Oregon

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MEMORANDUM

TO: Water Resources Commission

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SUBJECT: Agenda Item N, November 20, 2015
Water Resources Commission Meeting

Monitoring Strategy Update

I. Introduction

Beginning in 2014, the Department began a three-part process to develop a Monitoring Strategy for Water Resources to help prioritize locations for new stream gages and monitoring wells. This process included a re-write of protocols, development of a method to evaluate the current network of gages and wells, and finally the process for identifying locations for new wells. This report will provide a description of how the Monitoring Strategy has been constructed.

II. Background

In August 2012, the Water Resources Commission adopted Oregon's Integrated Water Resources Strategy (IWRS). The IWRS provides a blueprint for understanding and meeting Oregon's water quantity, water quality, and ecosystem needs now and into the future. One primary objective of the IWRS is to understand the status of the state's water resources. More specifically, this objective seeks to further understand Oregon's water supplies and systems, water quality/quantity information, and water management institutions. IWRS Recommended Action 1B (improve water resource data collection and monitoring) and 1C (coordinate interagency data collection, processing, and use in decision-making) of the IWRS support this objective.

In 2013, the Oregon Legislature approved staff resources and funding to establish, maintain, and upgrade streamflow gaging stations and monitoring wells throughout the state. As a result, in 2014, the Department began a process to ensure that it is placing these new gages and wells as efficiently and strategically as possible. The Monitoring Strategy will not only support recommended actions in the IWRS, but also the Department's Key Performance Measures.

III. Discussion

Overview of the Monitoring Strategy

The Monitoring Strategy builds on work conducted by Department staff in 2011, in which staff analyzed the Department's stream gage network for its usefulness in day-to-day water distribution duties. The new Monitoring Strategy takes a broader look, to determine where WRD's new monitoring sites should be located in order to meet the priorities of additional programs and interagency initiatives.

As part of the process, staff sought input from other WRD staff, partners, and stakeholders. In addition, this project benefitted from the Department's involvement in the interagency STREAM Team. 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 resource agencies. STREAM Team members, the Oregon Department of Agriculture, Department of Forestry, and Department of Environmental Quality all have monitoring strategies in place and are in the midst of updating and discussing them.

In developing the Monitoring Strategy, staff have updated Department protocols relating to landowner access agreements, protection of cultural resources, inter-agency and intra-agency coordination efforts, and equipment purchasing agreements.

Staff have identified Department priorities for monitoring and developed recommended monitoring actions that help identify locations for new stream gages and observation wells. Each of these monitoring priorities relies on data in order to understand particular water management issues. These priorities for monitoring include:

- Climate Change
- Extreme Events – Floods and Drought
- Groundwater Level Trends
- Understanding Surface Water / Groundwater Interactions
- Instream Needs
- Water Availability
- Increased Water Demand

Implementing the Monitoring Strategy

To implement the recommended monitoring actions identified in the Monitoring Strategy and to ensure effective monitoring for the priorities identified above, the Department plans to undertake an evaluation of its monitoring network, which includes all stream gages and observation wells.

The first step of this evaluation is to conduct an inventory of each stream gage and observation well. This inventory will enable the Department to enhance its data collection and querying capabilities to better determine where there are data gaps in the network.

Once the inventory is complete, the Department will evaluate the existing monitoring network of gaging stations and observation wells to determine whether or not monitoring sites are individually and collectively providing the data needed to support the priorities of the Department.

The evaluations will determine the value of the information being collected at a particular location. As part of the process, the Department will identify gaps and redundancies in the existing monitoring network, as well as evaluate how the network design for stream gages and monitoring wells supports data collection efforts. Monitoring recommendations will also be identified as to where to locate new stream gages and monitoring wells to capture data needed to monitor for each priority.

IV. Conclusion

In order to be able to meet Oregon's water needs now and into the future, the Department must continue to invest in understanding our water resources and the changes to those resources with coming pressures. In order to wisely utilize state funding for data collection and monitoring, the Department has undertaken efforts to identify and prioritize monitoring needs.

Mellony Hoskinson
503-986-0832

Attachment 1: Oregon Water Resources Monitoring Strategy (2015)

OREGON WATER RESOURCES MONITORING STRATEGY

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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 Management Team
USGS	U.S. Geological Survey

ACKNOWLEDGEMENTS

The development of this document has been a cooperative effort from Oregon Water Resources Department staff. In particular, the following people are gratefully acknowledged for their significant contributions in leading this effort and compiling the Department's Montioring Strategy.

Mellony Hoskinson, Rachel LovellFord, and Ken Stahr have been the leads on this task.

In addition, the Department would like to recognize 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. All of the contributions from each of these staff have been invaluable to the development of this strategy.

INTRODUCTION

The Oregon Water Resources Department's (Department) Monitoring Strategy positions the Department to evaluate the effectiveness of the current monitoring network of stream gages and observation wells. In addition, this Monitoring Strategy is being developed to identify monitoring priorities and to guide the design of the monitoring network into the future. 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 describes the Department's priorities and recommended monitoring actions necessary for a robust monitoring program. It then identifies desired site characteristics for effective monitoring of each priority and summarizes them into a succinct table format (see pages 16-17). This document then outlines next steps for evaluating the monitoring network. And finally it concludes with appendices identifying additional resources and tools that will be used for implementing the Department's new monitoring network.

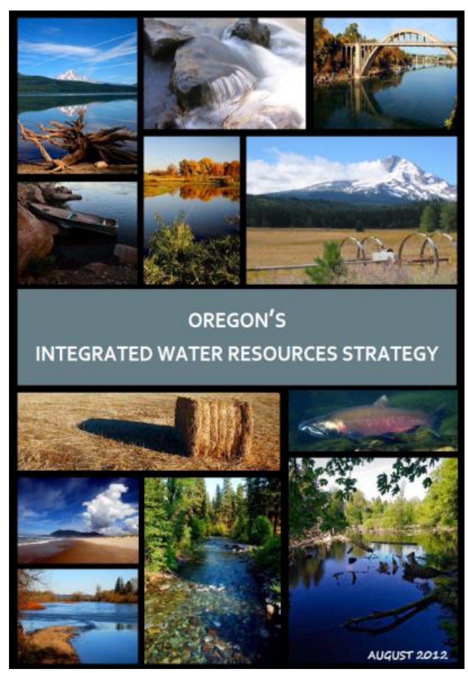
Background

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

In 2008, the Department undertook a formal evaluation of its stream gaging network. The purpose of this effort was to determine if the stream gage network was meeting 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 Department focused on distribution and regulation needs only and published the *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 our 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). Building upon the 2011 network evaluation, the Department's goal is to further develop a monitoring network that will expand the state's data collection efforts.

Another IWRS action addressed by the 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 many 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, measuring 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 the 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)

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.* The state agencies that make up this group are:

- Oregon Department of Agriculture
- Oregon Department of Environmental Quality
- Oregon Department of Fish and Wildlife
- Oregon Department of Forestry
- 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 resource 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.

For each priority, the Department has identified recommended monitoring actions to meet the related data needs. Each of these priorites along with associated recommended monitoring actions are described in further detail in the following pages.

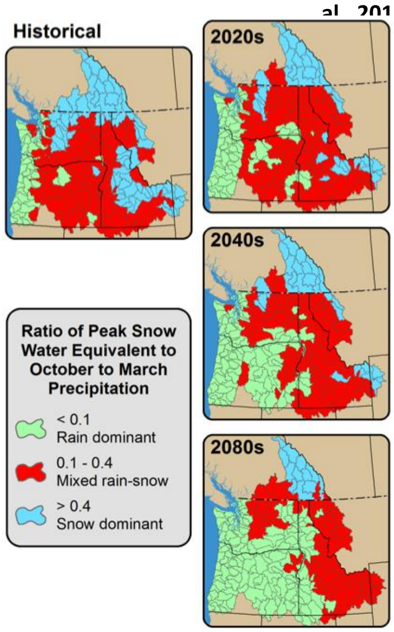
MONITORING PRIORITIES

Each of the following priorities rely on monitoring data in order to fully understand and address the Department's water management concerns. In addition, the Department has identified and recommended specific monitoring actions that should be taken in order to address each priority.

CLIMATE CHANGE

World renowned climate change research is taking place right here in Oregon's university system, and has helped the state to begin preparing 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 the 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 snow melt run-off, and reduced recharge to groundwater aquifers.

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



The state needs a monitoring network that is designed to capture data necessary to quantify and confirm these shifts and changes. These data will provide water users and planners with the information needed for adaptation and resiliency.

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

Recommended Monitoring Actions

- Identify basins susceptible to changing flow regimes (e.g., basins that receive a significant percent of precipitation as snow) and establish gages to quantify the rate of change in the magnitude, frequency, duration, and timing of stream flow.
- 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).

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, growing populations, and the after-effects of wildfires also contribute to the increasing effects 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.

Christmas flood of 1964

Gages that accurately capture high flow events help planners and engineers effectively plan for floods. However at this time, not all stream gages accurately capture flood data. The Department needs more gages that effectively monitor floods and have exceptional definitions at the upper end of the rating curves. 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 U.S. Army Corps of Engineers that characterizes the severity of florecast 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 gage rating curves throughout the state that lack accurate definitions of high flows. Increase the number of high flow measurements or relocate these gages.
- Upgrade gages in flood-prone areas to transmit data in real-time which will aid in flood forecasting and early warning. 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 result from low winter snowpack or rainfall. Oregon has a history of frequent, single-year droughts, particularly on the east side of the state. Currently, however, Oregon is in a multi-year drought. Water year 2015 has been record-setting for both high temperatures and little precipitation, which offers a glimpse into possible future water conditions for Oregon. Improved monitoring for low streamflows and groundwater levels is critical for both drought prediction and documentation.

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. Accurate low-flow measurements help to track water supplies for real-time distribution and allow for statistical summarization and modeling of future low-flow events. This type of information aids in planning and designing for drought resiliency. Gages useful for tracking drought are 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 gages in locations used in water supply forecasting that are vulnerable to low flow conditions.
- Identify reservoirs that provide water supplies or instream releases, that are susceptible to short-term drought, and that are currently without water level gages or inflow and outflow gages.
- Identify gages currently used for low-flow distribution and statistics and upgrade to near real-time as needed.

WILDFIRE CONDITIONS

With recent fires in the Pacific Northwest, especially those of intense severity, water managers can expect see extreme flash flooding conditions and debris flows during the fall and winter months following these fires. Other potential effects from wildfires include erosion, rapid run-off of precipitation due to decreased soil porosity, and resulting flash floods and debris flows. 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 gages or rapid deployment gages in recently burned watersheds to track and send alerts regarding potential flash flooding and debris flows.

GROUNDWATER

GROUNDWATER LEVEL TRENDS

Monitoring groundwater levels provides valuable scientific data for Department hydrogeologists, 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. In addition, these studies are needed to better assess groundwater availability and quantify surface water/groundwater interactions.

Karl Wozniak and Aurora Bouchier, OWRD Groundwater 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; focus 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, discharge to streams and springs).

UNDERSTANDING SURFACE WATER / GROUNDWATER INTERACTIONS

Groundwater discharges to streams, springs, and rivers year-round, 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, and these exchanges can change 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 the protection of senior water rights. By coupling stream and aquifer monitoring in key basins, Department scientists will have a better understanding of stream-aquifer interactions.

Recommended Monitoring Actions

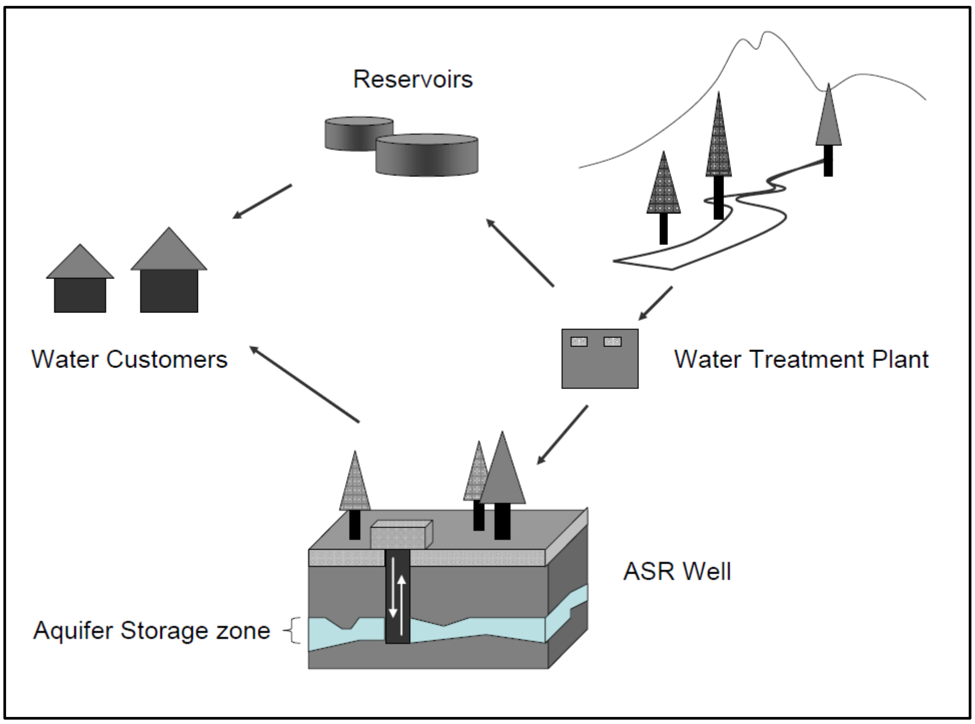
- Pair stream gages with observation wells in areas of stream-aquifer interactions.
- Target key basins for dedicated observation well installations to be monitored in conjunction with stream gages.
- Rank streams in Oregon based on the percent of annual yield contributed by groundwater. This ranking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

AQUIFER STORAGE AND RECOVERY (ASR) & AQUIFER RECHARGE (AR)

In Oregon, the relatively wet climate during the winter months makes ASR and AR good alternatives for water storage projects. During the summer dry season, water use peaks due to increased irrigation and municipal use, 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. Focusing wells in areas of potential ASR and AR projects with nearby surface water supply.
- 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, these staff need data that are accurate and up-to-date.

Watermaster Awbrey Perry measuring Tumalo Creek, 1948.

Recommended Monitoring Action

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

PREDICTING THE RESPONSE OF THE HYDROLOGIC SYSTEM TO DIVERSION / APPROPRIATION

Effective modeling can help predict the response of the hydrologic system to groundwater pumping and surface water diversions. The Deschutes Basin model, 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 that the determinations of well depth and well distance can affect other water users. They can also simulate groundwater travel time and water quality effect.

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 development of a Water Availability Program. The program uses computerized hydrologic models that include basin and sub-basin runoff characteristics and stream flow measurements to predict flow in streams without gages. 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 stored water projects in the near future.

- Establish gages above diversions and impoundments in major streams (i.e., measure natural streamflow) throughout the state.
- Establish measurements of evapotranspiration in areas with know water availability challenges.
- Improve the resolution of the water availability model by establishing gages in regions of the state where stream gage density needs to be increased.

DAM SAFETY

Willow Creek Dam above the City of Heppner

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 based on the hazard rating of the dam, 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 (signifying the potential for loss of life and property below the dam) that have been evaluated as unsafe.

WATER USE DATA

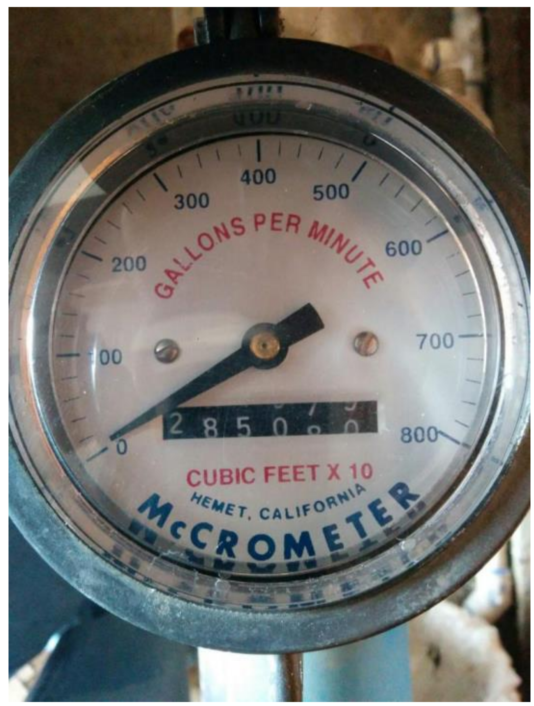
Water use information is critical for timely water management decisions, water resources planning, and hydrologic analyses. These data are often used to determine sustainable groundwater withdrawals or basin water budgets. Water use data differ from stream gage data collected at diversions in that they are self-reported by water users on a monthly basis. Totalizing flowmeters are typically installed to capture water use information at piped 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. In addition, some water permits have been conditioned since the late 1980's to report monthly water use information to the Department.

This Monitoring Strategy seeks to build upon existing investments in the Water Use Reporting Program and the Commission's 2007 Strategic Measurement Plan by gathering more water use information for groundwater withdrawals to supplement data obtained from conditioned water right permits.

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.



Inline Totalizing Flow Meter

INSTREAM NEEDS

CHARACTERIZING INSTREAM NEEDS

In 1987, the Oregon Legislature recognized 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 be able to 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 by priority date like all other 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 permits. New instream protections are often accompanied by a monitoring requirement designed to ensure the water rights are being met.

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 above and below instream transfer points in basins with water supply shortages.
- Increase the number of stream gages located at the mouths of each state Scenic Waterway.

WATER SUPPLY

MEETING FUTURE WATER DEMANDS

Oregon's water resource challenges are expected to intensify over time, driven by increases in population, changes in climate, and shifts in land use, water policy, and commodity markets. These drivers will affect water demands and water management practices across the state. In 2015, Oregon updated its water demand projections, which show an increase in total water demand by up to 15 percent by the year 2050 (OWRD, 2015). Due to these increasing demands, both surface water and groundwater supplies will need to be monitored carefully so as to not deplete the systems.

Irrigation in Central Oregon

In areas where surface water is fully allocated, groundwater is being turned to as an alternate 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 predicted 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 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 predictions 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 stream flow.

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.
- Partner with federal agencies to participate in 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 and work together with them to monitor and share data about Oregon's rivers and streams. These partnerships allow for the leveraging of limited state resources and serve as conduits for communication. Collaboratively operated gages and wells have been identified by state or federal agency partners as useful for meeting statutory requirements and identified by private entities as useful for meeting their institutional monitoring 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 Instream Water Rights is an effective method for protecting water instream, the state has other alternatives. Under new legislation passed in 2013, some storage projects funded through Oregon's Water Supply Development Fund will be required to operate in a manner that is protective of diverse ecological needs. In order for both the operator and the stream system to get the water they need, these 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 purview of the Department, plays a crucial role in water management decisions. The Department currently collects temperature data which are used as a measure of stream health. These data are collected according to USGS standards. In addition, temperature data is needed by field staff to ensure the accuracy in the equipment used while collecting data.

The Department has partnered with the Oregon Department of Environmental Quality 9DEQ) to install water quality monitoring (temperature) devices at several existing stream gages and monitoring wells. These data are publicly available through the Department's website.

Recommended Monitoring Actions

- Work with DEQ to develop instrumentation deployment protocols at Department monitoring sites to support of 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 thousands of dollars of watershed restoration and conservation projects every year. Monitoring is central to OWEB-funded projects, both as a fundamental component to project development and as a key method for tracking project effectiveness. Many local restoration and conservation partners operate long-term water quality and habitat monitoring networks in order to better understand baseline conditions in their watersheds. These baseline data, when compared to water quality or habitat standards, may trigger restoration or conservation activities. More recently, these groups have increased their interest in watershed characteristics that require continuous water quantity information. Essentially, monitoring streamflow conditions helps the state identify the most pressing restoration and conservation needs, ensures the effective use of funding, and confirms that funding recipients have delivered on their promised outcomes.

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

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 • 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 or snow-and-rain dominated basin • Located in snow-rain transition zone
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
Wildfire Conditions	• Tracks real-time streamflow in recently burned watersheds
Groundwater Protection	
Ensuring sustainable groundwater levels	• Record is long term, year round • Data is 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
Aquifer Recharge & Aquifer Storage and Recovery	• Tracks water level in areas of 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
Dam Safety	• Provides early warning system for high flow events
Water Use Data	• Monitors 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 stream flow 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

Table 1. The Site Characteristics listed in this table are the primary characteristics that a high quality monitoring site would possess in order to meet the monitoring requirements for each Monitoring Priority.

EVALUATING THE MONITORING NETWORK

The Department plans to evaluate current and potential monitoring sites for their effectiveness in meeting each of the monitoring priorities outlined in this Monitoring Strategy. In order to do this, however, the Department has additional work to do. Evaluating current and potential monitoring sites starts by adding new and updating current monitoring site characteristics in the database. Then network evaluations can be conducted to determine where there are gaps in the data and where the Department should place new monitoring sites. In order to coordinate and perform the network evaluations, the Department will require one additional full-time staff member.

Next steps for evaluating the monitoring network include:

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 attributes for each of its stream gages and observation wells. Examples of these attributes include but are not limited to: descriptions of streamflow type, latitude and longitude coordinates, elevations, county, watermaster district, USGS quad, hydrologic unit code, and stream code. Many of the monitoring sites do not yet have all attributes accurately described. The Department will update current attributes and add new attributes to each monitoring station record in the database. This will enhance the querying capabilities of the database which will provide answers to questions regarding where the Department and its partners are collecting different types of monitoring data.

2) Identifying and Rectifying 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 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) **Accepting input from outside agencies on monitoring locations.** The Department has a modest budget for the 2015-17 biennium to establish additional monitoring sites. These new sites will be established first and foremost, in support of the Department's mission. However, the Department historically and currently 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.

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APPENDIX A

PROTOCOLS & PROCEDURES FOR ESTABLISHING SITES

The Department has in place policies and procedures when establishing new monitoring sites for archaeological and cultural resource protection, property access, and cooperative agreements. A manual is being developed to outline specific steps and protocols the Department's staff will take in order to meet these requirements. In addition to these items, the manual will also include agency guidelines on requesting a new gage installation or update to an existing one, equipment purchase agreements, and safety in the field.

Archaeological and Cultural Resources Policy

OWRD 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 the safeguarding and management of the state's archaeological and cultural resources. In coordination with SHPO and Oregon's federally recognized tribes, WRD has established protocols prior to installing or maintaining gaging stations and monitoring wells. WRD understands both federal and state laws regarding cultural resources and has established an inadvertent discovery policy and procedures.

Property Access Agreements

Private Landowner: OWRD has in place a process to establish Property Access Agreements which must be signed by both OWRD and a property holder, establishing the conditions under which OWRD personnel are granted access to private property. The activities include installation, operation including site access to take water level measurements, and maintenance of water level monitoring devices, and the type of equipment located on the property. The permit also establishes an agreement with regards to ensuring the security of the property including gates and locks.

Public Landowner: OWRD also has agreements with other governmental agencies for accessing public properties for establishing and maintaining stream gages, including taking periodic water level measurements. These agencies include but are not limited to Oregon Department of State Lands, Oregon Department of Fish and Wildlife, the Bureau of Land Management, and the U.S. Forest Service. WRD also has agreements with DSL on removal-fill permits and counties and ODOT on right-of-way permits. Each agreement is unique as to each Department and OWRD abides by the established agreements.

Gaging Station Agreements

OWRD has developed a form to establish an agreement between potential data collection cooperators for the operation and maintenance of gages including funding. The agreements can be established between local governments, private entities, or other state agencies. This type of agreement establishes the conditions for easements, maintenance, funding and operation of the stream gage and as well as the use of the monitoring data itself.

APPENDIX B
SOLICITATION FOR INPUT ON STREAM GAGE NEEDS

Water Resources Department – Stream Monitoring Needs

WRD has a modest budget for the 2015-17 biennium to establish additional stream flow measuring sites (gages). These new gages will be established first and foremost, in support of the Department's mission. However, WRD 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 monitoring needs, the Department would like to know more about them. As WRD moves forward in assessing the stream monitoring network, these place-based needs will be evaluated as part of our decision 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 is/would be used.

4) Describe the 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 Oregon's water has always been critical to the management of the State's water resources. Although the policy priorities for monitoring have changed over time, Oregon has always relied on monitoring to provide an accurate quantification of surface and ground waters. The ability to conduct monitoring has largely been driven by the availability of resources to support the Department's mission. Throughout the history of water resource management, the extent to which the Department could meet its monitoring needs appears to be driven by four major factors: historical events driving availability of resources; changes in agency statutes, policies, and approaches; state-wide budget availability; and local interest and financial participation.

The following narrative will describe monitoring efforts by the Department through time as well as describe key events in agency, state, and federal history that shaped 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 WRD's monitoring needs. In 1909, the Oregon Office of the State Engineer officially began registering water use. The State Engineer worked in partnership with the U.S. Geological Survey (USGS) to monitor water resources for municipalities, irrigation, and water-power works. By 1906, there were 48 stream gages run cooperatively by the state and the USGS, though the USGS exclusively performed the hydrographic work.

1910s. World War I (1914-1918) is first time in history where a decrease in federal water resources monitoring responsed to international events. At the completion of the war, the USGS officially began using Oregon Office of the State Engineer to conduct hydrographic work; state-level staff increased substantially at this time. The Oregon Office of the State Engineer ran 85 gages cooperatively with the USGS by the end of 1920.

1920s. Severe droughts of the 1920s and 30s focused nationwide 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 stream flow records. The Federal government responded with an infusion of funding. In 1928, the State Engineer's Office began conducting snow surveys. This involved a new method of forecasting. Such information was readily appreciated and used by communities in Oregon and quatified the status of water supplies for the upcoming seasons. Farmers could then begin to plant accordingly and manage their stored water to supplement potential shortages.

1920s - 1930s. During the 1920s and 30s, the Oregon State Engineer 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. By 1935, the USGS and the Oregon Office of the State Engineer had begun a program of water-level measurements east of the Cascade Mountains. Statewide, a cooperative program between the USGS and the State

Engineer was born to inventory groundwater basins and to measure water levels in dedicated observation wells. State and federal resources provided initial funding.

1940s. Although groundwater funding was diverted to the war effort during World War II, by 1946 the cooperative investigations both in 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 resource distribution in the state. In addition, by 1958, the state was monitoring streamflows at 308 gaging stations.

1960s. 1964 marked the start of state funding for assistant watermasters who still to this day play an important role in managing the state's stream gage network. The number of stream gages has shrunk to 182 by 1964. 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 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 expanding groundwater development. 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 justified the 1984 nomination of 75 streams for minimum flows by the State Fish and Game Board (now Oregon Department of Fish and Wildlife).

1980s. The Water Resources Commission was established in 1985 and took over the role of the Water Policy Review Board. 1987 marked the passage of the Instream Water Rights Act allowing 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. Stream gagins station numbers were back up in the 1980's 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.

Use of computers began expanding in the 1980s, and as a result, the observation well net was reduced by 50 percent to eliminate duplication of data and provide adequate time for the geophysical well logging program. Data from this program were used in water-use planning and groundwater management. Data sheets were completed for the roughly 400 observation wells and were entered into the USGS Computer System 2000.

1990s. By 1990, overhaul of the statewide observation well network was about half 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 observation points where coverage was inadequate. Approximately 335 wells across the state were monitored as part of the state observation well network. That number gradually increased to about 350 observation wells until 2001 when the Department introduced Key Performance Measures.

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; the Department dropped approximately 44 gages down to an approximate 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. Previously, all stream gage records had been maintained on paper with computations being performed by hand. This was also the beginning of remotely accessed stream gage data.

In 1997, the Oregon Plan for Salmon and Watersheds was adopted by the 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 board's role of distributing funds for watershed restoration. Monitoring to support these efforts generally also moved into OWEB and the Watershed Council's arena.
ODFW applied for multiple instream water rights as well as the conversion of many earlier established minimum flows to instream water rights. The Department, who holds instream water rights in trust, continues to use the stream gage network to track instream water rights today.

1998, the Hydrographics Section began working on backlog reduction; the new water availability program required processing of approximately 500 water years of raw data.

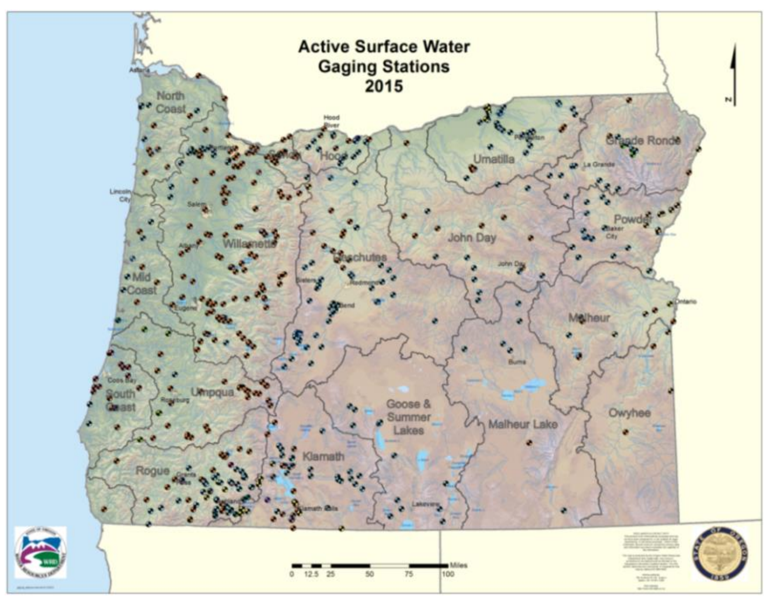
2000s. In 2002 and 2003, the Department worked with staff from the Oregon Progress Board to revise and update its performance measures. The goal was to build a stronger link to the Department's mission. It was recognized that measuring streamflow and groundwater levels is essential to effectively managing 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.

Key Performance Measure #4 – Streamflow Gaging calls for the Department to increase the number of operated or assisted gaging stations from the baseline year 2001. The baseline number of gaging stations is 215.

Key Performance Measure #5 – Assessing Groundwater Resources calls for the Department to have an increase in the number of wells routinely monitored to assess groundwater resources from the baseline year 2001. The baseline number of wells was 350. There are challenges in maintaining the number of monitoring wells including that the wells monitored by the Department are privately owned and access is commonly an issue. The Department is dependent on well owners for access to these wells. As property changes hands or other conditions change, some well owners have discontinued their participation in the State Observation Well Net, while other well owners have joined. The Department needs to ensure adequate budget and staff to maintain, collect and analyze data from these important monitoring stations, and continue providing data for the public's use. An expanded network that includes dedicated, long-term benchmark wells (wells drilled for the State of Oregon as monitoring sites) would ensure enduring access for tracking groundwater supplies in critical areas of the state.

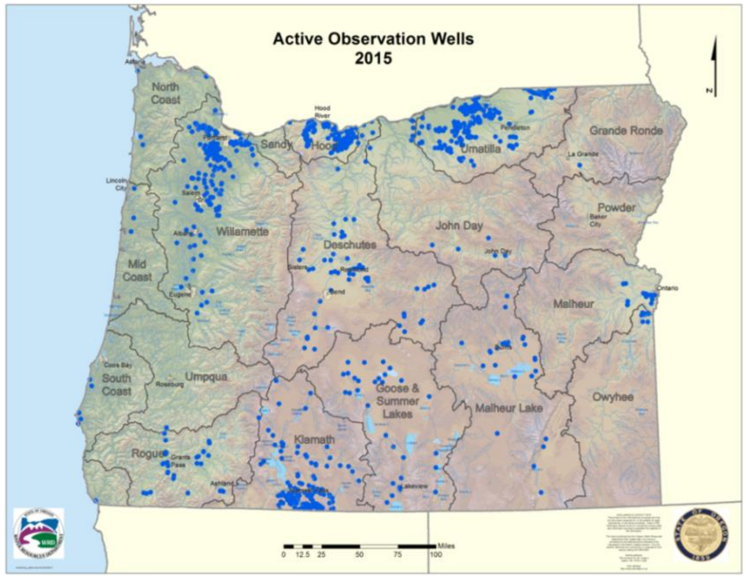
Despite fluctuating budgets and the deep national recession of the 2000s, the number of monitoring stations has rebounded, with an infusion of funding from the 2013 and 2015 Oregon Legislatures.

Present-Day Stream Gages. OWRD operates more than 240 stream gages of which about 80 percent are near real time. The entire network shown below 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. To the right is a map of WRD's active surface water gaging stations as of March 2015.



As part of the Upper Klamath Basin Comprehensive Agreement signed in 2014, WRD 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.

In addition, the 2015 Oregon Legislature provided the Department with resources to install 16 new gages during the 2015-2017 biennium. This 2015 Monitoring Strategy will help ensure that those 16 gages will be installed in areas that will provide the most benefit and data in support of our monitoring network objectives.



Present-Day Observation Wells. WRD currently has about 370 state observation wells, 60 of which have continuous recorders installed. A well is considered part of the state observation well network if data is collected on a quarterly basis. However, WRD currently measures water levels in about 1100 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, and groundwater studies. Staff members have prioritized areas for data collection and monitoring. After identifying a pool of eligible drillers, securing landowner access agreements, and establishing protocols for the protection of cultural resources, the Department installed 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 of and the processes in the system involved (WMO, 1986). To understand the interconnected water cycle of Oregon, we must consider how geology, topography, and climate interact to control water quantity across the state's diverse landscape through time.

Form of Precipitation. Oregon receives a majority of its precipitation, either as rain or snow, in the winter. In general, Oregon has a rather mild, winter-rain type 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 have greater extremes of temperature but somewhat less seasonal variation in precipitation; about 65 percent of the precipitation occurs in the period October to March." (Phillips, 1969).

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. 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 many annual hydrographs for basins that receive snow during the wet season.

Recharge. 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. This rate of fluctuation is greatly dependent on the permeability of the formation underlying the water. The occurrence of permeable rock formations 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. These permeable rock formations 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 chief 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 barren of permeable rock units. Even though these areas receive large amounts of precipitation, the aquifers yield small supplies of groundwater. Along the coastal area, there are many areas underlain by sand dune deposits. These sand dune areas absorb large quantities of water and are capable of producing large amounts of groundwater.

Coastal Mountain Effects. 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. The presence of the Cascade and Coast Ranges cause 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 the approximate mean altitude of Oregon.

Eastern Oregon Formations. In eastern Oregon, the central mountains are composed chiefly of relatively impermeable rock formations which are capable of yielding only small supplies of groundwater. Intermountain basins such as the Baker, the Wallowa, and the Grande Ronde Valleys contain permeable rock formations and moderate natural supplies of groundwater. The area lying north of the central mountains is underlain by the Columbia River basalt formation. This formation is of wide areal extent in both Oregon and Washington and is generally capable of yielding moderate to large supplies of groundwater. The basin and plateau areas of southeastern Oregon contain permeable rock formations. 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 rocks of Oregon produce variations in surface-water hydrology as well, particularly for storm runoff and low flow periods. For instance, the broad areas of pumice and young lava flows in the southern part of the Cascade Range such as the Upper Metolius basin, outside of established springs, have poorly developed stream systems because the highly permeable rocks at the surface readily absorb or 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 rocks 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 all 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. Spread throughout the basins, covering the geologic features and alongside streams and rivers are the trees and plants that utilize the habitats provided by the landscape to survive. 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.