EVALUATING FIVE YEARS OF SOIL HYDROLOGIC RESPONSE FOLLOWING THE 2009 LOCKHEED FIRE IN THE COASTAL SANTA CRUZ MOUNTAINS OF CALIFORNIA

A Thesis
Presented to
The Faculty of California Polytechnic State University,
San Luis Obispo

In Partial Fulfillment
Of the Requirements for the Degree
Masters of Science in Forestry Sciences

By
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December, 2014
COMMITTEE MEMBERSHIP

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ABSTRACT

Evaluating five years of soil hydrologic response following the 2009 Lockheed Fire in the coastal Santa Cruz Mountains of California

Mary Theresa Crable

The Lockheed Fire burned 31 km$^2$ (7,660 acres) of the Scotts Creek watershed in August 2009. 4.5 km$^2$ (1,100 acres) of California Polytechnic State University’s educational and research facility at Swanton Pacific Ranch. The burned region presented an opportunity for studying the hydrologic response of burned soils in the Santa Cruz Mountains where there is insufficient post-fire studies regarding fire-effects on watershed processes such as infiltration and near-surface runoff. Soil infiltration and soil water repellency were evaluated with rainfall simulations, Mini-disk Infiltrometer (MDI) and water drop penetration time tests (WDPT) at sites represented by variations in burn severity, soils, and vegetation types throughout the Scotts Creek watershed each year for 5 years following the burn. Mixed-effects modeling was utilized on the 3 datasets to evaluate if changes could be detected in infiltration rates and water repellency following the fire. Rainfall simulations and WDPT tests showed that the fire did not have a statistically-significant impact on infiltration rates or soil water repellency, whereas the MDI tests detected a statistically-significant impact on post-fire infiltration. While the MDI results showed that fire had a significant impact on the hydrologic response over time, questions arose regarding challenges associated with sampling suggesting the method may not be pursued on steep slopes with high surface rock fragments or in the presence of large soil macropores. It is recognized that additional understanding would be gained from having multiple replications at each site every year and tests could be conducted on a subwatershed scale to account for the naturally occurring variability of larger watersheds.

Keywords: soil water repellency, infiltration, hydrologic response, near-surface runoff, burn severity, soil burn severity, rainfall simulations, water drop penetration times, Mini-disk Infiltrometer.
ACKNOWLEDGMENTS

I would like to acknowledge my mother and sister, first and foremost, for encouraging me to pursue a graduate degree. I would also like to thank Ed Crable and Roger Chin, my fathers, for always supporting me and pushing me to reach personal and professional goals.

Next, I would like to acknowledge and give a tremendous thanks to Brian Dietterick for providing me with the opportunity to conduct this valuable post-fire research as well as take part in holding down the Little Creek Project. I would like to thank Karen Vaughan and Chris Dicus for making time in their busy schedules on numerous occasions to review and discuss my thesis. I truly appreciate the guidance and support provided by each of you throughout this program.

I would like to acknowledge all of the interns who collected data prior to my time on this project, and I would to thank all of the interns who helped either myself, Dylan Theobald, John Hardy, or Ashley Brubaker collect field data. Thanks everyone!

I would like to acknowledge Drew Perkins and Drew Loganbill; the pair of you taught me everything I know about the Little Creek Project.

Julie Dufresne, if it were not for this graduate program, I would have never found my best friend. Excuse me, best friends (Marley).

Last, but certainly not least, I would like to acknowledge and give a tremendous thanks to all of the Swanton Pacific Ranch staff for being supportive in every way possible. I will cherish every moment I spent with all of you and I shall remember the good times fondly.

This research was funded through the CSU Agricultural Research Initiative, the USDA McIntire-Stennis grant program, Cal Fire, and Swanton Pacific Ranch.

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1 Encouraging = harassing. I am grateful for your “encouragement” because I have truly found what I love to do. Thanks you two!
2 Provide me with opportunity = TRUSTING me.
3 The “Drizzles.”
4 To be pronounced Doo-frez-knee.
5 Outside of family members.
6 To be pronounced Mar Mar.
7 Sierra Alpha, Golf Charley, Sierra Bravo, Sierra Whisky, Sierra Lima, Charlie Delta, Charlie Mexico, Papa Delta, Indigo Kilo, Charlie Nebraska, Alpha Bravo, Sierra Charlie, Joy Llama, Nebraska Mexico, PartAy Alpha, Joy Whisky, Romeo Sierra, and Romeo Mexico.
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CHAPTER 1: INTRODUCTION

Soil infiltration rates are widely studied around the world for the purposes of land management. In California, a considerable amount of research focuses on post-fire soil infiltration rates because of the potential for increased runoff and overland flow as a result of fire-induced effects that reduce the infiltration capacity of burned regions. Such effects that may result in decreased infiltration rates include loss of canopy and surface cover, fire-induced soil water repellency, and soil sealing. Erosional events such as rilling, mass wasting, and debris flows, and possibly debris torrents, may arise due to an increase in overland flow following a fire (Wells, 1987; Wohl and Pearthree, 1991). While there is an abundance of literature from decades of research on the post-fire effects on soil hydrologic properties or on fire-induced mass wasting, there is insufficient data regarding the effect of fire on hydrologic processes within the Santa Cruz Mountains. What makes this area particularly intriguing is the vegetative gradient from mixed coniferous redwood dominated forests in the lowlands in lower-slope positions to the chaparral on the mid-upper slopes to knobcone dominating the higher, more xeric slope positions. A watershed of this nature would presumably produce varying responses in the soil hydrologic processes following wildfire.

The Lockheed Fire burned 31 km$^2$ (7,660 acres) of a predominantly forested landscape in the Coastal Mountains of Santa Cruz County in August of 2009. Although devastating to landowners, wildfire is an important ecosystem process and has been absent in this area since the 1948 Pine Mountain Fire. This burn presented a unique opportunity for studying the soil hydrologic processes of burned soils and provided an opportunity to improve our understanding of a post-fire watershed response.
Nearly 4.5 km\(^2\) (1,100 acres) of Cal Poly’s Swanton Pacific Ranch was in the burn area. Swanton Pacific Ranch is held by the Cal Poly Corporation for education and research purposes of the California Polytechnic State University, San Luis Obispo. In addition to being a working ranch that supports livestock, forestry, and crop operations, the 13 km\(^2\) (3,280 acres) property provides both faculty and students the opportunity to better understand land management influences and natural disturbances on ecosystem processes.

Following the wildfire, several projects were instituted in order to gain a better understanding of the watershed processes. This project offers an evaluation of soil infiltration rates, near-surface runoff and fire-induced water repellency. Soil infiltration and soil water repellency were evaluated with rainfall simulations, Mini-disk Infiltrometers and water drop penetration time tests. These tests were performed at sites across a range of burn severities, soils, and vegetation types throughout the Scotts Creek watershed each of the first five years following the burn.

1.1 Study objectives and goals:
This thesis analyzes the results of three field tests utilized to analyze if a fire-induced effect on soil hydrologic properties exists. The tests include 1) rainfall simulations, 2) Mini-disk Infiltrometers, and 3) water drop penetration times. The objectives of this study were:

1. Evaluate changes in infiltration and near-surface runoff using rainfall simulations.
2. Evaluate changes in soil water repellency using Mini-disk Infiltrometers.
3. Evaluate changes in penetration times using water drop penetration times.
The goals are to identify if temporal trends in hydrologic processes, namely infiltration, are evident and whether those trends can be statistically proven to be a result of the 2009 Lockheed Fire. This work provides both baseline data for future soil/water relations research as well as recommendations on how to effectively collect data using rainfall simulations, Mini-disk Infiltrometers and water drop penetration time tests. Understanding how a fire affects the hydrologic function of this watershed via rainfall simulations, Mini-disk Infiltrometers and /or water drop penetration time tests will help resource managers, landowners and other decision makers in regards to mitigation efforts immediately following the wildfire.
CHAPTER 2 : BACKGROUND

2.1 Study Location

This study occurred within the Scotts Creek watershed in Western Santa Cruz County, California (Figure 2-1.) The 190 km$^2$ (46,950 acres) coastal watershed is located north of Santa Cruz, CA and drains to the Pacific Ocean. Specifically, experimentation was carried out within Mill Creek, Boyer Creek, and Little Creek watersheds, subwatersheds to Scotts Creek watershed. Access to these sites was granted by Swanton Pacific Ranch, Lockheed Martin and the former Cemex property, known as San Vicente Redwoods, that is now owned by four conservation groups that include, the Land Trust of Santa Cruz County, Peninsula Open Space Trust, Sempervirens Fund, and Save the Redwoods League.

2.1.1 Climate

The Santa Cruz Mountains have a Mediterranean climate with year-round, coastal fog. Winters are mild and wet with the majority of rainfall occurring during this time. Summers tend to be warm and dry with a fairly consistent fog bank at lower elevations along the coast. The mean annual precipitation at the lowest elevation in the Scotts Creek watershed is 76.2 cm. The mean annual precipitation ranges from 102-127 cm along the ridgelines (Scotts Creek Watershed Assessment, 2005).
Figure 2-1: Scotts Creek (yellow) and Little Creek (shaded) watershed boundaries, Swanton Pacific Ranch (red).
2.1.2 Geology and Soils

The Scotts Creek watershed resides in the tectonically-active Coast Ranges. Steep, narrow valleys characterize much of the watershed and its subwatersheds. This is due to the rapid uplift of the region in combination with the continual down cutting of streams and erosional events such as landsliding, debris torrents and rotational slumps.

The watershed overlies the Salinian block which is composed of three main rock types: quartz diorite (Cretaceous), Santa Margarita Sandstone, and Santa Cruz Mudstone (Upper Miocene). The quartz diorite and some metamorphic marble and schist (Mesozoic or Paleozoic) make up the basement rock while the Santa Margarita Sandstone and Santa Cruz Mudstone makeup the overlying cover rock (Figure 2-2). As a result of the continuous uplifting, the Salinian block has been tilted ocean-ward and has been subject to surficial wind and rain erosion. The northeastern portion of the watershed is dominated by exposed granite while the rest of the watershed maintains a patchy distribution of sedimentary rock overlying the granite (Taskey, 2010).
Figure 2-2: Geologic map with the fire perimeter (yellow) and ranch boundary (red) within the Scotts Creek watershed. Qd- quartz diorite (pink), Tsm-Santa Margarita sandstone (beige), Tsc-Santa Cruz mudstone (light yellow).
Pedogenesis in the Scotts Creek watershed is strongly influenced by slope position, slope steepness and parent material (Taskey, 2010). There are numerous soil types within the Scotts Creek watershed, with soils derived from granite, sandstone and mudstone. Test sites represented variations among the soil parent materials.

The soil map unit and soil names are 113—Ben Lomond-Catelli-Sur complex, 30 to 75 percent slopes; 173—Sur-Catelli complex, 50 to 75 percent slopes; and 153—Maymen-Rock outcrop complex, 50 to 75 percent slopes (Figure 2-3). Table 2-1 lists the dominant soil types where field tests were conducted.

Table 2-1: Soil Series names and Family Classifications of soils mapped at site locations (Soil Survey of Santa Cruz County, California).

<table>
<thead>
<tr>
<th>Soil Series Name</th>
<th>Family Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ben Lomond-Catelli-Sur Complex</td>
<td>Coarse-loamy, mixed, super active, mesic Pachic</td>
</tr>
<tr>
<td></td>
<td>Ultic haploxerolls-Coarse-loamy, mixed, superactive, mesic Ultic Haploxerolls-Loamy-skeletal, mixed, superactive, mesic Entic Haploxerolls</td>
</tr>
<tr>
<td>Sur-Catelli Complex</td>
<td>Skeletal, mixed, superactive, mesic Entic</td>
</tr>
<tr>
<td></td>
<td>Haploxerolls-Coarse-loamy, mixed, superactive, mesic Ultic Haploxerolls.</td>
</tr>
<tr>
<td>Maymen-Rock outcrop complex</td>
<td>Loamy, mixed, active, mesic, shallow Typic</td>
</tr>
<tr>
<td></td>
<td>Dystroxerepts-Rock outcrop</td>
</tr>
</tbody>
</table>
Figure 2-3: Soils of the Scotts Creek watershed with the fire perimeter in yellow and the ranch boundary in red.
2.1.3 Vegetation

The Scotts Creek watershed contains a very diverse array of plant communities and forest types. This area that was once clearcut for its valuable redwood lumber, at the turn of the 19th century, now supports over 600 native plant species (West, 2014).

Adjacent to streams, the watershed supports a lush riparian plant community with an overstory of red alder (*Alnus rubra*), big-leaf maple (*Acer macrophyllum*) and California box elder (*Acer negundo* var. *californicum*), and an understory composed of arroyo willow (*Salix lasiolepis*), yellow willow (*Salix lutea*), blackberry (*Rubus ursinus*), thimbleberry (*Rubus parviflorus*), salmonberry (*Rubus spectabilis*), nightshade (*Atropa belladonna*), rush (*Juncus*), sedges (*Carex*) and poison oak (*Toxicodendron diversilobum*). Moving away from the streams laterally, the plant community transitions into mixed conifer stands of redwood (*Sequoia sempervirens*) and Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) and mixed hardwood and conifer stands consisting of Douglas fir, tanoak (*Lithocarpus densiflorus*), coast live oak (*Quercus agrifolia* var. *agrifolia*), California bay laurel and some interspersed madrone (*Arbutus menziesii*). The ridgelines tend to be dominated by chaparral species and knobcone pine (*Pinus attenuata*) forests. Manzanita (*Arctostaphylos*), chamise (*Adenostoma fasciculatum*), bush poppy (*Dendromecon rigida*), chaparral pea (*Pickeringia montana* var. *montana*), and huckleberry (*Vaccinium ovatum*) compose the understory vegetation while the overstory consists of primarily knobcone pine and some redwood.
2.2 The Lockheed Fire

The Lockheed Fire began at 7:12 the evening of August 12, 2009. A total of 31.642 \( \text{km}^2 \) (7,819 acres) burned by the time the wildfire was 100% contained on August 23, 2009. The majority of the burn occurred within the Scotts Creek watershed with a small percentage of the San Vicente watershed burned. Strong winds the day of the fire and a preceding dry winter combined with heavy fuel loads and ladder fuels had a large influence on the extent and severity of the burn. The fire spread rapidly throughout the watershed including riparian vegetation at lower elevations, redwood and mixed conifer stands at mid-slope elevations and completely consuming most knobcone pine and manzanita stands on the ridgelines.

A team of specialists from Cal Fire, Big Creek Lumber Company and Cal Poly evaluated burn severity by using ground observations, photos taken from a helicopter, and a Burned Area Reflectance Classification (BARC) map which is a satellite-derived map of the post-fire vegetation condition. The BARC map was the basis for the burn severity map and was fine-tuned as necessary using team members’ field observations (Figure 2-4).
Figure 2-4: Burn severity map from the 2009 Lockheed Fire.
Burn severity was highest on the ridgelines which are comprised predominantly of knobcone pine and chaparral species. Moderate severity was interspersed with the high and lower severity burn classifications in the upper, mid and lower slopes, and generally consisting of redwood and mixed conifer vegetative communities. Some areas of the coast redwood and Douglas fir forest type were fully consumed and were classified as high severity. Streamside vegetation including overstory trees, shrubs and ground cover experienced lower fire intensities and that resulted in low severity soil burn conditions. The percentage of each burn severity over the entire burned area is 14% very high, 37% high, 43% moderate, and 6% low. The breakdown of percent burned of individual subwatershed is presented in Table 2-2. A description of each burn severity classification can be found in Appendix A. Burn severity by vegetation type is presented in Table 2-3 to further illustrate the correlation between burn severity and specific vegetation types.

Table 2-2: Total percent burned of each subwatershed and percent of each burn severity within individual subwatersheds (Cal Fire, 2009).

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Total Acreage</th>
<th>Acreage burned</th>
<th>% Burned</th>
<th>Very High Severity</th>
<th>High Severity</th>
<th>Moderate Severity</th>
<th>Low Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boyer</td>
<td>1,354</td>
<td>432.0</td>
<td>31.9</td>
<td>13.8</td>
<td>31.8</td>
<td>47.6</td>
<td>6.80</td>
</tr>
<tr>
<td>Little Creek</td>
<td>1,306</td>
<td>1200</td>
<td>91.9</td>
<td>11.2</td>
<td>30.9</td>
<td>52.7</td>
<td>5.30</td>
</tr>
<tr>
<td>Mill Creek</td>
<td>2,404</td>
<td>1626</td>
<td>67.6</td>
<td>25.0</td>
<td>38.1</td>
<td>32.6</td>
<td>4.2</td>
</tr>
<tr>
<td>Lower Scotts</td>
<td>1503</td>
<td>150</td>
<td>10.0</td>
<td>2.0</td>
<td>30.6</td>
<td>27.2</td>
<td>40.1</td>
</tr>
<tr>
<td>Upper Scotts</td>
<td>5207</td>
<td>583</td>
<td>11.2</td>
<td>2.8</td>
<td>31.7</td>
<td>52.2</td>
<td>13.3</td>
</tr>
<tr>
<td>Entire Scotts Creek</td>
<td>19,001</td>
<td>6755</td>
<td>36.0</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Table 2-3: Soil burn severity by vegetation type (Cal Fire, 2009).

<table>
<thead>
<tr>
<th>Vegetation Type</th>
<th>Area Burned (ha)</th>
<th>Very High Severity (ha)</th>
<th>High Severity (ha)</th>
<th>Moderate Severity (ha)</th>
<th>Low Severity (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redwood Forest</td>
<td>979</td>
<td>17.4</td>
<td>240</td>
<td>667</td>
<td>55.6</td>
</tr>
<tr>
<td>Mixed Conifer Forest</td>
<td>790</td>
<td>37.6</td>
<td>283</td>
<td>448</td>
<td>21.0</td>
</tr>
<tr>
<td>Chaparral (including knobcone)</td>
<td>981</td>
<td>372</td>
<td>489</td>
<td>112</td>
<td>8.9</td>
</tr>
<tr>
<td>Coastal Scrub</td>
<td>217</td>
<td>6.9</td>
<td>124</td>
<td>78.9</td>
<td>6.9</td>
</tr>
<tr>
<td>Grassland</td>
<td>138</td>
<td>0</td>
<td>21.9</td>
<td>8.9</td>
<td>108</td>
</tr>
<tr>
<td>Agriculture</td>
<td>17.0</td>
<td>0</td>
<td>4.0</td>
<td>11.3</td>
<td>0.8</td>
</tr>
<tr>
<td>Monterey Pine</td>
<td>15.0</td>
<td>0</td>
<td>6.9</td>
<td>7.3</td>
<td>0.8</td>
</tr>
<tr>
<td>Quarry/Town</td>
<td>1.6</td>
<td>0</td>
<td>0</td>
<td>0.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Oak Woodland</td>
<td>6.1</td>
<td>0</td>
<td>1.2</td>
<td>4.9</td>
<td>0</td>
</tr>
</tbody>
</table>
CHAPTER 3 : LITERATURE REVIEW

Infiltration is the downward entry of water into soil (Hillel, 2004; Brady and Weil, 2009). In a watershed, infiltration depends on precipitation, soil properties, vegetation and topography. Precipitation will reach the soil surface directly from the sky or indirectly from plants. Water is then stored in soil macropores and micropores until it is returned to the atmosphere through evaporation and transpiration, or discharged as surface runoff or subsurface flow (Brady and Weil, 2009). In the event that water can no longer infiltrate, surface runoff will occur (Knighton, 1998).

The two types of surface runoff are saturation overland flow and infiltration excess overland flow. Saturation overland flow takes place when soil water storage is at capacity and additional water becomes runoff. Infiltration excess occurs when the precipitation rate is greater than the infiltration rate (Knighton, 1998). Following a fire, infiltration and runoff rates may be affected.

3.1 Factors leading to fire-induced changes in soil hydrologic properties

The fire-induced conditions that lead to physical changes in soil hydrologic processes are loss of duff, live vegetation and canopy cover in addition to soil sealing, ash deposition, surface roughness, and fire-induced hydrophobicity. Burn severity can significantly influence these post-fire conditions. Burn severity is a measure of organic matter loss or deposition of ash from aboveground combustion of biomass (Keeley, 2009). Rainfall simulations, Mini-disk
Infiltrometers and water drop penetration time tests can be used for evaluating post-fire effects on infiltration and runoff rates, and soil water repellency.

3.1.1 Loss of Duff

Forests soils tend to have greater infiltration rates because of the high percentage of macropores generated by old root channels, and/or burrows and tunnels made by animals, insects and worms and have the ability to exceed rainfall rates of 12 centimeters per hour (Fisher and Binkley, 2000; Ice et al., 2004; Rothacher et al., 1976). In addition, mature forests have thick O horizons underlain by deep soils, both of which rapidly absorb water like a sponge (Fisher and Binkley, 2000). As a result, undisturbed, mature forest soils generally have little surface runoff and the thick O horizon protects the soil surface from rainfall impact thus lessening soil particle detachment and overall erosion during storms (Fisher and Binkley, 2000).

The reduction or complete incineration of the O horizon during a fire lowers the overall water storage capacity of the landscape. The O horizon has the ability to absorb several times its own mass therefore the reduction or removal of this horizon may contribute to an increase in post-fire runoff (Fisher and Binkley, 2000; Pierson et al., 2008). Fire-induced soil water repellency is often described as having been formed by the combustion of the litter and duff in the O horizon that can lead to the development of a hydrophobic layer within the top 5 cm of mineral soil and has high spatial variability (DeBano, 2000b; Robichaud et al., 2008; Robichaud and Hungerford, 2000; Doerr and Moody, 2004). The addition of a hydrophobic layer restricts water movement downward through the soil profile thereby reducing the water holding capacity of the soil. A reduction in water holding capacity contributes to saturation excess overland flow (DeBano, 2000a; Ice et al., 2004; Robichaud et al., 2008; Larsen et al., 2009). Not only does the
combustion of organic litter and duff lead to fire-induced water repellent layers, but the destruction of these overlying organic layers exposes bare soil to rainfall impact that can lead to erosion through particle detachment and the formation of surface crusts and seals (Onda et al., 2008; McIntyre, 1958). Such fire induced changes have resulted in decreased infiltration capacities and increased overland flow (Shakesby and Doerr, 2005; Onda et al., 2008).

3.1.2 Loss of Vegetation

The removal of ground and canopy cover is a primary cause of increased surface runoff rates following a fire (Helvey, 1980; Pierson et al., 2008). Vegetation consumption reduces evapotranspiration losses which cause water storage capacities to remain high in the years following a wildfire. Elevated soil water storage capacities do not allow for additional precipitation to infiltrate, therefore, saturation excess overland flow occurs (Helvey, 1980). The regenerative process may take several years depending on burn severity and vegetation characteristics. Vegetation is important in balancing soil water storage. As vegetation growth progresses following a fire, moisture will be removed from the soil via plant roots and over time, the soil water holding capacity will increase (Helvey, 1980).

3.1.3 Soil sealing

Post-fire soil sealing can contribute to significant increases in infiltration excess overland flow. Reduced surface cover subjects bare ground to processes that cause soil sealing. Two types of seals can form: structural and depositional. Structural seals develop as a result of soil compaction, slaking, pore clogging, and destruction of soil aggregates by direct rainfall impact.
Depositional seals form by the settling of fine particles carried in runoff (Assouline and Maulem, 2000). The onset of a major storm event the first winter in a severely-burned watershed has the ability to drastically change the soil surface by compressing and eroding the ash layer thereby causing a seal (Onda et al., 2008) Seals can range in thickness from 0.1mm to several centimeters, and have a hydraulic conductivity (rate at which water can move through the soil) several magnitudes lower than underlying soils (Assouline, 2004; McIntyre, 1958). The inability of water to infiltrate the upper soil layers will lead to increases in infiltration excess overland flow. The difficulty of water to permeate the seal leads to increased post-fire runoff rates (Larsen et. al., 2009).

3.1.4 Ash deposition

Ash has a strong effect on infiltration and runoff rates following a fire. Depending on the amount, it can protect against soil sealing, absorb a lot of water because of its particle size and lead to a decrease in runoff rates (Mallik et al., 1984; Cerda and Doerr, 2008). The extent and thickness of the ashy layer is largely influenced by the amount of fuel and burn severity. Burn severity can range from unburned, where plants are unaltered from lack of heating, to severely burned, where surface litter is replaced with ash (Keeley, 2009). Immediately following a high severity wildfire, the thick ash layer protects bare soil from rainfall impact and absorbs water. Runoff rates are low during the first storm until the ash layer is completely saturated and the wetting front reaches the hydrophobic layer after which subsurface flow will continue laterally and infiltration excess flow will occur on the surface (Cerda and Doerr, 2008; Onda et al., 2008). Consequently, the time frame in which ash may significantly reduce runoff is in terms of days.
Because it is highly susceptible to wind and water erosion, the ash layer can be carried away within a short period following the fire (Cerda and Doerr, 2008).

Ash can also reduce infiltration rates. When the thick ash layer dissipates, any remaining ash particles may clog soil pores in the upper soil layer causing a structural seal (Lavee et al., 1995). Should any remaining ash become hydrated with water, it will expand significantly and enhance the formation of a structural seal (Etiegni and Campbell, 1991). The addition of ash can also change the proportion of macropores and micropores depending upon soil texture thus reducing percolation, but increasing water holding capacity (Mallik et al., 1984).

3.1.5 Surface roughness

On lower severity burn sites, surface roughness is a fire-induced condition that contributes to mitigating increased runoff rates. Partial consumption of surface litter and ground cover does not necessarily produce the same thick ash layers as a high severity burn, but remnants of charred organic matter, such as branches, and rock fragments protect against rainfall impact. As a result, post-fire surface roughness reduces soil sealing thereby promoting a higher rate of infiltration to take place. Surface roughness increases depression storage and decreases runoff velocities, which provides water with the chance and time to infiltrate (Lavee et al., 1995). This roughness is similar to unburned conditions. Litter and vegetation increase water storage and shield against the erosional forces of rainfall impact. Fire removes this protective covering and barriers to overland flow (Pierson et al., 2008). When total consumption of surface cover occurs on severely burned sites and the resulting thick ash layer has been eroded, a site with low surface roughness is expected to have higher runoff rates than unburned sites (Lavee et al., 1995).
3.1.6 Hydrophobicity

Fire-induced hydrophobicity (same as soil water repellency) is another factor that influences infiltration and runoff rates. Hydrophobic soils are formed by the accumulation of waxy organic substances from plants around soil particles. During a fire, the waxy substances are vaporized and the pulsating heat may force substances down through the soil where they cool and coalesce with other precipitates on to soil particles forming an impervious layer (DeBano et al., 1976). They can be found on the soil surface or a few to several centimeters down, parallel to the surface in variable thicknesses. The strength of hydrophobicity depends on the soil temperature. Weak soil water repellency occurs at lower burning temperatures, 175°C, and intense water repellency occurs between 175°C and 200°C burning temperatures. Hydrophobicity is broken down at temperatures exceeding the latter. Hydrophobic layers reduce the infiltration and percolation depth of soils; therefore, soils will become saturated sooner in a storm event and saturation excess runoff will occur (DeBano et al., 1976). However, instances where natural hydrophobicity is strong, burning may reduce the strength of the hydrophobic layer allowing water to infiltrate more readily and reduce runoff (Pierson et al., 2008).

3.2 Evaluating soil hydrologic processes

3.2.1 Rainfall simulation experiments

Physical rainfall simulations are a tool used to measure runoff rates following a fire (Johansen et al., 2001; Benavides-Solario and MacDonald, 2001). Specialized equipment are designed to apply controlled rainfall amounts and intensities for evaluating the effects of cover, soil sealing, ash deposition, surface roughness, and hydrophobicity (Larsen et al., 2009). Simulators are
particularly useful for measuring the soil hydrologic condition following disturbance such as wildfire. Soil physical and chemical properties exhibit a high degree of spatial variability throughout a watershed and the addition of fire may increase this variability (Lavee et al., 1995; Robichaud and Hungerford, 2000; Sposito, 2004). Therefore, simulators can be useful tools because of the ability to control rainfall intensity, duration, and volume of the output. Precipitation variability that occurs naturally during a storm event is limited. An overall rainfall simulator design to fit all field and/or laboratory conditions is not available, therefore each simulation is conducted on a research-specific basis (Bowyer and Burt, 1989). Project design takes into account the purpose of the research, natural rainfall characteristics of the location, along with available resources and ability to attain or custom build a simulator. In order to accurately measure runoff, multiple simulations are conducted.

3.2.2 Mini-disk Infiltrometer and water drop penetration time tests

The Mini-disk Infiltrometer (MDI) and water drop penetration time (WDPT) tests are methods utilized in the field to classify the soil water repellency (none, weak, strong) following prescribed and wild fires (Robichaud et al., 2008; Lewis et al., 2006). These two tests are typically conducted alongside one another because they are similar in their purpose and it time effect way to test soil with two methods. Although similar in their purpose, the MDI is credited with being less subjective and easier to perform than the WDPT. The MDI also provides an infiltration rate in addition to evaluating soil water repellency.
3.3 Summary

Post-fire conditions alter infiltration and runoff rates. Not every fire will have dramatic effects on a watershed, but burn severity and environmental factors greatly influence many hydrologic changes that occur following a fire (Ryan et al., 2011). Surface cover loss, soil sealing, ash deposition, surface roughness and hydrophobicity independently, or combined, alter waters ability to enter a soil either by enhancing or reducing that ability. Conducting rainfall simulations and utilizing additional methods such as the Mini-disk Infiltrometer and water drop penetration time tests are suitable for evaluating post-fire effects on soil hydrologic processes.
CHAPTER 4 : METHODS AND MATERIALS

4.1 Study Design

Rainfall simulations, Mini-disk Infiltrometers (MDI) and water drop penetration time (WDPT) tests were performed in the field at various locations throughout the Scotts Creek watershed following the Lockheed Fire. These tests were conducted in order to evaluate the changes in infiltration rates, hydrologic- responses (ratio of total runoff (L) to total rainfall (L)), and soil water repellency of soils burned at different severities. In addition to burn severity, test sites represented variations in soil parent material, percent slope, dominant vegetation type and aspect (Tables 4-1 and 4-2). Some control sites were established and tested in order to make the comparison between burned and unburned sites. Data collection using these three techniques began in the fall of 2009 and has been conducted annually during summers through 2013.

Table 4-1: Rainfall simulation sites listed by number, soil parent material, percent slope, vegetation type, dominant vegetation type, burn severity and aspect.

<table>
<thead>
<tr>
<th>Site Number</th>
<th>Soil Parent Material</th>
<th>Slope (%)</th>
<th>Veg Type</th>
<th>Dominant Veg Type</th>
<th>Burn Severity</th>
<th>Aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>MS</td>
<td>60</td>
<td>RW</td>
<td>RW</td>
<td>N</td>
<td>NE</td>
</tr>
<tr>
<td>4</td>
<td>MS</td>
<td>65-88</td>
<td>RW/DF</td>
<td>RW</td>
<td>N</td>
<td>SE</td>
</tr>
<tr>
<td>5</td>
<td>MS/SS</td>
<td>47-65</td>
<td>RW/DF</td>
<td>RW</td>
<td>M</td>
<td>SE</td>
</tr>
<tr>
<td>6</td>
<td>Granitic</td>
<td>40-52</td>
<td>RW/DF</td>
<td>RW</td>
<td>L</td>
<td>NW</td>
</tr>
<tr>
<td>7</td>
<td>MS</td>
<td>45-54</td>
<td>RW/TO</td>
<td>RW</td>
<td>M</td>
<td>NW</td>
</tr>
<tr>
<td>8</td>
<td>MS</td>
<td>47-60</td>
<td>KP/MZ</td>
<td>KP</td>
<td>H</td>
<td>S</td>
</tr>
<tr>
<td>9</td>
<td>MS/SS</td>
<td>55-65</td>
<td>KP/MZ</td>
<td>KP</td>
<td>N</td>
<td>S</td>
</tr>
<tr>
<td>10</td>
<td>MS</td>
<td>27-45</td>
<td>KP/MZ</td>
<td>KP</td>
<td>H</td>
<td>NE</td>
</tr>
<tr>
<td>11</td>
<td>MS</td>
<td>17-40</td>
<td>KP/MZ</td>
<td>KP</td>
<td>N</td>
<td>NW</td>
</tr>
<tr>
<td>12</td>
<td>Granitic</td>
<td>38-46</td>
<td>TO</td>
<td>TO</td>
<td>N</td>
<td>SE</td>
</tr>
<tr>
<td>13</td>
<td>MS</td>
<td>50-65</td>
<td>TO</td>
<td>TO</td>
<td>H</td>
<td>NW</td>
</tr>
<tr>
<td>14</td>
<td>MS</td>
<td>70-72</td>
<td>RW/TO</td>
<td>RW</td>
<td>M</td>
<td>NW</td>
</tr>
<tr>
<td>15</td>
<td>MS</td>
<td>35-38</td>
<td>KP/MZ</td>
<td>KP</td>
<td>H</td>
<td>N</td>
</tr>
</tbody>
</table>
Table 4-2: MDI and WDPT test sites listed by number, slope position, vegetation type, dominant vegetation type, burn severity and aspect.

<table>
<thead>
<tr>
<th>Site Number</th>
<th>Soil Parent Material</th>
<th>Slope Position</th>
<th>Vegetation. Type</th>
<th>Dominant Veg. Type</th>
<th>Burn Severity</th>
<th>Aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MS</td>
<td>Lower</td>
<td>RW</td>
<td>RW Dom</td>
<td>H</td>
<td>SE</td>
</tr>
<tr>
<td>2</td>
<td>MS/SS</td>
<td>Lower</td>
<td>RW/DF</td>
<td>RW Dom</td>
<td>M</td>
<td>SE</td>
</tr>
<tr>
<td>3</td>
<td>Granitic</td>
<td>Lower</td>
<td>RW</td>
<td>RW Dom</td>
<td>M</td>
<td>NW</td>
</tr>
<tr>
<td>4</td>
<td>MS</td>
<td>Upper</td>
<td>RW/TO</td>
<td>RW/Dom</td>
<td>H</td>
<td>N</td>
</tr>
<tr>
<td>5</td>
<td>MS</td>
<td>Lower</td>
<td>RW/TO</td>
<td>RW/Dom</td>
<td>M</td>
<td>W</td>
</tr>
<tr>
<td>6</td>
<td>MS</td>
<td>Upper</td>
<td>TO</td>
<td>TO</td>
<td>H</td>
<td>N</td>
</tr>
<tr>
<td>7</td>
<td>MS</td>
<td>Upper</td>
<td>KP/MZ</td>
<td>KP/MZ</td>
<td>H</td>
<td>N</td>
</tr>
<tr>
<td>8</td>
<td>MS</td>
<td>Upper</td>
<td>KP/MZ</td>
<td>KP/MZ</td>
<td>H</td>
<td>SE</td>
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<tr>
<td>9</td>
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<td>Lower</td>
<td>RW/TO</td>
<td>RW Dom</td>
<td>L</td>
<td>SE</td>
</tr>
<tr>
<td>10</td>
<td>MS</td>
<td>Upper</td>
<td>KP/MZ</td>
<td>KP/MZ</td>
<td>H</td>
<td>S</td>
</tr>
<tr>
<td>11</td>
<td>Granitic</td>
<td>Upper</td>
<td>RW/TO</td>
<td>RW Dom</td>
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<td>NW</td>
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<tr>
<td>12</td>
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<td>Upper</td>
<td>KP/MZ</td>
<td>KP/MZ</td>
<td>H</td>
<td>S</td>
</tr>
<tr>
<td>13</td>
<td>Granitic</td>
<td>Lower</td>
<td>RW</td>
<td>RW Dom</td>
<td>M</td>
<td>S</td>
</tr>
<tr>
<td>14</td>
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<td>N</td>
<td>S</td>
</tr>
<tr>
<td>15</td>
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<td>KP/MZ</td>
<td>KP/MZ</td>
<td>H</td>
<td>S/E</td>
</tr>
<tr>
<td>16</td>
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<td>SE</td>
</tr>
<tr>
<td>17</td>
<td>MS</td>
<td>Mid/Lower</td>
<td>KP/MZ</td>
<td>KP/MZ</td>
<td>H</td>
<td>SE</td>
</tr>
<tr>
<td>18</td>
<td>MS</td>
<td>Upper</td>
<td>KP/MZ</td>
<td>KP/MZ</td>
<td>H</td>
<td>SE</td>
</tr>
<tr>
<td>19</td>
<td>MS</td>
<td>Lower</td>
<td>KP/MZ</td>
<td>KP/MZ</td>
<td>H</td>
<td>SE</td>
</tr>
<tr>
<td>20</td>
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<td>Upper</td>
<td>KP/MZ</td>
<td>KP/MZ</td>
<td>H</td>
<td>NW</td>
</tr>
<tr>
<td>21</td>
<td>MS/SS</td>
<td>Lower</td>
<td>RW/TO</td>
<td>RW Dom</td>
<td>M/L</td>
<td>N</td>
</tr>
<tr>
<td>22</td>
<td>SS</td>
<td>Upper</td>
<td>KP/MZ</td>
<td>KP/MZ</td>
<td>M/H</td>
<td>N</td>
</tr>
<tr>
<td>23</td>
<td>MS</td>
<td>Upper</td>
<td>RW/TO</td>
<td>RW Dom</td>
<td>H</td>
<td>N</td>
</tr>
</tbody>
</table>

4.1.1 Rainfall simulation setup

A portable rainfall simulator was utilized to test infiltration rates and the hydrologic response of soils because the simulator has the ability to mimic natural rainfall in a field setting. Thirteen rainfall simulation locations are distributed throughout Little Creek and the greater Scotts Creek watersheds (Figure 4-1). Eight sites were established in 2009 and repeated each year through 2013. Four additional sites were added in 2010 and repeated each year through 2013. Specific site descriptions for all thirteen locations can be found in Appendix B.
Figure 4-1: Rainfall simulation locations within the Scotts Creek watershed. Ranch boundary is outlined in red, the Little Creek watershed is outlined in green and the fire perimeter is outlined in yellow.
A modified Purdue-style rainfall simulator that was fabricated in Moscow, ID at the Rocky Mountain Research Station by the USDA Forest Service was generously loaned to our research team (Figure 4-2). The simulator stands three meters above the soil surface on three adjustable fiberglass legs. The sprayer sweeps across a fixed opening and was set to maintain a spraying rate about 5 cm (2 in) per hour. Five centimeters per hour is greater than the typical high rainfall intensity for this area. This rate was chosen because it is an intensity that would produce a significant hydrologic response in soils with properties altered by fire. The simulator stands in the open air where rainfall is subject to wind, however, simulations were conducted with little to no wind. Water was supplied to the simulator through a garden hose that was attached to a gas-powered water pump which received water from a fifty-gallon barrel full of water. The oscillating motion of the simulator was powered by a 2000-watt generator and a control box that was used to turn the simulator on and off as well as turn the oscillating motion on and off.

The plot size is 1 m long by 1 m wide. The border (outside frame of the plot) is made of sheet metal. During setup, the sheet metal is driven down vertically into the soil profile several centimeters in depth. This is to prevent water from seeping into the plot through the back or two sides. Plastic was placed around the perimeter of the sheet metal as another preventative measure to help ensure water was not entering laterally through the two sides and top of the plot.
Figure 4-2: Rainfall simulator on the tripod above the 1x1 m plot enclosed by a trough in the front.
The front of the plot was confined by a trapezoidal trough designed to catch the near-surface runoff\(^8\). The goal was to capture near-surface runoff, the lateral subsurface or surface flow that may be shunted off laterally downslope due to fire-induced soil water repellency within the profile. This depth was estimated to be at the most 10 cm below the soil surface. Thus, the trough is inserted 8 and 10 cm below the soil surface and driven laterally into the soil so that the angle of the trough matched the angle of the existing natural slope. When near-surface runoff is present, it is captured in the trough along the downslope edge of the plot and then funneled into an outlet tube and then into a five gallon bucket. Any water percolating down below the 8-10 cm is regarded as water infiltrated to depth below where a fire-induced hydrophobic layer would normally be found. The infiltrated amount (expressed as a rate or a volume) is accounted for by the taking the difference between the rainfall rate and the near-surface runoff rate. Finding this difference provides an estimate of the infiltration rate which can also be regarded as a deep percolation rate to distinguish it from the water entering the soil surface but confined as near-surface runoff.

The rainfall intensity was determined by measuring the volume of rainfall that accumulated in a 1x1 m metal calibration pan that was placed over the plot. The pressure of the simulator could be adjusted to either increase or decrease the rainfall intensity in order to achieve as close to 5 cm (2 in) per hour. Once a consistent volume and rainfall intensity was obtained during the calibration process, the calibration pan was removed to begin the simulation. Simulations would be run for a minimum of 40 minutes to a maximum of 70 minutes\(^9\). The near-surface runoff collected in the 5 gallon bucket was recorded every 2 minutes using a ruler.

---

\(^8\) Near-surface runoff refers to the top 7 centimeters of soil where runoff is occurring because this is the depth at which runoff can impact the surface soil through mobilization.

\(^9\) Simulation times varied because of time constraints.
Following simulations, plots were disrupted in order to evaluate any fire-induced hydrophobicity by observing subsurface hydrologic flow paths.

4.1.2 MDI and WDPT setup

MDI and WDPT tests were utilized as time efficient means of evaluating soil water repellency by measuring infiltration volumes and penetration times. There are twenty-three sites distributed throughout the Little Creek watershed (Figure 4-3). All twenty-three sites were established in 2009 and tested annually until the amount of regrowth did not allow for sites to be accessed safely. These two tests were performed every 6.1 m (20 ft) along a 30.5 m (100 ft) transect. At each of the five locations along the transect, three replicate tests were conducted at 1 and 3 cm using the MDI. WDPT tests were conducted at 1, 2, and 3 cm at each of the five locations along the transect, using a water dropper. Specific site descriptions for all twenty-three locations can be found in Appendix C.

The MDI, created by Decagon Devices, Inc. in Pullman, Washington, is a portable, handheld device used to assess soil infiltration capacity in the field (Figure 4-4). The MDI measures the volume of water that has passed from the instrument into the soil over a 1 minute time interval thereby providing a total infiltration volume. An infiltration rate can be found utilizing this method, however, for the purposes of this project, total infiltration volume was analyzed. Following a wildfire, the MDI has proven to be very useful for a rapid field assessment of infiltration capacity and soil water repellency based upon the mean infiltration rate of test sites (Robichaud et al., 2008).
Figure 4-3: Soil infiltration sites located in the Little Creek watershed (green). The ranch boundary is outlined in red and the fire perimeter is outlined in yellow.
Figure 4-4: Diagram of the Mini-Disk Infiltrometer from Decagon Devices Inc.
4.2 Procedure

4.2.1 Rainfall simulation procedure

For a complete procedure on how rainfall simulations were carried out in the field and for a complete list of the equipment utilized by field technicians, see Appendix D: Instructions for conducting rainfall simulations.

4.2.2 MDI and WDPT procedure

For complete procedures on how MDI and WDPT tests were conducted in the field and for a complete list of the equipment used for each test, see Appendix E: Instructions for conducting Mini-disk Infiltrometer and water drop penetration time tests.

4.3 Data Analysis

4.3.1 Preliminary analysis

Microsoft Excel™ 2007 was utilized for data entry, quality control, and preliminary analysis for rainfall simulation, MDI, and WDPT datasets. Preliminary analysis for the rainfall simulations consisted of finding the infiltration rate and hydrologic response\(^\text{10}\) of each rainfall simulation. Preliminary analysis for the MDI dataset consisted of finding the average infiltration volume of the three replicate tests at each position and depth along the transect, and using the mean value to classify the soil water repellency. Preliminary analysis for the water drop penetration times dataset consisted of finding the average penetration time at each position and depth along the transect and using the mean value to classify the soil water repellency.

\(^{10}\) The hydrologic response is the ratio of total measured runoff (L) to total simulated rainfall (L).
4.3.1.1 Calculating rainfall simulation infiltration rate and hydrologic response

Equation 1 was developed in Microsoft Excel™ 2007. During simulations, runoff data or water depth, was collected and measured at two minute intervals from the start to the end of the simulation. The runoff rate was found by converting the water depth to a runoff volume using equation 1.

\[
\text{Runoff Volume (L)} = 0.009712 \times WD^2 + (1.377 \times WD)
\]

Where WD = water depth in bucket in cm. \((1)\)

Equation 1 was derived by finding the relationship between the depth of the bucket to the volume of water inside the bucket. This was accomplished by adding 500 mL of water sequentially into the bucket and recording each depth.

The near-surface runoff volumes and the simulated rainfall rates are then plotted against time and a regression line is added to the runoff values in order to define an average runoff rate. Next, taking the difference between the runoff rate and simulated rainfall rate provides an infiltration rate. Again, infiltration rate means that water percolates deeper in the soil profile (below the level we would assume would be uniformly wetted if fire-induced soil water repellency exists). The hydrologic response, was found by taking the ratio of total runoff in L to total simulated rainfall in L thus it is also referred to as the runoff ratio. Figure 4-1 shows an example plot of runoff and rainfall volume against time with the derived linear regression equation for runoff volume. Annual rainfall simulation data, raw data and graphs, can be found in Appendix F.
The purpose of the regression line is to identify if and when steady state runoff is achieved. Steady state runoff occurs when the infiltration capacity\textsuperscript{11} of the soil is met and infiltration occurs at a constant rate from which it can decrease no more even with the continuous addition of water (Hillel, 2004). When attempting to ascertain whether fire had an effect on soil infiltration, it is important to find the steady state runoff rates so that comparisons could be made pertaining to the infiltration capacities of the soil. Fire-induced water repellent layers can decrease the infiltration capacity (the three dimension depth at which water can infiltrate and percolate) of soil thus decreasing time to runoff and increasing runoff rates (DeBano et al., 1967).

\textsuperscript{11} Capacity is used to denote an amount or volume. Although capacity is met, water is still moving through the profile via gravitational potential thus infiltration can still occur.
4.3.1.2 Classifying soil water repellency for MDI tests

Microsoft Excel™ 2007 was utilized to find the mean of the infiltration volume for three field replicates and to classify the soil water repellency based upon the calculated mean. Table 4-3 is an example of the field data in excel with the soil water repellency classified.

Soil water repellency was classified based on the mean volume. When the infiltration volume exceeded 8 mL, soils were classified as being not repellent. Soils were classified as weak when the infiltration volume was between 3-8 mL, and strong when the infiltration volume was between 0-3 mL (Robichaud et al., 2008). See Appendix G for annual MDI field data and soil water repellency classifications.

Table 4-3: Data and water repellency classification of MDI field test at site 1.

<table>
<thead>
<tr>
<th>Date</th>
<th>Site</th>
<th>ID/TM12</th>
<th>Severity13</th>
<th>Aspect14</th>
<th>Slope Position15</th>
<th>Depth (cm)</th>
<th>Test 1 vol (mL)</th>
<th>Test 2 vol (mL)</th>
<th>Test 3 vol (mL)</th>
<th>Mean (mL)</th>
<th>Repellency</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/2/09</td>
<td>1</td>
<td>1/20</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>1</td>
<td>0</td>
<td>18</td>
<td>2</td>
<td>6.67</td>
<td>Weak</td>
</tr>
<tr>
<td>12/2/09</td>
<td>1</td>
<td>1/20</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>3</td>
<td>0.3</td>
<td>11</td>
<td>9</td>
<td>6.77</td>
<td>Weak</td>
</tr>
<tr>
<td>12/2/09</td>
<td>1</td>
<td>1/40</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.33</td>
<td>Strong</td>
</tr>
<tr>
<td>12/2/09</td>
<td>1</td>
<td>1/40</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>3</td>
<td>2.5</td>
<td>1</td>
<td>1</td>
<td>1.50</td>
<td>Strong</td>
</tr>
<tr>
<td>12/2/09</td>
<td>1</td>
<td>1/60</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td>0.17</td>
<td>Strong</td>
</tr>
<tr>
<td>12/2/09</td>
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<td>1/60</td>
<td>H</td>
<td>SE</td>
<td>L</td>
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<td>0</td>
<td>0</td>
<td>0.8</td>
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<td>12/2/09</td>
<td>1</td>
<td>1/80</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.33</td>
<td>Strong</td>
</tr>
<tr>
<td>12/2/09</td>
<td>1</td>
<td>1/80</td>
<td>H</td>
<td>SE</td>
<td>L</td>
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<td>0</td>
<td>0.5</td>
<td>0</td>
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<td>1/100</td>
<td>H</td>
<td>SE</td>
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<td>2</td>
<td>1</td>
<td>1</td>
<td>1.33</td>
<td>Strong</td>
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<tr>
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<td>1/100</td>
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<td>SE</td>
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<td>3</td>
<td>2</td>
<td>2</td>
<td>1.5</td>
<td>1.83</td>
<td>Strong</td>
</tr>
</tbody>
</table>

\[12\] ID indicates the site location and TM indicates the transect mark which is either 20, 40, 60, 80, or 100 feet away from the start of the transect at 0 feet.

\[13\] Severity can either be N= none, L= low, M= moderate or H= high and was classified by the BAER team.

\[14\] Aspect indicates the four cardinal directions N= North, E =East, S = South, and W= West, and the four ordinal directions NE, SE, NW and SW.

\[15\] Position indicates the position along the hillside that the plot is located. L=low, M=mid , U=upper
4.3.1.3 Classifying soil water repellency for WDPT tests

Microsoft Excel™ 2007 was utilized to classify the water repellency based off of penetration times. Table 4-4 is an example of repellency times recorded and classified at site 1. When penetration times were less than 5 seconds the soil was classified as wettable. Soils were classified as slightly repellent when times were between 5-60 seconds, moderately repellent when times were between 60-400 seconds and highly repellent when times were over 400 seconds. See Appendix H for annual field data and soil water repellency classifications.

<table>
<thead>
<tr>
<th>Date</th>
<th>Site</th>
<th>ID/ TM</th>
<th>Severity</th>
<th>Aspect</th>
<th>Position</th>
<th>Depth (cm)</th>
<th>Time (seconds)</th>
<th>Water repellency</th>
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<tr>
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<td>1/20</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>1</td>
<td>305</td>
<td>moderate</td>
</tr>
<tr>
<td>10/14/2010</td>
<td>1</td>
<td>1/20</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>2</td>
<td>305</td>
<td>moderate</td>
</tr>
<tr>
<td>10/14/2010</td>
<td>1</td>
<td>1/20</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>3</td>
<td>20</td>
<td>slight</td>
</tr>
<tr>
<td>10/14/2010</td>
<td>1</td>
<td>1/40</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>1</td>
<td>60</td>
<td>slight</td>
</tr>
<tr>
<td>10/14/2010</td>
<td>1</td>
<td>1/40</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>2</td>
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<td>slight</td>
</tr>
<tr>
<td>10/14/2010</td>
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<td>1/40</td>
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<td>SE</td>
<td>L</td>
<td>3</td>
<td>10</td>
<td>slight</td>
</tr>
<tr>
<td>10/14/2010</td>
<td>1</td>
<td>1/60</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>1</td>
<td>305</td>
<td>moderate</td>
</tr>
<tr>
<td>10/14/2010</td>
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<td>1/60</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>2</td>
<td>305</td>
<td>moderate</td>
</tr>
<tr>
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<td>1/60</td>
<td>H</td>
<td>SE</td>
<td>L</td>
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<td>305</td>
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<tr>
<td>10/14/2010</td>
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<td>1/80</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>1</td>
<td>305</td>
<td>moderate</td>
</tr>
<tr>
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<td>1/80</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>2</td>
<td>305</td>
<td>moderate</td>
</tr>
<tr>
<td>10/14/2010</td>
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<td>1/80</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>3</td>
<td>305</td>
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</tr>
<tr>
<td>10/14/2010</td>
<td>1</td>
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<td>H</td>
<td>SE</td>
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<td>305</td>
<td>moderate</td>
</tr>
<tr>
<td>10/14/2010</td>
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<td>1/100</td>
<td>H</td>
<td>SE</td>
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<td>2</td>
<td>305</td>
<td>moderate</td>
</tr>
<tr>
<td>10/14/2010</td>
<td>1</td>
<td>1/100</td>
<td>H</td>
<td>SE</td>
<td>L</td>
<td>3</td>
<td>305</td>
<td>moderate</td>
</tr>
</tbody>
</table>

4.3.2 Statistical analysis: Mixed-effects modeling

Following the preliminary analysis, further data analysis was conducted by Mr. Jack Lewis, USFS Pacific Southwest Research Station Mathematical Statistician (retired) with the use of the

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16 This is a modified version from the USDA Forest researchers (DeBano, 1983) as provided by Robichaud et. al., 2008
R language, an environment for statistical computing and graphics (R Development Core Team, 2010). Mixed effects models were used within the R framework to analyze all three datasets, rainfall simulations, MDI, and WDPT tests for the following reasons:

1. Mixed-effects models have the ability to model a variety of unbalanced experimental design involving grouped data, nested data, or repeated measures.
2. These models account for a combination of continuous and categorical variables.
3. Mixed effect models account for fixed and random effects.

All three studies exhibit these three characteristics. First, the annual data collected is not statistically independent from previous year’s data; data collected from the same location on successive occasions is not independent, for instance, site 1 is compared to site 1 each year. Therefore, the data from site 1 in 2009 is more likely to be similar to data from site 1 in subsequent years rather than being similar to data from another site thus it is not statistically independent. As well, nesting of transects, as with the MDI and WDPT tests, develops additional dependencies; observations at a specific position within a transect tend to be more similar than observations at other positions within the transect. Furthermore, the three datasets contain continuous and categorical data. Lastly, all three datasets contain both fixed effects, variables that remain unchanged throughout the testing period such as burn severity, soil parent material, dominant vegetation type and percent slope, as well as random effects, which are those attributes that were randomly assigned during the setup of the project such as site number. Therefore, mixed-effects modeling was used because this approach accounts for repeated measurements at multiple sites and transects within the same sites as well as a variety of variables that are either fixed or random.
Variables within mixed-effect models are categorized as either “fixed” or “random” effects. Fixed-effects are the variables tested within the model for having a statistically-significant impact on infiltration rates, infiltration volumes and penetration times at the conventional rejection level of $\alpha = 0.05$. Random effects are typically nuisance variables that were typically randomly chosen but must be accounted for in the model. Additionally, for each model, an interaction between time and each fixed-effect is tested in order to determine if the change over time can be attributed to the fixed-effect that time is interacted with in the model.

4.3.2.1 Statistical model for rainfall simulations

A modified version of a body weight model (Model 1) proposed by Pinheiro and Bates (2000, eq 5.20, p 222) is the basis for the rainfall simulation model created by Jack Lewis.

$$
\begin{equation}
Y_{ij} = \left( \beta_0 + \gamma_{02}S_{2i} + \gamma_{03}S_{3i} + \gamma_{04}S_{4i} + b_{0i} \right) \\
+ \left( \beta_1 + \gamma_{12}S_{2i} + \gamma_{13}S_{3i} + \gamma_{14}S_{4i} + b_{1i} \right) t_{ij} + \varepsilon_{ij}
\end{equation}
$$

where $Y_{ij}$ is the response (infiltration rate or hydrologic response) of the $j^{th}$ observation at site $i$; $t_{ij}$ is the time (day number or year) of the $j^{th}$ observation at site $i$; $S_{ki}$ is a binary variable taking the value 1 if the $i^{th}$ site was burned at severity level $k$ (2=low, 3=moderate, 4=high), otherwise $S_{ki} = 0$; $\beta_0$ and $\beta_1$ are the average intercept and average slope for unburned sites; $\gamma_{0k}$ and $\gamma_{1k}$ are the average difference in intercept and slope respectively, between unburned sites and those with burn severity $k$; $b_i$ is the vector of normally distributed within-site (residual) error, assumed
independent for different \(i, j\) and independent of the random effects. The 3 variance parameters estimated are \(\psi\), a vector of length 2, consisting of the variances of \(b_{0i}\) and \(b_{li}\); \(\sigma^2\), the within-site error variance. This model assumes that the burn severity is invariant for a given site (Lewis, 2013).

The responses analyzed are infiltration rates and hydrologic responses over the five-year period. The fixed effects tested for rainfall simulations were time (years), burn severity, percent slope, and dominant vegetation type. Burn severity was classified as unburned (N), low (L) moderate (M), and high (H). The three dominant vegetation types tested are redwood dominant (RW), tanoak (TO) and a combination of knobcone pine and manzanita (KP/MZ). These fixed-effects were treated as site-invariant because these characteristics remained the same every year although the plots were not located in precisely the same location each year.

The influence each fixed-effect had on infiltration rates and hydrologic responses was analyzed discretely. The goal of the study is to see if there was a fire induced effect on infiltration rates and hydrologic responses over a period of five years, therefore the interaction between burn severity and time was tested. If this interaction term is found to be significant, it could be inferred that the change over time is attributed to the fire. The change over time alone can be attributed to a multitude of factors, therefore, time was interacted with all fixed-effects in order to distinguish which variable influenced any change over time.

4.3.2.1.1 Burn dichotomy

Additional analysis was performed in order to test the maximum fire effect and any fire effect on infiltration rates and hydrologic responses by dividing sites into two burn dichotomies and
analyzing each burn dichotomy. The two burn dichotomies developed and tested as predictors in model 1 are “Hot burn versus all others” and “Unburned versus all others.” The “Hot burn versus all others” partitions out the high severity sites and tests high severity sites against all other sites which includes unburned, low and moderate burn severity sites. The second dichotomy tested unburned sites against all other sites which includes low, moderate and high burn severity sites.

4.3.2.1.2 Little Creek watershed

Additional analyses were performed on rainfall simulation sites located solely in the Little Creek watershed. The Little Creek watershed has been part of a long-term study designed to evaluate water quality and channel conditions, before, during, and after selective timber harvest. Additional analysis was performed solely on the Little Creek rainfall simulation sites in order to document fire related effects with respect to changes in infiltration rates and near-surface runoff. The reasons for this separate analysis include: 1) adds to understanding of fire effects to support Little Creek monitoring work, 2) includes sites that represent broad conditions within a single watershed boundary, and 3) excludes sites chosen because of pre-observed conditions of widespread strong natural soil water repellency.

Model 1 was utilized and the same fixed-effects were tested for this additional analysis. However, two p-values were generated from the model: sequential and marginal. The sequential p-value indicates the significance of each term as it is added to the model sequentially, for instance a model that only includes that term and the terms before it. Marginal p-values are the conventional p-value (p < 0.05) which indicate the significance of each term in the complete model. The raw rainfall simulation data utilized in R can be found in Appendix I. The R code and output for rainfall simulation analysis can be found in Appendix J.
4.3.2.2 Statistical model for MDI and WDPT

As with the rainfall simulation data, mixed-effects modeling was used to analyze both the MDI and WDPT datasets. This section will provide a detailed explanation of the mixed effects model used for both the MDI and WDPT datasets. While both the MDI and WDPT datasets are structured similar to that of the rainfall simulations, these datasets are slightly more complex because transects are nested and depth is an additional explanatory variable. Thus, the same general model used to analyze rainfall simulation data can be used for MDI and WDPT datasets, but with some additional terms to account for depth and transect location. Jack Lewis modified the continuous-time mixed effects Model 1 to account for transect location with the addition of subscript $m$ and a random effect for the $m^{th}$ location within each site (Model 2).

\[
y_{ijm} = (\beta_0 + \gamma_{02}S_{ki} + \gamma_{03}S_{si} + \gamma_{04}S_{4i} + b_{0i} + c_{0im})
+ (\beta_1 + \gamma_{12}S_{2i} + \gamma_{13}S_{3i} + \gamma_{14}S_{4i} + b_{1i} + c_{1im})t_{ijm} + e_{ijm}
\]

where $\mathbf{y}_{ijm}$ is the (possibly) transformed response (infiltration volume or penetration time) of the $j^{th}$ observation at transect location $m$ at site $i$; $t_{ijm}$ is the time (day number or year) of the $j^{th}$ observation at transect location $m$ at site $i$; $S_{ki}$ is a binary variable taking the value 1 if the $i^{th}$ site was burned at severity level $k$ (2=low, 3=moderate, 4=high), otherwise $S_{ki} = 0$; $\beta_0$ and $\beta_1$ are the average intercept and average slope for unburned sites; $\gamma_{0k}$ and $\gamma_{1k}$ are the average difference in intercept and average slope, respectively, between unburned sites and those with burn severity $k$; $\mathbf{b}_i$ is the vector of normally distributed random effects, assumed independent for different $i$; $b_{0i}$ and $b_{1i}$ are the perturbations on the intercept and slope, respectively, for the site $i$; $c_{0im}$ and $c_{1im}$ are the perturbations on the intercept and slope, respectively, for transect location $m$.
at site \(i\); \(\varepsilon_{ijmn}\) is the normally distributed within-a-point location (residual) error, assumed independent for different \(i, j, m\) and independent of random effects. The 5 variance parameters estimated are \(\psi\), a vector of length two, consisting of the variances of \(b_0i\) and \(b_1i\); \(\Phi\) a vector of length 2 consisting of variances of \(c_{0im}\) and \(c_{1im}\); and \(\sigma^2\), the within-a-point-location error variance. This model will focus on the hypothesis involving the \(\gamma_{1k}\) parameters, which characterize the time trends. In particular we want to test whether these parameters are all the same or whether they depend on \(k\), the burn severity (Lewis, 2013).

To test the depth effect, another set of terms was added to the model (Model 2-a). Since burn severity could depend on depth, or vice versa, the interaction between depth and burn severity must be modeled.

\[
+(\beta_2 + \gamma_{22}S_2 + \gamma_{23}S_3 + \gamma_{24}S_4 + b_{2i} + c_{2im})d_{ijm}
\]

\[
b_{ij} = \begin{bmatrix} b_{0i} \\ b_{1i} \\ b_{2i} \end{bmatrix} \sim \mathcal{N}(0, \psi), \ c_{im} = \begin{bmatrix} c_{0im} \\ c_{1im} \\ c_{2im} \end{bmatrix} \sim \mathcal{N}(0, \Phi), \ e_{ijm} \sim \mathcal{N}(0, \sigma^2)
\]

Model 2-a

where \(d_{ijm}\) is the depth of the \(j\)th observation at transect location \(m\) at site \(i\). The new slope parameters \(\gamma_{2k}\) describe the fixed effect of depth for each burn severity, and a new random effects are included for the perturbations in slope due to site and transect location within site. Having a new random effect to \(b_{1i}\) and \(c_{im}\), the number of variance parameters increases from 5 to 7; \(\psi\) \((3\times1)\), \(\Phi(3\times1)\), and \(\sigma\) must be estimated (Lewis, 2013).

If site and transect location had been modeled as fixed effects, it would have required estimating 115 slopes and 115 intercepts (for 5 transect locations at each of 23 sites). By instead modeling them as random effects the number of parameters to be estimated is limited to 7, while properly accounting for the groupings in the data.

The significance of fixed effects was evaluated using conditional F tests as described in
Pinheiro and Bates (2000, pp 89-92). The tests are conditioned on the estimates of the random effects variance-covariance parameters (Lewis, 2013).

4.3.2.2.1 MDI test variables

The fixed-effects tested in Model 2 were burn severity, soil parent material, dominant vegetation type, day number (from 12/31/2008), and the interactions between burn severity and time, soil parent material and time, and dominant vegetation type and time. The significance of the interaction between burn severity and time is of greatest concern for this analysis because it will suggest whether or not the fire had an effect on the response being analyzed, which is post-fire infiltration volumes. Yet, testing the additional, naturally occurring variables will shed some light on whether such variables had an influence on post-fire hydrologic processes. The random effects are site number and transect location.

Burn severity, soil parent material, and dominant vegetation type were treated as site-invariant because these characteristics remained the same every year although the transects were not located in precisely the same location each year. Because there is not an equal number of sites in each burn severity classification, two simplified burn classes were developed, “Cool” and “Hot.” “Cool” incorporates unburned (N), and moderate to low (ML) sites while “Hot” incorporates moderate (M), moderate to high (MH) and high (H) burn severities. The three dominant vegetation types tested are a combination of redwood and Douglas fir (RW/DF), a combination of redwood and tanoak (RW/TO) and tanoak (TO). The three soil parent materials are granitic, mudstone (MS), and a mixture of mudstone and sandstone (MS/SS). In these models, the time trend for the square root of the response (mean infiltration volume) is assumed to be linear.
Additionally, square root and logarithmic transformations were used in order to linearize the data. Both transformed datasets were modeled but the logarithmic model produced a better fit whereas residuals from the square root model were skewed.

The zeroes in the dataset (replications where no water infiltrated into the soil from the MDI) were problematic for computing logarithms therefore the zeroes were replaced with 0.10mL. The lowest non-zero value recorded is 0.17 mL therefore 0.10 was used in lieu of 0. The R code and output for the MDI analysis can be found in Appendix K.

4.3.2.2.2 WDPT test variables

The fixed-effects tested were burn severity, soil parent material, dominant vegetation type, day number (from 12/31/2008), and the interactions between burn severity and day number, dominant vegetation type and day number, and soil parent material and day number. The significance of the interaction between burn severity and time is of greatest concern for this analysis because it will suggest whether or not the fire had an effect on the response being analyzed, which is post-fire penetration times. As previously mentioned, testing the additional fixed-effects, such as soil parent material and dominant vegetation type, will help determine whether site characteristics had an influence on penetration times. The random effects are site number and transect location.

Burn severity, dominant vegetation type and soil parent material were treated as site-invariant because these characteristics remained the same every year although the transects were not located in precisely the same location each year. The same classifications for simplified burn classes, dominant vegetation types and soil parent materials used in the MDI analysis are used for WDPT analysis.
Continuous penetration times for the water drop tests were transformed using square roots and logarithms with the intent of normalizing the residuals distribution. As a note, the 164 zeroes in the dataset were recoded to 0.5 seconds for the logarithmic transformation so that they could be retained in the analysis. While the mixed-effects model for the square root transformed response was able to compute the effect of depth, the mixed effects model for the log transformed response did not include the effect of site on the depth coefficient due to computational reasons. The R code and output for WDPT analysis can be found in appendix L.
CHAPTER 5: DATA AND STATISTICAL RESULTS

5.1 Scotts Creek watershed rainfall simulation data and results

5.1.1 Scotts Creek watershed rainfall simulation sites sampled each year

Rainfall simulations were conducted at 13 sites for 5 years, but not necessarily at each site every year (refer to Figure 4-1 in Chapter 4 for specific locations). All, but one, of the simulations were conducted during the months of July through November. One simulation was conducted in February 2013, at site 12-Upper Boyer Creek, but is included in the 2012 dataset. The total number of complete simulations is 55. However, two simulations were carried out within 10 meters of one another at site 12-Boyer Unburned in July 2013 in order to compare the results of the two simulations. Results were similar, therefore, the infiltration rates and hydrologic responses were averaged to produce a single observation reducing the total sample size to 54. Table 5-1 shows rainfall simulations by site and years conducted.

The number indicates how many simulations were conducted that year at the specified site. Sites containing a 0 indicate no simulations were performed that year. There are a few reasons. Several sites were not established immediately following the burn, but they were established in 2010. Sites established in 2010 were site 2-Swanton Road, site 12-Upper Boyer, site 13-Lions Flat, site 14-Hillslope, and site 15-Mill/Boyer. Additional locations that contain a 0 were not visited because of time constraints or the amount of vegetative regrowth did not allow re-entry.
Table 5-1: Rainfall simulations by site and year conducted. The number below the year indicates the amount of times a simulations was conducted that year.

<table>
<thead>
<tr>
<th>Site Number</th>
<th>Site Name</th>
<th>Veg Type</th>
<th>Burn Severity</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Swanton Rd.</td>
<td>RW</td>
<td>N</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>L.C. Unburned</td>
<td>RW/DF</td>
<td>N</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Cabins</td>
<td>RW/DF</td>
<td>M</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Upper North Fork</td>
<td>RW/DF</td>
<td>L</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>South Fork</td>
<td>RW/TO</td>
<td>M</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Boyer</td>
<td>KP/MZ</td>
<td>H</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Mill Unburned</td>
<td>KP/MZ</td>
<td>N</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Scotts/Mill Burned</td>
<td>KP/MZ</td>
<td>H</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Scotts/Mill Unburned</td>
<td>KP/MZ</td>
<td>N</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>Upper Boyer Unburned</td>
<td>TO</td>
<td>N</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>Lions Flat</td>
<td>TO</td>
<td>H</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>Hillslope</td>
<td>RW/TO</td>
<td>M</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>Mill/Boyer Burned</td>
<td>KP/MZ</td>
<td>H</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

5.1.2 Scotts Creek watershed rainfall simulation data

Figure 5-1 displays infiltration rate \( \frac{L}{\text{min}} \) as a function of time (years) for all thirteen rainfall simulation sites. In general, there is an increasing trend present at all sights meaning that infiltration has increased since the fire regardless of burn severity. Some trends are stronger than others but the more notable observation is that infiltration rates at some sites peak in 2012 and decline in 2013.

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17 RW= Redwood, DF= Douglas fir, TO= tanoak, KP= knobcone pine and MZ= Manzanita
18 Soil Burn Severity: N=None, L=Low, M=Moderate, H=High
Figure 5-1: Infiltration rate (L/min) as a function of time (years) of each site with a letter that signifies the burn severity classification. N=unburned, L=low, M=moderate, and H=high.

Figure 5-2 displays the hydrologic response as a function of time (years) by each site. Graphs in Figure 5-2 displays a decreasing trend, illustrating that hydrologic response (ratio of total runoff (L) to total rainfall (L)) has decreased over time at almost all of the sites. In particular, sites 7 and 8 show the hydrologic response to be lowest in 2012 and increased in 2013.
Figure 5-2: Hydrologic response as a function of time (years) for each site location with a letter that signifies the burn severity classification. N=unburned, L=low, M=moderate, and H=high.

5.1.2.1 Burn severity

Figure 5-3 displays the infiltration rate \( \frac{L}{\text{min}} \) for each burn severity classification as a function of time (days). Sites are color coded and divided by burn severity classifications. Strong increasing trends in infiltration at the high burn severity sites and one unburned site from 2009 to 2010 are visible in Figure 5-3. The remaining unburned, low and moderate sites exhibit an
increase in infiltration over time as well, but are weaker from 2009 to 2010. Similar to Figure 5-1, there is a peak in infiltration in 2012 that is followed by a decline in 2013 at most of the sites.

Figure 5-3: Infiltration rates (L/min) of different burn severity classes as a function of time (days since 12/31/2008).

Figure 5-4 displays the hydrologic response for each burn severity classification as a function of time (days). A strong, decreasing trend is evident at high severity sites from 2009 to 2010 as a result of high runoff volumes at site 8-Boyer and site 10-Scotts/Mill. Oddly enough, however, there is a strong decreasing trend from 2009 to 2010 at site 11-Scotts/Mill which is an unburned site. Field notes following the simulation at site 11-Scotts/Mill indicated natural soil water repellency was suspected.
5.1.2.2 Dominant vegetation type

Figure 5-5 displays infiltration rates by dominant vegetation type as a function of time (years). This graph depicts the knobcone pine vegetation type having the strongest increasing trend of the three vegetation types. Yet, the tanoak site, site 13-Lion’s Flat does not contain 2009 data since this site was established in 2010, one year following the burn.
Figure 5-5: Infiltration rates based on vegetation type for the Scotts Creek watershed as a function of time (years). TO= tanoak, KP= knobcone pine and RW= redwood.

Figure 5-6 displays the hydrologic response by dominant vegetation type as a function of time (years). A decreasing trend in hydrologic response is present at all dominant vegetation types yet the knobcone pine sites have the greatest hydrologic response in 2009.
Figure 5-6: Square root of hydrologic response based vegetation type in the Scotts Creek watershed as a function of time (years). TO= tanoak, KP= knobcone pine and RW= redwood.

5.1.2.3 Percent Slope

Figure 5-7 displays the annual infiltration rates for all rainfall simulation sites as a function of percent slope. The trend line for the 2009 graph shows that infiltration increases with an increase
The trend lines of the remaining graphs are fairly linear suggesting infiltration is less affected by slope in the years following the fire.

![Figure 5-7: Annual infiltration rates (L/min) of all sites as a function of slope (%).](image)

Figure 5-8 displays the annual square root of hydrologic responses for all rainfall simulation sites as a function of percent slope. The trend line for the 2009 graph shows that near-surface runoff decreases with an increase in slope. The trend lines in the remaining graphs, 2010 to 2013, do not necessarily suggest slope influences runoff because trend lines are neither increasing nor decreasing.
5.1.3 Statistical results for rainfall simulations in the Scotts Creek watershed

5.1.3.1 Burn severity

Figure 5-9 is the residual distribution from model 1 with infiltration rate as the response. Residuals are slightly skewed away from the regression line but overall the residual distribution is fairly linear. In this model, time was highly significant (p=0.0052) but burn severity (p=0.32) and the interaction between burn severity and time (p=0.72) were not significant predictors, thus supporting that the fire did not have an effect on infiltration rates.
In analyzing hydrologic responses, residuals in the initial linear model were skewed, therefore, a square root transformation was applied in order to linearize the data. Figure 5-10 is the residual distribution from the square root of hydrologic responses. Model 1 with the transformed data showed that time was highly significant (p<0.001) however, burn severity (p=0.2288) and its interaction with time (p=0.4610) were not statistically-significant thus strengthening the notion that the fire did not have an effect on the post-fire hydrologic response.

Figure 5-9: Residual distribution from model 1 with infiltration rates as the response.
5.1.3.2 Vegetation and percent slope

Time was a significant predictor when testing the effect of vegetation and percent slope on infiltration rates and the hydrologic response, however, neither dominant vegetation type, slope nor the interactions between the two fixed effects and time were significant. From this model it can be inferred that there was not a particular dominant vegetation type or percent slope that impacted infiltration rates or hydrologic responses significantly more than any other vegetation type or percent slope following the fire.

Figure 5-10: Residual distribution from model 1 with square root of hydrologic response as the response.
5.1.3.3 Burn Dichotomy

Testing the burn severity classes alone did not reveal statistically-significant findings, therefore, additional analysis was performed in order to test the maximum fire effect and any fire effect on infiltration rates and runoff by using burn dichotomies. With infiltration rates as the response in the “Hot burn versus all others” model, time was highly significant (p<0.0001) while burn severity (p=0.095) and the interaction between burn severity and time (p=0.208) are not statistically-significant predictors. Regarding square root of hydrologic responses, time was highly significant (p<0.0001) and burn severity was slightly significant (p=0.023). However, the interaction between burn severity and time (p=0.123) was not significant.

Upon analyzing infiltration rates, the second burn dichotomy, “Unburned sites versus all others” revealed that time was highly significant (p<0.0001) but burn severity (p=0.419) and the interaction between burn severity and time (p=0.596) were not. Regarding the square root of the hydrologic responses, time was highly significant (p<0.0001) while burn severity (p=0.164) and the interaction between burn severity and time (p=0.211) were not.

5.2 Little Creek watershed rainfall simulation data results

5.2.1 Little Creek watershed rainfall simulation data

5.2.1.1 Burn severity

The six sites that were partitioned out and re-examined as a group are site 4-Little Creek (unburned), site 5-Cabins (moderate), site 6-Upper North Fork (low), site 7-South Fork (moderate), site 13-Lions Flat (high), and site 14-Hillslope (moderate). The influence of burn
severity, vegetation type and percent slope on infiltration rates and hydrologic responses were re-examined solely on the 6 sites using mixed-effects modeling as described in Section 4.3.2.1.

The dataset contains 1 unburned site, 1 low, 3 moderate, and 1 high severity sites. As is visible in Figure 5-11, infiltration rates increase over time (days since 12/31/2008) at all of the sites. There are two observations that stand out at site 5 in 2009 and 2010 because they have such low infiltration rates compared to the rest of the data including site 13, a high severity site. However, site 13 was established in 2010 and was not surveyed in 2013 due to the amount of vegetative regrowth, thus investigating the full scope of change over time for site 13 was not possible.

Figure 5-11: Infiltration rates (L/min) for each of the Little Creek rainfall simulation sites by burn severity as a function of time (days since 12/31/2008). Suffixes adjacent to site numbers indicated burn severity classification.

Figure 5-12 displays the hydrologic responses by burn severity classification as a function of time (days since 12/31/2008). There is a decreasing trend at all locations. Near-surface runoff at the low and moderate sites is high in 2009 and similar to site 13, a high severity site, in 2010. There does not appear to be a distinct difference among the four burn severities for either infiltration rates or hydrologic responses as shown by Figures 5-11 and 5-12.
5.2.1.2 Dominant vegetation type

Figure 5-13 displays infiltration rate by vegetation type as a function of time (years). There is a strong increasing trend for the first three years of the RW/DF classification. As well as an increasing trend in infiltration for the RW/TO and TO vegetation types.
Figure 5-14 displays the square root of hydrologic responses by vegetation type as a function of time (years). There is a decreasing trend present at all sites showing that the hydrologic responses decreased following the fire. Yet, based upon the Figure 5-13 and 5-14, there does not appear to be a distinct difference among the three vegetation types for both infiltration rates and hydrologic responses.

Figure 5-14: Hydrologic responses of each vegetation type as a function of time (years). RW/DF= redwood/Douglas fir, RW/TO= redwood/ tanoak, and TO= tanoak.

5.2.1.3 Percent Slope

Figure 5-15 displays the annual infiltration rates of the six Little Creek sites as a function of slope (%). Trend lines in each of the graphs does not suggest change in slope greatly affects infiltration rates.
Figure 5-15: Annual infiltration rate (L/min) of six Little Creek sites as a function of slope (%).

Figure 5-16 displays the annual square root of hydrologic responses as a function of slope (%). Although trend lines are not linear, trend lines do not strongly suggest that near-surface runoff is altered by changes in percent slope.
Figure 5-16: Annual square root of hydrologic response of six Little Creek sites as a function of slope (%).

5.2.2 Statistical results for rainfall simulations in the Little Creek watershed

With infiltration rate as the response, the residual distribution was fairly linear except for two lower lying outliers from site 5-Cabins (Figure 5-17). Time is highly significant (p=0.0035) sequentially\textsuperscript{19}, however, burn severity (p=0.8549) and the interaction between burn severity and time are not statistically-significant. Marginally\textsuperscript{20}, time (p=0.0691), burn severity (p=0.9474) and

\textsuperscript{19} Sequential p-values indicate the significance of each term as it is added sequentially to the model, i.e. in a model that includes only that term and the ones before it.

\textsuperscript{20} Marginal p-values are the conventional p-value (p < 0.05) which indicate the significance of each term in the complete model.
the interaction between burn severity and time (p=0.8632) were not significant predictors regarding infiltration rates at the 6 Little Creek sites.

![Normal Q-Q Plot]

Figure 5-17: Residual distribution from model 1 with infiltration rate as the response.

In the prior analysis containing all thirteen sites, a square root transformation was applied to hydrologic responses. A square root transformation was applied to the Little Creek sites to retain consistency although an improvement in the residual distribution was not obvious upon applying the transformation. Figure 5-18 shows the residual distribution of model 1 for the square root of hydrologic responses for the six Little Creek sites. Sequentially, time (p<0.0001) was highly significant while burn severity (p=0.8856) and the interaction between burn severity and time (p=0.7302) were not. Marginally, time (p=0.0003) was a significant predictor, but burn severity (p=0.6769) and the interaction between burn severity and time (p=0.7302) were not.
5.2.2.1 Vegetation

With infiltration rates as the response, time is highly significant both sequentially (p<0.0001) and marginally (p=0.0003), but vegetation type was neither sequentially (p=0.5044) nor marginally (p=0.2248) significant and the interaction between vegetation type and time was neither sequentially (p=0.2064) nor marginally (p=0.2064) significant. Regarding the square root of hydrologic responses, time was highly significant sequentially (p<0.0001) and marginally (p=0.0001). However, vegetation type was neither sequentially (p=0.8417) nor marginally (p=1.5194) significant. Similarly, the interaction between vegetation and time was neither sequentially (p=0.5352) nor marginally (p=0.5352) significant. These results suggest that...
vegetation type did not influence a change in infiltration or near-surface runoff following the Lockheed Fire.

5.2.2.2 Percent Slope

With infiltration rate as the response, slope and the interaction between slope and time are significant predictors marginally (p=0.0208) whereas time is not a significant predictor marginally (p=0.1132). Sequentially, time (p=0.0001) and the interaction between slope and time (p=0.0192) are significant predictors but slope alone (p=0.6494) is not.

Regarding the square root of the hydrologic responses, time is a significant predictor sequentially (p=0.0001), but is not a significant predictor marginally (p = 0.8300). Slope is neither sequentially (p=0.1603) nor marginally (p=0.2470) significant and the interaction between slope and time is neither sequentially (p=0.4966) nor marginally (p=0.4966) a significant predictor.

5.3 Mini-disk Infiltrometer data and results

5.3.1 MDI sites sampled each year

MDI tests were conducted at 23 sites for five years, but not necessarily at each site every year (refer to Figure 4-3 for specific locations). Tests were conducted during the summer months and early fall. The total number of complete MDI replications is 913. Table 5-2 shows the amount of annual MDI measurements recorded each year.

Table 5-2: Number of annual MDI measurements recorded. Burn severity classifications are N= None, M/L= Moderate/Low, M= Moderate, H/M= High/Moderate, and H=High.
<table>
<thead>
<tr>
<th>Site Number</th>
<th>Burn Severity</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>12</td>
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<td>2</td>
<td>M</td>
<td>10</td>
<td>10</td>
<td>12</td>
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<td>0</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>12</td>
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<td>0</td>
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<td>0</td>
</tr>
</tbody>
</table>

The number of measurements for any given site and year is normally the number of transect locations multiplied by the number of depths measured. Some sites were discontinued after either the first or second year of testing due to their close proximity to other sites. Site 16 and 17 were no longer tested after 2009 because they were in close proximity to sites 15 and 8. Site 19 was no longer tested after 2010 due its proximity to site 18.
Figures 5-19 displays the mean infiltration volume of three measurements as a function of time measured in days since 12/31/2008 for each individual site at 1 cm depth. The number indicates the site number and the letter signifies the soil burn severity classification.

Figure 5-19: Annual MDI mean infiltration volumes (mL) as a function of time (days since 12/31/2008) by site number at 1 cm depth. The number represents the site number and the letter represents a burn severity classification: H=High, MH= Moderate to High, M= Moderate, ML= Moderate to Low, N= Unburned.

Figure 5-20 displays the mean infiltration volume of three measurements as a function of time measured in days since 12/31/2008 for each individual site at 3 cm depth. When visually
comparing figures 5-19 and 5-20, there does not appear to be a distinct difference in mean infiltration volumes between 1 and 3 cm depths.

5.3.2.1 Burn Severity

Figure 5-21 displays the mean infiltration volume by year and simplified burn classification as a function of time (years). This graph shows that mean infiltration volume does not appear to be related to depth as a result of trend lines that are neither strongly increasing nor decreasing.
Figure 5.21: MDI mean volume infiltrated in (mL) as a function of depth (cm) for each year and simplified burn severity classification. For the simplified burn classes, “Hot” incorporates burn severity classes M, MH, and H. “Cool” incorporates N and ML. Volumes have been transformed for this display using square roots. Curves are fitted by loess (degree=1, span =1)

Figure 5-22 shows annual mean infiltration volumes by depth and simplified burn severity classification as a function of time (years). The trend lines show maximum infiltration volumes occur in 2012 regardless of depth or burn severity classification.
Figure 5.22: MDI mean infiltration volume (mL) as a function of time (years) for each depth (cm) and simplified burn classification. For simplified burn classes, “Hot” incorporates burn severity classes M, MH, and H. “Cool” incorporates N and ML. Volumes have been transformed for this display using square roots. Curves are fitted by loess (degree=1, span =0.5)

Figure 5.23 is a temporal display of the original burn severity classifications for each site. The moderate, moderate/high and high classifications show an increasing trend in infiltration volumes with a maximum in 2012 and leveling out or decline in 2013. The unburned sites and moderate/low sites show a less definitive increase in 2012 and decline in 2013.
5.3.2.2 Soil parent material

Figure 5-24 displays the square root of mean infiltration volume by depth, simplified burn class, and soil parent material as a function of time (years). Temporal trends are visible but not evident to suggest one soil parent material has greater or lower infiltration volumes from the remaining soil parent materials types.
Figure 5-24: Square root of mean infiltration volume (mL) by depth (cm), simplified burn class, and soil parent material as a function of time (years). For simplified burn classes, “Hot” incorporates burn severity classes M, MH, and H. “Cool” incorporates N and ML. For soil parent material MS = mudstone and MS/SS = mixture of mudstone and sandstone.
Figure 5-25 displays the square root of mean infiltration volume by soil type and simplified burn severity classification as a function of time (years).

Figure 5-25: Square root of mean infiltration volume (mL) by soil type, simplified burn class and depth (cm) as a function of time (years). For simplified burn classes “Hot” incorporates burn severity classes M, MH, and H. “Cool” incorporates N and ML. For soil parent material MS = mudstone, and MS/SS = mudstone/sandstone.
Table 5-3 provides the mean annual infiltration volumes for each of the three soil types. The lowest and greatest mean infiltration volumes change from year to year thus providing additional evidence that soil parent material is not a suitable predictor for infiltration volumes.

Table 5-3: Mean infiltration volume by year and soil type.

<table>
<thead>
<tr>
<th>Year</th>
<th>Granitic</th>
<th>Mudstone</th>
<th>Sandstone/Mudstone</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>2.37</td>
<td>1.90</td>
<td>3.96</td>
</tr>
<tr>
<td>2010</td>
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</tr>
<tr>
<td>2012</td>
<td>10.24</td>
<td>8.25</td>
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</tr>
<tr>
<td>2013</td>
<td>5.03</td>
<td>6.74</td>
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5.3.2.3 Dominant vegetation type

Figure 5-26 displays the square root of mean volume infiltrated by dominant vegetation type and simplified burn severity classification as a function of time (years). The knobcone pine and manzanita sites were all high burn severity sites therefore there are none of these sites in the “Cool” simplified burn class. Both vegetation types show a trend of increasing infiltration over time and neither vegetation type or burn severity classifications appears to have a stronger influence than the others.
Figure 5-26: Square root of infiltration volume by dominant vegetation type and simplified burn classification as a function of time (years). For simplified burn class “Hot” incorporates burn severity classes M, MH, and H. “Cool” incorporates N and ML. For dominant vegetation type KP/MZ= knobcone pine/ manzanita and RW= redwood dominant.
5.3.3 Statistical results for the MDI tests

5.3.3.1 Burn severity

This model for the log-transformed response had a more Gaussian distribution and showed that day number (p=0.044), burn severity (p=0.0017), depth (p=0.004), and the interaction between day number and burn severity (p<0.0001) were all significant (Figure 5-27). This model explains 50% of the variation in the logarithm of MDI volume. The coefficient is negative for depth, suggesting infiltration is reduced at greater depths. The interaction between burn severity and depth and was not found to be significant (p=0.17).

Figure 5-27: Logarithmic transformed residual distribution for model of MDI.
5.3.3.2 Soil parent material

The three soil parent materials were added to model 2 as fixed effects. While parent soil material is the attribute of most concern, additional fixed effects in the model are day number (time), depth, burn severity and the interaction between burn severity and time. The significance of the latter four fixed effects was tested and only day number (p<0.0001) and depth (p=0.0434) were found to be significant therefore burn severity and the interaction between burn severity and time were removed from the model. Nevertheless, soil parent material (p=0.4994), the interaction between soil parent material and day number (p=0.5285), and the interaction between soil parent material and depth (p =0.3062) were significant predictors. Depth alone (p=0.7634) was not a significant predictor either.

5.3.3.3 Dominant Vegetation Type

The same mixed-effects model for the logarithm of mean infiltration volume was refitted without the tanoak site and included the random effect of site on depth. With the random effect of depth, day number (p<0.0001) and depth (0.0467) were significant while vegetation (p=0.080) and the interaction between vegetation and day number (p=0.076) were not significant.

One more mixed-effects model was fitted to the aggregated dataset for vegetation type. The model analyzed the infiltration volumes averaged across depth and transect per site location by taking into account day number and year. Vegetation was not significant when modeled with day number (p=0.1762) nor was it significant when modeled with year (p=0.2330).
5.4 Water Drop Penetration Time Tests

5.4.1 WDPT sites sampled each year

WDPT tests were conducted at 23 sites for a total of four years starting in 2010 (refer to Figure 4-3 in Chapter 4 for specific locations). The 2009 WDPT field data was misplaced. Therefore, 2009 data is not included in this analysis. In 2011, the 2 cm depth was not tested. Tests were conducted during the summer months and early fall but not necessarily at each site every year. The total number of observations for water drop tests is 740. Table 5-4 shows the annual number of measurements recorded at each site location. The number of measurements for any given site and year is normally the number of transect locations multiplied by the number of depths measured.
Table 5-4: Number of annual WDPT measurements recorded. Burn severity classifications are None=N, Moderate/Low=M/L, Moderate=M, High/Moderate=H/M, and High=H.

<table>
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<th>2012</th>
<th>2013</th>
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</tbody>
</table>

5.4.2 WDPT Data

5.4.2.1 Burn severity

Penetration times are displayed on a square root scale to help visualize any trends. The response analyzed is the continuous penetration time as opposed to a hydrophobic classification. Figure 5-28 is a fundamental display of penetration times as a function of time for each individual site. Strong trends are not visibly apparent at 1 cm depth.
Figure 5-28: Annual water drop penetration times (s) of sites as a function of day number (since 12/31/2008) at 1 cm depth.

Figure 5-29 and Figure 5-30 are also fundamental displays of penetration times as a function of time (days) for each individual site. Figure 5-29 displays data from 2cm depth and figure 5-30 displays data from 3cm depth. Again, for both of these figures, there is no discernible trend visible.
Figure 5-29: Annual water drop penetration times (s) of sites as a function of day number (since 12/31/2008) at 2 cm depth.
Figure 5-30: Annual water drop penetration times (s) of sites as a function of day number (since 12/31/2008) at 3 cm depth.

Figure 5-31 is displayed on a square root scale to aid the visualization of trends. There appears to be greater/higher infiltration times in 2010 for the hot simplified burn class. Penetration times seem unrelated to depth. There is only one penetration time greater than 100 seconds in the cool simplified burn class while there are many in the hot burn class.
Figure 5-31: Square root of water drop penetration times (s) as a function of depth for each year and simplified burn classification. “Hot” incorporates burn severity classes M, MH, and H. “Cool” incorporates N and ML. Curves are fitted by loess (degree=1, span =1)

Figure 5-32 shows penetration times in seconds as a function of year at 1, 2, and 3 cm depths for the simplified burn classes. The penetration times have been transformed using square roots to display trends. Once more greatest penetration times are shown in 2010 for both modified burn severity classes. “Hot” burns have longer penetration times regardless of depth.
Figure 5-32: Square root of water drop penetration times (s) as a function of time (years) for each depth (cm) and simplified burn classification. For simplified burn classes, “Hot” incorporates burn severity classes M, MH, and H. “Cool” incorporates N and ML. Penetration time has been transformed for this display using square roots. Curves are fitted by loess (degree=1 and span =1).

Figure 5-33 is a breakdown of penetration times for the original burn severity classification as a function of time regardless of depth. Similar trends are present at each soil burn severity classification; penetration times are lowest between the 2011 and 2012 data followed by an increase in penetration times in 2013.
Figure 5-33: Square root of water drop penetration times (s) as a function of time (day number since 12/31/2008) for each burn severity class. Burn severity classifications are N= None, M/L= Moderate/Low, M= Moderate, H/M= High/Moderate, and H=High. Penetration time has been transformed for this display using square roots. Curves are fitted by loess (degree=2, span =1.25)

5.4.2.2 Soil parent material

Graphical displays of penetration times by soil parent material do not differ greatly than penetration times by burn severity classification. Figure 5-34 displays trends in penetration times by burn severity classification and soil type as a function of time. Penetration times are greatest in 2010, lower in 2011 and 2012 and then increase in 2013.
Figure 5-34: Logarithm of water drop penetration times (s) by burn severity class and soil type as a function of time (years). Burn severity classifications are N= None, M/L= Moderate/Low, M= Moderate, H/M= High/Moderate, and H= High. For soil parent material, MS= mudstone and SS/MS= sandstone/mudstone.

Figure 5-35 displays the logarithm of penetration times by soil parent material and simplified burn classification as a function of time (years). There are no sites located in the “cool” burn severity classification with a granitic parent material (bottom left) therefore that portion of the graph does not contain data. The general trend in Figure 5-35 is lowest penetration times occurring between 2011 and 2012 and then an increase in penetration times in 2013.
Figure 5-35: Logarithm of water drop penetration times (s) by soil parent material and simplified burn severity classification as a function of time. For soil parent material, MS = mudstone and SS/MS = sandstone/mudstone. For simplified burn classes, “Hot” incorporates burn severity classes M, MH, and H. “Cool” incorporates N and ML.

Figure 5-36 displays the logarithm of penetration times by soil parent material irrespective of soil burn severity classification and depth, as a function of time (days since 12/31/2008).
Figure 5-36: Logarithm of water drop penetration times (s) by soil type irrespective of burn severity and depth, as a function of time (days since 12/31/2008). For soil parent material, MS= mudstone and SS/MS= sandstone/mudstone.

Table 5-5 shows the mean annual water drop penetration time (seconds) by soil type. The granitic soil types have the lowest penetration times every year when compared to the other two soil parent materials.

Table 5-5: Mean annual water drop penetration time (s) by soil type.

<table>
<thead>
<tr>
<th>Year</th>
<th>Granitic</th>
<th>Mudstone</th>
<th>Sandstone/Mudstone</th>
</tr>
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<tbody>
<tr>
<td>2010</td>
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<td>2013</td>
<td>13.0</td>
<td>22.9</td>
<td>18.7</td>
</tr>
</tbody>
</table>

5.4.2.3 Dominant vegetation type

The knobcone pine and manzanita sites appear to have greater penetration times than the redwood dominant sites (Figure 5-37). There does not appear to be a difference among the burn
severity groups of the redwood dominant sites where as there is some noticeable difference among the moderate/high and high knobcone pine/manzanita sites. In spite of that, there is an absence of the lesser severity sites to compare the higher severity penetration times with for the knobcone pine/manzanita sites. The reason being that the knobcone pine/manzanita vegetation type throughout the Little Creek Watershed, for the most part, did not undergo low or moderately low burn severity.

Figure 5-37: Logarithm of water drop penetration times (s) by burn severity classification and dominant vegetation type as a function of time (years). Burn severity classifications are N=None, M/L=Moderate/Low, M=Moderate, H/M=High/Moderate, and H=High. For dominant vegetation type KP/MZ= knobcone pine/manzanita and RW= redwood dominant.

Figure 5-38 compares knobcone pine and manzanita vegetation type data to the redwood dominant vegetation type data irrespective of burn severity and depth. There are more data points with high penetration times in the knobcone pine and manzanita vegetation type, but the trends
are not indicative that one vegetation type might have a stronger influence on penetration times than the other vegetation type.

Figure 5-38: Logarithm of water drop penetration times (s) by dominant vegetation type, irrespective of burn severity classification and depth, as a function of time (days since 12/31/2008). Dominant vegetation types are KP/MZ=knobcone pine/manzanita, and RW Dom=redwood dominant.

5.4.3 Statistical results for the WDPT tests

5.4.3.1 Burn severity

The square root of penetration times was first modeled as a linear function of time However, the linear trend modeled showed that depth (p<0.566), burn severity (p=0.151) and the interaction between burn severity and day number (p=0.104) were not significant, Therefore, penetration
times were modeled as a quadratic function, which contains a square root transformation, because the square root transformation was better fitted to the data than the linear function. In this model, square of day number (p=0.02) was significant, depth was not significant (p<0.487), but burn severity (p=0.014) and its interactions with the linear (day number) (p=0.002) and quadratic (square root of day number) terms (p=0.002) were significant. However, the residuals distribution from this model is extremely long in the tails (Figure 5-39) rendering the significance test highly suspect.

![Normal Q-Q Plot](image)

**Figure 5-39**: Square root transformed residual distribution for model of WDPT.

The logarithm transformation did improve the residual distribution but did not entirely normalize it. The distribution is significantly right skewed (Figure 5-40). In the model with the log-transformed response, the quadratic term (square of day number) appeared to be highly
significant (p<0.0001), but burn severity (p=0.185) and the interaction between burn severity and day number (p=0.144) were not significant. The interaction between burn severity and the square of day number could not be tested, as singularities arose in solving the model. However it is the interaction between burn severity and the linear term (day number) that is probably of greater interest as this is the term that would best explain differences in rate of recovery after burning. The model whose residuals are depicted in Figure 5-40 explains 63% of the variation in the logarithm of WDPT.

![Normal Q-Q Plot]

Figure 5-40: Logarithmic transformed residual distribution for model of WDPT.
5.4.3.2 Soil parent material

The aforementioned quadratic trend mixed-effects model for the logarithm of water drop penetration times (Figure 5-40) was altered to include soil parent material and the interaction between soil parent material and day number, and the interaction between soil parent material and square of day number. The random effect of site on depth was dropped in order for the model to work. In this model, all fixed effects, soil parent material and the interactions between soil parent material and day number, and soil parent material and square of day number, were highly significant (p< 0.0001), thereby implying that the temporal pattern of penetration times varies by soil parent material. Yet, the significance may be overestimated as a result of omitting the random effect of site number on depth.

Since results from the quadratic trend model were suspect, a new aggregated dataset was generated that contained penetration times averaged across depth and transects thus providing one observation per site per year. A simpler mixed-effects model was fitted to the aggregated dataset that tested soil parent material and time in years. Neither soil parent material nor time were found to be significant predictors of penetration times.

5.4.3.3 Dominant vegetation type

Dominant vegetation type and the interaction between vegetation type and day number (days since 12/31/2008), and the interaction between dominant vegetation type and square of day number were added to the model. In order for the model to function, the random effect of depth had to be dropped from the model. All fixed effects were significant (p<0.001) after having dropped the random effect of depth. However, once again the significance may be overestimated as a result of dropping depth and other random effects from the model.
Since depth provided computation issues, a new mixed-effects model was fitted to the aggregated dataset which contained one observation per site, per year. In this model, dominant vegetation type was not significant and the interactions between vegetation type and day number, and between vegetation type and square of day number, could not be tested because singularities arose in fitting the model. As a result, one more model was fitted using time as the categorical variable year, but again, vegetation type was not significant as singularities arose when testing the interaction between vegetation type and year.
Low infiltration rates immediately following a fire have been attributed to fire-induced hydrophobicity, soil sealing, and surface compaction via rainfall impact on bare soils (DeBano, 2000a; Robichaud, 2000; Doerr et al.; Pierson et al., 2001; Ice et al., 2004; Assouline, 2004). Within a year following a burn, infiltration rates typically begin to increase as a result of regrowth, restored duff layer, breakdown of a hydrophobic layer, and/or the wetting of a hydrophobic layer (Robichaud, 2000; Larsen et al. 2009; MacDonald and Huffman, 2004; Onda et al., 2008). Similar response to soil hydrologic processes was presumed to occur within the Scotts Creek watershed following the 2009 Lockheed Fire. Rainfall simulations, Mini-disk Infiltrometers (MDI) and water drop penetration time tests (WDPT) were the three methods employed to measure infiltration annually from 2009 to 2013. While it was suspected that the Lockheed Fire would have an influence on infiltration, only MDI tests detected a statistically-significant difference in average infiltration volumes over the five-year period as a result of the fire. Statistical analysis conducted on the rainfall simulation dataset showed that there was a statistically-significant difference in the rate of change in infiltration rates and near-surface runoff over the five-year period, but the change over time was not influenced by the Lockheed Fire. As well, the statistical analysis conducted on the WDPT dataset showed that there was a statistically-significant difference in the rate of change in penetration times over the five-year period, but the change over time can not be attributed to the Lockheed Fire.

Results regarding temporal trends, burn severity, soil parent material, and dominant vegetation type for the rainfall simulations, MDI and WDPT tests will be discussed in this
section. Observations made during experimentation are presented in order to offer further explanation of the data and statistical results. Lastly, limitations and recommendations for future experimentation of the three tests are addressed.

6.1 Rainfall simulations

6.1.1 Scotts Creek watershed rainfall simulations

6.1.1.1 Temporal trends

Thirteen rainfall simulation sites were distributed throughout the Scotts Creek watershed. In an attempt to account for the variability associated with a fire of this magnitude and the natural variability of the landscape, rainfall simulation sites were represented by variations in burn severity and dominant vegetation type. Trends were present in the graphical displays showing that infiltration rates and hydrologic responses changed over time regardless of burn severity classification or vegetation type. This suggests that neither burn severity nor vegetation type strongly influenced the response variables over the five-year testing period.

6.1.1.2 Burn severity trends

There is a discernible increasing trend in infiltration rates and a discernible decreasing trend in hydrologic responses (ratio of runoff (L) to rainfall (L)) at all rainfall simulation sites, including the unburned sites, over the five-year testing period. Four of the five unburned sites displayed similar trends, with regards to infiltration rates and hydrologic responses, as the low and moderate burn severity sites. However, Site 11, mirrored the infiltration rates and the
hydrologic responses of high severity burned sites. This result was unexpected, but is not necessarily uncommon because chaparral vegetation is a plant community often associated with natural soil water repellency due to the leaching of hydrophobic compounds from organic surface matter (Doerr et al., 2000). WDPT tests on two sagebrush sites found strongly repellent soils in unburned conditions compared to sites that were severely burned because burning had decreased the strength of soil water repellency by breaking down the repellent layer as opposed to strengthening it (Pierson et al., 2008). Therefore, it is not abnormal for an unburned site located in a chaparral community to produce high near-surface runoff and retain a low infiltration rate.

Additionally, the lack of a thick litter/duff layer could explain the high near-surface runoff at Site 11 in 2009. The upper portion of the Scotts Creek watershed is referred to as the “chalks” because of the widespread off-white soil at the Scotts Creek/Mill Creek ridgeline. This area exhibits low vegetated density when compared to the Little Creek ridgelines, thus the accumulation of duff is slow. While two of the unburned sagebrush sites studied by Pierson et al. (2008) reported unburned sites with high runoff due to natural hydrophobicity but additional unburned sagebrush sites with 100% surface cover had high infiltration rates as a result of the water being stored in the ground litter regardless of the soil being strongly hydrophobic beneath the litter layer. While site 11 was suspected to be naturally hydrophobic, the lack of duff may have contributed to high near-surface runoff rates as well.
6.1.1.3 Statistical analysis- Burn severity

The effects of time, burn severity and the interaction between burn severity and time on infiltration rates and hydrologic responses were analyzed using mixed-effects modeling. Time was a highly-significant predictor for infiltration rates and the hydrologic response indicating that there was a statistically-significant difference in the average infiltration rate and hydrologic response among years. This is reasonable given that the unburned sites contained similar time trends as the burned sites. Burn severity was not a statistically-significant predictor for infiltration rates or hydrologic responses. This implies that burned sites are no different than unburned sites in regards to infiltration rates and hydrologic responses thus suggesting no fire effect. Similarly, the interaction between burn severity and time is not a significant predictor implying that the statistically-significant change in infiltration rates and hydrologic response among years cannot be attributed to the fire.

6.1.1.4 Statistical Analysis- Dichotomous burn contrasts

Burn severity is the variable utilized in the model as an indicator of a fire effect. However, there was some difficulty distinguishing between degrees of burn severity because ground observations suggested that the fire did not burn the landscape homogenously. Instead, the fire appeared to burn the landscape in a mosaic fashion. Hence, the two burn dichotomies were generated in order to test a maximum fire effect and any fire effect.

When considering the two dichotomous burn contrasts, “Hot burn versus all others” and “Unburned versus all others,” time is a highly-significant predictor for both infiltration rates and hydrologic responses. The indicators that would illuminate any fire effect, burn severity and the
interaction between burn severity and time were not significant except for one instance. Burn severity was slightly significant (p= 0.023) in predicting the hydrologic response. In this particular model, burn severity was classified as “Hot versus all others” which means that data from high severity burn sites was compared to no burn, low and moderate burn sites. Although burn severity is slightly significant, there are naturally-occurring soil physical characteristics at the high-burn severity sites that aid in understanding why the hydrologic response was statistically-significant.

All of the high-burn severity sites are located on the ridgelines where the soil depth to bedrock is very shallow, rocks are largely present on the soil surface and duff/leaf litter is scarce. Ridgelines of this watershed are noted for having a chaparral vegetation type (knobcone pine and manzanita) and naturally-occurring hydrophobic soils were suspected during experimentation for instance at site 11-Scott/Mill which is an unburned site. Site 11 as an unburned site is an outlier and will be addressed later in the discussion. Moving downward into the watershed, soils became more developed; the soil depth to bedrock can be significantly deeper, and duff and litter was widespread and thicker. Thus when considering near-surface runoff, the ridgeline sites generated more near-surface runoff than sites lower in the watershed likely due to the difference in water holding capabilities of the litter/duff layer. Rainfall simulation field notes indicated that the litter/duff layers were moist and retained the simulated rainfall where a litter/duff layer was present. The absence of a thick, contiguous litter/duff layer explains why there was more near-surface runoff at the high severity burned sites. Therefore, although burn severity is a slightly-significant predictor in the dichotomous burn classification model, naturally-occurring physical characteristics of the landscape such as mineral soil depth, vegetation type, and elevation within the watershed provide an alternate reason as to why the hydrologic response (near-surface
runoff) was significantly different on high severity sites versus all other sites. By chance, all high severity sites are located on the ridgelines where many of these physical characters are likely similar at all sites.

6.1.1.5 Statistical Analysis-The outlier
As previously mentioned, site 11-Scott/Mill unburned, showed similar temporal trends as the high burn severity sites regarding infiltration rates and hydrologic responses. Field notes indicated that natural soil water repellency was suspected after screeing away the upper 2.5 centimeters of soil; it was common to find that the soil matrix was mostly dry below with some evidence of preferential pathways by which water would infiltrate deeper within the profile. Over 50% of the plot was dry below the top 2.5 centimeters. The remaining unburned sites did not have as pronounced of an increase in infiltration and decrease in the hydrologic response as Site 11 from 2009 to 2010. Hence, the 2009 Site 11 observation is an outlier.\(^{21}\) Removing Site 11 from the analysis does not change the findings for infiltration rate. On the other hand, burn severity and the interaction between burn severity and time become significant predictors for the hydrologic response. Yet removing Site 11 is not justifiable and provides a less robust dataset.

6.1.1.6 Statistical Analysis-Vegetation type
Vegetation type is one attribute that was suspected to have a significant influence on post-fire hydrologic processes, however, this analysis showed that there was not a statistically-significant

\(^{21}\) Outlier denotes an observation that does not fit into a postulated model that has a specific set of implicit or explicit assumptions, or has some other ‘surprising’ characteristics. Thus, what may be considered an outlier in one model may not be considered an outlier in another model.
difference in infiltration rates or hydrologic responses based upon dominant vegetation type. Yet, Figures 5-5 and 5-6 show stronger trends for the knobcone pine/manzanita vegetation type. The trends in Figures 5-5 and 5-6 are similar to the trends for infiltration and runoff based upon burn severity classification at high severity sites because knobcone pine and manzanita are the dominant chaparral vegetation that occupies the ridgelines. While the trend exists, the absence of significant findings may be attributed to the fact that data is missing from 2009 at two ridgeline sites, Sites 15 and 13. Soils are highly vulnerable immediately following a burn in chaparral therefore the lack of 2009 data may have limited the ability to show a more significant fire-induced effect (DeBano et al., 1979).

6.1.2 Little Creek watershed rainfall simulations

The separate analysis performed on six Little Creek rainfall simulation sites was conducted to eliminate the upper Scotts Creek sites that exhibit naturally-occurring soil water repellency. The six Little Creek sites represent variations in soil burn severity and percent slope as well as a range vegetation types.

6.1.2.1 Temporal trends and statistical analyses

Trends were present at all sites within the Little Creek watershed regarding infiltration rates and hydrologic responses when displayed by burn severity classification, vegetation type and slope as a function of time. However, only sequential\textsuperscript{22} p-values indicated that time was a significant predictor of infiltration rates and hydrologic responses when modeled with the effect of burn severity, dominant vegetation type, and percent slope, and the interactions between burn severity

\textsuperscript{22} The sequential p-value indicates the significance of each term as it is added to the model sequentially.
and time, vegetation type and time, and percent slope and time. This suggests there is a statistically-significant difference in the average infiltration rate and hydrologic response among years.

While time was a significant predictor, burn severity and the interaction between burn severity and time were not statistically-significant predictors of infiltration rates and hydrologic responses suggesting there is no detectable fire-induced changes to the hydrologic process within the Little Creek watershed. Statistical analysis showed that vegetation type is not a statistically-significant predictor of infiltration rates or hydrologic responses indicating there is no difference in the hydrologic processes among vegetation types. The lack of statistically-significant findings may be attributed to gaps within the dataset; 2009 observations for sites 14 and 13, 2011 observation for site 14, and 2013 observations for sites 4, 14 and 13.

The effect of percent slope on infiltration rates was statistically-significant suggesting that higher infiltration rates occurred at lower percent slopes over the course of the study. However, percent slope was not a statistically-significant predictor of hydrologic responses over the course of the study. Slope steepness is positively correlated to near-surface runoff, thus, as slope steepness decreases, incoming rainwater has more opportunity to infiltrate deeper into the soil matrix.
6.2 Mini-disk Infiltrometer and water drop penetration time tests

6.2.1 Temporal Trends

Twenty-three MDI and WDPT sites were distributed throughout the Little Creek watershed. These sites represent variations in soil burn severities, vegetation and soil types. Mini-disk Infiltrometers measured the volume of water (mL) that infiltrated over a period of 30 seconds while water drop tests measured the total amount of time (in seconds) for applied water droplets to infiltrate into the soil. Temporal trends are present in the MDI dataset when considering burn severity, soil parent material and vegetation type. However, temporal trends are similar regardless of burn severity, soil parent material, or vegetation type. Similar results were observed for the water drop tests; there are not dramatic differences in the dataset, suggesting one variable does not have a stronger influence on the hydrologic processes than others in the grouping. While trends suggest there is no difference among burn severity, soil parent material, or vegetation type, a fire effect within the Little Creek watershed is dependent on the statistical significance of burn severity and the interaction between burn severity and time.

6.2.2 Statistical analysis

MDI tests showed that there was a statistically-significant difference in infiltration volumes between the burned and unburned sites, thereby supporting a fire effect on the hydrologic response of soils within the Little Creek watershed. Conversely, the WDPT tests showed that there is no significant difference in penetration times between burned and unburned sites even though these WDPT tests were conducted alongside the infiltrometer tests.
The difference in findings between the MDI and WDPT tests could be attributed to a variety of reasons. First, and perhaps most importantly, 2009 WDPT data is missing from the analysis because of a clerical error. Although there is debate on the strength and persistence of fire-induced hydrophobicity, experiments carried out in upper Michigan and coniferous forests in Montana found water repellency had disappeared within 1 year after burning (Reeder and Jurgensen, 1979; DeByle, 1973.) Thus, not having the 2009 WDPT data may have limited our ability to detect a significant change in post-fire infiltration.

Additionally, there was less consistency in the data collection for the WDPT tests. The methodology specified that there be 3 replications at 1, 2, and 3 cm depths at five positions along a transect. However, that did not necessarily get carried out at every site. In 2011, the 2 cm depth was not tested for unknown reasons. The absence of the 2009 data combined with the varied number of replications at each depth for the WDPT tests may be a contributing factor to explain why this test did not show a fire-induced effect.

Although the MDI showed significant changes in the soil hydrologic response, there was only 1 unburned site out of 23 sites total to compare with the burned sites. Furthermore, data not was collected from the unburned site in 2013 because of safety concerns with a wasp nest at the site. Had this non-burn site been tested, there is potential that this data could have bolstered the WDPT dataset and potentially contributed to a significant finding between the burn and unburned sites.
6.3 Limitations

There are overlapping limitations associated with the rainfall simulations, Mini-disk Infiltrometer, and water drop penetration time tests, therefore, each test is discussed in one section with the goal of explaining the varied results among the three tests.

6.3.1 Small sample size and unbalanced datasets

A couple of reasons noted for lacking a statistically-significant effect is having a small sample size or not having enough replications (Crawley, 2005). While there are thirteen rainfall simulation sites, simulations were not performed at every site each year. The reasons being that some sites were not established in 2009, time constraints, and accessibility as a result of the amount of regrowth. Two rainfall simulation sites in particular, site 15-Mill/Boyer burned and site 12-Lion’s Flat, were not established in 2009, but are located in a high burn severity region on the ridgelines. Collecting data from rainfall simulation sites in 2009 could have provided data similar to that of other high severity sites, Likewise, MDI and WDPT tests were not consistently conducted throughout the course of the study. Furthermore, there is only one unburned site to make comparisons to and that site was not tested in 2013. If MDI and WDPT data had been collected from the only unburned site, and had there been consistency in collecting data from all sites, there is a chance that the statistical analysis would have be strengthened and improved our understanding of a fire effect.

Additionally, thirteen rainfall simulation sites for this study may not have been a sufficient amount of sites to investigate a fire effect in a topographically- and geologically-diverse watershed such as the Scott Creek watershed. Visually pre and post-fire, the Scotts and
Mill ridgelines exhibited different characteristics than the Little Creek ridgelines. As previously mentioned, the Scotts/Mill ridgelines are referred to as the “chalks” because of the amount of visible ground surface which happens to be off-white. Pre-fire vegetation was present on the Scott/Mill ridgeline, but scattered such that the ground surface was prevalent when viewed aerially. Based upon post-fire observations, the amount of regrowth and plant diversity on the Scotts/Mill ridgelines does not compare to that of the Little Creek watershed. Within the five years following the burn, ridgelines in the Little Creek watershed contain an abundance of vegetation making it difficult to see the ground surface. As a result of such differences among the project sites, the Little Creek sites were partitioned from the rest of the Scotts Creek sites and analyzed separately because of the chance that sites within a smaller subwatershed would contain less variability than the sites located in the upper portion of the Scotts Creek watershed. However, the supplementary sample contained only six sites. Benavides-Solario and MacDonald (2001) reported finding from a total of 26 simulation plots distributed among three different fires and Pierson et al. reported findings from over 50 simulation plots dispersed over three different locations.

Computational issues arose during the analysis as a result of having unbalanced the datasets regarding burn severity, soil parent material, and vegetation type. Having an unbalanced dataset resulted in combining sites into simplified burn classification and dominant vegetation types. Thus, it is important to represent all variables equally during experimentation.

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23 This experiment had 11 high severity, 4 moderate severity, and 8 low severity or unburned sites.
6.3.2 Spatial and procedural variability

Permanent plots for rainfall simulations and permanent transects for MDI and WDPT testing were not established during the setup of this project. In order for flow paths to be observed and to observe the presence of water repellent layers, rainfall simulation plots were disturbed following the simulation. Likewise, MDI and WDPT transects were disturbed at the soil surface as part of testing. Due to the disturbance factor and the amount of regrowth, preserving rainfall simulation plots and transects to be sampled in subsequent years was not manageable. As a result, detecting the change over the five-year period at the initial plot and transect locations was missed.

Yet, creating a new plot for rainfall simulations or setting out new transects for MDI and WDPT tests at every site each year may have helped account for the naturally-occurring variability of the landscape within sites. The spatial variability of soil water repellency is high following forest fires and may vary at a 10 centimeter scale (Lewis et al., 2006). Moderately-burned areas are typically a mosaic of burn severities, thus have a mixture of strong and weak water repellency (Robichaud and Hungerford, 2000; Robichaud et al., 2008). Water drop tests in the Little Creek watershed confirmed that soil water repellency was highly variable during field tests. One drop would be placed on the soil and completely infiltrate while another adjacently placed drop never infiltrated. For that reason, it was beneficial to establish new simulation plots and new MDI and WDPT transects annually in order to account for landscape variability.

However, without having established permanent plots, there is room for error when constructing a new plot for rainfall simulations. Constructing a new plot is not an easy feat particularly in rocky soils like that of the ridgelines. If the plot is not constructed correctly, there is an increased chance for error during data collection. For instance, a bad seal between the
trough and soil can result in near-surface runoff leakage underneath the trough. Leaks became apparent after the simulation was complete, never during. Breaking down the equipment and removing the trough was the only way to be certain of a leak. If leaks were detected, that site was tested again. If the trough was installed flat instead of with the slope of the ground surface, near-surface runoff collected in the trough and did not exit thus providing an inaccurate runoff value.

Aside from the trough, setting up the border provided difficulties in rocky soil or in thick duff layers which made it challenging to vertically insert the border at a mineral soil depth of 6-8 centimeters. If the border is not inserted to the correct depth, there is a chance that exterior water could enter the plot and generate false results. Establishing a permanent plot would have minimized installation errors and would have allowed for documenting the change over time on that particular plot of land as opposed to comparing different plots from the same site to one another from year to year.

The MDI procedures suggests that spatial variability is accounted for during testing. This requires that the three replicate tests be conducted immediately adjacent to one another without being on top of, or beneath, a previous test in order to compensate for measurement variability (Robichaud et al, 2008). However, performing tests in this manner was not easily accomplished considering the nature of the sloped, rocky soils. For example, when scraping the soil aside to reach either 1 or 3 centimeters, rocks were exposed and in the test location. The Mini-disk Infiltrometer is meant to be placed flush and level with the mineral soil surface not on top of rocks and if the rock is removed, a large macropore or hole is created. Furthermore, rocks prohibited unbiased testing because testing had to shift away from the transect in order to find a rock-free zone.
A highly-sloped landscape was found to be problematic for conducting the MDI and WDPT tests. The Mini-disk Infiltrometer must be placed upright to function properly (Robichaud et al., 2008). The instructions provide additional directions for conducting MDI and WDPT test on slopes greater than 50 percent which are to cut a level shelf as close as possible to the desired depth. However, depth is not uniform across the benched surface because the depth is deeper at the hinge versus the toe of the bench. This discrepancy combined with rocky soils generated questions of the accuracy and representativeness of the data from this test.

Lastly, although the goal in conducting each of these three tests is to limit the variability and error by conducting each test the same way every time, the spatial and temporal variation along with the various field technicians made consistency one of the most significant challenges in carrying out each test from one year to the next.

### 6.4 Recommendations

These recommendations are made with the intent of aiding future researchers whose goal is to study post-fire effects on soil hydrologic processes using rainfall simulations, Mini-disk Infiltrometers and/or water drop penetration time tests. In the event that researchers face time or financial constraints during the field season, these recommendations may be of use to ensure that field sampling consistency is achieved.

One recommendation is to equally represent test variables and classifications within test variables to avoid computational errors from arising as a result of having an unbalanced dataset. For instance when analyzing the effects of burn severity (none, low, moderate and high) and vegetation types (redwood and tanoak), there should be similar numbers of unburned, low,
moderate, and high severity sites with redwood and tanoak vegetation types equally represented among each burn severity classifications.

Next, for a long-term field study, such as this one, it is key to maintain consistency during data collection from year to year. In the case of this project, time and staff constraints occasionally inhibited testing. Therefore, it will likely be more efficient and effective to conduct post-fire research on a more localized subwatershed scale.

As well, natural and fire-induced variability associated with an entire watershed is high. Therefore, in order to account for time and staffing constraints as well as natural variability of the landscape, it is recommended that sites be concentrated within a subwatershed as opposed to being distributed throughout an entire watershed. When testing at a smaller scale, multiple replications should be conducted at a site each year in order to account for microsite variability and limit the influence of any outliers. Lastly, a permanent plot or transect is recommended as well to observe how that plot or transect changed over time. Concentrating the sampling to a localized area and conducting multiple replications will allow for better comparisons to be made among sites. If resources permit, expanding beyond a subwatershed level to collect data from other burned regions is recommended as long as those regions are adequately sampled. These recommendations should aid in minimizing confounding factors that may lead to inconclusive findings.
CHAPTER 7 : CONCLUSION

Rainfall simulations, Mini-disk Infiltrometer and water drop penetration time tests were employed to test whether there was a fire-induced effect on the hydrologic processes namely infiltration and runoff, following the 2009 Lockheed Fire. Rainfall simulations and water drop penetration time tests detected a significant change in infiltration rates, the hydrologic response and penetration times over time, however, simulations and water drop tests did not detect a significant difference in the rate of change between burned versus unburned sites. Alternatively, significant changes between the burned and unburned sites were detected using the Mini-disk Infiltrometer, thereby suggesting that the significant change in infiltration volumes over time can be attributed to the Lockheed Fire.

The influence of soil parent material and vegetation type on the hydrologic processes over the course of the study were tested in order to determine whether any variance could be explained by a specific soil parent material or dominant vegetation type. A variety of models were generated in order to test both the effect of soil parent material and vegetation type. However, the statistics are not strong in supporting that soil parent material or vegetation type had a strong influence on the hydrologic processes (infiltration rates, the hydrologic response, infiltration volumes or penetration times).

While there are a variety of variables with subclasses tested for having a significant influence on the hydrologic processes following the fire, the lack of significant findings can be attributed to inconsistencies in the datasets as a result of not having each effect evaluated for this study, equally represented throughout the testing period. Hence, while visible trends were
present in each dataset, perhaps the inconsistencies in data collection limited the abilities of the mixed-effects modeling to detect a fire effect, especially for the rainfall simulations and water drop penetration time tests.

It is challenging to have perfectly controlled experiments in a natural, field setting. Evaluating the post-fire effects within the Scotts Creek watershed using rainfall simulations, Mini-disk Infiltrometer and water drop penetration time test has provided meaningful results regarding post-fire effects on soil hydrologic processes, limitations of each method, and recommendations for future researchers who choose to use these methods.

Future work pertaining to near-surface hydrology in the Scotts Creek should aim to better understand the trends over time that were seen at nearly all sites for each test by conducting multiple simulations at a site per year, conduct testing at a subwatershed scale, and maintain a balanced dataset by having equal amounts of the variable and subcategories represented in the datasets. A key part to understanding the influence of fire on soils lies within the physical characteristics of the sites including vegetation communities, soils, geology, antecedent moisture content, and duff depth, which, independent of fire, highly influence infiltration and runoff.
BIBLIOGRAPHY


Parsons (2003) defines soil burn severity as “the fire-caused changes to soil hydrologic function, as evidenced by soil characteristics and surface fuel and duff consumption.”

Burn Severity Characteristics (adapted from Parsons, 2003):

**Low:**
- Surface fire with no extension into the tree canopy
- Slight or no modification of vegetation structure
- Nearly all mature plants survive
- Consumption of fine fuels and litter
- Unburned islands of vegetation remain
- Duff intact
- No or slight soil heating

**Moderate:**
- Long stems remaining in the chaparral
- Fire extension into the tree canopy of a small number of individual trees
- Moderate stand modification
- Most mature plants survive, but some mortality
- Needles on trees may be scorched
- Consumption of fine fuels and litter
- Duff layer partially consumed
- Some soil heating
- Some areas may be more of a mosaic of low to high severity that are lumped into the Moderate rating

**High:**
- Chaparral mostly consumed
- Most tree canopies scorched
- Most small plants, litter and duff consumed
- High mortality of mature plants, including trees
- Some larger diameter fuels remain

**Very High:**
- Chaparral consumption with many burned out stumps and burls
- Complete consumption of the tree canopies of the majority of the trees within an area
- Complete consumption of small plants, litter and duff
- Almost total consumption of mature plants
- May be significant soil heating
Appendix B. Descriptions of the Rainfall Simulation Sites

Site 2: Swanton Road

Site 2 is located adjacent to Swanton Road approximately 1 mile from the Old Seaside Schoolhouse at the first turnout. The dominant vegetation type is redwood overstory and sparse redwood sorrel understory. A thick, 3-5 inch redwood duff layer overlies mineral soil. The soil parent material is mudstone. The slope of the site is 60 percent. This site was not burned.

Site 4: L.C. Unburned

Site 4 is located above the gate at the entrance of Little Creek road. The plot is adjacent to the mainstem of Little Creek under a redwood/Douglas fir dominant forest type. The understory is composed of hedge nettle, blackberry and redwood sorrel. The soil parent material is Santa Cruz mudstone. Slope ranges from 65-88 percent.

Site 5: Cabins

Site 5 is located below the confluence and near the Spafford Cabin on Little Creek Road. The dominant forest type is Redwood/Douglas fir. The soil parent material is sandstone/mudstone. Slope ranges from 47-65 percent. The fire burn severity is moderate. Following the fire, blackberry, ceanothus and hedge nettle grew vigorously are the current understory vegetation.

Site 6: Upper North Fork

Site 6 is located approximately 5 meters upslope from the Upper North Fork flume station. The dominant forest type is redwood/Douglas fir. The soil parent material is sandstone/mudstone. The slope ranges from 40-50 percent. The burn severity is low. Following the fire, ceanothus, redwood sorrel, and hedge nettle make up the current understory.

Site 7: South Fork

Site 7 is located near the landing at the bottom of the south fork road of Little Creek. The dominant vegetation type is Redwood with some tanoak and the soil parent material is mudstone. The slope of the site ranges from 45-54 percent. The burn severity is moderate.
Site 8: Boyer Burned

Site 8 is located on Lockheed Martin Property adjacent to the road on the Boyer/Mill creek ridgeline. The dominant vegetation type is knobcone/Manzanita. The soil parent material is mudstone. The average slope of the site is 47-60 percent. The burn severity is high.

Site 9: Mill Unburned

Site 9 is located near the road that follows the mill creek and Boyer Creek ridgeline. The dominant forest type is knobcone pine and manzanita. The soil parent material is granitic. The percent slope ranges from 55 to 65 percent. This site was not burned.

Site 10: Scotts/Mill Burned

Site 10 is located on the road that follows the Scott’s creek and mill creek ridgeline. The dominant forest type is knobcone pine and manzanita. The soil parent material is mudstone and the slope of the site ranges from 27 to 45 percent. This site has a high burn severity rating.

Site 11: Scotts/Mill Unburned

Site 11 is located across from site 10. The dominant vegetation type is knobcone pine and manzanita. The soil parent material is mudstone and the percent the slope of the site ranges from 17 to 40 percent. This site was not burned.

Site: Upper Boyer Unburned

Site 12 is located along the Boyer creek and Mill creek ridgeline. The dominant vegetation type is tanoak. The soil parent material is granitic and the slope of the site ranges from 38 to 46 percent. This site was not burned.

Site 13: Lions Flat

Site 13 is located along the Little Creek and Archibald creek ridgeline. The dominant vegetation type is redwood and tanoak and the soil parent material is mudstone. The percent slope of the site ranges from 60 to 65 percent. The burn severity of this site is high.

Site 14: Hillslope Erosion Study
Site 14 is located downslope of the south fork road adjacent to the rain gauge. The burn severity is moderate and the dominant vegetation type is redwood/tanoak. The soil parent material is mudstone and the slope of the site ranges from 70 to 72 percent.

**Site 15: Mill/Boyer Burned**

Site 15 is located along the Mill and Boyer creek ridgline. The burn severity is high and the dominant vegetation type is knobcone pine and Manzanita. The soil parent material is mudstone and the slope of the site ranges from 35-38 percent.
Appendix C. Description of Mini-disk Infiltrometer and Water Drop Penetration Time Test Sites

Site 1
Site 1 is located near the four wheel drive road of Little Creek. The site is just downslope of Little Creek road. The aspect is south east facing and the slope position is low. The soil burn severity is high as well as the overall burn severity.

Site 2
Site two is located in Little Creek upslope of the Spafford cabin. The aspect is south east facing and the slope position is low. The soil burn severity is high and the overall burn severity is moderate.

Site 3
Site 3 is located upslope of the Upper North Fork flume monitoring station in Little Creek. The burn severity is moderate and the site is on a north-west facing slope. The slope position is low.

Site 4
Site 4 is located near the hillslope erosion study site located on the southern ridgeline of little creek. The burn severity is high and the site is located on a north facing slope. The site is located on the upper slope of the hillside.

Site 5
Site 5 is located about 200 feet upslope of the south fork road in Little Creek above the landing. The burn severity is moderate and the site is on a west facing slope. The slope position is low.

Site 6
Site 6 is located a few hundred feet east of the yellow gate dividing San Vicente Redwoods and Swanton properties on Sea View Ridge Road. The burn severity is high and the aspect is north. The position of the site is upper slope.
Site 7
Site 7 is located on adjacent to a saddle on the top of Sea View Ridge road. The burn severity is high and the aspect is north. The slope position is upper slope.

Site 8
Site 8 is located just below the Ridgeline Smith rain gauge. The burn severity is high and the aspect is south east facing. The slope position is upper slope.

Site 9
Site 9 is located in between the General Smith Road and a skid trail near Upper Tributary 1. The burn severity is moderate and the aspect is south east facing. The slope position is low.

Site 10
Site 10 is located downslope of the Ridge Line south fork rain gauge. The burn severity is high and the aspect is south facing. The slope position is upper slope.

Site 11
Site 11 is located 100 feet south of the Ridge Line north fork rain gauge and 50 feet downslope of the road. The burn severity is moderate and the aspect is northwest facing. The slope position is upper slope.

Site 12
Site 12 is located on High Hill road between R7 and R8. The burn severity is high and the aspect is south facing. The slope position is upper slope.

Site 13
Site 13 is located upslope of landing 20, above the Timber Exclusion Zone. The burn severity is moderate on a south facing slope. The slope position is low.
Site 14

Site 14 is the only unburned site. It is located 300 feet down from the four wheel drive road. The site is located on a low slope position with a south facing aspect.

Site 15

Site 15 is located adjacent to High Hill ridge road. The burn severity is high and the aspect is south east facing. The slope position is upper slope.

Site 16

Site 16 is about 150 feet downslope of site 15. The burn severity is high/moderate with a south east facing aspect. The slope position is mid-slope.

Site 17

Site 17 is located near the ridgeline Smith rain gauge. The burn severity is high/moderate on a south-east facing aspect. The slope position is midslope.

Site 18

Site 18 is located on High Hill ridge. The burn severity is high and the aspect is south east facing. The slope position is upper slope.

Site 19

Site 19 is located just below site 18. The burn severity is moderate and the aspect is south-east facing. The slope position is low.

Site 20

Site 20 is located on the ridgeline between the north and south forks of Little Creek in a small drainage. The burn severity is high and the aspect is north west facing. The slope position is upper slope.
Site 21

Site 21 is located in the south fork of Little Creek. The burn severity is moderate/low and the aspect is north facing. The slope position is low.

Site 22

Site 22 is located upslope from site 21. The burn severity is high/moderate on a north facing slope. The slope position is upper slope.

Site 23

Site 23 is located adjacent to the hill slope erosion study site. The burn severity is high and the aspect is north facing. The slope position is upper slope.
Appendix D. Instructions for Conducting Rainfall Simulations

Permanent plots were not established during the set-up of this project in 2009 because plots were disrupted after the simulation so that infiltration and percolation paths (from macropores and burnt root paths) along with any soil water repellency could be observed with the hope of further explaining the role fire played on infiltration and runoff rates. Therefore, a new plot location was selected every year. New plots were located within the same general site and had the same aspect, soil type, vegetation type, and a similar in percent slope.

Once a plot location is chosen, the first step is to create the plot using the 3 sided sheet metal and trapezoidal trough making certain that the plot is sturdy and does not shift during the simulation. Simulations are often performed on steep slopes and if the sheet metal and trough are not inserted into the soil well, they can shift from gravity. The outlet tubing which is located at the outlet of the trough, should be stretched out the entire length and the five gallon bucket should be set up at the end of the tubing. A hole for the bucket to sit in is often needed so that the outlet tubing can remain at the natural slope ground. If the outlet tubing is flat, or not correctly sloped, runoff rates are more than likely to be inaccurate. Next, the simulator is placed over the plot with two legs adjacent to the trough and the third leg positioned behind the sheet metal at the top of the plot. Once the plot, five gallon bucket and simulator are setup, the calibration pan is then placed on top of the plot and secured using gorilla tape and stakes to keep it from sliding downhill. The calibration pan should cover the entire plot to ensure that the plot will not get wet during the calibration period. The position of the rainfall simulator over the plot should be adjusted so that there is uniform rainfall over the entire plot. Once there is uniform rainfall over the plot, the rainfall rate is calibrated by collecting the runoff in a 500 mL plastic cylinder over a thirty second period. The volume collected over thirty seconds is considered the calibration
runoff rate. From there the rainfall rate can be calculated. Once the simulator is calibrated to about 2.0 inches per hour, the calibration pan is removed and the simulation can begin.

Simulations should run at least an hour with measurements being taken every two minutes. Runoff measurements are recorded in a field notebook along with other essential notes such as time runoff started, time runoff ended, breeze, bucket emptied or any malfunctions that may have occurred such as the pump running out of gas or rock in the simulator nozzle. In some instances, the five gallon bucket may fill up prior to the end of the simulation therefore it is emptied and set back in place between the 2 minute measurements. The outlet tubing can be held upright allowing runoff to accumulate which can then be poured into the bucket once the bucket is set back into place.

Equipment used for rainfall simulations:

(2) 50 gal Barrels  (7) wooden stakes  (1) calibration pan
(1) 50 gal open barrel (1) single jack  (1) outflow tubing
(1) 50' hose  (1) generator  (1) bucket
(1) Simulator  (1) water pump  (1) shovel
(1) rectagle Plywood  (1) gallon gas  (1) pick mattock
(1) Trough  (1) loppers  (1) recirculation hose
(1) Plot Boundary  (1) hand saw  (3) legs
(7) rebar stakes  (1) roll of plastic  (1) chainsaw

Equipment for rainfall simulation in the dry box:

(1) extension cord  (1) pencil
(1) yellow cable  (1) infiltration rate sheet
(1) control box  (1) gorilla tape
(1) depth ruler  (1) masking tape
(1) field book  (1) 3 meter tent pole
Appendix E. Instructions for Conducting MDI and WDPT Tests

Permanent transects were not established during the set-up of this project in 2009. Locations within a transect were disturbed in order to conduct the tests requiring a new location for each site to be established each year. A new transect was established each time with the same aspect, soil type, vegetation type and as close to the same percent slope. After establishing the 100 foot transect, the tests were conducted every 6.5 meters (20 feet) along the transect at 1 and 3 centimeters for the MDI, and 1, 2, and 3 cm for the WDPT.

A trowel is used to cut to the soil depth being tested at each location along the transect. Many MDI and WDPT sites are located on steep slopes, therefore relatively flat benches were dug as close as possible to the depth being tested. Sloped surfaces can alter infiltration volumes and can cause water drops to roll downhill. Thus, conducting both tests on a flat surface helped to improve accuracy for the data being collected.

When conducting the MDI test, both chambers of the infiltrometer should be filled with water. The suction control tube in the upper chamber is set to 1 cm. The volume of water in the lower chamber is recorded as the start volume. The infiltrometer is then placed flat against and held perpendicular to the soil surface. Once the soil and infiltrometer come into contact, wait 1 minute before lifting/removing the infiltrometer. Record the end volume amount. This is repeated two more times for a total of three times every 6.5 meters within a transect. Water should be added to the lower chamber as necessary throughout testing.

For water drop tests, a squeeze water bottle filled with water is gently squeezed such that individual droplets are dispensed onto the soil surface. The squeeze bottle nozzle was placed as close to the soil surface in order to minimize the impact of the drop on infiltration times. Time was recorded from the moment the water droplet made contact with the soil surface to the time
the drop had completely infiltrated. Times were recorded up to 400 seconds. After 400 seconds, the drops were considered to have no penetration.

Equipment used for the MDI and WDPT tests:

<table>
<thead>
<tr>
<th>(2) MDI</th>
<th>(1) roll flagging</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2) liters of water</td>
<td>(1) sharpie</td>
</tr>
<tr>
<td>(2) laboratory wash bottle</td>
<td>(2) garden shovel</td>
</tr>
<tr>
<td>(1) 100 foot tape</td>
<td>(2) water droppers</td>
</tr>
</tbody>
</table>
Appendix F. Rainfall Simulator Preliminary Data and Graphs

2009

Site 4

Date and time: 10/28/2009 @ 14:45
Slope %: 70
Location: Approximately 600' downstream of 4WD road along Little Creek Road. 30' downslope from road edge below RW clump. Approximately 70' from Little Creek. Unburned.


Soils: 4” thick duff layer. Soil mudstone based and has many gravel to small cobble sized rocks. Many roots.

Calibration:

<table>
<thead>
<tr>
<th>Time on</th>
<th>Time off</th>
<th>Volume 1 (mL/30s)</th>
<th>Volume 2 (mL/30s)</th>
<th>Volume 3 (mL/30s)</th>
<th>Volume 4 (mL/30s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>310</td>
<td>308</td>
<td>315</td>
<td>488</td>
</tr>
<tr>
<td>0.9</td>
<td>0.1</td>
<td>470</td>
<td>467</td>
<td>485</td>
<td>488</td>
</tr>
</tbody>
</table>

Slope corrected rainfall: 1.79 in/hr 2.75 in/hr rate: 0.62 L/min 0.96 L/min

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-0.23</td>
<td>0.00</td>
<td>0.03</td>
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</tr>
<tr>
<td>8</td>
<td>-0.07</td>
<td>7.64</td>
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<td>10</td>
<td>0.08</td>
<td>9.55</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.24</td>
<td>11.46</td>
<td>0.68</td>
<td>leveled bucket</td>
</tr>
<tr>
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<td>0.48</td>
<td>13.37</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
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<td>15.28</td>
<td>1.17</td>
<td>62mL/30s</td>
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<tr>
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<td>0.75</td>
<td>17.19</td>
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<td></td>
</tr>
<tr>
<td>20</td>
<td>0.99</td>
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</tr>
<tr>
<td>23</td>
<td>1.27</td>
<td>21.97</td>
<td>2.11</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1.54</td>
<td>23.88</td>
<td>2.49</td>
<td></td>
</tr>
<tr>
<td>26</td>
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<td>24.83</td>
<td>65mL/30s</td>
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</tr>
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<td>27.70</td>
<td></td>
<td></td>
<td>Stop Rain</td>
</tr>
<tr>
<td>36</td>
<td>1.94</td>
<td>3.05</td>
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<td></td>
</tr>
</tbody>
</table>
**Results:** 26 minutes @ 2.75 in/hr: runoff after 6 minutes of rain; most runoff from duff layer, minimal evidence of runoff in soil; soil moist in middle of plot after simulator indicating good infiltration.
**Site 5**

*Date and time:* 10/29/2009 @11:55  
*Slope %:* 61  
*Location:* 400' up road from crossing R8 on Little Creek Road. 20' upslope from edge of road cut. Near intersection of trail/old road and haul road.  
*Vegetation:* Douglas-fir, bay, oak; south aspect; low to medium burn intensity.  
*Soils:* Sandstone parent material with some mudstone colluvium. 50% coverage by DF/bay/oak leaf litter. 10% rock fragments at surface. Common soil pedestels.

### Calibration:

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<tr>
<th></th>
<th>Time on</th>
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</thead>
<tbody>
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<td>Volume 2</td>
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<td>0.9</td>
</tr>
<tr>
<td>Volume 3</td>
<td>0.4</td>
<td>0.9</td>
</tr>
</tbody>
</table>

*Volume 1 365 mL/30s 118 mL/30s*  
*Volume 2 370 mL/30s 120 mL/30s*  
*Volume 3 370 mL/30s 115 mL/30s*

**Slope corrected rainfall rate:**  
- **2.04 in/hr**  
  - 0.74 L/min  
- **0.65 in/hr**  
  - 0.24 L/min

### Table: Slope corrected rainfall rate:

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<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
<th>&quot;2.04 in/hr&quot;</th>
<th>&quot;0.65 in/hr&quot;</th>
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</thead>
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<td>0.35</td>
<td>rain 2.04 in/hr</td>
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<tr>
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</tr>
<tr>
<td>6</td>
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<td>0.35</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
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<td>10.31</td>
<td>0.35</td>
<td>start runoff - runoff only from top 1&quot; of soil, below 1&quot; dry.</td>
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<td></td>
</tr>
<tr>
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<td>17.68</td>
<td>3.00</td>
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</tr>
<tr>
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<td>4.28</td>
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<td></td>
</tr>
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<td>30</td>
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<td>rain 0.65 in/hr</td>
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<td>33.23</td>
<td>11.37</td>
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<td></td>
</tr>
</tbody>
</table>
Total Rain: 33.23 L 1.53 in  
Total Runoff: 11.37 L 0.52 in  
Runoff Ratio: 0.3423

Rainfall Rate: 0.737 L/min 2.04 in/hr  
Runoff Rate: 0.374 L/min 1.03 in/hr  
Infiltration Rate: 0.363 L/min 1.00 in/hr

Rainfall Rate: 0.24 L/min 0.65 in/hr  
Runoff Rate: 0.13 L/min 0.35 in/hr  
Infiltration Rate: 0.11 L/min 0.30 in/hr

Results: Top layer saturated (1" depth) and majority of runoff coming from 1st inch of soil, with little to no surface flow. Below 1" soil was dry.
Site 6

Date and time: 10/30/2009 @ 12:05
Slope %: 50
Area m$^2$: 0.894
Location: Near UNF bridge directly uphill from top of trail to flume
Vegetation: Redwood/tanoak. Low burn intensity
Soils: decomposed granite. High clay content. Initially moist no dry layer.

Calibration:

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<th>Time on</th>
<th>Time off</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>0.2</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Volume 1 616 mL/30s 435 mL/30s
Volume 2 570 mL/30s 438 mL/30s
Volume 3 590 mL/30s 442 mL/30s

Slope corrected rainfall rate: 3.13 in/hr 2.32 in/hr
1.18 L/min 0.88 L/min

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
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<td>Start</td>
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<tr>
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</tr>
<tr>
<td>54</td>
<td>11.6</td>
<td>47.34</td>
<td>17.63</td>
<td>Off</td>
</tr>
</tbody>
</table>
Total Rain: 47.34 L  2.08 in
Total Runoff: 17.63 L  0.78 in
Runoff Ratio: 0.3724

Rainfall Rate: 0.877 L/min  2.32 in/hr
Runoff Rate: 0.373 L/min  0.98 in/hr
Infiltration Rate: 0.504 L/min  1.33 in/hr

**Results:** Collector plate 1.5 to 2" deep at downhill end of plot. Observed runoff after 6 mins of rainfall. Some surface flow was evident. Fairly consistent runoff rate.
Site 7

**Date and time:** 11/2/2009 @ 13:04

**Slope %:** 54

**Area m²:** 0.88

**Location:** South fork Little Creek approximately 150 feet uphill from first landing in the redwoods.

**Vegetation:** Redwood, Tan oak, Douglas-fir. Moderate burn intensity; scorch heights 3-10 ft. locally with 30 ft. plus within 50 ft.

**Soils:** Mudstone colluvium parent material.

**Calibration:**

<table>
<thead>
<tr>
<th>Time on (min)</th>
<th>Time off (min)</th>
<th>Volume 1 mL/30s</th>
<th>Volume 2 mL/30s</th>
<th>Volume 3 mL/30s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
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<td>397</td>
<td>388</td>
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</tr>
<tr>
<td>0.9</td>
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<td>670</td>
<td>660</td>
<td>660</td>
</tr>
</tbody>
</table>

**Slope Corrected Rainfall Rate:**

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.56 in/hr</td>
<td>0.79 L/min</td>
<td>1.33 L/min</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.00</td>
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<tr>
<td>9</td>
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</tr>
<tr>
<td>12</td>
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<td>1.18</td>
<td></td>
</tr>
<tr>
<td>14</td>
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<td></td>
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<tr>
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<td>12.69</td>
<td>1.87</td>
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</tr>
<tr>
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<td>14.28</td>
<td>2.22</td>
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</tr>
<tr>
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<td>1.5</td>
<td>15.87</td>
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<td>2.72</td>
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<td>3.00</td>
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<tr>
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<td>2.05</td>
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<td>40.46</td>
<td>5.43</td>
<td>Start 3.56 in/hr</td>
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<td>45.10</td>
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<td>47.09</td>
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<td>8.51</td>
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</tr>
</tbody>
</table>

**Total Rain:** 61.69 L 2.76 in  
**Total Runoff:** 8.51 L 0.38 in  
**Runoff Ratio:** 0.1380  

**Rainfall Rate:** 0.793 L/min 2.13 in/hr  
**Runoff Rate:** 0.081 L/min 0.22 in/hr  
**Infiltration Rate:** 0.713 L/min 1.91 in/hr  

**Results:** Had constant runoff rate after 10 min. No evidence of surface runoff. Site appeared to have good infiltration capacity, although after rainfall about 5% of plot had dry soil, possibly indicating hydrophobicity.
Site 8

**Date and time:** 11/04/2009 @ 12:30  
**Slope %:** 60  
**Area m²:** 0.857  
**Location:** Mill Creek/Boyer Creek ridgeline on south facing slope of Boyer Creek (Lockheed property). Very high burn intensity.  
**Vegetation:** Manzanita, Knobcone pine, scrub oak, (chaparral)  
**Soils:** Shallow mudstone. 95% of surface rock fragments.

### Calibration:

<table>
<thead>
<tr>
<th>Time on</th>
<th>Time off</th>
<th>Volume 1</th>
<th>Volume 2</th>
<th>Volume 3</th>
<th>Volume 4</th>
<th>Volume 5</th>
<th>Volume 6</th>
</tr>
</thead>
<tbody>
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<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
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<td>0.6</td>
<td>0.4</td>
<td>0.6</td>
<td>0.4</td>
<td>0.6</td>
<td>0.4</td>
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</tbody>
</table>

### Slope corrected rainfall rate:

2.43 in/hr | 1.75 in/hr  
0.88 L/min | 0.64 L/min

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
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</thead>
<tbody>
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<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
<td>5.2</td>
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<td>0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
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<td>0.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>6.19</td>
<td>1.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>7.07</td>
<td>2.29</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>7.95</td>
<td>3.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>8.84</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>10.60</td>
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<td>16.5</td>
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</tr>
<tr>
<td>18</td>
<td>15.90</td>
<td>9.56</td>
<td></td>
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<tr>
<td>20</td>
<td>17.67</td>
<td>10.99</td>
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</tr>
<tr>
<td>22</td>
<td>19.44</td>
<td>12.45</td>
<td></td>
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</tr>
<tr>
<td>24</td>
<td>21.21</td>
<td>13.99</td>
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</tr>
<tr>
<td>26</td>
<td>22.97</td>
<td>15.48</td>
<td>395 mL/30s @ 27</td>
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</tr>
<tr>
<td>28</td>
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</tr>
<tr>
<td>29.5</td>
<td>26.07</td>
<td>18.27</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Total Rain: 26.07 L 1.20 in
Total Runoff: 18.27 L 0.84 in
Runoff Ratio: 0.7009

Rainfall Rate: 0.884 L/min 2.43 in/hr
Runoff Rate: 0.769 L/min 2.12 in/hr
Infiltration Rate: 0.115 L/min 0.32 in/hr

Results: Strong evidence of hydrophobicity. Very high runoff rate with little to no infiltration in half inch plus depth of soil. Top half inch of soil removed after rainfall exposing nothing but dry soil.
Site 9

Date and time: 11/4/2009 @ 15:38
Slope %: 55
Area m²: 0.876
Location: Lockheed ridge on top of Mill Creek and Boyer Creek watersheds on Boyer Creek side. Unburned control site. Near rectangular fenced area.
Vegetation: Manzanita, Knobcone pine, Doug-fir, oak, (chaparral).
Soils: Mudstone/sandstone, possibly at contact of two parent materials. Sandy loam soil.

Calibration:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Time on</td>
<td>0.8</td>
</tr>
<tr>
<td>Time off</td>
<td>0.2</td>
</tr>
<tr>
<td>Volume 1</td>
<td>440 mL/30s</td>
</tr>
<tr>
<td>Volume 2</td>
<td>470 mL/30s</td>
</tr>
<tr>
<td>Volume 3</td>
<td>460 mL/30s</td>
</tr>
<tr>
<td>Volume 4</td>
<td>445 mL/30s</td>
</tr>
<tr>
<td>Volume 5</td>
<td>425 mL/30s</td>
</tr>
<tr>
<td>Volume 6</td>
<td>448 mL/30s</td>
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</table>

Slope corrected rainfall rate: 2.42 in/hr
0.90 L/min

<table>
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<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
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</thead>
<tbody>
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<td>0.00</td>
<td>0.35</td>
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</tr>
<tr>
<td>4</td>
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<td>3.58</td>
<td>0.35</td>
<td>runoff starts</td>
</tr>
<tr>
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<td>0</td>
<td>6.27</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.2</td>
<td>8.06</td>
<td>0.62</td>
<td></td>
</tr>
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<td>0.35</td>
<td>8.96</td>
<td>0.83</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.5</td>
<td>10.75</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.7</td>
<td>12.54</td>
<td>1.32</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.9</td>
<td>14.34</td>
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<td></td>
</tr>
<tr>
<td>18</td>
<td>1</td>
<td>16.13</td>
<td>1.73</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>1.2</td>
<td>17.92</td>
<td>2.01</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>1.35</td>
<td>19.71</td>
<td>2.22</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1.55</td>
<td>22.40</td>
<td>2.51</td>
<td></td>
</tr>
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<td>27</td>
<td>1.7</td>
<td>24.19</td>
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<td>25.09</td>
<td>2.86</td>
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<td>32</td>
<td>2.2</td>
<td>28.67</td>
<td>3.42</td>
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</tr>
<tr>
<td>36</td>
<td>2.4</td>
<td>32.26</td>
<td>3.71</td>
<td></td>
</tr>
</tbody>
</table>
Total Rain: 32.26 L 1.45 in  
Total Runoff: 3.71 L 0.17 in  
Runoff Ratio: 0.1150

Rainfall Rate: 0.896 L/min 2.42 in/hr  
Runoff Rate: 0.112 L/min 0.30 in/hr  
Infiltration Rate: 0.784 L/min 2.11 in/hr

**Results:** Low runoff rate indicating higher infiltration through soil. After rainfall simulation top inch of soil removed and 50% dry soil observed showing natural hydrophobicity although rainfall in finding avenues of infiltration.
Site 10

**Date and time:** 11/18/2009 @12:10

**Slope %:** 40

**Area m²:** 0.928

**Location:** Mill Creek and Upper Scotts ridge on Mill Creek side. Lockheed or State Parks property. High burn intensity.

**Vegetation:** Chaparral: Knobcone pine, manzanita, scrub oak.

**Soils:** Shallow mudstone.

### Calibration:

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<th>0.6</th>
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<th>0.7</th>
</tr>
</thead>
<tbody>
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<td>Time off</td>
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<td>0.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>460 mL/30s</th>
</tr>
</thead>
<tbody>
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<td>415 mL/30s</td>
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<tr>
<td>Volume 3</td>
<td>322 mL/30s</td>
<td>490 mL/30s</td>
<td>455 mL/30s</td>
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<td>Volume 4</td>
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<td>450 mL/30s</td>
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</tr>
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<td>Volume 5</td>
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<td>462 mL/30s</td>
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</tr>
<tr>
<td>Volume 6</td>
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<td>465 mL/30s</td>
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</table>

### Slope corrected rainfall rate:

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<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>0.35</td>
<td>Start</td>
</tr>
<tr>
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<td>1.80</td>
<td>0.35</td>
<td>drip every 2 sec</td>
</tr>
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</tr>
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<td>5.41</td>
<td>0.76</td>
<td>steady stream</td>
</tr>
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<td>1.2</td>
<td>7.22</td>
<td>2.01</td>
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<td>2.1</td>
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<td>3.88</td>
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<td>16</td>
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<td>7.40</td>
<td>runoff 0.74L/m</td>
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<td>28.87</td>
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<td>13.7</td>
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<td>38</td>
<td>15.8</td>
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<td>24.53</td>
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</tr>
</tbody>
</table>
Total Rain: 43.31 L 1.84 in
Total Runoff: 35.34 L 1.50 in
Runoff Ratio: **0.8160**

Rainfall Rate: 0.902 L/min 2.30 in/hr
Runoff Rate: 0.922 L/min 2.34 in/hr
Infiltration Rate: -0.019 L/min -0.05 in/hr

**Results:** Windy: 10-20 mph from NW; Sunny. High runoff rate. No evidence of rills but majority of rainfall runoff from top half inch of soil. After rainfall simulation, top half inch of soil removed and 95% of surface was dry and had strong evidence of hydrophobicity.
Site 11

Date and time: 11/19/2009 @ 11:45
Slope %: 30
Area m²: 0.958
Location: Mill Creek and Upper Scotts Creek ridge on Scotts side. Lockheed property? Control site - unburned.
Vegetation: Chaparral: knobcone pine, manzanita, oak.
Soils: Mudstone, silty clay loam. Initially slightly moist.

Calibration:

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Volume 1 438 mL/30s
Volume 2 451 mL/30s
Volume 3 450 mL/30s
Volume 4 450 mL/30s

Slope corrected rainfall rate: 2.22 in/hr
0.90 L/min

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Total Rain: 59.44 L 2.44 in
Total Runoff: 49.23 L 2.02 in
Runoff Ratio: 0.8281

Rainfall Rate: 0.901 L/min 2.22 in/hr
Runoff Rate: 0.825 L/min 2.03 in/hr
Infiltration Rate: 0.076 L/min 0.19 in/hr
**Results:** High runoff rate although rainfall is still infiltrating slowly. Top inch of soil removed after rainfall simulation and 50% of surface dry. Rainfall rate exceeds infiltration rate. Natural hydrophobicity observed.
Site 4

**Date:** 09/08/2010

**Slope %:** 88

**Area m²:** 0.751

**Location:** Approximately 600' downstream of 4WD road along Little Creek Road. 30' downslope from road edge below RW clump. Approximately 70' from Little Creek. Unburned

**Vegetation:** Riparian/Redwood. Redwood, alder, bay, Douglas-fir overstory. Fern, sorrel, poison oak understory.

**Soils:** 4" thick duff layer. Soil mudstone based and has many gravel to small cobble sized rocks. Many roots.

**Calibration:**

| Volume 1 | 350 mL/30s |
| Volume 2 | 357 mL/30s |
| Volume 3 | 360 mL/30s |

**Slope corrected rainfall rate:**

2.24 in/hr

0.71 L/min

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Total Rain: 28.45 L 1.49 in
Total Runoff: 4.58 L 0.24 in
Runoff Ratio: 0.1609

Rainfall Rate: 0.711 L/min 2.24 in/hr
Runoff Rate: 0.121 L/min 0.38 in/hr
Infiltration Rate: 0.590 L/min 1.86 in/hr

Results: No results recorded in field notes.
Site 5

Date and time: 9/15/2010
Slope %: 65
Area m²: 0.838
Location: 450’ up road from crossing R8 on Little Creek Road. 20’ upslope from edge of road cut. Near intersection of trail/old road and haul road. (move from previous location to avoid slash
Vegetation: Douglas-fir, bay, oak; south aspect; low to medium burn intensity.
Soils: Sandstone parent material with some mudstone colluvium. 50% coverage by DF/bay/oak
leaf litter. 10% rock fragments at surface. Common soil pedestals.

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| Volume 1     | 350 mL/30s | 485 mL/30s |
| Volume 2     | 330 mL/30s | 480 mL/30s |
| Volume 3     | 325 mL/30s | 465 mL/30s |

Slope corrected rainfall rate:
1.58 in/hr 2.25 in/hr
0.56 L/min 0.80 L/min

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Total Rain: 32.58 L 1.53 in  
Total Runoff: 8.46 L 0.40 in  
Runoff Ratio: 0.2597  
Rainfall Rate: 0.562 L/min 1.58 in/hr  
Runoff Rate: 0.295 L/min 0.70 in/hr  
Infiltration Rate: 0.266 L/min 0.88 in/hr  
Rainfall Rate: 0.80 L/min 2.25 in/hr  
Runoff Rate: 0.47 L/min 1.10 in/hr  
Infiltration Rate: 0.33 L/min 1.15 in/hr

**Results:** Top layer saturated (1" depth) and majority of runoff coming from 1st inch of soil, with little to no surface flow. Below 1" soil was dry.
Site 6

**Date and time:** 2/9/2010 @ 11:18  
**Slope %:** 47  
**Area m²:** 0.905  
**Location:** Near UNF bridge directly above flume on southern side of bank. (moved from previous spot to different aspect because all other soil was disturbed)  
**Vegetation:** Tan oak dominated. Redwood and Doug Fir nearby.  
**Soils:** Granitic soils, horizon on top 1 inch 12% clay. 6 inches down clay increases to around 24%. Clay is different than above.

**Calibration:**

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Volume 1 368 mL/30s

**Slope corrected rainfall rate:** 1.92 in/hr  
0.74 L/min

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turned off, reduced to small dripping

Total Rain: 47.10 L  2.05 in
Total Runoff: 9.36 L  0.41 in
Runoff Ratio: 0.1987

Rainfall Rate: 0.736 L/min  1.92 in/hr
Runoff Rate: 0.170 L/min  0.44 in/hr
Infiltration Rate: 0.566 L/min  1.48 in/hr

Results: No results recorded in field book.
Site 7

Date and time: 10/09/2010 @ 16:00
Slope %: 48
Area m²: 0.902
Location: South Fork Little Creek approximately 150 ft. uphill from first landing in the redwoods. Site was altered by slash thrown onto soil.
Vegetation: Redwood, Tan oak, Douglas-fir. Moderate burn intensity; scorch heights 3-10 ft. locally with 30 ft. plus within 50 ft.
Soils: Mudstone colluvium parent material. Duff layer high in pine needles 8% clay at surface. 6 inches down 19% clay.

Calibration:

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Slope corrected rainfall rate: 2.37 in/hr 2.89 in/hr
0.91 L/min 1.10 L/min

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41:30 stopped and switched to 9 on 1 off

Total Rain: 47.06 L 2.06 in
Total Runoff: 7.35 L 0.32 in
Runoff Ratio: 0.1562

Rainfall Rate: 0.905 L/min 2.37 in/hr
Runoff Rate: 0.136 L/min 0.36 in/hr
Infiltration Rate: 0.769 L/min 2.01 in/hr

Rainfall Rate: 1.10 L/min 2.89 in/hr
Runoff Rate: 0.22 L/min 0.59 in/hr
Infiltration Rate: 0.88 L/min 2.30 in/hr

Results: Water mainly stays in the top 3cm of soil, however water did infiltrate deeper in many spots. Extremely slow runoff signifies likely not impacted by fire.
Site 8

Date and time: 09/10/2010 @ 10:30  
Slope %: 47  
Area m²: 0.905  
Location: Lockheed above Boyer Creek.  
Vegetation: Knobcone pine and manzanita.  
Soils: Very rocky and soils are mudstone derived. Soil profile is A/Cr-very shallow soils.

Calibration:

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Slope corrected rainfall rate: 2.15 in/hr 2.64 in/hr  
0.82 L/min 1.01 L/min

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Total Rain: 32.93 L 1.43 in
Total Runoff: 13.33 L 0.58 in
Runoff Ratio: 0.4049

Rainfall Rate: 0.823 L/min 2.15 in/hr
Runoff Rate: 0.405 L/min 1.06 in/hr
Infiltration Rate: 0.419 L/min 1.09 in/hr

Results: After both trials only the top 1.0 cm of soil was wet. No evidence was found of water escaping through macropores.
Site 9

Date and time: 10/09/2010
Slope %: 60
Area m²: 0.857
Location: Lockheed ridge on top of Mill Creek and Boyer Creek watersheds on Boyer Creek side. Unburned control site. Near rectangular fenced area.
Vegetation: Manzanita, Knobcone pine, Doug-fir, oak, (chaparral)
Soils: mudstone/sandstone, possibly at contact of two parent materials. Sandy loam soil.

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Slope corrected rainfall rate: 2.47 in/hr 0.90 L/min

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**Total Rain:** 44.80 L  2.06 in  
**Total Runoff:** 3.95 L  0.18 in  
**Runoff Ratio:** 0.0881  

**Rainfall Rate:** 0.896 L/min  2.47 in/hr  
**Runoff Rate:** 0.082 L/min  0.23 in/hr  
**Infiltration Rate:** 0.814 L/min  2.24 in/hr

**Results:** The water stayed almost entirely in the top centimeter of soil. The material was very organic with a high occurrence of rootballs and mycorrhizal visible to naked eye. The oil becomes highly rocky at a depth of 4 in. All moisture found remained in duff layer. Some saturated spots got to about 3 in of moisture depth.
Site 10

Date and time: 9/13/2010 @ 14:01
Slope %: 45
Area m²: 0.912
Location: Mill Creek and Upper Scotts ridge on Mill Creek side. Lockheed or State Parks property. High burn intensity
Vegetation: Chaparral: Knobcone pine, manzanita, scrub oak.
Soils: shallow, mudstone, very little leaf litter, majority of surface is rock fragment.

Calibration:

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Slope corrected rainfall rate: 1.96 in/hr 3.32 in/hr

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Total Rain: 51.47 L  2.22 in  
Total Runoff: 14.27 L  0.62 in  
Runoff Ratio: 0.2773

Rainfall Rate: 0.760 L/min  1.96 in/hr  
Runoff Rate: 0.349 L/min  0.82 in/hr
Infiltration Rate: 0.411 L/min  1.14 in/hr

Results: Top inch of soil very wet. No signs of surface erosion (rills, pedestals, etc.). Some evidence of deeper wetting from macropores but no more than 2 in depth. Most runoff from surface and top inch. Some leakage at attachment board.
Site 11

Date and time: 9/13/2010 @ 10:45
Slope %: 40
Area m²: 0.928
Location: Mill Creek and Upper Scotts Creek ridge on Scotts side. Lockheed property. Control site - unburned.
Vegetation: Chaparral: knobcone pine, manzanita, oak.
Soils: Mudstone, silty clay loam. Initially slightly moist.

Calibration:

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Slope corrected rainfall rate:

- 2.14 in/hr: 0.84 L/min
- 2.95 in/hr: 1.16 L/min

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<th>Runoff Volume (L)</th>
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Total Rain: 85.84 L 3.64 in
Total Runoff: 15.93 L 0.68 in
Runoff Ratio: 0.1855
Rainfall Rate: 0.840 L/min 2.95 in/hr
Runoff Rate: 0.451 L/min 1.15 in/hr
Infiltration Rate: 0.389 L/min 1.80 in/hr

\[ y = 0.4514x - 3.2069 \]
\[ R^2 = 0.9994 \]
Results: Top inch of soil wet, below 1 in very dry. Large rock fragments in soil, platey, some areas most under 1in but no more than 2in in depth. Lots of surface runoff observed, but not rills or pedestals.
Site 12

**Date and time:** 09/14/2010  
**Slope %:** 38  
**Area m²:** 0.935  
**Location:** Upper Boyer Creek, unburned  
**Vegetation:** Tan Oak and madrone dominated leaf litter, redwood also nearby.  
**Soils:** Granitic parent material 8% caly high silt content. 3cm duff layer, variable sub-angular blocky and massive.

**Calibration:**

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**Slope corrected rainfall rate:** 2.17 in/hr  
**rate:** 0.86 L/min

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Results: Water infiltrated in most places to about 6in of depth. Runoff extremely slow.
Site 13

**Date and time:** 9/15/2010  
**Slope %:** 65  
**Area m²:** 0.838  
**Location:** South fork ridge on Lions Flat Road. 100 feet from property line.  
**Vegetation:** Tan oak, Doug Fir, Scrub Oak  
**Soils:** Mudstone parent material 8% clay high silt content. Very ashy in this area. Soil was likely burnt at very hot temp. Very rocky mudstone colluvium mixed in with duff layer.

**Calibration:**

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**Slope corrected rainfall rate:** 2.05 in/hr  

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Total Rain: 33.43 L 1.57 in
Total Runoff: 7.29 L 0.34 in
Runoff Ratio: 0.2181

Rainfall Rate: 0.727 L/min 2.05 in/hr
Runoff Rate: 0.194 L/min 0.55 in/hr
Infiltration Rate: 0.533 L/min 1.50 in/hr

Results: Water stayed mainly in the top 1.5cm of soil. The top layer was very high in organic matter and contained a lot of pine needles. The soil is very ashy beneath the top two centimeters. In some places this ash absorbed a large amount of water. Other places remained dry.
Site 14

Date: 9/8/2010  
Slope %: 72  
Area m²: 0.812  
Location: Hillslope erosion site.  
Vegetation: Redwood, Douglas fir, bay laurel.  
Soils: Mudstone derived soils.

Calibration:

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Volume 1 410 mL/30s  
Volume 2 350 mL/30s  
Volume 3 390 mL/30s  
Volume 4 360 mL/30s  
Volume 5 335 mL/30s

Slope corrected rainfall rate: 2.13 in/hr  
0.73 L/min

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Total Rain: 36.67 L  1.78 in
Total Runoff: 3.20 L  0.16 in
Runoff Ratio: 0.0874

Rainfall Rate: 0.733 L/min  2.13 in/hr
Runoff Rate: 0.080 L/min  0.23 in/hr
Infiltration Rate: 0.654 L/min  1.90 in/hr

Results: No results documented in the field notebook.
Site 15

Date: 9/14/2010
Slope %: 38
Area m$^2$: 0.935
Location: Mill/Boyer Creek Ridgeline. Very high burn severity site.
Vegetation: Knobcone pine, manzanita on ground along w/ deerweed
Soils: Mudstone derived soils.

Calibration:

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Volume 1 405 mL/30s
Volume 2 445 mL/30s
Volume 3 430 mL/30s
Volume 4 450 mL/30s
Volume 5 410 mL/30s

Slope corrected rainfall rate:
2.16 in/hr = 0.86 L/min

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Total Rain: 44.51 L  1.87 in
Total Runoff: 11.48 L  0.48 in
Runoff Ratio: **0.2580**

Rainfall Rate: 0.856 L/min  2.16 in/hr
Runoff Rate: 0.310 L/min  0.78 in/hr
Infiltration Rate: 0.546 L/min  **1.38 in/hr**

**Results:** Very rocky mudstone dominated soil. The water mainly stayed within the top 1cm of soil, however there were macropores wetting approximately 10% of the plot to about 5cm of depth.
2011

Site 2

Date and time: 07/13/2011 @ 13:52
Slope %: 60
Area m²: 0.857
Location: Upper Swanton Road, non-burned area. Semi-clear and windy weather. East/Southeast aspect.
Vegetation: Redwood understory, no vegetation on plot, 2-3 inches of duff.
Soils: Soils not described in the field book.

Calibration:

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Slope corrected rainfall rate: 2.04 in/hr

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Stopped simulation

Total Rain: 54.834 2.518
Total Runoff: 0.857 0.039
Runoff Ratio: 0.016

Rainfall Rate: 0.741 2.041
Runoff Rate: 0.012 0.034
Infiltration Rate: 0.729 2.007
Results: Not much runoff due to the duff. Slow, steady drip throughout most of the simulation. 1 mL of runoff occurred after the simulation.
Site 4

*Date and time:* 07/06/2011 @ 15:21  
*Slope %:* 65  
*Area m²:* 0.838  
*Location:* L.C. Control. Weather is sunny and there is a slight breeze present. Southeast aspect.  
*Vegetation:* No vegetation was recorded in the field book.  
*Soils:* Soil characteristics not recorded in the field book.

**Calibration:**

| Time on | Time off | Volume 1 455 mL/30s |

**Slope corrected rainfall rate:**  
*2.56 in/hr*  
*0.91 L/min*

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<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
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Total Rain: 40.04 L  1.88 in  
Total Runoff: 0.83 L  0.04 in  
Runoff Ratio: **0.0207**

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<th>Runoff Rate:</th>
<th>Infiltration Rate:</th>
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<tr>
<td></td>
<td>0.910 L/min</td>
<td>0.890 L/min</td>
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<td></td>
<td>2.56 in/hr</td>
<td>2.51 in/hr</td>
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<tr>
<td></td>
<td>0.020 L/min</td>
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</tr>
<tr>
<td></td>
<td>0.06 in/hr</td>
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Results: Some technical difficulties arose between 0-6 minutes. Forgot to cover the back with plastic.
Site 5

**Date and time:** 07/06/2011 @ 11:45

**Slope %:** 47

**Area m²:** 0.905

**Location:** Cabins, there was a yellow jackets nest so moved 50 yards up the road. Sunny and slight breeze present.

**Vegetation:** No vegetation recorded in field book.

**Soils:** No soil characteristics recorded in field book.

**Calibration:**

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</tr>
</thead>
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<th>mL/30s</th>
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<td>Volume 3</td>
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<td>Volume 6</td>
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**Slope corrected rainfall rate:** 1.98 in/hr

0.76 L/min

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<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
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<td>6.07</td>
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<td>Drips slowed down</td>
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<td>Drips about every 1 Minute</td>
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</tr>
<tr>
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<td>30.33</td>
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</table>
Jack removed 0.3475 const from col G from here down

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Rainfall (L)</th>
<th>Runoff (L)</th>
<th>Rainfall Rate (L/min)</th>
<th>Runoff Rate (L/min)</th>
<th>Infiltration Rate (L/min)</th>
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<td>0.00</td>
</tr>
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<td>0.00</td>
</tr>
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<td>48.53</td>
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Steady dripping begins

<table>
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<tr>
<th>Time (min)</th>
<th>Rainfall (L)</th>
<th>Runoff (L)</th>
<th>Rainfall Rate (L/min)</th>
<th>Runoff Rate (L/min)</th>
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<tr>
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<td>64</td>
<td>0.10</td>
<td>48.53</td>
<td>0.14</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Dripping stopped

Total Rain: 48.53 L 2.11 in
Total Runoff: 0.14 L 0.01 in
Runoff Ratio: 0.0028

Rainfall Rate: 0.758 L/min 1.98 in/hr
Runoff Rate: 0.000 L/min 0.00 in/hr
Infiltration Rate: 0.758 L/min 1.98 in/hr

Results: Little to no runoff. Duff and soil seem to be infiltrating all rainfall.
Site 6

**Date and time:** 7/5/2011 @ 15:00
**Slope %:** 40
**Area m²:** 0.928

**Location:** Upper North Fork of the Little Creek Watershed.
**Vegetation:** tanoak, ferns, Doug firs, and forested slope. Slope is burned. Redwood sorrel inside plot and there is a thick duff and leaf litter layer
**Soils:** Soil is moist, granite parent material.

**Calibration:**

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<th>Time off</th>
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<tbody>
<tr>
<td>Volume 1</td>
<td>420 mL/30s</td>
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**Slope corrected rainfall rate:** 2.14 in/hr 0.84 L/min

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<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
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<tbody>
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</tr>
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<tr>
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</tr>
<tr>
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</tr>
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<td></td>
</tr>
<tr>
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<td>0.00</td>
<td>Stopped</td>
</tr>
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</table>
Total Rain: 42.45 L 1.80 in
Total Runoff: 0.00 L 0.00 in
Runoff Ratio: 0.0000

Rainfall Rate: 0.840 L/min 2.14 in/hr
Runoff Rate: 0.000 L/min 0.00 in/hr
Infiltration Rate: 0.840 L/min 2.14 in/hr

Results: Little runoff with and without leaf litter. Duff and soil seem to be infiltrating all rainfall.
Site 7

**Date and time:** 07/11/2011 @ 15:03
**Slope %:** 47
**Area m²:** 0.905
**Location:** South fork on Cemex/Swanton boundary.
**Vegetation:** RW Chapparal, Tanoak, ferns and fir. Ground cover 95% mostly leaves
**Soils:** Mudstone parent material, thick duff layer, macropores visible, moderately deep soils, topsoil moist, 15% clay, mostly silt.

**Calibration:**

<table>
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<th>Time off</th>
</tr>
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<td>Volume 2</td>
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<td>0.4</td>
</tr>
<tr>
<td>Volume 3</td>
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<td>0.4</td>
</tr>
</tbody>
</table>

**Slope corrected rainfall rate:**

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<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
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</table>

2.20 in/hr
0.84 L/min
Total Rain: 45.54 L 1.98 in
Total Runoff: 1.04 L 0.05 in
Runoff Ratio: 0.0228

Rainfall Rate: 0.843 L/min 2.20 in/hr
Runoff Rate: 0.014 L/min 0.04 in/hr
Infiltration Rate: 0.829 L/min 2.16 in/hr

Results: Slow runoff rate due to ground cover being very steady. Most of the leaves were oak which took the initial impact of the rainfall and let the water percolate slowly through the soil.
Site 8

**Date and time:** 9/08/2011 @ 11:00

**Slope %:** 49

**Area m²:** 1.00

**Location:** Boyer Creek burned. Sunny, warm, slight breeze and no clouds.

**Vegetation:** Knobcone pine, dead knobcone, manzanita, no duff layer.

**Soils:** Mudstone rocks at surface. No duff layer. Hydrophobic layer. No overstory cover and 30% understory cover.

**Calibration:**

<table>
<thead>
<tr>
<th>Time on</th>
<th>0.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time off</td>
<td>0.4</td>
</tr>
</tbody>
</table>

- Volume 1: 410 mL/30s
- Volume 2: 425 mL/30s
- Volume 3: 435 mL/30s
- Volume 4: 450 mL/30s
- Volume 5: 460 mL/30s

**Slope corrected rainfall rate:**

- **2.06 in/hr**
- **0.87 L/min**

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<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
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</tbody>
</table>
Total Rain: 34.88 L 1.37 in
Total Runoff: 1.41 L 0.06 in
Runoff Ratio: 0.0406

Rainfall Rate: 0.872 L/min 2.06 in/hr
Runoff Rate: 0.046 L/min 0.11 in/hr
Infiltration Rate: 0.826 L/min 1.95 in/hr

Results: No results recorded in the field book.
Site 9

Date and time: 9/7/2011 @ 14:23
Slope %: 65
Area m²: 0.838
Location: Mill Creek ridge Unburned. Sunny, warm weather with some wind occasionally.
Vegetation: Lots of dead/dry materials. Manzanita, knobcone pine, possibly some interior live oak (or oak), madrone, doug fir. About 30% overstory canopy and about 55% understory.
Soils: 1-2 inch duff layer; rocks on the surface (mudstone) and a hydrophobic layer present.

Calibration:

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<td>Volume 1</td>
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<td>Volume 5</td>
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<tr>
<td>Volume 6</td>
<td>345 mL/30s</td>
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Slope corrected rainfall rate: 2.01 in/hr
0.72 L/min

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<tr>
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<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
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<td>0.00</td>
<td>2:51 first drop</td>
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<td>7.15</td>
<td>0.11</td>
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</table>
Steady stream till end of simulation

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</table>

Total Rain: 32.89 L 1.54 in
Total Runoff: 0.61 L 0.03 in
Runoff Ratio: 0.0185

Rainfall Rate: 0.715 L/min 2.01 in/hr
Runoff Rate: 0.014 L/min 0.04 in/hr
Infiltration Rate: 0.701 L/min 1.97 in/hr

Results: No results recorded in field book.
Site 10

Date and time: 9/6/2011 @ 14:00
Slope %: 27
Area m²: 0.965
Location: Lockheed ridge (aka LeHi) Southeast facing slope
Vegetation: scrub oak, knobcone pine, manzanita. Lots of dead knobcone.
Soils: Mudstone parent materials, shallow, lots of rocks on surface. 5% duff cover and 30% vegetative cover.

Calibration:

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<td>340 mL/30s</td>
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Slope corrected rainfall rate: 1.57 in/hr

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<td>36</td>
<td>0.56</td>
<td>23.10</td>
<td>0.77</td>
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</tr>
</tbody>
</table>

0.64 L/min
Total Rain: 23.10 L 0.94 in
Total Runoff: 0.77 L 0.03 in
Runoff Ratio: 0.0335

Rainfall Rate: 0.642 L/min 1.57 in/hr
Runoff Rate: 0.028 L/min 0.07 in/hr
Infiltration Rate: 0.614 L/min 1.50 in/hr

Results: No results recorded in field book.
Site 11

Date and time: 9/6/2011 @ 12:00
Slope %: 17
Area m²: 0.986
Location: Lockheed Ridge (LeHi) aka Scotts/Mill unburned/control. Northwest facing slopes.
Vegetation: Knobcone pine, manzanita, oak, about 50% surface cover.
Soils: Mudstone with 2-3 inch duff layer. Shallow soil with mudstone beneath.

Calibration:

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<th>Time off</th>
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<td></td>
</tr>
<tr>
<td>Volume 2</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

Volume 1 425 mL/30s
Volume 2 410 mL/30s
Volume 3 380 mL/30s
Volume 4 385 mL/30s

Slope corrected rainfall rate: 1.92 in/hr
0.80 L/min

<table>
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<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
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<td>Leveled bucket from here to end of simulation</td>
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<td>Rainfall Rate</td>
<td>Runoff Rate</td>
<td>Infiltration Rate</td>
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<td>62</td>
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</tbody>
</table>

**Total Rain:** 49.60 L  1.98 in  
**Total Runoff:** 0.37 L  0.01 in  
**Runoff Ratio:** 0.0075  

**Rainfall Rate:** 0.800 L/min  1.92 in/hr  
**Runoff Rate:** 0.006 L/min  0.02 in/hr  
**Infiltration Rate:** 0.794 L/min  **1.90 in/hr**

**Results:** No results recorded in the field book.
Site 12

Date and time: 9/7/2011 @ 11:30
Slope %: 46
Area m²: 0.908
Location: Boyer Creek Control Lockheed Property Unburned. Aspect is South facing slope. Sunny, warm, slight to no breeze.
Vegetation: Madrone, Tanoak, redwood
Soils: 3-4 inch duff layer (Tanoak and Madrone), perhaps a sandy clay loam. 95% cover from duff and 90% canopy cover. NO hydrophobicity

Calibration:

<table>
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<tr>
<th>Time on</th>
<th>Volume 1</th>
<th>Volume 2</th>
<th>Volume 3</th>
<th>Volume 4</th>
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<td>370 mL/30s</td>
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Slope corrected rainfall rate: 1.94 in/hr
0.75 L/min

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<th>Runoff Volume (L)</th>
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</tr>
<tr>
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<td>1.49</td>
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<td>Drips begin at 3:30</td>
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</tr>
</tbody>
</table>

Slow drip from here onward.
Slow drips about 3 per second.

Total Rain: 44.70 L 1.94 in
Total Runoff: 0.36 L 0.02 in
Runoff Ratio: 0.0081

Rainfall Rate: 0.745 L/min 1.94 in/hr
Runoff Rate: 0.008 L/min 0.02 in/hr
Infiltration Rate: 0.738 L/min 1.92 in/hr

Results: No results recorded in the field book.
Site 13

**Date:** 7/7/2011  
**Slope %:** 60  
**Area m²:** 0.857  
**Location:** Lions flat ridgeline (South fork ridge)  
**Vegetation:** Thick vetch, burnt redwood and fir.  
**Soils:** Nothing recorded in field book.

**Calibration:**

```
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<th>Time off</th>
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<tbody>
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**Volume 1** 405 mL/30s

**Slope corrected rainfall rate:** 2.23 in/hr  
0.81 L/min

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<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
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<td>drips started at 5:30 (likely from vegetation)</td>
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<td>Runoff (in)</td>
<td>Rainfall Rate (L/min)</td>
<td>Runoff Rate (L/min)</td>
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<td>0.045 L/min</td>
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<td>0.810 L/min 2.23 in/hr</td>
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<td>0.810 L/min 2.23 in/hr</td>
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<tr>
<td>72</td>
<td>2.15</td>
<td>58.32</td>
<td>0.810 L/min 2.23 in/hr</td>
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</tr>
</tbody>
</table>

**Results:** No results recorded in field book.
Site 15

Date and time: 9/8/2011  
Slope %: 36  
Area m²: 0.941  
Vegetation: Manzanita, knobcone sprouts, dead knobcone, lupine, scruboak. No overstory, 20% understory cover.  
Soils: Bare rock surface (mudstone) no duff layer, hydrophobic layer

Calibration:

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</tr>
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<td>325 mL/30s</td>
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<tr>
<td>Volume 5</td>
<td>335 mL/30s</td>
</tr>
</tbody>
</table>

Slope corrected rainfall rate: 1.65 in/hr  
0.66 L/min

<table>
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<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
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<td>1.4</td>
<td>30.17</td>
<td>1.99</td>
<td></td>
</tr>
</tbody>
</table>
Total Rain: 28.86 L  1.21 in
Total Runoff: 1.88 L  0.08 in
Runoff Ratio: 0.0650

Rainfall Rate: 0.656 L/min  1.65 in/hr
Runoff Rate: 0.051 L/min  0.13 in/hr
Infiltration Rate: 0.605 L/min  1.52 in/hr

Results: No results recorded in field book.
2012

Site 2

**Date and time:** 8/22/2012 @ 10:31

**Slope %:** 60

**Area m²:** 0.857

**Location:** Upper Swanton Road, non-burned area. Weather: nice day, warm and sunny

**Aspect:** East/Southeast

**Vegetation:** Redwood dominant with very thick redwood needle duff layer about 3-5 inches thick.

**Soils:** Soils under thick duff layer were well developed; not too rocky.

**Calibration:**

<table>
<thead>
<tr>
<th>Time on</th>
<th>Time off</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
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</table>

<table>
<thead>
<tr>
<th>Volume 1</th>
<th>Volume 2</th>
<th>Volume 3</th>
<th>Volume 4</th>
<th>Volume 5</th>
<th>Volume 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>455 mL/30s</td>
<td>460 mL/30s</td>
<td>495 mL/30s</td>
<td>480 mL/30s</td>
<td>500 mL/30s</td>
<td>495 mL/30s</td>
</tr>
</tbody>
</table>

**Slope corrected rainfall rate:**

2.65 in/hr

0.96 L/min

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
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<tbody>
<tr>
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<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>2</td>
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<tr>
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<td>0.01</td>
<td>Steady flow @4:00</td>
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<td>0.07</td>
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<tr>
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<td>11.54</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.08</td>
<td>13.46</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
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<td>0.09</td>
<td>15.39</td>
<td>0.12</td>
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<td>21.16</td>
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<tr>
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<td>28.85</td>
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</tr>
<tr>
<td>32</td>
<td>0.21</td>
<td>30.77</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>0.22</td>
<td>32.70</td>
<td>0.30</td>
<td></td>
</tr>
</tbody>
</table>
36 | 0.24 | 34.62 | 0.33
38 | 0.25 | 36.54 | 0.34
40 | 0.24 | 38.47 | 0.33
42 | 0.29 | 40.39 | 0.40
44 | 0.305 | 42.31 | 0.42
46 | 0.315 | 44.24 | 0.43
48 | 0.34 | 46.16 | 0.47  Sprayer stopped oscillating @ 48:00
50 | 0.375 | 48.08 | 0.52  Water started up again 13 minutes later and depth of bucket
      |       |       |   was at 0.36 depth
52 | 0.39 | 50.01 | 0.54
54 | 0.41 | 51.93 | 0.57
56 | 0.42 | 53.85 | 0.58

**Results:** A lot of the moisture was held in the duff layer. There was uneven moisture dispersal vertically throughout the plot. One spot in the middle of the plot was vertically moist about 0.5-1 foot depth. There were pockets of wetness but most of the moisture was held in the 2-3 inch duff layer. Back of plot (upslope side) was not moist because of slope.
Site 4

**Date and time:** 8/13/2012 @ 11:26

**Slope %:** 70

**Area m²:** 0.819

**Location:** L.C. unburned. Sunny with a slight breeze.

**Vegetation:** Aspect is southeast. Thick layer of duff (about 4 inches depth and greater in some areas of plot). Redwood sorrel, ferns, california bay and big leaf maple present near plot.

**Soils:** Santa Cruz mudstone over granite; high amount of cobble and gravels.

### Calibration:

<table>
<thead>
<tr>
<th>Time on</th>
<th>Time off</th>
<th>Volume 1</th>
<th>Volume 2</th>
<th>Volume 3</th>
<th>Volume 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>0.4</td>
<td>445 mL/30s</td>
<td>460 mL/30s</td>
<td>480 mL/30s</td>
<td>470 mL/30s</td>
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</table>

**Slope corrected rainfall rate:** 2.67 in/hr

0.93 L/min

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
<td>2</td>
<td>0.01</td>
<td>1.86</td>
<td>0.01</td>
<td>Start of runoff at 1 minute 24 seconds</td>
</tr>
<tr>
<td>4</td>
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<td>3.71</td>
<td>0.06</td>
<td>Consistent runoff</td>
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<td>0.06</td>
<td>5.57</td>
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<tr>
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<td>7.42</td>
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<td>0.26</td>
<td>20.41</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
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<td>0.28</td>
<td>22.26</td>
<td>0.39</td>
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</tr>
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<td>0.30</td>
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</tr>
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<td>31.54</td>
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<td></td>
</tr>
<tr>
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<td>38.96</td>
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</tr>
<tr>
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<td>40.81</td>
<td>0.72</td>
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</tr>
<tr>
<td>Time (min)</td>
<td>Rainfall (L/min)</td>
<td>Rainfall (in/hr)</td>
<td>Runoff (L/min)</td>
<td>Runoff (in/hr)</td>
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<tr>
<td>-----------</td>
<td>------------------</td>
<td>------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>46</td>
<td>0.55</td>
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<td>0.76</td>
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</tr>
<tr>
<td>48</td>
<td>0.57</td>
<td>44.52</td>
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</tr>
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<td>53.80</td>
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</tr>
<tr>
<td>60</td>
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<td>55.65</td>
<td>0.98</td>
<td>Stopped simulator at 12:26</td>
</tr>
<tr>
<td>62</td>
<td>0.72</td>
<td>57.51</td>
<td>1.00</td>
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</tr>
</tbody>
</table>

Total Rain: 57.51 L 2.76 in
Total Runoff: 1.00 L 0.05 in
Runoff Ratio: 0.0173

Rainfall Rate: 0.928 L/min 2.67 in/hr
Runoff Rate: 0.017 L/min 0.05 in/hr
Infiltration Rate: 0.911 L/min 2.63 in/hr

Results: Thick layer of duff about 4 inches in some areas. Only the top 1 cm of duff was wet. Nothing under 1 cm had water percolate through it—completely dry. Also, due to slope, back portion of plot (uphill side) was not moist.
Site 5

**Date and time:** 7/26/2012 @ 11:45
**Slope %:** 63
**Area m²:** 1.00

**Location:** Cabins. Some fog, no wind.
**Vegetation:** southeast aspect. Thick ground cover, poison oak, blackberry, ceanothus. Doug fir and Ca Bay present in the area.
**Soils:** Santa Cruz mudstone over granite.

**Calibration:**

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<tr>
<th></th>
<th>Time on</th>
<th>Time off</th>
</tr>
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<tbody>
<tr>
<td>Volume 1</td>
<td>450 mL/30s</td>
<td>490 mL/30s</td>
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<td>Volume 2</td>
<td>500 mL/30s</td>
<td>525 mL/30s</td>
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**Slope corrected rainfall rate:**

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<tr>
<th></th>
<th>2.38 in/hr</th>
<th>2.40 in/hr</th>
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</thead>
<tbody>
<tr>
<td>1.01 L/min</td>
<td>1.02 L/min</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
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<tr>
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</tr>
<tr>
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</tr>
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<td>0.06</td>
<td>10.08</td>
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<tr>
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<td>24.20</td>
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<td>30.25</td>
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<td>42</td>
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<td>68</td>
<td>0.6</td>
<td>68.57</td>
<td>0.83</td>
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</table>

**Results:** Runoff was mostly steady, but slowed down at times. Water appears to have fully saturated the layer of organic debris but did not significantly infiltrate the underlying soil. Completely dry about 1 inch beneath the surface. Some areas have higher infiltration where macropores are prevalent. At 1 inch depth, drop test performed and water only beaded for 3 seconds.

Total Rain: 68.57 L 2.70 in
Total Runoff: 0.83 L 0.03 in
Runoff Ratio: **0.0121**

<table>
<thead>
<tr>
<th></th>
<th>Runoff Rate</th>
<th>Rainfall Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.013 L/min</td>
<td>1.008 L/min</td>
</tr>
<tr>
<td></td>
<td>0.03 in/hr</td>
<td>2.40 in/hr</td>
</tr>
</tbody>
</table>

**Infiltration Rate:** 0.995 L/min **2.37 in/hr**
Site 6

**Date and time:** 7/25/2012 @ 15:00  
**Slope %:** 52  
**Area m²:** 0.887  
**Location:** UNF Little Creek watershed.  
**Vegetation:** 100% Cover-duff between 1 and 2 inches, redwood sorel, tanoak leaves. Northwest facing slope. Tanoak and redwood present.  
**Soils:** Granite soil parent material.

### Calibration:

<table>
<thead>
<tr>
<th>Time on</th>
<th>Time off</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volume</th>
<th>mL/30s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume 1</td>
<td>440</td>
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<tr>
<td>Volume 2</td>
<td>435</td>
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<tr>
<td>Volume 3</td>
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<td>Volume 4</td>
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</tr>
<tr>
<td>Volume 5</td>
<td>465</td>
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<tr>
<td>Volume 6</td>
<td>455</td>
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</table>

**Slope corrected rainfall rate:** 2.39 in/hr  
0.90 L/min

<table>
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<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>1.79</td>
<td>0.00</td>
<td>at 3:40 water starts to flow</td>
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<tr>
<td>4</td>
<td>0.02</td>
<td>3.59</td>
<td>0.03</td>
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</tr>
<tr>
<td>6</td>
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<td>5.38</td>
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<td>16.14</td>
<td>0.26</td>
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</tr>
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</tr>
<tr>
<td>22</td>
<td>0.25</td>
<td>19.73</td>
<td>0.34</td>
<td>We notice wood is not over trough entirely; water drops hitting trough directly</td>
</tr>
<tr>
<td>24</td>
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<td>21.52</td>
<td>0.36</td>
<td>At 22 min we cover trough with plywood</td>
</tr>
<tr>
<td>26</td>
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<td>0.39</td>
<td>at 24 min, looks like runoff slowed with adjustment of plywood</td>
</tr>
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<td>0.43</td>
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<tr>
<td>Time</td>
<td>Rainfall</td>
<td>Runoff</td>
<td>Infiltration</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>----------</td>
<td>--------</td>
<td>--------------</td>
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</tr>
<tr>
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<td>0.97</td>
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<tr>
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</table>

stopped simulator at 1:03:20

Total Rain: 59.18 L 2.63 in
Total Runoff: 1.00 L 0.04 in
Runoff Ratio: **0.0168**

<table>
<thead>
<tr>
<th>Rate</th>
<th>Value</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall Rate</td>
<td>0.897 L/min</td>
<td>2.39 in/hr</td>
</tr>
<tr>
<td>Runoff Rate</td>
<td>0.017 L/min</td>
<td>0.04 in/hr</td>
</tr>
<tr>
<td>Infiltration Rate</td>
<td>0.880 L/min</td>
<td>2.34 in/hr</td>
</tr>
</tbody>
</table>

**Results:** Plot was uniformly wetted but not saturated, soil was moist under duff layer.
Site 7

Date and time: 8/14/2012 @ 12:36
Slope %: 46
Area m²: 0.908
Location: South fork on Cemex property/Swanton boundary.
Vegetation: Northwest aspect. Redwood and tanoak, some Doug fir. Ground cover consists of sedge nettle, fern, iris and blackberry. There is some slash present from the logging in 2011.
Soils: Infiltration was about 7 inches deep in most areas of plot that had a duff layer of 1 inch. Where duff was 2 inches and greater, there was very little infiltration that occurred.

Calibration:
<table>
<thead>
<tr>
<th>Time on</th>
<th>Time off</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Volume 1 450 mL/30s
Volume 2 450 mL/30s
Volume 3 449 mL/30s

Slope corrected rainfall rate: 2.34 in/hr
0.90 L/min

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>1.80</td>
<td>0.00</td>
<td>2:30 start of drips</td>
</tr>
<tr>
<td>4</td>
<td>0.00</td>
<td>3.60</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.00</td>
<td>5.40</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.00</td>
<td>7.19</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
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<td>0.01</td>
<td>8.99</td>
<td>0.01</td>
<td>still dripping, not consistent flow</td>
</tr>
<tr>
<td>12</td>
<td>0.02</td>
<td>10.79</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.03</td>
<td>12.59</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.03</td>
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<tr>
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<td>0.03</td>
<td>16.19</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.03</td>
<td>17.99</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>0.04</td>
<td>19.79</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>0.04</td>
<td>21.58</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>0.04</td>
<td>23.38</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>28</td>
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<td>25.18</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>0.04</td>
<td>26.98</td>
<td>0.06</td>
<td>still dripping, not consistent flow</td>
</tr>
<tr>
<td>32</td>
<td>0.04</td>
<td>28.78</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>0.04</td>
<td>30.58</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>0.04</td>
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<td>0.04</td>
<td>34.17</td>
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<tr>
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<td>35.97</td>
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</tr>
<tr>
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<td>37.77</td>
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</tr>
<tr>
<td>44</td>
<td>0.045</td>
<td>39.57</td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>
Results: Infiltration was about 7 inches deep in most areas of plot that had a duff layer of 1 inch. Where duff was 2 inches and greater, there was very little infiltration that occurred.
**Site 8**

**Date and time:** 8/29/2012 @ 13:00  
**Slope %:** 49  
**Area m²:** 1.00  
**Location:** Boyer Creek burned. Slight wind and sunny, HOT day.  
**Vegetation:** manzanita, small oak bushes, dead deerweed, knobcone sprouts, chamise, bush poppy.  
**Soils:** Soil is somewhat rock and soil is granular and gravelly. There is a charred organic black layer under rocks on surface.

### Calibration:

<table>
<thead>
<tr>
<th>Time on</th>
<th>0.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time off</td>
<td>0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volume 1</th>
<th>410 mL/30s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume 2</td>
<td>410 mL/30s</td>
</tr>
<tr>
<td>Volume 3</td>
<td>360 mL/30s</td>
</tr>
<tr>
<td>Volume 4</td>
<td>355 mL/30s</td>
</tr>
<tr>
<td>Volume 5</td>
<td>395 mL/30s</td>
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<tr>
<td>Volume 6</td>
<td>360 mL/30s</td>
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</tbody>
</table>

### Slope corrected rainfall rate:

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>0.00</td>
<td>0.00</td>
<td>Wind is slight but present</td>
</tr>
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<td>0.00</td>
<td>1.53</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.00</td>
<td>3.05</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.00</td>
<td>4.58</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.00</td>
<td>6.11</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.01</td>
<td>7.63</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.02</td>
<td>9.16</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.03</td>
<td>10.69</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.05</td>
<td>12.21</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>0.08</td>
<td>13.74</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.11</td>
<td>15.27</td>
<td>0.14</td>
<td>Wind picks up</td>
</tr>
<tr>
<td>22</td>
<td>0.12</td>
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<td>0.17</td>
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<td>0.14</td>
<td>18.32</td>
<td>0.19</td>
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</tr>
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<td>25.95</td>
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<td>0.275</td>
<td>27.48</td>
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</tr>
</tbody>
</table>
Total Rain: 50.38 L  1.98 in
Total Runoff: 0.84 L  0.03 in
Runoff Ratio: 0.0167

Rainfall Rate: 0.763 L/min  1.82 in/hr
Runoff Rate: 0.015 L/min  0.04 in/hr
Infiltration Rate: 0.748 L/min  1.78 in/hr

Results: Topsoil was thin about 0.5-1 inch deep and is composed of charred organics.
Site 9

Date and time: 9/5/2012 @ 12:39
Slope %: 65
Area m²: 0.838
Location: Mill Creek ridge-unburned. Weather: slight wind/breeze. It did start to sprinkle a little when conducting simulation-nothing substantial.
Vegetation: Oak brush, manzanita, doug fir, madrone and knobcone. Plot has madrone leaves, manzanita leaves and needles, small twigs and doug fir cones.
Soils: 2-3 inch duff layer; rocks on the surface (mudstone)

Calibration:

<table>
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<tr>
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<th>Time on</th>
<th>Time off</th>
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<tbody>
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<td>Volume 1</td>
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</tr>
<tr>
<td>Volume 5</td>
<td>455 mL/30s</td>
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</tr>
<tr>
<td>Volume 6</td>
<td>470 mL/30s</td>
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</table>

Slope corrected rainfall rate: 2.48 in/hr, 0.88 L/min

<table>
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<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
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<td>1.76</td>
<td>0.06</td>
<td>2:51 first drop</td>
</tr>
<tr>
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<td>3.53</td>
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<td>0.06</td>
<td>7.05</td>
<td>0.08</td>
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<td>12.34</td>
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<td>0.25</td>
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</tr>
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<td>22.92</td>
<td>0.37</td>
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<td>0.41</td>
<td>Resumed simulation at depth .295 depth.</td>
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</tr>
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<td>0.34</td>
<td>28.21</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>0.37</td>
<td>29.98</td>
<td>0.51</td>
<td></td>
</tr>
</tbody>
</table>
Jack removed constant 0.3475 from col G starting here

<p>| | | |</p>
<table>
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<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
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<td>58.19</td>
</tr>
</tbody>
</table>

Total Rain: 58.19 L 2.73 in
Total Runoff: 1.07 L 0.05 in
Runoff Ratio: 0.0184

Rainfall Rate: 0.882 L/min 2.48 in/hr
Runoff Rate: 0.018 L/min 0.05 in/hr
Infiltration Rate: 0.864 L/min 2.43 in/hr
**Results:** Upper most organic layer (2-3 inches) was very intact and held most of the water; this layer was moist. Under about 3 inches of the organic matter, the material was more of a fine organic matter and it was dry. The top 2 inches of plot on uphill side were dry because of the slope (water did not get sprinkled on that portion of the plot). Bottom of the plot had the deepest penetration of moisture.
Date and time: 8/27/2012 @ 12:00
Slope %: 36
Area m²: 0.941
Location: Scotts/Mill burned; Mild breeze
Vegetation: scrub oak, knobcone pine, manzanita. Lots of dead knobcone, deer weed
Soils: Mudstone parent materials, shallow, lots of rocks on surface.

Calibration:

<table>
<thead>
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<th>Time on</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Time off</td>
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</tr>
</tbody>
</table>

| Volume 1 | 450 mL/30s |
| Volume 2 | 465 mL/30s |
| Volume 3 | 470 mL/30s |
| Volume 4 | 480 mL/30s |

Slope corrected rainfall rate:

2.34 in/hr

0.93 L/min

<table>
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<tr>
<th>time (min)</th>
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<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
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</tr>
<tr>
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<td>9.33</td>
<td>0.01</td>
<td>@ 9:22 drips start</td>
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<tr>
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<td>@ 9:38 steady flow</td>
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<td>Total Runoff (L)</td>
<td>Runoff Ratio</td>
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</table>

Total Rain: 57.82 L 2.42 in  
Total Runoff: 1.22 L 0.05 in  
Runoff Ratio: 0.0211

Rainfall Rate: 0.933 L/min 2.34 in/hr  
Runoff Rate: 0.031 L/min 0.08 in/hr  
Infiltration Rate: 0.902 L/min 2.26 in/hr

**Results:** 1-2 cm of infiltration, below that there is a hydrophobic layer.
Site 11

Date and time: 8/23/2012 @ 13:00
Slope %: 30
Area m²: 0.958
Location: Scotts/Mill Control/unburned. Northwest facing slopes.
Vegetation: Mosses present.
Soils: Mudstone derived; plot contains mudstone shards.

Calibration:

<table>
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<tr>
<th>Time on</th>
<th>Time off</th>
<th>Volume 1</th>
<th>Volume 2</th>
<th>Volume 3</th>
<th>Volume 4</th>
<th>Volume 5</th>
<th>Volume 6</th>
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<td>470 mL/30s</td>
<td>470 mL/30s</td>
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Slope corrected rainfall rate:

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<th>Runoff Volume (L)</th>
<th>Notes</th>
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<td>72</td>
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</tbody>
</table>

**Results:** There was some leakage due to a gap between trough and soil. The top layer of soil about 1 inch was moist. Below one inch was not moist.

<table>
<thead>
<tr>
<th></th>
<th>Total Rain: 71.52 L</th>
<th>2.94 in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Runoff:</td>
<td>0.58 L</td>
<td>0.02 in</td>
</tr>
<tr>
<td>Runoff Ratio:</td>
<td>0.0081</td>
<td></td>
</tr>
</tbody>
</table>

Rainfall Rate: 0.993 L/min 2.45 in/hr
Runoff Rate: 0.009 L/min 0.02 in/hr
Infiltration Rate: 0.984 L/min **2.43 in/hr**
Site 12

**Date and time:** 2/5/2013 @ 13:03  
**Slope %:** 46%  
**Area m²:** 1.0  
**Location:** Upper Boyer Non-burned  
**Vegetation:** Tanoak dominant and some madrone redwood, and fir. Understory has small tanoaks. Very thick duff layer composed of tanoak leaves and madrone leaves.  
**Soils:** soils are thick and deep, they contain some moisture because it has rained this season. Moisture content is unknown.

**Calibration:**

<table>
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<th>0.6</th>
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<tr>
<td>Time off</td>
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<p>| | | |</p>
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<tr>
<th></th>
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</thead>
<tbody>
<tr>
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<td>440 mL/30s</td>
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</tr>
<tr>
<td>Volume 2</td>
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</tr>
<tr>
<td>Volume 4</td>
<td>450 mL/30s</td>
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</table>

**Slope corrected rainfall rate:**  
2.13 in/hr  
0.90 L/min

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</tr>
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<td>Rainfall Rate (in/hr)</td>
<td>Runoff Rate (L/min)</td>
<td>Runoff Rate (in/hr)</td>
</tr>
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<td>64</td>
<td>0.090</td>
<td>57.60</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
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<td>0.090</td>
<td>59.40</td>
<td>0.12</td>
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<tr>
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<td>0.090</td>
<td>61.20</td>
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</tr>
<tr>
<td>74</td>
<td>0.1</td>
<td>66.60</td>
<td>0.14</td>
<td>Still Dripping</td>
</tr>
<tr>
<td>76</td>
<td>0.1</td>
<td>68.40</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>78</td>
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<td>70.20</td>
<td>0.14</td>
<td>Water turned off at 78 minutes</td>
</tr>
<tr>
<td>80</td>
<td>0.1</td>
<td>72.00</td>
<td>0.14</td>
<td>Final Depth of bucket</td>
</tr>
</tbody>
</table>

---

**Total Rain:** 72.00 L  2.83 in  
**Total Runoff:** 0.14 L  0.01 in  
**Runoff Ratio:** 0.0019  

**Rainfall Rate:** 0.900 L/min  2.13 in/hr  
**Runoff Rate:** 0.002 L/min  0.00 in/hr
Infiltration Rate: 0.898 L/min 2.12 in/hr

**Results:** About 2 inches of coarse organic material (mostly leaves). Below this is more broken down organic matter (leaves). Both these layers are saturated from the simulation. Below these two layers you get to soil that is granular and also moist - not sure if moisture content is attributed to simulation or natural rainfall. Runoff dripped throughout the simulation, there was never a consistent stream of runoff into the bucket.
Site 13

**Date and time:** 8/20/2012 @ 11:09  
**Slope %:** 50  
**Area m²:** 0.894  
**Location:** Lions Flat (South fork ridge)  
**Vegetation:** Northwest aspect. Redwood sprouts, ceanothus, salmon berry, tanoak sprouts, dead standing tanoak and redwoods. In the plot there are a lot of tanoak leaves. There is a bee plant stems, redwood needles and doug fir cones. Duff depth ranged from 0.5 inch to 1.5 inches  
**Soils:** Nothing recorded in field book.

### Calibration:

<table>
<thead>
<tr>
<th></th>
<th>Time on</th>
<th>Time off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume 1</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Volume 2</td>
<td>425 mL/30s</td>
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<tr>
<td>Volume 3</td>
<td>450 mL/30s</td>
<td></td>
</tr>
<tr>
<td>Volume 4</td>
<td>450 mL/30s</td>
<td></td>
</tr>
</tbody>
</table>

**Slope corrected rainfall rate:** 2.34 in/hr  
0.89 L/min

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
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<tbody>
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<td>0.00</td>
<td>0.00</td>
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<td>3.55</td>
<td>0.00</td>
<td>Started dripping</td>
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<td>6</td>
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<td>7.10</td>
<td>0.04</td>
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<td>0.06</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.05</td>
<td>12.43</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.06</td>
<td>14.20</td>
<td>0.08</td>
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</tr>
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<td>0.09</td>
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<td>20</td>
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<td>22</td>
<td>0.08</td>
<td>19.53</td>
<td>0.11</td>
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<td>30.18</td>
<td>0.17</td>
<td></td>
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<td>31.95</td>
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<td>38</td>
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<td>33.73</td>
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<tr>
<td>40</td>
<td>0.14</td>
<td>35.50</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>0.15</td>
<td>37.28</td>
<td>0.21</td>
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219
<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Rainfall Rate (L/min)</th>
<th>Rainfall Rate (in/hr)</th>
<th>Runoff Rate (L/min)</th>
<th>Runoff Rate (in/hr)</th>
<th>Infiltration Rate (L/min)</th>
<th>Infiltration Rate (in/hr)</th>
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<tbody>
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<td>0.16</td>
<td>39.05</td>
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<td>46</td>
<td>0.165</td>
<td>40.83</td>
<td>0.23</td>
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<td></td>
</tr>
<tr>
<td>48</td>
<td>0.18</td>
<td>42.60</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>0.19</td>
<td>44.38</td>
<td>0.26</td>
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</tr>
<tr>
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<td>0.19</td>
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<td>0.26</td>
<td></td>
<td></td>
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</tr>
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<td>0.28</td>
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<td></td>
</tr>
<tr>
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<td>0.21</td>
<td>51.48</td>
<td>0.29</td>
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</tr>
<tr>
<td>60</td>
<td>0.22</td>
<td>53.25</td>
<td>0.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>62</td>
<td>0.22</td>
<td>55.03</td>
<td>0.30</td>
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<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Runoff (L)</th>
<th>Runoff (in)</th>
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<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0.0051x - 0.0056</td>
<td>0.01 in/hr</td>
</tr>
<tr>
<td>20</td>
<td>0.0051x - 0.0056</td>
<td>0.01 in/hr</td>
</tr>
<tr>
<td>30</td>
<td>0.0051x - 0.0056</td>
<td>0.01 in/hr</td>
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<tr>
<td>40</td>
<td>0.0051x - 0.0056</td>
<td>0.01 in/hr</td>
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<td>50</td>
<td>0.0051x - 0.0056</td>
<td>0.01 in/hr</td>
</tr>
<tr>
<td>60</td>
<td>0.0051x - 0.0056</td>
<td>0.01 in/hr</td>
</tr>
</tbody>
</table>

**Total Rain:** 55.03 L 2.42 in  
**Total Runoff:** 0.30 L 0.01 in  
**Runoff Ratio:** **0.0055**

**Rainfall Rate:** 0.888 L/min 2.34 in/hr  
**Runoff Rate:** 0.005 L/min 0.01 in/hr

**Infiltration Rate:** 0.882 L/min **2.33 in/hr**

**Results:** Uneven distribution of vertical moisture. Greater vertical moisture depth closer to the trough/bottom portion of plot. Moisture depth decreased as you move upslope in plot. Very back of plot was barely moist. Where duff was thicker, there was less penetration of water vertically.
Site 14

**Date and time:** 8/16/2012 @ 10:40  
**Slope %:** 70  
**Area m²:** 0.819  
**Location:** Hillslope. Weather-slight breeze. SIDE NOTE: A simulation was performed here the day before on 08-15-2012 for about 36 minutes until the pump stopped working. Therefore the plot was moist when conducting the simulation today.

**Vegetation:** Site is overgrown with ceanothus, eldererry, sticky monkey flower, poison oak, and blackberry. A lot of stems in the plot because we cut the leaves off of the plants. There is about 100% duff cover throughout entire plot. Northwest aspect.

**Soils:** Mudstone parent material, (soil was Initiall dry before first simulation) shallow, rocky soils with shallow duff layer 0.5-1 inch.

**Calibration:**

<table>
<thead>
<tr>
<th></th>
<th>Time on</th>
<th>Time off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume 1</td>
<td>654 mL/30s</td>
<td>0.4</td>
</tr>
<tr>
<td>Volume 2</td>
<td>459 mL/30s</td>
<td></td>
</tr>
<tr>
<td>Volume 3</td>
<td>503 mL/30s</td>
<td></td>
</tr>
<tr>
<td>Volume 4</td>
<td>500 mL/30s</td>
<td></td>
</tr>
<tr>
<td>Volume 5</td>
<td>450 mL/30s</td>
<td></td>
</tr>
<tr>
<td>Volume 6</td>
<td>450 mL/30s</td>
<td></td>
</tr>
</tbody>
</table>

**Slope corrected rainfall rate:** 2.71 in/hr  
0.94 L/min

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>@ 42 seconds dripping occurs</td>
</tr>
<tr>
<td>2</td>
<td>0.02</td>
<td>1.88</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.02</td>
<td>3.75</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.03</td>
<td>5.63</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.04</td>
<td>7.51</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.04</td>
<td>9.39</td>
<td>0.06</td>
<td>Steady flow at 11:30</td>
</tr>
<tr>
<td>12</td>
<td>0.05</td>
<td>11.26</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.06</td>
<td>13.14</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.07</td>
<td>15.02</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>0.08</td>
<td>16.90</td>
<td>0.11</td>
<td>Notice minor leakage over trough which is contributing to runoff. Fixed leakage and runoff went back to dripping.</td>
</tr>
<tr>
<td>20</td>
<td>0.09</td>
<td>18.77</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>0.10</td>
<td>20.65</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>0.10</td>
<td>22.53</td>
<td>0.14</td>
<td>Runoff still dripping since fixed leak</td>
</tr>
<tr>
<td>26</td>
<td>0.11</td>
<td>24.41</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>0.12</td>
<td>26.28</td>
<td>0.17</td>
<td>Wind picks up a little</td>
</tr>
</tbody>
</table>
Still dripping, no steady flow since fixing the leak

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Volume (L)</th>
<th>Rate (L/min)</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.12</td>
<td>28.16</td>
<td>0.17</td>
</tr>
<tr>
<td>32</td>
<td>0.125</td>
<td>30.04</td>
<td>0.17</td>
</tr>
<tr>
<td>34</td>
<td>0.13</td>
<td>31.91</td>
<td>0.18</td>
</tr>
</tbody>
</table>
| 36         | 0.14       | 33.79        | 0.19  | Still dripping, no steady flow since fixing the leak
| 38         | 0.14       | 35.67        | 0.19  |
| 40         | 0.14       | 37.55        | 0.19  |
| 42         | 0.15       | 39.42        | 0.21  |
| 44         | 0.15       | 41.30        | 0.21  |
| 46         | 0.15       | 43.18        | 0.21  |
| 48         | 0.15       | 45.06        | 0.21  |
| 50         | 0.155      | 46.93        | 0.21  |
| 52         | 0.16       | 48.81        | 0.22  |
| 54         | 0.16       | 50.69        | 0.22  | Still dripping
| 56         | 0.165      | 52.57        | 0.23  |
| 58         | 0.17       | 54.44        | 0.23  |
| 60         | 0.175      | 56.32        | 0.24  |
| 62         | 0.175      | 58.20        | 0.24  |
| 64         | 0.18       | 60.07        | 0.25  |
| 66         | 0.18       | 61.95        | 0.25  | End of simulation, water still dripping, no steady flow.

Total Rain: 61.95 L 2.98 in
Total Runoff: 0.25 L 0.01 in
Runoff Ratio: 0.0040

Rainfall Rate: 0.939 L/min 2.71 in/hr
Runoff Rate: 0.002 L/min 0.01 in/hr
Infiltration Rate: 0.937 L/min 2.70 in/hr
**Results:** Lowed half of plot had evenly distributed moisture about 1 foot vertically. As you move upslope towards back of plot, depth of vertical moisture decreased until you reach back boarder where plot was slightly moist.
2013

Site 2

Date and time: 7/23/2013 @ 13:30
Slope %: 60
Area $m^2$: 0.857
Location: Upper Swanton Road, non-burned area. Nice weather, Aspect is southeast facing.
Vegetation: Redwood dominant. Duff is very thick and is composed of mostly redwood and some tanoak. There are ferns present in the area and solomans seal.
Soils: Deep, rich soil beneath thick, redwood duff layer.

Calibration:

<table>
<thead>
<tr>
<th>Time on</th>
<th>0.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time off</td>
<td>0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volume 1</th>
<th>427 mL/30s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume 2</td>
<td>445 mL/30s</td>
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<tr>
<td>Volume 3</td>
<td>420 mL/30s</td>
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<tr>
<td>Volume 4</td>
<td>420 mL/30s</td>
</tr>
<tr>
<td>Volume 5</td>
<td>430 mL/30s</td>
</tr>
</tbody>
</table>

Slope corrected rainfall rate: 2.36 in/hr
0.86 L/min

<table>
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<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
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<tbody>
<tr>
<td>0</td>
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<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>1.71</td>
<td>0.00</td>
<td>Drips begin at 2:23</td>
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<td>0.02</td>
<td>3.43</td>
<td>0.02</td>
<td>Flow starts at 2:50</td>
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<td>0.03</td>
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</tr>
<tr>
<td>8</td>
<td>0.04</td>
<td>6.85</td>
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<td>10</td>
<td>0.06</td>
<td>8.57</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.06</td>
<td>10.28</td>
<td>0.08</td>
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<td>0.08</td>
<td>12.00</td>
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<td>0.17</td>
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<td>18.85</td>
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<td>25.70</td>
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<td>0.23</td>
<td>29.13</td>
<td>0.32</td>
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<tr>
<td>36</td>
<td>0.25</td>
<td>30.84</td>
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<td>0.26</td>
<td>32.56</td>
<td>0.36</td>
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</tr>
<tr>
<td>Time (min)</td>
<td>Rainfall</td>
<td>Runoff</td>
<td>Total Runoff</td>
<td>Runoff Ratio</td>
</tr>
<tr>
<td>-----------</td>
<td>----------</td>
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<th>Rainfall Rate</th>
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Total Rain: 61.690 2.832
Total Runoff: 0.712 0.033
Runoff Ratio: 0.0115

Rainfall Rate: 0.857 2.36 in/hr
Runoff Rate: 0.011 0.03 in/hr
Infiltration Rate: 0.846 2.33 in/hr
**Results:** Duff layer is moist in upper portion 1.0-1.5" and below that duff is dry. There are macropores within the duff and soil so water was able to infiltrate. Below duff, soil is wetted in some areas of plot to a depth of about 2". Soil throughout plot is not equally wetted but did have some infiltration of water through soil.
Site 5

Date and time: 8/2/2013 @ 10:12
Slope %: 56
Area $m^2$: 0.873
Location: Cabins.
Vegetation: There is blackberry and sedge nettle. Also some poison oak. Lots of twigs and blackberry vines in plot. Duff is not thick, just the blackberry vines are.
Soils: Duff is around .5-1 cm which is composed of some redwood needles and some sandstone rocks. There is soil beneath duff with lots of mica.

Calibration:

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<tr>
<td>Time off</td>
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| Volume 1 | 390 mL/30s |
| Volume 2 | 410 mL/30s |
| Volume 3 | 380 mL/30s |
| Volume 4 | 380 mL/30s |
| Volume 5 | 415 mL/30s |

Slope corrected rainfall rate:

2.14 in/hr
0.79 L/min

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<td>0.25 Jack removed constant 0.3475 from col G starting here</td>
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<td>Volume</td>
<td>Infiltration</td>
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<td>0.33 Final Depth</td>
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</table>

**Results:** Patchy infiltration throughout plot, some dry pockets but mostly wet. Infiltration is about 1 foot deep.
Site 6

**Date and time:** 7/31/2013 @ 12:50  
**Slope %:** 50  
**Area m²:** 0.894  
**Location:** Upper North Fork of Little Creek.  
**Vegetation:** Sorel and star flower. Duff is composed of redwood and tanoak leaves, some twigs present. Duff depth ranges from 0.5 inches to 1 inch.  
**Soils:** Soil is beneath duff layer, looks like thick rich soil.

**Calibration:**

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</thead>
<tbody>
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<td>Time off</td>
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</table>

Volume 1 415 mL/30s  
Volume 2 430 mL/30s  
Volume 3 445 mL/30s  
Volume 4 440 mL/30s  
Volume 5 425 mL/30s  
Volume 6 440 mL/30s

**Slope corrected rainfall rate:**  
2.28 in/hr  
0.87 L/min

<table>
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<td>0.04</td>
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<tr>
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<td>15.57</td>
<td>0.04</td>
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</table>
Total Rain: 57.09 L  2.51 in
Total Runoff: 0.12 L  0.01 in
Runoff Ratio: 0.0022

Rainfall Rate: 0.865 L/min  2.28 in/hr
Runoff Rate: 0.002 L/min  0.00 in/hr
Infiltration Rate: 0.863 L/min  2.28 in/hr

Results: Plot has a lot of infiltration that is deep (greater than 2 feet). Infiltration on downhill side of plot has greater infiltration and infiltration depth decreases slightly uphill. Plot seems to be uniformly wetted.
Site 7

**Date and time:** 7/25/2013 @ 12:20

**Slope %:** 45

**Area m²:** 0.912

**Location:** South fork on Cemex/Swanton boundary.

**Vegetation:** Redwood and tanoak. Duff is thick composed of redwood and tanoak litter. Blackberry, fern, and wild iris present in area. Duff ranges from 1-2" thickness. Below duff is decomposed duff and below that is soil. Soil has mycelium in it.

**Soils:** No soils recorded in field book.

### Calibration:

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<th>Time on</th>
<th>0.6</th>
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</thead>
<tbody>
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<td>Time off</td>
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<table>
<thead>
<tr>
<th>Volume</th>
<th>mL/30s</th>
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</thead>
<tbody>
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<td>Volume 4</td>
<td>425 mL/30s</td>
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<td>Volume 5</td>
<td>420 mL/30s</td>
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**Slope corrected rainfall rate:**

- **2.15 in/hr**
- **0.83 L/min**

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</table>

**Simulation stopped**

Final Depth

**Simulation Results:**

- **Total Rain:** 58.10 L, 2.51 in
- **Total Runoff:** 0.61 L, 0.03 in
- **Runoff Ratio:** 0.0106
- **Rainfall Rate:** 0.830 L/min, 2.15 in/hr
- **Runoff Rate:** 0.011 L/min, 0.03 in/hr
- **Infiltration Rate:** 0.819 L/min, 2.12 in/hr
Results: Water infiltrated through duff and soil. Water infiltrated soil greater than 8 inches in some areas of plot. Large pockets of wetness throughout the plot. Some areas below duff was dry and could be attributed to mycorrhizal fungi.
Site 8

Date and time: 7/16/2013 @ 13:00
Slope %: 50
Area m²: 1.0
Location: Boyer Creek burned. Sunny weather and on a southeast facing slope.
Vegetation: Knobcone pine, dead knobcone, manzanita, some deerweed-Those seedlings and deerweed were removed.
Soils: No continuous duff layer present, mostly rock fragments. Some are charred but mostly larger coarse fragments. Thickness of this rock layer ranges from 0.25" to about 1".

Calibration:

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<thead>
<tr>
<th>Time on</th>
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</thead>
<tbody>
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<tr>
<td>Volume 1</td>
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<tr>
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<tr>
<td>Volume 3</td>
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<tr>
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<tr>
<td>Volume 5</td>
<td>420 mL/30s</td>
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Slope corrected rainfall rate: 2.00 in/hr
0.85 L/min

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<th>Runoff Volume (L)</th>
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<td>Time (min)</td>
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<td>Rainfall (in)</td>
<td>Runoff Rate (L/min)</td>
<td>Infiltration Rate (L/min)</td>
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<td>--------------</td>
<td>---------------------</td>
<td>--------------------------</td>
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<td>37.22</td>
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<td>57.53</td>
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<td>Final depth is 1.08</td>
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</table>

**Results:** Infiltration is only in topmost layer of rock and charcoaled soil/material. Below the rock is ashy layer about 0.5” to 1” with smaller rock fragments. Below ash/soil is larger rock.
There was a very high runoff rate, we had to empty the bucket midway through. Ash layer is hydrophobic and water does not infiltrate below rock/surface layer.
Site 9

*Date and time:* 7/3/2013 @ 14:40  
*Slope %:* 62  
*Area m²:* 0.850  
*Location:* Mill Creek ridgeline unburned. Sunny, warm weather with some wind gusts.  
*Vegetation:* Thick duff layer composed of manzanita, knobcone, chamise. Duff is 2-3” thick, below is decomposed duff and some mycorrhizal fungi. Below is soil and Mycorrhizal fungi.  
*Soils:* Granite parent material.

**Calibration:**

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<th>Time off</th>
</tr>
</thead>
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<table>
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<tr>
<td>Volume 3</td>
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<tr>
<td>Volume 4</td>
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**Slope corrected rainfall rate:**

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<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
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</thead>
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<td>42.35</td>
<td>0.61</td>
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</tr>
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</table>

2.68 in/hr  
0.96 L/min
Results: Only the top 2-3” Duff layer was moist. Below that, the decomposed layer was not saturated. The soil underneath all of this was not moist and had a lot of mycorrhizal fungi woven throughout.
Site 10

**Date and time:** 7/11/2013  
**Slope %:** 36  
**Area m²:** 0.941  
**Location:** Lockheed ridge (aka LeHi); Southeast facing slope.  
**Vegetation:** Deer weed, a couple pine needles.  
**Soils:** No duff layer present, there are shards of small rock-Mudstone. Some pieces are charred and black. Below rocks there is an ash layer—so I think. Some black charcoal present. Below the 1 cm ash is hydrophobic layer.

**Calibration:**

<table>
<thead>
<tr>
<th>Time on</th>
<th>Time off</th>
<th>Volume 1</th>
<th>Volume 2</th>
<th>Volume 3</th>
<th>Volume 4</th>
<th>Volume 5</th>
<th>Volume 6</th>
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<td>380 mL/30s</td>
<td>370 mL/30s</td>
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**Slope corrected rainfall rate:**  
1.99 in/hr  
0.79 L/min

<table>
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<th>Bucket Water Depth (in)</th>
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<th>Runoff Volume (L)</th>
<th>Notes</th>
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</tr>
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</tr>
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</tbody>
</table>

Simulator stopped at 60 min and final depth is 0.77

Total Rain: 49.08 L 2.05 in  
Total Runoff: 1.07 L 0.04 in  
Runoff Ratio: 0.0217

Rainfall Rate: 0.792 L/min 1.99 in/hr  
Runoff Rate: 0.021 L/min 0.05 in/hr  
Infiltration Rate: 0.771 L/min 1.94 in/hr

**Results:** Water stayed within the top 1 cm of soil below soil at 1 cm it is hydrophobic. Water did not infiltrate below 1 cm.
Site 11

**Date and time:** 7/22/2013 @ 12:34

**Slope %:** 36

**Area m²:** 0.941

**Location:** Lockheed ridge (LeHi) on Lockheed Martin Property Ridgetop. Northwest facing slopes

**Vegetation:** Site has leather oak, maybe scrub oak? Some knobcone pine needles and some madrone litter. Some lichen and cones present in the plot. Duff layer is about 0.5-1.5” thick.

**Soils:** Soil was below the duff layer. Some rocks present in soil.

### Calibration:

<table>
<thead>
<tr>
<th>Time on</th>
<th>Volume 1</th>
<th>Volume 2</th>
<th>Volume 3</th>
<th>Volume 4</th>
<th>Volume 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>445 mL/30s</td>
<td>465 mL/30s</td>
<td>480 mL/30s</td>
<td>450 mL/30s</td>
<td>445 mL/30s</td>
</tr>
</tbody>
</table>

### Slope corrected rainfall rate:

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
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<td>1.83</td>
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<tr>
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<td>constant flow at 5:25</td>
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<tr>
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<td>29.25</td>
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<td></td>
</tr>
<tr>
<td>34</td>
<td>0.45</td>
<td>31.08</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>0.48</td>
<td>32.90</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>0.51</td>
<td>34.73</td>
<td>0.70</td>
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</tr>
<tr>
<td>40</td>
<td>0.54</td>
<td>36.56</td>
<td>0.75</td>
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</table>

2.29 in/hr

0.91 L/min
<table>
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<tr>
<th>Time (min)</th>
<th>Runoff</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.57</td>
<td>38.39</td>
</tr>
<tr>
<td>44</td>
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<td>40.22</td>
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<tr>
<td>46</td>
<td>0.63</td>
<td>42.04</td>
</tr>
<tr>
<td>48</td>
<td>0.66</td>
<td>43.87</td>
</tr>
<tr>
<td>50</td>
<td>0.69</td>
<td>45.70</td>
</tr>
<tr>
<td>52</td>
<td>0.72</td>
<td>47.53</td>
</tr>
<tr>
<td>54</td>
<td>0.75</td>
<td>49.36</td>
</tr>
<tr>
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<td>0.78</td>
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<td>0.8</td>
<td>53.01</td>
</tr>
<tr>
<td>60</td>
<td>0.84</td>
<td>54.84</td>
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<td>62</td>
<td>0.88</td>
<td>56.67</td>
</tr>
<tr>
<td>64</td>
<td>0.9</td>
<td>58.50</td>
</tr>
<tr>
<td>66</td>
<td>0.93</td>
<td>60.32</td>
</tr>
</tbody>
</table>

**Total Rain:** 60.32 L  2.52 in
**Total Runoff:** 1.29 L  0.05 in
**Runoff Ratio:** 0.0214

**Rainfall Rate:** 0.914 L/min  2.29 in/hr
**Runoff Rate:** 0.022 L/min  0.05 in/hr
**Infiltration Rate:** 0.892 L/min  2.24 in/hr

**Results:** Duff retained moisture. Soil below duff remained dry. Was is hydrophobic but not as strongly hydrophobic as other sites previously tested with hydrophobicity.
Site 12

**Date and time:** 7/9/2013 @ 10:46  
**Slope %:** 45  
**Area m²:** 0.912  
**Location:** Boyer Creek control.  
**Vegetation:** Madrone, tanoak, and redwood.  
**Soils:** Tanoak is dominant duff litter, some twigs and some redwood needles. Duff is about 1-2” and below duff is decomposed duff layer with mycorrhizal fungi and below that is soil.

**Calibration:**

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Time on</td>
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<td></td>
</tr>
<tr>
<td>Time off</td>
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<td></td>
</tr>
<tr>
<td>Volume 1</td>
<td>420 mL/30s</td>
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</tr>
<tr>
<td>Volume 2</td>
<td>435 mL/30s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume 3</td>
<td>445 mL/30s</td>
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<td></td>
</tr>
<tr>
<td>Volume 4</td>
<td>415 mL/30s</td>
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</tr>
<tr>
<td>Volume 5</td>
<td>430 mL/30s</td>
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<td></td>
</tr>
</tbody>
</table>

**Slope corrected rainfall rate:** 2.22 in/hr  
0.86 L/min

<table>
<thead>
<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>0</td>
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<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>2</td>
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<td>1.72</td>
<td>0.00</td>
<td>2:52 drips start and quickly after light constant flow</td>
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<tr>
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<td>0.02</td>
<td>3.43</td>
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</tr>
<tr>
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</tr>
<tr>
<td>8</td>
<td>0.04</td>
<td>6.86</td>
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</tr>
<tr>
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<td>0.04</td>
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<td>0.06</td>
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</tr>
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<td>0.06</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.05</td>
<td>12.01</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.06</td>
<td>13.73</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>0.07</td>
<td>15.44</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
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<td>0.07</td>
<td>17.16</td>
<td>0.10</td>
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</tr>
<tr>
<td>22</td>
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<td>18.88</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>0.09</td>
<td>20.59</td>
<td>0.12</td>
<td></td>
</tr>
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<td>26</td>
<td>0.10</td>
<td>22.31</td>
<td>0.13</td>
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</tr>
<tr>
<td>32</td>
<td>0.12</td>
<td>27.46</td>
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</tr>
<tr>
<td>34</td>
<td>0.13</td>
<td>29.17</td>
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</tr>
<tr>
<td>36</td>
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<tr>
<td>40</td>
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<td>34.32</td>
<td>0.21</td>
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</tr>
<tr>
<td>42</td>
<td>0.16</td>
<td>36.04</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>0.17</td>
<td>37.75</td>
<td>0.23</td>
<td></td>
</tr>
</tbody>
</table>
### Results

Infiltration in upper duff and decomposed duff and some infiltration in macropores. However, soil is mostly dry.

---

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Runoff</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>0.175</td>
<td>39.47</td>
</tr>
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<td>48</td>
<td>0.18</td>
<td>41.18</td>
</tr>
<tr>
<td>50</td>
<td>0.19</td>
<td>42.90</td>
</tr>
<tr>
<td>52</td>
<td>0.2</td>
<td>44.62</td>
</tr>
<tr>
<td>54</td>
<td>0.21</td>
<td>46.33</td>
</tr>
<tr>
<td>56</td>
<td>0.22</td>
<td>48.05</td>
</tr>
<tr>
<td>58</td>
<td>0.235</td>
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</tr>
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</tr>
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<td>56.63</td>
</tr>
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</tr>
<tr>
<td>72</td>
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<tr>
<td>74</td>
<td>0.285</td>
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</table>

**Turned off simulator**

**Final Depth**

<table>
<thead>
<tr>
<th>Volume (liters)</th>
<th>Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0053x - 0.0063</td>
<td>0.9975</td>
</tr>
</tbody>
</table>

**Total Rain:** 63.49 L  2.74 in

**Total Runoff:** 0.39 L  0.02 in

**Runoff Ratio:** 0.0062

**Rainfall Rate:** 0.858 L/min  2.22 in/hr

**Runoff Rate:** 0.005 L/min  0.01 in/hr

**Infiltration Rate:** 0.853 L/min  2.21 in/hr
Site 12

**Date and time:** 7/9/2013 @ 14:17
**Slope %:** 43
**Area m²:** 0.919
**Location:** Boyer Creek Control Lockheed Property Unburned. Aspect is South facing slope. This is the second simulation for this site this year. This was done to get more data for unburned sites.
**Vegetation:** Madrone, tanoak, redwood.
**Soils:** Duff is 1-2" thick, mostly tanoak litter. Below the decomposed duff is 0.5-1" thick and contains mycorrhizal fungi. Also in this decomposed layer there are lots of insects and holes.

### Calibration:

<table>
<thead>
<tr>
<th>Time on</th>
<th>Time off</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Volume 1</td>
<td>425 mL/30s</td>
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<tr>
<td>Volume 2</td>
<td>385 mL/30s</td>
</tr>
<tr>
<td>Volume 3</td>
<td>430 mL/30s</td>
</tr>
<tr>
<td>Volume 4</td>
<td>430 mL/30s</td>
</tr>
<tr>
<td>Volume 5</td>
<td>440 mL/30s</td>
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### Slope corrected rainfall rate:

<table>
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<tr>
<th>time (min)</th>
<th>Bucket Water Depth (in)</th>
<th>Rainfall Volume (L)</th>
<th>Runoff Volume (L)</th>
<th>Notes</th>
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<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>1.69</td>
<td>0.00</td>
<td>2:00 drips, 2:20 faster drips</td>
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<tr>
<td>4</td>
<td>0.01</td>
<td>3.38</td>
<td>0.01</td>
<td>3:00 consistent low flow.</td>
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<td>0.05</td>
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<td>0.09</td>
<td>13.50</td>
<td>0.12</td>
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<td>27.01</td>
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<td>28.70</td>
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<tr>
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<td>0.24</td>
<td>30.38</td>
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</table>

Slope corrected rainfall rate: 2.17 in/hr

0.84 L/min
<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Volume (L)</th>
<th>Rainfall (in/hr)</th>
<th>Runoff (L)</th>
<th>Runoff Rate (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>0.25</td>
<td>32.07</td>
<td>0.34</td>
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</tr>
<tr>
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<td>0.27</td>
<td>33.76</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>0.28</td>
<td>35.45</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>0.29</td>
<td>37.14</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>0.31</td>
<td>38.82</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>0.32</td>
<td>40.51</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>0.34</td>
<td>42.20</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>0.36</td>
<td>43.89</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>54</td>
<td>0.37</td>
<td>45.58</td>
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<td>0.38</td>
<td>47.26</td>
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<tr>
<td>62</td>
<td>0.405</td>
<td>52.33</td>
<td>0.56</td>
<td>Turned off simulator @ 60:00</td>
</tr>
</tbody>
</table>

Total Rain: 52.33 L 2.24 in
Total Runoff: 0.57 L 0.02 in
Runoff Ratio: **0.0108**

Rainfall Rate: 0.844 L/min 2.17 in/hr
Runoff Rate: 0.010 L/min 0.03 in/hr
Infiltration Rate: 0.834 L/min **2.14 in/hr**

**Results:** Similar findings as previous site 12. The duff layer is moist but below the mineral surface is dry. Some macropores may have infiltrated some water but moist soil not seen often. Duff retains water very well.
Site 15

**Date and time:** 7/17/2013 @ 10:42  
**Slope %:** 35  
**Area m²:** 0.944  
**Location:** Mill Creek ridge burned.  
**Vegetation:** Plot has some knobcone seedlings and deer weed. They were cut out and trimmed up.  
**Soils:** Shards/pieces of rocks cover surface. Some charred mudstone, mostly fragments and not very large rocks. Below rock surface is charred duff and soil, and more rock. Below this is ash I think. There are also a lot of roots present in soil. Not large roots but small to fine sized.

### Calibration:

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Slope corrected rainfall rate:  

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**Results:** Some infiltration in upper layers (rock down to soil and black charred soil/material). Beneath these layers what looks to be grey ash and it is not wet. It is hydrophobic. Also, we had to empty bucket midway through because of the high runoff rate. Uneven depths of infiltration. 0.5cm to 3 and 4 cm. Sometimes infiltration was greater and that was dependent on the depth of soil and charred organic matter present.
# Appendix G. Mini-disk Infiltrometer Field Data

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|------|----------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 2012 | 8/7/2012 | 1314 | 5    | 80   | M    | Hot  | 5M   | W    | L    | 2    | 3    | 2    | 2    | 2    | 2    |       |      |
| 2012 | 8/7/2012 | 1314 | 5    | 80   | M    | Hot  | 5M   | W    | L    | 2    | 5    | 5    | 5    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 5    | 100  | M    | Hot  | 5M   | W    | L    | 3    | 3    | 3    | 3    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 0    | H    | Hot  | 6H   | N    | U    | 1    | 4    | 4    | 4    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 20   | H    | Hot  | 6H   | N    | U    | 2    | 2    | 2    | 2    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 20   | H    | Hot  | 6H   | N    | U    | 3    | 5    | 5    | 5    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 40   | H    | Hot  | 6H   | N    | U    | 2    | 0    | 0    | 0.5  |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 0    | H    | Hot  | 6H   | N    | U    | 3    | 30   | 30   | 30   |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 20   | H    | Hot  | 6H   | N    | U    | 4    | 9    | 9    | 9    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 60   | H    | Hot  | 6H   | N    | U    | 2    | 24   | 24   | 24   |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 60   | H    | Hot  | 6H   | N    | U    | 3    | 3    | 3    | 3    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 40   | H    | Hot  | 6H   | N    | U    | 3    | 30   | 30   | 30   |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 40   | H    | Hot  | 6H   | N    | U    | 2    | 3    | 3    | 3    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 60   | H    | Hot  | 6H   | N    | U    | 1    | 9    | 9    | 9    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 80   | H    | Hot  | 6H   | N    | U    | 2    | 24   | 24   | 24   |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 40   | H    | Hot  | 6H   | N    | U    | 7    | 7    | 7    |      |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 80   | H    | Hot  | 6H   | N    | U    | 2    | 0    | 0    | 0.5  |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 100  | H    | Hot  | 6H   | N    | U    | 1    | 0    | 0    | 0.5  |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 100  | H    | Hot  | 6H   | N    | U    | 2    | 6    | 6    | 6    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 6    | 100  | H    | Hot  | 6H   | N    | U    | 3    | 4    | 4    | 4    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 7    | 0    | H    | Hot  | 7H   | N    | U    | 2    | 2    | 2    | 2    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 7    | 0    | H    | Hot  | 7H   | N    | U    | 2    | 2    | 2    | 2    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 7    | 20   | H    | Hot  | 7H   | N    | U    | 2    | 1    | 1    | 1    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 7    | 20   | H    | Hot  | 7H   | N    | U    | 3    | 2    | 2    | 2    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 7    | 40   | H    | Hot  | 7H   | N    | U    | 1    | 1    | 1    | 1    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 7    | 40   | H    | Hot  | 7H   | N    | U    | 2    | 1    | 1    | 1    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 7    | 60   | H    | Hot  | 7H   | N    | U    | 3    | 5    | 5    | 5    |      |      |      |      |
| 2012 | 8/7/2012 | 1314 | 7    | 60   | H    | Hot  | 7H   | N    | U    | 3    | 2    | 2    | 2    |      |      |      |      |
| 2012 | 8/2/2012 | 1309 | 7    | 0    | H    | Hot  | 7H   | N    | U    | 2    | 2    | 2    | 2    |      |      |      |      |
| 2012 | 8/2/2012 | 1309 | 7    | 20   | H    | Hot  | 7H   | N    | U    | 2    | 1    | 1    | 1    |      |      |      |      |
| 2012 | 8/2/2012 | 1309 | 7    | 20   | H    | Hot  | 7H   | N    | U    | 3    | 2    | 2    | 2    |      |      |      |      |
| 2012 | 8/2/2012 | 1309 | 7    | 40   | H    | Hot  | 7H   | N    | U    | 1    | 1    | 1    | 1    |      |      |      |      |
| 2012 | 8/2/2012 | 1309 | 7    | 40   | H    | Hot  | 7H   | N    | U    | 2    | 1    | 1    | 1    |      |      |      |      |
| 2012 | 8/2/2012 | 1309 | 7    | 60   | H    | Hot  | 7H   | N    | U    | 3    | 5    | 5    | 5    |      |      |      |      |
| 2012 | 8/2/2012 | 1309 | 7    | 60   | H    | Hot  | 7H   | N    | U    | 3    | 2    | 2    | 2    |      |      |      |      |
|------|--------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 2012 | 8/2/2012 | 1309 | 7     | 80    | H     | Hot   | 7H    | N     | U     | 1     | 1     | 1      | 1      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |</p>
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## Appendix I. Rainfall Simulation Data utilized in R

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Appendix J. R Code and output for rainfall simulation dataset.

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library("chron")
library("lattice")
library("car")
library(nlme)

raindat.old <- raindat
# Note well the replicated measurement at Upper Boyer in 2013 was entered
# in "rainsim2013.csv" as one averaged record instead of two.
# Runoff ratio was calc'ed as the ratio of total runoff to total rainfall
# Also the negative infiltration rate for site 10 in 2009 was set to zero.
raindat <- read.csv("rainsim2013.csv")
raindat$sitenum <- paste(format(raindat$sitenum,width=2),
                       substring(raindat$burn.sev,1,1), sep="")
raindat$sitenum <- ordered(raindat$sitenum)
raindat$burn.sev <- ordered(raindat$burn.sev, levels = c("None","Low","Moderate","High"))
raindat$date <- dates(as.character(raindat$date))
raindat$year <- years(raindat$date)
raindat$time <- as.numeric(raindat$date - dates("1/1/2009"))
# In the first round, results varied somewhat depending on the time shift
# raindat$time <- as.numeric(raindat$date)
xyplot(inf.rate ~ date | sitename, data=raindat, type="b",xlab="",ylab="Infiltration rate")
```
xyplot(inf.rate ~ date | burn.sev, data=raindat, ylab="Infiltration rate", xlab="")

xyplot(ro.ratio ~ date | sitename, data=raindat, type="b", xlab="", ylab="Runoff ratio")
Boyer and Scott's Mill Burned were both hot burns. The other hot burns: Mill/Bouy. and Lions Flat were not measured in the first year so might have followed the same pattern. Cabins is a moderate burn and UNF is a Low intensity burn, and these do show the expected reduced response but in the same pattern. The bugaboo is that the Burned and Control at Scott's Mill behaved identically.

```r
xplot(ro.ratio ~ date | burn.sev, data=raindat,xlab="",ylab="Runoff ratio")
```
Bugaboo is the 2009 point in None (from ScottsMill Control)
Notes say "Natural Hydrophobicity Observed". Could it be due to ash fall?

What would have really enhanced this study is more measurements in 2009.
xyplot(inf.rate ~ date | burn.sev=="High", data=raindat, xlab="", ylab="Infiltration rate")

xyplot(ro.ratio ~ date | burned, data=raindat, xlab="", ylab="Runoff ratio")
raindat.gd <- groupedData(inf.rate ~ time | sitenum, outer =~ burn.sev, data=raindat)
,
# The above is similar to an xy plot shown earlier.

```r
superpose.line <- trellis.par.get("superpose.line")
superpose.line$col <- rainbow(13)
superpose.line$lwd <- 2
superpose.line$lty <- 1:2
trellis.par.set("superpose.line", superpose.line)

plot(raindat.gd, outer=T, aspect=1, layout=c(4,1), xlab="Days since 12/31/2008", ylab="Infiltration rate")
```
options(contrasts= c("contr.treatment", "contr.treatment"))
# Forces ordered factors to use treatment contrasts
# Note this affects the p-values in the summary
ir.fit1 <- lme(inf.rate ~ time * burn.sev, raindat.gd, random = ~ time)

anova(ir.fit1)
# Note: by default anova does sequential tests, i.e. each p-value is the significance of
# the given variable when added to a model defined by the variables listed above that
# variable. i.e. it tests the variables entering the model in the specific sequence shown
numDF denDF F-value p-value
(Intercept) 1 37 1430.7228 <.0001
time 1 37 30.6441 <.0001
burn.sev 3 9 1.3518 0.3182
time:burn.sev 3 37 0.4545 0.7157
# Only time is significant
# Burn severity and its interaction with time is not

anova(ir.fit1,type="marginal")
# The marginal p-values compare the full model to a model that omits the variable on that
# line. i.e. it tests each variable as the final variable added to the model.
numDF denDF F-value p-value
(Intercept) 1 37 12.137905 0.0013
time 1 37 8.816425 0.0052
burn.sev          3     9  0.902008  0.4773
time:burn.sev     3    37  0.454490  0.7157

qqnorm(resid(ir.fit1,type="p"))
qqline(resid(ir.fit1,type="p"))
ir.fit1a <- update(ir.fit1, weights = varPower())
anova(ir.fit1, ir.fit1a)

<table>
<thead>
<tr>
<th>Model</th>
<th>df</th>
<th>AIC</th>
<th>BIC</th>
<th>logLik</th>
<th>Test</th>
<th>L.Ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ir.fit1</td>
<td>1</td>
<td>12</td>
<td>42.09187</td>
<td>64.03557</td>
<td>-9.045936</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ir.fit1a</td>
<td>2</td>
<td>13</td>
<td>43.38869</td>
<td>67.16103</td>
<td>-8.694347</td>
<td>1 vs 2</td>
<td>0.7031784 0.4017</td>
</tr>
</tbody>
</table>

# No need for the variance function; residuals distribution is OK

# Try contrasting High burn severity with all the other levels
ir.fit2 <- lme(inf.rate ~ time * (burn.sev=="High"), raindat.gd, random = ~ time)
anova(ir.fit2)

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>39</td>
<td>1552.4170</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>39</td>
<td>37.2899</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>burn.sev == &quot;High&quot;</td>
<td>1</td>
<td>11</td>
<td>4.5467</td>
<td>0.0564</td>
</tr>
<tr>
<td>time:burn.sev == &quot;High&quot;</td>
<td>1</td>
<td>39</td>
<td>1.6424</td>
<td>0.2076</td>
</tr>
</tbody>
</table>

anova(ir.fit2, type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>39</td>
<td>27.480131</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>39</td>
<td>19.029008</td>
<td>0.0001</td>
</tr>
<tr>
<td>burn.sev == &quot;High&quot;</td>
<td>1</td>
<td>11</td>
<td>3.334351</td>
<td>0.0951</td>
</tr>
<tr>
<td>time:burn.sev == &quot;High&quot;</td>
<td>1</td>
<td>39</td>
<td>1.642429</td>
<td>0.2076</td>
</tr>
</tbody>
</table>

# There is not a significant difference in the rate of change of infiltration between High burn severity and all the others.
# But of course there is a time trend in the High severity burns, and it seems more pronounced than at least the Moderate and Low burn levels:

```r
summary(lme(inf.rate ~ time, raindat.gd, subset=burn.sev=="High", random = ~ time))
```

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Std.Error</th>
<th>DF</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>0.1378</td>
<td>0.1019</td>
<td>11</td>
<td>1.3518</td>
<td>0.2036</td>
</tr>
<tr>
<td>time</td>
<td>0.0005</td>
<td>0.0001</td>
<td>11</td>
<td>5.6998</td>
<td>0.0001</td>
</tr>
<tr>
<td>Number of Observations: 16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Groups: 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

```r
summary(lme(inf.rate ~ time, raindat.gd, subset=burn.sev=="Moderate", random = ~ time))
```

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Std.Error</th>
<th>DF</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>0.461</td>
<td>0.171</td>
<td>8</td>
<td>2.6935</td>
<td>0.0273</td>
</tr>
<tr>
<td>time</td>
<td>0.0003</td>
<td>0.0001</td>
<td>8</td>
<td>2.1199</td>
<td>0.0668</td>
</tr>
<tr>
<td>Number of Observations: 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Groups: 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

```r
summary(lme(inf.rate ~ time, raindat.gd, subset=burn.sev=="Low", random = ~ time))
```

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Std.Error</th>
<th>DF</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>0.448</td>
<td>0.150</td>
<td>3</td>
<td>2.9829</td>
<td>0.0585</td>
</tr>
<tr>
<td>time</td>
<td>0.0003</td>
<td>0.0001</td>
<td>3</td>
<td>2.1024</td>
<td>0.1263</td>
</tr>
<tr>
<td>Number of Observations: 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Groups: 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

```r
summary(lme(inf.rate ~ time, raindat.gd, subset=burn.sev=="None", random = ~ time))
```

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Std.Error</th>
<th>DF</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>0.4672</td>
<td>0.1466</td>
<td>15</td>
<td>3.1865</td>
<td>0.0061</td>
</tr>
<tr>
<td>time</td>
<td>0.0003</td>
<td>0.0001</td>
<td>15</td>
<td>2.5659</td>
<td>0.0215</td>
</tr>
<tr>
<td>Number of Observations: 21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Groups: 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

# But as the coefficient of time:burn.sevHigh in ir.fit1 shows, High and None aren't significantly different

```r
time:burn.sevHigh    0.0001525 0.00015295 37  0.996788 0.3253
```

# WE could have done this with simple regression, although it ignores the relation between observations from the same site. Conclusions are similar though.

```r
ir.lm1 <- lm(inf.rate ~ time * burn.sev, data=raindat)
```

**Coefficients:**

|                | Estimate | Std. Error | t value | Pr(>|t|) |
|----------------|----------|------------|---------|---------|
| (Intercept)    | 4.223e-01| 8.330e-02  | 5.069   | 6.96e-06*** |
| time           | 3.246e-04| 7.380e-05  | 4.398   | 6.41e-05*** |
| burn.sevLow    | 2.630e-02| 1.744e-01  | 0.151   | 0.8808  |
| burn.sevModerate| 2.367e-02| 1.334e-01  | 0.177   | 0.8599  |
| burn.sevHigh   | -3.057e-01| 1.264e-01  | -2.418  | 0.0196  * |
| time:burn.sevLow| -3.075e-05| 1.604e-04  | -0.192  | 0.8488  |
| time:burn.sevModerate| -3.172e-05| 1.213e-04  | -0.262  | 0.7949  |
| time:burn.sevHigh| 1.732e-04| 1.143e-04  | 1.515   | 0.1366  |

# Looks like high is different than None this time, but the interaction still is NOT

# Contrast None and High directly
summary(lm(inf.rate ~ time * burn.sev, data=raindat, subset=burn.sev %in% c("None","High")))

|            | Estimate | Std. Error | t value | Pr(>|t|) |
|------------|----------|------------|---------|----------|
| (Intercept)| 4.223e-01| 8.250e-02  | 5.119   | 1.30e-05 *** |
| time       | 3.246e-04| 7.309e-05  | 4.441   | 9.48e-05 *** |
| burn.sevHigh| -3.057e-01| 1.252e-01 | -2.442  | 0.0202 *    |
| time:burn.sevHigh| 1.732e-04| 1.132e-04 | 1.530  | 0.1356       |

# Agreement with above except in degrees of freedom

# Contrast High and all others
summary(lm(inf.rate ~ time * (burn.sev="High"), data=raindat))

|            | Estimate | Std. Error | t value | Pr(>|t|) |
|------------|----------|------------|---------|----------|
| (Intercept)| 4.336e-01| 5.747e-02  | 7.545   | 8.46e-10 *** |
| time       | 3.106e-04| 5.190e-05  | 5.983   | 2.32e-07 *** |
| burn.sev == "High"TRUE| -3.171e-01| 1.079e-01 | -2.939  | 0.00498 ** |
| time:burn.sev == "High"TRUE| 1.872e-04| 9.856e-05| 1.899  | 0.06330 . |

# The interaction is NOT significant, so the time trend does not depend on burn severity

# Back to mixed effects modeling. What happens if Scotts Mill Control is dropped from the analysis?
anova(lme(inf.rate ~ time * burn.sev, raindat.gd, random = ~ time, subset=sitenum!="11N"))

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>33</td>
<td>1368.3174</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>33</td>
<td>37.4461</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>burn.sev</td>
<td>3</td>
<td>8</td>
<td>1.8869</td>
<td>0.2102</td>
</tr>
<tr>
<td>time:burn.sev</td>
<td>3</td>
<td>33</td>
<td>1.4896</td>
<td>0.2354</td>
</tr>
</tbody>
</table>

# Burn severity and its interaction is still not significant

# What if just observation 38 is dropped from the analysis
anova(lme(inf.rate ~ time * burn.sev, raindat.gd, random = ~ time, subset=38))

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>36</td>
<td>1484.1907</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>36</td>
<td>39.2095</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>burn.sev</td>
<td>3</td>
<td>9</td>
<td>1.7686</td>
<td>0.2229</td>
</tr>
<tr>
<td>time:burn.sev</td>
<td>3</td>
<td>36</td>
<td>0.9831</td>
<td>0.4115</td>
</tr>
</tbody>
</table>

# Omit Scotts Mill Control from the model that contrasts High with all the others
anova(lme(inf.rate ~ time * (burn.sev="High"), raindat.gd, random = ~ time, subset=sitenum!="11N"))

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>35</td>
<td>1479.4521</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>35</td>
<td>43.4146</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>burn.sev == &quot;High&quot;</td>
<td>1</td>
<td>10</td>
<td>5.7872</td>
<td>0.037</td>
</tr>
<tr>
<td>time:burn.sev == &quot;High&quot;</td>
<td>1</td>
<td>35</td>
<td>4.5493</td>
<td>0.040</td>
</tr>
</tbody>
</table>

# Only now does it look barely significant.

# What about runoff ratio as a response

raindat.gd2 <- groupedData(ro.ratio ~ time | sitenum, outer = ~ burn.sev, data=raindat)
plot(raindat.gd2, outer=T, aspect=1, layout=c(4,1), xlab="Days since 12/31/2008", ylab="Runoff ratio")
# So 2012 and 2013 look like post-recovery years similar to 2011 (irrespective of burn intensity. This analysis looks even more sensitive to the 2009 point at Scotts Mill Control

ro.fit1 <- lme(ro.ratio ~ time * burn.sev, raindat.gd2, random = ~ time)
plot(ro.fit1)
qqnorm(resid(ro.fit1,type="p"))
qqline(resid(ro.fit1,type="p"))
# Not a good residuals distribution
# Try transforming the response; cannot do logarithms because one of the responses=0

ro.fit2 <- lme(sqrt(ro.ratio) ~ time * burn.sev, raindat.gd2, random = ~ time)
Residuals are much closer to a normal distribution. The outlier is 11N 2009.

```r
anova(ro.fit2)
  numDF denDF  F-value p-value
(Intercept)   1  37  110.07016   <.0001
time          1  37   56.27666   <.0001
burn.sev      3   9   1.89646   0.2007
time:burn.sev 3  37   0.87861   0.4610
```

```r
anova(ro.fit2, type="marginal")
  numDF denDF  F-value p-value
(Intercept)   1  37  27.779296  <.0001
time          1  37  13.178069   0.0009
burn.sev      3   9  1.737430   0.2288
time:burn.sev 3  37  0.878608   0.4610
```

# Burn severity and its interaction are not significant

```r
# Contrast High burn severity with others
ro.fit2a <- lme(sqrt(ro.ratio) ~ time * (burn.sev=="High"), raindat.gd2, random = ~
              time)
anova(ro.fit2a, type="sequential")
  numDF denDF  F-value p-value
(Intercept)   1  39  139.97077  <.0001
time          1  39  67.20444  <.0001
burn.sev == "High" 1  11  7.01215   0.0227
time:burn.sev == "High" 1  39  2.48822   0.1228
```

# Contrast Unburned with others

321
```r
ro.fit2b <- lme(sqrt(ro.ratio) ~ time * (burn.sev=="None"), raindat.gd2, random = ~time)
anova(ro.fit2b)

numDF denDF F-value p-value
(Intercept) 1 39 75.24670 <.0001
time 1 39 54.58454 <.0001
burn.sev == "None" 1 11 0.72694 0.4121
time:burn.sev == "None" 1 39 1.62048 0.2106

# Contrast "High" and "None"
ro.fit2c <- lme(sqrt(ro.ratio) ~ time * (burn.sev=="High"), raindat.gd2, random = ~time, subset=burn.sev %in% c("High","None"))
anova(ro.fit2c)

numDF denDF F-value p-value
(Intercept) 1 26 73.92108 <.0001
time 1 26 34.16429 <.0001
burn.sev == "High" 1 7 3.64807 0.0978
time:burn.sev == "High" 1 26 2.15876 0.1538

# Burn severity does not affect the trend in any of the above (interaction NS)

# What if just one outlier is discarded, first year at site 11N
plot(raindat.gd2, outer=T, aspect=1, layout=c(4,1), subset=-38,xlab="Days since 12/31/2008",ylab="Runoff ratio")

ro.fit3 <- lme(sqrt(ro.ratio) ~ time * burn.sev, raindat.gd2, random = ~ time, subset=-38)
```
par(mfrow=c(1,2))
plot(fitted(ro.fit3), resid(ro.fit3,type="p"), xlab="Fitted values", ylab="Standardized residuals")
abline(0,0)
qqresid(ro.fit3)

# Very nice distribution of residuals

anova(ro.fit3)

numDF  denDF   F-value  p-value
(Intercept)  1  36 251.61640  <.0001
time         1  36  97.94409  <.0001
burn.sev     3   9  5.44986  0.0206
time:burn.sev 3  36  3.62551  0.0220

anova(ro.fit3,type="marginal")

numDF  denDF   F-value  p-value
(Intercept)  1  36 35.04656  <.0001
time         1  36 12.15793  0.0013
burn.sev     3   9  6.83808  0.0107
time:burn.sev 3  36  3.62551  0.0220

# NOW there is a significant interaction

# Only in the runoff model and only when observation 38 is dropped does there appear to
# be a significant interaction between burn severity and time. This makes sense looking at
# the data
For infiltration rate models, the interaction was only significant when (1) Scotts Mill Control was entirely removed from the analysis, AND only in the model contrasting "High" burn severity with all others. And only marginally significant (p=0.04). Hence not very convincing at all.

Wikipedia calls this multilevel modeling
http://en.wikipedia.org/wiki/Multilevel_modeling_for_repeated_measures
More generally it's a subcategory of mixed-effects models

If we had measurements from every site each year it could be analyzed as a repeated measures nested ANOVA, with sites nested within burn levels. But the unbalanced nature makes it even more difficult to analyze than usual for repeated measures analyses. You can disaggregate and analyze each burn level individually (which I did above using subset), but you still have a random effect from each site; it doesn't represent the fact that each site might have its own regression line. Or you could ignore that and just look for differences between the trends at each burn level (which I did above using lm).

Recommend coding so that all site descriptors are invariant at a site. I've done that for burn severity and some others.
Refer to section 3.2.1 Bodyweight data set pp 104-106, 221, 427
II. Analyze fixed-effects of veg type and slope

> table(raindat$veg)

<table>
<thead>
<tr>
<th></th>
<th>RW</th>
<th>RW/DF</th>
<th>RW/TO</th>
<th>TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>KP/manz</td>
<td>23</td>
<td>3</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>RW</td>
<td>24</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>TO</td>
<td>7</td>
<td></td>
<td></td>
<td>7</td>
</tr>
</tbody>
</table>

# Define coarse veg type
raindat$v3 <- factor(substr(raindat$veg,1,2))
raindat.gd3 <- groupedData(inf.rate ~ time | sitenum, outer = ~ v3, data=raindat.gd)

> table(raindat$v3)

<table>
<thead>
<tr>
<th></th>
<th>RW</th>
<th>TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>KP</td>
<td>23</td>
<td>7</td>
</tr>
<tr>
<td>RW</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>

# Look at the time trend for each veg type
library(lattice)

xyplot(inf.rate ~ date | v3, data=raindat, ylab="Infiltration rate", xlab="",
       panel=function(x,y) {
         panel.xyplot(x,y)
         panel.loess(x,y,span=1)
       })
xyplot(sqrt(ro.ratio) ~ date | v3, data=raindat, ylab="Square root of runoff ratio", xlab="", panel=function(x,y) {
  panel.xyplot(x,y)
  panel.loess(x,y, span=1)
})
# Doesn't look like there is a vegetation effect

```r
ir.vegfit <- lme(inf.rate ~ time * v3, raindat.gd3, random = ~ time)
ro.vegfit <- lme(sqrt(ro.ratio) ~ time * v3, raindat.gd3, random = ~ time)
par(mfrow=c(1,2))
qqresid(ir.vegfit)
qqresid(ro.vegfit)
```
These look pretty good

```
anova(ir.vegfit)
  numDF denDF   F-value p-value
     (Intercept)     1    38 1374.4628  <.0001
       time            1    38   35.6230  <.0001
       v3              2    10    1.0775  0.3769
       time:v3         2    38    1.0059  0.3753
# Vegetation and its interaction with time are not significant for infiltration rate
```

```
anova(ro.vegfit)
  numDF denDF   F-value p-value
     (Intercept)     1    38 111.81047  <.0001
       time            1    38  54.76643  <.0001
       v3              2    10   3.04192  0.0929
       time:v3         2    38   0.71506  0.4956
# Vegetation and its interaction with time are not significant for runoff ratio
```

# Test for a slope effect

```
xplot(inf.rate ~ slope | year, data=raindat, ylab="Infiltration rate", xlab="Slope", panel=function(x,y) {
  panel.xyplot(x,y)
  panel.loess(x,y,span=1)
})
xplot(inf.rate ~ slope | v3, data=raindat, ylab="Infiltration rate", xlab="Slope", panel=function(x,y) {
  panel.xyplot(x,y)
  panel.loess(x,y,span=1)
})
```
xyplot(sqrt(ro.ratio) ~ slope | year, data=raindat, ylab="Square root of runoff ratio", xlab="Slope",
    panel=function(x,y) {
        panel.xyplot(x,y)
        panel.loess(x,y,span=1)
    })

xyplot(sqrt(ro.ratio) ~ slope | v3, data=raindat, ylab="Square root of runoff ratio ", xlab="Slope",
    panel=function(x,y) {
        panel.xyplot(x,y)
        panel.loess(x,y,span=1)
    })
ir.slopefit <- lme(inf.rate ~ time*slope, raindat.gd3, random = ~ time)
ro.slopefit <- lme(sqrt(ro.ratio) ~ time*slope, raindat.gd3, random = ~ time)
```r
> anova(ir.slopefit)
numDF denDF  F-value p-value
(Intercept) 1 38 1464.1077 <.0001
time 1 38 25.7454 <.0001
slope 1 38 0.0107 0.9181
time:slope 1 38 1.8020 0.1874

> anova(ro.slopefit)
numDF denDF  F-value p-value
(Intercept) 1 38 50.27700 <.0001
time 1 38 49.58711 <.0001
slope 1 38 0.41476 0.5234
time:slope 1 38 0.01192 0.9136

# No slope effect

# Fixed effects models
> anova(lm(sqrt(ro.ratio) ~ slope*v3, data=raindat))
Analysis of Variance Table

Response: sqrt(ro.ratio)
 Df Sum Sq Mean Sq F value Pr(>F)
slope 1 0.0000 0.000000 0.0000 0.9983
v3 2 0.2281 0.114048 2.2784 0.1134
slope:v3 2 0.0456 0.022800 0.4555 0.6368
Residuals 48 2.4026 0.050055

> anova(lm(inf.rate ~ slope*v3, data=raindat))
Analysis of Variance Table

Response: inf.rate
 Df Sum Sq Mean Sq F value Pr(>F)
```
slope    1  0.00468  0.004675  0.0848  0.7721
v3       2  0.15675  0.078374  1.4218  0.2513
slope:v3 2  0.06985  0.034924  0.6336  0.5351
Residuals 48  2.64596  0.055124

# No slope or vegetation effects

ir.slopefit <- lme(inf.rate ~ slope*v3, raindat.gd3, random = ~ 1)
anova(ir.slopev3fit,type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>38</td>
<td>10.939733</td>
<td>0.0021</td>
</tr>
<tr>
<td>slope</td>
<td>1</td>
<td>38</td>
<td>0.159537</td>
<td>0.6918</td>
</tr>
<tr>
<td>v3</td>
<td>2</td>
<td>10</td>
<td>1.120235</td>
<td>0.3639</td>
</tr>
<tr>
<td>slope:v3</td>
<td>2</td>
<td>38</td>
<td>0.633560</td>
<td>0.5362</td>
</tr>
</tbody>
</table>

ro.slopefit <- lme(sqrt(ro.ratio) ~ slope*v3, raindat.gd3, random = ~ 1)
anova(ro.slopev3fit,type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>38</td>
<td>3.539286</td>
<td>0.0676</td>
</tr>
<tr>
<td>slope</td>
<td>1</td>
<td>38</td>
<td>0.009734</td>
<td>0.9219</td>
</tr>
<tr>
<td>v3</td>
<td>2</td>
<td>10</td>
<td>1.007054</td>
<td>0.3995</td>
</tr>
<tr>
<td>slope:v3</td>
<td>2</td>
<td>38</td>
<td>0.455492</td>
<td>0.6376</td>
</tr>
</tbody>
</table>

Contrasting Unburned with Burned sites

# Create a factor so that labels on xyplot will be clear
burned <- factor(raindat$burn.sev == "None", labels=c("Burned","Unburned"))

xyplot(inf.rate ~ date | burned, data=raindat, xlab="", ylab="Infiltration rate")
xyplot(ro.ratio ~ date | burned, data=raindat, xlab='', ylab="Runoff ratio")
# Looks like there is a good chance runoff ratio is significantly affected by the above burn dichotomy.

# Contrast Unburned with all others
anova(lme(inf.rate ~  time * (burn.sev=="None"), raindat.gd, random = ~ time),type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>39</td>
<td>9.685144</td>
<td>0.0035</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>39</td>
<td>22.416925</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>burn.sev == &quot;None&quot;</td>
<td>1</td>
<td>11</td>
<td>0.703450</td>
<td>0.4195</td>
</tr>
<tr>
<td>time:burn.sev == &quot;None&quot;</td>
<td>1</td>
<td>39</td>
<td>0.286395</td>
<td>0.5956</td>
</tr>
</tbody>
</table>

# The interaction is NOT significant, so the time trend does not depend on burn severity. The main effect of burning is not even significant.

# Try omitting Scotts Mill Control
anova(lme(inf.rate ~  time * (burn.sev=="None"), raindat.gd, subset= sitenum !="11N", random = ~ time),type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>35</td>
<td>13.45058</td>
<td>0.0008</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>35</td>
<td>32.31901</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>burn.sev == &quot;None&quot;</td>
<td>1</td>
<td>10</td>
<td>3.41879</td>
<td>0.0942</td>
</tr>
<tr>
<td>time:burn.sev == &quot;None&quot;</td>
<td>1</td>
<td>35</td>
<td>2.36307</td>
<td>0.1332</td>
</tr>
</tbody>
</table>

# Still not significant

# Runoff ratio
anova(lme(sqrt(ro.ratio) ~  time * (burn.sev=="None"), raindat.gd2, random = ~ time),type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
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<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>35</td>
<td>13.45058</td>
<td>0.0008</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>35</td>
<td>32.31901</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>burn.sev == &quot;None&quot;</td>
<td>1</td>
<td>10</td>
<td>3.41879</td>
<td>0.0942</td>
</tr>
<tr>
<td>time:burn.sev == &quot;None&quot;</td>
<td>1</td>
<td>35</td>
<td>2.36307</td>
<td>0.1332</td>
</tr>
</tbody>
</table>

# Still not significant
(Intercept)       1   39   78.10397  <.0001
time             1   39   43.14031  <.0001
burn.sev == "None" 1   11   2.22278  0.1641
time:burn.sev == "None" 1   39   1.62048  0.2106

# Again, neither burning nor its interaction with time is significant

# Try omitting observation 38

anova(lme(sqrt(ro.ratio) ~ time * (burn.sev=="None"), raindat.gd2, subset=-38, random = ~ time), type="marginal")

<table>
<thead>
<tr>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
</table>
| (Intercept) | 1   38 130.92437 <.0001
| time          | 1   38  69.00563  <.0001
| burn.sev == "None" | 1   11   8.31619  0.0149
| time:burn.sev == "None" | 1   38   6.45318  0.0153

# Yes now these variables are significant but not strongly

tmpfit <- lme(sqrt(ro.ratio) ~ time * (burn.sev=="None"), raindat.gd2, subset=-38, random = ~ time)

plot(fitted(tmpfit), resid(tmpfit,type="p"),xlab="Fitted values",ylab="Standardized residuals")

abline(0,0)

qqresid(tmpfit)  # Nice normal residuals, just a couple of outliers in the lower tail

Results for the Unburned/Burned dichotomy are consistent with the analyses in which burn severity was a categorical variable with 4 levels.

# Only in the runoff model and only when observation 38 is dropped does there appear to be a significant interaction between burn severity and time.
# For infiltration rate models, the interaction not significant regardless of the inclusion of Scotts Mill Control or observation 38.

**Little Creek Sites**

library("chron")
library("lattice")
library("car")
library(nlme)

# Create new data frame Little Creek sites only
4N: Little Creek
5M: Cabins
6L: UNF
7M: South Fork
13H: Lions Flat
14M: Hillslope

# First trim leading and trailing white space from site numbers
trim <- function (x) gsub("^\s+|\s+$", "", x)
raindat$sitenum <- trim(raindat$sitenum)
# Next extract the Little Creek sites
rainlit <- raindat[raindat$sitenum %in% c("4N","5M","6L","7M","13H","14M"),]
# Eliminate unused categories
rainlit$sitenum <- factor(rainlit$sitenum)
rainlit$sitename <- factor(rainlit$sitename)
table(rainlit$sitenum)

13H 14M 4N 5M 6L 7M
 3 2  4  5  5  5

xyplot(inf.rate ~ date | sitename, data=rainlit, type="b",xlab="",ylab="Infiltration rate")
# Infiltration rate increasing at all sites

```
xyplot(inf.rate ~ date | burn.sev, data=rainlit,ylab="Infiltration rate",xlab="")
```
# The number of Moderates and Lows is unchanged. None and High are highly depleted.
# Lions Flat is the only hot burn and LC Control is the only unburned

```r
xyplot(ro.ratio ~ date | sitename, data=rainlit, type="b", xlab="", ylab="Runoff ratio")
```
Lions Flat is the only hot burn, UNF is a Low intensity burn, LC Control did not burn

Runoff ratio decreasing at all sites

```
xyplot(ro.ratio ~ date | burn.sev, data=rainlit,xlab="",ylab="Runoff ratio")
```
Because of the sample sizes, it doesn't make sense to contrast High or None with the other categories. Contrast (High and Moderate) with (None and Low)

```R
xyplot(inf.rate ~ date | burn.sev%in% c("High","Moderate"), data=rainlit, xlab="", ylab="Infiltration rate")
```
# TRUE indicates High and Moderate burn severity; does not look important

```r
xyplot(ro.ratio ~ date | burn.sev%in% c("High","Moderate"), data=rainlit, xlab="", ylab="Runoff ratio")
```
rainlit.gd <- groupedData(inf.rate ~ time | sitenum, outer = ~ burn.sev, data=rainlit)
plot(rainlit.gd,layout=c(6,1))

# The above is similar to an xy plot shown earlier.
# It's obvious that there is not going to be a statistical difference between the time trends for different burn severity classes

```r
superpose.line <- trellis.par.get("superpose.line")
superpose.line$col <- rainbow(13)
superpose.line$lwd <- 2
superpose.line$lty <- 1:2
trellis.par.set("superpose.line",superpose.line)
```

```r
plot(rainlit.gd, outer=T, aspect=1, layout=c(4,1),xlab="Days since 12/31/2008",ylab="Infiltration rate")
```

```
options(contrasts= c("contr.treatment", "contr.treatment"))
# Forces ordered factors to use treatment contrasts
# Note this affects the p-values in the summary
ir.LCfit1 <- lme(inf.rate ~ time * burn.sev, rainlit.gd, random = ~ time)
anova(ir.LCfit1)
```

```
# Note: by default anova does sequential tests, i.e. each p-value is the significance of the given variable when added to a model defined by the variables listed above that variable. i.e. it tests the variables entering the model in the specific sequence shown
numDF denDF F-value p-value
(Intercept) 1 14 486.7144 <.0001
time 1 14 12.2920 0.0035
burn.sev 3 2 0.2543 0.8549
time:burn.sev 3 14 0.2454 0.8632
# Only time is significant
# Burn severity and its interaction with time is not
```
anova(ir.LCfit1,type="marginal")
# The marginal p-values compare the full model to a model that omits the variable on that line. i.e. it tests each variable as the final variable added to the model.

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>14</td>
<td>1.611484</td>
<td>0.2250</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>14</td>
<td>3.875314</td>
<td>0.0691</td>
</tr>
<tr>
<td>burn.sev</td>
<td>3</td>
<td>2</td>
<td>0.108829</td>
<td>0.9474</td>
</tr>
<tr>
<td>time:burn.sev</td>
<td>3</td>
<td>14</td>
<td>0.245375</td>
<td>0.8632</td>
</tr>
</tbody>
</table>

# Burn severity and its interaction with time are not significant

qqnorm(resid(ir.LCfit1,type="p"))
qqline(resid(ir.LCfit1,type="p"))
# Try contrasting High/Moderate burn severity with Low/None

```r
ir.LCfit2 <- lme(inf.rate ~ time * (burn.sev=='High' | burn.sev=='Moderate'),
data=rainlit.gd, random = ~ time)
```

```
        numDF denDF  F-value p-value
(Intercept)                                          1    16 650.4481  <.0001
time                                                 1    16  17.7786  0.0007
burn.sev == "High" | burn.sev == "Moderate"          1     4   0.1784  0.6944
time:burn.sev == "High" | burn.sev == "Moderate"     1    16   0.0400  0.8440
```

```
anova(ir.LCfit2, type="marginal")
```

```
        numDF denDF  F-value p-value
(Intercept)                                          1    16 8.513564  0.0101
time                                                 1    16  7.677507  0.0136
burn.sev == "High" | burn.sev == "Moderate"          1     4  0.001548  0.9705
time:burn.sev == "High" | burn.sev == "Moderate"     1    16  0.040012  0.8440
```

# There is not a significant difference in the rate of change of infiltration between High/Moderate burn severities and Low/None.

# But it does look like there is a time trend regardless of burn severity

```r
summary(lme(inf.rate ~ time, rainlit.gd, random = ~ time))
```

```
Fixed effects: inf.rate ~ time

                Value  Std.Error  DF   t-value p-value
(Intercept)  0.4289482  0.08124626 17 5.279606  1e-04
```

Normal Q-Q Plot

![Normal Q-Q Plot](image)

Theoretical Quantiles

```r
def qnorm(x, mean=0, sd=1) {
  return(x * sd + mean)
}
```
time 0.0003207 0.00006958 17 4.608703 3e-04
Number of Observations: 24
Number of Groups: 6

summary(lme(ro.ratio ~ time, rainlit.gd, random = ~ time))
Fixed effects: ro.ratio ~ time
   Value    Std.Error  DF  t-value  p-value
(Intercept) 0.27154266 0.04581059 17  5.927508   0e+00
time -0.00019147 0.00003943 17 -4.855538   1e-04
Number of Observations: 24
Number of Groups: 6

# What about runoff ratio as a response

rainlit.gd2 <- groupedData(ro.ratio ~ time | sitenum, outer = ~ burn.sev, data=rainlit)
plot(rainlit.gd2, outer=T, aspect=1, layout=c(4,1), xlab="Days since 12/31/2008", ylab="Runoff ratio", auto.key=list(columns=3))

# 2012 and 2013 look like post-recovery years similar to 2011 (irrespective of burn intensity.
ro.LCfit1 <- lme(ro.ratio ~ time * burn.sev, rainlit.gd2, random = ~ time)
plot(ro.LCfit1)
# The outliers below -1.5 are sites 5M and 6L in 2011, because the trend is non-linear

```r
d <- resid(ro.LCfit1, type="p")
qqnorm(d)
qqline(d)
```

![Q-Q plot of residuals](image)
# Not a good residuals distribution
# Try transforming the response; cannot do logarithms because one of the responses=0
ro.LCfit2 <- lme(sqrt(ro.ratio) ~ time * burn.sev, rainlit.gd2, random =~ time)
# Not really an improvement, but linearity of the time trend is improved (see next section for plots)

```r
> anova(ro.LCfit2)
```

<table>
<thead>
<tr>
<th>Time</th>
<th>NumDF</th>
<th>DenDF</th>
<th>F</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>14</td>
<td>92.92428</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>14</td>
<td>38.14187</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>burn.sev</td>
<td>3</td>
<td>2</td>
<td>0.20550</td>
<td>0.8856</td>
</tr>
<tr>
<td>time:burn.sev</td>
<td>3</td>
<td>14</td>
<td>0.43664</td>
<td>0.7302</td>
</tr>
</tbody>
</table>

```r
> anova(ro.LCfit2,type="marginal")
```

<table>
<thead>
<tr>
<th>Time</th>
<th>NumDF</th>
<th>DenDF</th>
<th>F</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>14</td>
<td>58.26406</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>14</td>
<td>22.72458</td>
<td>0.0003</td>
</tr>
<tr>
<td>burn.sev</td>
<td>3</td>
<td>2</td>
<td>0.59316</td>
<td>0.6769</td>
</tr>
<tr>
<td>time:burn.sev</td>
<td>3</td>
<td>14</td>
<td>0.43664</td>
<td>0.7302</td>
</tr>
</tbody>
</table>

# Contrast High and Moderate burn severity with Low and None

```r
ro.LCfit2 <- lme(inf.rate ~ time * (burn.sev=="High" | burn.sev=="Moderate"),
data=rainlit.gd, random = ~ time)
```

```r
anova(ro.LCfit2)
```

<table>
<thead>
<tr>
<th>Time</th>
<th>NumDF</th>
<th>DenDF</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>16</td>
<td>650.4481</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>16</td>
<td>17.7786</td>
<td>0.0007</td>
</tr>
<tr>
<td>burn.sev == &quot;High&quot;</td>
<td>1</td>
<td>4</td>
<td>0.1784</td>
<td>0.6944</td>
</tr>
<tr>
<td>time:burn.sev == &quot;High&quot;</td>
<td>1</td>
<td>16</td>
<td>0.0400</td>
<td>0.8440</td>
</tr>
</tbody>
</table>

# Burn severity and its interaction are not significant
anova(ro.LCfit2,type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>16</td>
<td>8.513564</td>
<td>0.0101</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>16</td>
<td>7.677507</td>
<td>0.0136</td>
</tr>
<tr>
<td>burn.sev == &quot;High&quot;</td>
<td>1</td>
<td>4</td>
<td>0.001548</td>
<td>0.9705</td>
</tr>
<tr>
<td>burn.sev == &quot;Moderate&quot;</td>
<td>1</td>
<td>16</td>
<td>0.040012</td>
<td>0.8440</td>
</tr>
</tbody>
</table>

# Burn severity does not affect the trend

II. Analyze fixed-effects of veg type and slope

table(rainlit$veg)

<table>
<thead>
<tr>
<th></th>
<th>KP/manz.</th>
<th>RW</th>
<th>RW/DF</th>
<th>RW/TO</th>
<th>TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>14</td>
<td>7</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

table(rainlit$v3)

<table>
<thead>
<tr>
<th></th>
<th>KP</th>
<th>RW</th>
<th>TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>21</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

# Use original veg types, as they are more balanced than simplified v3

# Look at the time trend for each veg type

rainlit$veg <- factor(rainlit$veg)
rainlit$v3 <- factor(rainlit$v3)

xyplot(inf.rate ~ date | veg, data=rainlit, ylab="Infiltration rate", xlab="",
panel=function(x,y) {
  panel.xyplot(x,y)
  panel.loess(x,y,span=1)
},layout=c(3,1))

# RW/DF had some lower infiltration rates initially but finished as high or higher
# than the other veg types. It might have a stronger trend
xyplot(sqrt(ro.ratio) ~ date | veg, data=rainlit, ylab="Square root of runoff ratio", xlab="",
    panel=function(x,y) {
        panel.xyplot(x,y)
        panel.loess(x,y,span=1)
    })

# These are more linear. Still doesn't look like there is a vegetation effect.
# Although RW/DF might have a stronger trend than the others.

ir.vegfit <- lme(inf.rate ~ time * veg, rainlit.gd, random = ~ time)
ro.vegfit <- lme(sqrt(ro.ratio) ~ time * veg, rainlit.gd, random = ~ time)
par(mfrow=c(1,2))
qqresid(ir.vegfit)
qqresid(ro.vegfit)
# These don't look so great, so be conservative in interpreting hypothesis tests

```r
anova(ir.vegfit)
numDF denDF  F  value  p  value
(Intercept)  1    15  649.4583 <.0001
  time    1    15   30.9063  0.0001
     veg   2     3   0.8673  0.5044
time:veg  2    15   1.7563  0.2064
```

```r
anova(ir.vegfit,type="marginal")
numDF denDF  F  value  p  value
(Intercept)  1    15  21.703659  0.0003
  time    1    15   27.340946  <.0001
     veg   2     3   0.18267  0.8417
time:veg  2    15   0.65187  0.5352
```

# Vegetation and its interaction with time are not significant for infiltration rate

```r
anova(ro.vegfit)
numDF denDF  F  value  p  value
(Intercept)  1    15 101.95755 <.0001
  time    1    15  41.84969 <.0001
     veg   2     3  0.18267  0.8417
time:veg  2    15  0.65187  0.5352
```

```r
anova(ro.vegfit,type="marginal")
numDF denDF  F  value  p  value
(Intercept)  1    15  72.74647 <.0001
  time    1    15  29.08184  0.0001
     veg   2     3  0.82158  0.5194
```
time:veg  2   15  0.65187  0.5352
# Vegetation and its interaction with time are not significant for runoff ratio

# Collapse into two veg classes: RW/DF vs TO and RW/TO
rainlit.gd$v2 <- rainlit.gd$veg=="RW/DF"
ir.vegfit <- lme(inf.rate ~ time * v2, rainlit.gd, random = ~ time)
ro.vegfit <- lme(sqrt(ro.ratio) ~ time * v2, rainlit.gd, random = ~ time)

anova(ir.vegfit)
    numDF denDF  F value p-value
(Intercept)     1    16 657.5591 <.0001
time            1    16  25.5035  0.0001
v2              1     4   0.8097  0.4191
time:v2         1    16   1.2597  0.2783

anova(ro.vegfit)
    numDF denDF  F value p-value
(Intercept)     1    16 104.93132 <.0001
time            1    16  43.07030 <.0001
v2              1     4   0.08866  0.7807
time:v2         1    16   0.15410  0.6998
# Still no significant vegetation effect or interaction

# Test for a slope effect
par(mfrow=c(1,2))
scatter.smooth(rainlit$slope, rainlit$inf.rate, type="p", xlab="Slope (%)", ylab="Infiltration rate", span=0.9)
scatter.smooth(rainlit$slope, sqrt(rainlit$ro.ratio), type="p", xlab="Slope (%)", ylab="Runoff ratio (square root)", span=0.9)
### Infiltration Rate vs Slope

```r
xyplot(inf.rate ~ slope | year, data=rainlit, ylab="Infiltration rate", xlab="Slope",
panel=function(x,y) {
  panel.xyplot(x,y)
  panel.loess(x,y,span=1)
})
```

# There don't appear to be any slope effects

### Infiltration vs Time

```r
xyplot(inf.rate ~ date | equal.count(slope), data=rainlit, ylab="Infiltration rate", xlab="",
panel=function(x,y) {
  panel.xyplot(x,y)
  panel.loess(x,y,span=1)
})
```

# Plot infiltration vs time for overlapping slope classes with equal counts

```r
equal.count(rainlit$slope)
```

#### Data:

```
[1] 70 88 65 70 61 65 47 63 56 50 47 40 52 50 54 48 47 46 45 65 60 50 72 70
```
Intervals:

<table>
<thead>
<tr>
<th>min</th>
<th>max</th>
<th>count</th>
</tr>
</thead>
<tbody>
<tr>
<td>39.5</td>
<td>48.5</td>
<td>7</td>
</tr>
<tr>
<td>46.5</td>
<td>50.5</td>
<td>7</td>
</tr>
<tr>
<td>49.5</td>
<td>60.5</td>
<td>7</td>
</tr>
<tr>
<td>51.5</td>
<td>65.5</td>
<td>9</td>
</tr>
<tr>
<td>60.5</td>
<td>70.5</td>
<td>8</td>
</tr>
<tr>
<td>64.5</td>
<td>88.5</td>
<td>8</td>
</tr>
</tbody>
</table>

Overlap between adjacent intervals:

[1] 4 3 4 5 6

The trend may be a bit stronger on steeper sites (steepest is upper right frame).

```r
xyplot(inf.rate ~ slope | veg, data=rainlit, ylab="Infiltration rate", xlab="Slope", panel=function(x,y) {
  panel.xyplot(x,y)
  panel.loess(x,y,span=1)
}, layout=c(3,1))
```
xyplot(sqrt(ro.ratio) ~ slope | year, data=rainlit, ylab="Square root of runoff ratio", xlab="Slope",
panel=function(x,y) {
  panel.xyplot(x,y)
  panel.loess(x,y,span=1)
}, lattice.options = list(panel.error = "warning")
xyplot(sqrt(ro.ratio) ~ date | equal.count(slope), data=rainlit, ylab="Square root of runoff ratio", xlab="", panel=function(x,y) {
  panel.xyplot(x,y)
  panel.loess(x,y,span=1)
})
# I don't see an effect of slope on the runoff ratio or its trend

```r
xypplot(sqrt(ro.ratio) ~ slope | (veg=="RW/DF"), data=rainlit, ylab="Square root of runoff ratio ", xlab="Slope",
    panel=function(x,y) {
        panel.xyplot(x,y)
        panel.loess(x,y,span=1)
    },layout=c(2,1))
```
two()
ir.slopefit <- lme(inf.rate ~ time*slope, rainlit.gd, random = ~ time)
ro.slopefit <- lme(sqrt(ro.ratio) ~ time*slope, rainlit.gd, random = ~ time)
anova(ir.slopefit)

<table>
<thead>
<tr>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>683.4679</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>26.9456</td>
<td>0.0001</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>0.2152</td>
<td>0.6494</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>6.8852</td>
<td>0.0192</td>
</tr>
</tbody>
</table>

anova(ir.slopefit,type="marginal")

<table>
<thead>
<tr>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>13.030153</td>
<td>0.0026</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>2.830827</td>
<td>0.1132</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>6.664455</td>
<td>0.0208</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>6.885166</td>
<td>0.0192</td>
</tr>
</tbody>
</table>

Although a couple of these are significant, I am not convinced that anything is going on. See above graph of Infiltration rate vs slope by year.

Try refitting either just slope, or just time:slope interaction.

```r
> anova(lme(inf.rate ~ time + time:slope, rainlit.gd, random = ~ time))

<table>
<thead>
<tr>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>660.7608</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>1</td>
<td>16</td>
<td>21.4235</td>
<td>0.0003</td>
</tr>
<tr>
<td>1</td>
<td>16</td>
<td>0.1779</td>
<td>0.6788</td>
</tr>
</tbody>
</table>

> anova(lme(inf.rate ~ time + slope, rainlit.gd, random = ~ time))

<table>
<thead>
<tr>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>640.9889</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>1</td>
<td>16</td>
<td>21.1910</td>
<td>0.0003</td>
</tr>
<tr>
<td>1</td>
<td>16</td>
<td>0.1903</td>
<td>0.6685</td>
</tr>
</tbody>
</table>

It seems these variables are only significant when considered together.

anova(ro.slopefit)

<table>
<thead>
<tr>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>39.71884</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>29.62347</td>
<td>0.0001</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>2.18261</td>
<td>0.1603</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>0.48555</td>
<td>0.4966</td>
</tr>
</tbody>
</table>

anova(ro.slopefit,type="marginal")

<table>
<thead>
<tr>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>0.0477218</td>
<td>0.8300</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>0.0364329</td>
<td>0.8512</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>1.4512424</td>
<td>0.2470</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>0.4855517</td>
<td>0.4966</td>
</tr>
</tbody>
</table>

No slope effect on runoff ratio.

Test the interaction of slope and vegetation.

```r
ir.slopevegfit <- lme(inf.rate ~ veg*slope, rainlit.gd, random = ~ time)
ro.slopevegfit <- lme(sqrt(ro.ratio) ~ veg*slope, rainlit.gd, random = ~ time)
```

Error in `lme`:
```
nlminb problem, convergence error code = 1
message = iteration limit reached without convergence (9)
```

Contrasting Unburned with Burned sites
# Create a factor so that labels on xyplot will be clear
burned <- factor(rainlit$burn.sev == "None", labels=c("Burned","Unburned"))

xyplot(inf.rate ~ date | burned, data=rainlit, xlab="", ylab="Infiltration rate")

xyplot(ro.ratio ~ date | burned, data=rainlit, xlab="", ylab="Runoff ratio")
# There aren't enough unburned sites to permit a statistical comparison, but it's
# easy enough to re-run the commands to see that there's no significant difference

# Contrast Unburned with all others
anova(lme(inf.rate ~ time * (burn.sev=="None"), rainlit.gd, random = ~
time),type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>16</td>
<td>19.44660</td>
<td>0.0004</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>16</td>
<td>14.155253</td>
<td>0.0017</td>
</tr>
<tr>
<td>burn.sev == &quot;None&quot;</td>
<td>1</td>
<td>4</td>
<td>0.123682</td>
<td>0.7428</td>
</tr>
<tr>
<td>time:burn.sev == &quot;None&quot;</td>
<td>1</td>
<td>16</td>
<td>0.558565</td>
<td>0.4657</td>
</tr>
</tbody>
</table>

# The interaction is NOT significant, so the time trend does not depend on burn severity.
The main effect of burning is not even significant.

# Runoff ratio
anova(lme(sqrt(ro.ratio) ~ time * (burn.sev=="None"), rainlit.gd, random = ~
time),type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>16</td>
<td>99.04408</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>time</td>
<td>1</td>
<td>16</td>
<td>43.36663</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>burn.sev == &quot;None&quot;</td>
<td>1</td>
<td>4</td>
<td>1.02459</td>
<td>0.3687</td>
</tr>
<tr>
<td>time:burn.sev == &quot;None&quot;</td>
<td>1</td>
<td>16</td>
<td>0.54153</td>
<td>0.4657</td>
</tr>
</tbody>
</table>

# Again, neither burning nor its interaction with time is significant

====================================================================
Contrasting soil types

Contrasting soil types

Contrasting soil types

table(rainlit.gd$soil)
Two soil types are unspecified. These are for site 6L in 2012-2013.

# The undefined soils are at site 6

> table(rainlit.gd$sitenum, rainlit.gd$soil)

<table>
<thead>
<tr>
<th></th>
<th>Granitic</th>
<th>MS</th>
<th>MS/SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>13H</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>6L</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>7M</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>14M</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>5M</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>4N</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

xyplot(inf.rate ~ date | soil, data=rainlit, ylab="Infiltration rate", xlab="", lattice.options = list(panel.error = "warning"),
panel=function(x,y) {
  panel.xyplot(x,y)
  panel.loess(x,y,span=1)
},layout=c(4,1))
xyplot(sqrt(ro.ratio) ~ date | soil, data=rainlit, ylab="Square root of runoff ratio",
    xlab="", lattice.options = list(panel.error = "warning"),
    panel=function(x,y) {
        panel.xyplot(x,y)
        panel.loess(x,y,span=1)
    }, layout=c(4,1))

ir.soilfit <- lme(inf.rate ~ time*soil, rainlit.gd, random = ~ time)
ro.soilfit <- lme(sqrt(ro.ratio) ~ time*soil, rainlit.gd, random = ~ time)

> anova(ir.soilfit,type="marginal")
   numDF denDF    F-value p-value

367
(Intercept)     1    11  1.6708843  0.2226
  time          1    11  0.0001238  0.9913
  soil          3    11  0.8430121  0.4984
  time:soil     3    11  0.6226004  0.6150
> anova(ro.soilfit,type="marginal")
  numDF denDF F-value   p
  (Intercept)    1    11  0.5586946  0.4705
  time           1    11  0.3538313  0.5640
  soil           3    11  2.6561603  0.1003
  time:soil      3    11  2.5591137  0.1084
# Soil does not significantly affect either response nor their trends

# Re-test soils after combining Granitic and unspecified soils
rainlit.gd$s3 <- as.character(rainlit.gd$soil)
rainlit.gd$s3[!(rainlit.gd$soil %in% c("MS","MS/SS"))] <- "Other"
rainlit.gd$s3 <- factor(rainlit.gd$s3)
table(rainlit.gd$s3)
  MS  MS/SS Other
   14   6    4
ir.soilfit <- lme(inf.rate ~ time*s3, rainlit.gd, random = ~ time)
ro.soilfit <- lme(sqrt(ro.ratio) ~ time*s3, rainlit.gd, random = ~ time)
> anova(ir.soilfit,type="marginal")
  numDF denDF F-value   p
  (Intercept)    1    13 19.568794  0.0007
  time           1    13  8.447856  0.0123
  s3             2    13  0.619964  0.5531
  time:s3        2    13  0.065316  0.9371
> anova(ro.soilfit,type="marginal")
  numDF denDF F-value   p
  (Intercept)    1    13 46.08301<.0001
  time           1    13 16.36743  0.0014
  s3             2    13  1.48998  0.2615
  time:s3        2    13  0.73908  0.4966
There is a significant uptrend in infiltration rates from 2010 to 2013 and corresponding
downtrend in runoff ratios.

We've tested burn severity (detailed classes and Burned/Unburned dichotomy), vegetation,
slope, and soils for effects on both responses, and for effects on the trends. The ONLY
significant effects found were the effects of slope on infiltration rate and trend (i.e.
time:slope interaction). Their significance was not strong (p=0.02), neither slope nor
its time interaction were significant by themselves, and no effects of slope were found
on runoff ratio.
Appendix K. R Code and Output for the MDI Dataset.

Effects of Burn Severity

```r
library("chron")
library("lattice")
library(nlme)

read.csv("mdi13.csv",as.is=T) -> mdii3

mdii3$date <- dates(mdii3$date)
mdii3$daynum <- as.numeric(mdii3$date)
mdii3$dist <- ordered(sapply(strsplit(mdii3$site.dist,"/"),function(x) x[2]),levels=as.character(seq(0,100,20)))
mdii3$burn.sev <- ordered(mdii3$burn.sev,levels=c("UB","M/L","M","H/M","H"),labels=c("N","ML","M","MH","H")
mdii3$site <- ordered(paste(format(mdii3$sitenum,width=2),
substring(mdii3$site.dist,1,2), sep=""))
mdii3$aspect <- factor(mdii3$aspect)
mdii3$slope.pos <- ordered(mdii3$slope.pos,levels=c("L","ML","M","U"))
mdii3$repel <- factor(mdii3$repel)
mdii3$burn.sev2 <- mdii3$burn %in% c("M","MH","H")
mdii3$burn.sev2 <- factor(mdii3$burn.sev2,labels=c("Cool","Hot"))

year date sitenum site.dist burn.sev aspect slope.pos depth vol1 vol2 vol3 meanvol
1 2013 07/17/13       1       1/0        H     SE         L     1    0    3    1    1.33
2 2013 07/17/13       1       1/0        H     SE         L     3    3    2    1    2.00
3 2013 07/17/13       1       1/20       H     SE         L    16   11    2    9.67

# There are fewer sites and slope positions but rbind will expand the levels
mdi.old <- mdi
mdi <- rbind(mdi.old, mdii3)
mdi$daynum08 <- mdi$daynum - as.numeric(dates("1/1/2009"))

superpose.line <- trellis.par.get("superpose.line")
superpose.line$col <- rainbow(23)
superpose.line$lwd <- 2
superpose.line$lty <- 1:2
trellis.par.set("superpose.line",superpose.line)

mdi.gd.old <- mdi.gd
mdi.gd <- groupedData(meanvol ~ daynum | site , outer = ~ burn.sev, data=mdi)

tmp <- mdi.gd[mdi.gd$depth==1, ]; tmp$daynum <- as.numeric(dates("1/1/2009"))
plot(tmp, aspect=1, outer=T, xlab="Days since 12/31/2008",ylab="Mean volume",main="MDI results at depth = 1 cm")
# Multiple measurements on a transect show up as vertical segments in plot
```r
tmp <- mdi.gd[mdi.gd$depth==3, ]; tmp$daynum <- tmp$daynum - as.numeric(dates("1/1/2009"))
plot(tmp, aspect=1, outer=T, xlab="Days since 12/31/2008", ylab="Mean volume", main="MDI results at depth = 3 cm")
```
MDI results at depth = 3 cm

Days since 12/31/2008

Mean volume

0
10
20
30
500 1000 1500
N ML
500 1000...
1H
2M
3M
4H
5M
6H
7H
8H
9M
10H
11M
12H
13M
14M
15M
16MH
17MH
18H
19M
20H
21ML
22MH
23H

```
tmp <- mdi.gd[mdi.gd$depth==1, ]; tmp$daynum <- tmp$daynum -
as.numeric(dates("1/1/2009"))
plot(tmp, aspect=1, layout=c(6,4), xlab="Days since 12/31/2008", ylab="Mean
volume",main="MDI results at depth = 1 cm")
```
```r
tmp <- mdi.gd[mdi.gd$depth==3, ]; tmp$daynum <- tmp$daynum - as.numeric(dates("1/1/2009"))
plot(tmp, aspect=1, layout=c(6,4), xlab="Days since 12/31/2008", ylab="Mean volume", main="MDI results at depth = 3 cm")
```
MDI results at depth = 3 cm

superpose.line$lwd <- 1
superpose.line$lty <- 1
trellis.par.set("superpose.line",superpose.line)
xyplot(meanvol ~ depth | burn.sev*factor(year), data=mdi, groups=site,
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y, subscripts, groups, "panel.lmline")
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  }, subset = depth %in% c(1,3), xlab = "Depth (cm)", ylab="Mean volume (ml)", main="MDI test results", auto.key=list(columns=7)
)

superpose.line$lwd <- 1
superpose.line$lty <- 1
trellis.par.set("superpose.line",superpose.line)
xyplot(meanvol ~ depth | burn.sev*factor(year), data=mdi, groups=site,
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y, subscripts, groups, "panel.lmline")
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  }, subset = depth %in% c(1,3), xlab = "Depth (cm)", ylab="Mean volume (ml)", main="MDI test results", auto.key=list(columns=7)
)
### MDI Test Results

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Mean Volume (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**2009**
- N: 2009 ML
- M: 2009 MH
- H: 2009 MH

**2010**
- N: 2010 ML
- M: 2010 MH
- H: 2010 MH

**2011**
- N: 2011 ML
- M: 2011 MH
- H: 2011 MH

**2012**
- N: 2012 ML
- M: 2012 MH
- H: 2012 MH

**2013**
- N: 2013 ML
- M: 2013 MH
- H: 2013 MH
# Not much effect from depth

# 3-way plot layout
par(ask=T)
xyplot(meanvol ~ depth | factor(dist)*factor(year)*burn.sev, data=mdi, groups=site,
aspect=0.5,
panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y, subscripts, groups, "panel.lmline")
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
}, subset=depth %in% c(1,3)
)
<table>
<thead>
<tr>
<th>Year</th>
<th>MH</th>
<th>MH</th>
<th>MH</th>
<th>MH</th>
<th>MH</th>
<th>MH</th>
<th>MH</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
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<tr>
<td>2012</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
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<tr>
<td>2011</td>
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<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>
xyplot(meanvol ~ depth | factor(dist)*factor(year)*burn.sev2, data=mdi, groups=site,
aspect=0.6,
panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y, subscripts, groups, "panel.lmline")
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
}, subset=depth %in% c(1,3)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
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<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
# Collapse over transect distance

xyplot(sqrt(meanvol) ~ depth | factor(year)*burn.sev2, data=mdi, groups=site, aspect=1,
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y, subscripts, groups, "panel.xyplot")
    panel.loess(x,y,xpan=1)
  }, subset=depth %in% c(1,3), xlab="Depth (cm)", ylab="Mean volume: square root (ml)"
)
# Look at the effect of time by depth

xyplot(sqrt(meanvol) ~ year | factor(depth)*burn.sev2, data=mdi, groups=site, aspect=1,
panel=function(x,y, subscripts, groups) {
  # panel.superpose(x,y, subscripts, groups, "panel.loess",span=0.333)
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  panel.loess(x,y,span=0.5)
}, subset=depth %in% c(1,3),ylab="Mean volume: square root (ml)"
# Before I saw the 2013 data I thought there was an increase in volume over time regardless of burn severity. Now I'm not so sure. In the Cool categories, volume seems to have dropped back to what was normal in 2009-2011. Need to get the data points to appear in the "Hot" frames above.

```r
xyplot(meanvol ~ year | factor(depth), data=mdi, groups=site, aspect=1, panel=function(x,y, subscripts, groups) {
  # panel.superpose(x,y, subscripts, groups, "panel.loess",span=0.333)
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  panel.loess(x,y,span=0.5)
}, subset=depth %in% c(1,3) & burn.sev2=="Hot")
```
# Collapse over both transect distance and depth
xyplot(meanvol ~ year | burn.sev2, data=mdi, groups=site, aspect=1,
panel=function(x,y, subscripts, groups) {
# panel.superpose(x,y, subscripts, groups, "panel.loess",span=0.33)
panel.superpose(x,y,subscripts,groups, "panel.xyplot")
panel.loess(x,y,span=0.5)
}, subset=depth %in% c(1,3)
)
```
xyplot(sqrt(meanvol) ~ year | burn.sev2, data=mdi, groups=site, aspect=1,
panel=function(x,y, subscripts, groups) {
  # panel.superpose(x,y, subscripts, groups, "panel.loess",span=0.33)
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  panel.loess(x,y,span=0.5)
}, subset=depth %in% c(1,3)
}

# Repeat with original burn categories, loess line, and sqrt(meanvol)
xyplot(sqrt(meanvol) ~ factor(year) | burn.sev, data=mdi, groups=site, aspect=1,
panel=function(x,y, subscripts, groups) {
  # panel.superpose(x,y, subscripts, groups, "panel.lmline")
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
```
```r
panel.loess(x, y, span=0.67)
}

MDI test results

Year
Mean volume: square root(ml)
0
2
4
6
2009 2010 2011 2012 2013
N ML
2009 2010 2011 2012 ... 1H
 2M
 3M
 4H
 5M
 6H
 7H
 8H
 9M
10H
11M
12H
13M
14N
15H
16MH
17MH
18H
19M
20H
21ML
22MH
23H

# Plot against day number instead of year for a bit more resolution
xyplot(sqrt(meanvol) ~ daynum08 | burn.sev, data=mdi, groups=site, aspect=1,
   panel=function(x,y, subscripts, groups) {
     # panel.superpose(x,y, subscripts, groups, "panel.lmline")
     panel.superpose(x,y,subscripts,groups, "panel.xyplot")
     panel.loess(x,y,degree=2,span=1)
   }, subset=depth %in% c(1,3), main="MDI test results",
   xlab="Days since 12/31/2008", ylab="Mean volume: square root(ml)", auto.key=list(columns=7)
)`
# Compare original burn categories for each year

```
xyplot(sqrt(meanvol) ~ burn.sev | factor(year), data=mdi, groups=site, aspect=1,
panel=function(x,y, subscripts, groups) {
  panel.superpose(x,y, subscripts, groups, "panel.xyplot")
  panel.loess(x,y,span=0.67)
}, subset=depth %in% c(1,3)
```

MDI test results

Days since 12/31/2008

Mean volume: square root(ml)

0

2

4

6

500 1000 1500

N ML

500 1000 ... 1H

2M

3M

4H

5M

6H

7H

8H

9M

10H

11M

12H

13M

14N

15H

16MH

17MH

18H

19M

20H
# Would like to test the interaction between daynum and burn severity
mdi.gd <- groupedData(meanvol ~ daynum | site/dist, outer = ~ burn.sev, data=mdi[mdi$depth %in% c(1,3),])
options(contrasts=c("contr.treatment","contr.treatment"))
mdi.fit0 <- lme(sqrt(meanvol) ~ daynum*burn.sev, data=mdi.gd, random=~1)
mdi.fit1 <- lme(sqrt(meanvol) ~ daynum*burn.sev, data=mdi.gd, random=~daynum)
anova(mdi.fit0,mdi.fit1)

<table>
<thead>
<tr>
<th>Model</th>
<th>df</th>
<th>AIC</th>
<th>BIC</th>
<th>logLik</th>
<th>Test</th>
<th>L.Ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>mdi.fit0</td>
<td>1</td>
<td>13 2620.657</td>
<td>2683.088</td>
<td>-1297.328</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mdi.fit1</td>
<td>2</td>
<td>17 2609.412</td>
<td>2691.052</td>
<td>-1287.706</td>
<td>1 vs 2</td>
<td>19.24527</td>
<td>7e-04</td>
</tr>
</tbody>
</table>

# So we definitely need a random effect on daynum, i.e. the time trend depends randomly on site and transect location within site.
# Do we need the nesting of transect within site?
mdi.gd0 <- groupedData(meanvol ~ daynum | site, outer = ~ burn.sev, data=mdi[mdi$depth %in% c(1,3),])

mdi.fit00 <- lme(sqrt(meanvol) ~ daynum*burn.sev, data=mdi.gd0, random=~1)
mdi.fit01 <- update(mdi.fit00, random=~daynum)

anova(mdi.fit0,mdi.fit00)
  Model df      AIC      BIC    logLik   Test   L.Ratio p-value
mdi.fit0  1 13 2620.657 2683.088 -1297.328
mdi.fit00 2 12 2620.912 2678.541 -1298.456 1 vs 2  2.25501  0.1332
# The nesting is not significant at the intercept level

anova(mdi.fit1,mdi.fit01)
  Model df      AIC      BIC    logLik   Test L.Ratio p-value
mdi.fit1  1 17 2609.412 2691.052 -1287.706
mdi.fit01 2 14 2623.304 2690.537 -1297.652 1 vs 2 19.89242 2e-04
# But the nesting is significant for its effect on daynum

# Look at the fixed effects using conditional F tests
#
# Sequential tests test each term as it is added sequentially to the model
> anova(mdi.fit1, type="sequential")
   numDF denDF  F-value p-value
(Intercept)         1   771 715.9803  <.0001
daynum              1   771 133.8000  <.0001
burn.sev            4    18   2.0361  0.1322
daynum:burn.sev     4   771   5.0264  0.0005

# Marginal tests delete each term from the full model
> anova(mdi.fit1, type="marginal")
   numDF denDF  F-value p-value
(Intercept)         1   771 4.132986  0.0424
daynum              1   771 5.014182  0.0254
burn.sev            4    18 5.264591  0.0055
daynum:burn.sev     4   771 5.026393  0.0005

# Add depth to the model
mdi.fit2 <- update(mdi.fit1, sqrt(meanvol) ~ daynum*burn.sev + depth)
#
# Try to add a random effect for depth
mdi.fit2a <- update(mdi.fit2a, random=list(site=~daynum+depth, dist=~1+daynum))
mdi.fit2b <- update(mdi.fit2a, random=list(site=~daynum+depth, dist=~1+daynum+depth))
# Fail
mdi.fit2b <- update(mdi.fit2a, random=list(site=~daynum+depth, dist=~daynum))

anova(mdi.fit2,mdi.fit2a,mdi.fit2b)
  Model df      AIC      BIC    logLik   Test L.Ratio p-value
mdi.fit2  1 18 2604.979 2691.403 -1284.490
mdi.fit2a 2 19 2579.282 2670.506 -1270.641 1 vs 2 27.697743 <.0001
mdi.fit2b 3 21 2577.887 2678.714 -1267.944 2 vs 3  5.394248  0.0674
# The random effect on depth is significant
# OK so we need random effects at the site level for the coefficients of daynum and depth
# And we need random effects for dist %in% site for the coefficient of daynum only
# We do not need a random effect for dist %in% site on the intercept

# Test interaction of depth with burn severity

389
```r
mdi.fit2ab <- update(mdi.fit2a, ~ . + depth*burn.sev)
anova(mdi.fit2ab)
  numDF denDF  F  value p-value
(Intercept)   1   766 431.3538 <.0001
 daynum        1   766  38.9971 <.0001
 burn.sev      4    18   1.2257  0.3348
  depth        1   766   5.4838  0.0194
 daynum:burn.sev  4   766   1.4121  0.2281
 burn.sev:depth 4   766   0.5577  0.6935
# The interaction is not significant.

anova(mdi.fit2a, type="sequential")
  numDF denDF  F  value p-value
(Intercept)   1   770 423.4428 <.0001
 daynum        1   770  39.1426 <.0001
 burn.sev      4    18   1.2091  0.3413
  depth        1   770   5.9778  0.0147
 daynum:burn.sev  4   770   1.4076  0.2296

anova(mdi.fit2a, type="marginal")
  numDF denDF  F  value p-value
(Intercept)   1   770  3.858137  0.0499
 daynum        1   770  4.531298  0.0336
 burn.sev      4    18  1.487035  0.2477
  depth        1   770  5.768841  0.0165
 daynum:burn.sev 4   770  1.407563  0.2296
# Only day number and depth are significant and not impressively so.
Burn severity and its interaction with trend is not significant

# Here's another view of the significance of each fixed effect
 Value Std.Error  DF    t.value p-value
(Intercept) -20.711915 10.544632 770 -1.9642140  0.0499
 daynum      0.001496  0.000703 770  2.1286846  0.0336
 burn.sevML  21.545700 13.827018  18  1.5582319  0.1366
 burn.sevM   10.403742 11.138886  18  0.9340020  0.3627
 burn.sevMH  10.214069 13.234017  18  0.7718041  0.4502
 burn.sevH   2.838338 10.903636  18  0.2603112  0.8118
 depth      -0.097614  0.040641 770 -2.4018412  0.0165
 daynum:burn.sevML -0.001378  0.000920 770 -1.4975617  0.1347
 daynum:burn.sevM -0.000662  0.000742 770 -0.8928316  0.3722
 daynum:burn.sevMH -0.000685  0.000886 770 -0.7727938  0.4399
 daynum:burn.sevH -0.000173  0.000726 770 -0.2382075  0.8118

# We can visualize this
xyplot(sqrt(meanvol) ~ daynum | burn.sev, data=mdi, groups=site, aspect=1,
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    panel.lmline(x,y)
  }, subset=depth %in% c(1,3), main="MDI test results",
  xlab="Day number", ylab="Mean volume: square root(ml)", auto.key=list(columns=7))
```
The slopes are ordered the same as the burn classes, except for N. If we had measured the unburned sites in 2013 this would probably lower the slope for the unburned category and maybe things would fall into line.

We can try fitting the model without 2013:

```r
summary(update(mdi.fit2a, subset=year!="2013"))
```

<table>
<thead>
<tr>
<th>factor</th>
<th>mean</th>
<th>se</th>
<th>df</th>
<th>p.value</th>
</tr>
</thead>
<tbody>
<tr>
<td>daynum:burn.sevML</td>
<td>0.000358</td>
<td>0.001060</td>
<td>650</td>
<td>0.3374228</td>
</tr>
<tr>
<td>daynum:burn.sevM</td>
<td>0.000259</td>
<td>0.000815</td>
<td>650</td>
<td>0.3179932</td>
</tr>
<tr>
<td>daynum:burn.sevMH</td>
<td>0.000590</td>
<td>0.000990</td>
<td>650</td>
<td>0.5964904</td>
</tr>
<tr>
<td>daynum:burn.sevH</td>
<td>0.000068</td>
<td>0.000794</td>
<td>650</td>
<td>0.0858701</td>
</tr>
</tbody>
</table>

That doesn't solve the problem because 2012 is high in the unburned class.

In any case, among the burned sites we should see a pattern.

```r
mdi.fit2ac <- update(mdi.fit2a, subset=burn.sev!="N")
anova(mdi.fit2ac, type="marginal")
```

<table>
<thead>
<tr>
<th>factor</th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>738</td>
<td>0.004340</td>
<td>0.9475</td>
</tr>
</tbody>
</table>

# The slopes are ordered the same as the burn classes, except for N. If we had measured the unburned sites in 2013 this would probably lower the slope for the unburned category and maybe things would fall into line.

# We can try fitting the model without 2013

# That doesn't solve the problem because 2012 is high in the unburned class

# In any case, among the burned sites we should see a pattern.
daynum              1    738  0.048942  0.8250
burn.sev            3     18  1.832250  0.1774
depth               1    738  6.375243  0.0118
daynum:burn.sev     3    738  1.739358  0.1575

# The model assumes a linear effect for daynum. That's not really reasonable given the pattern seen above. What if we substitute year as a factor in place of daynum. That doesn't impose any kind of a form on the trend.

mdi.gd$year <- factor(mdi.gd$year)
tmp <- update(mdi.fit2a, sqrt(meanvol) ~ year*burn.sev + depth)

Error in MEEM(object, conLin, control$niterEM) :
  Singularity in backsolve at level 0, block 1

# Darn! Well we could try modeling daynum as a quadratic but that will be harder to interpret

# First look at the residuals distribution
qqresid(mdi.fit2a)

Normal Q-Q Plot

Theoretical Quantiles
Sample Quantiles

# Try modeling the logarithm, but there are zeroes to deal with
sum(mdi$meanvol==0)
[1] 33

min(mdi$meanvol[mdi$meanvol>0])
[1] 0.17

# Set the zeroes to 0.10
mdi.gd$meanvol2 <- mdi.gd$meanvol
mdi.gd$meanvol2[mdi.gd$meanvol==0] <- 0.10

mdi.logfit2a <- update(mdi.fit2a, log(meanvol2) ~ daynum + burn.sev + depth + daynum:burn.sev)
mdi.logfit2a <- update(mdi.fit2a, log(meanvol2) ~ daynum + burn.sev + depth + daynum:burn.sev)
Error in lme.formula(fixed = log(meanvol2) ~ daynum + burn.sev + depth + :
  nlmib problem, convergence error code = 1
  message = iteration limit reached without convergence (9)

# Drop the random effect of site on depth to get convergence
# This model still has the transect within site random effect
mdi.logfit2a <- update(mdi.fit2a, log(meanvol2) ~ daynum + burn.sev + depth +
daynum:burn.sev, random=~daynum)

anova(mdi.logfit2a) # Sequential
numDF denDF  F-value p-value
(Intercept)  1   770 144.74715  <.0001
 daynum       1   770 137.28548  <.0001
 burn.sev     4    18  1.73627  0.1859
  depth       1   770  8.32041  0.0040
daynum:burn.sev 4   770  6.50662  <.0001

anova(mdi.logfit2a,type="marginal")
numDF denDF  F-value p-value
(Intercept)  1   770  3.628593  0.0572
 daynum       1   770  4.064027  0.0442
 burn.sev     4    18  6.729386  0.0017
  depth       1   770  8.320410  0.0040
daynum:burn.sev 4   770  6.506619  <.0001
# The burn severity and its interaction have become significant
# and depth is even more so than it was.

# Retest the interaction between depth and burn severity
mdi.logfit2b <- update(mdi.logfit2a, ~ . + depth*burn.sev)

anova(mdi.logfit2b)
numDF denDF  F-value p-value
(Intercept)  1   766 144.85504  <.0001
 daynum       1   766 137.26354  <.0001
 burn.sev     4    18  1.73714  0.1858
  depth       1   766  8.34878  0.0040
daynum:burn.sev 4   766  6.49962  <.0001
 burn.sev:depth 4   766  1.60722  0.1705
# Interaction burn.sev:depth not significant

qqresid(mdi.logfit2a)
# That looks better

```r
as.data.frame(fixef(mdi.logfit2a))

  (Intercept)       daynum  burn.sevML  burn.sevM  burn.sevMH  burn.sevH  depth
daynum:burn.sevML 1.230902-03 4.608035-04 3.713781-04 5.179825-04
daynum:burn.sevM   7.478379-00 1.946006+01 1.166340-03 1.668866+01

# The slope coefficients are ordered the same as the burn severities
# except that the unburned is in the middle (where the signs change)

# We can visualize the model (except for the random effects and depth effect)
xyplot(log(meanvol2) ~ daynum | burn.sev, data=mdi.gd, groups=site, aspect=1,
  panel=function(x,y,subscripts,groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    panel.lmline(x,y)
    panel.loess(x,y, lty=2, degree=2, span=1)
  }, subset=depth %in% c(1,3), main="MDI test results",
  xlab="Day number", ylab="Mean volume: logarithm(ml)", auto.key=list(columns=7)
)
# Maybe we don’t need a quadratic trend model. Only the MH class seems to demand it.
# Here it is anyway

```r
mdi.logfit3 <- update(mdi.logfit2a, ~ . + burn.sev*I(daynum^2))
anova(mdi.logfit3)
```

```
numDF denDF    F-value  p-value
(Intercept)     1   765 145.87442  <.0001
daynum           1   765  47.96116  <.0001
burn.sev         4    18   0.86432  0.5040
depth            1   765  9.39319  0.0023
I(daynum^2)      1   765  58.96132  <.0001
daynum:burn.sev  4   765   1.36828  0.2432
burn.sev:I(daynum^2)  4   765   9.01459  <.0001
```

```
anova(mdi.logfit3,type="marginal")
```

```
numDF denDF    F-value  p-value
(Intercept)     1   765  4.845265  0.0280
daynum          1   765  4.961891  0.0262
burn.sev         4    18  9.177912  0.0003
```
# Burn severity and its interactions are all significant as.data.frame(fixef(mdi.logfit3))

|                | Estimate | Std. Error | t value | Pr(>|t|) |
|----------------|----------|------------|---------|----------|
| (Intercept)    | 7.088565 | 2e-02      | 331.15  | < 2e-16  |
| daynum         | -9.526205| 2e-02      | -143.11 | < 2e-16  |
| burn.sevML     | -9.993453| 2e-02      | -244.87 | < 2e-16  |
| burn.sevM      | -1.006520| 3e-03      | -26.37  | < 2e-16  |
| burn.sevMH     | -1.854252| 3e-03      | -61.74  | < 2e-16  |
| burn.sevH      | -1.045688| 3e-03      | -34.58  | < 2e-16  |
| depth          | -9.140327| 2e-02      | -87.58  | < 2e-16  |
| I(daynum^2)    | 3.202241 | 6e-06      | 503.71  | < 2e-16  |
| daynum:burn.sevML | 1.336908 | 1e-01     | 1.33   | 0.248    |
| daynum:burn.sevM | 1.339266 | 1e-01     | 1.34   | 0.246    |
| daynum:burn.sevMH | 2.446665 | 1e-01     | 2.45   | 0.016    |
| daynum:burn.sevH | 1.382569 | 1e-01     | 1.38   | 0.242    |
| burn.sevML:I(daynum^2) | -4.464184 | 6e-06 | -74.02| < 2e-16  |
| burn.sevM:I(daynum^2) | -4.449961 | 6e-06 | -74.00| < 2e-16  |
| burn.sevMH:I(daynum^2) | -8.064157 | 6e-06 | -134.02| < 2e-16  |
| burn.sevH:I(daynum^2) | -4.566445 | 6e-06 | -75.10| < 2e-16  |

# There aren't monotone patterns in the linear interactions (daynum:burn.sevXX)
# nor in the quadratic interaction coefficients (daynum.sevXX:I(daynum^2)
# Is this consistent with the results of the linear trend model?
# It's not clear if the quadratic trend model sheds any new light.

# Naïve standard linear regression model for comparison
mdi.lmfit1 <- lm(sqrt(meanvol) ~ daynum, data=mdi, subset=depth %in% c(1,3))
mdi.lmfit2 <- update(mdi.lmfit1, ~ . + burn.sev)
mdi.lmfit3 <- update(mdi.lmfit1, ~ . + daynum*burn.sev)
mdi.lmfit4 <- update(mdi.lmfit3, ~ . + depth)
anova(mdi.lmfit1, mdi.lmfit2, mdi.lmfit3,mdi.lmfit4)

Analysis of Variance Table

| Res.Df | RSS | Df | Sum of Sq | F     | Pr(>|F|) |
|---------|-----|----|-----------|-------|----------|
| 1       | 908 |    | 917.99    |      |          |
| 2       | 904 | 4  | 17.5209   | 4.5526| 0.001208 **|
| 3       | 900 | 4  | 6.8425    | 1.996e-05 |            |
| 4       | 899 | 1  | 9.5319    | 9.5319| 0.002081 **|

# All terms highly significant

# What if we average over depth and transect?
# Now each combination of year and burn severity will have equal weight
# As long as that combination exists (N is missing in 2013)
attach(mdi)
tmp <- tapply(meanvol, list(sitenum, year), mean)
mv <- as.vector(tmp)
yr <- rep(2009:2013, rep(23, 5))
bs <- rep(substring(unique(site), 3, 4), 5)
bs <- ordered(bs, levels = c("N", "ML", "M", "MH", "H"))
site <- rep(1:23, 5)

mdi.mean <- data.frame(site, yr, bs, mv)
mdi.mean <- mdi.mean[!is.na(mdi.mean$mv), ]
detach(mdi)

mdi.mean.gd <- groupedData(mv ~ yr | site, outer=~bs, data=mdi.mean)

plot(mdi.mean.gd, outer=T, layout=c(5,1), aspect=1.5)

plot(mdi.mean.gd, outer=T, layout=c(5,1), aspect=1.5,
     panel=function(x,y, subscripts, groups) {
       panel.superpose(x,y, subscripts, groups, "panel.xyplot")
       panel.lmline(x,y)
     })

xyplot(mv ~ yr | bs, data=mdi.mean.gd, aspect=1,
       panel=function(x,y) {
         panel.xyplot(x,y)
         panel.lmline(x,y)
       }, main="MDI test results",
       xlab="Year", ylab="Mean volume (ml)")
# Re-do without 2013

```
xyplot(mv ~ yr | bs, data=mdi.mean.gd, aspect=1, subset=yr<2013,
    panel=function(x,y) {
        panel.xyplot(x,y)
        panel.lmline(x,y)
    },
    main="MDI test results", xlab="Year", ylab="Mean volume (ml)"
)
```
# Excluding 2013, the slopes are pretty similar each year
mdim.fit1 <- lme(mv ~ yr*bs, data=mdi.mean.gd, random=~yr)
# System is computationally singular.

mdim.fit1 <- lme(mv ~ yr*bs, data=mdi.mean.gd, random=~1)
summary(mdim.fit1)

Fixed effects: mv ~ yr * bs

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Std.Error</th>
<th>DF</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-3825.523</td>
<td>2510.7877</td>
<td>57</td>
<td>-1.5236346</td>
<td>0.1331</td>
</tr>
<tr>
<td>yr</td>
<td>1.905</td>
<td>1.2488</td>
<td>57</td>
<td>1.5251587</td>
<td>0.1327</td>
</tr>
<tr>
<td>bsML</td>
<td>2661.394</td>
<td>3075.3293</td>
<td>18</td>
<td>0.8654013</td>
<td>0.3982</td>
</tr>
<tr>
<td>bsM</td>
<td>2264.364</td>
<td>2623.1288</td>
<td>18</td>
<td>0.8632301</td>
<td>0.3994</td>
</tr>
<tr>
<td>bsMH</td>
<td>1355.538</td>
<td>2882.6634</td>
<td>18</td>
<td>0.4702381</td>
<td>0.6438</td>
</tr>
<tr>
<td>bsH</td>
<td>384.128</td>
<td>2593.1714</td>
<td>18</td>
<td>0.1481306</td>
<td>0.8839</td>
</tr>
</tbody>
</table>
# OK, but nothing is significant

# Or go to a pure fixed effects model

```r
mdim.lmfit1 <- lm(mv ~ yr*bs, data=mdi.mean)
```

Coefficients:

|                  | Estimate | Std. Error | t value | Pr(>|t|) |
|------------------|----------|------------|---------|----------|
| (Intercept)      | -3825.5230 | 2510.7877  | -1.524  | 0.132    |
| yr               | 1.9047   | 1.2488     | 1.525   | 0.131    |
| bsML             | 2661.3940 | 3075.3294  | 0.865   | 0.390    |
| bsM              | 2264.3636 | 2623.1288  | 0.863   | 0.391    |
| bsMH             | 1355.5380 | 2882.6634  | 0.470   | 0.640    |
| bsH              | 384.1281  | 2593.1715  | 0.148   | 0.883    |
| yr:bsML          | -1.3224  | 1.5295     | -0.865  | 0.390    |
| yr:bsM           | -1.1256  | 1.3047     | -0.863  | 0.391    |
| yr:bsMH          | -0.6742  | 1.4338     | -0.470  | 0.640    |
| yr:bsH           | -0.1906  | 1.2898     | -0.148  | 0.883    |

# Again nothing is significant

# I would speculate that it is because this data set is much much smaller

## Effects of Soil Parent Material

```r
library(nlme)
library(lattice)
table(soil$soil)
```

<table>
<thead>
<tr>
<th></th>
<th>Granitic</th>
<th>MS</th>
<th>MS/SS</th>
<th>SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>16</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

```r
table(mdi$soil)
```

<table>
<thead>
<tr>
<th></th>
<th>Granitic</th>
<th>MS</th>
<th>SS/MS</th>
<th>SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>191</td>
<td>580</td>
<td>98</td>
<td>54</td>
<td></td>
</tr>
</tbody>
</table>

# Combine MS/SS and SS into "SS/MS" in new variable: s3

```r
mdi$s3 <- as.character(mdi$soil)
mdi$s3[mdi$soil %in% c("MS/SS","SS")]<- "SS/MS"
mdi$s3 <- factor(mdi$s3)
table(mdi$s3)
```

<table>
<thead>
<tr>
<th></th>
<th>Granitic</th>
<th>SS/MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>191</td>
<td>580</td>
<td>152</td>
</tr>
</tbody>
</table>

```r
superpose.line <- trellis.par.get("superpose.line")
superpose.line$col <- rainbow(23)
superpose.line$1wd <- 2
superpose.line$1ty <- 1:2
```
trellis.par.set("superpose.line",superpose.line)
# Collapse over transect distance
xypplot(sqrt(meanvol) ~ depth | factor(year)*burn.sev2*s3, data=mdi, groups=site,
    panel=function(x,y, subscripts, groups) {
        panel.superpose(x,y, subscripts, groups, "panel.xyplot")
        panel.loess(x,y,xpan=1)
    }, subset=depth %in% c(1,3), xlab="Depth (cm)", ylab="Mean volume: square root (ml)",layout=c(5,6), strip = strip.custom(par.strip.text = list(cex = 0.66)),
     par.set
tings = list(layout.heights=list(strip=0.66)))
# Look at the effect of time by depth

```R
xyplot(sqrt(meanvol) ~ year | factor(depth)*burn.sev2*s3, data=mdi, groups=site,
       panel=function(x,y,subscripts,groups) {
           # panel.superpose(x,y,subscripts,groups, "panel.loess",span=0.333)
           panel.superpose(x,y,subscripts,groups, "panel.xyplot")
           panel.loess(x,y,span=0.5)
       }, subset=depth %in% c(1,3), ylab="Mean volume: square root (ml)", layout=c(4,3))
```
xyplot(meanvol ~ year | s3*factor(depth), data=mdi, groups=site, aspect=1, 
panel=function(x,y,subscripts,groups) {
  # panel.superpose(x,y,subscripts,groups,"panel.loess",span=0.333)
  panel.superpose(x,y,subscripts,groups,"panel.xyplot")
  panel.loess(x,y,span=0.5)
}, subset=depth %in% c(1,3) & burn.sev2=="Hot")

# Look closer at the "Hot" frames above
# Collapse over both transect distance and depth

```
xypplot(meanvol ~ year | s3*burn.sev2, data=mdi, groups=site, aspect=1,  
  panel=function(x,y, subscripts, groups) {  
    # panel.superpose(x,y, subscripts, groups, "panel.loess",span=0.33) 
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")  
    panel.loess(x,y,span=0.5)  
  }, subset=depth %in% c(1,3))
```
# Look at transformed responses (square roots)

```r
xyplot(sqrt(meanvol) ~ year | s3*burn.sev2, data=mdi, groups=site, aspect=1,
    panel=function(x,y, subscripts, groups) {
        # panel.superpose(x,y, subscripts, groups, "panel.loess",span=0.33)
        panel.superpose(x,y,subscripts,groups, "panel.xyplot")
        panel.loess(x,y,span=0.5)
    }, subset=depth %in% c(1,3), xlab="", ylab="Mean volume: sqrt (ml)"
```

# Repeat with original burn categories, loess line, and sqrt(meanvol)

```r
xyplot(sqrt(meanvol) ~ factor(year) | burn.sev*s3, data=mdi, groups=site, aspect=1,
panel=function(x,y, subscripts, groups) {
  # panel.superpose(x,y, subscripts, groups, "panel.lmline")
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  panel.loess(x,y,span=0.67)
}, subset=depth %in% c(1,3) & s3 !="To", main="MDI test results",
xlab="Year", ylab="Mean volume: square root(ml)", auto.key=list(columns=7)"
)```

Only category M is represented by all 3 soil types.

Plot against day number instead of year for a bit more resolution.

```r
xyplot(sqrt(meanvol) ~ daynum08 | burn.sev * s3, data=mdi, groups=site, aspect=1,
lattice.options = list(panel.error = "warning"),
panel=function(x,y, subscripts, groups) {
  # panel.superpose(x,y, subscripts, groups, "panel.lmline")
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  panel.loess(x,y,degree=2,span=1)
}, subset=depth %in% c(1,3), main="MDI test results",
xlab="Days since 12/31/2008", ylab="Mean volume: square root(ml)",
auto.key=list(columns=7))
```
# Compare original burn categories for each year
# I had to increase the smoothing parameter to get sensible curves in frames that include only 2 burn classes

```r
xyplot(sqrt(meanvol) ~ burn.sev | factor(year) * s3, data=mdi, groups=site, aspect=1,
        panel=function(x,y, subscripts, groups) {
            panel.superpose(x,y, subscripts, groups, "panel.xyplot")
            panel.loess(x,y,span=1)
        }, subset=depth %in% c(1,3)
)
```
xyplot(sqrt(meanvol) ~ daynum08 | burn.sev*s3, data=mdi, groups=site, aspect=1,
lattice.options = list(panel.error = "warning"),
panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y, subscripts, groups, "panel.xyplot")
    panel.lmline(x,y)
    panel.loess(x,y,lty=2,degree=2,span=1)
}, subset=depth %in% c(1,3), main="MDI test resu
xlab="Day number since 12/31/2008", ylab="Mean volume: square root(ml)",
auto.key=list(columns=7)
# Replot last one with log transformed response
mdi$meanvol2 <- mdi$meanvol
mdi$meanvol2[mdi$meanvol==0] <- 0.10
xyplot(log(meanvol2) ~ daynum08 | burn.sev * s3, data=mdi, groups=site, aspect=1,
lattice.options = list(panel.error = "warning"),
panel=function(x,y, subscripts, groups) {
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  panel.lmline(x,y)
  panel.loess(x,y,lty=2,degree=2,span=1)
}, subset=depth %in% c(1,3), main="MDI test results",
xlab="Day number since 12/31/2008", ylab="Mean volume: logarithm(ml)",
auto.key=list(columns=7)
# Mixed effects models
mdi.gd <- groupedData(meanvol ~ daynum | site/dist, outer = ~ burn.sev, data=mdi[mdi$depth %in% c(1,3),])
options(contrasts=c("contr.treatment","contr.treatment"))

# Start with the random effects model that we had for the full data set/
# Try to add the random effect of site on depth.
mdi3.fit0 <- mdi.logfit2a <- lme(log(meanvol2) ~ daynum + burn.sev + depth + daynum:burn.sev, random=list(site=~daynum+depth, dist=~1+daynum), data=mdi.gd)

# Failed to converge; tweak convergence criteria
mdi3.fit0 <- lme(log(meanvol2) ~ daynum + burn.sev + depth + daynum:burn.sev, random=list(site=~daynum+depth, dist=~1+daynum), data=mdi.gd, control=list(msMaxIter=100))

# Compare to previously reported model
anova mdi.logfit2a, mdi3.fit0)
That's a good improvement

anova(mdi3.fit0, type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>770</td>
<td>16.384275</td>
<td>0.0001</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>770</td>
<td>18.756166</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>burn.sev</td>
<td>4</td>
<td>18</td>
<td>2.291389</td>
<td>0.0994</td>
</tr>
<tr>
<td>depth</td>
<td>1</td>
<td>770</td>
<td>4.093988</td>
<td>0.0434</td>
</tr>
<tr>
<td>daynum:burn.sev</td>
<td>4</td>
<td>770</td>
<td>2.202098</td>
<td>0.0671</td>
</tr>
</tbody>
</table>

# Burn severity and its interaction with daynum are not significant
# Depth is marginally significant

# Retest the interaction between daynum and burn severity
mdi3.fit1 <- update(mdi3.fit0, ~ . + depth*burn.sev)

# Fails to converge; tweak convergence criteria
mdi3.fit1 <- update(mdi3.fit0, ~ . + depth*burn.sev, control=list(msMaxIter=100))

# Fails to converge; tweak convergence criteria

# Drop non-significant terms
mdi3.fit1 <- update(mdi3.fit0, log(meanvol2) ~ daynum + depth, control=list(msMaxIter=100))

anova(mdi3.fit1)

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>774</td>
<td>234.98725</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>774</td>
<td>38.48625</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>depth</td>
<td>1</td>
<td>774</td>
<td>4.98721</td>
<td>0.0258</td>
</tr>
</tbody>
</table>

# Add soil terms
mdi3.fit2 <- update(mdi3.fit1, ~ . + daynum*s3 + depth*s3)

anova(mdi3.fit2, type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>773</td>
<td>5.614660</td>
<td>0.0181</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>773</td>
<td>7.059411</td>
<td>0.0080</td>
</tr>
<tr>
<td>s3</td>
<td>2</td>
<td>20</td>
<td>4.538904</td>
<td>0.0237</td>
</tr>
<tr>
<td>daynum:s3</td>
<td>2</td>
<td>773</td>
<td>1.185258</td>
<td>0.3062</td>
</tr>
</tbody>
</table>

# None of the new terms are significant

# Re-test without depth
mdi3.fit3 <- update(mdi3.fit2, log(meanvol2) ~ daynum*s3)

anova(mdi3.fit3)

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
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<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>773</td>
<td>5.614660</td>
<td>0.0181</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>773</td>
<td>7.059411</td>
<td>0.0080</td>
</tr>
<tr>
<td>s3</td>
<td>2</td>
<td>20</td>
<td>4.538904</td>
<td>0.0237</td>
</tr>
<tr>
<td>daynum:s3</td>
<td>2</td>
<td>773</td>
<td>4.477970</td>
<td>0.0117</td>
</tr>
</tbody>
</table>

# Without depth in the model, soil type looks significant

# Which soil types are different
Fixed effects: log(meanvol2) ~ daynum + s3 + daynum:s3

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Std.Error</th>
<th>DF</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-12.470676</td>
<td>5.262938</td>
<td>773</td>
<td>-2.3695273</td>
<td>0.0181</td>
</tr>
</tbody>
</table>

413
daynum           0.000913  0.000344 773  2.6569552  0.0080
s3MS            -5.730192  6.051917  20 -0.9468392  0.3550
s3SS/MS         14.337619  7.972325  20  1.7984239  0.0872
daynum:s3MS     0.000356  0.000396 773  0.8998853  0.3685
daynum:s3SS/MS  -0.000949  0.000521 773 -1.8227743  0.0687

# Granitic is the "baseline"; SS/MS might be different but not MS
# Looks like it has a higher intercept and lower slope
# But none of the individual p-values is less than 0.05

# See if this result holds up if we drop the random effect of site on depth
# This matches the random effects reported in October 2013.
midi3.fit3a <- update(midi3.fit3, random= ~ daynum)
anova(midi3.fit3,midi3.fit3a)

    Model df      AIC      BIC    logLik   Test  L.Ratio p-value
midi3.fit3      1 14 2713.608 2780.904 -1342.804
midi3.fit3a     2 13 2731.478 2793.967 -1352.739 1 vs 2 19.86985  <.0001

# The first model has the lower AIC so is supposedly better

anova(midi3.fit3a,type="marginal")

     numDF denDF F-value p-value
(Intercept)     1   773 3.500152  0.0617
daynum          1   773 4.278019  0.0389
s3               2    20 0.694240  0.5111
daynum:s3       2   773 0.669122  0.5125

# The simpler model doesn't support the effect of soil nor its interaction with daynum
# That's a surprise because usually dropping important random effects makes the fixed
# effects look more significant.

# Compare residuals distributions of these two models
par(mfrow=c(1,2))
qqresid(midi3.fit3)
qqresid(midi3.fit3a)
# The second model has a slightly smaller departure from normality

# Try testing soils and its interaction with day number in the October 2013 model
# (i.e. with one less random effect, but with depth and burn severity included)
mdi.logfit2c <- update(mdi.logfit2a, ~ . + s3*daynum)
# This is equivalent to
mdi3.fit3c <- update(mdi3.fit3a, ~ . + depth + burn.sev + daynum:burn.sev)
> AIC(mdi.logfit2c)
[1] 2810.794
> AIC(mdi3.fit3c)
[1] 2810.795

anova(mdi.logfit2c, type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>768</td>
<td>13.371609</td>
<td>0.0003</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>768</td>
<td>15.186221</td>
<td>0.0001</td>
</tr>
<tr>
<td>burn.sev</td>
<td>4</td>
<td>16</td>
<td>7.517636</td>
<td>0.0013</td>
</tr>
<tr>
<td>depth</td>
<td>1</td>
<td>768</td>
<td>8.311845</td>
<td>0.0040</td>
</tr>
<tr>
<td>s3</td>
<td>2</td>
<td>16</td>
<td>3.731824</td>
<td>0.0468</td>
</tr>
<tr>
<td>daynum:burn.sev</td>
<td>4</td>
<td>768</td>
<td>7.363396</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>daynum:s3</td>
<td>2</td>
<td>768</td>
<td>3.805177</td>
<td>0.0227</td>
</tr>
</tbody>
</table>

# Weird: Now everything appears to be at least somewhat significant.
# Compare this model directly with mdi3.fit3a above.

# Must fit using maximum likelihood for a valid comparison
mdi3.fit3aML <- update(mdi3.fit3a, method="ML")
mdi3.fit3cML <- update(mdi3.fit3c, method="ML")
anova(mdi3.fit3aML, mdi3.fit3cML)
Suggests that the bigger model is no better, in fact has a higher AIC, but Pinheiro and Bates say (pg 91) that the conditional F-tests (in the anova tables showing p-values for each term) are more "realistic"; but these 2 results are radically different

# Compare with the simple fixed effects model: log(meanvol2) ~ daynum
AIC(update(mdi3.fit3a, log(meanvol2) ~ daynum, method="ML"))
[1] 2680.564
# this has the lowest AIC of all, suggesting all those terms are useless

# Try a model that treats year as a categorical variable
# There is a loss of information in the categorization of time, but
# we don't have to assume the effect of time is linear
mdi3.fit4 <- update(mdi3.fit3, log(meanvol2) ~ s3*year, control=list(msMaxIter=150))
# Fails to converge (I tried a variety of convergence criteria)

# Summary plot of fixed effects in model mdi3.fit3
xyplot(log(meanvol2) ~ daynum08 | s3, data=mdi.gd, groups=site, aspect=1,
    panel=function(x,y, subscripts, groups) {
      panel.superpose(x,y,subscripts,groups, "panel.xyplot")
      panel.lmline(x,y)
      panel.loess(x,y,lty=2,degree=2,span=1)
    }, subset=depth %in% c(1,3), main="MDI test results", layout=c(3,1),
    xlab="Day number since 12/31/2008", ylab="Mean volume: logarithm(ml)",
    auto.key=list(columns=7) )
The lines are not the lines fitted by the model, they are independent linear fits for each frame. The higher intercept and lower slope suggested by mdi3.fit3 for SS/MS relative to Granitic is not apparent; the MS curve is the steepest and the SS/MS curve is shifted lower (than Granitic). I'm skeptical of the soils effect since it only was significant in one of the three models I fitted, 0.01 < p < 0.05, the individual soil coefficients were not significant (p > 0.05), and the model without the depth random effect had a slightly more normal residuals distribution. There seems to be some sort of confounding of depth and soil type.

# Look at the mean volumes by year and soil type
tapply(mdi$meanvol,list(mdi$year,mdi$s3),mean)

<table>
<thead>
<tr>
<th>Year</th>
<th>Granitic</th>
<th>MS</th>
<th>SS/MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>2.372326</td>
<td>1.899882</td>
<td>3.960667</td>
</tr>
<tr>
<td>2010</td>
<td>5.422500</td>
<td>5.190593</td>
<td>3.322667</td>
</tr>
<tr>
<td>2011</td>
<td>5.438611</td>
<td>3.446809</td>
<td>6.802812</td>
</tr>
<tr>
<td>2012</td>
<td>10.236458</td>
<td>8.247174</td>
<td>8.532222</td>
</tr>
<tr>
<td>2013</td>
<td>5.032778</td>
<td>6.743667</td>
<td>4.097500</td>
</tr>
</tbody>
</table>

# Look at log(mean volume) by year and soil
tapply(log(mdi$meanvol2),list(mdi$year,mdi$s3),mean)

<table>
<thead>
<tr>
<th>Year</th>
<th>Granitic</th>
<th>MS</th>
<th>SS/MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>-0.0384497</td>
<td>0.2773883</td>
<td>0.5930171</td>
</tr>
<tr>
<td>2010</td>
<td>1.4263308</td>
<td>1.11251027</td>
<td>0.9025328</td>
</tr>
</tbody>
</table>
In summary, there is very inconsistent evidence for a soils effect

**Effects of Vegetation Type**

```r
library(nlme)
library(lattice)

# READ in the Veg and Soil types
soilveg <- read.csv("Update Jun 2014/MDI WDPT soil veg.csv")
  veg  v3  soil
  1  RW  RW  Dom       MS
  2  RW/DF  RW  Dom    MS/SS
  3  RW  RW  Dom Granitic
  4  RW/TO  RW  Dom    MS
  5  RW/TO  RW  Dom    MS
  6   TO   To       MS
  7  KP/MZ  KP/MZ       MS
  8  KP/MZ  KP/MZ       MS
  9  RW/TO  RW  Dom Granitic
 10  KP/MZ  KP/MZ       MS
 11  RW/TO  RW  Dom Granitic
 12  KP/MZ  KP/MZ       MS
 13  RW  RW  Dom Granitic
 14  RW  RW  Dom       MS
 15  KP/MZ  KP/MZ       MS
 16  KP/MZ  KP/MZ       MS
 17  KP/MZ  KP/MZ       MS
 18  KP/MZ  KP/MZ       MS
 19  KP/MZ  KP/MZ       MS
 20  KP/MZ  KP/MZ       MS
 21  RW/TO  RW  Dom    MS/SS
 22  KP/MZ  KP/MZ       SS
 23  RW/TP  RW  Dom       MS

# The row names coincide with the site numbers
# The veg types can be accessed by using site number as the subscript

mdi$v3 <- soilveg$v3[mdi$sitenum]
mdi$soil <- soilveg$soil[mdi$sitenum]
wdpt$v3 <- soilveg$v3[wdpt$sitenum]
wdpt$soil <- soilveg$soil[wdpt$sitenum]

save.image()

superpose.line <- trellis.par.get("superpose.line")
superpose.line$col <- rainbow(23)
superpose.line$lwd <- 2
superpose.line$lty <- 1:2
trellis.par.set("superpose.line",superpose.line)
# Collapse over transect distance
xyplot(sqrt(meanvol) ~ depth | factor(year)*burn.sev2*v3, data=mdi, groups=site, panel=function(x,y, subscripts, groups) {
  panel.superpose(x,y, subscripts, groups, "panel.xyplot")
```

418
panel.loess(x,y,xpan=1)
}, subset=depth %in% c(1,3) & v3!="To", xlab="Depth (cm)", ylab="Mean volume: square root (ml)", layout=c(5,4))

# Look at the effect of time by depth
xyplot(sqrt(meanvol) ~ year | factor(depth)*burn.sev2*v3, data=mdi, groups=site, aspect=1,
panel=function(x,y, subscripts, groups) {
    # panel.superpose(x,y, subscripts, groups, "panel.loess",span=0.333)
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    panel.loess(x,y,span=0.5)
}, subset=depth %in% c(1,3) & v3!="To",ylab="Mean volume: square root (ml)",layout=c(4,2),xlab=""

# Look closer at the "Hot" frames above

xyplot(sqrt(meanvol) ~ year | factor(depth) * v3, data=mdi, groups=site, aspect=1,
    panel=function(x,y, subscripts, groups) {
        # panel.superpose(x,y, subscripts, groups, "panel.loess",span=0.333)
        panel.superpose(x,y,subscripts,groups, "panel.xyplot")
        panel.loess(x,y,span=0.5)
    }, subset=depth %in% c(1,3) & burn.sev2=="Hot" & v3!="To", ylab="Mean volume: square root (ml)"
# Collapse over both transect distance and depth

```r
xyplot(sqrt(meanvol) ~ year | v3*burn.sev2, data=mdi, groups=site, aspect=1,
    panel=function(x,y, subscripts, groups) {
        panel.superpose(x,y, subscripts, groups, "panel.loess", span=0.33)
        panel.superpose(x,y,subscripts,groups, "panel.xyplot")
        panel.loess(x,y,span=0.5)
    }, subset=depth %in% c(1,3) & v3!="To", xlab="", ylab="Mean volume: square root (ml)"
)```

```r
# Collapse over both transect distance and depth
xyplot(sqrt(meanvol) ~ year | v3*burn.sev2, data=mdi, groups=site, aspect=1,
    panel=function(x,y, subscripts, groups) {
        panel.superpose(x,y, subscripts, groups, "panel.loess", span=0.33)
        panel.superpose(x,y,subscripts,groups, "panel.xyplot")
        panel.loess(x,y,span=0.5)
    }, subset=depth %in% c(1,3) & v3!="To", xlab="", ylab="Mean volume: square root (ml)"
)```
# Repeat with original burn categories, loess line, and sqrt(meanvol)

```r
xyplot(sqrt(meanvol) ~ factor(year) | burn.sev * v3, data=mdi, groups=site, aspect=1,
  panel=function(x,y,subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    panel.loess(x,y,span=0.67)
  }, subset=depth %in% c(1,3) & v3 !="To", main="MDI test results",
  xlab="", ylab="Mean volume: square root(ml)", auto.key=list(columns=7)
}
```
# Plot against day number instead of year for a bit more resolution

```
xyplot(sqrt(meanvol) ~ daynum08 | burn.sev * v3, data=mdi, groups=site, aspect=1,
  panel=function(x,y, subscripts, groups) {
    # panel.superpose(x,y, subscripts, groups, "panel.lmline")
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    panel.loess(x,y,degree=2,span=1)
  }, subset=depth %in% c(1,3) & v3 != "To", main="MDI test results",
  xlab="Days since 12/31/2008", ylab="Mean volume: square root(ml)",
  auto.key=list(columns=7)
}
```
# Compare original burn categories for each year
# I had to increase the smoothing parameter to get sensible curves in frames that include only 2 burn classes

xyplot(sqrt(meanvol) ~ burn.sev | factor(year) * v3, data=mdi, groups=site, aspect=1, 
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y, subscripts, groups, "panel.xyplot")
    panel.loess(x,y,span=0.9)
  }, subset=depth %in% c(1,3) & v3 != "To"
)
xyplot(sqrt(meanvol) ~ daynum08 | burn.sev*v3, data=mdi2.gd, groups=site, aspect=1, panel=function(x,y, subscripts, groups) {
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  panel.lmline(x,y)
  panel.loess(x, y, lty=2, degree=2, span=1)
}, subset=depth %in% c(1,3), main="MDI test results", xlab="Day number since 12/31/2008", ylab="Mean volume: square root(ml)", auto.key=list(columns=7) )
# Replot last one with log transformed response

```r
xyplot(log(meanvol2) ~ daynum08 | burn.sev * v3, data=mdi2.gd, groups=site, aspect=1,
   panel=function(x,y,subscripts,groups) {
     panel.superpose(x,y,subscripts,groups, "panel.xyplot")
     panel.lmline(x,y)
     panel.loess(x,y,lty=2,degree=2,span=1)
   }, subset=depth %in% c(1,3), main="MDI test results",
   xlab="Day number since 12/31/2008", ylab="Mean volume: logarithm(ml)",
   auto.key=list(columns=7)
)
```
# Mixed effects models
mdi2.gd <- groupedData(meanvol ~ daynum | site/dist, outer = ~ burn.sev, data=mdi[mdi$depth %in% c(1,3) &mdi$v3 != "To"],)
options(contrasts=c("contr.treatment","contr.treatment"))

# Try modeling the logarithm, which was successful before
# Must first deal with zeroes
sum(mdi2.gd$meanvol==0)
[1] 32
# Set the zeroes to 0.10
mdi2.gd$meanvol2 <- mdi2.gd$meanvol
mdi2.gd$meanvol2[mdi2.gd$meanvol==0] <- 0.10

# Fit the random effects model that we had for the full data set
mdi2.fit0 <- lme(log(meanvol2) ~ daynum + burn.sev + depth + daynum:burn.sev, random=list(site=~daynum+depth, dist=~1+daynum), data=mdi2.gd)
anova(mdi2.fit0) # Sequential

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>742</td>
<td>181.63490</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>742</td>
<td>45.53880</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>burn.sev</td>
<td>4</td>
<td>17</td>
<td>1.37084</td>
<td>0.2855</td>
</tr>
<tr>
<td>depth</td>
<td>1</td>
<td>742</td>
<td>3.96905</td>
<td>0.0467</td>
</tr>
<tr>
<td>daynum:burn.sev</td>
<td>4</td>
<td>742</td>
<td>1.94609</td>
<td>0.1010</td>
</tr>
</tbody>
</table>

anova(mdi2.fit0,type="marginal")
# The burn severity and its interaction are not significant 
# and depth is only marginally significant.

# Retest the interaction between depth and burn severity 
mdi2.fit1 <- update(mdi2.fit0, ~ . + depth*burn.sev)
# Fails to converge; tweak convergence criteria
mdi2.fit1 <- update(mdi2.fit0, ~ . + depth*burn.sev, control=list(msMaxIter=100))

# Only daynum is significant; drop non-significant interactions
mdi2.fit2 <- update(mdi2.fit0, log(meanvol2) ~ daynum + depth + burn.sev, 
control=list(msMaxIter=100))

# See if the veg terms hold up after dropping insignificant terms
mdi2.fit4 <- update(mdi2.fit0, log(meanvol2) ~ daynum + depth + v3*daynum, 
control=list(msMaxIter=100))

# Vegetation is not significant at the 0.05 level

<table>
<thead>
<tr>
<th>Value</th>
<th>Std.Error</th>
<th>DF</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-21.955297</td>
<td>3.851478</td>
<td>745</td>
<td>-5.700486</td>
</tr>
<tr>
<td>daynum</td>
<td>0.001520</td>
<td>0.000256</td>
<td>745</td>
<td>5.945497</td>
</tr>
</tbody>
</table>
Although not significant the coefficients suggest higher MDI volumes in the RW dominant veg type, with slightly lower slopes.

# Compare models with different fixed effects using maximum likelihood
tmp1 <- update(mdi2.fit4, method="ML")
tmp0 <- update(tmp1, ~ . - depth - v3*daynum)
anova(tmp0, tmp1)

# This suggests keeping depth and the v3:daynum interaction
# Pinheiro and Bates recommend going by the conditional F and t-tests,
# i.e. the 0.0804 and 0.0756, but can 2 nearly significant terms considered
# together can constitute an improvement? Thats' probably pushing things too far.

# What happens if we go to a slightly simpler random effects model
# This is probably not wise either because then the residuals might not be
# fully independent. So the following is just to satisfy curiosity.
# Drop the effect of site on depth
mdi2.fit4a <- update(mdi2.fit4, random= ~ daynum)
anova(mdi2.fit4, mdi2.fit4a)

# The original model is better by AIC
anova(mdi2.fit4a, type="marginal")

Fixed effects: log(meanvol2) ~ daynum + depth + v3 + daynum:v3
Value Std.Error  DF   t-value p-value
(Intercept)     -25.088569 4.308891 745  5.822512 0.0000
daynum            0.001727 0.000284 745  6.083660 0.0000
depth           -0.093025 0.032516 745  2.860857 0.0043
v3RW Dom         13.884383 5.843830  20  2.375905 0.0276
daynum:v3RW Dom  -0.000892 0.000384 745  2.323496 0.0204

# Compare residuals distributions
par(mfrow=c(1,2))
qqresid(mdi2.fit4)
qqresid(mdi2.fit4a)
# Very similar; the latter is perhaps slightly more normal

```r
xyplot(log(meanvol2) ~ daynum08 | v3, data=mdi2.gd, groups=site, aspect=1,
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    panel.lmline(x,y)
    panel.loess(x,y,lty=2,degree=2,span=1)
  }, subset=depth %in% c(1,3), main="MDI test results",
xlab="Day number since 12/31/2008", ylab="Mean volume: logarithm(ml)",
auto.key=list(columns=7)
)
```

Normal Q-Q Plot

Sample Quantiles

Theoretical Quantiles

Sample Quantiles

Theoretical Quantiles

Sample Quantiles

Theoretical Quantiles
# The statistical significance of vegetation depends on the random effects

# Try a model that treats year as a categorical variable
mdi2.fit5 <- update(mdi2.fit0, log(meanvol2) ~ daynum + depth + v3*year, control=list(msMaxIter=100))

anova(mdi2.fit5,type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>744</td>
<td>13.991677</td>
<td>0.0002</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>744</td>
<td>8.971751</td>
<td>0.0028</td>
</tr>
<tr>
<td>depth</td>
<td>1</td>
<td>744</td>
<td>3.902272</td>
<td>0.0486</td>
</tr>
<tr>
<td>v3</td>
<td>1</td>
<td>20</td>
<td>3.176608</td>
<td>0.0899</td>
</tr>
<tr>
<td>year</td>
<td>1</td>
<td>744</td>
<td>13.873266</td>
<td>0.0002</td>
</tr>
<tr>
<td>v3:year</td>
<td>1</td>
<td>744</td>
<td>3.171963</td>
<td>0.0753</td>
</tr>
</tbody>
</table>

# Essentially the same result

# Look at mean volumes by year and veg type
tapply(mdi$meanvol,list(mdi$year,mdi$v3),mean)

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>KP/MZ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>1.537250</td>
<td>3.095929</td>
<td>0.950000</td>
</tr>
<tr>
<td>2010</td>
<td>4.814250</td>
<td>4.988125</td>
<td>NA</td>
</tr>
<tr>
<td>2011</td>
<td>4.196290</td>
<td>4.901250</td>
<td>3.833333</td>
</tr>
<tr>
<td>2012</td>
<td>7.559405</td>
<td>9.227381</td>
<td>11.581667</td>
</tr>
<tr>
<td>2013</td>
<td>7.040833</td>
<td>4.808056</td>
<td>NA</td>
</tr>
</tbody>
</table>

# Same thing: logarithms
tapply(log(mdi$meanvol2),list(mdi$year,mdi$v3),mean)

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>KP/MZ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>-0.3696405</td>
<td>0.6705739</td>
<td>-0.4132257</td>
</tr>
<tr>
<td>Year</td>
<td>RW Dom</td>
<td>KP/MZ1</td>
<td>KP/MZ2</td>
</tr>
<tr>
<td>------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>2010</td>
<td>1.0859993</td>
<td><strong>1.1605157</strong></td>
<td>NA</td>
</tr>
<tr>
<td>2011</td>
<td><strong>0.9335343</strong></td>
<td>1.1957786</td>
<td><strong>1.2791047</strong></td>
</tr>
<tr>
<td>2012</td>
<td><strong>1.6532094</strong></td>
<td>1.9073606</td>
<td><strong>2.2567524</strong></td>
</tr>
<tr>
<td>2013</td>
<td><strong>1.4720946</strong></td>
<td>1.2733552</td>
<td>NA</td>
</tr>
</tbody>
</table>

# RW Dom appears to have had higher volumes than KP/MZ except in 2013
Appendix L. R Code and Output for the WDPT Dataset

Effects of Burn Severity

library("chron")
library("lattice")
library(nlme)

# Correct the depths

table(wdpt$depth)

<table>
<thead>
<tr>
<th>Depth</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.394</td>
<td>72</td>
</tr>
<tr>
<td>1</td>
<td>261</td>
</tr>
<tr>
<td>1.181</td>
<td>65</td>
</tr>
<tr>
<td>2</td>
<td>261</td>
</tr>
<tr>
<td>3</td>
<td>261</td>
</tr>
</tbody>
</table>

sum(wdpt$depth < 1)
[1] 72

wdpt$depth[wdpt$depth < 1] <- 1
sum(wdpt$depth > 1 & wdpt$dept < 2)
[1] 65

wdpt$depth[wdpt$depth > 1 & wdpt$dept < 2] <- 3

table(wdpt$depth)

<table>
<thead>
<tr>
<th>Depth</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>333</td>
</tr>
<tr>
<td>2</td>
<td>261</td>
</tr>
<tr>
<td>3</td>
<td>326</td>
</tr>
</tbody>
</table>

save.image()

superpose.line <- trellis.par.get("superpose.line")
superpose.line$col <- rainbow(23)
superpose.line$lwd <- 2
superpose.line$lty <- 1:2
trellis.par.set("superpose.line",superpose.line)

wdpt.gd <- groupedData(time2 ~ daynum | site, outer = ~ burn.sev, data=wdpt)
save.image()

tmp <- wdpt.gd[wdpt.gd$depth==1, ]
plot(tmp, aspect=1, outer=T ,xlab="Days since 12/31/2008",ylab="Penetration time",main="WDPT results at depth = 1 cm")
tmp <- wdpt.gd[wdpt.gd$depth==2, ]
plot(tmp, aspect=1, outer=T, xlab="Days since 12/31/2008", ylab="Penetration time", main="WDPT results at depth = 2 cm")
```r
tmp <- wdpt.gd[wdpt.gd$depth==3, ]
plot(tmp, aspect=1, outer=T, xlab="Days since 12/31/2008", ylab="Penetration time", main="WDPT results at depth = 3 cm")
```
```r
tmp <- wdpt.gd[wdpt.gd$depth == 1, ]; tmp$daynum <- as.numeric(dates("1/1/2009"))
plot(tmp, aspect=1, layout=c(6,4), xlab="Days since 12/31/2008", ylab="Penetration time", main="WDPT results at depth = 1 cm")
```
```r
tmp <- wdpt.gd[wdpt.gd$depth==2, ]; tmp$daynum <- tmp$daynum - as.numeric(dates("1/1/2009"))
plot(tmp, aspect=1, layout=c(6,4), xlab="Days since 12/31/2008", ylab="Penetration time", main="WDPT results at depth = 2 cm")
```
WDPT results at depth = 2 cm

tmp <- wdpt.gd[wdpt.gd$depth==3, ]; tmp$daynum <- as.numeric(dates("1/1/2009"))
plot(tmp, aspect=1, layout=c(6,4), xlab="Days since 12/31/2008", ylab="Penetration time", main="WDPT results at depth = 3 cm", ylim=c(-50,425))
WDPT results at depth = 3 cm

xyplot(time ~ depth | burn.sev*year, data=wdpt, group=site,
       panel=function(x,y, subscripts, groups) {
           panel.superpose(x,y, subscripts, groups, "panel.lmline")
           panel.superpose(x,y,subscripts,groups, "panel.xyplot")
       })

# Recode time=1000 to 400

superpose.line$lwd <- 1
superpose.line$lty <- 1
trellis.par.set("superpose.line",superpose.line)

xyplot(time2 ~ depth | burn.sev*year, data=wdpt, groups=site,
       panel=function(x,y, subscripts, groups) {
           panel.superpose(x,y, subscripts, groups, "panel.lmline")
           panel.superpose(x,y,subscripts,groups, "panel.xyplot")
       }, xlab = "Depth (cm)", ylab="Penetration time (secs)"
, main="WDPT test results", auto.key=list(columns=6))
WDPT test results

Depth (cm)
Penetration time (secs)

# 3-way plot layout
par(ask=T)
xyplot(time2 ~ depth | factor(dist)*year*burn.sev, data=wdpt, groups=site, aspect=1, xlab="Depth (cm)", ylab="Time of penetration (secs)", panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y, subscripts, groups, "panel.lmline")
    panel.superpose(x,y, subscripts, groups, "panel.xyplot")
}
)
<table>
<thead>
<tr>
<th>Year</th>
<th>Time of penetration (secs)</th>
<th>Depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0 20 40 60 80 100</td>
<td>1.0 1.5 2.0 2.5 3.0</td>
</tr>
<tr>
<td>2011</td>
<td>0 20 40 60 80 100</td>
<td>1.0 1.5 2.0 2.5 3.0</td>
</tr>
<tr>
<td>2012</td>
<td>0 20 40 60 80 100</td>
<td>1.0 1.5 2.0 2.5 3.0</td>
</tr>
<tr>
<td>2013</td>
<td>0 20 40 60 80 100</td>
<td>1.0 1.5 2.0 2.5 3.0</td>
</tr>
</tbody>
</table>

For using packet where TRUE/FALSE needed.

Error using packet 36.

Error using packet 36.
Error using packet 58
missing value where TRUE/FALSE needed
The image shows a graph with the following details:

- **Depth (cm):** The depth is measured in centimeters and ranges from 0 to 100.
- **Time of penetration (secs):** The time of penetration is measured in seconds and ranges from 0 to 400.
- **Years:** The graph includes data for the years 2010, 2011, 2012, and 2013.
- **MH:** The graph indicates measurements for MH across the years.
# 3-way plot layout, combine burn groups into cool=N,ML and hot=M,MH,H
wdpt$burn.sev2 <- wdpt$burn %in% c("M","MH","H")
wdpt$burn.sev2 <- factor(wdpt$burn.sev2,labels=c("Cool","Hot"))
xyplot(time2 ~ depth | factor(dist)*year*burn.sev2, data=wdpt, groups=site, aspect=1, panel=function(x,y, subscripts, groups) {
  panel.superpose(x,y, subscripts, groups, "panel.lmline")
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
})
# Collapse over transect distance

```r
xyplot(sqrt(time2) ~ depth | year*burn.sev2, data=wdpt, groups=site,
       aspect=1,
       panel=function(x,y, subscripts, groups) {
         # panel.superpose(x,y, subscripts, groups, "panel.lmline")
         panel.superpose(x,y,subscripts,groups, "panel.xyplot")
         panel.loess(x,y,span=1)
       },
       ylab="Penetration time: square root (secs)", xlab="Depth (cm)"
)
```
This makes it clear that hot burns had longer penetration times in all years.
AND depth doesn't seem to have a consistent effect if any.

```r
xyplot(sqrt(time2) ~ year | factor(depth)*burn.sev2, data=wdpt, groups=site, aspect=1,
    panel=function(x,y, subscripts, groups) {
        # panel.superpose(x,y, subscripts, groups, "panel.loess",span=0.333)
        panel.superpose(x,y,subscripts,groups, "panel.xyplot")
        panel.loess(x,y,degree=1, span=1)
    }, ylab="Penetration time: square root (secs)"
)"
# Collapse over both transect distance AND depth;
xyplot(time2 ~ daynum08 | burn.sev, data=wdpt, groups=site, aspect=1,
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    # panel.superpose(x,y,subscripts,groups, "panel.lmline")   fails
    panel.loess(x,y,span=1.25,degree=2)
    # had to increase span to eliminate warnings
  }, ylab="Penetration time (secs)", xlab="Days since 12/31/2008",
  main="WDPT test results", auto.key=list(columns=7)
)
# Use square root transformation

```r
xyplot(sqrt(time2) ~ daynum08 | burn.sev, data=wdpt, groups=site, aspect=1,
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
    panel.loess(x,y,span=1.25,degree=2)
    # had to increase span to avoid warnings
  }, ylab="Penetration time: square root(secs)", xlab="Days since 12/31/2008",
  main="WDPT test results", auto.key=list(columns=7))
```
The decline in times seems to have reversed in 2013

Use log transformation

```r
xyplot(log(time2) ~ daynum08 | burn.sev, data=wdpt, groups=site, aspect=1,
panel=function(x,y, subscripts, groups) {
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  # panel.superpose(x,y,subscripts,groups, "panel.lmline")  fails
  panel.loess(x,y,span=1.25,degree=2)  # had to increase span to
  avoid warnings
}, ylab="Penetration time: logarithm(secs)", xlab="Days since 12/31/2008",
```

WDPT test results

<table>
<thead>
<tr>
<th>Days since 12/31/2008</th>
<th>Penetration time: square root(secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>600</td>
</tr>
<tr>
<td>5</td>
<td>800</td>
</tr>
<tr>
<td>10</td>
<td>1000</td>
</tr>
<tr>
<td>15</td>
<td>1200</td>
</tr>
<tr>
<td>20</td>
<td>1400</td>
</tr>
</tbody>
</table>

Days since 12/31/2008

Penetration time: square root(secs)

600 800 1000 1200 1400 1600

MH  H  N  ML  M

WDPT test results
main="WDPT test results", auto.key=list(columns=7)

WDPT test results

# But we cannot ignore 164 values of penetration time that are 0
# Use log transformation with 0's recoded to 0.5
wdpt$time3 <- wdpt$time2
wdpt$time3[wdpt$time2==0] <- 0.5

xyplot(log(time3) ~ year | burn.sev, data=wdpt, groups=site, aspect=1,
panel=function(x,y,subscripts,groups) {
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
panel.loess(x,y,span=1.25, degree=2)  # had to increase span to avoid warnings
}, ylab="Penetration time: logarithm(secs)", xlab="Year",
main="WDPT test results", auto.key=list(columns=7)
)

# OK it's pretty clear that 2010 had higher penetration times than 2011 and 2012. And 2013 is intermediate.

# Combining N and ML severity levels
xyplot(time2 ~ year | burn.sev2, data=wdpt, groups=site, aspect=1,
panel=function(x,y, subscripts, groups) {

```r

WDPT test results

<table>
<thead>
<tr>
<th>Severity</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>1H</td>
<td>1H</td>
<td>1H</td>
<td>1H</td>
<td>1H</td>
</tr>
<tr>
<td>2M</td>
<td>2M</td>
<td>2M</td>
<td>2M</td>
<td>2M</td>
</tr>
<tr>
<td>3M</td>
<td>3M</td>
<td>3M</td>
<td>3M</td>
<td>3M</td>
</tr>
</tbody>
</table>

```
xyplot(sqrt(time2) ~ year | burn.sev2, data=wdpt, groups=site, aspect=1,
panel=function(x,y, subscripts, groups) {
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
  panel.loess(x,y,span=1)
  }, ylab="Penetration time (secs)", xlab="Year"
)
```r
xyplot(log(time3) ~ year | burn.sev2, data=wdpt, groups=site, aspect=1,
panel=function(x,y, subscripts, groups) {
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  # panel.superpose(x,y,subscripts,groups, "panel.lmline")   fails
  panel.loess(x,y,span=1,degree=1)
}, ylab="Penetration time: logarithm(secs)", xlab="Year"
)
```
table(wdpt$depth)

1 2 3
333 261 326

wdpt.gd <- groupedData(sqrt(time2) ~ year | site/dist, outer = ~ burn.sev, data=wdpt)
options(contrasts=c("contr.treatment","contr.treatment"))
# Test a random effect of transect within site on the coefficient of daynum
wdpt.fit0 <- lme(sqrt(time2) ~ daynum*burn.sev, data=wdpt.gd, random=~1)
wdpt.fit1 <- lme(sqrt(time2) ~ daynum*burn.sev, data=wdpt.gd, random=~daynum)
anova(wdpt.fit0, wdpt.fit1)

<table>
<thead>
<tr>
<th>Model</th>
<th>df</th>
<th>AIC</th>
<th>BIC</th>
<th>logLik</th>
<th>Test</th>
<th>L.Ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>wdpt.fit0</td>
<td>1</td>
<td>5314.497</td>
<td>5377.072</td>
<td>-2644.25</td>
<td>2 vs 1</td>
<td>77.7</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

# Keep the random effects on daynum

# Are nested random effects (transects within site) really needed?
wdpt.fit11 <- lme(sqrt(time2) ~ daynum*burn.sev, data=wdpt.gd, random=list(site=~daynum))
anova(wdpt.fit11, wdpt.fit1)

<table>
<thead>
<tr>
<th>Model</th>
<th>df</th>
<th>AIC</th>
<th>BIC</th>
<th>logLik</th>
<th>Test</th>
<th>L.Ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>wdpt.fit11</td>
<td>1</td>
<td>5326.191</td>
<td>5393.58</td>
<td>-2649.09</td>
<td>2 vs 1</td>
<td>87.4</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

# Yes the nested random effect is needed

anova(wdpt.fit11, type="marginal")

numDF denDF F-value p-value
(Intercept) 1   790  6.216169 0.0129
daynum      1   790  6.139258 0.0134
burn.sev    4   16  1.953027 0.1506
daynum:burn.sev 4   790  1.928779 0.1037

# Burn severity and its interaction with daynum are not significant

wdpt.fit2 <- update(wdpt.fit1, ~ . + depth)
anova(wdpt.fit2, type="marginal")

numDF denDF F-value p-value
(Intercept) 1   789  6.198319 0.0130
daynum      1   789  6.138708 0.0134
burn.sev    4   16  1.949458 0.1512
depth       1   789  0.329874 0.5659
daynum:burn.sev 4   789  1.925247 0.1043

depth was highly significant when miscoded, now it is unimportant

anova(wdpt.fit2, type="sequential")

numDF denDF F-value p-value
(Intercept) 1   789 41.78695 <.0001
daynum      1   789 44.86518 <.0001
burn.sev    4   16  0.66365 0.6263
depth       1   789  0.34783 0.5555
daynum:burn.sev 4   789  1.92525 0.1043
daynum:depth 1   788  2.23640 0.1352

# Burn severity and its interaction with day number are not significant

# Only day number is significant

wdpt.fit2a <- update(wdpt.fit2, ~ . + depth*daynum)
anova(wdpt.fit2a)

| (Intercept) | 1 | 788 | 41.83086 | <.0001 |
daynum      | 1 | 788 | 44.82616 | <.0001 |
burn.sev    | 4 | 16  | 0.66478  | 0.6255 |
depth       | 1 | 788 | 0.34832  | 0.5552 |
daynum:burn.sev 4   788  1.92373 0.1046
daynum:depth 1   788  2.23640 0.1352

# Depth interaction is not significant either
# Best model so far is wdpt.fit1. But is the trend linear? No. A quadratic would be a much better fit. Here goes:

```r
wdpt.fit3 <- update(wdpt.fit1, ~ . + I(daynum^2)*burn.sev)
anova(wdpt.fit3)
```

```
  numDF denDF   F-value  p-value
(Intercept)          1   785  49.56129 <.0001
  daynum              1   785  49.77195 <.0001
  burn.sev             4    16   0.79771   0.5440
  I(daynum^2)          1   785 117.54848 <.0001
  daynum:burn.sev     4   785   0.83308   0.5043
  burn.sev:I(daynum^2) 4   785   4.39200   0.0016
```

```r
anova(wdpt.fit3, type="marginal")
```

```
  numDF denDF   F-value  p-value
(Intercept)          1   785  5.599882  0.0182
  daynum              1   785  5.496387  0.0193
  burn.sev             4    16  4.358494  0.0142
  I(daynum^2)          1   785  5.397587  0.0204
  depth                1   780  0.483869  0.4869
  daynum:burn.sev     4   780  4.381489  0.0016
  burn.sev:I(daynum^2) 4   780  4.392002  0.0016
```

# OK so keep the quadratic term. Note that burn severity has significant interactions with both the linear and quadratic trend terms.

```r
wdpt.fit3a <- update(wdpt.fit3, ~ . + depth*burn.sev)
anova(wdpt.fit3a, type="marginal")
```

```
  numDF denDF   F-value  p-value
(Intercept)          1   780  5.596618  0.0180
  daynum              1   780  5.491764  0.0194
  burn.sev             4    16  4.363992  0.0142
  I(daynum^2)          1   780  5.397587  0.0205
  depth               4   780  0.483869  0.4869
  daynum:burn.sev     4   780  4.381489  0.0016
  burn.sev:I(daynum^2) 4   780  4.395265  0.0016
  burn.sev:depth     4   780  1.001095  0.4061
```

# Depth is not significant nor is its interaction with burn severity.

# The best model remains wdpt.fit3.

```r
qqresid(wdpt.fit3)
```
# Very bad. We really cannot trust the significance tests above.
# Try a model with log(response)
wdpt.fit4 <- update(wdpt.fit3, log(time3) ~ burn.sev*daynum + burn.sev*I(daynum^2))

Error in lme.formula(fixed = log(time3) ~ burn.sev + daynum + I(daynum^2) + :
  nlminb problem, convergence error code = 1
message = iteration limit reached without convergence (9)

# Can get convergence by removing the quadratic term interaction with burn severity
# Probably not as important to test as the linear term interaction
wdpt.fit4 <- update(wdpt.fit3, log(time3) ~ daynum * burn.sev + I(daynum^2))
anova(wdpt.fit4, type = "marginal")

          numDF denDF F-value  p-value
(Intercept)     1  789  334.5511 <.0001
daynum          1  789  326.0395 <.0001
burn.sev        4   16   1.7680  0.1847
I(daynum^2)     1  789  315.0162 <.0001
daynum:burn.sev 4   789  1.7186  0.1438

# Neither burn severity term is significant but the residuals distribution still doesn't look great
# Figure 13 for report
par(mfrow=c(1,2))
qqresid(wdpt.fit3,main="a")
qqresid(wdpt.fit4,main="b")

# Take a look at the coefficients
as.data.frame(fixef(wdpt.fit4))
fixef(wdpt.fit4)
(Intercept) 1.918641e+03
daynum -2.471129e-01
burn.sevML -2.088823e+01
burn.sevM -2.620042e+01
burn.sevMH -4.340682e+00
burn.sevH -1.336605e+01
I(daynum^2) 7.955678e-06
daynum:burn.sevML 1.406284e-03
daynum:burn.sevM 1.729130e-03
daynum:burn.sevMH 3.272330e-04
daynum:burn.sevH 9.358705e-04

# If recovery were faster for higher burn severities the daynum:burn.sev coefficients would all be negative and increasingly so from ML to H. They are not.
# Some diagnostics
par(mfrow=c(1,2))
qqresid(wdpt.fit4)
plot(fitted(wdpt.fit4), log(wdpt$time3), xlab="Predicted log(WDPT)", ylab="Observed log(WDPT)")
abline(0,1)
cor(fitted(wdpt.fit4), log(wdpt$time3))^2
[1] 0.6267522 # This is the proportion of variance explained by the model

![Normal Q-Q Plot](image)

# It is possible to find a model with fewer fixed effects that has Gaussian (normal) residuals but as we add more fixed effects to the model (esp the squared day number) the distribution gets more and more skewed. For example:

qqresid(update(wdpt.fit4, log(time3) ~ burn.sev + daynum))
qqresid(update(wdpt.fit4, log(time3) ~ daynum + I(daynum^2)))
We wound up with the same model as before (when depth was miscoded), but now depth is no longer a significant predictor.

# Try a simple regression model

```r
f0 <- lm(log(time3) ~ burn.sev*daynum + burn.sev*I(daynum^2) + depth, data=wdpt)
anova(f0)
```

Analysis of Variance Table

Response: log(time3)

<table>
<thead>
<tr>
<th></th>
<th>Df</th>
<th>Sum Sq</th>
<th>Mean Sq</th>
<th>F value</th>
<th>Pr(&gt;F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>burn.sev</td>
<td>4</td>
<td>104.02</td>
<td>26.01</td>
<td>10.7350</td>
<td>1.670e-08 ***</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>272.62</td>
<td>272.62</td>
<td>112.5320</td>
<td>&lt; 2.2e-16 ***</td>
</tr>
<tr>
<td>I(daynum^2)</td>
<td>1</td>
<td>754.37</td>
<td>754.37</td>
<td>311.3916</td>
<td>&lt; 2.2e-16 ***</td>
</tr>
<tr>
<td>depth</td>
<td>1</td>
<td>0.96</td>
<td>0.96</td>
<td>0.3971</td>
<td>0.52876</td>
</tr>
<tr>
<td>burn.sev:daynum</td>
<td>4</td>
<td>24.55</td>
<td>6.14</td>
<td>2.5337</td>
<td>0.03895 *</td>
</tr>
<tr>
<td>burn.sev:I(daynum^2)</td>
<td>4</td>
<td>71.07</td>
<td>17.77</td>
<td>7.3341</td>
<td>8.182e-06 ***</td>
</tr>
<tr>
<td>Residuals</td>
<td>904</td>
<td>2190.00</td>
<td>2.42</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Residual standard error: 1.556 on 904 degrees of freedom
Multiple R-squared: 0.3592, Adjusted R-squared: 0.3486
F-statistic: 33.78 on 15 and 904 DF, p-value: < 2.2e-16

# Most terms highly significant, but depth is not and the linear interaction with burn.sev is barely significant, certainly not reliable since the model ignores the dependencies created by the groupings.
Effects of Soil Parent Material

```r
library("chron")
library("lattice")
library(nlme)

table(wdpt$soil)
Granitic MS MS/SS SS
   204  554  101   61

# Combine MS/SS and SS into "SS/MS" in new variable: s3
wdpt$s3 <- as.character(wdpt$soil)
wdpt$s3[wdpt$soil %in% c("MS/SS","SS")]
  <- "SS/MS"
wdpt$s3 <- factor(wdpt$s3)
table(wdpt$s3)
Granitic MS SS/MS
   204  554  162

superpose.line <- trellis.par.get("superpose.line")
superpose.line$col <- rainbow(23)
superpose.line$lwd <- 2
superpose.line$lty <- 1:2
trellis.par.set("superpose.line",superpose.line)

# Collapse over transect distance
xyplot(sqrt(time2) ~ depth | year*burn.sev2*s3, data=wdpt, groups=site,
lattice.options = list(panel.error = "warning"),
panel=function(x,y, subscripts, groups) {
  # panel.superpose(x,y, subscripts, groups, "panel.lmline")
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  panel.loess(x,y,span=1)
}, ylab="Penetration time: square root (secs)", layout=c(4,6), strip = strip.custom(par.strip.text = list(cex = 0.66)), par.settings = list(layout.heights=list(strip=0.66)))
```
# Collapse over transect distance and burn severity

```
xyplot(sqrt(time2) ~ depth | s3*year, data=wdpt, groups=site,
```
lattice.options = list(panel.error = "warning"),
panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y, subscripts, groups, "panel.lmline")
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    panel.loess(x,y,span=1)
}, ylab="Penetration time: square root (secs)", layout=c(3,4), strip =
strip.custom(par.strip.text = list(cex = 0.66)), par.settings =
list(layout.heights=list(strip=0.66))
# Soil type seems to have been important only in 2010
xyplot(sqrt(time2) ~ year | factor(depth)*burn.sev2*s3, data=wdpt, groups=site, layout=c(3,6), panel=function(x,y, subscripts, groups) {
  # panel.superpose(x,y, subscripts, groups, "panel.loess",span=0.333)
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  panel.loess(x,y,degree=1, span=1)
},subset=depth %in% c(1,2,3), ylab="Penetration time: square root (secs)", strip = strip.custom(par.strip.text = list(cex = 0.66)), par.settings = list(layout.heights=list(strip=0.66)))
# Collapse over transect distance and burn severity
```r
xyplot(sqrt(time2) ~ year | s3*factor(depth), data=wdpt, groups=site, layout=c(3,3),
panel=function(x,y, subscripts, groups) {
    # panel.superpose(x,y, subscripts, groups, "panel.loess",span=0.333)
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    panel.loess(x,y,degree=1, span=1) 
},subset=depth %in% c(1,2,3), xlab="", ylab="Penetration time: square root (secs)"

# Collapse over transect distance and depth
xyplot(time2 ~ daynum08 | burn.sev*s3, data=wdpt, groups=site, aspect=1, layout=c(5,3),
lattice.options = list(panel.error = "warning"),
panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    # panel.superpose(x,y,subscripts,groups, "panel.lmline")   fails
```

# Collapse over transect distance and depth
```r
xyplot(time2 ~ daynum08 | burn.sev*s3, data=wdpt, groups=site, aspect=1, layout=c(5,3),
lattice.options = list(panel.error = "warning"),
panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    # panel.superpose(x,y,subscripts,groups, "panel.lmline")   fails
```
# panel.loess(x,y,span=1.25,degree=2)
panel.lmline(x,y)
}, ylab="Penetration time(secs)", xlab="Days since 12/31/2008",
main="WDPT test results", auto.key=list(columns=7)
)

WDPT test results

<table>
<thead>
<tr>
<th>Penetration time (secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>300</td>
</tr>
<tr>
<td>400</td>
</tr>
<tr>
<td>600</td>
</tr>
<tr>
<td>1000</td>
</tr>
<tr>
<td>1400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Days since 12/31/2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>300</td>
</tr>
<tr>
<td>400</td>
</tr>
<tr>
<td>600</td>
</tr>
<tr>
<td>1000</td>
</tr>
<tr>
<td>1400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel</th>
<th>SS/MS</th>
<th>SS/MS</th>
<th>SS/MS</th>
<th>SS/MS</th>
<th>SS/MS</th>
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<tbody>
<tr>
<td></td>
<td>N</td>
<td>ML</td>
<td>M</td>
<td>MH</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>MS</td>
<td>MS</td>
<td>MS</td>
<td>MS</td>
<td>MS</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>ML</td>
<td>M</td>
<td>MH</td>
<td>H</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Granitic</th>
<th>Granitic</th>
<th>Granitic</th>
<th>Granitic</th>
<th>Granitic</th>
<th>Granitic</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>ML</td>
<td>M</td>
<td>MH</td>
<td>H</td>
<td></td>
</tr>
</tbody>
</table>
# Use square root transformation
xyplot(sqrt(time2) ~ daynum08 | burn.sev*s3, data=wdpt, groups=site, aspect=1, layout=c(5,3), lattice.options = list(panel.error = "warning"),
   panel=function(x,y, subscripts, groups) {
      panel.superpose(x,y,subscripts,groups, "panel.xyplot")
      # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
      panel.loess(x,y,span=1.25,degree=2)
      # had to increase span to avoid warnings
   }, ylab="Penetration time: square root(secs)", xlab="Days since 12/31/2008",
   main="WDPT test results", auto.key=list(columns=7)
# As noted before, the decline in times seems to have reversed in 2013

# Use log transformation

```r
xyplot(log(time2) ~ daynum08 | burn.sev*s3, data=wdpt, groups=site, aspect=1, layout=c(5,3), lattice.options = list(panel.error = "warning"),
panel=function(x,y, subscripts, groups) {
```

472
panel.superpose(x,y,subscripts,groups, "panel.xyplot")

# panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
panel.loess(x,y,span=1.25,degree=2)

# had to increase span to avoid warnings
}

, ylab="Penetration time: logarithm(secs)", xlab="Days since 12/31/2008",
main="WDPT test results", auto.key=list(columns=7)
)
WDPT test results

Penetration time: logarithm (secs)

Days since 12/31/2008

# But we should not ignore 164 values of penetration time that are 0
# Use log transformation with 0's recoded to 0.5
xyplot(log(time3) ~ year | burn.sev*s3, data=wdpt, groups=site, aspect=1,
   layout=c(5,3),
   lattice.options = list(panel.error = "warning"),
   panel=function(x,y, subscripts, groups) {
     panel.superpose(x,y,subscripts,groups, "panel.xyplot")
   })
As noted before, 2010 had higher penetration times, 2011 and 2012 are lower. And 2013 is intermediate. If there is a soils effect, it's not obvious so far.

Go back to the Hot/Cool dichotomy:

```r
xyplot(log(time3) ~ year | s3*burn.sev2, data=wdpt, groups=site, panel=function(x,y, subscripts, groups) {
 panel.superpose(x,y,subscripts,groups, "panel.xyplot")
 # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
}
```
It looks like the granitic soils had lower penetration times than the other soils in the hot burns. Actually all the granitic burns were of moderate severity.

```r
xyplot(log(time3) ~ year | s3, data=wdpt, groups=site, layout=c(3,1),
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
    panel.loess(x,y,subscripts,groups, "panel.loess")
  }, xlab="",ylab="Penetration time: logarithm(secs)"
)
```
Do granitic soils have lower penetration times in general?

Look at means by soil and year

tapply(wdpt$time2, list(wdpt$s3,wdpt$year),mean)

<table>
<thead>
<tr>
<th>Year</th>
<th>Granitic</th>
<th>MS</th>
<th>SS/MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>43.33333</td>
<td>90.27778</td>
<td>113.80952</td>
</tr>
<tr>
<td>2011</td>
<td>0.416667</td>
<td>40.2253521</td>
<td>1.5666667</td>
</tr>
<tr>
<td>2012</td>
<td>2.055556</td>
<td>32.197797</td>
<td>4.277778</td>
</tr>
<tr>
<td>2013</td>
<td>13.01667</td>
<td>22.89737</td>
<td>18.68056</td>
</tr>
</tbody>
</table>

Logarithms

tapply(log(wdpt$time3), list(wdpt$s3,wdpt$year),mean)

<table>
<thead>
<tr>
<th>Year</th>
<th>Granitic</th>
<th>MS</th>
<th>SS/MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>2.685195</td>
<td>3.363894</td>
<td>4.010686</td>
</tr>
<tr>
<td>2011</td>
<td>-0.404336</td>
<td>0.7468353</td>
<td>-0.1229174</td>
</tr>
<tr>
<td>2012</td>
<td>0.2318470</td>
<td>1.3625989</td>
<td>0.7119686</td>
</tr>
<tr>
<td>2013</td>
<td>1.954713</td>
<td>2.154982</td>
<td>2.251108</td>
</tr>
</tbody>
</table>

Replot using day number in place of year

xyplot(log(time3) ~ daynum08 | s3, data=wdpt, groups=site, layout=c(3,1),
   panel=function(x,y, subscripts, groups) {
       panel.superpose(x,y, subscripts, groups, "panel.xyplot")
       # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
       panel.loess(x,y,span=1)
   }, ylab="Penetration time: logarithm(secs)", xlab="Days since 12/31/2008"
> dim(wdpt)
[1] 920  19
> dim(wdpt.gd)
[1] 920  18

# Add s3 to wdpt.gd
wdpt.gd$s3 <- wdpt$s3

options(contrasts=c("contr.treatment","contr.treatment"))
wdpt3.fit0 <- lme(sqrt(time2) ~ daynum*burn.sev, data=wdpt.gd, random=~1)
wdpt3.fit1 <- lme(sqrt(time2) ~ daynum*burn.sev, data=wdpt.gd, random=~daynum)

anova(wdpt3.fit0,wdpt3.fit1)

> anova(wdpt3.fit0,wdpt3.fit1)

Model df      AIC      BIC    logLik   Test  L.Ratio p-value
wdpt3.fit0     1 13 5314.497 5377.072   -2644.249
wdpt3.fit1     2 17 5244.759 5326.588   -2605.380 1 vs 2  77.73851 <.0001

# Keep the random effects of site (and transect within site) on daynum

> anova(wdpt3.fit1,type="marginal")

numDF denDF    F-value    p-value
(Intercept)    1  790  6.216169   0.0129
 daynum         1  790  6.139258   0.0134
 burn.sev       4  16   1.953027   0.1506
 daynum:burn.sev 4  16  1.928779   0.1037

> anova(wdpt3.fit0,type="marginal")

numDF denDF    F-value    p-value
(Intercept)    1  790 11.482839 7e-04
# It makes a big difference which random effects are included
# The better model says daynum is the only significant fixed effect (so far)

# Let's not mess with these models. We know the fit is poor and the residuals
distribution is terrible. Go straight to the quadratic trend model for log(WDPT)

daynum:burn.sev <- update(wdpt3.fit1, log(time3) ~ daynum + I(daynum^2))
Error in logLik.lmeStructInt(lmeSt, lmePars)
  NA/NaN/Inf in foreign function call (arg 3)

# Cannot fit the complete random effects model (with site effects on depth)

daynum:burn.sev <- update(wdpt3.fit0, log(time3) ~ daynum + I(daynum^2))
anova(wdpt3.fit2)
numDF  denDF  F-value  p-value
(Intercept)     1   793  82.2013  <.0001
daynum          1   793 170.3924  <.0001
I(daynum^2)     1   793 321.5489  <.0001

# Test depth in this model
anova(wdpt3.fit3)
numDF  denDF  F-value  p-value
(Intercept)     1   792  82.1000  <.0001
daynum          1   792 170.3500  <.0001
I(daynum^2)     1   792 321.4372  <.0001
depth           1   792   0.8004  0.3712
# Depth not significant

# Test burn severity
wdpt3.fit4 <- update(wdpt3.fit2, ~ . + burn.sev)
anova(wdpt3.fit4)
numDF  denDF  F-value  p-value
(Intercept)     1   793  74.8750  <.0001
daynum          1   793 170.5697  <.0001
I(daynum^2)     1   793 321.1177  <.0001
burn.sev        4    16   0.5651  0.6915
# Burn severity not significant

# Test soil and its influences on trend
wdpt3.fit5 <- update(wdpt3.fit2, ~ . + s3*daynum + s3*I(daynum^2))
anova(wdpt3.fit5,type="marginal")
numDF  denDF  F-value  p-value
(Intercept)     1   789 110.94626 <.0001
daynum          1   789 110.51750 <.0001
I(daynum^2)     1   789 110.16765 <.0001
s3              2    18  20.71270 <.0001
daynum:s3       2   789  20.77988 <.0001
I(daynum^2):s3  2   789  20.83631 <.0001
# All terms very significant

# Take another look at burn severity
wdpt3.fit5a <- update(wdpt3.fit5, ~ . + burn.sev)
anova(wdpt3.fit5a)
anova(wdpt3.fit5a,type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>789</td>
<td>110.54535</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>789</td>
<td>110.18363</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>I(daynum^2)</td>
<td>1</td>
<td>789</td>
<td>109.83342</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>s3</td>
<td>2</td>
<td>14</td>
<td>20.819898</td>
<td>0.0001</td>
</tr>
<tr>
<td>burn.sev</td>
<td>4</td>
<td>14</td>
<td>0.28764</td>
<td>0.8811</td>
</tr>
<tr>
<td>daynum:s3</td>
<td>2</td>
<td>789</td>
<td>20.87597</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>I(daynum^2):s3</td>
<td>2</td>
<td>789</td>
<td>20.93541</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

# Also cannot test interaction of s3 and burn severity at this point
# Had same issue with testing interaction of v3 and burn severity
"Error in MEEM: Singularity in backsolve at level 0, block 1"

# Take a look at the coefficients of wdpt3.fit5
as.data.frame(fixef(wdpt3.fit5))

```r
fixef(wdpt3.fit5)
```

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>2245</td>
</tr>
<tr>
<td>daynum</td>
<td>-2.91</td>
</tr>
<tr>
<td>I(daynum^2)</td>
<td>9.44</td>
</tr>
<tr>
<td>s3</td>
<td>-9.28</td>
</tr>
<tr>
<td>s3SS/MS</td>
<td>7.11</td>
</tr>
<tr>
<td>daynum:s3</td>
<td>1.22</td>
</tr>
<tr>
<td>daynum:s3SS/MS</td>
<td>-9.15</td>
</tr>
<tr>
<td>I(daynum^2):s3</td>
<td>-4.00</td>
</tr>
<tr>
<td>I(daynum^2):s3SS/MS</td>
<td>2.94</td>
</tr>
</tbody>
</table>

# linear interaction is negative, the quadratic is positive

Granitic     2245 -0.2911d + 9.4409e-06d^2
MS delta     -929 +0.1220d - 4.0034e-06d^2
MS curve     1316 -0.1691d + 5.4375e-06d^2
SS/MS delta  711 -0.0915d + 2.9445e-06d^2
SS/MS curve  2956 -0.3826d + 1.2385e-05d^2

# Some diagnostics
par(mfrow=c(1,2))
qqresid(wdpt3.fit5)
plot(fitted(wdpt3.fit5),log(wdpt.gd$time3),xlab="Predicted log(WDPT)",ylab="Observed log(WDPT)"
abline(0,1)
cor(fitted(wdpt3.fit5),log(wdpt.gd$time3))^2
[1] 0.5564504  # This is the proportion of variance explained by the model
# Plot the quadratic curves determined from the model coefficients
Granitic  2245 -0.2911d + 9.4409e-06d^2
MS delta  -929 +0.1220d - 4.0034e-06d^2
MS curve  1316 -0.1691d + 5.4375e-06d^2
SS/MS delta  711 -0.0915d + 2.9445e-06d^2
SS/MS curve 2956 -0.3826d + 1.2385e-05d^2

x0 <- seq(600,1700,50)
x1 <- x0 + 14245  # Day numbers used for model fitting used R's origin 1/1/70
y1 <- 2245 -0.2911*x1 + 9.4409e-06*x1^2
y2 <- 1316 -0.1691*x1 + 5.4375e-06*x1^2
y3 <- 2956 -0.3826*x1 + 1.2385e-05*x1^2
par(mfrow=c(1,3))
attach(wdpt.gd[wdpt.gd$s3=="Granitic",])
plot(daynum08,log(time3),xlab="Days since 12/31/2008",ylab="log(WDPT)",main="Granitic")
lines(x0,y1)
detach(2)
attach(wdpt.gd[wdpt.gd$s3=="MS",])
plot(daynum08,log(time3),xlab="Days since 12/31/2008",ylab="log(WDPT)",main="MS")
lines(x0,y2)
detach(2)
attach(wdpt.gd[wdpt.gd$s3=="SS/MS",])
plot(daynum08,log(time3),xlab="Days since 12/31/2008",ylab="log(WDPT)",main="SS/MS")
lines(x0,y3)
detach(2)

# These curves aren't really very good fits to the data

# We could also have treated year as a categorical variable
# And this is probably the most informative for identifying systematic differences
wdpt3.fit6 <- update(wdpt3.fit2, log(time3) ~ year*s3)
anova(wdpt3.fit6,type="marginal")

<table>
<thead>
<tr>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>786</td>
<td>28.36376</td>
</tr>
<tr>
<td>year</td>
<td>3</td>
<td>786</td>
<td>43.97105</td>
</tr>
<tr>
<td>s3</td>
<td>2</td>
<td>18</td>
<td>1.78542</td>
</tr>
<tr>
<td>year:s3</td>
<td>6</td>
<td>786</td>
<td>7.23915</td>
</tr>
</tbody>
</table>

# There's an interaction but not a soil effect by itself

# Drop the solo soil effect
wdpt3.fit6a <- update(wdpt3.fit6, log(time3) ~ year + year:s3)
anova(wdpt3.fit6a,type="marginal")

<table>
<thead>
<tr>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>784</td>
<td>28.36376</td>
</tr>
<tr>
<td>year</td>
<td>3</td>
<td>784</td>
<td>43.97105</td>
</tr>
<tr>
<td>year:s3</td>
<td>8</td>
<td>784</td>
<td>5.62921</td>
</tr>
</tbody>
</table>

# Look at individual effects
fixef(wdpt3.fit6a)

(Intercept)  year2011  year2012  year2013
  2.6318994  -2.8890936  -2.4000523  -0.7191309
year2010:s3MS  year2011:s3MS  year2012:s3MS  year2013:s3MS
   0.7932075    1.0034920    0.9375594    0.3667029
year2010:s3SS/MS  year2011:s3SS/MS  year2012:s3SS/MS  year2013:s3SS/MS
  1.3684331     0.1094009     0.4801216     0.4860827

# this model says that WDPT decreased in 2011 and subsequently increased

# Compared to the Granitic sites:
# MS sites had higher penetration times in all years but 2013
# SS/MS sites had higher penetration times in all years
But the individual contrasts are not necessarily significant
The model only says there are soil related differences
summary(wdpt3$fit6a)

Fixed effects: log(time3) ~ year + year:s3

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Std.Error</th>
<th>DF</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>2.631899</td>
<td>0.494182</td>
<td>784</td>
<td>5.325764</td>
<td>0.0000</td>
</tr>
<tr>
<td>year2011</td>
<td>-2.88909</td>
<td>0.307569</td>
<td>784</td>
<td>-9.393304</td>
<td>0.0000</td>
</tr>
<tr>
<td>year2012</td>
<td>-2.40005</td>
<td>0.258314</td>
<td>784</td>
<td>-9.291235</td>
<td>0.0000</td>
</tr>
<tr>
<td>year2013</td>
<td>-0.719131</td>
<td>0.264441</td>
<td>784</td>
<td>-2.719437</td>
<td>0.0067</td>
</tr>
<tr>
<td>year2010:s3MS</td>
<td>0.793208</td>
<td>0.557901</td>
<td>784</td>
<td>1.421772</td>
<td>0.1555</td>
</tr>
<tr>
<td>year2011:s3MS</td>
<td>1.003492</td>
<td>0.575645</td>
<td>784</td>
<td>1.743249</td>
<td>0.0817</td>
</tr>
<tr>
<td>year2012:s3MS</td>
<td>0.937559</td>
<td>0.536614</td>
<td>784</td>
<td>1.747176</td>
<td>0.0810</td>
</tr>
<tr>
<td>year2013:s3MS</td>
<td>-0.366703</td>
<td>0.566628</td>
<td>784</td>
<td>0.647167</td>
<td>0.5177</td>
</tr>
<tr>
<td>year2010:s3SS/MS</td>
<td>1.368433</td>
<td>0.742201</td>
<td>784</td>
<td>1.843751</td>
<td>0.0656</td>
</tr>
<tr>
<td>year2011:s3SS/MS</td>
<td>0.109401</td>
<td>0.754609</td>
<td>784</td>
<td>0.144977</td>
<td>0.8848</td>
</tr>
<tr>
<td>year2012:s3SS/MS</td>
<td>0.480121</td>
<td>0.720376</td>
<td>784</td>
<td>0.666487</td>
<td>0.5053</td>
</tr>
<tr>
<td>year2013:s3SS/MS</td>
<td>0.486083</td>
<td>0.742889</td>
<td>784</td>
<td>0.654314</td>
<td>0.5131</td>
</tr>
</tbody>
</table>

In fact none of the soil-related coefficients individually pass at 0.05

Look back at mean WDPT by year and veg type

# Look at means by soil and year
tapply(wdpt$time3, list(wdpt$s3, wdpt$year), mean)

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granitic</td>
<td>43.3333</td>
<td>0.4167</td>
<td>2.0556</td>
<td>13.0167</td>
</tr>
<tr>
<td>MS</td>
<td>90.2778</td>
<td>40.2253</td>
<td>32.2078</td>
<td>22.8974</td>
</tr>
<tr>
<td>SS/MS</td>
<td>113.81</td>
<td>1.5667</td>
<td>4.2778</td>
<td>18.6806</td>
</tr>
</tbody>
</table>

# Logarithms
tapply(log(wdpt$time3), list(wdpt$s3, wdpt$year), mean)

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granitic</td>
<td>2.685195</td>
<td>-0.404336</td>
<td>0.23185</td>
<td>1.954713</td>
</tr>
<tr>
<td>MS</td>
<td>3.363894</td>
<td>0.746835</td>
<td>1.3626</td>
<td>2.154982</td>
</tr>
<tr>
<td>SS/MS</td>
<td>4.0107</td>
<td>-0.1229</td>
<td>0.7119</td>
<td>2.251108</td>
</tr>
</tbody>
</table>

# Try simple regression models
fl <- lm(log(time3) ~ s3*daynum + s3*I(daynum^2), data=wdpt.gd)
summary(fl)

Coefficients:

|                | Estimate  | Std. Error | t value | Pr(>|t|) |
|----------------|-----------|------------|---------|---------|
| (Intercept)    | 2.374e+03 | 2.293e+02  | 10.355  | < 2e-16 *** |
| s3MS           | -8.269e+02| 2.728e+02  | -3.031  | 0.00251 **  |
| s3SS/MS        | 4.935e+02 | 3.489e+02  | 1.415   | 0.15752   |
| daynum         | -3.081e-01| 2.980e-02  | -10.340 | < 2e-16 *** |
| I(daynum^2)    | 9.993e-06 | 9.676e-07  | 10.327  | < 2e-16 *** |
| s3MS:daynum    | 1.082e-01 | 3.549e-02  | 3.049   | 0.00236 **  |
| s3SS/MS:daynum | -6.302e-02| 4.536e-02  | -1.389  | 0.16504   |
| s3MS:I(daynum^2)|-3.535e-06| 1.154e-06  | -3.064  | 0.00225 **  |
| s3SS/MS:I(daynum^2) | 2.013e-06 | 1.473e-06 | 1.366  | 0.17227   |

Residual standard error: 1.558 on 911 degrees of freedom
Multiple R-squared: 0.3525, Adjusted R-squared: 0.3469
F-statistic: 62.01 on 8 and 911 DF, p-value: < 2.2e-16
# The contrasts of MS with Granitic are significant
# The contrasts of SS/MS with Granitic are not
# Of course we can’t accept these tests because the observations are not independent, which is why we had to use mixed-effects models in the first place.

**Effects of Vegetation Type**

```r
library("chron")
library("lattice")
library(nlme)

wdpt$v3 <- soilveg$v3[wdpt$sitenum]
wdpt$soil <- soilveg$soil[wdpt$sitenum]
save.image()

superpose.line <- trellis.par.get("superpose.line")
superpose.line$col <- rainbow(23)
superpose.line$lwd <- 2
superpose.line$lty <- 1:2
trellis.par.set("superpose.line",superpose.line)

wdpt2.gd <- groupedData(sqrt(time2) ~ year | site/dist, outer = ~ burn.sev, data=wdpt[wdpt$v3 != "To",])

# Collapse over transect distance
xyplot(sqrt(time2) ~ depth | year*burn.sev2*v3, data=wdpt2.gd, groups=site,
panel=function(x,y,subscripts,groups) {
    # panel.superpose(x,y,subscripts,groups,"panel.lmline")
    panel.superpose(x,y,subscripts,groups,"panel.xyplot")
    panel.loess(x,y,span=1)
}, ylab="Penetration time: square root (secs)", layout=c(4,4)

```
Previous observation that hot burns have longer penetration times may not have been correct. We see that in the RW Dom vegetation, there's not much difference in penetration time between Hot and Cool burns. Most of the long penetration times were on the KP/MZ vegetations, which were all Hot, but there are no Cool burns on KP/MZ to compare with.

Depth doesn't seem to have a consistent effect.
xyplot(sqrt(time2) ~ year | factor(depth)*burn.sev2*v3, data=wdpt2.gd, groups=site, layout=c(3,4), panel=function(x,y, subscripts, groups) {
  # panel.superpose(x,y, subscripts, groups, "panel.loess", span=0.333)
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  panel.loess(x,y,degree=1, span=1)
},subset=depth %in% c(1,2,3), ylab="Penetration time: square root (secs)"
)
# Collapse over both transect distance AND depth;

```
xyplot(time2 ~ daynum08 | burn.sev*v3, data=wdpt2.gd, groups=site, aspect=1,
      layout=c(5,2), lattice.options = list(panel.error = "warning"),
      panel=function(x,y, subscripts, groups) {
          panel.superpose(x,y,subscripts,groups, "panel.xyplot")
          #   panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
          panel.loess(x,y,span=1.25,degree=2)
          #    had to increase span to eliminate warnings
      }, ylab="Penetration time(secs)", xlab="Days since 12/31/2008",
      main="WDPT test results", auto.key=list(columns=7)
    }
```
# Use square root transformation
```
xyplot(sqrt(time2) ~ daynum08 | burn.sev*v3, data=wdpt2.gd, groups=site, aspect=1,
        layout=c(5,2),
        lattice.options = list(panel.error = "warning"),
        panel=function(x,y, subscripts, groups) {
          panel.superpose(x,y,subscripts,groups, "panel.xyplot")
          # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
          panel.loess(x,y,span=1.25,degree=2)
```

The decline in times seems to have reversed in 2013
The big contrast is between RW Dom and KP/MZ in the Hot burns
There are many more long penetration times in the KP/MZ hot burns
# Use log transformation
xyplot(log(time2) ~ daynum08 | burn.sev*v3, data=wdpt2.gd, groups=site, aspect=1,
  layout=c(5,2), lattice.options = list(panel.error = "warning"),
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
    panel.loess(x,y,span=1.25,degree=2)
    # had to increase span to avoid warnings
  }, ylab="Penetration time: logarithm(secs)", xlab="Days since 12/31/2008",
  main="WDPT test results", auto.key=list(columns=7)
)

# But we cannot ignore 164 values of penetration time that are 0
# Use log transformation with 0's recoded to 0.5
xyplot(log(time3) ~ year | burn.sev*v3, data=wdpt2.gd, groups=site, aspect=1,
  layout=c(5,2), lattice.options = list(panel.error = "warning"),
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
  }, ylab="Penetration time: logarithm(secs)", xlab="Days since 12/31/2008",
  main="WDPT test results", auto.key=list(columns=7)
)
panel.loess(x,y,span=1.25,degree=2)
# had to increase span to avoid warnings
}, ylab="Penetration time: logarithm(secs)", xlab="",
main="WDPT test results", auto.key=list(columns=7)
)

# OK it's pretty clear that KP/MZ had higher penetration times than RW Dom in the hot burns. And as noted before, 2010 had higher penetration times, 2011 and 2012 are lower. And 2013 is intermediate.
# It looks like burn severity is unimportant in the RW types, but might be important in KP/MZ.
# Go back to the Hot/Cool dichotomy

xyplot(log(time3) ~ year | burn.sev2*v3, data=wdpt2.gd, groups=site,
panel=function(x,y, subscripts, groups) {
  panel.superpose(x,y,subscripts,groups, "panel.xyplot")
  panel.xyplot(x,y,subscripts,groups, "panel.xyplot")
})
# panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
panel.loess(x,y,span=1)
}, ylab="Penetration time: logarithm(secs)", xlab=""
)

```
  table(wdpt2.gd$depth)

   1  2  3
322 255 315
```

options(contrasts=c("contr.treatment","contr.treatment"))
wdpt2.fit0 <- lme(sqrt(time2) ~ daynum*burn.sev, data=wdpt2.gd, random=~1)
wdpt2.fit1 <- lme(sqrt(time2) ~ daynum*burn.sev, data=wdpt2.gd, random=~daynum)
Error in logLik.lmeStructInt(lmeSt, lmePars) :
NA/NaN/Inf in foreign function call (arg 3)
Warning messages:
1: In logLik.lmeStructInt(lmeSt, lmePars) :
Singular precision matrix in level -1, block 1
# I cannot get a solution with random=~daynum, although that was the best random effects model in the full data set. I'm not sure what's causing the error.

anova(wdpt2.fit0,type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>768</td>
<td>11.635045</td>
<td>7e-04</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>768</td>
<td>11.244478</td>
<td>8e-04</td>
</tr>
<tr>
<td>burn.sev</td>
<td>4</td>
<td>15</td>
<td>10.103408</td>
<td>4e-04</td>
</tr>
<tr>
<td>daynum:burn.sev</td>
<td>4</td>
<td>768</td>
<td>9.873789</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

# Everything is significant

wdpt2.fit1 <- update(wdpt2.fit0, ~ . + depth)

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>767</td>
<td>11.589360</td>
<td>0.0007</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>767</td>
<td>11.232393</td>
<td>0.0008</td>
</tr>
<tr>
<td>burn.sev</td>
<td>4</td>
<td>15</td>
<td>10.083881</td>
<td>0.0004</td>
</tr>
<tr>
<td>depth</td>
<td>1</td>
<td>767</td>
<td>0.244772</td>
<td>0.6209</td>
</tr>
<tr>
<td>daynum:burn.sev</td>
<td>4</td>
<td>767</td>
<td>9.854759</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

# Depth is not significant

# Best model so far is wdpt2.fit0.

But is the trend linear? No. A quadratic would be a much better fit. Here goes:

wdpt2.fit2 <- update(wdpt2.fit0, ~ . + I(daynum^2))

anova(wdpt2.fit2)

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>767</td>
<td>39.62613</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>767</td>
<td>172.78062</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>burn.sev</td>
<td>4</td>
<td>15</td>
<td>0.56442</td>
<td>0.6922</td>
</tr>
<tr>
<td>I(daynum^2)</td>
<td>1</td>
<td>767</td>
<td>110.69500</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>daynum:burn.sev</td>
<td>4</td>
<td>767</td>
<td>6.67173</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

# Burn severity drops out.

wdpt2.fit2a <- update(wdpt2.fit2, ~ . - burn.sev)

anova(wdpt2.fit2a, type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>767</td>
<td>112.57020</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>767</td>
<td>109.72151</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>I(daynum^2)</td>
<td>1</td>
<td>767</td>
<td>107.00285</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>daynum:burn.sev</td>
<td>4</td>
<td>767</td>
<td>0.26569</td>
<td>0.9</td>
</tr>
</tbody>
</table>

# And the burn.sev interaction drops out too

wdpt2.fit2b <- update(wdpt2.fit2a, sqrt(time2) ~ daynum + I(daynum^2))

anova(wdpt2.fit2b)

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>771</td>
<td>47.27846</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>771</td>
<td>167.15880</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>I(daynum^2)</td>
<td>1</td>
<td>771</td>
<td>107.44988</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

qqresid(wdpt2.fit2b)

493
# Very bad. We really cannot trust the significance tests above.
# Try a model with log(response)
wdpt2.fit3 <- update(wdpt2.fit2b, log(time3) ~ daynum + I(daynum^2))
anova(wdpt.fit3)

```
numDF  denDF F-value  p-value
  (Intercept)  1    771   78.2666   <.0001
     daynum  1    771  188.0971   <.0001
   I(daynum^2)  1    771  331.0722   <.0001
```

![Normal Q-Q Plot](chart.png)
# A little better

# See if we can use the same random-effects models we used in the full data set
wdpt2.fit3a <- update(wdpt2.fit3, random= ~daynum)
# Yes, got a solution this time!
anova(wdpt2.fit3,wdpt2.fit3a)

<table>
<thead>
<tr>
<th>Model</th>
<th>df</th>
<th>AIC</th>
<th>BIC</th>
<th>logLik</th>
<th>Test L.Ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>wdpt2.fit3</td>
<td>1</td>
<td>3218.143</td>
<td>3246.883</td>
<td>-1603.071</td>
<td></td>
<td></td>
</tr>
<tr>
<td>wdpt2.fit3a</td>
<td>2</td>
<td>3184.253</td>
<td>3232.154</td>
<td>-1582.127</td>
<td>41.8896</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

# We're good

anova(wdpt2.fit3a)

| (Intercept) | 1  | 771  | 71.5654 | <.0001 |
daynum      | 1  | 771  | 93.4679 | <.0001 |
I(daynum^2) | 1  | 771  | 342.7361| <.0001 |

# NOW, look at vegetation
wdpt2.fit4 <- update(wdpt2.fit3a, ~ . + v3*daynum + v3*I(daynum^2))
Error in logLik.lmeStructInt(lmeSt, lmePars) :
  NA/NaN/Inf in foreign function call (arg 3)
In addition: There were 28 warnings (use warnings() to see them)

# Back to the simpler random effects model
wdpt2.fit4 <- update(wdpt2.fit3, ~ . + v3*daynum + v3*I(daynum^2))

anova(wdpt2.fit4)

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>769</td>
<td>99.0394</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>769</td>
<td>195.6808</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>I(daynum^2)</td>
<td>1</td>
<td>769</td>
<td>346.7013</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>v3</td>
<td>1</td>
<td>18</td>
<td>4.8363</td>
<td>0.0412</td>
<td></td>
</tr>
<tr>
<td>daynum:v3</td>
<td>1</td>
<td>769</td>
<td>7.7373</td>
<td>0.0055</td>
<td></td>
</tr>
<tr>
<td>I(daynum^2):v3</td>
<td>1</td>
<td>769</td>
<td>31.3615</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

# All terms significant

anova(wdpt2.fit4,type="marginal")

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>769</td>
<td>56.69346</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>769</td>
<td>54.82295</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>I(daynum^2)</td>
<td>1</td>
<td>769</td>
<td>53.18647</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>v3</td>
<td>1</td>
<td>14</td>
<td>3.8549</td>
<td>0.0698</td>
<td></td>
</tr>
<tr>
<td>burn.sev</td>
<td>4</td>
<td>14</td>
<td>0.2245</td>
<td>0.9202</td>
<td></td>
</tr>
<tr>
<td>daynum:v3</td>
<td>1</td>
<td>769</td>
<td>7.9898</td>
<td>0.0048</td>
<td></td>
</tr>
<tr>
<td>I(daynum^2):v3</td>
<td>1</td>
<td>769</td>
<td>30.7475</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

# All terms very significant

# Take another look at burn severity
wdpt2.fit4a <- update(wdpt2.fit4, ~ . + burn.sev)

anova(wdpt2.fit4a)

<table>
<thead>
<tr>
<th></th>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>769</td>
<td>79.7968</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>daynum</td>
<td>1</td>
<td>769</td>
<td>196.2969</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>I(daynum^2)</td>
<td>1</td>
<td>769</td>
<td>345.9304</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>v3</td>
<td>1</td>
<td>14</td>
<td>3.8549</td>
<td>0.0698</td>
<td></td>
</tr>
<tr>
<td>burn.sev</td>
<td>4</td>
<td>14</td>
<td>0.2245</td>
<td>0.9202</td>
<td></td>
</tr>
<tr>
<td>daynum:v3</td>
<td>1</td>
<td>769</td>
<td>7.9898</td>
<td>0.0048</td>
<td></td>
</tr>
<tr>
<td>I(daynum^2):v3</td>
<td>1</td>
<td>769</td>
<td>30.7475</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

# NOT

# Also cannot test interaction of v3 and burn severity at this point
"Error in MEEM: Singularity in backsolve at level 0, block 1"

# Take a look at the coefficients of wdpt2.fit4
as.data.frame(fixef(wdpt2.fit4))

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1.208317e+03</td>
</tr>
<tr>
<td>daynum</td>
<td>-1.548418e-01</td>
</tr>
<tr>
<td>I(daynum^2)</td>
<td>4.965975e-06</td>
</tr>
<tr>
<td>v3RW Dom</td>
<td>1.145296e+03</td>
</tr>
<tr>
<td>daynum:v3RW Dom</td>
<td>-1.500842e-01</td>
</tr>
<tr>
<td>I(daynum^2):v3RW Dom</td>
<td>4.910395e-06</td>
</tr>
</tbody>
</table>

# linear interaction is negative, the quadratic is positive
KP/MZ  1208 – 0.1548d + 4.966e-06d^2
diff  1145 – 0.1501d + 4.910e-06d^2
RWDom  2353 – 0.3049d + 9.876e-06d^2

# Some diagnostics
par(mfrow=c(1,2))
qqresid(wdpt2.fit4)
plot(fitted(wdpt2.fit4), log(wdpt2.gd$time3), xlab="Predicted log(WDPT)", ylab="Observed log(WDPT)")
abline(0,1)
cor(fitted(wdpt2.fit4), log(wdpt2.gd$time3))^2
[1] 0.5631743  # This is the proportion of variance explained by the model

# Display the fixed effects in this model
xyplot(log(time3) ~ daynum | v3, data=wdpt2.gd, groups=site, aspect=1, lattice.options =
  list(panel.error = "warning"),
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
    panel.loess(x,y,span=0.8)
    # had to increase span to eliminate warnings
  }, ylab="Penetration time: logarithm(secs)", xlab="Days since 12/31/2008", main="WDPT test results", auto.key=list(columns=7)
}

xyplot(log(time3) ~ daynum08 | v3, data=wdpt2.gd, groups=site, aspect=1, lattice.options =
  list(panel.error = "warning"),
  panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
    panel.loess(x,y,span=0.8)
    # had to increase span to eliminate warnings

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WDPT test results

1H  4H  7H  10H  13M  18H  21ML
2M  5M  8H  11M  14N  19M  22MH
3M  6H  9M  12H  15H  20H  23H

Days since 12/31/2008

Penetration time: logarithm(secs)

# For the heck of it include the TO site

# For the heck of it include the TO site

xplot(log(time3) ~ daynum08 | v3, data=wdpt.gd, groups=site, aspect=1, lattice.options =
list(panel.error = "warning"), layout=c(3,1),
panel=function(x,y, subscripts, groups) {
    panel.superpose(x,y,subscripts,groups, "panel.xyplot")
    # panel.superpose(x,y,subscripts,groups, "panel.lmline") fails
    panel.loess(x,y,span=0.8)
    # had to increase span to eliminate warnings
}, ylab="Penetration time: logarithm(secs)", xlab="Days since 12/31/2008",
main="WDPT test results", auto.key=list(columns=7)"
)
That wasn't very helpful. It looks like the tanoak site is similar to the others in 2012 (third column of points). Look at the mean WDPT by year and veg type:

`tapply(log(wdpt.gd$time3),list(wdpt.gd$v3,wdpt.gd$year),mean)[,"2012"]`

<table>
<thead>
<tr>
<th>KD/MZ</th>
<th>RW Dom</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8391637</td>
<td>0.4149558</td>
<td>1.4472190</td>
</tr>
</tbody>
</table>

Plot the quadratic curves determined from the model coefficients:

KP/MZ: $1208 - 0.1548d + 4.966d^2$

RWDom: $2353 - 0.3049d + 9.876d^2$

```r
x0 <- seq(14800,16000,50)
y1 <- 1208 - 0.1548*x0 + 4.966e-06*x0^2
y2 <- 2353 - 0.3049*x0 + 9.876e-06*x0^2
par(mfrow=c(1,2))
attach(wdpt2.gd[wdpt2.gd$v3=="KP/MZ",])
plot(daynum08,log(time3),xlab="Days since 12/31/2008",ylab="log(WDPT)",main="KP/MZ")
lines(x0-14245,y1)
detach(2)
attach(wdpt2.gd[wdpt2.gd$v3=="RW Dom",])
plot(daynum08,log(time3),xlab="Days since 12/31/2008",ylab="log(WDPT)",main="RW Dom")
lines(x0-14245,y2)
detach(2)
```
# compute mean of log penetration time by year
\[
\text{tapply}(\log(\text{wdpt2.gd$time3}), \text{list}(\text{wdpt2.gd$v3}, \text{wdpt2.gd$year}), \text{mean})
\]

\begin{align*}
\text{2010} & \quad 3.715101 & \quad 1.2349101 & \quad 1.8391637 & \quad 1.995007 \\
\text{2011} & \quad -0.1355711 & \quad 0.4149558 & \quad 2.172802
\end{align*}

# So penetration times were higher in KP/MZ except in 2013

# Same for untransformed times (truncated at 400 secs)
\[
\text{tapply}(\text{wdpt2.gd$time2}, \text{list}(\text{wdpt2.gd$v3}, \text{wdpt2.gd$year}), \text{mean})
\]

\begin{align*}
\text{2010} & \quad 105.70833 & \quad 64.069767 & \quad 44.413571 & \quad 21.53966 \\
\text{2011} & \quad 70.59028 & \quad 1.940476 & \quad 4.938462 & \quad 17.28056
\end{align*}

# We could also have treated year as a categorical variable
\[
\text{wdpt2.fit5} \leftarrow \text{update}(\text{wdpt2.fit4}, \log(\text{time3}) \sim \text{year} \times \text{v3})
\]
\[
\text{anova}(\text{wdpt2.fit5}, \text{type}="\text{marginal})
\]

\begin{tabular}{cccc}
\text{numDF} & \text{denDF} & \text{F-value} & \text{p-value} \\
\text{(Intercept)} & 1 & 767 & 172.92632 & <.0001 \\
\text{year} & 3 & 767 & 71.20616 & <.0001 \\
\text{v3} & 1 & 18 & 3.75018 & 0.0687 \\
\text{year:v3} & 3 & 767 & 9.08867 & <.0001 \\
\end{tabular}

\[
\text{fixef}(\text{wdpt2.fit5})
\]

\begin{tabular}{cccc}
\text{(Intercept)} & \text{year2011} & \text{year2012} & \text{year2013} \\
3.7985722 & -2.6146990 & -2.2867710 & -2.0387909 \\
\text{v3RW Dom year2011:v3RW Dom year2012:v3RW Dom year2013:v3RW Dom} & -0.7545649 & -0.5568813 & -0.3515950 & 0.9687823 \\
\end{tabular}

\[
\text{wdpt2.fit5a} \leftarrow \text{update}(\text{wdpt2.fit4}, \log(\text{time3}) \sim \text{year} + \text{year:v3})
\]
anova(wdpt2.fit5a,type="marginal")

<table>
<thead>
<tr>
<th>numDF</th>
<th>denDF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1</td>
<td>766</td>
<td>172.92632</td>
</tr>
<tr>
<td>year</td>
<td>3</td>
<td>766</td>
<td>71.20616</td>
</tr>
<tr>
<td>year:v3</td>
<td>4</td>
<td>766</td>
<td>8.03158</td>
</tr>
</tbody>
</table>

fixef(wdpt2.fit5a)

<table>
<thead>
<tr>
<th></th>
<th>year2011</th>
<th>year2012</th>
<th>year2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>3.7985722</td>
<td>-2.6146990</td>
<td>-2.2867710</td>
</tr>
<tr>
<td>year2010:v3RW Dom</td>
<td>-0.7545649</td>
<td>-1.3114463</td>
<td>0.2142174</td>
</tr>
<tr>
<td>year2011:v3RW Dom</td>
<td>-2.6146990</td>
<td>-2.2867710</td>
<td>-2.0387909</td>
</tr>
<tr>
<td>year2012:v3RW Dom</td>
<td>-2.6146990</td>
<td>-2.2867710</td>
<td>-2.0387909</td>
</tr>
<tr>
<td>year2013:v3RW Dom</td>
<td>-2.6146990</td>
<td>-2.2867710</td>
<td>-2.0387909</td>
</tr>
</tbody>
</table>

# this model says the WDPT difference varies by year; WDPT was significantly higher at the KP/MZ sites every year except 2013.

===================================================================
# Try simple regression models

f0 <- lm(log(time3) ~ v3*daynum + v3*I(daynum^2), data=wdpt2.gd)
anova(f0)

Analysis of Variance Table

Coefficients:

|            | Estimate | Std. Error | t value | Pr(>|t|) |
|------------|----------|------------|---------|---------|
| (Intercept)| 1.055e+03| 1.742e+02  | 6.056   | 2.06e-09***|
| v3RW Dom  | 1.427e+03| 2.239e+02  | 6.371   | 3.02e-10***|
| daynum    | -1.352e-01| 2.269e-02  | -5.961  | 3.62e-09***|
| I(daynum^2)| 4.342e-06| 7.386e-07  | 5.879   | 5.84e-09***|
| v3RW Dom:daynum | -1.864e-01| 2.916e-02  | -6.393  | 2.63e-10***|
| v3RW Dom:I(daynum^2)| 6.084e-06| 9.490e-07  | 6.410   | 2.36e-10***|

Residual standard error: 1.512 on 886 degrees of freedom
Multiple R-squared: 0.3874, Adjusted R-squared: 0.3839
F-statistic: 112.1 on 5 and 886 DF, p-value: < 2.2e-16

# All terms highly significant despite the low R-squared, which is because the random effects of site and transect within site are not accounted for.