Impacts of a Warming Climate on Water Availability in Snow Dominated Regions

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ABSTRACT

Predictions of future climate conditions in a greenhouse world are sometimes ignored because they are 'uncertain'. One common trait of all greenhouse predictions to date (warming of the near surface air temperature) has a profound negative impact on regional hydrology, particularly in snowmelt dominated environments: warmer air temperatures cause reductions in maximum snow accumulations, earlier melt, and hence earlier spring runoff. These impacts occur almost independently of changes in future precipitation. (These same simple physics will apply, at least in part, to the world's mountain glaciers and may partially explain why they are in retreat over most of the globe.) The model-predicted changes are already seen in the observed data. If maintained at current levels, these changes will lead to a serious reduction in dry season water availability in many regions of the Earth within the next few decades. The fact that all models predict a warming, and that warming is being observed now, suggests that mitigation strategies can be undertaken now with high confidence.

We present new results from a global land surface hydrology model that identifies the regions of the globe where snowmelt dominates the seasonal patterns of streamflow. In general, we find that snowmelt dominates those parts of the globe that are at latitudes greater than ~45 (North and South), with some exceptions for mountainous regions, regions that are warmed by oceans, and cold dry regions that experience little wintertime precipitation. The disappearance of the glaciers and snow pack reduction affect over one-sixth of the world's population. We also utilized a global data set of major reservoirs to identify regions where reservoir storage is large enough that timing shifts associated with earlier snowmelt are likely to be mitigated by reservoir storage. This is the case, for instance, in the U.S. Colorado River basin, but globally, only a relatively small part of the area identified as being hydrologically dominated by snowmelt would have global warming effects substantially mitigated by reservoirs. In total, we estimate that one-quarter of the global GDP is in areas that are susceptible to change in seasonal patterns of snowmelt.

1. Warming Effects on Runoff Regime

• Consider regions where runoff generation is snowmelt dominated (versus rainfall dominated). For the US Pacific Northwest, the hydrographs for each case look like those in Figure 1: flows peak in the spring/summer for snowmelt dominated basins; flows peak in the winter for rainfall dominated basins.

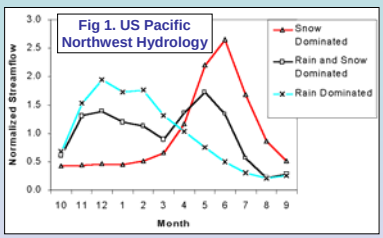


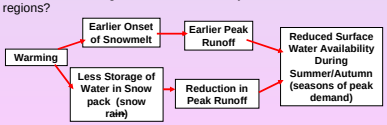
Fig 1. US Pacific Northwest Hydrology

• What do the climate models predict (IPCC, 2001)?

-consistent predictions of temperature increases: temperature changes mainly affect flow seasonality (timing)

-models are inconsistent regarding precipitation changes: these changes are thought to mainly affect annual volumes and not so much flow seasonality

• How does warming affect water availability in snowmelt dominated regions?



• There is a regime change, away from snowmelt dominated runoff (more winter/spring runoff, less summer/autumn runoff)

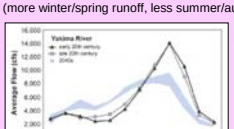


Fig 2. Shift of the hydrograph away from a snowmelt dominated regime

2. Global Distribution of Snowmelt-Dominated Runoff

We used a large-scale land surface hydrology model (the Variable Infiltration Capacity model, Liang et al. 1994) to identify the regions of the globe where snowmelt plays a dominant role in the seasonal patterns of streamflow. A grid cell (at ½° resolution) was included in this domain if the depth of snowfall it received per year was at least 50% of the depth of runoff generated in that grid cell per year (red lines in Figure 3). We also included grid cells in sub-basins downstream of snowmelt-dominated grid cells if at least 50% of the runoff generated in the entire sub-basin was generated in the snowmelt-dominated part of the sub-basin (black lines in Figure 3). These are the regions of the globe where streamflow seasonality is sensitive to warming and populations living there are likely to experience increased summer/autumn water shortages as warming continues. Basins for which the shift in the hydrograph is buffered by adequate reservoir storages are excluded from this domain (the Colorado, Churchill, Grand, and Angara Rivers).

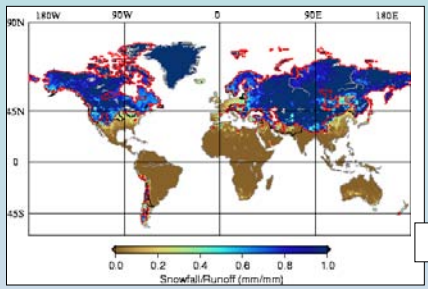


Fig 3. Snowfall ÷ Runoff ≥ 50%

Legend

{Snowfall÷Runoff ≥ 50%} – {Basins with large storage}

Basins with ≥ 50% Runoff Derived from Snowmelt-Dominated Regions

Generally, regions where runoff is snowmelt-dominated are at latitudes greater than ~45° (North and South) with exceptions, e.g. some mountainous regions at lower latitudes are snowmelt dominated (Figure 4).

Fig 4. Mountainous Regions

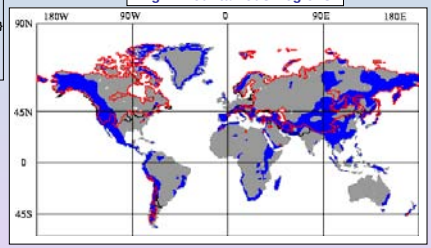
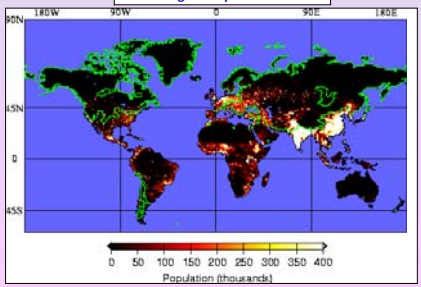
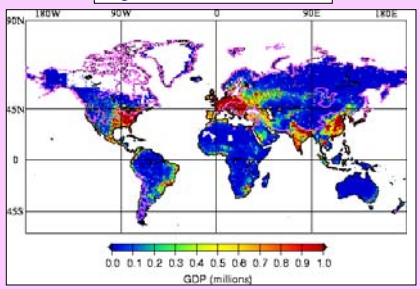


Fig 5. Population



According to a year 2000 population map (CIESIN, 2004), roughly one sixth of the world's population dwells within this combined snowmelt-dominated, low-reservoir-storage domain (Figure 5).

Fig 6. Gross Domestic Product



This domain encompasses much of the industrialized world, accounting for roughly one-quarter of the global gross domestic product (according to 1990 estimates; Figure 6).

3. Impacts on Water Resources

Example 1: Columbia River

By 2050, residents and industries will have to face a choice of water releases for summer and autumn hydroelectric power or spring and summer releases for salmon runs; with predicted climate change, the river cannot be managed to accommodate both (Payne et al. 2004).

Example 2: Rhine River

Implications include: a reduction in water availability for all users; an increase in the number of low-flow days (affecting shipping); and a decrease in annual hydropower generation in some parts of the basin (Middelkoop, 2001).

Example 3: Canadian Prairies

Agriculture will become more sensitive (as the frequency and severity of droughts increase), and increased water demand for irrigation will lead to heightened competition with other water needs (Gan, 2000; de Loë et al. 2001).

Fig 7. Low reservoir levels at Snow Lake, Washington, USA (September, 2005)

The same simple physics can also be applied to regions that rely on glacier melt for their water supply, except that even more serious problems may occur for these regions. This is because, once the glaciers have melted in a warmer world, there will be no replacement for the water they now provide, in contrast to the present snow pack-dependent water supply that is renewed seasonally. It is well documented that the glaciers are in retreat over most of the world (Thompson, 2003; Combes et al. 2004), so the threat is both real and immediate.

Fig 8. Recession of Grinnell Glacier, Glacier National Park (1911 and 2000)

CONCLUDING REMARKS

• The most robust and simplest of changes associated with global warming (a modest increase in near-surface air temperature) will be responsible for changes in streamflow seasonality over much of the globe. The model-predicted changes are already being seen in observed data.

• Without adequate water storage capacity, these changes will lead to a serious reduction in dry-season water availability in many regions of the Earth within the next few decades.

• Time is running out for nations in the sensitive areas we have evaluated, particularly those whose water supplies are dependent on glacier-melt, to understand how their water supplies will be affected by warming and to initiate strategic planning.

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