Bark Beetles: Cause for Concern in Snowy Western Watersheds?

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The spring of 2011 was a particularly high runoff year in Colorado's northern mountains. In response to the huge snowpack, Dillon Reservoir, which is part of the Denver Water system, was drawn down significantly prior to the spring snowmelt to reduce the flood risk for the town of Silverthorne, located below the dam. Bob Steger, Manager of Raw Water Supply for Denver Water, described it as “a very challenging balancing act.” After filling began, the reservoir level came close to the spillway crest, but forecasts indicated that the inflows would soon begin going down. Unfortunately, the inflows increased and stayed high for nearly a week longer than the forecast, raising concerns that significant flooding would occur. Luckily, inflows started going down just in time to avoid a serious flooding event. This incident and others like it led some to suspect that widespread tree death due to bark beetle infestations might be responsible; reducing forest uptake of water and increasing the amount of water in surface streams would have major consequences for water resources management in snow-dominated mountain regions. There was reason to believe that was occurring–but as it turns out, the story of how tree death from beetle infestations affects water supplies is far more complicated than simply turning off the “straws” of water uptake by trees.

Before we discuss that story in more detail, though, what are these tiny insects that have killed so many trees in western North America and are worrying water managers? The term “bark beetles” refers to a family of insect species, all of which eat through bark and the living tissue of trees. In the West, the most abundant of these bugs is the native mountain pine beetle, which feeds off a variety of trees such as lodgepole pine, ponderosa pine, and limber pine. Normally, bark beetles kill relatively few trees each year, but under certain conditions they are able to multiply rapidly and spread across entire landscapes. Scientists believe that the current beetle outbreak, which began in the mid-1990s, was spurred on by the drought that has affected much of the west since the early 2000s.

[FIGURE 1 HERE - Included below article]

Unprecedented in human history, this insect outbreak has changed whole mountainsides from green to red to brown and then to grey (Figure 1), with the biggest devastation occurring in lodgepole pine forests that cover subalpine regions of the Rockies. Estimates indicate that, since the mid-1990s, nearly 400,000 square miles of total forest in western North America have been affected by bark beetles. It is important to remember, however, that although the current infestation may be larger than ever observed before, beetle epidemics are normal in coniferous forests. The hydrologic impacts of such a large landscape changes can last for decades, giving greater impetus to understanding how these infestations affect surface water supplies.

Although detailed investigations into beetle impacts on hydrology have been done relatively recently, research into the connections between other types of changes in forest cover and streamflow dates back to the early 20th century and has shaped much of the conventional wisdom about tree death and water supplies. At sites such as Wagon Wheel Gap in Colorado and Hubbard Brook in New Hampshire, scientists first assessed the effects of changes to forests, such as fire and clear-cutting, on streamflow. The results were clear, especially in snow-dominated areas–the removal of forest cover increased snow accumulation in the winter and reduced transpiration in the summer, leaving more water available to enter streams. Subsequent investigations found some mitigating effects of increased sunlight on the snow surface and increased wind speeds in open areas, but nearly a century's worth of observations confirmed this general principle–removal of forest cover results in increased water yield, an effect that is more pronounced in areas with higher snowfall.

However, much of that research was based on rather dramatic changes to forest cover, usually through clear-cutting or patch cutting, which removes virtually all of the vegetative cover in certain areas. With bark beetle infestations like the current one that concerned Bob Steger, things are notably different. Despite the fact that the vast majority of a given patch of forest may be killed during a bark beetle infestation, the trees are not removed from the landscape. Furthermore, in contrast to fire and clear-cutting, the rate of forest disturbance is much slower with beetles–in the former, whole swaths of forest could be removed in hours, while beetle infestations kill trees slowly over years. Finally, those remaining living trees, which are usually the youngest ones, continue to grow, often at a faster rate. Thus we cannot assume that what past experiments found will wholly apply to beetle infestations; rather a mixed story emerges.

To begin with, we can consider how beetle-killed affect the growth and melting of snowpacks. At the forest plot level (think of a "plot" as a square of roughly 100 yards on a side), tree death from bark beetle infestations can affect snowpack in two specific ways–by increasing total snow accumulation and by changing factors that control how the snow disappears through melt or sublimation, collectively known as ablation.

Overall changes in total snow accumulation are connected to interception, the primary mechanism that controls the amount of precipitation reaching the forest floor. Tree leaves and branches retain snow very effectively, preventing more than half of incoming snowfall from reaching the ground in some cases. Of that intercepted snow, nearly two-fifths can sublimate directly back into the atmosphere. However, in bark beetle-infested coniferous forests, trees drop their needles and develop drooping branches, reducing their ability to intercept snow and leaving more snow to accumulate on the ground. Calculations based on field observations conducted in northern Colorado by the authors demonstrate that this "grey phase" could result in roughly 5-15 percent more total snow accumulation.

[FIGURE 2 HERE - Included below article]

Although this reduction in tree canopy material can lead to greater snowpack accumulation in forests, bark beetle-related changes in forests also generally result in an overall increase in the rate at which snow melts. Snowmelt is driven by a number of factors, but the primary mechanism is incoming shortwave radiation, otherwise known as visible sunlight. Just as trees shield the ground from greater snow accumulation, trees also reduce the amount of incoming sunlight reaching the snowpack. Thus as trees killed by beetle infestations lose needles and twigs, more sunlight can reach the ground, with the authors' field research demonstrating an increase of roughly 10-15 percent. This additional sunlight leads to increased melting of snow. In addition, the dead needles and twigs that fall out of the tree canopies accumulate on the snowpack and reduce the reflectivity of the snow, increasing melt rates–in fact, studies in Colorado have shown up to a one week advance in the timing of snowmelt. Finally, dead trees do less to block the wind, resulting in higher rates of snow sublimation on the ground.

[FIGURE 3 HERE - Included below article]

With more snow and faster melt, what might we see in terms of water yield, especially at scales that are of interest to water managers? The authors and their colleagues have used computer models to assess how sensitive streamflow is to beetle impacts at catchment scales, roughly the size of a small western creek watershed. Results showed that the amount of water coming from the catchment could rise up to 10 percent just due to forest canopy loss due from bark beetle kill, as compared with expected flow in the same catchment prior to the infestation.

A number of factors, however, are likely to make real-world changes less impressive. First, growth of the surviving younger understory trees can accelerate dramatically after beetles kill older trees–up to three times their previous growth rates in some cases, due to a new abundance of root-zone water and sunlight. Our modeling suggests that this alone could reduce the increase in water yield sensitivities by half. Second, the patchwork nature of beetle infestations means that we rarely see entire watersheds completely killed at the same time, which can moderate impacts. Third, year-to-year variability in snowfall (up to 300 percent change is not uncommon in Colorado) can essentially disguise most of the contribution of changes in water yield due to beetle infestations.

In addition to the water quantity changes described, forest hydrology research has demonstrated that removal of large sections of forested watersheds may also result in significant impacts on water quality. In particular, researchers found that removal of forest canopy from clear-cutting resulted in significant short-term spikes in nitrate concentrations in surface waters. A lack of vegetative cover also contributes to erosion during significant precipitation events, and both the decomposition of organic material and the mobilization of minerals in soils can negatively impact water quality.

With respect to bark beetle infestations, however, there is reason to believe that impacts would be much less severe than those seen from clear-cutting. Remaining live trees, especially young trees, are still capable of taking up nitrate. In addition, standing dead trees can help anchor soil and reduce erosion and mobilization of minerals and other chemicals into streams.

Recent research generally agrees with this line of thinking, although with some cautionary notes. One study of streams in Colorado found no significant changes in total nitrate concentrations when comparing watersheds with significant beetle kill against those without. Another study, however, did see greater levels of regulated carcinogenic trihalomethanes in water treatment plants located downstream of significant beetle kill compared to nearby plants in watersheds with less mortality. Again, as with streamflow, the effects of bark beetle infestations on water quality are likely much less impressive than seen in clear-cutting, and may not be easily detectable at large scales.

In the end, should water managers whose utilities depend on watersheds with significant bark beetle infestations be concerned about the quantity or quality of raw water supplies? As of now, prudence warrants monitoring the scope of the infestation and keeping an eye on water supplies. To date we have seen plenty of information demonstrating that bark beetle infestations do increase snow accumulation, speed up snowmelt, and lead to modest additional streamflow, but a variety of mitigating factors may make such changes hard to detect. At the watershed and basin scales that are most often of concern to water managers, it may be that the slow progression of tree death and decomposition, along with the patchwork nature of beetle infestations and the effects of rapid growth from young trees, will keep effects from being particularly great, although more significant changes are certainly possible as forests continue to respond to climate change.

It is worth remembering, however, that bark beetle infestations are just one of many land cover changes in western North America that can have serious impacts on water supplies and utility operations. Mechanical harvesting often results in greater streamflow, and road building or land clearing can increase overland flow rates and sedimentation. Dust from southwestern deserts can be deposited on mountain snowpacks, accelerating springtime melt and reducing overall streamflow volume. Finally, wildfires can have perhaps the most serious consequences, including high erodibility in fire-scarred areas, accelerated runoff from landscapes, and increased mobilization of metals and other pollutants into surface waters.

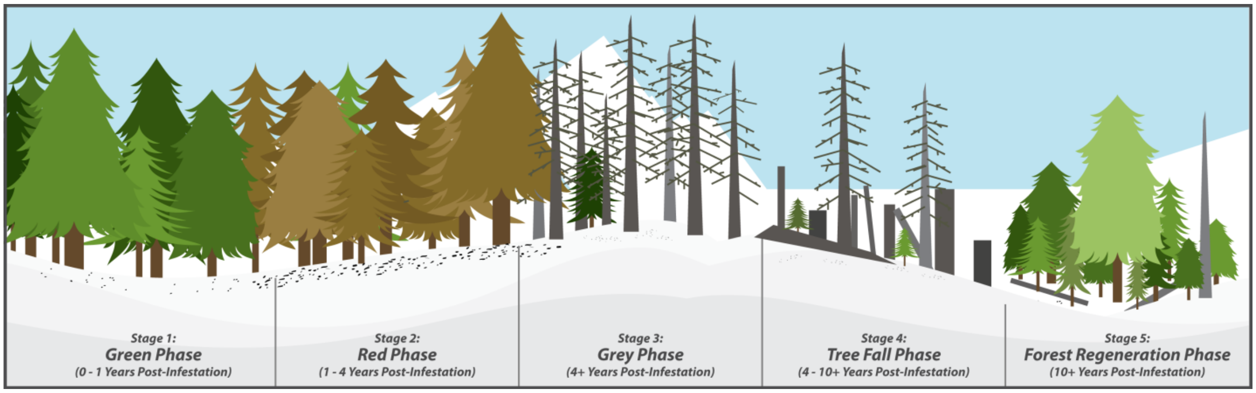
For more information

Pugh, E. T. and Gordon, E. S. (2013), A conceptual model of water yield effects from beetle-induced tree death in snow-dominated lodgepole pine forests, *Hydrological Processes* 27: 2048–2060. doi: 10.1002/hyp.9312

Rhoades, C. C., J. H. McCutchan, Jr., L. A. Cooper, D. Clow, T. M. Detmer, J. S. Briggs, J. D. Stednick, T. T. Veblen, R. M. Ertz, G. E. Likens, and W. M. Lewis, Jr. (2013). Biogeochemistry of beetle-killed forests: Explaining a weak nitrate response. Proceedings of the National Academy of Sciences, 10.1073/pnas.1221029110.

Mikkelson, K. M., E. R. V. Dickenson, R. M. Maxwell, J. E. McCray, and J. O. Sharp (2013). Water quality impacts from climate-induced forest die-off. *Nature Climate Change* 3: 218-222. doi:10.1038/nclimate1724

Figure 1:



Caption: Unlike impacts from forest fire or clear-cutting, which are immediate and dramatic, tree death from bark beetles often results in standing dead timber that proceeds through a number of mortality stages following death. Though it depends on the tree species, dead trees have been known to remain standing for 50 years.

Figure 2:

Caption: Thinned canopies in dead conifer forests allow more precipitation, as well as more sunlight, to reach the ground.

Figure 3:

Caption: Sub-canopy snowpack under dead conifers has reduced surface reflectivity due to fallen needles, twigs, and branches. This "dirty" snow surface causes the snow to melt more rapidly.