Hydrologic and ecologic impacts of climate change in the Grande Ronde River Basin

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ABSTRACT

A key component of the River Continuum Concept, which conceptualizes a riverine ecosystem as a continuous gradient from headwaters to mouth, is the physical template, including climate and hydrologic regime. The Grande Ronde River basin in northeastern Oregon is characterized by snowfed streams from the Wallowa Mountains in the southern part of the basin and from the Blue mountains in the north and west. Precipitation as snowfall in the colder months (January through May) melts during the springtime, resulting in peak flows in the spring and low flows around September. There is little precipitation during the hotter summer months. The climate is expected to change, however, resulting in an altered hydrologic regime. Predictions indicate a general increase in temperature in the Pacific Northwest over the next few decades, consistent with past observations. While precipitation is generally predicted to rise in the Pacific Northwest, it has in fact decreased in the Grande Ronde region over the past few decades. Climate change is predicted to result in reduced snow water equivalent, earlier peak flows, higher colder month flows, and lower warm month flows. Both changes in climate and the hydrologic regime will change vegetation patterns, which further affects the local water cycle. These changes will alter the physical template upon which the biological community depends, but will not alter the underlying assumptions of the River Continuum Concept.

INTRODUCTION

The River Continuum Concept proposes that changes in riverine ecosystems along a rivers longitudinal direction can be represented as a gradient driven by gradients in the physical environment including, among other things, climate and hydrologic regime (Vannote et al. 1980). Thus, it is important to understand the relationship between climate, hydrology, and biotic communities along rivers.

A significant change in global climate has been observed over the past century and is predicted to continue to change, affecting hydrologic functioning globally and in the Pacific

Northwest in particular (Hamlet 2006). But what exactly those changes will be and what the effects of the changes on ecosystem behavior are not well known. The goal of this paper is to examine the nexus of climate, hydrology, and the River Continuum Concept (RCC) by identifying the major geomorphological characteristics of the Grande Ronde River basin, describing the climatic and hydrologic regime of the basin, assessing the effects of climate change on the hydrologic regime, and discussing how these those climate change driven alterations within the basin fit within the RCC.

GRANDE RONDE CLIMATE & HYDROLOGY

Before discussing climate change and its observed and predicted effects, it is important to describe the geologic setting of the Grande Ronde River basin and its general hydrographic and hydrologic characteristics.

Basin landscape morphology and hydrography

Dominant geological features defining the network structure of and affecting water quantity (described in more detail below) in the Grande Ronde basin include the Blue Mountains, which rise to greater than 7,710 ft, to the north and east of the basin, the Wallowa Mountains, greater than 10,000 ft, to the south, and the lower canyons in the central/eastern area of the basin (Fig. 1). The Columbia River basalts are a feature of the Columbia River basin in general, and define to a large extent the landscape morphologic characteristics of the river network patterns in the area, especially in the lower elevations canyon valleys (Nowak 2004). Caldwell (2007, this volume) discusses regional geologic features in detail.

The mountainous topography defines the hydrography of the area. Generally, the Upper Grande Ronde River originates as snowmelt in the Blue Mountains to the west, while the Catherine Creek and Wallowa River and western tributaries originate in the Wallowa Mountains to the south. In the Lower Grande Ronde, the Wenaha River descends from the northern section of the Blue Mountains, Joseph Creek drains the low mountains east of the Wallowa Mountains, and the smaller canyon tributaries drain the lower exposed Columbia River Basalts closer to the Lower Grande Ronde (Nowak 2004).

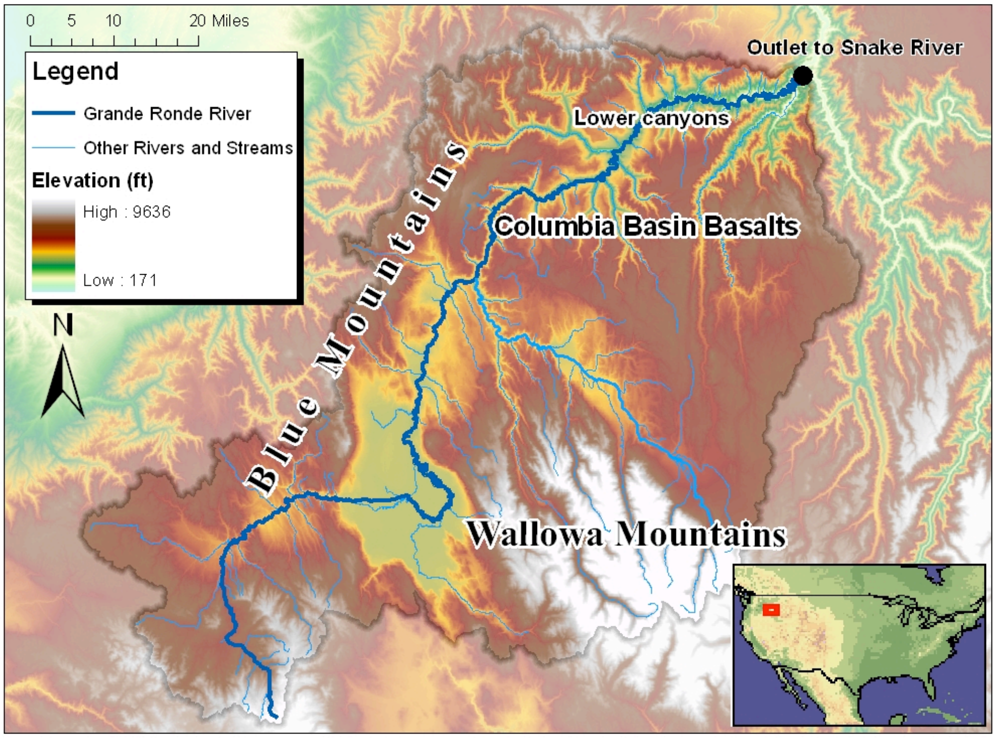


Figure 1: Grande Ronde River basin elevation map showing dominant landscape morphology and hydrography.

Basin climate and hydrology

Herein, the climate and hydrologic characteristics of the Grande Ronde River Basin are described. The temporal scale of discussion is limited to the average monthly flows (over a year or more). Fissekis (2007, this volume) discusses finer scale hydrologic characteristics of importance such as magnitude, frequency, duration, timing, and rate of change of streamflow.

Basic climate and hydrology

Climate in the Grande Ronde basin and eastern Washington and Oregon as a whole is affected to a large degree by the Cascade Mountains to the west, where much of the moisture of the Pacific Ocean air is lost to orographic precipitation (i.e. precipitation that occurs when moving air is forced upward—and consequently cooled—by mountains), resulting in relatively dry air east of the Cascades. Much of the precipitation in the Grande Ronde falls as snow in the higher elevations of the Blue and Wallowa Mountains during the colder winter months, again due to orographic precipitation. Precipitation generally increases by about 5 in per 1,000 ft rise in elevation in the Grande Ronde area (Nowak 2004). Temperatures, meanwhile, follow typical mid-latitude patterns, with an average low temperature of 25 °F in January and an average high of 84 °F in July.

As a result of these geologic features (as they influence meteorological conditions) and climatic patterns, river flows in the Lower Grande Ronde peak around April and May and are at their lowest in August through October (Nowak 2004). Figure 2 shows this historical pattern of cold month precipitation (primarily snow) followed by increased runoff as snowmelt as the ambient air temperature increases. Note Figure 2 shows monthly average precipitation only; actual precipitation varies significantly from day-to-day and year-to-year. Here, temperature is a proxy indicator of other incoming energy sources, such as solar radiation, which collectively melt snow.

Precipitation

Most precipitation in both the Grande Ronde and Columbia River basins occurs in the form of snow during the colder months and in the higher elevations. Figure 3 shows modeled snow water equivalent (SWE), or the amount of liquid water frozen as snow, for April 1, 2006 (April 1 SWE is a standard surrogate measurement of total snow-season precipitation (Bohr and Aguado 2001)) in the Grande Ronde region. Generally, peak snow occurs in the area around February at the lower elevations (e.g. around La Grande) with a continued increase of snow in the higher elevations of the Blue and Wallowa Mountains through March. It is this snow that, when melted during the spring and summer months and combined with the less significant spring rains, contributes the bulk of water to the Grande Ronde tributaries.

The domination of snow-fed streams in the Grande Ronde Basin results in two significant characteristics of the Grande Ronde River mainstem and the network as a whole. First, the snow acts as the flow regulator, resulting in the annual hydrograph shown in Figure 2. The snow acts as a storage mechanism, holding a significant proportion of the precipitation in the area during the winter and releasing it later in the year as it melts. Second, the snow acts as a temperature regulator. Because the tributaries are supplied by snowmelt, they are consistently cold in their headwaters. Periods of high snowmelt result in a large supply of water that has not had a chance to warm significantly.

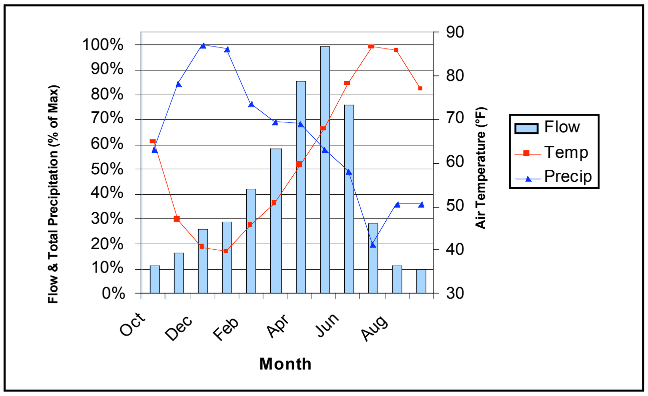


Figure 2. Mean monthly Grande Ronde River flow at Troy, OR (1945-2006) and mean monthly temperature at La Grande, OR (1961-1990) (USGS 2007, WRCC 2007).

By late June, most of the snow in the Blue Mountains has melted and by late July little is left in the Wallowa Mountains. From about late-July to mid-December there is little new supply of snow-fed direct runoff, and little precipitation. This is significant especially during the hot summer months of July and August when air temperature and solar radiation are high causing what little flow there is to heat quickly to temperatures that adversely affect migrating fish (*Hersh-Burdick 2007, this volume*). This snow-fed system also has important implications when considering the hydrologic effects of climate change, as discussed below.

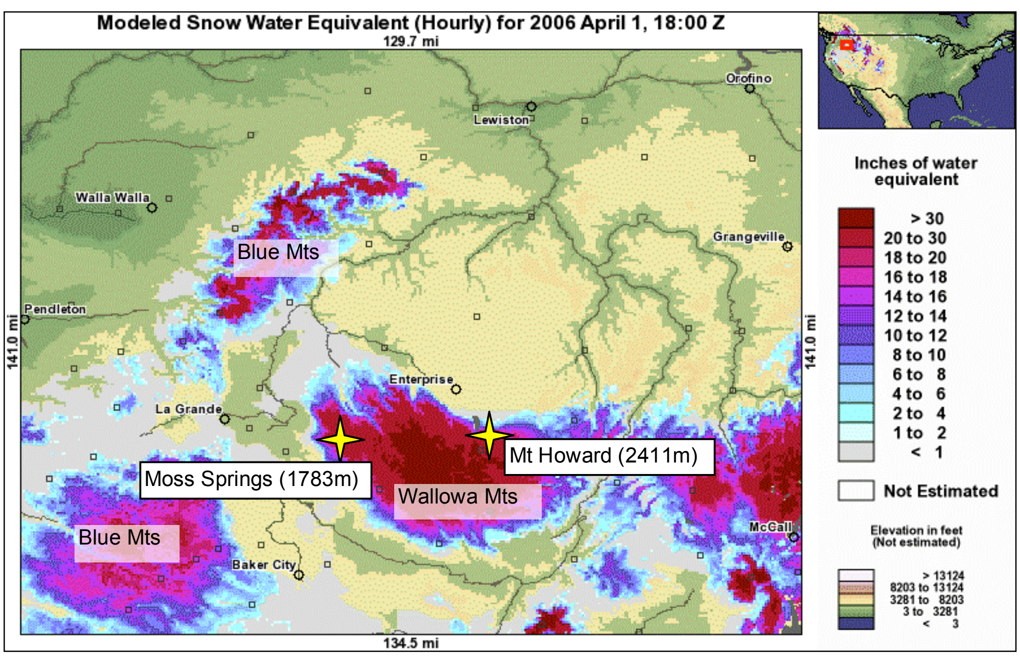


Figure 3. Snow water equivalent, April 1, 2006, Wallowa and Blue Mountains (NOHRSC 2007).

Runoff

Although flows from the basin as a whole peak around May, i.e. downstream of Wenaha River (USGS 2007), there is significant variety in flow patterns amongst the streams. On average, the Upper Grande Ronde River peak annual flows occur around March/April, Catherine Creek around May/June, and Wallowa River around late May/June (Nowak 2004). The differences in peak occurrence amongst streams is due primarily to their different lengths and elevation levels—higher streams will come from snow melting later in the year. These peak occurrences are predicted to—and have been observed to—change with global climate change, as discussed below.

Groundwater

Groundwater in western mountainous watersheds such as that of the Grande Ronde is supplied by rainfall and by snowmelt (Earman and Dettinger 2006). The water pressure and its flow rate varies throughout the Grande Ronde region, depending on the underlying geologic features of the area. Both confined and unconfined aquifers are found there, with the water table of the unconfined regions at or just above the nearest surface flow channel. Wells in unconfined aquifers generally need to go to 2 to 15 feet for water while confined aquifers have been observed to produce about 100 feet of pressure. The water tables of the unconfined aquifers roughly mimic the shape of the overlying ground surface, more closely nearer to the streams (Hampton and Brown 1964). Significantly, groundwater feeds water to the baseflow of the streams and rivers, in the form of detectable coldwater seeps useful for fish during times of warm ambient stream temperatures (Ebersole et al. 2003). It is important to note that the amount of rainfall that infiltrates becomes groundwater depends not only on both the underlying soil and rock types and existing saturation conditions, but also on the surface vegetation through a variety of mechanisms (Dingman 2002). Changes to the surface vegetation regime will therefore change the amount and timing of groundwater flow.

CLIMATE CHANGE

The effects of climate change on various components of the ecosystem are somewhat difficult to predict. This is in part because climate change itself is difficult to predict but also because the relationships between climate, hydrology, and the ecosystem are complex and not fully understood (CUAHSI 2007). Climate variability and change in the Pacific Northwest are presented below, followed by a discussion of the potential impacts of climate change on the hydrologic regime in the Columbia and Grande Ronde River basins. The impact of climate change on biota is discussed in general terms.

Climate Change Predictions

Climate in the Pacific Northwest is heterogeneous at smaller spatiotemporal scales, but generally follows the same trends in inter-annual climate variation. Year-to-year and decade-to-decade climate variability is strongly influenced by global-scale El Niño/Southern Oscillation (ENSO) and by the more local Pacific Decadal Oscillation (PDO), respectively. In addition, the Pacific Northwest is impacted by longer temporal changes in global climate patterns (climate change) such as the global warming that has been occurring over the past century and longer (Mote et al. 2003).

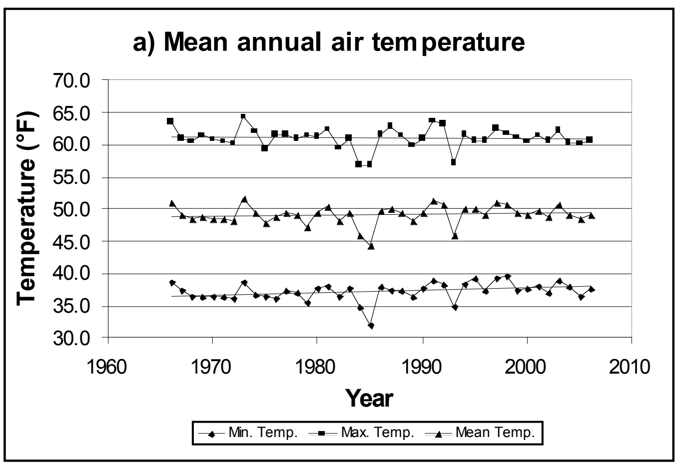
Climate models generally—and with a fairly high degree of certainty—predict warmer global temperatures, on average, over the next half century or so. Specifically, temperatures in the Pacific Northwest are expected to rise by about 3.6-5.4 °F (2-3 °C) (Mote et al. 2003, Payne et al. 2004). Although predictions for precipitation changes are much less certain than those for temperature change, the models, on average, predict increased precipitation during the cooler months of October through March and possibly slightly increased precipitation during the warmer months from the 1900s to the 2040s. These model predictions, shown in Table 1, are discussed in detail by Mote et al. (2003).

	Temperature change	Precipitation change	
	Annual	Oct–Mar	Apr–Sep
2020s			
Low	0.5 °C (HadCM3)	+2% (PCM)	–4% (HadCM3)
Average	1.5 °C	+8%	+4%
High	2.6 °C (CCSR)	+18% (HadCM2)	+14% (HadCM2)
2040s			
Low	1.5 °C (PCM)	–2% (ECHAM4)	–7% (ECHAM4)
Average	2.3 °C	+9%	+2%
High	3.2 °C (CCSR)	+22% (CGCM1)	+9% (CSIRO)

Table 1. Changes in Pacific Northwest climate from eight climate models (Mote et al. 2003).

How do these climate change predictions compare with observed trends? Records show a distinct increase in annual mean minimum temperature, a slight increase in annual mean temperature, and very little change in annual mean maximum temperature at La Grande (Fig. 4a). This small but detectable change is consistent with both the temperature change predictions and the certainty in those predictions noted above.

McIntosh et al. (1994) note a decrease of 15-20% in monthly precipitation from 1904 to 1988 in La Grande, in contrast to predictions of increased precipitation in the Pacific Northwest. Figure 4b shows that trend for calendar years 1966 through 2006. Thus, the greater uncertainty in modeled precipitation change is demonstrated by the observed decrease in precipitation at La Grande. It should be noted that predictions about precipitation for mountains in the Pacific Northwest are general; there are likely to be deviations from the predictions at least in part due to local microclimate influences.



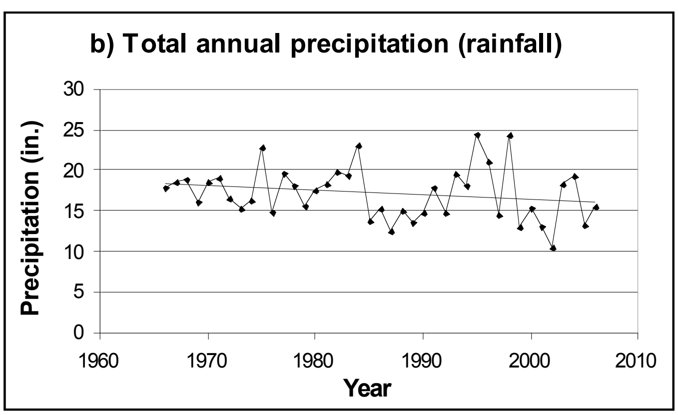


Figure 4. Observed mean annual air temperature (a) and total annual precipitation (b) at La Grande (2756 ft) 1966-2006 (National Climatic Data Center 2007).

Climate Change Impacts

Two pathways of climate change impact on the local hydrologic regime (and, implicitly, on the ecosystems depending on that regime) are discussed here. First are those pathways directly affecting the water cycle. This includes, for example, higher temperatures causing less snow. (Globally, documented changes over the past century cover all aspects of the hydrologic cycle: cloud cover, precipitation, snow, glaciers, evapotranspiration, streamflow, and sea level. Dingman 2002, e.g.) Second are those of the ecosystems response to climate change, and the resulting impact of a changed ecosystem on the hydrologic regime. Both of these pathways are discussed below.

Direct pathways and effects

From a purely Newtonian point of view, where vegetation is seen as somewhat passive with respect to the transitioning of water from one phase and location to another, the hydrologic effects of climate change on the Columbia River basin, including the Grande Ronde River basin, are fairly straight forward. Hydrologic simulations using the modeled precipitation and temperature results show a decrease in moderate-elevation snowpack (measured as snow water equivalent), such as that in the Blue Mountains and Wallowa Mountains in northeast Oregon and southeast Washington (Hamlet et al. 2005). Because snowpack serves to store water and release it as runoff later in the year, the combination of increased precipitation and reduced snowpack would result in a general shift in peak annual runoff to earlier in the year. Since snow acts as a flood control mechanism, slowing the release of water from single storm events, one impact of increased temperatures and the resultant decreased snow would be greater immediate runoff following precipitation events. All else being equal, this would result in greater earlier springtime flooding and will in all cases mean a greater rate of change in event-induced streamflow. To summarize, climate change induced hydrologic impacts are predicted to be:

- reduced snow water equivalent (SWE),
- increased winter flows (runoff),
- reduced summer flows, and
- earlier peak streamflows (Mote et al. 2003, Hamlet et al. 2005).

Again it is important to compare these predictions to observations. Figure 5 shows a general decrease in April 1 SWE (1955-2006) and average annual SWE (1981-2006) at Moss

Springs, located 5850 ft high in the windward (western) Wallowa Mountains (see Fig. 3). This is consistent with the general 25% decrease in snowpack as reported by McIntosh et al. (2004) from 1938 to 1990, although not as dramatic. For comparison, April 1 and annual average SWE at Mt. Howard (7910 ft high), on the leeward (eastern) Wallowa Mountains is also included in Figure 5. The Mt. Howard April 1 SWE actually displays a slight increasing trend over its 26-year record (1981-2006). Annual averages show little change. It is important to recall that total SWE is expected to decrease less at higher elevations. Further, because of the great variability compared with the short period of record, the increasing trend is less meaningful than that for Moss Springs, with the longer period of record. It is also interesting to note that Moss Springs gets more snow even though it is lower in elevation than Mt. Howard. This is due to the fact that it is on the windward side of the Wallowa Mountains and is thus subject to more orographic precipitation.

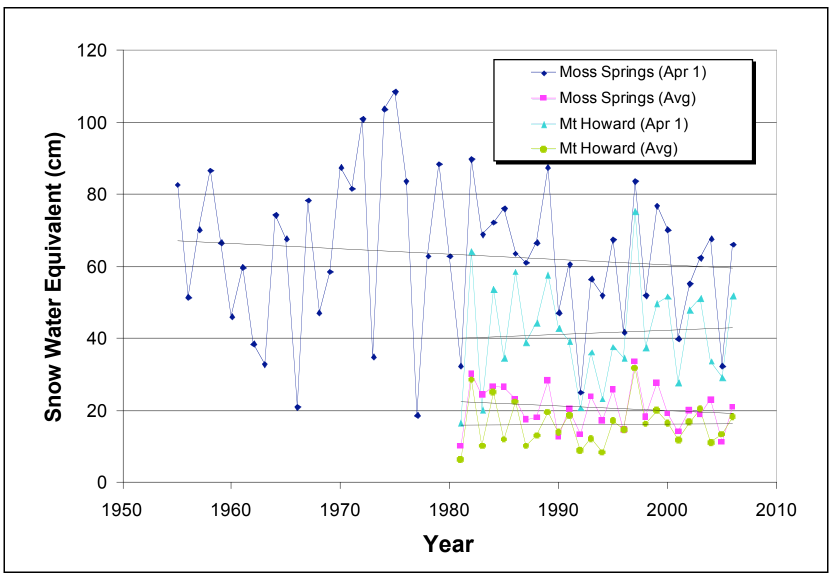


Figure 5. Snow Water Equivalent (SWE) west (windward) and east (leeward) of the Wallowa Mountains at Moss Springs (west, 1783m) and Mt Howard (east, 2411m), eastern Oregon. (Natural Resources Conservation Service 2007).

For flow changes, McIntosh et al. (1994) report that from 1904 to 1990 the base flow of the Upper Grande Ronde River (Blue Mountains) nearly doubled at La Grande while that of Catherine Creek (Wallowa Mountains) increased by about one quarter from 1926 to 1990. Both of these streams are relatively undisturbed by withdrawals (McIntosh et al. 1994). Analysis of USGS streamflow records for the Minam River (Fig. 6), which flows relatively undisturbed directly from the Wallowa Mountains, shows consistent trends. Figure 6 shows a clear increase in flow rates for the month of April and a slightly decreasing trend for September from water years 1966 through 2006.

McIntosh et al. (1994) further highlight a shift in timing of peak annual flow about one month earlier from 1904 to 1989. Again, this is consistent with observations from 1966 through 2006 when both peak flow (discharge) and flow center of mass of the Minam River flow tended toward earlier annual occurrence (Fig. 7)

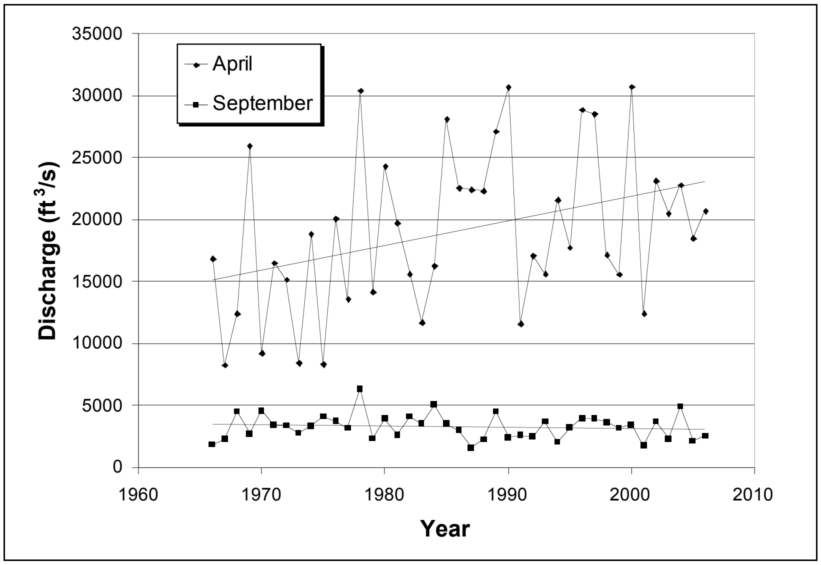


Figure 6. April and September average Minam River discharge, Water Years 1966- 2006 (USGS 2007).

While these observations serve as useful indicators of the validity of modeled predictions, the observed shifts in trends are not necessarily due to global warming-induced climate change alone. Other impacts on the basin hydrologic regime include changed evapotranspiration, infiltration, runoff, and sublimation rates due to, for example, loss of vegetation from timber harvests or grazing, and other human landscape modifications (McIntosh et al. 1994). A full analysis of human-induced hydrologic regime change other than that of climate change is provided by Fissekis (2007, this volume).

In addition to quantitative aspects of flow, climate also directly impacts water quality, temperature in particular. A warming trend will cause a significant increase in surface water temperatures, especially during projected reduced summer flows, causing impacts on aquatic species, especially in the downstream reaches, farther away from colder headwaters (Eaton and

Scheller 1996, Ebersole et al. 2003). Stream temperature is discussed in more detail by Hersh-Burdick (2007, this volume).

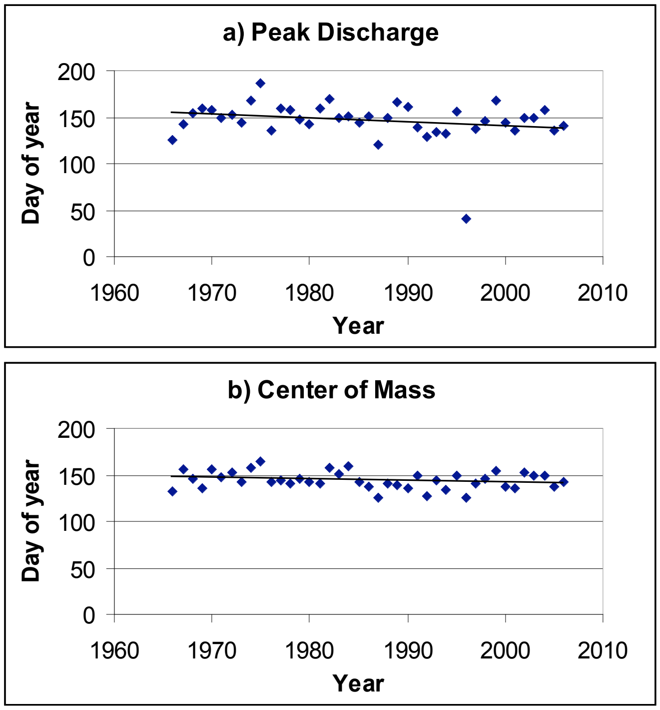


Figure 7. Peak discharge (a) and discharge center of mass (b) occurrence of the Minam River (USGS 2007)

Indirect pathways and effects

Vegetation is not passive, but rather plays an active role in the hydrologic regime by regulating to a large degree soil moisture, evaporation, transpiration, groundwater recharge, runoff (Dingman 2002, Rodriguez-Iturbe and Porporato 2004), and snow accumulation, sublimation, and melting rates (Greene et al. 1999). The sensitivity of riparian biotic communities to climate change would thus affect the hydrologic regulation role of an ecosystem. Changes in vegetative cover due to changed climate would impact all of these hydrologic processes, affecting the amount, timing, and routing of water as it travels toward, away from, or through stream drainage networks.

Nowak (2004) notes how the climatic characteristics of the Grande Ronde Basin strongly impact the basin's ecosystem structure and dynamics. The lower elevations toward the confluence with the Snake River tend to be warmer and drier, whereas the higher elevations are generally colder and wetter, causing a "progression of upland vegetation communities from shrub-steppe through ponderosa pine and grasslands to mixed conifer forests". The floral structure then influences the fauna of the area. Mote et al. (2003) discuss the effect of a changing climate on forested regions in the Pacific Northwest, emphasizing the fact that forests respond dynamically to climatic conditions in both direct and indirect ways, ultimately resulting in not only a change in overall forest health but also a change in the upper and lower elevation limits of forest existence. These vegetation distribution patterns within a river basin are thus controlled by climatic and conditions and patterns within the basin, which, in turn, are controlled partly by the landform characteristics of the basin.

The shifted vegetation patterns noted above will have an effect on the surface and subsurface hydrologic regime of the area. To what extent that regime has been altered by land cover changes due to climate change alone is not clear (although could become clear with further analysis and study of the region). Hydrologic effects of anthropogenic modifications of land cover is explored by Lawson (2007, this volume).

Climate change, hydrology, and the River Continuum Concept

The River Continuum Concept as proposed by Vannote et al. (1980) emphasizes, inter alia, the importance of the "gradient of physical factors formed by the drainage network…" when considering aquatic biological community dynamics and that "the physical structure coupled with the hydrologic cycle form a templet [sic] for biological responses…". In other words, aquatic biological communities change along a river's longitudinal course due to changing energy inputs from headwaters to the mouth which, in turn, is caused by changing riparian vegetation makeup and hydrogeomorphologic gradients (Vannote et al. 1980). Thus, continually changing riparian vegetation and hydrologic patterns are primary inputs to the RCC and a thorough understanding of what influences these patterns is needed to inform an explanation of the RCC (or other hypotheses explaining spatiotemporal structure and dynamics of aquatic and/or riparian ecosystems).

Given that climate contributes significantly both directly and indirectly via the climate-influenced hydrologic regime on regional riverine ecosystem structure and dynamics, what role does climate and climate change play in the RCC? Elevation has a significant impact on climatic conditions at any given location, influencing at the very least air temperature and precipitation, which, directly and indirectly, are energy inputs to the system. Since stream networks by definition decrease in elevation in their drainage directions (i.e. the flow downstream), it follows that those components of the riverine ecosystem dependent on those gradient-like climatic energy inputs would support the RCC on the scale that it considers.

While longitudinal gradients in riparian vegetation along a river from the headwaters to the mouth are observed, there are many causes of those longitudinal patterns. For example, riparian vegetation patterns have been considered as a flow of genetic information (Manlanson 1993) and as being influenced by, for example, past changes in sea level, channel gradient, valley constraint, geomorphic processes, fire regimes, and so on (Naiman et al. 2005), rather than simply based solely on a predictable cascade of energy inputs upon which the RCC is predicated and which is more relevant in the instream environment. As mentioned previously, regional climatic conditions and local hydrologic regime are defined in large part by both regional geologic structure and composition, as well as other factors such as riparian vegetation itself. Geologic structure significantly impacts both microclimatic conditions and hydrologic regime (due to, for example, dependence of infiltration and groundwater flow on surface and subsurface soil structure) (Dingman 2002). Thus, only some aspects of climate can help explain shifts in longitudinal gradation of riparian ecosystems.

Climate change is not likely to change the validity of the RCC, where the RCC is applicable. That is not to say, however, that aquatic or terrestrial biological communities will not be stressed—possibly to the point of species extinction—by changes in their environment caused by climate change. Changes in climate will alter the spatiotemporal distribution of energy inputs and dynamics. These changes may cause a shift in communities, as some members of the community are able to more readily adapt to changed environmental and community composition conditions, but the general principles behind the RCC—including the opposing tendencies of communities to achieve spatial equilibrium and their desire to maximize energy usage efficiency in a longitudinal gradation of energy inputs—are still valid, given climate change will simply shift the existing climatic energy contributions (including affected hydrologic inputs) rather than cause any major disruption.

CONCLUSION

It is clear that climate change will include an increase in temperature and possibly an increase in precipitation in the Pacific Northwest. These changes will impact the region in a variety of ways. In particular, it will reduce winter snowpack in areas such as the Grande Ronde River basin resulting in earlier peak flows, although not necessarily greater peak flows. More importantly, though, these changes in climate will result in direct changes in the hydrologic regime in the area and indirect changes via changed vegetation patterns and those patterns' influences on the hydrologic regime. Ultimately, this will affect—most likely adversely—instream biological communities that have adapted to current hydrologic and biotic patterns. Earlier peak flows will result in lower and warmer flows when key species are already facing severe coldwater shortages.

What do these known and unknown changes mean to the future of the Grande Ronde River basin and the Columbia River basin as a whole? Will the aquatic biological communities crash or will they simply adapt as a whole with some species possibly disappearing altogether to have their role in the ecosystem either replaced or eliminated altogether? There are known engineered solutions to creating critical coldwater habitats, but will those be enough? Ironically, whereas major dams along the Lower Snake River and the Lower Columbia River are known to have significant adverse impacts on basin salmon populations, dams could possibly be built in the headwaters of the Grande Ronde Basin and other similar basins with the purpose of regulating stream flows solely for the aquatic ecosystems, serving the same function the snowpack does now.

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