Mountain Pine Beetle Science Symposium:
Impacts on the Hydrologic Cycle and Water Quality
April 8, 2010 - Boulder, CO

ABSTRACTS OF PRESENTATIONS (IN ORDER PRESENTED):

Questions and Concerns from the Field: A Land Management Perspective

Schnackenberg, L., Chambers, C., Hays, P.
USDA Forest Service, Region 2

How does salvage logging/forest management in beetle killed stands affect hydrological processes, particularly water yield (i.e. what is the effect of harvest beyond the effects from beetle kill)?

How does salvage logging/forest management in beetle killed stands affect stand regeneration and how does that affect hydrological processes?

How does the ground disturbance from salvage logging/forest management in beetle killed stands affect water quality and soils?

What is the potential (if any) for channel adjustments in response to changes in water yield from tree mortality/salvage?

What is the potential (if any) impact to infrastructure (culverts, etc.) in response to changes in water yield from tree mortality/salvage?

What are the impacts to groundwater, especially shallow groundwater tables, from tree mortality/salvage?

How is water yield affected by dead trees vs timber harvest of live trees-- are they the same?

Does salvage of dead timber increase water yield over just dead timber staying in place?

Does salvage of dead trees result in faster reforestation, and/or recovery of water yield increases?

The impact of pine beetle infestation on snowpack accumulation and melt in the headwaters of the Colorado River: results from the 'red phase' of tree death

Pugh, Evan T ; **Small**, Eric E; **Molotch**, Noah; **Petrello**, Danielle
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More than 8,000 km2 of lodgepole pine forest in Colorado have been infested by mountain pine beetles since 1996. We examine the impact of beetle-induced tree death on snowpack accumulation and ablation. The data were collected one to two years after beetle infestation, when most needles remain on the trees but the trees are dead. During the winter of 2009, snowpack and meteorological properties were measured at eight pairs of dead and living lodgepole pine stands. All stands are located at an elevation of 2720 ± 32m, in a subalpine region along the headwaters of the Colorado River. Trees in living stands were generally smaller in diameter and more densely populated than trees in dead stands. Snowpack accumulated equally beneath living and dead tree stands. In addition, snow under all tree stands became isothermal on the same date regardless of mortality. However, the snow melted more rapidly under dead trees. As a result, the snow was depleted as much as one week earlier beneath dead stands. During the melt interval, the lower SWE in dead stands was due to shallower snow, not lower snow density. Canopy transmission of solar radiation was not consistently different between living and dead stands. We noted more ground litter in dead stands which would decrease snowpack albedo and lead to the snowmelt differences observed. Earlier snowmelt caused by tree mortality accentuates established one to four week advances in snowmelt due to global warming. However, as beetle-induced tree death progresses, earlier snowmelt under dead stands may no longer occur. Once dead trees are denuded of needles and small branches, more snow may accumulate under dead stands due to a reduction in canopy interception of snow and subsequent sublimation.

Impacts of Mountain Pine Beetle outbreak on distributed snowpack processes

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The recent mountain pine beetle epidemic in the Colorado River Basin has resulted in widespread tree mortality in lodgepole pine stands across the Colorado Plateau. Arguably one of the most important issues regarding the recent mountain pine beetle epidemic involves the hydrologic impacts of changes in vegetation distribution and forest management practices. In particular, the complex interactions between vegetation and snow largely determines the hydrologic impacts of vegetation change as snow represents the dominant input of water into these water-limited forests. In this regard, a stand's tree canopy tempers snow ablation through attenuation of shortwave

radiation, thereby slowing snowmelt rate. As the crowns of beetle-killed trees die and their needles (and eventually boles) fall to the ground, a reasonable hypothesis is that the affected stands will have decreased snow surface albedo due to litter input to the snow surface, increased sub-canopy shortwave radiation, and reduced transpiration rates. The result of these impacts on the basin scale hydrology is largely unknown given the complexity of these interactions and the spatial complexity of beetle infestation. We have developed a mechanistic approach toward understanding these impacts using distributed hydrologic instrument clusters, hyperspectral snowpack characterization techniques, a detailed distributed snowpack model (SNTHERM), and hemispherical photography. The detailed measurement and modeling approach is able to resolve the spatio-temporal evolution of snow accumulation and melt at the micro-scale (i.e. < 10 – cm). As a result scenarios of vegetation distribution are conducted to simulate green, red, and grey phase stages of beetle-related mortality. With the aid of remotely sensed snow and vegetation information, these results will provide the basis for larger scale simulations of the hydrologic impacts of beetle infestation across the Colorado River Basin.

Hydrological Response to Mountain Pine Bark Beetle Infestation in Western Subalpine Watersheds

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Water supply in western North America is controlled primarily by snow accumulation and melt in forested headwater basins. Trees impact runoff through wintertime canopy interception losses of snowfall and summertime transpiration losses. The mountain pine bark beetle (*Dendroctonus ponderosae*) epidemic attacking western pine forests will produce an estimated 90% mortality in lodgepole (*Pinus contorta*) stands, and will likely impact other tree species at significant levels over large areas of the US and Canada. Management studies suggest that changes in water quantity and quality will occur in response to beetle induced tree mortality. Hydrological responses to beetle mortality are dependent on local climatology, age and species composition of forests, understory response, and degree of impact. Changes in discharge measured at the watershed level are typically identified and quantified using statistical methods applied to time series data. Critical assumptions are stationarity, and sufficient data record for statistically significant detection of changes. Short-term studies comparing statistical properties of flow should be examined with caution. Data are presented to show why short-term studies related to pine beetle impact on hydrology are unreliable. Double mass plots using control basins and ANCOVAs show no significant response to date.

Comparing Water, Soil, Vegetation, Fuel and Fire Behavior Responses to Management Options in Mountain Pine Beetle-Infested Forests

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Overstory mortality from current mountain pine beetle activity surpasses the extent of forest disturbance experienced by the public and land management communities in recent memory. The perceived increase in wildfire risk and concerns about human safety and infrastructure damage has prompted a rapid and extensive management response on federal, state and private forest land across northern Colorado and southern Wyoming. Harvesting will treat only a fraction of the landscape altered by bark beetles, but current decisions will alter delivery of ecosystem services from these forests for the coming century. Here we describe an experimental comparison of four management alternatives designed to result in distinct amounts of aboveground structure, surface roughness and soil disturbance. For example, Fuel Reduction prescriptions common to beetle salvage operations remove both canopy and surface fuels and minimize residual surface roughness. The Forest Regeneration option combines surface fuel (slash) reduction and mechanical scarification to enhance seedling establishment. In contrast, areas logged with Watershed Protection goals intentionally retain logging residue in order to retain nutrients and surface roughness and to avoid soil disturbance. The No Action option retains canopy fuels in the short term but will generate the highest amount of surface roughness and surface fuels as windthrow topples the dead overstory. Harvest treatments were completed in summer 2009 at four project study areas on Colorado State and U.S. Forest Service land in the North Platte and Upper Colorado River Basins. In this presentation we summarize study objectives and design, share initial findings and discuss options for collaboration.

Response of Evapotranspiration and Greenhouse Gas Emissions to the Bark Beetle and Blue Stain Fungus Epidemic in Rocky Mountain Forests

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Background/Questions/Methods

The ongoing epidemic of bark beetles (BB) and their associated xylem blocking blue-stain fungi is unprecedented in Rocky Mountain forests. Besides the well-documented outbreak of mountain pine beetle (*Dendroctonus ponderosae)* and associated blue-stain fungi (*Ophiostoma spp.*) on lodgepole pine (*Pinus contorta*); high rates of infection by related beetles *(Dendroctonus rufipennis, and Dryocoetes confusus*) and fungi in higher elevation Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) have also been reported. As this epidemic progresses, we are investigating (1) what are the first order effects of BB on the temporal and spatial extent of evapotranspiration (ET) and (2) what are the second and higher order impacts on the emissions of greenhouse gases(GHG) (i.e., CO2, N2O, and CH4)? We are investigating these questions with measurements of eddy covariance fluxes, sap flow, and soil GHG emissions at two instrumented forests: one dominated by lodgepole pine (~2,750 m elevation) and the other by spruce-fir (~3,200 m). We have incorporated two different sampling strategies: (a) the lodgepole pine forest was subdivided spatially into stands with varying degrees of bark beetle and blue stain infection; and (b) GHG and ET fluxes in both forest types were monitored as the outbreak continued at a point in space.

Results/Conclusions

The impacts of the beetles in the spruce-fir forest are slower in comparison to infected lodgepole pine forests taking two years or more to kill the trees and transpiration declines taking an entire growing season perhaps reflecting the cooler temperatures of this higher elevation forest. Eddy covariance measurements from the spruce-fir indicate no significant change in ET, but a 1.5 MgC ha^{-1} yr^{-1} (40%) decline in NEE from 2005 to 2008. For lodgepole pine, the reduction in transpiration exceeds 50% per tree within a month of infection. This change occurs even before the characteristic red tinge in the needles and the sapwood is stained blue. The second and higher order effects in this forest are equally dramatic starting with a seasonal soil moisture increase of up to 100%. When comparing a rapidly regenerating stand at the sapling phase to a mature stand hit two years prior, both soil respiration and CH4 consumption were >50% lower in the mature, infested stand while N2O fluxes were 133% higher. We hypothesize that these higher order impacts are related to a combination of soil moisture, temperature and N changes all of which involve the decoupling of C and N cycles within two years of infection. These impacts are not as dramatic when scaled up to the eddy covariance footprint which still includes uninfested areas, but our plot level measurements allow us to predict these near future larger scale impacts. Our future work includes the addition of measurements within a mixed conifer stand with low beetle infestation (Niwot Ridge) and the investigation of beetle impacts on runoff dynamics, changes in mobile solutes and stream nutrient chemistry, and shifts in proportional contributions of evaporation versus transpiration.

Impacts of beetle-kill and wildland fire on regional water and energy cycles in western North America

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In this project, recently funded by the NOAA Climate Prediction Program for the Americas (CPPA), we seek to explore the impacts of western forests affected by bark beetle and fire on regional water and energy cycles and their associated intraseasonal to interannual climate variability. To analyze the recovery of physical and physiological parameters important for land surface modeling in forested regions following bark beetle outbreak and wildland fire, we use remote-sensing observations (e.g., 500-m Moderate Resolution Imaging Spectroradiometer, MODIS, and Monitoring Trends in Burn Severity, MTBS). One goal is to develop MODIS-based products to detect tree mortality caused by bark beetle epidemics. These analyses will be used for improving the representation of these forest disturbances in the Noah land surface model (LSM). The modified Noah LSM is used in the context of high-resolution land data assimilation system (HRLDAS) to perform a ten-year (2000-2010) 1-km (covering the area of 30-55oN and 101-120oW) reanalysis of land surface conditions (surface sensible heat flux, evaporation, runoff, soil moisture) by integrating a number of atmospheric observations and fire and bark-beetle outbreak data. The model results will be evaluated against flux-tower observations obtained from affected forest sites (e.g., Flagstaff burned site, Arizona; beetle-infested sites at GLEES and Chimney Park, Wyoming). By contrasting this reanalysis to the one conducted using undisturbed forest data, we can isolate impacts of affected forests on surface exchange of heat and water vapor, snow accumulation, and runoff. Lastly, we will conduct regional climate simulations with the modified WRF/Noah coupled model for selected years to investigate the impacts of the improved realism in representing the modified forest structures on intra-seasonal to interannual precipitation prediction. We will present the analysis of data and HRLDAS simulation results and invite collaboration from other groups.

Baseline information to help understand hydrological and hydrochemical responses to the Mountain Pine Beetle outbreak, Como Creek watershed, CO

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Understanding the effects of a major disturbance to an ecosystem requires knowledge of baseline conditions, and ideally, a real-time documentation of subsequent change. To date, no one has successfully captured baseline information prior to a MPB outbreak. Here we introduce our approach to capture such baseline information at the Niwot LTER and Niwot Ameriflux Site.

To date, while major regions of Colorado have already seen MPB outbreaks that include areas of 100% tree mortality, the core study areas at Niwot remain largely unaffected. Yet, we are literally surrounded: regions just to the south, west and north of Niwot have all seen large outbreaks with areas of 100% mortality, and the first signs of infection appeared in our core study areas in the summer of 2007. By preparing for the inevitable outbreaks to come, we can ensure that our baseline data-collection infrastructure is well-poised to capture the ecosystem-level consequences of an MPB outbreak. We have developed a consortium of investigators and programs to investigate the ecological, biogeochemical, hydrological, and social impacts of the MPB epidemic in and near the Como Creek drainage and the Colorado Front Range: NWT LTER, NWT Ameriflux), Alpine Microbial Observatory, USGS-Biological Resources Discipline's Western Mountain Initiative and noted social scientist W. Travis.

Here we focus on hydrological and hydrochemical advances in knowledge. A vertical array of soil moisture probes to a depth of 2 m shows that infiltrating water from the soil surface (both snowmelt and rainfall) did not reach a depth of 100 cm at any time at this site. In contrast, years with high antecedent soil moisture were characterized by a rising water table from below which saturated the soil profile. Hydrologic mixing models show that "old" water accounted for 80-84% of total streamflow throughout the year and that summer rains made a negligible contribution. End-member mixing analysis indicates that "old" water is similar to that of wells and thus represents groundwater. A convolution algorithm using delta-O18 suggests an average groundwater residence time of about 2.5 years, roughly consistent with tritium results. In contrast to nearby alpine sites, the Como Creek watershed is highly N-limited, with little nitrate in surface waters during the growing season and elevated DOC:DIN ratios. We anticipate that the MPB will cause an increase in discharge, higher peak flows, and large increases in nitrate.

Effects of Mountain Pine Beetle on Water Quality in the Upper Colorado River Basin

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The mountain pine beetle (*Dendroctonus ponderosae*) is devastating lodgepole forests in the upper Colorado River basin (UCRB). Although the mountain pine beetle is a native insect, several factors have contributed to its current epidemic population outbreak: increasing air temperatures, recent drought, and the presence of contiguous stands of mature, dense forest. Trees are now dead and dying throughout over 2 million acres of Colorado's forests. USGS scientists are collaborating with the USDA Forest Service, National Park Service, state and local government agencies, and universities on interdisciplinary research to characterize impacts of this large-scale forest mortality on water resources in the UCRB. Although nitrate concentrations in streams flowing into and out of key drinking water reservoirs in the headwaters of the Colorado River have remained stable or even declined, total phosphorus concentrations have increased by 30 to 60% since 2000, when the MPB infestation began. Episodic algal blooms have occurred recently in several of the reservoirs, and collaborative studies by the USGS and BOR are under way to ascertain the cause. Results from these studies will help water resource managers and water suppliers to understand, plan for, and adapt to changes in the quality of water available for consumptive use in the UCRB and adjacent watersheds.

Preliminary Investigations into the Impact on Hydrology and Metal Fluxes in Mountain Pine Beetle Infected Watersheds: Summit County, Colorado

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The mountain pine beetle (MPB) epidemic in Western North America is generating growing concern in recent years with an estimated two million acres of forest in Colorado and Wyoming affected during 2008. Given the substantial acreage of prematurely dying forests within Colorado, it has been hypothesized that the effects of the MPB outbreak will be similar to those observed after widespread forest harvesting. We hypothesize that physical and biogeochemical phenomena typically experienced after deforestation, such as increases in soil erosion, runoff, shortwave radiation, pore-water acidity, and dissolved organic matter will affect the transport of metals through the groundwater/surface water interface. Summit County, Colorado provides an excellent field site for researching the MPB impacts because specific reaches of Pennsylvania Creek have been affected by MPB while others have remained untouched. Field data from Pennsylvania Creek and surrounding areas are being collected and analyzed to determine the physical relationships between the groundwater and surface water and to lay the groundwork for long-term observation of metal fluxes. Currently, measurements are taken on a timescale to understand the daily and seasonal fluxes of water between the groundwater and surface water at multiple locations along a two mile reach of Pennsylvania Creek and Cucumber Creek. Surface water samples are analyzed for metal and cationic constituents using ICP-AES at locations corresponding to high MPB impact and no observed MPB impacts. The implications of these results for the transfer of metals and cations through the groundwater/surface water interface are presented along with a comparison of USGS stream flow data pre and post-MPB from infected watersheds to better understand the transport of metals on a larger scale.

Effects of the mountain pine beetle on water quality in Colorado mountain streams

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The mountain pine beetle is affecting forest resources and tourism across western North America, but tree mortality associated with the mountain pine beetle also may be affecting the quantity and quality of water leaving watersheds where tree mortality has been high. Growing forests intercept some of the precipitation and nutrients that fall within a watershed. Thus, forest disturbance can be followed by large increases in water yield and nutrient export. We are investigating the effects of mountain pine beetle on water quality in Colorado Mountain streams; our work is focused largely on fractions of carbon, nitrogen, and phosphorus, but we also are measuring concentrations of pesticides used to control the mountain pine beetle. Sampling has been conducted at multiple spatial and temporal scales, including “snapshots” of water quality spanning almost 200 sites in Rocky Mountain National Park on a single date. Effects of the mountain pine beetle on nutrient concentrations in Colorado mountain streams appear to be modest, although effects may be sufficient to cause measurable changes to downstream ecosystems.

Water resource responses in beetle-killed catchments in north-central Colorado

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The mountain pine beetle has dramatically increased over the past 8 years, especially in north-central Colorado. The current beetle epidemic is the result of a convergence of several ecological factors including climate, tree age and forest density. The effect of the beetle is dramatic, as approximately 810,000 ha of lodgepole pine forest in Colorado are dead. As the forests die, the hydrological processes of interception and evapotranspiration decrease, thus potentially increasing soil moisture and streamflows. The first ever research looking at the effects of deforestation by insects on streamflow was conducted on the White River Plateau in Colorado and documented increased streamflow following a spruce beetle epidemic. The current situation in Colorado again allows us to assess the effects of beetle-killed forests on water resources.

Beetle caused tree mortality should be comparable to timber harvesting as interception and evapotranspiration are both decreased. Literature reviews on the effects of timber harvesting on water yield concluded that the increased annual water yield in higher elevation forests is proportional to the amount of forest canopy (as measured by basal area) removed. As the forest regrows after harvest, the increased annual water yield decreases. Commonly, at least 20% of the basal area needs to be removed for a detectable increase in annual water yield. Thus annual water yields are expected to increase with increased beetle-killed area. Using long-term stream gauging, and vegetation and forest health data, we mapped a series of catchments with increasing levels of beetle-killed area. We used an iterative cumulative sum of squares statistic (akin to analysis of covariance) to separate “pre-treatment” (few beetles) and “post-treatment” (after beetle outbreak) periods. Surprisingly, we identified both water yield increases and decreases. There were no significant relationships between water yield increases and the beetle-killed area or other catchment characteristics. The variability in the water yield response may be due to the forest mapping criterion. Forest cover types were separated as even-aged or uneven-aged and provided additional insight into water yield responses.

Forested catchments are excellent sources of water quality, due to the efficiency of nutrient cycling and the effectiveness of streamside vegetation in protecting surface waters from sediment and thermal loading. Little research has been done on the effects of beetle-killed trees on surface water quality. Water quality samples were collected and data compared to historical records. Variability would be expected, nonetheless, water quality sampling results from the study catchments showed some interesting differences. Nitrate-nitrogen concentrations increased after beetle infestation in some catchments and appear to persist after the infestation. Water temperatures were higher at several sites as well, especially if streamside vegetation was lodgepole pine. Additional water resources monitoring is ongoing and additional results will better illustrate casual mechanisms.

Quantifying the Effects of Large-Scale Vegetation Change on Coupled Water, Carbon and Nutrient Cycles: Beetle Kill in Western Montane Forest

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Mountain Pine Beetle (MPB) infestation and associated fungal pathogens radically change ecosystem structure by killing host trees, altering surface energy and water partitioning, reducing carbon uptake, and putting organic matter into soil on both short and long time scales. The widespread extent of this disturbance presents a major challenge for governments and resource managers who must respond to the changes, yet lack a predictive understanding of how these systems will respond to the disturbance over various temporal and spatial scales. This project addresses this knowledge gap by quantifying the effects of MPB on water and biogeochemical cycles, including both land surface-atmosphere exchanges and streamflow quantity and chemistry. Specifically, we address two overarching questions:
How do changes in vegetation structure associated with MPB, including density, leaf area, and species composition, alter the partitioning of energy and water, including sublimation, evaporation, transpiration, recharge, and stream flow?
How do these changes in energy and water availability affect local to regional scale biogeochemical cycles including a) carbon uptake, respiration, and export in stream

flow, b) N deposition, availability, emission, and N export in stream flow, and c) emissions of biogenic trace gases?

Our observation strategy includes 1) Plot-scale measurements of biogeochemical, hydrological, and ecological processes, 2) Simultaneous flux tower and catchment measurements; integrating water and biogeochemical cycles in catchment ecosystems, 3) Development of distributed data sets and synoptic sampling, and 4) Develop and refine quantitative models of water and biogeochemical cycles. Our project has intensively instrumented sites in both CO and WY that vary primarily in the timing and severity of beetle infestation, with larger scale observations in nested catchments around our plots, and model evaluation at other study locations with less extensive data. Simultaneous measurements of both land-atmosphere exchange and catchment fluxes of water and biogeochemicals serve as integrated measures of ecosystem-scale biogeochemical cycles. Together, these observations will be used to inform and improve coupled hydrological and biogeochemical models from both land-surface and catchment communities, advancing our theory of environmental response to disturbance.