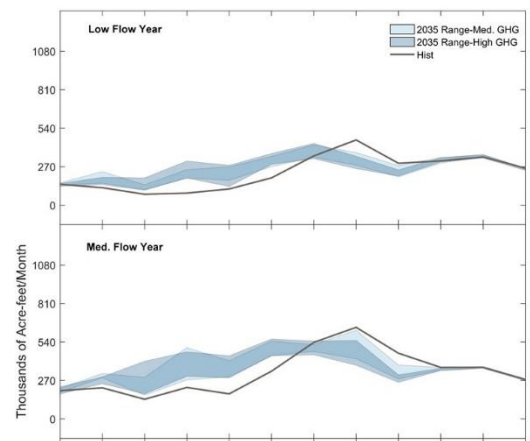


MODELING ENVIRONMENTAL CHANGE:

SCENARIOS IN THE WASHINGTON WATER SUPPLY AND DEMAND FORECAST



Abstract

This publication introduces policy makers and natural resource managers to the use of **scenarios** in environmental modeling. Managers increasingly recognize that the climate is changing and that those changes pose a threat that must be understood in more detail and incorporated into planning decisions at all scales. High quality information about likely environmental change impacts is critically important to help decision-makers address risks in an adaptive manner. To provide concrete examples of the types of scenarios that may be considered in making management decisions, we draw from the 2016 Columbia River Basin Long-Term Water Supply and Demand **Forecast**, which the Washington Department of Ecology publishes every five years to assist stakeholders in planning for future water resource conditions. There are many different approaches to developing and testing scenarios to inform decision-making. When decision-makers understand how scenarios are developed and how models are run, they can better use model outputs to inform their management decisions.

Introduction: Why Do Natural Resource Managers Need Scenarios?

Many policy makers and natural resources managers are experienced at adaptive decision-making, which involves considering multiple alternatives, updating approaches as new information becomes available, and looking beyond single issues to assess system-level vulnerabilities and resilience. They also increasingly recognize that the climate is changing and that those changes pose a threat that must be understood in more detail and incorporated into planning decisions at all scales. High quality information about likely environmental change impacts is critically important to help decision-makers address risks in an adaptive manner.

Process-based environmental models can improve our understanding of risks associated with changing environmental, policy, and socioeconomic conditions. Models can be run to represent alternative combinations of those conditions to explore the implications of different situations or decisions. These alternatives are generally called scenarios. When natural resource managers understand how scenarios are developed and how models are run, they can better use model outputs to inform their management decisions.

There are many different approaches to developing and testing scenarios to inform decision-making. Some scenarios may be created to explore the implications of changes in management and policy that are internal to the system being modeled—within the power of managers and policy-makers to affect change (**endogenous** scenarios). Modeling the impacts of several different endogenous management scenarios can serve as a first step in selecting and formulating a management strategy. In other cases, scenarios are used to explore changes in external conditions that impact the system of interest—but are not under the direct influence of decision-makers (**exogenous** scenarios). Exogenous scenarios are selected by modelers to represent a range of plausible future conditions.

This publication complements the Extension publication [Modeling Environmental Change: A Guide to Understanding Model Results that Explore the Impacts of Climate Change on Regional Environmental Systems](#) that discusses key considerations related to understanding the results from process-based models (Allen et al. 2015).

This publication was designed to be used by regional water managers and other natural resource decision-makers in the Northwest United States. Within it, we draw examples from the 2016 Columbia River Basin Long-Term Water Supply and Demand Forecast (hereafter referred to as the Forecast). The Forecast is prepared by the Washington Department of Ecology's Office of the Columbia River every five years to assist stakeholders in planning for future water supply and demand conditions. The Office of the Columbia River partnered with researchers from the State of Washington Water Research Center at Washington State University and its partners to

develop the Forecast. Input from other regional and local water management agencies and members of the interested public also informed the project.

Key concepts and general lessons from the Modeling Environmental Change series are applicable to many other geographic contexts and to other natural resource systems. However, in this publication we use the Forecast to explain and explore the use of scenarios, because referencing the Forecast enables us to provide concrete examples of the types of scenarios that may be considered in making management decisions about complex environmental systems. In addition, within the water management community in the Northwest US, the focus on the Forecast results allows regional resource managers to understand, in more depth, how important findings about the future of water supply and demand in the Columbia River Basin were generated, encourages consideration of the assumptions embedded in those results, and supports Northwest US resource managers' and other stakeholders' participation in conversations about developing and applying scenarios in future Columbia River water resources research so that model outputs better inform management decisions.

What Are the Goals of Modeling with Scenarios?

Generally speaking, a scenario is a description of a possible future which includes assumptions about actions and reactions as well as assumptions about changes in conditions and trends. Scenarios are used for several key reasons. First, developing scenarios requires making those assumptions explicit, so they can be modeled. The decisions about what assumptions are made usually influences what the scenarios are useful for. In addition, creating scenarios enables exploration of uncertainty in key variables related to forces of change. This includes factors that are external to the system being modeled—such as global climate change. It also includes variables that are internal to the system being modeled—such as decisions about allocation of water resources among users, reservoir operations, and other management alternatives (Brown and Wilby 2012). (For further discussion on uncertainty, see Hall et al. [2016].)

In some cases, scenarios are developed through conversations between researchers and stakeholders. This can strengthen trust and encourage mutual learning among the stakeholders and researchers, enabling individuals with different areas of expertise and different perceptions of the dynamics of the system of interest to compare their expectations about the future (Wiek et al. 2006; Birkmann et al. 2013). Modeling scenarios can also support adaptive management by encouraging consideration of multiple alternatives, with modification and re-testing of scenarios as new information becomes available (Peterson et al. 2003).

Although natural resource decision-makers have diverse information needs, improving understanding of which risks pose the greatest threats to existing and proposed infrastructure and managed systems is a common priority. The goal of developing outputs that are relevant to the needs of decision-makers often

requires modelers to look at different possible climate change scenarios, integrate climate **projections** under each of those scenarios with environmental models, and consider the possible implications of multiple different management scenarios (Brown et al. 2012; Brown and Wilby 2012)

The History of Modeling Scenarios

Modern approaches to developing and testing scenarios using models have roots in military and business applications. Military strategist and systems theorist Herman Kahn pioneered the use of scenario analysis at the RAND Corporation after World War II to understand nuclear threats and to develop strategies to manage those threats (Kahn and Wiener 1967). Kahn and Wiener emphasized that scenarios are not forecasts or projections of the future, but rather stories to explore (Peterson et al. 2003). Shell oil executive Pierre Wack led early applications of scenario planning in the private sector. In the late 1960s, he encouraged corporate decision-makers to consider forces that could drive global oil price changes and to immerse themselves in those scenarios to develop management strategies (Peterson et al. 2003; Ogilvy and Smith 2004; Prudhomme et al. 2010).

How Are Scenarios Used in Environmental Modeling?

There are multiple types of scenarios, including environmental change projections and management alternatives. At the same time, there are multiple approaches to using scenarios in regional environmental change analyses. In the most common approach, sometimes referred to as a scenario-first approach, modelers start by using general circulation models (GCMs) to project regional climate change impacts (Wilby and Dessai 2010). GCMs numerically simulate oceanic, atmospheric, and land-surface behavior at a coarse spatial resolution (grid cells of 4000 square miles or more).

Numerous GCMs exist, each with their own set of relationships that describe the underlying physical behavior of the climate system. Much in the way that a group of people with different areas of expertise may be able to make a more informed decision than a single individual, running multiple models with differing strengths and weaknesses can provide more reliable information about global environmental change. Many models can be run for a single scenario to understand the range of projections and to obtain a measure of model uncertainty. Then an ensemble of models, made up of multiple GCMs, are used to run a range of scenario, such as for varying trajectories of greenhouse gas concentrations (e.g. Representative Concentration Pathways) that are reflective of how different human decisions could lead to different concentrations of greenhouse gasses in the atmosphere. The GCMs simulate how these RCPs impact climate. These ensemble model projections are then downscaled to match the spatial and temporal scales of detailed, regional-

scale hydrologic and vegetation models (Wilby and Dessai 2010).

After modeling regional environmental responses to climate change scenarios, possible impacts of specific management scenarios can be assessed. For example, using a scenario-first approach, modelers might first simulate regional hydrological conditions under a range of climate scenarios and then run management scenarios to evaluate the potential outcomes of several different approaches to managing water resources.

Complementing this approach, a number of researchers have advocated a vulnerability analysis approach, in which researchers and stakeholders focus on identifying vulnerabilities and running scenarios to test system responses under a wide range of climatic- and non-climatic pressures (Prudhomme et al. 2010; Brown et al. 2012; Brown and Wilby 2012). This vulnerability analysis approach is also sometimes called a **sensitivity**-led approach or a scenario-neutral approach because modelers focus on understanding system responses under a broad range of possible future conditions (Lempert et al. 2004; Brown et al. 2012; Brown and Wilby 2012; Birkmann et al. 2013). For example, a vulnerability analysis might begin by identifying flooded roads as a hazard of concern. Modelers would then test hydrological responses under a range of potential climatic and non-climatic pressures. Based on model results, managers might identify which roads are most vulnerable to flooding under a large range of potential changes in storm intensity and frequency and select locations to install larger culverts. This approach may be particularly useful for understanding the vulnerability to extreme weather events or other types of events that are not currently captured well in GCMs.

Key similarities and differences of the scenario-first approach and vulnerability analysis approach are listed in Table 1. Figure 1 illustrates steps in conducting scenario-first change impacts assessments and vulnerability analyses.

These two approaches to developing and using scenarios are complementary and are applicable in different contexts. A strength of assessing climate change impacts using the scenario-first approach is that projections of future regional climate conditions are based on sophisticated global climate models. However, downscaled global climate projections may not adequately describe the full range of possible climate change impacts—particularly linked to difficult-to-model extreme weather events (Stainforth et al. 2007; Prudhomme et al. 2010; Brown and Wilby 2012). Meanwhile, the vulnerability analysis approach is well suited to considering the effects of climate extremes on model outputs (Stainforth et al. 2007; Prudhomme et al. 2010; Stakhiv 2011).

Both the scenario-first approach and the vulnerability analysis approach have a place in informing management decisions. The scenario-first approach is well suited to situations where grounding impacts models in realistic future climate projections is helpful. The vulnerability analysis approach is well suited to defining tipping points or thresholds at which specific impacts are expected. These approaches to developing and testing scenarios can complement one another, and it is possible to combine scenario-first and vulnerability analysis approaches. For example, modelers might project regional climate change impacts with downscaled GCMs, and then consider the implications of extreme weather events for a few specific systems.

Table 1. Similarities and differences of two unique approaches to using scenarios to inform environmental management decisions.

	Scenario-First Approach	Vulnerability Analysis Approach
General modeling approach	Process-based environmental models are run to simulate system behavior under a range of projected future conditions.	
Approach to climate change analysis	Large investment of resources in designing feasible emissions scenarios then running global climate models and downscaling to regional scale.	Assumptions made about a wide range of feasible future climatic conditions.
Approach to risk analysis	Assess risks based on specific projections of regional climate change impacts.	Large investment of resources in comparing a range of management behaviors under different future climate conditions.
Role in informing management decisions	Emphasis on making realistic projections of future conditions then testing specific management scenarios.	Emphasis on defining vulnerabilities and then evaluating management alternatives to select for approaches that promote resilience across a broad range of possible future conditions.

Scenario-First Approach



Vulnerability Analysis Approach

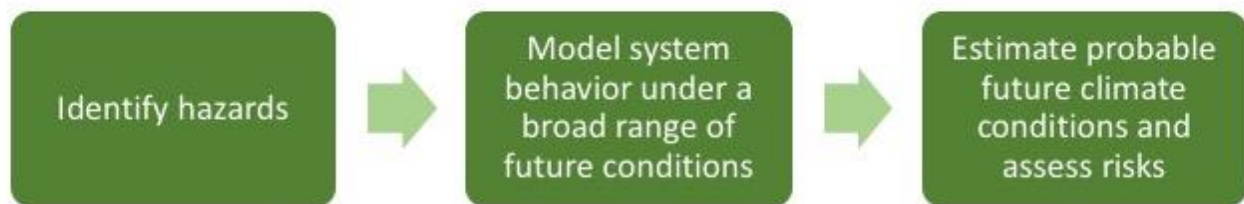


Figure 1. Comparison of the steps involved in conducting a scenario-first climate change impacts assessment and a vulnerability analysis to assess climate change impacts.

The Forecast represents a scenario-first approach to assessing climate change impacts. In the Columbia River Basin, the seasonality of river flows is expected to change considerably as more winter precipitation falls as rain rather than as snow, leading to peak flows earlier in the spring and lower water levels during summer months when mountain snowpack is diminished. In this system, it is important to accurately represent the link between temperature and precipitation, thus, beginning the analysis of future environmental change impacts with realistic downscaled simulations of the regional climate is an advantage. The research approach used in the Forecast lends itself to “layering” different scenarios to answer specific questions about system behavior under possible future conditions. Scenarios representing exogenous factors (climate change and economic conditions) and endogenous factors (management alternatives) were run sequentially.

How Are Scenarios Developed?

This section focuses on approaches to developing scenarios. The process of defining scenarios to be modeled most frequently starts with looking for the forces that drive the trends of interest and establishing a picture of the future under “base case” or “business as usual” conditions, in other words, assuming that current and historical trends will continue into the future (Peterson et al. 2003). Alternate scenarios can then be compared to this “base case.” Expert and stakeholder opinion play

important roles in determining which base case and alternate scenarios are explored (Hallegatte et al. 2012).

The forces that are considered and the management alternatives that are compared depend upon the kinds of decisions the modeling analysis is meant to inform, and at what scale. For example, the International Panel on Climate Change (IPCC) reports on results from global climate models to inform national and international policies. The IPCC 5th Assessment Report explores different Representative Concentration Pathways, or radiative forcing scenarios. Radiative forcing is a measure of the heat-trapping effect in Earth’s atmosphere, and is determined by the atmospheric concentration of greenhouse gasses. Considering global climate change under the Representative Concentration Pathways defined by the IPCC can help policy makers understand the global climate implications of particular emissions targets.

The Columbia River Forecast relies on downscaled global models of future climate under different Representative Concentration Pathways to make realistic projections of regional hydrological conditions. The approach used in the Forecast views global radiative forcing as an external force that is outside of the control of regional managers. This assumption is practical for the intended use of the Forecast for making decisions about regional water resource management (although in reality it is understood that management practices at all scales have some effect on total global greenhouse gas emissions). After downscaling global climate models representing a range of climate change scenarios, the Forecast explores the impacts of exogenous economic pressures and endogenous management

scenarios. Climate, economic, and management scenarios used in the Forecast are described in detail in *The Use of Scenarios in the Columbia River Forecast* section.

An Example of Formalized Scenario Planning

Many natural resource managers have some exposure to formal scenario planning approaches, in which detailed storylines about the future are created to encourage decision makers to imagine themselves in alternate possible conditions. Shared socioeconomic pathways (SSPs) are detailed descriptions of plausible trends in the evolution of society and natural systems over the 21st century at the global scale (Moss et al. 2010; Kriegler et al. 2012; van Vuuren et al. 2014; O’Neill et al. 2014; Birkmann et al. 2013).

Although SSPs are not used in the Forecast, it is useful to be familiar with the leading example of SSPs for climate change impacts analysis. The Millennium Ecosystem Assessment was called for by the United Nations Secretary General in 2000 to address challenges related to climate change adaptation decision-making. This research effort involved over 1000 government agencies, businesses, and non-governmental organizations in 95 countries working together to document how humans have changed ecosystems and to explore linkages between human health and well-being and environmental conditions. Millennium Assessment scenarios (Figure 2) comprise four internally consistent and policy-relevant SSPs looking at adaptation trajectories through the year 2050, globally.

Model outputs are only relevant to natural resource managers to the extent that the model explores possible futures that are of interest to those managers (Lempert et al. 2004). While a vast array of possible ecological, economic, social, and political changes could possibly occur within natural resource systems, both modelers and decision-makers have a need to narrow the range of possible changes to consider. The process of defining scenarios can in some cases be guided by the principle of determining what future conditions are most “realistic” and are anticipated by modelers and stakeholders. In other contexts, decision-makers may find scenarios to be most useful when they describe “extremes.” For example, land-use scenarios could be defined to bound opposite extremes—one in which all development ceases immediately, and another in which population growth and development occur at twice the rate expected by demographers. By selecting possible but highly unlikely scenarios, decision-makers can assess the range of likely outcomes, as well as potential tipping points, or critical moments, at which a significant or irreversible change in the system takes effect. Hallegatte et al. (2012) put forth the following criteria for constructing scenarios that describe management alternatives:

- Scenarios should be plausible, describing a rational pathway from present conditions to future conditions that makes causal processes and decisions explicit;
- Each scenario should be internally consistent; and
- The future conditions that are described by scenarios should be interesting and exciting, prompting decision-makers to consider strategic responses to new conditions.

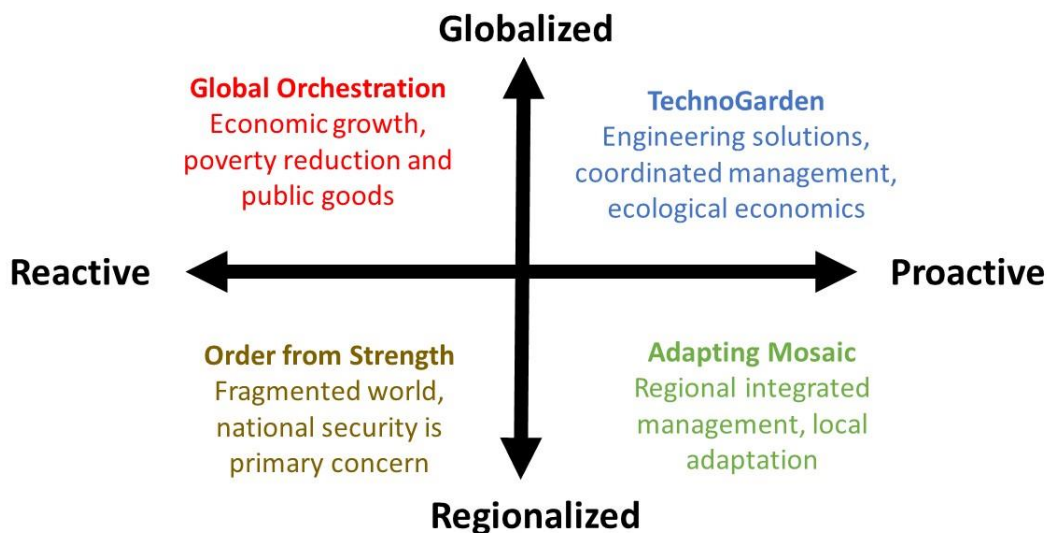


Figure 2. Millennium Ecosystem Assessment shared socioeconomic pathways (SSPs) describe four plausible futures for ecosystems and human well-being. The scenarios describe two global development paths (globalized versus regionalized societies and economies) and two different approaches for ecosystem management (in reactive management, problems are addressed only after they become obvious; in the case of proactive management, attempts are made early to maintain ecosystem services for the long term).

The growing body of literature on different approaches to developing scenarios for climate change impacts research and management decision-making suggests that the most effective approach to capturing existing understanding on emerging drivers of change and possible system feedback loops is to engage individuals with different perspectives and areas of expertise (Mote et al. 2011; Hallegatte et al. 2012). By engaging a range of stakeholders, including individuals from industry, government, non-governmental, and academic sectors, various insights can be integrated. Participatory scenario development enhances the relevance and usability of models for decision-makers. Scenario planning efforts, including the Forecast’s scenario planning process, can be expected to evolve over time, as partners on both the stakeholder and research side gain familiarity and experience with each other and develop increased understanding of each other’s needs and constraints.

The Use of Scenarios in the Columbia River Forecast

The scenarios used in the 2016 Forecast represent the result of iterative conversations between modelers and decision-makers, going back to 2009 (when work on the 2011 Forecast was initiated). The research team worked closely with individuals at the Office of the Columbia River, who have knowledge of the needs of their agency, and of a variety of stakeholders across eastern Washington. In addition, the scenarios also integrated insights from direct conversations between stakeholders and researchers. The most notable fora for conversations were:

- Three public workshops held in Richland, Wenatchee, and Spokane during the development of the 2011 and 2016 Forecasts, and,

- Repeated interactions with the Office of Columbia River Policy Advisory Group, a group of external stakeholders that provides Ecology with a range of perspectives on policy choices and priorities and assists Ecology in setting criteria for prioritizing storage and conservation projects for funding.

Scenarios that were modeled in the Forecast were defined and driven based on priority questions and information needs at the Washington Department of Ecology’s Office of Columbia River. These scenarios were used to support better understanding of system behavior, vulnerabilities, and sensitivities. In this publication, we focus on specific examples from the Forecast to illustrate the types of scenarios that were explored and how they fit together.

Some of the scenarios that were considered in the Forecast describe forces that are external to the hydrological system being modeled—the climate scenarios and economic trend scenarios are exogenous. Additionally, modelers considered the implications of management practices internal to the system being modeled: water storage capacity adjustments and the agronomic practice of double-cropping (growing two consecutive crops on the same land in a single growing season). It is important to note that while explicit management scenarios for water storage and double cropping could be developed, these management practices were only explored using preliminary post-modeling calculations in the 2016 Forecast, because stakeholder interest in these management questions arose close to the end of the project. In the 2021 Forecast, researchers expect to define and model specific scenarios exploring these management alternatives. Figure 3 illustrates how these exogenous and endogenous scenarios were integrated into the Forecast modeling approach.

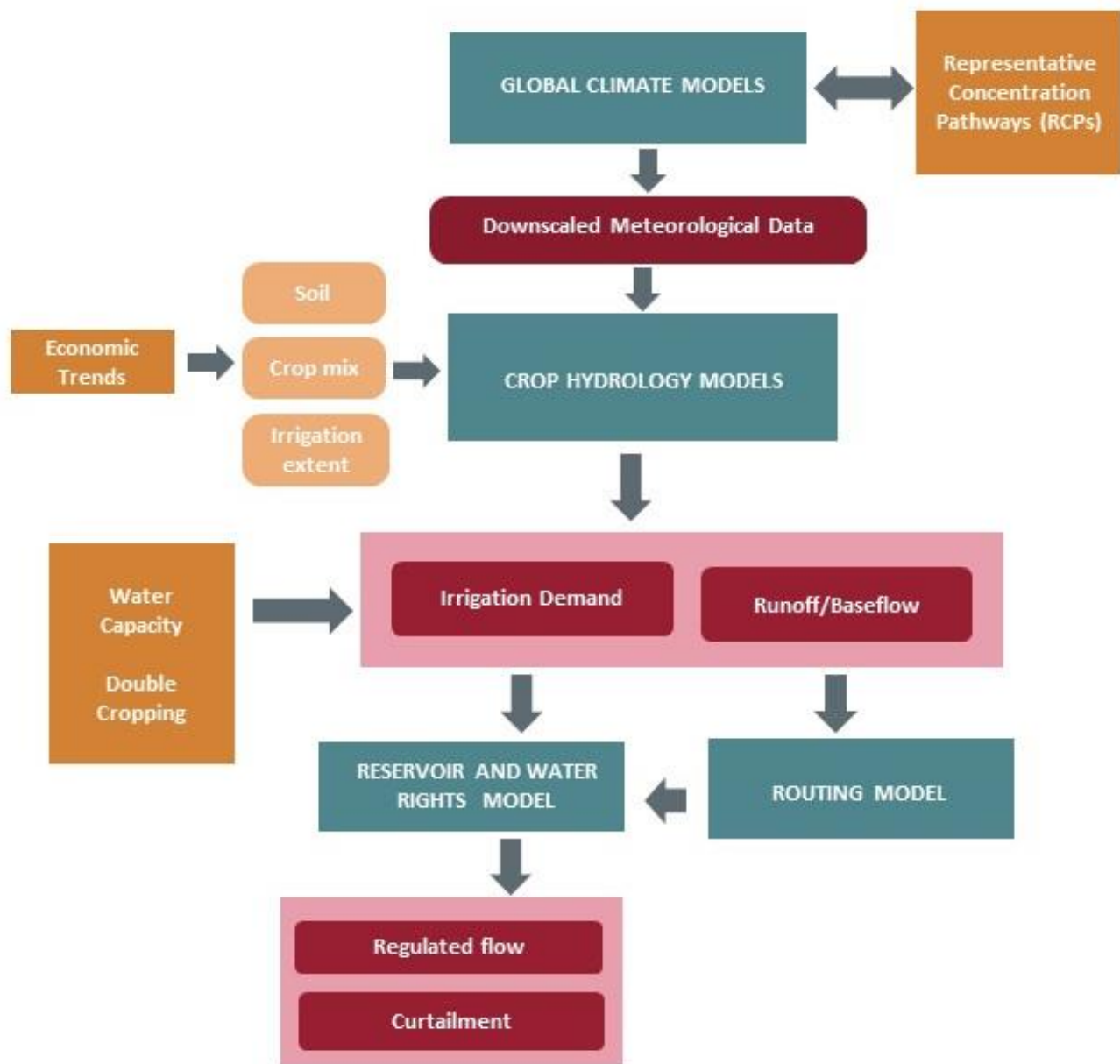


Figure 3. The approach to scenario planning used in the Columbia River Forecast. Orange boxes indicate groups of scenarios, blue boxes are models, and red boxes are model outputs.

Climate Scenarios

Future climate scenarios used in the Forecast draw from existing climate scenarios defined by the Intergovernmental Panel on Climate Change. Utilizing a common scenario reference point for climate facilitates comparison of model outputs and integration of results from different teams of researchers looking at different questions. In the IPCC 5th Assessment Report (2014), projected global climate trajectories are based on four different Representative Concentration Pathways (RCPs, see

Table 2). The RCPs are greenhouse gas concentration trajectories and are named according to projected radiative forcing (sunlight absorption) values in the year 2100 relative to pre-industrial values (+ 2.6, + 4.5, + 6.0, and + 8.5 watts per square meter). For reference, the additional radiative forcing in 2011 (89 years before the year 2100) was estimated as + 2.2 W/m². If current emission trends were to continue uninterrupted, that would be most consistent with the RCP 8.5 scenario, or the most extreme of these four projected climate change scenarios.

Table 2. Representative Concentration Pathways and generalized emissions scenarios used in IPCC 5th Assessment Report (see also van Vuuren et al., 2011).

RCP 2.6	Global annual greenhouse gas emissions (measured in CO ₂ -equivalents) peak between 2010 and 2020, with emissions declining substantially thereafter
RCP 4.5	Emissions peak around 2040, then decline
RCP 6	Emissions peak around 2080, then decline
RCP 8.5	Emissions continue to rise throughout the 21st century

RCPs do not have “built-in” assumptions about social, political, and technological conditions that might lead to different impacts. Considering a range of RCPs gives researchers the ability to place boundaries on the atmospheric conditions specified for projecting future climate, while accounting for a range of possible greenhouse gas emissions scenarios and global socioeconomic change trajectories. Focusing on radiative forcing scenarios simplifies the process of assessing climate change impacts for decision-makers, because the connection between emissions and temperature change is made explicit. In analyzing model outputs for different RCP scenarios, there is room for debate and discussion about how different social, economic, and political changes might bring about changes in emissions globally. However, potential climate change mitigation impacts of regional management practices are not incorporated in regional climate change impacts assessments, such as the Forecast, because those impacts are assumed to be small within the context of global forces.

As part of a comprehensive community effort coordinated by the IPCC, many modeling teams have developed and run global models under these four radiative forcing scenarios. Prior to using the climate model output for local to regional applications, the climate model output were usually downscaled by one of two general approaches: dynamical downscaling, which uses high-resolution regional climate simulations where the coarser-resolution global climate models are used as boundary conditions, and statistical downscaling, in which statistical relationships between the coarse-resolution climate model output and local-scale observations are applied to future climate model projections. Forecast modelers used statistically downscaled data from the University of Idaho (Abatzoglou and Brown 2012). In total, ten “climate scenarios”, based on two RCP scenarios and five downscaled climate models (which were selected to capture a broad range of temperature and precipitation change projections for the area for the 2035s), were then used to drive an integrated hydrology-crop model for the region (Adam et al. 2017).

Economic Change Scenarios

In theory, Forecast modelers could test a vast array of possible social and economic changes happening globally and within the

region that might plausibly impact water supply and agricultural demand (trade, land values, consumer demand, policy at all levels of governance, development, population growth, technology). However, in order to keep the level of modeling computation and the interpretation of results reasonable, there is a need to reduce consideration of possible futures to a few key variables that decision-makers understand and that to relate to water supply and agricultural demand in the region.

In the 2016 Forecast, Washington State University researchers built upon the foundations laid in the 2011 Columbia River Basin Long-Term Water Supply and Demand Forecast (Yorgey et al. 2011). The economic scenarios considered in the 2016 Forecast are relatively minimalist and big-picture. This represents a deliberate decision on the part of modelers and decision-makers to focus on change factors that are known to influence water demand and use. The 2011 Forecast had explored a wider range of global economic scenarios and revealed that even radically divergent global economic and trade scenarios resulted in only minor impacts on water demand for the Columbia River Basin (Yorgey et al. 2011). Therefore, in 2016, economic modelers working on the Forecast focused their analysis on current vs. future crop mix and used historical trends in acreage of different crops to model changes in acreage into 2035.

An econometric analysis was used to predict future crop mix. Econometric models are statistical models that are informed by economic theory. They analyze data from the past to identify trends and make judgements about the future (see Figure 4 and Figure 5 for historical and forecast crop acreage). The advantage of this approach is that it focuses on cropping patterns and avoids the need to use complex models about food production and consumption in Washington, the United States, and the entire world. The weakness of conducting an econometric analysis focused solely on crop mix is that new and unprecedented drivers of change will not be incorporated into **predictions**. For example, the use of corn to produce ethanol would not have been captured in a forecast made in the late 1990s because this trend started around 2001. Similarly, until about 2007, blueberries had almost no production in eastern Washington. Now that modelers can look at a ten-year record of blueberry production trends, they can extrapolate growth of blueberry acreage into the future.

Results from the econometric analysis conducted for the 2016 Forecast suggested several key trends, and thus helped to define a likely scenario for future crop production in the region from

2015 to 2034. Four key trends from the econometric analysis are listed in Figure 4 and the future crop acreage scenario is illustrated in Figure 5.

1. Apple and cherry production are expected to remain fairly constant.

2. Vineyard acreage is projected to expand significantly on a percentage basis.
This is important in terms of water use because vineyards often use less water than other crops and are highly concentrated in specific locations.

3. Interannual variability in hay and grain crops is very large, and expected to continue to be so.
This makes results very sensitive to what year of the forecast is selected (see a discussion of the impact of this variability in Hall et al., 2017).

4. The proportional acreage of all crops historically grown in the region has been close to constant. However, the total acreage under cultivation is projected to increase.
Growth in acreage for vegetables, grains, and hay were not offset by reductions in acreage for other crops.

Figure 4. Four key trends from the econometric analysis informed the future crop acreage projections in the 2016 Forecast.

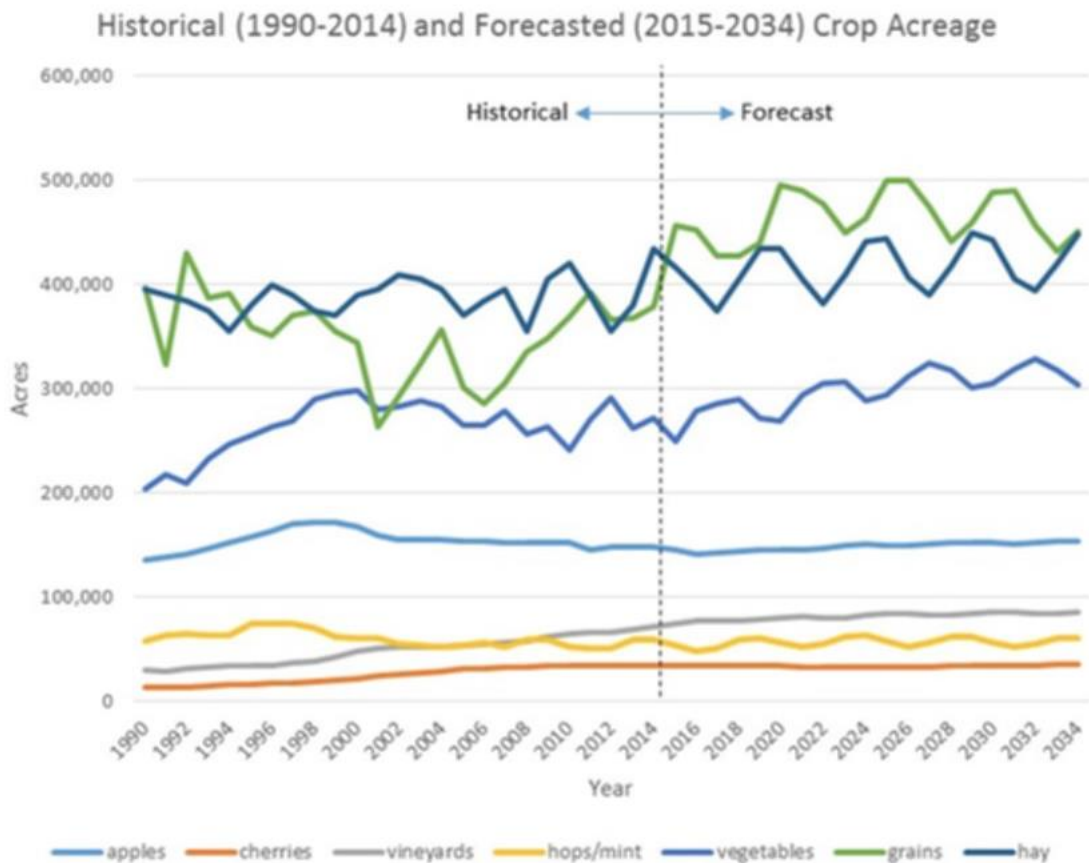


Figure 5. Historical and forecast crop acreage trends for Washington State. Data source for the historical time period (1990–2014) is the USDA’s crop database, aggregated to the state level. Forecast acreages (2015–2034) were projected using time-series econometric models.

Water Capacity and Double Cropping Scenarios

The Forecast focused on modeling for the current irrigation extent and current water storage capacity. However, modelers also responded to specific questions raised by regional regulatory agencies and other stakeholders by starting to explore reference scenarios for changes in water supply. The intent of such reference scenarios is to describe endogenous management practices and to assess whether there are thresholds for water supply in the Columbia River Basin, beyond which system behavior dramatically changes.

Stakeholders suggested that removing water in late winter when predicted flows are high and storing this water for uses including irrigation, instream flows (fish), and municipal use would alleviate most water management concerns in the region for planning horizons of interest. The Department of Ecology was interested in a rough calculation of what would happen to water demand if, for example, 300,000 new acre-feet of water were added to the system, representing increases in water storage capacity from planned water storage projects over the next ten years. This was explored by developing and testing a simple scenario. Based on planned water storage projects, this scenario made specific assumptions about where water would be made available and also assumed that the irrigated area in the Basin would increase.

Stakeholders at public input meetings also voiced interest in the potential water use implications of double cropping, a practice where a second crop is grown in the season, to maintain soil cover or for other monetary or non-monetary benefits. This question was of interest, in part because climate change impacts models projected that regional crops would mature earlier, thus, creating new opportunities for double cropping. Also, double cropping would lead to increased water demand late in the growing season, when water scarcity will be felt the most, thus, with the potential to increase water scarcity. Currently, data are lacking about the prevalence of double cropping and about the locations where it is occurring, and, yet, there is anecdotal evidence to suggest that the frequency of double cropping is increasing. In the future, there may be potential to better assess regional double cropping patterns using remote sensing. For the 2016 Forecast, modelers considered scenarios where 10% of eligible acres (that is, acres already growing crops that were amenable to being followed by another) were double cropped, and where the 10% double cropping was coupled with the increased water storage scenario (which led to increased extent of irrigated agriculture).

It is important to note that these water storage and double cropping tests were completed in a “back-of-the-envelope” manner and that future investigation will be needed to explore whether the scenarios proposed are realistic for the region. It is also possible that different conclusions would be drawn from a more detailed modeled scenario of double cropping and new water storage infrastructure. However, even running these initial scenarios provides information about system sensitivity to

changing conditions. In the case of the 2016 Forecast, these back-of-the-envelope estimates were enough to change projections of agricultural water demand from an overall decrease in demand by 2035 to an overall increase in demand (Hall et al. 2016)—thus, indicating that further investigation is warranted.

Assumptions Built into Scenarios in the Forecast

Each of the climate, economic, water storage, and double cropping scenarios considered in the 2016 Forecast is based on explicit framing principles. In addition, each scenario also involves built-in assumptions. Assumptions are an inevitable part of the process of defining and testing future scenarios, because not all possible dimensions of future change can be considered—especially not all at the same time—and not all aspects of the system can be modeled. Simplifying assumptions are thus necessary to bound the scope of possible circumstances and changes considered in an analysis. And simplifying assumptions are needed to restrict the analysis to the variables for which models are designed to make projections.

Among the assumptions built into the scenarios considered in the Forecast, there are several that are particularly important for natural resource managers to understand. First, the scenarios that were run in the Forecast make simplifying assumptions about how water could be allocated for different uses. Opportunities to transfer water from one use to another are clearly location-dependent and limited by existing water laws.

An example of a simplifying assumption in the 2016 Forecast is that modelers did not individually model all of the dams in the Columbia River Basin, as there are more than 400 dams (both storage and run-of-the-river) operated to meet a variety of purposes. Instead, reservoir modeling captured operations of the major storage dams on the Columbia and Snake Rivers, and the five major reservoirs in the Yakima Basin. Additionally, scenarios were run that explored the implications of adding new reservoir storage. In practice, resource managers know that adding storage infrastructure would require a multi-agency planning process and substantial investments and would only be practical in a limited number of specific locations, and, therefore, the additional water would be available in particular areas of the Basin.

Assumptions made in different parts of an integrated modeling effort sometimes contradict each other. In this case, corrections are made to outputs from models that make different assumptions before those model results can be integrated. While the econometric model used in the Forecast projects that the total amount of cultivated acreage in the Columbia River Basin will increase, these results implicitly assume that irrigation water will not limit such an increase. Yet because such water limitations exist, the hydrological and cropping system models used to project irrigation demand have as a framing principle the assumption that the land base for irrigated agriculture will remain constant between the historical timeframe (1981–2011) and the future timeframe (2035) (Hall et al. 2016). This framing

principle is based on the understanding that increasing the irrigated acreage in the Columbia River Basin would be dependent on additional water development. The statistical model parameters in the econometric model, however, do not provide a hard cap on acreage, even though the model is designed to capture crops that tend to move in opposite directions (some crops are expected to increase in acreage at the expense of others that decrease). Therefore, an integration step between the economics and the biophysical models was required to normalize total acreage in the forecast period (2035) to the historical limit that is based on existing water rights. In this way, Forecast modelers resolved a contradiction in the assumptions made in hydrologic and economic scenarios that were modeled.

Conclusions: Refining the Use of Scenarios in the Forecast to Manage Columbia River Basin Water Resources

While natural resource managers are accustomed to making decisions under multiple uncertainties, climate change impacts introduce an additional layer of deep uncertainty to considerations about new infrastructure and management practices and policies (Hallegatte et al. 2012). There is a demonstrated need for natural resource decision-makers to move from awareness of potential climate change impacts to tangible adaptation measures and to coordinate management efforts among multiple agencies and interests (Wilby et al. 2009). Layering scenarios that describe external pressures on the systems of interest and internal management practice scenarios enables decision-makers to tease out the influence of specific factors.

This publication has focused on supporting natural resource decision-makers in using information from climate change impacts models by describing how exogenous and endogenous scenarios are selected, with particular attention to the scenarios in the 2016 Forecast. Future efforts that continue to develop these scenarios in close collaboration with regulatory agencies, regional industry representatives, and environmental protection and green technology organizations will help ensure that variables of interest to decision-makers are represented in future management scenarios and quantified appropriately. Continuity in engagement, with each Forecast building on lessons learned during the last, allows a back-and-forth process to take place and for more specific and detailed management scenarios to be explored. Over time, addressing communication challenges between natural resource decision-makers and researchers will be one key to construct and test the management scenarios that are most relevant to the needs of decision-makers in the region.

Glossary Terms

endogenous: Internal to the system.

exogenous: External to the system.

forecast: An estimate of what is likely to happen in the future. A forecast can be thought of as a “best” prediction made with a particular technique or representation of current conditions (Allen et al. 2015).

prediction: An estimate of what is likely to happen in the future based on what is known today (Allen et al. 2015).

projection: The extension of particular predictions under particular conditions. Projection allows for defining a range of conditions that might influence the prediction, creating “if this, then that” types of statements. A projection is a simulation of what might happen under some conditions, and does not preclude other possible outcomes (Allen et al. 2015).

scenario: A description of a plausible alternative future, including actions and reactions. Scenarios provide an indication of possible future conditions, but not definitive probabilities (Allen et al. 2015).

sensitivity: The degree of system responsiveness—whether beneficial or detrimental—to climate change impacts.

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