Oregon Water Supply and Conservation Initiative

Inventory of Potential Below Ground Storage Sites

Prepared by:

Oregon Water Resources Department
Ground Water Hydrology Section

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State of Oregon

Water Resources Department

Phillip C. Ward

Director

Oregon Water Supply and Conservation Initiative:

Inventory of Potential Below Ground Storage Sites

By

Jen Woody

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Abstract

The overarching goal of the Oregon Water Supply and Conservation Initiative (OWSCI) is to provide a foundation for improved long-term water resource planning. The Initiative includes statewide water demand forecasting, an inventory of potential conservation opportunities, identification of potential above and below ground storage sites, and community water planning grants. In addition to data collection, two important products of this Initiative include the methodology used to collect and process information, and online database structures into which the Department will place future data.

The below ground storage site inventory presents an evaluation of the physical capacity of regional aquifers in Oregon to accept water into storage. This assessment provides a tool for communities and individuals to assess whether underground storage is an option for them. This study does not replace the need for site-specific investigation to identify aquifer variability and storage feasibility.

The study collected existing aquifer data about more than 50 hydrogeologic units statewide. A weighted aquifer rating system assessing the physical capacity of aquifers to accept water into storage indicates that approximately 30% of aquifers are highly suitable. A secondary analysis of storage capacity suggests there is more than 8.4×10^7 ac-ft of potential underground storage available statewide, based on storage coefficient, depth to static water level and aquifer extent.

The most suitable aquifers include the Columbia River Basalt Group, which is hydrogeologically unique due to their low vertical hydraulic conductivity combined with distinct flow tops, bottoms and interflow zones that have high horizontal hydraulic conductivity. This characteristic makes them a favorable environment for Aquifer Storage and Recovery (ASR). Glacial flood deposits of north-central Oregon are a favorable hydrogeologic environment for spreading basin-style recharge.

The least suitable aquifers include low-yield marine sedimentary and volcanic units of the Coast Range, low permeability metamorphic rocks of the Klamath Mountains, and low-yield volcanics of the Western Cascades.

A searchable online database and interactive map feature, located at www.wrd.state.or.us, presents data, analysis and source documents. The Department intends to update the database and related documents as new information becomes available.

Site-specific investigation is essential before implementation of any project, including consideration of local aquifer characteristics, infrastructure, water availability, cost-benefit relationships, water quality, and authorization requirements. However, this study does indicate that there is significant potential for expanded underground storage in Oregon. It is a useful tool for water managers across the state, in combination with conservation, efficiency and traditional water storage methods.

Introduction to Underground Storage in Oregon: Methods, Activities and Authorizations

Background

As Oregon population, climate and water needs evolve over time, water management techniques must also adapt. Underground storage can be a useful tool that lends flexibility to water supply timing and availability, while avoiding some of the costs and environmental impacts of above ground storage. Current techniques include injection of treated surface water into aquifers and surface water spreading that allows infiltration down to the water table. Many projects later recover the water for municipal or agricultural use; others may allow it to move through the aquifer and discharge to the surface to enhance stream flow. Underground storage has increased dramatically in the last decade.

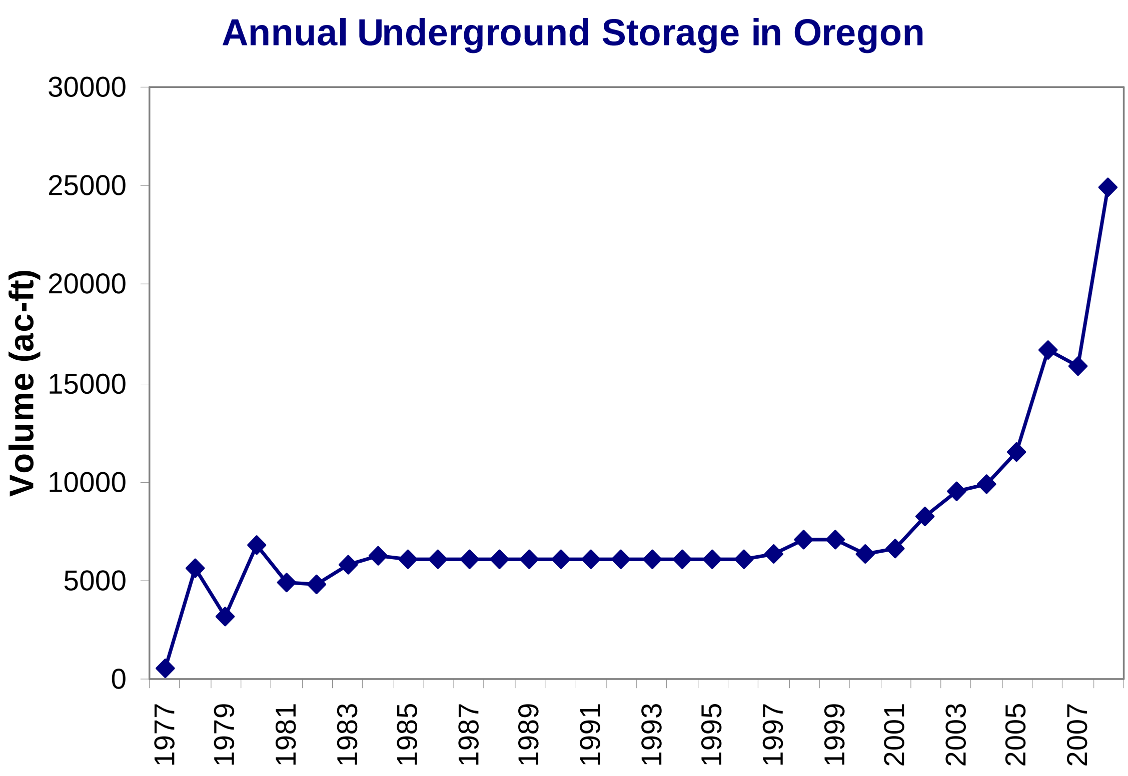


Figure 1. Annual underground storage in Oregon has tripled since 2000.

Injection and recovery wells

- A typical injection and recovery system relies on surface water withdrawn during times of low demand, treats it to drinking water quality standards and injects it into an aquifer.
- During subsequent periods of high demand, the system pumps out (recovers) stored water at the same well, treats the water as necessary to drinking water quality, and adds it to the distribution system.
- An injection system usually stores water in deep or confined aquifers (water-bearing zones that are bounded above and below by low permeability layers).

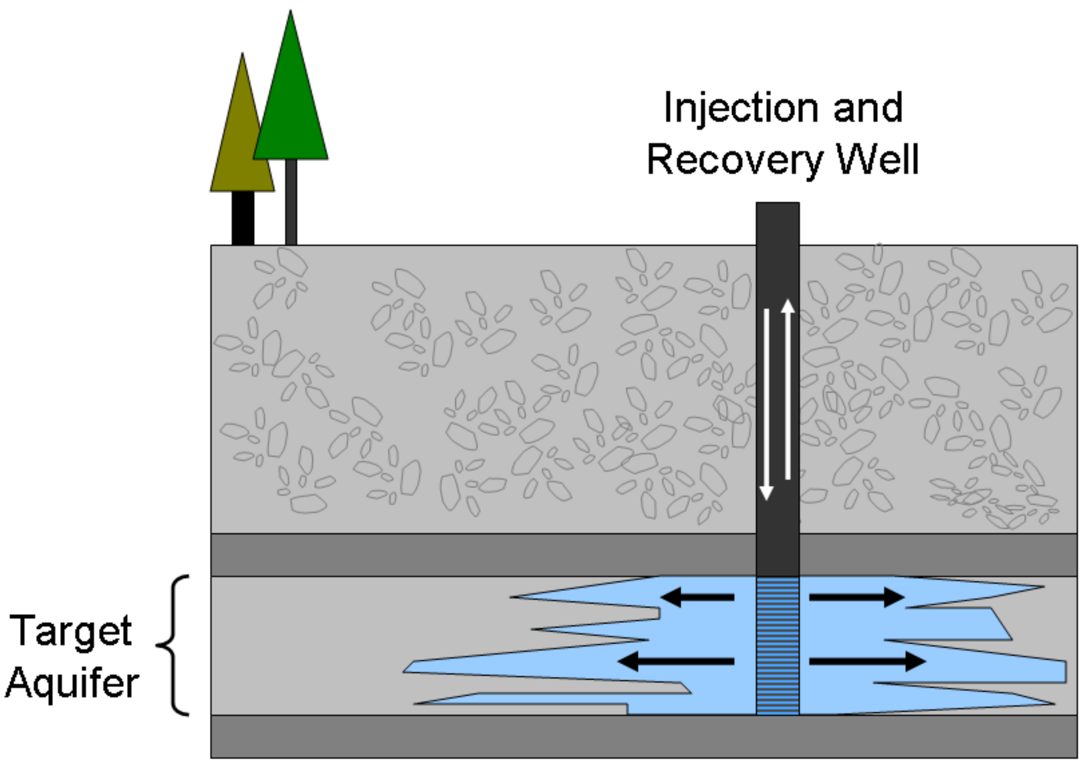


Figure 2. In a municipal injection and recovery system, surface water is treated to drinking water quality, stored underground, and later withdrawn and distributed to water customers.

Recharge by surface spreading

- A typical infiltration system spreads water into shallow basins or canals, which allow infiltration into the underlying aquifer. Water quality must meet the Oregon Department of Environmental Quality's anti-degradation standards.
- Recharge through infiltration occurs in unconsolidated or highly fractured aquifers that are close to the ground surface.
- Water users recover stored water through nearby wells. In other situations, the water flows underground and into streams to increase flow or improve water quality for fish and wildlife.

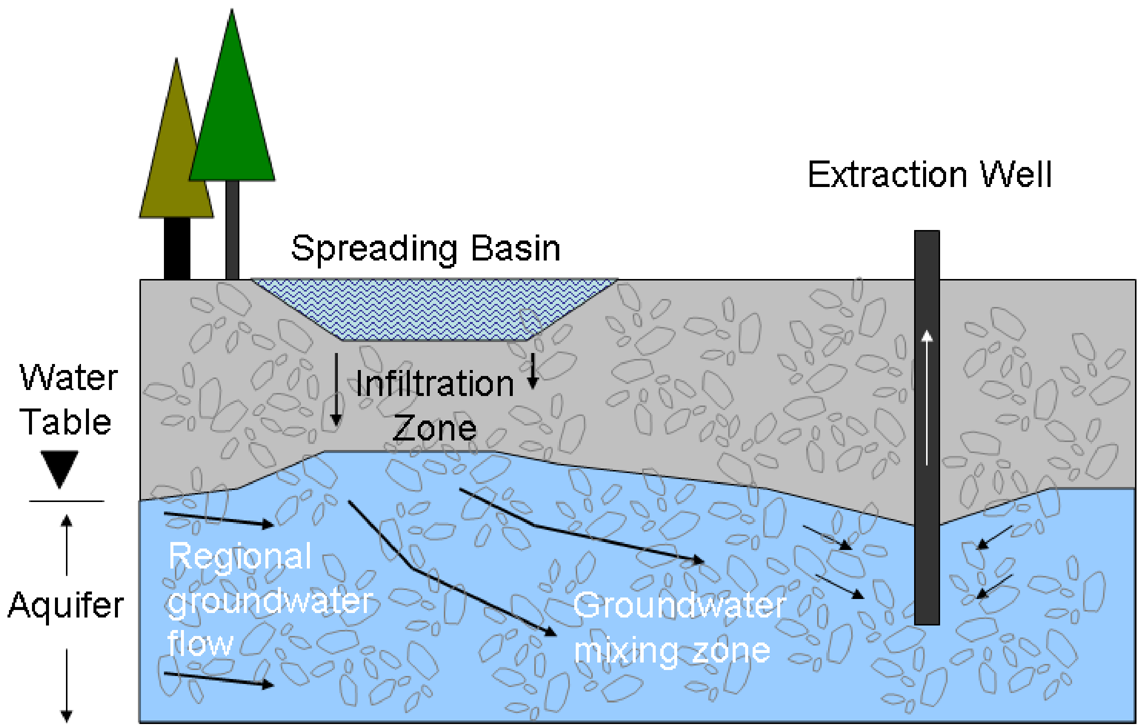


Figure 3. In a typical spreading basin project, water infiltrates through shallow basins or canals. Withdrawal occurs down gradient through a well or the water discharges to the surface and augments stream flow.

Why use these techniques in Oregon?

- The state receives nearly two-thirds of its precipitation during the winter months, with a pronounced dry summer season on both sides of the Cascades.
- Storage is necessary because water use peaks during the dry season 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 months that they are not fully utilizing. ASR and AR provide a mechanism to capture and store some of this flow. Underground storage can have a lower impact on fish passage than traditional dams.

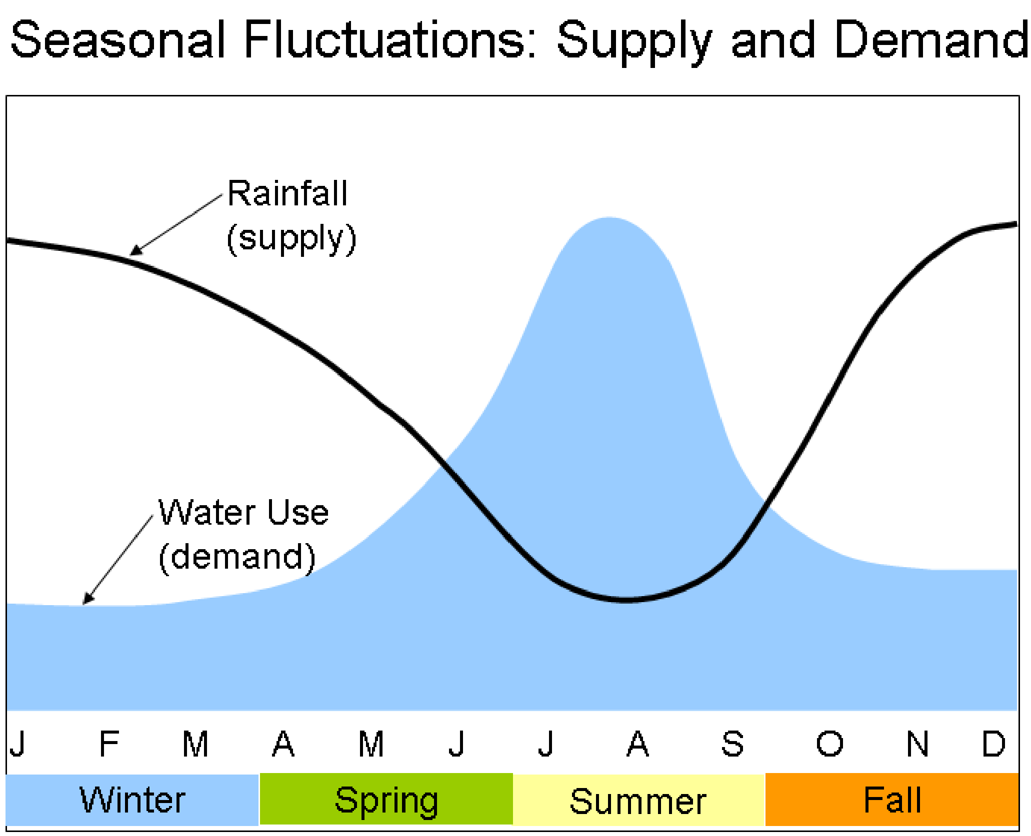


Figure 4. In Oregon, surface water flow peaks in winter months; conversely, demand peaks in summer months (graphic courtesy of Washington Department of Ecology). Conservation measures combined with storage of some of this peak flow is necessary to meet demand.

Feasibility Considerations

Many factors affect whether underground storage is feasible at a given site. While this study focuses on the physical capacity of regional aquifers to accept water, the following issues require site-specific evaluation:

- Surface water availability (rate and timing)
- Local aquifer complexity and boundaries
- Storage capacity vs. storage needs
- Water quality before and after storage
- Water treatment requirements
- Proximity to other wells
- Infrastructure availability and capacity
- Cost-benefit

Although underground storage can be less expensive than constructing above ground storage facilities, the cost can still be significant. Expenses vary, but the following actions are necessary:

- First, conduct a feasibility study that includes hydrogeologic site characterization, water quality and water level monitoring.
- Second, evaluate and improve infrastructure, such as pumping systems, pipes, water treatment filtration and disinfection systems, monitoring and injection wells.
- Ongoing maintenance, water quality and water level monitoring will be part of any underground storage project operation.

Authorization of Underground Storage Projects in Oregon

Two permitting paths exist for underground storage in Oregon: Aquifer Storage and Recovery (ASR) and Artificial Ground Water Recharge (AR). The authorization process occurs through Oregon Water Resources Department (OWRD), which coordinates input from Oregon Department of Environmental Quality (ODEQ), Oregon Department of Human Services (ODHS) and Oregon Department of Fish and Wildlife (ODFW).

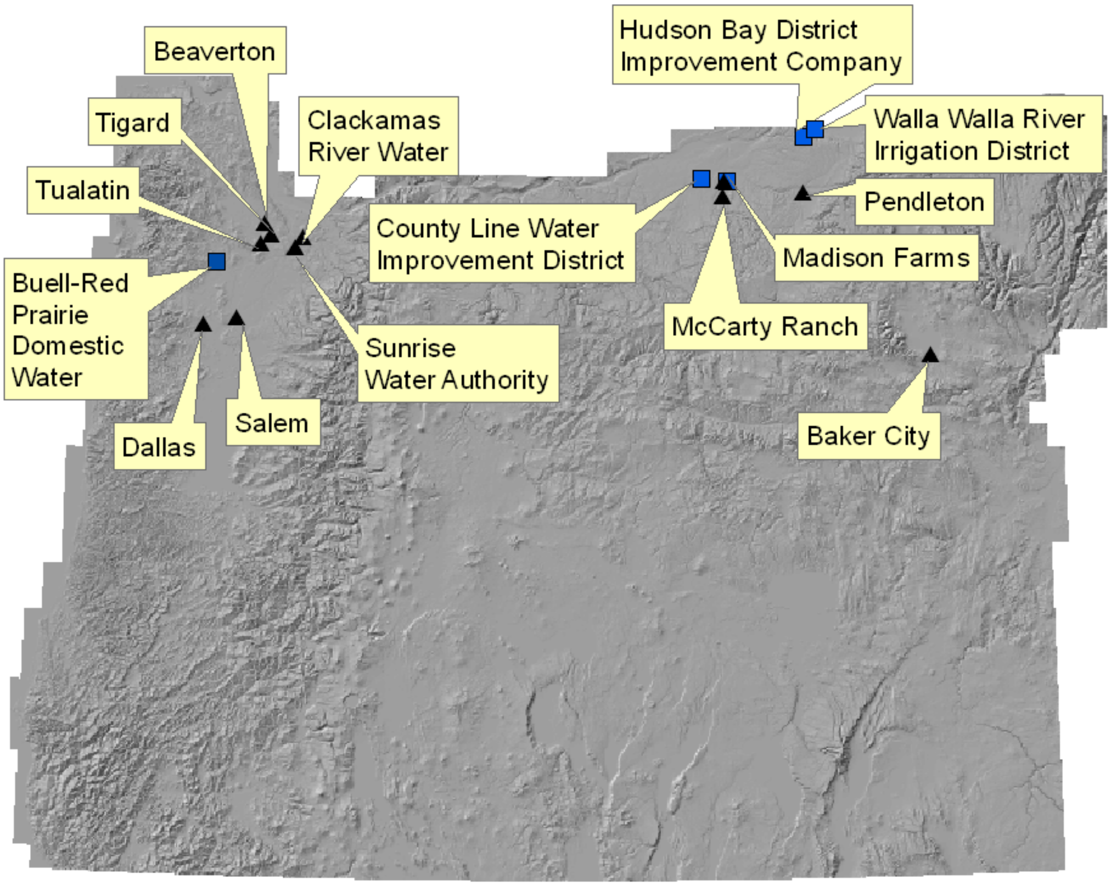


Figure 5. Underground storage sites (as of December 2008) are located in the northern portion of Oregon, where geology, water availability and cost-benefit circumstances create a favorable environment for this water management tool.

ASR in Oregon

- There are currently eleven ASR test sites in Oregon.
- Municipal operations are located in Beaverton, Tualatin, Tigard, Salem, Clackamas, Happy Valley/Damascus, Baker City, Pendleton, and Dallas.
- Two agricultural projects near Hermiston are testing ASR.
- Ten sites store water in basalt aquifers.
- One project targets an alluvial aquifer.

Figure 6. Agricultural ASR well near Hermiston, Oregon

ASR authorization in Oregon

- ASR projects are required to test operations under an ASR limited license before applying for an ASR permit.
- Existing surface water rights generally provide the source water for storage. Use of the stored water must conform to that described under the existing right.
- ASR requires well injection as the storage technique. Injection water must be treated to drinking water standards, so ASR from a surface water source may require both filtration and disinfection infrastructure before injection
- The operator may recover up to 100% of that stored but is typically less, to account for water migration in the aquifer environment.
- ASR is described by statute and rule in ORS 537.531-.534 and OAR 690-350.
- Due to the complexities and costs associated with recharge projects, a pre-application conference with OWRD staff is required.

Figure 7. AR project near Milton-Freewater, Oregon

AR in Oregon

- There are five authorized AR sites in Oregon, with purposes including irrigation and domestic water supply augmentation, water level decline mitigation, and stream flow enhancement.
- Projects include the County Line Water Improvement District in Morrow/Umatilla Counties, Buell-Red Prairie Domestic Water Association in Polk County, Hudson Bay District Improvement Company, and Walla Walla River Irrigation District in Umatilla County.
- Additionally, an agricultural ASR site near Echo, in the Umatilla Basin, uses AR to filter surface water before injecting it into an ASR well.

AR authorization in Oregon

- Source water for AR must meet anti-degradation standards of Oregon Department of Environmental Quality (ODEQ). This means that the recharge water must maintain the aquifer water at its original quality or better. Raw surface water sometimes meets these standards, but periodic water quality monitoring is necessary.
- AR projects require a new permit to divert water for the purpose of aquifer recharge and a secondary groundwater permit to extract this water. AR and secondary permit holders need not be the same entity.

- If the source water does not have an in-stream water right, the project requires an ODFW (Oregon Department of Fish and Wildlife) waiver before permit issuance.
- AR projects may use well injection or infiltration as the means to store.
- AR is described by statute and rule in ORS 537.135 and OAR 690-350.
- Due to the complexities and costs associated with recharge projects, a pre-application conference with OWRD staff is required.

Objectives and Scope of Study

The overarching goal of the Oregon Water Supply and Conservation Initiative (OWSCI) is to provide a foundation for improved long-term water resource planning. The Initiative includes statewide water demand forecasting, an inventory of potential conservation opportunities, identification of potential above and below ground storage sites, and community water planning grants. In addition to data collection, two important products resulting from this Initiative include the methodology used to collect and process information, and the online database structures into which the Department will place future data.

The primary goal of this study is to present a statewide evaluation of the physical capacity of aquifers in Oregon to accept water into underground storage. The project team collected aquifer data from the U.S. Geological Survey, Oregon Water Resources Department groundwater studies, databases, well log reports and consultants' studies. This evaluation provides a tool for communities and individuals to assess whether underground storage is an option for them. Specifically, this study includes the following objectives:

- Conduct a state-wide study
- Assemble data about existing underground storage projects in Oregon
- Collect the range of aquifer parameters available for selected geologic units
- Construct a searchable database of these parameters
- Analyze this data for each aquifer's physical ability to accept water into storage
- Present data and its interpretation on the Department website

These parts form a starting point for decision makers considering underground storage. When the underground assessment is considered along with the other Initiative products, interested parties can integrate long-term demand forecasting with storage and conservation planning. Interested parties can also combine this information with new site-specific data to refine their water supply planning.

Aquifer Assessment Methods

This study focuses on hydrogeologic suitability for underground storage. It is a general, regional assessment of aquifers. Therefore, site-specific investigation is necessary to evaluate local variations in aquifer parameters.

An aquifer rating system examines the physical capacity of aquifers to accept water into storage. The five evaluated parameters in the aquifer rating system include depth to target formation, saturated thickness, head freeboard (depth to static water), storage coefficient, and hydraulic conductivity. A secondary analysis estimates the storage capacity available beyond what naturally occurring groundwater occupies.

Previous Studies

Data and analysis methods from previous studies influenced the design of this project. The following works are referenced:

- Robison (1968) completed an Open-File Report for the U.S. Geological Survey that analyzed aquifers across Oregon and estimated storage potential for each. Results indicated that approximately 57 million acre-feet of storage was available across the state in underground potential.
- Topper et al. (2004) developed a method to prioritize large-scale aquifers across Colorado for aquifer recharge potential.
- Woody (2008) completed a statewide study of aquifer suitability for Aquifer Storage and Recovery (ASR), using a site rating system and a metric that compared current water rights to aquifer storage capability. Results identified approximately 500,000 acre-feet of potential underground storage associated with municipal wells.

How does the rating system work?

For each evaluated aquifer, the rating system requires a sampling of data that provides a range of aquifer parameter values, as well as an average or most typical value. The analysis also requires identifying the aquifer as either consolidated bedrock or unconsolidated, so some generalization about regional geologic units is required. The weighted rating system varies based on this distinction. The analysis process is as follows:

- The appropriate rating system is selected for either a consolidated or an unconsolidated aquifer.
- Due to aquifer complexity and variability, a range of values is reported for each parameter. An average value is identified for each parameter, as well as the data quality. For example, hydraulic conductivity determined from a 72-hour

aquifer test would be of a higher data quality than that estimated from specific capacity and the open interval of a well.

- A rating is selected for each parameter, weighted for its importance to storage potential. The parameter ratings are totaled to represent an overall rating for the aquifer.
- This system produces a percentage of ideal physical parameters for artificial recharge found in a given aquifer. It is important to recognize that an aquifer that has 100% of ideal parameters for underground storage will rarely exist in nature. Existing sites in Oregon typically possess about 60% of ideal conditions for aquifer recharge.
- The system accommodates the flexible relationship between aquifer parameters. For example, a high hydraulic conductivity may compensate for a small saturated thickness in terms of the aquifer's capacity to accept water into storage.

Evaluated aquifer parameters

Each aquifer parameter has a different impact on storage potential. The weighted rating system approximates this complexity as follows:

- Depth to formation top: In general, a small depth to a geologic formation receives a higher rating than a large depth. This is because it is more expensive to recharge and recover water from a deep aquifer than a shallow one, due to power requirements to lift the water and well construction costs. There is some nuance to this rating. An unconsolidated aquifer is most easily recharged when it is located at the surface, through spreading basins. However, a consolidated aquifer is most likely recharged by injection wells, and a moderate depth to formation suggests less potential for leakage through fractures than if the formation is located at the surface.
- Unit thickness: As thickness increases, so does an aquifer's capacity for recharge. Conversely, water stored in a thin aquifer must spread out from the well, and may move beyond a recoverable radius from the well.
- Head freeboard: This refers to the depth to static water in a well, or the head space in a well that can accommodate water level rise during recharge operations. A small head freeboard presents the risk of raising the water level close to the surface in an unconfined aquifer. In a confined aquifer with a small head freeboard, increasing the pressure in the aquifer risks pushing water to the surface through other wells or fractures. In general, storage capacity rises with increasing head freeboard.
- Storage coefficient: Storage coefficient is defined as the volume of water an aquifer releases from, or takes into storage, per unit area of aquifer per unit change in head (resulting in units such as $ft^3/(ft^2*ft)$, or ft^3/ft^3). This results in a

dimensionless property. For recharge, a higher storage coefficient indicates a greater storage capacity and is therefore preferable.

- Hydraulic conductivity: This is generally defined as the volume of water per unit time that passes though a unit area of an aquifer material in response to a unit hydraulic head gradient (resulting in units such as $(ft^3/d)/(ft^2)$, or ft/d). The term incorporates aquifer properties and the water's density and viscosity. Low hydraulic conductivity indicates a site with low artificial recharge potential. Injection and recovery rates, as well as total storage capacity will be directly proportional to this factor.

Examples of the Aquifer Rating System

As illustrated below in the examples of aquifer rating tables, the weighting of aquifer parameters varies for unconsolidated and consolidated aquifers. This reflects the different hydraulic characteristics of these aquifers; for example, sandy deposits accept water differently than fractured bedrock.

Table 1. Example of the Aquifer Rating System for a Consolidated Unit, where yellow highlight indicates the selected ratings:

	Range of reported values	Value for calculation	Find the "value range" where the "value for calculation" falls, and select the corresponding rating										Selected Rating	Data Quality
			Value Range	Rating	Value Range	Rating	Value Range	Rating	Value Range	Rating	Value Range	Rating		
Depth to Formation (ft)	20-500	90	0-99	10	100-499	20	500-999	15	1000-1999	3	>2000	1	10	3
Saturated Thickness (ft)	6-250	111	0-99	1	100-249	3	250-499		500-999	15	>1000	30	3	3
Head Freeboard (ft)	0-65	29	0-49	1	50-99	2	100-299	6	300-749	15	750	30	1	3
Storage Coefficient	0.02	0.02	0-0.0009	1	0.001-0.009	5	0.01-0.09	10	>0.1	25			10	4
Hydraulic Conductivity (ft/d)	0.04-17	4	0-0.0009	1	0.001-0.009	5	0.01-0.9	10	1-9	50	>10	100	50	3
													74	16

Sum of Selected Ratings/Perfect Rating = 74/205 = 36%

Data Quality: 1=based on general values for this aquifer lithology
2=based on 10 or less well logs
3=based on more than 10 well logs
4=based on published information and/or data specific to this aquifer

Totals:

Table 2. Example of the Aquifer Rating System for an Unconsolidated Unit, where yellow highlight indicates selected ratings:

	Range of Reported Values	Value for Calc-ulation	Value Range	Rating	Value Range	Rating	Value Range	Rating	Value Range	Rating	Value Range	Rating	Selected Rating	Data Quality
			Find the "value range" where the "value for calculation" falls, and select the corresponding rating											
Depth to Formation (ft)	0-4	2	0-4	20	5-9	15	10-24	10	25-49	3	>50	1	20	2
Saturated Thickness (ft)	30-340	173	0-19	1	20-39	2	40-79	4	80-159	8	>160	10	10	2
Head Freeboard (ft)	8-245	94	0-4	1	5-9	2	10-19	4	20-29	8	>30	50	50	2
Storage Coefficient	0.10-0.25	0.18	0-0.09	1	0.1-0.14	5	0.15-0.19	10	0.2-0.24	25	>0.25	50	10	4
Hydraulic Conductivity (ft/d)	0.29-19	3	0-0.9	1	1-9	5	10-99	10	100-999	25	>1000	50	5	2
													95	12

Sum of Selected Ratings/Perfect Rating = 95/180 = 53%

Data Quality: 1=based on general values for this aquifer lithology
2=based on 10 or less well logs
3=based on more than 10 well logs
4=based on published information and/or data specific to this aquifer

Totals =

Storage Capacity Estimates

In addition to the aquifer rating system, this study also estimates the storage capacity of aquifers by quantifying how much “unused” storage exists under 2008 conditions. A basic estimation of available storage is calculated as follows:

$$\text{Volume} = SA \max \Delta h$$

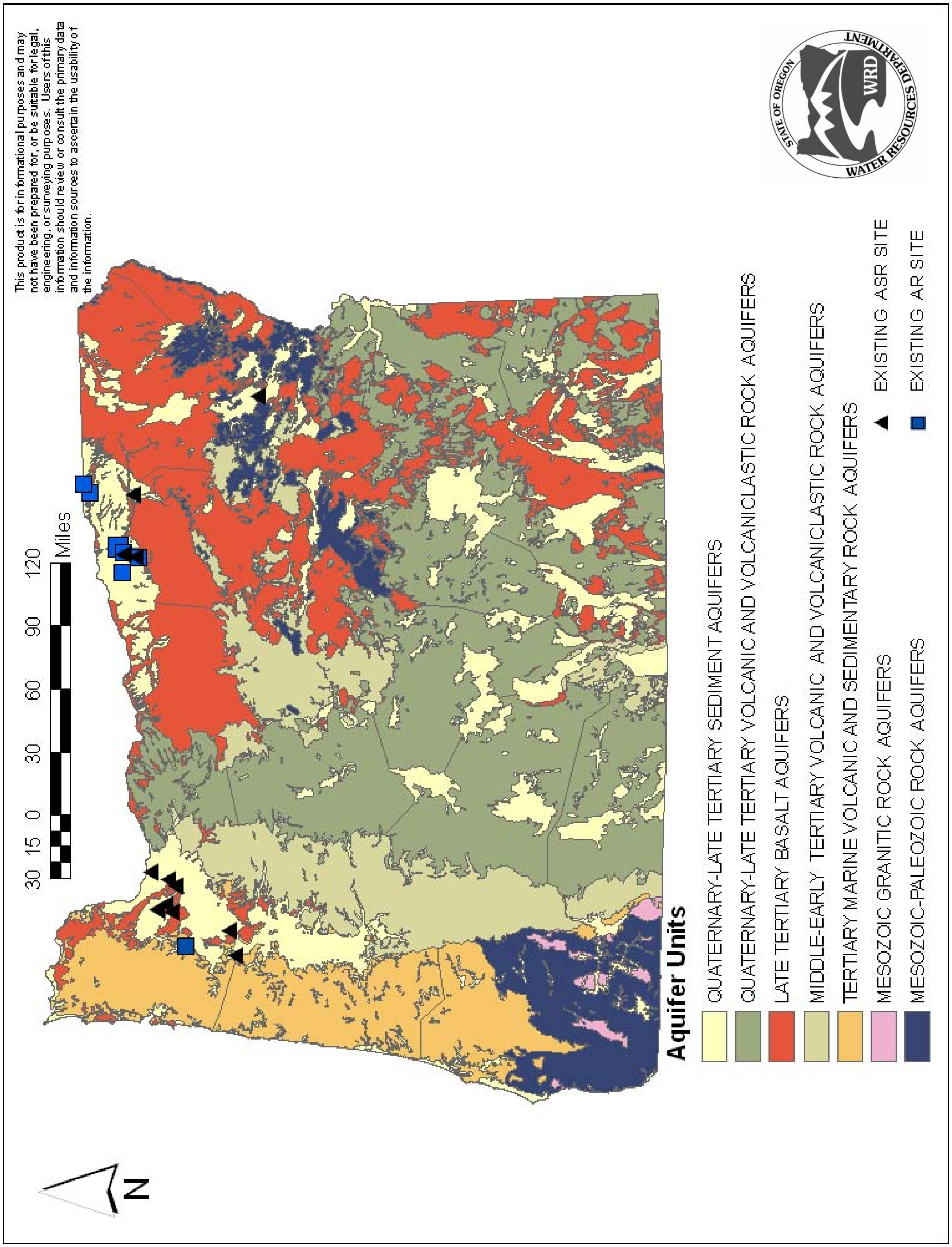
Where S is the storage coefficient, A is the aquifer extent or area, and max Δh is the depth to static water level. This is a simplification of the natural system, and assumes the aquifer has a constant storage coefficient and thickness throughout its extent. To be conservative, the static water level selected represents an aquifer’s seasonal high, and a high water level limit of 20 feet below the surface was selected as a factor of safety. The aquifer extent was estimated when possible from geologic maps. Despite these assumptions, this method provides an indication of the potential storage capacity of the aquifer, and a point to compare between various aquifers in terms of their potential for underground storage.

Results Summary and Discussion

General Conclusions about Oregon Aquifers and Underground Storage

Oregon has a variety of aquifers. The north and northeastern portion of the state is characterized by extensive flood basalts of the Columbia River Basalt Group, which are hydrogeologically unique due to their low vertical conductivity combined with distinct flow tops, bottoms and interflow zones that have high horizontal conductivity. This characteristic makes them a favorable environment for ASR in some places. A mix of volcanics and sediments characterizes central and south-central Oregon, with highly variable hydraulic conductivity and suitability for aquifer recharge. The Coast Range consists of low-yield marine sedimentary and volcanic deposits, while the Klamath Mountains of Southwest Oregon consist of low permeability metamorphic rocks. Neither of these represent desirable aquifer recharge environments. The Willamette Valley consists of a variety of ice-age flood deposits and more recent alluvial deposits, with varying clay content. Some of the alluvial deposits have been tested for ASR with varying degrees of success. Closed basins throughout south-central and southeastern Oregon have generally low to moderate hydraulic conductivity; there may be opportunities for spreading basin-style recharge in some areas, although clay content will preclude recharge in other areas. Surface spreading basins and canals successfully recharge alluvium and glacial deposits of north-central Oregon and southeastern Washington.

Figure 8. On the following page: Generalized geologic map of Oregon, where units are grouped by similar hydrogeologic characteristics.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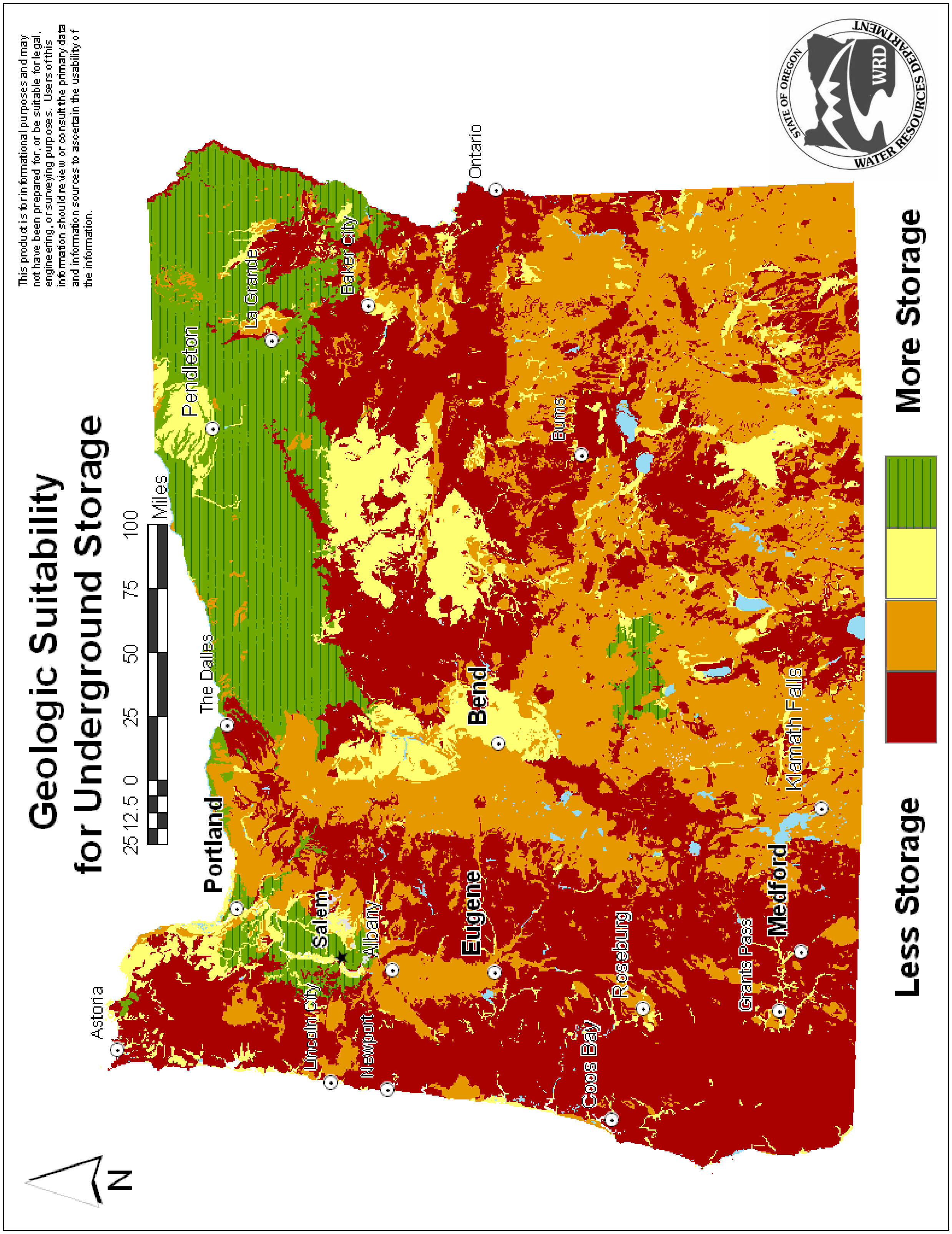
Aquifer Units
QUATERNARY-LATE TERTIARY SEDIMENT AQUIFERS
QUATERNARY-LATE TERTIARY VOLCANIC AND VOLCANICLASTIC ROCK AQUIFERS
LATE TERTIARY BASALT AQUIFERS
MIDDLE-EARLY TERTIARY VOLCANIC AND VOLCANICLASTIC ROCK AQUIFERS
TERTIARY MARINE VOLCANIC AND SEDIMENTARY ROCK AQUIFERS
MESOZOIC GRANITIC ROCK AQUIFERS
MESOZOIC-PALEOZOIC ROCK AQUIFERS
EXISTING ASR SITE
EXISTING AR SITE

Summary of Results

The underground storage assessment database includes aquifer characteristics and underground storage suitability information on more than 50 Oregon aquifers. It provides information on aquifers of varying storage capacity and, to the extent possible, represents an even geographic distribution across the state. While the specifics about each aquifer are accessible through the website, the following general conclusions are offered:

- Favorable hydrogeologic conditions for underground storage exist in both consolidated and unconsolidated aquifers across the state.
- The weighted aquifer rating system indicates that approximately one-third of aquifers statewide have potential as significant underground storage sites.
- According to this assessment system, existing Oregon underground storage sites have 39 to 62% of ideal conditions. No evaluated aquifers have 80 to 100% of ideal conditions. Considering these are natural geologic systems it is reasonable that they are not theoretically ideal. This also demonstrates that there is flexibility in the aquifer characteristics that will support underground storage.
- Columbia River Basalt Group aquifers score highest. These layered volcanic units contain highly permeable zones between dense layers of lava. This creates an environment that is conducive to underground storage by injection and recovery.
- Other aquifer types with storage potential include unconsolidated units of glacial and fluvial origin found in valleys and closed basins. These units may be conducive to storage through basin or canal infiltration or by injection and recovery, depending on local conditions.
- Aquifers with less storage potential include Coast Range marine sedimentary rock, Western Cascades volcanics and Klamath Mountains metamorphics, although there may be local exceptions within these units.

Figure 9. On the following page: Surficial geologic map of Oregon, where units are color coded for relative underground storage suitability. Red indicates little storage, while green stripes indicates high suitability. Geologic units overlap, so the delineated suitability refers to the approximate extent of the most feasible aquifer in the vicinity.


Geologic Suitability
for Underground Storage
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Bend
Ontario
Burns
Coos Bay
Roseburg
Grants Pass
Medford
Klamath Falls
Less Storage
More Storage
STATE OF OREGON
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Table 3. The following list presents regional aquifer ratings and storage capacity estimates. Storage estimates assume that a project would not raise water closer than 20 feet below ground surface. Consequently, aquifers with a typical depth to water less than 20 feet are assigned zero storage capacity and a low storage priority. Site-specific investigation is important to clarify when a water level less than 20 feet below the surface is acceptable.

Storage Priority	Aquifer Name	Percent of Ideal Conditions to Accept Water	Estimated Storage Capacity (ac-ft)
1	Fort Rock Basin Quaternary-Late Tertiary Volcanic and Volcaniclastic Rock Aquifers	72%	56,000
2	Walla Walla Basin Quaternary-Late Tertiary Sediment Aquifers	71%	19,000
3	Willamette Valley Quaternary-Late Tertiary Sediment Aquifers: Lower Unit	69%	20,000,000
4	Deschutes Basin Quaternary-Late Tertiary Volcanic and Volcaniclastic Rock Aquifers: Arc-adjacent Alluvial-plain Facies	67%	1,100,000
5	Willamette Valley Late Tertiary Basalt Aquifers: Columbia River Basalt Group	65%	34,000
6	Klamath Basin Quaternary-Late Tertiary Volcanic and Volcaniclastic Rock Aquifers	62%	2,600,000
7	Gilliam County Late Tertiary Basalt Aquifers: Columbia River Basalt Group	62%	53,000
8	Hood Basin Late Tertiary Basalt Aquifers: Columbia River Basalt Group	62%	12,000
9	Powder Basin Late Tertiary Basalt Aquifers: Columbia River Basalt Group	62%	2,000
10	North Coast Basin Late Tertiary Basalt Aquifers: Columbia River Basalt Group	62%	4,000
11	Grande Ronde Basin Late Tertiary Basalt Aquifers: Columbia River Basalt Group	57%	86,000
12	Coast Range Tertiary Marine Volcanic and Sedimentary Rock Aquifers: Siletz River Volcanics	55%	150

Storage Priority	Aquifer Name	Percent of Ideal Conditions to Accept Water	Estimated Storage Capacity (ac-ft)
13	Umatilla Basin Quaternary-Late Tertiary Sediment Aquifers: Coarse-Grained Flood Deposits	54%	520,000
14	Deschutes Basin Quaternary-Late Tertiary Volcanic and Volcaniclastic Aquifers: Ancestral Channel Deposits	52%	2,200
15	Cow Valley Quaternary-Late Tertiary Sediment Aquifer	47%	150
16	Deschutes Basin Quaternary-Late Tertiary Volcanic and Volcaniclastic Rock Aquifers: Inactive Margin Facies	45%	500
17	Blitzen Area Quaternary-Late Tertiary Sediment Aquifers	45%	280,000
18	Prineville Area Quaternary-Late Tertiary Sediment Aquifers	43%	200
19	Umatilla Basin Late Tertiary Basalt Aquifers: Columbia River Basalt Group	42%	1,400,000
20	Deschutes Basin Quaternary-Late Tertiary Volcanic and Volcaniclastic Rock Aquifers: Proximal Lava Flows	41%	5,000
21	John Day Basin Middle-Early Tertiary Volcanic and Volcaniclastic Rock Aquifers: Clarno Formation	40%	22,000
22	Klamath Basin Quaternary-Late Tertiary Sediment Aquifers	39%	1,300,000
23	Owyhee Basin Late Tertiary Basalt Aquifers	39%	33,000
24	Brothers Area Quaternary-Late Tertiary Volcanic and Volcaniclastic Rock Aquifers	38%	15,000
25	Umpqua Basin Tertiary Marine Volcanic and Sedimentary Rock Aquifers	38%	23,000
26	Warner Valley Quaternary-Late Tertiary Volcanic and Volcaniclastic Rock Aquifers	36%	8,900

Storage Priority	Aquifer Name	Percent of Ideal Conditions to Accept Water	Estimated Storage Capacity (ac-ft)
27	North Coast Basin Tertiary Marine Volcanic and Sedimentary Rock Aquifers	35%	8,100
28	Willamette Valley Quaternary-Late Tertiary Sediment Aquifers: Upper Unit	33%	75,000
29	Drewsey Area Quaternary-Late Tertiary Volcanic and Volcaniclastic Rock Aquifers: Lake Deposits	33%	1,400
30	Umpqua Basin Middle-Early Tertiary Volcanic and Volcaniclastic Rock Aquifers: Western Cascades Volcanics	33%	1,300
31	Grant County Late Tertiary Basalt Aquifers: Columbia River Basalt Group	30%	1,700
32	Rogue Basin Mesozoic Granitic Rock Aquifers	30%	16,000
33	Burns Area Quaternary-Late Tertiary Sediment Aquifers	28%	3,000
34	Clatsop County Quaternary-Late Tertiary Sediment Aquifers: Dunes	27%	3,900
35	La Pine Area Quaternary-Late Tertiary Sediment Aquifers	23%	60,000
36	John Day Basin Middle-Early Tertiary Volcanic and Volcaniclastic Rock Aquifers: John Day Formation	20%	1,200,000
37	Baker Valley Quaternary-Late Tertiary Sediment Aquifers	20%	8,900
38	Eugene Area Middle-Early Tertiary Volcanic and Volcaniclastic Rock Aquifers	20%	1,300
39	Hood Basin Quaternary-Late Tertiary Volcanic and Volcaniclastic Rock Aquifers	19%	50
40	Western Cascades Middle-Early Tertiary Volcanic and Volcaniclastic Rock Aquifers	19%	42,000
41	Willamette Valley Tertiary Marine Volcanic and Sedimentary Rock Aquifers	17%	1,500,000

Storage Priority	Aquifer Name	Percent of Ideal Conditions to Accept Water	Estimated Storage Capacity (ac-ft)
42	La Grande Area Quaternary-Late Tertiary Sediment Aquifers	17%	130,000
43	Rogue Basin Tertiary Marine Volcanic and Sedimentary Rock Aquifers: Payne Cliffs Formation	16%	200
44	High Cascades Quaternary-Late Tertiary Volcanic and Volcaniclastic Rock Aquifers	16%	1,200
45	Jordan Valley Quaternary-Late Tertiary Sediment Aquifers	15%	100
46	Lakeview Area Quaternary-Late Tertiary Sediment Aquifers	14%	300
47	Middle Coast Range Tertiary Marine Volcanic and Sedimentary Rock Aquifers	13%	3,900
48	Willamette Valley Quaternary-Late Tertiary Sediment Aquifers: Silt	10%	0
49	John Day Basin Quaternary-Late Tertiary Sediment Aquifers	61%	0
50	Middle Coast Basin Quaternary-Late Tertiary Sediment Aquifers: Dunes	53%	0
51	Willamette Valley Quaternary-Late Tertiary Sediment Aquifers: Middle Sedimentary Unit	39%	0
52	Coos Bay Area Quaternary-Late Tertiary Sediment Aquifers: Dunes	33%	0
53	South Coast Basin Quaternary-Late Tertiary Sediment Aquifers: Marine Terrace Deposits	25%	0
54	Ontario Area Quaternary-Late Tertiary Sediment Aquifers	22%	0
55	Tillamook Area Quaternary-Late Tertiary Sediment Aquifers	18%	0
56	Illinois Valley Quaternary-Late Tertiary Sediment Aquifers	17%	0

Future Underground Storage Implementation

This study provides a starting point for underground water storage planning. Beyond regional aquifer suitability there are many other factors influencing underground storage feasibility. Implementation of an underground storage project also includes consideration of the following:

- Definition of project objectives will determine the appropriate recharge techniques.
- Site-specific study is essential to identify geologic complexity and aquifer parameters that are critical to underground storage operations.
- Water availability, in terms of timing and quantity, may be a limiting factor and requires careful investigation.
- The quality and chemical characteristics of the source water, native groundwater and recovered water is a determinant factor in the cost and feasibility of the project.
- Projects must obtain authorization from Oregon Water Resources Department to begin testing. This requires site investigation reporting, site-specific hydrogeologic data, and pilot test planning.
- Start-up, monitoring, maintenance costs and benefits vary by site. Although underground storage is generally less expensive than above ground reservoir construction, water quality monitoring, water level monitoring and treatment costs can be significant.

Conclusions

Out-of-stream water demand projections for 2010 (HDR, 2008) are less than the potential underground storage found in some basins. In others, such as coastal, Malheur and Rogue basins where geologic units are typically low-permeability, low-yield bedrock, underground storage is insufficient. However, underground storage may play a part in the overall water management of these basins, in conjunction with other methods.

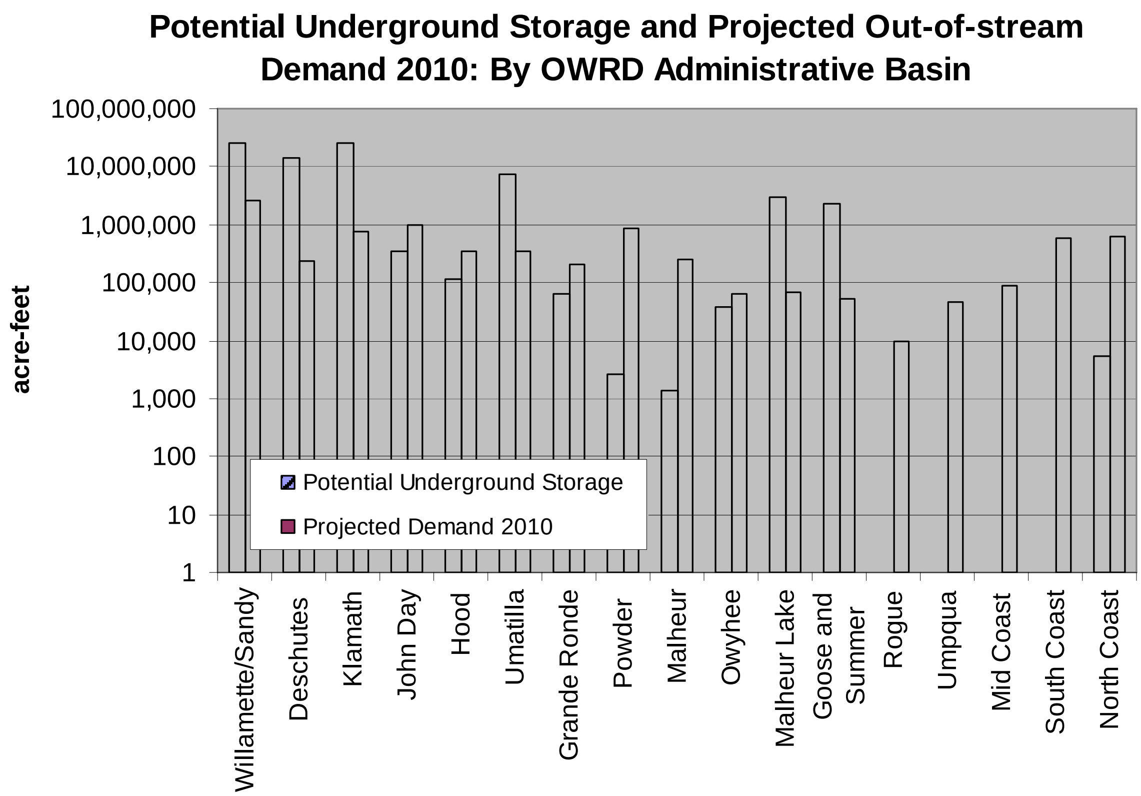

Figure 10. Demand projections by HDR (2008) and storage capacity estimates from this study indicate that expanded underground storage can help meet need in many Oregon basins. Potential underground storage capacity calculations in this figure include only aquifers that scored higher than 39% of ideal conditions in the aquifer rating system.

In conclusion, there is significant potential for underground storage in Oregon. Experience to date has been largely positive, especially for municipal water systems. As new aquifer data become available and climate change shifts Oregon's water supply patterns, future groundwater management should consider underground storage as one useful tool in an array of water management alternatives.

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