Water in the Willamette River Basin:

Problem-based learning using science, engineering and technology

Oregon State University

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NSF

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About these Slides

The following presentation is based on work from the Willamette Water 2100 project, a scientific research project that evaluated how climate change, population growth, and economic growth will change the availability and the use of water in the Willamette River Basin (WRB) over the 21st century. The project ran from October 2010 through September 2016, and was a collaborative effort led by faculty from Oregon State University (OSU), the University of Oregon (UO), Portland State University (PSU) and the University of California-Santa Barbara.

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Standards Addressed (NGSS)

- Evaluate competing design solutions for maintaining biodiversity and ecosystem services. (MS-LS2-5)
- Examine how increases in human population and changing uses of natural resources impact Earth's systems. (MS-ESS3-4)
- Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. (MS-ETS1-1)
- Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. (HS-LS2-2)
- Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. (HS-LS2-6)
- Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity. (HS-ESS3-6)
- Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. (HS-ETS1-3)

Possible Pre- and Post-Quiz Questions

1. List all the important *processes* in the Water Cycle you know of.
2. Is clean, usable water evenly available in the Willamette Water Basin? What are the *reasons* for your answer?
3. Name two (2) important *end-users* in Willamette River water.
4. Name and describe two (2) changes in *regional or climate conditions* that could effect the availability of water use in the Basin?
5. Why is fresh water the focus of so much research and study here and around the world. *Give as detailed an answer as possible*.

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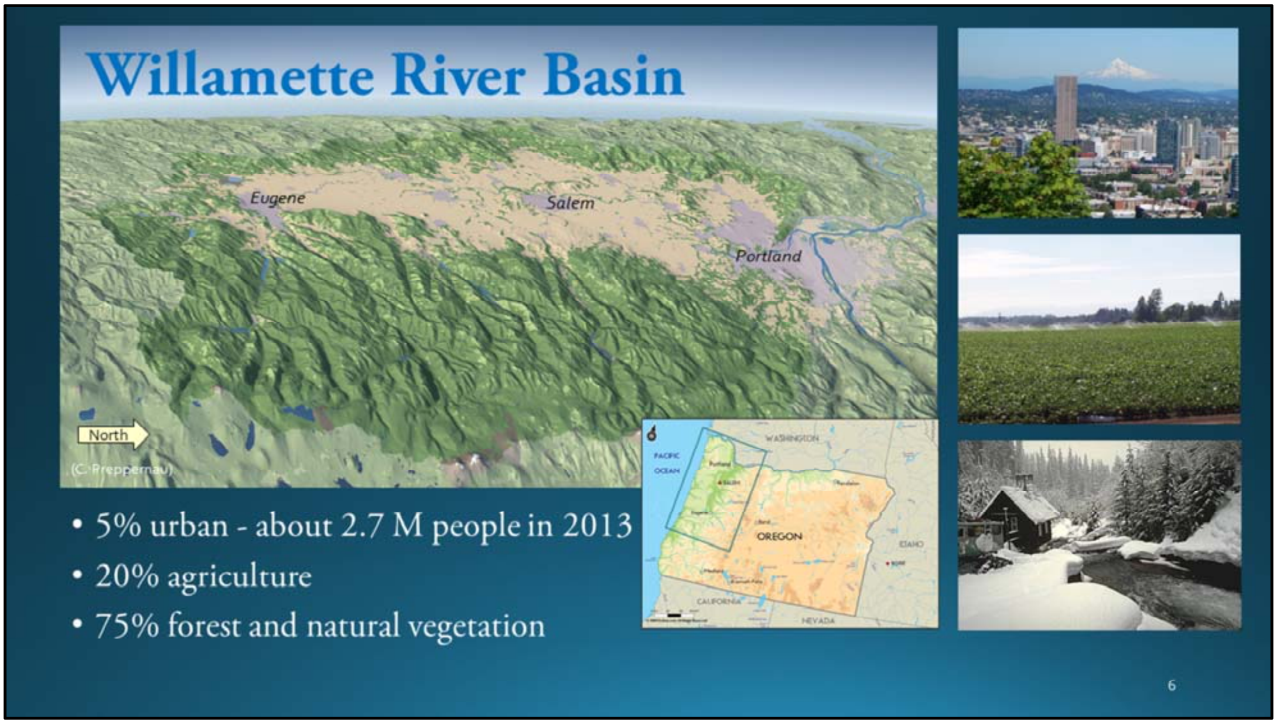
Learning Targets

- Describe the water cycle in the Willamette Basin.
- Describe how seasons and geography affect water supply and demand.
- Introduce how different sectors use and manage water.
- Consider how climate change and population growth may effect water supply and demand in the future.

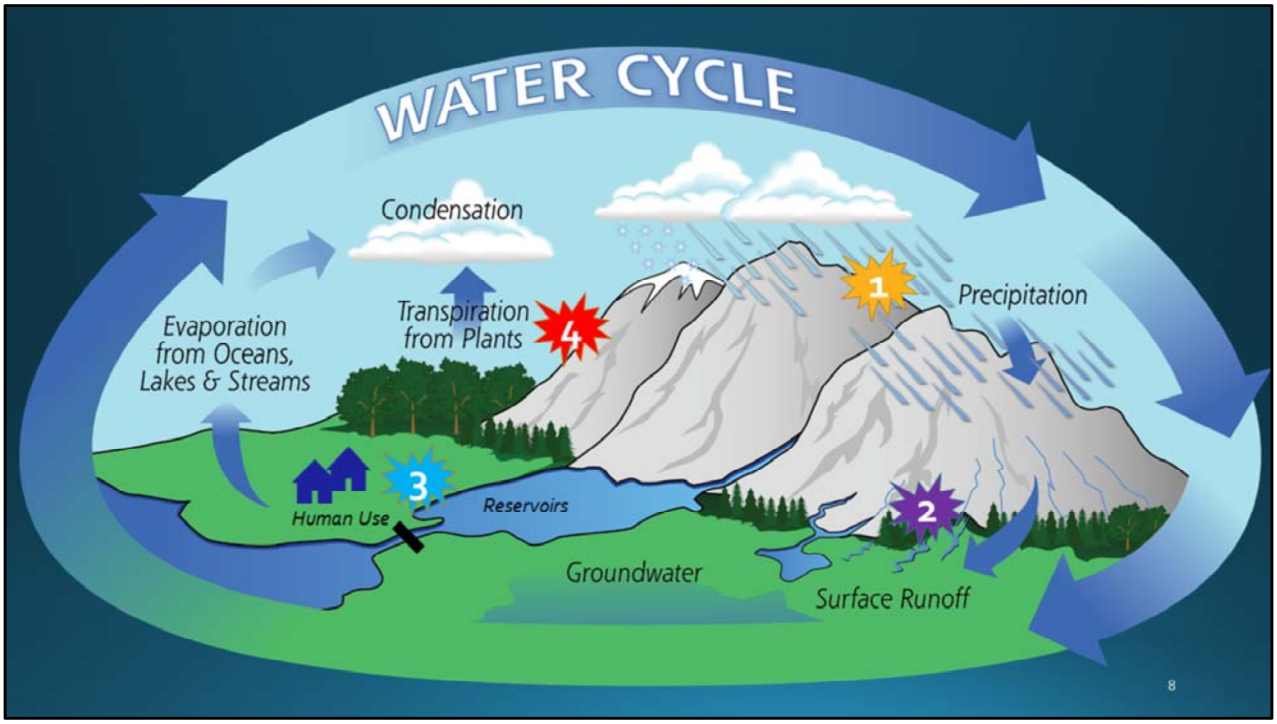


Context -- Our basin has diverse landscapes – from the forested Cascade Mountains, the agricultural Willamette Valley, to the densely populated cities of Eugene, Salem, and Portland. Water flows through all of these landscapes and links them together.

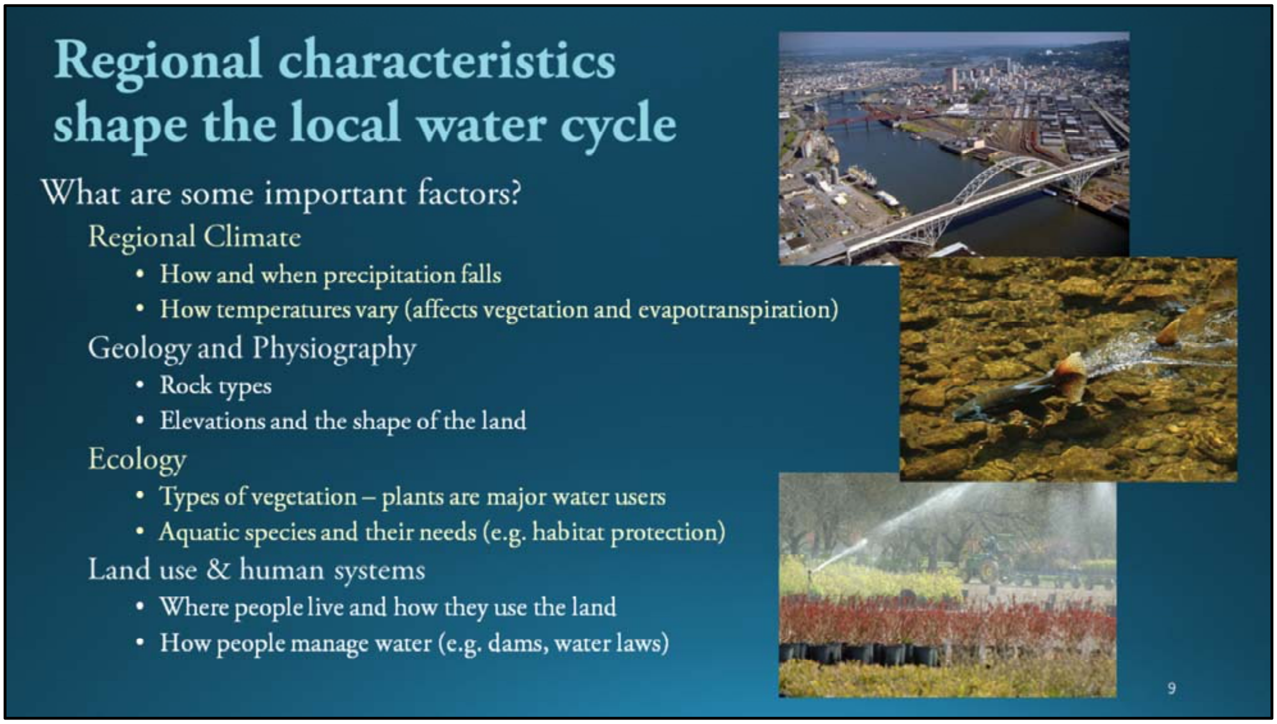
Population number from Population Research Center, 2013
Photo sources (top to bottom) : USACE, OSU, USFS (HJ Andrews Experimental Forest)

Willamette River Basin: Questions to Consider

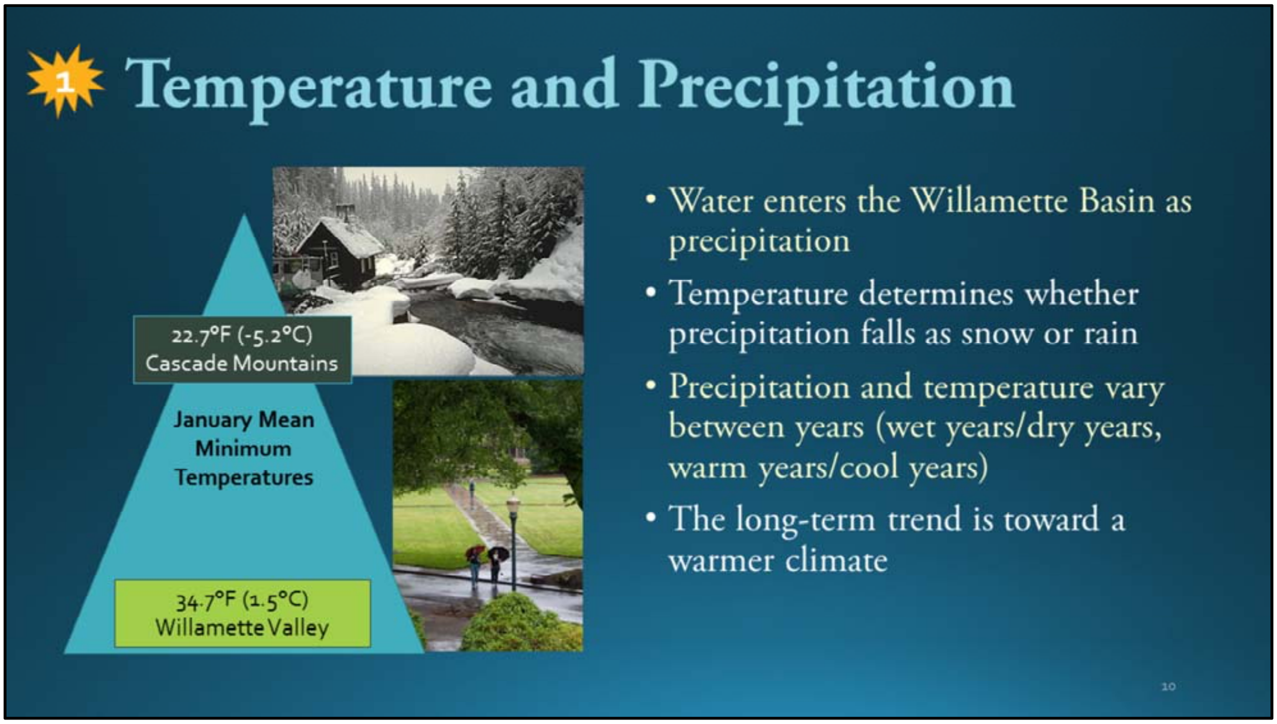
1. What does the water cycle look like in our home watershed?
2. Where does the water we use come from, and what affects its availability and quality?
3. Where does water go after we've used it?
4. Who are the major water users in the Willamette River Basin?
5. How might future climate change and population growth affect water supply and demand in our basin?



Modified from image by NASA, https://pmm.nasa.gov/education/water-cycle



Slide set walks through how these factors affect the Willamette Basin Water cycle.



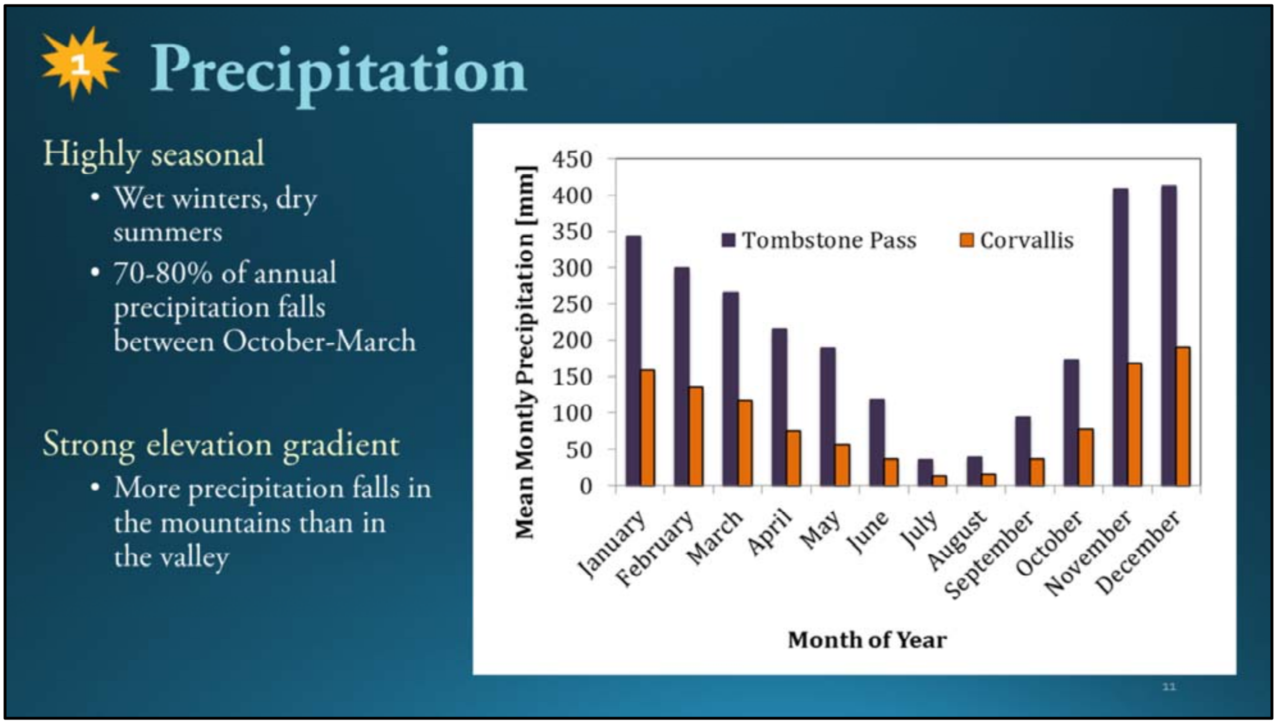
Temperatures from these locations:
Salem (Willamette Valley) (NCDC for 1981-2010)

January mean min. temperature - 34.7°F (1.5°C)
August mean max. temperature - 82.4°F (28°C)
Annual mean precipitation - 39.67 inches (101 cm)

Santiam Junction (Cascade Mountains) (NCDC for 1981-2010)

January mean min. temperature - 22.7°F (-5.2°C)
August mean max. temperature - 76.5°F (27.5°C)
Annual mean precipitation - 65.66 inches (166 cm)

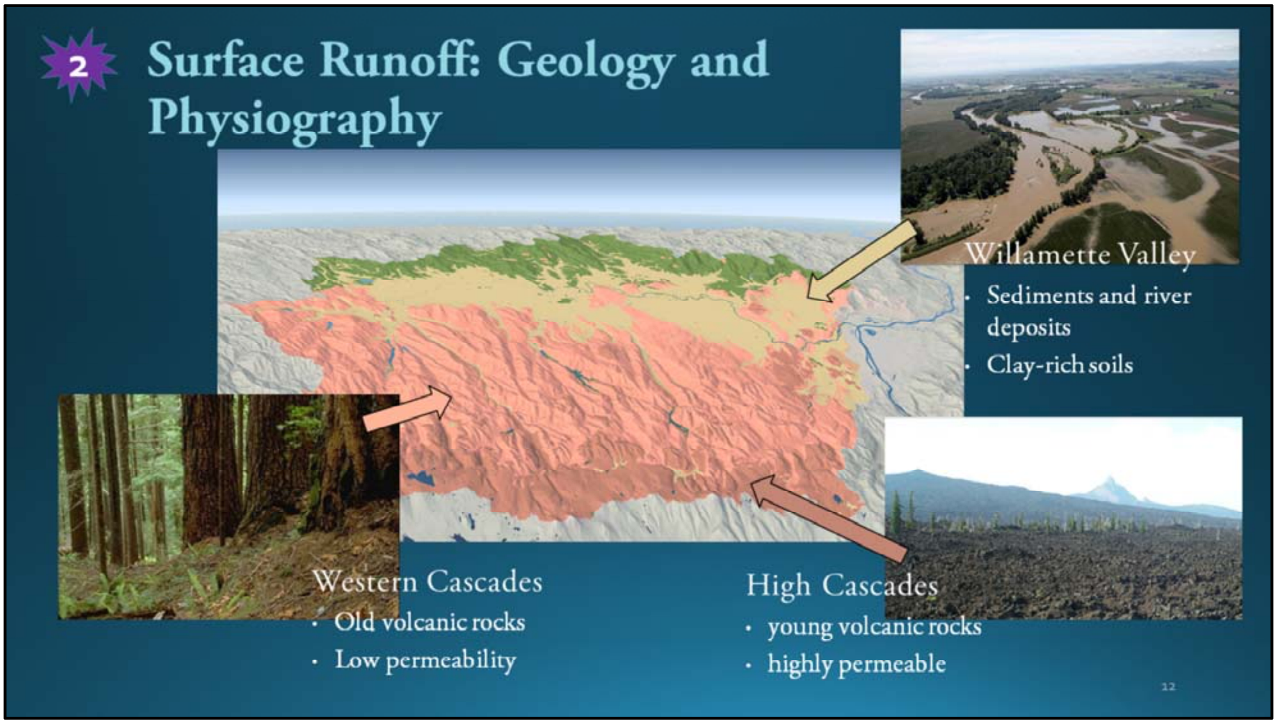
Photo credits: top, OSU, Andrews Experimental Forest; bottom, OSU Gildha Cumming



In the Willamette Basin, precipitation (and therefore water availability) is strongly affected by seasons and elevation.

This graph expands on the previous slide by providing a graph of monthly mean precipitation at two locations with different elevations.

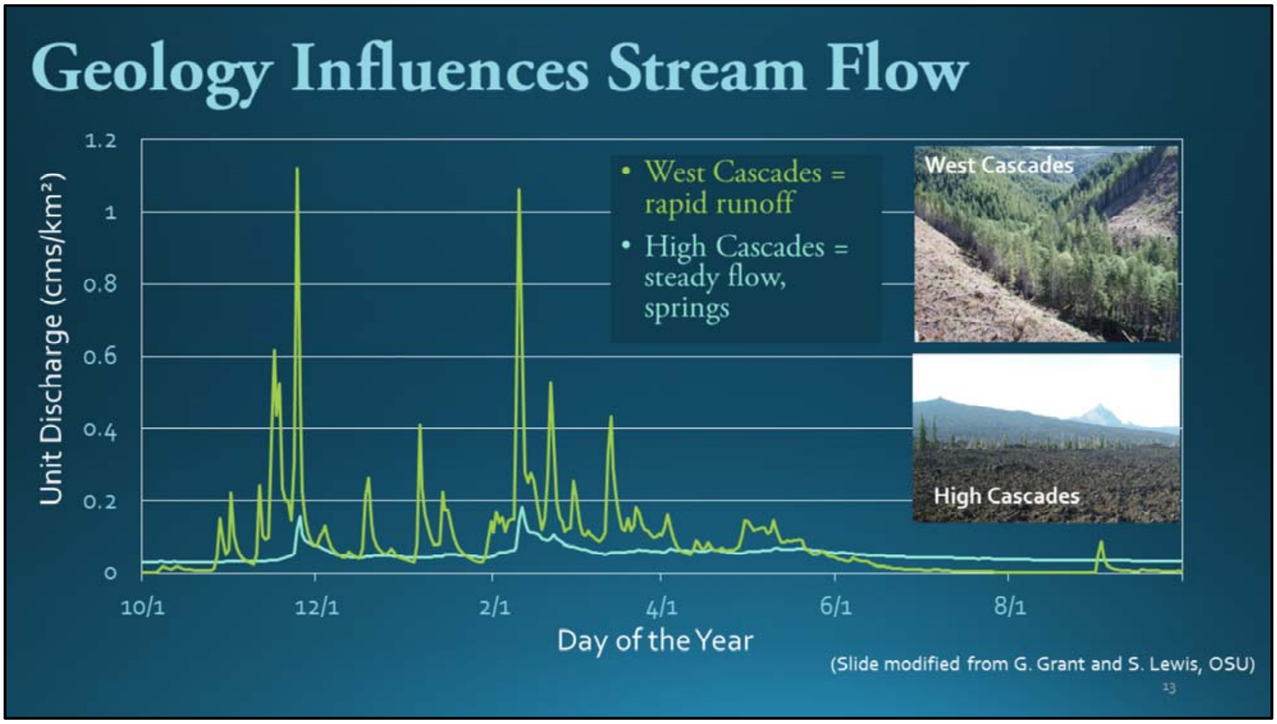
Graph source: OSU, Anne Nolin



Water that reaches the land soaks in, or runs off the landscape to form creeks and rivers. Rock types, vegetation, and topography determines what happens to precipitation once it reaches the landscape.

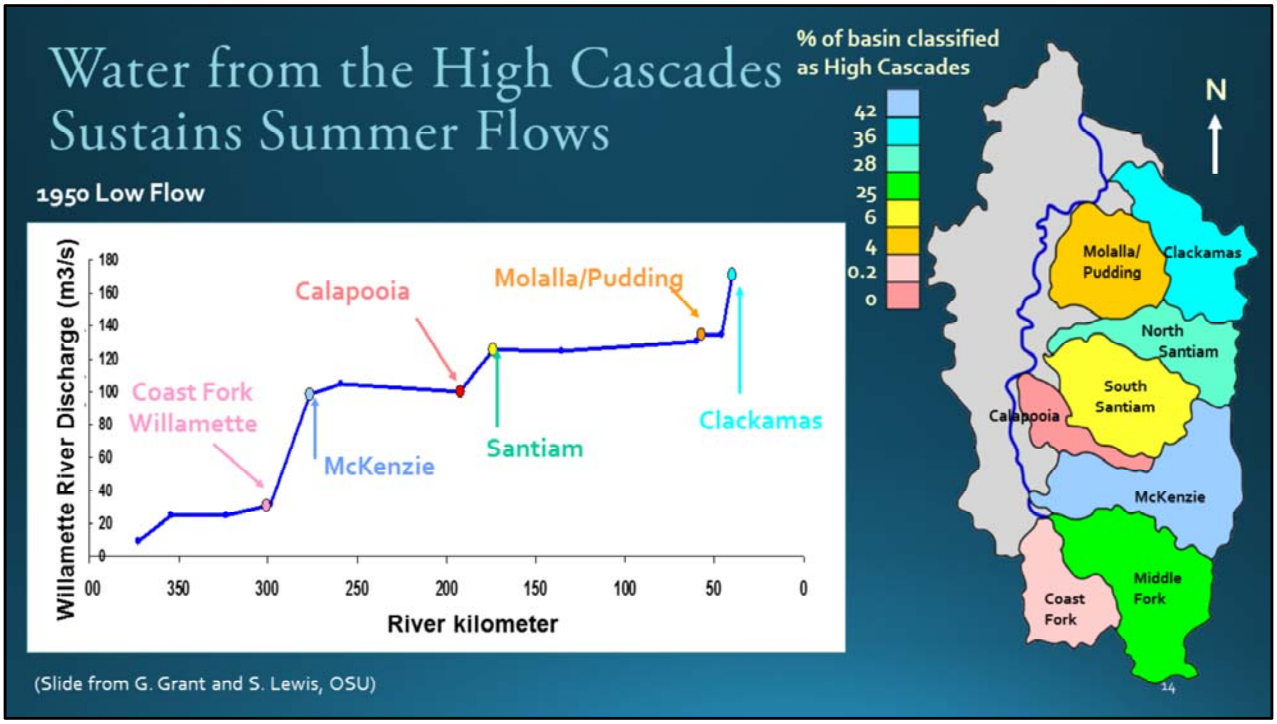
This map shows the main geologic and physiographic provinces of Willamette Basin. The High Cascades are made up of young volcanoes – for example, Mount Hood, Mount Jefferson, North Sister, Middle, Sister, South Sister. These volcanoes deposited ash and lava flows that are so young in geologic time, that they haven't yet formed soils or stream channels. The rocks are very permeable – rain sinks into them and flows underground until it discharges at springs. The Western Cascades and Coast Range (green on map) are made up of older volcanic rocks that have lower permeability. They have developed soils and thick forests. Water tends to run off them rapidly. The Willamette Valley is flat and filled with sediment deposited by water. Water ponds in wetlands.

Photo credits:
top: Michael Pope, Greenbelt Land Trust
Bottom left: USFS Andrews Experimental Forest
Bottom right: Gordon Grant and Sarah Lewis, OSU



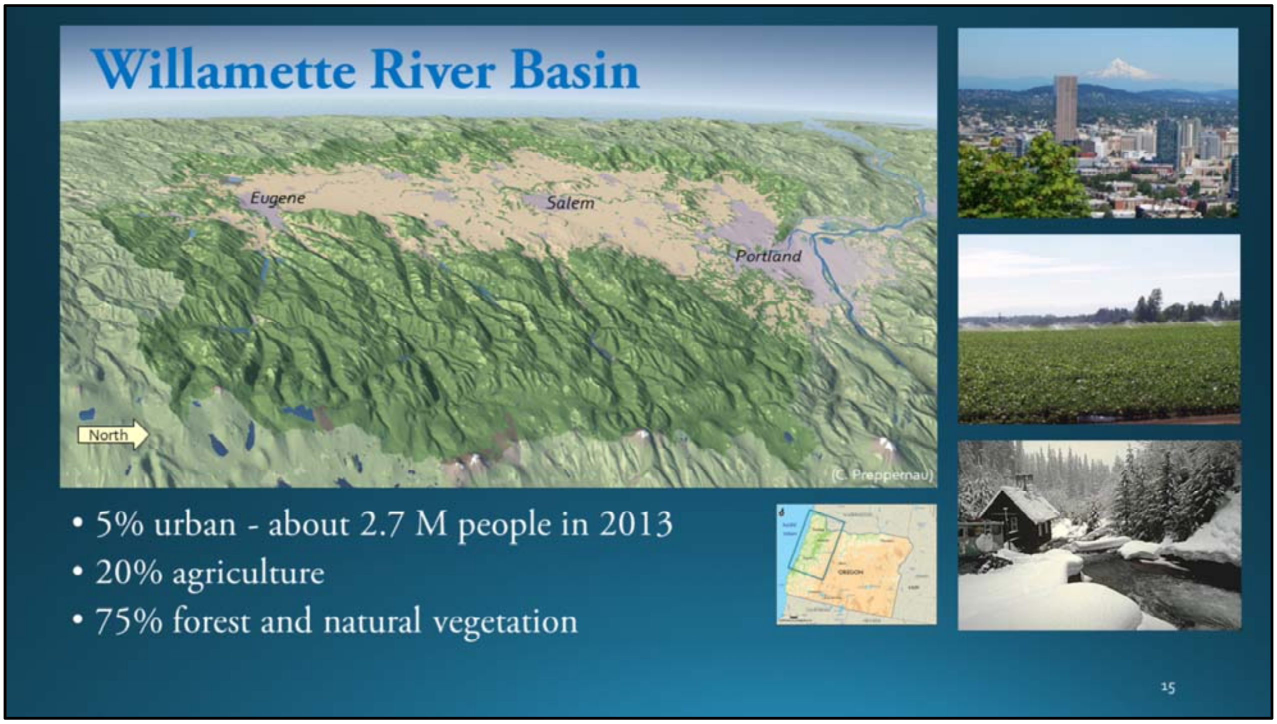
The chart is a hydrograph. It shows the amount of water flowing (stream discharge) at a specific location in a stream. This example compares discharge in a High Cascades stream to a Western Cascades stream. In the High Cascades, rain falls and soaks into the highly permeable young volcanic rocks. It then flows underground and discharges at springs. This creates streams with a flat hydrograph with fairly steady flow all year long. In contrast, the other hydrograph (green) shows rapid changes in flow (sharp peaks). Each peak signals as storm – heavy rain, that runs off the landscape rapidly and creates high flows in the stream channel. In between rain events, and especially in the dry summer, there is very little water in the stream (low discharge).

Photos credits: top, OSU, G. Grant, S. Lewis; bottom, OSU



This chart shows how discharge in the Willamette River increases as one travels downstream toward Portland (river kilometer 0 = Portland). The colored labels show where major tributaries flow into the Willamette River. The discharge rises rapidly where tributaries enter the main stem river. This is especially true where tributaries that source in the High Cascades, enter the river. For example, Willamette River discharge jumps, at the confluence of the McKenzie River. Much of the McKenzie River headwater are in the High Cascades (42% of the watershed area, as shown on map), where winter snowfall percolates into young volcanic rocks and feeds springs that sustain summer flows.

The McKenzie, North Santiam, Clackamas and Middle Fork Willamette providing a disproportionate amount of discharge in the summer. The amount of discharge they provide correlates with the percent of their watershed area that is made up of High Cascades geology.



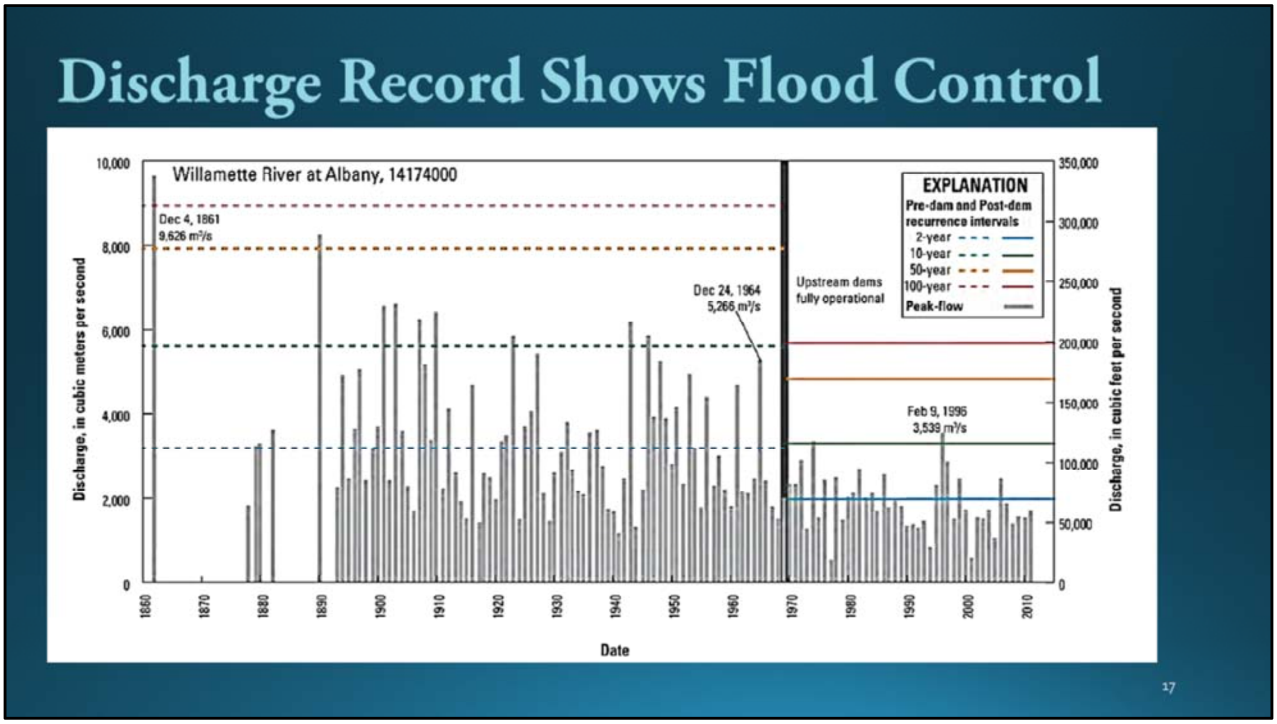
People and the way we use the land also strongly influences the water cycle. The major land uses in the Willamette Basin are forestry, agriculture, and development (cities). The next set of slides highlight specific ways that people affect the water cycle in the Willamette Basin.

Population number from Population Research Center, 2013
Photo sources (top to bottom) : USACE, OSU, USFS (HJ Andrews)

The federal reservoirs, called the Willamette Project, have a large effect on timing and magnitude of discharge in the Willamette River.

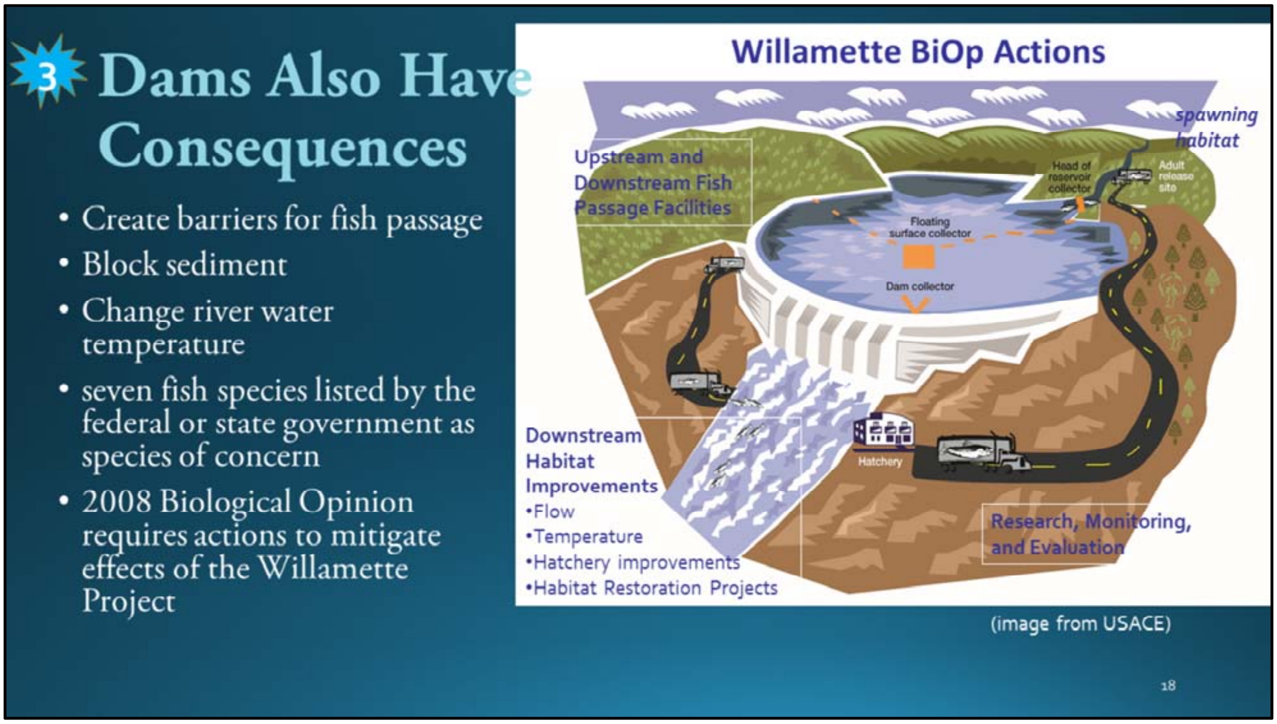
Sources: Map from USACE: http://www.nwp.usace.army.mil/Locations/Willamette-Valley/

Photo: Hills Creek Dam and Lake, USACE, http://www.nwd-wc.usace.army.mil/dd/common/projects/www/hcr.html



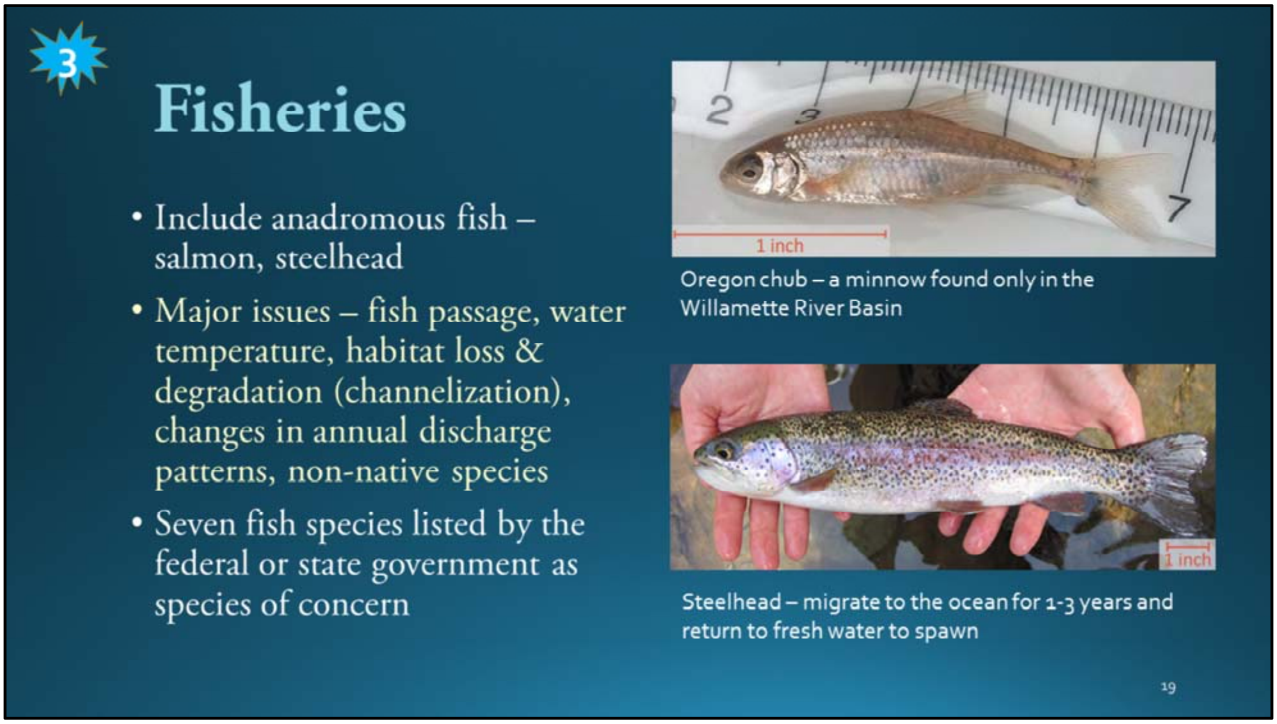
The primary purpose of the Willamette Project dams is to protect Willamette valley farms and cities from flooding. This diagram shows discharge (river flow) for major floods measured on the Willamette River at Albany, since 1860. The heavy black line shows when the Willamette Project dams were in place and operational. Since the Willamette Project was completed, there have been fewer large floods. The dams hold back water, and release it slowly.

Graph source: Wallick, J.R., Jones, K.L. O’Connor, J.E., Keith, M.K., Hulse, David, and Gregory, S.V., 2013, Geomorphic and
vegetation processes of the Willamette River floodplain, Oregon—Current understanding and unanswered questions:
U.S. Geological Survey Open-File Report 2013-1246., 70 p.,
http://dx.doi.org/10.3133/ofr20131246



FMI about the Biological Opinion:
http://www.westcoast.fisheries.noaa.gov/fish_passage/willamette_opinion/

U.S. Fish and Wildlife Service (USFWS) listed Oregon chub as endangered under the Endangered Species Act in 1993. The agency listed bull trout as threatened in 1999. The National Oceanic and Atmospheric Administration’s National Marine Fisheries Service (NMFS) listed both the Upper Willamette River spring Chinook and the Upper Willamette River winter steelhead as threatened species in 1999. From BiOp fact sheet:
http://www.nwp.usace.army.mil/Portals/24/docs/environment/biop/WillametteBiOp_Overview_FS.pdf

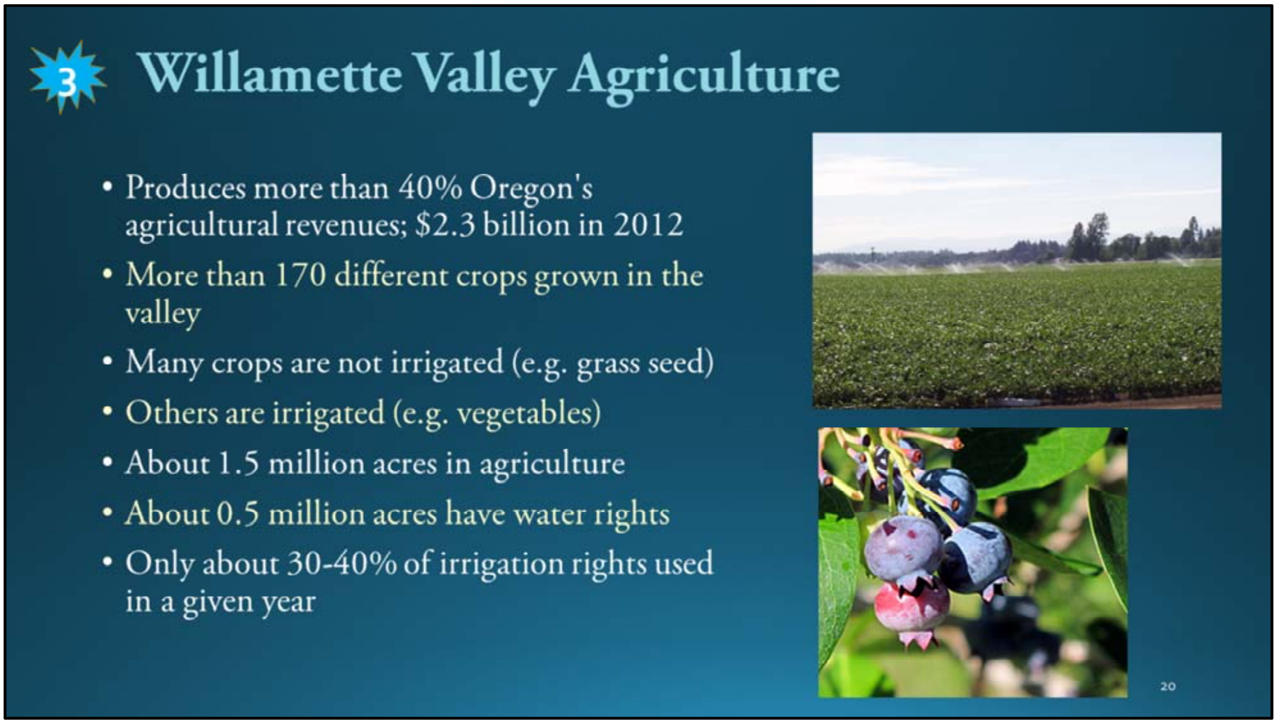


As a nation and a state, we have put in place laws and regulations to protect fish and wildlife. Laws such as the "Endangered Species Act" protect fish whose population and distribution have declined since modern settlement.

U.S. Fish and Wildlife Service (USFWS) listed Oregon chub as endangered under the Endangered Species Act in 1993. After an intensive conservation effort, it was removed in 2015.

The National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) listed both the Upper Willamette River spring Chinook and the Upper Willamette River winter steelhead as threatened species in 1999. Read more in the BiOp fact sheet: http://www.nwp.usace.army.mil/Portals/24/docs/environment/biop/WillametteBiOp_Overview_FS.pdf

For a guidebook to Willamette River fish see: Williams J, Giannico G.R., Withrow-Robinson B.. 2014. Field guide to common fish of the Willamette Valley floodplain. Oregon State University Extension Service Publication. :42. http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/50100/em9091.pdf . Photos from this source.



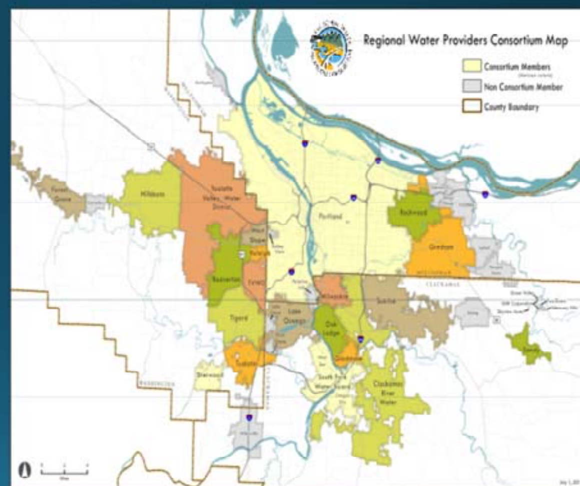
Winter annuals (e.g. grass seed) do especially well in the Willamette Valley (because they grow over the winter when there is rain and can be harvested in the dry summer.

Statistics on acres of ag and water rights, from Bill Jaeger, OSU

Photo source: OSU

Municipal Water Use

- Industrial and household uses
- Most water is used and returned (down the drain)
- "Consumptive use" is water that is not returned – mostly water used on lawns and gardens in summer
- Water use is strongly seasonal – peaks in summer
- 40% of Willamette Basin residents get their water from sources outside the Willamette Basin (Bull Run)
- Many different water providers – ~40 drinking water providers in Greater Portland METRO region



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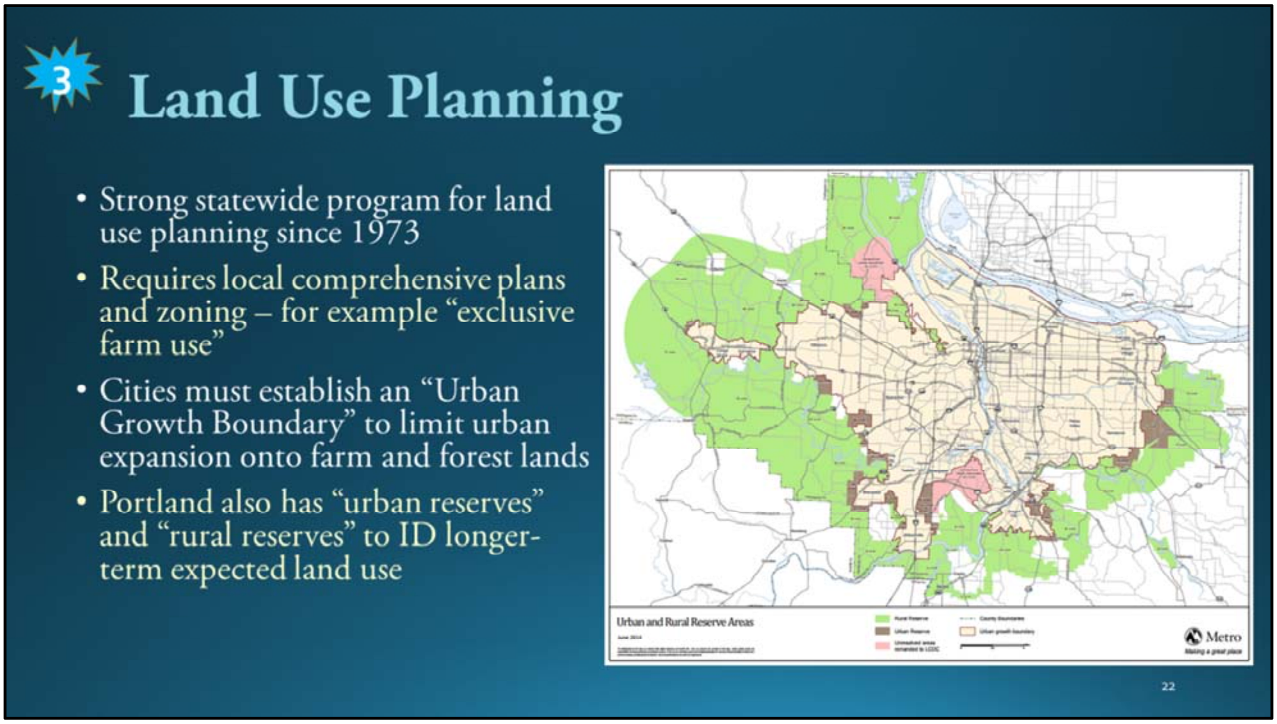
Read more about municipal water supplies for the Portland area at http://www.conserveh2o.org/our--regions-water

Map from the: Regional Water Providers Consortium, http://www.conserveh2o.org/our--regions-water



Under Oregon law, each city must create an "urban growth boundary" – a land use planning line that contains urban development. This map shows the urban growth boundary (tan shading, urban reserves (brown shading), and rural reserves (green shading).

Read more about zoning in the Portland area:

Urban Growth Boundary: http://www.oregonmetro.gov/urban-growth-boundary

Urban and Rural Reserves: http://www.oregonmetro.gov/urban-and-rural-reserves

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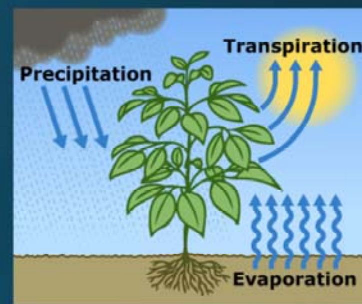
Evapotranspiration



- Water returns to the atmosphere by evaporation and transpiration, combined they are called evapotranspiration or ET
- Plant type and growth stage affect ET
- Land use and land cover affect ET

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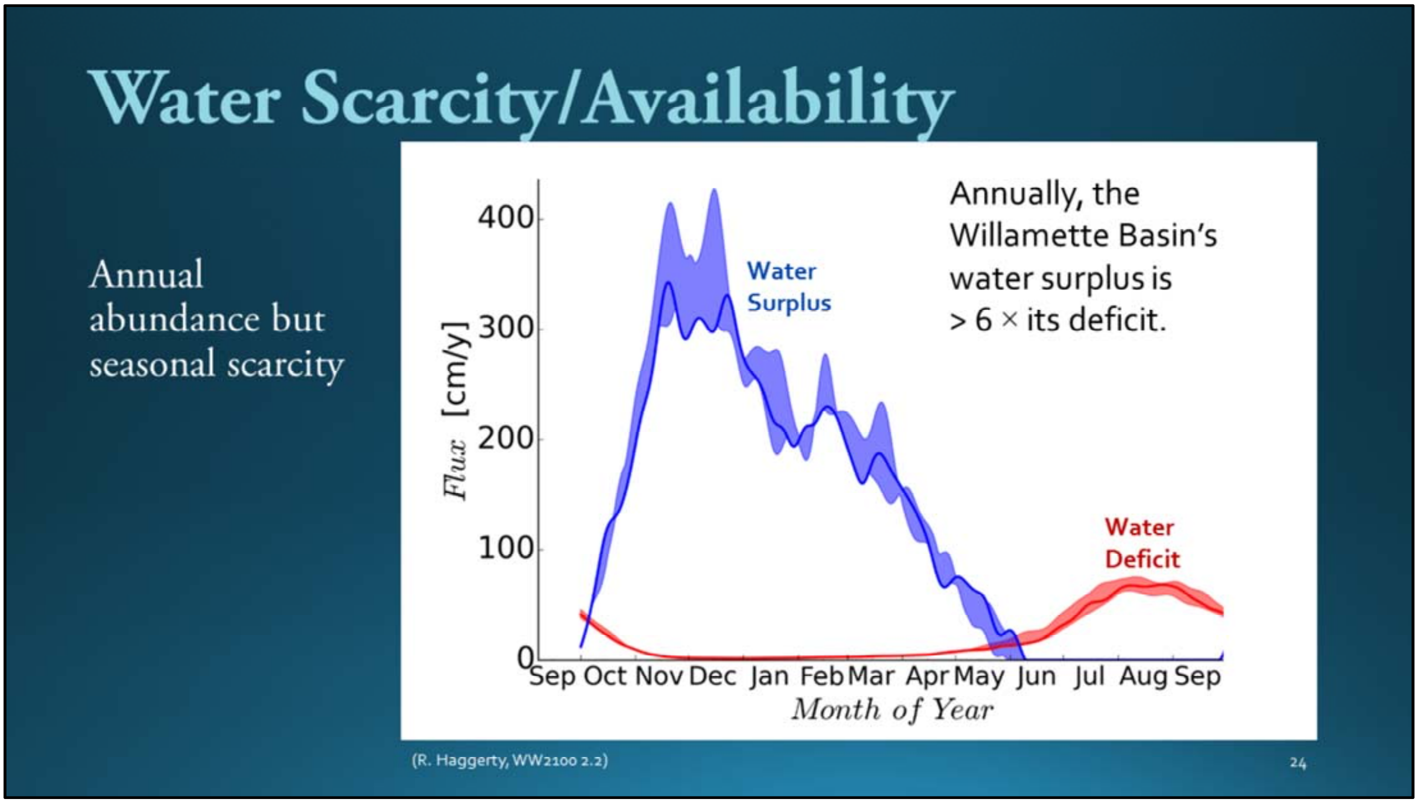
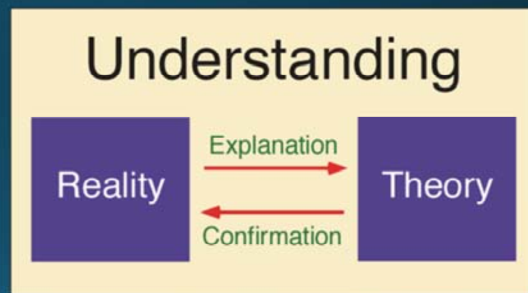


Another way to think of the water cycle is as a balance – how much water enters the basin from the atmosphere (as precipitation) minus how much leaves the basin as evapotranspiration. In the winter, precipitation is abundant and much more rain falls than is used by plants (ET), so there is a water surplus. In summer however, there is very little precipitation, yet plants are growing and ET is high. In fact, during dry summers, plants could use more water than is available in the soil, so we say that there is a water deficit.

This figure shows basin-wide water surplus and water deficit by day of the year. Water Surplus is equal to precipitation minus actual evapotranspiration (how much water enters the basin from the atmosphere minus how much returns to the atmosphere) and Water Deficit is equal to potential evapotranspiration minus actual evapotranspiration (how much water plants would use if an unlimited supply was available minus how much they actually use). The graph was generated by Roy Haggerty (OSU) with Willamette Water 2100 modeling results. Dark lines are the average for a modeling scenario that spanned the period 1950-2010, and was driven by weather data that represented historical climate conditions (the scenario was called the Simulated Historical Scenario or HistoricRef). The shading represents the interannual variability (dry years and wet years), and the potential for change under future conditions. The shading spans all years for the Simulated Historical Scenario (HistoricRef) 1950 - 2000, plus the Reference Scenario and High Change Climate Scenario for years 2050-2100. The graph suggests that even with climate change, the Willamette River Basin will continue to have abundant water on an annual basis, but seasonal scarcity during the dry summer months.

Why create a computer model of the Willamette water system?

- A model helps you think about how the system is connected – interactions and feedbacks
- With a model, you can ask "what if" questions – make a change and see how that affects the system
- Allows you to go from a conceptual "water cycle" to a quantitative "water budget"
- Allows you to compare the Willamette water system to others around the world



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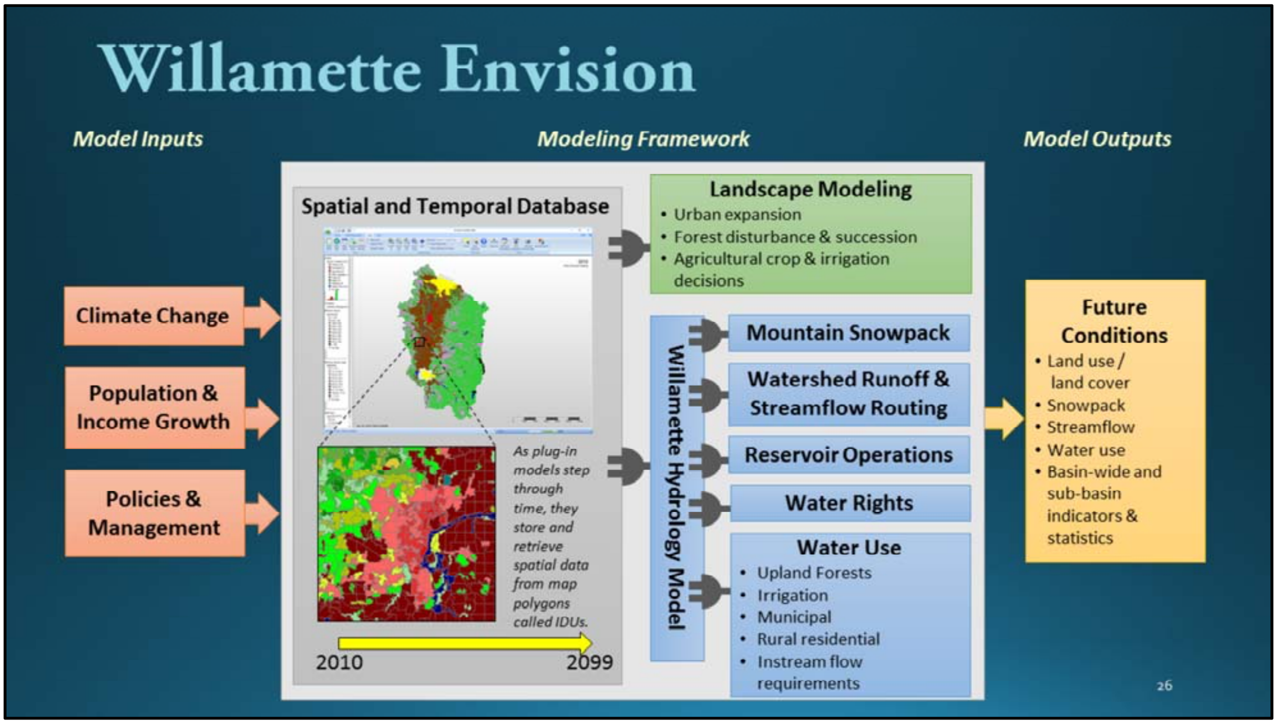
The Willamette Water 2100 project was a scientific research project that created a computer model of the water cycle in the Willamette Basin. These are some of the reasons the scientists created the model.

Diagram from http://www.physicalgeography.net/fundamentals/4a.html



The WW2100 model is a whole watershed model, i.e. it attempts to represent all the significant processes related to the supply and fate of water in the entire basin. These processes are both natural (e.g. precip, snow dynamics, infiltration, runoff, evapotranspiration) and human (e.g. reservoir operations, irrigation, municipal water use, crop choice). The model takes exogenous projections of climate, population, and income as its drivers. It operates by simulating the processes across the entire basin for one time step, recording the effects on the landscape, and then advancing to the next timestep. This is a "space before time" approach. Some processes are modeled at a daily timestep, for example streamflow and evapotranspiration, while others are modeled at an annual timestep, such as population growth and urban expansion. Using the landscape polygons to integrate the effects of all the relevant processes at fine temporal resolution exposes interactions which are sometimes counterintuitive. As far as the WW2100 science team knows, Willamette Envision is the first attempt at a whole watershed model (WWM) for a major river basin. We anticipate that WWMs will find uses in analyses related to land management, especially as related to climate change adaptation.

This diagram shows the modeling process within Willamette Envision. Model inputs such as daily weather conditions and annual population growth drive component models that operate within the modeling framework. These sub-models are called "plug-ins" because they run independently but share data with each other through the modeling framework.

As a simulation runs, the plug-in models store and retrieve information from a shared database -- output from one model becomes input for others as each steps through time. At the end of a run, spatial and tabular outputs summarize changes in the landscape, water, and economic systems over the 90 years of the simulation.

Fast Facts about Willamette Envision:
Geographic extent: Willamette River basin, 7.2 million acres
Geographic resolution: the basin is divided into 165,000 irregular polygons, averaging 40 ac in size but ranging from a few acres to a few hundred acres. The polygons are meaningful spatial units, representing for example agricultural fields, forest stands, or developed areas. The polygons are the spatial units of computation. Climate data is gridded at a resolution of 2.5 arc-minutes (about 4 km).

Reference Case Scenario

Elements	Example Assumptions
Climate	~4°C (~7.5°F) increase in annual mean temp. over century
Population & Income	Population: 2.41 → 5.37M Mean household income: $87.9 →$242K (in 2005 dollars)
Forests	wildfire suppression at historical rates
Development	UGB's expand when 80% developed
Reservoir Ops	rule curves implemented as of 2011
Urban Water Price	6% rise 2010-2015, 1.5% rise 2016-2025, then constant in real terms for city size
Agriculture	crop mixes similar to today crop and energy prices do not rise in real terms about 2/3 acres with rights irrigated in an average year
Water Claims	no new water rights and no new deliveries of stored water
Environmental Flows	instream water rights implemented as of 2010 BiOp recommendations as of 2009

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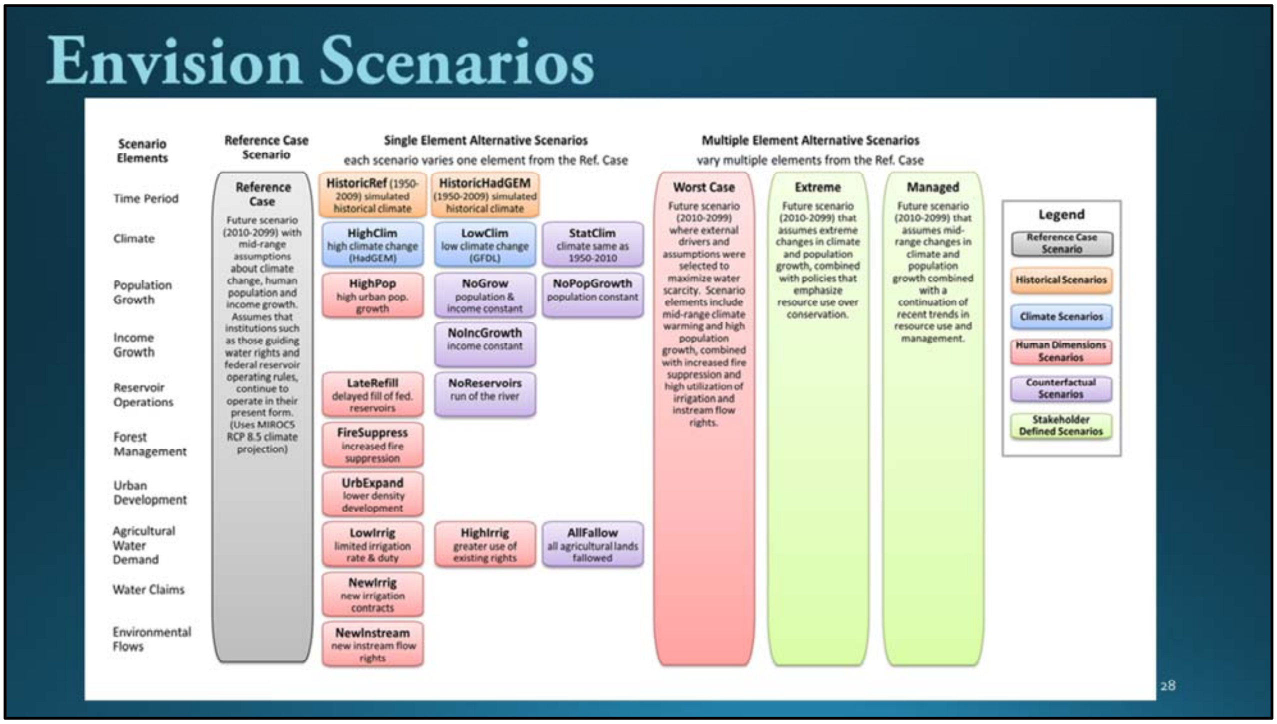
Based on project goals and input from regional stakeholders, the scientists created and then compared alternative future scenarios. Each scenario included a suite of model settings and assumptions about future conditions. They started out by modeling a "Reference Case Scenario" that adopted mid-range assumptions about climate change, population and income growth, and also assumes that institutions such as water rights, the land-use planning system, reservoir operating rules, forest practices, and urban water pricing continue to operate in their present form. This table shows some of those assumptions.



After the Reference Case, the scientists modeled 21 other scenarios. The left column in this diagram lists the ten scenario elements that vary between scenarios. In the Reference Case scenario, these elements match mid-range assumptions about climate change, population, and income growth, and reflect existing management practices, policies and institutions. The 18 “Single Variable Alternative Scenarios” isolate the influence of individual model settings or policy choices, and each varies one scenario element at a time. The last three columns depict the “Multiple Variable Alternative Scenarios” that vary multiple scenario elements to align with a theme. The scientists developed two of these scenarios (highlighted in green) in collaboration with a group of regional water managers and educators.

Link to Envision Results

Selected Findings

- The climate is warming – by 2100 mean annual temperatures will likely be 1°C (2°F) to 7°C (13°F) warmer than today.
- Warmer, drier conditions in the mountains will stress forests, increasing wildfires as much as ninefold. The fires will eventually trigger changes in forest ecosystems; younger, sparser forests may use less water than today's lusher ones.
- Rising populations and incomes in the Portland metro area and other cities will increase urban demand for water. Urban growth will spill out onto neighboring farmland in some locations. That will reduce demand for irrigation in those areas, offsetting some of the increased demand from cities.
- Water scarcity can be driven by human decisions, costs, laws and regulations, as much as by a lack of physical abundance.

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Some Dynamic Models and Resources Related to Willamette Water 2100

Willamette Water 2100 website with summaries of project key findings:
- http://inr.oregonstate.edu/ww2100

Interactive water budget of the Willamette Basin:
- http://hydro-prod.library.oregonstate.edu/figures/willamette_flows/waterchart.html

Interactive map showing outcomes for futures scenarios:
- http://inr.oregonstate.edu/ww2100/data/interactive-map

Oregon's Integrated Water Resources Strategy:
- https://www.oregon.gov/owrd/LAW/docs/IWRS_Executive_Summary_Final.pdf
- https://www.oregon.gov/owrd/Pages/law/integrated_water_supply_strategy.aspx

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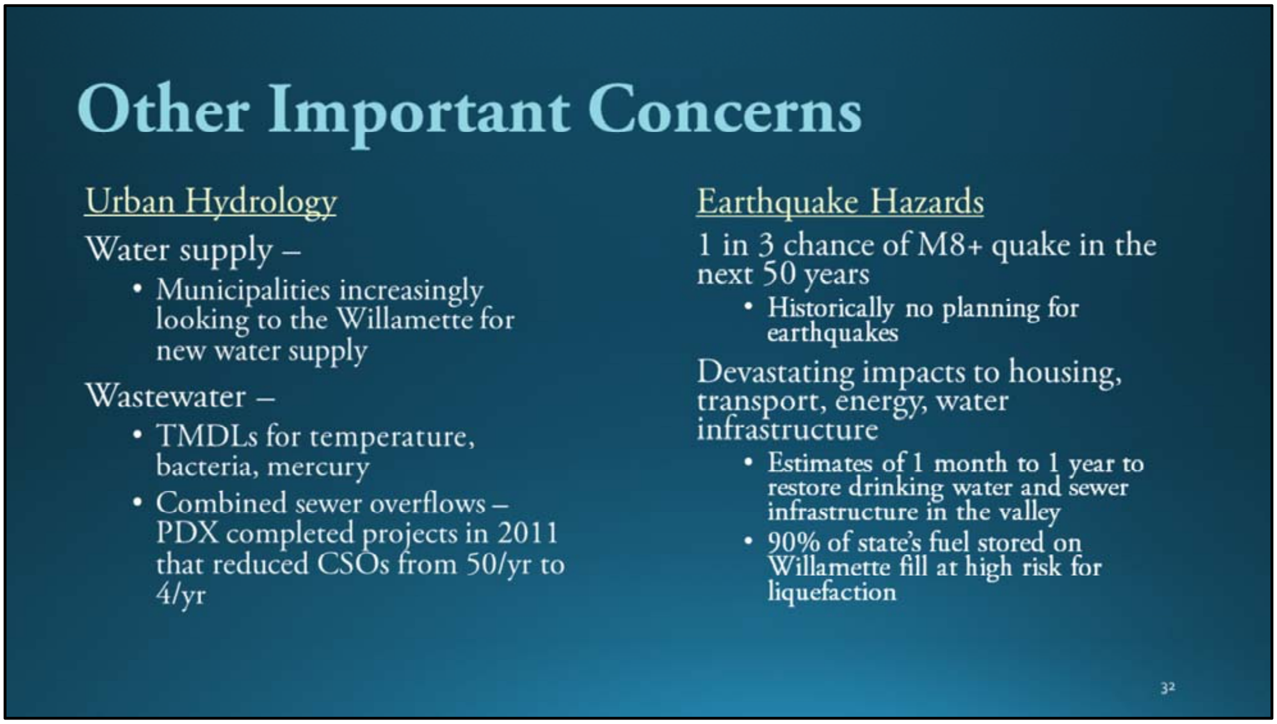

Oregon Resources Water Strategy - https://www.oregon.gov/owrd/Pages/law/integrated_water_supply_strategy.aspx

2013 Oregon Resilience Plan - http://www.oregon.gov/OMD/OEM/osspac/docs/Oregon_Resilience_Plan_Final.pdf

Acknowledgements

- The Willamette Water 2100 team consisted of more than 30 researchers and students from Oregon State University, University of Oregon, Portland State University, and the University of California-Santa Barbara and a Learning and Action Network of more than 100 regional water managers and educators.
- Slide set developed by Maria Wright, Thea Hayes, Anne Nolin, Sam Chan, and Kayla Martin with material from the Willamette Water 2100 project team.
- Project Contact: Maria Wright, Oregon State University, maria.wright@oregonstate.edu

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