A RISK ASSESSMENT OF

California's Key Source Watershed Infrastructure

REPAIR AND MAINTENANCE NEEDS FOR THE FEATHER, PIT, MCCLOUD, UPPER SACRAMENTO, AND UPPER TRINITY RIVER WATERSHEDS

PACIFIC FOREST TRUST

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FRONT COVER: Oroville Dam spillway in February 2017, Hector Amezcua, *The Sacramento Bee*, ZUMA Press

BACK COVER: Lake Shasta at low water level in January 2014, Paul Hames, California Department of Water Resources

Executive Summary

In 2016, California enacted AB 2480, which defined source watersheds — the forests, meadows, and streams that supply water to its reservoirs — as an integral part of the state's water system infrastructure. The new law acknowledges that source watershed restoration and conservation are an essential complement to built water system infrastructure repair and maintenance, and necessary for a more reliable water supply. This report presents the first comprehensive assessment of conditions and restoration needs for the five source watersheds that deliver water to the Shasta and Oroville reservoirs, the state's two largest reservoirs and the core of the state's water supply. Together, these reservoirs provide drinking water for over 28 million Californians and agricultural water for millions of acres of farmland.

The assessment shows that virtually half of this source water infrastructure is degraded and in danger of further fragmentation and deterioration. This degraded state poses significant risk to the reliability, quality, and security of the water supply that California's residents, hydro-power generation, and agricultural economy depend on.

Almost 65% of forest area and over 90% of wet and dry meadow area are in need of restoration. While there are significant impacts from development and fragmentation, there is still an opportunity to ensure these watersheds remain functionally intact for future generations.

These watersheds are already the primary source of the state's water supply, and California's reliance on them will only increase with advancing climate change, as their northern region will remain cooler and wetter than the rest of the state, which warms and dries.

Climate change is exacerbating the intensity of the floods, fires, and pest outbreaks which have become common across these watersheds, further threatening water supply and water quality. Responding to such disasters costs billions of dollars — and the harm has already been done. AB 2480 presents the opportunity to proactively and cost-effectively address these threats, reduce risk, and increase water security.

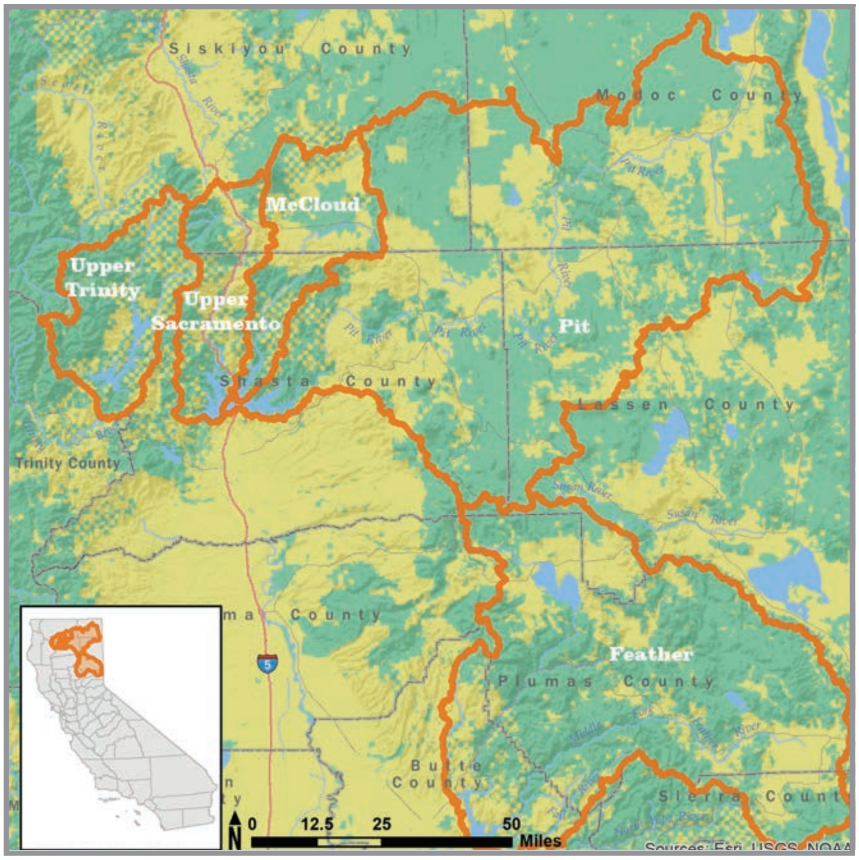


FIGURE 1. The Feather, Pit, McCloud, Upper Sacramento, and Trinity watersheds supply the Oroville and Shasta reservoirs. With their ultimate confluence in the Sacramento River, these watersheds also provide over 80% of the freshwater flowing into the San Francisco Bay.

Restoring wet meadows and the streams that run through them provides multiple benefits for water supplies: replenishing groundwater, holding water later into the summer, decreasing flood velocities and flows, reducing sediment transport, and maintaining cooler water temperatures.

Our assessment lays the foundation for proactively repairing the state's essential source water infrastructure. To date, such repair has been underfunded, crisis-driven, and piecemeal. Investing in integrated restoration will produce synergistic benefits for water reliability, supply, and public safety **at a fraction of the cost of building new infrastructure**.

Source watersheds are a mosaic of forests, meadows, and streams, historically shaped by low-intensity, frequent fire. Over the past 150 years, they have been heavily impacted by increased human activities: logging, grazing, mining, fire suppression, and a patchwork of uncoordinated development and management approaches. These once fire- and pest-resilient forests have been transformed into crowded stands of young trees prone to burning and disease. Meadows have been choked out, their water absorbed by thickets of young trees, while streams have become channelized, eroded, and more prone to downstream flooding. These stress factors degrade watershed function, a condition only worsened by climate change.

Restoration and protection of these forested source watersheds is a proven tool to reduce flood events and intensity, increase water supply and storage, improve timing of water releases, and improve water quality. However, watershed restoration has never been carried out comprehensively or at scale. Compatible with sustainable forest and range management, this infrastructure repair includes forest fuels reduction, reintroduction of prescribed and managed fire, wet and dry meadow restoration, road repair, and protecting watershed integrity by preventing fragmentation and future degradation.

Water reliability and quality benefits include:

- Increased capture of precipitation by forests
- Increased groundwater infiltration
- Increased forest snow retention, with later season melt
- Increased retention time in wet meadows, with later summer release
- Cooler, cleaner water available for fish and farms later into summer
- Reduced fire intensity and fire suppression costs
- Reduced flood incidence and intensity

Restoration in California's source watersheds has resulted in 9–16% increases in flows, substantial increases in storage, and positive impacts on the timing, intensity, and rate of release into reservoirs.

Restoring source water infrastructure is a "least-cost" approach to increasing water supply reliability and quality with synergistic benefits that help California adapt to climate change. It also reduces the risk of floods and fires, supports thousands of jobs, and restores resilience in rural communities as well as the watersheds. Our assessment outlines a comprehensive approach to improving these watersheds systemically, building a more secure future water supply with natural infrastructure.

Background and Purpose

There is broad recognition that California's source watersheds, the forests, meadows, and streams which deliver water to our dams, are highly degraded,[1] as evidenced by more than a decade of uncharacteristically intense, large fires, major pest and disease outbreaks, and recent extreme flood events.

Such degradation has led to reduced natural water capture and storage, altered flow regimes, and more intense flooding. The natural infrastructure of these watersheds is in dire need of repair. This report is the first comprehensive assessment of the scale and type of restoration and conservation needed in these source watersheds to improve the long-term security, quality, and reliability of the state's water supply. Improvements in watershed condition are particularly important for the source watersheds of the state's two largest water storage facilities, the Shasta and Oroville reservoirs (Figure 1). These source watersheds have been cooler and received more precipitation than the rest of the state over the past 100 years, and, as climate change advances, this region is projected to remain so. As such, the state's reliance on these source watersheds for drinking and agricultural water will increase as more southerly watersheds become hotter and drier (Figure 2).

These source watersheds are forest ecosystems: a mosaic of trees and meadows interlaced by streams. Comprising almost seven million acres, these watersheds are a checkerboard of public and private ownerships. Since the large majority of water deliveries under the State Water Project and Central Valley Project rely on these watersheds, their function, health, and resilience is critical to the reliability of the state's water system. We developed this report in order to envision a new approach

CLIMATE CHANGE IMPACTS ON TEMPERATURE AND PRECIPITATION

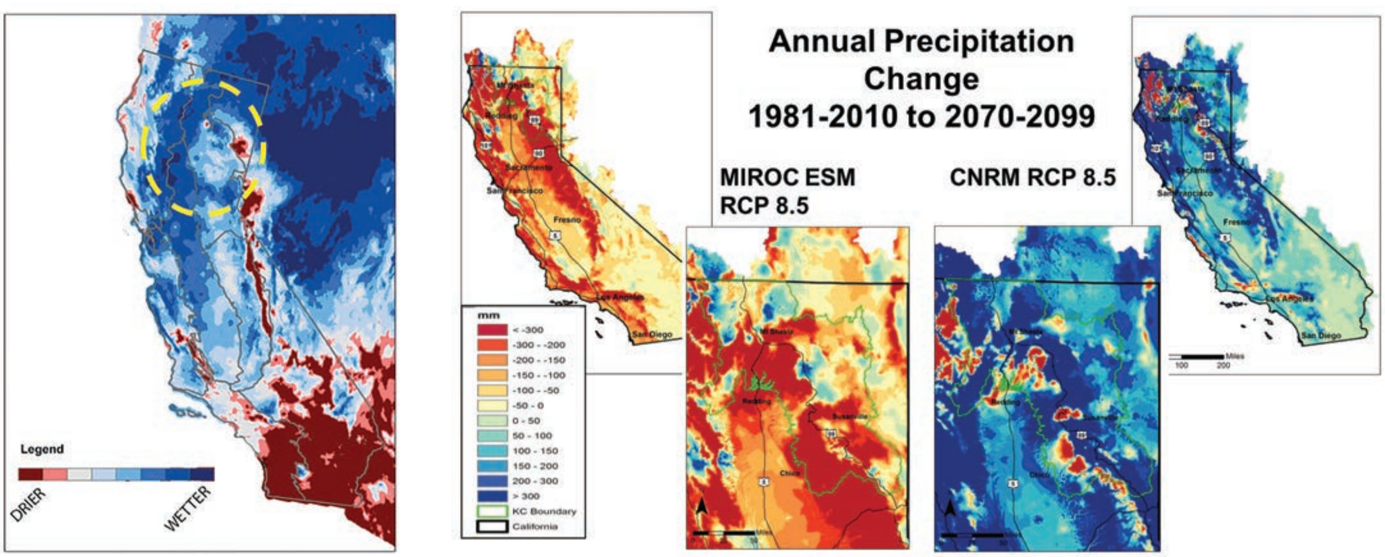


FIGURE 2. The region in which these watersheds sit, California's Klamath Cascade, has been cooler and wetter than the rest of the state over the past 100 years.[2] Global change modeling projects that the region will remain cooler and wetter over the next hundred years as well, as climate change advances, underscoring its importance for continuing water supplies.[3]

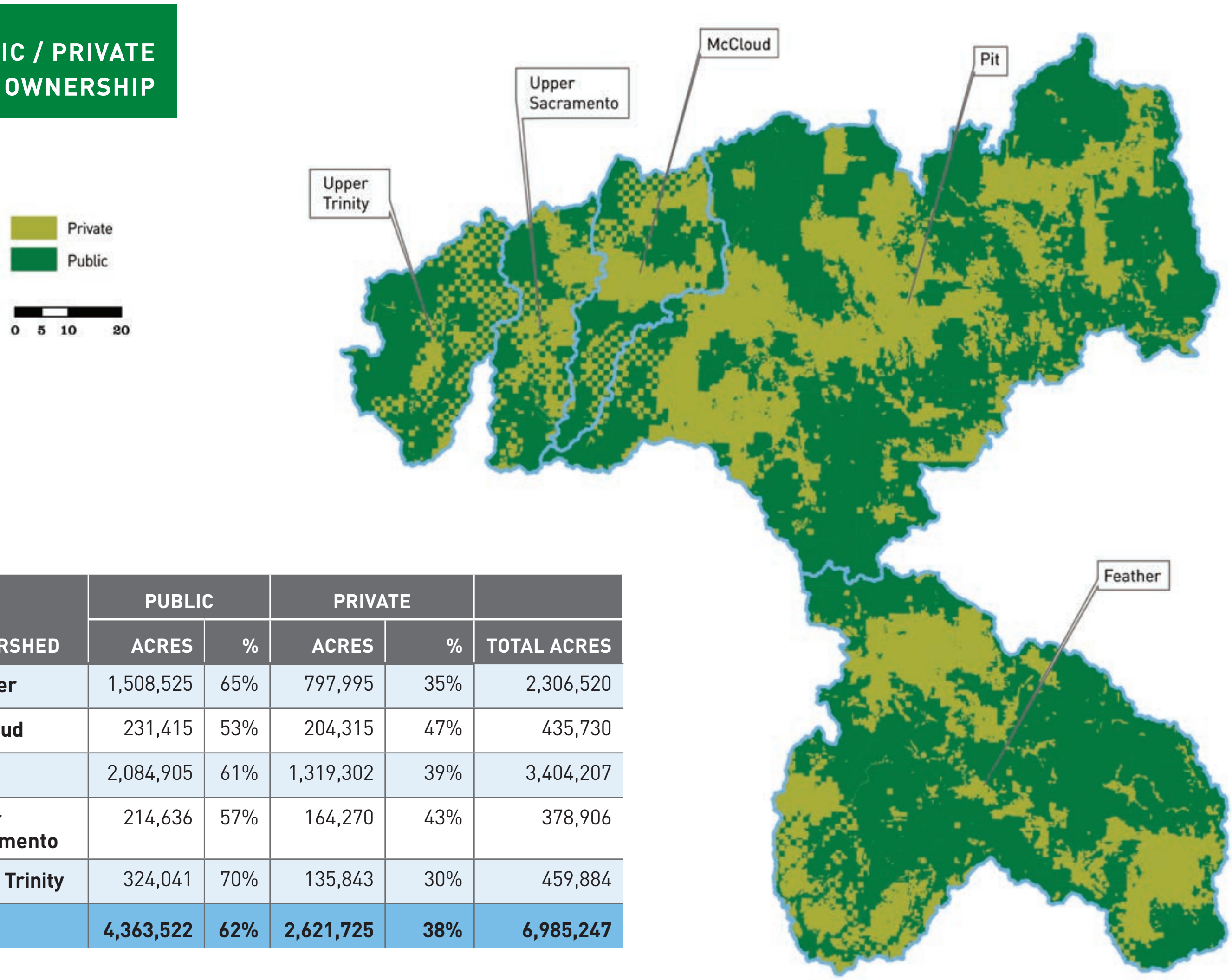
to ensuring the reliable, safe function of this water infrastructure, and outline a comprehensive plan of work for implementing restoration and conservation activities across ownerships. Such an approach is essential if we are to successfully address dual water supply crises — too little in summer and too much in winter. Only a comprehensive and integrated approach will deliver needed improvements in watershed function such as more reliable water quality, quantity, and timing. As climate change continues to warm and dry the state and demand for water increases with population growth, repairing watershed infrastructure will reduce risks to water security by improving overall system resilience and adaptation.

This report assesses the condition of key watershed characteristics and identifies the type and scale of restoration actions that would have the greatest impact on restoring watershed health and function, providing both short and long term benefits. (Table 1).

A Key Planning Tool

This analysis is intended to provide a comprehensive, cross-boundary planning framework for restoration at the watershed level, rather than as a prescription for site-specific, project-level implementation. It identifies the type and scale of restoration as well as the overall location of that work which is merited in each watershed, rather than identifying the exact acres where specific restoration activities should be implemented. As such, while the analysis uses the best currently available geo-spatially referenced data, there may be some variation between what is found on the ground and what the data represents.

PUBLIC / PRIVATE OWNERSHIP



WATERSHED	PUBLIC		PRIVATE		
	ACRES	%	ACRES	%	TOTAL ACRES
Feather	1,508,525	65%	797,995	35%	2,306,520
McCloud	231,415	53%	204,315	47%	435,730
Pit	2,084,905	61%	1,319,302	39%	3,404,207
Upper Sacramento	214,636	57%	164,270	43%	378,906
Upper Trinity	324,041	70%	135,843	30%	459,884
Total	**4,363,522**	**62%**	**2,621,725**	**38%**	**6,985,247**

Analysis Approach

We evaluated the potential scale for actions in these five restoration activity areas outlined in Table 1, using geospatial information system (GIS) analyses based on data from both public and private sources (Appendix/References), identifying the location and spatial extent of the following components:

1. Watershed characteristic
2. Areas of watershed characteristic in degraded/at risk condition
3. Areas where restoration treatments are permissible (not prohibited by legal, administrative, or other operational limits)

The overlap of these components (Figure 3) represents the scale of the restoration opportunities related to each element within a given watershed. Spatial data representing each of these components was identified for each watershed characteristic.

We utilized multiple data sets for each feature (see Appendix). These data sets focused on specific aspects, such as forest condition or wet meadow extent, and often had differing scales. To integrate these and apply them across the watersheds, we deployed a sequencing of data and assumptions enabling the identification of the scale of the area, in acres or miles, to be restored with each activity (see Appendix for full set of flow charts, data sources, and assumptions).

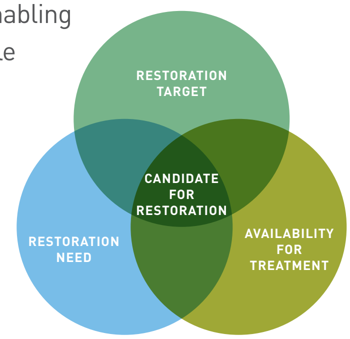


FIGURE 3. Conceptual diagram of GIS overlay analyses

TABLE 1. Restoration Actions and Their Watershed Benefits

WATERSHED CHARACTERISTIC	RESTORATION ACTIVITY	WATER BENEFITS OF RESTORATION
Forests	Mechanical thinning	Increased water yield, greater capture, and retention of precipitation (mist, rain, snow), prolonged release of snowmelt, decreased peak run-off, prevention of post-wildfire erosion, increased soil moisture, improved water quality
	Prescribed burning	Increased water yield, greater penetration of precipitation, delayed/prolonged release of snowmelt, reduced fire intensity, prevention of post-catastrophic wildfire erosion, improved water quality
Meadows	Removal of encroaching conifers	Increased water yield, raised water table
	Restoration of wet meadow hydrological function and stream channel integrity via pond-and-plug, check dams, channel reconstruction, stream bank stabilization	Flood attenuation, increased flow reliability, prolonged dry-season base flows with extended summer release, reduced erosion, improved water quality
	Realignment of unpaved roads and trails intersecting wet meadows	Reduced erosion and channel incision, improved water quality
Streams	Restoring natural stream channels; herd management in grazing allotments and exclusionary fencing	Reduced erosion, stream channel protection, improved water quality, reduced flood events
Roads and Trails	Upgrading unpaved roads, especially those in stream buffers	Reduced erosion and sediment delivery to watercourses, improved water quality
	Decommissioning roads (federal lands)	Reduced erosion and sedimentation, improved water quality
Integrity/ Intactness	Acquisition of conservation easements (private lands)	Protection of long-term watershed function via secured land base

Forests

These source watersheds are naturally characterized by a diverse mix of conifers with large, older trees in relatively open stands.[4] These forests have been heavily altered in the past 150 years.

Dense, closed canopy forest stands are more susceptible to uncharacteristic fire, and reduce infiltration of both snow and rain. Fire suppression has vastly increased tree density. Reducing stand densities and restoring more natural stand structure provides conditions where managed fire can maintain both forest and meadow functions as shown in these paired photos.

Initial timber harvest removed the large trees. Heavy reforestation, both active and natural, has led to a relatively even-age and homogeneous stand structure. Fire suppression across all ownerships, combined with reduction of timber harvest on public lands, has created unnaturally dense stands loaded with dangerous levels of fuels that can lead to uncharacteristically severe wildfires[5,6]. Such intense fires denude soils that increase peak runoff, and notably increased sedimentation. Indeed, the Bagley Fire in August of 2012 is estimated to have increased sediment delivery into Lake Shasta by 10%.[7]

Ongoing forest management for timber products has further simplified these otherwise diverse forests. Simplification in forest structure and composition increases vulnerability to fire, pests, and disease as well as the intensity of their impacts.[8,9,10] Climate change is also increasing stress on these forests.[11] Further, changes in the timber products industry and energy markets in recent decades have severely reduced the market for small diameter trees,[12,13] leading to declining commercial harvest and increasing stand densities. The resulting simplified forest conditions have significantly reduced overall watershed health, impairing their ability to provide a reliable and clean supply of water to downstream users.[14]

Restoring degraded forests to a more natural, resilient condition enhances overall watershed function and health.[15,16] Benefits include reducing the risk of catastrophic wildfires[17] and their associated adverse effects on water quality from ash and sediment as well as temperature;[18,19] increasing water yield from snow dominated areas;[20,21] and delaying the release of snowmelt later into the dry summer months.[22]

Restoring low intensity prescribed fire at regular intervals (as pictured right) to reduce fuel loads and restore soil productivity also helps prevent the uncharacteristic intensity fires such as occurred in the Bagley Fire (left).

The primary opportunities for restoring these source watershed forests are through a combination of mechanical thinning[23] and prescribed burning.[24,25,26] Although returning fire to these forests has been limited largely to public lands, there is growing support for broader use of prescribed fire across all ownerships in appropriate landscapes.[27,28] These approaches benefit both conifer and hardwood tree species, and are especially beneficial to the regeneration of aspen stands.

Aspen will not regenerate without fire disturbances, and oak regeneration is enhanced by low-intensity fire regimes which reduce competing non-native grass root mats. We identified all areas appropriate for thinning or where the reintroduction of fire was feasible. As the forest ages, the thicker bark on older trees is not harmed by low-intensity fires that consume younger trees and seedlings. This restores the diversity of species and spacing that supports more resilient and productive watershed functions.

We found 64% of all forests in these watersheds to be significantly degraded and at risk, meriting restoration. The efficiencies of dealing with such a high percentage of the forested land base comprehensively, as opposed to piecemeal or through periodic smaller scale operations, is clear, as the logistics of these operations—getting people, equipment, and materials into the watersheds—will be streamlined, and the benefits will be both cumulative and synergistic, rather than diluted over time.

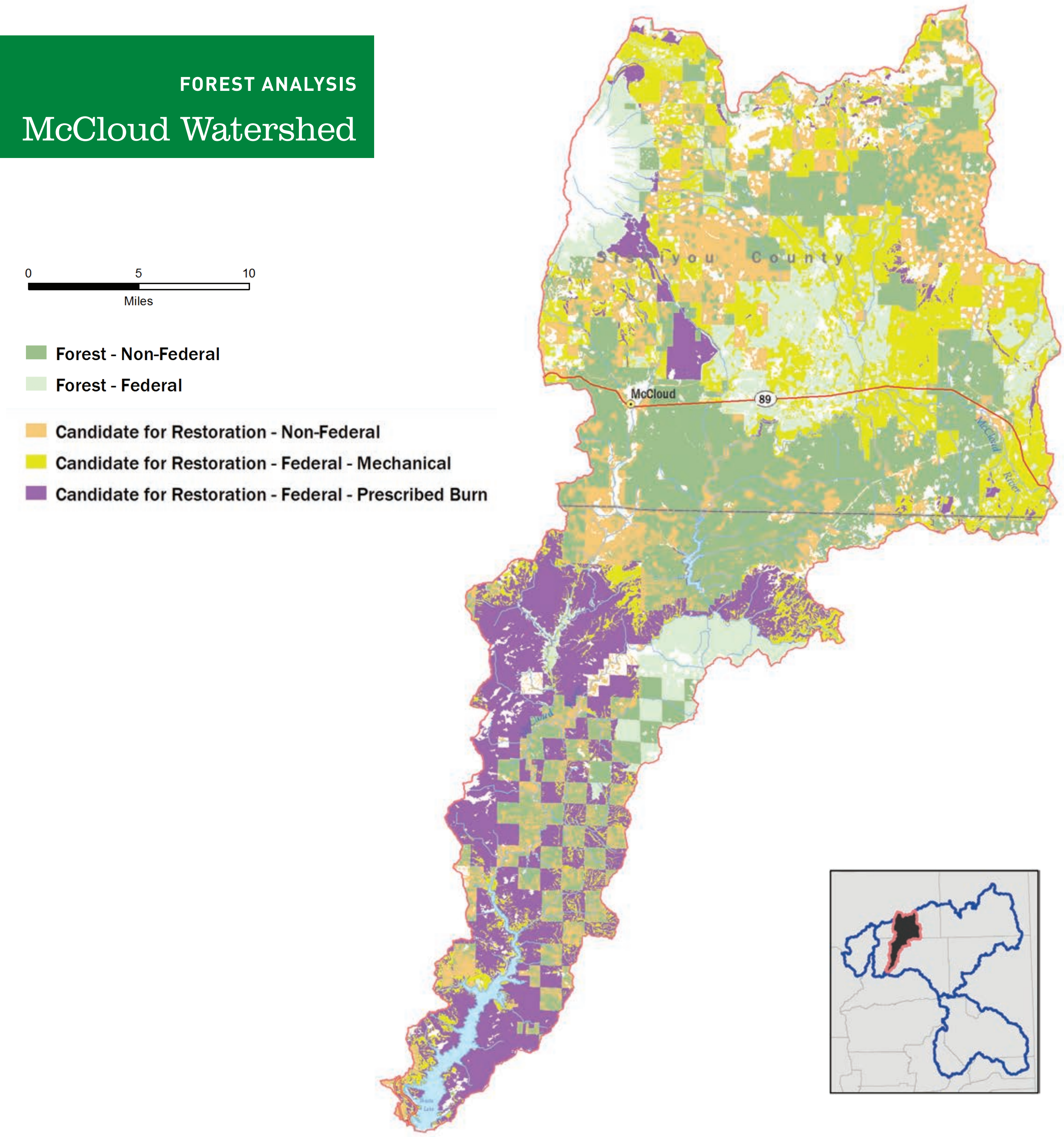
TABLE 2. Forest restoration *(acre targets in italics)*

	FEATHER	MCCLOUD	PIT	UPPER SACRAMENTO	UPPER TRINITY	TOTAL
	ACRES					
Federal Forestland Area	1,150,018	201,859	1,205,802	163,391	241,704	2,962,774
Candidate Acres for Mechanical Thinning Operations	*465,224*	*82,231*	*612,245*	*58,406*	*71,388*	*1,289,494*
Candidate Acres for Restoration via Prescribed Fire[i]	*757,727*	*154,155*	*822,005*	*145,216*	*217,999*	*2,097,102*
Non-Federal Forestland Area	539,972	184,766	739,607	145,922	117,755	1,728,022
Candidate Acres for Restoration	*285,354*	*65,687*	*412,077*	*81,864*	*69,451*	*914,433*
All Candidate Acres for Restoration	***1,043,081***	***219,842***	***1,234,082***	***227,080***	*287,450*	*3,011,535*

i The initial reduction of stand density achieved by thinning is then maintained by regular prescribed fire in subsequent years, rather than by an on-going thinning regime.

FOREST ANALYSIS

McCloud Watershed



Across all five watersheds, 64% of the forests were significantly degraded, posing major risks to watershed function. In the McCloud watershed, 220,000 acres of forests warrant restoration.

Meadows

Meadows, while small in area, are disproportionately important for watershed and ecological function as well as biodiversity.[29] Wet meadows and associated aspen stands host a more diverse array of species than surrounding forest habitat.[30,31,32]

Dry meadows provide vital forage and hunting grounds for adjacent forest wildlife.[33] Historically, Native Americans maintained meadows though frequent burning, using them extensively to cultivate and regenerate a number of native plants, as well as to maintain forage for game and open hunting areas. This meadow maintenance also helped water storage and flow regulation.

Over the past 150 years, meadows have become severely degraded. Grazing, combined with fire suppression, has altered the hydrology, plant species composition, and regeneration in meadows and aspen stands.[34,35,36] Fire suppression has allowed major conifer encroachment, which dries meadows up, a condition climate change exacerbates.[37,38] Logging, road construction, and direct stream manipulation such as channel straightening have also degraded wet meadow and aspen grove hydrology.[39,40]

Meadow and aspen restoration provides numerous benefits to overall watershed health and function.[41,42]

This time series of images demonstrates the effective restoration in meadows along the upper Fall River. The degraded and straightened dry channel in the upper left was transformed through bank stabilization and allowed to return to its natural channel shape, slowing water flows and raising water levels throughout the year.

Glaciers and annual snowfall on Mt. Shasta provide water into both meadows and springs that are crucial to ensuring cold water flows into Lake Shasta throughout the year. In some cases, glacial melt arises in springs many miles from Mt. Shasta before pouring forth in springs from underground lava tubes.

Conifer removal increases groundwater penetration and recharge as well as raising the water table.[43] Restoring wet meadows enhances storage of snowmelt and attenuates peak flows by up to 40%.[44] Combined, these actions reduce flood intensity and frequency;[45,46,47] improve summer water flow reliability;[48] reduce erosion;[49] and lower downstream temperatures[50] while increasing groundwater recharge and raising water tables.

Conifer removal and reintroduction of fire are key tools in the restoration of wet and dry meadows as well as forests.[51,52] Additionally, common wet meadow restoration activities include stream bank stabilization, channel reconstruction, check dam installation, grazing management, pond-and-plug treatment, and relocating unpaved roads and trails.[53] **We found 100% of dry meadows and 85% of wet meadows were candidates for restoration.**[ii]

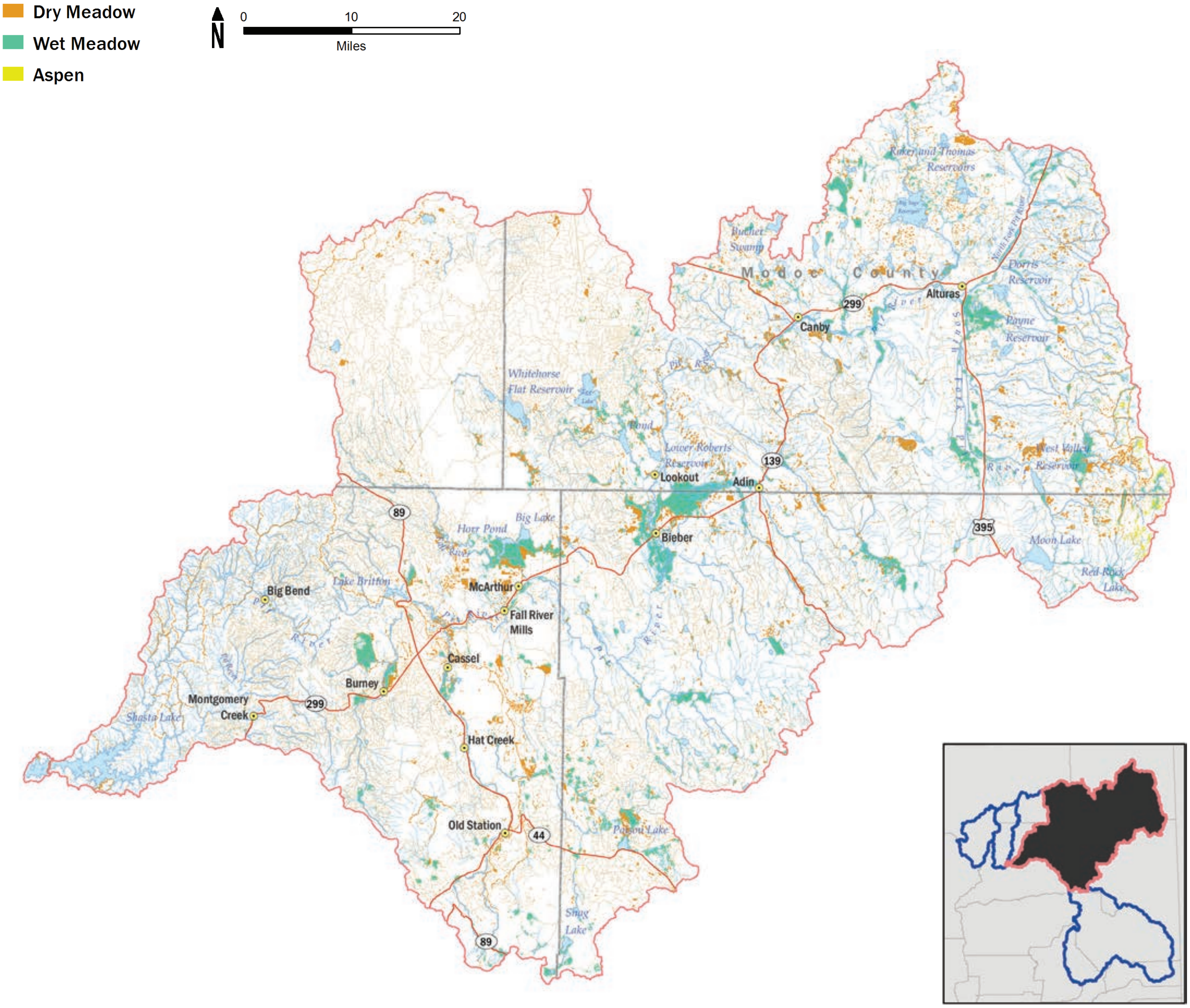
TABLE 3. Dry and wet meadow restoration

	FEATHER	MCCLOUD	PIT	UPPER SACRAMENTO	UPPER TRINITY	TOTAL
	ACRES					
Dry Meadows						
Federal	27,438	951	58,982	987	2,286	90,644
Candidates for Restoration	*27,438*	*951*	*58,982*	*987*	*2,286*	*90,644*
Non-Federal	38,123	1,400	55,357	2,123	1,422	98,425
Candidates for Restoration	*38,123*	*1,400*	*55,357*	*2,123*	*1,422*	*98,425*
Total	***65,561***	***2,351***	***114,339***	***3,110***	***3,708***	***189,069***
Wet Meadows						
Federal	18,332	234	51,177	520	2,230	72,493
Candidates for Restoration	*15,582*	*199*	*44,148*	*442*	*1,895*	*62,266*
Non-Federal	66,926	1,278	94,997	1,716	649	165,568
Candidates for Restoration	*56,887*	*1,087*	*80,759*	*1,459*	*552*	*140,744*
Total	***72,469***	***1,286***	***124,907***	***1,901***	***2,447***	***203,010***

ii This is exclusive of the miles of streams in wet meadows, which are included in the streams section.

WET AND DRY MEADOW ANALYSIS

Pit Watershed



Across all watersheds, 393,000 acres of wet and dry meadow were significantly degraded, posing major risks to watershed function. In the Pit watershed, the state's largest groundwater supply, 240,000 acres of wet and dry meadow, warrant restoration.

Streams

Channel integrity is essential for the ecological function of streams and adjacent habitats.[54] It is also critical for the production of clean, cool water supplies downstream.

Roads and grazing are the most significant factors in degraded stream channel integrity. Trail impacts may also be significant in areas where trails impact streams in wet meadows.[55] Grazing impacts on streams are well documented, including denuding streambanks of vegetation, raising stream temperature, reducing streambank stability, increasing soil erosion, and increasing phosphorous concentrations.[56,57,58] Managing grazing and restoring degraded channels restores clean, cool water supplies to downstream users and adjacent riparian habitat. Herd management (e.g., timing and intensity of grazing) and exclusionary fencing are also key tools for channel restoration and protection.[59,60,61]

Fires exacerbate soil erosion, which is already a leading cause of water pollution. Sediment delivery in streams post-fire is largely affected by rainfall intensity. Increases in soil erosion during major precipitation events can heavily impact reservoirs and dams, such as with the 2017 flooding over Oroville Dam. Such sediment transport into reservoirs can also reduce their storage capacity."

We analyzed and identified stream segments affected by unpaved roads, trails, and grazing. **We found that 10,513 stream miles overall merited restoration**, with the large majority of impacts due to roads (see next section).

Stream channel restoration in the McCloud River watershed demonstrates the increased and later season retention of water as well as increased groundwater infiltration.

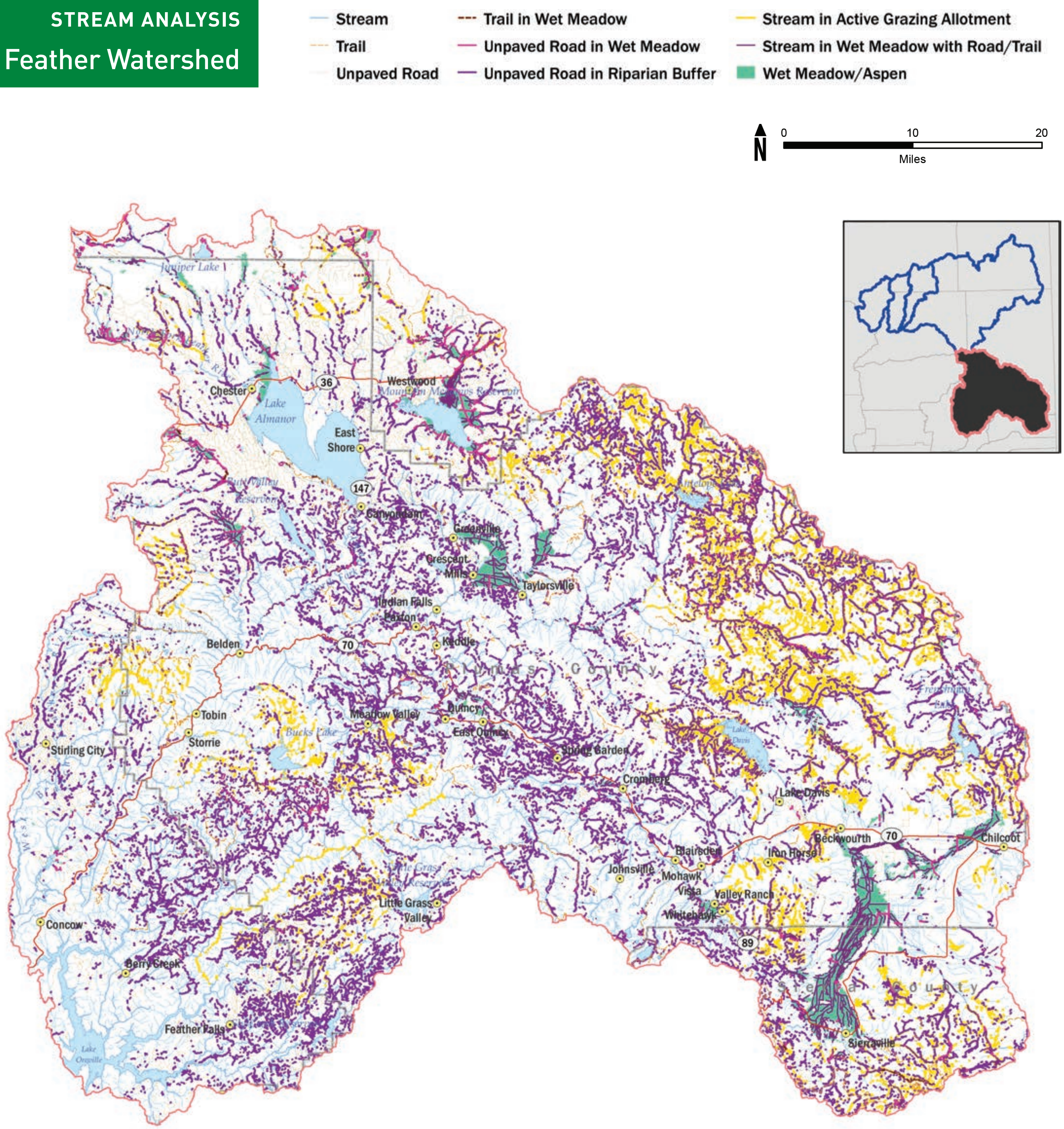
Sediment increases from erosion after high-intensity fires such as the Rim Fire, pictured left showing sediment deposit post-fire, is a major concern for downstream water users with major impact on water quality as well as reservoir storage capacity and hydro-electric facilities. Grazing impacts in stream zones also can break down channel banks, causing sedimentation (pictured right).

TABLE 4. Stream restoration

	FEATHER	MCCLOUD	PIT	UPPER SACRAMENTO	UPPER TRINITY	TOTAL
	ACRES					
Trails in Wet Meadows Containing Streams						
Federal	6	1	10	1	7	25
Non-Federal	1	0	1	1	1	4
Total	***7***	***1***	***11***	***2***	***8***	***29***
Unpaved Roads in Wet Meadows Containing Streams						
Federal	53	1	136	1	7	198
Non-Federal	75	4	153	5	2	239
Total	***128***	***5***	***289***	***6***	***9***	***437***
Unpaved Roads in Stream Buffers						
Federal	1,664	119	819	113	239	2,954
Non-Federal	931	310	986	292	277	2,796
Total	***2,595***	***429***	***1,805***	***405***	***516***	***5,750***
Streams in Wet Meadows with Roads/Trails						
Federal	360	4	375	11	32	782
Non-Federal	568	15	765	13	10	1,371
Total	***928***	***19***	***1,140***	***24***	***42***	***2,153***
Streams in Active Grazing Allotments						
Federal	448	22	1,134	4	8	1,616
Non-Federal	124	12	389	0	3	528
Total	***572***	***34***	***1,523***	***4***	***11***	***2,144***

STREAM ANALYSIS

Feather Watershed



Across all watersheds, over 10,510 miles of stream were significantly degraded, posing major risks to watershed function. Over 4,230 miles of streams in the Feather River watershed warrant restoration.

Roads

Roads, especially unpaved roads, significantly impair water quality.[62,63] Erosion from unpaved roads, resulting in both chronic and episodic sediment delivery, is one of the most significant sources of water quality impairment in California's managed forested watersheds.[64]

Sedimentation can also lead to in-stream habitat alteration, channel incision, and sediment loading in reservoirs. Although surface erosion causes much of the degradation, increased runoff and surface flow from roads also cause stream channel incisions. Problematic roads include those near streams[65] and those with long uninterrupted segments,[66] especially with steeper grades.[67] Unpaved roads in areas with high road densities contribute to cumulative effects, including sedimentation, that result in poorer watershed health.[68] Road densities above two miles per square mile indicate degraded watershed function and are detrimental to fish.[69,70,71] **These source watersheds have 29,000 miles of unpaved roads with densities above 2.6 miles per square mile, indicating significant impairment.**

Two key tools can improve road conditions and reduce erosion: road upgrading (re-contouring, improving culverts and ditches, rocking) and decommissioning unnecessary roads. Realigning roads that intersect wet meadows with streams or within stream buffers is another tool, discussed in the previous section.

A total of 3,733 miles of roads were identified as candidates for upgrading, decommissioning, and realignment. Of this, the U.S. Forest Service recommended decommissioning 394 miles on federal lands only. Private lands may have roads that merit decommissioning, but no data are currently available. As such, this is a conservative estimate.

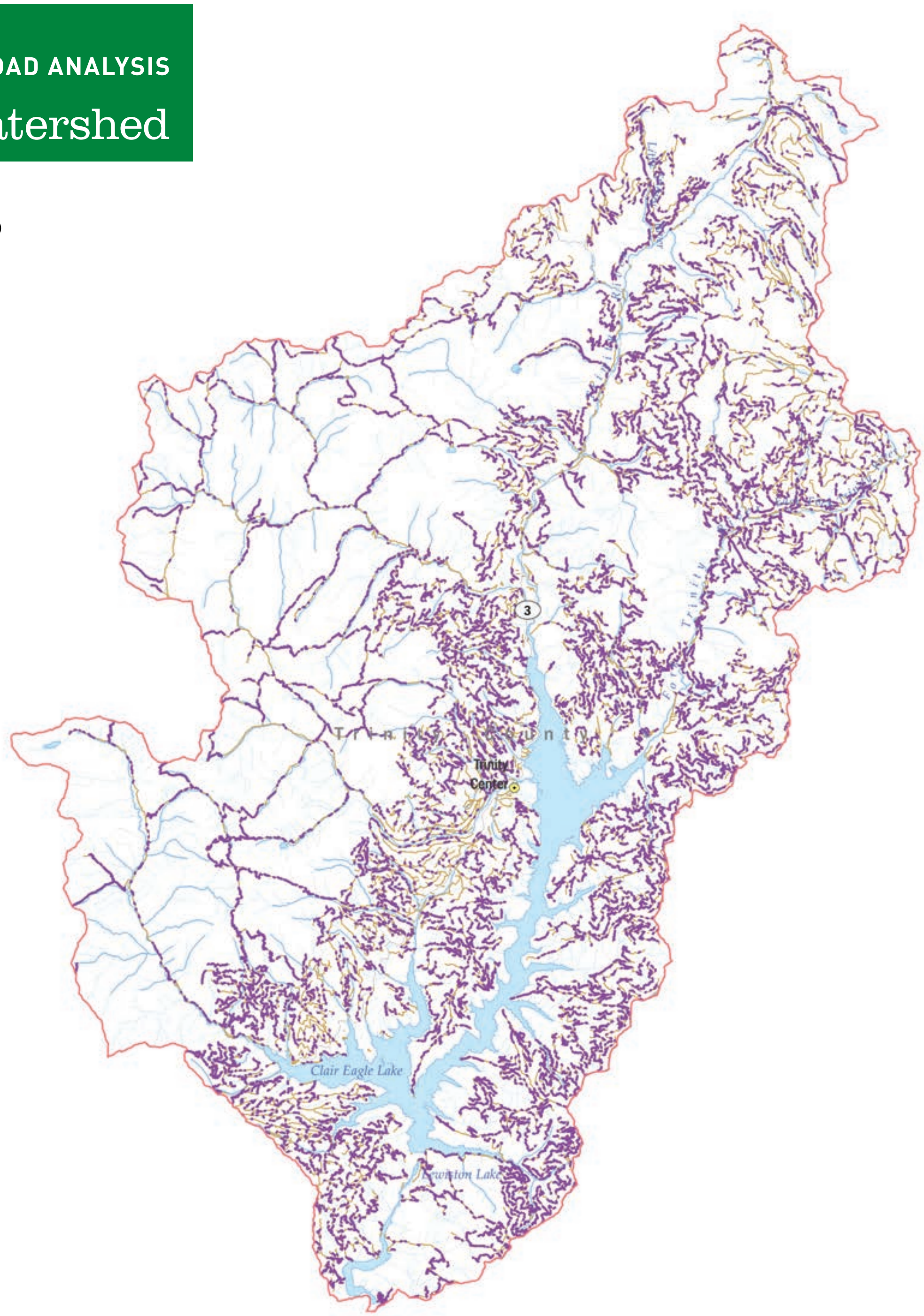
Unpaved roads, especially those adjacent to streams, such as here in the Trinity watershed, often fail after major rain and flood events, adding to erosion and sediment delivery.

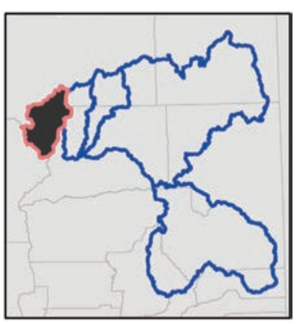
TABLE 5. Results from analysis of candidate sites for road upgrading and decommissioning

	FEATHER	MCCLOUD	PIT	UPPER SACRAMENTO	UPPER TRINITY	TOTAL
	MILES					
Unpaved Roads >10% Grade for >200 ft						
Federal	483	88	368	139	251	1,329
Non-Federal	507	237	561	378	327	2,010
Total	***990***	***325***	***929***	***517***	***578***	***3,339***
Unpaved Roads Recommended for Decommissioning						
Federal	198	46	65	30	55	394
Non-Federal	n/a	n/a	n/a	n/a	n/a	n/a
Total	***198***	***46***	***65***	***30***	***55***	***394***

ROAD ANALYSIS

Upper Trinity Watershed





Across all watersheds, a total of 29,000 miles of unpaved roads have an average of 2.6 miles per square mile, posing major risks to watershed function. In the Upper Trinity River watershed (illustrated above), 550 miles of road warrant upgrading or decommissioning.

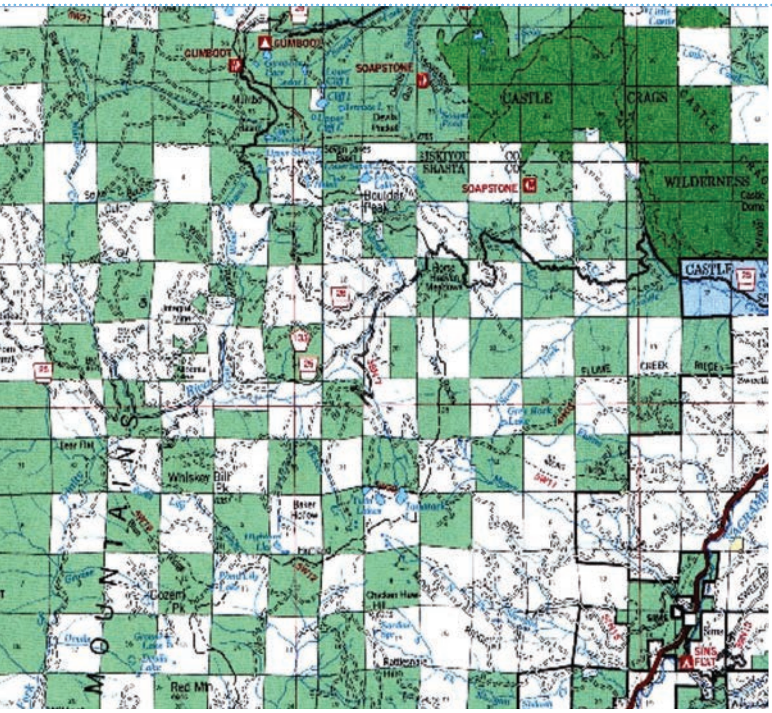
Watershed Integrity

Watershed integrity, or intactness, is an essential factor in watershed function.[72,73] The ability to effectively restore and maintain watershed health and resilience over time depends on the integrity of the natural land base.

Fragmentation by roads and management styles, development, removal of land cover, and conversion to agriculture impact watershed integrity and function. Watershed function is known to be adversely impacted when more than 10% of its area becomes impervious.[74,75] Retention of forest cover and undisturbed soil may be even more critical to limiting degradation of stream hydrology and watershed condition.[76] The proportion of forest cover and agricultural use within a watershed also affects watershed condition and function; reduction of forest cover by 25–35% leads to severe degradation.[77,78] Conversion of 50% or more to agriculture significantly impacts stream function and quality.[79] While none of the source watersheds in toto currently approach these thresholds, there are certain sub-basins and smaller tributaries that may. Forest cover can be regenerated as long as the land base is maintained in forest use. Maintaining current forest use, reducing risks of cover type conversion, and preventing further fragmentation and land use conversion are the key activities that will promote watershed integrity.

We targeted a goal of retaining 85% of the land base in forest or other natural land use, including 62% of the watershed area in public ownership. **Protecting an additional 20% through partnerships with willing private landowners would ensure watershed integrity** and function is maintained for

The Feather River watershed demonstrates the fragmentation in land management approaches between private (left) and public (right) lands. The amount of forest cover significantly affects infiltration of precipitation, as well as the amount of runoff and sedimentation.



Checker-boarded ownership patterns can result in highly fragmented vegetation cover, as well as conversion and forest loss. Easy road access, such as along a major interstate or highway, can lead to increased development pressure, with a tripling of cost for community services for rural residential development over that for working lands. The aerial imagery on the right reflects the map pattern on the left.

future generations. Conservation easements on working lands are the most common tool for private land protection while keeping the land in private ownership. This preserves the potential for healthy watershed function and enables restoration gains to be maintained, while also keeping lands in production and on tax roles, an important factor in rural areas. Such conservation easements limit future fragmentation and development, set management goals to maintain or restore watershed function, and limit widespread land conversion. Conservation easements have been used in many watershed protection programs, such as in the New York City watershed, and are identified as the preferred protection tool under California law.[80]

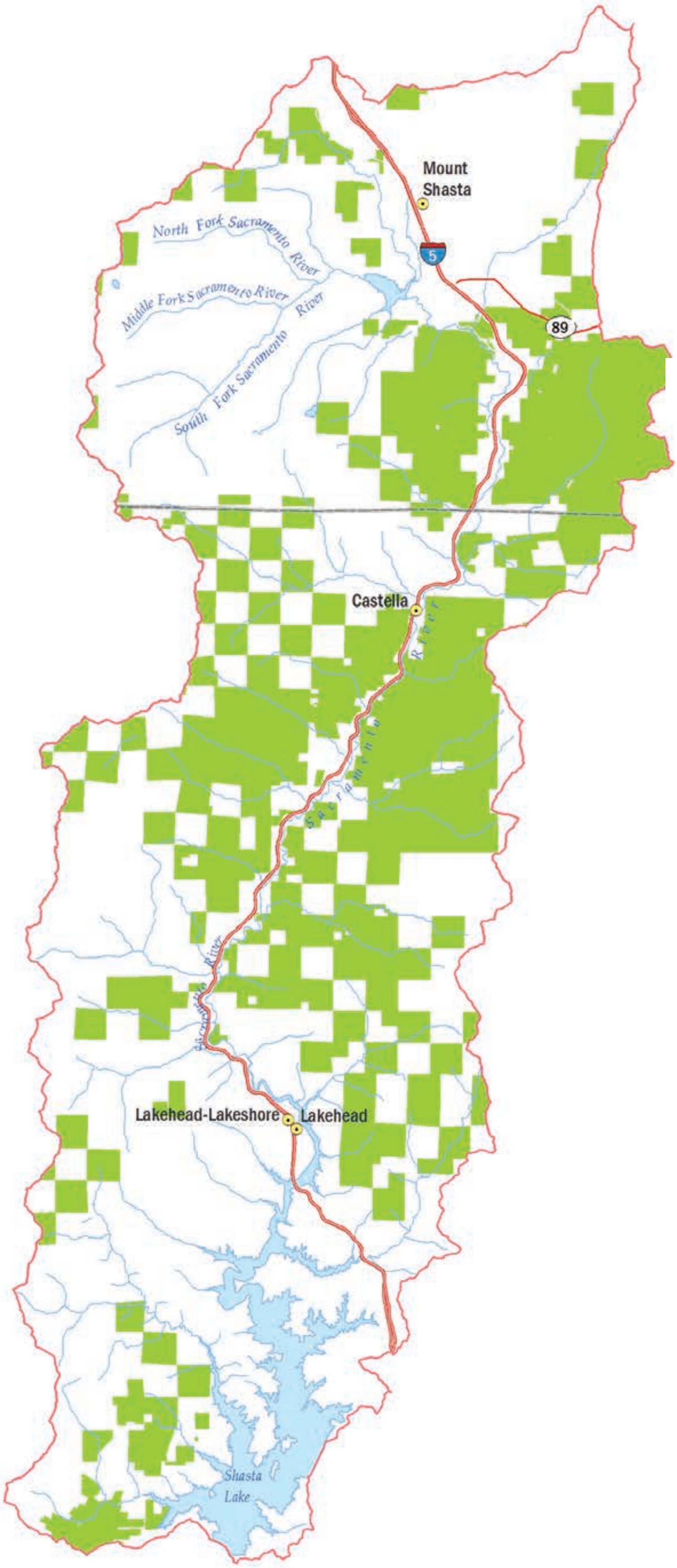
Based on county parcel data, we analyzed private ownerships greater than 500 acres in each watershed, focusing on larger ownerships for more impact and lower cost per project. Parcels already under conservation easement or owned by nonprofit conservation organizations were removed from consideration.

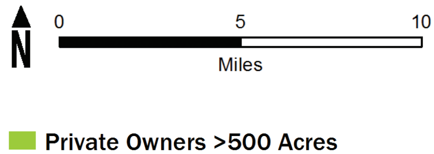
TABLE 6. Watershed integrity, acres for conservation

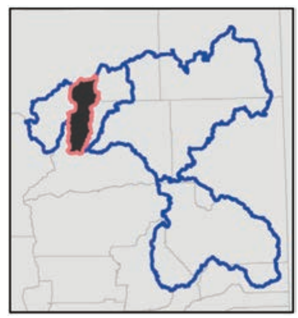
	FEATHER	MCCLOUD	PIT	UPPER SACRAMENTO	UPPER TRINITY	TOTAL
Total Acres in Watershed	2,306,520	435,730	3,404,207	378,906	459,884	6,985,247
% Public Ownership	65%	53%	61%	57%	70%	62%
Acres Private Ownerships >500 Acres	538,410	192,810	1,082,917	119,955	122,573	2,056,665
Private Acres Already Conserved	37,816	28,819	32,896	2,104	2	101,637
Total Acres to Conserve as Watershed	***414,202***	***110,137***	***775,775***	***105,330***	***66,859***	***1,472,303***

WATERSHED INTEGRITY ANALYSIS

Upper Sacramento Watershed







Across all watersheds, protecting a further 20% of the land base, and dedicating these lands to be managed as watersheds, would ensure their functional integrity. Conserving 100,000 acres would achieve this goal in the Upper Sacramento watershed (left).

Conclusions

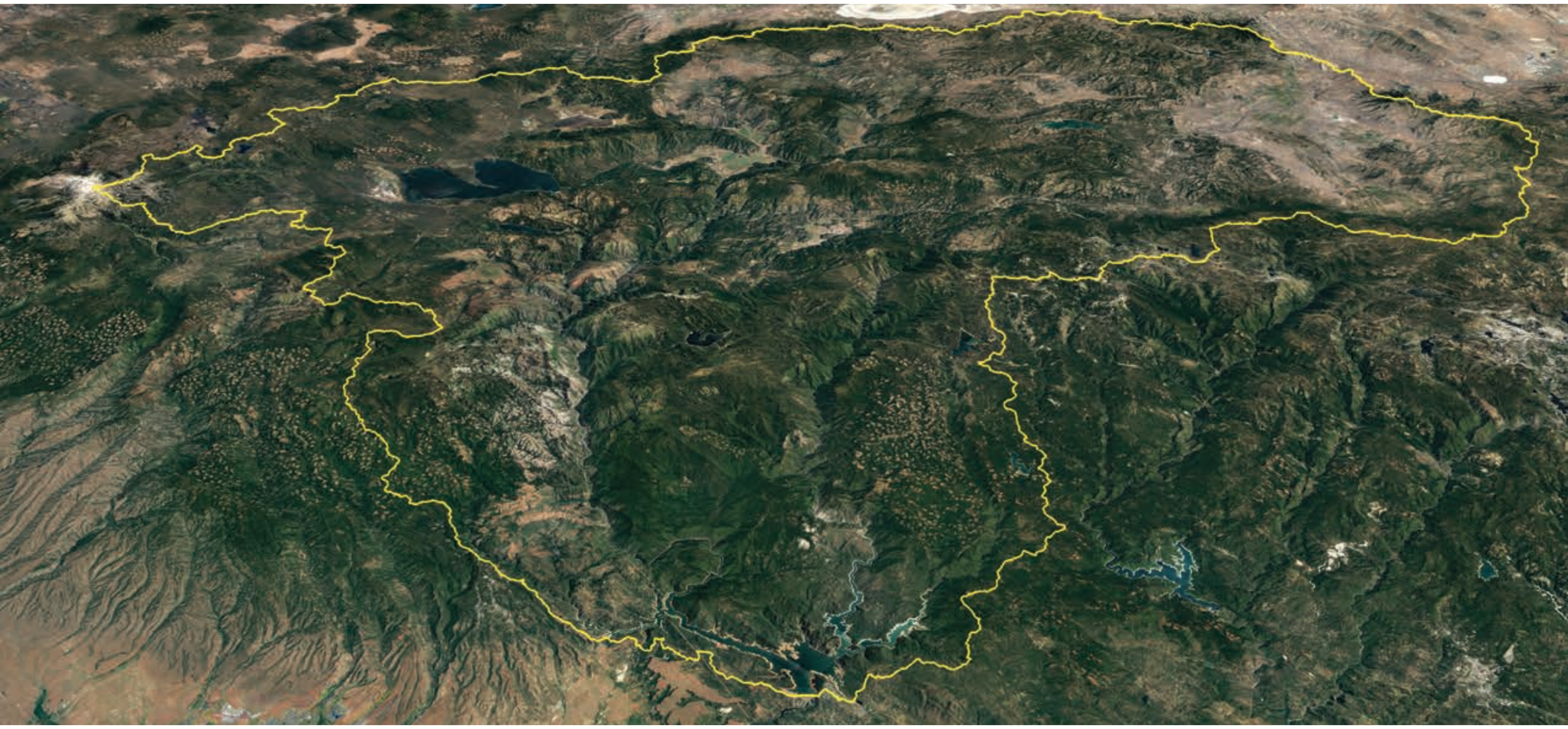
Virtually half (49%) of the source watersheds that supply the two largest reservoirs in California's water system are in degraded condition, creating significant costs and risks for the state and all who rely on these water and related hydropower supplies.

High-intensity, large-scale fires and floods over the past several decades, such as the 2012 and 2014 Rush and Happy Camp fires, and the 2017 Oroville flooding, have cost billions of dollars and put many communities at risk. Poor watershed condition has led to diminished water quality, supply, and reliability. This latter factor, which includes reduced and warmer summer flows, also creates increased challenges for agricultural planning as summer flows are particularly important for many crops as well as environmental needs such as cool and sufficient water for fish. Reducing these risks can be cost-effectively done through improving the condition and function of source water infrastructure. This will require a significant change in how we address the repair and maintenance of source watersheds, planning and implementing these as comprehensive infrastructure improvement projects, rather than the traditional piecemeal, scattered, small-scale individual projects. Doing so would benefit California's water system enormously with outcomes including increases in natural storage and summer flows as well as improved reliability of flows and likely increases in overall quantity. Conservatively estimating these in the 3–5% range, and based on average water deliveries over the 10 years of 2005–2014,[81,82,83] we calculate that restoring natural water infrastructure in these five watersheds could yield an average of 300,000 acre feet, almost 100 trillion gallons of water, annually. It could also reduce peak flooding, such as the 2017 flooding disaster from the overflow of the Oroville Dam, by up to 40%.[84] Benefits to water and hydropower suppliers and users include reduced risk and improved reliability of supply predictions.

Implementing an infrastructure project on this scale would require significant labor, creating and sustaining thousands of jobs in rural California, benefitting state, regional, and local economies. There are also significant gains for the state in terms of improved resilience and adaptation under climate change, benefitting habitats for a suite of fish and wildlife species as well as for people. These are substantial co-benefits, over and above the increased reliability and predictability of flows overall (especially those cooler summer flows) and decreased risk to existing water and hydropower supplies—as well as decreased disaster costs.

Climate change is exacerbating the extremes in weather variability and concomitant stresses on forest watersheds, such as this tree mortality (left). Supporting natural forest conditions and processes helps re-establish more resilient watershed function and greater water security.

Watersheds are areas defined by mountains and high ridges of land that determine the direction water flows. California's key watersheds are dominated by two volcanic mountains, Mounts Shasta and Lassen. These are the major sources for the five rivers which feed the Shasta and Oroville reservoirs: the Upper Trinity, Upper Sacramento, McCloud, Pit, and Feather. Mount Shasta's glacial melt flows both into vast volcanic tubes that surface in a massive spring miles away, feeding the Pit and McCloud Rivers, as well as into the McCloud and Sacramento Rivers. Mount Lassen feeds the Feather River, providing the large majority of that river's total flows.



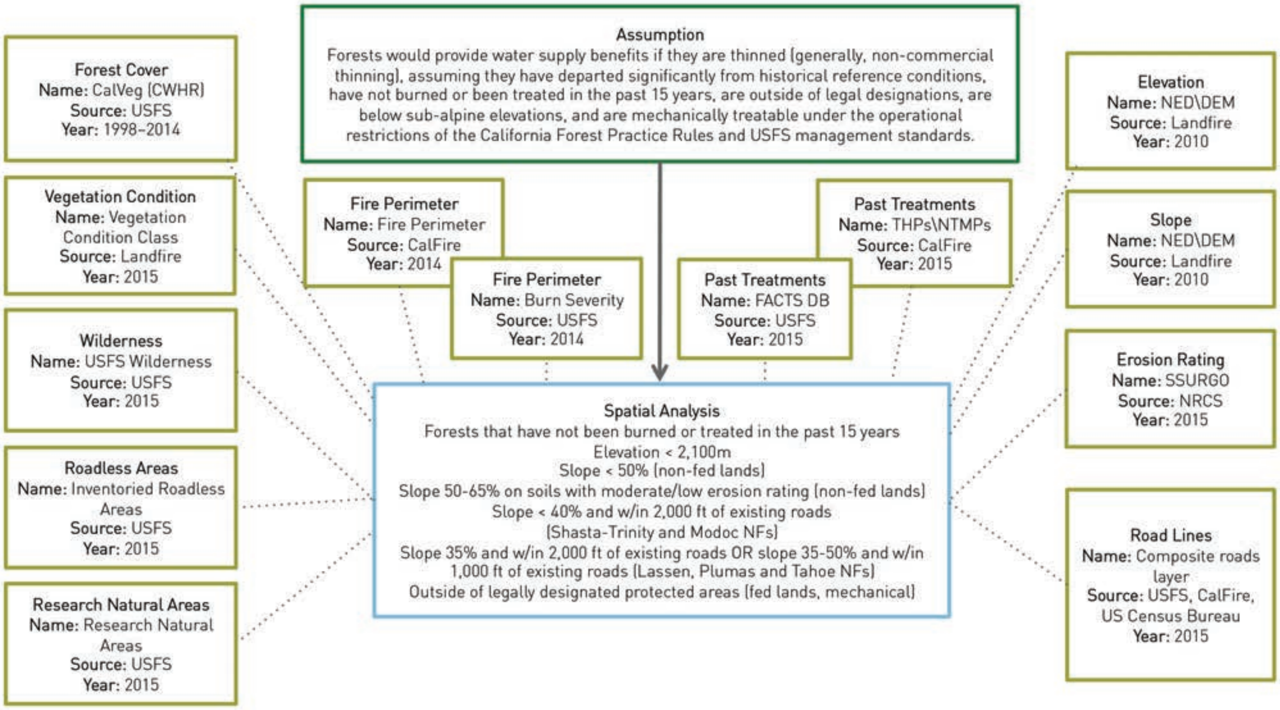
With such large areas feeding the core of the state's water system, such as the Lake Oroville watershed pictured here, restoration and conservation needs to be implemented comprehensively at the landscape scale to be effective and yield the improvements in function that can reduce the risks of further declines in productivity. This will also reduce the risks of catastrophic events and threats to the water and hydropower systems such as from the 2017 floods which forced a shutdown of the Oroville facility, or future infernos similar to those of the Rim, Happy Camp or Bagley fires. Equally, implementing the suite of restoration techniques in meadows, forests, and streams across the landscape increases the range of water benefits achieved. These include increased infiltration and groundwater storage, restored flow regimes, reduced sedimentation and enhanced water quality. Combined, these greatly promote resilience and enhance water security in a rapidly changing climate.

Appendix: Analysis, Data Sources, Assumptions and Flow Charts

FORESTS

CONDITIONS ADDRESSED	DATA CATEGORY	DATA GENERAL DESCRIPTION	DATA SOURCE	ASSUMPTION(S) APPLIED
FOREST MANAGEMENT — OVERLY DENSE STANDS WITH SIMPLIFIED STRUCTURE AND COMPOSITION	Restoration Target	Forest cover	Existing Vegetation — CALVEG/WHR	All forest-based WHR Lifeforms included Canopy cover >10%
	Restoration Need	Vegetation Condition Class	Landfire Vegetation Condition Class	Condition classes 2 and 3 (moderate and high departures, respectively, from simulated historical reference conditions) are in an over-dense condition, for which thinning/fuel reduction would provide watershed benefits
		Fire Perimeters, based on fire intensity	USFS Vegetation Burn Severity — % Change in Canopy Cover (2014 v3) CalFire Fire Perimeters database (2014 v2)	Areas where fires occurred prior to 2000 would be suitable for treatment. Areas with canopy cover loss >50% are not in need of additional thinning to produce watershed benefits. Burn severity polygons not assigned specific canopy cover loss value due to cloud cover or other reasons were assumed to have >50% canopy cover loss. CalFire fire perimeters outside of burn severity data perimeters were assumed to have >50% canopy cover loss.
		Previously treated sites — federal	USFS FACTS Database (Regional Activities in the Past 20 Years)	Areas where treatment occurred prior to 2000 are suitable for restoration. Areas where treatment is planned for future or occurred since 2000 are not suitable for restoration if prescribed treatment would or did significantly reduce canopy cover/ fuels.
		Previously treated sites — non-federal	CalFire THP/NTMP database	Areas where treatment occurred prior to 2000 are suitable for restoration. Areas where treatment is planned for future or occurred since 2000 are not suitable for restoration if prescribed treatment would or did significantly reduce canopy cover/ fuels.
	Availability for Treatment	Elevation — federal and non-federal	USGS NED/DEM	Subalpine conifer stands (>2100m) are not treated for fuel reductions
		Slope — federal	USGS NED/DEM	Mechanical treatments are only applied to federally managed areas with slopes <35% in Feather watershed, Lassen NF, and Lassen NP, and to areas with slopes <40% on all other federal lands in study area. Prescribed burns are applied to all slopes.
		Slope — non-federal	USGS NED/DEM	Mechanical treatments are only applied to areas with slopes <50% on non-federal lands or slopes 50–65% with non-severe Erosion Hazard Rating (assumed equivalent to CalFire "high" and "extreme" ratings). Prescribed burns are applied to all slopes.
		Erosion Hazard Rating — non-federal	NRCS SSURGO	Mechanical treatments applied to areas with slopes 50–65% and non-severe Erosion Hazard Rating (assumed equivalent to CalFire "high" and "extreme" ratings).
		Legal Designations	USFS — Research Natural Areas — Inventoried Roadless Areas — Wilderness Areas	Prescribed burning could occur in areas where other management activities are generally prohibited, such as wilderness areas, Research Natural Areas and Inventoried Roadless Areas where road construction is prohibited.

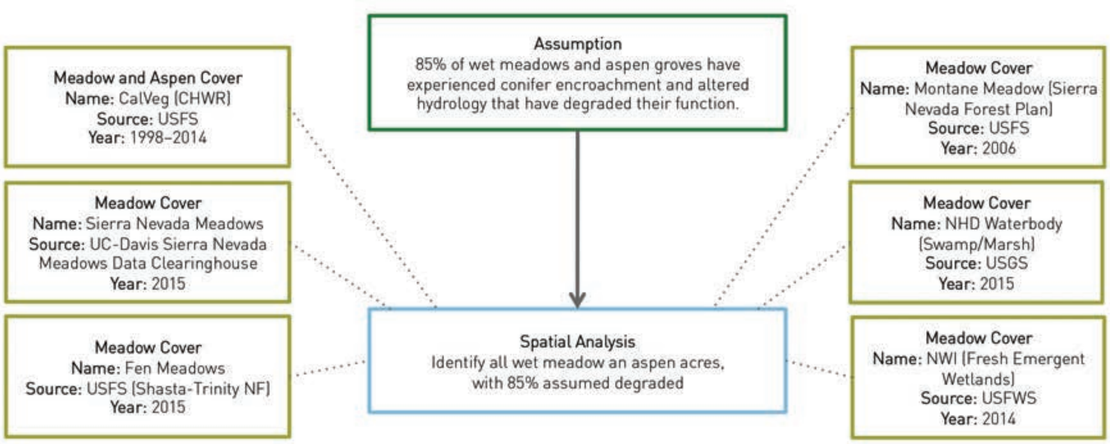
FOREST MANAGEMENT



MEADOWS

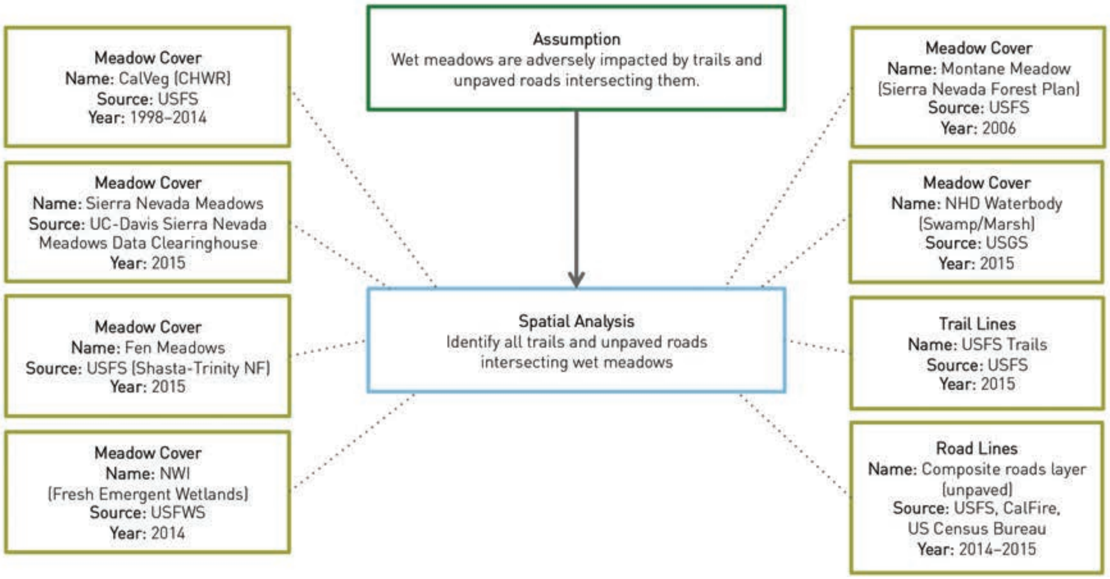
CONDITIONS ADDRESSED	DATA CATEGORY	DATA GENERAL DESCRIPTION	DATA SOURCE	ASSUMPTION(S) APPLIED
WET AND DRY MEADOWS AND ASPEN STANDS — ENCROACHED BY CONIFERS	Restoration Target	Dry Meadow	Existing Vegetation — CALVEG/WHR	WHR Type = annual grassland, perennial grassland (and not classified as forest under Anderson classification)
		Dry Meadow	Sierra Nevada Forest Plan Montane Meadow Vegetation	All dry meadow types are eligible targets
		Aspen	Existing Vegetation — CALVEG/WHR	WHR Type = aspen
		Wet Meadow	Existing Vegetation — CALVEG/WHR	WHR Type = wet meadow, fresh emergent wetland
		Wet Meadow	UC-Davis Sierra Nevada Meadows Data Clearinghouse	All meadow polygons are eligible targets
		Wet Meadow	USFS Shasta-Trinity NF Fen Meadow dataset	All fen polygons are eligible targets
		Wet Meadow	USGS National Hydrography Dataset (NHD) Waterbodies	Areas identified as swamp/marsh areas in the NHD are assumed to be meadows
		Wet Meadow	USFWS National Wetlands Inventory (NWI)	Areas identified as freshwater emergent wetlands in the NWI are assumed to be meadows
		Wet Meadow	Sierra Nevada Forest Plan Montane Meadow Vegetation	All wet meadow types are eligible targets
	Restoration Need	Conifer Encroachment	USFS et al. 2015 and adjusted to source watersheds according to expert opinion (M. Coppoletta and R. Posey)	USFS personnel estimated that 100% of dry meadows and 85% of wet meadows and aspen have conifer encroachment in these source watersheds; 63% of all Sierra Nevada wet meadows are encroached.
	Availability for Treatment		See assumptions	All areas assumed available for treatment.

WET MEADOWS/ASPEN



CONDITIONS ADDRESSED	DATA CATEGORY	DATA GENERAL DESCRIPTION	DATA SOURCE	ASSUMPTION(S) APPLIED
WET MEADOWS — ALTERED HYDROLOGY VIA INCISED CHANNELS	Restoration Target	Wet Meadow	See data sources for "Wet and Dry Meadows and Aspen Stands — Encroached by Conifers"	
		Unpaved Roads	USFS Transportation System Roads	Roads identified as having unpaved surface types
		Unpaved Roads	CalFire Timber Harvest Roads	Excludes roads identified as primary and secondary roads. "Existing Permanent" road segments are assumed unpaved unless within Incorporated or Census Designated Places and inspection of satellite imagery clearly revealed paved surface.
		Unpaved Roads	US Census Bureau TIGER/Line files	Roads not coincident with USFS and CalFire roads data were assumed unpaved unless inspection of satellite imagery clearly revealed paved surface.
		Trails	USFS Transportation System Trails	All trails included.
		Streams	USGS NHD streams	Streams in wet meadows with unpaved roads in or adjacent to them experience degradation caused by such roads.
	Restoration Need	Channel Incision — Observed rate reported in literature, modified based on proportion of meadows intersected by streams and unpaved roads or trails	USFS et al. 2015 and results from "Wet Meadows — Altered Hydrology Resulting from Unpaved Roads" and "Wet Meadows — Altered Hydrology Resulting from Trails" analysis	Assumed 76.5% of stream segments in wet meadows are degraded with incised channels, based on the average of the proportion of surveyed meadows reported as having incised channels (70%) and proportion of meadows determined to have both streams and unpaved roads/trails intersecting them (83%). Wet meadows in study area are assumed to be experiencing the same proportional rate of degradation as observed in surveyed Sierra Nevada meadows.
	Availability for Treatment		See assumptions	All stream segments assumed available for treatment.

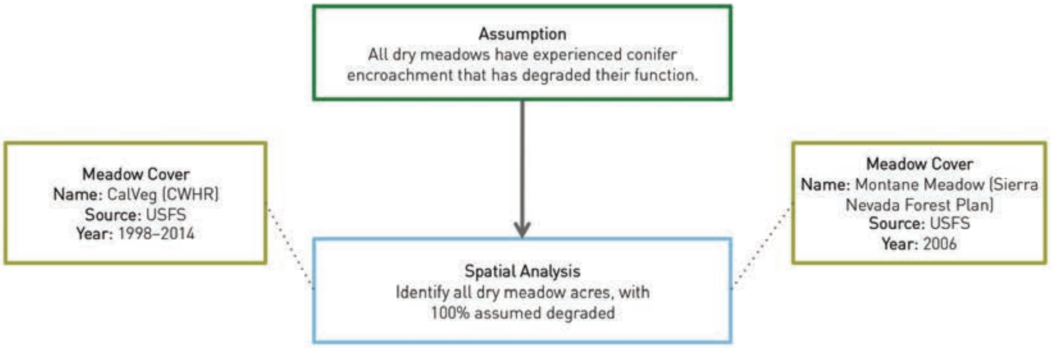
DRY MEADOWS/WET MEADOWS — ROADS AND TRAILS



MEADOWS

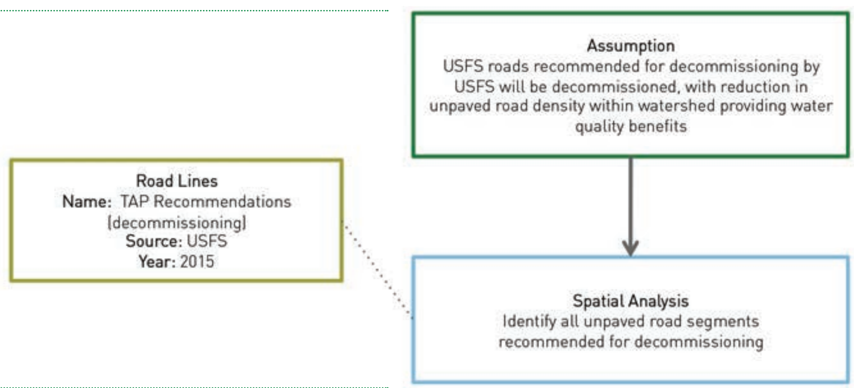
CONDITIONS ADDRESSED	DATA CATEGORY	DATA GENERAL DESCRIPTION	DATA SOURCE	ASSUMPTION(S) APPLIED
WET MEADOWS — ALTERED HYDROLOGY RESULTING FROM UNPAVED ROADS	Restoration Target	Unpaved Roads	See data sources for "Wet Meadows — Altered Hydrology via Incised Channels"	Unpaved roads impact hydrological conditions of wet meadows when they are in or adjacent to them.
		Wet Meadows	See data sources for "Wet and Dry Meadows and Aspen Stands — Encroached by Conifers"	
	Restoration Need		See assumptions	All roads in wet meadows are causing adverse hydrological impacts.
	Availability for Treatment		See assumptions	All road segments assumed available for treatment.
WET MEADOWS — ALTERED HYDROLOGY RESULTING FROM TRAILS	Restoration Target	Trails	USFS Transportation System Trails	Trails impact hydrological conditions of wet meadows when they are in or adjacent to them.
		Wet Meadows	See data sources for "Wet and Dry Meadows and Aspen Stands — Encroached by Conifers"	
	Restoration Need		See assumptions	All trails in wet meadows are causing adverse hydrological impacts.
	Availability for Treatment		See assumptions	All trails are available for treatment.

DRY MEADOWS

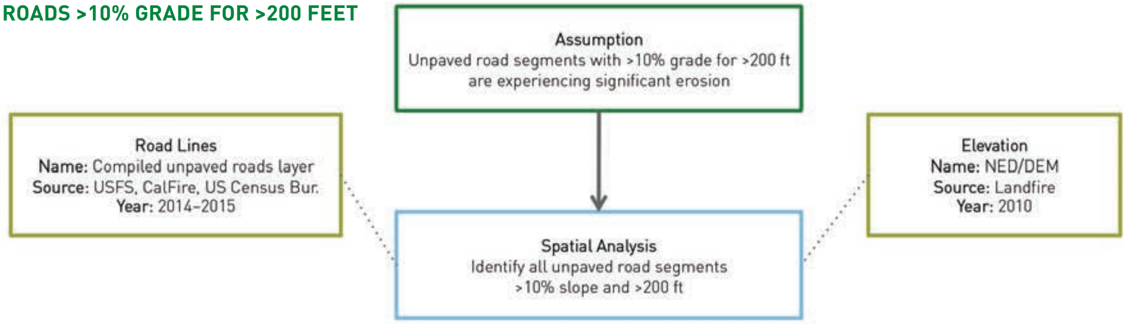


CONDITIONS ADDRESSED	DATA CATEGORY	DATA GENERAL DESCRIPTION	DATA SOURCE	ASSUMPTION(S) APPLIED
UNPAVED ROADS — ADVERSELY IMPACTED WATER QUALITY VIA SEDIMENT DELIVERY	Restoration Target	Unpaved roads — federal	USFS TAP Recommendations	Road segments evaluated by USFS for future use/non-use.
		Unpaved roads — all	See data sources for "Wet Meadows — Altered Hydrology via Incised Channels"	
	Restoration Need	Unpaved federal roads recom- mended for decommissioning	USFS TAP Recommendations	Decommissioning of sites recommended by USFS would reduce unpaved road density, providing benefits related to cumulative impacts.
		Unpaved roads (federal and non-federal) that are >200 ft long and >10% slope	Derived from: Unpaved roads layer (as described above) USGS NED (used to derive slope)	Unpaved roads that are >200 ft long with >10% slope have more erosion problems that impact water quality.
		Stream buffers	Derived from USGS NHD Streams	Unpaved roads in stream buffers have direct impact on water quality. Regardless of ownership, stream buffers from Northwest Forest Plan applied to all streams within Northwest Forest Plan boundaries and buffers from Sierra Nevada Forest Plan Amendment applied to all streams not within Northwest Forest Plan boundaries. Unclassified perennial streams are assumed to be fish-bearing/Class I.
	Availability for Treatment		See assumptions	All unpaved roads are available for treatment.

ROADS RECOMMENDED FOR DECOMMISSIONING



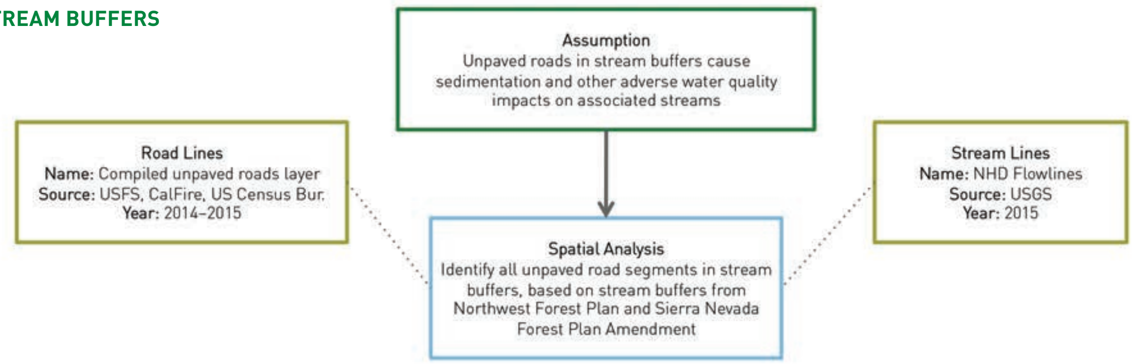
ROADS >10% GRADE FOR >200 FEET



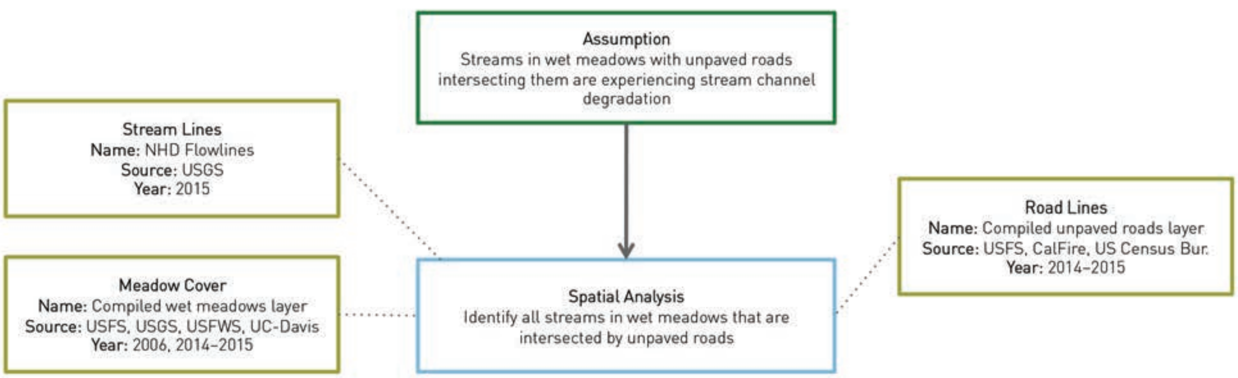
STREAMS

CONDITIONS ADDRESSED	DATA CATEGORY	DATA GENERAL DESCRIPTION	DATA SOURCE	ASSUMPTION(S) APPLIED
STREAM CHANNELS — ADVERSELY IMPACTED FROM LIVESTOCK GRAZING	Restoration Target	Streams	USGS NHD streams	Perennial and intermittent streams in active grazing allotments experience degradation as livestock access streams. Ephemeral streams not included.
		Federal grazing allotments	USFS R5 Grazing Allotments BLM Grazing Allotments	Active grazing allotments are being grazed by livestock with access to streams.
	Restoration Need	Forest cover	Existing Vegetation — CALVEG/WHR	Canopy cover <60%
		Slope	USGS NED/DEM	Slope <20%
	Availability for Treatment		See assumptions	All streams are available for treatment.

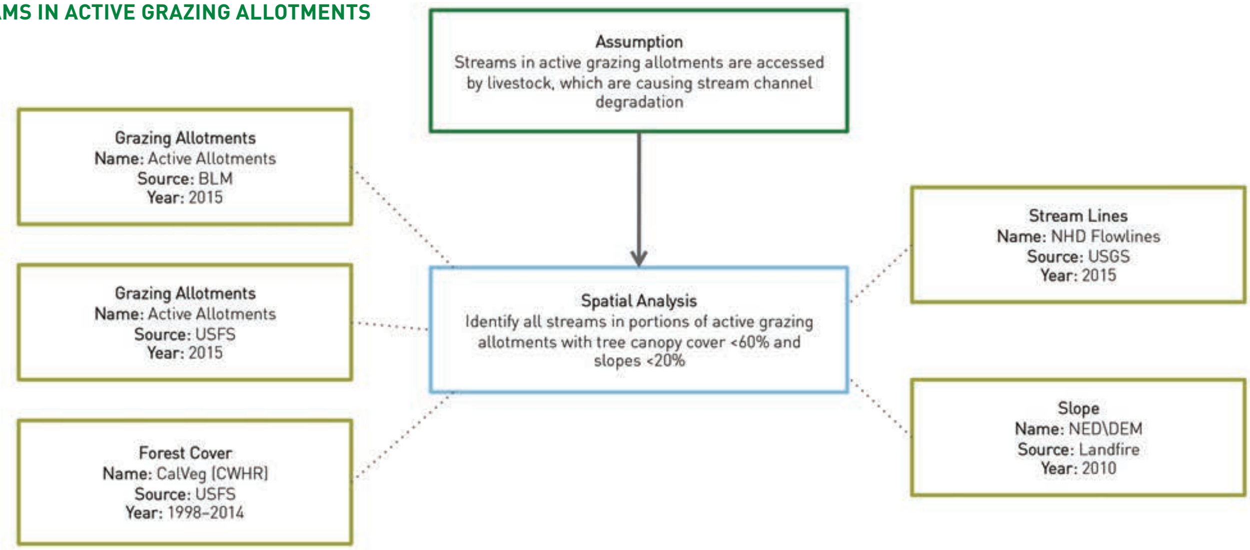
ROADS IN STREAM BUFFERS



STREAMS IN WET MEADOWS INTERSECTED BY UNPAVED ROADS



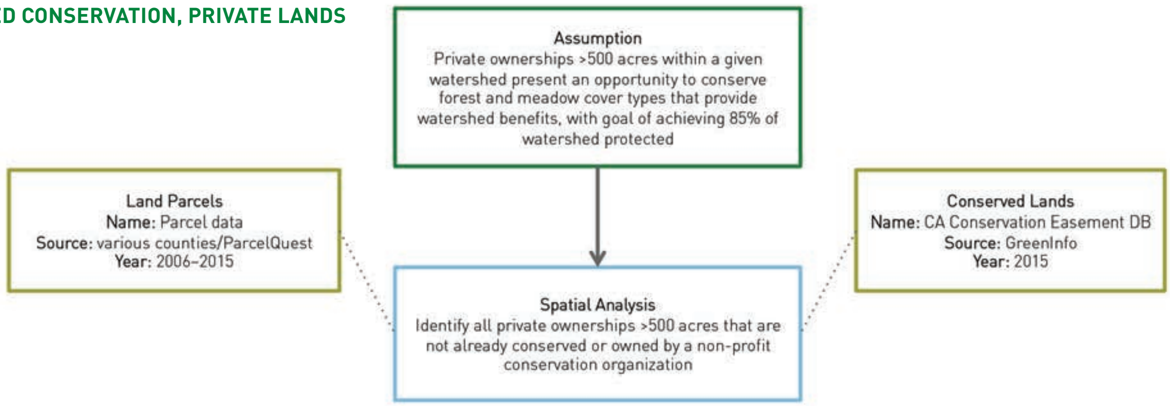
STREAMS IN ACTIVE GRAZING ALLOTMENTS



WATERSHED INTEGRITY

CONDITIONS ADDRESSED	DATA CATEGORY	DATA GENERAL DESCRIPTION	DATA SOURCE	ASSUMPTION(S) APPLIED
LAND BASE — LACK OF SECURE LAND BASE TO SUPPORT FUTURE WATERSHED INTEGRITY	Restoration Target	Private ownerships	Parcel data from counties covered by study area	All private ownerships with reconcilable ownership attributes were included.
	Restoration Need	Ownerships >500 acres within focal watersheds	Parcel data from Shasta and Siskiyou counties	Transactions <500 acres are less cost-efficient.
	Availability for Treatment	Conserved private lands	California Conservation Easement Database	All ownerships are assumed available unless owned in fee by non-profit conservation organization or conservation easement already in place.

WATERSHED CONSERVATION, PRIVATE LANDS



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