OREGON WATER RESOURCES MONITORING STRATEGY

February 2016

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LIST OF ACRONYMS

ASR/AR	Aquifer Storage and Recovery/Aquifer Recharge
DEQ	Oregon Department of Environmental Quality
Department	Oregon Water Resources Department
IWRS	Integrated Water Resources Strategy
NRCS	Natural Resources Conservation Service
ODFW	Oregon Department of Fish and Wildlife
OWEB	Oregon Watershed Enhancement Board
RAFT	Rapid Assessment of Flooding Tool
STREAM Team	STRategic Enterprise Approach to Monitoring Team
USGS	U.S. Geological Survey

ACKNOWLEDGEMENTS

The development of this Monitoring Strategy was a cooperative effort among various staff at the Water Resources Department. In particular, the following people are gratefully acknowledged for their significant contributions in leading this effort and completing the Department's first Monitoring Strategy.

Mellony Hoskinson, Rachel LovellFord, and Ken Stahr led its development.

In addition, Brenda Bateman, Technical Services Division Administrator; Jonathan LaMarche, South Central Region Office; Rich Marvin, Surface Water Hydrology Section; Ivan Gall, Karl Wozniak, and Ken Lite, Groundwater Hydrology Section; and Alyssa Mucken from the Director's Office participated and contributed to the development of this strategy.

INTRODUCTION

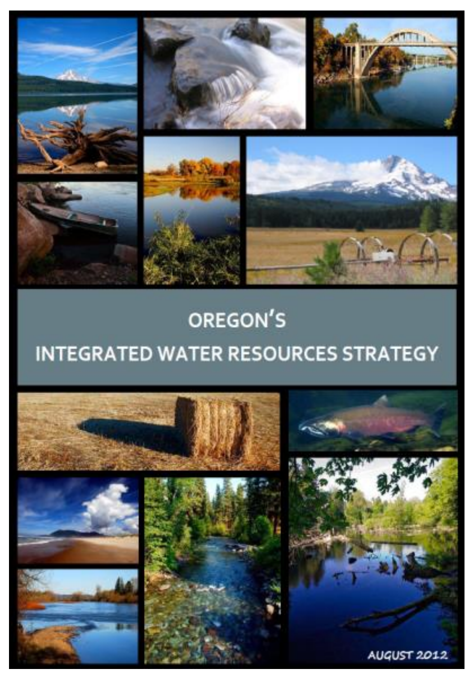
The vision of the Water Resources Department is to assure sufficient and sustainable water supplies are available to meet current and future needs. In order to properly manage Oregon's water resources to meet these needs, the Department must have a strategy in place and have the means for measuring both surface water and groundwater resources. A network of strategically placed stream gages and observation wells enable Department staff to collect valuable data about water resource conditions across the state at any given time. The challenge is to have a monitoring network design that adequately, efficiently, and effectively captures water resource data essential for proper management of the state's water resources. This strategy identifies the Department's monitoring priorities and recommends monitoring actions that will ensure the vision of the Department is being met.

Background

In 1988, the Department's groundwater section developed a framework as part of its Observation Well Network Review (Miller and Lite, 1988). The framework helped determine whether a proposed well was suitable for the state's observation well network and whether the resulting data would be valuable. A review form was developed and instructions and flow diagrams were provided to determine how to rank each proposed well in the network.

In 2008, the Department undertook a similar evaluation of its stream gage network. The purpose of this effort was to determine if the network met the needs of the Department, to identify "high value" stream gages, and to describe an optimum network, given staffing and budget constraints. As an initial step, the evaluation focused solely on distribution and regulation needs. The Department published its findings and recommendations in an open file report titled, *OWRD Stream Gaging Network Evaluation for Water Distribution* (LaMarche, 2011).

Integrated Water Resources Strategy



Oregon's Integrated Water Resources Strategy (IWRS), adopted by the Water Resources Commission in 2012, describes numerous coming pressures that may affect Oregon's water needs and supplies in the future. These include climate change, population growth, economic development, and changes in land use, among others.

Oregon's IWRS also calls on the Department to improve water resources data collection and monitoring methods (Recommended Action 1B). This Monitoring Strategy is a response to the IWRS, further strengthening the state's monitoring and data collection network.

Another IWRS action addressed by this Monitoring Strategy is Recommended Action 1C, "coordinate inter-agency data collection, processing, and use in decision-making." The Department's data collection standards were developed in coordination with the U.S. Geological Survey (USGS). The Department shares groundwater and streamflow data with several federal agencies, including the USGS, the Natural Resources Conservation Service (NRCS), the U.S. Army Corps of Engineers, and the U.S Bureau of Reclamation. The Department is also a member of

Oregon's STREAM Team (see inset), which is made up of several state agencies that monitor Oregon's waters, both quantity and quality.

Efficient Use of Resources

This Monitoring Strategy is designed to ensure that the Department is making the most efficient and effective use of funding and resources to build its monitoring network. The Department is designing its network around the monitoring needs of the state and providing staff and partners with much needed information to anticipate and adapt to coming pressures.

Monitoring Priorities

The Department has identified the following priorities for monitoring:

- Climate Change
- Extreme Events
- Groundwater
- Water Management
- Instream Needs
- Water Supply
- Partnering with Other Agencies (see STREAM Team box)

For each priority, the Department has identified recommended monitoring actions to meet the related data needs. These are described in further detail in the following pages.

STREAM Team

Oregon's STREAM Team is made up of many of the state's natural resource agencies which all monitor Oregon's water for various public purposes. 'STREAM' stands for *STRategic Enterprise Approach to Monitoring.* State agencies that make up this team include:

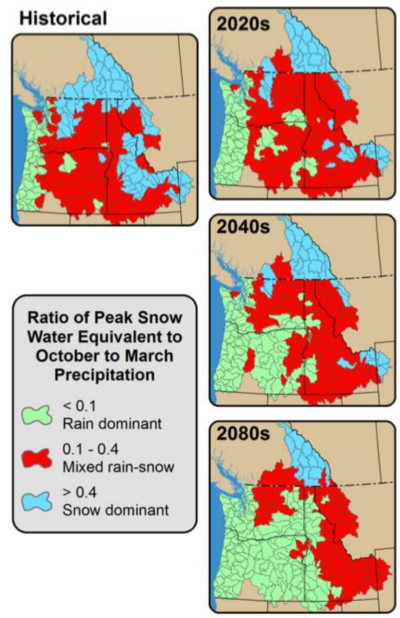
- Oregon Department of Agriculture
- Oregon Department of Environmental Quality
- Oregon Department of Fish and Wildlife
- Oregon Department of Forestry
- Oregon Department of State Lands
- Oregon Health Authority
- Oregon Water Resources Department
- Oregon Watershed Enhancement Board
- Oregon State University's Institute of Natural Resources

The STREAM Team facilitates collaborative decision making to support a healthy environment through coordinated planning, monitoring, and communication of water-related data and information among Oregon's natural resources agencies. One of the main goals of the STREAM Team is for each agency to develop an interactive monitoring strategy in support of collaborative decision making for water quality, water quantity, and ecosystem services. These strategies are designed to be used as communication tools among the agencies in managing the state's water resources.

MONITORING PRIORITIES

To fully understand and address each of the following priorities, the Department relies on monitoring data. Below, the Department has identified and recommended specific monitoring actions that should be taken in order to address each priority.

Changes in snowpack over time (Hamlet, et al., 2013)



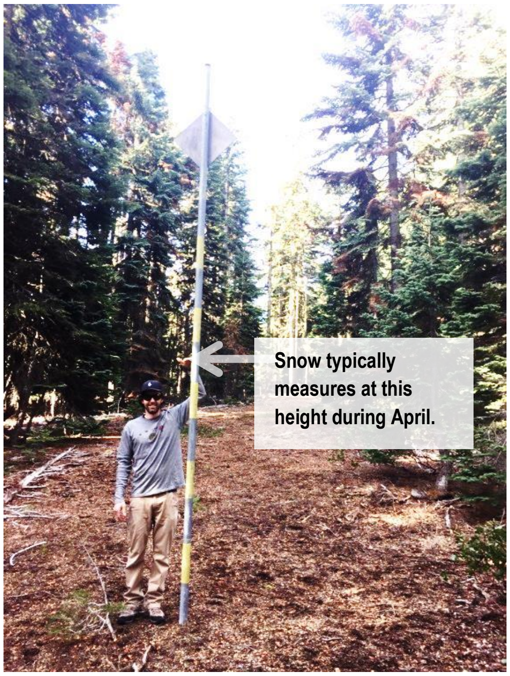
CLIMATE CHANGE

World renowned climate change research is taking place within Oregon's university system, and is helping the state prepare for a changing hydrologic regime. With a predicted increase in regional mean temperature of 3.3 to 9.7 degrees Fahrenheit by the end of this century, Oregon can expect to see the percentage of precipitation that falls as rain instead of snow to increase significantly (Mote, et al., 2014). Precipitation arriving as rain instead of snow may contribute to increased frequency and magnitude of high flow events, decreased summertime snowmelt run-off, and reduced recharge to groundwater aquifers.

The state needs a monitoring network that is designed to capture data necessary to observe and quantify these shifts and changes. These data can provide water users and planners with the information needed to adapt and build resiliency within our water management systems.

Recommended Monitoring Actions

- Identify basins susceptible to changing flow regimes (e.g., basins that receive a significant percentage of precipitation as snow) and establish gages to quantify the rate of change in the magnitude, frequency, duration, and timing of streamflow.
- Identify groundwater systems with areas of recharge within the rain-snow transition zone; monitor groundwater level responses to climatic impacts.
- Work with the USGS and other partners to support long-term, natural streamflow monitoring stations that have previously been used to assess climate impacts on water supplies (e.g., USGS Hydro-Climatic Data Network stations, Geospatial Attributes of Gages for Evaluating Streamflow stations).



Watermaster Travis Kelly at Mt. Ashland Ski Bowl Road Snow Course Site (April 1, 2015)

EXTREME EVENTS

FLOODS

Floods are common and widespread natural hazards in Oregon and increasing occurrences of floods are anticipated due to a changing climate (Mote, 2013). Changing land-use patterns, a growing population, and the occurrence of wildfires also contribute to the increasing impacts of floods. In Oregon, flooding generally occurs due to extreme precipitation events, rapid snowmelt, or rain-on-snow precipitation events. In the next few decades, extreme precipitation events may increase, but exact locations cannot be predicted with certainty.

Oregon Christmas flood of 1964

Gages that accurately capture high flow events help planners and engineers effectively plan for floods. However, not all stream gages accurately capture flood data. In some cases, the stream comes out of bank and the flow by-passes the gage. In other cases, there is not suitable cross-section in which to measure high flows. The Department needs more gages that effectively monitor floods and accurately capture high flow data. Such gages are used in the Department's Peak Flow Estimation Program and in real-time emergency response tools such as the Rapid Assessment of Flooding Tool (RAFT). RAFT is an interactive, near real-time tool developed by the Oregon Silver Jackets team that characterizes the severity of forecast flooding. Gages used for monitoring floods also play a key role in statistical flood frequency analysis (i.e., the frequency and impact of 10-year, 100-year, or 1,000-year floods). Combined with the Federal Emergency Management Agency (FEMA) floodplain maps, these gages can help communities respond to flood events in real time.

Recommended Monitoring Actions

- Identify gages that measure natural peak flows contained within channel and can be measured. Increase the number of high flow measurements or relocate these gages.
- Upgrade gages in flood-prone areas to transmit data in real-time for flood forecasting and early warning systems. Work with other state agencies and municipalities to identify at-risk areas.
- Identify watersheds within the RAFT program that would benefit from additional gages and/or additional measurements.
- Deploy temporary gages for real-time monitoring of high flow events.

DROUGHT

Drought conditions can result from low winter snowpack, a lack of precipitation, and warm temperatures. Oregon has a history of frequent, single-year droughts, particularly on the east side of the state. In 2015, some parts of Oregon were in year four of a multi-year drought, breaking historic records for the lowest observed snowpack and high summer temperatures. This provided water managers a glimpse into potential future water conditions in Oregon. Improved monitoring for low streamflows and groundwater levels is critical for both drought management and resiliency planning.

Stream gage on Fifteenmile Creek measuring 0.00 cfs. August 24, 2015

Water supply forecasts, such as those developed by the NRCS and the Northwest River Forecast Center, rely on stream gage data from rivers throughout the state. However, not all gages accurately capture low-flow events. In some cases, the stream should have an engineered control structure in place, such as a v-notch weir to focus flow so that it can be measured. Accurate low-flow measurements help to track water supplies for real-time distribution and allow for trend analysis and prediction of future low-flow events. Gages useful for tracking drought include those used to distribute water during low-flow periods (e.g., summer and fall), gages with high-quality records associated with the lower end of the rating curves, and gages used by other regulatory agencies that compute low-flow statistics.

Recommended Monitoring Actions

- Establish streamflow gages in locations that are vulnerable to low-flow conditions, to help with water supply forecasting.
- Establish water-level gages or inflow and outflow gages on reservoirs that provide water supplies or instream releases and that are also susceptible to short-term drought.
- Identify gages currently used for low-flow distribution and drought statistics; upgrade to near real-time, as needed.

WILDFIRE CONDITIONS

With recent fires in the Pacific Northwest, especially those of intense severity, expect to see extreme flash flooding conditions and debris flows during the fall and winter months following these fires. Other potential effects from wildfires include erosion and rapid run-off of precipitation due to decreased soil porosity. Watersheds under burned conditions may see the rate of streamflow increase by 10-100 times or more, compared to previously recorded high flows (Neary, 2003).

Recommended Monitoring Action

- Place traditional streamflow gages or rapid deployment gages in recently burned watersheds to track and send alerts regarding potential flash flooding and debris flows.

GROUNDWATER PROTECTION

GROUNDWATER LEVEL TRENDS

Monitoring groundwater levels provides valuable scientific data for hydrogeologic studies and informs the Department's decision-making with regard to permitting and conjunctive water management. The Department has a need for additional groundwater data and basin studies to better understand the capacity, location, and extent of Oregon's aquifers. These studies are also useful for assessing groundwater availability and quantifying surface water/ groundwater interactions.

Karl Wozniak and Aurora Bouchier, OWRD staff, near City of Sublimity, 2014

Recommended Monitoring Actions

- Construct dedicated observation wells in key aquifers around Oregon to expand and improve long-term groundwater level data collection; locate wells in areas of high groundwater demand, hydraulic connection between aquifers and streams, and groundwater recharge locations.
- Install data logging equipment in key observation wells to expand the continuous groundwater level data collection network.
- Estimate annual aquifer recharge rates for basins in Oregon, and compare aquifer recharge to aquifer discharge (via pumping wells, or discharge to streams and springs).

UNDERSTANDING SURFACE WATER / GROUNDWATER INTERACTIONS

Groundwater discharges to streams, springs, and rivers throughout the year, providing critical surface water flows during the dry months of the year. Groundwater and surface water are hydraulically connected at multiple scales, with the interaction controlled primarily by the geologic framework of the basin. Streams often gain flow from groundwater, but in some cases streams lose water into the aquifer. These exchanges can reverse seasonally or more frequently depending on the basin. Both groundwater level and stream discharge monitoring help Department scientists understand and quantify the stream-aquifer interaction. Oregon manages surface water and groundwater conjunctively, so a clear understanding of stream-aquifer interaction is key to protecting senior water rights. By coupling stream and aquifer monitoring in key basins, Department scientists will have a better understanding of these interactions.

Recommended Monitoring Actions

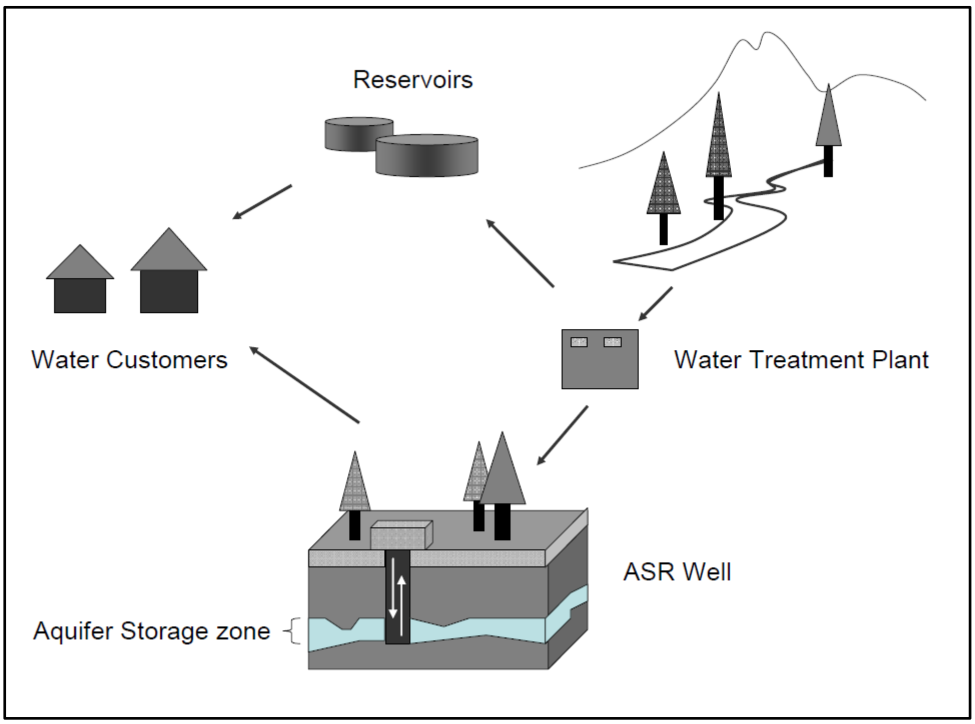
- Pair stream gages with observation wells in areas of stream-aquifer interactions.
- Target key basins for dedicated observation well installations to be monitored in conjunction with stream gages.
- Rank streams in Oregon based on the percent of annual yield contributed by groundwater. This ranking would provide a way to structure and prioritize long-term monitoring activities.

AQUIFER STORAGE AND RECOVERY & AQUIFER RECHARGE

In Oregon, the relatively wet climate during the winter months makes Aquifer Storage and Recovery (ASR) and Aquifer Recharge (AR) viable water storage techniques. During the summer dry season, water use typically peaks due to increased irrigation and municipal demand, while surface water supply is at its lowest. Many communities have surface water rights in the high flow winter months that are not fully utilized. ASR and AR can capture some of this flow and store it in aquifers to supplement dry season water supplies (Woody, 2007).

Recommended Monitoring Actions

- Construct dedicated observation wells in key basalt aquifers around Oregon to expand and improve long-term groundwater level data collection. Target wells in areas of potential ASR and AR projects with nearby surface water supplies.
- Expand continuous groundwater level data collection in key observation wells.
- Work with local water users to conduct ASR and AR feasibility studies for specific projects and water needs.

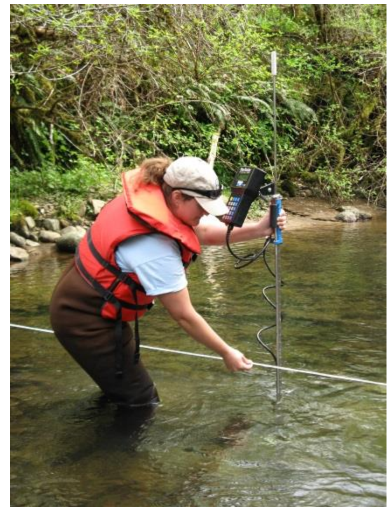


ASR system illustration. (Woody, 2007)

WATER MANAGEMENT

IMPROVE EFFECTIVENESS OF DISTRIBUTION AND REGULATION

The Department's watermaster corps is responsible for enforcing Oregon water laws in the field. In order to make effective and timely decisions, including calls for regulation of water, field staff need access to data that are accurate and up-to-date.



OWRD Watermaster Nikki Hendricks

Recommended Monitoring Action

- Place gages in locations that will help distribute water and validate regulation calls quickly. In particular, select reaches where regulation takes place frequently. Optimal sites may include areas near large water withdrawals or at specific locations named in water rights.

PREDICTING THE RESPONSE OF THE HYDROLOGIC SYSTEM TO DIVERSION / APPROPRIATION

Effective modeling can help determine the response of the hydrologic system to groundwater pumping and surface water diversions. The Deschutes Basin model, for example, developed in partnership with the USGS, demonstrates the effects of groundwater pumping on other wells in the system and also on streamflows. The sophisticated models used by the Department and its partners show how varying well depths and distances can affect other water users, while also affecting groundwater travel time and water quality.

Recommended Monitoring Actions

- Establish observation wells and stream gages in areas where groundwater basin studies will take place.
- Establish observation wells where the volume of requests for groundwater permits is high, and the number of recent groundwater-level measurements is low.

WATER AVAILABILITY

During the 1989 – 1991 biennium, the Department began to develop a Water Availability Program.   The program uses computerized hydrologic models that include streamflow and run-off measurements to characterize the timing and volume of streamflow throughout the basin. This model is used by Department staff to determine the availability of water when conducting evaluations of new water use applications.

Recommended Monitoring Actions

- Establish natural flow stream gages in areas likely to see an increase in water development in the near future to adequately capture before and after conditions.
- Establish gages above diversions and impoundments in major streams (i.e., measure natural streamflow) throughout the state.
- Establish evapotranspiration measurements to improve water availability consumptive use estimates.

➢ Improve the resolution of the water availability model by establishing gages in regions of the state where stream gage density needs to be increased.

WATER USE DATA

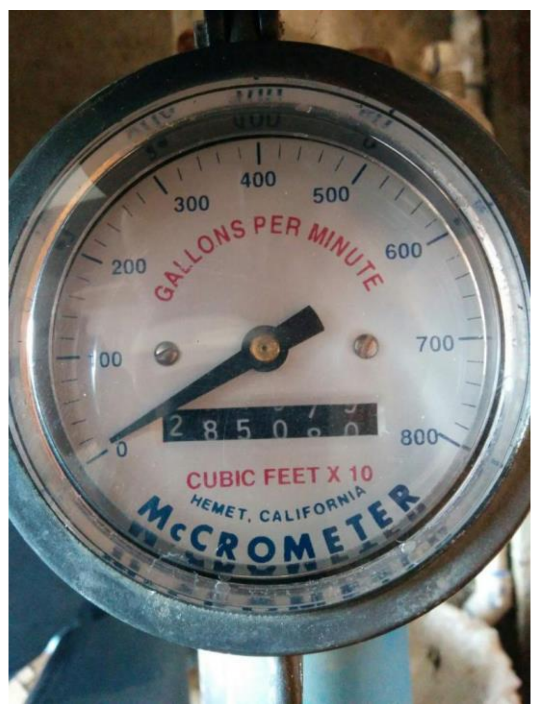
Water use information is critical for timely water management decisions, water resources planning, and hydrologic analyses. These data are often used to determine sustainable groundwater withdrawals or basin water budgets. Water use data differ from stream gage data collected at diversions in that they are self-reported by water users on a monthly basis. Totalizing flowmeters are typically installed to capture water use information at diversions or wells.

Water use reporting is required for approximately 23 percent of water rights in Oregon. Governmental entities, such as municipalities and irrigation districts, are required to track and report water use data. Since the late 1980's, some water permits have been conditioned to report monthly water use information annually to the Department. This Monitoring Strategy seeks to build upon already existing investments in the Water Use Reporting Program.

In 2000, the Water Resources Commission approved a strategic plan for improving water management statewide. The Plan focuses on measurement of diversions with the greatest impact on streamflows in areas with the greatest needs for fish. The Water Resources Department developed a statewide inventory of approximately 2,300 "significant diversions" within 300 high priority watersheds across the state. This represents about 10 percent of all the diversions in these watersheds, but accounts for about 50 percent of all water diverted in the state.

Recommended Monitoring Actions

➢ Coordinate the Water Use Reporting and Significant Points of Diversion programs.
➢ Establish quality assurance procedures to verify the accuracy of water use data.
➢ Monitor and report surface water diversions in high priority watersheds.
➢ Establish a water use reporting requirement for irrigation wells in declining or critical groundwater areas.
➢ Integrate the Water Use Reporting program with quasi-real-time water management.
➢ Utilize satellite-based remote sensing imagery to estimate consumptive use on irrigated lands.
➢ Collect groundwater use data from observation wells that are actively pumped.



Inline Totalizing Flow Meter

DAM SAFETY

Willow Creek Dam above the City of Heppner

Oregon's dam safety program pertains to dams that are taller than 10 feet and that hold more than 9.2 acre-feet of water. The program assigns hazard ratings, based on the density of population and property located below the dam. The program also assesses whether each dam is in satisfactory, fair, poor, or unsatisfactory condition. Water managers monitor the condition of local dams to guard against dam failures and downstream loss of life and property. Dam designs must include methods for determining if the dam is operating properly, and may include monitoring reservoir water levels to ensure the safe operation of a storage project. Regular inspections, coupled with monitoring capability and early warning systems, are critical to public safety and the success of Oregon's Dam Safety Program.

Recommended Monitoring Action

- Place gages to appropriately serve as early warning systems for high flow events that could indicate dam failures. Prioritize high hazard dams that have been evaluated as unsafe.

INSTREAM NEEDS

CHARACTERIZING INSTREAM NEEDS

In 1987, the Oregon Legislature recognized the protection of water instream as a beneficial use. The Water Resources Commission and the Department were directed to hold water in trust for recreation, pollution abatement, navigation, and the maintenance and enhancement of fish and wildlife populations and their habitats. To meet this directive, Department hydrologists must quantify the amount of instream flows needed to meet each beneficial use. Quantifying instream flow needs requires an understanding of the magnitude, frequency, duration, timing, and rate of change of streamflow.

Recommended Monitoring Actions

- Identify basins with sensitive, threatened, and endangered species (e.g., coastal tributaries) and install monitoring equipment to help characterize the suite of flows through these basins.
- Collaborate with other state agencies and watershed councils to monitor streamflow in order to support restoration and conservation activities.

Coho Salmon, Eagle Creek

PROTECTING A SUITE OF INSTREAM FLOWS

Instream water rights are enforced based upon priority date similar to consumptive water rights. There are a variety of tools available to protect water instream, from issuing instream water rights and designating scenic waterways, to authorizing instream transfers, and conditioning new permits. New instream protections often include some type of monitoring requirement.

Recommended Monitoring Actions

- Increase the number of stream gages with telemetry (real-time monitoring) in reaches with instream water rights.
- Increase the number of gages in streams where water has been transferred to instream water rights.
- Ensure there is a stream gage located at the mouth of each state scenic waterway.

WATER SUPPLY

MEETING FUTURE WATER DEMANDS

Oregon's water challenges are expected to intensify over time, driven by increases in population, changes in climate, and shifts in land use, and economic conditions. These drivers will affect water demands and water management practices across the state. In 2015, Oregon updated its water demand projections, which show a potential increase in total consumptive water demand by up to 15 percent before the year 2050 (OWRD, 2015). Both surface water and groundwater supplies will need to be monitored carefully to prevent further depletion of limited water supplies.

Irrigation in Central Oregon

In areas where surface water is fully allocated, groundwater is becoming a commonly used new source of supply. In a natural groundwater system, recharge is equal to discharge, with the net recharge equal to zero. In a groundwater system with pumping, understanding the balance between recharge and discharge is important for responsible management of the resource.

Recommended Monitoring Actions

- Establish stream gages and monitoring wells in watersheds with projected increased demand in locations that allow for tracking of the entire water distribution network.
- Employ the Department's Water Use Reporting Program to track demand over time.
- Use telemetry in wells to monitor actual groundwater use in each basin.

FORECASTING SEASONAL WATER SUPPLY

Gages that provide key information about streamflow patterns are crucial for accurately characterizing water supplies. Spring and summer forecasts utilize stream gage data from earlier in the year to predict the likely median streamflow at a site. These forecasts are based on historic streamflows, snowpack amounts, groundwater levels, and climate data. Gages that can be used to provide information for water supply forecasting include gages with a minimum of 20 to 30 years of record and gages that monitor natural streamflow.

Recommended Monitoring Actions

- Ensure communities in every basin have access to natural streamflow data from long-term, high-elevation gages, mid-level snow survey sites, and baseline groundwater levels.
- Participate with federal partners in the Jet Propulsion Laboratory's "Airborne Snow Observatory" (ASO) Program. ASO is a LiDAR-based system used to quantify snowpack conditions which will provide complete, accurate real-time water supply data for water management.

PARTNERING WITH OTHER AGENCIES

The Department partners with public and private sector entities to monitor and share data about Oregon's streams and aquifers. These partnerships help leverage limited state resources and serve as conduits for communication. Cooperative gages and wells have been identified by state and federal partners as useful for meeting various legal obligations and institutional needs.

DEVELOPING FLOW PRESCRIPTIONS

The state of science on instream flow needs has evolved greatly since the establishment of Oregon's Instream Water Rights Act in 1987. Although establishing new instream water rights is an effective strategy for protecting water instream, the state has other tools and options at its disposal as well. Under legislation passed in 2013, some storage projects funded through Oregon's newly created Water Supply Development Fund will be required to operate in a manner that protects diverse ecological needs. In order for both the users and the stream system to benefit, such projects will require thoughtful flow prescriptions, monitoring, and response programs.

Recommended Monitoring Action

- Work with Oregon Department of Fish and Wildlife, Department of Environmental Quality, and tribes to develop monitoring protocols in support of water supply development projects and requirements to protect seasonally varying flows.

MONITORING WATER QUALITY

Water quantity and water quality are inextricably linked. Decreased water quantity (streamflow and groundwater levels) impairs water quality; impaired water quality can have an effect on the accessibility and reliability of water supplies.

Water quality information, although generally outside of the regulatory responsibilities of the Department, plays a crucial role in water management decisions. The Department currently collects temperature data for partners who are monitoring watershed or stream health. The Department recently partnered with the Oregon Department of Environmental Quality (DEQ) to install water quality monitoring (temperature) devices at several stream gages and monitoring wells. These data are collected according to USGS standards and are publicly available through the Department's website.

Recommended Monitoring Actions

- Continue to work with DEQ to develop instrumentation deployment protocols at Department monitoring sites to support water quality monitoring programs.
- Increase the number of stream gages with reportable water temperature data to support DEQ, Oregon Department of Fish and Wildlife (ODFW), and other entities that might use the data. This includes linking the telemetered data sets with agency databases.

RESTORING AND CONSERVING HABITAT

The Oregon Watershed Enhancement Board (OWEB) funds millions of dollars of watershed restoration and conservation projects every year. Monitoring is a central component of OWEB-funded projects for project development reasons and for tracking effectiveness over time. Many local restoration and conservation partners operate long-term water quality and habitat monitoring networks in order to better understand baseline conditions and track trends in their watersheds. Baseline data, when compared to water quality or habitat standards, may trigger restoration or conservation activities. More recently, these groups have an increased interest in watershed characteristics that require continuous water quantity information. Essentially, monitoring streamflow conditions helps the state and its partners identify the most pressing restoration and conservation needs, ensures the effective use of funding, and confirms whether funding recipients have met their commitments.

Recommended Monitoring Action

- Work with OWEB to develop monitoring protocols for collecting and managing water quality and water quantity monitoring data.

Whychus Creek Watershed Restoration Project, 2011

EVALUATING THE MONITORING NETWORK

A well designed monitoring network provides accurate and reliable streamflow and groundwater level data for decision makers inside and outside the Department. This Monitoring Strategy provides a framework for evaluating the effectiveness of the Water Resources Department's current monitoring network of stream gages and observation wells.

In addition, this Monitoring Strategy identifies monitoring priorities and offers recommended actions to guide the design of the monitoring network in the future. It identifies desired site characteristics for effective monitoring of each priority and summarizes them into a succinct table format (see Table 1). This document also outlines next steps for evaluating the monitoring network. Included are a set of appendices identifying additional resources and tools that will be used for implementation.

The Department plans to evaluate current and potential monitoring sites for their effectiveness in meeting each of the priorities outlined in this Monitoring Strategy. In order to do this, however, the Department has additional work ahead. Evaluating current and potential monitoring sites starts by updating and adding site characteristics for each monitoring site in the database. Evaluating the network also means determining where there are gaps in the data and where the Department should place new monitoring sites[1].

Next steps for evaluating the monitoring network are:

1) Update and add new attributes for each monitoring site in a centralized database
2) Identify and rectify problematic sites
3) Solicit input from external partners on future monitoring locations
4) Evaluate current and potential monitoring sites
5) Determine gaps in monitoring data based on network evaluations

1) **Update and add new attributes for each monitoring site in the Department's database.** The Department has a list of about 40 different types of attributes for each of its stream gages and observation wells. Approximately 70% of these data have been filled in thus far. Department staff are working to update and populate 100% of these attributes. These attributes are primarily location related, such as latitude and longitude, county, and basin.

   One goal of the Monitoring Strategy is to capture even more precise information about Oregon's network of monitoring stations. For example, each gage record should reflect if the streamflow is natural or if there are diversions or impoundments upstream. In addition, we should note whether the site helps to characterize surface water/groundwater interactions. Refer to Table 1 to see the set of attributes associated with each monitoring priority. The Department is updating and adding these attributes to each monitoring station record in the database, improving its ability to query information.

2) **Identify and rectify problematic sites.** A number of monitoring sites have issues related to poor data quality, difficult access, or serious safety concerns. As Department staff update attributes

[1] One full-time staff member could coordinate and perform these network evaluations.

in the database, these sites will be flagged as requiring relocation, service, replacement, or removal.

Poor data quality can result when field conditions, equipment, methods, or lack of staff resources do not produce accurate or usable data. Equipment may not be properly calibrated, cleaned, or functioning, or methods may not meet Department and USGS standards. Access to monitoring sites may be physically hampered by items blocking the way such as wires, tree limbs, etc.

Some monitoring sites are in locations where new landowners may deny staff access to the site. Other sites are in remote locations surrounded by steep, slippery, or difficult terrain. Some of these sites can be accessed by all-terrain vehicles, while others can only be accessed by foot. Even locations close to urban areas can present safety concerns, with heavy traffic, dogs, vandalism, or unhealthy conditions posing serious threats.

Monitoring sites that are a cause for health or safety concerns and those yielding sub-standard data should be considered for removal or relocation within the network. Alternately, these problematic sites could be rectified by implementing different types of instrumentation and/or access.

3) **Solicit input from external partners on future monitoring locations.** The Department has a modest budget to establish additional monitoring sites. These new sites will be established first and foremost, in support of the Department's mission. However, the Department seeks input from other agencies and stakeholder groups, in areas of mutual interest. If a partner has specific monitoring needs, the Department would like to learn more. Department staff have developed a form for soliciting input on stream gage needs for outside agencies or groups (see Appendix B). This form has been used by members of the STREAM Team to provide recommendations for stream gage locations. As the Department moves forward in assessing its monitoring network, these needs will be incorporated into the process.

4) **Evaluate current and potential monitoring sites.** The Department will conduct evaluations of its monitoring network to determine whether or not monitoring sites are individually and collectively providing the data needed to support the monitoring priorities of the Department. For each monitoring site, the evaluations will determine the value of the information being collected at a particular location. In addition, the evaluations will determine the effectiveness of the network as a whole and identify areas for improvement.

5) **Determine gaps in monitoring data based on network evaluations.** Once the network evaluations and scientific studies for each monitoring priority are completed, the Department can determine where any data gaps and redundancies exist. These results will also show where there are high value monitoring sites and sites that need to be decommissioned.

TABLE 1. MONITORING PRIORITIES - SITE CHARACTERISTICS

OWRD's Surface Water and Groundwater Monitoring Priorities	Sample Monitoring Site Characteristics
Climate Change	
Tracking the immediate hydrologic effects of climate change	• Measures natural streamflow • Record is long term, year round • Data are transmitted in real-time • Located in snow-rain transition zone • Located in snow dominated or snow-and-rain dominated basin • Paired with snow level monitoring sites (i.e.; SNOTEL stations)
Tracking the long-term hydrologic effects of climate change	• Differentiates climate effects from land use trends • Record is long term, year round • Located in snow-rain transition zone • Located in snow or snow-and-rain dominated basin
Extreme Events	
Predicting and memorializing floods, debris flows, and inundation	• Serves as early warning indicator of high flows and debris • Gage rating curves provide accurate measurement of high flows • Contributes to statewide flood warning response (e.g., RAFT)
Predicting and memorializing short-term drought	• Measures flow in rain and snow dominated streams, reservoirs, and aquifers • Quantifies water supplies in drought susceptible streams and aquifers • Gage rating curves provide accurate definition of low flows
Predicting and memorializing long-term drought	• Record is long term, year round • Quantifies water supplies in in drought susceptible streams and aquifers • Measures natural streamflow and water levels
Monitoring post-wildfire conditions	• Tracks real-time streamflow in recently burned watersheds
Groundwater Protection	
Ensuring sustainable groundwater levels	• Record is long term, year round • Data are transmitted in real-time • Tracks water level in areas of groundwater recharge • Monitors water level in declining areas • Monitors water level in high demand areas without many records
Gaining a better understanding of surface water/groundwater interactions	• Installation of well is in conjunction with related stream gages • Monitors water level in basins with large annual surface water yield from groundwater
Supporting Aquifer Recharge & Aquifer Storage and Recovery	• Tracks water level in areas of current or potential ASR and AR projects, especially key basalt aquifers

Water Management	
Improving effectiveness of distribution and regulation	• Picks up timely and effective signals • Tracks points of diversion/appropriation, storage, outflows • Tracks significant points of diversion
Predicting response of the hydrologic system to diversion/appropriation	• Provides data to an existing or potential model • Fills in a geographic gap in a model • Monitors water level or streamflow in groundwater study basins
Determining water availability	• Fills in a geographic gap in the Water Availability Model • Measures natural streamflow • Measures return flow • Record is long term, year round
Supporting dam safety	• Provides early warning system for high flow events
Providing water use data	• Monitors use from surface water or groundwater diversions
Instream Needs	
Characterizing instream needs	• Identifies stream type (e.g., perennial, intermittent) • Record is long term, year round • Characterizes flow regime in stream with STE species
Protecting a suite of instream flows	• Monitors stream reach with instream water rights or instream transfer • Characterizes streamflow regime in basin with storage potential
Water Supply	
Forecasting water supply	• Measures run-off from high elevation watersheds • Measures snowpack and run-off at mid-level elevations • Measures baseline groundwater levels
Meeting future water demands	• Measures actual surface water and/or groundwater use • Tracks water use in basins with projected increased demand
Partnering with Other Agencies	
Developing flow prescriptions	• Measures streamflow variability
Monitoring water quality	• Measures water quality, in addition to temperature
Restoring and conserving habitat	• Measures floodplain connectivity and stream complexity • Documents relationship between sediment transport and streamflow • Documents relationship between habitat features and streamflow

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APPENDIX A

PROTOCOLS & PROCEDURES FOR ESTABLISHING SITES

The Department has policies and procedures in place for establishing new monitoring sites to protect archaeological and cultural resources and public and private property. These procedures include direction for obtaining property access and developing cooperative agreements. Protocols are being developed to outline specific steps the Department's staff will take in order to meet these requirements. In addition to these items, the protocols will also include agency guidelines for requesting a new gage installation or updating an existing one, equipment purchase agreements, and safety considerations for field-related work.

Archaeological and Cultural Resources Policy

The Department acknowledges the significance of archaeological, historic, and cultural resources and is committed to the protection and preservation of these resources. Oregon's State Historic Preservation Office (SHPO) within the Oregon Parks and Recreation Department (OPRD) is responsible for safeguarding and managing the state's archaeological and cultural resources. In coordination with SHPO and Oregon's federally recognized tribes, the Department established protocols for installing or maintaining gaging stations and monitoring wells. The Department has also established procedures for any inadvertent discoveries.

Property Access Agreements

Private Landowner: The Department has in place a process for obtaining Property Access Agreements, which must be signed by the property holder, and allow personnel access to private property. Activities covered include installation, operation, and maintenance, including site access for taking water level measurements. The agreement also ensures the security of the state's property, including gates and locks.

Public Landowner: The Department also has agreements with other governmental agencies for accessing public properties to establish and maintain stream gages, including taking periodic water level measurements. Such agencies include, but are not limited to, the Oregon Department of State Lands, Oregon Department of Fish and Wildlife, the U.S. Bureau of Land Management, and the U.S. Forest Service. The Department also has agreements with DSL on removal-fill permits and counties and Oregon Department of Transportation on right-of-way permits.

Gaging Station Cooperative Agreements

The Department's procedure is to establish cooperative agreements with entities interested in sharing gaging operation and maintenance responsibilities, including funding. These types of agreements outline the conditions for easements, maintenance, financial obligations, and operation of the stream gage. Sharing and use of the monitoring data is also outlined in the agreement.

APPENDIX B
SOLICITATION FOR INPUT ON STREAM GAGE NEEDS

Water Resources Department – Stream Monitoring Needs

The Department has a modest budget to establish additional streamflow measurement sites (gages). These new gages will be established first and foremost, in support of the Department's mission. However, the Department is also interested in seeking input from other agencies or stakeholder groups to potentially focus on areas of mutual interest.

If your agency or group has specific water monitoring needs in Oregon, the Department would like to know more about them. As the Department moves forward in assessing its stream monitoring network, these place-based needs will be considered as part of its decision-making process.

Contact Information	
Agency/Program	
Name/Title	
Address	
Phone Number	
Email	
Website	

1) Does your project focus on monitoring streamflow or water quality or both?

2) Is this a current monitoring project or a planned project for the future? (If a future project, please provide a date for when monitoring data would be needed.)

3) Please provide a description of the project/program and how the data would be used.

4) Describe the geographic area(s) of interest that your agency would like to monitor.

5) In addition to streamflow data, what other parameters are you interested in collecting?

6) Please provide us with any other pertinent information.

APPENDIX C
HISTORY OF WATER QUANTITY MONITORING IN OREGON

Monitoring streamflow and groundwater has always been critical to the management of the state's water resources. Although policy priorities for monitoring change over time, Oregon continues to rely on consistent monitoring to provide an accurate characterization of surface and groundwater. The Department's ability to conduct monitoring has largely been driven by the availability of resources. The extent to which the Department has met its monitoring objectives appears to be driven by four major factors: historical events driving the availability of resources; changes in agency statutes, policies, and approaches; state-wide budget availability; and local interest and financial participation.

The following narrative describes monitoring efforts by the Department over time including key events that shaped agency monitoring priorities and resources.

1900s. The initial priorities for monitoring for the state were to quantify surface water supplies, to support allocation, adjudication, and regulation. These three priorities remain fundamental to the Department's monitoring needs. In 1909, the Oregon Office of the State Engineer officially began registering water use. The State Engineer's office worked in partnership with the U.S. Geological Survey (USGS) to monitor water resources for municipalities, irrigation, and water-power works. During this decade there were 48 stream gages operating cooperatively by the state and the USGS, although the USGS exclusively performed the hydrographic work.

1910s. World War I (1914-1918) was the first time in history where a decrease in federal water resources monitoring occurred in response to international events. At the completion of the war, the USGS officially began using the State Engineer's office to conduct hydrographic work. During this time, state-level staff increased substantially. By the end of 1920, the State Engineer's office operated 85 gages cooperatively with the USGS.

1920s-30s. Severe droughts during the 1920s and 1930s focused national attention on water resources. Federal and state planning agencies recognized the need for additional hydrologic data, including climatic records, snow surveys, evaporation records, groundwater studies, and streamflow records. The federal government responded with an infusion of funding. By 1928, the State Engineer's Office was conducting snow surveys, while employing a new method of forecasting. This new forecasting approach quantified the status of water supplies for the upcoming season, allowing farmers to plant accordingly and manage stored water to supplement potential shortages.

During the 1920s and 1930s, the State Engineer's office also called for prudent use of groundwater, considering it essential to avoid aquifer depletion, unsustainable withdrawals, or excessive costs. This required accurate data to calculate estimates of sustainable yields. In 1927, the code for appropriation of underground water east of the Cascade Mountains was adopted, and by 1935, the USGS and the State Engineer's office were running a program to collect groundwater water-level measurements. A statewide, cooperative program was later born to inventory groundwater basins and to measure water levels in dedicated observation wells. State and federal agencies provided initial funding.

1940s. Although groundwater funding was diverted to the war effort during World War II, by 1946, cooperative investigations for both surface water and groundwater had resumed. A public information service began in response to 100 public inquiries on groundwater resources of the state. In response, the Department's watermaster corps was strengthened.

1950s. In the 1950s, the number of observation wells in the network rapidly increased. The Oregon Groundwater Act was passed in 1955, paving the way for the public appropriation of groundwater west of the Cascades. By 1958, 140 observation wells were being monitored and two critical groundwater areas had been designated, Cow Valley and The Dalles. Also in the 1950s, the State Water Resources Board was established to oversee water distribution across the state. By 1958, the state was monitoring streamflows at 308 gaging stations.

1960s. The year 1964 marked the beginning of state funding for assistant watermasters, who still play an important role in managing the state's stream gage network. Also in the 1960s, the observation well network had grown to around 150 wells and funds were made available to establish and maintain an observation well program. By the end of 1962, the well net had been expanded to 593 wells, a significant increase in such a short time. During the remainder of the decade, the number of wells had expanded to more than 800 and requests for additional staff were made to meet the increased workload.

Basic data collection must be expanded if a sound factual basis for groundwater controls is to be obtained. Increased uses of groundwater will continue to strain the capacity of our aquifers. The state must face the need for increased funding and immediate expansion of the investigation of surface and groundwater resources. The southwestern United States is already in need of outside water supplies and is looking to the Pacific Northwest. An expanded groundwater program must be initiated by the State Engineer soon, if we are to effectively answer our total water needs in the future.

(1966-1968 State Engineer Report)

1970s. By 1970, five critical groundwater areas had been designated due to groundwater development pressures. During this time, there was a significant increase in the number of public inquiries regarding groundwater. In 1975, the Oregon Legislature created the Water Policy Review Board and merged the State Engineer's Office with the State Water Resources Board to create the Water Resources Department. The national recession of the late 1970s drove agency budgets down, resulting in the start of a long-running stream gage record processing backlog. Record low flows of 1977 and 1978 were captured by gages around the state and resulted in the 1984 nomination of 75 streams for minimum flows by the State Fish and Game Board (now Oregon Department of Fish and Wildlife).

1980s. In 1985, the Water Resources Commission was established to take over the role of the Water Policy Review Board. The Instream Water Rights Act was enacted in 1987, granting authority to the Oregon Department of Fish and Wildlife (ODFW), Department of Environmental Quality (DEQ), and Oregon Parks and Recreation Department (OPRD) to apply for instream water rights. By the 1980'stream gaging station numbers had dipped and rebounded to around 275 gaging stations.

In 1988, the Commission adopted administrative rules governing groundwater interference with surface water, known commonly as the Division 9 rules. These rules guide the Department in making determinations regarding whether existing or proposed groundwater wells have the potential to cause substantial interference with a surface water supply and provides authority for controlling such interference. The Governor's Watershed Enhancement Board, established in 1989, granted funds to watershed restoration and enhancement activities across the state and was operated out of the Water Resources Department.

In the 1980s, the observation well net was reduced by 50 percent to eliminate unnecessary duplication of data and provide adequate time for the geophysical well logging program. Data from this program were used for groundwater management. Data sheets were completed and entered for the roughly 400 observation wells.

1990s. By 1990, overhaul of the statewide observation well network was about halfway complete. The existing wells on the net had been thoroughly screened to ensure the adequacy of each well for this purpose. The next step was to add monitoring sites where coverage was inadequate. Approximately 335 wells across the state were included as part of the state observation well network. That number gradually increased to about 350 observation wells by the year 2001. It was during this time that the Department developed key performance measures to track the network's growth.

Starting in 1990, the Department initiated the Water Availability program, developing an analytical tool for use in surface water allocation. In 1993, the Department discontinued many of its co-operative gage agreements with the USGS due to budget restrictions, bringing the total number of state-run gages to approximately 200 statewide.

Also in the 1990s, the Field Services Division organized in to five regions in order to better serve local water issues. These regions have largely determined the need and location of stream gages throughout Oregon. This also ushered in a new era of regulation with the Commission being permitted to issue civil penalties for violation of Oregon's water law. Stream gages and the careful tracking of water use became crucial to this new regulatory tool.

Significant improvements in computer systems allowed more timely tracking and comparison of stream gage data. Prior to this, all stream gage records had to be maintained on paper with computations later performed by hand. This was also the beginning of remotely accessed stream gage data.

ODFW applied for multiple instream water rights as well. During this time period many of the previously established minimum perennial streamflows were converted to instream water rights. The Department, which holds instream water rights in trust, continues to use the stream gage network to protect instream water rights today.

In 1997, the Oregon Plan for Salmon and Watersheds was adopted by the Oregon Legislature, in large part, to initiate a home-grown response to the listings of Coho and other salmon species under the federal Endangered Species Act. The Oregon Watershed Enhancement Board (OWEB) was established around this time and took over the funding role of the Governor's Watershed Enhancement Board for watershed restoration projects. Funds for monitoring to support such efforts also fall within OWEB's purview.

In 1998, the Hydrographics Section began working on a backlog reduction project to support the recently established water availability program, which required processing of approximately 500 water years of raw data.

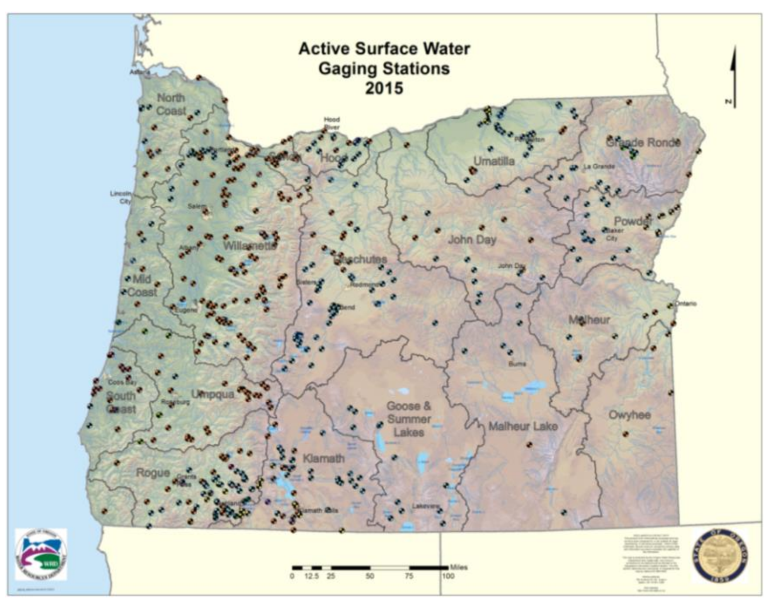
2000s. In 2002 and 2003, the Department worked with staff from the Oregon Progress Board to revise and update its key performance measures. The goal was to build a stronger link to the Department's mission. It was recognized that measuring streamflow and groundwater levels is essential to effectively managing these water resources. However, maintaining streamflow gaging stations and groundwater measurement sites is dependent on sufficient funding to operate stations and analyze and publish the data. Related key performance measures in existence today include:

> *Key Performance Measure #4* – Focused on streamflow gaging, this measure tracks the Department's progress toward increasing the number of state-operated or assisted gaging stations from the baseline year 2001. The baseline number of gaging stations is 215.
>
> *Key Performance Measure #5* – Focused on assessing groundwater resources, this measure tracks the Department's progress toward increasing the number of wells routinely monitored to assess groundwater resources from the baseline year 2001. The baseline number of wells is 350. There are challenges in maintaining the number of monitoring wells. Wells monitored by the Department are privately owned and access is commonly an issue. As property changes hands or other conditions change, some well owners have discontinued their participation in the State Observation Well Net.

The Department needs to ensure adequate budget and staff to maintain, collect, and analyze data from these important monitoring sites, and to continue providing publicly accessible data. Key to this success is an expanded network that includes dedicated sites with a long-term record.

Despite fluctuating budgets and the deep national recession of the 2000s, the number of monitoring stations has rebounded. An infusion of funding from the 2013 and 2015 Oregon Legislatures, discussed below, will help the state expand its programs and make significant progress on these key performance measures.

Present-Day Stream Gages. The Department operates more than 250 stream gages, of which about 80 percent are near real-time. The entire network shown on the accompanying map includes an additional 345 gages operated by cooperators, such as the USGS. The Department includes cooperators' gages as part of our network and utilizes the data collected at those sites in day-to-day operations and scientific studies.

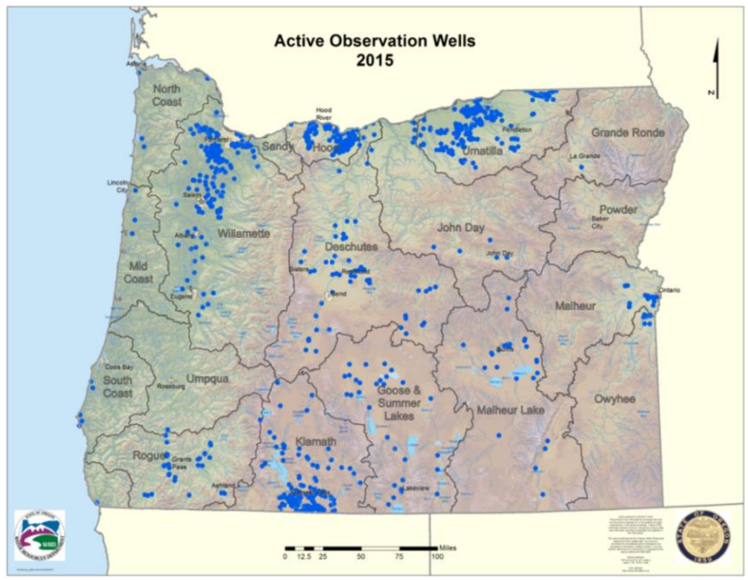


As part of the Upper Klamath Basin Comprehensive Agreement signed in 2014, the Department partnered with the

Klamath Tribes and the U.S. Fish and Wildlife Service to install several gaging stations within the Klamath River Basin. The gages will be used to monitor and assess streamflow conditions on a real-time basis in support of Tribal water rights. As of September 2015, six new gages had been installed in support of this effort.

The 2013 Oregon Legislature provided the Department with resources to install 16 new gages each biennium. This Monitoring Strategy will help ensure that will be installed in areas that provide the most benefit and data in support of our monitoring network objectives.

Present-Day Observation Wells. The Department currently has 370 state observation wells, 60 of which have continuous recorders installed. A well is considered part of the state observation well network if data are collected on a quarterly basis. However, the Department currently measures water levels in a total of about 1,100 observation wells across the state, some of which are project based wells.



The Department is actively installing new observation wells. The 2013 Oregon Legislature provided funding for new monitoring wells, groundwater studies, and staff. With this new funding, the Department has installed new monitoring wells in the Umatilla Basin, near The Dalles, Harney Valley in the Malheur Basin, and the Deschutes/Metolius area.

APPENDIX D
HYDROLOGY OF THE STATE OF OREGON

When designing a hydrological observation network, it is necessary to have as much knowledge as possible about the physical properties and the processes in the system involved (Netherlands Organization for Applied Scientific Research, 1986). Climate, hydrology, topography, and geology play a key role in understanding the interconnected water cycle of Oregon.

Precipitation. Oregon receives a majority of its precipitation in the winter. In general, Oregon has a rather mild, winter climate. The climate of the western third of Oregon is characterized by moderate temperatures, wet winters, and dry summers; about 78 percent of the annual precipitation occurs in the period October to March. The eastern two-thirds of the state, on the other hand, have greater extremes of temperature but somewhat less seasonal variation in precipitation. On the east side, about 65 percent of the precipitation occurs in the period October to March. (Phillips, 1969).

The Cascade Range, about 90 miles inland from the Pacific Ocean, lies parallel to the coastline and acts as a natural barrier to marine air masses and the prevailing westerly winds. This causes a significant statewide variation in annual rainfall. Average annual precipitation ranges from 200 inches in places in the Coast Range to less than 40 inches on the Willamette Valley floor in western Oregon and less than 10 inches in parts of north-central and south-eastern Oregon. Much of the precipitation falls as snow at altitudes above 3,500 feet, which is the approximate mean altitude of Oregon.

Precipitation does not all arrive at once, but in a series of storms or events. Each event elicits a unique combination of responses from the effected watersheds, including plant uptake, surface water runoff, and groundwater recharge.

Run-Off. Surface water runoff is relatively abundant in Oregon, but it is unevenly distributed with respect to location and timing. Major river systems drain the Coast Range, the Cascades, Klamath, John Day and Wallowa Mountains, and the terminal lake basins of the Great Basin. Each of these areas has a distinct topography and plant community, which interact with climate and geology to produce unique runoff patterns. Floods may occur every few years in the humid, western part of the state; although less frequent, floods are not unknown in the semiarid eastern region. Water shortages common to eastern Oregon can also occur in the humid western section, especially during typical dry summers. Some streams that lie almost side by side can differ markedly in their patterns of flow. Snow, and the period during which it melts, plays a major role in shaping annual hydrographs.

Recharge and Groundwater. In Oregon, most of the groundwater recharge occurs in the winter and spring months. This seasonal distribution of groundwater recharge results in a seasonal fluctuation of the water table. The magnitude of fluctuation is greatly dependent on the permeability of the underlying geologic formations. The occurrence of permeable rocks capable of absorbing and transmitting groundwater varies greatly from place to place in the state. Many of the geologic features of Oregon are of volcanic origin, but parts of the state have marine and continental sediments, metamorphic rocks, or unconsolidated deposits laid down by water, wind, or ice. The most permeable rock formations occur in the Cascade Mountains and are composed chiefly of young volcanic rocks.

They lie in a belt that receives relatively large quantities of recharge. The groundwater discharge from these rock formations create the many large springs that occur on both sides of the Cascade Mountains.

Coarse alluvial sediments were deposited along the eastern part of the Willamette River Valley by the swift streams flowing off the Cascade Mountains. These coarse-grained sediments form the high-production water bearing zones in the Willamette Valley. Slower moving streams flowing off the Coast Range deposited relatively fine-grained deposits along the western margin of the Willamette Valley. This difference in character of the alluvial sediments from one side of the Willamette Valley to the other accounts for the great difference in the availability of groundwater in these two areas.

In general, the Coast Range and Klamath Mountains are composed of extremely low-permeable rock units. Even though these areas receive large amounts of precipitation, the aquifers yield small supplies of groundwater.

Along the coast, there are many areas underlain by recent sand dune deposits. These areas absorb large quantities of water and are capable of producing large amounts of groundwater. Other parts of the coast are underlain by less-permeable marine terrace deposits which are composed of older beach deposits and which make up many of the aquifers along the southern coast.

In eastern Oregon, the central mountains are composed chiefly of relatively impermeable rock formations that are capable of yielding only small supplies of groundwater. Intermountain basins such as the Baker, Wallowa, and Grande Ronde Valleys often contain permeable rock formations and moderate natural supplies of groundwater. Much of the north-central part of the state is underlain by the Columbia River Basalt Group. These formations are of wide areal extent in both Oregon and Washington and are generally capable of yielding moderate to large supplies of groundwater. The deeper basalt aquifers do not recharge rapidly; mining this resource has led to significant declines in groundwater levels. Much of the basin and plateau areas of southeastern Oregon contain permeable rock formations, and where these formations contain water, they generally produce moderate to large amounts of groundwater.

Groundwater/Surface Water Interactions. Along with controlling rates of recharge to aquifers, the diverse geology of Oregon produce other variations in surface-water hydrology as well. For instance, the broad areas of pumice and young lava flows in the southern part of the Cascade Range (the Upper Metolius basin) have poorly developed stream systems because the highly permeable rocks at the surface readily absorb and retain rainfall. As a result, peak flows from rainstorm and snowmelt runoff are relatively low, but the discharge of groundwater through springs and seeps produces relatively large and sustained annual flows in Oregon’s rivers and streams. By contrast, altered volcanic and marine rocks in parts of the Coast Range and some of the older rock formations in the Klamath and Blue Mountains have low permeability, allowing little infiltration of precipitation. Streams draining such areas respond rapidly to intense precipitation, and may recede to nearly zero during the drier months.

Between these two extremes are varying degrees of gradation. In places, surficial deposits allow a sizable amount of infiltration from moderate rates of precipitation, but reject a large part of precipitation from intense storms. This interaction among geography, geology, and climate is most evident in places where streams and groundwater directly exchange water. Groundwater/surface water interaction occurs in three basic ways: 1) streams gain water from inflow of groundwater via springs or seepage through the streambed; 2) streams lose water to groundwater by outflow through the streambed; or 3) they do both, gaining in some reaches and losing in others. Gaining streams represent locations where cooler groundwater emerges and contributes to a stable base flow, helping to sustain surface water during the summer months. Losing streams can act as a potential route of groundwater contamination, as polluted runoff enters streams that eventually percolate back into the ground. Stream reaches may seasonally shift between gaining and losing depending on the local water table and the rate and volume of precipitation and infiltration.

Vegetation. Evapotranspiration makes up a major part of the water cycle. During the rainy season, tree canopies intercept substantial amounts of water and slow the rate at which water seeps into the ground or runs off into streams. As the precipitation rates decrease and plants increase their rate of water use each summer, they can significantly influence surface and groundwater levels.

Conclusion. Together, the geology, topography, vegetation, and climate of Oregon produce a diverse system of water movement. Understanding this diversity is key to effectively managing Oregon's water resources.