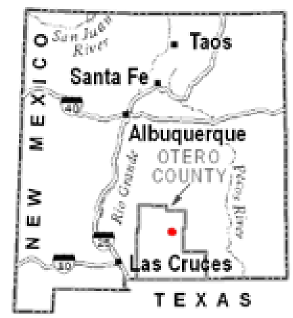
New Mexico Bureau of Geology and Mineral Resources at New Mexico Tech

Sacramento Mountains Watershed Study: Can we increase our water resources by thinning trees in the mountains?

Preliminary report
June 2012

Figure 1–Study area location in Otero County, New Mexico



The Sacramento Mountains, located in south-central New Mexico, receive among the largest annual rainfall amounts in New Mexico. Average annual precipitation ranges from 26 inches in the high mountains to approximately 14 inches in the foothills to the east. Precipitation in these mountains is the source of groundwater and surface water in the area, sustains water supplies for local communities, and also recharges adjacent regional aquifers. Concerns about future groundwater resources has resulted in an interest by land managers to possibly increase the groundwater and surface water supply by thinning trees in the high mountain watersheds in the Sacramento Mountains. This is an overview of preliminary results from the Sacramento Mountains watershed study, which is focused on assessing the effects of tree thinning on the local hydrologic system in the southern Sacramento Mountains.

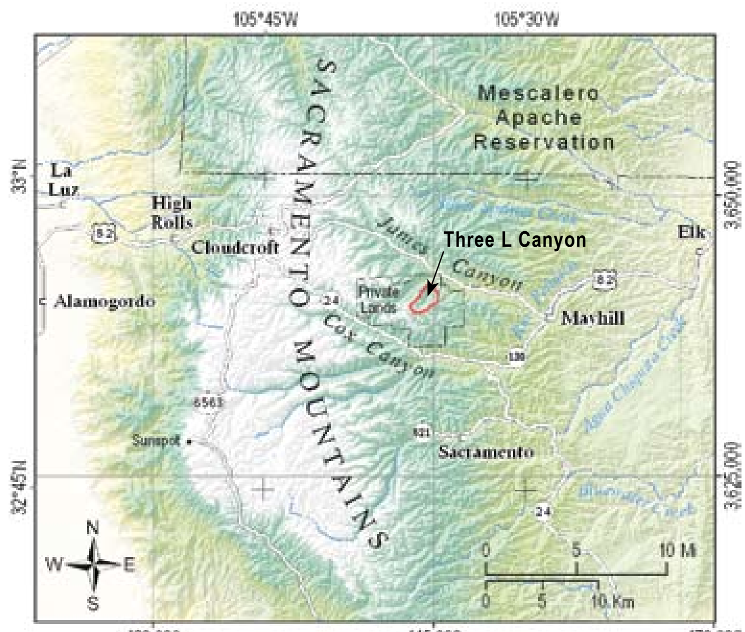


Figure 2–Sacramento Mountains Watershed study area.

SHOULD WE BE CONCERNED ABOUT OUR WATER SUPPLY?

Scarcity of groundwater and surface water is currently a problem faced by communities all over the world. Increases in groundwater pumping due to population growth combined with drought over the last decade has resulted in significant groundwater level declines in much of the western United States. Water managers and users in local communities in the Sacramento Mountains have observed declines in water levels and spring discharges in the past few decades, with dramatic decreases in the early 2000s. The Sacramento Mountains watersheds have undergone significant land use and hydrologic changes during the 20th century, including changes in vegetation patterns, an increase in tree density, variable climatic conditions, localized and severe fire impacts, and new groundwater and surface water diversions.

Solutions to these problems need to be addressed by deciding the best ways to use water and how to conserve this precious resource. However, there are perhaps some ways to increase the amount of available water at the supply side. Climate and geology are the primary factors that control groundwater and surface water supply, with precipitation providing the primary water input, and the geology controling how water moves from the recharge area and headwaters to where it is used. Presently, we cannot significantly alter either climate or regional geology in a controlled manner. However, we can, and do, change the interface between these two systems, which includes the shallow subsurface and vegetation. By altering vegetation patterns and or the landscape, we change the way climate interacts with the geology, and therefore can possibly affect the amount of water that makes its way into the groundwater and surface water systems.

Figure 3–Forests in the southern Sacramento Mountains are characterized by high tree densities as seen in the top photograph (up to 1000 trees per acre). Thinning trees (bottom photograph) decreases fire danger, improves wild life habitat, and may increase groundwater recharge.

DOES TREE THINNING INCREASE WATER SUPPLY?

Thinning trees in the Sacramento Mountains is a popular restoration technique that is being used to improve wildlife habitat and reduce fire danger (Fig. 3). This restoration technique also has implications for increasing the groundwater and surface water supply. Presumably, a decrease in tree density will correlate to a decrease in the amount of water used by trees and therefore increase groundwater recharge and stream base flow. Much research has been done on the effect of thinning and clear cutting of trees on stream flow due to concerns about the consequences of logging. These studies usually focus on a watershed with a perennial stream and compare the amount of precipitation in the watershed to stream flow before and after thinning. Water that is produced in streams is termed "water yield." In general, the increase in water yield due to tree thinning depends on the proportion of trees that are cut. For many of the Southwestern states, including New Mexico, Colorado and Arizona, data suggest that the removal of at least 15% of trees is necessary to result in a measurable increase in water yield. (Stednick, 1996). There is a rough correlation between the percentage of trees cut and the measured increase in water yield. However, measured increases in water yield were highly variable. The effects of tree thinning on water yield appear to depend on many different factors that vary from site to site. In some areas, tree thinning may not have a significant effect on water yield.

Because the effects of tree thinning on the local hydrology are largely site specific, it is necessary to understand the regional and local hydrogeology and to conduct scientific research to assess the effects of tree thinning on the local hydrology in the area of interest. Then a cost benefit analysis can be conducted before tree thinning is implemented as a method to increase the water supply. Researchers at the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) recently completed a comprehensive hydrogeology study in the southern Sacramento Mountains (Newton et al., 2012) that identified recharge areas, determined groundwater flow directions and velocities, and assessed groundwater/surface water interactions. This regional scale study set the groundwork for the Sacramento Mountains watershed study.

Sacramento Mountains Watershed Study

INTRODUCTION

The Sacramento Mountains watershed study (SMWS) is focused on understanding the local hydrologic system in a high-mountain watershed, and the impacts that forest management has at this scale. The SMWS utilizes hydrologic, geochemical and remote sensing techniques to examine how local precipitation is partitioned and distributed in the watershed, and how this partitioning changes with vegetation density, type and distribution due to tree thinning. Researchers from New Mexico Bureau of Geology and Mineral Resources (NMBGMR), New Mexico State University (NMSU), the New Mexico Forest and Watershed Restoration Institute, and New Mexico Institute of Mining and Technology (New Mexico Tech) are working to accomplish the following goals:

- Assess local hydrogeology and recharge mechanisms
- Assess how trees interact with local hydrologic system
- Quantify the water balance at different scales before and after tree thinning treatment
- Relate the observed changes in the water balance to the local hydrogeology

STUDY AREA

The study area is located in Three L Canyon, which is on private property (Fig. 4). Three L Canyon is a tributary to James Canyon between Cloudcroft and Mayhill. The study area covers approximately 800 acres and elevations range from ~8,800 ft at the tops of the ridges to ~7,700 ft at the canyon bottom. Vegetation in the area consists of mixed conifer (Douglas Fir, Ponderosa Pine, White Fir, and White Pine) on the hill slopes and ridge tops, and grass on the canyon floors. Two springs discharge water in the canyon that is stored in small ponds. Streamflow in this canyon is very rare. In 2011, approximately 352 acres of forest were thinned. Initial tree densities ranged from 30 to 1100 trees per acre. In the area that was thinned, tree densities were, on average, reduced by 50%.

We have been collecting data since 2008. Much of this data is collected continuously by instruments installed in the study area. Data includes:

- Groundwater levels
- Precipitation and weather data
- Soil moisture
- Spring discharge
- Canopy interception

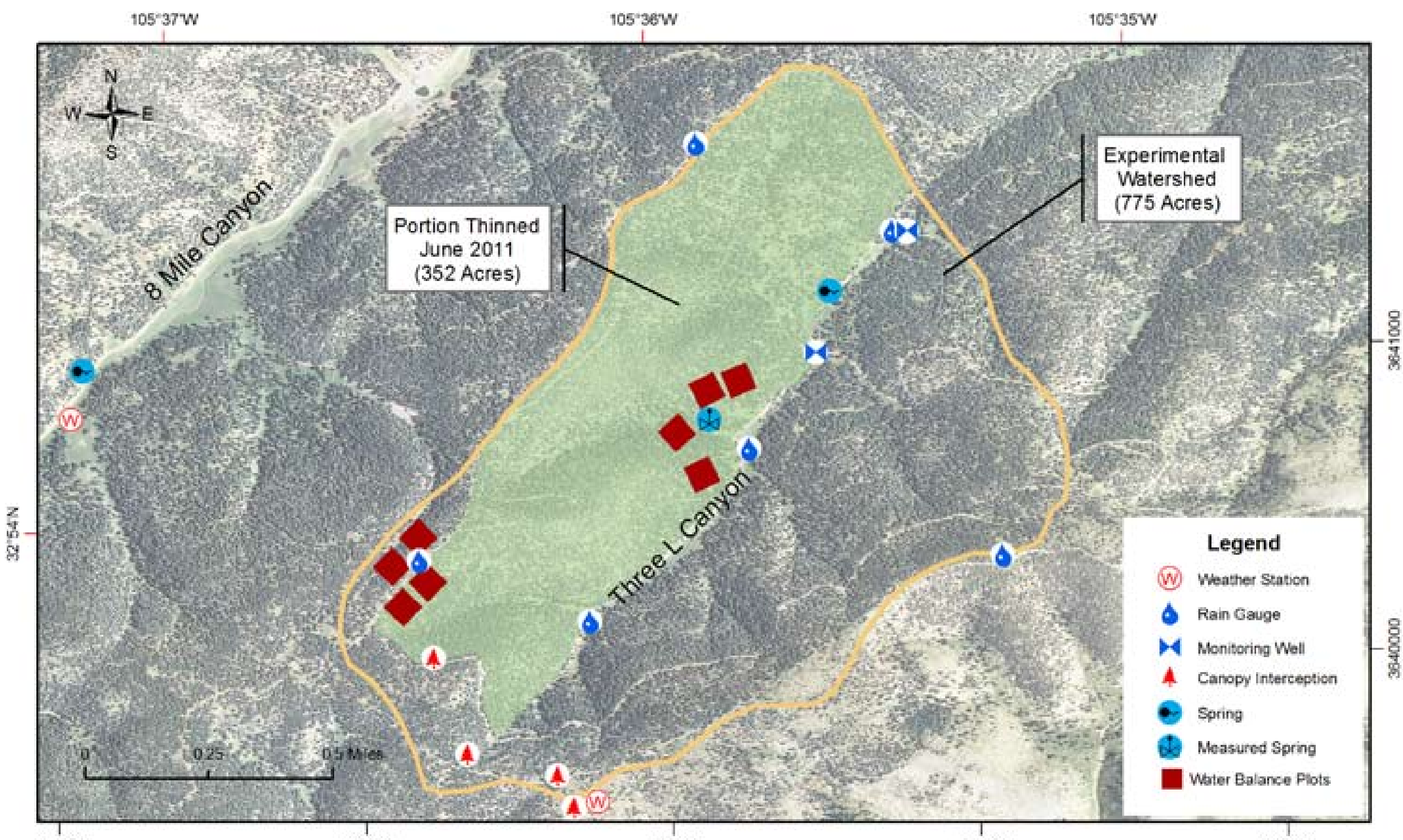


Figure 4–Sacramento Mountains watershed study area. Three-L Canyon is an experimental watershed being used to investigate the effects of tree thinning on the local hydrology. Instruments installed in the study area collect data, including climate data, precipitation, groundwater levels, spring discharge and soil moisture. Experimental plots are being used to calculate small scale water balance.

We have been collecting well and spring samples for isotope and chemical analyses. We have also been extracting water from soils and trees for isotopic analyses. These data have helped us to begin to assess the local hydrogeology, quantify different components of the water balance, and assess tree watersources.

HYDROGEOLOGY

In the high mountains, limestones of the San Andres Formation cap the ridges and overlie the Yeso formation, which makes up the lower hill slopes and canyon bottoms (Fig. 5). The Yeso Formation, which forms the primary aquifer in the study area, is composed of limestone, dolomite, siltstone, and sandstone. This geologic unit is characterized by chaotic bedding produced by dissolution of soluble dolomite and limestone in the subsurface and subsequent collapse of overlying rocks. Mountain ridge and hill slope soils that overlay fractured bedrock are thin and poorly developed (Fig. 6).

The high degree of heterogeneity within the Yeso Formation, which is exposed in this area, combined with regional fracture systems, results in a complex hydrologic system that allows a significant portion of high-altitude precipitation to move relatively quickly through a series of shallow perched carbonate aquifers that are connected by fracture networks and surface water drainages. These perched aquifers are present at multiple stratigraphic levels (Fig. 5), resulting in the hundreds of springs scattered throughout the southern Sacramento Mountains. Groundwater in the high mountains is also stored in unsaturated and saturated soils, alluvium, fractures and pores that are not directly connected to this carbonate aquifer system. Ultimately, this groundwater makes its way to the Roswell Artesian Basin and the Salt Basin.

HOW DOES GROUNDWATER RECHARGE OCCUR?

Our study area is located in the recharge area as determined by the Sacramento Mountains Hydrogeology Study (Newton et al., 2012). With exception of some areas along the high ridge tops where bedrock is exposed, water must infiltrate through soils to recharge the groundwater system. Therefore it is important to understand how water infiltrates through these soils.

We are using the stable isotopes of oxygen and hydrogen to investigate infiltration processes in the soils. We focus on two different types, or isotopes, of oxygen and hydrogen that make up the water molecule. The most common oxygen isotope is oxygen-16 (^{16}O), which is made up of 8 protons and 8 neutrons, and the most common isotope of hydrogen (H) is comprised of 1 proton. However, in a given water sample, a small fraction of water molecules contain Oxygen-18 (^{18}O), which contain 2 additional neutrons and hydrogen-2 (deuterium or ^{2}H), which contains one additional neutron. The ratio

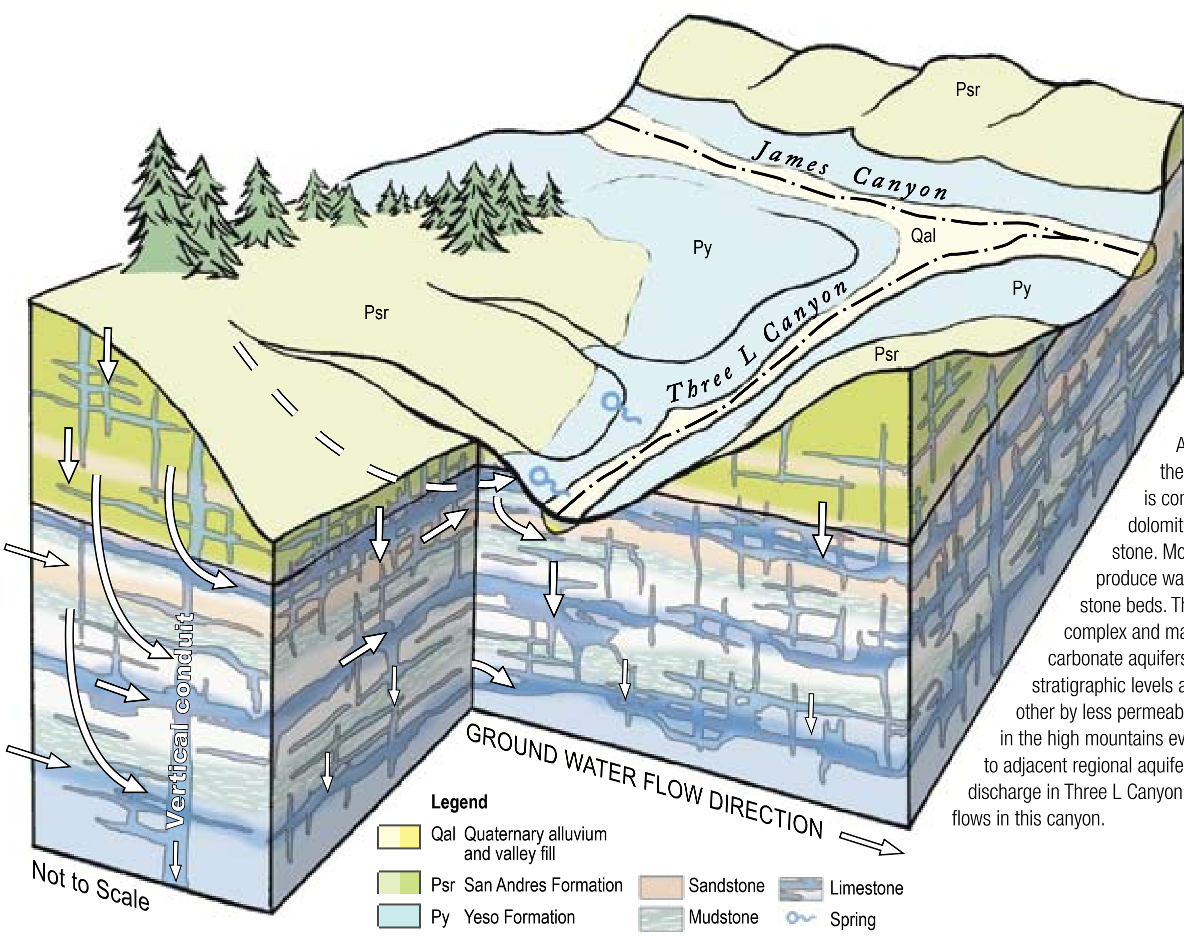


Figure 5–The geology is characterized by San Andres Limestone overlying the Yeso Formation, which is composed of limestone, dolomite, siltstone, and sandstone. Most wells and springs produce water from fractured limestone beds. The groundwater system is complex and made up of multiple perched carbonate aquifers found at different stratigraphic levels and separated from each other by less permeable rocks. Groundwater in the high mountains eventually makes its way to adjacent regional aquifer systems. Two springs discharge in Three L Canyon. Surface water rarely flows in this canyon.

Figure 6–Thin poorly developed soils that overlay the Yeso Formation. Water must infiltrate through these soils to reach the fractured bedrock below and potentially recharge the groundwater system.

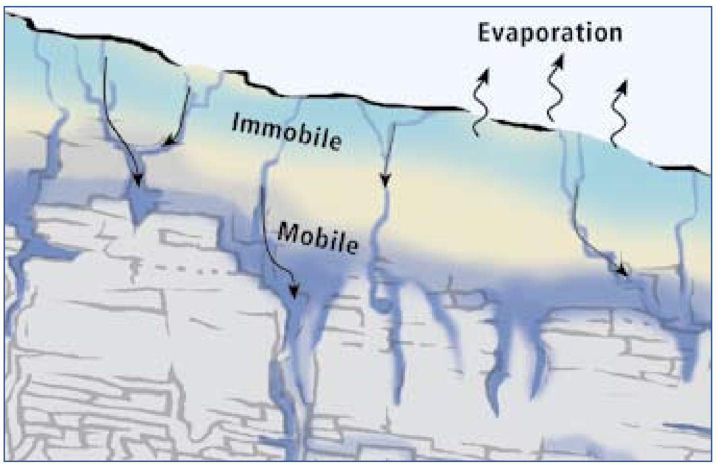


Figure 7–Immobile water is tightly bound to soil in micropores, and therefore does not drain downward very quickly. Immobile water undergoes evaporation near the soil surface. Mobile water flows quickly through preferential flow paths as a result of heavy monsoon rains. This water moves through thin soils without undergoing evaporation.

of $^{18}O/^{16}O$ and $^{2}H/H$ in precipitation is largely dependent on geographic location and seasonal weather conditions. In other words, we can tell the difference between summer rain and winter snow by looking at these isotopes. We can also determine if water has undergone evaporation by looking at the stable isotopes of oxygen and hydrogen.

By looking at the stable isotopic composition of water in the soil, we have identified two different water types: "immobile" soil water and "mobile" soil water (Fig. 7). Soil water samples collected in the spring indicate evaporation. This water appears to be primarily snow melt that is stored in the soil and is slowly evaporating. It appears that this water is strongly bound to the clay and silt particles in the soil and therefore is relatively immobile. Shortly after the onset of monsoons in July, we found that the isotopic composition of some soil water began to change rapidly. The isotopic composition of this water resembled that of monsoon rainfall with no sign of evaporation. Interestingly, this water was only observed at very discrete sampling points while most soil water surrounding these sampling points remained unchanged with an evaporative signature. The soil water with an isotopic composition of summer rain is mobile water that infiltrates through the soils very quickly through preferential flow paths. This water likely reaches the underlying bedrock to potentially recharge the groundwater system.

Preferential flow paths are very common in mountain soils and are caused by a variety of different factors, including natural variability in soil grain size, worm and root channels, and fractures in underlying bedrock. Understanding these preferential flow paths in the Sacramento Mountains is very important in order to quantify potential groundwater recharge.

WHERE DO TREES GET THEIR WATER?

(Getting to the root of the matter)

When evaluating the effect of tree thinning on the local hydrologic system, it is necessary to know exactly from where trees are extracting water. Do trees extract their water from the shallow soil, fractures in the underlying bedrock or possibly from a shallow aquifer system? To answer these questions, we extracted water from trees in the study area and analyzed it for the stable isotopes of oxygen and hydrogen. It appears that during the spring time, trees primarily extract the immobile water from the soil. After the onset of monsoons, they appear to extract greater than 50% of their water from mobile soil water, which is likely being stored in fractures in the underlying bedrock (Fig. 8). After the monsoon season, trees begin to extract water primarily from the shallow soil again.

These results have important implications on how tree thinning might affect potential groundwater recharge. If trees are extracting summer precipitation that has infiltrated through the soil and resides in fractures in the underlying bedrock, a decrease in the number of trees may correlate to an increase in the amount of water that can percolate below the root zone in the bedrock to recharge the groundwater system.

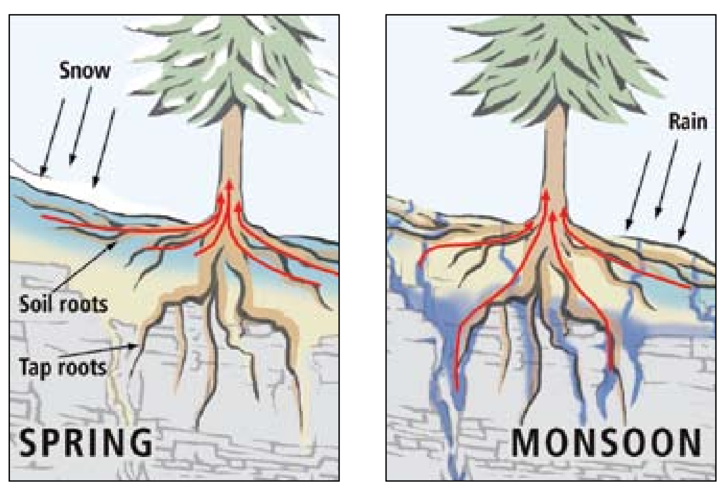


Figure 8–Trees appear to extract immobile water (light blue) from soils in the spring time. During the monsoon season, more than half of the water used by trees is mobile water (dark blue). This mobile water is likely extracted from fractures in the underlying bedrock.

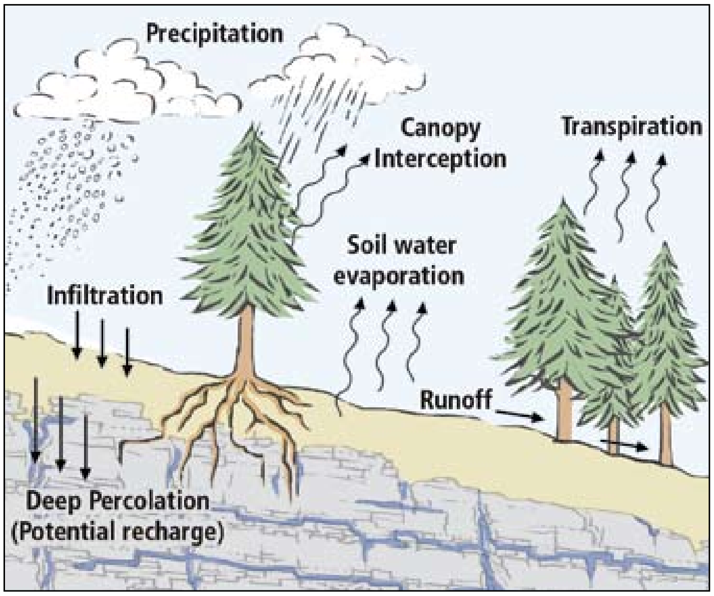


Figure 9–For a soil water balance, the only input is precipitation that reaches the surface. A significant amount of rain may be lost as canopy interception. Outputs include runoff, evapotranspiration (soil evaporation and uptake by vegetation), and potential recharge that moves downward past the soil column. Water is stored in the soil.

WHAT HAPPENS TO RAIN AND SNOW AFTER IT FALLS FROM THE SKY?

When it rains or snows, water is distributed as different components of the hydrologic cycle by a variety of processes. Some water is intercepted by trees and evaporates, never reaching the ground. Some water reaches the ground, but runs off into local streams, and some water infiltrates into the soil. Some of the water in the soil evaporates or gets used by vegetation, while some percolates downward to recharge local and regional aquifers. We are interested in how tree thinning changes the partitioning of precipitation among these different components of the water budget.

We are using a water balance approach to evaluate this problem (Fig. 9). The water balance method is a simple concept based on the conservation of mass which is represented in the following equation:

$$I - O = \Delta S$$

where I is inputs, O is outputs and ΔS is change in storage. If inputs are greater than outputs, water storage will increase. If outputs are greater than inputs, water storage will decrease. For our purposes, water is stored in the soils, and the only input is precipitation. Outputs include evapotranspiration, runoff, and water that percolates past the soil into the underlying bedrock. Evapotranspiration is water that evaporates from soil and that is used by vegetation. The water percolating into the bedrock can potentially recharge the groundwater system, and therefore we will call it potential recharge. It is this component that we are interested in potentially increasing by thinning trees. If we measure or estimate the amount of precipitation that falls on the ground, the amount of evapotranspiration, and runoff, we can calculate the potential recharge.

Precipitation and canopy interception

Rain gages that are installed in the open away from trees measure the total amount of precipitation that reaches the forest floor. These data help to estimate the input component of the water balance. Precipitation measurements must be adjusted for areas beneath the forest canopy, where significantly less precipitation reaches the ground. During rainstorms in the Sacramento Mountains, water which falls on the leaves, needles and branches in the forest becomes stored in the canopy. The canopy can store a maximum amount of water called the canopy storage capacity. Until the canopy storage capacity is reached, only a small percentage of intercepted water will drip or run from the trees all the way to the ground. Evaporation continues to be an active process during a rainstorm, despite cloudy skies and elevated humidity, and at the level of the tree canopy, exposure to wind and solar radiation is greater than at ground level. This can lead to high evaporation rates of water intercepted by the canopy. The volume of water dripping from the canopy quickly decreases after rainfall ceases, so any water remaining on the canopy will evaporate after the storm. The total amount of water that does not reach the ground due to these processes is called canopy interception (Fig. 10).

We measured canopy interception in areas characterized by different canopy densities. For large storms with high intensity, canopy interception can account for 25 to 40% of

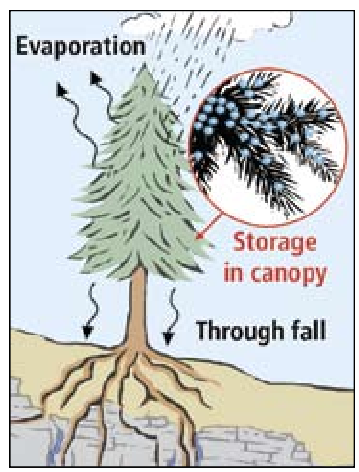
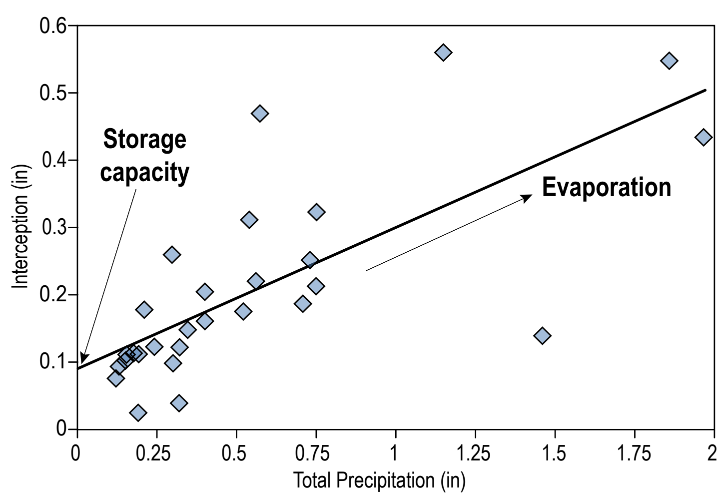


Figure 10–The forest canopy can intercept a significant amount of rain. The amount of water the canopy can hold is called the canopy storage capacity. Water is also lost due to evaporation of water in canopy during the storm.

Figure 11–Measured canopy interception as a function of total precipitation. Canopy interception is usually greater than the storage capacity because water being stored in the canopy evaporates during the storm event.



Weather station installed on a ridge top in the study area.

A weir measures spring discharge in Three L Canyon.

The long troughs catch precipitation under the canopy and guide it into a rain gage.

A snow storm near the study area in the Sacramento Mountains.

the total storm rainfall in the un-thinned woodland areas of the watershed (Fig. 11). During low-intensity storms, such as those that occur in the spring, or accompanying the heavier summer monsoons, the small volume of rain water does not fall fast enough to exceed the storage volume necessary to saturate the canopy. Therefore, interception losses can be as high as 70% for these storms. Canopy interception will decrease due to tree thinning, and more water will reach the ground to potentially infiltrate through the soils and to recharge the groundwater system.

Runoff and evapotranspiration

As part of this study, we monitored the soil water balance on 90 meter by 90 meter plots in the study area (Fig. 4). These experiments have yielded good values for runoff and evapotranspiration. Rain simulation experiments indicate that runoff is low. In general only 1 to 8% of the water that reached the ground left the experimental plot as surface runoff. When considering the entire watershed, runoff is even lower, as water rarely leaves the watershed as stream flow. These low runoff values are probably due to high infiltration rates through preferential flow paths in soils as discussed above. It was also determined that tree thinning does not significantly affect runoff.

Evapotranspiration is by far the largest output in the water balance. Water balance results indicate that tree thinning does significantly affect evapotranspiration rates. With a 70% reduction of canopy cover, evapotranspiration rates decreased by up to 16%.

Soil water storage and potential recharge

To date, preliminary results from plot-scale water balance experiments are largely inconclusive in determining the effects of tree thinning on soil water storage and potential recharge. Although more precipitation reaches the ground to infiltrate into the soil, there are processes that may decrease soil water storage as a result of tree thinning. For example, an increase in solar radiation can increase soil water evaporation. Also, an increase in understory vegetation may increase water uptake from the shallow soil.

It appears that preferential flow paths in soils play an important role in groundwater recharge. We are currently working on ways of characterizing and modeling water flow through these flow paths in order to account for them in water balance calculations.

FUTURE WORK

We are currently working on modeling a watershed-scale soil water balance, where the Three L watershed is divided into 30 meter by 30 meter cells (Fig. 12). A soil water balance will be calculated in each cell. The sum of these water balances will determine the water balance for the entire watershed. With this model, the water balance will be calculated on a daily basis over a time period that begins before tree thinning and ends well after thinning. Precipitation and climate data will be used to determine water balance inputs. We are characterizing important features such as soil texture, soil depth, tree type and tree density, at a high spatial resolution so that differences in these parameters from one cell to the next will result in spatial variability in the local water balance. This type of model is advantageous for evaluating the effect of changes in land use (like tree thinning) because you can run models with the same inputs under different land use scenarios.

We are also putting efforts towards characterizing preferential flow paths in the soil, which appear to play a very important role in groundwater recharge in the study area. It is necessary to account for these preferential flow paths in the water balance model described above. A graduate student at New Mexico Tech will begin this work this fall. Post-thinning monitoring will be continued through 2013, and we will prepare a final report in 2014.

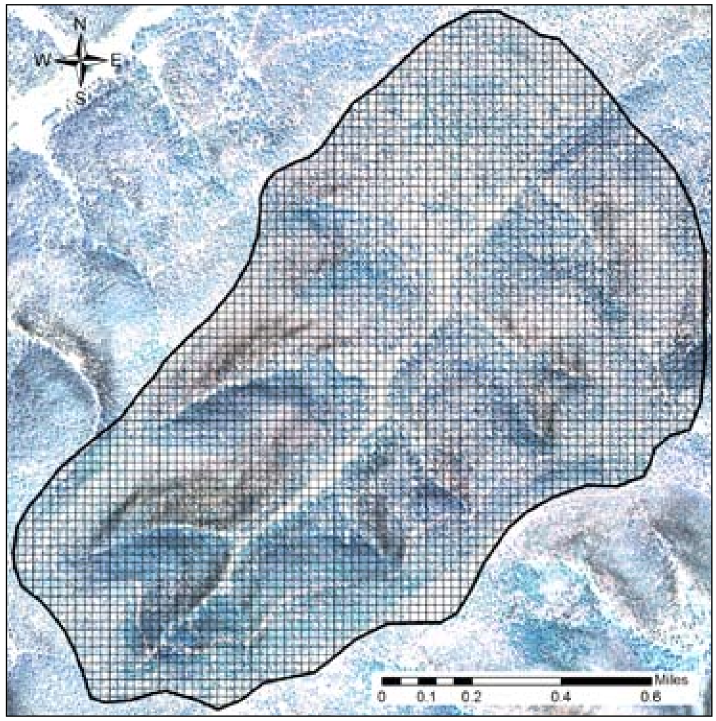


Figure 12–Three L Canyon is divided into 30 by 30 meter plots. A soil water balance will be calculated in each plot and then added together to calculate the soil water balance for the entire watershed. The calculated potential recharge will be compared before and after tree thinning.

Funding for this work came from the Otero Soil and Water Conservation District through legislative appropriation administered by the New Mexico State Department of Agriculture at New Mexico State University, Las Cruces, New Mexico. Additional funding was provided by the New Mexico Interstate Stream Commission and through the USFS Secure Rural Schools Title II Program.We would also like to thank the following people and agencies for helping us to do this study: New Mexico Forest and Watershed Restoration Institute, New Mexico State Forestry, NRCS, NMBGMR Chemistry Lab, Andy Campbell, Jed Frechette, Sam Fernald, Michael Coleman, and Dan Abercrombie.

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