Yolla Bolly Mountain (7,868' elevation)

Prior to the filling of Trinity and Lewiston Reservoirs in 1964, much of the summer flow in the river system came from snow melt and gradual seep flow from springs and the soil mantle. Snow melt recharged streams were reliable enough that on one community (Hayfork) relied on any water storage reservoirs to meet community needs.

Above 4000 elevation snow accumulates and spring and early summer melt recharges streams and the soil column. The soil recharge plays a vital role in extending stream flow well into summer. This is critical in a watershed where only 6% of annual precipitation occurs between June and October in an average year.

The South Fork Trinity River watershed represents 34% of the Trinity River watershed but less than one percent of the watershed is above ~6,000' elevation (Figure3). Approximately 30% of the South Fork watershed is above ~4,000' elevation. The smaller percent watershed above 4,000' elevation contributes to the lower summer base flows and higher summer water temperatures compared to the rivers that flow into the Main Stem.

The other rivers that form parts of Trinity County (Mad, Van Duzen and Eel) have even less snowmelt benefits, lower summer base flows and higher water temperatures. Management for snow melt in these watersheds would be of limited value, but the same analysis used here could be translated to those watersheds.

2.1. TRINITY RIVER — A STATE WIDE RESOURCE

Since 1964 storage of snow melt water from the portions of the Alps and the Eddy Mountains upstream of Trinity and Lewiston Reservoirs has been an important source of economic wealth in the State of California. The Trinity River diversion is a central component of the federal Central Valley Project, a multi-billion dollar series of dams, tunnels, hydro-electric turbines and irrigation canals that shift water from the Trinity River as far south as Fresno.

Approximately 50% percent of the runoff from the Trinity Alps and Eddy Mountains (upstream of Lewiston) is diverted into the Sacramento River to annually generate hundreds of millions of dollars of hydroelectric power, irrigation (~approximately 800,000 acres of semi-arid farmland), and water for towns and cities reliant on the California Water Project and the federal Central Valley Project (CVP). At the same time Trinity Dam operations and water diversions impacts local economics, disrupts traditional Tribal cultural practices and contributes to other social concerns. For these reasons residents and Tribes in the watershed are vigilant regarding the management of the Trinity River flows. There is a strong interest within the watershed to look at management options that can restore flow in the river while improving local economic conditions.

3. WATER POLICY PLANNING EFFORTS

3.1. DOWNSTREAM OF LEWISTON DAM

In 2009 Peréz and Lancaster prepared a report on water supply that examined three levels of development and impacts on beneficial uses of water downstream of Lewiston Reservoir (within Trinity County). That study suggested that some watersheds were already failing to meet beneficial uses of water and other watersheds were at risk of degraded water supply and loss of habitat from new development. The study made recommendations to the Trinity County Board of Supervisors to consider amending existing land use policy to avoid or lessen impacts of future development. While no changes to land use polices occurred over the next five years a massive influx of marijuana farming and stream diversion did occur.

In 2014 and Peréz and Lancaster again looked at the watersheds studied in 2009 in light of the rapid growth of marijuana farming and determined that the potential effects discussed in the 2009 report were likely occurring. During that same period a significant drought with almost no snow pack highlighted some of the water problems. That paper noted rapid increases in ground water drilling, increase in water exports from community service districts, local declarations of drought emergency, reports of illegal water pumping and thefts of stored water, fish kills associated with water diversions, and other changes indicating issues around water reliability.

The 2014 report again recommended that new county water policies be developed. In 2015 the Trinity County Board of Supervisors and Planning Commission began holding public hearings on changes in policies within the Zoning and Subdivision Ordinances to protect beneficial uses of water. In July 2016, the Trinity County Grand Jury published findings that supported the findings of the 2014 study. On August 8th and September 8th 2016 the Trinity County Planning Commission forwarded recommendations to the Board of Supervisors new stream setback policies, expansion of proof of water requirements and water conservation measures to be applied for new building activity.

3.2. STATE WATER POLICY UPSTREAM OF LEWISTON DAM

Approximately 50% of the Trinity River flow at Lewiston is diverted to the Sacramento River. This water then becomes a part of the Sacramento River and essentially creates two significantly different set of water polices in the Trinity River watershed. The Lewiston Dam forms a barrier to salmon migration and state and federal regulations to protect Threatened coho salmon which apply to lands downstream of the dam do not apply upstream of the dam. The Trinity River above Lewiston and two other river systems- the Sacramento above Keswick Dam and the Feather River above Oroville Dam- provide 80 percent of California's reservoir water storage capacity and are referred to as the "*Source watersheds*". These reservoirs supply drinking water for over 25 million people, irrigate 8 million acres of farmland and account for over 80 percent of the freshwater for the San Francisco Bay. With California's population projected to reach ~50 million by 2050 the demand for this water will significantly increase. This increased demand in a warmer and drier state dramatically highlights the states desire to assure that the upper Trinity River will remain a reliable primary water supply source to the Sacramento River.

In September 2016 the Governor signed into law AB 2480 (Bloom) declaring "*It is hereby declared to be the established policy of the state that source watersheds are recognized and defined as integral components of California's water infrastructure. As climate change advances, source watersheds that provide the majority of the state's drinking and irrigated agricultural water are of particular importance to maintaining the reliability, quantity, timing, and quality of California's environmental, drinking, and agricultural water supply.*[1]

The bill makes maintenance and repair of source watersheds eligible for the same forms of financing as other water collection and treatment infrastructure and would specify that the maintenance and repair activities that are eligible are limited to specified forest ecosystem restoration and conservation activities. Other projects with a demonstrated likelihood of increasing conditions for water and snow attraction, retention, and release under changing climate conditions are also eligible.

In presenting the need for AB 2480 the author noted: "*Without these source watersheds, our dams cannot provide the water we rely on. The northern California region in which they are found is projected to remain far cooler and wetter than the rest of the state under climate change. As a result, our dependence on these source watersheds is likely to increase. Just like dams, levees, and canals, natural watershed infrastructure needs repair and maintenance. Now is the time to make a focused investment to ensure its restoration and protection, building climate resilience and enhancing our water security.*"

Under AB 2480 a number of forest ecosystem restoration and conservation activities would be eligible for funding including:

1 http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2480

(1) Upland vegetation management to restore the watershed's productivity and resiliency.

(2) Wet and dry meadow restoration.

(3) Road removal and repair.

(4) Stream channel restoration.

(5) Conservation of private forests to preserve watershed integrity through permanent prevention of land use conversion and improved land management, achieved through, and secured with, conservation easements.

(6) Other projects with a demonstrated likelihood of increasing conditions for water and snow attraction, retention, and release under changing climate conditions.

While AB2480 may have beneficial effects for the Trinity River watershed its focus is not protecting and maintaining the watershed to enhance the Trinity River or communities, but rather to protect and improve water delivery to the Central Valley Project water uses.

An effort to direct management of the Trinity River for the benefit of the Central Valley Project was also introduced on the federal side in 2015 bill in the House of Representatives. Under House Amendment 210 (LaMalfa) to H.R. 2028 there was a proposed ban on releasing water into the Trinity River from Lewiston to cool the downstream Klamath River to protect salmon holding in pools in the river in August and September of 2015. These fish wait in pools for the higher rainfalls of October and November to allow them to move upstream. Cold water releases from Lewiston and Trinity River Reservoirs have been used in dry years to save federally and state Threatended coho salmon as well as Chinook salmon and steelhead trout.

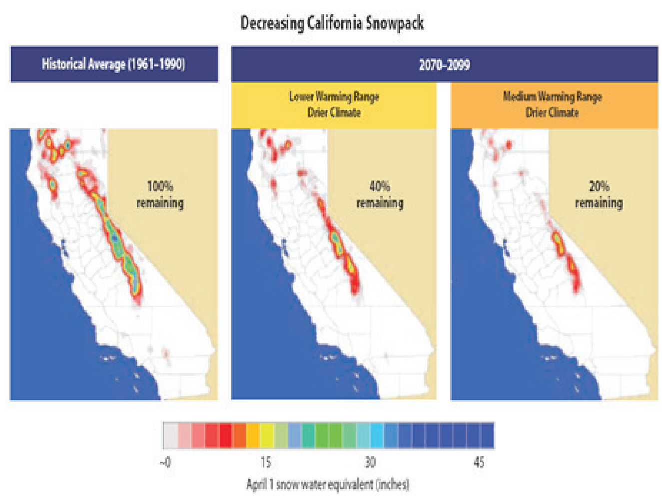
Both bills underscore the Trinity River's vital role in the operations of all California water needs, whether it is providing farmers irrigation water, hydro-electric power generation or meeting Delta water quality objectives. One thing that is very clear is that legislative efforts have not been directed at maintaining or improving water supply, reliability or ecological values downstream of Lewiston Dam.

4. PRECIPITATION/WATER YIELD

4.1. PRECIPITATION PATTERNS

The Trinity River watershed has a Mediterranean climate characterized by wet cool winters and warm dry summers and actual precipitation patterns are the result of oceanic and atmospheric climatic features influenced by local topographic features (Trinity Alps, Pacific Ocean, Trinity Reservoir, etc.). In Between 1950 and 2000 winter snow (or snow water equivalent (SWE)) storage throughout the Pacific Northwest and northwestern California declined 30% (Mote, 2003a) and a gradual increase in winter temperatures both globally and within California (Groisman et al, 2001; Lund et al, 2001) reduces snow accumulation and results in earlier snow melt (Figure 4).

Figure 4: Presentation to forest landowner's workshop — June 15th, 2011 Susie Kocher

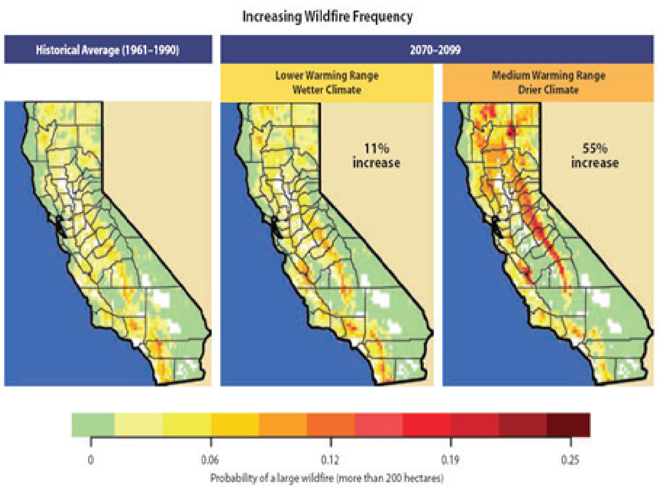


Peréz and Lancaster documented significant changes in precipitation patterns in their 2009 and 2014 reports showing annual precipitation patterns have become more erratic over the past 41 years- compared to the prior 80 year record. Between 1974 and 2016 there has been a 500% increase in the number of extreme wet and extreme dry years[2] compared to the period 1935-1974. Since 1974 there have been 12 extreme precipitation years compared to 7 for the prior 80 year period (1985-1973).

2 Extremely wet or dry in *this* report is defined as more, or less than, 1.5 Standard Deviation from the mean for the Weaverville Ranger Station annual precipitation totals. This translates into years where more than 52.9" precipitation falls or less than 21.2" of annual precipitation falls. The mean annual precipitation is 37.0" for the 121 year record. While annual precipitation extremes have increased over time so has Weaverville's mean annual precipitation. The mean average precipitation shifted from 36.3" per year based on records from 1895 to 1955, to 37.8" per year between 1936 and 2015. The average for the whole 120 year period is 37.0" but the 5% increase in precipitation has been more than offset by the 30% decrease in SWE.

This erratic trend contributes to summer water insecurity, fisheries declines, increased fire intensity and size, severe flooding, and social disruption in communities. The extreme weather patterns have had economic impacts with local, state and federal declared disasters in extreme precipitation years. In the past 30 years, fire, flood and drought costs have exceeded $700 million dollars in direct costs. Some studies suggest that the true costs can be 5-20 times higher than that amount for forest fire impacts.

Figure 5: Presentation to forest landowner's workshop — June 15th, 2011 Susie Kocher



5. TRINITY RIVER SNOW WATER STORAGE POTENTIAL

Approximately 43% of the Trinity River watershed within Trinity County (696,319 acres) is above 4000' elevation (Table 1 and Figure 15). The area above 4000' is the critical elevation band for extended snow melt and resulting summer base flows for streams.

Forest Ecologist James Agee in his 2007 book "Stewards Fork" succinctly discussed the influence and timing of snow runoff from the higher elevation portions of the Trinity Alps: "*Coffee Creek has 40 percent of its base area above 6,000 feet elevation. Snow and snowmelt would be expected to be more important in the hydrology of the Coffee Creek drainage than they are in the upper Trinity. Stewart and LaMarche noted that in 1960, the upper Trinity River peak storm flows occurred during a storm in February, whereas Coffee Creek's peak stream flow in June during snowmelt exceeded its peak during the February storm.*"

Table 1. Summary of All Lands Capable of Extended Snow Accumulation within the Trinity River Watershed[3]

Total Acres above `4000' Elevation	
Outside Designated Wilderness	378,690
Chanchelulla Wilderness	7,300
Trinity Alps Wilderness	302,420
Yolla Bolly-Middle Eel Wilderness	7,908
Grand Total	*696,319*
Total Acres above ~4000' Elevation by Watershed	
South Fork Trinity	193,759
Trinity	502,559
Grand Total	*696,318*

Snow depth is influenced by numerous factors including elevation, aspect, climatic conditions, geology, and forest canopy cover. A unique feature of higher elevation areas are "U" shaped valleys formed by glaciers. These valleys form lakes, ponds and wet meadows that capture snow melt and act as sponges, slowly percolating water into the ground (Figure 6 & 7). The stored water acts as a water bank and extends runoff into spring/summer.

5.1. CANOPY INFLUENCE ON SNOW WATER STORAGE POTENTIAL

Forest canopy is the one constantly changing factor that can be readily and reliably managed. Forest canopies intercept snow fall allowing it to sublimate before it can slide off of the needles or melt. Conifer forests, with their evergreen canopies, have greater effects on snowfall interception than hardwood forest canopies, which drop leaves before snow arrives.

The extent of canopy closure has a significant influence on snow water storage. Stands with canopies open enough to allow snow to reach the ground but closed enough to reduce understory brush development are best suited to maximize snow water equivalent (SWE) storage potential (Strock and Lettenmaier, 2002; Varhola, et al, 2010, Lundquist, et al. 2013).

Stands with ~40-60%[4] canopy closure appear to be optimal to allow snow to fall through to the ground) while partially shading the ground. Partially open canopy levels appear to both shade snow during sunny winter days while allowing warmer air to escape the tree canopy. Studies in the Mediterranean climate of this region suggest that as temperatures rise in February and March, dense closed tree canopies trap and store

3 Acreage is based on GIS analysis from Baldwin, Blomstrom, Wilkinson and Associates as part of this assessment. Minor rounding errors or watershed boundary factors may result in insignificant differences in totals.

4 Studies of the relation between canopy conditions and snow depth cite the lack of detailed analysis of elevation, aspect, annual climatic conditions (winds, precipitation, temperature and other factors) which limit researchers ability to determine optimal stand conditions for maximizing snow retention and delay melt out period (Varhola, et al. 2010).

heat that offset daytime shade benefits (Dobre, et al 2012, Hagberg, et al, 2012). The rise of average winter temperatures in the region in the past 50 years appears to be driving an increase in early winter snowmelt (Mote, 2003, Dobre, et al 2012, Hagberg, et al, 2012). Opening the stand too much (~<30% crown closure) can trigger dense brush growth (Figure 9) which acts similarly to closed forest canopy, trapping snow in the tops of the brush where sublimation removes it before it can form a snow pack on the ground.

Figures 6 and 7. Snow melt runoff from the Coffee Creek watershed at 5000' forms a pond until late May or early June (left). In July the pond has drained leaving a wet meadow, which by August has dried out completely (right).

5.2. FIRE INFLUENCE ON SNOW WATER STORAGE POTENTIAL

Decades of fire suppression has contributed to dense forest stands with interlaced canopies and woody debris accumulations in the understory (Figure 8) that create an explosive fire mix. The addition of fire starts (typically lightning[5]) have contributed to the mega fire conditions that have defined the Trinity River watershed over the past three decades (Table 2 and Figure 10-12). The size of fires, combined with greater burn severity (30%-60% area with moderate to high burn severity (Lydersena, et al 2014)) has outpaced many planning assumptions about fire, water yield and stand management. Fire exclusion has also allowed trees to invade high elevation wet meadows, potentially reducing their water storage benefits.[6]

While the need to consider stand thinning for water yield and fuels reduction is critical, mega fires of the past few decades may create adverse cumulative impacts that can constrain management options[1].

Figures 8 and 9: A dense mature, even-aged stand at 5300 feet elevation along the Packers Creek Trail in the Coffee Creek watershed (left) and an open forest canopy at 6,500' along the same trail and watershed (right). The overstocked stand has both a closed crown and significant fuel loads on the forest floor while the very open canopy at the higher elevation has a dense shrub layer. Both stands allow for high snow sublimation losses.

5 For example, Romps et al. (2014), estimates that lightning frequency will increase about 12 percent for every 1° Celsius (1.8° Fahrenheit) in warming. Within the Trinity River watershed lightning sparked fires burn the most acreage. Computer models of climate forecast that by the end of this century, average air temperatures at Earth's surface will rise by 4 °C.

6 Spring and summer wet meadow soil conditions deprives seedling root systems of oxygen and limits successional regrowth, thereby maintaining open meadows. As the snow pack diminishes and meadows dry up earlier in the season, seedlings mortality is reduced and meadows acreage decreases.

Table 2. Total Acres Burned since 1987	
Outside Designated Wilderness	351,142
Chanchelulla Wilderness	3,872
Trinity Alps Wilderness	216,132
Yolla Bolly-Middle Eel Wilderness	6,341
Acres Reburned Since 1987	108,920
Grand Total	**686,408**

Figure 10. Acres Burned by Decade in Trinity River Watershed in Trinity County.

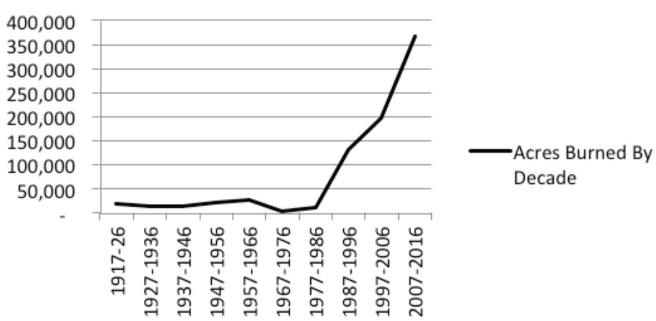


Figure 11: The 2013 Corral Fire (foreground) and 1999 Meagram Fire (background) form a mosaic including conversion of mature conifers to brush as well as canopy thinning (Photo:Thomas Dunklin).

Figure 12: Stand conversion from dense conifer pole stand to grass as a result of the 2015 Johnson Fire.

Fire has not burned evenly within the Trinity River watershed. While 28% of the watershed (466,476 acres) has burned since 2006, nearly all of it (459,790 acres) has been in the western two-thirds of the watershed (Figure 13). Approximately 63% of the western 2/3 of the watershed (~676,184.98 acres) has burned since 1987, including 108,920 acres that has reburned in that time period (Figure 14). In contrast, less than 1% of the northeastern third of the watershed has burned since 2006 and less than 2% has burned since 1987. Within the eastern third of the watershed, logging has accounted for approximately 90% of stand changes (~120,000 acres), with fire, insect disease mortality and wind throw accounting for the remaining 10% of stand structural changes.

Figure 13. 30 Year Fire History of the Trinity River Watershed 1987-2016

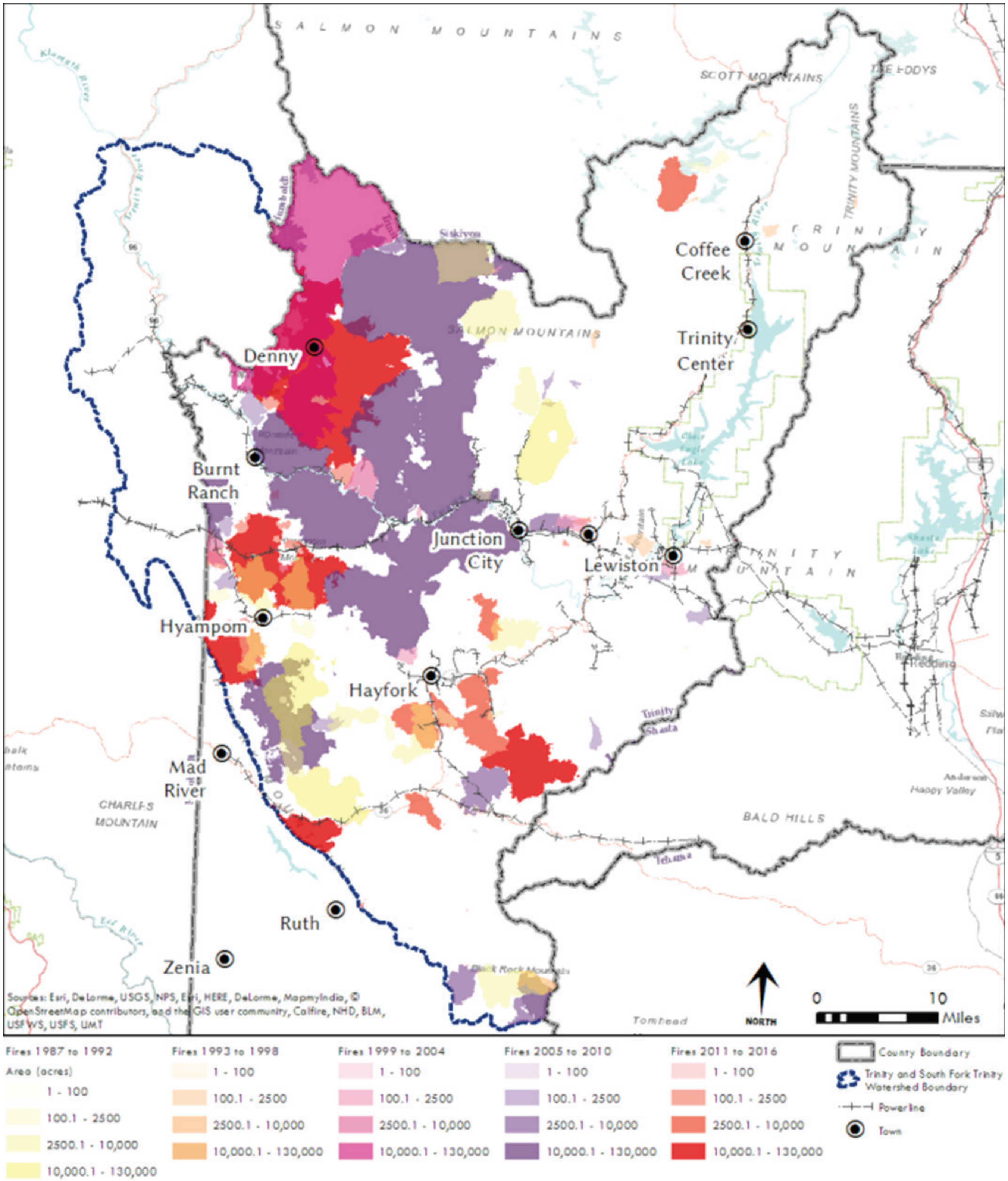


Figure 14. Areas that have burned more than once between 1987-2016

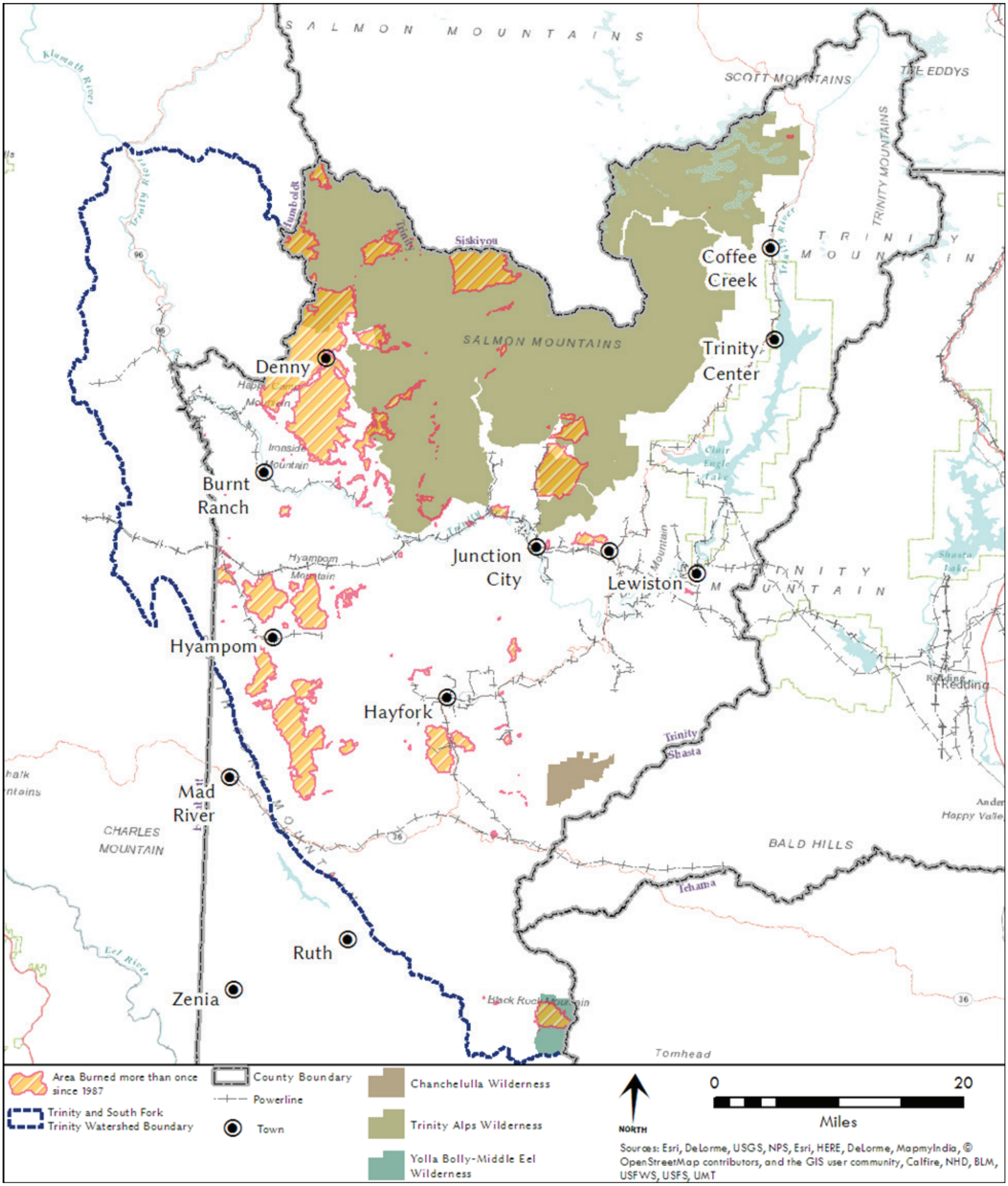
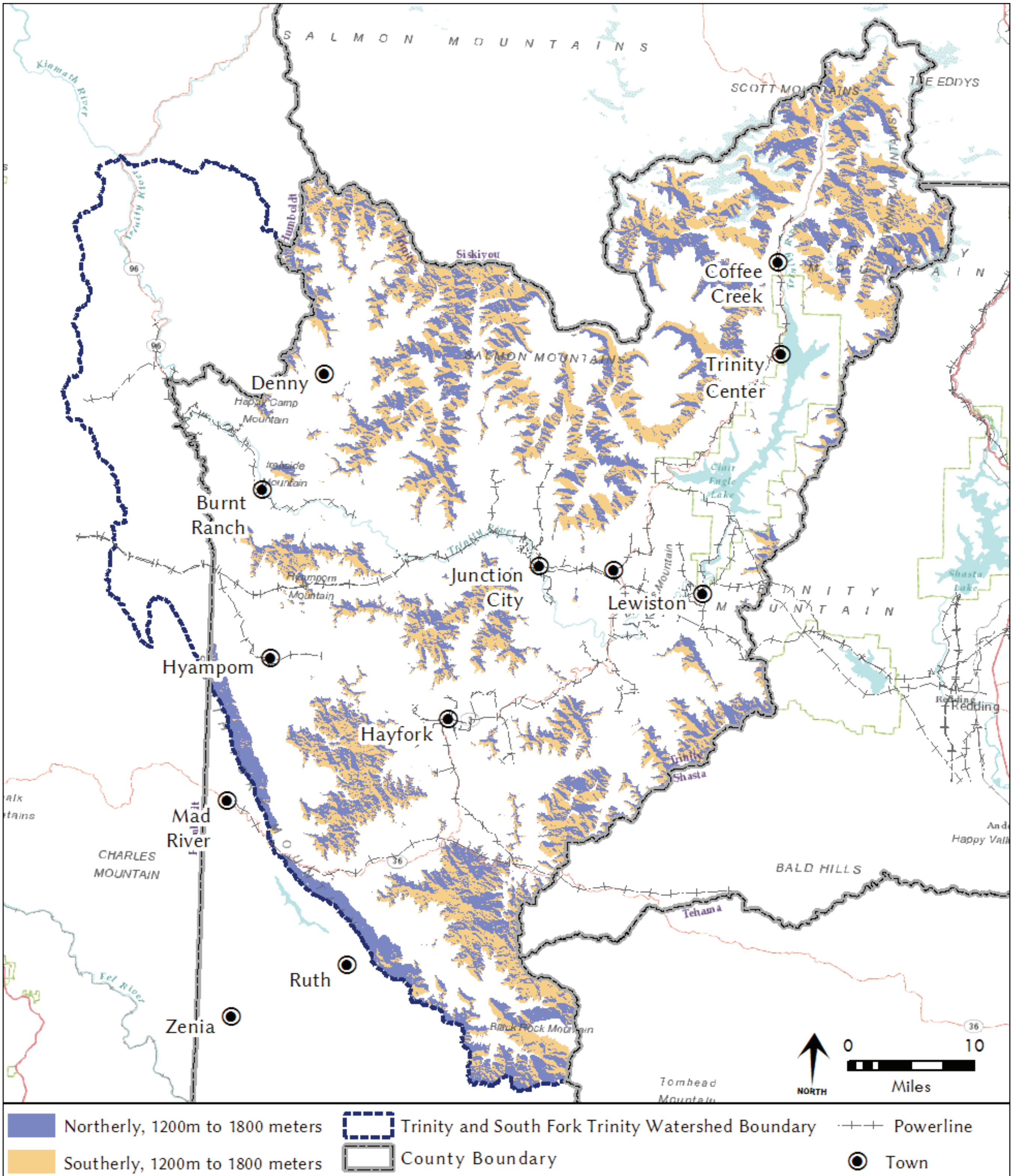


Figure 15. All Areas Of The Trinity River Watershed In Trinity County Between ~4000' and 6000' Elevation By Aspect.



Sources: Esri, DeLorme, USGS, NPS, Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community, Calfire, NHD, BLM, USFWS, USFS, UMT

6. SELECTION CRITERIA FOR STANDS

Elevation, aspect, and forest cover explains about 80–90% of the variability in snow accumulation at a watershed scale (Jost, et al.,2007; Anderson et al., 2004; Pomeroy et al., 1998). To assure efficient use of funds, the following criteria were used for selection of stands that could be treated to increase SWE, snow melt extension and potentially reduce fire behavior under moderate fire danger conditions.

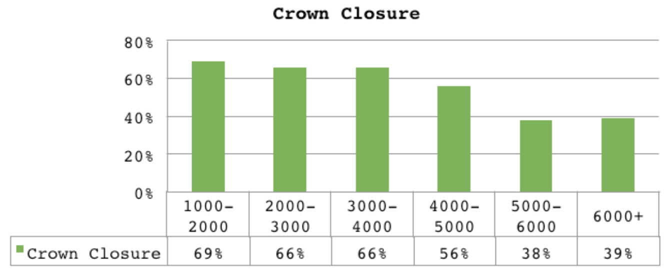
6.1. ELEVATION

The 4000' elevation band is the lowest elevation where snow accumulation extends into spring[7], but because it is well below the snow monitoring stations (Big Flat is the lowest at 5100') there is limited data on SWE yields. However, stands below ~4000' elevation are known to have a risk of "rain on snow" events that can exacerbate downstream flooding (Surfleet and Tollos, 2013). Intentionally increasing the snow pack at these elevations is not as beneficial with some increased risk of flooding. While rain on snow can occur at higher elevations it is much rarer.

To determine the optimal upper elevation band in the Trinity River we looked at research that indicates that stands with ~40%-60% crown closure will have the greatest SWE benefits[8]. Forest Inventory and Analysis (FIA) forest canopy closure measurements taken between 2001 and 2009 were examined to find the elevation where canopy closure naturally declines. The 2001 to 2009 data set also captured large stand changes that resulted from mega fires (1987, 1999, 2006 and 2008)[9].

The stand data showed a significant decline of crown closure above 5000' elevation (Table 3). Given the variability of canopy closure by aspect (denser on northerly aspects) the upper elevation for treatment was established as 6000', slightly above the significant change in crown closure found in the FIA data. Approximately ~11% of the watershed in the County (154,000 acres) is above 6000' elevation and receives greater snow fall, but snow depth at the highest elevations often is not as deep as lower slopes due to exposure, wind, gravity (slough), avalanches, and other factors (Grünewald, et al., 2014). Forest stands above 6000' elevation are generally within Wilderness areas and are already sufficiently open to allow for snow to reach the ground.

Table 3. Percent Crown Closure By Elevation Band for Trinity River Watershed for FIA Plots Measured Between 2001-2009 (BBWA, 2017)



6.2. ASPECT

Elevation plays the most important role in snowmelt, but aspect and forest cover are only slightly less influential (Jost, et al. 2007). A 1960 study of snow accumulation and melt out (USFS, 1979) found that northern aspect plots had higher SWE levels for the same sample period compared to plots on southern aspects. It also found snow melted out 4-5 weeks later on northern slopes compared to snow on southerly facing plots. The influence of aspect on snow pack melt out is obvious to anyone that has climbed up a snow free south facing slope but crossed over to the north side to encounter a deep snow pack.

Stand management for fire behavior is also expected to be more beneficial on northerly aspect stands than on south slope stands. Examination of the 2006 Big Bar complex of fires in the watershed showed that forest stands on northerly facing slopes have lower burn severity compared to stands on southerly slopes in the same fire (Alexander, et al. 2006).

Slightly less than half of the area between 4000' and 6000' elevation in the Trinity River watershed in Trinity County (267,534 acres) has northwest to northeast aspects (Table 4). These reaches provide the greatest opportunity to both increase SWE and extend snow melt out utilizing thinning of forest crowns (Table 4) and influence fire behavior.

Table 4. Total Acres ~4000' Elevation - ~6000' Elevation With Northerly Aspect By Watershed

South Fork Trinity Watershed Total	**99,697**
Outside Designated Wilderness	95,059
Chanchelulla Wilderness	2,214
Yolla Bolly-Middle Eel Wilderness	2,423
Trinity Watershed Total	**167,837**
Outside Designated Wilderness	78,707
Chanchelulla Wilderness	1,108
Trinity Alps Wilderness	88,021
Grand Total	**267,534**

7 4000' elevation was selected as the baseline elevation based on published snow yield research in the region (e.g. Storck et al., 2002)

8 Hagberg, et al (2012) found that the medium canopy density (30-60%) strikes the best balance between initial snowfall accumulations and its ability to retain SWE over time.

9 ~ 516,000 acres (or 65% of all acres burned since 1911) burned between 1987-2009.

6.3. FOREST CANOPY

There is substantial research linking snow related water yield with forest stand density and thinning. Changes in sublimation rates by thinning forest stands are among the most effective ways land managers can increase snow depth on the ground.[2] Increasing snow through fall by 33% could increase snow water equivalent amounts by 10%-20% compared to untreated stands (Reid and Lewis, 2004, Storck et al, 2002, Troendle, et al,1980). Thinning can also reduce the melting effects of warm air trapped under dense forest canopies. Snow melt out in February/March can be greater for snow packs under heavily shaded stands than in open areas or under partially shaded stands. The closed canopy traps warm air longer into the night, and in Mediterranean climates, can hasten snowmelt.

While there are numerous studies on the changes in water yield from thinning, there is less certainty on the optimal level of thinning for SWE benefit. This is due partly to the difficulty that researchers have controlling many of the variables that affect snow accumulation and melt rates (e.g. temperature, precipitation, wind, animal damage within plots etc.). Most studies did not have adequate equipment to measure these variables to a precision that would allow for harmonizing data. Because of these and other factors, it is difficult for researchers to develop a single optimal canopy closure level for maximum snow benefit. Instead, authors suggest a range of canopy closure of ~30% to 60%. In many stands a 30% closure is not sufficient to prevent brush development. For that reason we recommend that stands not be thinned below 40% crown closure for maximum water yield into spring/summer. Studies also suggest that stands over 70% crown closure have high rates of sublimation and possible early snow melt due to heat trapped under the canopy.

In selecting an optimal crown closure range for spring/summer snow melt, a review of fire behavior modeling and canopy closure can also be considered. Fire modeling[10] of 96 plots from ~3,200 acres in the Weaver Creek watershed found that a fire in August after a "moderate" fuels reduction thinning would have flame lengths similar to untreated stands for the first 5 years following treatment[11], but that flames lengths 15 years later would be 40% lower than the untreated stands. Only 8.8% stand mortality would occur for the moderate fuels treatment compared to 31.2% mortality for the untreated stand condition. More significantly is the effects in specific stand types such as dense Douglas-fir stands would have 18.7% mortality in the treated stand, while untreated the stands would be expected to be completely killed (BBWA, 2004).

6.4. LAND OWNERSHIP

Snow water/ fuels management thinning objectives, costs, and options, are significantly different depending on land ownership. There are four types of ownership of the 267,534 acres lying between 4000' and 6000' elevation and on northerly aspects (Figure 16).

National Forest Wilderness areas are limited to natural processes such as allowing lower intensity fires to burn and, potentially, allowing prescribed fire to be used to reduce understory and midstory fuels. Wilderness lands, which cannot be actively managed, are not considered further in this assessment. However, the water yield and reduced risks of catastrophic fire benefits of prescribed burns or frequent natural low intensity fires are recognized as being as valuable as stand management options on other lands. Likewise Sierra Pacific Industries (SPI) lands, which are actively managed to maximize timber production, already meet or exceed the thinning standards proposed in this assessment. For that reason, they are not further analyzed.

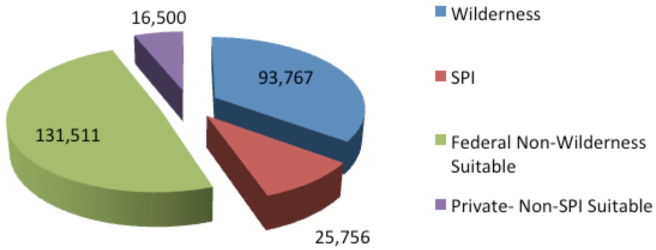
The active management option proposed in this assessment would target the 148,011 acres of National Forest lands and private, non-SPI, ownerships between 4000' and 6000' elevation on northwest to northeast aspects.

For private land owners, thinning objectives often include reducing fire danger, generating income, and/or improving forest health. Improvement of downstream water yields for the benefit of others is typically not a primary objective but rather an outcome of stewardship management. For these private landowners, state environmental exemptions for thinning of pre-commercial and commercial stands provide a relatively low cost option. However, low log prices, lack of markets for some species and/or lack of logging contractors may still be disincentives for some landowners to implement thinning projects. State and federal cost share programs, such as CFIP and EQIP, often help offset costs for projects that thin small trees for non-industrial private landowners.

10 Using USFS Forest Vegetation Simulator/FFE (Fire and Fuel Effects) (USFS, 2003) with the FVS WESSIN variant for fire behavior and each plot assigned an FBPS fuel model (NWCG, 1982) based on vegetation and overstory condition (generally fuel models 8-10).

11 The flame length in the treated stands was partially due to the influence of a set of hardwood/conifer stand types that are not likely to be found at the elevations of this study, suggesting that the effects reported in BBWA (2004) overstate flame length.

Figure 16. Land Ownership For Areas Between 4000'-6000' Elevation with Northwest to Northeast Aspect



Thinning operations on National Forest managed lands will often have watershed, healthy forest and fire reduction objectives and may focus less on activities with an economic return. The process of implementing any management activity on the National Forest is relatively slow, cumbersome and costly. Environmental compliance often means that projects may take 1-3 years of assessment. Often the costs of implementing treatments will exceed budgeted funds, adding further delay to implementation.

6.5. LAND MANAGEMENT/ FIRE HISTORY

Application of the physical and ownership factors are relatively permanent, but land use history is constantly evolving. Of the 148,011 acres of National Forest lands (outside Wilderness areas) and private ownerships between 4000' and 6000' elevation with northwest to northeast aspects, 29,659 acres burned between 2006 and 2015 (Table 5). Fires effects in managed stands that burned in the past 10 years range from light understory clearing to complete stand killing. For that reason, burned lands are withdrawn from the suitable land base for thinning operations to improve SWE and water yields. If stand management activities and historic fire patterns of the past three decades continue in the near future, many stands will burn before any other form of thinning treatment can be completed.

Table 5. Theoretical Treatable Acres ~4000' Elevation - ~6000' Elevation

Not Burned Since 2005 by Ownership

Northerly Aspect Total	118,352
Federal	101,849
State	3
Private & Other	16,500

6.6. CUMULATIVE EFFECTS (DEFORESTATION, STAND CONVERSION AND WATERSHED INSTABILITY)

The extent of recent fire in the western two-thirds of the watershed have resulted in significant disturbances levels that will impact opportunities for some thinning practices. Watershed impacts are greatest in areas of repetitive high intensity fires. Within the watershed, approximately 109,000 acres, of the 689,000 acres burned since 1987 have reburned (Figure 14).

Figures 17 low intensity fire in the understory and moderate burn intensity

Figure 18 Below Right of the 2015 Peak Fire, South Fork Trinity River watershed.

Figure 19 (Below) Low intensity prescribed burn in 2015, north of Weaverville

These areas have increased extent of hydrophobic soils, loss of large wood sediment filters, increased rill and gully erosion and greater levels of channel incision. The effects of high intensity fires and repetitive fires hinder watershed recovery. The loss of root strength to stabilize soils following a fire is greatest 10-20 years after the fire. In this period the roots of trees killed in the fire deteriorate and new root growth is not sufficient to provide soil stability.

Burn Area Emergency Rehabilitation (BAER) Reports for the Saddle Fire, Fork Complex and other recent fires in the Trinity River watershed indicate increased risks of accelerated runoff and mass wasting potential in these burned areas.[12] Portions of these areas have converted to hardwood, brush or grass vegetation types, while a significant portion moved from nearly all conifer composition to mixed hardwood-conifer compositions (refer to Appendix A- Photolog of Fire Affected Stands). Some papers suggest that increased water yield under these conditions occurs primarily as winter runoff, may damage watersheds and does not enhance summer flows (Rhodes and Fissell, 2015).

Where water is stored in reservoirs, increased winter runoff may be beneficial if it is captured for summer use. However, capture of winter runoff and storage behind Trinity Dam is limited due to dam safety criteria that does not allow the lake maximum pool storage to exceed 80% of capacity before April 1st of each year.

7. SELECTED STANDS FOR DETAILED ANALYSIS

Application of the selection criteria described in the preceding section identified 118,278 acres from the total 1.63 million acres within Trinity County as suitable for thinning to improve water yield (Figures 20 and 21). The majority of the acreage is concentrated in the Mt. Eddy area and the headwaters of the South Fork Trinity River. Within these areas the largest sections were dropped from detailed analysis because they were primarily owned by SPI and the Forest Service, entirely under National Forest Management, or had significant burn histories over the past 30 years. Additionally, several other areas potentially suitable for water yield based treatments are relatively small and inaccessible and are excluded from this analysis.

Areas selected for detailed assessment (Coffee Creek, Burnt Ranch, South Fork Mountain) have a number of desirable characteristics, they are accessible, incorporate a mix of National Forest and private ownerships, are accessible, represent the diversity of stands in the watershed, and that have not burned in the past 30+ years.

12 (http://inciweb.nwcg.gov/photos/CASRF/2015-09-01-1730-2015-Six-Rivers-PostFire-BAER/related_files/pict20150916-220213-0.pdf); Fork Complex http://inciweb.nwcg.gov/photos/CASHF/2015-09-01-1727-2015-ShastaTrinity-PostFire-BAER/related_files/pict20150826-003838-0.pdf).

Figure 20. Criteria Used to Select Areas For Detailed Assessment.

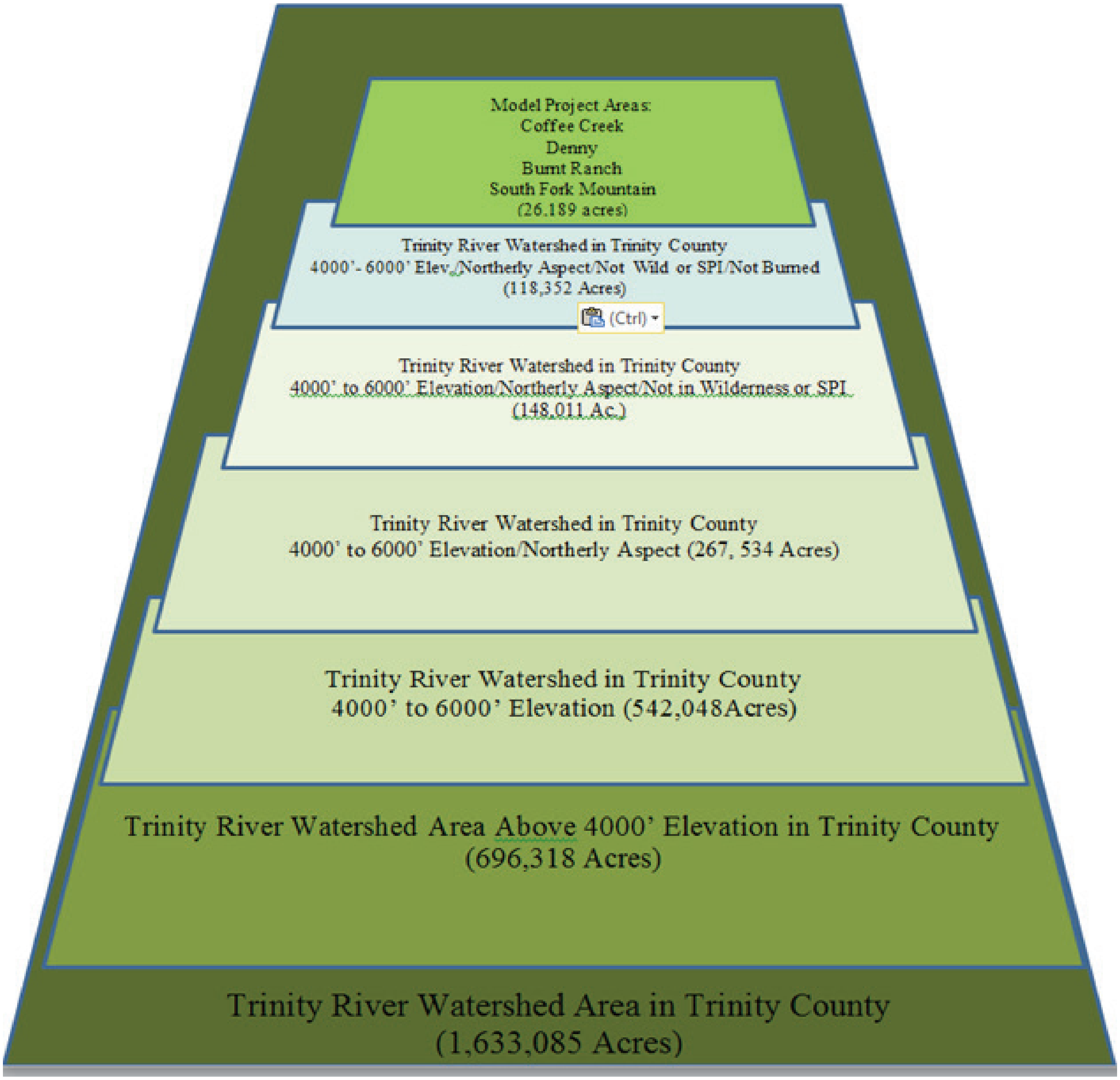
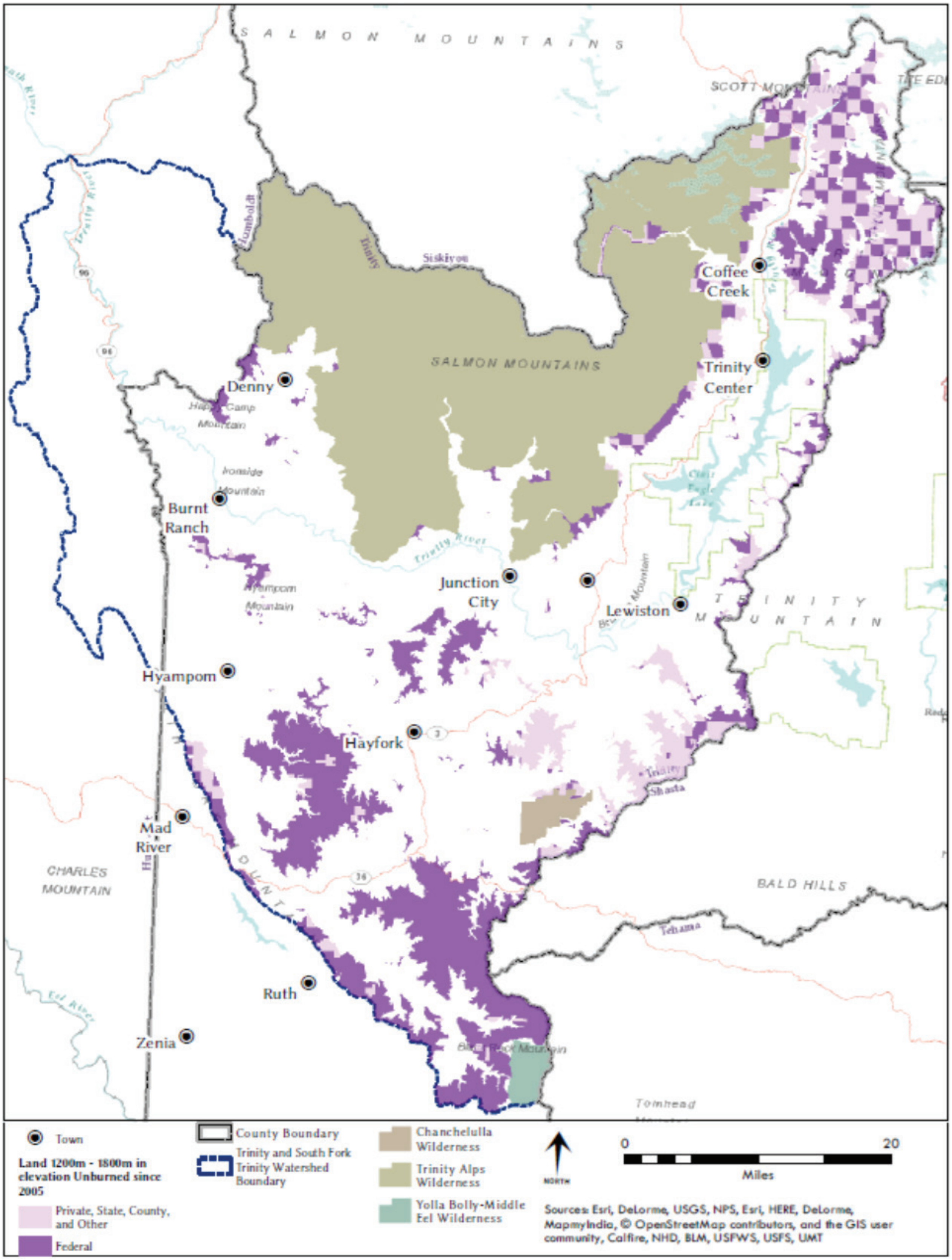


Figure 21. All lands meeting criteria of elevation, aspect and unburned since 2006.



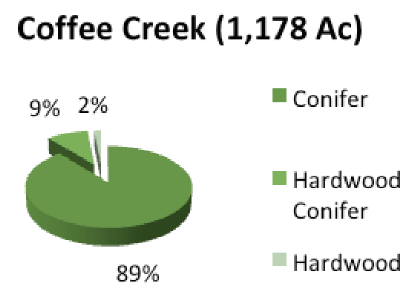
The three areas selected- Upper Coffee Creek, Burnt Ranch, and South Fork Mountain total 10,715 acres with an average elevation of ~4,600 feet.

7.1. COFFEE CREEK

The Coffee Creek Road corridor was selected primarily because of the nearly equal mix of public and private ownership, high ecological and water capacity values, the high potential for fuel break benefits, and the potential effects of a fire moving from the road area into the Wilderness area. With elevations ranging from 4,000 to 5,200, the 1,178 acre project area is relatively flat and is characterized by the Coffee Creek valley and adjacent mountain slopes. The project area is entirely surrounded by the Trinity Alps Wilderness area. Approximately 40% of the area is owned by private landowners holding less than 160 acre parcels. The remainder is under National Forest management.

Wet meadows form the non-forested portions of the area and serve as "sponges" absorbing snow melt and extending runoff late into spring and summer. With designated Wilderness surrounding it, the corridor is the only opportunity to restore more open forest stands, reduce fuels and maintain or enhance wet meadow reaches. The project site represents much of the Trinity Alps vegetation types at these elevations. Conifers stands account for 90% of the assessment area with white fir the dominant species. Jeffrey/ponderosa pine, incense cedar, Douglas-fir, and sugar pine combined make up about half of the stand composition. Past timber harvest and fire exclusion has influenced species composition. Larger diameter tree stands (>20" dbh) account for 54% of the assessment area. Hardwood-Conifer stands (Jeffery and ponderosa pine, Douglas fir, California black oak, interior live oak, and Pacific madrone) make up 9% of the area and pure Hardwood stands (cottonwood, white alder, big leaf maple, and willows) make up only 2% of the area, forming the Coffee Creek riparian and meadow edges. Figures 22-24 summarize the stands

Figure 22 and 23. Coffee Creek assessment area vegetation summaries.



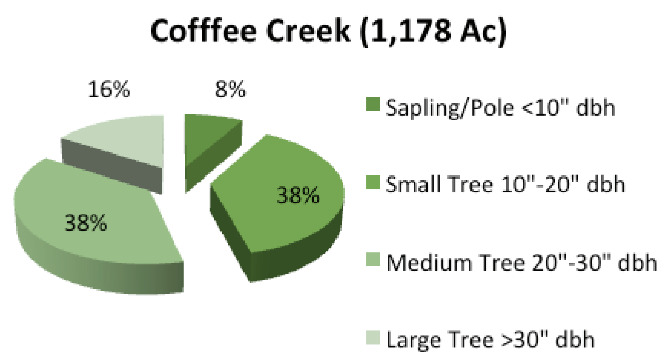
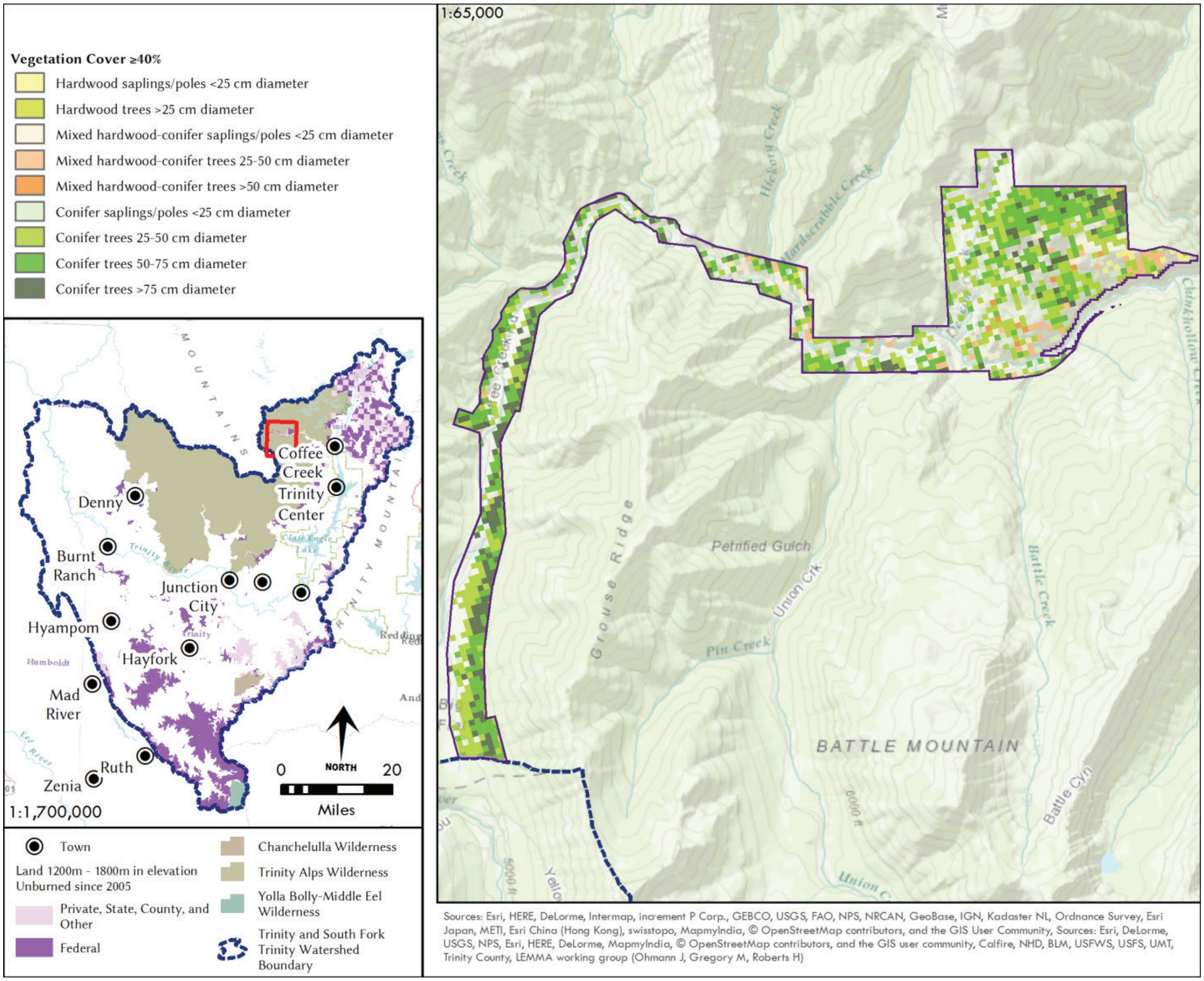


Figure 24. Coffee Creek Vegetation Communities

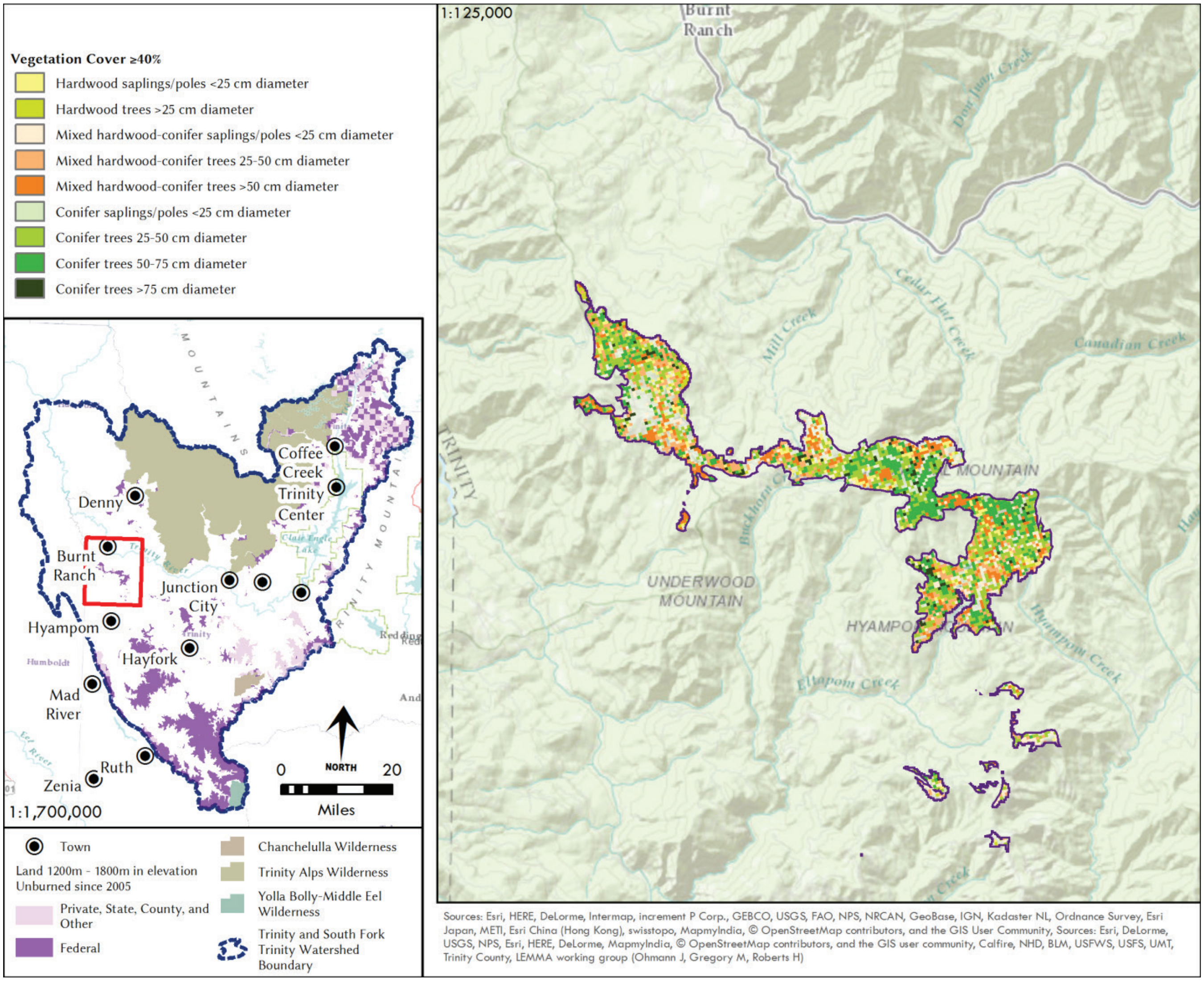


Increased water yield in this area benefits Trinity Reservoir and downstream river users, but will not significantly affect cold water or endangered fisheries because of the Trinity dam. Fuels reduction programs could have a significant positive effect on Wilderness values.

7.2. BURNT RANCH

The Burnt Ranch assessment area consists of the Underwood, Hyampom and Chaparral Mountain areas that separate the mainstem and the South Fork Trinity watersheds. The average elevation in this project area is ~4,400 feet and elevation ranges from 4,000-5,600 feet. It is characterized by steep hillslopes and complex topography. National Forest managed lands account for the majority of ownership with SPI and small private landowners accounting for ~20% of the area. The area is upslope of a Forest Service and Fire Safe Council collaborative community fuels reduction project. Permitted and unpermitted marijuana growing is a common activity in this area.

Figure 25. Vegetation Communities for Burnt Ranch Assessment Area

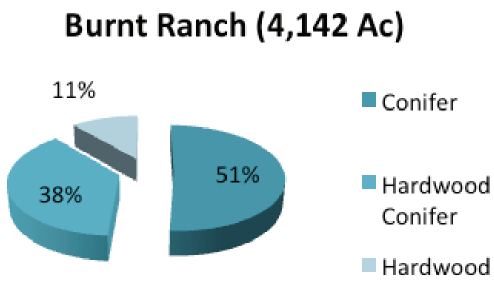


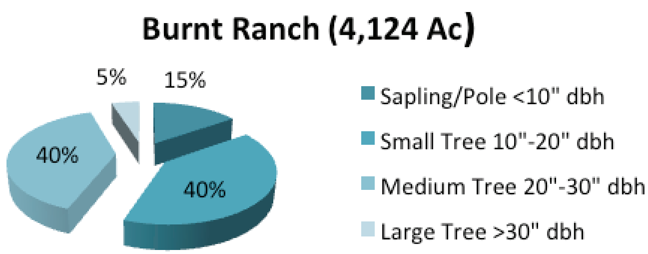
The 4,124 acre area lies in the rain shadow of South Fork Mountain and is drier than the other two assessment areas. It is more floristically diverse, consisting of Hardwood-Conifer stands (38%) and Hardwood stands (11%). Neither Hardwood nor Hardwood-Conifer stands require significant amounts of thinning to create the desired canopy closure needed to maximize SWE or extended snow melt.

Species composition is also significantly different for these stand compared to Coffee Creek (Figures 25-27). Conifer stands are dominated by Douglas-fir with white fir, ponderosa pine, sugar pine, incense cedar, and red fir as lessor components. Hardwoods are dominated by interior live oak, madrone, CA black oak, Oregon white oak, tanoak and chinquapin. Pure hardwood stands tend to be dominated by oaks rather than the riparian hardwoods found in Coffee Creek. Dense understory brush can develop in these stands following disturbance. Only 45% of stands in this assessment are 20" dbh or larger, compared to 54% for Coffee Creek and 61% for South Fork Mountain.

Increased water yields would primarily benefit downstream domestic uses, including the community of Burnt Ranch. Increased flows in this area would not significantly benefit endangered fisheries in tributaries due to steep gradient migration barriers within most tributary streams. Increased cold water flows to the Trinity River would have some benefit fisheries and domestic uses in the river.

Figures 26 and 27. Burnt Ranch Vegetation Community





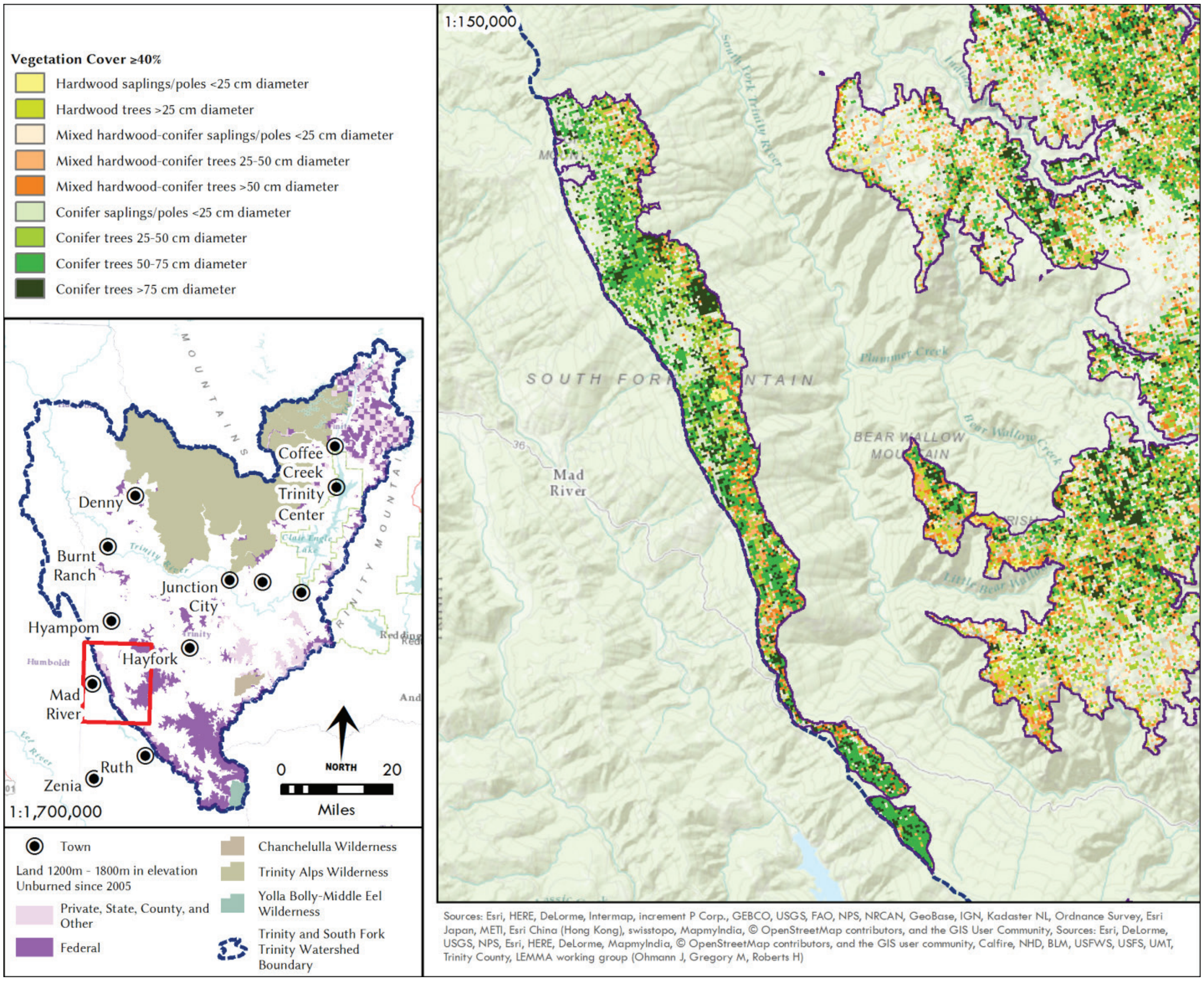
7.3. SOUTH FORK MOUNTAIN

The 5,411 acre South Fork assessment area consists of the east side of South Fork Mountain, south of Cold Springs Creek and north of Horse Ridge. South Fork Mountain divides the South Fork and Mad Rivers. The average elevation in the assessment area is ~4,200 feet and ranges from ~4,000 - 4,900 feet. South Fork Mountain is the longest contiguous ridge in the United States and at ~5,000 feet elevation traps storms coming off of the Pacific Ocean. Precipitation on the ridge system tends to be significantly higher than surrounding areas.

The assessment area is characterized by flat ridge tops and moderate side slopes with relatively consistent northeast aspect. Landownership is evenly divided between National Forest managed lands, which account for the southern half of the assessment area, and a mix of larger and smaller private landownership in the norther half. The area incorporates portions of the Forest Service's proposed Red Fir Restoration Project as well as private lands managed under a carbon easement with the CA Air Resources Control Board. Permitted and unpermitted marijuana growing is a common activity in this area.

Unlike the Burnt Ranch assessment area, Hardwood and Hardwood-Conifer stands represent a much small percentage of the stands (17% compared to 49% in Burnt Ranch area). The wet climate on South Fork Mountain supports vigorous conifer stands which are dominated by white fir and Douglas-fir. Red fir, ponderosa pine, sugar pine, incense cedar and Pacific yew are less common. Hardwoods are dominated by tanoak, chinquapin, madrone, and California black oak. Pure hardwood stands tend to be dominated by oaks rather than the riparian hardwoods. Dense understory brush consisting of whitethorn and ceanothus can develop in these stands following disturbance. There are two distinct stand ages in the assessment area (Figure 28-30). The northern half tends to have younger stands with smaller average diameters and the southern half tends to be larger, old growth and mature stands, on National Forest lands. Overall this assessment area has the highest percentage of large diameter stands (61% of all stands).

Figure 28. South Fork Mountain Assessment Area Vegetation Communities.



Increased water yields would primarily benefit downstream endangered fisheries species and domestic uses to a limited extent. Increased flows in this area would provide cold water refugia in tributaries as well as the South Fork Trinity River. Recent large fires surrounding these stands demonstrate the potential for stand conversion.

Figure 29. South Fork Mountain Assessment Area Vegetation Communities Tree Type.

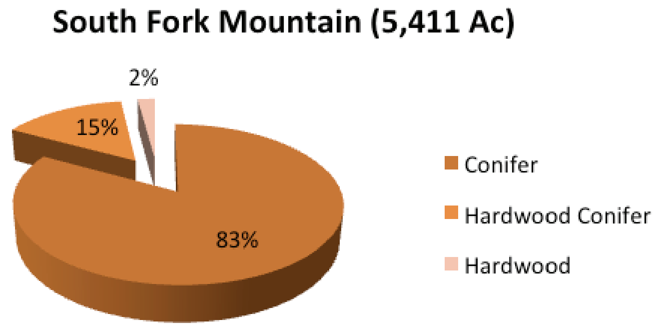
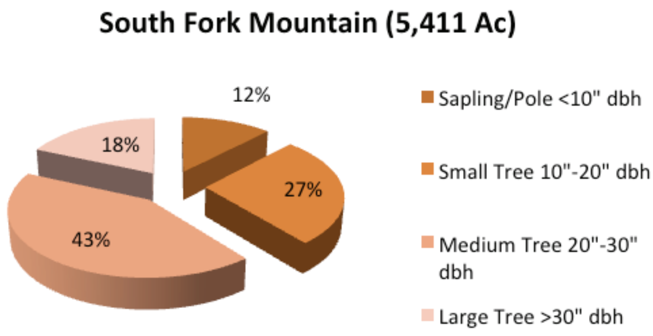


Figure 30. South Fork Mountain Assessment Area Vegetation Communities Tree Size



7.4. WATER YIELD

As discussed in a previous sections, the project area selection criteria is intended to target areas for forest thinning that would extend runoff later into spring and summer and not adversely affect watershed processes,. Within the 10,715 acres forming the three assessment areas, stands were aggregated into three broad species groupings (Hardwood, Hardwood-Conifer and Conifer types) and stratified into four average diameter classes(<10" dbh, 10-20" dbh, 20-30" dbh and greater than 30" dbh).

Vegetation data was derived from Landscape Ecology, Modeling, Mapping & Analysis (LEMMA) working group's Gradient Nearest Neighbor (GNN) dataset.[13] This raster dataset represents model output generated by the GNN method (Ohmann & Gregory 2002, CJFR) for assigning forest inventory plot identities to unsampled spatial locations. This model uses satellite imagery processed using the LandTrendr algorithm (Kennedy et. al., 2010). LandTrendr is a trajectory-based change detection method that minimizes annual variability from noise (e.g. differences in sun angle, phenology, atmospheric effects), such that the remaining signal more closely reflects real changes in vegetation.

These data are most appropriately used to characterize vegetation conditions across landscapes, counties, watersheds, or ecoregions (areas larger than stands or patches). In general the data are appropriately used for planning and policy level analyses and decisions. Local map accuracy may be insufficient to support local- (e.g. stand-) scale decisions.

We utilized GIS level vegetation data, stand reconnaissance (basal area), aerial photo review (canopy closure), and limited stand inventory data to estimated basal area/acre and crown closure for each diameter class grouping. Significant portions of the assessment area had basal areas ranging from 150-300 ft^2 per acre and crown closure of 70%-90%. These sites are the focus of thinning treatments.

Table 6. Stand Table For Assessment Areas

Species Groups	Size Class	Diameter Class (dbh)	Coffee Creek	Burnt Ranch	SF Mountain
Hardwood	Small Tree	<10	15	289	89
Hardwood	Medium Tree	>10	3	176	24
MHC *	Small Tree	<10	51	257	47
MHC	Medium Tree	10-20	49	604	414
MHC	Medium Tree	>20	10	694	344
Conifer	Sap/pole	>10	31	86	525
Conifer	Small Tree	10-20	394	883	1,018
Conifer	Medium Tree	20-30	438	931	1,954
Conifer	Medium Tree	>30	187	204	996
Total			**1,178**	**4,124**	**5,411**
*MHC: Mixed Harwood-Confer					

Stand data and fire modeling in the Weaver Creek watershed was used as a template for modeling thinning assumptions (BBWA, 2004). A review of residual basal area, crown closure and stand conditions was done for units harvested within the USFS "Browns" Project in the Weaver Creek watershed (Figure 30), as well. Modeling completed by BBWA used pre-harvest basal area, diameter distributions and crown conditions data similar to many stands in the assessment area. Based on these analogous assessment efforts, this assessment applies a 20% reduction of basal area per treated acre of conifer stands.

13 (Ohmann J, Gregory M, Roberts H) http://lemma.forestry.oregonstate.edu/

Figure 31. A thinned conifer stand in the Weaver Creek watershed where ~30% of the stand basal area was removed leaving ~80-120 ft2 basal area per acre and a 60% crown closure.

To estimate potential per-acre water yield benefits of forest thinning, we relied on existing research on conifer forest water yields in response to forest stand structural changes (Brown et al., 2005). As Podolak et. al. (2015) notes:

> *"Despite this extensive literature on the relationship between forest harvest and water yield, there are no empirical studies completed yet on the effect of ecologically based forest thinning on water yield in the Sierra Nevada. These synthesis studies show a linear increase in water yield with increases in the percentage of forest removed regardless of the forest type or the precise logging method. Based on these studies, we used the average increase in water yield as a low estimate of water yield change, and the reported maximum increases to estimate the high end: 22–40 mm for 10 percent reduction in forest basal area (i.e., the area of tree trunks) or 0.14–0.41 acre-foot (AF) per acre of forest treated."*

Stands with average diameters of less than 10" and Hardwood stands, which drop their leaves in fall and thus have lower sublimation and heat trapping effects, were not modeled for water yield treatment in this assessment.

8. RESULTS

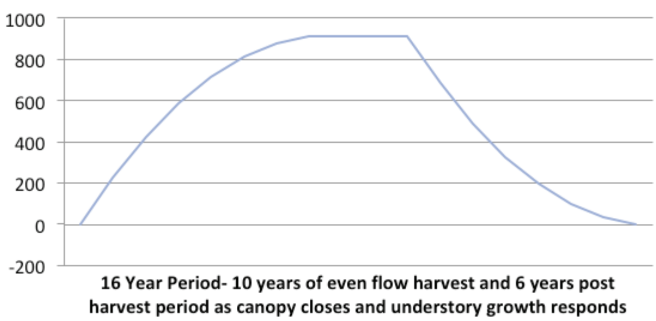
For our water yield estimate, we utilized the same assumptions as Podolak, et al. (2015) with 0.14 Acre-feet/year (AF) for 10 percent basal area reduction of conifer stands. Hardwood-Conifer stands with average diameters greater than 10" dbh were modeled assuming a 10% reduction in stand basal area. These stands were assigned a water yield increase of 0.05 AF per treated acre for the low water yield estimate and 0.14 AF for the high water yield estimate. Within Hardwood-Conifer stands reduction of conifer basal area does not result in the same water yield benefits as reductions in Conifer stands, as crown closure varies seasonally and is already more open in the critical periods of snow fall and melt out.

Conifer stands greater than 10" dbh were modeled assuming a 20-40 ft2 basal area reduction or approximately 20% reduction in average stand density. The maximum acreage targeted for thinning was 25% of any stand group. The 25% area target allows for exclusion of already managed or disturbed stands within the project areas as well as National Forest administratively withdrawn lands (e.g. Riparian Reserves, Roadless Areas). The 25% target is feasible in part based on the private lands portions of the assessment area.

The estimated water yield results assumes that thinning would occur in an even flow, 10 year period with 2.5% of selected stands (228 acres) thinned annually. Research shows that without maintenance (thinning or burning) canopies will regrow and understory species respond such that within approximately 7 years of thinning any water yield benefits have been negated. The net acreage effect of a 10 year thinning cycle with a 7 year linear response/recovery of growth is to create a 16 year period with peak beneficial acreage related water yield occurring in the middle portion of that period (Figure 32).

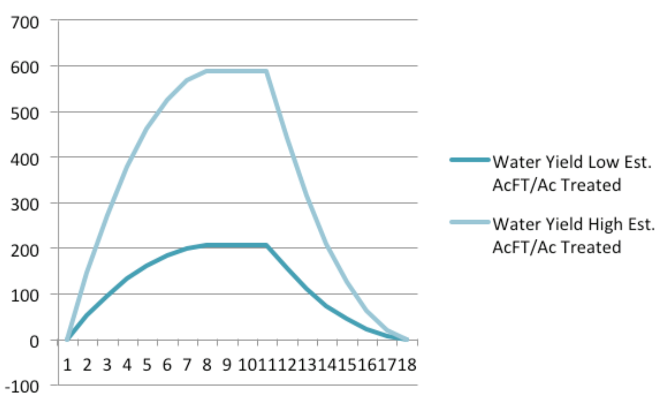
Based on the assumptions in the model, low and high water yield estimates were generated over the 16 year period of effect (Figure 32). Thinning of dense conifer stands by 20% of basal area (20-40 ft^2/acre) and light thinning 10% of conifer basal area within mixed Hardwood-Conifer stands will yield an average of 0.22 AF of additional water per year per acre based on the aggregate stands of the three assessment areas examined.

Figure 32. Harvest Changes Over Time. Shows the equivalent annual acres of thinning for an even flow thinning regime of 228 acres harvested per year for a 10 year period and a 7 year period before the thinned biomass is replaced (assuming a linear growth response in crowns and understory of thinned stands).



Thinning of 2,280 acres in these assessment areas over a ten year period would yield an average 130 acre feet of additional water per year, with peak yields of 207 acre feet in years 7 through 10 (Figure 33). Greater water yields would be achieved by increasing the acres treated per year or extending the period of active thinning.

Figure 33. Acre Feet of Annual Water Benefit from Thinning Targeted Stands



Another vegetation management technique used to enhance water yield has been the conversion of conifer forests to hardwood stands. Conifer forests generally intercept more water than hardwoods, especially in snow zones. Snow intercepted in trees often evaporates before ever reaching the forest floor, where it can be absorbed into the soil mantle or runoff. Some studies indicate significant increases in groundwater recharge in hardwoods stands that were previously conifer stands and similar decreases in groundwater recharge in stands that were converted from hardwood to conifer (Dunn and Leopold, 1978).

Planned conversion of conifer to hardwood, brush, or grass stands is not considered a likely feasible option to improve water yield as it is already in progress due to forest conversion by fire. In addition, the Forest Service is not likely to specifically plan timber sales to convert conifers stands to other forest types. Any such planning would likely be appealed and/or litigated under the National Environmental Policy Act and/or the Endangered Species Act. While some conversion of conifer stands will occur on private lands[14] these tend to be done at lower elevations that support year round occupant management.

8.1. CARBON SEQUESTRATION

Climate change management is outside of the short term control of land managers in the 1.83 million acre Trinity River watershed, but carbon storage and sequestration within the watershed are important climatic benefits and priorities of the state of California's Carbon Cap and Trade Program (http://www.arb.ca.gov/cc/capandtrade/capandtrade.htm).

There are several California carbon sequestration projects within the Trinity River watershed and surrounding watersheds. Projects have been done by the Yurok Tribe, Round Valley Tribes, Green Diamond Resources, Sierra Pacific Industries and others. These projects have stored several million metric ton of carbon dioxide (or its equivalent in other greenhouse gases). The people of California have invested millions of dollars of in these projects, but increased fire activity threatens to undermine the carbon storage of these forests. Already stand replacing fire has burned into areas covered by carbon offset purchases.

Thinning to increase SWE water yields and reduce the intensity of wildland fires, could also reduce the carbon released from wildfires. As noted in the previous section approximately 2/3 of all burn acreage in the past decade as been of moderate to high severity with associated tree loss.

An estimate of carbon release from fires was done by sampling 735 ARB Forest Protocol compliant carbon inventory plots in 2013. In 2015 about 65% of these plots were burned in a series of wildland fires. The burned areas had ~35% low intensity fire effects, 33% moderate intensity effects and 32% had high intensity effects (killing all trees and understory). Plots within the burn areas were then remeasured in 2015/2016. The resulting results were used to estimate the CO2e emitted (the sum of the difference in pre and post fire aboveground and belowground live CO2e). Stands within the burn areas were similar to stands selected in this assessment. For the plots remeasured, 328,893

14 In July 2016 the Trinity County Board of Supervisors imposed a short term moratorium on "less than 3 acres" conversions of private conifer stands in response to an estimated 2,000 to 5,000 illegal conversions that occurred between 2009-2016.

metric tonnes of CO2e were available for release into the atmosphere. This is approximately 20 metric tonnes CO2e per acre burned, with the vast majority of that being from vegetation killed in the high severity burn class.

Salvage logging could capture or store some of the potential CO2e release and a case could be made that the standing dead and belowground dead will not be emitted soon because the char associated with the burned trees is not readily lost back to the atmosphere.

Under the fire regimes of the past decade, high elevation conifer stands will continue to burn with ~66% of area experiencing moderate to high fire severity. With an assumption of ~20 tonnes CO2e per acre released an estimate of carbon benefits of thinning to improve SWE can be made.

Fire modeling of thinned stands suggests that under moderate fire weather conditions, fire severity in treated stands could reduce high severity damage. As noted previously, modeling of plots in the Weaver Creek watershed found that only 8.8% stand mortality would occur for the moderate fuels treatment (with slash treatment) compared to 31.2% mortality for the untreated stand condition for a fire occurring in typical August weather conditions (BBWA,2004). The actual mortality observed in the 2015 fires sampled in this carbon effort was approximately 32%, which is similar to the modeled mortality rate of 31% in actual stand with generally similar stand conditions.

Assuming a simplistic linear relationship would suggest that thinning 2,280 acres and changing fire intensity from high to low, would retain approximately 15 tonnes of stored CO2e per acre if fire should burn through the stands. This would retain approximately 12,500 tonnes of CO2e within stand vegetation.

9. CONCLUSION

We recommend that policy makers look at forest thinning of stands at sufficient elevation and favorable aspect to improve late spring and summer water yield. Based on the assumptions in the model, low and high water yield estimates were generated over the 16 year period of effect. Thinning of dense conifer stands by 20% of basal area (20-40 ft2.acre) and light thinning 10% of conifer basal area within mixed Hardwood-Conifer stands will yield an average of 0.22 acre feet of additional water per year per acre based on the aggregate stands of the three assessment areas examined.

Thinning can create the right balance of stand openings and ground shade to maximize snow accumulation on the forest floor. At the same time thinning combined with pruning and fuels reduction can create shaded fuel break conditions. While this treatment can be used at all elevations and aspects, to increase summer water yield it is most effective between 4,000 feet and 6,000 feet elevation on northwest to east facing aspects.

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ENDNOTES

1 An assessment done by the Nature Conservancy in 2015 called for increased stand thinning to both increase SWE and reduce effects of large fires (Podolak et al, 2015). That paper suggests that increased SWE runoff could increase hydro-electric power production by 6%. The paper suggests that increased revenues from power output can help pay for fuels reduction programs. The paper however, ignored the positive effects of increased runoff from mega fires in the study area (including the >260,000 acre Rim Fire of 2013) as well as the negative watershed impacts of these fires. Moderate to high burn severity fire can thin conifer stands or converts them to early seral (grass/brush) habitats (Figures 6 and 7). Frequent fires with moderate to high severity fires can also increase runoff and other cumulative watershed impacts that may further preclude pre-emptive management options to reduce future fire behavior and improve snow melt timing benefits.

2 Hagberg, et al (2012) found that "*four unique canopy densities, ranging from 0%-60%, result in different initial snowfall accumulations and loss rates. It was found that as forest canopy density increases, the amount of snowfall reaching the forest floor decreases. However, vice versa, as canopy density decreases, the ablation rates increase. From this study, it was found that the medium canopy density (30-60%) strikes the best balance between initial snowfall accumulations and its ability to retain SWE over time. The rate of snow sublimation is most drastically affected by the presence of even a slight wind. More specifically, the sublimation rates were observed to be maximized when the humidity was low and wind was present. This study applies specifically to the ponderosa pine type forest of northern Arizona, however, similar trends would be expected in other similar environments*." Strock et al (2010) found that "*during periods when air temperature remained below freezing after snowfall, sublimation was an important mechanism for removal of intercepted snow, with average annual totals of 100 mm SWE. Given that average winter precipitation depths in the region studied here are approximately 2 m, a loss of 100 mm of SWE through sublimation is less significant than in drier climates, were precipitation is less frequent and overall conditions are more conducive to sublimation. Even though this study observed instantaneous sublimation rates in excess of 0.5 mm per hour, meltwater drip and mass release are the dominant process affecting the ground snowpack in maritime mountainous climates. "Field experiments conducted in maritime climates have reported a wide range of snow interception maxima. Sauterland and Haupt (1967) report a maximum interception of 4 mm snow water equivalent (SWE) on conifers while snow interception approaching 30 mm SWE was reported by Bunnell et al. (1985) and Calder (1990)."*

Troendle, et al (1980) summarized the effects of interception and thinning as follows: "*The magnitude and significance of interception losses by forest vegetation to the overall water balance have been documented by Kittredge (1948), Coleman (1953), and others. Interception losses may account for 25 to 35 percent of the annual precipitation, depending on the amount, type, and intensity of precipitation and the type and density of forest vegetation. The increase in net precipitation resulting from forest removal is proportional to the reduction in stand density and can range up to 15 to 30 percent for individual storm events (Kittredge 1948*)" (Forest Service RMRS-GTR-231, 2010). Reid and Lewis (2004) reported that conifer forests interception can be greater than 20% of precipitation. More recent research suggests that overlapping tree crowns can act as heat traps as daylight lengthens in February-March and may partially account for the rapid winter melt out of some snow packs (Lundquist, et al 2013).