Climanosco Research Articles

Collection 1, Launch challenge

A new way to quickly estimate climate change impacts on rivers and streams

By Julie A. Vano and Meghan M. Dalton, 19 July 2016

RESEARCH ARTICLE

We outline a new method that offers quick insights into how the amount of water in rivers and streams will be impacted by warmer temperatures and future precipitation change. This method yields comparable results to more conventional model-intense climate change impact studies and is faster and cheaper to implement, making it a practical alternative for those exploring future water supply changes in places with limited computational access. Using rivers and streams in the Pacific Northwest of North America as an example, we share what this new method can (and cannot) do, and highlight the steps one could take to quickly begin exploring how climate change could impact their water supply.

Why develop a new approach?

Climate change, through rising temperatures and changes in precipitation, will change where and when water is available for ecosystems and human communities. Understanding what these changes might be at a local, river basin scale is valuable for planning purposes. For example, people who manage reservoirs in the Yakima River basin in the state of Washington, USA, need to know how much water to expect in the rivers in each season so they can decide how much water they need to store and when to release it throughout the year to avoid both floods (too much water) and water shortages (too little water). These water managers, like many throughout the world, are being asked to find a delicate balance between water supply, which comes as rain and snow, with increasing water demands for growing food, letting fish swim, and enabling growing communities to prosper. As such, to prepare for the future, we need to better understand how climate change may alter where, when, and how much water is in our rivers and streams.

Estimating how the amount of water flowing in a river or stream will change in the future is often time-consuming and expensive, limiting its usefulness to those with adequate resources. Conventional approaches typically begin with information on spatial scales larger than 150 km as provided by global climate models. To make that information more locally relevant, it is converted to information on spatial scales of 5 km through extensive use of statistics and multiple, linked computer simulations of the world's climate system and water cycle. Whenever new information from global climate models becomes available, the first link of the model chain changes, and the whole chain of computer simulations needs to be redone.

A quick, new method developed by [J. A. Vano et al., 2015] addresses these challenges by providing an inexpensive, yet comparable estimate of the nature of future changes, without having to run the time-consuming chain of models used in the conventional approach. This new approach, termed the "seasonal sensitivity approach", begins by first understanding the sensitivity of streams and rivers to temperature and precipitation change. It then uses these sensitivities to characterize changes across the landscape and provide estimations of the amount of water in a river according to what global climate models project for future climate in the region. This quick estimate of future change can give resource managers important context and aid decisions on how further investigations of climate change impacts should proceed. [J. A. Vano et al., 2015] demonstrate this approach in a data-rich environment, where the approach could be adequately tested. Importantly, however, these tests show potential for the approach to also be useful in places in the world that have less data and resources.

Where should this approach be used?

The seasonal sensitivity approach was developed in the Pacific Northwest of North America, with a focus on five diverse locations, including the Yakima River. This region depends heavily on mountain snow accumulation to determine when and how much water is available to use in each season. Each year the amount of water in streams or rivers, which we refer to as streamflow, is much bigger (on average, three times more) than the amount of space available to store water in man-made reservoirs. Therefore, any change in when the water arrives can have serious implications on water management. As such, it is important to understand the impact of climate change on streamflow in each month throughout the year. This approach is well suited to the challenge of understanding seasonal change and is particularly helpful in locations where the ability to store water is small relative to the total amount of water that flows in the river or stream throughout the year.

Other locations can store a larger portion of their annual streamflow, and therefore may be less concerned with seasonal changes. For example, the Colorado River basin can store over four times the total amount of water on average that flows in the river throughout the year. In places like this another approach such as the one outlined in [J. A. Vano and D. P. Lettenmaier, 2014] may be more useful.

What does the approach provide?

The seasonal sensitivity approach identifies locations more likely to experience changes in seasonal water availability because of warming temperatures and precipitation changes. It does this through:

Sensitivity Maps

Maps of seasonal sensitivities indicate locations that are more or less sensitive to changes in temperature and precipitation in both the warm (April to September) and cool (October to March) seasons. Most notably, in the Pacific Northwest, intermediate elevation river basins (1500-2500 m), which is the elevation range in the Yakima River, are the most sensitive to changes in cool season temperatures. Warmer temperatures at these elevations during the cool season result in more rain than snow and snow that melts earlier in the year. This increases streamflow in the cool season and subsequently reduces streamflow in the warm season.

Lower and higher elevation locations are less sensitive to warming than intermediate elevation locations, but for different reasons. Lower elevation locations are less sensitive because cool season temperatures are warm enough such that most of their precipitation already falls as rain instead of snow. In contrast, higher elevation locations are less sensitive because cool season temperatures are cold enough that the same amount of warming applied to intermediate elevation locations does not change the snowfall to rainfall and snow is still able to persist. Said in Goldilocks terms, temperatures of intermediate elevation locations in the Pacific Northwest are neither too hot nor too cold, but are at just the right temperature to be noticeably affected by modest temperature increases, especially in the cool season.

Short-cut Streamflow Estimates

While sensitivities to simple temperature and precipitation perturbations can help us identify places most vulnerable to future change, managers really want to know how streamflow is projected to change under future climate conditions. By using both sensitivities from hydrologic models and projected temperature and precipitation changes from global climate models, we can quickly calculate short-cut estimates of future monthly streamflow for 30-year average time periods (e.g., from 2030–2059).

Comparisons of future streamflow changes between the quick, efficient seasonal sensitivity approach and the computationally intense conventional approach done by [A. F. Hamlet et al., 2010]) were strikingly similar for a variety of different locations (see [J. A. Vano et al., 2015] for direct comparisons). For example, in the Yakima River, both approaches showed us that streamflow, which currently peaks in the late spring from melting snow, is going to increase in the wintertime and subsequently decrease in the spring and summer. This shift to more water in the river earlier in the year is problematic because this water system depends on late-spring snow melt to refill reservoirs for summertime irrigation. To avoid summertime water stress, water managers and planners in the basin now know they must find ways to manage the water without relying on melt from late-season snowpack.

The seasonal sensitivity approach works best when: (1) sensitivities to small changes are proportional to sensitivities to larger changes (referred to here as the principle of linearity), and (2) when changes in individual seasons added together equal the amount of change seen when a change is applied throughout the year (referred to here as the principle of superposition). When tested, these two principles applied to most locations and seasons throughout the Pacific Northwest, and thus we have increased confidence the seasonal sensitivity approach can provide quick estimates of how the region's rivers and streams will be impacted by climate change, without having to do the more involved conventional approach.

What does the approach not provide?

The seasonal sensitivity approach provides an overview of likely long-term average changes (for example, 30-year averages) on a monthly or seasonal basis. While it can be an inexpensive alternative to other more resource intensive approaches, it does not provide the same level of detail. For example, it *does not* provide daily or monthly streamflow sequences. The approach is intended to capture the nature of changes in *seasonality*, not absolute streamflow amount, especially in summer and when temperature increases are large.

The seasonal sensitivity approach is not appropriate in places where sensitivities depend on the size of the applied change in temperature or precipitation (i.e., violates the principle of linearity) or where the additive effects of changes in temperature and precipitation during each season are not equal to the effects of temperature and precipitation changes applied year round (i.e., violates the principle of superposition). These principles should be tested before implementing this method. If tests for linearity and superposition identify locations where assumptions are not appropriate, estimations of future change require more careful consideration. However, all is not lost. Instead, these tests have identified locations where something interesting is happening and more understanding of the underlying physical processes may be quite valuable.

How does it work?

Below is a step-by-step guide that highlights how the method works. We intend these steps to simply illustrate what is involved. To see five examples in the Pacific Northwest and more specifics on how to implement this in your region, please refer to [J. A. Vano et al., 2015].

Step 1. *Obtain simulated historical streamflow:*
Run a hydrologic model to estimate how water flows through a river basin, simulating weather (e.g., temperature and precipitation), basin-specific characteristics (e.g., topography, soil, and vegetation types), and important physical processes (e.g., evaporation of water to the atmosphere and infiltration of water into the soil).

Step 2. *Obtain simulated streamflow with an annual temperature perturbation:*
Run the same hydrologic model again, keeping everything the same as in Step 1 except increase the temperature every day of the year by 0.1°C.

Step 3. *Compute annual temperature sensitivities:*
Compare the streamflow generated in Step 1 and Step 2. Calculate how much streamflow changes per °C increase in temperature. This value is the annual temperature sensitivity.

Step 4. *Compute seasonal temperature sensitivities:*
Repeat Steps 2 and 3, but change the temperature only in the cool season (October to March) or only in the warm season (April to September), or only in the fall, winter, spring, and summer. These values are seasonal temperature sensitivities.

Step 5. *Compute precipitation sensitivities:*
Repeat Steps 2, 3, and 4 but instead of changing temperature, change precipitation by 1% and calculate how much streamflow changes per % increase in precipitation. These are values of precipitation sensitivities.

Step 6. *Estimate future monthly streamflow:*
Multiply temperature and precipitation sensitivities, calculated for each month using perturbations done in the four seasons (48 values for temperature, 48 values for precipitation) by the seasonal temperature and precipitation changes that come from the global climate models. This calculation, applied to monthly historical streamflow values, will give approximate values of future monthly streamflow.

Take home message

How the amount of water in rivers and streams will respond to climate change depends on many factors, including the season, a river basin’s elevation, vegetation, soil, and changes in temperature and precipitation. We have outlined an approach that provides a relatively quick way to account for these factors in understanding what future changes in streamflow might be, both spatially and, on average, in every month throughout the year. This approach provides reasonable first-order estimates, when compared with more conventional approaches, of future streamflow change in a diversity of rivers in the Pacific Northwest, demonstrating a technique that could be employed in rivers throughout the world.

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