EMC Completed Research Assessment

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EMC-2019-003 Fuel Treatments and Hydrologic Implications in the Sierra Nevada
Peer-Reviewed Publications dated April 2023 and June 2024

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Part 1. Does the study fulfill and address scientific questions posed in the proposed research?

A. **Does the study inform a rule, numeric target, performance target, or resource objective?**
B. **Does the study inform the Forest Practice Rules?**

The completed research addresses questions regarding how various forest treatments may affect hydrological response and discharge in an upstream versus downstream comparison and on a sub-basin and basin scale. The rules affected by the results of this study are 14 CCR 15355 (Cumulative Impacts) and 14 CCR 937 (Treatment of Snags and Logging Slash). The results of the research are communicated in two published journals paper:

Boden, K. et al. 2023. A multi-scale assessment of forest treatment impacts on evapotranspiration and water yield in the Sierra Nevada. Ecohydrology 16(5)
https://doi.org/10.1002eco2548

Smith, K. et al. 2024. Water yield response to forest treatment patterns in a Sierra Nevada watershed. Journal of Hydrology: Regional Studies 53
https://doi.org/10.1016/j.ejrh.2024.101762

The research summarized by Boden et al (2023) presented a method in which remote sensing could be utilized to quantify preliminary treatment effects of forest structure, as well as determine metrics to quantify habitat and hydrological changes. In summary, the study set out to determine if the minimal changes in forest structure achieved in treatment had implication for regional or state water resources, and how to measure that using pre-established data collection methods or technology.

Boden et al (2023) provides data on hydrological impacts of singular and cumulative forest treatments implemented at Sagehen Creek and defined in the forest practice rules using a replicable methodology. The study location and land-use history provided a unique opportunity to evaluate a range of potential hydrological changes in relation to compounding impacts from common forest treatments over a relatively short period of time. This evaluation used an in-situ observational network for data collection which could be used or replicated for the preparation of planning or permitting documents if such a need for hydrological evaluation is identified.

The research summarized by Smith et al (2024) presents results from a physically based and spatially explicit calibrated hydrologic model using the DHI model MIKESHE to further investigate the relationship between changes in forest cover and hydrologic processes focusing on hypothetical reductions in cover density and treated forest area (removal of primary forest canopy) and resulting modeled changes in stream runoff in the Sagehen Creek experimental watershed. This modeling investigation sought to better understand the magnitude of forest treatment required to generate significant increases in annual streamflow.

Part 2. Is the study scientifically sound?

The hydrological effects research methodology of Boden et al (2023) was based upon past studies and the metrics evaluated therein and was reasonably limited to the two primary datasets of field collected data (USGS stream data and Colorado School of Mines network of pressure transducers) alongside remote sensing data of vegetation. This was done for the purposes of developing a scientifically and statistically sound model which could be used in practice by decision makers when assessing or evaluating cumulative impacts of forest treatments of hydrological resources. The research used robust, distribution-free statistical methods to analyze trends in monitoring data, accounting for uncertainty and presenting results with 95% confidence. Data was cross checked with other data sets and field data where needed. The scale of the study area was large, but the use of multiple data sources led to sound conclusions.

The hydrologic modeling investigation by Smith et al (2024) of potential streamflow increases resulting from a range of hypothetical forest treatments is a scientifically sound application of a sophisticated hydrologic model that explicitly simulates all the processes and feedbacks within the hydrologic cycle including surface water and groundwater interactions and evapotranspiration by vegetation. The modeling investigation is well-documented and acknowledges data limitations and necessary assumptions.

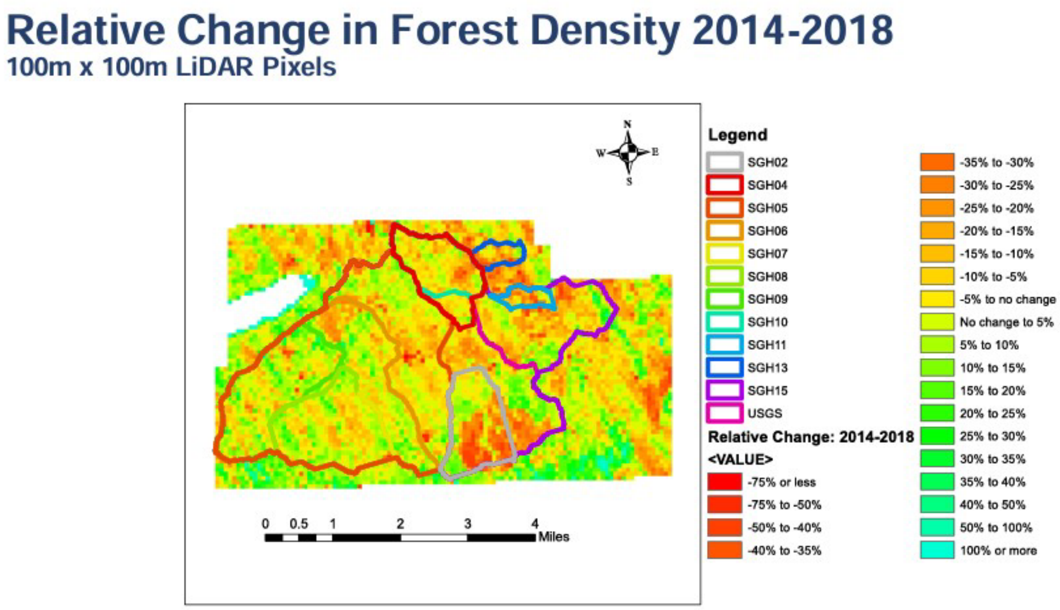
Part 3. Is the study scalable?

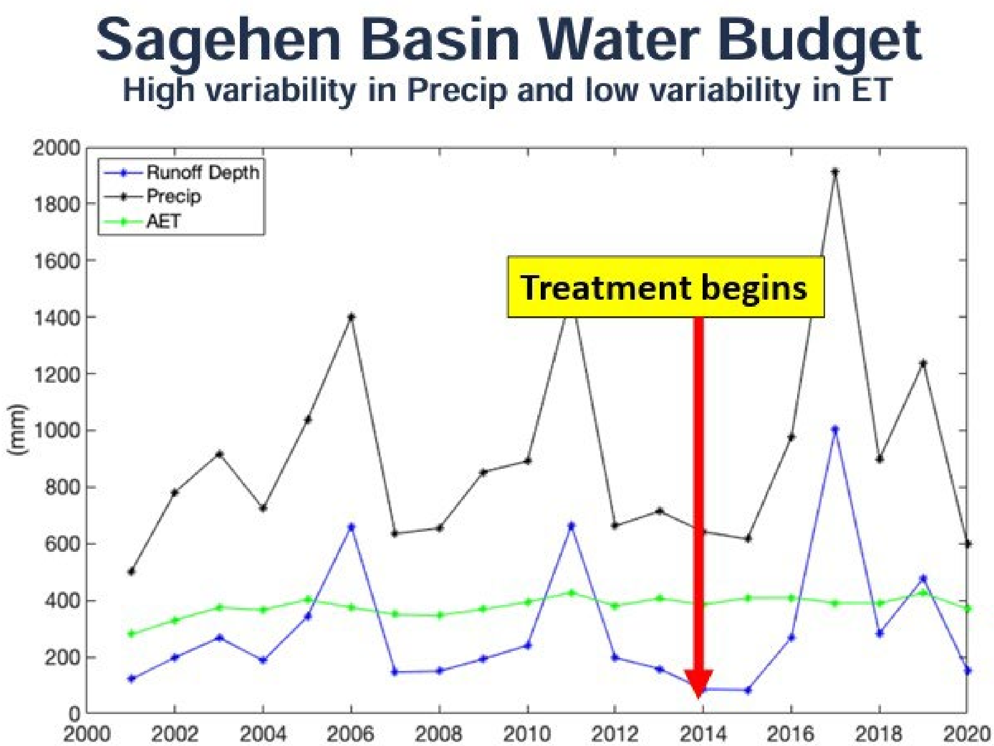
Part 3 addresses each of the two research papers separately, beginning with Boden et al (2023).

Boden et al (2023) yielded applicable data and results for use of FPRs in the Sierra Nevada watersheds and regions with similar hydroclimatic regimes, as designed. The data itself is specific to the Sagehen watershed and its associated forest practices at the time of the study, but the model used for data collection and analysis is more widely applicable. The data is limited in that it is an assessment of specific past and current management practices, watershed systems and the record of data collection. It is also temporarily specific, as it is constrained by the data quality. That being said, the data quality is notably greater than what a decision maker would usually find in many other parts of similar forest regions sense the study was based in an experimental forest, and this should be taken into account when considering scalability.

The study provided a scientifically based methodology for data collection and analysis for the purposes of assessing hydrological impacts in similar hydroclimatic regions where forest practices are taking place. In the PIs use of statistical analysis, the methodology is scalable.

The study found that the scope and scale of forest treatments with the study area and time frame were too small in scale to measure notable change in hydrological functions on a sub-basin or basin scale with few exceptions on a scale much smaller than the study units. This would imply that the methodology may not be applicable to assessments in which larger scale, cumulative or singular and over time or size of treatment(s), are being assessed. Furthermore, the scale of forest treatments in the study could not account for the hydrological function changes that were detected due to the methodology and outside-average variability in precipitation.

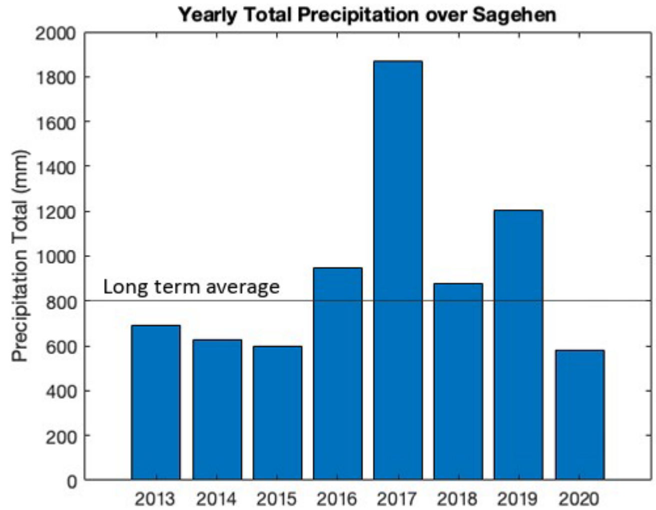




Synthesis of Key Findings

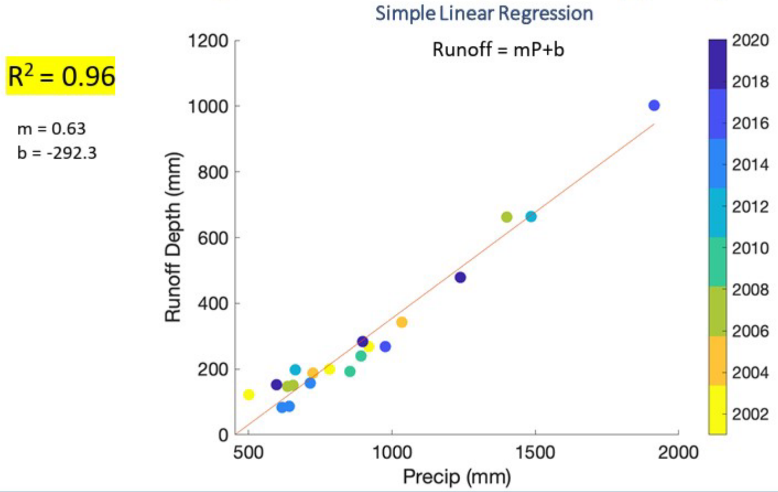
Question 1: (Within Sagehen Watershed) How do forest treatments impact annual runoff? At what spatial scale? Annual water budgets were assessed at basin and sub-basin scales. At the basin scale and sub-basin scale precipitation, while outside average annuals amounts, accounted for greater or equal to than 85% of water yield variability. There was no measurable impact of forest treatments on water yield.

Variable precipitation over Sagehen during period of study



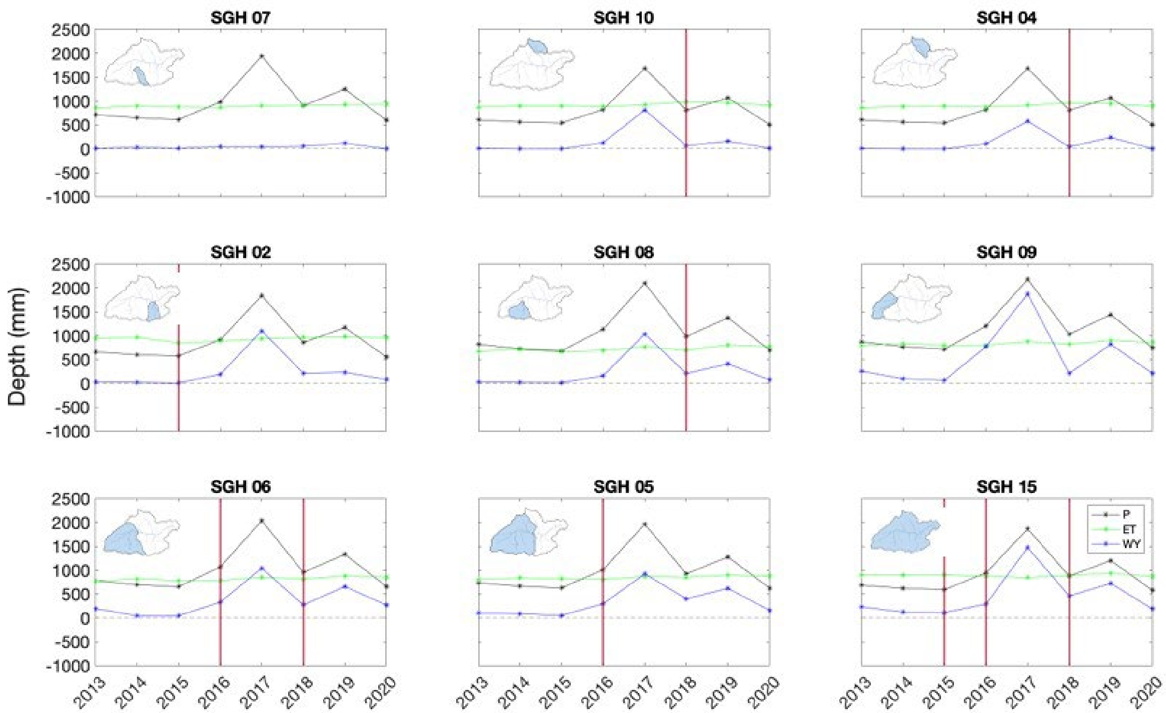
Changes in runoff is explained by precipitation

Simple Linear Regression

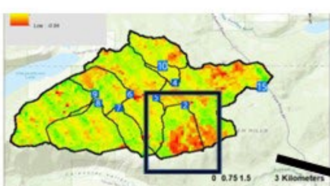


Question 2: (in Sagehen Watershed) What are the impacts of forest treatment on annual evapotranspiration (ET) at various spatial scales? At basin and sub-basin scales, ET was shown to be unaffected by forest treatments during the course of the study period. Despite high variability in precipitation, there was low variability in ET. At a smaller scale, referred to as “hot spots”, changes in forest density detected by the LiDAR data could be linked to changes in ET. This led the PIs to the conclusion that while forest treatments could have impacts on hydrological functions like ET, and those impacts could be assessed on a singular or cumulative scale utilizing this methodology, the forest treatments studies were to small in scope and scale to make a measurable change at larger spatial scales.

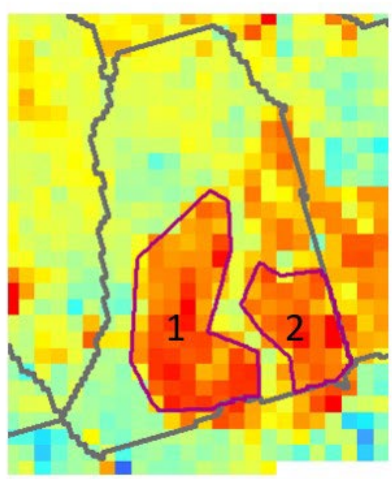
Sub-basin analysis of changes in precipitation and ET



Change in forest density "hot spots" can be linked with change in ET



Basin	SGH 15	SGH 2
Total Area (km^2)	34.22	3.02
Median Forest Density Change	-0%	-5%
Median ET Change	< 1 %	< 1 %



Hotspots	1	2
Area of change (km^2)	~0.5	~0.3
Median Forest Density Change	-25%	-22%
Median ET Change	-25%	-12%

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Smith et al. (2024) provided model simulations for a substantial northern Sierra Nevada watershed (Sagehen Creek) that are somewhat applicable to other forested watersheds depending on several factors including climate, elevation, vegetation cover, soils and geology. The authors acknowledge potentially significant data limitations regarding subsurface hydraulic and hydrologic conditions in soils and aquifer materials and simplifications in simulated forest cover (i.e. Jeffery Pine) including an assumption that no new vegetation cover developed over a simulated 5-year post-treatment phase. Despite these limitations, the model simulations should be considered generally indicative of the type and scale of forest treatments necessary to produce significant increases in streamflow. Quoting from the authors' conclusions:

Statistical testing showed that a significant change (99% confidence interval) in simulated runoff occurred for every forest treatment scenario tested on the annual scale using the calibrated MIKESHE model. A 25% increase in average annual water yield was observed when the entire basin was treated with a CDR [canopy density reduction] *of 40–60%. When quantifying changes in water yield after CDR verses area treatments, we observed that increasing CDR treatments were more effective at enhancing water yield than increasing treatment area. Like much of the Sierra Nevada, water yield in the Sagehen basin is highly correlated with, and dominated by, precipitation. However, we found that treatments have a compounding effect on water budget partitioning over the years and the calibrated MIKESHE illustrated how each component of the watershed system responds to these longer-term effects. Antecedent basin storage conditions in Sagehen likely contribute to water yield…*

The primary research question was what level of forest canopy reduction is necessary to produce a 25% increase in streamflow (runoff). The study found that canopy density reduction of 40 to 60% was necessary to produce simulated annual runoff increases of 25%. This finding from a model simulation provides a valuable complementary finding to the findings of Boden et al (2023) that found no substantial change in runoff resulting from actual forest treatments in the Sagehen Creek watershed. The results from both Boden et al and Smith et al are of interest in comparison with recent results from the third Caspar Creek watershed in the coastal redwood forest region that investigated the relationship between variation in the reduction of forest canopy and streamflow.

These findings may help forest and watershed managers anticipate the likely magnitude of hydrologic change resulting from forest treatment (or fire disturbance). It does not provide simulations of likely changes in hydrologic processes during ensuing forest vegetation recovery following disturbance that has been shown in other studies to reverse stream flow increases over a period of about 10 to 30 years.

The key hydrologic simulation results are reproduced from Smith et al (2024), Figures 4, 5 and 6 below. Runoff ratio is defined as the proportion of annual watershed precipitation depth that leaves the watershed as runoff (streamflow).

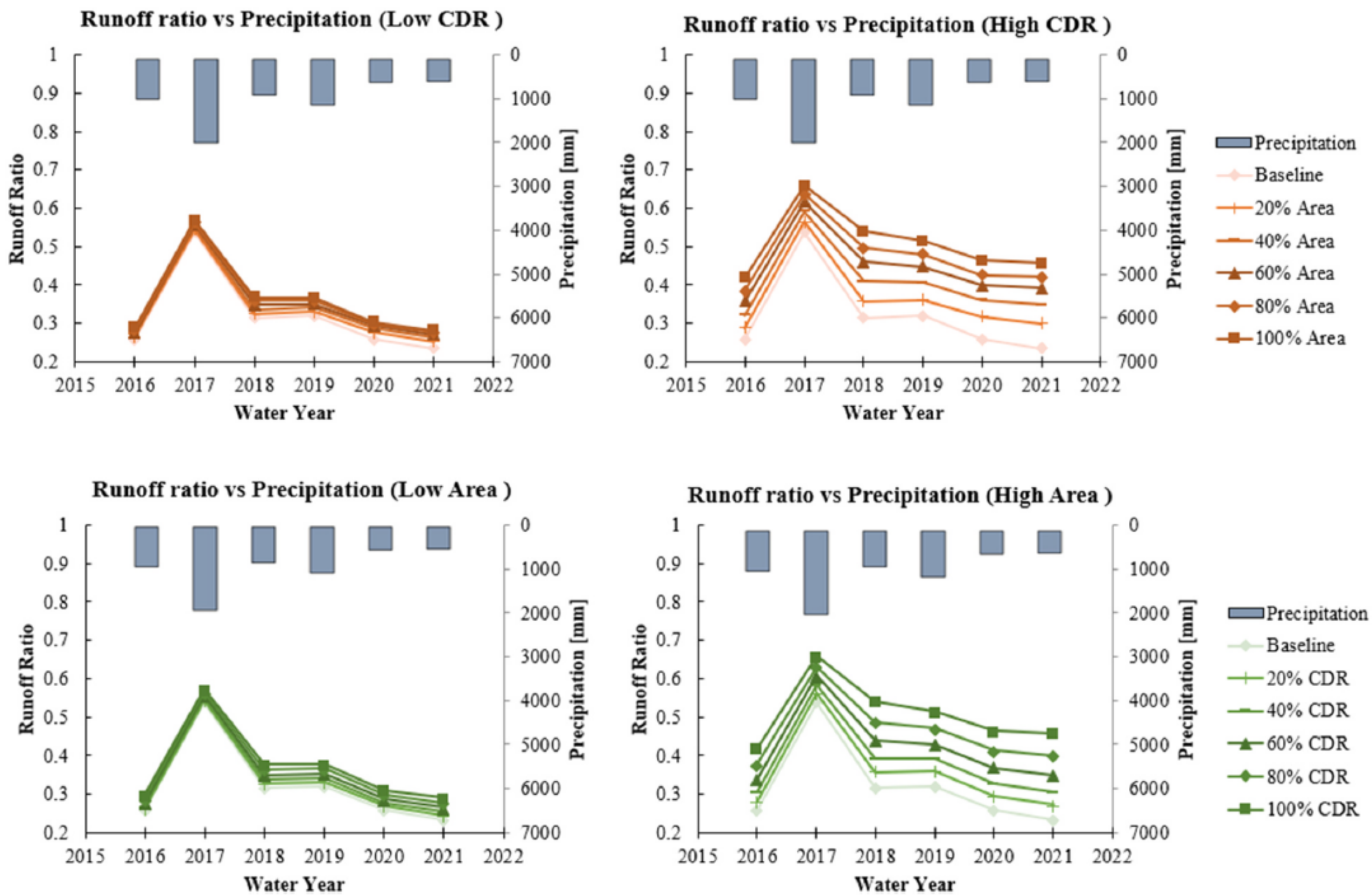

Fig. 4. Runoff Ratio for Baseline and Canopy Density Reduction (CDR) Treatment Scenarios Compared to Precipitation. Treatment was applied at the start of WY 2016.

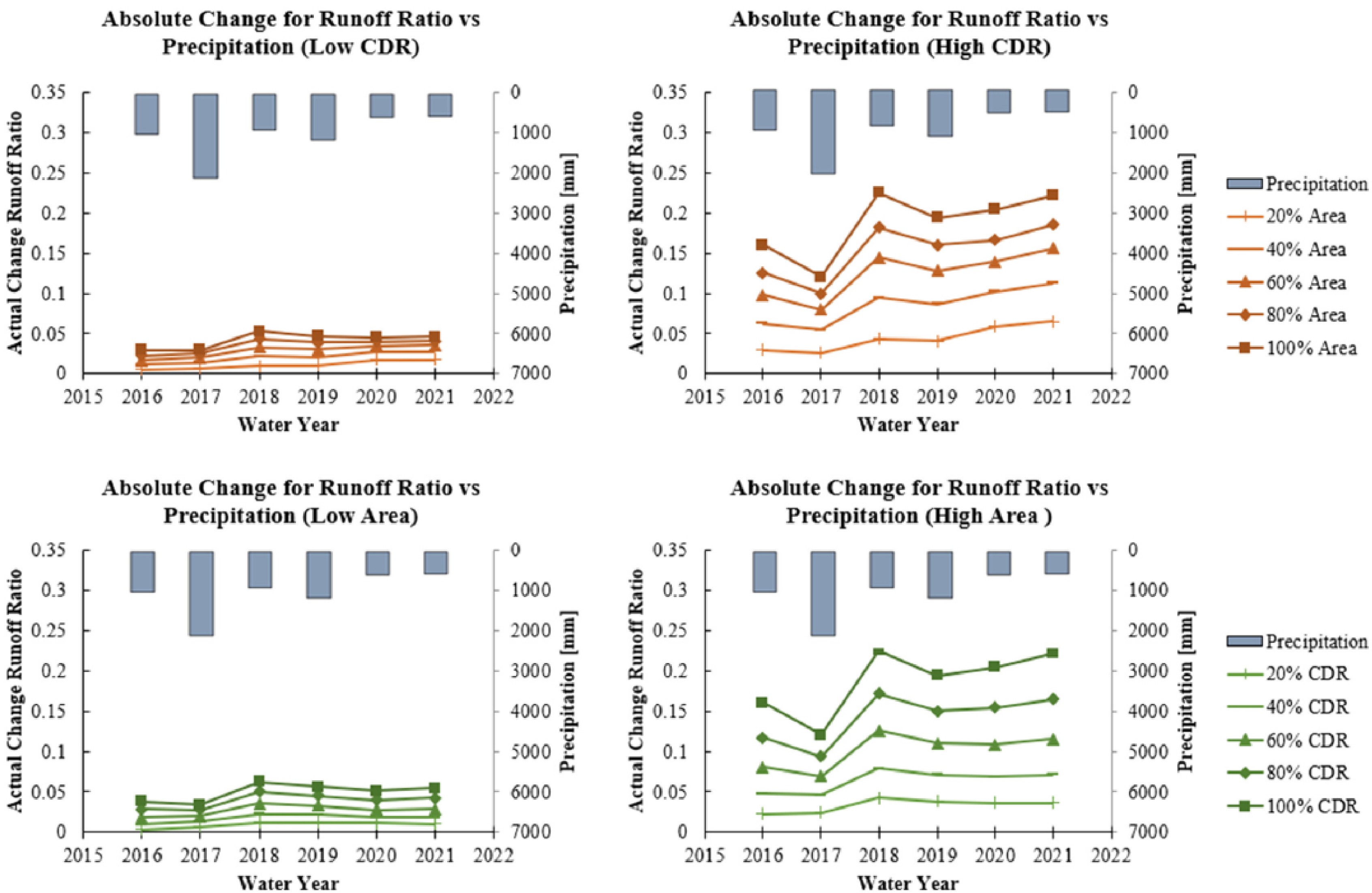

Fig. 5. Absolute Change in Runoff Ratio from Baseline to Scenario Compared to Precipitation. Treatment was applied at the start of WY 2016.

A graphical representation of the maximum simulated forest treatment effect is provided by Figure 6 from Smith et al (2024) reproduced below showing effects on the basin water balance.

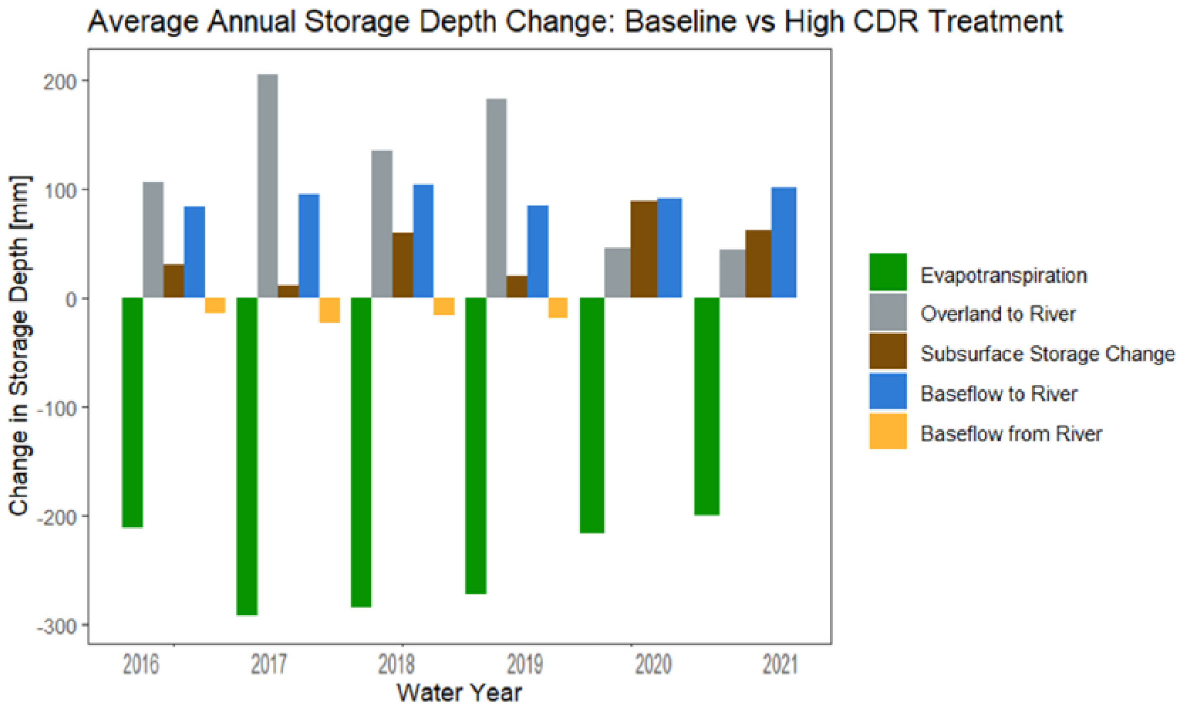

Fig. 6. The change in water balance parameters from Baseline to 100% Area and 100% CDR Treatment scenario.

Part 4. More research needed?

1. **Literature Review Sufficient?** Boden et al (2023) methodology and statistical analysis were based off and referenced a variety of literature that was sufficient relative to the scope of this project. Publications on the finding of small-scale "hot spot" forest density changes correlating to change in ET appear to be missing in the literature review. Smith et al (2024) performed a very good literature review that puts the hydrologic modeling approach in perspective with both other modeling studies and watershed experiments.
2. **Further Funding Needed?** This study comprised of two separate but related publications effectively accomplished what it set out to complete. Further study and associated funding could be put into replicating methodology with larger forest treatment scales, or in different regions or watersheds, or in the same region but during different time frames. Forest watershed hydrologic studies produce varied results, and the need remains to better quantify the relationship between change in forest vegetation, climate, and streamflow. Additional studies in other geographies in California would be of value, particularly where MIKESHE modeling could be combined with hydrologic data sets.
3. **What is the relationship between this study and any others that may be planned, underway or recently completed?** This study is related to EMC 2018-006 and 2023-002 in

terms of monitoring FPR effects on stream temperature. The ongoing watershed experiments at Caspar Creek provide perspective on the findings from Smith et al (2024).

Part 5. Scientific Applications - What is the scientific basis that underlies the rule, numeric target, performance target, or resource objective that the study informs? How much of an incremental gain in understanding do the study results represent?

Boden et al (2023) collected and analyzed data to assess hydrological function impacts from a variety of forest treatments in a watershed with a robust data collection network in situ, and created a model to replicate this methodology and similarly analyze the data. These tools can be used by decision makers in planning a permitting forest treatment, specifically when accessing hydrological functions like yield and ET. Similarly, Smith et al (2024) provides some insight and guidance regarding the effects of forest management and disturbance on streamflow.

From the 2025 FPR's Addendum No.2: Cumulative Impacts, pursuant to 14 CCR § 15355, refers to two or more individual Effects which, when considered together, are considerable or which compound or increase other environmental Impacts. This assessment shall include evaluation of both on-site and off-site interactions of proposed project activities with the Impacts of Past Projects and Reasonably Foreseeable Probable Future Projects. In regards to the regulation, the study developed methodology that could assist.

The study methodology took advantage of a research watershed with extensive hydrologic monitoring equipment that collected an extensive amount of pre-treatment data. The two studies comprising this project took significantly different approaches. Boden et al (2023) was a more empirical study of implemented forest treatments and it concluded that variability in streamflow (runoff) was not likely caused by forest treatments and were more likely caused by precipitation. It found that ET was non-variable and conclude this could be due to the scale of forest treatments. Smith et al (2024) confirmed that the magnitude of effect on forest evapotranspiration investigated by Boden et al (2023) was insufficient to generate a measurable change in streamflow (runoff) and identified an approximate effect threshold about ten times greater than that evaluated by Boden et al (2023). This study overall provides good evidence regarding a forest treatment threshold that could be expected to have significant effects on streamflow (runoff) in the region represented by Sagehen Creek.