Diurnal and Seasonal Soil Moisture Variation along a Forested and Regenerating Clearcut Hillslope in Colorado

Angus Goodbody[1], Kelly Elder[2] and Robert Davis[3]

ABSTRACT

Soils in midlatitude subalpine catchments play an important role in regulating the movement of melt water from seasonal snowpacks to drainage networks. Removal of forest canopy and undergrowth can change the soil moisture regime by decreasing evapotranspiration and eliminating interception of precipitation and radiation. Seasonal and diurnal soil moisture variation are examined along a clearcut and forested hillslope within a high-elevation mixed conifer forest in the Fraser Experimental Forest near Fraser, Colorado, USA. Volumetric soil moisture content was measured on both hillslopes during 53 separate neutron probe surveys starting on April 16, 2001 and ending on June 20, 2001. Prior to complete snow ablation, which occurred on May 14 on both hillslopes, intensive sampling schemes were used to characterize the diurnal variability during early, middle and late melt periods. Following melt out, soil moisture was sampled biweekly with the exception of one diurnal sampling period. Volumetric soil moisture content was generally greater on the clearcut hillslope during the period of observation. Differences in average maximum diurnal soil moisture content change between hillslopes were not significant. Both hillslopes showed a decrease in maximum diurnal soil moisture content change as the melt season progressed and soil moisture content increased.

INTRODUCTION

In mountainous watersheds with seasonal snowpacks, soil moisture content is a crucial component for determining the magnitude and timing of spring runoff. For many seasonal snow environments, the most important annual hydrologic event is the release of water from the snowpack during the spring melt season. In wet years, subalpine soils can buffer large snow melt events, reducing flooding downstream. Conversely, during dry years, or a sequence of dry years, snow melt will largely go toward replenishing soil moisture deficits, limiting steamflow generation. Since maximum melt rates rarely exceed infiltration capacity at the soil surface, most melt water enters the soil directly. Mountain soils are often thin and underlain by impermeable bedrock, so the infiltrating melt water becomes part of shallow groundwater systems. Shallow groundwater systems are the primary source of streamflow in mountainous watersheds (Kattelmann, 1989). Forest canopy removal can affect the local surface and subsurface hydrology dramatically, and ultimately may affect regional hydrology.

SITE DESCRIPTION

The hillslopes for this study are located in the Vasquez Mountains of north central Colorado within the Fraser Experimental Forest (FEF). FEF encompasses nearly 100 km^2 of the St. Louis Creek watershed ranging in elevation from 2700-3900 m. The watershed contains subalpine and alpine ecosystems representative of the western slope of the central Rocky Mountains. Naturally a Colorado River headwater basin, much of the streamflow from the St. Louis Creek and surrounding basins is diverted across the continental divide for agricultural, industrial, and municipal uses in eastern Colorado. The long-term mean precipitation at FEF headquarters is 580 mm. Nearly 70% of this precipitation falls as snow. The study area lies along a 10 ha section of lateral moraine 1.2 km southwest of the FEF headquarters between 2800-2900 m elevation. The study plots are roughly 200 meters long, west northwest facing, and have a relatively uniform 30% slope. The "clearcut" plot is a

[1]Masters Candidate and Research Assistant, Department of Earth Resources, Colorado State University, Fort Collins, CO 80523, Email: goodbody@lamar.colostate.edu

[2]Research Hydrologist, Rocky Mountain Research Station, USDA Forest Service, 240 West Prospect Road, Fort Collins, CO 80526, Email: kelder@fs.fed.us

[3] U.S. Army, Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755, Email: bert@crrel.usace.army.mil

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regenerating clearcut that was harvested in 1984-1985. The "forested" plot is fully forested with Englemann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta*), and aspen (*Populus tremuloides*). The soil is classified as a coarse-loamy mixed Dystric Cryochrept and is underlain by nearly impermeable clay subsoil on top of gneiss and schist bedrock.

METHODS

Soil moisture content in the top 2 m of soil was monitored along the hillslopes from April 16, 2001 to June 20, 2001. Sampling protocol included use of a neutron probe and a subset of existing access tubes on both hillslopes. The neutron probe indirectly measures soil moisture by emitting fast neutrons from an Americum-Beryllium radioactive source and measuring the return of slow neutrons to a detector. Slow neutrons result from collisions between a fast neutron and a hydrogen atom in a water molecule, so the amount of slow moving neutrons in the sampling zone can be used as a proxy for the soil moisture content within the sampled zone of the soil profile. 53 soil moisture surveys were completed during the period of observation. Each survey started on the clearcut slope and five access tubes were sampled along transect 1 running upslope. After moving north to the top of the forested slope, four access tubes were sampled on transect 2 heading downslope (see figure 1). Each survey took between 1 and 2 hours to complete depending on snow conditions.

Measurements were made from 30 to 180 cm depth where possible (some access tubes are less than 180 cm deep) using 30 cm increments. In an effort to characterize diurnal soil moisture cycles during active melt, 45 of the soil moisture surveys were completed during the four weeks leading up to complete ablation on May 14. The remaining eight surveys were completed during the five-week post melt period. Diurnal sampling schemes produced ten complete days of data. Four of these days used an 8-hour (three times daily) sampling frequency. One day featured a 2-hour (12 times daily) interval, although only nine surveys were completed before rainy weather halted use of the instrument. The remaining five days used a 6-hour (four times daily) sampling frequency.

Of the ten diurnal sampling days, two represent the early melt, three represent mid melt, four represent late melt, and one represents the post melt period. Average volumetric soil moisture content for each hillslope and at each time step was determined for upper (0-1 meter) and lower (1-2 meters) depth zones. Measurements from the 30, 60, and 90 cm depths were integrated to produce average volumetric soil moisture content for the first meter of soil. In the same fashion, measurements from the 120, 150, and 180 cm depths were used to calculate average volumetric soil moisture content for the second meter of soil. These depth zones correspond to textural breaks between the more developed sandy clay loam surface soil horizons and the deeper clay loam horizons.

Surface snowmelt measurements were made using a snowmelt lysimeter and tipping bucket assembly. The collector was triangular in size with a surface area just under 6 m^2. Snowmelt water from the collector was routed downslope through buried pipes to a tipping bucket with 0.5 liter buckets. Tip events were measured automatically with an event logger that would record the time and date when each tip occurred. Knowledge of the collector size, tipping bucket volume, and tip event times allowed back calculation of surface snowmelt rates. Tipping bucket resolution was less than 0.01 cm of snow water equivalent per tip.

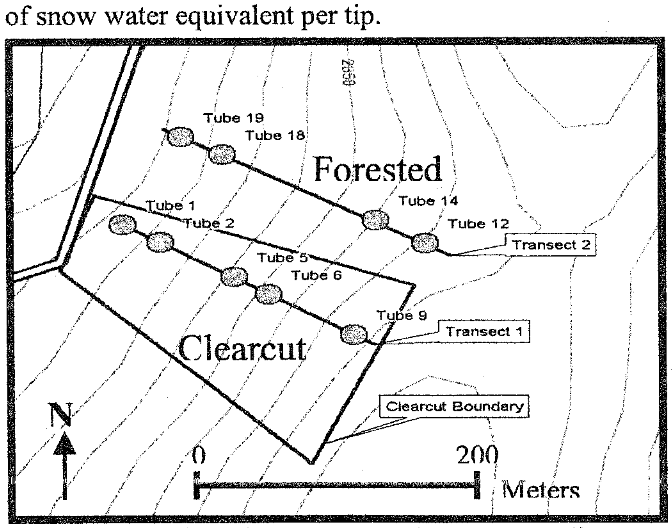

Figure 1 Study site map showing layout of soil moisture access tubes and sampling transects along the forested and clearcut hillslopes.

RESULTS AND DISCUSSION

Seasonal Soil Moisture Variation

Table 1 summarizes the seasonal minimum, maximum and total change in volumetric soil moisture contents. Figure 2 shows the seasonal soil moisture cycle for both plots and soil horizons. The near surface soil zones on both slopes experience far greater variability than the deeper soil zones. The soil moisture contents in the upper and lower depth zones of the clearcut hillslope are significantly greater than moisture contents for the forested hillslope ($p<0.001$) during the period of active melt. In the clearcut, soil moisture content in the lower depth zone is significantly greater than in the upper depth zone ($p<0.001$) for the entire period of observation. The same is true in the forest ($p=0.062$). In the top meter of soil, both hillslopes show dynamic increases in soil moisture until May 1 when the clearcut hillslope reaches an equilibrium moisture content. As more melt water enters the soil in the days leading to complete ablation, the clearcut hillslope experiences diurnal changes but no overall increase in soil moisture content. Meanwhile, the forested hillslope continues to increase soil moisture content, eventually reaching the same moisture content as the clearcut. As soon as the hillslopes are snow free, they enter a period of rapid drying with the upper zones nearly reaching premelt soil moisture content levels by June 20.

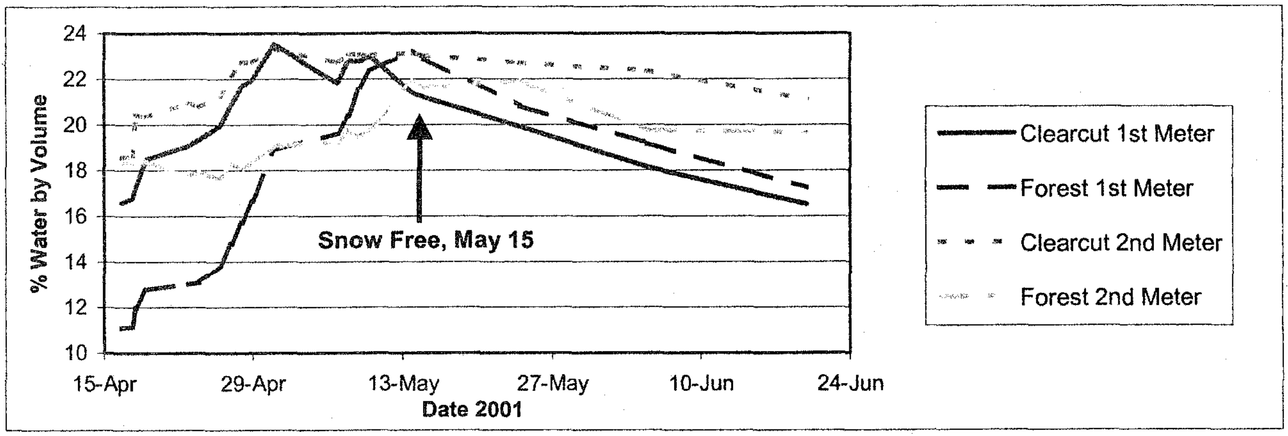

Figure 2 Comparison of seasonal soil moisture trends along the clearcut and forested hillslope within the first and second meter of soil, Spring 2001.

Soil Zone	Seasonal Minimum	Seasonal Maximum	Total Change
Clearcut Upper	16.6%	23.9%	7.3%
Forest Upper	11.1%	23.2%	12.1%
Clearcut Lower	18.6%	23.5%	4.9%
Forest Lower	18.3%	22.0%	3.7%

Table 1 Spring 2001 seasonal minimum, maximum and total volumetric soil moisture change.

Diurnal Soil Moisture Variation

Comparisons between plots and depth zones are made by examining each day that a diurnal sampling scheme was used and determining the maximum soil moisture content change for that day. Average maximum diurnal soil moisture content change during the entire melt period is 0.8% (upper) and 0.5% (lower) on the clearcut hillslope versus 0.7% and 0.5% in the forest. A summary of average diurnal soil moisture content change for each melt period is listed in table 2. Although the average diurnal changes are not significant between plots ($p=0.39$ in the upper depth zone and $p=0.74$ in the lower depth zone), there is a clear trend toward less diurnal variability as the melt season progresses despite an increase in snowmelt inputs. In the clearcut, the average diurnal change difference between the upper and lower depth zones is not significant ($p=0.23$), whereas in the forest the upper zone experiences significantly larger diurnal differences than the lower zone ($p=0.02$). The pronounced increase in soil moisture is clear in the late afternoon/early evening followed by a decrease during the night and into the next morning on both hillslopes (figures 3 and 4). This result mimics the diurnal cycle of melt water release from the snowpack (figure 5), with most intense melt occurring in the early evening hours.

Soil Zone	Early Melt Period 1	Mid Melt Period 2	Late Melt Period 3	Post Melt Period 4
Clearcut Upper	1.1%	1.1%	0.5%	0.1%
Forest Upper	1.1%	0.9%	0.5%	0.3%
Clearcut Lower	1.1%	0.5%	0.3%	0.3%
Forest Lower	0.7%	0.5%	0.3%	0.3%

Table 2 Spring 2001 Maximum diurnal volumetric soil moisture change along the clearcut and forested hillslope within the first and second meter of soil.

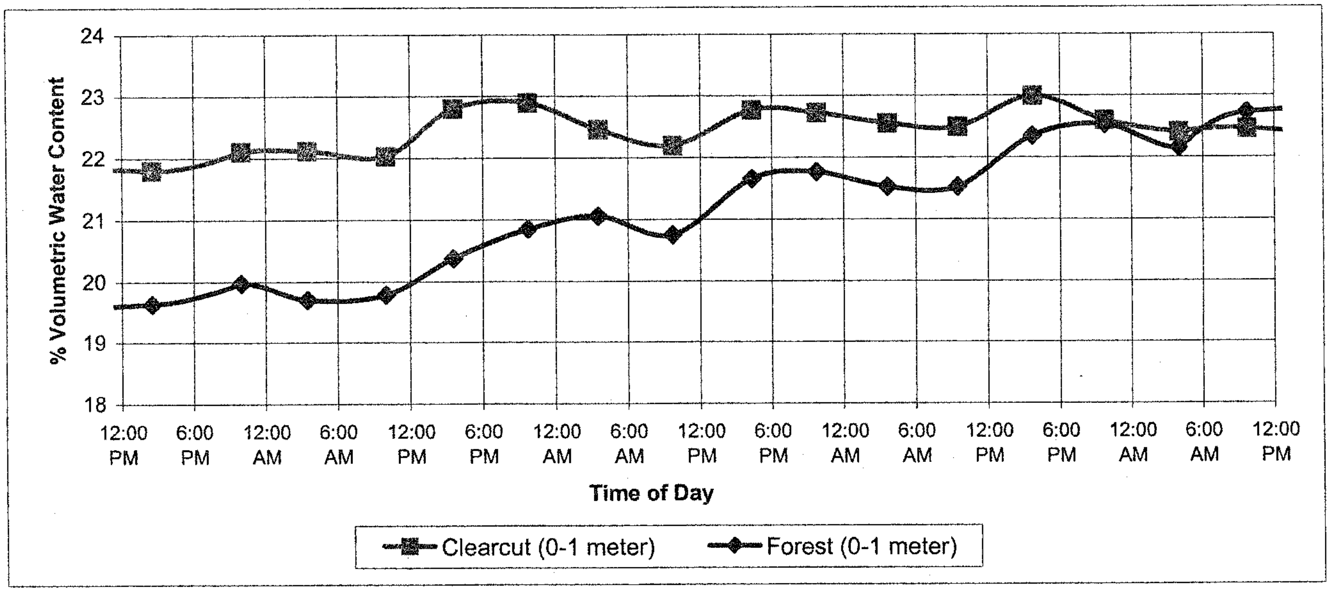

Figure 3 Diurnal soil moisture content trends along the clearcut and forested hillslopes in the first meter of soil. Mid melt, 2 hour sampling interval. May 7-11, 2001.

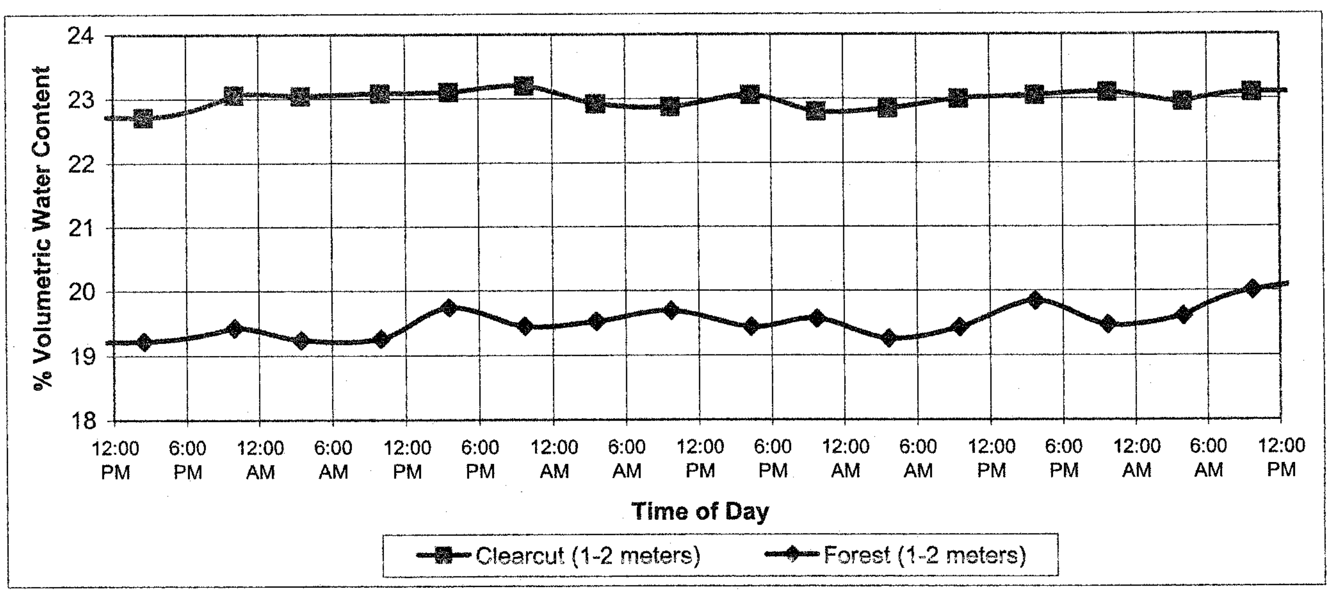

Figure 4 Diurnal soil moisture content trends along the clearcut and forested hillslopes in the second meter of soil. Mid melt, 2 hour sampling interval. May 7-11, 2001.

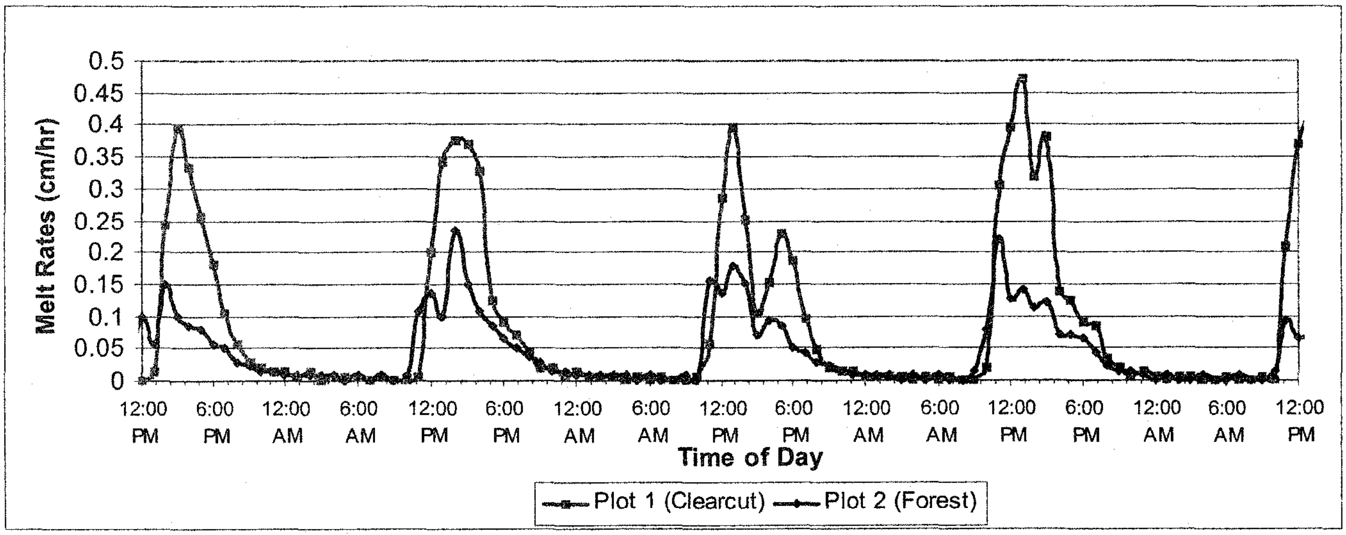

Figure 5 Snowmelt rates at the soil surface on the clearcut and forested hillslope.

Conclusions

- Soil moisture variability is more dynamic in the near surface soil layers than in the deeper subsurface layers both at diurnal and seasonal time scales.
- Significant seasonal soil moisture differences are found between hillslopes. The forested hillslope has a greater soil moisture deficit at the beginning of the melt season possibly due to greater evapotranspirational demand during the previous growing season.
- Immediately after complete ablation, the clearcut hillslope near surface soil dries more rapidly than the forested slope, perhaps due to intense evaporation from the unshaded clearcut surface soils.
- The clearcut and forested hillslopes' diurnal soil moisture cycles coincide with the diurnal snowmelt cycles on the hillslopes.
- Diurnal differences in soil moisture change are not significant between hillslopes even though snowmelt rates are greater on the clearcut hillslope.
- The magnitude of diurnal soil moisture variation decreases on both hillslopes and at both depths as the melt season progresses and soil moisture values increase.

References

Bengtsson, L., Movement of meltwater in small basins. *Nordic Hydrology*, 19, pp. 237-244, 1988.

Buttle, J. M., Soil Moisture and groundwater responses to snowmelt on a drumlin sideslope. *Journal of Hydrology*, 104, pp. 335-355, 1989.

Kattelmann, R., Ground Water contributions in an alpine basin in the Sierra Nevada, in *Symposium Proceedings on Headwater Hydrology*, edited by W. W. Woessner and D. F. Potts, American Water Resource Association, AWRA Technical Publication Series TPS-89-1, pp. 361-369, 1989.

Price, A. G. and L. K. Hendrie, Water motion in a deciduous forest during snowmelt. *Journal of Hydrology*, 64, pp. 339-356, 1983.

Tattari, S. M. and K. A. Granlund, Comparison of water storage variations inside a soil profile in different soil and vegetation types, in: *Hydrological Interactions Between Atmosphere, Soil and Vegetation*, edited by G. Kienitz, P. C. D. Milly, M. Th. Van Genuchten, D. Rosbjerg and W. J. Shuttleworth, IAHS publication number 204, International Association of Hydrological Sciences, Wallingford, UK, pp. 387-399, 1991.

Troendle, C. A., Streamflow generation from subalpine forests. *Watershed Management in the Eighties.* American Society of Civil Engineering, New York, NY, pp. 240-247, 1985.

Troendle, C. A., Effect of clearcutting on streamflow generating processes from a subalpine forest Slope, in *Forest Hydrology and Watershed Management*, edited by R. H. Swanson, P. Y. Bernier and P. D. Woodard, IAHS publication number 167, International Association of Hydrological Sciences, Wallingford, UK, pp. 545-552, 1987.

Troendle, C. A. and M. R. Kauffman, Influence of forests on the hydrology of the subalpine forests, in *Management of Subalpine Forests, Building on 50 Years of Research,* Proceedings of a Technical Conference in Silver Creek, Colorado, USDA, Forest Service, Rocky Mountain Forest and Range Experimental Station, General Technical Report RM-149, pp. 68-78, 1987.

Troendle, C. A. and J. O. Reuss, Effect of clear cutting on snow accumulation and water outflow at Fraser, Colorado. *Hydrology and Earth System Sciences*, 1(2), pp. 313-324, 1997.

Weyman, D. R., Measurements of the downslope flow of water in a soil, *Journal of Hydrology*, 20, pp. 267-288, 1973.