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Effects of climate change on hydrology and water resources in the Blue Mountains, Oregon, USA

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ABSTRACT

In the semi-arid environment of the Blue Mountains, Oregon (USA), water is a critical resource for both ecosystems and human uses and will be affected by climate change in both the near- and long-term. Warmer temperatures will reduce snowpack and snow-dominated watersheds will transition to mixed rain and snow, while mixed rain and snow dominated watersheds will shift towards rain dominated. This will result in high flows occurring more commonly in late autumn and winter rather than spring, and lower low flows in summer, phenomena that may already be occurring in the Pacific Northwest. Higher peak flows are expected to increase the frequency and magnitude of flooding, which may increase erosion and scouring of the streambed and concurrent risks to roads, culverts, and bridges. Mapping of projected peak flow changes near roads gives an opportunity to mitigate these potential risks. Diminished snowpack and low summer flows are expected to cause a reduction in water supply for aquatic ecosystems, agriculture, municipal consumption, and livestock grazing, although this effect will not be as prominent in areas with substantial amounts of groundwater. Advanced planning could help reduce conflict among water users. Responding pro-actively to climate risks by improving current management practices, like road design and water management as highlighted here, may be among the most efficient and effective methods for adaptation.

Practical Implications

Water is a particularly valuable resource in the relatively dry landscapes of the Blue Mountains region, Oregon (USA). Most of that water is sourced from high-elevation public lands, specifically the Malheur, Umatilla, and Wallowa-Whitman National Forests. Snowpack, which is the key to downstream water supply during the summer, may already be decreasing in response to a warmer climate and will continue to decrease in future decades. This will inevitably affect ecological processes and human enterprises in the region.

A higher rain:snow ratio in the Blue Mountains is expected to cause higher peak streamflows in late autumn and winter, leading to increased frequency and magnitude of flooding downstream. This will have the potential to damage roads, especially in and near floodplains, and associated infrastructure such as culverts and bridges. Refitting this infrastructure for more severe conditions will create a financial burden for the U.S. Forest Service, other public agencies, and private landowners. Increase flooding may also reduce access for recreational activities and resource management, possibly for long periods of time. If damage is high enough, it will require a prioritization of roads that can be maintained within a sustainable transportation system, and perhaps the permanent closure of some roads.

Reduced snowpack and earlier snowmelt will reduce hydrologic recharge of both surface and subsurface flows in spring and summer. This will lead to lower streamflows in summer in both rivers and smaller streams, creating adverse conditions for coldwater fish species and other aquatic

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organisms. It will also reduce water supply for agriculture, municipal uses (drinking water), industrial uses, livestock grazing, and recreation. Reduced water supply will be an especially important issue when multiple consecutive drought years decrease water available for both aquatic ecosystems and downstream human uses.

Currently, water allocation is mostly satisfactory in the Blue Mountains region, and conflicts are occasional and localized. However, competition among different users may become acute during future drought periods, and if low water supply becomes a chronic situation, social and political solutions may be needed to resolve conflicts. Finding a balance in the near term among water allocated for ecological functions, local communities, and economic benefits will help forestall those conflicts.

1. Introduction

Water is a critical resource in arid and semi-arid forest and rangeland environments of western North America, typically limiting the distribution of plant and animal species. Water is also a critical element for human activities, affecting where and how human communities and local economies persist across the landscape (Hartter et al., 2018). The Blue Mountains of northeast Oregon and southeast Washington, most of which are located within federal land, are the primary water source for human uses, which include agriculture, drinking water, industrial uses, livestock grazing, and recreation.

Climate change is expected to alter hydrologic processes in the Pacific Northwest region of North America, thereby affecting key resources and processes including water supply, infrastructure, aquatic habitat, and access. A warmer climate will affect the amount, timing, and type of precipitation, and the timing and rate of snowmelt (Luce et al., 2012, 2013; Safeeq et al., 2013), which will in turn affect snowpack volume (Hamlet et al., 2005; Luce et al., 2014a), streamflow (Hidalgo et al., 2009; Elsner et al., 2010; Hamlet et al., 2013), and stream temperature (Isaak et al., 2012; Luce et al., 2014b; Mantua et al. 2010). Altered precipitation patterns would also affect vegetation (Kerns et al., 2018), which would in turn affect water supply (Adams et al., 2012, Vose et al., 2016).

Federal lands dominate the headwaters of the major basins in the Blue Mountains Ecoregion (Fig. 1). Understanding how climate change will affect hydrologic processes will help federal land managers and their many partners identify planning and management strategies that maintain ecosystem function, water supply, and a sustainable road system (Peterson and Halofsky, 2018). Reduced or less reliable water supply affects local economic activities, planning, and resource management. Anticipatory planning can reduce conflicts and improve economic and ecological outcomes during droughts. Damage to roads, bridges, and culverts creates safety hazards, affects aquatic resources, and incurs high repair costs. Reduced access to public lands reduces the ability of land managers to preserve, protect, and restore resources and to provide for public use of resources. Designing a less vulnerable road network would again protect both ecological and economic interests.

Here we describe hydrologic processes in the Blue Mountains of Oregon, historical trends in hydrologic parameters (snowpack, peak streamflow, low streamflow, and stream temperatures), and projected effects of climate change on these hydrologic parameters. We also identify and map key sensitivities of water supply, roads, and infrastructure to changes in climate and hydrology.

2. Effects of climate change on hydrologic processes

2.1. Methods

Hydrologic simulations of streamflow were prepared using the Variable Infiltration Capacity (VIC) model (Liang et al., 1994) to simulate streamflow driven by downscaled forcing data from global circulation models (GCMs) that have contributed to the Intergovernmental Panel on Climate Change AR4 (CMIP3) assessment (Elsner et al., 2010; IPCC, 2007). VIC projections were prepared from an ensemble of 10 GCM models using A1B emission scenarios and having the best match with observations in the historical period (Littell et al., 2011). Projections for the “2040s” cover an average from 2030 to 2059, and the “2080s” cover 2070 to 2099. Historical metrics were based on the period 1977 through 1997 (Wenger et al., 2010). VIC data were computed on a 1/16th-degree (~6 km) grid to produce daily flow data that were further routed downstream and analyzed for metrics important to aquatic ecology (Wenger et al., 2010, 2011). VIC outputs were further processed with a linear groundwater reservoir routing algorithm using the calibrated recession coefficient values of Safeeq et al. (2014) to estimate impacts to low flows, which are sensitive to groundwater dynamics.

To assess changes in snowpack, we used the model of Luce et al. (2014a), who evaluated snow sensitivity to climate at Snowpack Telemetry (SNOTEL) sites in the Pacific Northwest, developing projections for April 1 snow water equivalent (SWE) for a scenario of 3 °C warmer than the last 20 years. Validation of the model shows that it is suitable to assess climate change effects (Lute and Luce, 2017).

Stream temperature changes were projected using the The NorWeST Regional Stream Temperature Database (http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html). NorWeST uses extensive stream temperature observations and spatial statistical models to characterize and project stream temperatures in the Blue Mountains (Isaak et al., 2015, Isaak et al., this issue). Future stream temperatures were projected based on historical conditions, model projections of future climate, and assessments of past sensitivity to climate.

2.2. Effects of climate change on snowpack

The role of snow in watershed runoff in the Pacific Northwest is determined to a great extent by mid-winter temperatures (Hamlet and Lettenmaier, 2007). Rain-dominated basins are above freezing most of the time in winter, and snow accumulation is minimal (< 10% of October-March precipitation). These basins typically have peak streamflows in winter, coinciding with peak precipitation, but may have multiple peaks associated with individual rain events. Mixed rain and snow (or transitional) basins collect substantial snowpack (10–40% of October-March precipitation), and are typically slightly below freezing in mid-winter. These basins have multiple seasonal streamflow peaks. Snow-dominated basins are cold in winter, capturing > 40% of October-March precipitation as snow and have low flows through winter, often with streamflow peaks in spring. The Blue Mountain region has all three types of basins.

Over the last 50 years, increasing temperatures in the Pacific Northwest have caused earlier snowmelt (Stewart et al., 2005; Hamlet et al., 2007), and lower spring snowpack (Mote, 2003; Hamlet et al., 2005; Mote et al., 2005). Snowpack is expected to be particularly sensitive to future temperature increases, facilitating a change from snowmelt-dominant to transitional basins, and from transitional to rain-dominant basins (Tohver et al., 2014).

Decreases in snowpack persistence and April 1 SWE will be widespread in the Blue Mountains, with the largest decreases in low to mid-elevation locations. Large areas of the ecoregion are likely to lose significant portions of April 1 SWE by the 2080s (Fig. 2). Snowpack sensitivity will be relatively high even in some of the locally higher elevation ranges such as the Strawberry Mountains, Monument Rock