Scraps

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The connection between forests and water supplies is well documented. Around 65% of surface water in the western states originates from forested lands, which cover just 29% of the land area [**?**]. The average annual precipitation in the Lower Colorado River Basin is about 330 mm, and only about 10 mm of that precipitation becomes streamflow, while much of the rest is lost to evapotranspiration [**?**]. Regional studies have found that up to 90% of annual precipitation in semi-arid forests is lost evapotranspiration [**? ? ? ?**]. Sublimation has been shown to remove 10 - 90% of snowfall in the Colorado River Basin, while the remaining snowmelt provides over 80% of streamflow to the Colorado River [**?**]. Over half of streamflow from the Upper Colorado River basin comes from groundwater sources primarily recharged by snowmelt [**?**]. Therefore, small reductions in evaporative losses could have out-sized impacts on available water supplies, particularly enhancing groundwater recharge in terrains underlain by karst lithology [**? ?**].

** Papers on how thinning works primarily in snow-dominated systems**

This research aims to develop criteria for areas suitable for thinning to enhance groundwater recharge. It focuses primarily on regional studies to determine suitability criteria, which are likely the best predictor of hydrologic response to treatment [**?**].

1. Regional Hydrologic Responses to Treatment

Several regional studies link forest treatment to changes in stand-level ecohydrology, including increased tree growth in Ponderosa Pines greater soil moisture and total ecosystem moisture leading to increased drought resilience [**? ?**], increased snow retention [**? ?**], greater streamflow [**?**], water table rise [Denver et al in Prep][[**?**]][**?**] and increased springflow [**?**][Hart prarie and hoxworth in prep].

1.1. Water Yield/Runoff

Several regional studies link forest treatment to increased streamflow [**? ? ?**]. However, there appears to be a threshold response, with water yield increasing

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only in treated forests receiving over 500mm of annual precipitation or in snow-dominated forests [**?** **?** **?** **?** **?**].

1.2. Soil Moisture and Drought Resilience

A synthesis of several treatment types across Northern Arizona, including thinning at various levels and prescribed burning, found that treated sites had significantly greater total ecosystem moisture, making forests more resilient to drought[**?** **?**]. Treatments were shown to increase tree growth, improving resilience to drought in Ponderosa Pine forests[**?**]. Thinned Ponderosa Pine forests have higher soil moisture for two to eight years post-thinning, a result also found in semi-arid forests around the Mediterranean [**?** **?** **?** **?**].

1.3. Justification

- regional studies are the best predictor of hydrologic response to thinning in Arizona forests [**?**]
- A snythesis of all 4FRI treatments found that thinned and burned forests have signifiantly greater total ecosystem moisture and are thus more resilient to drought and wildfire [**?**]
- Thinned forests are better buffered against drought impacts in terms of both soil moisture and tree health [**?**].
- Soil moisture and ET may be affected by thinning for 3.6 - 8.6 years [**?**].
- Prescribed burning or thinning can increase tree growth, improving resilience to drought in ponderosa pine forests [**?**].
- Thinned forests (around Flagstaff) have higher soil moisture at 25 and 50cm in the first two years post-thinning [**?**].
- Thinning in semi-arid forests around the Mediterranean increased antecedent soil moisture and below ground hydrologic processes and increased deep soil moisture by 50mm/year over the control [**?**].
- a review of 35 studies published from 1971 to 2018 found that thinning was more effective than clear-cutting in terms of increasing groundwater recharge due to reduced sublimation and evaporation. Springs can effectively monitor groundwater recharge effects in arid lands [**?**].
- A review of studies on forest mgmt effects on groundwater resources found that a rise in the water table can generally be expected following forest thinning in all forested landscapes [**?**].

1.3.1. Snow retention

- The effects of forest thinning and subsequent snowmelt are highly variable, with responses depending on forest structure and local climate, where thinning in dense and taller vegetation generally increases snow retention, thinning in shorter, less dense forests may decrease retention [**?**].

- In semi-arid forested watersheds, thinning can influence streamflow variability by modifying snowpack accumulation and melt, particularly in wetter years where thinning can either reduce or increase snow retention based on site-specific conditions.[**?**].
- Thinning in semi-arid forested watersheds can significantly impact streamflow by altering snowmelt timing, with reduced forest cover tending to delay snowmelt at warmer sites while advancing melt at cooler, snowpack-persistent sites [**?**].
- Thinned forests around Flagstaff have greater snow persistence at 25%-35% canopy cover [**?**]
- Thinned forests in Northern Arizona have more snow and soil moisture [**?**]
- Found that thinned and burned vs. control forests had varying rates of snowmelt and snow persistence. Canopy cover is most predictive of snow persistence [**?**].

1.3.2. Thresholds in literature

- A review of 94 catchment studies showed that significant changes in water yield are correlated to forest growth in forests that receive 600-1200 mm of mean annual precipitation Bosch and Hewlett, 1982 The caveat being there were not many coniferous forests studies in that precipitation range [**?**].
- [**?**] hypothesized that where annual precipitation exceeds ~500 mm or water yield is dominated by snowmelt, watershed will experience significantly decreased evapotranspiration and increased flows if canopy cover is reduced by over 20%. However, their recent observations suggest that in dry forests, water yield may decrease. More research is needed. This paper was focused on tree-die off not thinning.
- [**?**] found a threshold hydrologic response when evaluating the thinning of a snow-dominated semi-arid Pinyon-Juniper community in the Great Basin. They found that a positive water yield in thinned plots was only observed when precipitation exceeded 400mm annually (wet years)
- [**?**] suggests that disturbance will positively impact streamflow for a minimum of several years following disturbance in areas where mean annual precipitation exceeds ~500mm. "Presumably because below 500 mm, most precipitation is evaporated regardless of forest condition (Hibbert, 1979)[@]
- [**?**] evaluated 250 worldwide catchment studies and found that the differences in ET between forested and non-forested catchments diminish in areas with annual rainfall less than 500 mm