Harney Basin Groundwater Study Summary

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Presentation Recording Script

Slide 1: Title page

Hi, my name is Jerry Grondin, and I'm a Hydrogeologist in the Groundwater section at the Oregon Water Resource Department.

Thank you for the opportunity to present a summary of the USGS-OWRD groundwater study in this recording.

Slide 2: Presentation Outline

This presentation is divided into the following sections or components:

1. Key Takeaways
2. Harney Basin groundwater study introduction and background
3. Water chemistry sampling, analyses, and results
4. Harney Basin groundwater levels and their relationship to basin geology
5. Harney Basin groundwater budget
6. Conclusion, which is a repeat of the key takeaways
7. References

Slide 3: Key Takeaways

There are four key takeaways from the Harney Basin groundwater study important to understanding the basin's groundwater and for making effective resource management decisions and rules

1. Most Harney Basin groundwater is ancient (recharged 5,000 to 30,000 years ago); modern groundwater (recharged after 1953) is limited to a thin, shallow zone beneath recharge areas
2. Geology (hydrostratigraphy) is a major key to understanding Harney Basin groundwater and finding solutions to groundwater problems
3. Harney Basin groundwater is a single, hydraulically connected groundwater flow system, a continuum vertically and laterally. No impermeable barriers to groundwater flow are known to exist. Having said that, there are many significant variations that relate to the various geologic (hydrostratigraphic) units and their hydraulic properties
4. Harney Basin groundwater budget balances in the Uplands; it does not balance in the Lowlands where there is a deficit of 110,000 acre-feet/year…110,000 acre-feet is enough water to cover nearly 172 square miles with one-foot of water or to stack water more than 15.75 miles high on a single football field (about twice as high as most airlines fly)

Slide 4: Groundwater Study Area

- The 5,243 square-mile Harney Basin GW study area is the color shaded area in both maps.
  - The study area is located in the northern portion of the OWRD Malheur Lake Administrative Basin (the administrative basin boundary is the heavy black outline)
  - As shown in the right hand map, the study area is mostly in Harney County, and it encompasses 3 watersheds
    - Silvies River watershed
    - Donner und Blitzen River watershed
    - Silver Creek watershed
    - Those watersheds were defined by the Oregon Water Resources Board (1967)
  - The study area and the watershed boundaries on these maps were delineated using a USGS national system (hydrologic unit code (HUC)) that delineates watersheds at different scales from national regions to sub-watersheds. The sub-watershed scale was used to delineate the 3 Harney Basin watersheds to match the 3 watershed areas defined by the Oregon Water Resources Board (1967) and the 3 watersheds were then used to delineate the study area
- In addition to the watersheds and study area, rules (OAR 690-512) adopted in 2016 define a 2,410 square mile Greater Harney Valley Groundwater Area of Concern (GHVGAC) where new permits for groundwater use are being denied. The GHVGAC is the black hatched area in the left map and black striped area in the right map

Slide 5: Groundwater Study Reports

- This presentation summarizes the groundwater study results published in 6 reports (2 primary reports by the USGS & 4 supporting reports by OWRD) and 2 fact sheets (one by the USGS and one by OWRD)
- The groundwater study water budget divides the study area for analyses, discussion, and comparison reasons only
  - First, it divides the study area into regions (all hydraulically connected)
    - North
    - South
    - West
    - The regions are similar to the watersheds but are different. The regions include groundwater considerations whereas the watersheds are based solely on surface water considerations.
  - Second, it divides the study area into uplands (outside yellow boundary) and lowlands (inside yellow boundary) which are hydraulically connected. The lowlands are about 1,000 square-miles within the center of the basin and is generally based upon the mapped extent of Quaternary alluvium (sedimentary deposits of clay, silt, sand, and gravel generally less than 2.5 million years old)

Slide 6: Groundwater Study Authors

- The 6 Harney Basin reports list one or more of these authors
- The reports acknowledge other USGS and OWRD staff as well as other federal, state, county, and local agencies, departments, and individuals
- The study benefited from legislative House Bills collaboratively, jointly sponsored by State Rep. Mark Owens and Rep Ken Helm
- The study also benefitted from OWRD and USGS management who made resources and staff available

Slide 7: Previous Hydrologic Studies

- Multiple previous hydrologic studies were conducted in the Harney Basin beginning in the early 1900s. They are referenced in our reports. I want to note three:
- Groundwater:
  - Two reports: Piper and others (published in 1939) and Leonard (published in 1970)
  - Both studies are generally limited geographically to the Harney Valley area
    - The blue contours are copied from the Piper & others study…the data are from 1931-1932
    - The red contours are copied from the Leonard study…the data are from 1968-1969
    - The current study presented today addresses the entire Harney Basin
  - Both Piper and Leonard distinguish groundwater at shallow wells versus groundwater at deeper wells…the current study presented today addresses groundwater at shallow wells versus groundwater at deeper wells…they are hydraulically connected even when they behave differently
  - Piper's report noted the influence of native vegetation on groundwater levels at shallow wells…the current study's water budget accounts for groundwater discharge via evapotranspiration (ET)…by native vegetation and by crops
- Malheur Lake:
  - One report: Hubbard (1975)
  - The report noted the Sodhouse Spring discharge to the lake was estimated as 8,000 to 9,000 acre-feet in 1972 and 1973 respectively
  - Apart from Sodhouse Spring, the water exchange between the lake and groundwater (inflow-outflow) was determined to be negligible…
    - Similarly, the current study's water budget calculated an inflow and outflow exchange of less than 1,000 acre-feet/year for both Harney and Malheur Lakes
    - This is notable given the lakes are usually the low-point and end-point for both surface water and groundwater
    - When the study team discussed the small exchange of water between the lakes and groundwater, Amanda Garcia (the water budget report lead author), noted observing similar small exchanges in Nevada closed basins…often groundwater dependent vegetation surrounding the lakes suck-up and use the groundwater before it can flow into the lakes…subsequent study data (flow direction and water chemistry) indicates the same is occurring in the Harney Basin

Slide 8: Pre-Groundwater Study Background

- So…what led up to the current groundwater study…let's begin with the Crane vicinity
- The Crane Vicinity is at the star on the east side of the basin on the inset map
- Prior to 2010, OWRD received repeated well complaints that noted:
  - Well to well groundwater level interference, and
  - Well site instability causing the ground to repeatedly collapse around at least one well as shown in the inset photo that required repeated loads of gravel to refill the collapse
- Additionally, there was concern about possible long-term groundwater level decline:
  - Leonard in 1970 noted observing possible 1960s decline (see upper left corner of the hydrograph) and warned of a risk of future decline
  - After 2000, OWRD measured groundwater levels at more wells (5 wells from 2008 to 2012)
    - A definite groundwater level decline was observed
    - A more recent closer look shows the groundwater levels after 2000 (right side of the hydrograph) are lower than Malheur Lake and Harney Lake levels (which were 4098-feet amsl in 1983)

Slide 9: Pre-Groundwater Study Background (cont.)

- Let's next look at the Weaver Springs Vicinity
- The Weaver Springs Vicinity is at the star near the center of the study area (left inset map) and the lower left (southwest) portion of the zoomed-in map (right inset map)
- Groundwater development:
    - After the 1980s, there was significant groundwater development requested and authorized for the Weaver Springs vicinity
    - The green shapes on the right inset map show authorized groundwater use with priority (application) dates before 1990
    - The red shapes on the right inset map show authorized groundwater use with priority (application) dates 1990 and later
- Groundwater level measurements at Weaver Springs vicinity wells began showing a decline about the mid-1990s:
    - After 2000, OWRD measured groundwater levels at more Weaver Springs vicinity wells starting with 15 wells from 2008 to 2012 to assess the situation
    - The data in this graph shows the decline rate varies with location whereby the decline is greatest within the "heart" of the development and less at the development outskirts-periphery (spoiler alert…the smaller decline is due to distance and a change in geology)

Slide 10: Pre-Groundwater Study Background (cont.)

- Now let's jump to February 2014: OWRD received multiple protests, each protest addressed a different proposed final order (PFO) approving a new groundwater permit
- From Fall 2014 to Spring 2015: OWRD conducted a preliminary analysis comparing OWRD authorized use (volume) to annual groundwater recharge (volume):
    - A USGS review noted groundwater recharge estimates by Robison published in 1968
    - The OWRD analysis indicated authorized annual groundwater use exceeded annual groundwater recharge
    - The results of this 2014-2015 analysis as well as the observed groundwater level declines, and the limited geographic scope of previous studies made apparent the need for a comprehensive, basin-wide groundwater study
- Before moving to the next slide, I would like to note the following in table shown:
    - The values in the Groundwater discharge column implies groundwater discharge to surface water (including likely discharge to springs). The values were from the OWRD "Water Availability" tables (Cooper, 2002, 50% exceedance) during the lowest flow months (August-October)
    - The values in the Unaccounted difference column implies unaccounted natural groundwater discharge such as evaporation and plant transpiration (it does not imply groundwater available for use)
    - An earlier version of this table was adapted to create the bar graph frequently seen at previous presentations and used by Rep. Owens. The earlier table had a smaller volume for permitted groundwater (nearly 26,000 acre-feet less) due to pending data entry of water rights

Slide 11: Groundwater Study Chronology

- The chronology in this slide lists a number of events from 2015 to 2022 that directly or indirectly related to the Harney Basin Groundwater Study. The highlights are:
- 2015: OWRD begins increasing well network for groundwater level measurements in anticipation of a groundwater study
- 2016:
  - The Harney Basin Rules adopted in April 2016:
    - The rules create the Greater Harney Valley Groundwater Area of Concern (GHVGAC) and restricts issuance of any new groundwater permits;
    - The rules order a groundwater study and notes a completion date for reports (end of 2020)
    - The rules order the creation of a Harney Basin Study Advisory Committee (SAC) organized by the county court & OWRD (17 meetings were conducted from May 2016-December 2019)
  - The USGS-OWRD groundwater study plan was approved in December 2016
- 2017-2019:
  - Data collection and analyses were conducted during this period
  - Initial data interpretations were reported to the Harney Basin SAC in December 2019
- 2020: Was devoted to writing multiple reports and conducting initial report reviews
- 2021-2022: Focused on completing reviews and releasing 6 reports

Slide 12: Study and DEQ Water Chemistry Data

- Hank Johnson at the USGS led the study's water chemistry collection and data analyses
  - The chemistry data significantly informed our understanding of the basin's groundwater flow system
  - Samples came from wells, springs, and streams as well as Moon Reservoir, Malheur Maar, groundwater exposed in Malheur Cave, plant tissue, and soil water
  - Samples were analyzed for geochemical tracers: tritium, carbon-14, and stable isotopes
  - These tracers are useful for determining:
    - Groundwater recharge sources
    - Rate of water movement and residence time
    - Confirming and refining groundwater flowpaths
  - The USGS Hydrology report by Gingerich and others (2022) provides an excellent explanation of the tracers, how they are used, and the implication of the data results for understanding the groundwater system within different portions of the study area
  - Additionally, Hank gave a thorough presentation at the 30 May 2019 Harney Basin Study Advisory Committee meeting
- Additionally, DEQ conducted their own sampling and analyses independent of the USGS-OWRD study:
  - DEQ made their data and analyses available to study
  - The DEQ samples came from 91 wells
  - The samples were analyzed for multiple water quality parameters that can be divided into the major categories listed on this slide

Slide 13: Study Takeaway #1

- **Takeaway #1: Most Harney Basin groundwater is ancient**
- What does the chemistry tell us…
- The study water chemistry tells us most of the Harney Basin groundwater is ancient
  - Much of the deep upland groundwater and most of the lowland groundwater was recharged 5,000 to 30,000 years ago when conditions were cooler and wetter than today
  - Modern groundwater (recharge after 1953) is mostly limited to a thin shallow zone beneath recharge areas
- The DEQ results indicate:
  - 58% of the 91 wells samples had one or more contaminants posing a human health concern
  - 80% (78 wells) of the 91 wells sampled had arsenic detected with 31% (28 wells) of the 91 wells sampled had arsenic exceeding EPA maximum contaminant level
  - 93% (78 wells) of the 91 wells sampled had boron detected with 23 of the 91 wells exceeding the Long-Term Health Advisory Level for children and 6 of the 91 wells exceeding the Lifetime Health Advisory for adults

Slide 14: Study Groundwater Level Data

- The study's groundwater level data came from:
  - Study measurements at about 230 study located wells (most located in the lowlands)
  - Reported water right permit condition groundwater level measurements at about 200 wells (most located in the lowlands)
  - National Hydrologic Database locations for more than 2,500 springs (most located in the uplands)
  - Harney County Watershed Council groundwater level measurements (27 wells, not shown)
  - Temporary shallow borings (not shown)
- Groundwater level data used for:
  - Groundwater level maps used to determine groundwater flow direction (hydraulic gradient), recharge areas, discharge areas
  - Groundwater level graphs used to determine groundwater level trends, any vertical gradients, and groundwater response to stress (pumping, recharge, etc.)

Slide 15: Study Groundwater Level Maps

- A USGS-OWRD collaborative team led by Steve Gingerich worked multiple weeks to produce 2 groundwater level maps consistent with all available groundwater level and other data:
- A Water Table Map (the left map):
  - This map is an elevation contour map of the top of groundwater across the basin
  - The lowlands contour lines in the center of the basin are 10-ft contour intervals and are predominantly based upon shallow well related data (wells <150-ft total depth)
  - The uplands contour lines are 500-ft contour intervals and are predominantly based upon spring related data
- A Potentiometric Surface Map (the right map):
  - This map is an elevation contour map of the static groundwater levels representing groundwater at depth (groundwater below the water table)
  - The groundwater at depth is hydraulically connected to the groundwater at or near the water table
  - The contour lines in this map are limited to the lowlands only given the available data
  - The contour lines are 10-foot contour intervals, based upon data predominantly related to deeper wells (wells >150-ft total depth)

Slide 16: Groundwater Level Maps (Lowland)

- Now let's zoom in to both maps and take a closer look at the contours within the Lowlands:
- The first thing to note are cones of depression…a deep depression within a limited area
  - Note the solid line and dotted line circles and ovals
  - At Weaver Springs-Dog Mountain (solid line north of Harney Lake in both maps), the depression occurs in both shallow and deep groundwater
  - At Crane (solid line east of Malheur Lake in both maps), the depression again occurs in both shallow and deep groundwater
  - At north Harney Valley (solid line north of Hwy 20 east of Burns in the potentiometric map) the depression occurs in the deep groundwater, not the shallow groundwater
  - Then there are Isolated depressions (enclosed by dotted line in the potentiometric map): these isolated depressions occur in the deep groundwater, not shallow groundwater
- The second thing to note are Flat gradient areas:
  - At Virginia Valley (dashed line southeast of Malheur Lake in the water table map): a flat gradient occurs in shallow groundwater and there is a gradual area-wide decline
  - At the Silver Creek drainage (dashed line on the left side of the potentiometric map): a flat gradient occurs in the deep groundwater and there is a gradual area-wide decline
- So why?
  - Why is there a Flat gradient in some areas and a cone of depression-steeper gradient in other areas?
  - Why is a cone of depression shallow and deep in some areas and deep only in other areas?

Slide 17: Groundwater Level Graphs (Lowland)

- Now let's look at some groundwater level graphs representing different lowland areas
- These two graphs represent 2 different locations within the Weaver Springs-Dog Mountain cone of depression…each graph represent the groundwater level at closely spaced well pairs constructed for the study (a shallow well and a deep well for each well pair)
- At the Weaver Springs well pair:
  - The shallow well (HARN 52630) total depth is 191 ft.
  - The deep well (HARN 52631) total depth is 490 ft.
  - Note the shallow and deep groundwater level decline rates are similar (~8 ft./yr.)
  - Also note the shallow and deep seasonal groundwater level fluctuations are similar, and
  - The shallow and deep groundwater levels are within 5 ft.
  - The shallow level is above the deeper level indicating a downward gradient
- At the Dog Mountain well pair:
  - This well pair is located 8.1 miles north of Weaver Springs well pair
  - The deep well (HARN 52606) total depth is 510 ft., and
  - The shallow well (HARN 52629) total depth is 105 ft.
  - Note the shallow and deep groundwater level decline rates differ
  - Also note the shallow and deep seasonal groundwater level fluctuations differ, and
  - The shallow and deep groundwater levels are ~15 ft. apart
  - The deep level is above the shallow level indicating an upward gradient
- So why?
  - Why are the Weaver Springs and Dog Mountain hydrographs different?
  - The well pairs are only 8.1 miles apart

Slide 18: Groundwater Level Graphs (Lowland)…cont.

- Now let's look at the groundwater levels at a triple set of wells north of the EOARC (Eastern Oregon Agricultural Research Center, Burns) headquarters:
  - The well site is about 6.3 miles north of the Dog Mountain well pair
  - There is no cone of depression, but the contour lines are closer together indicating a steeper gradient
  - The deep well (HARN 52747) total depth is 543 ft.
  - The shallow well (HARN 52749) total depth is 22 ft., and
  - The intermediate well (HARN 52748) total depth is 125 ft.
  - The shallow to deep groundwater level decline rates are somewhat similar (~1 to 2 ft./yr.)
  - The shallow to deep seasonal fluctuations have similarities and differences
    - Shallow and deep seasonal fluctuations are smoother than the intermediate
    - Deep seasonal fluctuations have a smaller amplitude than the shallow and intermediate
  - The shallow to deep groundwater levels are within 5 ft.
  - Note the vertical gradient is toward the intermediate groundwater (downward gradient from above and upward gradient from below) given the shallow and deep groundwater levels are most often above the intermediate groundwater levels
- So why?
  - Why is there a dual vertical gradient?
  - Why is the amplitude of the deeper groundwater seasonal fluctuation smaller than the shallow and intermediate? groundwater seasonal fluctuations?

Slide 19: Groundwater Level Graphs (Lowland)…cont.

- Now let's look at a shallow and deep well pair near Lawen and at 2 nearby wells in the Crane vicinity
- The Lawen vicinity and the Crane vicinity are within different cones of depression
- First, the Lawen well pair:
  - The shallow well (HARN 52234) total depth is 76 ft.
  - The deep well (HARN 52235) total depth is 496 ft.
  - The shallow and deep groundwater level decline rates are very different…the shallow level is relatively steady, whereas the deep level has a decline rate of about 2.3 ft./yr.
  - The shallow and deep seasonal fluctuations are very different (about 1 ft. vs. more than 40 ft.)
  - The shallow and deep groundwater level difference is increasing with time (increasing downward gradient)
- Next, the Crane vicinity nearby wells:
  - The shallow well (HARN 1245) total depth is 130 ft.
  - The deep well (HARN 52050) total depth is 600 ft.
  - These 2 wells are about 6.7 miles apart
  - The shallow and deep annual groundwater level decline rates differ (~1 ft. vs. ~2.5ft)
  - The shallow and deep seasonal groundwater level fluctuations are very different (about 1 to 5 ft. vs. more than 80 ft)
  - The shallow and deep groundwater levels before each irrigation season are similar (within 5 ft.?)
- So why?
  - Why is there large seasonal fluctuation in deep groundwater and muted to no seasonal fluctuation in shallow groundwater?
  - Why does shallow groundwater shows no or minimal annual decline at Lawen and a persistent steady decline in the Crane vicinity?

Slide 20: Groundwater Level Graphs (Lowland)…cont.

- Now let's look at 2 nearby wells in Bitzen Valley near Malheur Lake and at a shallow and deep well pair in Virginia Valley
- These wells are at the west and east ends of a flat gradient area south of Malheur Lake
- First the nearby wells in the Blitzen Valley near Malheur Lake (USFWS MNWR):
  - The shallow well (HARN 1360) total depth is 147 ft.
  - The deep well (HARN 1467) total depth is 500 ft.
  - The wells are about 2.1 miles apart
  - The shallow and deep annual decline rates are the same (~1.3 ft./yr.)
  - The shallow and deep seasonal fluctuations are the same (< 2.0 ft.)
  - The shallow and deep groundwater levels are essentially the same (no vertical gradient)
- Next, the Virginia Valley well pair:
  - The shallow well (HARN 52608) total depth is 145 ft.
  - The deep well (HARN 52607) total depth is 371 ft.
  - This well pair is more than 19 miles east of the Blitzen Valley wells
  - The shallow and deep annual decline rate are the same (~0.5 ft./yr.)
  - The shallow and deep seasonal fluctuations are the same (<3.5 ft.)
  - The shallow and deep groundwater levels are the same (no vertical gradient)
- So why?
  - Why are the shallow and deep groundwater levels, annual decline, and seasonal fluctuation locally the same?
  - Why do the shallow and deep groundwater levels, annual decline, and seasonal fluctuation differ with location?

Slide 21: Groundwater Level Graphs (Lowland)…cont.

- Lowland groundwater level graphs: Flat gradient area
- Lastly, let's look at 3 dispersed wells near Riley in the Silver Creek Valley:
  - The south deep well (HARN 52717) total depth is 425 ft. and is 3.3 miles south of Riley junction
  - The south shallow well (HARN 754) total depth is 75 ft. and is 3.8 miles southeast of Riley junction and about 1.7 miles east of the south deep well
  - The north deep well (HARN 52102) total depth is 595 ft. and is 3.9 miles northwest of Riley junction and about 7.2 miles northwest of the south deep well
  - The annual decline rates are generally similar (~0.4 to 0.7 ft./yr.)
  - The seasonal fluctuations are generally similar, ranging from 2 to 4 ft.
  - The groundwater levels are generally within 5 ft.
  - The vertical gradient is downward
- So, why?
  - Why such similarity over a large area?

Slide 22: Study Needed to Answer…Why?

- So, the study needed to answer why:
- Regarding cones of depression and flat gradient areas:
  - Why are there cones of depression in some areas and flat gradient in other areas?
  - Why are cones of depression shallow & deep in some areas and just deep in other areas?
- Regarding shallow and deep groundwater level trends, both seasonal & annual:
  - Why are the seasonal and annual trends the same & close in some areas?
  - Why do the trends in some areas show different seasonal amplitude but the same annual decline?
  - Why do the trends in some areas show different seasonal amplitude & different annual decline?
- Answering why required exploring the hydraulic property relationship to geology & GW development

Slide 23: Study Area Geology

- Geology controls groundwater occurrence, recharge, flow, storage, and discharge
- Over multiple decades, the geology of the basin has been studied and mapped at various scales by state and federal agencies and university researchers.
  - These studies identified a complex sequence of interfingering and faulted volcanic deposits and sedimentary deposits from various sources that rest, at least in part, upon a basement of older rocks. The numerous eruptive centers and fissures appear as red dots, circles, and lines on the tectonic map.
  - Most of the rocks are less than 16-million years as displayed on the time chart.
  - The oldest rocks are marine deposits, more than 145-million years, and is the lone unit near the bottom of the time chart.
    - These rocks are exposed in the northern uplands within the shaded area near the top of the tectonic map.
    - These rocks are presumed to be the basement underlying most of the basin occurring at depths below the bottom of 1513 to 8480-feet deep oil exploration wells in Harney Valley
- For this study, Darrick Boschmann (2021) developed a seamless and consistent geologic map for the entire Harney Basin compiled from 15 maps (1956 to 2001) with the aid of available rock age dating and/or geochemical analyses, elevation data, high resolution aerial imagery, new detailed geologic mapping by DOGAMI and PSU, and field reconnaissance by Darrick.
  - More than 100 unique geologic map unit names in the 15 maps were grouped into 18 geologic map units for the Harney Basin geologic map based upon similar geologic origins, physical properties, and stratigraphic position.
  - Darrick used the 18 geologic units to interpret subsurface materials reported by well drillers at more than 1,100 wells within the basin.
- Before leaving this slide, I would like to draw your attention to two things on the tectonic map:
  - First is the NW trending Brothers Fault Zone that extends from Steens Mountain through the SW portion of the study area (note on tectonic map)
  - Second is the blue shaded area on the tectonic map that shows the maximum extent of paleo Lake Malheur

Slide 24: Geology and Groundwater Flow

- Now let's connect geology to groundwater flow…**Keep it simple Jerry!!**
- To do that, we visit Henry Darcy, an Engineer in Dijon, France
    - Darcy was studying the flow of water through sand…he needed to engineer a sand filter for the city water supply
    - He noted the volumetric flow rate of water through the sand was directly proportional to
        - The change in water level across the length of the filter (hydraulic gradient), and
        - The cross-sectional area of the filter
    - He developed the flow equation now called "Darcy's Law"
    - Hydraulic conductivity (K) is the proportionality constant
- The Darcy's Law equation is the basic governing equation for groundwater flow
- The Darcy's Law equation is essentially the water (fluid) version of the Ohm's Law equation for electricity ($I = V/R$)
    - Different wires (gage and material) have different resistances that directly affect the rate of electric flow
    - Different geologic deposits have different hydraulic conductivity that directly affect the rate of water flow
- Transmissivity is related to hydraulic conductivity ($T = Kb$ = hydraulic conductivity times the cross-sectional area height) and is often used to indicate the flow properties of geologic deposits. It is used in this presentation.

Slide 25: Geology and Groundwater Drawdown

- So, how do we determine local transmissivity:
- Aquifer tests (also called pump tests) is the first, preferred method
    - Turn on a single well and monitor the groundwater level drawdown (cone of depression development) during pumping and the groundwater level recovery (cone dissipation) during shutoff
        - During the test, we monitor (measure) the water level over time within the pumped well and hopefully at nearby well(s) (observation wells)
        - Measurement data for each well will yield a time-drawdown-recovery graph
    - Theis in 1935 published an equation used to determine two things from the drawdown data:
        - Transmissivity
        - Storage Coefficient (an indicator of how groundwater is stored and released at the wells measured …from actual filling & drainage to pressure compaction & release)
    - Cooper-Jacob (1946) found the Theis equation can be simplified when certain conditions are met…this is the better equation to use for the pumped well data
    - I should note that it is best to determine the storage coefficient from the nearby well (observation well) data rather than the pumped well data
- Well yield tests (specific capacity tests) is a second method for determining transmissivity
    - Measurement occurs at the pumped well only…typically two measurements only
        - Measure the water level just before pumping
        - Measure the water level just before pump shutoff
    - The measurements and pumping rate are used to calculate a specific capacity…total drawdown divided by the pumping rate
    - This study used a Theis equation based numerical method by Vorhis (1979) to convert the specific capacity to a transmissivity

Slide 26: Transmissivity Data Sources

- Transmissivity data sources for the Harney Basin study include
- 33 aquifer tests:
  - 1 interference test conducted by OWRD (a pumping well & 2 observation wells)
  - 2 wells with OWRD recorders installed located near irrigation wells, and
  - 41 single well pump tests submitted to OWRD
- 1,451 driller reported well yield tests (specific capacity):
  - 1,161 within the Harney Basin
  - 290 in area surrounding the Harney Basin

Slide 27: Transmissivity Data Calculations

- Different methods were used to calculate Transmissivity depending upon the data source type
- For Aquifer tests, a graphical method was used :
  - For all the aquifer tests: the Jacob-Cooper semi-log plot method was used (upper left graph)
  - For tests with observation wells: the Theis log-log curve match method was additionally used
  - The results from recorder data were tested by matching hydrograph for the 2 recorder wells
    - The red line is the actual May through October 2018 data
    - The blue line is the calculated hydrograph that assumes only the closest well is pumping and only the longer duration pumping and shutoff events are represented.
  - The method and the results are presented in the appendices in Grondin (2021)
- For the Well yield tests:
  - The Vorhis (1979) iterative numerical method based upon the Theis equation was used
  - The method and the results are presented in the appendices in Grondin (2021)

Slide 28: Calculated Transmissivity Range

- The range of transmissivity values calculated is large, 6-orders of magnitude (from 1 to 1-million ft^2/day)
- The median value (circle) is about 1,000 ft^2/day (half the values are larger and half are smaller)
- 90% of the values calculated are less than 13,000 ft^2/day
- The multi-colored curved line representing transmissivity determined from aquifer test data (generally data from irrigation wells) show slightly larger transmissivity than the green curved line representing transmissivity determined from well yield test data…this is not surprising given wells selected for irrigation are often higher production and yield
- However, for wells where there is both aquifer test data and well yield test data…
  - The transmissivity calculated from the well yield test data for a given well is generally larger than the transmissivity calculated from aquifer test data for the same well (the dots above the diagonal line in the right graph)
  - This may be due to the well yield test occurring when the well is young and fresh and the aquifer test occurring after the well has been used and has degraded (lost some efficiency)

Slide 29: Transmissivity Spatial Distribution

- This slide shows the spatial distribution of the transmissivity values calculated
- The smaller transmissivity values occur across the entire basin, even among larger values (left map)
- The larger transmissivity value locations are more limited
- The largest transmissivity values are shown in the right map. They occur…
    - Along the periphery of Harney Valley
    - Within the upper Silver Creek floodplain near Riley
    - Within the Weaver Springs-Dog Mountain vicinity
    - South of Malheur Lake to Virginia Valley
    - The distribution gets even more segregated for different well depths (>150 ft vs. <150 ft)
- The important point here is the transmissivity spatial distribution is heterogeneous (mixed) which is important to understanding the groundwater system response to development

Slide 30: Transmissivity Tied to Geologic Units

- The study explored tying the transmissivity values to the stratigraphic (geologic) units
- The first step was identifying stratigraphic units for as many wells as possible:
    - Driller descriptions on well reports (well logs) for 2,242 wells were converted to one or more lithology code per well
    - Then each lithology code for 1,495 of the 2,242 wells were related to a stratigraphic unit
- The second step was assigning a well's transmissivity to a single stratigraphic (geologic) unit
    - The assignment occurred only if a single unit occupies 90% of well's open interval
    - The study used the well's total open interval

Slide 31: Stratigraphic to Hydrostratigraphic Units

- The study was successful tying the transmissivity values to the 18 stratigraphic units
    - It yielded a range of values per stratigraphic unit as shown in the left graph…
    - The stratigraphic units are arranged from the largest transmissivity values and value median at the top to the lowest values and value median at the bottom
- The 18 stratigraphic units were then grouped into 9 hydrostratigraphic units (right graph) based upon:
    - Similar geologic properties
    - Similar hydraulic (transmissivity) properties
- Largest median values:
    - Generally younger units
    - Younger volcanic deposits
    - Deposits with secondary permeability
- Intermediate median values:
    - Silicic lava flows and domes
    - High Lava Plains basalt
    - Basin-fill sediments
- Smallest median values:
    - Generally older units
    - Upland volcanic rocks
    - Marine sedimentary rocks

Slide 32: Stratigraphic to Hydrostratigraphic Units (cont.)

- The successful correlation of transmissivity to stratigraphic units and the successful grouping in hydrostratigraphic units informed other parts of the study:
  - Determination of hydrostratigraphic units
  - Groundwater flow within the basin
  - Groundwater response to pumping
  - Water budget within the basin

Slide 33: Study Takeaway # 2

- **Study Takeaway #2: <u>Hydrostratigraphy is a major key to understanding Harney Basin groundwater</u>**
- Hydrostratigraphy & related transmissivity informs:
  - The understanding of groundwater flow within the basin (flat gradient vs. steeper gradient areas)
  - The understanding of groundwater response to pumping (cones of depression vs. area-wide decline)
    - The effects of pumping vary across the basin depending on the local geology, the amount of recharge, and the amount of withdrawal
    - Pumping large volumes of groundwater from low-transmissivity (low permeability) rocks causes deep drawdown over relatively small areas
    - Pumping large volumes of groundwater from high-transmissivity (high permeability) rocks causes shallow drawdown over large areas
  - The understanding of the water budget within the basin (controls on recharge and discharge)

Slide 34: Hydrostratigraphy: Weaver Springs

- So, let's look at 5 locations
- First stop is Weaver Springs:
- Here we have vent deposits (large transmissivity) occurring both shallow and deep
- Those vent deposits are enclosed by low permeability deposits
- The groundwater response to pumping is efficient laterally & vertically within vent deposits
- However, the surrounding low transmissivity deposits yield water slowly to vent deposits
- As a result, a significant cone depression (both shallow & deep) occurs in the vent deposits that spreads more slowly into the low transmissivity deposits

Slide 35: Hydrostratigraphy: North Harney Valley

- Second stop is north Harney Valley
- The area is dominated with younger and older basin fill
- The local basin fill deposits are generally coalescing alluvial fans related to multiple streams entering the lowlands from the uplands
  - Coarser grained (higher transmissivity) deposits occur near the uplands
  - Smaller grained (lower transmissivity) deposits occur away from the uplands
- Mostly deeper groundwater in the area was developed
  - A cone of depression developed, but within the deeper groundwater only
  - The shallow (water table) groundwater response is muted…the shallow groundwater levels generally stay within 5 to 20 feet below land surface

Slide 36: Hydrostratigraphy: Crane Vicinity

- Third stop is the Crane Vicinity
- The area is dominated with younger and older basin fill
  - Coarser grained (higher transmissivity) deposits near the Stinkwater uplands…most local development is within these deposits
  - Smaller grained (lower transmissivity) deposits away from the uplands
- There is a relatively small island of vent deposits at Warm Springs Butte (some development along the margins of these deposits)
- An extensive cone of depression (shallow and deep) has developed near the Stinkwater uplands
- Less extensive cones of depression (primarily deep) are developing away from the Stinkwater uplands

Slide 37: Hydrostratigraphy: Silver Creek

- Fourth stop is the Silver Creek floodplain above and below Riley from ~Mayo Ranch to ~Moon Reservoir
- The area has an extensive large transmissivity zone that occurs deep only (hatched zone in the figure)
  - The large transmissivity zone include multiple stratigraphic units including some that are generally lower transmissivity
  - It appears something happened after the units were deposited, such as the development of the Brothers Fault Zone, causing secondary permeability resulting in larger transmissivity
  - Groundwater development is mostly within the extensive large transmissivity zone resulting in:
    - Near uniform seasonal fluctuations within the deeper groundwater over a broad area
    - Near annual groundwater level decline within the deeper groundwater over a broad area
- Lower transmissivity (Younger Basin Fill) overlies (blankets) the deeper large transmissivity deposits
  - The water table is generally within a few tens of feet of land surface
  - The shallow groundwater response to deeper pumping is often muted

Slide 38: Hydrostratigraphy: North Uplands

- Fifth and final stop for this presentation is the north Uplands
- The upland deposits are generally low transmissivity
- Consequently:
  - Most groundwater recharge (~83%) travels short flowpaths to become upland spring discharge or upland stream baseflow
  - The remaining recharge (~17%) travels thousands of years directly to the lowlands

Slide 39: Study Takeaway #3

- **Study Takeaway #3: Harney Basin groundwater is a single, hydraulically connected system, a continuum**
- Groundwater generally flows toward Harney and Malheur Lakes from the surrounding uplands
- Groundwater from land surface to depth is hydraulically connected even when static water levels and water level trends differ
- Groundwater from location to location is hydraulically connected even when groundwater source and flowpaths differ
- Hydrostratigraphy is the predominant control on groundwater flow and response to development
- Water chemistry data supports this finding. Chemical changes with depth and/or location have logical explanations including but not limited to mixing and chemical processes

Slide 40: Groundwater Budget Concepts

- Now let's consider groundwater budgets beginning with concepts:
- During pre-development, there is a dynamic equilibrium where inflow = outflow
- Natural inflow to groundwater includes:
  - Precipitation
  - Surface water loss to subsurface
  - Groundwater inflow from a neighboring area
- Natural groundwater outflow includes:
  - Groundwater outflow to surface water
  - Evaporation
  - Plant transpiration
  - Groundwater outflow to a neighboring area
- Groundwater levels are steady long-term but can have short-term variability
- "Stored" water is not static but moves from where inflow occurs to where outflow occurs similar to water moving through a lake or reservoir

Slide 41: Groundwater Budget Concepts (cont.)

- Groundwater budget concepts: Post-development
- During post-developed, engineered withdrawals are added to the groundwater system, primarily wells.
- Water removed by wells is often at the expense of the "stored" water component and/or the natural discharge component of the groundwater system. This is reflected over the long-term by lower groundwater levels and decreased discharge to streams, springs, lakes, and vegetation
- If development is within the capacity of the groundwater resource, a new equilibrium is established where the average annual water "gained" and "lost" balances, but a smaller volume of "stored" water is maintained. This is reflected by a stable lower groundwater level and less water discharging naturally from the system.
- If development exceeds the capacity of the groundwater resource, the average annual water "gained" and "lost" does not balance. The imbalance is at the expense of the "stored" groundwater component which shrinks over time (reflected by groundwater level declines over the long-term) and at the expense of the natural discharge component which shrinks and may stop over the long-term. Exceeding the capacity of the groundwater resource can cause long-term injury to existing groundwater and surface water rights and to the local groundwater and surface water resource.
- Note: "capacity of the groundwater resource" is used here in the sense of describing the ability to balance inflows and outflows without continuous depletion of storage, as opposed to the similar statutory term defined in OAR 690-400-0010(4)

Slide 42: Harney Basin Water Budget Data Sources

- The Harney Basin Water Budget Data Sources included: climate data from multiple sources; soil data; land cover data; satellite imagery; published, unpublished and/or study conducted flow measurements; study conducted water and plant chemistry sampling and analyses; OWRD water right data; Oregon Health Authority community (public facility) water system data; OWRD well construction data; reported groundwater pumpage data submitted to OWRD; and published indexes for various water uses from multiple sources.
- The water budget details and results are presented in:
    - Garcia and others (2022): the entire water budget in detail
    - Gingerich and others (2022a): the entire water budget in summary
    - Beamer and Hoskinson (2021): the irrigation usage in detail, and
    - Grondin (2021): the non-irrigation usage in detail

Slide 43: Harney Basin Upland GW Budget

- Let's first look at the upland water budget, namely upland Recharge and Discharge:
- Upland groundwater flow paths are shallow and limited by low permeability
    - As a result, most upland recharge travels relatively short distances in the subsurface and then discharges nearby
    - This groundwater discharge is the primary source of flow in upland streams, springs, wetlands, and meadows during the dry summer months
- About 17 percent of the recharge stays in the subsurface and flows to the lowlands
- The Uplands are closest to near natural conditions
    - There is limited groundwater development, and
    - total recharge and total discharge are essentially equal

Slide 44: Harney Basin Lowland GW Recharge

- Now let's move to the lowlands and look at Lowland Groundwater Recharge:
- Total lowland recharge is about 173,000 acre-feet per year
    - About 68 percent of the lowland recharge is from infiltration of surface water that mostly originated in the uplands as upland runoff and upland groundwater discharge to upland surface water. The infiltration in the lowland occurs via
        - Stream channel seepage
        - Floodwater seepage
        - Lake seepage
        - Surface water sourced irrigation seepage
    - About 28 percent of the lowland recharge is from groundwater inflow from the uplands
    - About 5 percent of the lowland recharge is from infiltration of pumped groundwater
        - Groundwater sourced irrigation seepage
        - Groundwater sourced non-irrigation seepage (septic systems, etc.)

Slide 45: Harney Basin Lowland GW Discharge

- The next consideration is Lowland Groundwater Discharge:
- Total lowland discharge is about 283,000 acre-feet per year
  - About 45-percent of the lowland groundwater discharge occurs via evapotranspiration and spring discharge
  - About 54-percent of the lowland groundwater discharge occurs via groundwater pumpage:
    - The mean annual GW pumpage for 2017-2018 for irrigation was about 145,000 acre-feet, which accounts for more than 95% of all GW pumpage and has increased ~3x since early 1990s
    - Non-irrigaton pumpage accounts for nearly 5% of all GW pumpage
  - About 1-percent of the lowland groundwater discharge occurs via groundwater flow to the Malheur River Basin
- The Total Lowland Recharge minus the Total Lowland Discharge yields…
  - A Total imbalance (deficit) of about – 110,000 acre-feet per year
  - Pumpage is removing groundwater from aquifer storage and is likely capturing a small amount of natural discharge
  - The largest budget deficit is in the northern region where pumpage exceeds recharge

Slide 46: Harney Basin GW Pumpage

- Let's take a closer look at groundwater pumpage from 1930 to 2018
- This graph shows groundwater pumpage estimated for the GHVGAC area:
- Groundwater pumpage for non-irrigation uses dominated from the 1930s to 1950s but total pumpage was less than 20,000 ac-ft/yr
- Groundwater pumpage for irrigation uses dominated after 1980

Slide 47: Harney Basin GW Pumpage (cont.)

- This graph shows groundwater pumpage estimated for the entire GW Model area which includes areas outside the study area:
- The current entire model area pumpage total difference from GHVGAC area pumpage total is less than 20,000 ac-ft

Slide 48: Study Takeaway #4

- **Study Takeaway #4: Harney Basin Groundwater Budget Balances in the Uplands and Does Not Balance in the Lowlands**
- The Upland groundwater budget:
  - Is minimally affected by groundwater development
  - Generally represents the natural system
- The Lowland groundwater budget:
  - Accounts for most groundwater development
  - Is out of balance by about -110,000 acre-feet/year
  - The imbalance is primarily seen as groundwater removed from storage accompanied by declining groundwater levels
  - Capture of a small amount of natural discharge is likely
  - The largest deficit is in the north region where pumpage exceeds recharge

Slide 49: Key Takeaways

- Repeating the study's four key takeaways:
  1. Most Harney Basin groundwater is ancient (recharged 5,000 to 30,000 years ago); modern groundwater (recharged after 1953) is limited to a thin, shallow zone beneath recharge areas
  2. Geology (hydrostratigraphy) is a major key to understanding Harney Basin groundwater and finding solutions to groundwater problems
  3. Harney Basin groundwater is a single, hydraulically connected groundwater flow system, a continuum vertically and laterally. No impermeable barriers to groundwater flow are known to exist. Having said that, there are many significant variations that relate to the various geologic (hydrostratigraphic) units and their hydraulic properties
  4. Harney Basin groundwater budget balances in the Uplands; it does not balance in the Lowlands where there is a deficit of 110,000 acre-feet/year…110,000 acre-feet is enough water to cover nearly 172 square miles with one-foot of water or to stack water more than 15.75 miles high on a single football field (about twice as high as most airlines fly)

Slide 50: Closing Slide

- Thank You!
- I look forward to your questions when we meet live online on 27 July 2027

Slide 51: References

Slide 52: References (cont.)