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Spatial and temporal changes in runoff caused by climate change in a complex large river basin in Oregon

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SUMMARY

We estimated potential changes in annual, seasonal, and high and low runoff and associated uncertainty in the 218 sub-basins of the Willamette River basin of Oregon for the 2040s and the 2080s. The US Geological Survey's Precipitation–Runoff Modeling System (PRMS) was calibrated and validated for representative river basins between 1973 and 2006. A regionalization method and GIS analysis determined the PRMS model parameters for ungauged basins. We used a combination of eight general circulation models (GCMs) and two emission scenarios downscaled to 1/16° resolution to estimate spatial and temporal changes in future runoff at a sub-basin scale. The seasonal variability of runoff is projected to increase consistently with increases in winter flow and decreases in summer flow. These trends are amplified under the A1B emission scenario by the end of the 21st century with increases in top 5% flow and decreases in 7-day low flow. The ratio of snow water equivalent to precipitation declined consistently throughout the basins extending into the Cascade Range. The center timing of runoff, the day when half of the water-year flow has passed, is projected to occur earlier in the water year. Snowmelt-dominated basins exhibit large reductions in summer flow in response to increased temperature, while rainfall-dominated basins show large increases in winter flow in response to precipitation change. The spatial and temporal variability of runoff may increase in the future, but the direction and magnitude of these changes depend on sub-basin characteristics such as elevation and geology. Streams flowing from High Cascade basins that contain a large component of groundwater are projected to sustain summer flows, although the uncertainty associated with future projections is high. The main source of uncertainty stems from GCM structure rather than emission scenarios or hydrologic model parameters, but the hydrologic model parameter uncertainty for projecting summer runoff and 7-day low flow is relatively high for Western Cascade basins.

1. Introduction

Climate change resulting from increasing anthropogenic greenhouse gas concentrations in the atmosphere is likely to shift the spatial and temporal distribution of water resources in river basins throughout the 21st century (Kundzewicz et al., 2007). Because the capacity of the air to hold water vapor increases exponentially in a warming climate, water can be recycled at an accelerated rate (Huntington, 2006), potentially causing more frequent extreme hydrologic events. As precipitation variability increases and air temperature rises, water stored in multiple reservoirs can move at different rates and amounts at different times in the hydrologic cycle. These spatial and temporal changes in runoff regime will potentially threaten the sustainability of existing water use practices in regions traditionally considered as "water-rich", including the Pacific Northwest (PNW) of North America Barnett et al. (2005).

In mountain watersheds located in humid temperate climates, climate change may result in more frequent winter flooding and summer droughts. This is due to the fact that a higher amount of winter rainfall is expected and warmer temperatures will result in early snowmelt. Barnett et al. (2008), for example, using the 50 year record of observed flow, showed that water availability has already declined in Colorado, Columbia and Sierra river basins, the three largest river basins in the western United States. Luce and Holden (2009), in a study of 43 weather stations in the PNW, reported that 72% show significant declines in the 25th percent annual flow. At a finer geographical scale, Graves and Chang (2007) showed that 1 April snow water equivalent declined significantly in a mountain watershed of the PNW of USA between 1948 and 2000. Similar findings have been reported elsewhere. In a study of nine Irish catchments, Steele-Dunne et al. (2008) found that the seasonal cycle of runoff would be amplified across the country with increased winter precipitation, decreased summer precipitation,

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and increased summer temperature. Snowpack is projected to decline up to 78% at 1500 m elevation in a Spanish mountain watershed (Lopez-Moreno et al., 2009).

The changes in flow characteristics resulting from climate change depend on individual catchment characteristics. In particular, basin geology and elevation are first order controls on the timing and magnitude of basin runoff to climate change. If a drainage basin is located in a low elevation and is dominated by rainfall, runoff change is more controlled by changes in precipitation than temperature, while basins located in high elevations with snowmelt-dominated regimes are highly sensitive to temperature changes (Loukas et al., 2002; Hamlet and Lettenmaier, 2007). Another important factor is the geology of the basin. Basins in which a significant proportion of the streamflow comes from groundwater may be less sensitive to changes in climate. This has been demonstrated by a comparative modeling study in Oregon's Cascade Range between one basin that has a large component of groundwater and another basin that is runoff dominated (Tague et al., 2008).

Understanding changes in spatial and temporal variations of runoff in a spatially-explicit way is important for water resource management in a large river basin. In most large river basins, river flow is typically regulated for flood control and supplying different water uses, including municipal use, irrigation, hydropower generation, and aquatic wildlife. In a changing climate, water resource managers simply cannot rely on past statistics of runoff (Milly et al., 2008). This paper contributes to the scientific understanding of changing hydrology in a large river basin and offers baseline information for adaptive water resource management in a changing climate. While a few previous studies investigated potential impacts of climate change on runoff in sub-basins of the Lower Willamette River (e.g. Graves and Chang, 2007; Franczyk and Chang, 2009; Chang et al., 2010; Praskievicz and Chang, in press) and the Upper Willamette River (Tague and Grant, 2004; Jefferson et al., 2008; Tague et al., 2008; Tague and Grant, 2009), no previous studies examined the spatial and temporal changes of runoff for the entire basin with a suite of multiple climate change scenarios. Additionally, no previous climate change impact studies quantified various sources of uncertainties. Using multiple climate change scenarios is useful for identifying a range of possible runoff changes and quantifying uncertainties stemming from various

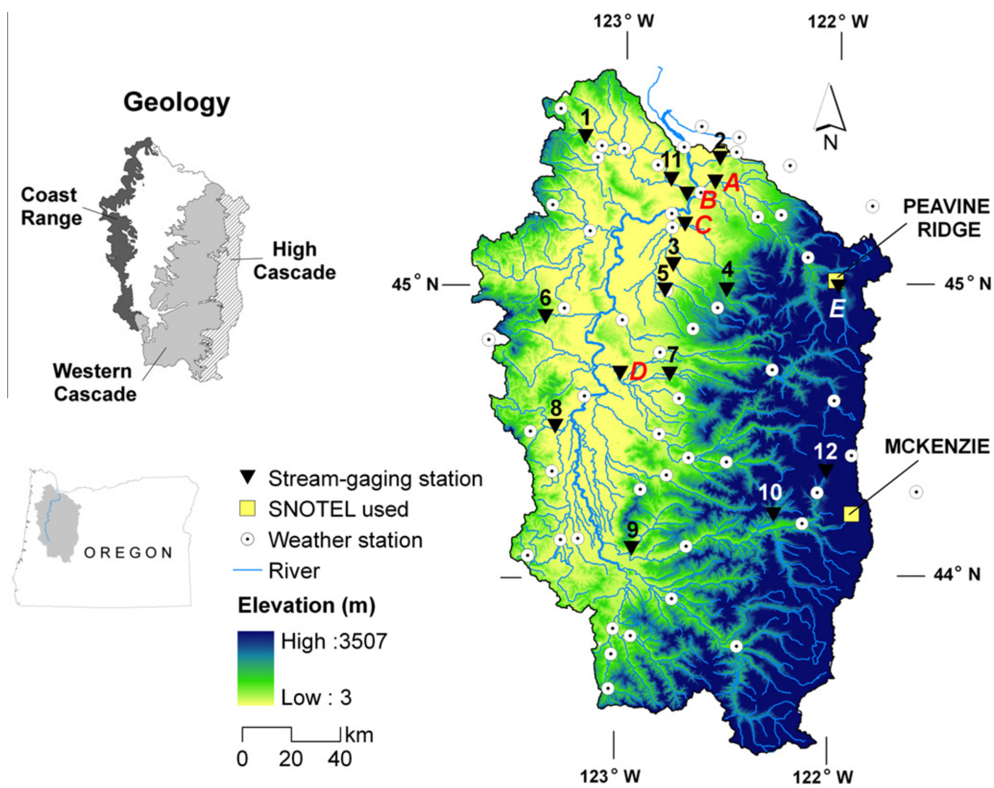

Fig. 1. Willamette River basin, Oregon, the basin boundary, rivers, weather stations (circle), flow stations (down-pointing triangle), and SNOTEL station (rectangular). Letter symbols indicate stations used for testing the regionalization method in Table 5.

Table 1
Datasets used in this study.

Datasets		Format	Resolution	Source
Climate	Daily precipitation	.txt	Point	NOAA COOP (2009)
	Monthly mean precipitation	Raster	800 m	OCS (2009)
	Daily maximum and minimum temperature	.txt	Point	NOAA COOP (2009)
Snow	Daily snow water equivalent	.txt	Point	NRCS SNOTEL (2009)
Hydrology	Daily mean flow	.txt	Point	USGS NWIS (2009)
Topography	Digital Elevation Model (DEM)	Raster	30 m	USGS Seamless (2009)
	Soil map	Shapefile	Vary	NRCS (1986)
	Land cover	Shapefile	Vary	USGS Seamless (2009)
	Geology	Shapefile	Vary	McFarland (1983)