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Food, water and energy resources – the rule of three

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Rapid population growth, economic development and the associated impacts of climate change are altering vital water, energy and agricultural resources in important ways. These three resources are not only critical to our global society, they are linked by complex, interdependent relationships. This interlinked triptych is known as the food-energy-water (FEW) nexus. The connections within the FEW nexus must be carefully managed to withstand environmental and societal change to ensure the continued security of FEW resources. A team from the Northwest Region of the United States is working to identify and examine effective strategies to develop our understanding of these relationships and to balance the benefits between FEW sectors in a bid to predict and enhance the resilience of these systems for sustainable growth.

OVERVIEW OF STUDY DOMAIN AND PROJECT GOALS

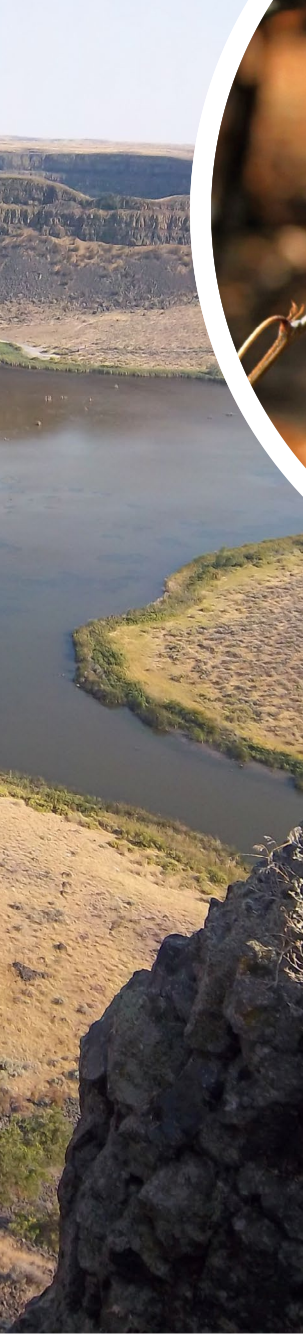
The team's research focuses on the Columbia River Basin (CRB), one of the most highly managed basins in the US. Hydropower from the CRB contributes 77% of the energy demand within the basin, equating to more than 15,000 megawatts of renewable energy from 75 dams. The dams are also important in flood control which is a major concern within the basin and is a prioritised function in the reservoir management system.

However, this renewable energy and flood management capability comes with an environmental cost. The river basin supports wildlife important for the economy, culture and wellbeing of the region. Fish populations have been significantly impacted by the diversity of management across the river basin: 12 fish species have been listed for protection under the Endangered Species Act and the annual salmon run has decreased from 16 to frequently less than 1 million fish per year. In a similar example of the delicate balance between competing interests in FEW resource management, large-scale mechanised farming has significantly increased agricultural yields but requires substantially greater water and energy inputs to grow, harvest and distribute the food. Furthermore, the CRB is particularly sensitive to climate change. Currently, snowpack stores winter precipitation for use in the summer. The system's built storage capability is less than half of the mean annual discharge (the total amount of surface water passing through the basin) making the system sensitive to warming.

The interrelated and co-dependant nature of the FEW nexus is clear but, because global change affects the environment, society, and institutions, it is increasingly important to understand what these changes mean for food, energy, and water sectors individually and how solutions aimed at each sector affect the system as a whole. This gap in our understanding means there is no clear strategy for dealing with the increasing complexities of the integrated systems. In the CRB, the competition for limited surface water resources to sustain irrigated agriculture, hydropower generation, and in-stream flow requirements for endangered fish populations aptly indicates the challenges within the FEW nexus. This individual example is characteristic of the global challenges in this area.

Research needs to consider where and why strong FEW system interdependencies occur

In the face of a growing human population and catalysed by the industrial revolution, FEW sectors have become increasingly interdependent such that the resilience



Left: The mighty Columbia River flows through the channelled scablands (or coulees, which are long channels cut into the bedrock), formed by ice age megafloods.

Inset: Irrigated agriculture in the Columbia Basin is vulnerable to warming-induced loss of snowpack, which stores winter precipitation for summer water use.

Right: Hydropower dominates energy production in the Columbia Basin, producing 77% of total energy in the region and 40% of hydropower in the US.

in each sector is affected by the capacity of the other sectors to weather and even capitalise on external biophysical and economic disturbances. By truly understanding the characteristics of the FEW nexus, the research team hopes to be able to predict how FEW dynamics will impact the economic, political, social, and environmental resilience of the whole CRB system. This in turn will help to identify the types of technological advancements, institutional adaptations and/or legislative requirements most appropriate for responding to change.

The team's work focuses on the idea that coordinated management of storage systems across the three sectors can increase FEW system resilience. This involves looking at not only physical storages, such as surface water reservoirs, but exploring how non-physical storages can improve FEW management. Non-physical storages, such as water markets, help redistribute resources from areas of low-value use to high-value use in times of shortage. The overall aim of the project is to develop, evaluate and apply a framework to understand FEW linkages, quantify innovative solutions, remove barriers to adoption of these solutions and increase system-wide resilience on a global scale.

THE FOUR STAGES OF THE PROJECT:

Develop a theoretical foundation to characterise FEW system resilience.

Assessment of resilience is generally performed for a single system, such as the resilience of an ecosystem to land use change. When researching the FEW "system of systems", resilience assessment must be broadened to consider multiple resource sectors (for example irrigated agriculture, fish flows, flood protection, and hydropower generation). However, a management action to benefit one sector may be at the expense of the others due to their tightly-interacting nature. Therefore, within this phase, the team explores metrics that are best able to capture resilience of the FEW system as a whole, which will form the basis of a "FEW Resilience Calculator". This theoretical framework is tested both specific to the CRB and to its ability to be generalised to other regions and the globe.

Integrate computer-based modelling systems to capture FEW system interactions in a quantitative system dynamics model.

By integrating and refining existing modelling platforms, the team is able to combine a deep understanding of each of the food, energy, and water sectors into a single framework to simulate the production and management of FEW resources. This

The US Northwest, with its rich soils, varied climate, and water available for irrigation, is one of the most productive agricultural regions in the world. It is also home to 12 endangered fish species.

allows the modelling outputs to quantify the extent to which the connected FEW system will be impacted (exacerbated or alleviated) by existing and new drivers, such as changes in climate, land use, and population.

Evaluate the benefits and impacts of FEW solutions using the modelling platforms.
The modelling platform allows researchers to understand the system's pressure points, such as a shift in the timing of snow melt away from the summer season of peak water use, and other disturbances, such as changes in commodity pricing resulting in changes in demand for the impressive array of food and fibre produced in the basin. It also identifies how and why innovations such as smart metering, precision agriculture and wind and solar energy generation impact the pressure points and opportunity cost of resource use across the system and therefore the system's resilience, as defined by the FEW Resilience Calculator. Application of the calculator will inform decision making based on economic, environmental and social equity indicators specific to the local system, alongside resilience metrics within the FEW systems to align short and longer-term properties for FEW management.

Make direct impacts on FEW resilience through engaging stakeholders to understand and remove potential barriers to adoption of solutions.
The team's challenge during this stage is to identify stakeholders willing to engage on FEW nexus issues rather than solutions specifically targeted at their own sector. The CRB system presents a good example of the diversity and scale of this challenge. The system spans seven US states, 13 federally recognised Indian reservations and one Canadian province. In addition to the rich diversity of natural ecosystems, there are human and cultural activities which should be accounted for when evaluating future management strategies for FEW in the CRB. Stakeholders will provide the team with information related to the barriers of adoption (and strategies to remove these barriers) of new innovative solutions to manage the FEW nexus.

An important factor that provides context for all potential solutions is the Columbia River Treaty (CRT), which was signed between Canada and the US in 1964 to manage flood control and hydropower generation in the CRB. Starting in the year 2014, either country can provide a ten-year notice to withdraw from or negotiate on treaty terms, so it is timely to assess the impact of treaty alternatives on the water resources of the region. CRT modifications to the

This project will inform which specific innovations would be most effective in fostering a resilient FEW system

Q&A

Your initial case studies of the Columbia and Yakima River basins will both provide temperate examples of the proposed model. What differences in model outputs would you expect to see in, for example, a tropical river system?
The methodology developed as part of the ColumbiaFEW project is applicable to other regions of the world, although the models would need to be tailored to accommodate the differences that may occur in and among the institutions that manage natural resources. In the tropics, in particular, tools that help plan for climate change adaptation are especially important. These regions are already showing signs of increased floods and droughts, as well as infrastructure damage due to climate change. Crops are anticipated to be more negatively impacted by warming, and in many cases there is a lack of infrastructure (for example through irrigation systems) that allow these regions to buffer the impact of shifts in climate patterns. The conflicting demands between allocating river water for hydropower production versus water for irrigated agriculture are global challenges that exist in temperate and tropical climates alike.

Can the model be applied to marine systems which have similar demands for FEW such as fisheries?
The modelling tools and data outputs we are producing are already incorporating fresh water and anadromous (species that use both fresh and marine water such as salmon, sturgeon and lamprey) fish species.

Protection of the environment for many of these endangered species is a component of the solutions that we are currently exploring. We are also quantifying the discharge of water and nutrients to marine environments that impact these ecosystems. More generally, the approach that we are developing starts with critical analysis of multi-sector management, with a focus on developing solutions across these multi-sector systems. Once developed, the framework can be applied to marine systems where the sectors themselves are quite different, but the frictions across sectors are at least as complex, particularly in coastal ocean systems.

What do you envisage will present the greatest barriers to success of this project?
The greatest challenge our team has encountered is the vast breadth of issues that come under the purview of FEW in the basin, particularly given how incredibly complex this basin is with respect to hydrology, climate, agriculture, and water resources management. To make this scope more tractable, our team has identified unique case studies focused on specific elements that have strong influence on FEW resources, e.g., a specific innovation that has high potential to alleviate conflicts, or a specific industry in which innovation would greatly improve efficiencies across multiple sectors. As we develop more case studies, a general and holistic understanding of the FEW nexus and its potential solutions will emerge.

Will the models be able to accurately quantify metrics for FEW resilience, e.g., actual levels of precipitation which may trigger flooding?
The "engine" behind the ColumbiaFEW project is a set of sophisticated computer models that represent the mechanisms that govern how the FEW system responds to global change and more local changes in management. Therefore, there is a degree of realism in our model predictions that would not otherwise be possible. Even the best models, however, have shortcomings and may not give exact answers to some very specific questions. To address this, we explore solutions that remain robust despite known limitations and uncertainties in the model and the data that are used to drive it. For example, if a specific solution shows optimal results across the FEW nexus for a large set of future climate conditions, we know that this is a solution that we should bring to our stakeholders for more intense scrutiny and analysis.

If the framework outputs are able to inform changes to the Columbia River Treaty, do you think this model has an application on global treaties, decisions and legislation?
Absolutely. While we do not intend to develop new policy alternatives, we can quantify the regional-scale impacts to proposed changes in national or even global policy. It is critical that regional-scale models be used in addition to larger-scale models, because the regional-scale models can capture the realism of how resources are managed. Without this realism, there is a large potential for unintended consequences.

way reservoirs are managed could have important and wide-ranging impacts on the rest of the FEW system.

This research is transformational in terms of increasing our understanding of interactions and trade-offs between the FEW sectors initially within the CRB, and ultimately on a global scale. We may see global change in action with tangible, demonstrable solutions that concurrently address the problems faced by multiple industries and sectors. These researchers are addressing important challenges to identify appropriate balances and potential trade-offs between technological (e.g., products or processes) and institutional (e.g., legal or policy-based) approaches for improving the efficiency and productivity of food, energy and water systems in the wake of increased global demand. Recognising how these two approaches complement, substitute for, or conflict with each other within and between sectors will play a key role in determining the appropriate management strategies which are essential to manage potentially limiting resources for a growing population.

Detail

RESEARCH OBJECTIVES
The FEW group's work focuses on how water interacts with food and energy production, and how people can respond and adapt to global change. Their current project aims to increase regional- to global-scale resilience in Food-Energy-Water systems through coordinated management of water and energy storage and through technological and institutional innovations.

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COLLABORATORS
For a full list of team members please visit https://fewstorage.wsu.edu/people/

BIO
The team involves over 40 members from Washington State University, the University of Idaho, the University of Utah, Utah State University, and the Pacific Northwest National Laboratory and together spans the disciplines of agronomy, communications, economics, engineering, environmental sciences, geophysics, law, philosophy, and social sciences.

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