OREGON STATE UNIVERSITY EXTENSION SERVICE

Water, Economics, and Climate Change in the Willamette Basin, Oregon

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Executive Summary

Climate change, population growth, and income growth have the potential to significantly affect the availability and use of water in the Willamette River Basin (WRB). How these changes will affect water scarcity is uncertain. Individuals, communities, and governments across the WRB need to better understand how the supply and demand for water will evolve and vary across space and time in coming decades. The Willamette Water 2100 project (WW2100) was motivated in response to that need. The project was a 6-year research effort aimed at developing a computer simulation model that represents the important processes of both the natural and human systems related to water supply and demand. Our understanding of water supply relies heavily on hydrology and related natural sciences, whereas our understanding of the demand for, and allocation of, water comes from economics, law, engineering, and related social sciences. The linkages, interconnections, and feedbacks in complex systems of this kind are very difficult to fully understand without a detailed model.

The WW2100 model allows us to project into the future the ways that changes in climate, population, and income from 2010 to 2100 will alter the supply, demand, allocation, and scarcity of water. This report describes results from the WW2100 model, with a focus on its economic dimensions, i.e., the impacts on people who live in the WRB.

Water supply

On the water supply side, the severe decline in snowpack in the next 80 years will reduce the amount of snowmelt runoff from April to June. The projected reduction in average available snowmelt (as of April 1 each year) represents a decline of about 600,000 acre-feet of stored water. However, precipitation plays a far greater role than snowmelt in determining spring streamflows in the WRB. Indeed, the projected decline in snowmelt is only one-tenth of average April–July precipitation (nearly 7 million acre-feet). As a result, unlike arid basins in eastern Oregon or neighboring states, the loss of snowmelt will have a relatively small impact on water availability in the lower elevations of the WRB in spring and summer. Nevertheless, reduced snowpack, when combined with higher summer temperatures, is projected to increase stress on upland forests and, as a result, increase the risk of wildfire.

Water use

In general, water use is influenced by both the demand (willingness to pay) for water and the cost of transporting, storing, or transforming water to make it available for a given use. The importance of cost considerations is critical. Demand for transported water depends on the value of water for a specific purpose relative to conveyance costs. For example, water is transported up to 25 miles from outside the WRB (often aided by gravity) to serve urban users. In contrast, we estimate that a quarter mile of horizontal or uphill conveyance can be costly enough to make delivery of water for irrigation uneconomic on most currently unirrigated agricultural lands in the Basin. Indeed, economic considerations explain why one-third of irrigable farmland (parcels with irrigation water rights) goes unirrigated each year. Irrigation involves costs and benefits, and, in some years and on some lands, the costs outweigh the benefits.

Key findings related to water use are as follows:

- **Water use for irrigated agriculture** fluctuates from year to year, but has exhibited no significant upward trend in recent decades. The per-acre amount of water required for irrigation is expected to remain relatively stable. However, seasonal patterns of irrigation are likely to shift about 2 weeks earlier in response to earlier planting dates resulting from climate change. The potential use of stored water to expand irrigation to farmlands that currently do not have irrigation water rights is limited by economic realities; conveyance costs are high relative to the economic gain from irrigating.
- **Urban water use** is projected to rise significantly by 2100, due primarily to population growth, but also to rising income. The growth in demand will be tempered to some degree by recent and near-term price increases related to cost recovery for infrastructure investments. The burden of these increases on WRB water supplies will be limited by several factors. First, most urban water is used indoors and

is nonconsumptive, i.e., it is returned to the surface-water source from which it originated. Second, a large fraction of urban water supplies in the WRB come from sources outside the Basin. Thus, consumptive use from in-basin surface water sources represents only about 7 percent of total urban water deliveries and is projected to increase by only 16,000 acre-feet by 2100. Urban consumptive use of water from in-basin sources is small compared to other uses. Agricultural use (475,000 acre-feet) is 25 times greater, and regulatory minimum flows in the Willamette River (3.5 to 4 million acre-feet at Salem) are 200 times greater.

- **Protection of in-stream flows** (by federal and state law) is the largest allocation of water in the Basin under human influence or control. These flows serve multiple purposes, but are determined largely by habitat requirements of native fish. These minimum streamflows result from both federal requirements under the Endangered Species Act and state-mandated perennial minimum flows protected by in-stream water rights.
- **The 13 federal storage reservoirs** in the Basin produce enormous social value by reducing the risk of flood events. This benefit has been estimated at more than $1 billion per year. As urban areas expand, the value of potential damages during a flood will rise. Thus, the economic benefits of flood damage reduction will increase. To the extent that climate change leads to increases in high flow events, these benefits will become even more valuable.

Water scarcity

In some parts of the WRB and at some times of year, water is scarce, and that scarcity is likely to increase in the future. The potential for increased water scarcity will be location- and time-specific.

Our model results suggest the following:

- The municipal water rights currently relied upon may reach capacity in the Metro area (in 30 years) and in Salem (in 60 years). However, when the model accounts for currently underutilized water rights and those under development, urban water rights appear to be capable of meeting the overall growth in urban water demand.
- Climate change is projected to result in earlier planting for agriculture. Earlier planting will lead to more crop growth during the months when temperatures are cooler and soil moisture is more available. Earlier planting will also lead to an earlier start, and completion, of irrigation. In the future, more farmers will have finished irrigating by the time the threat of a shutoff arises, according to the model results. As a result, the model shows a slight decrease in irrigation shutoffs. Climate models differ, however, in terms of whether precipitation is predicted to increase or decrease overall, although most models suggest somewhat wetter winters and drier summers.
- Implementation of all of the "unconverted" in-stream water rights intended to protect perennial flows would represent a significant increase in the amount of water allocated under state law to environmental values. Overall, however, our results suggest that flow requirements to protect salmon and steelhead can be met, based on 10-year average flows. Exceptions are likely to occur in drought years.
- The effects of changes in forest wildfires and fire suppression policies could have a larger effect on water supply in the Valley than all of the changes in human water use combined. If forest cover is dramatically reduced, the resulting decrease in forest evapotranspiration will increase streamflows and make more water available for human use.

Introduction

Climate change, population growth, and income growth have the potential to significantly affect the availability and use of water in the Willamette River Basin (WRB). Human decisions will contribute to these potential changes. Indirectly, changes in land use will affect where and when water is used for various purposes. Legal and regulatory changes, such as modifications to augment required in-stream flows for salmon and steelhead, will also influence the supply and demand for water.

Uncertainty about future supply of and demand for water across space and time created the motivation for this report. Individuals, communities, and governments across the WRB have a strong interest in gaining a better understanding of how changes in land use, climate, population, income, and regulatory requirements will affect the supply, demand, and scarcity of water. Policy makers, government agencies, and private interests need to better understand what kinds of changes are likely to occur so that they can act to mitigate or adapt.

Predicting the magnitude, timing, and location where water scarcity will arise requires a detailed understanding of the region's biophysical and human systems—often referred to as a "coupled human–natural system." Economic and biophysical components interact across space and time in complex ways.

The linkages, interconnections, and feedbacks in complex systems of this kind are very difficult to fully understand without a detailed model. Such a model was constructed by Willamette Water 2100 (WW2100), a 6-year research project.[1] The WW2100 project involved dozens of researchers from Oregon State University, Portland State University, and the University of Oregon, bringing expertise in biophysical sciences, economics, engineering, planning, and law. The centerpiece of the project was the development of a large simulation model integrating all of these dimensions.

Creating a model of the human system for this region required a broad economics perspective of human actions and interactions. The model includes a system-wide representation of how humans interact with the natural system individually and collectively, as reflected in laws, regulations, property rights, and other institutions that guide and constrain our choices. These individual and public aspects of the human system manifest themselves in land use and land-use change; water supply and demand for urban, agricultural, reservoir, and in-stream flow allocations; and ecological water use by forests and other vegetation.

The main goals of the WW2100 study were twofold: (1) to project where, when, and under what institutional conditions (laws, regulations, and rights) water scarcity might increase in the WRB, and (2) to consider what kinds of policies and other actions might be warranted to prepare for, mitigate, or adapt to changes in water scarcity.

This report describes results from the WW2100 model, with a focus on its economic dimensions, i.e., the impacts on people who live in the WRB. Those impacts include two types:

- Changes in the availability of resources that are priced and exchanged in markets, such as land and urban water supplies
- Changes in nonmarket resources valued by society, including in-stream flows, forest health, flood risk protection, and recreational opportunities

The body of this report does the following:

- Describes the WW2100 model and provides an understanding of how the model and its components represent processes, interactions, and changes in the way people and resources interact
- Describes the main findings of the model's simulations
- Highlights the economic aspects of expected changes in the Basin as they relate to water supply, demand, and availability for specific uses

Much of the technical background about the model components is included in the Appendix.

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[1] The project was funded by the National Science Foundation (EAR 1039192, 1038925, and 1038899).

It is important to recognize the kinds of questions that our research, and this report, are not intended or able to answer. This work does not provide specific guidance to individual local governments, for example, regarding decisions to invest in or finance water supply infrastructure. Nor does our model provide advice to individual farms about adopting new irrigation methods or other farm-level investments. Although many characteristics and processes in the WRB have been modeled at high spatial and temporal detail, many other important dimensions cannot be described at the level of detail needed for decision making by individuals, farms, and local governments.

Moreover, it is important to acknowledge that results from most models, especially ones that make projections decades into the future, should be interpreted not as precise predictions, but as likely trajectories of change. Models are based on our best understanding of biophysical and human processes and how they are likely to interact in the future. In this way, a model is a tool that describes future conditions under a range of alternative assumptions and scenarios.

Water Allocation and Scarcity

Economics is the study of the allocation of scarce resources—how people use and value resources such as water and land. Some resources are exchanged in markets. In this case, prices reflect their marginal (incremental) value, provide incentives, and encourage efficient use. For other resources, including water, some other allocation mechanism is often used.

Allocating water is complicated for a variety of reasons. Water is essential to all living things; as a result, most water is left *in situ,* or in the environment. Water has been described as a "fugitive" resource due to how it moves around, flows, seeps, evaporates, and is transpired by plants. In this and other ways, water poses challenges for individuals and society. For example:

- The availability of water varies and is uncertain across space and time.
- The cost of transporting or storing large amounts of water is high due to its high volume and weight relative to its value per unit.
- Water plays a key role in complex natural–human systems and is strongly related to public goods, such as ecosystems, fish and wildlife habitat, and recreation.
- Water plays a role in quasi-public goods, such as municipal water delivery, flood control, and power generation.

"Water scarcity" can be understood as the cost (or benefit) of having one less (or more) unit of water. It is therefore the marginal, or incremental, cost or value of water. Another way to look at this is as the cost of a decrease in water availability or the benefit of an increase in water supply.

Water scarcity can vary greatly and is often specific to a particular use, at a given time, in a particular location (Jaeger et al., 2013). It is useful to recognize that the scarcity of water depends in part on whether water can be transported to where it is needed, stored for later use, or transformed in quality (e.g., temperature, salinity, or potability) in order to be suitable for a particular use. Therefore, this key economic reality—the costs of transportation, storage, and transformation of water—is central to understanding where, when, and for what uses water will be scarce.

The Willamette River Basin and the WW2100 Model

The Willamette River Basin encompasses 11,500 square miles in northwest Oregon, or 12 percent of Oregon's land area (Figure 1). The Coast Fork of the Willamette River (originating in the Coast Range), the Middle Fork of the Willamette River, and the McKenzie River (both originating in the Cascade Range) join near Eugene, Oregon to form the mainstem Willamette River. From this confluence, the Willamette flows north between the Cascades and the Coast Range for

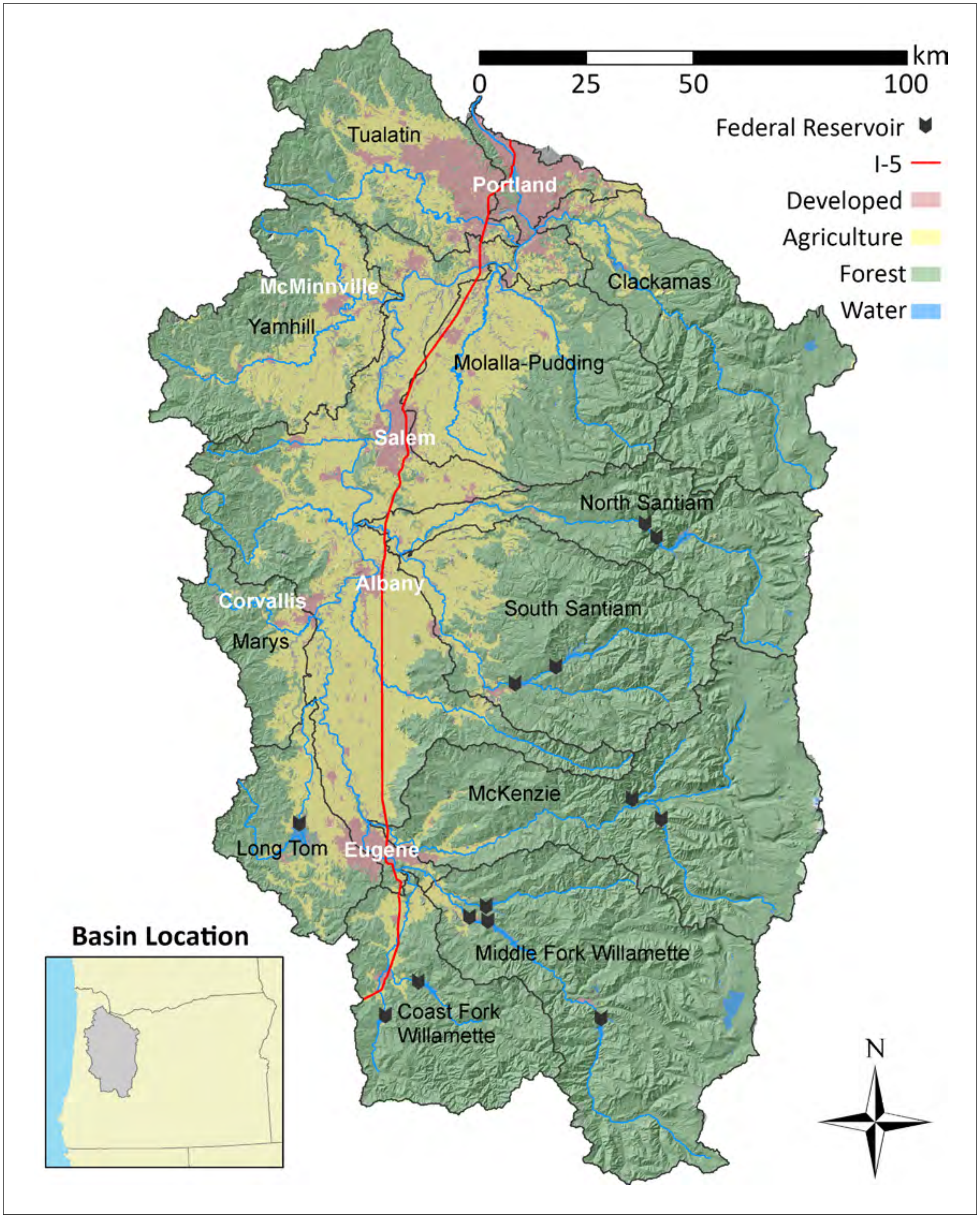

Figure 1. The Willamette River Basin.

283 river km (176 miles) and enters the Columbia River near Portland, Oregon. The Willamette Valley, an agriculturally intensive region, contains Oregon's three largest cities—Portland, Salem, and Eugene—home to over 60 percent of the state's population.

The Basin's underlying geology creates a setting in which various drivers of landscape change may impact hydrological processes. Thus, the Basin provides a rich and varied environment for studying the potential impacts of climate and human change on water resources.

The Cascade Mountains form the eastern border of the WRB. In this region, glaciers and extensive areas of mid-elevation snowpack are underlain by layers of low- and high-permeability volcanic bedrock. On the western border of the WRB, the Coast Range includes steep slopes underlain by low-permeability sedimentary and volcanic rock. This region receives more than 2,500 mm (98 inches) of rain per year, but little snowfall.

Tributaries of the Willamette traverse the region, providing the opportunity to examine streamflow response across a range of climatic, geologic, and ecological gradients and boundaries. After the McKenzie River, the largest tributaries are the Clackamas River, the North Santiam River, and the South Santiam River.

The WW2100 project developed a computer-based model of the Basin's human and natural system components across time and space.[2] The large number of detailed relationships and processes makes this model innovative and exceptional. The model includes physically and empirically based submodels of the biophysical system, as well as empirically based economic submodels of the human system. These submodels are linked using a simulation software platform, Envision.[3]

The model's main components and linkages are represented in Figure 2 (page 9). Processes determined outside the model (exogenous to the model) include daily temperature, precipitation, humidity, wind, and radiation (derived from downscaled regional climate data) and annual changes in population and income.[4]

The model's economic components incorporate human behavior. The use of land and water for different purposes reflects the multitude of decisions that farmers, firms, and households make on a daily basis. Thus, the economic models incorporate choices and responses to prices in order to predict how agricultural and urban water withdrawals will vary by year and by season.

In the case of agriculture, evolving temperature and precipitation conditions affect plant growth, daily evapotranspiration (ET), and soil moisture. In turn, these factors affect decisions about crop choices, planting dates, and irrigation. In urban areas, population and income growth lead to increased water use, while other changes, such as higher water prices or increased urban density, limit the rate of increase.

The WW2100 climate projections are based on three General Circulation Models (GCMs) downscaled to 4-km resolution. The model's reference scenario uses MIROC5. The "high climate change" scenario uses HadGEM, and the "low climate change" scenario uses GFDL.[5]

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[2] The Willamette Water 2100 Project involved more than 40 researchers at Oregon State University, Portland State University, and the University of Oregon (see http://water.oregonstate.edu/ww2100/). The project leadership team and main investigators included Adell Amos (UO), John Bolte (OSU), Samuel Chan (OSU), Heejun Chang (PSU), Stan Gregory (OSU), Roy Haggerty (OSU), David Hulse (UO), William Jaeger (OSU), Christian Langpap (OSU), Hamid Moradkhani (PSU), Philip Mote (OSU), Anne Nolin (OSU), Andrew Plantinga (OSU), Desiree Tullos (OSU), David Turner (OSU), Kellie Vache (OSU), and Scott Wells (PSU). See http://water.oregonstate.edu/ww2100/project-team for a list of the entire project team.

[3] The computer modeling platform Envision was developed by John Bolte at OSU (http://envision.bioe.orst.edu/). The economic model components were designed by William Jaeger, Andrew Plantinga, and Christian Langpap and were coded by David Conklin. The water rights model was developed, specified, and coded by James Sulzman, David Conklin, and William Jaeger. The forest model was developed by David Turner and David Conklin (see Turner et al., 2015). The reservoir model was developed using ResSim Lite by Desiree Tullos and Matt Cox. The hydrology modeling framework was developed by Kellie Vache. The biological water demand (ET) models were developed by Cynthia Schwartz.

[4] Downscaling is a procedure whereby climate model projections for a large area (say 100 square miles) are converted into sets of estimates at a higher resolution (e.g., each 10-square mile area within the 100-square mile region).

[5] For more detail on the climate model, see Turner et al. (2015).

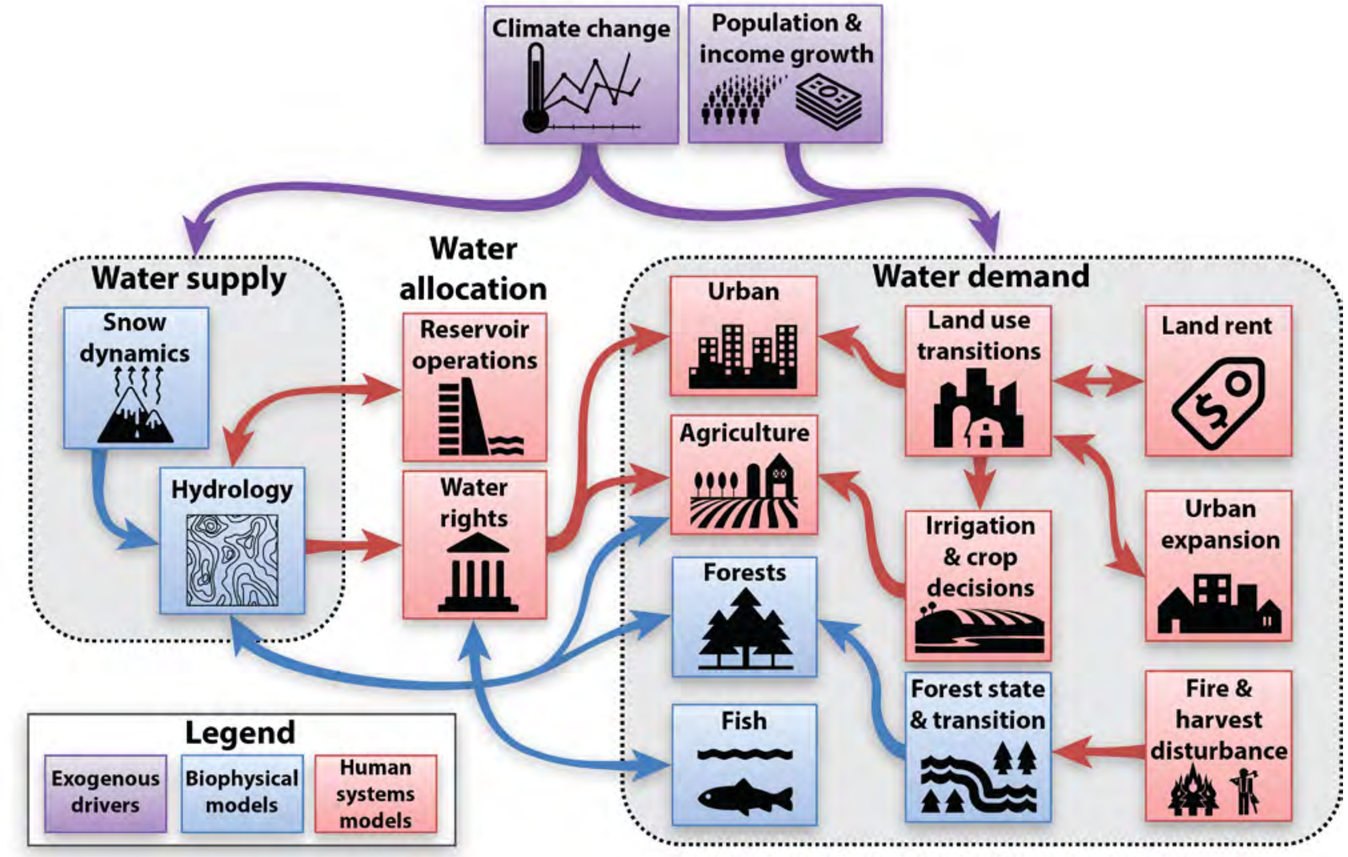

Figure 2. The WW2100 model, main components and linkages.

The Basin's hydrology is represented by stocks and/or flows of rain, snow, soil moisture, groundwater, and streamflow in each of 160,000 landscape polygons, an overlapping network of river reaches and nodes, and 13 U.S. government reservoirs (11 of which store significant volumes of water). Daily temperature, precipitation, and atmospheric humidity determine surface hydrology, including snowmelt, ET, streamflows, and water temperatures.

The relationships between these hydrologic factors generate daily average streamflow and reservoir levels throughout the Basin's network of stream reaches and reservoirs, all the way to the Columbia River. A reservoir model simulates reservoir fill and discharge to meet federal flood control, storage, and streamflow targets. All irrigation, municipal, and in-stream water rights are fully represented by a detailed submodel reflecting their point of use, point of diversion, priority date, maximum rate, duty (maximum total annual diversion), and beginning and end date.

Forest water use is modeled on a daily basis according to estimated ET rates, which vary with evolving forest characteristics (stand age, species type) and meteorological conditions. Forest fire and forest harvest models introduce disturbances to forest land cover and stand age.

At a fine spatial scale, the model simulates the period 2010 to 2100, with some processes adjusting annually and others taking daily time steps. Model processes that follow an annual time step include forest growth, harvest, and wildfires; the determination of land values and land-use changes; regulatory adjustments to urban growth boundaries; crop choices; and irrigation decisions. Daily time-step processes include routing of surface hydrology throughout the Basin's stream network; water use (ET) by forests and other vegetation; and timing of crop planting, crop growth, irrigation diversions, urban water use, soil moisture, groundwater flows, and reservoir management.

Projected Changes in Climate, Population, and Land Use, 2010–2100

The WW2100 model, as described above, can simulate current or recent patterns of water supply and use. However, its main purpose is to simulate the future. In our model, future years will differ from current years due to three factors: changes in climate, changes in population, and changes in household income.

The model's reference scenario generates trajectories of change for 2010–2100 in response to changes in climate, population, and income. The reference scenario is intended to reflect the most likely trajectory of change. It is based on "business-as-usual" assumptions about the existing system, including midrange estimates for exogenous drivers such as climate change, population growth, and rising incomes.

The reference scenario is one of more than 20 scenarios (see Appendix). Other scenarios include five different types of alternative scenarios developed for different purposes. See the Appendix (page 99) for more detail.

Alternative scenarios can be very useful in helping to attribute outcomes to specific factors. They are also useful for policy analysis. The comparison of a reference scenario to a scenario that represents a policy change can provide insights into "what-if" questions about the costs, benefits, or effectiveness of public policies. See the Appendix for more details.

Natural system changes

The climate models used in WW2100 generate daily temperature, precipitation, and other variables from 2010 to 2100, based on major General Circulation Model (GCM) outputs. The WW2100 model includes three different climate scenarios. Results indicate that by the year 2100, temperatures in the WRB will rise by 1°C to 7°C (2°F to 13°F). Summer temperatures are projected to warm about 2°C (3.6°F) more than winter temperatures.

In the case of precipitation, the three climate scenarios indicate that winters will become slightly wetter and summers slightly drier (Figure 3, p. 11) . However, there is no consensus, based on examination of more than 40 climate models, about whether the Basin's climate will become wetter or drier overall.

Climate change will result in changes in water supply at specific times and locations. Snowmelt has historically contributed about 600,000 acre-feet of water to streamflows from April 1 through midsummer, primarily in the Cascade Range. Snowpack may respond dramatically to even a few degrees of climate warming. The WW2100 model predicts dramatic reductions in winter snowpack (65 to 95 percent by late in the 21st century); see Figure 4, p. 12.

Where streamflow depends on snowmelt, this loss of "natural" water storage will result in flows that are smaller and come earlier in spring and summer than has been the case historically (Figures 5 and 6, p. 13). However, spring precipitation plays a much larger role than snowpack in determining spring and summer flows in the WRB. Thus, the reduction in snowpack likely will have little effect on the supply of water for human uses in the lower basin. In Figure 7 (p. 14), we compare the 10-year-average midsummer (July and August) discharge for each subbasin. In both the reference scenario and the high climate change scenario, we see no significant decline in average summer flows.

However, the loss of spring snowmelt may have serious ecological ramifications for forests and their ecosystems. In the Mediterranean-like climate of the Pacific Northwest, available soil water declines in mid- to late summer. If less snowpack is available to delay soil water depletion, the result will be a longer summer dry period. Across the three climate scenarios, the result is an increase in the area of wildfires of 200 to 900 percent. Wildfires can be expected to increase the transition to new forest types and reduce the availability of forest land for timber harvest (see Figure 8, p. 15, and Turner et al., 2015). As forest cover declines, reduced forest water use will allow more surface water to flow into the Willamette Valley.

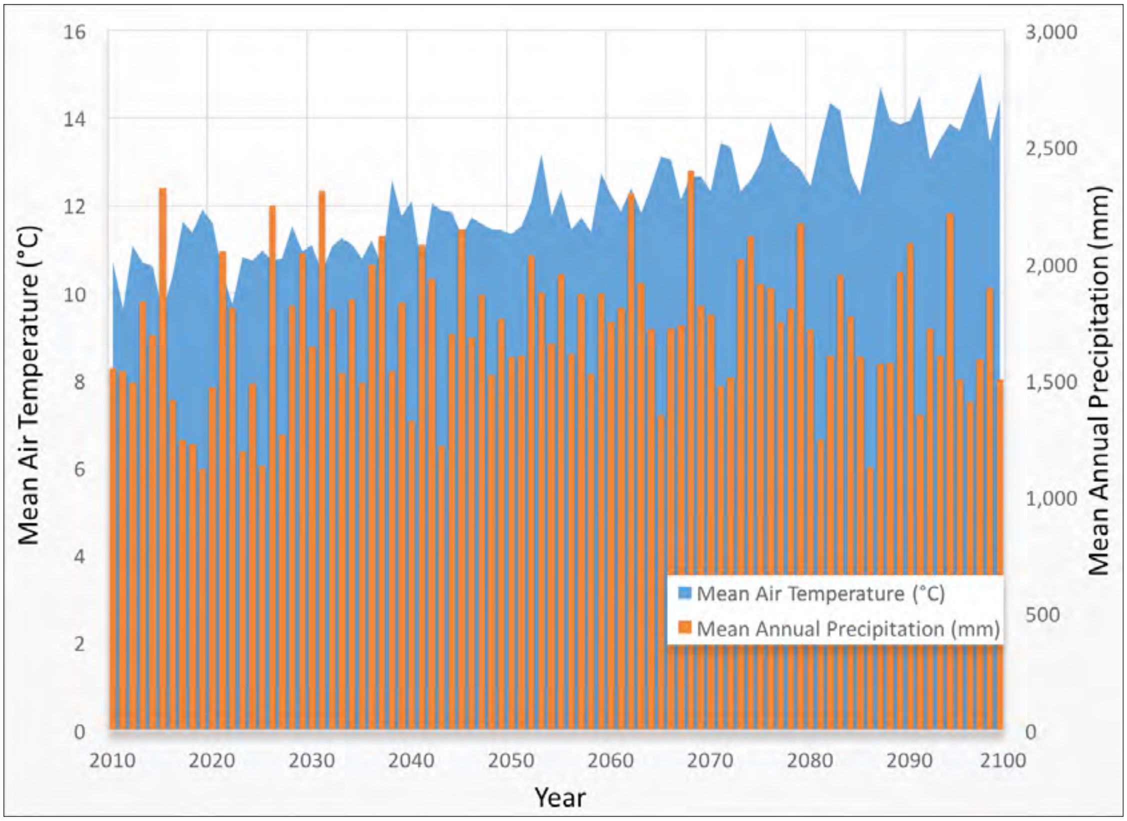

Figure 3. Temperature and precipitation.

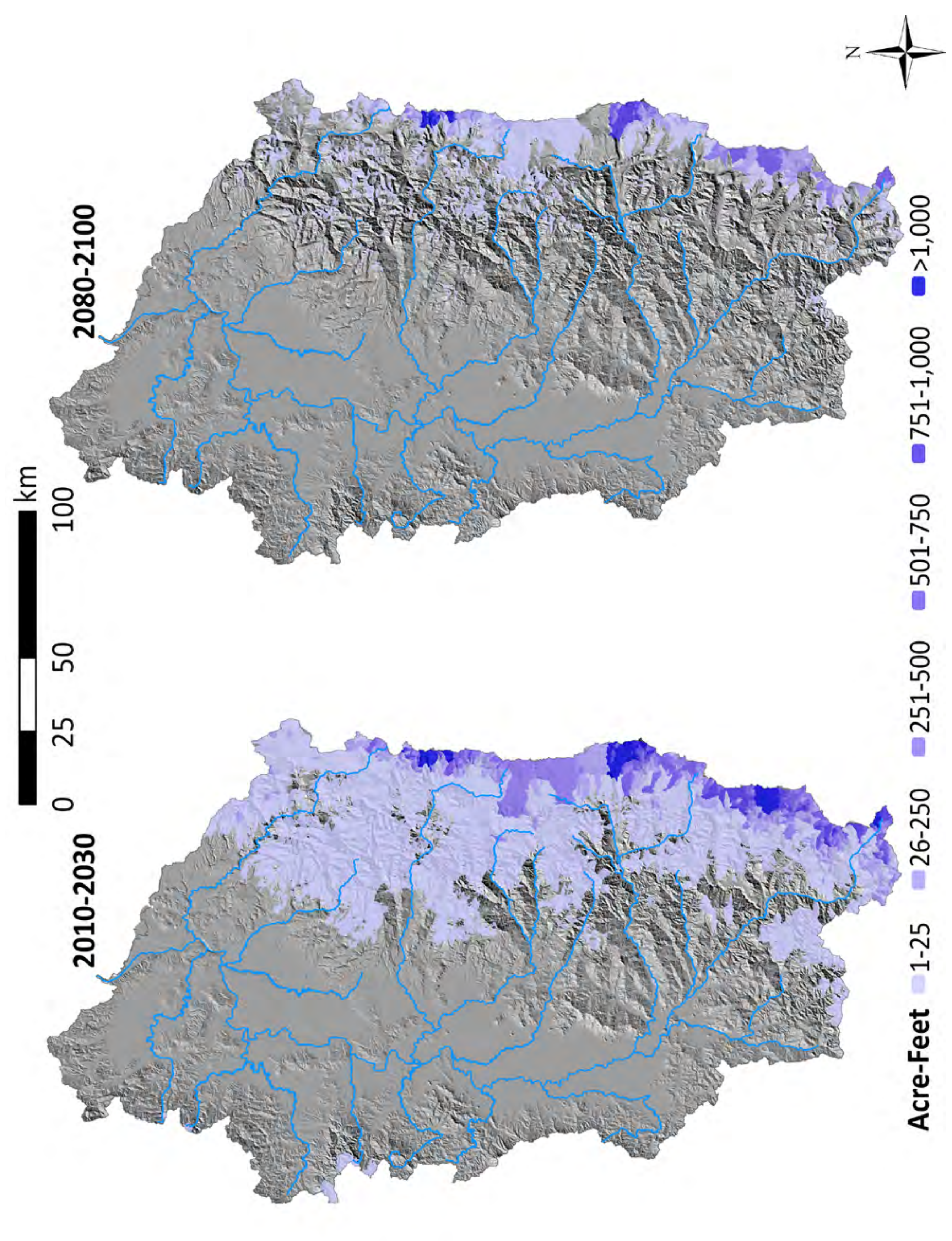

Figure 4. Distribution and depth of April 1 snowpack (snow water equivalent, SWE)

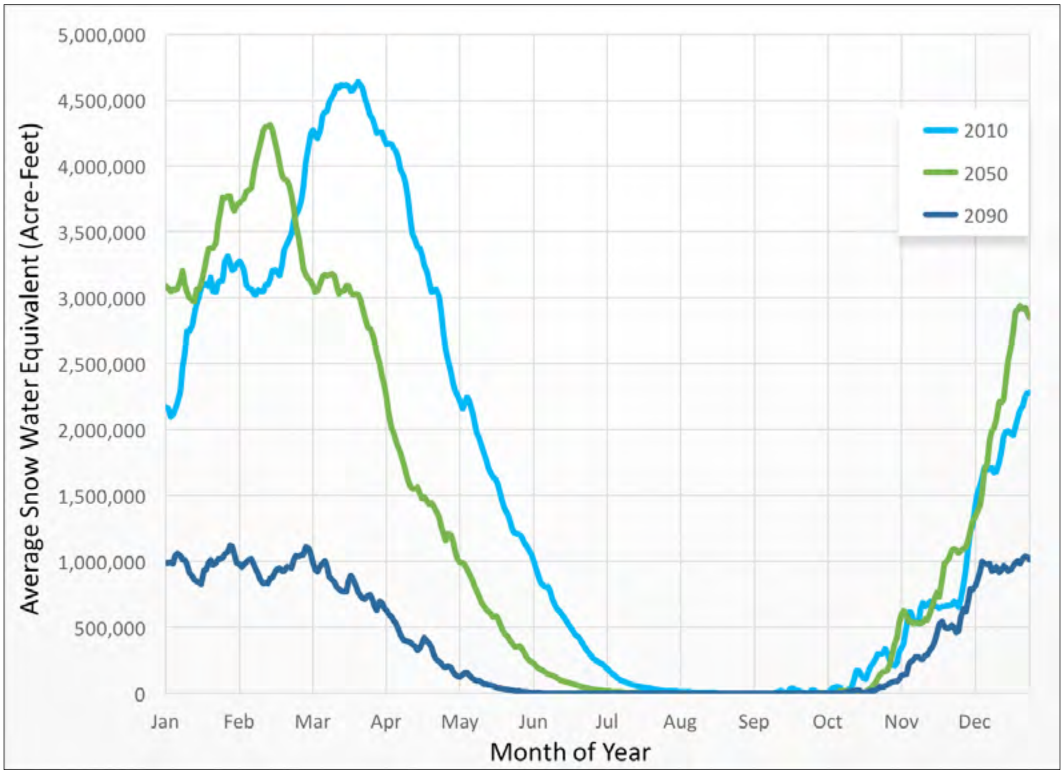

Figure 5. Seasonal average snow water equivalent (SWE) by decade at high elevations (>4,000 feet), reference scenario.

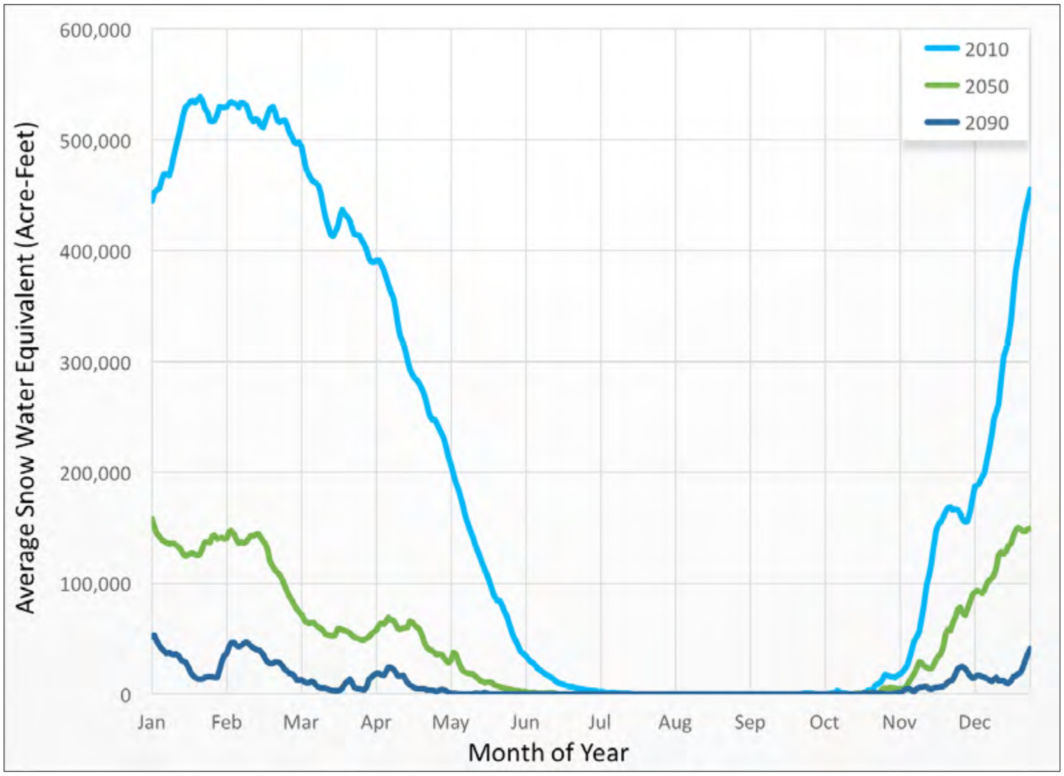

Figure 6. Seasonal average snow water equivalent (SWE) by decade at high elevations (>4,000 feet), high climate change scenario.

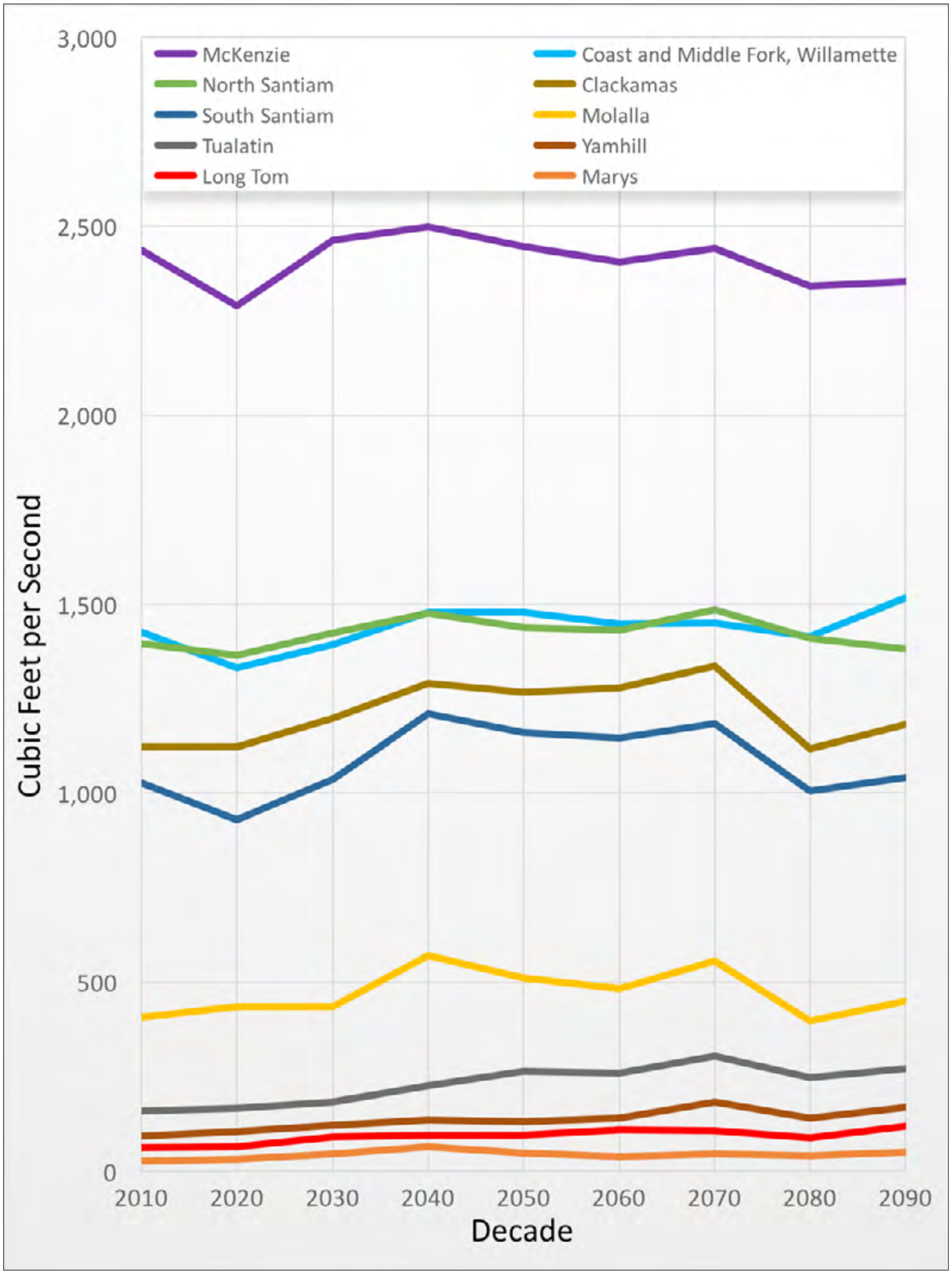

Figure 7. Subbasin outflows, July–August (decade average).

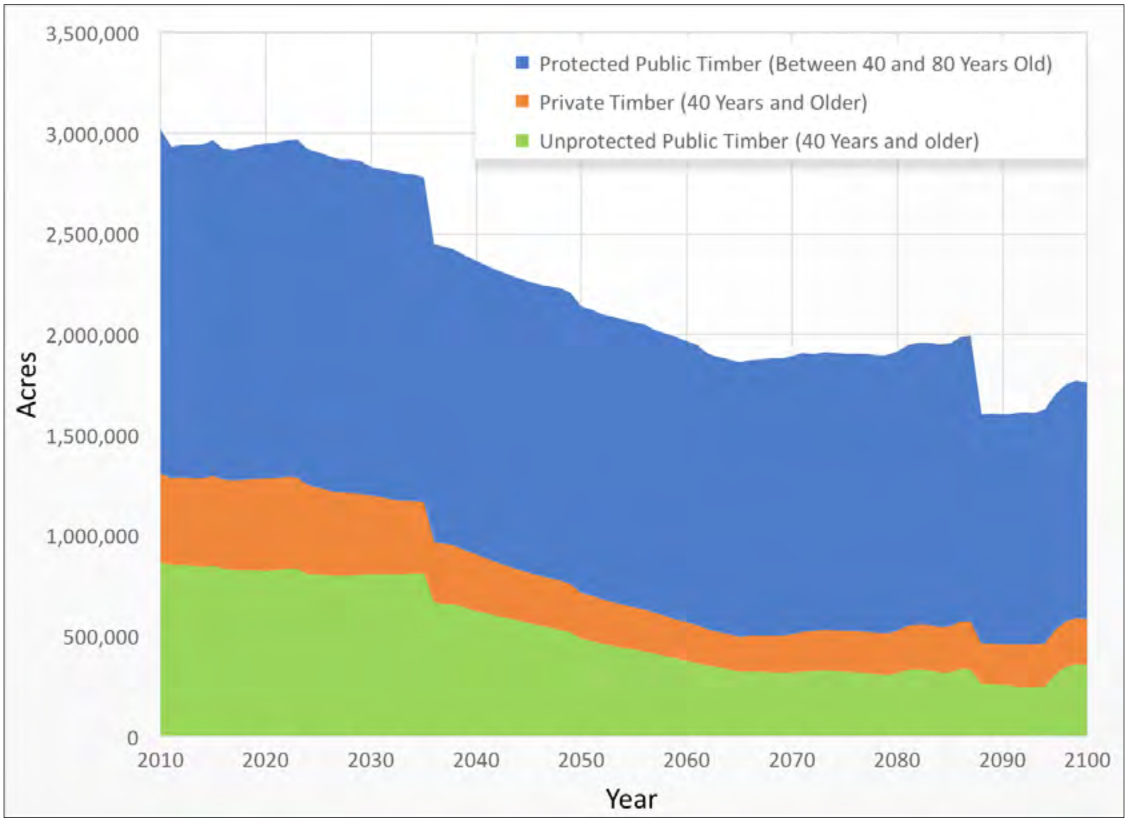

Figure 8. Changes in forested areas due to harvest and wildfire.

Changes in population, income, and land use

Population and income growth are assumed to be determined by forces outside the model. Thus, like climate change, these factors are exogenous to any actions by individuals or policy makers in the Basin. These trajectories are shown in Figures 9 and 10 (p. 17).[6]

County-level population projections to 2050 are taken from the Oregon Office of Economic Analysis. Income projections to 2040 are from Woods & Poole Economics, Inc.(http://www.woodsandpoole.com/). Beyond 2050 and 2040, population and income are assumed to increase at the historical average annual rate. Income figures represent mean total personal household income expressed in "real" (inflation-adjusted) 2005 dollars. Projected trends are described in more detail and compared to historical trends in the Appendix.

The land-use model is based on historical data from the National Resources Inventory (NRI) and county assessors' offices. The land-use models incorporate the economic returns to forest, developed, and agricultural uses for each parcel, or IDU (Integrated Decision Unit). Relevant characteristics of IDUs include distance to the nearest city, population density and household income in the nearest city, and soil quality. The calculated value for each use changes over time with evolving IDU characteristics. For example, growth in population and income increases the returns to developed uses of land, relative to forest and farm uses.

The functions that estimate the economic returns to each land use were derived from historical data for the Willamette Valley (Bigelow, 2015).[7] During a model run, land-use changes may occur annually at the IDU level; in response to changes in the relative returns to different uses, IDUs may shift among agricultural, forest, and urban uses.

Urban expansion is regulated by Oregon's statewide land-use planning system, which requires the use of urban growth boundaries (UGBs) to guide the location of urban development. It is assumed for the reference scenario that future land development will take place inside UGBs, although UGBs can expand (i.e., IDUs are added to a UGB area) when the amount of developed land within the UGB exceeds a specified percentage. Approximating rules under Oregon's land-use planning system, the model adds IDUs to a UGB on the basis of adjacency, distance to the UGB center, distance to a major road, and zoning. As a result, development in 2100 is clustered in a way that resembles the pattern in 2010. Figure 11 (p. 18) shows that most urban expansion will occur in the Portland Metro area, where population increases are projected to be greatest.

Population density is an important determinant of developed land values. In many of the major cities in the Basin, population density is projected to increase under the reference scenario, although in some cases it remains relatively constant (Figure 12, p. 19). Increasing urban populations and population density will lead to rising values for developed land (Figures 13, p. 19; and 14, p. 20), thus increasing the conversion of land to developed uses. Other contributing factors to land conversion are income growth, which raises per-capita consumption of land for housing, and expansion of UGBs, which makes more land available for development.

In 2010, developed land accounted for about 4.7 percent of the total land area of the WRB; this share is projected to rise to about 7.2 percent by 2100, a 54 percent increase (Figure 15, p. 21). This increase is mirrored by declines in agricultural land (from almost 22 percent of the total area to 20.2 percent) and forest land (from 70.6 percent to 69.7 percent). Thus, despite large increases in population and income, a large amount of agricultural and forest land is expected to remain in the Basin at the end of the 21st century.

Two alternative scenarios show the sensitivity of model results to assumptions about population growth and UGB expansion rules. As expected, when

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[6] Recently, there has been discussion about the possibility that climate change might lead to large increases in migration from other regions of the country to relatively wet, cool regions such as western Oregon and Washington. Existing economic studies do not find evidence that migration is significantly responsive to changes in temperature in the U.S. The availability of air conditioning is one reason. Another is the fact that agriculture, as a source of employment and income, plays a much smaller role in the U.S. economy than in the past, for example, during the Dust Bowl. (See Lewis and Peri, 2015, for an overview.)

[7] In the same way that population, income, and climate are treated as exogenous, we assume that prices for agricultural and forest commodities, which influence forest and agricultural land values, are exogenous, since they are determined in global markets. We assume that they will remain at current levels in real, inflation-adjusted terms, since we have no specific basis for assuming that they will rise faster or slower than other prices or wages.

population is assumed to grow at double the projected rate, or the threshold for expansion of UGBs is relaxed, urban development increases at considerably greater rates. These two alternative scenarios are compared to the reference scenario in Figure 16 (p. 22). In these scenarios, total developed land increases by approximately 96 percent (high population growth) and 64 percent (relaxed UGB expansion rules).

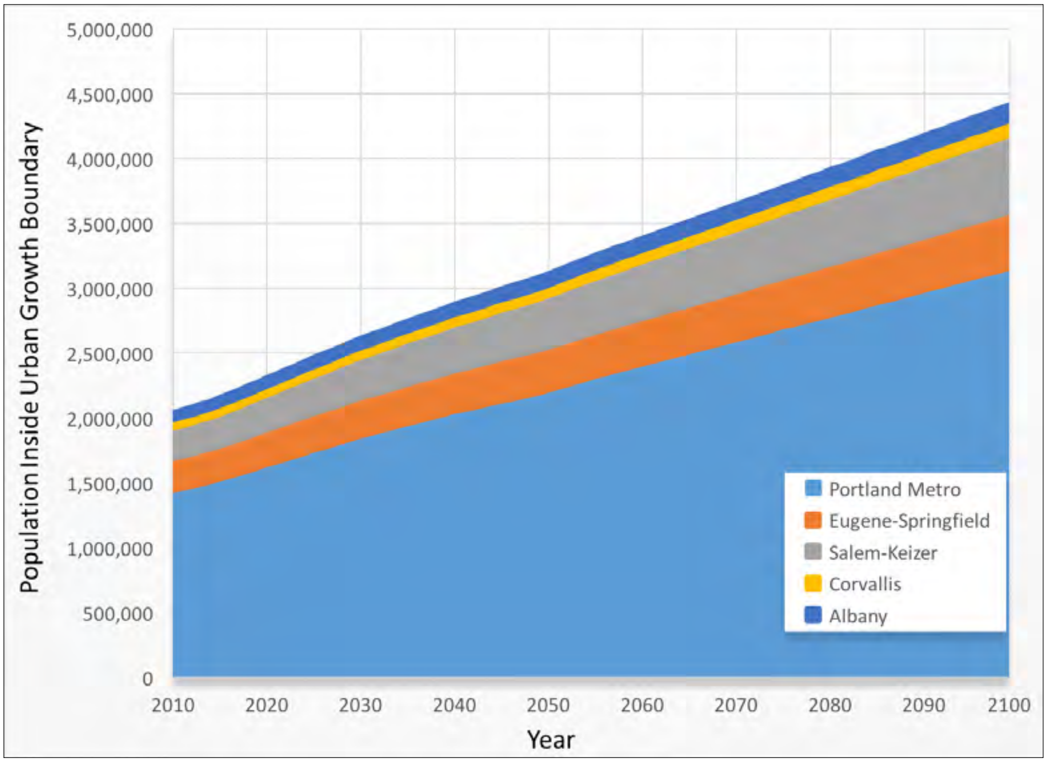

Figure 9. Population, largest cities.

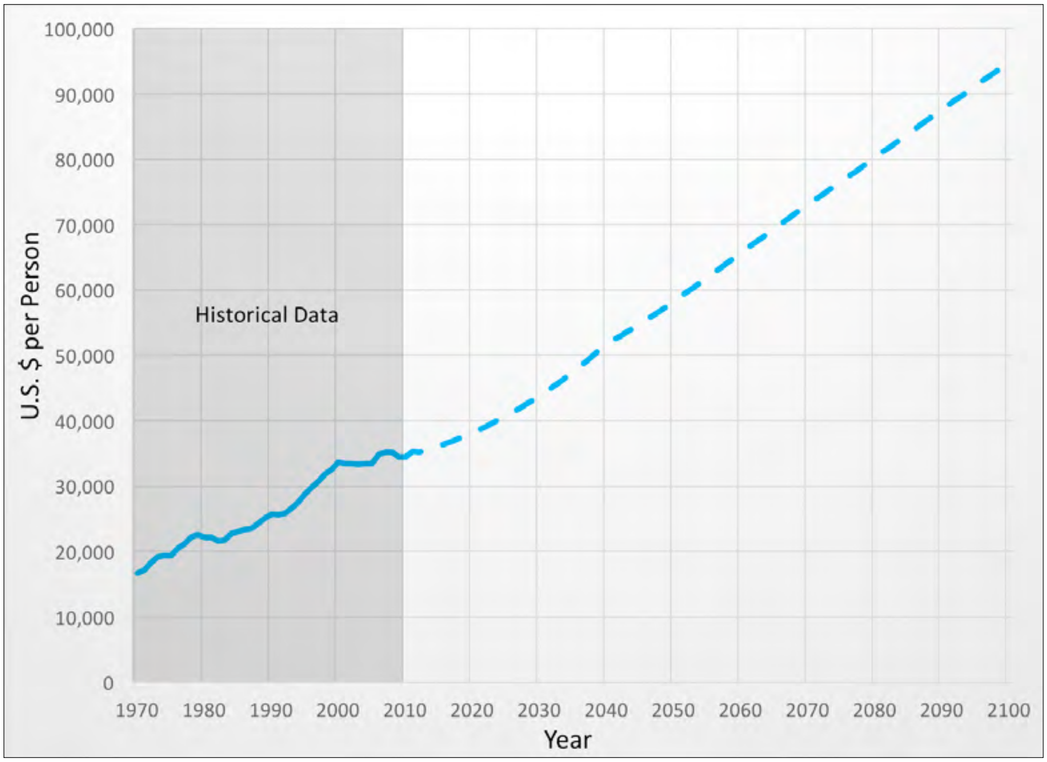

Figure 10. Per-capita income.

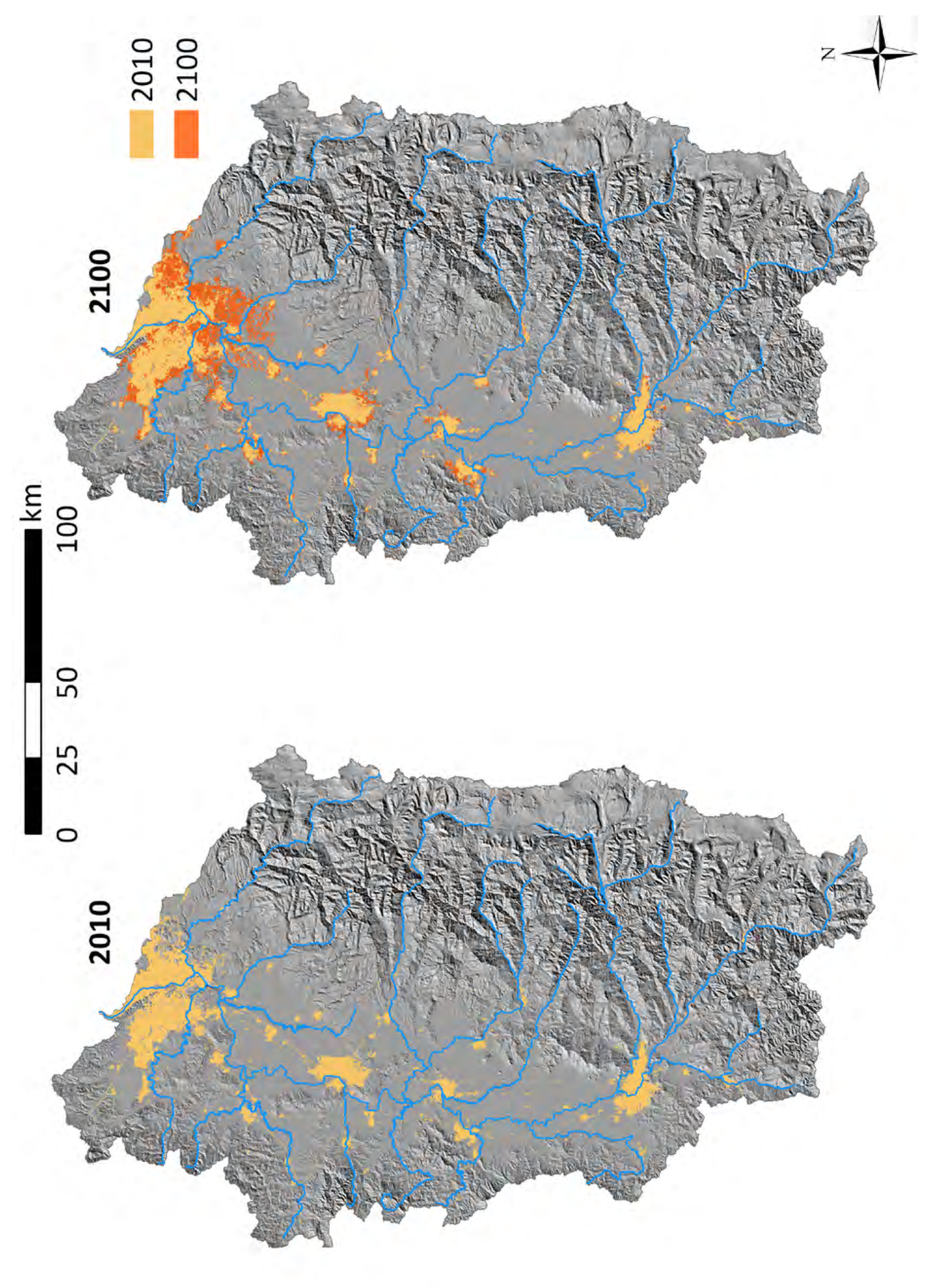

Figure 11. Expansion of urban growth boundaries (UGBs).

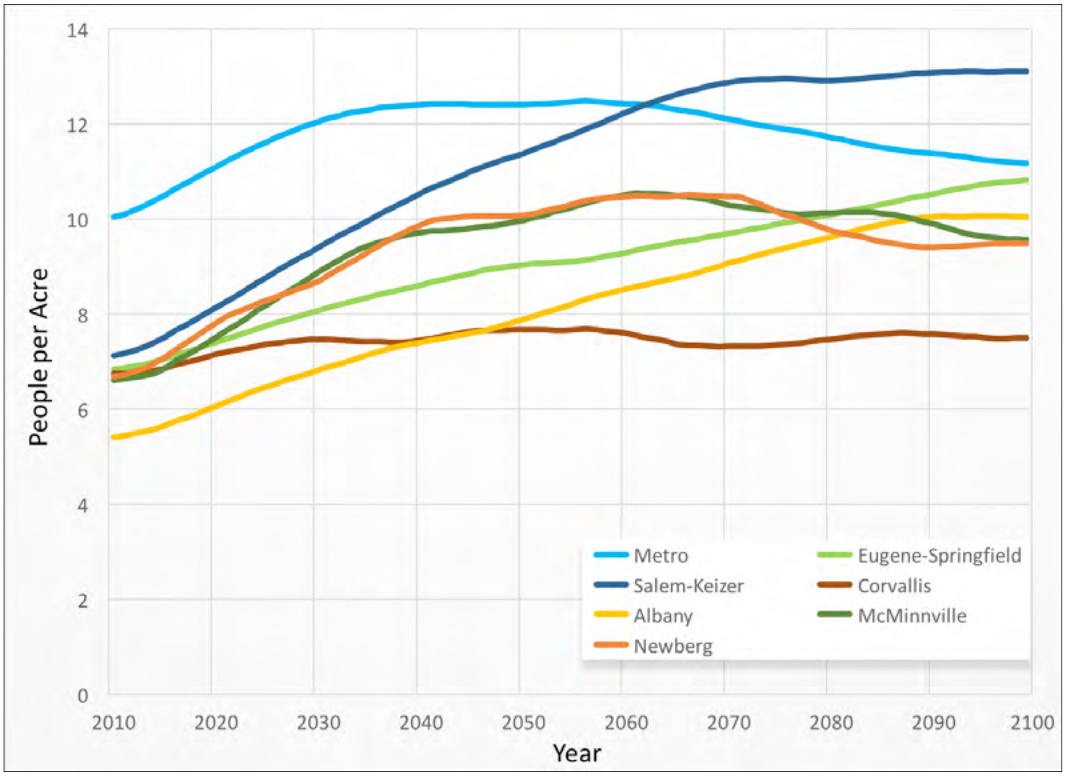

Figure 12. Urban population density, largest cities.

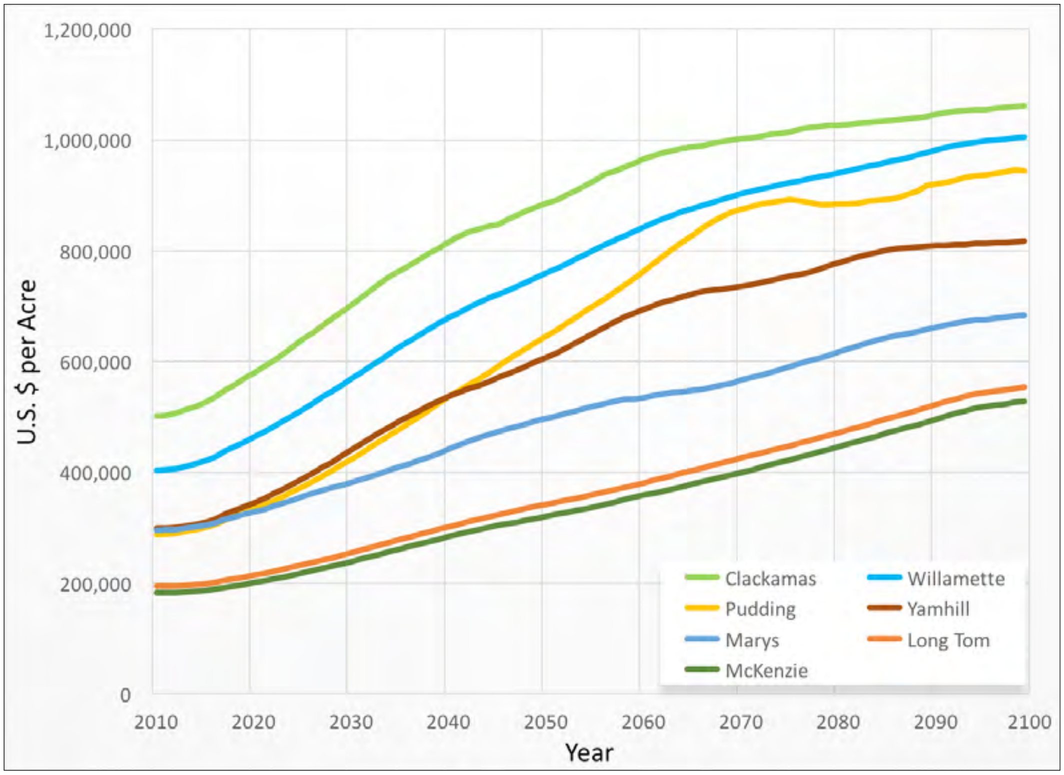

Figure 13. Developed land prices by subbasin.

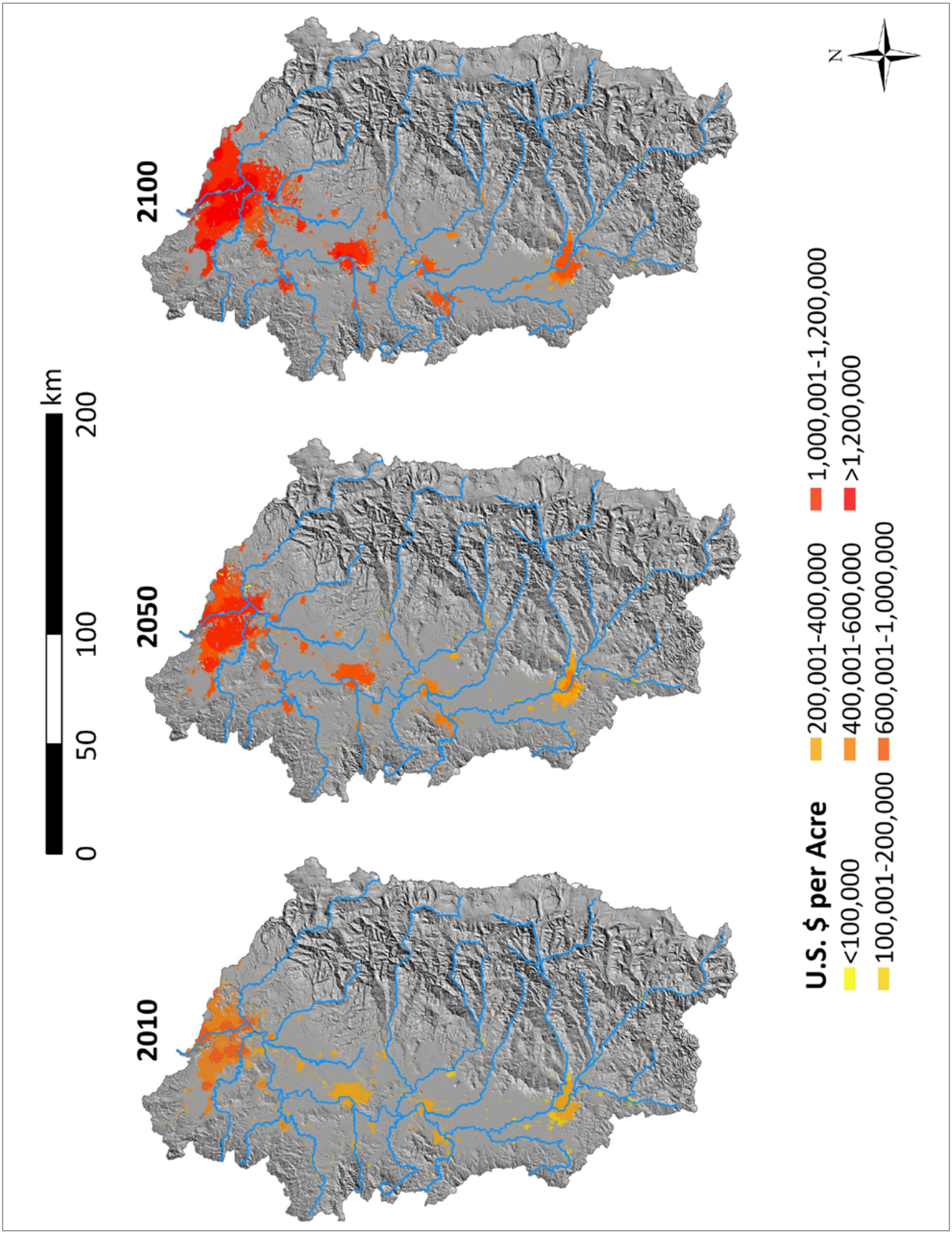

Figure 14. Developed land values.

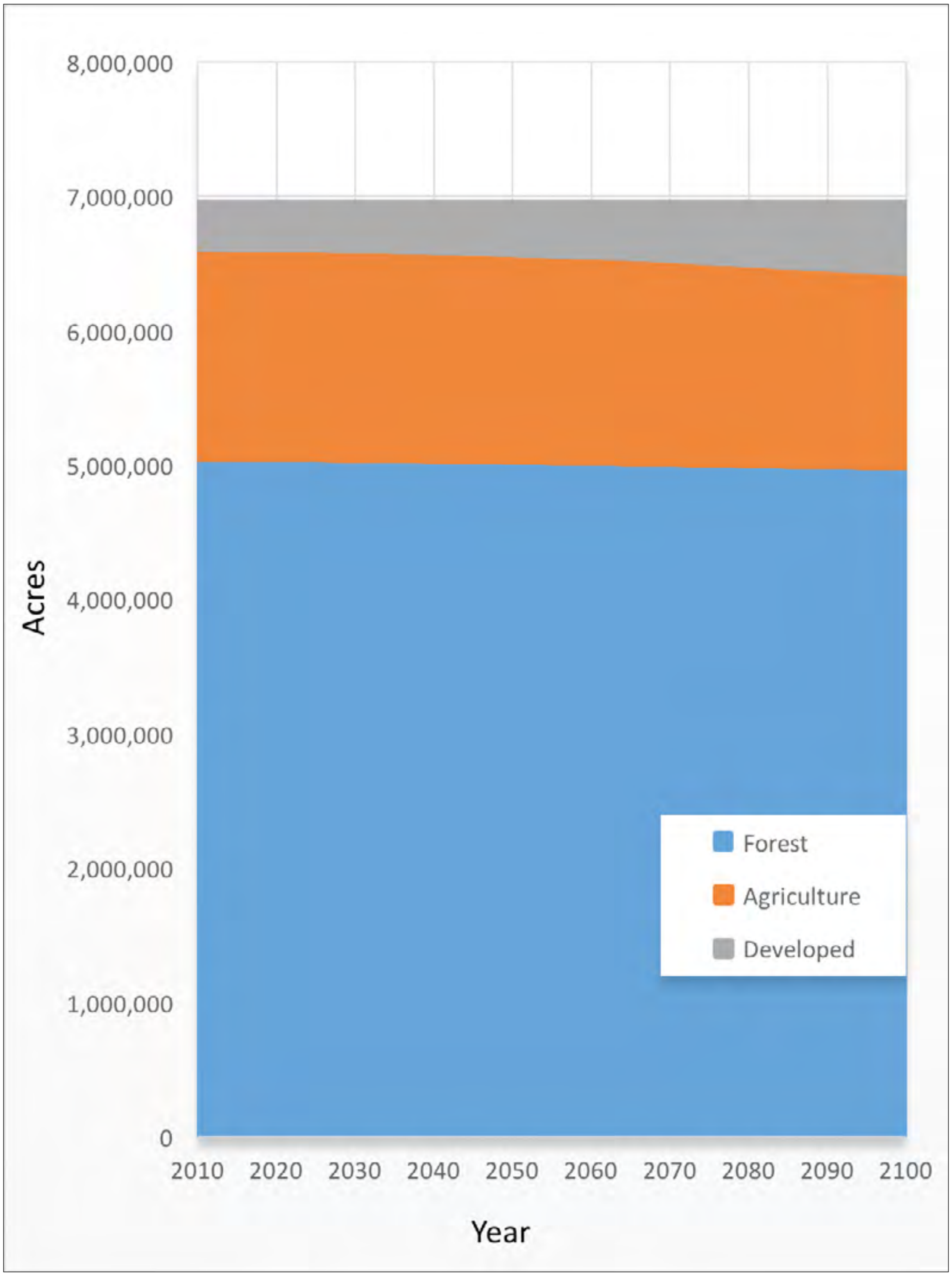

Figure 15. Land use and land-use change.

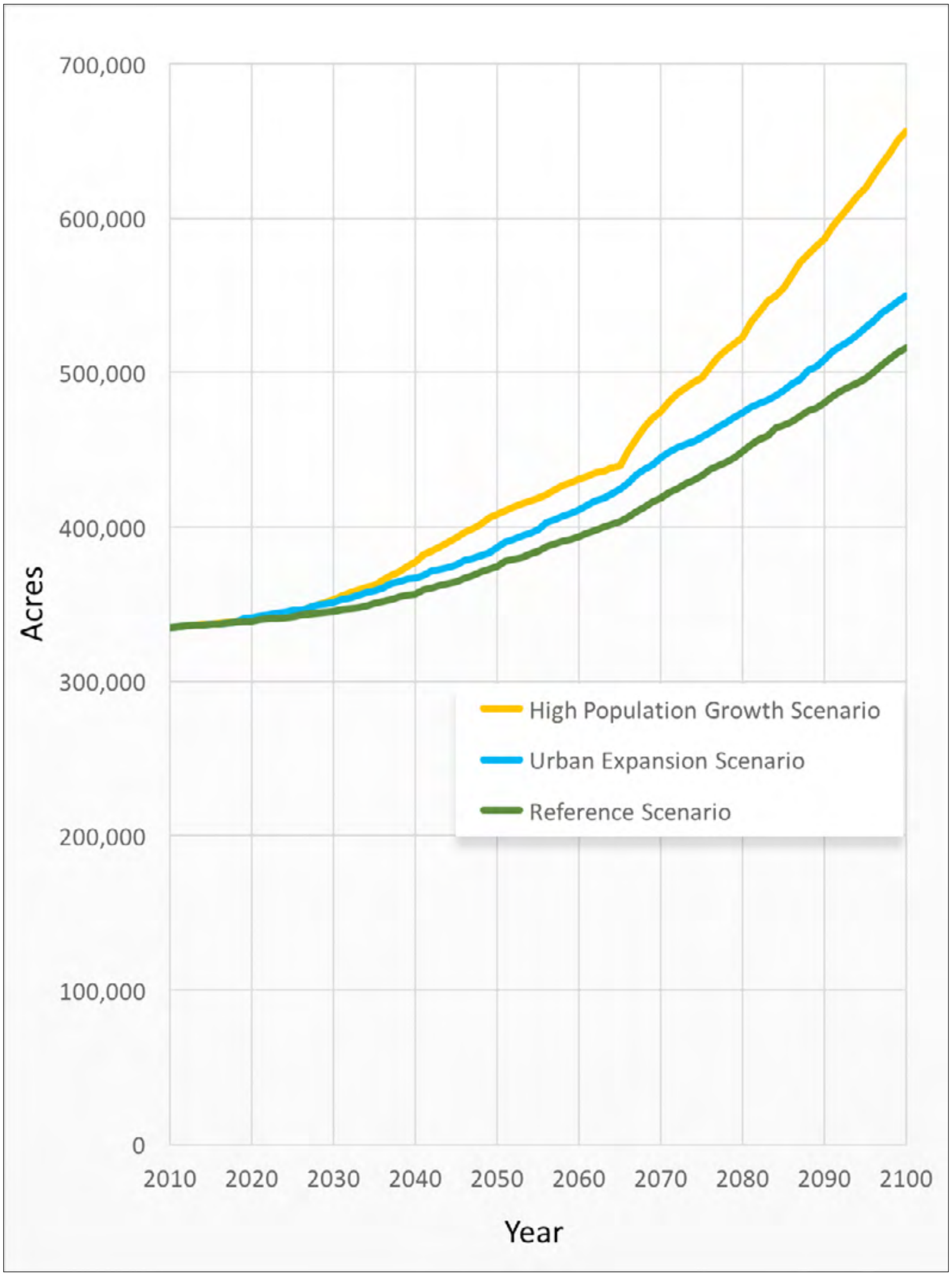

Figure 16. Growth in developed land area, three scenarios.