Final Technical Report: Oregon Water Resources National Ground-Water Monitoring Network Cooperative Agreement G19AC00188 (07/01/2019 through 06/30/2021)

Award Number: G19AC00188

Agency Name: Oregon Water Resources Department

Title: Oregon National Ground-Water Monitoring Network

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Background

The Oregon Water Resources Department (OWRD) manages water supplies in the state of Oregon. The Department monitors groundwater levels throughout the state to evaluate aquifer sustainability, the impacts of groundwater withdrawals on surface water sources, and the availability of groundwater for new proposed uses. Five principal USGS aquifers underlie extensive areas of Oregon (Miller, 1998; Whitehead, 1994): Willamette Lowland basin-fill aquifers, Pacific Northwest basin-fill aquifers, Pacific Northwest basaltic-rock aquifers, Columbia Plateau basin-fill aquifers, and Columbia Plateau basaltic-rock aquifers. Three additional principal aquifers underlie small areas of the state. Snake River Plain basin-fill aquifers and Snake River Plain basaltic-rock aquifers occur in a narrow strip in eastern Oregon, adjacent to Idaho, and Basin and Range basin-fill aquifers occur in southeastern Oregon adjacent to Nevada. A sizable fraction of Oregon is underlain by pre-Miocene rock that hosts low-yield fractured bedrock aquifers. Although these are not defined as a USGS principal aquifer, they represent an important water supply in many areas of the state, especially west of the Cascade Mountains.

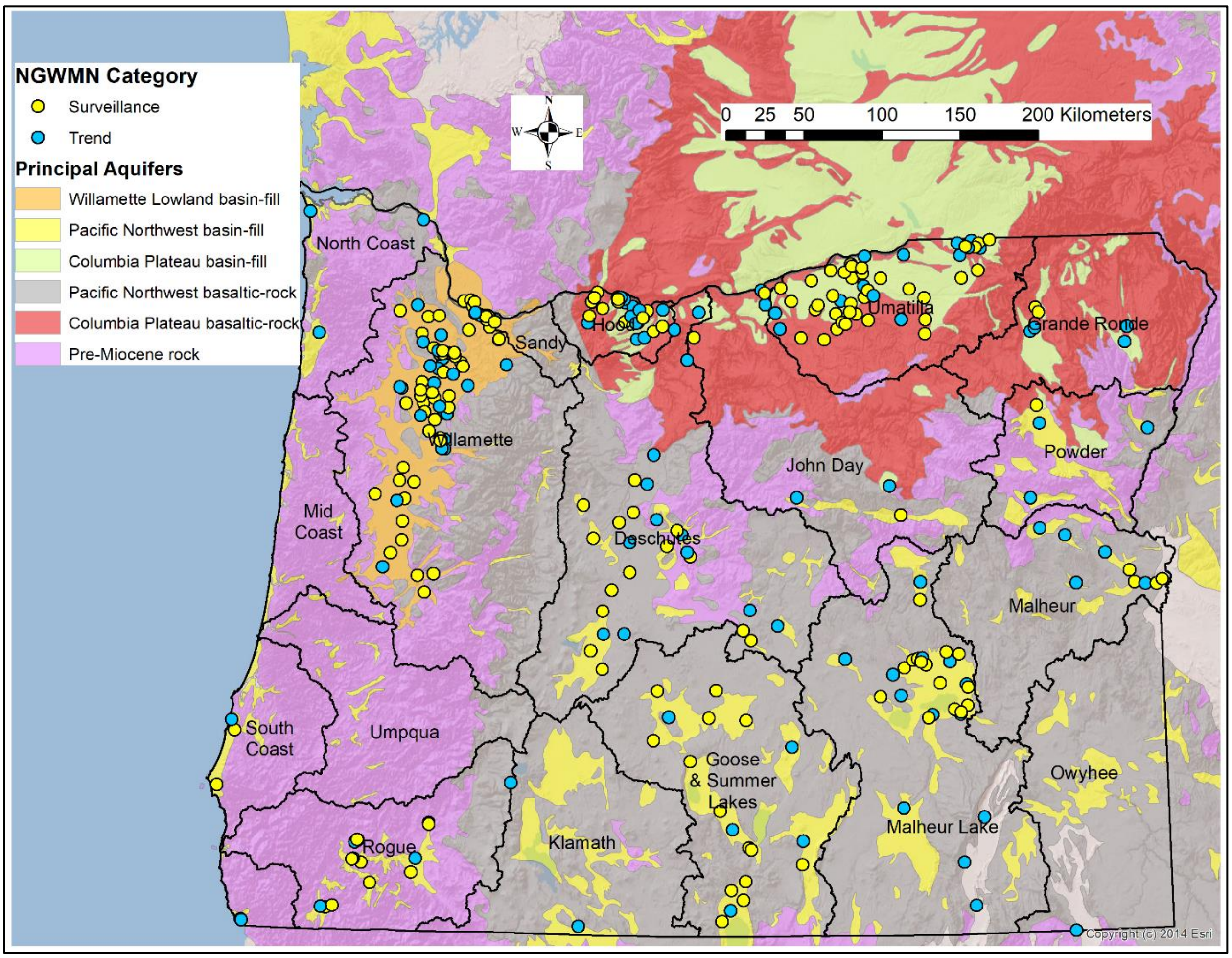

Figure 1: Current OWRD National Groundwater Monitoring Network wells.

OWRD became a new NGWMN provider in 2015 and currently maintains 298 active NGWMN sites that represent 5 USGS principal aquifers and several locally important pre-Miocene bedrock aquifers (Figure 1). Continuous recorders are installed in 67 wells (Table 1).

Table 1: Summary of active OWRD NGWMN wells by aquifer, monitoring category, and recorder use. Trend monitoring provides high-frequency data over a long period of at a limited number of wells, while surveillance monitoring provides higher spatial resolution through measurement of more wells at lower temporal frequency.

USGS Principal Aquifer	Trend	Surveillance	Recorder	Total
Columbia Plateau basaltic-rock aquifers	34	44	17	78
Columbia Plateau basin-fill aquifers	5	9	6	14
Other (Pre-Miocene rock)	6	5	5	11
Pacific Northwest basaltic-rock aquifers	23	46	15	69
Pacific Northwest basin-fill aquifers	29	39	18	68
Willamette Lowland basin-fill aquifers	21	37	6	58
Total	118	180	67	298

Description of Work Done to Support the NGWMN under Award G19AC00188

Award G19AC00188 provided funds to significantly expand the number of sites in the Portland Basin (Years 1 and 2), support persistent data services (Year 1 and 2), and fill information gaps for existing NGWMN wells (Year 2). The completion of all of all tasks in the award proposal, except for Task 2 of Objective 3, is documented in the following sections under each of the major objectives that were listed in the original proposal.

Objective 1: Expansion of services / sites

Despite the relatively-large number of wells that comprise the OWRD State Observation Well Network (about 380), there is a notable deficiency of OWRD groundwater level data for the Portland Basin. The Portland Basin is a geologic structural basin encompassing about 1280 square miles. It is part of a major forearc complex formed by development of the Cascadia Subduction Zone that extends from near Eugene, Oregon north to Puget Sound, Washington (i.e., the “Puget-Willamette Basin”). The Portland Basin hosts a “Pacific Northwest basin-fill aquifer”, which is an important groundwater resource that provides drinking water for approximately 1.5 million people in the Portland, Oregon-Vancouver, Washington metropolitan area. It is also an important water source for industrial and irrigation uses in the Basin.

Despite the importance of the Portland Basin as a groundwater resource, in 2019 there were only three wells in the State Observation Well Network located in the Basin. At the same time, there were 16 Oregon wells in the Portland Basin that are part of the NGWMN, maintained and measured by the USGS Water Science Center in Portland. However, almost all of these NGWMN wells support USGS studies of

Johnson Creek, a key urban watershed. Consequently, data from these generally shallow and geographically-focused wells are not suitable for assessing regional groundwater conditions throughout the entire Portland Basin. A key objective of this proposal was to support the expansion of an observation well network within the Portland Basin that serves multiple needs.

OWRD engaged with municipal water providers to improve understanding of local groundwater conditions in the Portland Basin. The primary water source for many of these municipal providers is groundwater from the alluvial aquifer system in the Basin. The purpose for the current collaborative effort between OWRD and the local municipalities was to facilitate access and exchange of groundwater level data that is currently not readily available to all of the respective municipalities.

The Portland Basin municipal water providers maintain several hundred production and observation wells, many of which have served as sources of historic and current groundwater level data in the Basin. The participating municipalities provided about 250 candidate wells for this local monitoring network. From this relatively-large number of candidate wells, OWRD worked with the municipalities to develop a smaller shared monitoring well network that will serve the various needs of not only the municipal water providers, but also OWRD and the NGWMN.

The purpose for Objective 1 was to support OWRD's efforts to establish a subset of key municipal observation wells in the Portland Basin to be considered for inclusion in the NGWMN. It was anticipated that this new data network would consist of approximately 25 to 30 wells that are geographically and stratigraphically representative of groundwater conditions across the Basin. This objective has been met by selecting additional sites for the NGWMN Portland Basin (task 1), classifying the sites for monitoring category and subnetwork type (task 2), entering additional required data elements (task 3), populating the NGWMN Well Registry (task 4), and reporting in this final report (task 5).

Given the large number of candidate wells, Task 1 required significant effort by OWRD staff, including obtaining and assessing existing well documentation (e.g., well logs and historic water level records). Portland Basin candidate wells were initially screened to ensure compliance with NGWMN standards. In addition, initial work on Task 1 quickly made apparent the importance of first completing task 1 of objective 3, "Evaluate and process historic water level data for new Portland Basin NGWMN sites," which was originally planned for year 2 of the project. Importing water levels was found to be a critical prerequisite for selecting wells due to the significant redundancy of the data, as multiple wells showed highly correlated water level deviations. For the sake of the NGWMN, OWRD, and municipalities, limiting such redundancy was considered an important objective. This change was approved by Daryll Pope in an email exchange on 7/9/2020.

Once the water level data had been imported, they were analyzed to identify groups of wells within each aquifer displaying similar behavior. Groups were defined based on the similarity of near-synchronous water level behavior between two wells, because many of the wells shared different periods of record and measurement frequencies (typically quarterly or monthly). Water levels were considered synchronous if they were measured in the same month, and when more than one water level was available, the highest was used. Two wells were considered to behave similarly if the deviations from mean in monthly high water levels over the shared period of record were correlated (Pearson's $R^2 > 0.6$) and had limited root mean squared error (<5 feet). Well behavior was clustered into groups using a modified version of the algorithm named “cautious” from Bansal *et al.*, (2004), where δ was set to 0.5 for addition of wells and to 1 for removal. This means roughly that wells were added to a cluster if their behavior was similar with at least half of the wells already in the cluster, and wells were never removed from clusters. The tolerances on correlation and cluster membership were tuned manually in order to capture qualitatively distinct water level trends (Figure 3, Figure 4, Figure 5, and Figure 6). This clustering algorithm was the most appropriate among those tested because of its ability to identify distinct groups without over-grouping due to chains of similarity between individual wells (Ackerman *et al.*, 2010; Aggarwal *et al.*, 2019; Ailon *et al.*, 2008; Bagon and Galun, 2011; Balcan *et al.*, 2008; Strehl and Ghosh, 2003). However, an exhaustive analysis of the clustering algorithm and the sensitivity to initial conditions was not performed due to time constraints.

All of the wells considered for addition under this project access the “Willamette Lowland basin-fill aquifers” Principal Aquifer. However, wells with similar water level behavior were allowed to be grouped together only if they access the same aquifer as defined in the USGS WRIR 90-4196 (Swanson *et al.*, 1993), indicated by the cooperating utility, and verified by OWRD[1] (see Figure 2). In order of increasing depth, these aquifers are:

- Unconsolidated sedimentary aquifer (USA)
- Troutdale gravel aquifer (TGA)
- Confining unit 1 (CU1)
- Troutdale sandstone aquifer (TSA)
- Confining unit 2 (CU2)
- Sand and gravel aquifer (SGA)
- Older rocks (OR)

These aquifers are more refined than the USGS Principal Aquifers but provide meaningful distinctions in water level behavior among wells in the Portland basin. All of the corresponding WRIR 90-4196 alluvial aquifers are hydraulically connected to each other. However, two significant confining layers allow water levels in the aquifers to show somewhat distinct behavior. The sand and gravel aquifer is the primary target for expected future municipal development in the basin, but the potential for impacts to wells in other aquifers through commingling wells and thinner sections in the confining layers motivates interest in monitoring all the aquifers.

[1] Some aquifers were indicated within the system proposed by Hartford and McFarland, (1989), and these were reclassified into the Swanson et al., (1993) system. In addition, all wells indicated as accessing the Upper and Lower Orchards Aquifers were reclassified as accessing the Unconsolidated Sedimentary Aquifer.

Table 2: List of all wells added to the NGWMN under this project. All wells access the Willamette Lowland basin-fill aquifers (N100WLMLWD). In the Aquifer column, USA = unconsolidated sedimentary aquifer. TGA = Troutdale gravel aquifer. CU1 = confining unit 1. TSA = Troutdale sandstone aquifer. SGA = sand and gravel aquifer (Swanson *et al.*, 1993). In the Status column, proposed wells are intended for addition to the NGWMN but require further negotiation with municipal partners to confirm monitoring responsibilities. In the Subnetwork Type column, BG = background, DC = documented / known changes, SC = suspected / anticipated changes. In the Monitoring Category column, TR = trend and SV = surveillance. Well MULT0063294 was formerly monitored and submitted by the USGS under site ID 452825122355501.

Aquifer	Site Number	Status	Subnetwork Type	Monitoring Category	Primary Use	Group Number	Number of Wells
USA	MULT0001138	Active	BG	TR	MONITORING	7	14
USA	MULT0001290	Active	BG	TR	MONITORING	8	5
USA	MULT0001300	Active	BG	SV	UNUSED	0	6
USA	STWA0237648	Active	BG	SV	MUNICIPAL	1	1
USA	STWA0239370	Active	DC	SV	MUNICIPAL	3	1
TGA	NLOG0000035	Active	BG	TR	OBSERVATION	13	1
TGA	MULT0056399	Active	BG	TR	MONITORING	16	45
TGA	MULT0063294	Active	BG	SV	MONITORING	11	3
TGA	STWA0239011	Active	DC	SV	MUNICIPAL	14	1
TGA	MULT0056401	Proposed	BG	SV	MONITORING	18	4
TGA	MULT0056392	Proposed	DC	SV	MONITORING	19	1
CU1	MULT0082314	Active	BG	SV	MONITORING	20	2
TSA	MULT0056391	Active	BG	TR	MONITORING	24	12
TSA	NLOG0000036	Active	BG	TR	MONITORING	23	1
TSA	MULT0002164	Active	DC	SV	IRRIGATION	22	1
TSA	MULT0001187	Active	BG	SV	MUNICIPAL	25	5
TSA	MULT0003142	Active	DC	SV	MONITORING	27	2
TSA	MULT0001255	Active	SC	SV	UNUSED	29	2
SGA	MULT0001446	Active	SC	TR	MONITORING	31	2
SGA	NLOG0000009	Active	SC	TR	MONITORING	36	7
SGA	MULT0059149	Active	DC	TR	MONITORING	44	5
SGA	MULT0126710	Active	SC	SV	MONITORING	31	2
SGA	STWA0239128	Active	BG	SV	MUNICIPAL	33	2
SGA	MULT0001122	Active	DC	SV	MUNICIPAL	37	12
SGA	MULT0004413	Active	SC	SV	MONITORING	40	2
SGA	MULT0054069	Active	DC	SV	MONITORING	41	2
SGA	MULT0070128	Active	BG	SV	MUNICIPAL	46	3

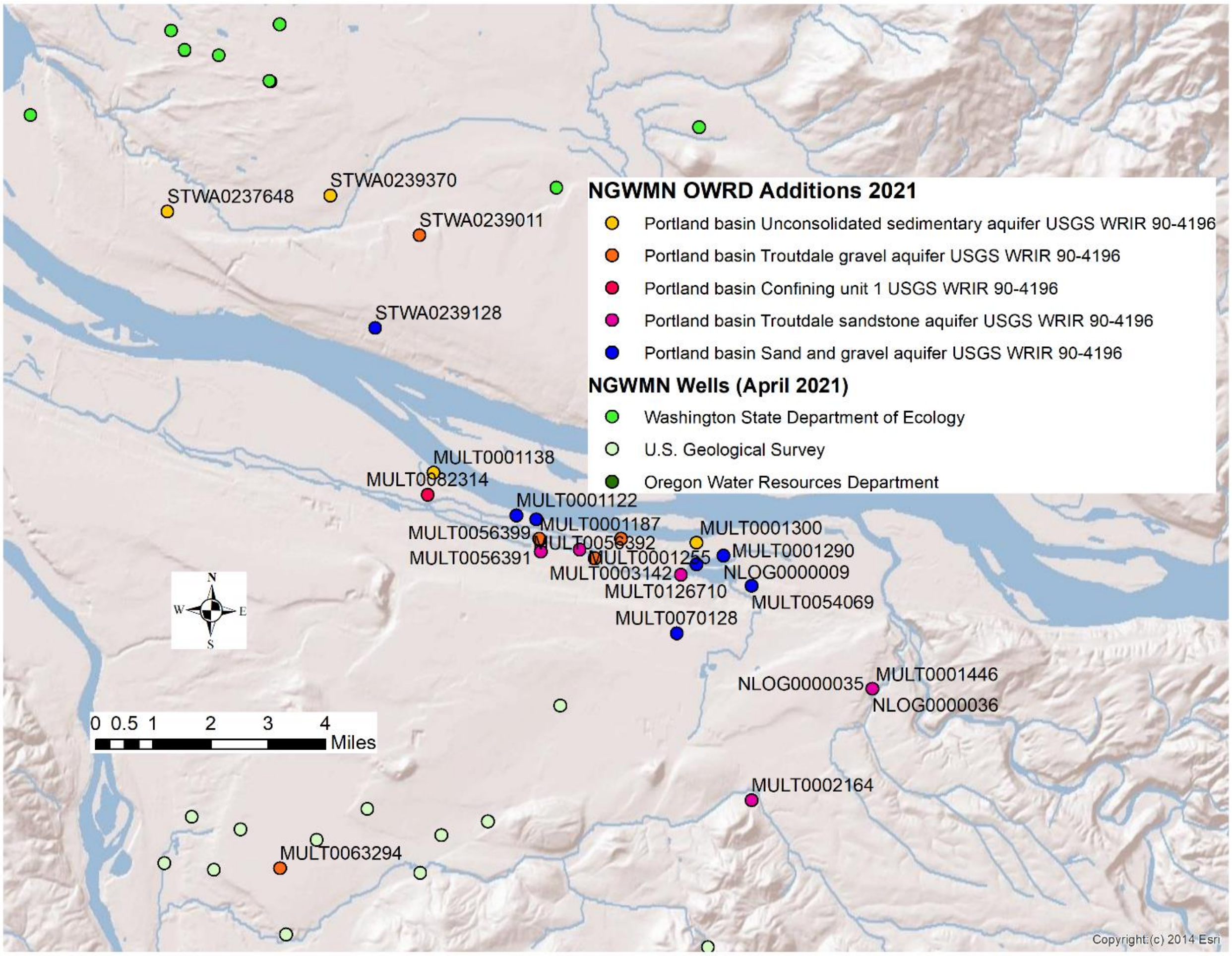

Figure 2: Map of wells added to the NGWMN under this project in 2021, along with existing NGWMN wells in the vicinity.

Multi-well groups, especially those representing a large number of wells, were prioritized for inclusion in the NGWMN and nomination as Trend wells (Table 2). Wells not behaving similarly with any others (groups of only 1 well) were also considered for inclusion if their water levels, location, and aquifer membership suggested that they would provide distinct, important information. In addition, collocated wells and nested piezometers in multiple aquifers were prioritized for inclusion as Trend wells, as recommended by NGWMN (see discussion below). When multiple wells within any group were eligible for inclusion, preference was given to wells that:

- Are already active in the NGWMN or any OWRD observation network, or else formerly NGWMN measured by OR WSC and now inactive. For example, MULT0056392 was picked up from the USGS Oregon Water Science Center, which was forced reluctantly to drop the well from the Johnson Creek monitoring network due to budgetary constraints.
- Are dedicated monitoring wells.
- Have water levels most strongly correlated to the largest number of other wells.

- Have a long history of measurement. Between wells with similar durations of measurement, prioritize wells drilled more recently, such that they may have a longer lifetime as observation wells.
- Were included in USGS Studies, because these wells were selected for their ability to represent important aspects of the regional hydrogeology:
    - McCarthy and Anderson (1990)
    - Swanson *et al.* (1993), which proposed the system of aquifers utilized for this analysis.
    - Two cooperative studies between the USGS and OWRD (Conlon, 2005; Herrera *et al.*, 2014).
- Were recommended based on analysis of Portland Water Bureau (PWB) wells by GSI Water Solutions consultants, who have been responsible for running PWB's MODFLOW model of the Columbia South Shore Well Field for quite some time.

Each aquifer was assigned at most two Trend wells, except for the sand and gravel aquifer, which was assigned three based on the variety of behavior (Figure 6) and anticipated changes with development. Consequently, a total of 9 additional Trend wells were added (Table 2), in every aquifer except confining units 1 and 2, which had no suitable wells and are not considered to be important water sources. Even with this restriction, the spatial density of Trend wells exceeds that recommended in the Tip Sheet on Well Selection Criteria for Water Levels: 1 to 8 Trend sites per 10000 square miles. The increased density reflects the further recommendation that, "More sites may be required if the Principal aquifer is made up of several major aquifers which vary with depth. Nested wells at these locations are ideal 'Trend' sites." Two sets of nested wells were added to the network for this project:

- NLOG0000035, NLOG0000036, and MULT0001446, which are part of the Troutdale "Drinker" piezometer multi-completion observation well in the TGA, TSA, and SGA, respectively. All are added as Trend wells.
- MULT0001290, NLOG0000037, NLOG0000009, and NLOG0000010 in the USA, USA, SGA, and SGA, respectively. MULT0001290 and NLOG0000009 are Trend wells, and the others were considered to provide redundant data.

The combined selection of wells added to NGWMN provide a useful summary of the major water-level trends in the Portland Basin aquifers. Due to the incomplete aquifer confinement and imperfect grouping of wells, some well groups showed water level behavior correlated with other well groups (Figure 3, Figure 4, Figure 5, and Figure 6), even in different aquifers. Tracking reliable water level trends that are similar between aquifers provides useful hydrogeologic insight and may help identify wells constructed as to commingle between multiple aquifers. Nonetheless, OWRD and its municipal partners will continue to analyze these data and remove truly redundant wells from the NGWMN.

Objective 2: Support Persistent Data Service

During year 1 and 2 of the award period, OWRD's Information Services Section performed routine backup, performance tuning, and stored procedure modifications to ensure continuity of web services. Time was also dedicated to improving the rules for data entry and water level review to minimize errors in data entry and display.

In addition, OWRD's Groundwater Section periodically reviewed and updated metadata for all existing sites in the NGWMN site table. A routine query of wells with overdue measurements helped to identify 6 sites in need of replacement due to access restrictions. We are working to identify appropriate replacements using the water level correlation technique developed for this project. Furthermore, the 2021 Oregon Legislature funded a significant expansion of OWRD's groundwater monitoring network, and wells will be added to the NGWMN when appropriate.

Objective 3: Fill Information Gaps for Existing NGWMN Sites

Only Task 1 was completed during the award period, with work in both years. Task 2 (Reconciliation of OWRD and USGS Oregon Water Science Center databases) remains a goal of OWRD's.

<u>Task 1: Evaluate and process historic water level data for new Portland Basin NGWMN sites</u>

A portion of Task 1 (Evaluate and process historic water level data for new Portland Basin NGWMN sites) was completed before completion of Objective 1, because identifying representative wells required having the water level data accessible in OWRD's database. Although more than 20,000 associated manual water level measurements were imported for 220 candidate site, time was only charged to NGWMN for a small portion of these representing the final number of sites added to the Network. Additional work included reviewing the imported water level data for quality control.

In addition to the ongoing work of importing manually measured water levels, OWRD seeks to develop the capacity for importing transducer data from external organizations. When this capacity is complete, we expect to make SCADA data available for some of the sites added under this project. Future gap-filling work should also include generating independent well logs for the 3 'NLOG' sites added to the NGWMN, each of which represents an individual completion in a multi-completion well.

<u>Task 2: Reconciliation of OWRD and USGS Oregon Water Science Center databases</u>

OWRD and the USGS Oregon Water Science Center each maintain databases of water-level data, and a significant number of wells occur simultaneously in both databases. Historically, updates to these multi-database wells were reconciled using an automated system within OWRD, but this system has not yet been updated to interface with the new OWRD GWIS database. We remain in contact with colleagues at the Oregon Water Science Center and the team working on the Groundwater Site Inventory modernization effort and expect to prioritize this project in order to facilitate the ongoing cooperative Groundwater Basin Study with the USGS in the Walla Walla sub-basin.

In-Kind Data-Collection Activities

During the award period, routine water-level measurements were continued at all active NGWMN sites, and automatic recorders were maintained at 67 sites. All data were routinely entered into OWRD database tables and are now available to the NGWMN via OWRD's web services.

Data-Collection Methods and Quality Assurance Procedures

OWRD collects water-levels and well metadata using procedures and data collection standards that parallel those outlined in the NGWMN Framework document and in Groundwater Technical Procedures of the U.S. Geological Survey (Cunningham and Schalk, 2011). The Department uses steel tapes in a few wells but generally uses commercially available electric tapes from several vendors. Tapes are calibrated annually, or more frequently as needed, using a 500-foot dedicated steel tape that has been calibrated by the USGS Oregon Water Science Center. Calibrated flat tapes (electric tapes with a steel core) are used in all dedicated observation wells without pumps. Coaxial electric tapes are used in all wells with pumps. In flowing artesian wells, calibrated gages are used to measure shut-in pressure. A few of our NGWMN wells are measured using an airline and a calibrated gage. Whenever possible, independent calibrated electric tape measurements are made to verify airline lengths.

Water-level measurement errors are initially assigned to each measurement based on the tool used to obtain the measurement as follows:

- Calibrated steel tapes 0.01 feet
- Calibrated flat electric tapes 0.01 feet
- Calibrated coaxial electric tapes 0.02 feet
- Uncalibrated coaxial electric tapes 0.10 feet
- Calibrated gage measurements used for shut-in pressures 0.25 feet
- Calibrated gage measurements used for airlines with verified airline lengths 2 feet
- Calibrated gage measurements used for airlines with unverified airline lengths 4 feet
- Water levels from a SCADA system 0.10 feet

However, these initial error estimates are adjusted upward as needed based on conditions encountered in the field.

Due to the collaborative nature of this project, nearly all of the water levels in the subject wells are measured by municipal utility staff. We appreciate that this situation is not ideal from the perspective of NGWMN, and offer that these staff are typically Professional Engineers, or in some cases Registered Geologists hired to perform the measurements. Many measurements are supported by SCADA system readings. Nonetheless, OWRD staff will seek opportunities to train these staff on the USGS data collection standards. Trainings will also enable other agency staff to enter data directly into OWRD's database, allowing more frequent data entry than the current method of periodic spreadsheet transfers. Each digital water level record captures relevant metadata including the source (measuring) organization that enables quality control. Records for each well are reviewed annually to assess the overall quality of the data and to assign a reliability index to individual measurements based on the entire record for the year. Records found to be unreliable or not to represent static conditions in the aquifer are censored from view through the NGWMN portal but are available for download from OWRD. Historical records are periodically reviewed in the same manner; a mid-2020 review of anomalous historic water level behavior evaluated over 28,000 water levels on 774 wells.

Measuring points are documented relative to land surface at each well along with the horizontal and vertical errors associated with the well location and well-head elevation.

All current recorder data is processed and reviewed using WISKI, a time-series water-information management system developed by the KISTERS Company. A customized processing file is established in WISKI for each monitoring site based on unique site attributes. Standard protocols are used to subtract barometric pressure (most of our transducers are non-vented models), correct for drift using independent measurements made with calibrated electrical or steel tapes during each site visit, and correct for miscellaneous baseline shifts. Some of these processes are automated by the WISKI software but each file is also reviewed at various times by a hydrogeologist to ensure that the final product meets our quality control standards. The data is also processed to provide a table of mean daily levels. The final, corrected unit measurements and the daily mean values are uploaded into SQL tables, which are then available to the NGWMN Portal via OWRD's web services.

OWRD does not currently have a formal groundwater field-collection manual. However, we are in the process of developing a manual that will outline our standard data collection, processing, and quality control procedures. We anticipate providing this manual to the NGWMN in conjunction with future projects.

Status of OWRD Databases and Web Services

OWRD initially established web services for discrete water levels, mean daily recorder water levels, lithology, and well construction when it became a new data provider in 2015. As noted above, substantial changes were made to OWRD's Groundwater database in Year 1 of the current award. These changes required a number of adjustments to our web services to ensure the continued flow of data to the NGWMN during the performance period. No changes to our database tables or web services are anticipated in the near future.

OWRD web service requests currently available at:
https://apps.wrd.state.or.us//apps/gw/gw_data_usgs/IndexUSGS.html

Documentation of the web services is available at:
https://apps.wrd.state.or.us/apps/gw/gw_data_usgs/IndexUSGS.html#hide1

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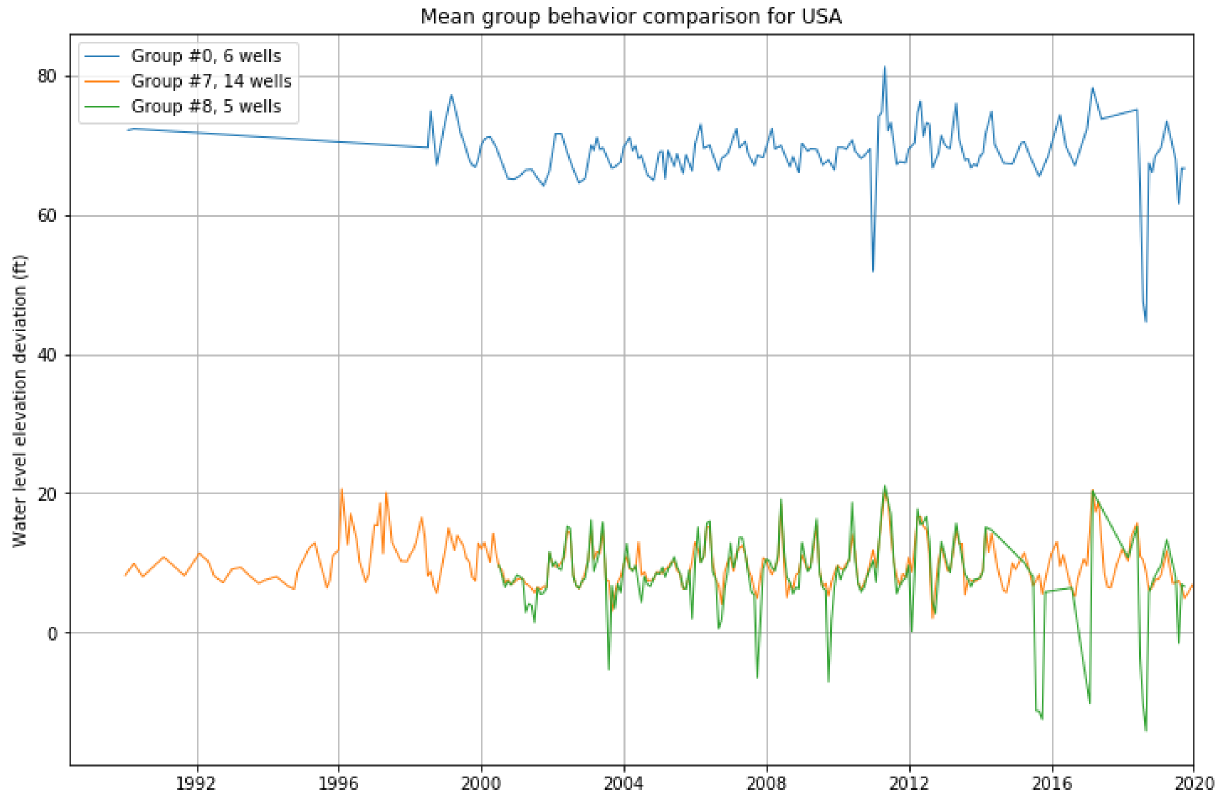

Figure 3: mean water level behavior among wells in multi-well groups in the unconsolidated sedimentary aquifer.

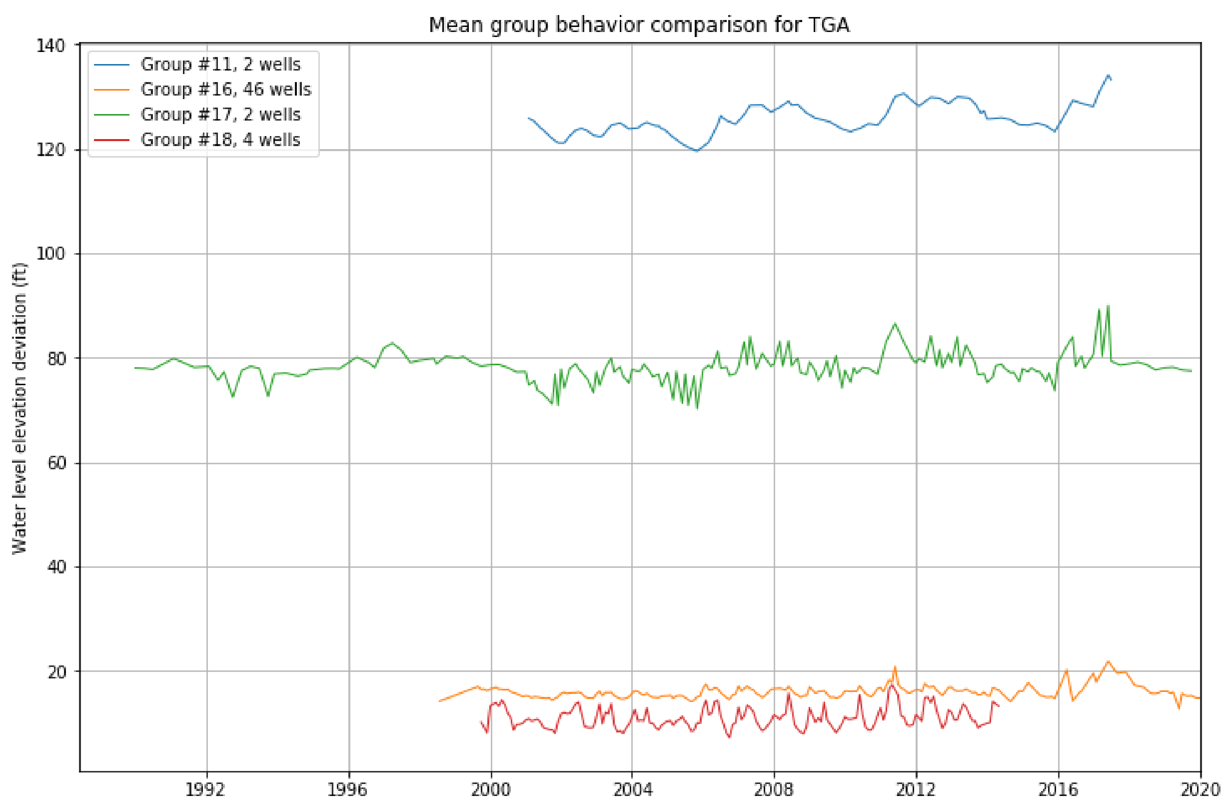

Figure 4: mean water level behavior among wells in multi-well groups in the Troutdale gravel aquifer.

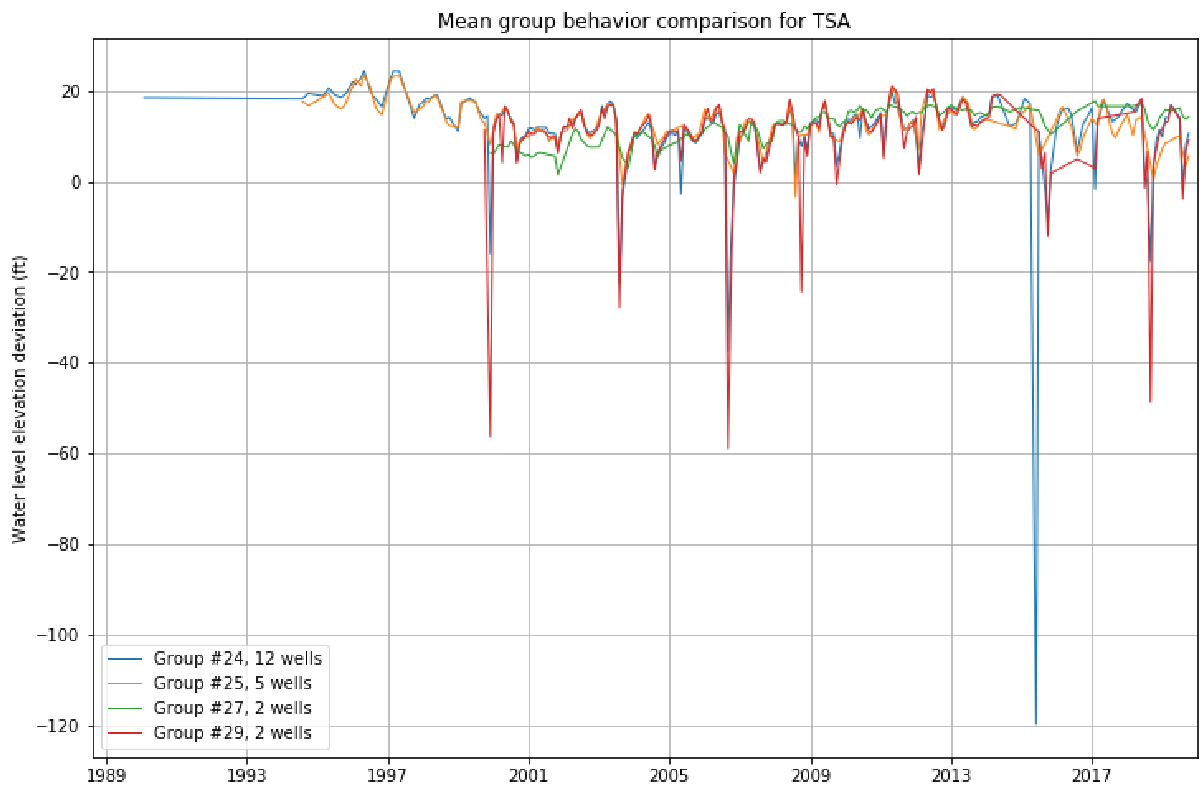

Figure 5: mean water level behavior among wells in multi-well groups in the Troutdale sandstone aquifer

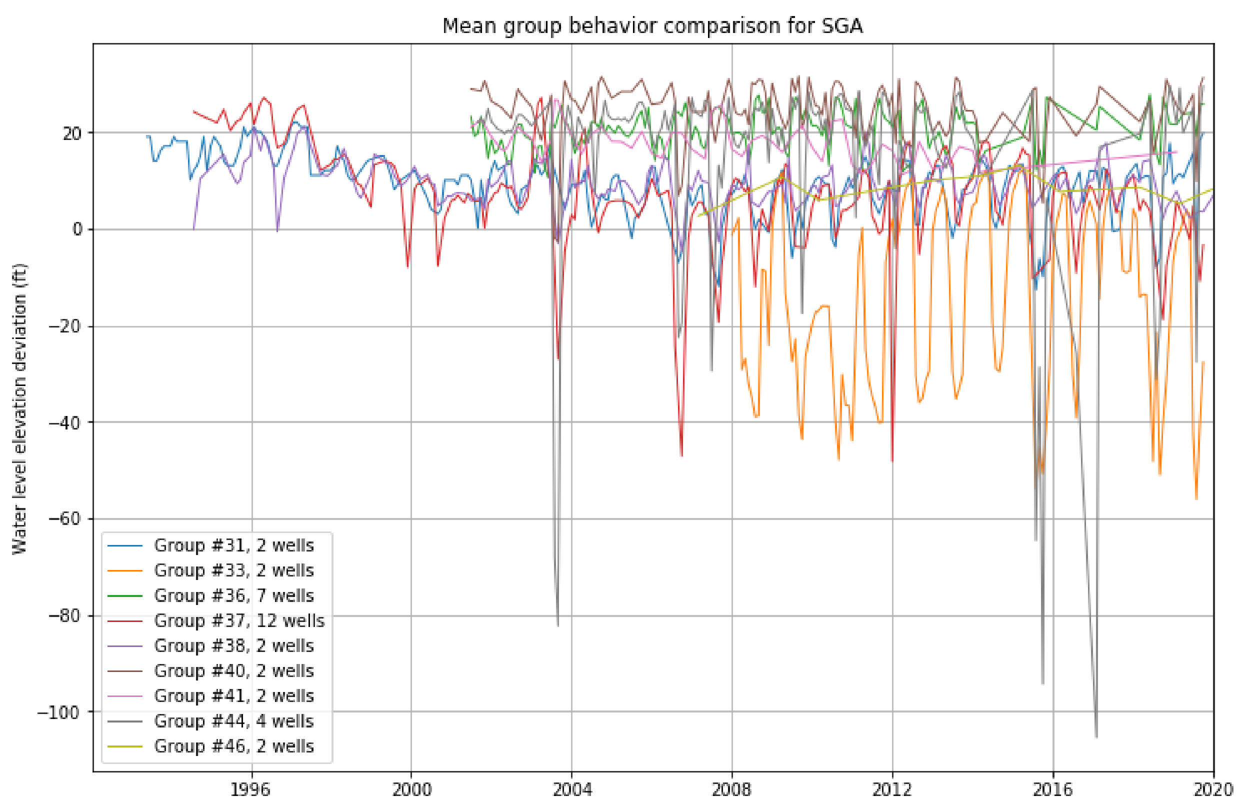

Figure 6: mean water level behavior among wells in multi-well groups in the sand and gravel aquifer.