Modelling water resource allocation and scarcity in the American northwest

Increasing population, urbanisation and agricultural demands are taking a toll on the availability of water. Coupled with the effects climate change, this issue of water scarcity is becoming an ever-increasing concern. **Dr Alejandro Flores** of Boise State University employs integrative biophysical and social models to evaluate the factors that govern water availability and usage. This approach has also been applied to potential climatic scenarios in order to predict water availability.

Population growth and climate change influence the availability of water for domestic and agricultural uses. This is particularly important in semi-arid environments and areas with extensive and developed infrastructure requiring water. Predicting changes in the availability of this precious commodity requires models which integrate biophysical and human decision-making processes. This has the potential to highlight areas particularly susceptible to water scarcity, and develop solutions to best mitigate this problem.

PARCHED LANDS

Dr Flores' research primarily centres around the Treasure Valley region in Southwest Idaho. Covering 3323 km^2 it is the state's most populous region and consequently one where water use is most intensive and changing. Treasure Valley is home to 1700 km of constructed canals which provide water for agriculture through irrigation. Farmland makes up 40% of the total landscape of Treasure Valley and is thus a major sector in consumption of water. The climate is semi-arid with Msediterranean weather patterning consisting of hot dry summers and cooler wet winters. The historical prosperity of this region derives from its successful irrigation system which distributes snow melt water throughout the dry summer when most crops are grown.

> **Dr Flores highlights the urgency for much more efficient forms of agricultural irrigation, or the consideration of options like water banking and water markets**

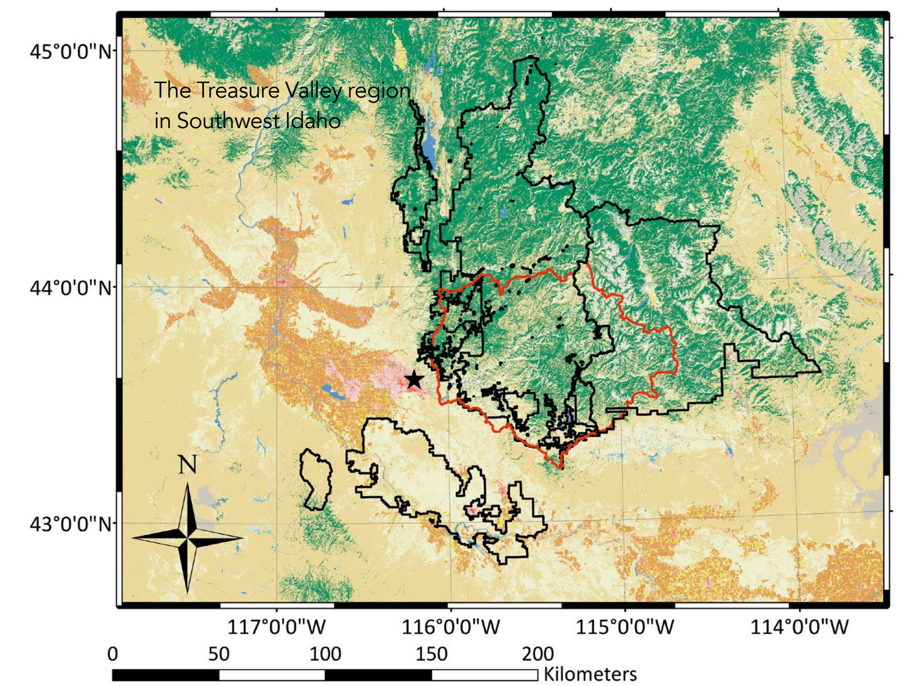
However, the region's booming urban population coupled with climate change means that the potential for conflict between competing uses and scarcity of water is becoming a bigger concern. This extensive irrigation network must be heavily utilised during hot summers when precipitation is at its lowest and climate change threatens the efficacy of this system. As snow melts ever earlier each year, reservoirs risk flooding downstream cities and managers must release water that would ordinarily be stored earlier than is desirable from the farmers' perspective. Come late summer, what water is left is not sufficient to meet the demands. Furthermore, the source regions for this water supply are the expansive and iconic public lands of the American West that the federal government is entrusted to manage for many, sometimes competing interests.

THREE DUSTY VISIONS

To understand the severity of this situation, Dr Flores' team processed historical data through a set of statistical weather models and GCMs (Global Circulation Models) to project three potential climatic scenarios for the area. These three scenarios reflect increasingly severe climates, defined by varying levels of greenhouse gases (GHG) in the atmosphere. He then examined how the irrigation system would be affected using a water use model 'Envision' which assessed available water, water demand for each location, water rights, evapotranspiration (evaporation plus transpiration), snow melting and runoff by the year 2100.

The benefits to Dr Flores' novel approach are numerous. Most importantly by integrating stochastic weather generators (statistical models that aim at quickly sim- ulating realistic random sequences of atmospheric variables such as temperature, pre- cipitation and wind) with multiple GCMs, he avoids discrepancies between individual GCMs and can generate a large ensemble of climate data on a daily time-scale. A hydrological analysis of these projected scenarios using the 'Envision' framework provides a contextual glimpse into the future performance of Treasure Valley's water governance system. For stakeholders, water management and farmers, this kind of information is gold dust.

Dr Flores found that scenarios with consistently higher temperatures were associated with an increased demand of water for irrigation, due to higher demands for water by crops. However, the amount that can be correspondingly allocated to irrigation in the region is constrained by the legal framework that allocates water to a broad range of water uses. Ultimately by 2100, the southwest region of Treasure Valley would suffer severe water scarcity because the farmers there, per that legal framework, are among the first to have their water use curtailed as reservoir storage is depleted. But what about precipitation? Unfortunately, the wettest season does not align with the irrigation season, and much of this water is stored in reservoirs. Moreover, much of the water diverted for irrigation is ultimately lost to leakage from that dendritic network canals and ditches that feed the agricultural fields. More reliance is weighted on the snow packs in the mountains above the Treasure Valley, which melt in spring-time, and are a natural water reservoir.



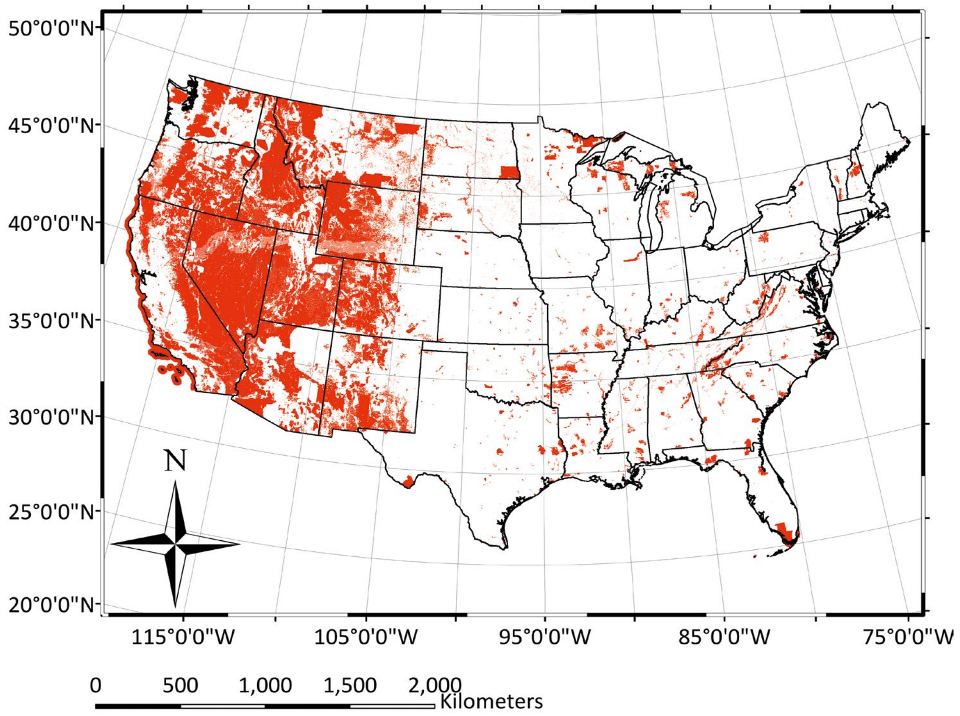
In a suite of complementary investigations, projections heavily suggested that snow pack melting would occur significantly earlier by the year 2100. To avoid flooding, water would have to be released from reservoirs around 14 days earlier (the warmest projections suggest up to a month earlier), potentially resulting in scarcity towards the end of summer. This earlier melt coupled with the increased water demand from the atmosphere brought by climate change (a warm atmosphere can hold more water, putting stress on plants and crops to extract more water from the soil) and further population increases that will drive up uses of water for domestic uses (including irrigating water-hungry turf grass) during this time, will only further intensify water conflict. Dr Flores highlights the urgency for much more efficient forms of agricultural irrigation, or the consideration of options like water banking and water markets, prompting him to look deeper into social solutions for a potentially contentious future.

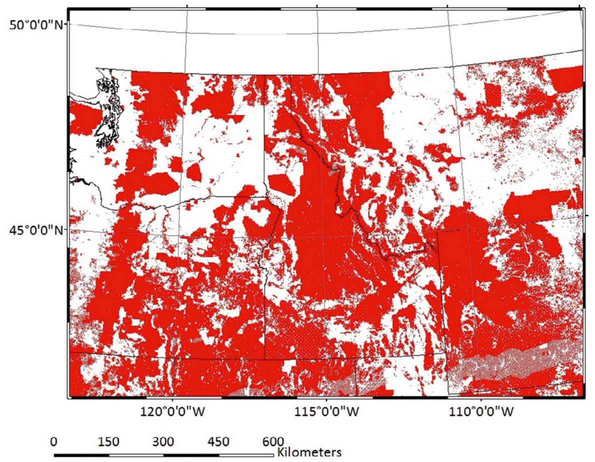
A RIGHT FOR WATER

Aside from physical constraints, the allocation of water of is primarily based on legally defined water rights which are determined by priority of beneficial use. In this scenario, historical use of water defines priority of usage, ultimately affecting the current-day availability of water for irrigation, in conjunction with physical processes such as basin-scale water availability and evaporative demand. To date, few studies have fully integrated water rights into a model which assesses the redistribution of water.

A 2017 study by Flores and colleagues sought to develop a model which represents the allocation of water for irrigation in a more accurate way. Using the same Envision integrated modelling platform, Dr Flores specifically integrates the social constraint of water rights in order to further understand the spatial distribution of irrigation waters for agricultural use in the Boise River of the Treasure Valley region. The model created was calibrated and validated against historical observations of streamflow in the Boise River and diversion into major canals.

The study revealed that the water allocated to agricultural areas matched that prescribed by water rights as well as areas of water scarcity and the associated causes for this. For instance, the downstream region of the Treasure Valley (where water rights tend to be more junior) tended to experience higher water scarcity. But because the amount of water during the period of study was relatively abundant, Dr Flores and his colleagues deduced that water scarcity was mainly due to the water rights framework. This gives some optimism that, even under future scenarios of climate change, there is some capacity of the water management framework to adapt to prevent and mitigate potential conflicts between water users. Findings like these have now provided avenues for policy makers and stakeholders to make important decisions about water management. Furthermore, this model can be extended to evaluate the inevitable future social and climatic changes this region will experience, allowing more efficient implementation of changes in water resource management when (and where) necessary, as well as a more integrative vision for managing the public lands that serve as natural "water towers" for downstream populations.





Above: Dr Flores' study area, like much of the western United States, is a region of striking contrast in vegetation cover. Forested mountains give way to dry valleys and plains where only shrubs and grasses can grow naturally. But humans have significantly modified these landscapes to support irrigated agriculture and other development.

Left: Most of the land in the western United States is publicly owned and serves as a critical source region for water for agriculture and populations in otherwise dry areas.

BETTER MODELS, BETTER SOLUTIONS

Predictive modelling like that being done by Dr Flores and colleagues opens many avenues to address future challenges to sustainability. For example, technological innovations in the agricultural and renewable energy realms are more deeply coupling food, energy, and water (FEW) systems. By modelling the impacts of these innovations on FEW systems, Dr Flores can assess how they potentially disrupt coupled FEW systems and lead to unanticipated consequences that might prove problematic. For example, pumped storage hydroelectricity (PSH) is an emerging way to store energy from renewable sources like wind and solar, without the problematic issues associated with batteries. But installing PSH presumably requires procuring water rights, which would most likely come from purchasing some farmland that would then be fallowed. The overarching necessity when studying these complex systems is to integrate across previously isolated fields to form dynamic, cross-sector socio-ecological systems approaches and models that efficiently traverse the human-environmental boundary.

For Dr Flores, this work is ongoing. The continuous refinement, adaptation and application of these models to new and old data is essential to advance our understanding of the way humans and their environment are linked. Through further research, Dr Flores is developing the theory and practice of applying these predictive models to problems where biophysical and social processes are intimately joined. Through this continuing cycle of applying models to new problems, testing how well they do against old and new data, and refining and improving the models, based on those results, this will allow for these problems to be addressed and improved upon.

When studying these systems it is vital to integrate across isolated fields to form dynamic, cross-sector socio-ecological systems approaches and models that efficiently traverse the human-environmental boundary

Q&A

Would it be possible to adapt your models for other water intensive regions worldwide?

We strive to ground our models in the fundamental physics of the biophysical systems they represent and use models of social systems that integrate current theories of human decision-making. Thus, the modelling frameworks are meant to be generic in nature and can be applied anywhere. Investigating a particular system, however, requires local datasets capturing the climate, soils, topography, etc., which may not exist. However, modelling data-rich regions of the world like the US gives us the opportunity to refine the process of defining what those data needs are, and what contingencies can be undertaken when data does not exist.

Is there a possibility for better water storage? What about underground reservoirs?

We will likely need to continue to look for ways to more effectively manage the reservoirs that already exist, potentially retrofitting them in ways that increases the ability of water managers to manage for both flood control and water supply. There is increasing interest in using groundwater aquifers as reservoirs, and I expect this interest to continue. The concept, known as aquifer storage and recovery, often compensates farmers for irrigating fields without growing crops. This recharges the aquifers below for later use. California is one place to monitor the efficacy of these programs.

Are water rights subject to change?

That is the $1 million question. The answer is technically "yes," but politically it is potentially a "third rail." In many states in the western US, the current doctrine of prior appropriation (which grants those water users that have the oldest water rights the highest priority of use) is literally written into state constitution. Often changes to water rights frameworks are only accomplished through legal action, a process that takes years or decades. It remains to be seen whether climate change and increasing land conversion from urbanisation leads to creative "grass roots" solutions that potentially circumvent the need for litigation.

What do you think the future holds for semi-arid environments in terms of water availability?

I would surmise that the answer lies in how brittle or flexible water resource management infrastructure is in those regions. Regions that are most able to cope with a warmer future with more variable precipitation are those where there is flexibility and resilience in both the social and biophysical systems to accommodate future change. Attributes of those systems potentially include having diverse storage resources, advanced understanding and monitoring of water resources from mountains to meadows, and (perhaps most importantly) flexible frameworks for managing water demand in years where scarcity is particularly problematic.

What can be done to improve irrigation efficiency?

The technology to improve efficiency of irrigation exists and its adoption is very much in the interests of farmers. Common measures include switching from flood irrigation to sprinkler or drip systems, installing sensors to monitor soil water status and plant stress, and field-level practices to prevent loss of water. These technologies require large capital expenditures for farmers. Improving irrigation efficiency often requires programs to provide loans or grants for those capital purchases. Interestingly, some electrical utilities in the US are doing just that, to reduce their potential peak load burden in the middle of hot summer days.

The technology to improve efficiency of irrigation exists and its adoption is very much in the interests of farmers

Detail

RESEARCH OBJECTIVES

Dr Alejandro Flores of Boise State University aims to advance socio-ecological models regarding the issue of water availability in the Treasure Valley region of Idaho, USA. These models will provide future projections and likely scenarios which can be used to inform stakeholders, policy makers and the agricultural sector about water management solutions.

FUNDING

National Science Foundation (NSF)

COLLABORATORS

- Bangshuai Han (Ball State University)
- Shawn Benner (Boise State University)
- Kendra Kaiser (Boise State University)
- John Bolte (Oregon State University)
- Kellie Vache (Oregon State University)

BIO

Dr Flores is an Associate Professor in the Department of Geosciences. In 2008, he earned his PhD in Civil and Environmental Engineering with a focus in hydrology from the Massachusetts Institute of Technology. His current research focuses on using numerical tools and geospatial data to quantify how humans impact the water cycle at a range of scales.

CONTACT

Alejandro N Flores, PhD
Associate Professor, Department of Geosciences
Director, Lab for Ecohydrology and Alternative Futuring
ERB-4151
Boise State University
1910 University Dr.
Boise, ID 83725-1535
USA

E: lejoflores@boisestate.edu
T: +1 208 426 2903
W: http://leaf.boisestate.edu/