Predicting the Long Term Hydrologic Effects of the Four Forest Restoration Project at Tonto Creek Basin, Arizona

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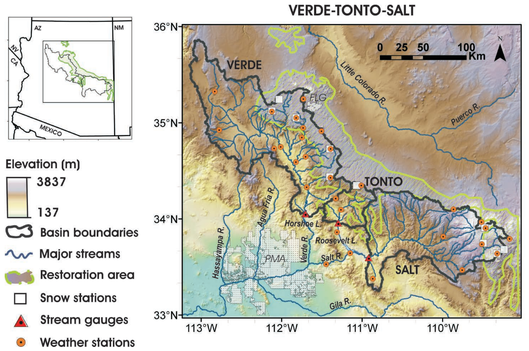
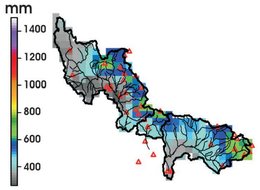
Abstract

Understanding the effects of intensive forest thinning on the hydrology of semi-arid basins is critical to achieving water resources sustainability in the water limited Southwestern US, where disturbances to headwater catchment forests can scale up to significant perturbations of the basin-scale water balance components. In northern Arizona, the Four Forest Restoration Initiative (4FRI) is being developed with the goal of restoring 2.4 million acres of Ponderosa pine along the Mogollon Rim. In this study, we select the Tonto river, as a prototypical semi-arid watershed, for the inference of long-term impacts on water yield and extreme conditions on neighboring basins. Long-term (20 year) simulations conducted using the tRIBS physically based spatially distributed model reveal shifts in the spatio-temporal regimes, and in the triggering processes of runoff and integrated discharge as a response to feasible forest thinning scenarios. Specifically, our analysis suggests that alterations to the interception, infiltration, evapotranspiration and snow processes within the forested areas will result in changes to long term water yield, and to extreme (peak and low flow) values. The results are helping local and regional water managers and policy makers to better understand the potential consequences of intensive forest removal and thereby influence decision making related to land use and the management of water resources.

Study Area

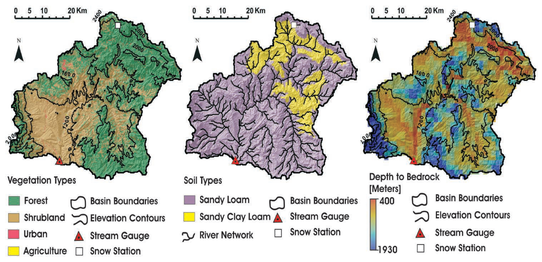


Multi-Annual, Bias Corrected Regional Precipitation



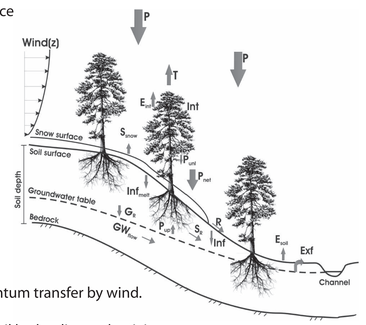
- 1990-2010 NLDAS raw precipitiation data is locally bias corrected with 30 regional rain gauges.
- Topographic complexity along Mogollon Rim promotes rainfall development.
- Spatial distribution of rainfall reveals that area to restore is the rainiest.
- Winter systems build up on-the-ground snow.
- Monsoon driven rainfall occurs during the summer season.

Tonto Creek: Vegetation, Soils and Bedrock Depth

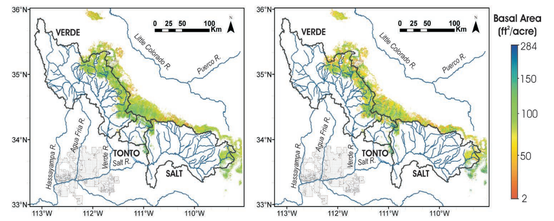


Hydrologic Impacts

- Forest thinning affects surface and vadose zone dynamics:
- Reductions in interception.
- Shifts in snow peak and melt timing.
- Changes in runoff magnitude and time.
- Decreased ET rates.
- Shifts in soil moisture.
- Increased turbulent momentum transfer by wind.
- Decreased infiltration and soil hydraulic conductivity.



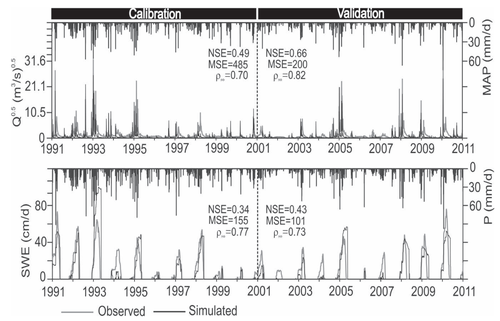
Arizona 4FRI Restoration Plan



- U.S. Forest Service to restore 2.4 million acres of Ponderosa Pine to reduce fire risk.
- Using mechanical thinning and prescribed burning project will reduce current basal areas to 1900's historic tree densities (120 ft2/ac to 58 ft2/ac).

Hydrologic Model

tRIBS hydrologic model calibrated and validated with historical time series of snow water equivalent and discharge.

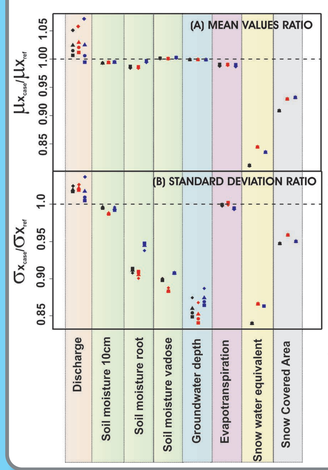


Simulation Cases

A thinning scenario (V) is considered along with three cases of 10%, 20% and 40% reductions in the soil saturated hydraulic conductivity (Ks).

Case	Soils	Forest
Current	Calibrated Ks	2006 basal area map
V	Calibrated Ks	Projected post-treatment basal area
VS10	10% reduction in Ks across soil types in ponderosa pine areas	Projected post-treatment basal area
VS20	20% reduction in Ks across soil types in ponderosa pine areas	Projected Post-treatment basal area
VS40	40% reduction in Ks across soil types in ponderosa pine areas	Projected Post-treatment basal area

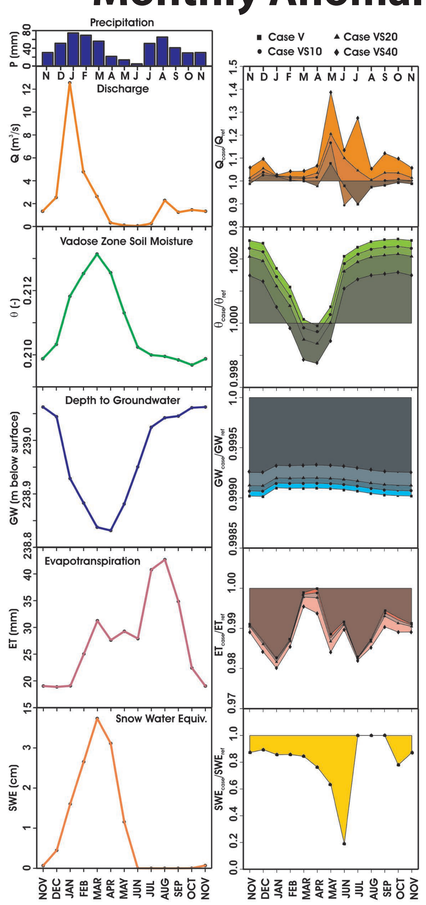
Basin Scale Water Balance



Case
- V — All years: μ(P)= 509 mm/y, σ(P)= 48 mm/y
- VS10 — El Niño: μ(P)= 613 mm/y, σ(P)= 48 mm/y
- VS20 — La Niña: μ(P)= 453 mm/y, σ(P)= 41 mm/y
- VS40

- Forest thinning affects surface and vadose zone dynamics at the basin scale.
- Mean and standard deviation of anomalies in water budget components differ between El Nino and La Nina years.
- Mean and variability of runoff is increased by up to 5% in the VS20 and VS40 cases.
- Soil moisture and evapotranspiration are reduced in less than 3%.
- Snow covered areas and snow water equivalent are heavily reduced (~5 to 15%) in all cases.

Monthly Anomalies



Forest thinning increases runoff during winter in as much as 10% for the VS40 case. For V and VS10 decreases in summer runoff are observed, meaning lower baseflows.

Reductions in soil water storage are are observed when soil moisture is at annual peak, particularly for VS40.

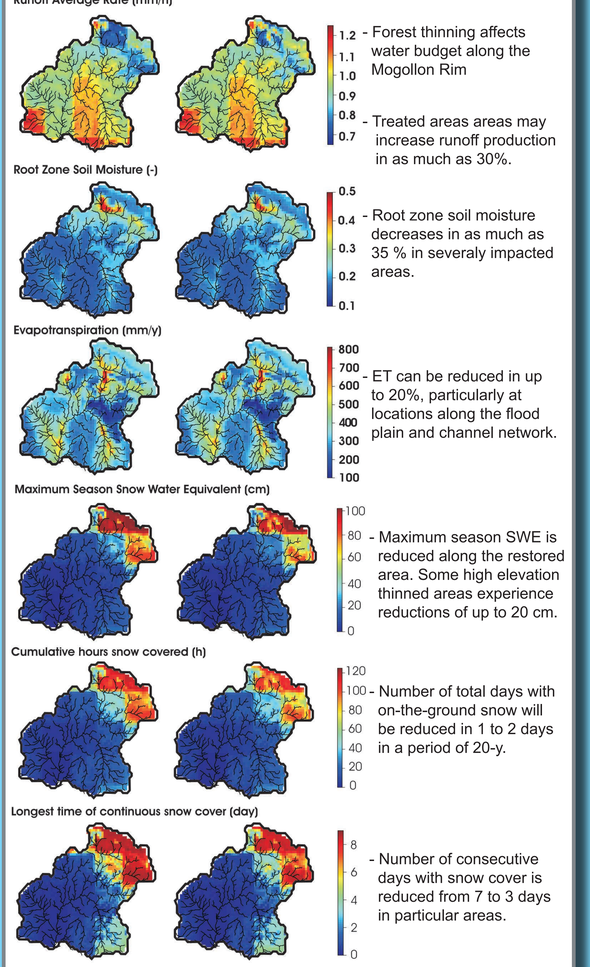
Forest thinning appears to have small effect on groundwater system.

In all cases ET appears to be reduced by up to 2%.

At the SWE peak in March, all cases represent a reduction of about 20%.

Distributed Water Footprint

Current Case VS10 Case



- Forest thinning affects water budget along the Mogollon Rim
- Treated areas areas may increase runoff production in as much as 30%.
- Root zone soil moisture decreases in as much as 35 % in severaly impacted areas.
- ET can be reduced in up to 20%, particularly at locations along the flood plain and channel network.
- Maximum season SWE is reduced along the restored area. Some high elevation thinned areas experience reductions of up to 20 cm.
- Number of total days with on-the-ground snow will be reduced in 1 to 2 days in a period of 20-y.
- Number of consecutive days with snow cover is reduced from 7 to 3 days in particular areas.

Summary

- Headwater forest thinning triggers changes in the components of the hydrologic cycle from the plot to the full basin scale.
- Positive changes in runoff production are expected, particularly during wet El Nino years and the winter season. Effects of thining on runoff are mixed during summer.
- Negative changes in snow water equivalent and snow covered area are consistently observed across simulated cases.
- Spatially distributed effects of forest thinning may have dramatic changes in snow cover and runoff production at particular locations within the treated areas.

Acknowledgments

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