

# INTERMOUNTAIN WEST CLIMATE SUMMARY



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## Impacts of the mountain pine beetle infestation on the hydrologic cycle and water quality: A symposium report and summary of the latest science

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The ongoing mountain pine beetle (MPB) infestation in Colorado and southern Wyoming has left a very obvious and visually dramatic imprint on forest ecosystems (Figure 1). Less obvious, but no less important, are the impacts this widespread tree mortality may have on the water resources that come from these affected forests.

While studies of previous insect infestations and other forest disturbances (e.g., clearcutting) provide some guidance as to how hydrologic regimes and water quality may be affected, there has been very little published research specific to the ongoing infestation in the Rocky Mountain region. There are, however, a number of recently completed and ongoing research projects that investigate how the MPB infestation may be affecting water resources.

On April 8, 2010, the Western Water Assessment convened a meeting in Boulder, CO, entitled “MPB Science Symposium: Impacts on the Hydrologic Cycle and Water Quality.” This symposium brought together the investigators on these projects to present their research results and future plans, and discuss the implications for both forest managers and water resource managers. The 50 participants represented research units at the University of Colorado, Colorado State University, Colorado School of Mines, the University of Arizona, the University of Wyoming, the University of Idaho, University of California–Los Angeles, US Forest Service, US Geological Survey, and the National Center for Atmospheric Research, and also included resource managers from the US Forest Service, Bureau of Reclamation, National Park Service, Northern Colorado Water Conservancy District, and Aurora Water.

The day began with a presentation by US Forest Service hydrologists Liz Schnackenberg and Carl Chambers on the outstanding questions regarding MPB impacts of greatest relevance to their agency. They split these questions into “natural processes” (what are the impacts of MPB-killed forests on water yield, peak flows, sediment yield, stream channel stability, woody debris inputs to streams, riparian areas, and groundwater) and “management effects” (how will salvage logging and associated road-building modify these impacts).



Figure 1: As watersheds experience significant tree mortality from mountain pine beetle, how will the hydrologic cycle and water quality be affected? (Williams Fork Mountains, Colorado; Photo: US Geological Survey)

The subsequent presentations, however, covered only a subset of these natural processes, and only one presenter explicitly treated management effects. This appears to indicate a gap between the information needs of the principal forest management agency dealing with the MPB infestation and the MPB-water research that is being done in the region.

The 12 talks that followed presented the findings from research projects led by university and agency scientists (see Sidebar on p. 2, *Symposium Presentations*). Collectively, these projects use a diverse set of tools—field sampling, designed treatment and controls, remotely sensed imagery, computer modeling, and statistical methods—to investigate the impacts of MPB on hydrology and water quality over multiple time scales and spatial scales. Overall, there was significant commonality in the research questions and results, so here we have attempted to synthesize the findings of all of the projects. The paragraphs in *italics* provide high-level summaries of the findings in each section. Specific results or statements are attributed to the individual presenters where appropriate.



## Symposium Presentations

Note: All abstracts, and PDFs of most of these presentations, are available at <http://www.colorado.edu/ecology/beetle/mpb-water-apr2010.html>

### *Beetles and Water: Some Questions from Managers*

Liz Schnackenberg (1) and Carl Chambers (2)  
(1) Medicine Bow-Routt National Forest (2) Arapaho & Roosevelt National Forest; USDA Forest Service, Region 2

### *The impact of the pine beetle infestation on snowpack accumulation and melt: Red phase*

Evan Pugh, University of Colorado-Boulder

### *Impacts of mountain pine beetle outbreak on distributed snowpack processes*

Noah Molotch, University of Colorado-Boulder

### *Hydrological response to mountain pine bark beetle infestation in Western subalpine watersheds*

Kelly Elder, USFS Rocky Mountain Research Station (presented by Rob Hubbard, USFS-RMRS)

### *Forest & watershed responses to beetle-related management*

Chuck Rhoades, USFS Rocky Mountain Research Station

### *Response of evapotranspiration and greenhouse gas emissions to the bark beetle and blue stain fungus epidemic in Rocky Mountain forests*

Holly Barnard, University of Colorado-Boulder

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

Fei Chen, National Center for Atmospheric Research

### *Baseline information to help understand hydrological and hydrochemical responses to the mountain pine beetle outbreak, Como Creek watershed, CO*

Ty Atkins, University of Colorado-Boulder

### *Effects of mountain pine beetle on water quality in the Upper Colorado River Basin*

David Clow, United States Geological Survey

### *Preliminary investigations into the impact on hydrology and metal fluxes in mountain pine beetle infected watersheds: Summit County, Colorado*

Kristen Mikkelsen, Colorado School of Mines

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

James McCutchan, University of Colorado-Boulder

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

John Stednick, Colorado State University

### *Quantifying the effects of large-scale vegetation change on coupled water, carbon, and nutrient cycles: Beetle kill in Western montane forest*

Paul Brooks, University of Arizona

## Water yield and timing of peak runoff

*Based on experimental studies of tree harvesting and observational studies following previous infestations in Colorado and elsewhere, there has been a general expectation that the widespread tree mortality will significantly increase water yield at the basin scale and lead to earlier runoff peaks. However, there is no compelling evidence yet for runoff changes caused by the current MPB infestation, and there is increasing evidence that the story is much more complex than the simple “fewer live trees = more runoff” formulation.*

In the high-elevation watersheds most affected by beetle-killed trees, runoff is largely controlled by the cycle of snowpack accumulation and melt, so we must start by looking at the beetle infestation's effects on snowpack processes (Figure 2).

Multiple snowpack processes are influenced by the forest canopy and thus are affected by canopy loss, whether caused by MPB or another agent. While the directions of these individual effects are predictable at the plot scale, the net effect on snowpack is difficult to generalize, especially at the basin scale. The decrease in canopy interception of snowfall in the “gray phase” (after the dead needles have been shed) is likely to dominate in many locations, leading to increases in snowpack accumulation. Snowmelt is likely to occur earlier in the gray phase as the snowpack has less shading from incoming solar radiation.

Specific snowpack process changes include:

- Canopy interception, and associated sublimation loss, changes little from “green phase” (live tree or just killed) to “red phase” (red needles still on tree), but decreases significantly in gray phase, leading to greater snow accumulation (Pugh, Molotch).
- Shortwave (solar) radiation reaching snow surface does not change much from green phase to red phase, but increases significantly in gray phase, enhancing melt (Pugh, Molotch).
- Albedo (reflectivity) of snow surface decreases significantly from green phase to red phase as needle litter falls on snow and “rises” to top of snowpack, enhancing melt, but likely increases during the gray phase after trees have completely shed their needles (Pugh).
- Windspeed and turbulent vapor flux increase from green and red phases to gray phase as needles drop, increasing sublimation loss from the snowpack (Molotch).

Changes in snowpack, however, do not necessarily translate into equivalent changes in runoff. As snowmelt infiltrates the soil in forested areas, much of is taken up by the vegetation and transpired back into the atmosphere. Beetle-caused tree mortality has a large and time-dependent effect on stand-level transpiration. Thus the movement of the remaining snowmelt to streams is not as fast or straightforward as one might expect.

When pine beetles successfully attack a tree, the blue-stain fungus carried by the beetles clogs the xylem (sapwood), reduc-



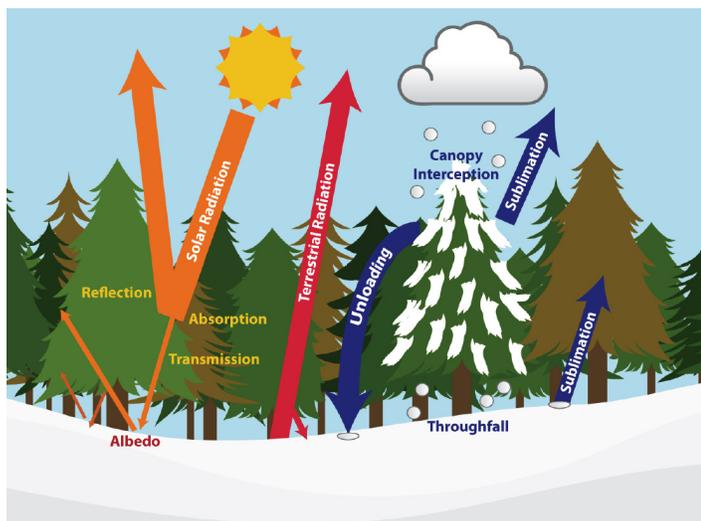


Figure 2: Many physical processes that influence the snowpack are modulated by the forest canopy. (Graphic: Evan Pugh)

ing the tree's transpiration significantly within a few weeks, and ending it within a year (Elder/Hubbard, Barnard). So in stands with high levels of beetle-killed trees in the red phase and gray phase, overall transpiration declines substantially, theoretically making more snowmelt available for runoff. However, younger understory trees are "released" by the loss of canopy and immediately begin taking up and transpiring more water, using a portion of what is no longer taken up by the dead canopy trees. Depending on the level of MPB mortality, species composition, and understory tree density, stand transpiration may recover to pre-infestation levels over the course of several decades (Elder/Hubbard). Soil moisture was observed to increase post-infestation, suggesting that increased snow accumulation, reduced transpiration, or both, allows more snowmelt to reach the soil (Barnard).

The snowmelt that makes it past the "gauntlet" of transpiring vegetation into the deeper soils may not move directly to the stream. In Como Creek on Niwot Ridge in Boulder County, Colorado, oxygen isotope tracing indicates that "new" melt pushes the older groundwater into stream channels, and that the mean residence time of snowmelt as groundwater is 2.5 years (Atkins). In the lower portions of the watershed, still within the lodgepole pine zone, this "pushing" effect causes upwelling of groundwater towards the surface (Atkins). Clearly, groundwater processes need to be considered when evaluating the effects of MPB on runoff.

Three studies on Colorado's western slope, two of which are described in more detail below, have assessed potential changes in runoff over time as a function of beetle mortality (Elder/Hubbard, Stednick, Brooks). None of the studies found consistent changes in runoff that can be associated with the beetle kill.

Monitoring of East St. Louis Creek in the Fraser Experimental Forest has found that, relative to a paired uninfested watershed, post-infestation annual runoff has been within the range of variability observed prior to the infestation (Elder/Hubbard). In 2008,

the uninfested watershed was itself infested by MPB, obviating the paired-watershed analysis. This is becoming an issue across the region, necessitating the formulation of alternative study design and statistical approaches to tease out MPB effects.

A study of 26 watersheds in western Colorado and south-central Wyoming found that change in annual runoff and peak runoff since the MPB infestation was unrelated to the proportion of the watershed covered by beetle-killed forest. Some of these watersheds show declining trends in annual, seasonal, and peak runoff that began prior to the infestation (post-1990), making it difficult to discriminate changes caused by the beetle kill (Stednick).

*Continued monitoring and additional studies in beetle-affected watersheds may yet show detectable runoff changes that can be attributed to the impacts of beetle kill. Previous studies suggest a lag after infestation before the expected increase in runoff is detectable (Rhoades, Elder/Hubbard). But the complexity of the processes involved and the difficulty of scaling those processes from the tree level to the watershed level should caution against assuming that total yield will change in a consistent direction and magnitude across all beetle-affected watersheds (Chen, Brooks). A change in runoff timing to earlier runoff peaks is more likely to occur.*

### Water quality

*As with water yield, there has been an expectation of significant changes in some parameters of water quality in watersheds with high tree mortality from MPB. But initial results from recent field studies, in general, do not indicate nutrient loading or other water chemistry changes of the magnitude that would present problems for either human water use or aquatic ecosystems.*

The death of trees in MPB-affected forests is expected to have several potential consequences for water chemistry and water quality:

- Decaying wood and foliage after tree death could result in the release of carbon and other nutrients (especially nitrogen) that could be exported to streams and lakes.
- The cycling of nutrients (nitrogen, phosphorus, etc.) between the soils and the trees is interrupted as tree uptake ceases, making some fraction of those nutrients available for export from soils to streams and lakes.
- Water temperatures could increase as shading is reduced by the death of trees adjacent to streams and other surface waters. This could also increase the rate at which some chemical reactions and metabolic processes occur.

The recent and ongoing field studies in MPB-affected watersheds—mainly on Colorado's West Slope (Figure 3)—that were presented at the symposium have found these results:

*Carbon in soils and streams appears to have increased post-infestation.*

- Soil organic matter increased post-infestation (Barnard)





Figure 3: Sampling for water quality in a beetle-affected watershed in Rocky Mountain National Park, Colorado, in August 2009. (Photo: National Park Service)

- Total organic carbon in streams increased from needle cast (Stednick)
- Dissolved organic carbon (DOC) levels at 200 water sampling sites had a statistically significant but weak relationship with percent tree mortality in the watershed (McCutchan)

*Nitrogen appears to have increased in soils post-infestation, but the export of nitrate to streams has either not increased or has increased to levels that are still lower than any threshold of concern.*

- Nitrogen levels increased in soils under affected stands (Stednick, Clow)
- Nitrate levels in streams generally decreased over time (Clow)
- Nitrate levels in streams increased after infestation, but remained relatively low (Rhoades)
- Differences in nitrate levels between watersheds were explained better by topographic variables (elevation, aspect) than by proportion of watershed affected by infestation (Clow, McCutchan)

*Some other nutrients appear to have increased post-infestation.*

- Phosphorus levels in streams generally increased over time (Clow)
- Magnesium levels at 200 water sites had a statistically significant but weak relationship with percent tree mortality in watershed (McCutchan)
- Stream temperatures have increased where lodgepole pines, now beetle-killed, formed the canopy in riparian areas (Stednick)

A new study in central Colorado is examining whether physical and biogeochemical changes associated with MPB infestation will lead, as hypothesized, to greater transport of metals from groundwater to surface waters (Mikkelsen).

*Again, observed changes in water chemistry and water quality parameters that might be attributed to the MPB infestation were less than expected, with no “red flags” in terms of water quality standards. As with runoff quantity, these recent findings don’t preclude larger effects occurring later as the infested area increases and more time elapses since infestation. As suggested earlier, groundwater processes could cause the export of nutrients to streams to lag the export to soils by several years.*

*Lurking in the background of the discussion of MPB impacts on water quality is the prospect of dramatic changes in water quality, especially sedimentation, that would occur if a large and intense wildfire were to occur in an MPB-affected forest. The enormous sedimentation problems caused by the Buffalo Creek (1996) and Hayman (2002) fires in the South Platte basin has made water resource managers very concerned about wildfires that may follow the MPB infestation. Recent synthesis reports (Romme et al. 2006, Kaufmann et al. 2008) provide a more nuanced view of the relationship between MPB and fire than the widespread assumption that “dead trees = more fire.”*

### Management practices, MPB, and Water

*Management practices associated with MPB, such as harvesting for fuels reduction, have the potential for greater effects on water yield and water quality than those caused by MPB alone, at least at the stand level. Unlike MPB, harvesting activity generally compacts and disturbs the soil, and in the case of clearcutting, removes all of the trees and the understory at once.*

One research presentation (Rhoades) focused on the effects of MPB-related management treatments (e.g., harvesting for fuels reduction; Figure 4) on hydrology and water quality, as indicated by past studies of treatments, and ongoing studies at MPB-affected sites. Others (including Stednick) touched on concerns related to management treatments.

Past studies of forest management in the region show that complete removal of the forest canopy (i.e., clearcutting) has large effects on both water yield and water quality. Harvests in the 1950s in predominantly lodgepole pine stands at Fraser Experimental Forest (FEF) produced a 40% increase in water yield over the next 30 years, with recovery to pre-harvest yield occurring after about 60 years (Rhoades). Companion studies at FEF found that nitrate export to streams increased several-fold following clearcutting and remained above pre-harvest levels even after 20 years (Rhoades).

In the wake of the MPB infestation, harvesting of both infested and uninfested stands for fuels reduction and the removal of dead “hazard” trees has increased substantially (Rhoades, Stednick). On the Sulphur Ranger District in the Colorado River headwaters, harvesting levels are now higher than at any time since the 1970s, with over 90% of the harvesting being conducted as clearcuts (Rhoades). Across the western US, harvesting for fuels reduction is being carried out in riparian areas in half of all Forest Service ranger districts. While current Best Management

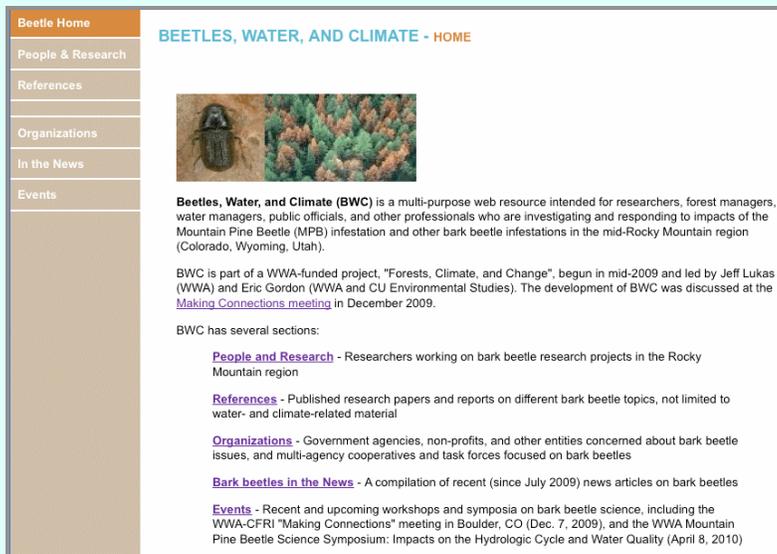


## Beetles, Water, and Climate (<http://wwa.colorado.edu/ecology/beetle/>)

This site is a multi-purpose web resource intended for researchers, forest managers, water managers, public officials, and other professionals who are investigating and responding to impacts of the Mountain Pine Beetle (MPB) infestation and other bark beetle infestations in the mid-Rocky Mountain region (Colorado, Wyoming, Utah). It was developed as part of a WWA-funded project, "Forests, Climate, and Change", begun in mid-2009 and led by Jeff Lukas (WWA) and Eric Gordon (WWA and CU Environmental Studies).

*Beetles, Water, and Climate* has several sections:

- *People and Research* - Researchers working on bark beetle research projects in the Rocky Mountain region
- *References* - Published research papers and reports on different bark beetle topics, not limited to water- and climate-related material
- *Organizations* - Links to government agencies, non-profits, and other entities concerned about bark beetle issues, and multi-agency cooperatives and task forces focused on bark beetles
- *Bark beetles in the News* - A compilation of recent (since July 2009) news articles on bark beetles
- *Events* - Recent and upcoming workshops and symposia on bark beetle science, including the WWA Mountain Pine Beetle Science Symposium: Impacts on the Hydrologic Cycle and Water Quality (April 8, 2010) and the WWA-CFRI "Making Connections" meeting (Dec. 7, 2009)



**Beetles, Water, and Climate (BWC)** is a multi-purpose web resource intended for researchers, forest managers, water managers, public officials, and other professionals who are investigating and responding to impacts of the Mountain Pine Beetle (MPB) infestation and other bark beetle infestations in the mid-Rocky Mountain region (Colorado, Wyoming, Utah).

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Practices (BMPs) can protect water quality much better than past harvest practices, it is unclear whether riparian buffer zones—a key component of BMPs—can protect water quality if the riparian trees have been killed by beetles (Rhoades).

Ongoing US Forest Service research at four MPB-affected sites in north-central Colorado is investigating the effects of three different forest harvest treatments, along with no treatment, on snow accumulation, soil moisture, and water yield, and nutrient cycling, as well as tree regeneration and growth, and fuels and fire behavior (Rhoades).

Management for the MPB infestation also includes the use of carbamate and pyrethroid pesticides to prevent MPB attacks on high-value trees. Both federal land managers (US Forest Service, National Park Service) and private landowners are annually treating thousands of trees within infested areas. It is not known whether these pesticides—highly toxic to aquatic invertebrates and fish—are ending up in surface waters at levels that would be of concern for ecosystems or human health. Water sampling for pesticides to be carried out in May 2010 in locations in and around Rocky Mountain National Park may help answer this question (McCutchan).

### Concluding thoughts

Two overarching themes emerged from the findings presented at the symposium: the impacts of MPB infestations on water

resources that have yet been observed are not as significant as was expected, and we need a much better understanding of the physical processes behind water-related effects of forest change.

There are a few reasons why the impacts of MPB may not be as significant as expected. First, it appears that harvesting may be a poor analog for the effects of MPB infestation. Second, the effectiveness of residual trees (i.e., those not killed by MPB) and the understory vegetation in carrying out stand-level functions related to the hydrologic cycle and nutrient cycling may have been underestimated.

Finally, we do not understand the underlying physical processes well enough to predict the impacts of MPB on water resources at the basin scale. As two of the symposium participants observed, we have an insufficient understanding of the "static" picture of forest hydrology, let alone what happens when a large change like an MPB infestation occurs. A new project will be intensively studying the hydrological and biogeochemical process responses to MPB, at both a highly infested site and a relatively uninfested site (Brooks). Ideally, this study and others like it will ultimately provide resource managers with better tools to assess and predict watershed impacts from MPB.

While the research synthesized above represents a large sample of ongoing and recent work in the Rocky Mountain





Figure 4: Harvesting with a feller-buncher in a beetle-killed lodgepole pine stand in North Park, Medicine Bow-Routt National Forests, Colorado (Photo: David Harasimtchuk, US Forest Service)

region on MPB-water questions, it is not a complete picture of the state of the science, and there are many unanswered questions that will drive the science in new directions. As new research and monitoring is conducted, the picture of MPB-water impacts will undoubtedly change. WWA will continue to help resource managers and other decision-makers stay informed of developments in this fast-moving area of research. We encourage readers who want more information about these studies to contact the presenters directly, and to contact us ([wwa@noaa.gov](mailto:wwa@noaa.gov)) with suggestions on how the communication of MPB research to stakeholders can be improved.

### Acknowledgements

We again thank the presenters and other participants for making the symposium a success. Many of the presenters also provided helpful comments on a draft of this article.

### References

For a list of journal articles and reports relevant to MPB impacts on water resources, please visit the *References* page at the *Beetles, Water, and Climate* web resource: <http://www.colorado.edu/ecology/beetle/references.html>

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Romme, W.H., et al. 2006. Recent forest insect outbreaks and fire risk in Colorado forests: a brief synthesis of relevant research. Colorado Forest Restoration Institute, Fort Collins, CO.

