Technical Memorandum

Cardno ENTRIX

5415 SW Westgate Dr.
Suite 100
Portland, OR 97221
USA

Phone 503-233-3608
Toll-free 800 368 7511
Fax 503-575-3340
www.cardno.com

www.cardnoentrix.com

Date September 26, 2012

To: Jeff Beehler
Santa Ana Watershed Protection Authority

cc:

From: Barbara Wyse, Travis Greenwalt, and Duane Paul; Cardno ENTRIX

RE: **Methodology to Estimate Economic Benefits of Forest Restoration Projects**

1.0 Introduction

This paper describes the methodology and data used to estimate the expected economic benefits related to Santa Ana River Watershed water supplies of restoring forest health in the San Bernardino and Cleveland National Forests. Specifically, we describe methods to estimate the cost savings to the Santa Ana River Watershed that would result from two types of forest restoration projects: forest thinning to restore stand density and forest road retrofitting. The analysis is limited to estimating benefits related to water quantity and water quality; additional benefits related to avoided damage to infrastructure and private property, recreation, species habitat, and human health are not estimated.

Benefits are estimated in dollar terms, either in dollars per acre thinned, or dollars per mile of road retrofitted. Benefits are presented both in annual dollar terms (i.e. $/acre/year or $/mile/year) as well as present value benefits ($/acre or $/mile). Present value benefits represent the total stream of benefits through time of thinning one acre of forest or retrofitting one mile of road. For example, a thinning project occurring in Year 1 will provide water supply benefits not only in Year 1, but will also likely provide water supply benefits in future years. As a society we tend to value benefits in Year 1 more than benefits received in later years. To account for this, we estimate present value by applying a discount rate that converts future benefits to their value in present day terms. For example, if we apply an annual 3 percent discount rate, then $100 of benefits received in Year 2 is equal to $97 of benefits received in Year 1.

2.0 Approach Overview

Our analysis focuses on water quantity and water quality benefits that result from reducing stand density to healthy levels through thinning and from retrofitting forest roads. Thinning, or fuel reduction, provides both water quantity and water quality benefits. Retrofitting forest roads provides water quality benefits. We developed three models in the analysis to quantify these effects:

1. **Model 1: Water Quantity Benefits of Thinning**: This model quantifies the relationship between thinning and increased streamflow volume due to reduced water use by vegetation (i.e., reduced evapotranspiration). The model then translates this increased streamflow into cost savings by water districts based on reduced requirement for imported water (increased use of natural stream flows results in less spending on water that would be purchased from outside the basin from such sources as the State Water Project).

2. **Model 2: Water Quality Benefits of Thinning**: This model quantifies the relationship between thinning and decreased severity and frequency of forest fires. As forest fires increase sediment loads in streams, the model quantifies how a reduction in forest fire risk decreases sediment loading. The model then quantifies the economic benefits of reduced sediment loading by estimating the cost savings of reduced sediment removal in Santa Ana River Watershed recharge basins.

3. **Model 3: Water Quality Benefits of Road Retrofitting**: Road retrofitting reduces sedimentation in nearby streams and rivers by stabilizing soils along roadways. This model estimates how road retrofitting in the Cleveland and San Bernardino National Forests would reduce sediment loads in the Santa Ana River Watershed. Similar to the water quality benefits of thinning model, this model then quantifies the economic benefits of reduced sediment loading by estimating the cost savings of reduced sediment removal in Santa Ana River Watershed recharge basins.

Each of these models thus involves three primary steps: quantifying the effects on forest conditions (i.e. what is the stand density change, what is the change in road condition due to retrofitting), quantifying the resulting effects on hydrological conditions (water quantity and/or water quality), and then translating into economic terms the benefits of estimated hydrological changes. Each of these steps is characterized by significant levels of uncertainty. The next section describes how uncertainty is incorporated into the analysis, while the remainder of the paper provides detailed methods and data used in each of the three models.

2.1 Incorporating Uncertainty

There is significant uncertainty in both the ecological and economic benefits of restoration. Our understanding of natural ecosystems and their response to restoration efforts is still evolving. Furthermore, ecological responses can differ widely between sites due to differences in local conditions, such as weather, vegetation, stream flow, slope, and soil conditions. We have no available studies directly estimating the magnitude of restoration effects in our study area, and so our uncertainty is increased by the need to extrapolate from effects found in other locations.

We directly incorporate uncertainty in our benefits analysis by defining reasonable ranges (high, low, and most likely) for each key variable affecting benefit estimation. Based on these ranges, we then conduct a

Monte Carlo simulation to estimate the most likely ecological effects and economic benefits. Monte Carlo methods are commonly used for modeling when there is significant uncertainty in inputs. Monte Carlo analysis is a statistical technique that systematically incorporates uncertainty into quantitative analysis to improve decision-making. It was first developed for the Manhattan Project and has been used for over 60 years to understand the impact of multiple sources of uncertainty. We used the software @Risk from Palisade Corporation to create the Monte Carlo simulation models.

This analysis uses Pert distributions in the Monte Carlo simulations. Pert distributions are specified with three parameters: a minimum value, a maximum value, and a most likely value (the mode). Pert distributions are useful when drawing from expert opinion regarding the range of possible values and the most likely value. The mean for the Pert distribution depends to a much greater extent on the most likely value specified rather than the low and high values.

3.0 Model 1: Water Quantity Benefits of Forest Thinning

Recent studies on the impacts of thinning in the Western United States indicate that reducing fuels from the forest floor increases streamflow volume in the forest (i.e. thinned forests with lower and healthier stand densities have higher streamflow volumes). Greater streamflow is primarily due to reduced use of water by vegetation through evapotransporation (ET).

We complete the following steps to estimate the value of increased water availability:

1. Identify effects on streamflow from thinning in the published literature.
2. Gather site specific stream flow and forest stand density data from San Bernardino and Cleveland National Forests.
3. Evaluate potential cost savings from increased streamflows based on reduced imports of out of basin water supplies.
4. Combine values from steps 1 through 3 to model expected economic benefits and level of certainty.

Table 1 summarizes the key parameters used as inputs to Model 1.

Table 1 Table 1: Key Inputs and Assumptions to Model 1: Water Quantity Benefits of Forest Thinning

		Parameter Value Range Used in Model		
Model Parameter	Unit	Low	Most Likely	High
Streamflow % response to 1% reduction in stand density	%	0.5%	0.59%	0.81%
Minimum reduction in stand density for streamflow benefits	%		25%	
Target stand density in San Bernardino/Cleveland NF	Trees/Acre		150	
Stand density minimum for thinning to affect streamflow	Trees/Acre		200	
Acreage in study area sub-basins (6 tributaries with data)	Acres		114,600	

Acreage in study area sub-basins with stand density > 200 trees / acre	Acres		1,142	
Average annual streamflow volumes in study area sub-basins	Acre-Feet/Year		84,528	
Average annual streamflow volume per acre drained in study area sub-basins	Acre-Feet/Year/Acre		0.74	
Percent increased streamflow put to beneficial use			100%	
Value per acre-foot increased streamflow	Dollars	$125	$250	$450

3.1 Step 1: Data from literature on streamflow effects from thinning

All streamflow responses to thinning are based on a US Geological Survey (USGS) study summarizing available data from the literature.[1] The summarized studies indicate that stream flow response to thinning is heavily influenced by the timing and amount of precipitation, which can vary significantly from year to year. Additionally, stream flow response depends on the percent reduction in stand density, with a minimal level of thinning required before responses can be detected. Several published studies indicate that a reduction of at least 25 percent is needed before any increase in stream flow can be measured. However, with high levels of stand density volume reduction, streamflow response can be significant. For example, increased stream flows of up to 80 percent have been measured in response to a 100 percent reduction in vegetation (clear cutting). **Table 2** provides the data from 13 water yield studies used in this analysis. These 13 study sites were selected from 31 studies presented in the USGS publication based on vegetation type and mean average precipitation, and stand density reduction of 25 percent or more (see **Appendix A** for a table detailing all 31 studies).

Based on these studies, this analysis assumes that stand density must be reduced by a minimum of 25 percent for positive effects on stream flow volumes to result. Second, the analysis identifies a reasonable range of how a percent change in stand density volume translates into a percent change in streamflow. For every 1 percent change in stand density, we assume that the effect on streamflow volume ranges from 0.5 percent to 0.81 percent, with 0.59 percent the most likely streamflow response to each incremental percent reduction in stand density.

Table 2 Streamflow Response to Thinning: Data from Other Studies

Watershed	A Mean Annual Precipitation (mm)	B Mean Annual Flow (mm)	C Increase in Flow (mm)	D % change flow	E % watershed treated	D/E % Change Flow Per 1% Decrease in Stand Density
Values in Literature						
Beaver Creek, AZ	457	20	0	0%	100%	0.76%
Beaver Creek, AZ	508	67	11.3	17%	100%	0.17%
Beaver Creek, AZ	621	152	68.7	45%	100%	0.45%

1 Studies summarized in: Marvin, Sarah, Possible Changes in Water Yield and Peak Flows in Response to Forest Management, Vol. 3, Chapt. 4, pp.153-199, United States Geological Survey, accessed online at http://pubs.usgs.gov/dds/dds-43/VOL_III/VIII_C04.PDF.

Watershed	A Mean Annual Precipitation (mm)	B Mean Annual Flow (mm)	C Increase in Flow (mm)	D % change flow	E % watershed treated	D/E % Change Flow Per 1% Decrease in Stand Density
Beaver Creek, AZ	686	172	72.9	42%	33%	1.28%
Castle Creek, AZ	639	71	16.5	23%	100%	0.23%
Deadhorse Creek, CO	648	147	75	51%	35%	1.46%
Entiat, WA	579	112	91	81%	100%	0.81%
Entiat, WA	597	155	74	48%	100%	0.48%
Entiat, WA	N/A	175	112	64%	100%	0.64%
Frazer, CO	762	283	115	41%	40%	1.02%
Meeker, CO	400	261	39	15%	30%	0.50%
Wagon Wheel Gap, CO	536	157	28.2	18%	100%	0.18%
Thomas Creek, AZ	768	82	44	54%	34%	1.58%
Values Used in Analysis						
Average	600	142	58	43%	73%	0.59%
Minimum	400	18	11	15%	30%	0.50%
Maximum	768	283	115	81%	100%	0.81%

Note the minimum and maximum values used in the analysis are based on the studies that show the lowest and highest percent changes in flow.

3.2 Step 2: Stand Density and Streamflow Data from San Bernardino and Cleveland National Forests

In order to compute the increase in stream flow from thinning, data on existing streamflow volumes and stand densities are required. For this analysis, we did not have access to streamflow volumes from all areas of the San Bernardino and Cleveland NF. We did have data on streamflows, however, for six tributaries draining basins totaling approximately 114,600 acres. This data was provided by the San Bernardino Valley Municipal Water District (SBVMWD).[2]

Per the Forest Care Program funded by the US Forest Service and the State of California, target stand density for thinning operations in the San Bernardino and Cleveland NF region is 150 trees per acre. Based on Forest Service GIS data, approximately 85 percent of the total land area in each sub-basin drained by the six tributaries is owned and managed by the National Forest Service. Forest Service data also indicates that ten percent of this land, or 1,142 acres, have tree stand densities that exceed target density by over 25 percent (i.e. are over 200 trees per acre). Stand densities over 200 trees per acre represent an opportunity to thin at least 25 percent of the volume and cause a measurable increase in stream flow.

Table 3 below presents the streamflow and stand density data used in Model 1, including existing flow volumes and flow volumes on a per acre basis, as well as the acreage in each sub-basin that could be thinned for potential streamflow benefits.

2 Personal communication with Bob Tincher, San Bernardino Valley Municipal Water District.

Table 3 Current Flow Volumes and Stand Densities in Select Sub Basins of Santa Ana River Watershed

Sub Basin Name	USGS Stream Identification Number	Current flow (Acre Feet / Year)	Acreage in Sub Basin	Acre Feet / Year / Acre	Acreage with Stand Density > 200 Trees/Acre
Lytle	11062001	33,612	29,654	1.13	503
Cajon	11063510	8,825	36,201	0.24	117
Devil Canyon	11063680	1,959	3,530	0.56	49
East Twin	11058500	3,887	5,579	0.70	28
City Creek (NR Highland)	11055801	8,512	12,487	0.68	84
Mill Creek (Yucaipa)	11054001	27,733	27,172	1.02	362
Total		84,528	114,623	0.74	1,142

Combining the values in **Tables 2 and 3**, we develop a distribution curve to estimate the range of streamflow effects of thinning in each of the six sub-basin areas. Streamflow effects are estimated for each raster of forest service land in the sub-basin boundaries; in other words, the analysis is conducted at the most detailed spatial scale (raster level from US Forest Service GIS data) to combine streamflow, current stand densities, and acreage data in each sub-basin. Streamflow volume increases on an average annual basis are modeled as:

*Change in streamflow volume = % stand density reduction * % streamflow response per 1% stand reduction * streamflow/acre * acres thinned.*

The result is a range of potential impacts on stream flows for each of the tributaries considered in the analysis. For example, **Figure 1** below illustrates the range of potential stream flow benefits from thinning tree stands in the Lytle Creek sub-basin to target stand densities of 150 trees per acre. (In Figure 1 and other histograms presented in this document, the y-axis presents the probability of the x-axis value resulting, in this case, the probability of a given stream flow increase.) As shown in the figure, with 90 percent certainty, we expect thinning in Lytle Creek sub-basin will increase stream flows by approximately 190 to 260 acre-feet per year (AFY), with a mean expected increase of approximately 214 AFY. Similar simulations estimated changes in streamflows from thinning in each of the other five tributaries analyzed: Lytle, Cajon Creek, Devil Canyon, East Twin Creek, City Creek and Mill Creek.

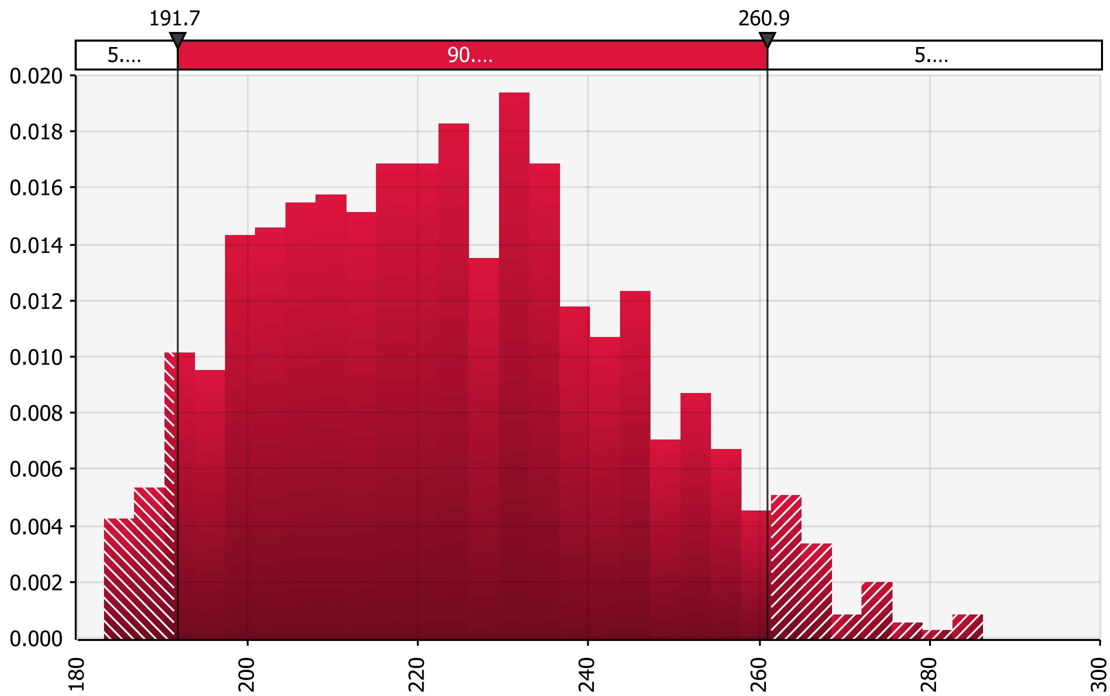

Figure 1 **Stream Flow Increase (AFY) from Thinning Lytle Creek Sub Basin to 150 Trees per Acre**

Important assumptions for this analysis include:

- Streamflows (and thus precipitation) are assumed to be held constant at average historic rates.
- Timing of flows was not considered; only average annual flow volumes were used.
- Future re-growth of forest vegetation was not modeled as part of this analysis, thus, results represent potential impacts at the time of thinning with no consideration of diminished effects resulting from new growth in the future.

3.3 Step 3: Cost savings per acre-foot of increased supply

Increased streamflows in the Santa Ana River Watershed are expected to decrease water costs by allowing water districts to use local water supplies in place of costly, imported water from outside the Basin. Currently, water districts purchase water as needed from the State Water Project and from Metropolitan Water District (MWD). These water purchases vary in cost from $125 (lowest State Water Project rate) to $450 per AF (MWD untreated replenishment water rate), with a most likely value of $250 cost savings per acre-foot.

3.4 Step 4: Cost savings from thinning

In this final step, we combine the probability distributions from Steps 2 and 3 to estimate the range of total water supply cost savings related to thinning. We assume that all increased streamflow volumes are utilized by Santa Ana River Watershed water users. In other words, we apply the range of $125 to $450 cost savings per AF to every AF of increased water supply estimated in Step 2. Annual water supply benefits of thinning are presented in **Table 4**. Water supply cost savings per acre thinned are estimated to range with 90 percent certainty from approximately $60 to $140 per acre, with a mean value of approximately $100 per acre.

Table 4 Annual Water Supply Benefits from Thinning 1,140 acres in Six Sub-Basins

Select Tributaries	Acres Thinned	Supply Impact (AFY)	Annual Benefits (min, 5th Percentile)	Annual Benefits (mean)	Annual Benefits (max, 95 Percentile)
Lytle	503	214	$36,175	$58,329	$84,454
Cajon	117	10	$1,698	$2,739	$3,965
Devil Canyon	49	9	$1,522	$2,454	$3,552
East Twin	28	7	$1,246	$2,008	$2,908
City Creek (NR Highland)	84	22	$3,655	$5,893	$8,533
Mill Creek (Yucaipa)	362	141	$23,742	$38,282	$55,427
Total	1,142	403	$68,038	$109,705	$158,839
Per Acre Thinned		0.35	$60	$96	$139

The present value benefits of thinning over a 20-year period are also estimated in the analysis. Based on a discount rate ranging from 3 percent to 7 percent (with a most likely value of 5 percent), present value per acre thinned is estimated to range with 90 percent certainty from approximately $700 to $1,750 per acre, with a mean value of $1,200 per acre.

Table 5 Present Value Water Supply Benefits from Thinning 1,140 acres in Six Sub-Basins

Select Tributaries	Present Value Benefits (min, 5th Percentile)	Present Value Benefits (mean)	Present Value Benefits (max, 95th Percentile
Lytle	$447,000	$729,150	$1,061,000
Cajon	$20,963	$34,234	$49,800
Devil Canyon	$18,782	$30,671	$44,616
East Twin	$15,374	$25,107	$36,523
City Creek (NR Highland)	$45,111	$73,667	$107,162
Mill Creek (Yucaipa)	$293,000	$478,535	$696,000
Total	$840,230	$1,371,364	$1,995,101
Per Acre Thinned	$736	$1,201	$1,748

3.5 Model 2: Water Quality Benefits of Forest Thinning

Reducing fuel in forests through thinning has water quality benefits that result from reducing the occurrence and severity of fires. Fire events that clear vegetation from the forest floor can result in erosion and heavy sediment loads in waterways if followed by storm event(s). Sediment loads are then transported to downstream areas where the sediment often adversely affects water infrastructure. For example, sediment deposition in recharge basins can reduce or eliminate percolation of water into the groundwater table, increasing maintenance costs to recharge basin managers. The magnitudes of these impacts vary based on numerous site specific conditions, including forest management, weather patterns, fire behavior, and location of infrastructure and sediment deposition. This section presents the methods and data to estimate the total cost savings associated with water quality benefits (reduced sedimentation) from thinning.

We complete the following steps to estimate the value of decreased sediment loads from thinning:

1. Identify relationship between forest fire severity and sediment loads.
2. Estimate reduction in forest fire frequency and severity from thinning.
3. Estimate reduction in sediment loads from thinning
4. Evaluate potential cost savings from reduced sediment loads based on reduced maintenance costs of recharge ponds.
5. Combine values from steps 1 through 4 to model expected economic benefits and level of certainty.

Table 6 summarizes the key parameters used as inputs to Model 2.

Table 6 Key Inputs and Assumptions to Model 2: Water Quality Benefits of Forest Thinning

		Parameter Value Range Used in Model		
Model Parameter	Unit	Low	Most Likely	High
Sediment Loads from Forest Fire Magnitude I	Cubic Yards	100	500	1,000
Sediment Loads from Forest Fire Magnitude II	Cubic Yards	1,000	5,000	10,000
Sediment Loads from Forest Fire Magnitude III	Cubic Yards	10,000	20,000	100,000
Existing Fire Risk Magnitude I	%		3.8%	
Existing Fire Risk Magnitude II	%		3.6%	
Existing Fire Risk Magnitude III	%		6.3%	
Fire Risk Reduction from Thinning	%	30	50	60
Minimum Existing Stand Density for Thinning to Reduce Fire Risk	Trees/Acre		200	
Acreage in Santa Ana River Watershed in the San Bernardino/Cleveland NF with stand density > 200 trees / acre	Acres		3,800	
Value per cubic yard of decreased sediment	$/Cubic Yard	$3	$16	$43

3.6 Step 1: Effect of Fire on Sediment Loads

This study uses data specific to the San Gabriel Mountains on the effect of fire on sediment loads from a study conducted jointly by the USGS, National Oceanic and Atmospheric Administration (NOAA), and the National Weather Service.[3] This paper defines the relationship between fire magnitudes and sediment load events as shown in **Table 7**. The most likely values for all fire magnitudes and the maximum values for Magnitude III fires were assumed by this analysis.

Table 7 Effects of Fire on Sediment Loads in Recharge Basins

Fire Level	Sediment loads (Cubic Yards) Min	Most likely	Max	# Recharge Basins Affected
Magnitude I	100	500	1,000	2
Magnitude II	1,000	5,000	10,000	2-5
Magnitude III	10,000	20,000	100,000	5-15

3.7 Step 2: Effect of Thinning on Fire Frequency

Table 8 presents data from the USGS study on existing fire frequency and magnitude in the San Gabriel Mountains, based on fires in the San Gabriel Mountains over approximately the last 80 years. For example, there were three debris flow events of Magnitude I within the SAWPA boundary over the last 78 years, three debris flows of Magnitude II over the last 84 years, and five debris flows of Magnitude III over the last 79 years. During this time, fuel loads have in general been increasing in the forest, so current fire risk is likely at least as great as represented during this time period.

To estimate the change in the frequency of fires of each magnitude, we use a range of 30 to 60 percent forest fire reduction after a thinning event, with a most likely reduction of 50 percent. This range is our best estimate of the effect of thinning on fire frequency based on interviews with forest fire experts at the Forest Service Fire Laboratory in Missoula, Montana.

Table 8 Effect of Thinning on Fire Frequency

Fire Magnitude	Annual Probability of Occurrence Before Thinning	Annual Probability of Occurrence After Thinning		
		Low	**Most Likely**	**High**
I	3.8%	1.2%	1.9%	2.3%
II	3.6%	1.1%	1.8%	2.1%
III	6.3%	1.9%	3.2%	3.8%
All Fires	13.7%	1.2%	1.9%	2.3%

3.8 Step 3: Effect of Thinning on Sediment Loads

By combining the results from Steps 1 and 2, we estimate the effects of thinning on sediment loading in recharge ponds. Similar to streamflow effects, we assume that stand density must be reduced by 25 percent to measurably affect fire frequency and severity. Based on US Forest Service data, there are

[3] Cannon, Susan, and Eric Bold, Jason Kean, Jayme Laber, and Dennis Staley, Relations Between Rainfall and Postfire Debris-Flow and Flood Magnitudes for Emergency-Response Planning, San Gabriel Mountains, Southern California, USGS / NOAA / NWS, Open File Report 2010-1039.)

approximately 3,800 acres in the San Bernardino/Cleveland NF with stand density greater than 200 trees per acre. We assume for the purposes of this analysis that all 3,800 acres are thinned. For each fire magnitude level, we estimate the reduction in sediment loading due to thinning 3,800 acres as:

Change in sediment loading in recharge ponds =
*Sediment loads in recharge ponds per fire event * percent reduction in annual fire frequency*

Figure 2 presents the probability distribution of sediment reduction in recharge ponds from thinning 3,800 acres on the San Bernardino and Cleveland National Forests. With 90 percent certainty, annual sediment reduction is estimated to range from approximately 4,000 to 20,000 cubic yards, with a mean value of approximately 10,000 cubic yards.

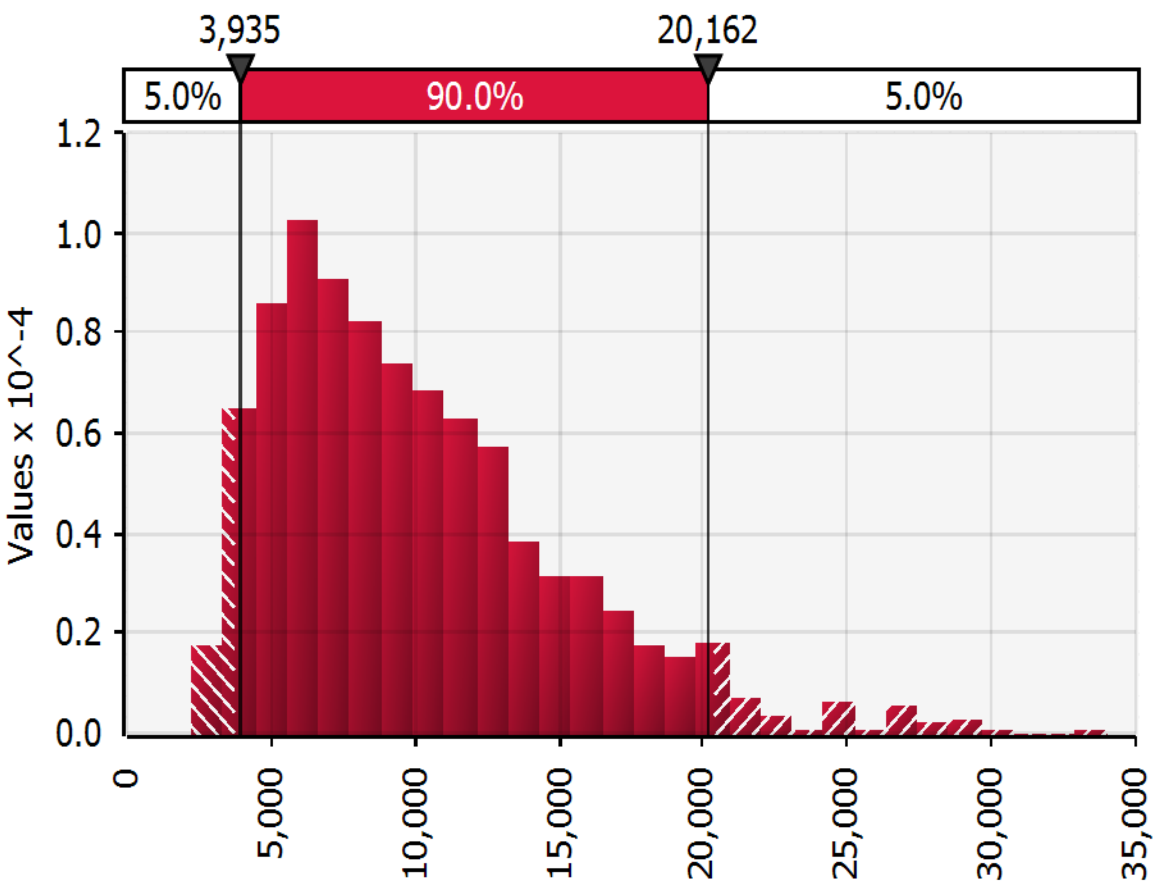

Figure 2 **Probability Distribution of Annual Sediment Reduction (Cubic Yards) in Recharge Ponds**

3.9 Step 4: Cost savings per ton of decreased sediment loads

Nearly all basins within the Santa Ana River watershed have calculated "safe yields," or the amount of water that can be pumped from a basin. It is common for water districts to increase the yield from these basins through artificial replenishment. This is often referred to as "spreading," where water from other sources is spread into open pits or recharge basins, allowing the water to soak into the ground down to the water table. Because groundwater is so heavily relied upon in the Santa Ana River Watershed, and many water districts operate groundwater tables as reservoirs of drinking water, the potential debris flows resulting from fire and storm can result in costly maintenance. Based on a study of sediment removal costs (and corroborated through interviews with Santa Ana River Watershed water district managers), costs to remove sediment are estimated to range from a low of $3 to a high of $43 per cubic yard, with a most likely value of $16 per cubic yard.[4]

3.10 Step 5: Water Quality Cost Savings from Thinning

In this final step, we combine the probability distributions from Steps 3 and 4 to estimate the range of total recharge pond maintenance cost savings related to thinning. We apply the range of $3 to $43 cost savings per cubic yard to every cubic yard of decreased sedimentation estimated in Step 3. Annual water quality benefits of thinning are presented in **Figure 3**, and are anticipated to range with 90 percent certainty from $47,000 to $435,000, with a mean value of $186,000.

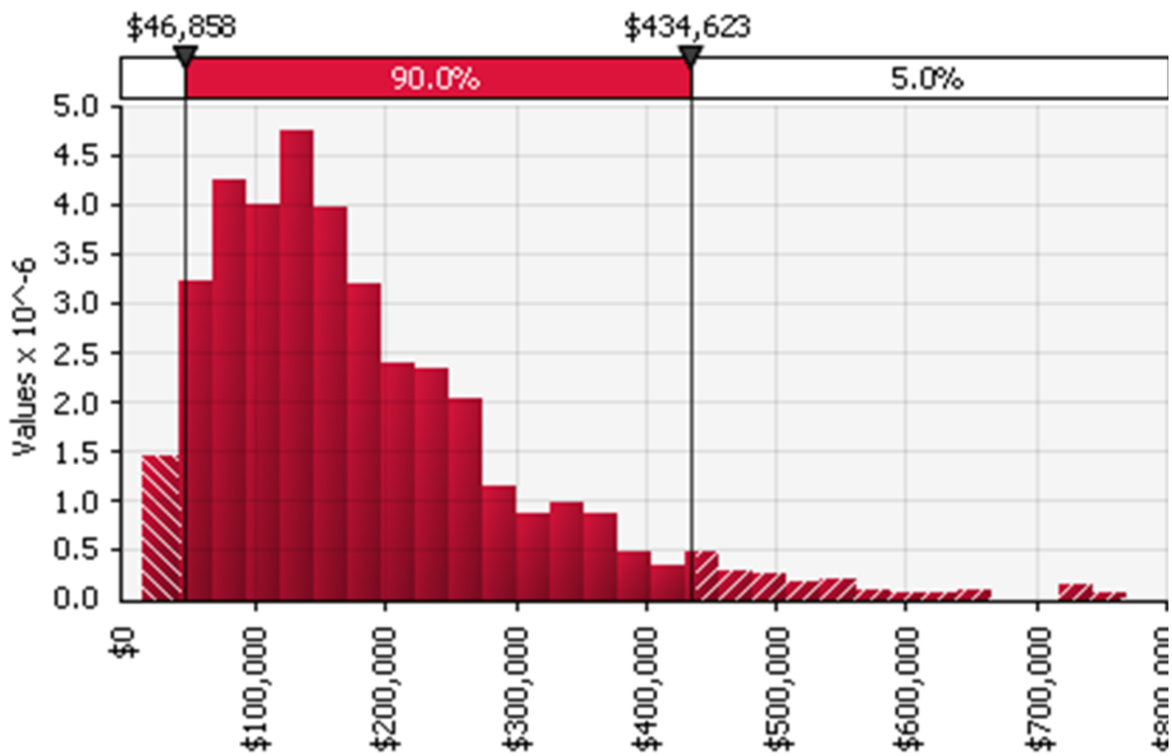

Figure 3 Annual Water Quality Benefits of Thinning 3,800 Acres (Avoided Sedimentation Removal Costs)

4 Armando Gonzalex-Caban, et al, 2000, Costs and Benefits of Reducing Sediment Production from WildfiresThrough Prescribed Burning: The Kinneloa Fire Case Study, Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View. (Dollar values updated from 2000 to 2012 values using Consumer Price Index.)

The present value over 20 years of water quality benefits from thinning are also estimated in the analysis. We use a discount rate ranging from 3 percent to 7 percent, with a most likely value of 5 percent. Results suggest that the present value of expected benefits (avoided sedimentation costs) from thinning range with 90 percent certainty from approximately $0.6 million to $5.3 million, with a mean value of $2.3 million (see **Figure 4**).

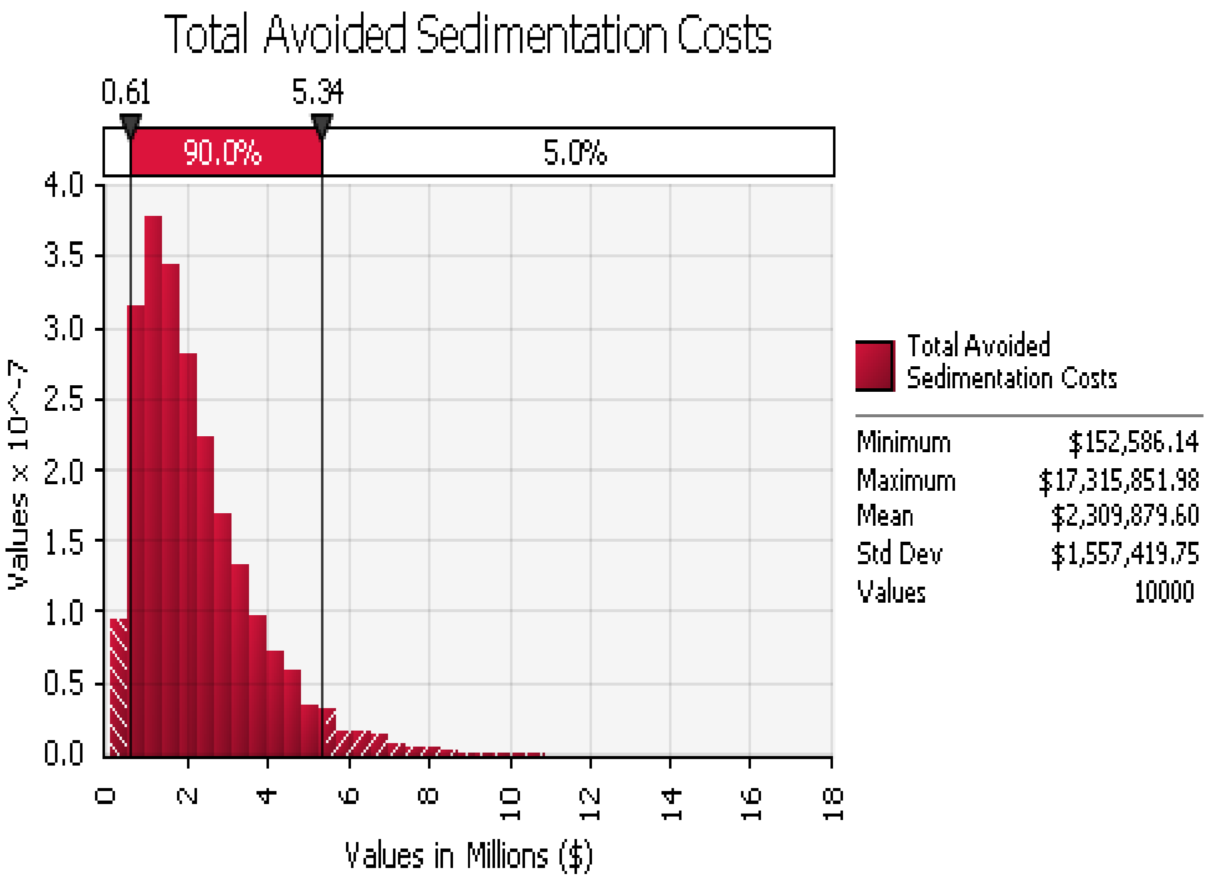

Figure 4 **Present Values of Water Quality Benefits of Thinning 3,800 Acres (Avoided Sedimentation Removal Costs)**

4.0 Road Retrofitting

Forest roads are sources of sedimentation in watersheds, largely due to the lack of vegetation in road areas to stabilize soils and also due to hill cuts that alter slope formations and further destabilize soils. Retrofitting roads through adding gravel and/or installing a vegetated ditch may slow erosion and associated sedimentation in the watershed. As discussed above, sediment loads are transported to downstream areas where the sediment often adversely affects water infrastructure and maintenance costs. This section presents the methods and data to estimate the total cost savings associated with water quality benefits (reduced sedimentation) from road retrofitting.

We complete the following steps to estimate the value of decreased sediment loads from road retrofitting:

1. Identify existing relationship between roads and sediment loads.
2. Estimate reduction in sediment loads from road retrofitting.
3. Evaluate potential cost savings from reduced sediment loads based on reduced maintenance costs of recharge ponds.
4. Combine values from steps 1 through 3 to model expected economic benefits and level of certainty.

Table 9 summarizes the key parameters used as inputs to Model 3.

Table 9 Key Inputs and Assumptions to Model 3: Water Quality Benefits of Road Retrofitting

		Parameter Value Range Used in Model		
Model Parameter	**Unit**	**Low**	**Most Likely**	**High**
Existing Sediment Loads from Forest Roads	Cubic Yard/ Mile	1	2.1	18
Reduction in Sediment Loads from Retrofitting	%	40%	65%	90%
Value per cubic yard of decreased sediment	$/Cubic Yard	$3	$16	$43

4.1 Step 1: Existing Sediment Loads from Roads

This study uses data from Washington State to estimate sediment loads from a wide range of roads located throughout the state in different climatic zones.[5] Based on this data, the analysis assumes that the average sediment contribution to waterways in the Santa Ana River Watershed from roads in the San Bernardino and Cleveland National Forests is between 1 and 18 tons of sediment per mile of road, with an expected value of 2.1 tons per mile. As there is significant uncertainty in applying values from Washington to the San Bernardino and Cleveland National Forests, we use this wide range of sedimentation effects.

4.2 Step 2: Effect of Road Retrofitting on Sediment Loads

Data from the study of road retrofitting in Washington State forests indicates that installation of a vegetated ditch reduces sediment in waterways by between 50 and 90 percent (mean value of 70 percent). The addition of gravel is estimated to reduce sediment in streams by 40 to 80 percent (most likely value of 60 percent).[6] We assume that road retrofitting in the San Bernardino and Cleveland NF would therefore reduce sediment in waterways from 40 to 90 percent, with a most likely value of 65 percent. Annual

5 Dube, Kathy et al, Washington Road Sub-Basin Scale Effectiveness Monitoring First Sampling Event (06-08) Report, Cooperative Monitoring Evaluation and Research Committee (CMER), WA Dept of Natural Resources, CMER 08-801, May 2010.

6 Ibid.

sediment reduction in waterways from road retrofitting, as illustrated in **Figure 5**, is estimated to range from 0.4 to 9.2 cubic yards per mile, with a mean value of 2.2 cubic yards per mile.

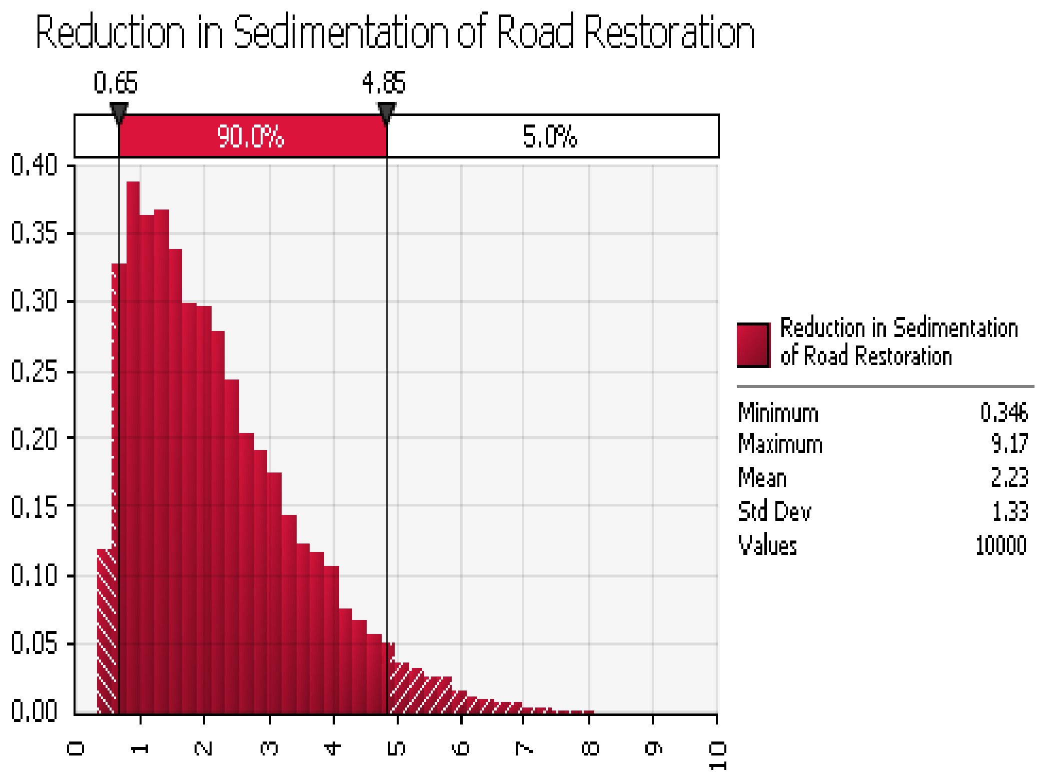

Figure 5 **Reduced Sedimentation in Waterways (Cubic Yards) from Road Retrofitting**

4.3 Step 3: Cost Savings from Sediment Load Reduction

Cost savings per cubic yard sediment load reduction from road retrofitting are the same as sediment-related savings from thinning described in Model 2. The cost savings from reduced of sediment removal from recharge ponds, as presented above, are $3.33 to $43 per cubic yard with a most likely value of $16 per cubic yard.

4.4 Step 4: Cost Savings to Santa Ana River Watershed from Road Retrofitting

This analysis assumes that all sediment load reduction from road retrofitting results in reduced sediment removal from recharge areas. While this is likely not the case, we believe that this is a reasonable assumption as we expect that sedimentation, regardless of deposition location, will result in reduced groundwater infiltration and thereby increase water supply costs to water districts. Combining values from steps 1 through 3, we estimate that that retrofitting roads can reduce recharge basin maintenance costs with 90 percent certainty by $10 to $80 dollars, with a mean expected cost savings of $35 per year per mile of road retrofitted (see **Figure 6**). Data on miles of forest road in Santa Ana Watershed requiring retrofitting in the San Bernardino and Cleveland NF are not available at the time of analysis, so we only estimate benefits on a per mile retrofitted basis.

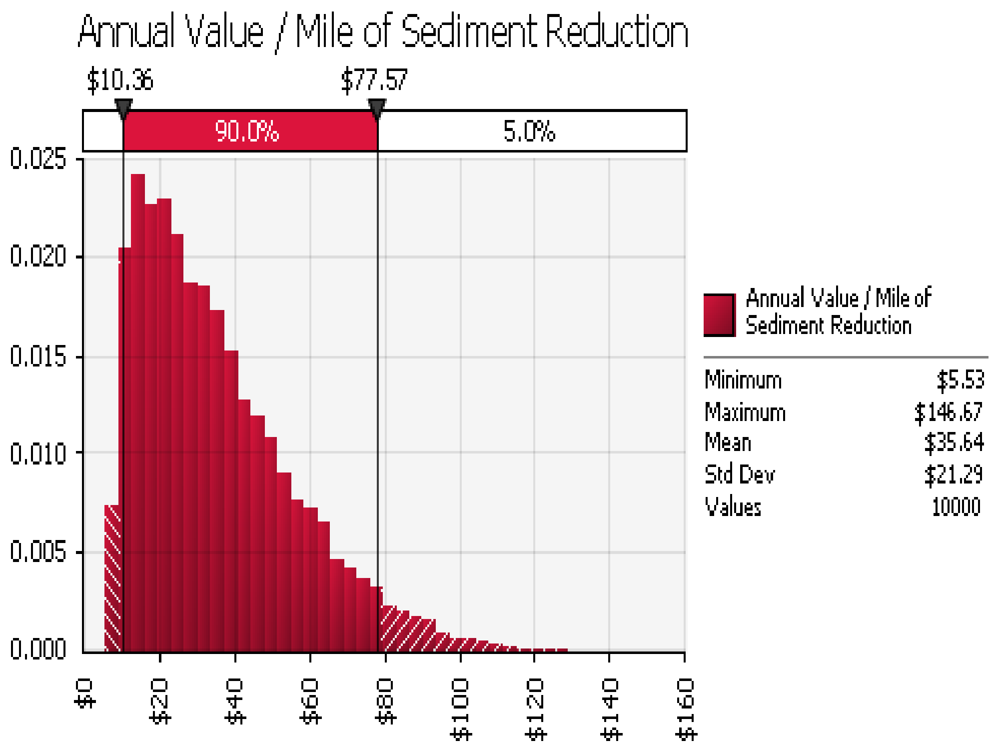

Figure6 Annual Values of Avoided Costs of Sedimentation per Mile of Road Retrofitting

We apply a discount rate of between 3 and 7 percent is applied, along with an expected project life of between 5 and 25 years. The present value of benefits (avoided costs) associated with reduced sedimentation from road retrofitting projects modeled is estimated to range with 90 percent certainty between $90 and $700 per mile, with a mean expected value of approximately $300 (see **Figure 7**).

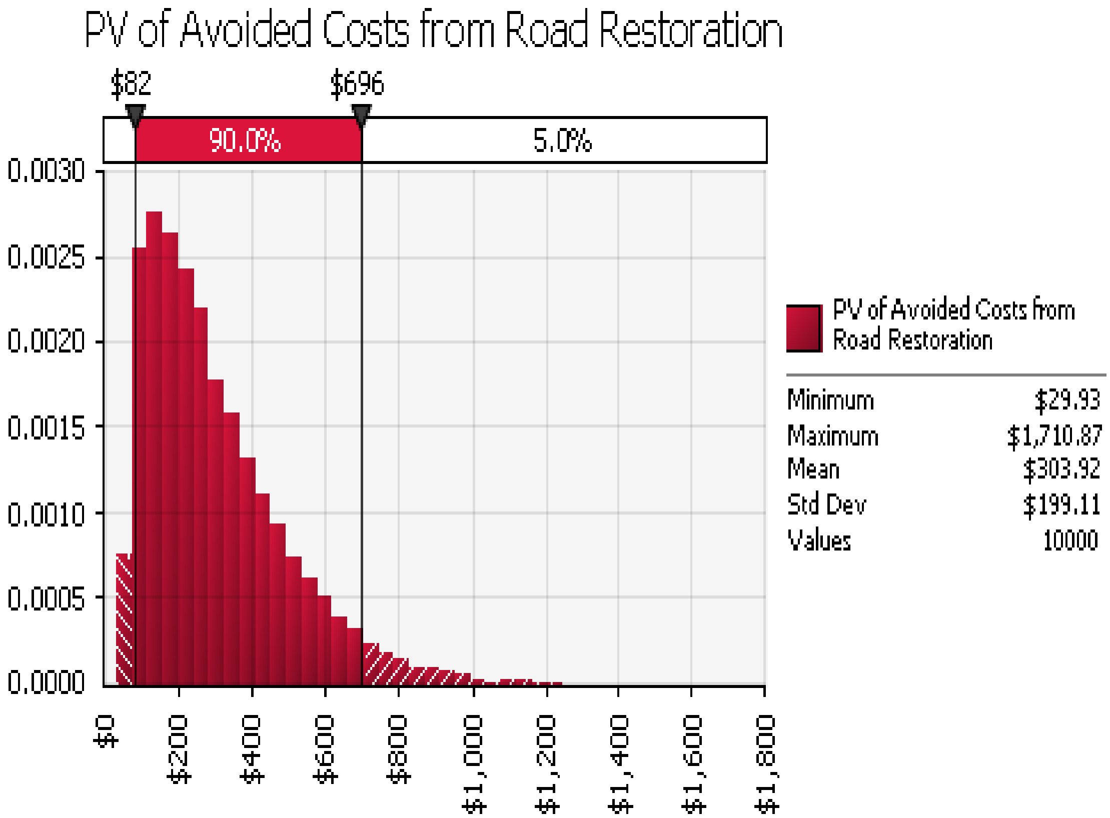

Figure 7 Present Values of Avoided Costs of Sedimentation per Mile of Road Retrofitting

Appendix A
Streamflow Response Data

Table A-1 below provides the data on the 31 studies on streamflow response to thinning reviewed in this analysis and cited in the USGS publication authored by Sarah Marvin.

Table A-1 Streamflow Response Data

Watershed	% watershed treated	Mean Annual Precipitation (mm)	Mean Annual Flow (mm)	Increase in Flow (mm)	% change flow	Drainage area hectares	Aspect	Percent Slope	Vegetation	Soils	Treatment
Beaver Creek, AZ	100%	457	20	0	0%	124	W	21%	Utah juniper-pinyon forest	volcanic rock, soils, stoney clay	cabling and burning
Beaver Creek, AZ	83%	457	18	11.4	63%	146	W	7%	Utah juniper-pinyon forest	volcanic rock, soils, stoney clay	herbicide application to overstory, no vegetation removal
Beaver Creek, AZ	100%	508	67	11.3	17%	42	SW	5%	alligator and Utah Junipir-ponderosa pine forest	silty clay	clear cut
Beaver Creek, AZ	100%	621	152	68.7	45%	184	SW	7%	ponderosa pine, gambel oak, alligator juniper	silty clay	clear cut
Beaver Creek, AZ	33%	686	172	72.9	42%	452	W	6%	ponderosa pine, gambel oak, alligator juniper	silty clay loam	clear cut in strips
Castle Creek, AZ	100%	639	71	16.5	23%	364	SE		ponderosa pine	igneous origin	clear cut and thinned
Coyote Creek, OR	50%	1229	627	60	10%	69	NE	23 - 36%	Doug fir, mixed conifer	gravely loam	shelterwood cut by tractor
Coyote Creek, OR	30%	1229	643	90	14%	68	NE	23-36%	Doug fir, mixed conifer	gravely loam	patch cut, tractor and high lead
Coyote Creek, OR	100%	1229	674	290	43%	50	NE	23-36%	Doug fir, mixed conifer	gravely loam	clear cut, tractor and high lead
Deadhorse Creek, CO	35%	648	147	75	51%	41	S	40%	old-growth lodgepole pine	angular gravel and stone	commercial clear cut

Watershed	% watershed treated	Mean Annual Precipitation (mm)	Mean Annual Flow (mm)	Increase in Flow (mm)	% change flow	Drainage area hectares	Aspect	Percent Slope	Vegetation	Soils	Treatment
Entiat, WA	100%	579	112	91	81%	514	SE	-	Ponderosa pine and Doug fir	sandy loam	burned
Entiat, WA	100%	597	155	74	48%	563	-	-	Ponderosa pine and Doug fir	sandy loam	burned
Entiat, WA	100%	0	175	112	64%	473	-	-	Ponderosa pine and Doug fir	sandy loam	burned
Fox Creek, OR	25%	2790	2710	0	0%	59	WNW	5-9%	Pacific Silver fir, overmature western Hemlock and Doug fir	silt loams or stony, cobbly loams	clear cut by high lead
Fox Creek, OR	25%	2840	2350	0	0%	71	W	5-9%	Doug fir, western Hemlock	silt loams or stony, cobbly loams	clear cut by tractor and high lead
Frazer, CO	40%	762	283	115	41%	289	N	-	77% subalpine forest (lodgepole pine, spruce-fir): 23% alpine forest	angular gravel and stone	commercial cut in strips perpendicular to contour
H.J. Andrews, OR	100%	2388	1376	418	30%	96	NW	53-63%	Doug fir, western Hemlock	gravely loam	commercial clear cut by skyline suspension
H.J. Andrews, OR	25%	2388	1346	218	16%	101	NW	53-63%	Doug fir, western Hemlock	gravely loam	patch cut by high lead cable
H.J. Andrews, OR	100%	2150	1290	322	25%	131	S	27-31%	Doug fir	volcaniclastic parent material	clear cut by cable
H.J. Andrews, OR	60%	2150	1290	176	14%	21	S	27-31%	Doug fir	volcaniclastic parent material	shelterwood cut by cable and tractor
H.J. Andrews, OR	100%	2330	1650	243	15%	9	SW	65-70%	Doug fir, western Hemlock	volcaniclastic parent material	clear cut by high lead cable
Meeker, CO	30%	400	261	39	15%	308	-	-	spruce	volcaniclastic	80% killed by

Watershed	% watershed treated	Mean Annual Precipitation (mm)	Mean Annual Flow (mm)	Increase in Flow (mm)	% change flow	Drainage area hectares	Aspect	Percent Slope	Vegetation	Soils	Treatment
										parent material	insect infestation
Salmon Creek, CA	25%	953	157	0	0%	119	N	30-50%	montane chaparral and ponderosa pine-red fir forest	gravely loam	commercial selection harvest
Sierra Ancha, AZ	32%	813	86	31.4	37%	100	SW	-	ponderosa pine	clay loam	moist site cleared
Sierra Ancha, AZ	73%	813	86	75.6	88%	100	SW	-	ponderosa pine	clay loam	dry site cleared
Sierra Ancha, AZ	45%	813	87	0	0%	129	NW	-	ponderosa pine	clay loam	clear-cut and thinned
Sierra Ancha, AZ	83%	813	87	93	107%	78	E	40%	spruce fir, lodgepole pine	angular gravel and stone	partial cut
Wagon Wheel Gap, CO	100%	536	157	28.2	18%	81	NE	-	84% aspen and conifer	rocky clay loam	clear cut
Deadhorse Creek, CO	28%	0	0	0		141	E	40%	lodgepole pine - spruce-fir	angular gravel and stone	
Deadhorse Creek, CO	40%	0	0	0		41	N	40%	spruce fir	angular gravel and stone	selection cut
Thomas Creek, AZ	34%	768	82	44	54%	227	N and S	22%	old growth southwestern mixed conifer	loamy-skeletal Alfisols	patch clear-cutting, group selection and single tree selection