Science Brief

Water Resource Benefits from Forest Fuels Reduction

Fifty percent of water supplies in the United States originate in forested watersheds where healthy forests capture and slowly release precipitation. However, forests across the western US are overstocked as a result of 200 years of fire suppression efforts. In many of these forests, vegetation density places a growing burden on the water supply of critical watersheds as younger trees and thirsty, fire-sensitive species compete for water.[1] [2]

More than a decade of scientific analyses demonstrate that, in addition to reducing the risk of catastrophic wildfires, fuels reduction projects also increase water availability for consumptive, hydroelectric, and ecosystem health uses, such as ecological flows.[3] These findings are rooted in the relationship between precipitation (rain and snow), evapotranspiration (vegetation water use), and runoff (water available for infiltration and human use): precipitation (P) - evapotranspiration (ET) = runoff (P-ET).[4] This relationship assumes year-to-year changes in soil moisture are negligible which is true over long time periods and given the geology of the Sierra Nevada.[5] Given this relationship (Fig 1), scientists can measure changes in ET after wildfires or fuels reduction projects to reliably estimate increases in runoff that are likely to result from these activities.

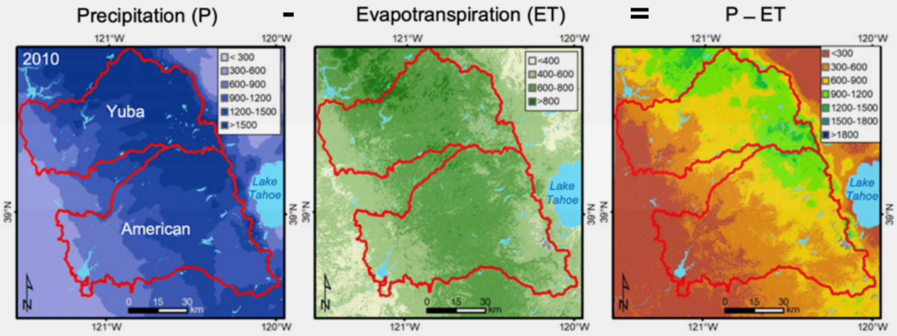

Fig 1. Relationship between precipitation, evapotranspiration, and runoff in the Yuba and American River watersheds of the Central Sierra Nevada.

Estimating Water Benefits of Fuels Reduction

Estimating the impact of fuels reduction on water supply is possible by measuring evapotranspiration (ET). However, measuring ET directly in the field requires expensive, maintenance-prone hardware such as the Critical Zone Observatory. Alternatively, many peer-reviewed papers show that ET can be predicted with a high correlation using the Normalized Difference Vegetation Index (NDVI), an easily measured remote sensing metric for vegetation "greenness." Most recently, a 2020 study by Roche shows a strong correlation between NDVI and ET in the Sierra Nevada by plotting NDVI against direct ground measurements of ET from flux tower data (Fig 2).[6] NDVI is measurable using Landsat satellite data available starting in 1986. **Using NDVI as a predictive tool offers an efficient and affordable approach for estimating the impacts of fuels reduction on ET while accounting for variables unique to individual project sites.**

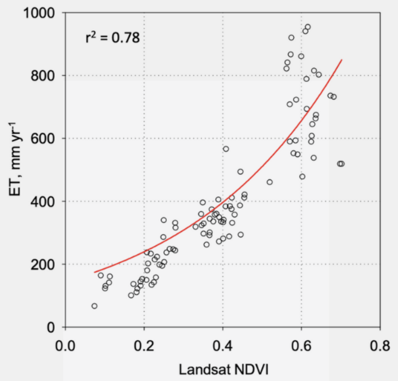

Fig 2. Relationship between evapotranspiration (ET) measured with flux tower data in the Sierra Nevada and NDVI measured by satellite. The high R-squared value indicates NDVI is a very reliable predictor of ET in the Sierra Nevada region.

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[1] Knapp, et al. 2013 (https://www.sciencedirect.com/science/article/abs/pii/S0378112713006555?via%3Dihub)
[2] Collins, et al. 2017 (https://esajournals.onlinelibrary.wiley.com/doi/10.1002/eap.1622)
[3] Ma, et al. 2020 (https://www.sciencedirect.com/science/article/abs/pii/S0022169420308246?via%3Dihub)
[4] Roche, et al. 2020 (https://www.frontiersin.org/articles/10.3389/ffgc.2020.00069/full)
[5] Enzminger et al. 2019 (https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL084589)
[6] Roche, et al. 2020 (https://www.frontiersin.org/articles/10.3389/ffgc.2020.00069/full)

Calculating Annual Evapotranspiration from NDVI

The mean NDVI value for each pixel of the Landsat satellite image can be calculated for a full water year (October 1 - September 30) before fuels reduction activities begin. This NDVI value can then be used to estimate ET in millimeters using the function for the fitted line in Fig 2 (equation 1 below).[7] Millimeters of ET can also be converted to acre-feet (ac-ft) of ET for every pixel (2500 m2 area) using conversion 1 below.

Equation 1:

$$ET_{mm} = 118.4136^{(NDVI \times 2.822)}$$

Conversion 1:

$$ET_{ac-ft} = \left[ET_{mm} \times \frac{1.0_{ft}}{304.8_{mm}} \right] \times \left[2500_{m^2} \times \frac{1.0_{ac}}{4046.9_{m^2}} \right]$$

Calculating Annual Runoff from Evapotranspiration

The calculations outlined above generate an ET value for existing forest conditions. To estimate changes in annual ET resulting from fuels reduction, it is conservative to assume a 25% reduction in NDVI for each acre of treatment. This is consistent with NDVI reductions observed from historical low-severity wildfires.[8] The difference in ET before treatments and after treatments returns the expected increase in runoff from a project of interest.

Supporting Literature from the Sierra Nevada

Several recent studies demonstrate the correlation between fuels reduction and reductions in ET throughout the Central and Northern Sierra Nevada, with effects from a single project lasting for 15-20 years.[9] [10] Reductions in ET may vary in dry or wet years, but generally range from 0.2 to 0.8 ac-ft of water per acre of fuels reduction per year, with results persisting for 15 years or more. Projects in middle elevations (5000-6500 ft) have the greatest effect on ET.[11] [12] For example, in the North Fork Yuba River watershed, fuels reduction across 1,325 acres resulted in an initial reduction in ET (and therefore increase in runoff) of half an acre-foot of water for every acre restored over the course of three years (Fig 3).[13] Models further suggest the potential for a 14% increase in runoff in the Central Sierra Nevada following fuels reduction projects, with a greater effect in dry years when water is most valuable.[14]

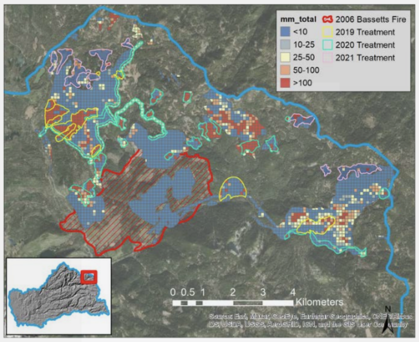

Fig 3. Total reduction in forest ET (2019-2021) compared to five years prior to implementation (2014-2018) in the North Fork Yuba River.

Timing of Flows From Fuels Reduction Projects

An important consideration regarding increases in runoff from fuels reduction is the timing of additional flows. One potential interaction between fuels reduction and the timing of flows pertains to snowpack and snowmelt. A 2013 analysis (Lundquist, 2013) found that regions with winter temperatures averaging above 30 degrees Fahrenheit, such as the Sierra Nevada and Pacific Northwest, hold snow longer into the water year in small forest clearings than under dense forest canopy.[15] Another study (Krogh, 2020) found that decreasing forest canopy cover through the use of ecological thinning, mastication, and prescribed fire can allow more snow to reach the ground and accumulate while reducing the effect of long-wave radiation emitted by trees (Fig 4).[16] These findings highlight the opportunity for fuels reductions projects to protect, and potentially enhance, the timing of flows in forested watersheds.

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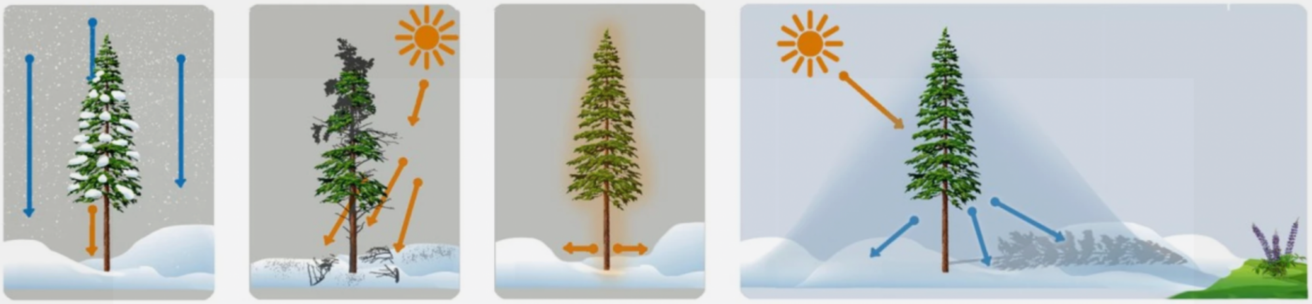
[7] Ibid.
[8] Ibid.
[9] Ibid.
[10] Ma, et al. 2020 (https://www.sciencedirect.com/science/article/abs/pii/S0022169420308246?via%3Dihub)
[11] Roche, et al. 2020 (https://www.frontiersin.org/articles/10.3389/ffgc.2020.00069/full)
[12] Saksa et al. (https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2016WR019240)
[13] Blue Forest 2022 Forest Resilince Bond report to Yuba Water Agency
[14] Saksa et al. (https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2016WR019240)
[15] Lindquist et al. 2013 (https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/wrcr.20504)
[16] Krogh et al. 2020 (https://www.frontiersin.org/articles/10.3389/ffgc.2020.00021/full)

Fig 4. Interactions between forest density, fire, and snowpack



Snow won't accumulate directly under healthy trees where snowfall is blocked by branches.

Wildfire indirectly accelerates snowmelt by producing litter that absorbs energy and heat.

Trees emit low and persistent levels of long-wave energy that melt adjacent drifts.

But big trees also offer lots of shade, which blocks significant amounts of solar energy and keeps surrounding snowdrifts intact longer into the spring and summer months, feeding thirsty forests and reservoirs.

S.J. & Jessie E. Quinney College Of Natural Resources | Utah State University

Avoiding negative impacts on flow timing is another method to interpret the benefits of fuels reduction projects on the timing of flows. Unlike low-intensity fires and selective fuels reduction practices, ***high-intensity wildfires can negatively impact the timing of flows*** and produce challenges for the environment and water resource managers. One example, the 2007 Moonlight Fire in the Sierra Nevada, resulted in canopy reduction that led to earlier snowpack melt-out compared to the unburned part of the basin.[17] High-severity wildfires can also "cook" soils, making them water-repellent, or hydrophobic. As a result, severe wildfires can lead to heavy flows immediately following a fire (particularly in spring and fall) that can overwhelm water infrastructure and increase the risk for catastrophic flooding and landslides in and around burn areas.[18]

Using ET Models to Inform Forest Investments

Water agencies that rely on forested watersheds for their water supply have an opportunity to use the methods and literature outlined in this brief to justify investments in forest restoration projects that promote watershed health. Please contact the Blue Forest team at **science@blueforest.org** to learn more about approaches and considerations for modeling ET reduction benefits in your watershed.

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[17] Micheletty et al. 2014 (https://hess.copernicus.org/articles/18/4601/2014/hess-18-4601-2014.pdf)

[18] Williams et al. 2022 (https://www.pnas.org/doi/10.1073/pnas.2114069119)