*In summer 2002 (left), pinyon trees in the Jemez Mountains of northern New Mexico began dying from drought stress and an associated bark beetle outbreak. By May 2004 (right), the landscape had changed from pinyon-juniper to just juniper woodlands.*

Photos: Craig D. Allen

# Transformative Landscape Change in the West: Implications for Watershed Management

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My original intent was to write about where and how manipulation of vegetation might result in increased water yields, such as in streamflow or groundwater recharge. However, this traditional approach is becoming largely irrelevant. Not long ago, such a statement would have been considered heresy in the watershed- and land-management circles. After all, the two major tenets of watershed management have been that vegetation and land-cover management can 1) maintain and enhance water quality, and 2) augment water yields. In regard to the first, there has been spectacular success: literally hundreds of cases where water quality has improved have been documented at both large and small scales. These improvements were evidenced primarily by reduced sediment and nutrient loads, but also include improvements in other water quality parameters. In regard to the second, however, we have been largely unsuccessful.

A recent review by the National Academy of Sciences (2008) concluded that while extensive watershed research has established a clear linkage between forest cover and water yield, *managing forests for increased water yield is not a viable strategy*. This conclusion was based on several observations, including: 1) increases in water yields are small and unsustainable; 2) water quality can be diminished; 3) little return is achievable during dry periods; and 4) the size of the area needing treatment is prohibitively large. Gradual recognition of this fact, both within and outside of the land-management profession, has robbed the profession of some of the vitality it displayed in the 1960s, 1970s, and early 1980s. And it is fair to say that the profession has been in decline—judging by student numbers and work opportunities—for some time.

*While research has established a clear linkage between forest cover and water yield, managing forests for increased water yield is not a viable strategy.*

I believe that this decline is about to be reversed. We are entering a new era of transformative landscape change. Our forests and rangelands are changing at an unprecedented rate. Understanding and mitigating the hydrologic implications of transformative landscape change is an emerging and urgent need, and will be the major challenge for land and watershed management as the 21st century unfolds. The effort to meet this challenge will reinvigorate and transform the discipline. The emergence of and growing interest in ecohydrology is evidence that this disciplinary transformation is already happening.

## Implications for the Water Cycle

Many examples of transformative landscape change have occurred recently just in the western United States. These include changes in snow patterns at high elevations, increases in forest mortality due to insect infestations, invasion of rangelands by non-native perennial and annual grass species, invasion of riparian areas by non-native shrubs, and woody-plant encroachment and land degradation. While the effects of these changes on streamflow and groundwater recharge are not fully understood, some educated guesses can be proffered, based on available information.

***Changes in snow cover:*** Of all the landscape changes listed above, changes in the patterns and amounts of snow accumulation and snowmelt at high elevations may have the most profound effects on streamflow. Declines in summer and fall flows have already been detected for many western rivers, with serious consequences for water supply and environmental flows (Rood and others, 2008; Stewart and others, 2004). For example, low flows for some streams in Idaho have diminished by 30 to 50 percent in recent years (Charlie Luce, personal communication). More changes are expected as the climate continues to change.

***Large-scale forest die-off:*** Perhaps the most dramatic example of transformative landscape change in the West has been the die-off of forests, largely pine forests, as a result of insect infestations (see photos). These insect outbreaks have been facilitated by years of low precipitation and relatively mild winters. Some have suggested that most if not all of the lodgepole pine forests from Mexico to Canada will eventually succumb. Understanding and dealing with the hydrological consequences of such a massive loss will be a major challenge for watershed managers (see sidebar), although we can build on previous watershed research. Potts (1984), for example, found that streamflow from a 133-km$^2$ watershed in Montana increased by 15 percent following a mountain pine beetle epidemic in the 1970s. These results are consistent with many forest hydrology studies showing that water yield does increase following timber removal. However, if snow accumulation is lower in these mid-elevation forests, the expected increases in streamflow may not materialize.

As forest die-off proceeds, there may be an increased risk of forest fires, at least until the dead needles fall off. The hydrological changes following severe forest fires, in the short term, are dramatic. Runoff—and especially erosion—can be expected to increase one or two orders of magnitude following intense wildfires.

Significant die-off has occurred in the lower-elevation Ponderosa and pinyon pine forests as well, but given the lesser sensitivity of streamflow to tree cover at these elevations, any changes would probably be very small and difficult to detect.

***Invasion of rangelands by non-native grasses:*** Another dramatic example of transformative landscape change is the conversion of native rangelands to exotic grasslands. Prominent examples of invasive grasses that are transforming rangelands include cheatgrass in the Great Basin and buffelgrass and Lehmann lovegrass in the Southwest. These invasive grasses have been called "transformer species" because of the fundamental ecosystem changes that follow their installation. Most prominently, fire regimes intensify because these grasses provide a large amount of very flammable material. To date, relatively little work has examined the large-scale hydrological implications of such invasions.

***Invasion of riparian areas by non-native shrubs:*** Riparian landscapes, especially in the Southwest, have been significantly altered by the presence of invasive shrubs such as saltcedar and Russian olive. The hydrological implications of these changes have been much debated. A consensus seems to be building, however, that eradication of non-native shrubs would result in little if any gain in streamflow, especially if the non-native species are replaced by native shrubs. I suspect that management strategies will shift away from attempts at eradication toward managing flow regimes to give native species a competitive advantage.

*see Transformative, page 34*

## Watershed Response to Tree Die-Off?

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The water budget for a watershed is greatly influenced by land surface. One of the most important land surface characteristics is the amount and type of tree cover, which influences interception of precipitation, runoff, soil-water dynamics, and transpiration losses. Drought has recently triggered tree die-off throughout the southwestern United States (Breshears and others, 2005; Gitlin and others, 2006). According to the U.S. Forest Service, 27 percent of the Four Corners states is covered by woodlands and forests, and 30 percent of that area has been impacted by drought-related mortality affecting scores of tree species within ecosystems ranging from pinyon-juniper woodlands to mixed-conifer forests. Such drought-triggered die-offs may become more frequent as global climate change progresses. What are the potential watershed consequences of such die-offs?

Large-scale reductions in tree cover will certainly impact the water budget of a watershed, but exactly how remains highly uncertain. Research has suggested that small increases in streamflow may be feasible from tree harvesting, although that practice is usually not very practical or effective (see main article). In contrast, the increase in downed woody debris and modifications in runoff channeling associated with tree die-off may actually result in less, not more, overland flow. The most notable impact of tree die-off on the water budget would likely be the reverse of woody plant enchroachment (Huxman and others, 2005), where evaporation would increase and transpiration would decrease due to reductions in tree biomass and the corresponding warmer microclimate. This shift in turn could alter total evapotranspiration, soil moisture, and/or groundwater recharge, although these responses are complex, interrelated, and hard to predict. Managers need to consider this additional uncertainty while researchers focus on reducing it.

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***Woody plant encroachment:*** Large tracts of grasslands and savannas have been converted to woodlands through a process often described as woody plant encroachment. These conversions result from a combination of factors, including overgrazing, reduction in fire frequency, and increases in greenhouse gases. They are likely to significantly affect the water cycle in terms of ecological processes and distribution of water across the landscape. In addition, there is good evidence that a shift from grasses to shrubs diminishes groundwater recharge—although not to a degree important for water supply. Little if any evidence suggests that woody plant encroachment has led to large-scale changes in streamflow, except where it is accompanied by degradation or desertification. Surface runoff and erosion will be significantly higher under degraded than nondegraded conditions. For example, Wilcox and others (2008) demonstrated that floods in west Texas in the earlier part of the last century were much greater than now because rangelands were much more degraded.

## Looking Ahead

Understanding and mitigating the effects of transformative landscape change will dominate and transform land and watershed management in the future. The rich and diverse legacy of research into the relationship between vegetation management and water yields will provide a solid foundation for building new strategies to meet these future challenges.

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# Business Directory



*Native Trout, continued from page 27*

Apache trout metapopulation (see map, page 26). The plan requires removal of some existing barriers and construction of a new barrier farther downstream on the West Fork, thereby increasing Apache trout habitat within the streams from 33.4 to 53.1 km. Although some downstream habitat may be warmer during summer, it will also contain deep, shaded pools that offer cooler refuges.

The new barrier will help isolate downstream non-native fishes from Apache trout. Non-native trout likely will have to be removed from the upstream area by chemical treatment. Regular stream monitoring will be needed to determine the relative status of native and non-native species as well as the effectiveness of barriers and control treatments.

State, federal, and tribal agencies typically lack sufficient funding to restore needed interconnected metapopulations such as in the West Fork of Black River. For Apache trout, the National Fish and Wildlife Foundation, Trout Unlimited, and other nongovernmental groups are providing additional support to create a few larger interconnected stream systems that complement existing recovery programs. These efforts may afford the best opportunity for native southwestern trout to survive a future that is past peak water.

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