COMMENTARY

Climate change and the aridification of North America

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Discussions of droughts and their impacts often center on the lack of precipitation, just as assessments of hydrologic impacts under a changing climate most often focus on how average precipitation in a given locale is likely to change in the future. Within climate science, however, focus has begun to include the growing role warming temperatures are playing as a potent driver of greater aridity: hotter climate extremes; drier soil conditions; more severe drought; and the impacts of hydrologic stress on rivers, forests, agriculture, and other systems. This shift in the hydrologic paradigm is most clear in the American Southwest, where declining flows in the region's two most important rivers, the Colorado (Fig. 1) and Rio Grande, have been attributed in part to increasing temperatures caused by human activities, most notably the burning of fossil fuels (1–5). Warmer summers are also likely to reduce flows in the Columbia River, as well as in rivers along the Sierra Nevada in California (6). Now, an important study (7) documents how warming is also causing flow declines in the northern Rocky Mountains and in the largest river basin in the United States, the Missouri. This work further highlights the mechanisms behind the temperature-driven river flow declines and places more focus on how anthropogenic climate warming is progressively increasing the risk of hot drought and more arid conditions across an expanding swath of the United States.

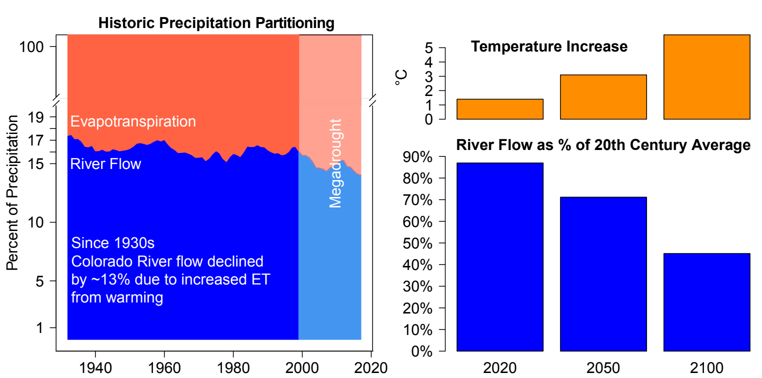

Fig. 1. Climate change is causing the Southwest to aridify. (*Left*) Since the 1930s, increasing temperatures have caused the percentage of precipitation going to evapotranspiration (ET) to increase at the expense of precipitation going to Colorado River flow, resulting in an unprecedented and still ongoing megadrought (shading) starting in 1999 (8). (*Right*) Higher temperatures have already reduced Colorado River flow by 13%, and projected additional warming, assuming continued high emissions of greenhouse gases, will increase ET while reducing river flow even more through the 21st century. Data on *Left* are 20-y running means from ref. 5, and data on *Right* are calculated from Representative Concentration Pathways (RCP) 8.5 multimodel Coupled Model Intercomparison Project–Phase 5 (CMIP5) ensemble temperature increases projected for the Upper Colorado River Basin combined with temperature sensitivity of −9.3%/°C estimated by ref. 5, assuming no change in precipitation.

The work by Martin et al. (7) on the temperature-driven flow reductions in the Upper Missouri River has broader implications. As they note, many aspects of river management could be increasingly impacted by a more arid river basin, including agricultural water deliveries, river management and navigation, and ecosystem services associated with the river; economies of a large region will likely suffer if the aridification continues. This mirrors the change occurring in the Southwest, where rivers provide the only large sustainable water supply to the region and more than 40 million water users, yet flows have already declined significantly since just the late 20th century (3, 4). Across the US West, warming is also contributing to drier soils (8), widespread tree death (9), and more severe wildfires (10). The recent unprecedented drought conditions in California also have been tied to human-caused warming (11). Greater aridity is redefining the West in many ways, and the costs to human and natural systems will only increase as we let the warming continue.

Martin et al. (7) also highlight how increasing temperature-driven aridity is more often framed in the West in terms of episodic drought. Just as in the Southwest, where an unprecedented drought began in 1999 and has continued through 2020 with drier-than-normal soils, reduced river flows, and low levels in major reservoirs, the worst drought of the instrumental era gripped the Upper Missouri River Basin

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between 2000 and 2010. This drought framing is also common among many water and land managers, as well as the public, and implicitly assumes an end to arid conditions must come with the return of rain and snow. However, anthropogenic climate change calls this assumption into question because we now know with high confidence that continued emissions of greenhouse gases into the atmosphere guarantee continued warming and that this continued warming makes more widespread, prolonged, and severe dry spells and drought almost a sure bet. This translates into an increasingly arid Southwest and West, with progressively lower river flows, drier landscapes, higher forest mortality, and more severe and widespread wildfires—not year on year, but instead a clear longer-term trend toward greater aridification, a trend that only climate action can stop.

In the West, declining river flows and soil moisture, as well as more severe wildfires and drought, are now a matter of record. The search for "why" starts with the increasing moisture-holding capacity of the atmosphere. As the atmosphere has warmed, the amount of water vapor in the atmosphere has gone up, consistent with the Clausius–Clapeyron relationship [about 7%/°C (12)]. This, in turn, has increased the demand for moisture by the atmosphere from the land surface and water bodies. Whereas the latter translates to increased evaporation, the former takes place primarily via greater evapotranspiration from soils and vegetation (2, 13). Soils dry out in a straightforward manner understood by anyone gardening on a hot day, and they dry out faster the warmer it gets. Plants also lose more water to a hotter atmosphere through the small pores (stomata) in their leaves. Although plant physiologists have postulated that increased concentrations of carbon dioxide in the atmosphere help plants keep these pores less open and thus retain water, evidence now suggests that this water efficiency gain is often more than offset by greater plant growth owing to the same carbon dioxide increases (14). It makes sense that longer growing seasons enabled by warming temperatures mean more total evapotranspiration, drier soils, and reduced river flows.

Martin et al. (7) showcase additional processes likely implicated in the observed aridification in the West. Warming is leading to more rain, rather than snow; a reduction in snowpack; and thus a reduction in surface reflectivity (albedo), further increasing warming, evaporation, and evapotranspiration (5). Others have focused on yet more ways warming can reduce river flows and soil moisture. Once there is too little water in soil and vegetation to continue evapotranspiration, solar radiation has a bigger warming impact on the atmosphere—the cooling effect of evaporation can no longer do its job, and excess heat can accumulate in ways that amplify the warming and the drying impact of the warming (15).

The impact of warming on the West's river flows, soils, and forests is now unequivocal. Will higher precipitation save the day? It is true that precipitation is increasing in many regions outside the Southwest, but as in the past, there will always be dry spells and droughts throughout the West and across the High Plains, as well as in eastern North America (16). Importantly, during these dry periods, some lasting just weeks in the summer and some lasting years like the High Plains "Dust Bowl" drought of the 1930s, the full impact of warming temperatures will be fully felt without the relief of increased rainfall. The net result of these more frequent and severe hot–dry events translates into a climate that can manifest increasing aridity and extreme event impacts, particularly in summer, even if the mean annual climate paradoxically becomes wetter in response to anthropogenic climate change.

Increasing aridity is already a clear trend in the West, but greater aridity is also expanding its reach eastward with continued warming. Recent exceptional "flash droughts" in 2012 and 2017 on the High Plains of the United States and Canada, as well as the Dust Bowl drought of the 1930s, highlight how extreme spring and summer temperatures can speed the onset, and worsen the impact, of dry spells and droughts (17, 18). Climate change farther east, in the Midwest, also means that summer dry spells will tend not only to become hotter but also to lengthen (19). It is no surprise that irrigated agriculture is expanding eastward in response to climate warming. Perhaps most troubling is the growing co-occurrence of hot and dry summer conditions and the likely expansion, absent climate change action, of these hot–dry extremes all of the way to the East Coast of North America, north deep into Canada, and south into Mexico (20). It is no surprise that the boreal forest of Canada is starting to show a substantial increase in wildfire and a related net increase in carbon emissions to the atmosphere (21).

Other parts of North America likely will not see the widespread aridification and decadal to multidecadal droughts of the West, but will nonetheless continue to see more frequent and severe arid events—extreme dry spells, flash droughts, and interannual droughts will become part of the new normal.

"Aridity" means many things to many people, but at its core it means extreme dryness of the kind that can have serious impacts on humans and the natural systems upon which they depend. Climate change, and in particular warming, will continue as long as humans burn fossil fuels or otherwise increase the concentrations of greenhouse gases in the atmosphere. This is known with high scientific confidence and means that the warming that is already driving an increase in aridity in many parts of North America is sure to continue and expand geographically until climate warming ceases. In the southwest United States and adjacent Mexico, the implications are dire for water security and ecosystems. More severe extreme heatwaves and dust storms are also already occurring, and these and other impacts of aridity will only increase until the cause is halted. Across North America, greater aridity is being offset with increased groundwater use, but this strategy has limits in the many places, such as the Southwest and the High Plains, where groundwater use exceeds recharge and is thus unsustainable (22).

Other parts of North America likely will not see the widespread aridification and decadal to multidecadal droughts of the West, but will nonetheless continue to see more frequent and severe arid events—extreme dry spells, flash droughts, and interannual droughts will become part of the new normal. Even in many places where mean annual precipitation is increasing, there will be an increase in aridity and the deleterious impacts that come with this increase. The good news is that we know the cause of expanding aridification. Unfortunately, climate change and this aridification are likely irreversible on human timescales (23), so the sooner emissions of greenhouse gases to the atmosphere are eliminated, the sooner the aridification of North America will stop getting worse.

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