Forests, Water, and Climate Change

Preparers

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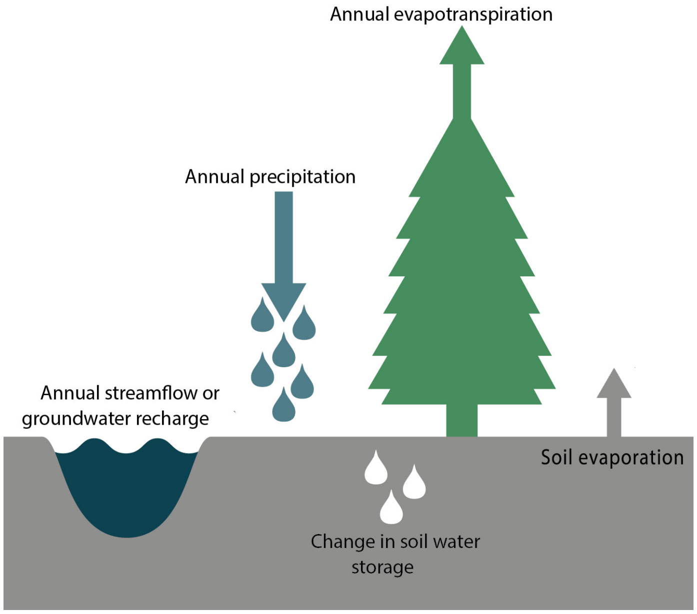
Introduction



The remainder of the 21st century will present significant challenges for forest watershed management, as rapid and compounded climatic and socioeconomic changes contribute to an increasingly uncertain future [1]. Among these challenges is an increased risk of water scarcity for a growing human population [2], even in regions where water has historically been abundant [3]. Periods of low precipitation combined with elevated air temperature are likely to be punctuated by episodes of heavy precipitation in some regions [4]. In many areas of the Western US, declining mountain snowpack and earlier snowmelt are already impacting water resources [5]. Due to their ability to moderate hydrologic extremes and improve water quality by filtering nutrients and sediment, forests from rural to urban landscapes will be increasingly relied upon to provide clean, reliable water supplies for human uses, as well as for aquatic ecosystems [6]. In many cases, climate change represents hydrological change because it has direct and indirect impacts on forest watershed processes. In addition to warming, one of the most observable, direct responses to climate change is hydrologic intensification: the increased frequency of hydrologic extremes such as low and high flows. Recent studies have detected both decreasing and increasing flows in the US which are attributed, at least in part, to greater precipitation variability [7, 8]. The timing of streamflow is also affected by climate change, not only due to shifts in the seasonality of precipitation, but also as winter precipitation falls as rain rather than snow [9]. In the western US, when winter precipitation falls as rain rather than snow, winter stream flows are higher. The reduced snowpack also results in lower spring flows and reduced steamflow and soil moisture throughout the summer [10]. Climate change causes indirect hydrologic effects as forest ecosystems are impacted by disturbances that may worsen with climate change such as wildfires [11, 12], insect outbreaks (19, 21, 22), or selective mortality of drought and heat sensitive trees [13, 17, 18, 20]. Forests also play a critical role in regulating stream water quality including temperature; disturbances that decrease forests cover and disrupts the soil (especially in the near stream areas), may have negative effects on stream nutrients, sediment, and temperature [14]. Understanding how climate change impacts water resources now and in the future can be conveyed in the simplest terms by examining components of the water balance, which describes water flow into and out of forests, as illustrated in figure 1. Changes in stream flow can occur due to changes in precipitation inputs (i.e., amount, seasonal distribution, and amount and timing of snowmelt) or changes in evapotranspiration outputs. In most temperate forests (with the exception of young forests where leaf area index is rapidly aggrading or disturbed stands where leaf area index is rapidly declining), evapotranspiration has been shown to be relatively constant from year to year, so most annual variation in stream flow is driven by variation in precipitation. Some evidence suggests that higher atmospheric CO2 concentration may decrease transpiration at the leaf-level because trees might become more water efficient, although this has not been demonstrated at canopy scales [15]. A warming climate is likely to increase the energy available for evapotranspiration or potential evapotranspiration, a major driver of actual evapotranspiration of forests, especially when soil water is not limited. Changes in watershed evapotranspiration have been observed when the structure (e.g., the amount and duration of leaf area, root depth) or the function (e.g., xylem anatomy, stomatal control, etc.) of the forest is changed by successional processes, management actions, or disturbance. For example, converting a hardwood forest to a conifer forest may increase evapotranspiration in some cases by extending the duration of leaf area display (24). Management decisions, such as planting or using frequent prescribed fires, may favor species that have different water demands and responsiveness to climate change; exacerbating or decreasing the vulnerability of forest watersheds to climate change. For example, in general, oaks can tolerate drought conditions better than more drought sensitive species such as maples [16].

Likely Changes in Water Resources

As noted above, the impacts of climate change on water resources will be driven primarily by changes in the balance between precipitation and evapotranspiration. While long-term paired watershed studies provide some guidance on potential changes (24), accurately projecting the long term changes in both precipitation and evapotranspiration presents a considerable challenge in forested watersheds. One of the challenges for predicting the effects of climate change on water resources are major uncertainties in predicting future precipitation in global climate change models. Annual precipitation totals in the US are projected to decrease in the Southwest and increase in the Northeast, but confidence in these projections is moderate because of the complexity in downscaling climate change data [4]. There is greater confidence in projections that some regions in the US will experience greater precipitation variability (e.g., heavier rainfall events and longer dry spells) [4]. There is high confidence in projections of warming and extreme high temperatures; higher temperatures can exacerbate the impacts of drought, increase plant water needs, and alter snow amount and snowmelt recharge. Combined, these increases in extreme events, coupled with more frequent and intense disturbances, portend a future where forest watersheds are increasingly vulnerable to changes that could impact their structure and function, and ultimately the quality and quantity of water resources derived from them. Changes in evapotranspiration will occur from both direct climate impacts (i.e., changes in climatic drivers of evapotranspiration including air temperature and vapor pressure deficit) and from long and short terms changes in forest conditions. Forest watersheds are inherently resilient to stressors and disturbances, but this resiliency is not unlimited [11]. Large scale forest die-off is occurring in many areas in the western US due to the combined effects of drought, heat, wildfire, and insect outbreaks [15]. Some of these disturbances are so severe that forest do not recover and are replaced by shrub or grasslands. Although not as widespread or large-scale as in the western US, tree mortality has accelerated in the past few decades in many areas of the eastern US as well [16]. Hydrologic processes can be impacted by large-scale mortality. For example, in western coniferous forests, streamflow has been shown to increase in some cases after large-scale mortality events [17]; however, responses are inconsistent and can be difficult to detect at large spatial scales [18]. In one study, annual water yield increased by 11% in western US watersheds affected by mountain pine bark beetle mortality [21], yet in other studies, annual water yield has remained the same or even decreased [20, 22]. This variability in response pattern depends in part on the rate and magnitude of mortality and vegetation regrowth (overstory and understory) that may utilize additional available water [20]. Establishing linkages between hydrologic processes and climate change mediated disturbances in eastern forests is more challenging; however, watershed scale studies show a clear linkage between vegetation structure and function and streamflow. For example, recent studies suggest that changes in forest species (i.e., a shift to more water demanding species) has resulted in decreased streamflow in some watersheds [23].

Management Considerations

Understanding the linkages among forest structure, function, and streamflow has important implications for forest management. Knowledge of these linkages suggests that management actions that alter structure and function can be used to increase resilience and minimize impacts from climate change on streamflow [24, 25]. For example, in areas where the risks of large scale mortality and wildfire are greatest, immediate forest management actions that keep trees alive and reduce risks to life and property may be the highest priority [26]. Many of the areas at high risk are dry, western conifer ecosystems, including western lodgepole pine forests, which tend to burn at high severity. Areas upslope of population centers and forests buffering municipal water supplies might also be prioritized to maintain soil stability during forest disturbances. Options to reduce risk may include reducing density [27] which reduces fuels and provides more soil water to remaining trees, particularly during drought [28]. Further, intensive and extensive fuels management might be necessary to reduce wildfire risk. In addition to thinning to reduce ladder fuels, treatments may include prescribed fire, herbicides, and mastication. Fuels reduction is particularly critical in areas with extensive wildland-urban interface, where fire breaks must be maintained and managers might consider conversion to more fire-resistant vegetation. Once immediate risks are addressed, land managers may consider long terms strategies that shift the focus to increasing resilience. Strategies to increase resiliency include creating multi-aged stands and favoring more drought and fire tolerant trees in existing stands. For example, managing for oak species in eastern forests will likely increase drought and fire tolerance [13]. Further, forests can be planted with drought and fire tolerant species. In the Southeastern coastal plain for example, longleaf pine is thought to confer higher resilience to fire, insect pests, drought, and extreme storm events when compared to other southern pine species [29-31]. Within species, managers can select genotypes that create stands more resilient to future climatic conditions [32, 33]. Resilience is likely to become increasingly critical as climate change is likely to result not only in drier conditions, but at the other extreme, larger storms that increase flood and landslide risks. Such events will challenge the effectiveness of current Best Management Practices (BMPs) for road design, bridges, and culvert sizing and location. Maintaining as much forest cover as possible is a first line of defense, but precipitation extremes can overwhelm the capacity of forest watersheds to mitigate high flows. Hence, land managers will need to consider future climatic conditions as they plan, design, restore, or build roads and other watershed infrastructure. For example, modifications of current BMPs to address greater precipitation variability might include wider riparian buffers, larger culverts at road crossings, and more efficient and stable road design. Across the spectrum of current risk, anticipating future conditions that are likely to be warmer, with greater precipitation extremes, and with an increased risk of insect outbreaks and wildfire can guide today’s management decisions. A key challenge will be to implement management actions at landscape scales, especially in the eastern US where much of the forest area is in private ownership.

How to cite

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Recommended Reading

Melillo, J.M., T.C. Richmond, and G.W. Yohe (eds). Climate change impacts in the United States: The Third National Climate Assessment. US Global Change Research Program, 2014. http://nca2014.globalchange.gov/ Peterson, D.L, J.M. Vose, T. Patel-Weynard. Climate Change and United States Forests. Springer, 2014. Sample. V.A., R.P. Bixler. Forest conservation and management in the Anthropocene: Conference proceedings. USDA Forest Service Rocky Mountain Research Station, 2014. https://www.treesearch.fs.fed.us/pubs/46127 Shifley, S.R., K.W. Moser. Future forests of the northern United States. USDA Forest Service Northern Research Station, 2016. https://www.nrs.fs.fed.us/pubs/50448 Wear, D.N. and J.G. Greis. The Southern Forest Futures Project: technical report. USDA Forest Service Southern Research Station, 2014. https://www.srs.fs.usda.gov/futures/ Vose, J.M. and K.D. Klepzig. Climate Change Adaptation and Mitigation Management Options: A Guide for Natural Resource Managers in Southern Forest Ecosystems. CRC Press, 2016.

Related Links

Adaptive Silviculture for Climate Change is a large-scale collaboration between the USDA Forest Service, university and private partners to establish a series of experimental silviculture trials across US Forest types: https://cfri.colostate.edu/projects/adaptive-silviculture-for-climate-change/ Cal-Adapt, the state of California’s guide to climate change impacts and options for adaptation: http://beta.cal-adapt.org/ Climate Change Response Framework, a collaborative website of forest managers and scientists across the northeastern US, maintained by the Northern Institute of Applied Climate Science (NIACS): https://forestadaptation.org/ USGS

Climate and Land Use Change mission area website provides resources related to USGS studies and partners: https://www.usgs.gov/science/mission-areas/climate-and-land-use-change?qt-mission_areas_l2_landing_page_ta=0#qt-mission_areas_l2_landing_page_ta

Tools

Climate change model projections and data visualization tools are available here: https://www.data.gov/climate/portals/

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