Harney Basin Groundwater Study Summary

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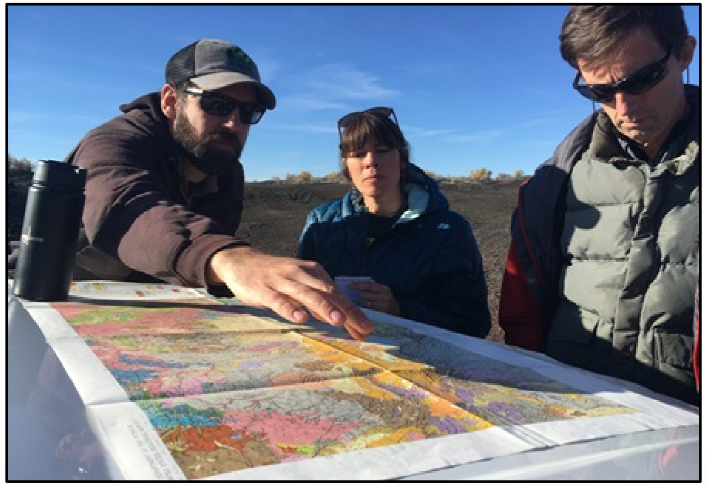

Jerry Grondin, OWRD Hydrogeologist

OAR 690-512 Rule Advisory Committee

Information Session

27 July 2023

Presentation Outline

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
7. References

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Groundwater Study Key Takeaways

Key Takeaways

1. Most Harney Basin groundwater is ancient (recharged 5,000 to 30,000 years ago), and modern groundwater (recharged after 1953) is limited to a thin, shallow zone beneath recharge areas

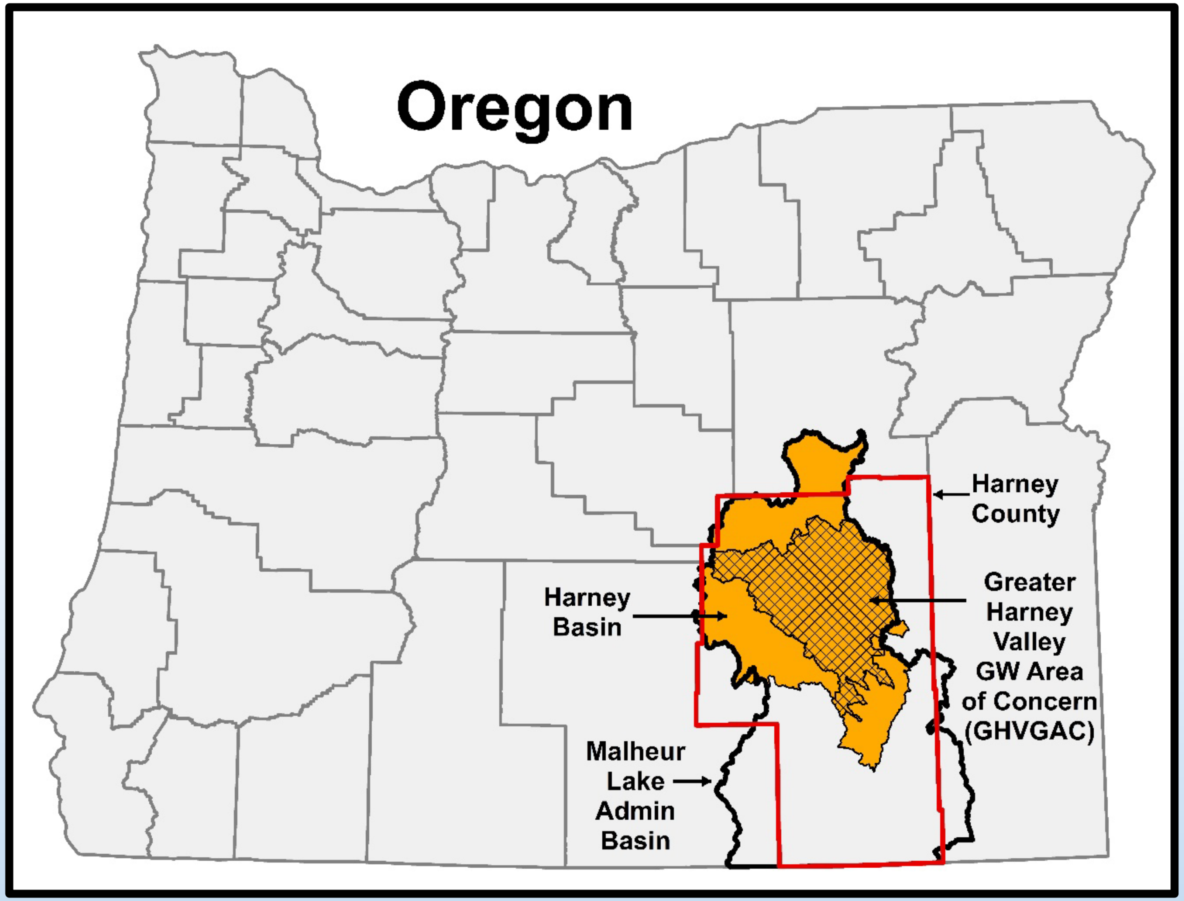
2. Geology (hydrostratigraphy) is a major key to understanding Harney Basin groundwater and finding solutions to groundwater problems

3. Harney Basin groundwater is a single, hydraulically connected system, a continuum

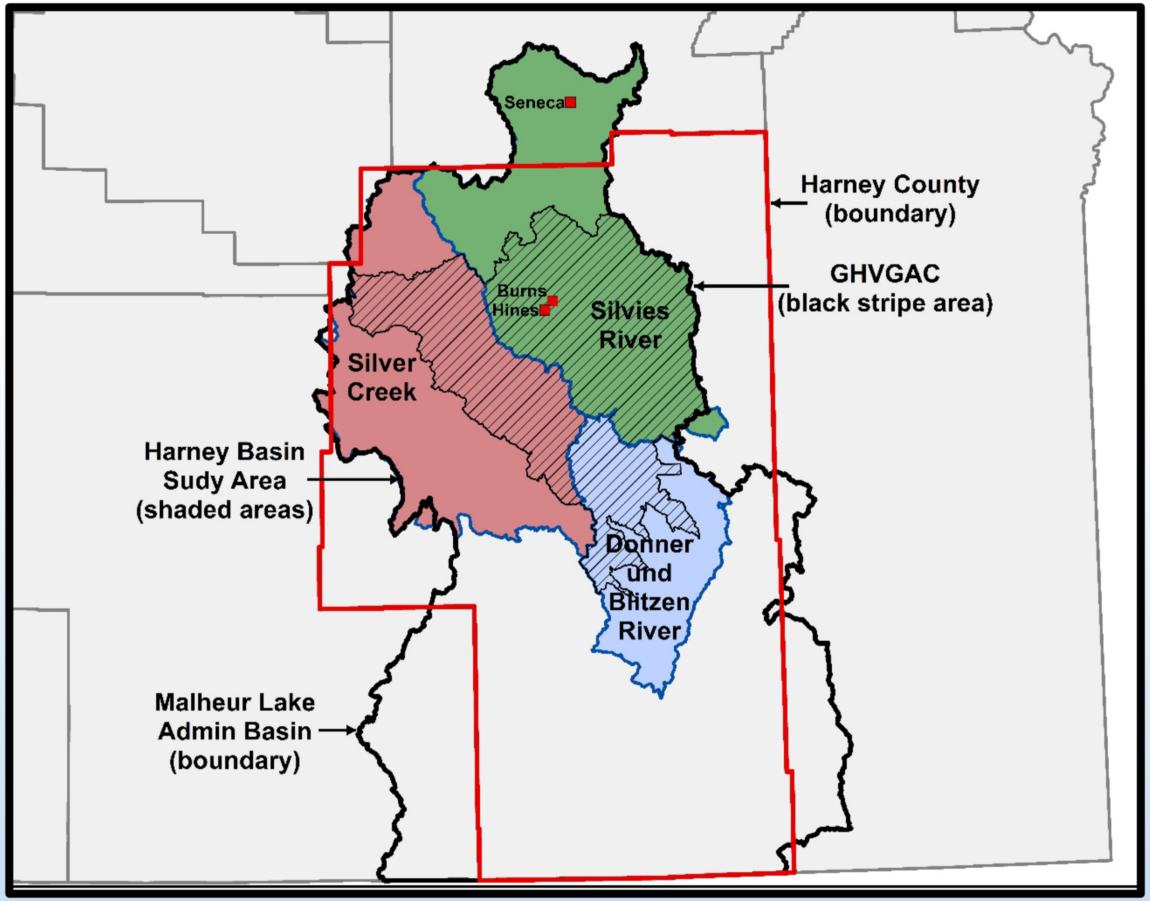
4. Harney Basin groundwater budget balances in the uplands; it does not balance in the lowlands (deficit of 110,000 acre-feet/year)

Groundwater Study Area

Harney Basin Groundwater Study Area
5,243 mile^2

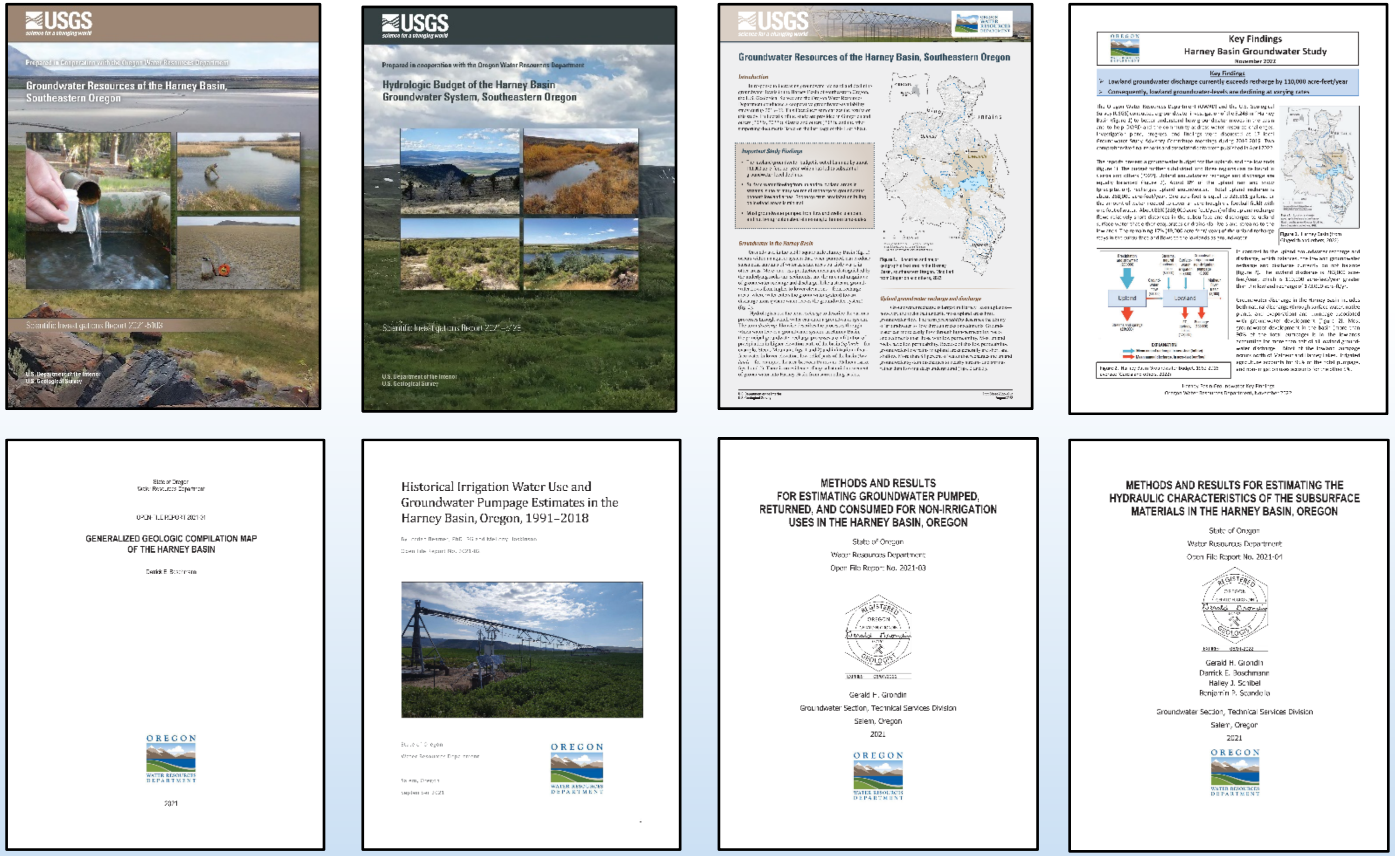


Harney Basin Watersheds
Oregon Water Resources Board (1967)

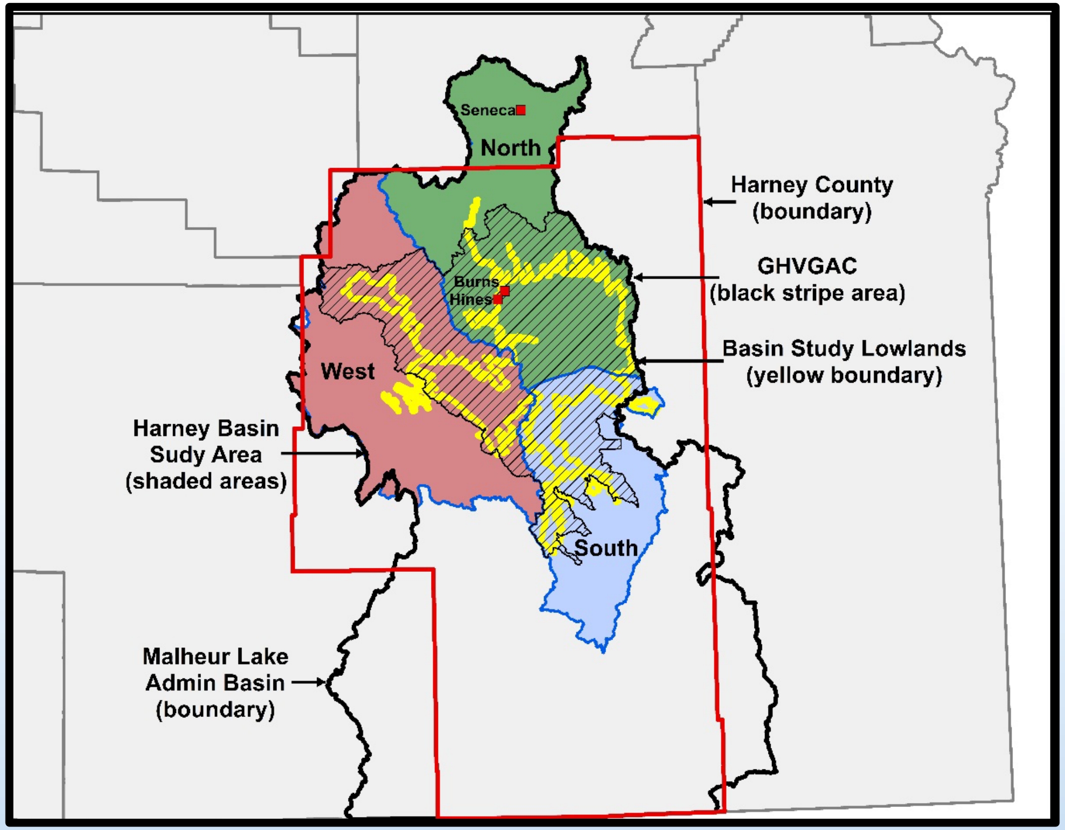


Groundwater Study Reports

Groundwater Reports (6) & Fact Sheets (2) Published 2021-2022



Harney Basin Groundwater Study Area Water Budget Regions & Lowlands



Work in Progress: USGS Groundwater Model & Reports

Groundwater Study Authors

U.S. Geological Survey

Steve Gingerich
Amanda Garcia
Hank Johnson
Nick Corson-Dosch
Brandon Overstreet
Jonathan Haynes

Oregon Water Resources Department

Jerry Grondin
Darrick Boschmann
Jordan Beamer
Mellony Hoskinson
Halley Schibel
Ben Scandella

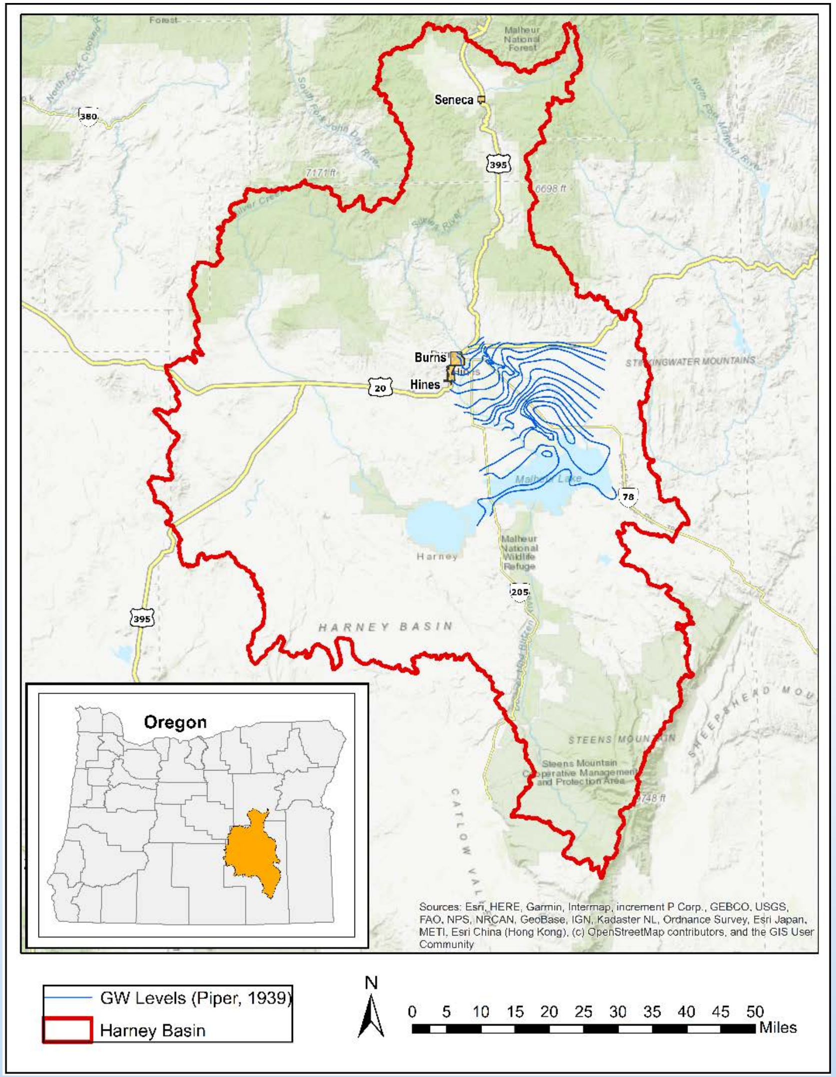
Previous Hydrologic Studies

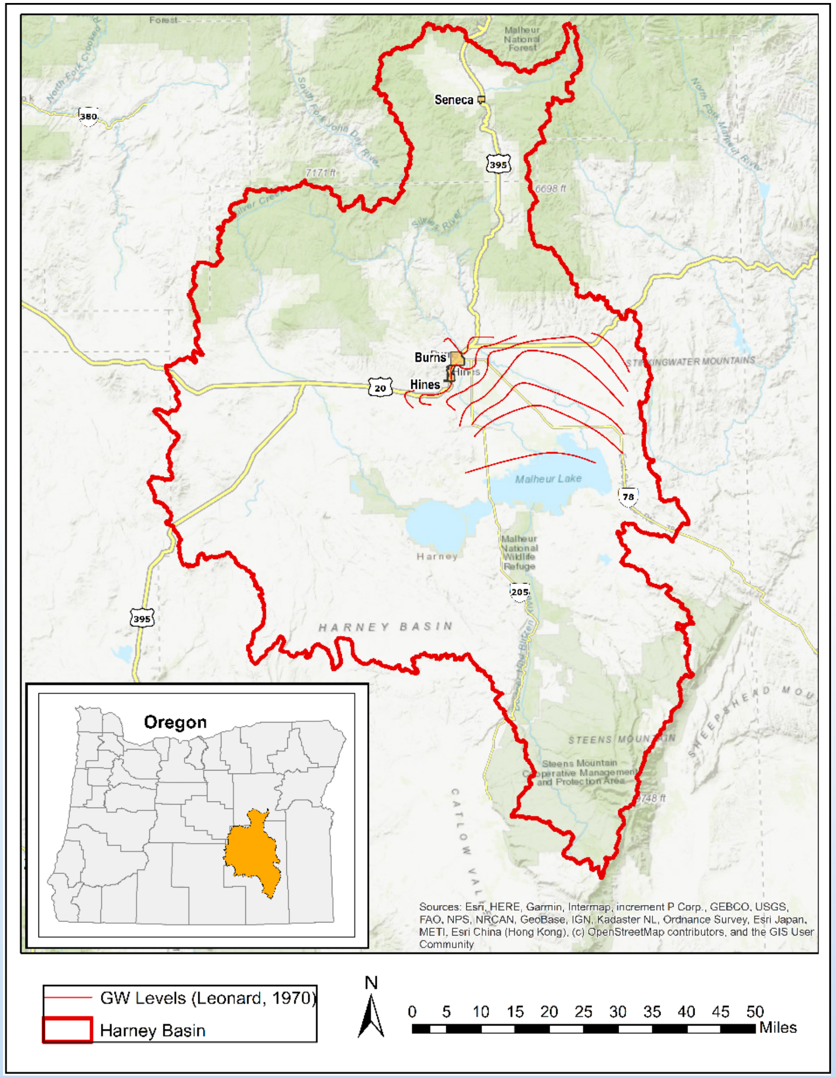
Groundwater

Piper, Robinson, & Park (1939) (blue contours) & Leonard (1970) (red contours)

Malheur Lake

Hubbard (1975) (not shown)

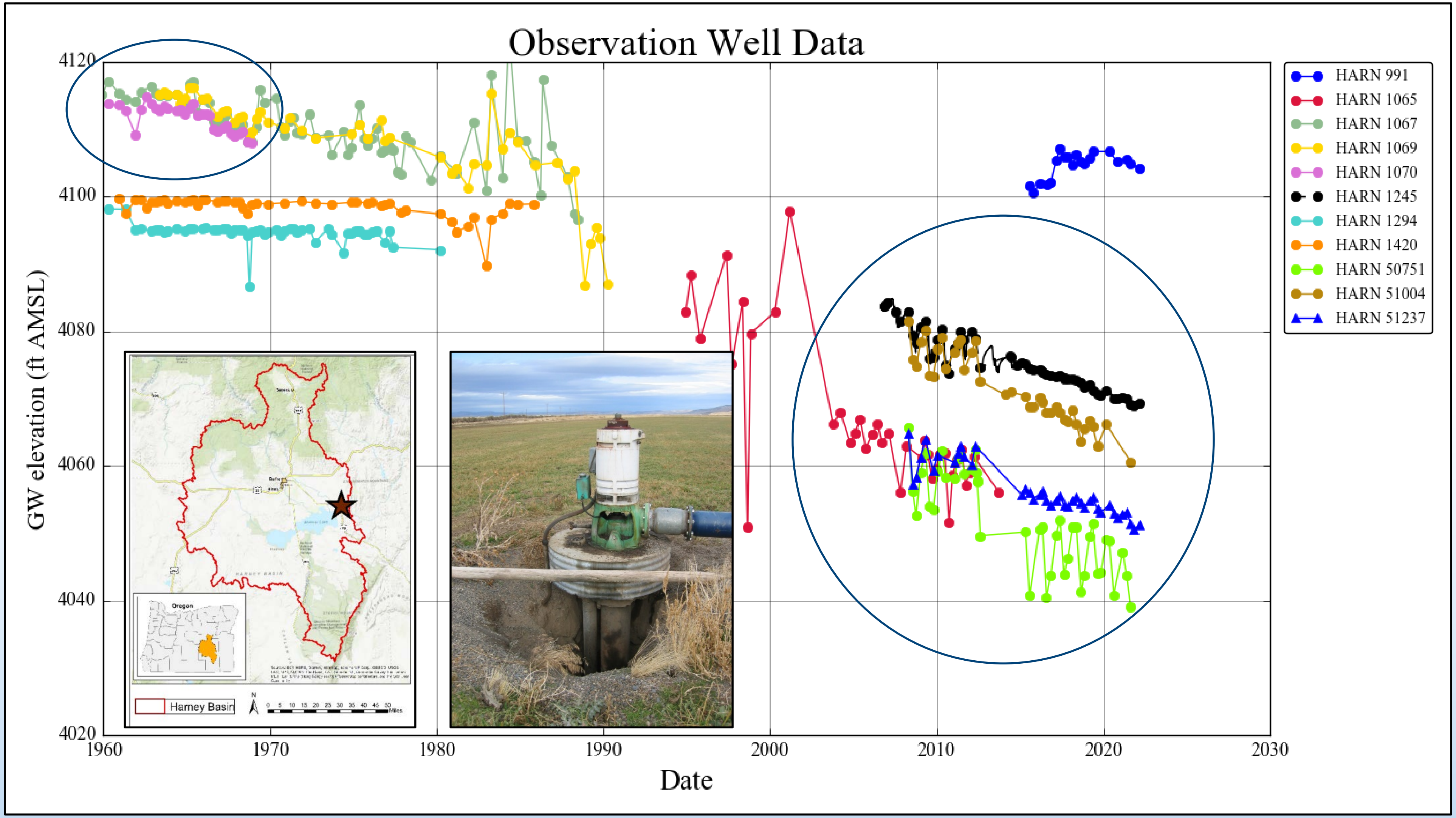




Pre-Groundwater Study Background

Crane Vicinity

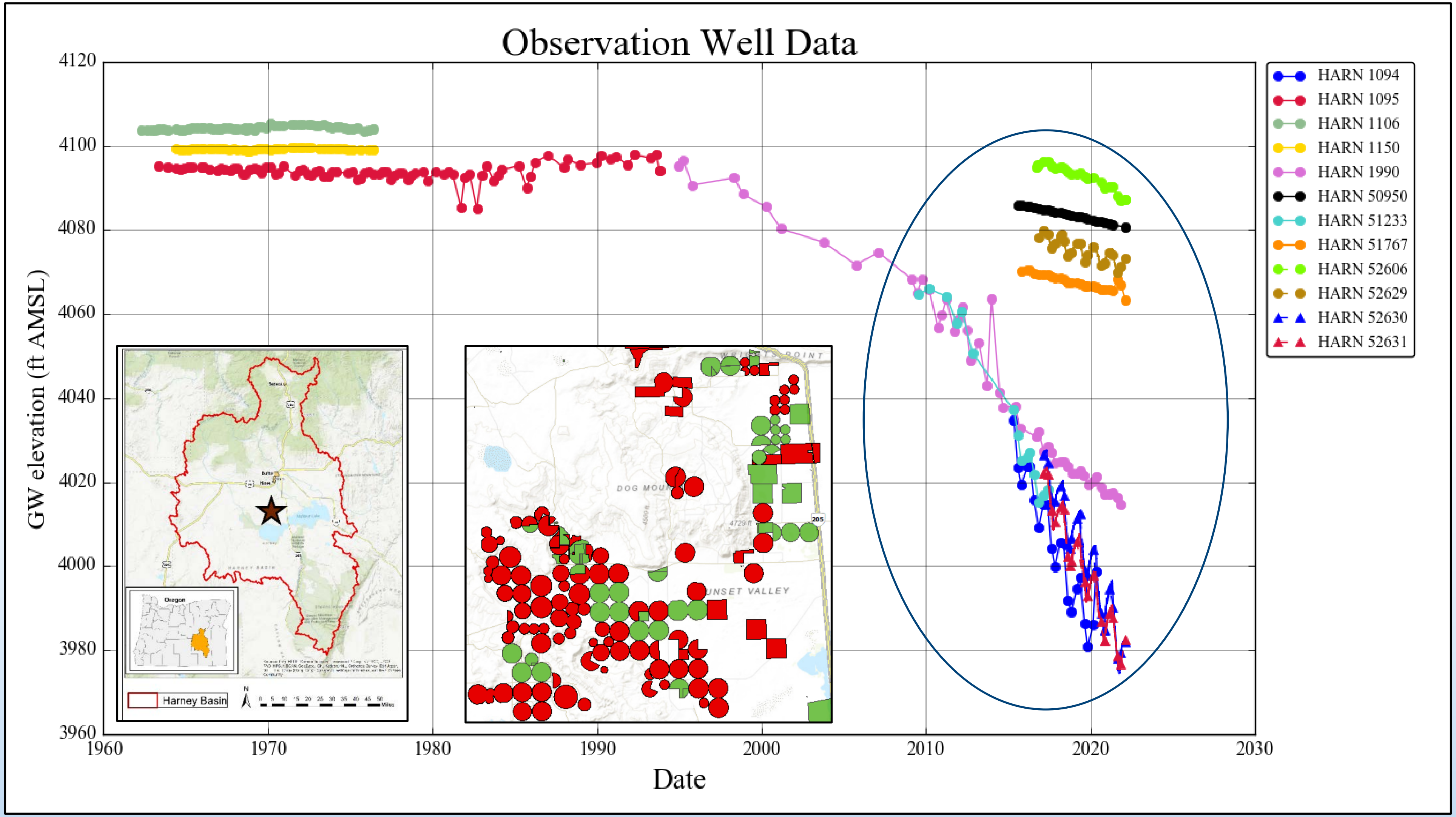
Well Interference Complaint & Groundwater Level Trend



Pre-Groundwater Study Background

Weaver Springs Vicinity

Groundwater Development & Groundwater Level Trend



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Pre-Groundwater Study Background

OWRD Received GW Permit Protests (February 2014)

Analysis Conducted (2014-2015)

Groundwater Budget vs. Permitted Groundwater Rights

Table 8: Comparison of the Harney Basin Groundwater Budget to the "Greater Harney Valley Area" Permitted Groundwater Use for Irrigation

Watershed	Harney Basin Groundwater Budget			Permitted Groundwater Volume (acre-feet) (OWRD)
	Groundwater Recharge (acre-feet) (Robison, 1968)	Groundwater Discharge (acre-feet) (OWRD)	Unaccounted Difference (acre-feet) (OWRD)	
Silver Creek	60,000	30,793	29,207	66,921
Silvies River	100,000	18,756	81,244	212,253
Donner und Blitzen	100,000	39,625	60,375	7,875
Harney Basin	**260,000**	**89,173**	**170,827**	**287,049**

Note: The total unaccounted difference is 1 acre-foot more than the sum of the unaccounted difference for each watershed due to number rounding.

Note: The total annual groundwater volume permitted in acre-feet is for the "Greater Harney Valley Area" only, given that is the area of significant interest to OWRD.

Note: Only 138 permitted acres are outside the "Greater Harney Valley Area."

Table 8 of OWRD Memo Draft 07 dated 15 June 2015

Draft Memo Title: "Harney Basin: Permitted Groundwater Rights and Groundwater Budget"

Groundwater Study Chronology

2015 (May)	OWRD conducted Harney Basin groundwater open house meeting
2015 (Nov)	OWRD drafted a preliminary plan for a Harney Basin groundwater investigation
2015 to 2018	OWRD Salem staff increased Harney Basin well network for groundwater measuring
2016 to 2018	OWRD conducted quarterly and synoptic groundwater level measurements
2016 to 2019	Harney Basin Study Advisory Committee (SAC) organized, and 17 meetings conducted
2016 (April)	Oregon Water Resources Commission adopted OAR 690-512 for the Harney Basin
2016 (Dec)	OWRD conducted Harney Basin town hall water forum meeting
2016 (Dec)	USGS plan for USGS-OWRD Harney Basin groundwater investigation approved
2017 (Jan)	USGS plan for USGS-OWRD Harney Basin groundwater investigation public release
2017 to 2019	USGS and OWRD conducted data collection field work and began data analysis
2017 to present	Harney Basin Collaborative organized and meet monthly
2018 (Oct)	OWRD conducted Harney Basin town hall water forum meeting
2019 to present	OWRD Salem staff decreases Harney Basin well network for groundwater measuring
2019 (Dec)	USGS & OWRD presented initial data interpretations to Harney Basin SAC
2020 to 2021	OWRD and USGS write Harney Basin groundwater investigation reports
2021	OWRD releases 4 supplemental Harney Basin groundwater investigation reports
2022	USGS releases 2 primary Harney Basin groundwater investigation reports

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Study & DEQ Water Chemistry Data

Photo by Hank Johnson from Gingerich and others (2022)

Study (USGS) Water Chemistry Samples

284 Study or Related Project Samples (2016-May 2019)

31 Historic Samples (1982-2015)

202 Wells/Springs
85 Streams/Rivers
22 Plant Tissue
6 Soil Water

Study Samples Collected by

USGS, OWRD, PSU, ODEQ

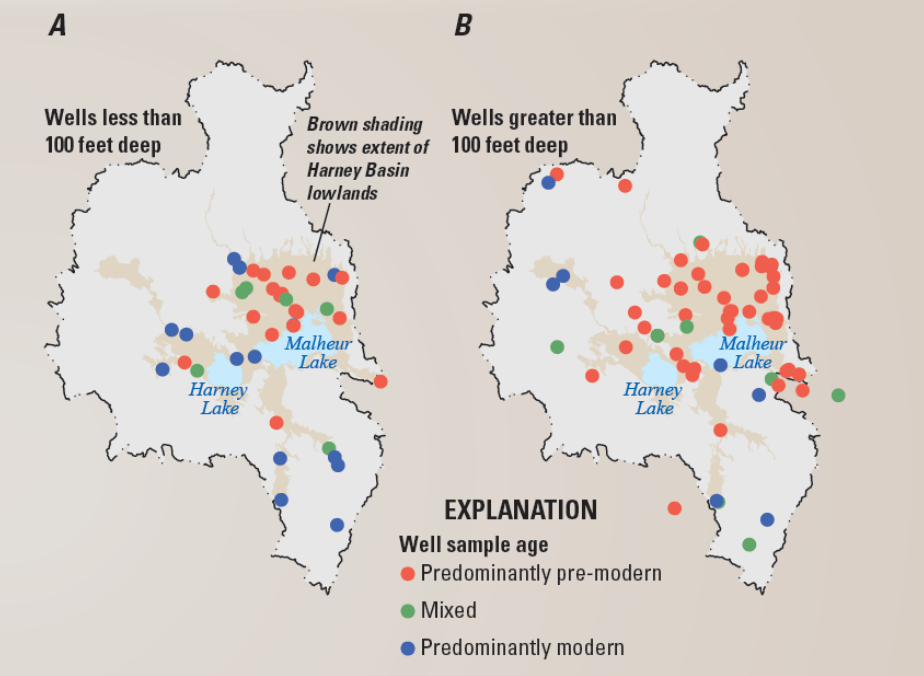
Study Water Chemistry Analyses

Tritium
Carbon-14
Stable Isotopes

Additional Data by DEQ (91 wells)

Field Parameters
Standard Parameters
Metals
Bacteria
Fungicides
Herbicides
Legacy Pesticides
Volatile Organic Compounds

Study Takeaway #1



Relative groundwater age in (A) shallow wells (less than 100 feet deep) and (B) deep wells (greater than 100 feet deep) within and adjacent to the Harney Basin, southeastern Oregon. Relative age is based on the analysis of stable isotopes of hydrogen in water and its relation to tritium and carbon-14 age dates. Modified from Gingerich and others, 2022.

From USGS Fact Sheet (Gingerich and others, 2022)

Study Takeaway #1: Most 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**

Study Groundwater Level Data

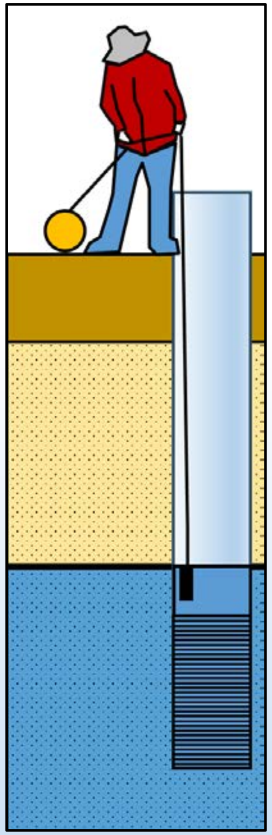
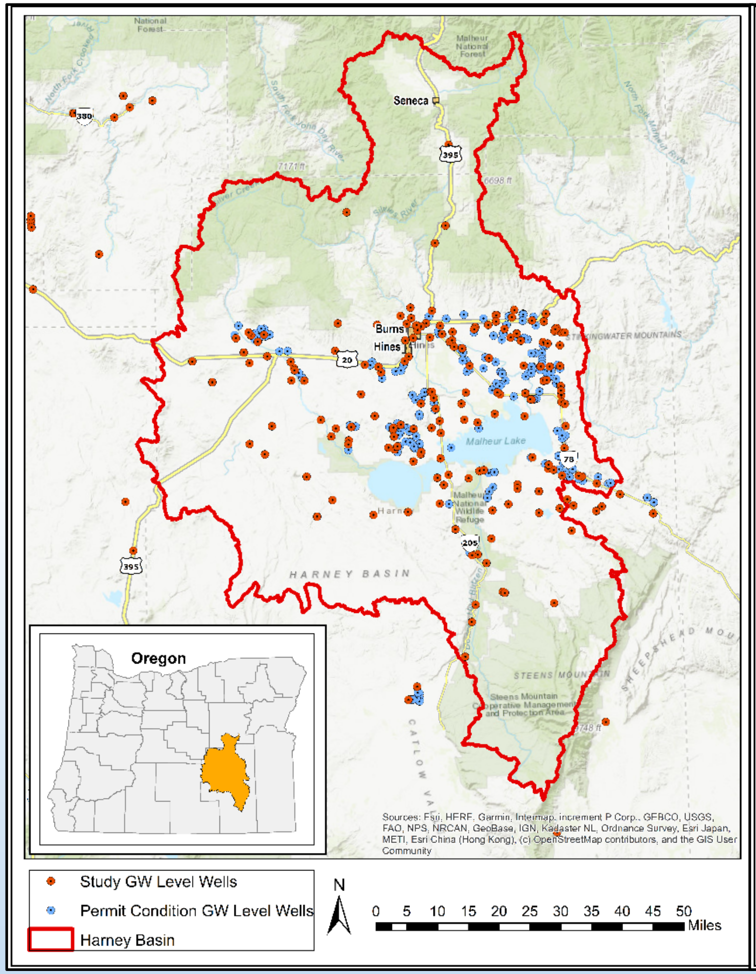
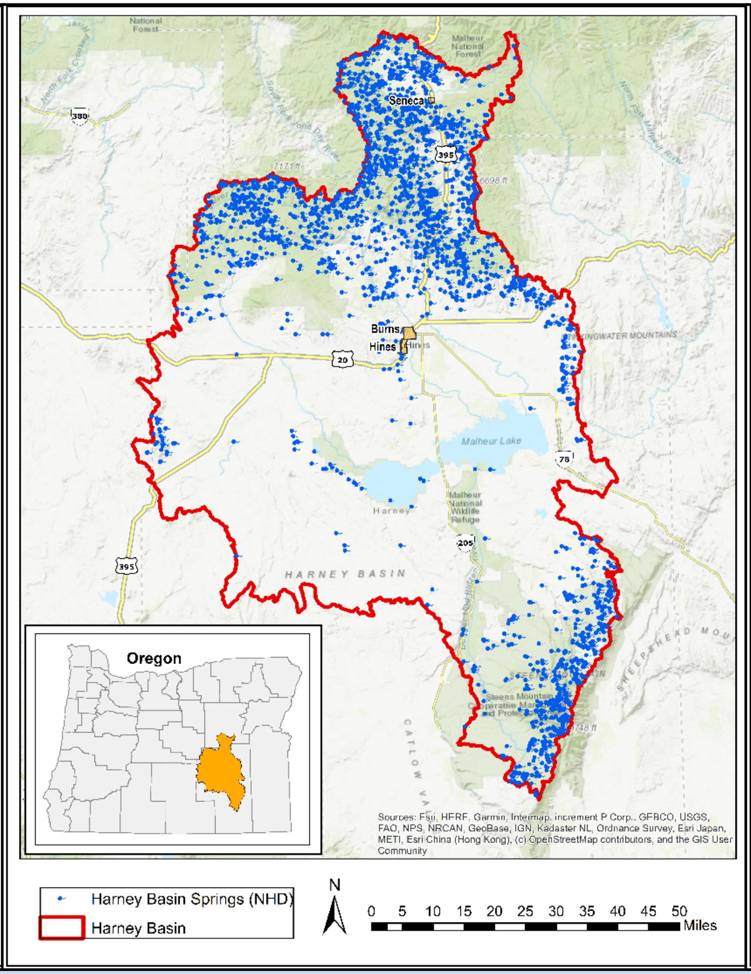


Figure by Woody (2023)

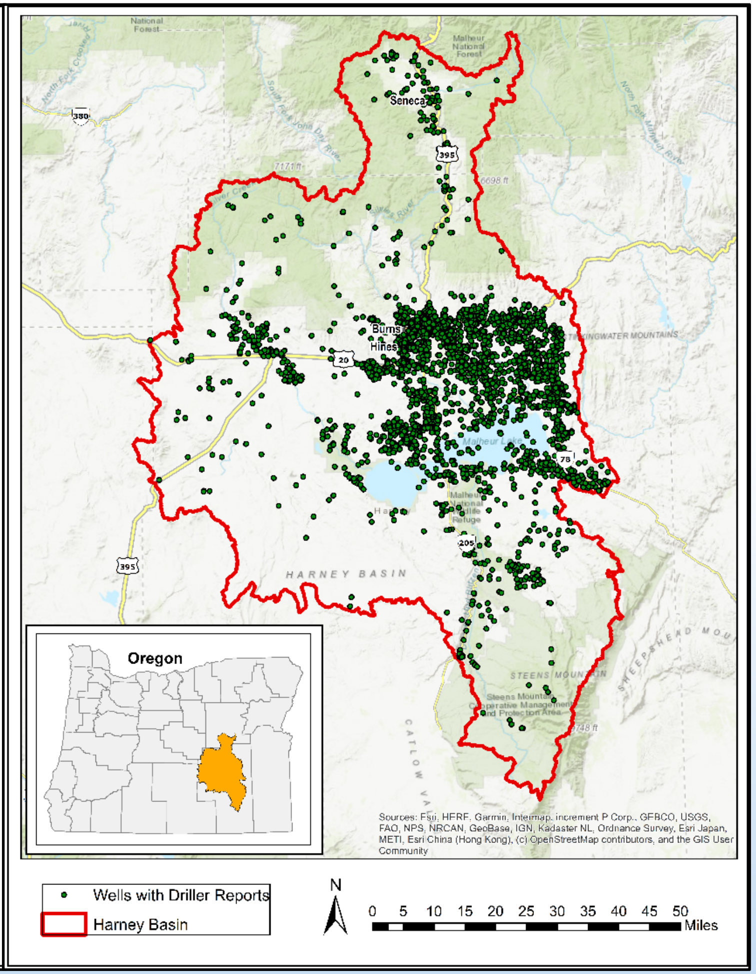
GW Study & GW Right Wells



NHD Located Springs



Driller Well Reports



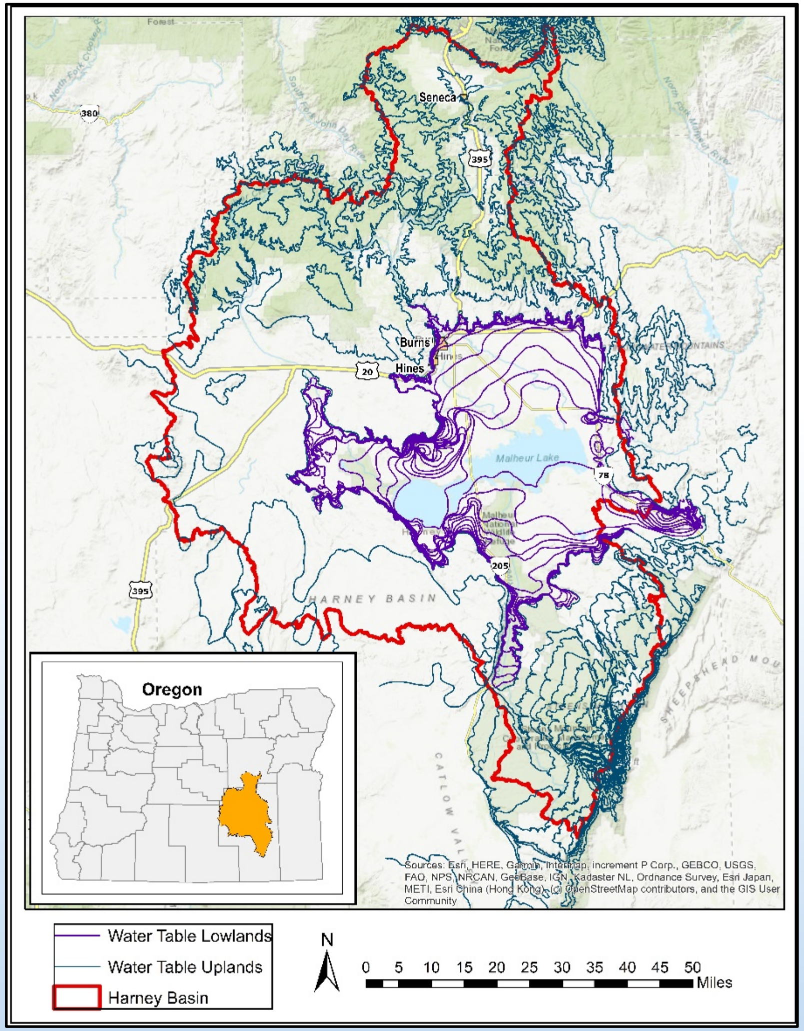
Study Groundwater Level Maps

Groundwater Level Contour Maps

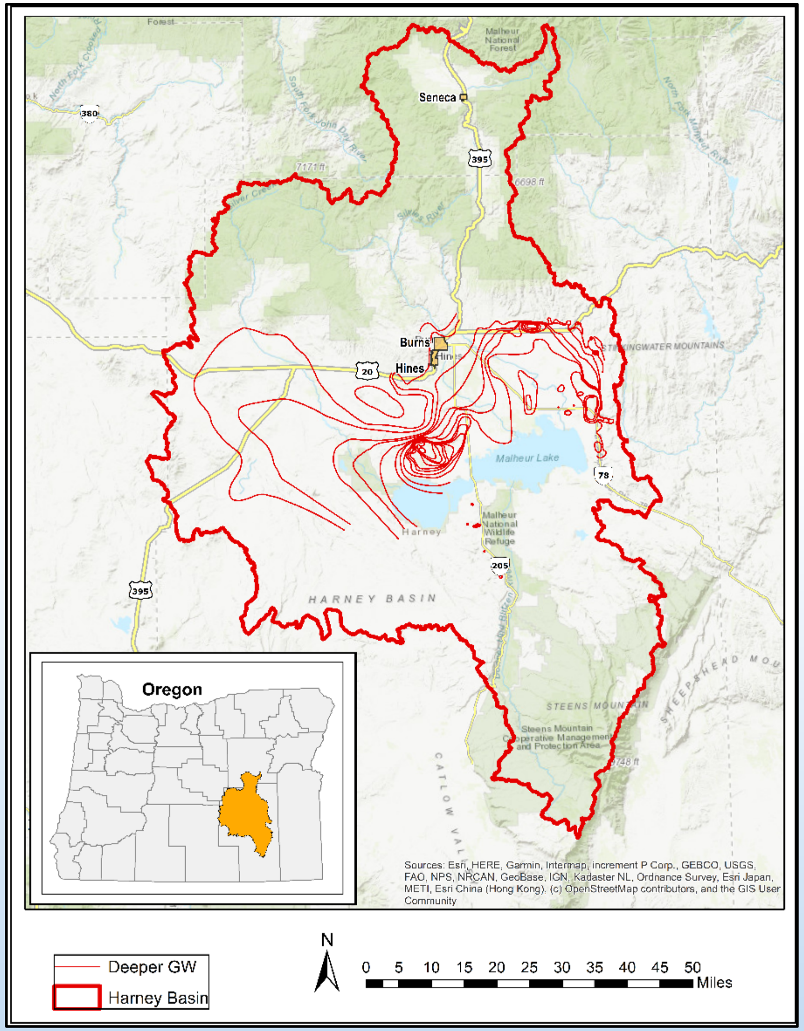
Water Table Map
(groundwater top)
(wells <150-ft deep)
(uplands & lowlands)

Potentiometric Surface Map
(groundwater at depth)
(wells >150-ft deep)
(lowlands only)

Water-Table



Potentiometric Surface



Groundwater Level Maps (Lowland)

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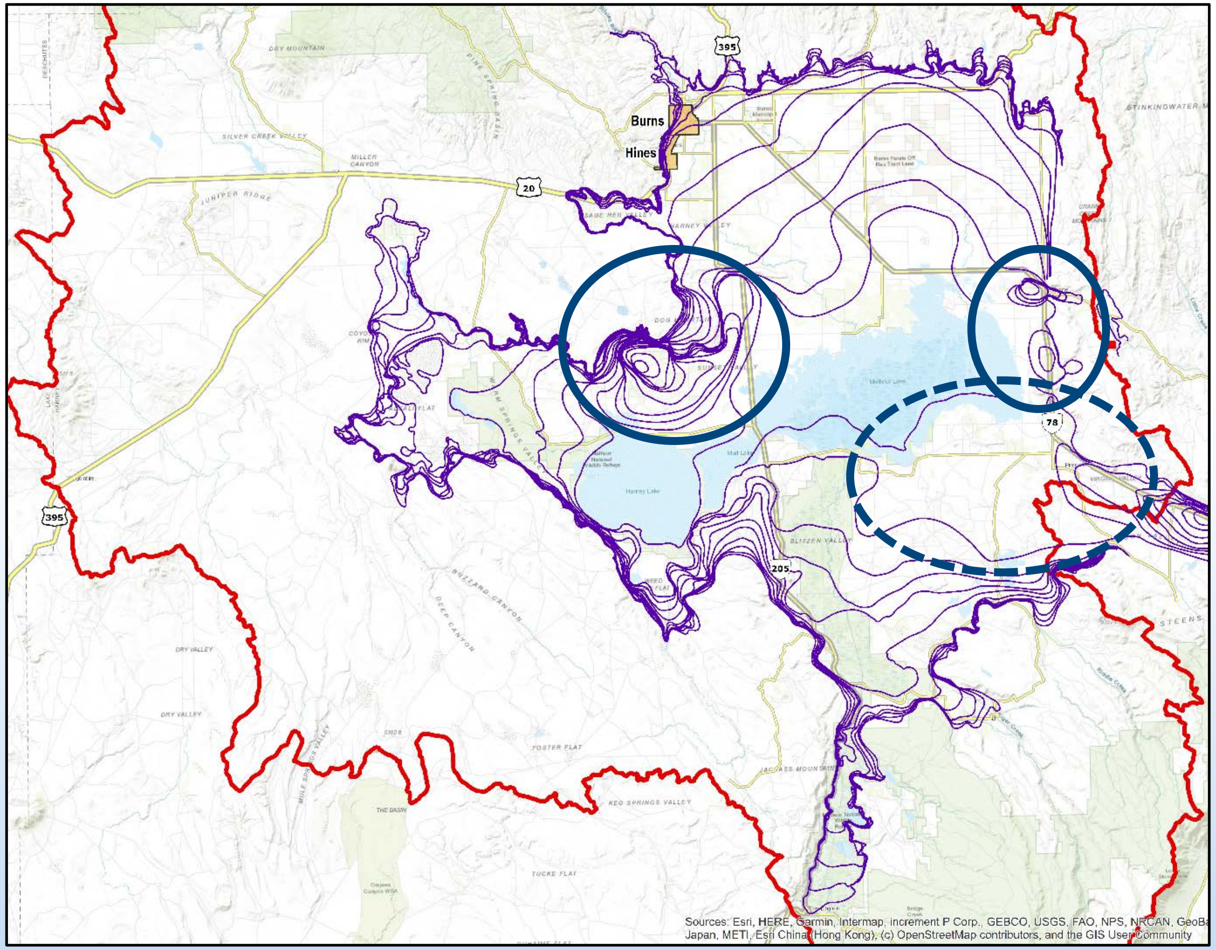
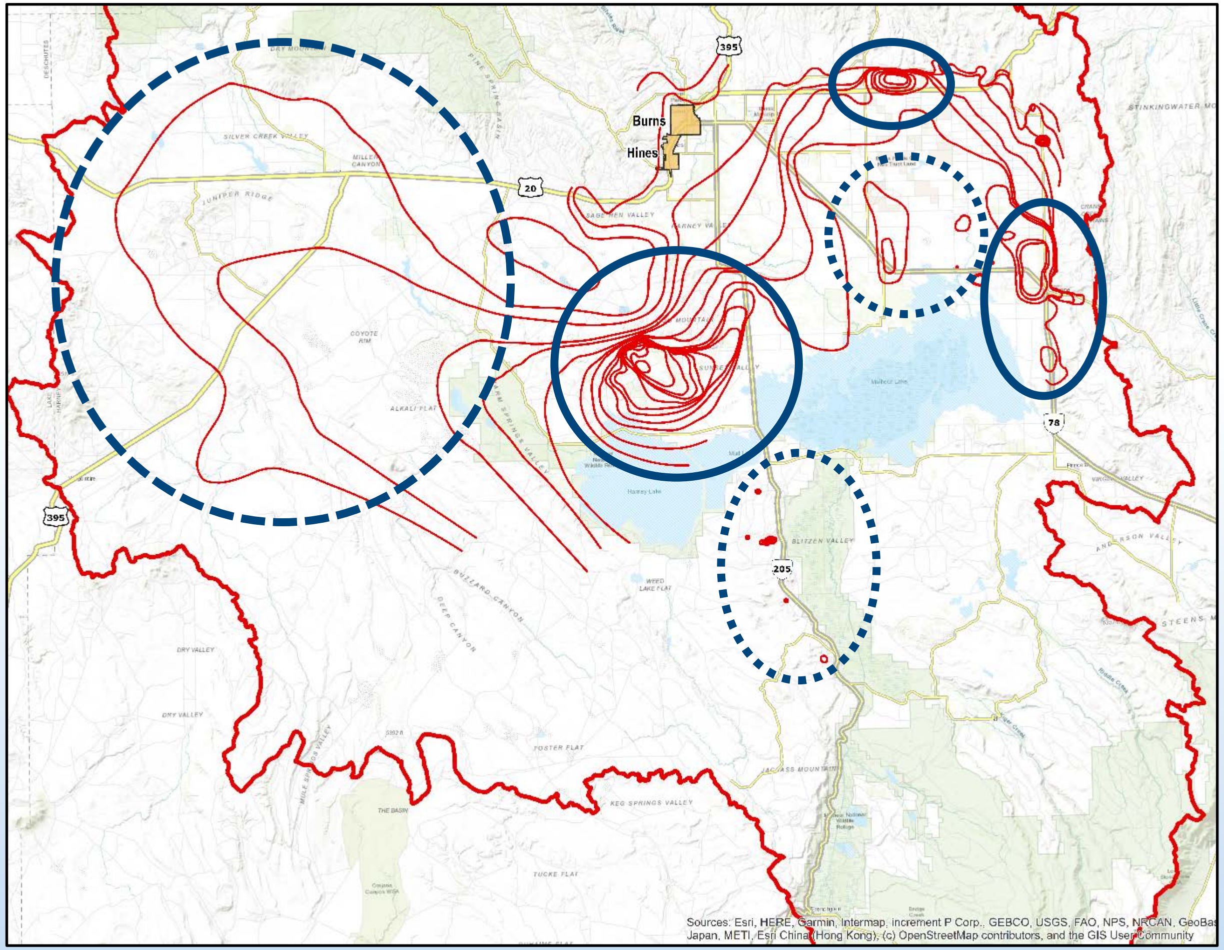
Water-Table (wells <150-ft total depth)



Potentiometric Surface (wells >150-ft total depth)



Groundwater Level Graphs (Lowland)

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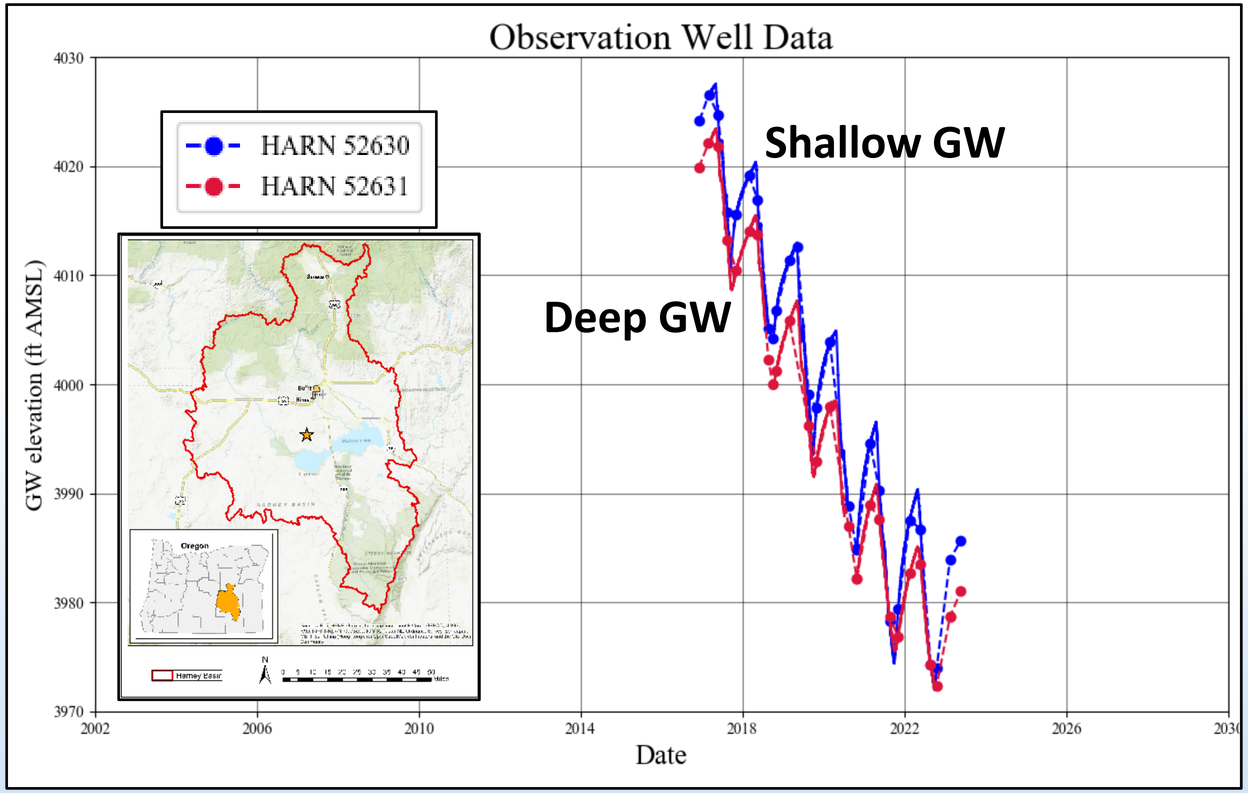
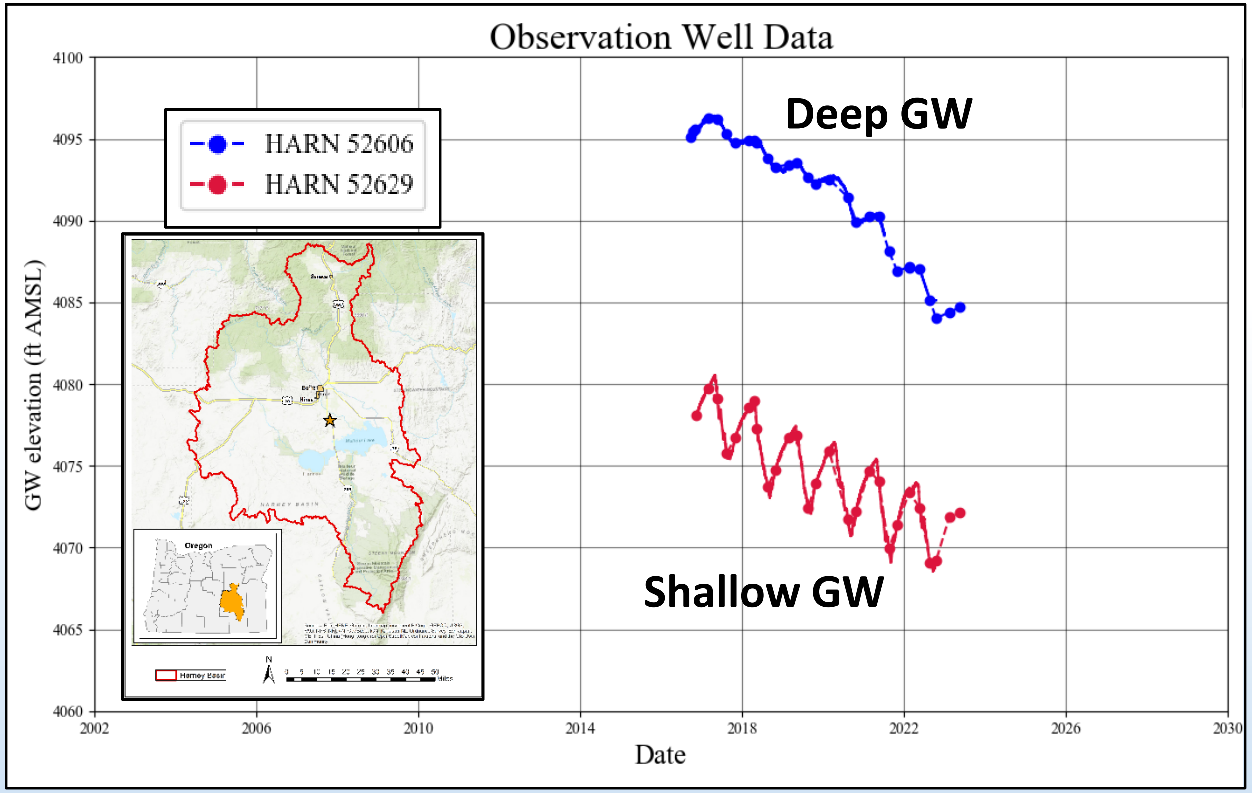
Weaver Springs (well pair)

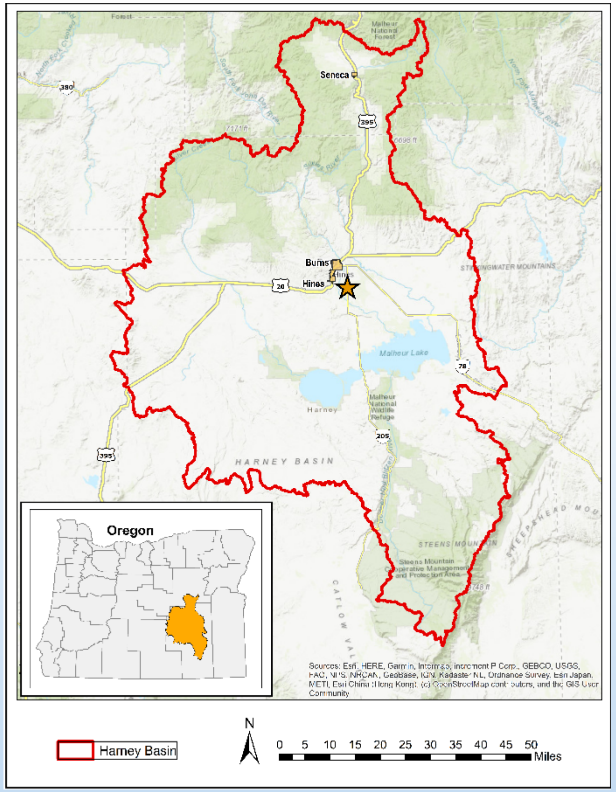


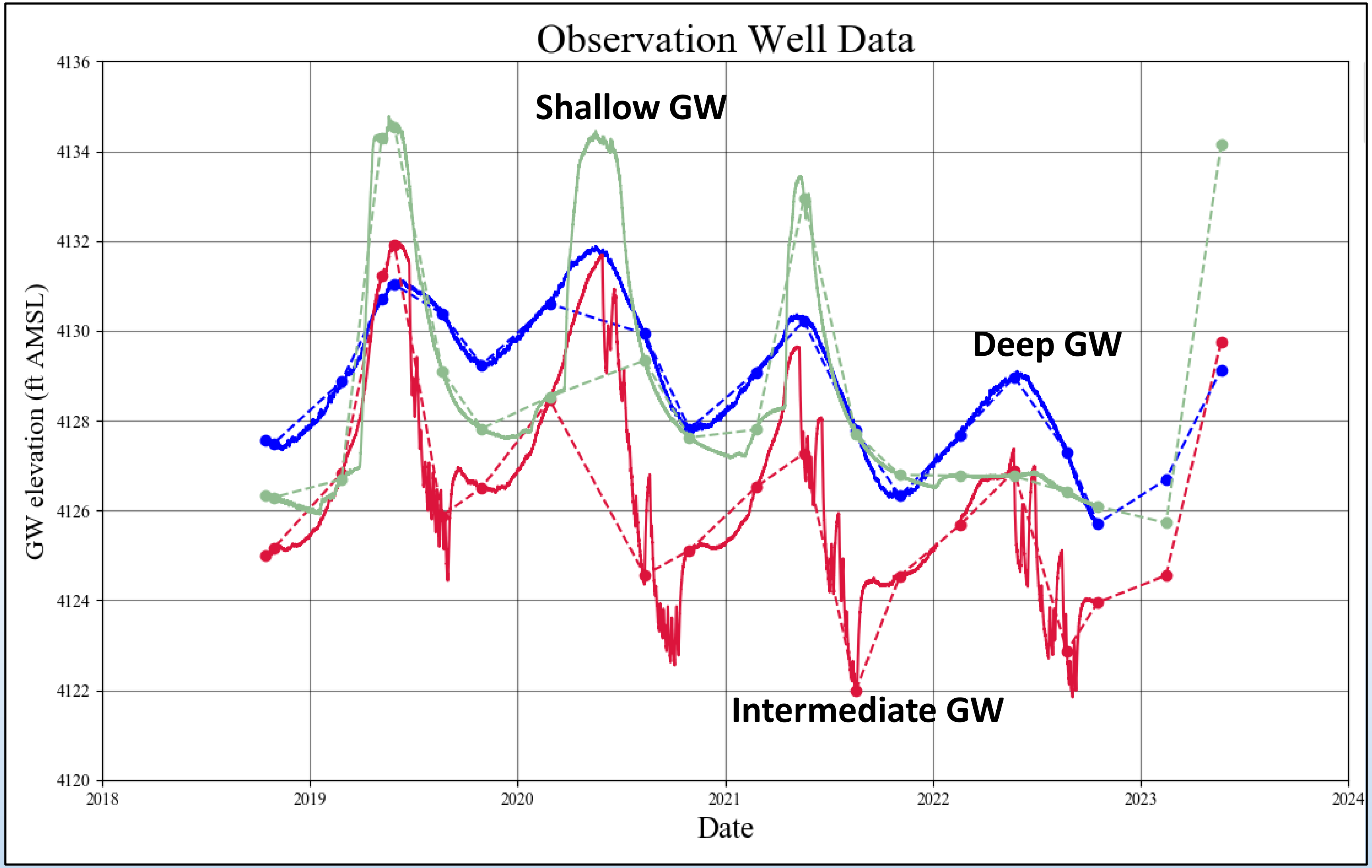
Dog Mountain (well pair)



Groundwater Level Graphs (Lowland)

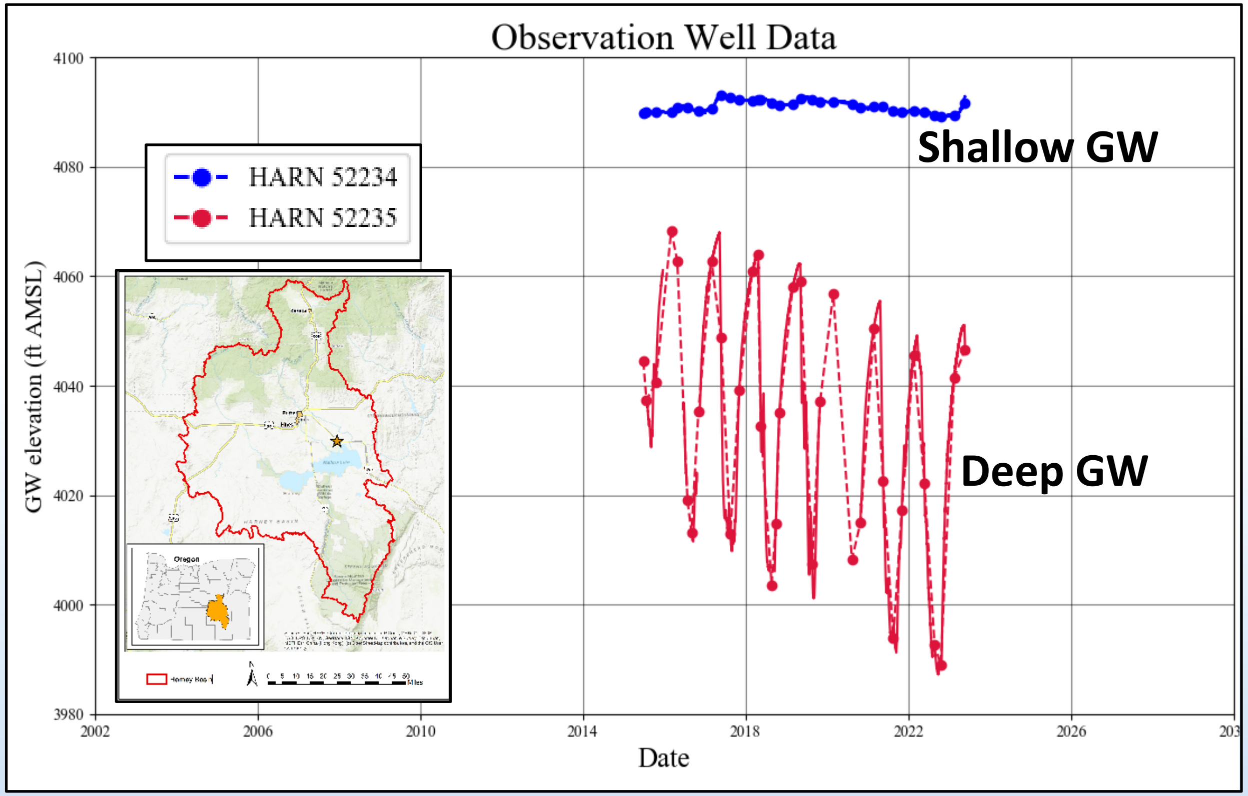
EOARC (triple wells)



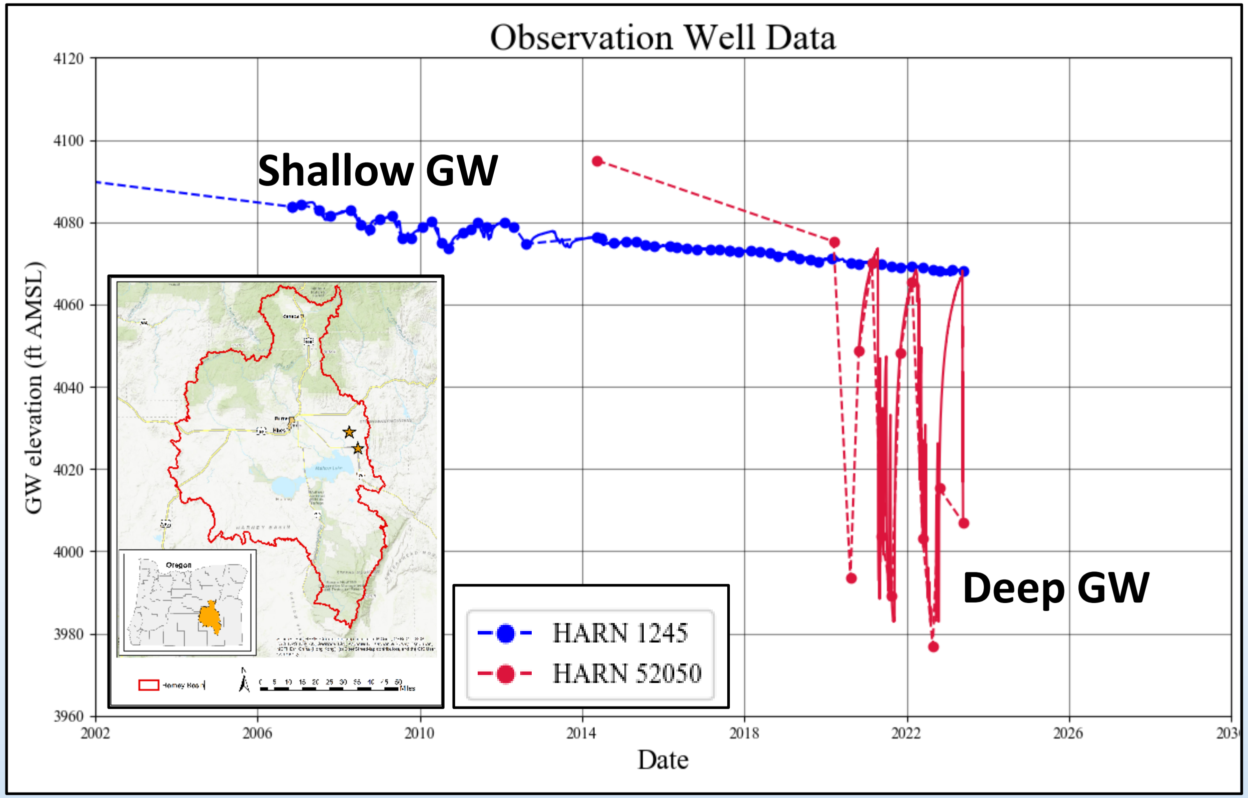


Groundwater Level Graphs (Lowland)

Lawen (well pair)

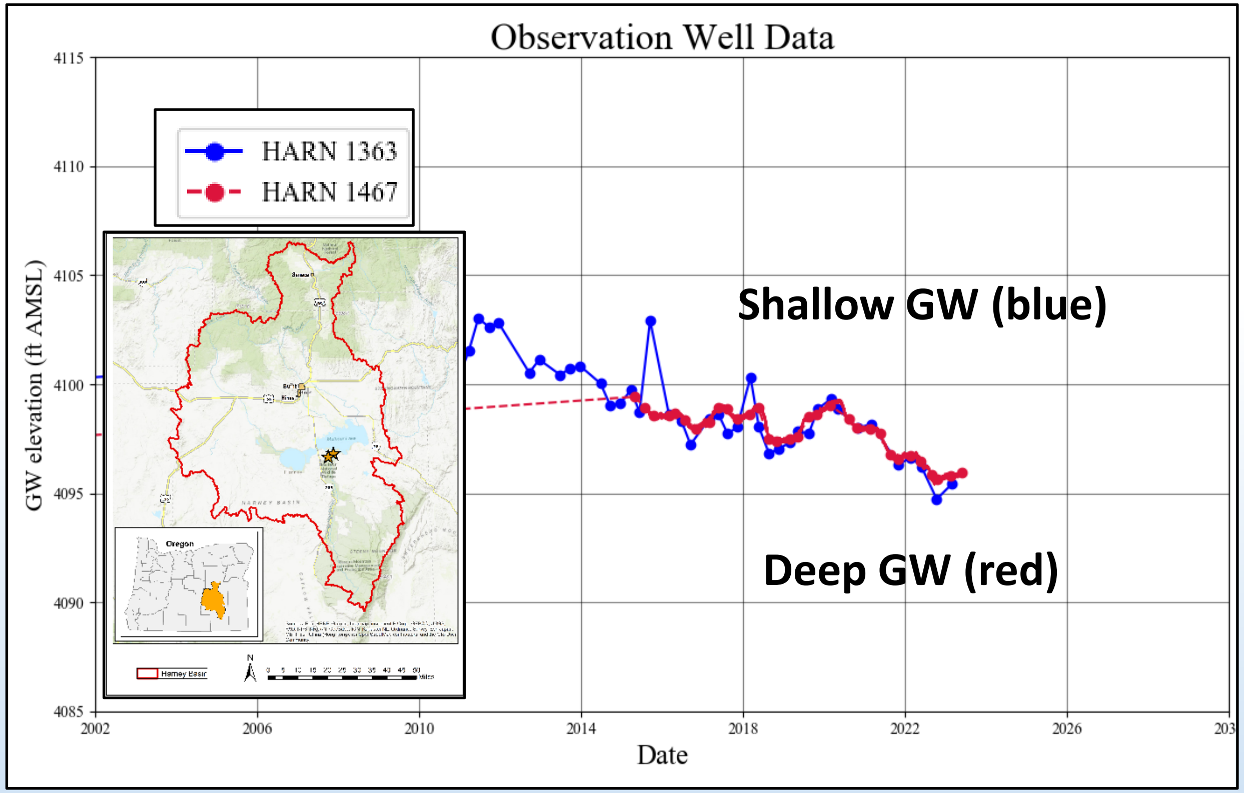


Crane Vicinity (nearby wells)

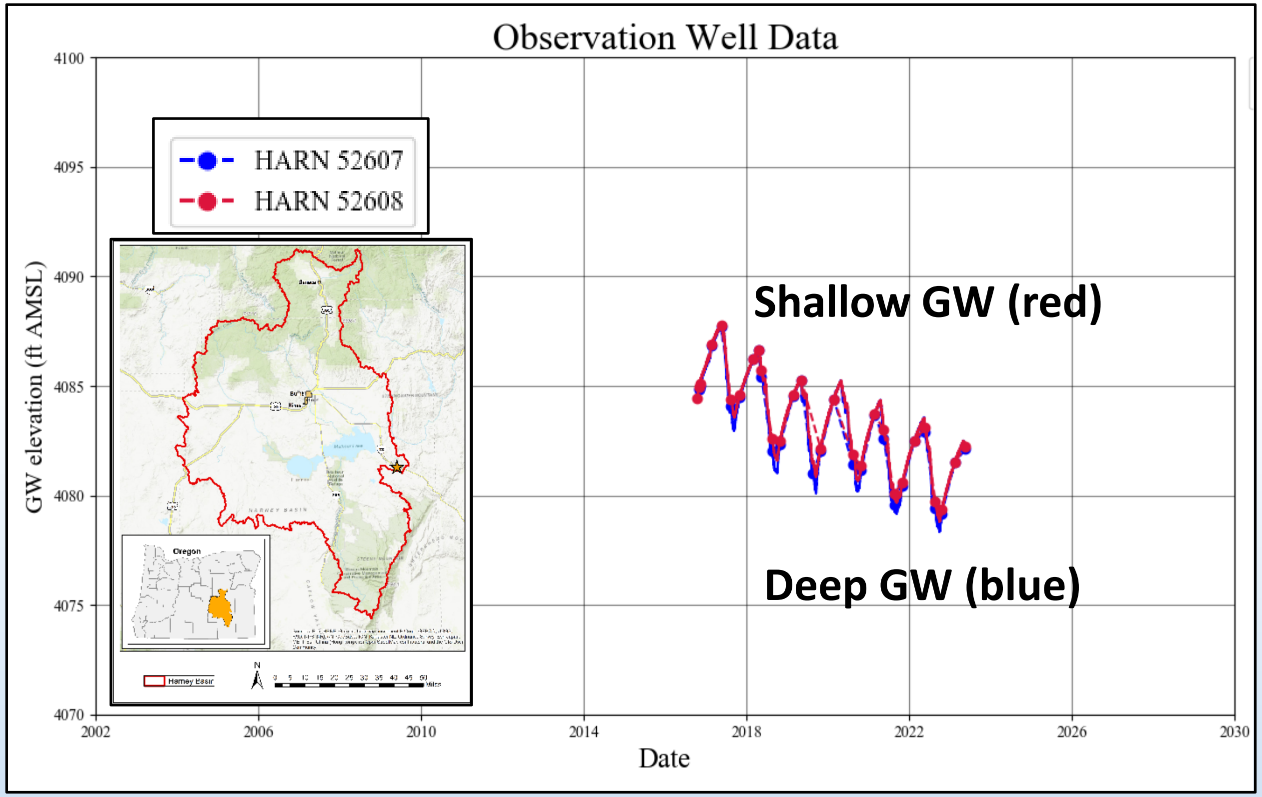


Groundwater Level Graphs (Lowland)

Blitzen Valley Near Malheur Lake (nearby wells)

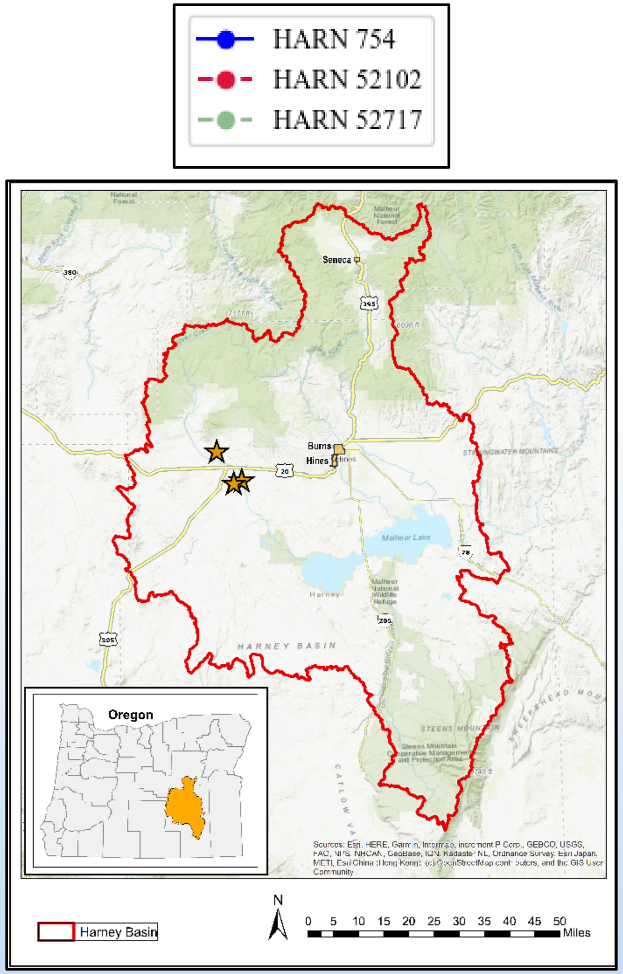


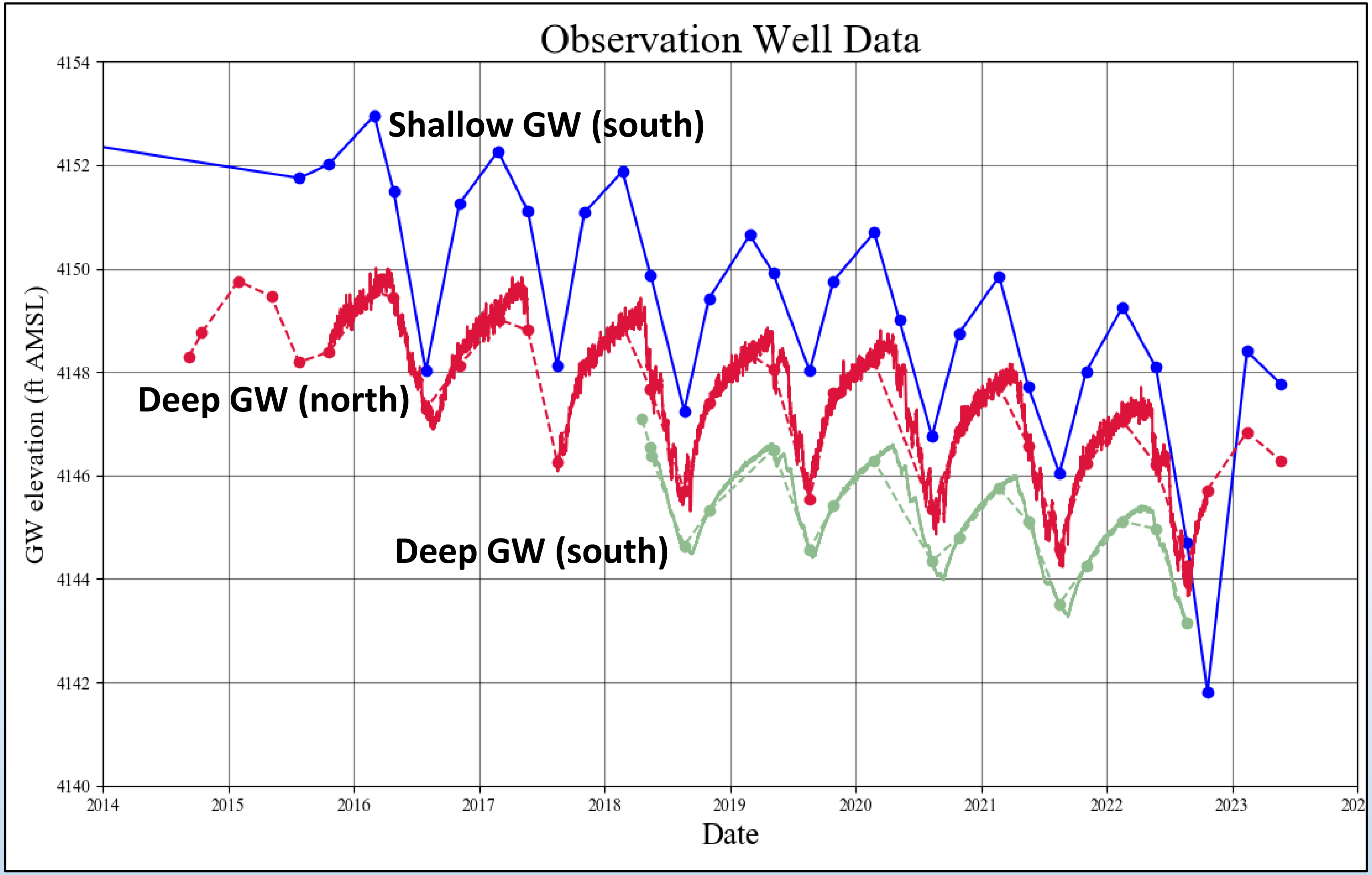
Virginia Valley (well pair)



Groundwater Level Graphs (Lowland)

Riley Vicinity Wells





Study Needed to Answer…Why?

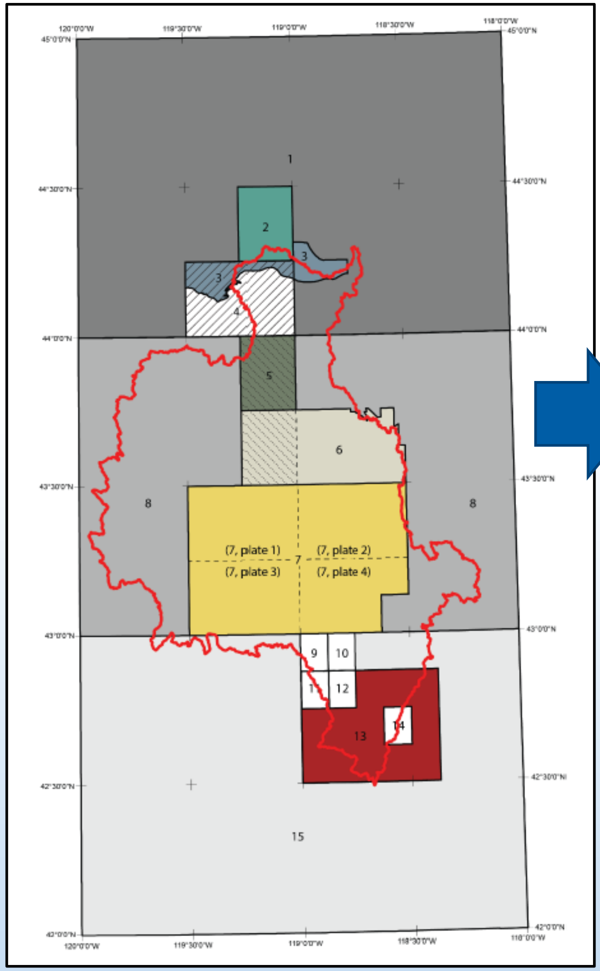
- Cones of depression:
  - Why do cones of depression occur in some areas & flat gradient decline occur in other areas?
  - Why do cones of depression occur shallow & deep some areas, but deep only other areas?

- GW levels: For a given location, why is…
  - The shallow & deep elevations, annual trend, & seasonal amplitude similar in some areas?
  - The shallow & deep annual trend the same but the seasonal amplitude differs in some areas?
  - The shallow & deep annual trend and the seasonal amplitude different in some areas?
  - The highest GW elevation shallow GW in some areas & deeper GW in other areas?
  - The larger seasonal amplitude shallow GW in some areas & deeper GW in other areas?
  - The steeper annual trend (decline) shallow GW in some areas & deeper GW in other areas?

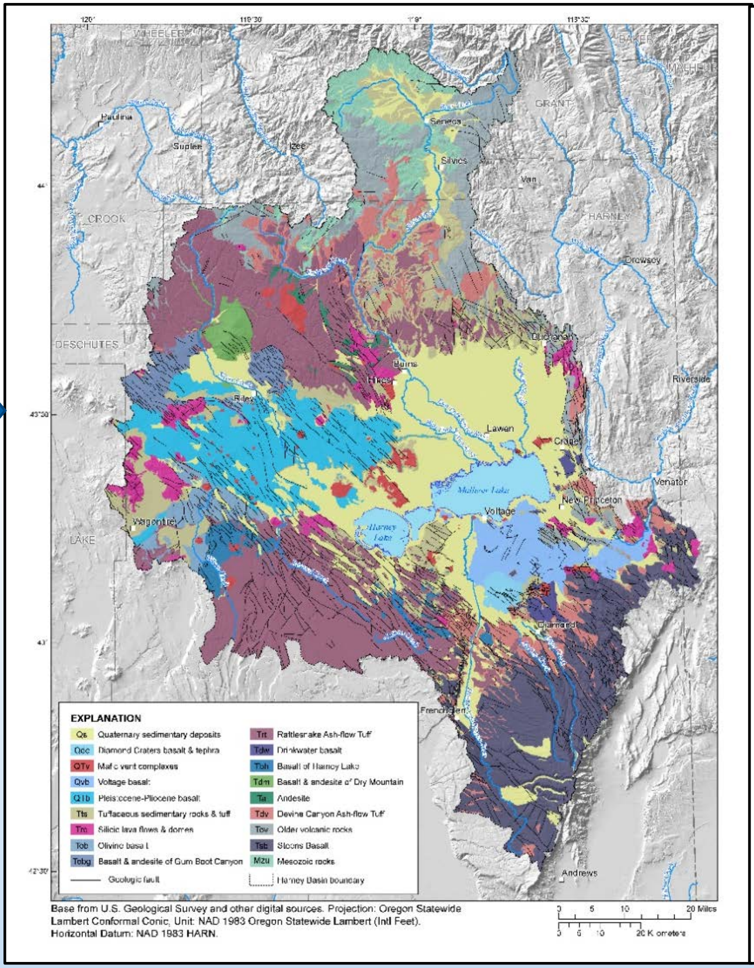
- Needed to explore:
  - hydraulic property relationship to geology
  - hydraulic property control on GW flow and response to GW development

Study Area Geology

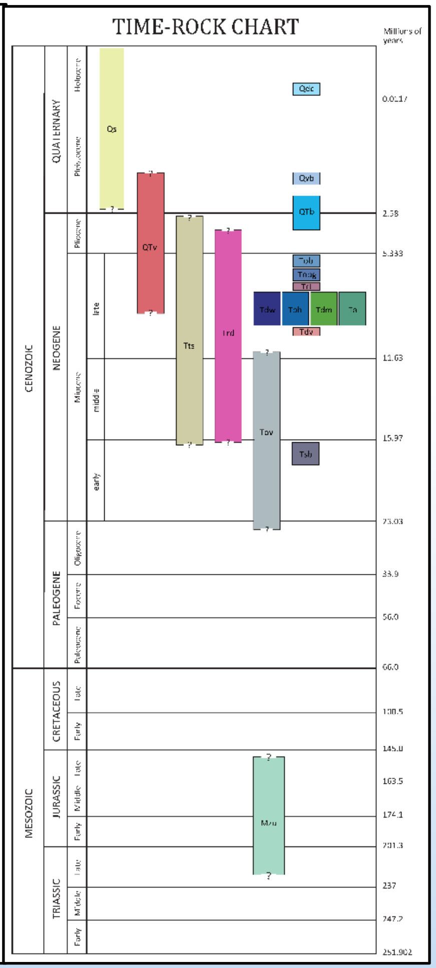
Data Source (15 Maps)



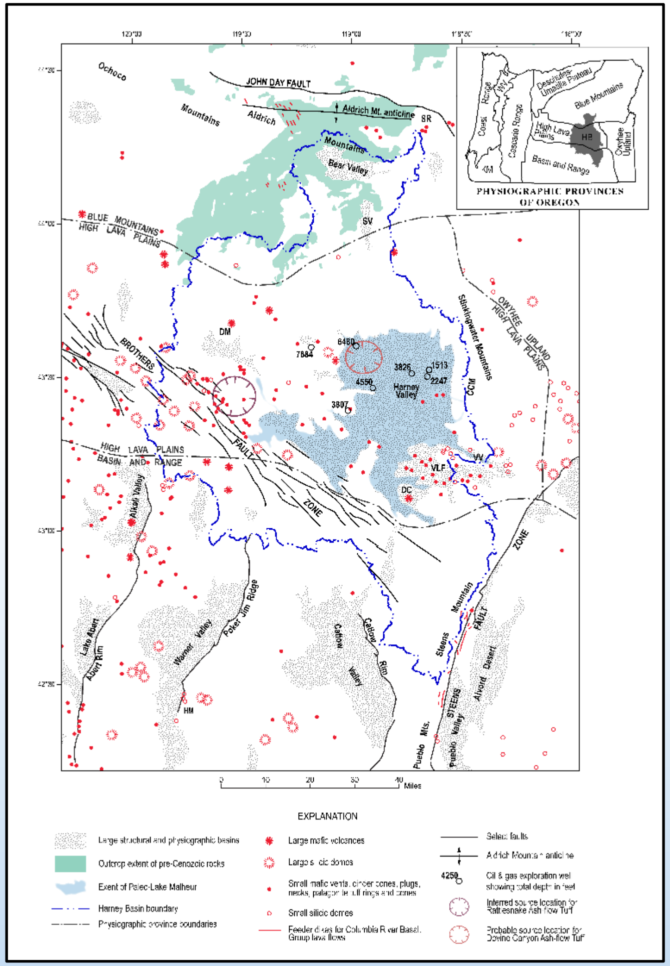
Geologic Compilation Map



Time-Rock Chart



Tectonic Overview Map



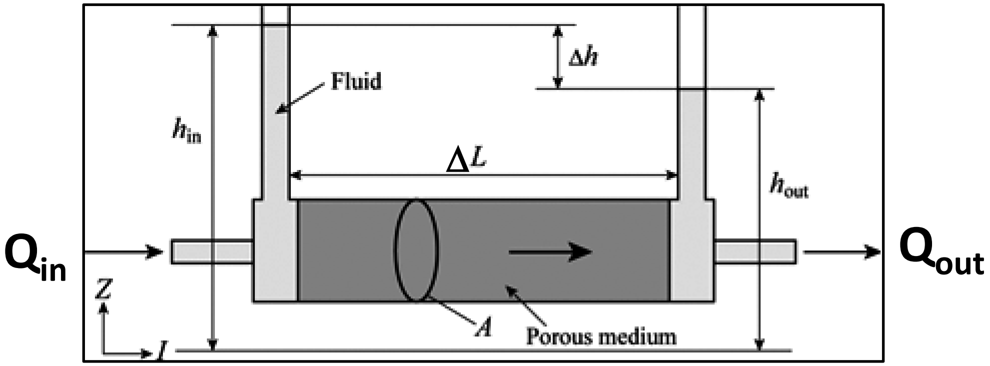
All figures and maps as displayed or redisplayed from Boschmann (2021)

Geology & Groundwater Flow

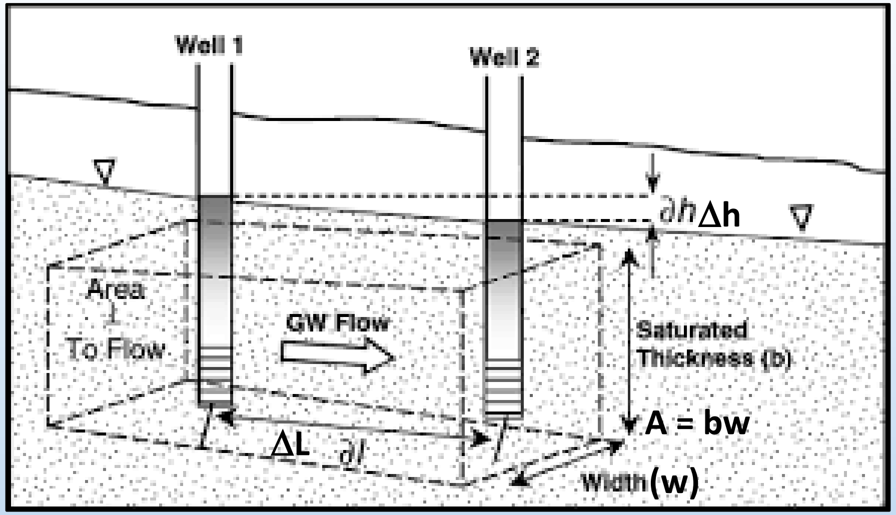
Henry Darcy
1803-1858

Engineer
Dijon, France

Laboratory Experiment



Field Application



Darcy's Law

$$Q = KA\,(\Delta h / \Delta L)$$

Q = volumetric flow rate
K = hydraulic conductivity
A = cross-sectional area at right angles to the fluid flow direction = bw
$(\Delta h / \Delta L)$ = hydraulic gradient
$= [(h_{out} - h_{in}) / (L_{out} - L_{in})]$

$$Q = Tw\,(\Delta h / \Delta L)$$

T = transmissivity = Kb
K = hydraulic conductivity
b = cross-sectional area height
w = cross-sectional area width

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Geology & Groundwater Drawdown

Radial Flow to a Well

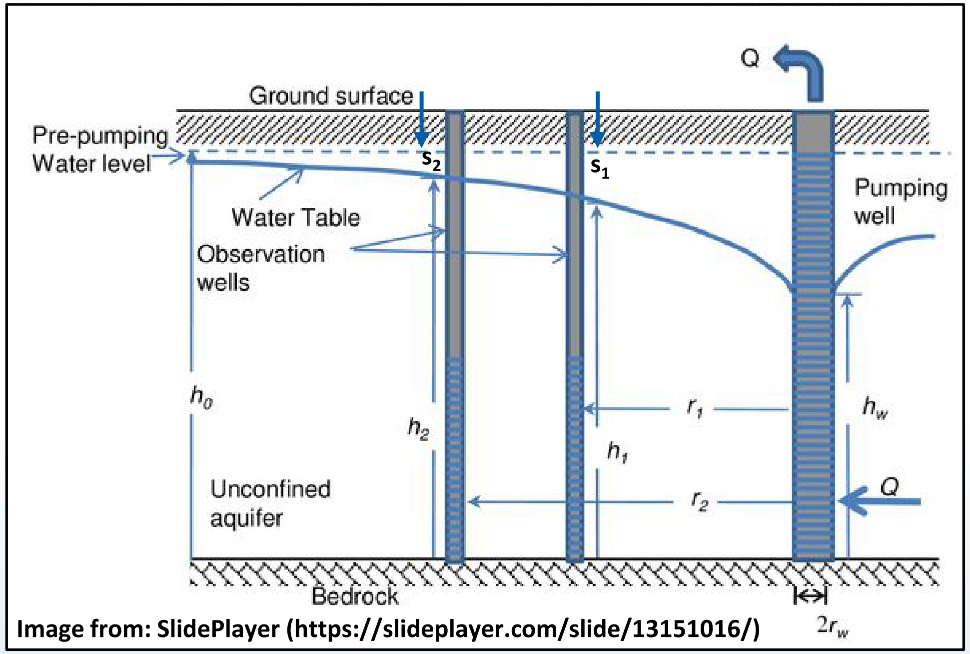
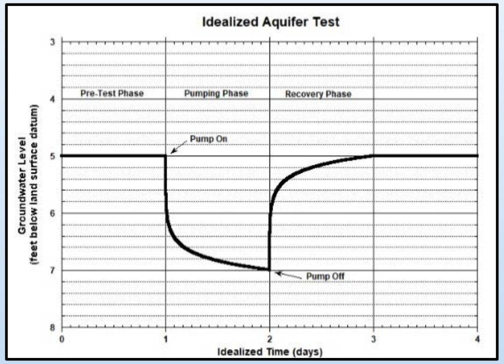


Image from: SlidePlayer (https://slideplayer.com/slide/13151016/)

Theis Equation

$$T = [Q/(4\Pi s)]W(u)$$
$$S = (4Ttu)/r^2$$

T = transmissivity
Q = volumetric flow rate
Π = pi = 3.141592654
s = drawdown
W(u) = well function
= (-ln u)-(0.5772157)+(u/1*1!)-(u²/2*2!)+(u³/3*3!)-(u⁴/4*4!)+...
S = storage coefficient
t = elapsed time since pumping began
r = radial distance from pumping well
u = r²S/4Tt



Idealized Time Drawdown & Recovery Graph

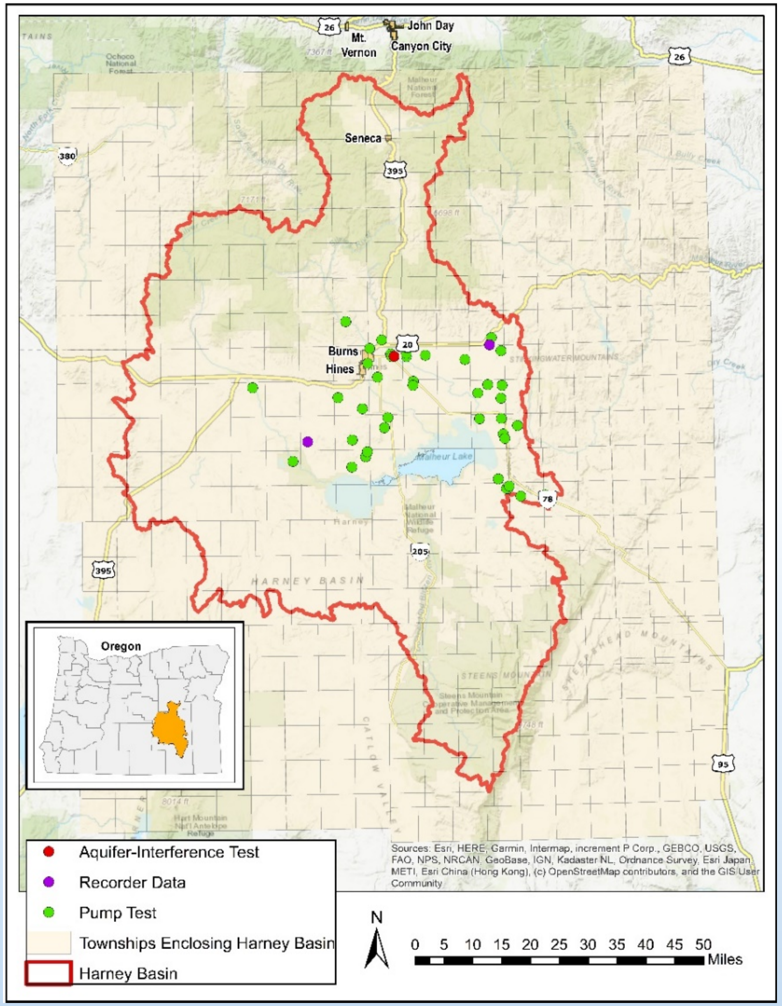
Cooper-Jacob Equation

$$T = [2.303Q/(4\Pi s)]\ [\log_{10}(2.25Tt/r^2S)]$$
or
$$T = (2.303Q)/(4\Pi\Delta s)$$
$$S = (2.25Tt_o)/r^2$$

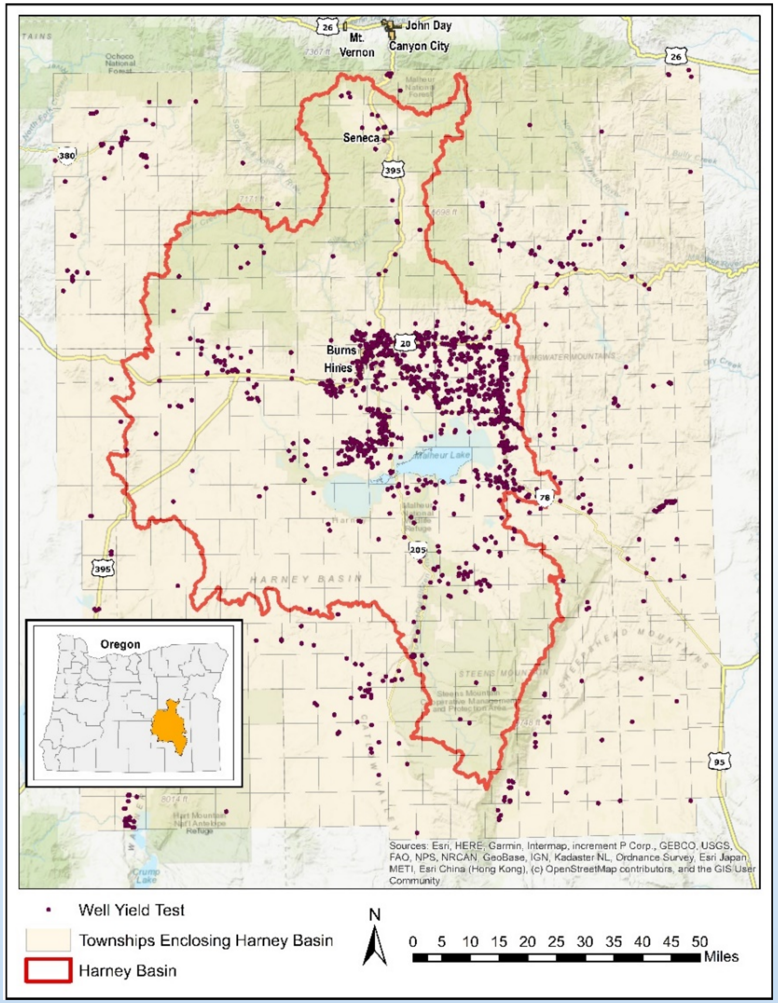
T = transmissivity
Q = volumetric flow rate
Π = pi = 3.141592654
s = drawdown
Δs = drawdown for one log cycle of time
S = storage coefficient
t = elapsed time since pumping began
t_o = time intercept, time where the drawdown line intercepts the zero-drawdown line
r = radial distance from pumping well

Transmissivity Data Sources

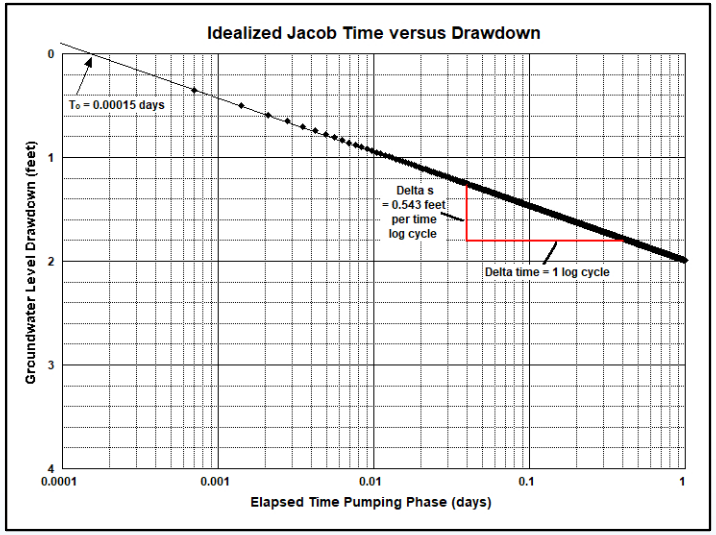
44 Aquifer Tests



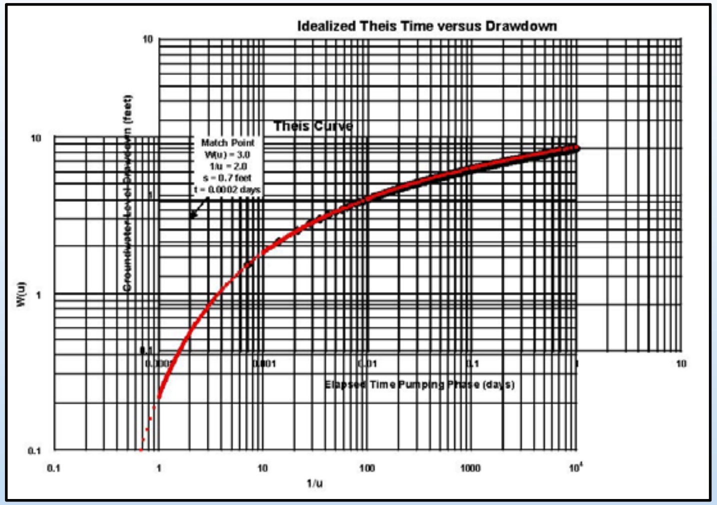
1,451 Well Yield Tests (Specific Capacity)



Transmissivity Calculations

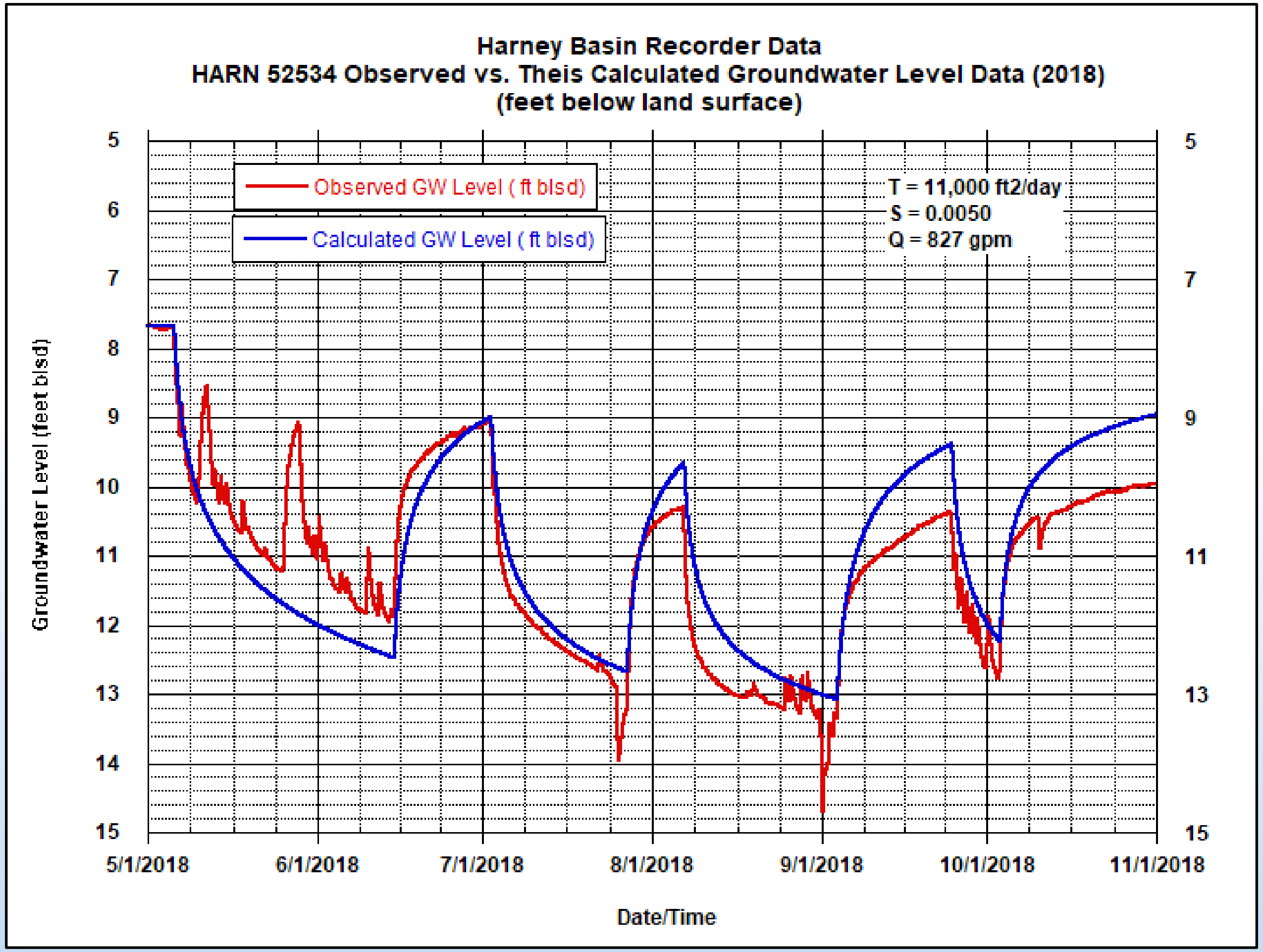


Cooper-Jacob Semi-Log Graphical Analysis



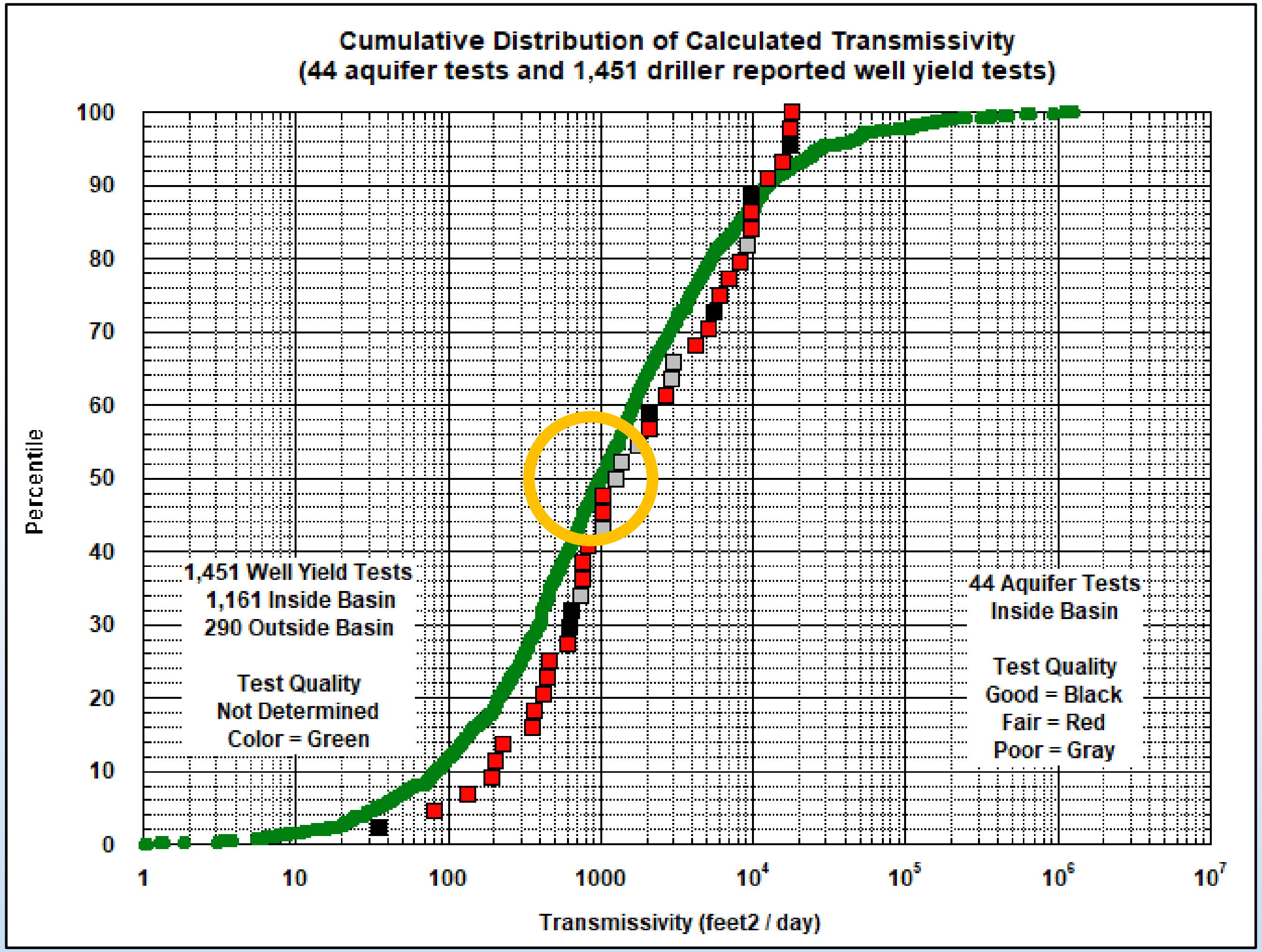
Theis Log-Log Graphical Analysis

Test of Analysis Results: Compare Observed vs. Calculated Groundwater Level Response to Pumping & Shutoffs

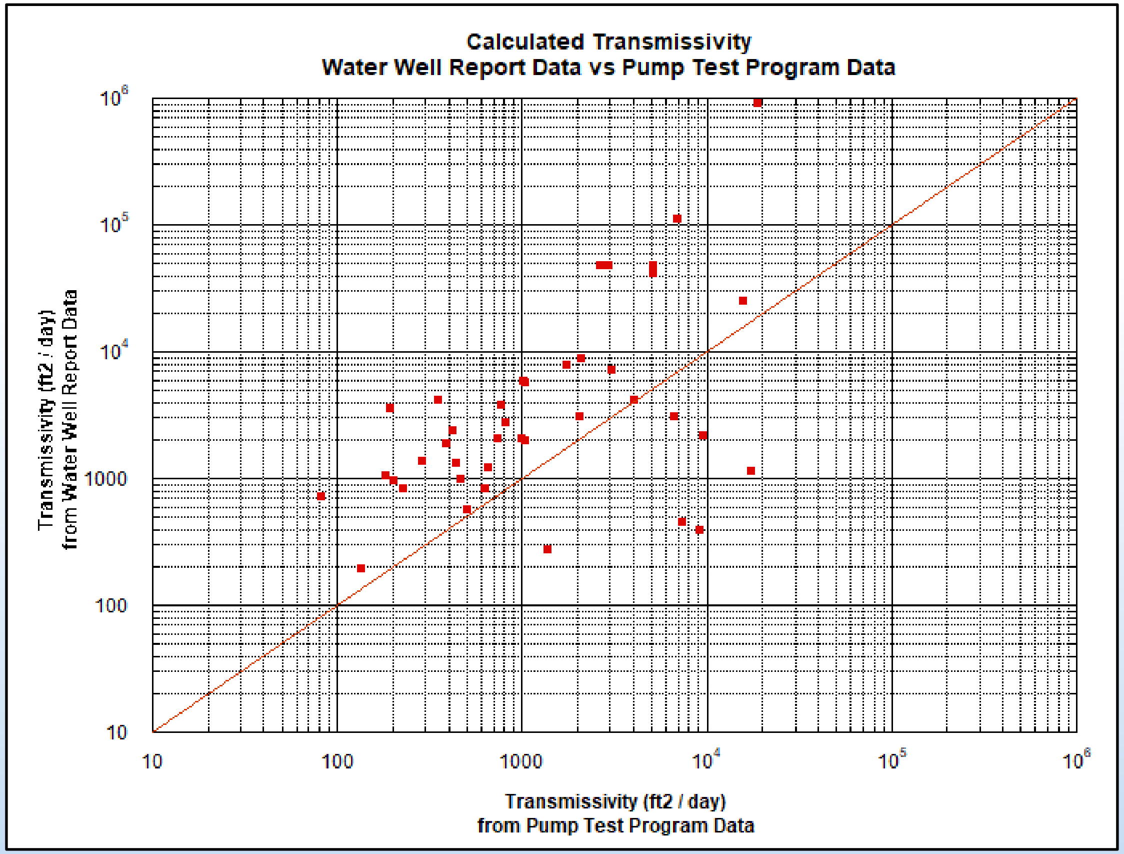


Calculated Transmissivity Range

Transmissivity Cumulative Distribution



Transmissivity Compare Well Yield (Specific Capacity)Test vs. Aquifer Test



Transmissivity Spatial Distribution

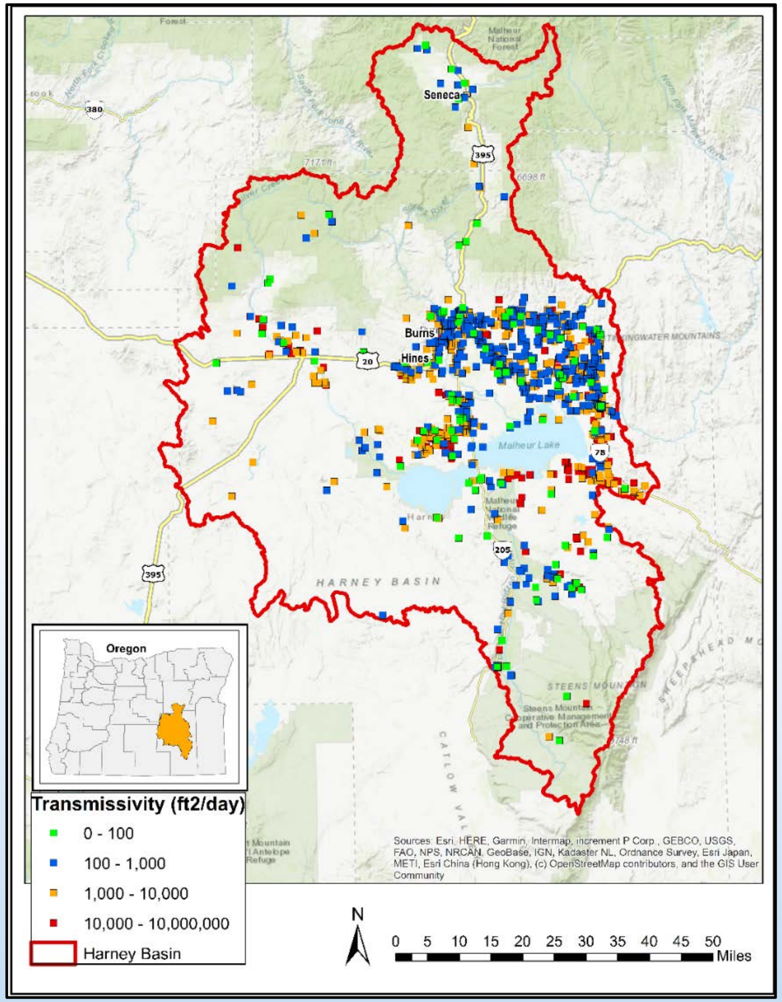
Smaller Transmissivity

- Found entire basin
- Even mixed with large transmissivity

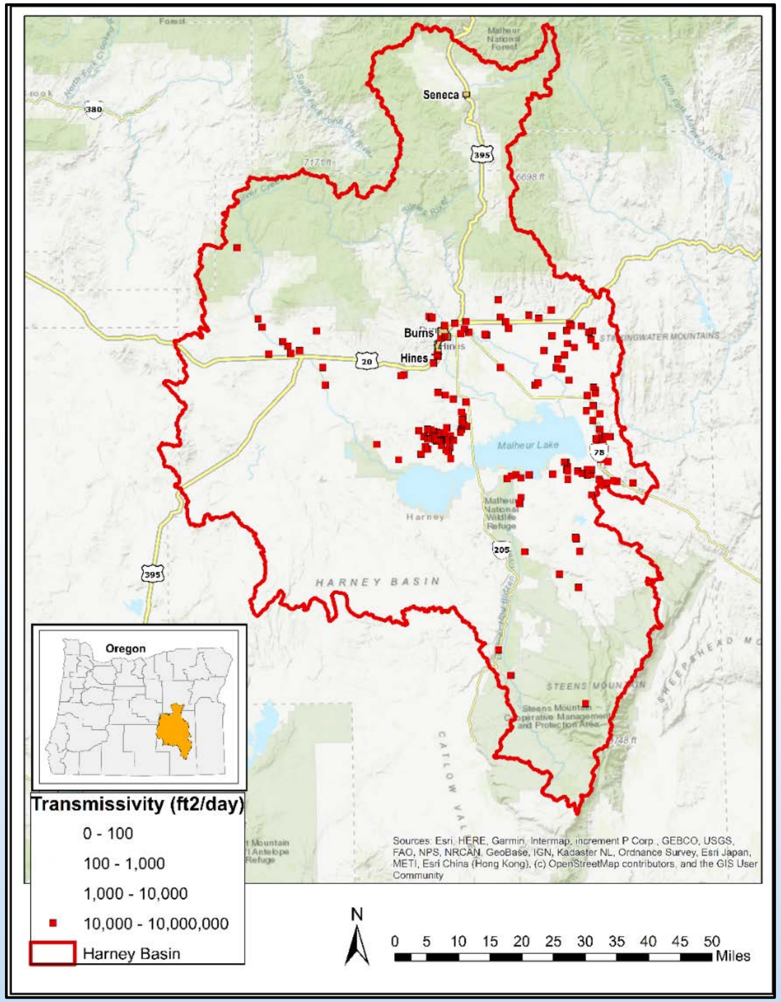
Largest Transmissivity

- Limited distribution
- Harney Valley margin
- Upper Silver Creek

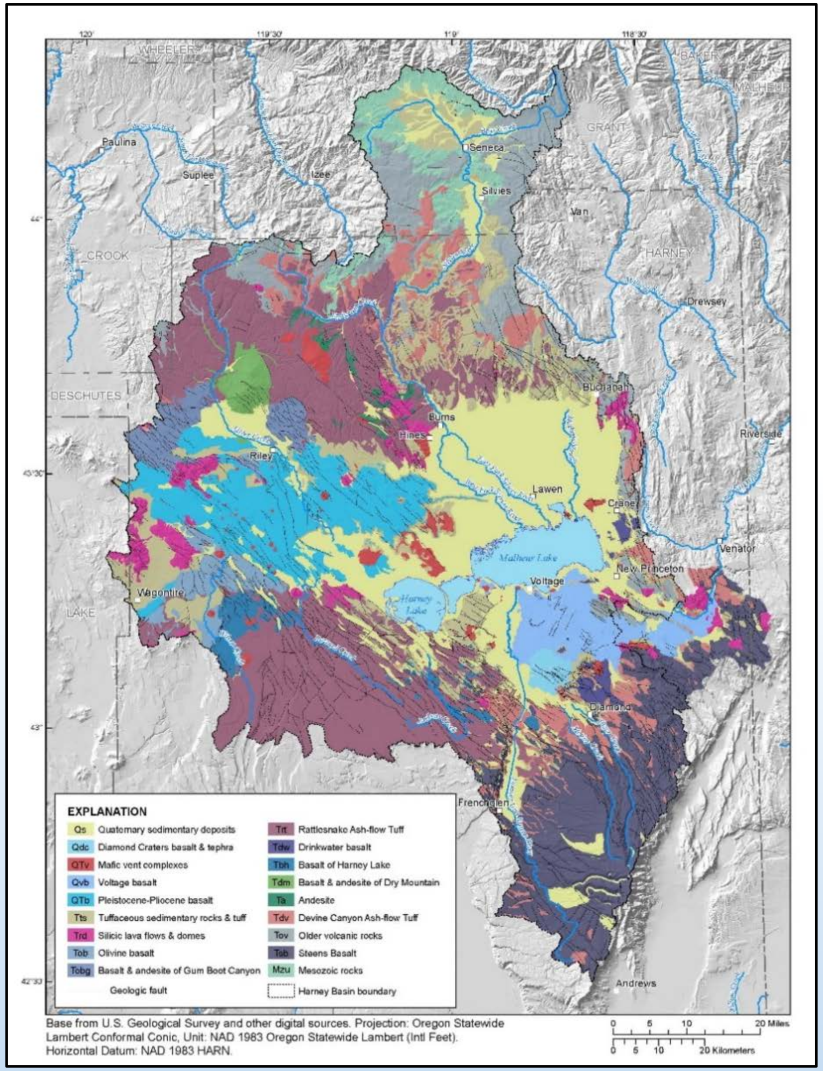
All Transmissivity



Largest Transmissivity



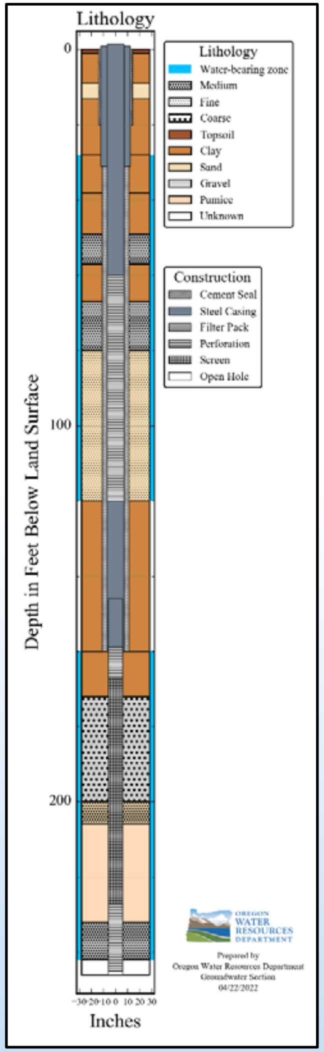
Transmissivity Tied to Geologic Units

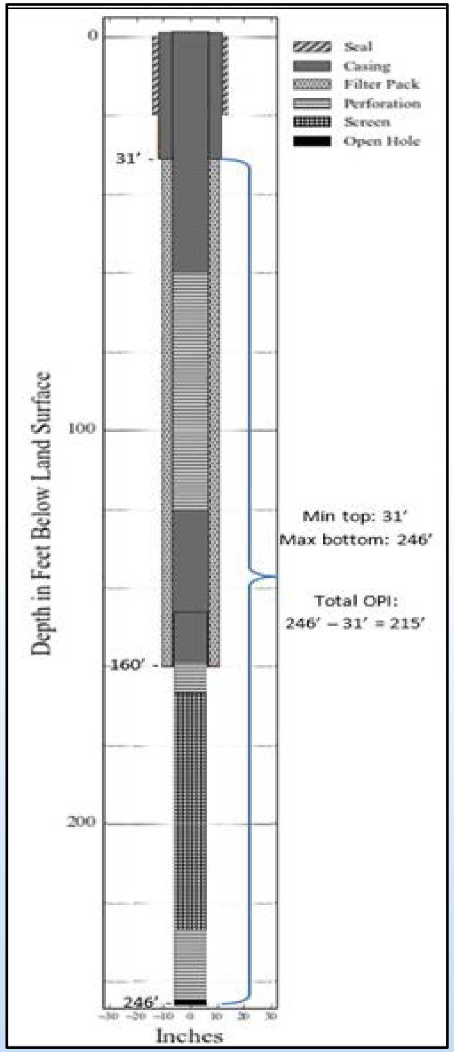


Redisplayed from Boschmann (2021)

Stratigraphic Unit Map (18 Units)

Well Lithology Construction Open Interval





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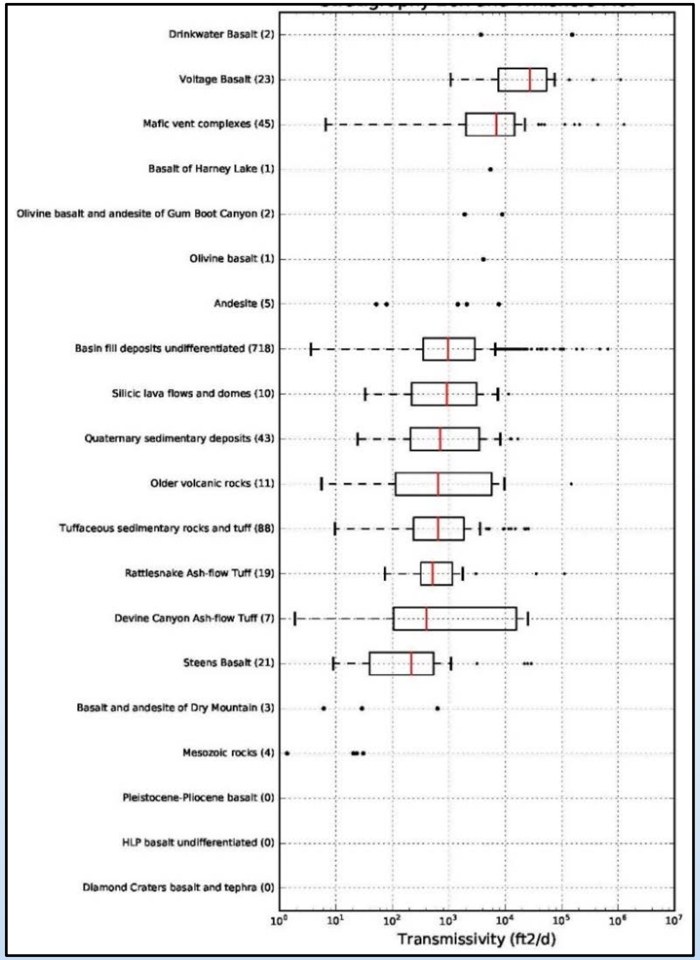
Stratigraphic to Hydrostratigraphic Units

18 Stratigraphic Units Transmissivity Range (ft^2/d)



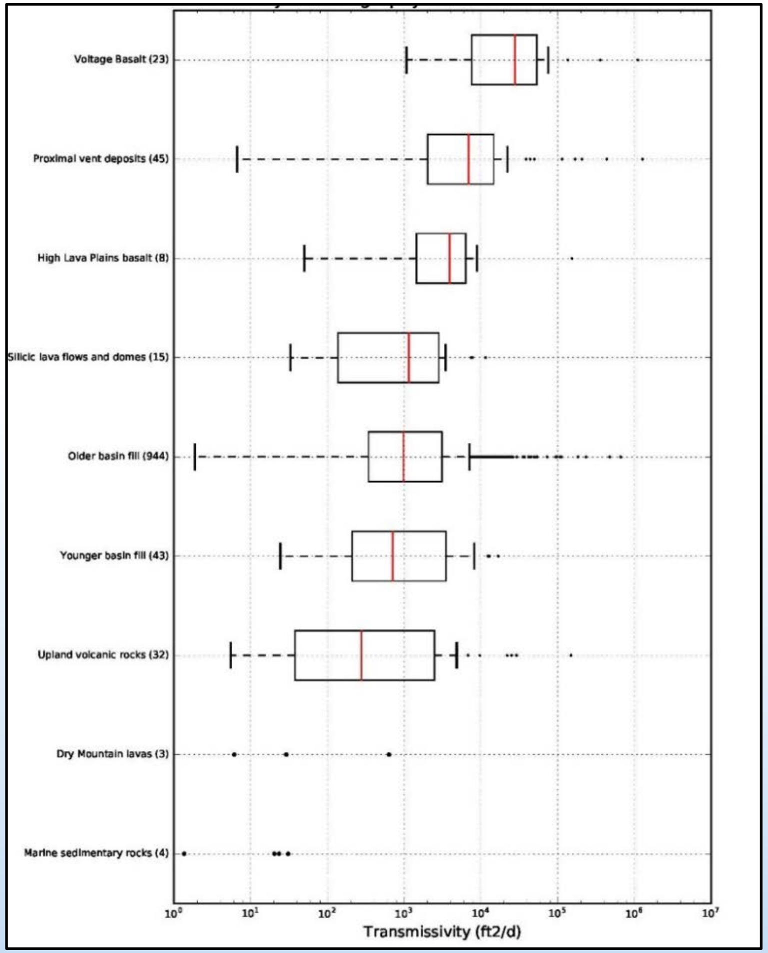
From Grondin (2021)

Group Stratigraphic Units to Hydrostratigraphic Units

Similar Hydraulic Properties

Similar Geologic Properties

9 Hydrostratigraphic Units Transmissivity Range (ft^2/d)

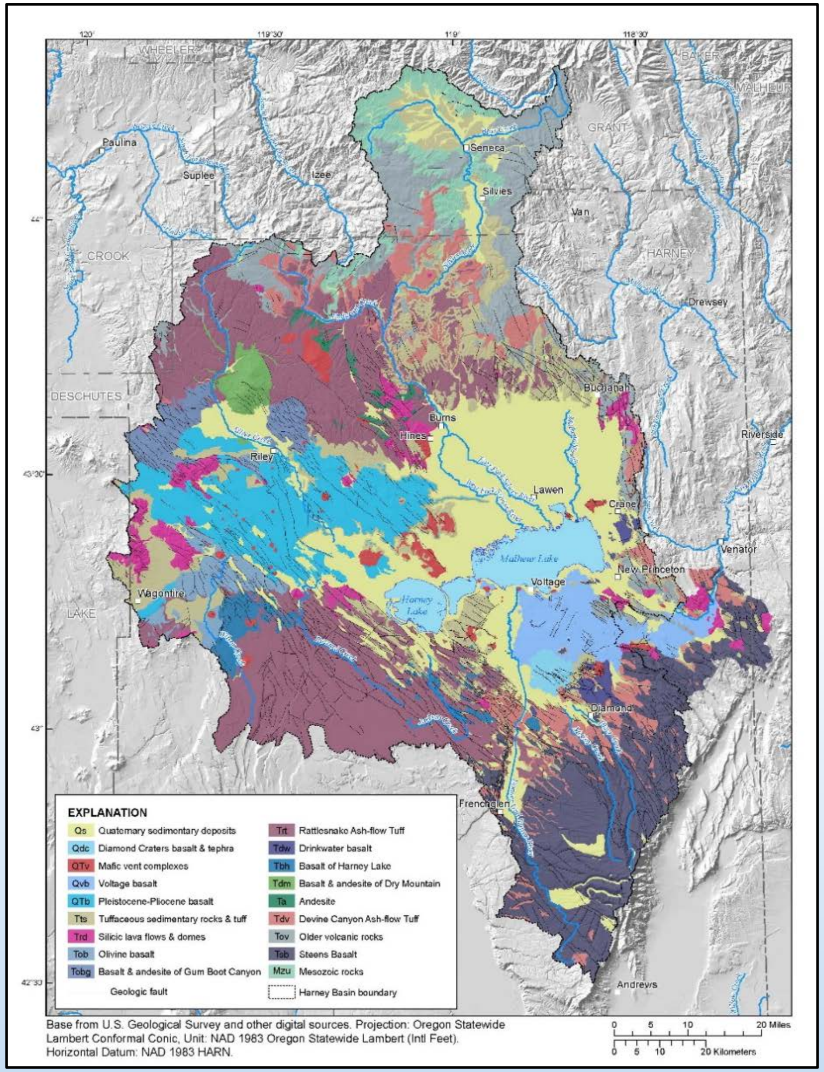


From Grondin (2021)

Younger Units Larger Transmissivity

Older Units Smaller Transmissivity

Stratigraphic to Hydrostratigraphic Units

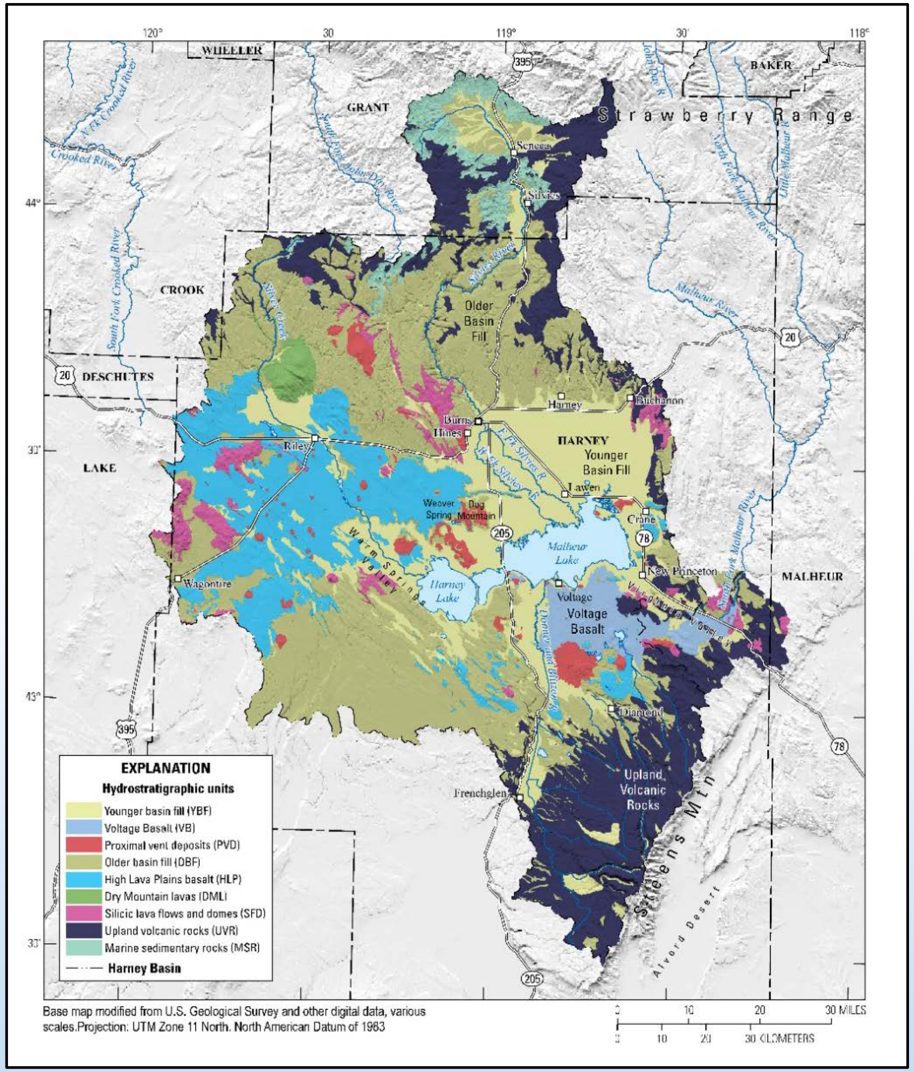


Redisplayed from Boschmann (2021)

Group 18 Stratigraphic Units to 9 Hydrostratigraphic Units

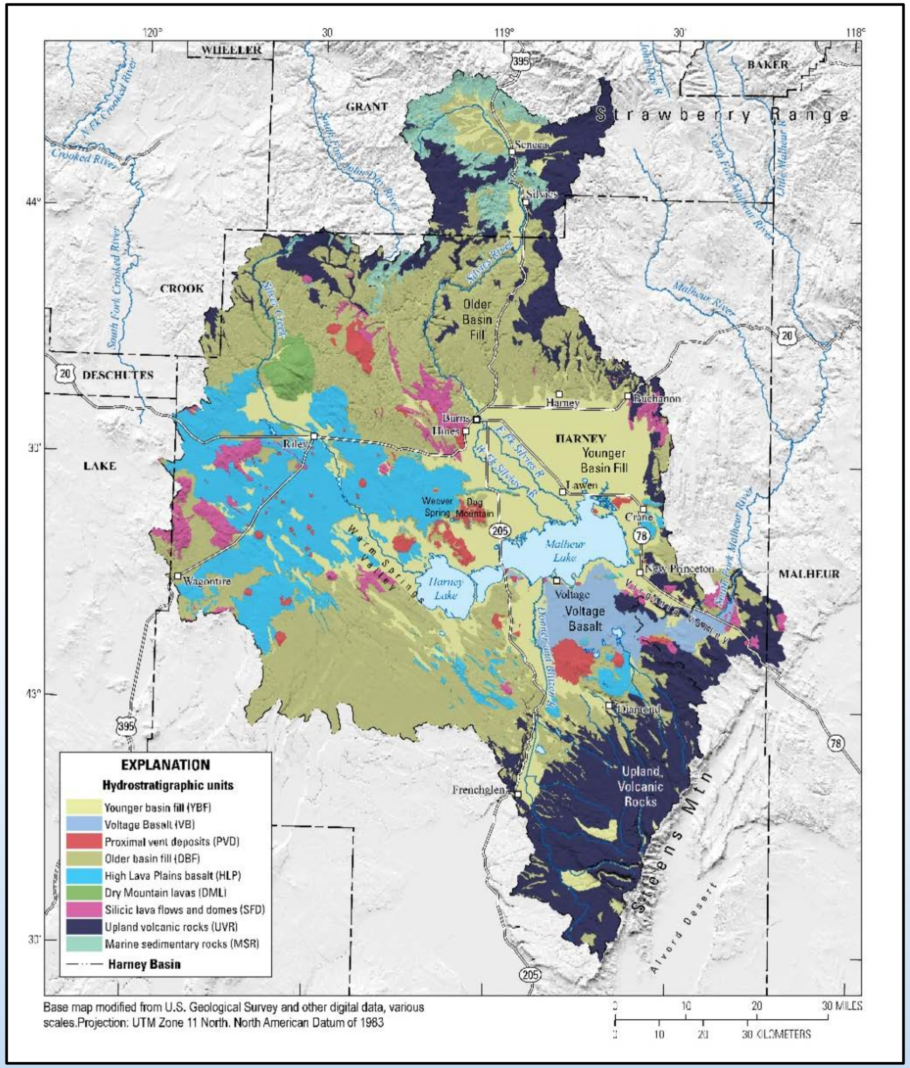
Similar Hydraulic Properties

Similar Geologic Properties



From Grondin (2021)

Study Takeaway #2



From Grondin (2021)

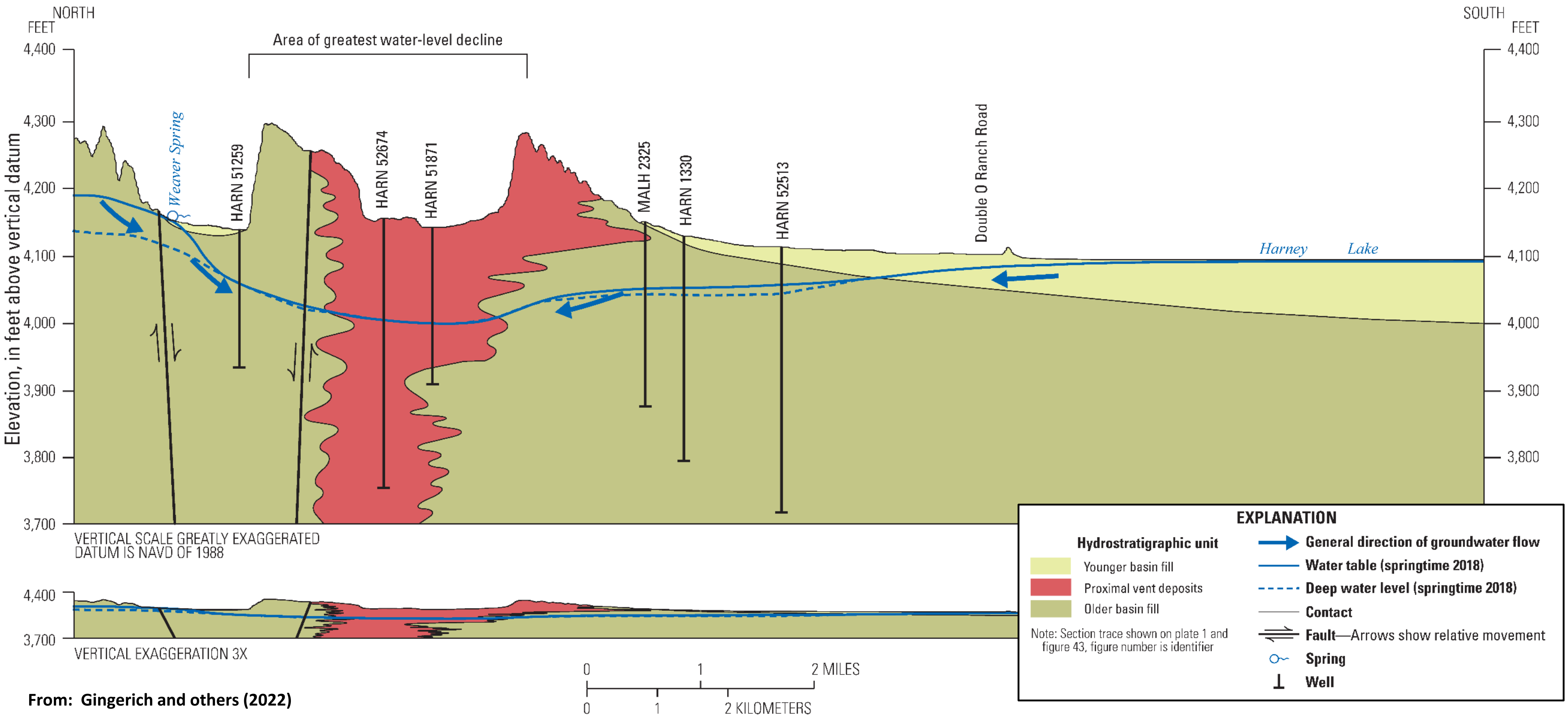
<u>Study Takeaway #2:</u>

<u>Hydrostratigraphy is a major key to understanding Harney Basin groundwater and finding solutions to groundwater problems</u>

Hydrostratigraphy & related transmissivity informs:

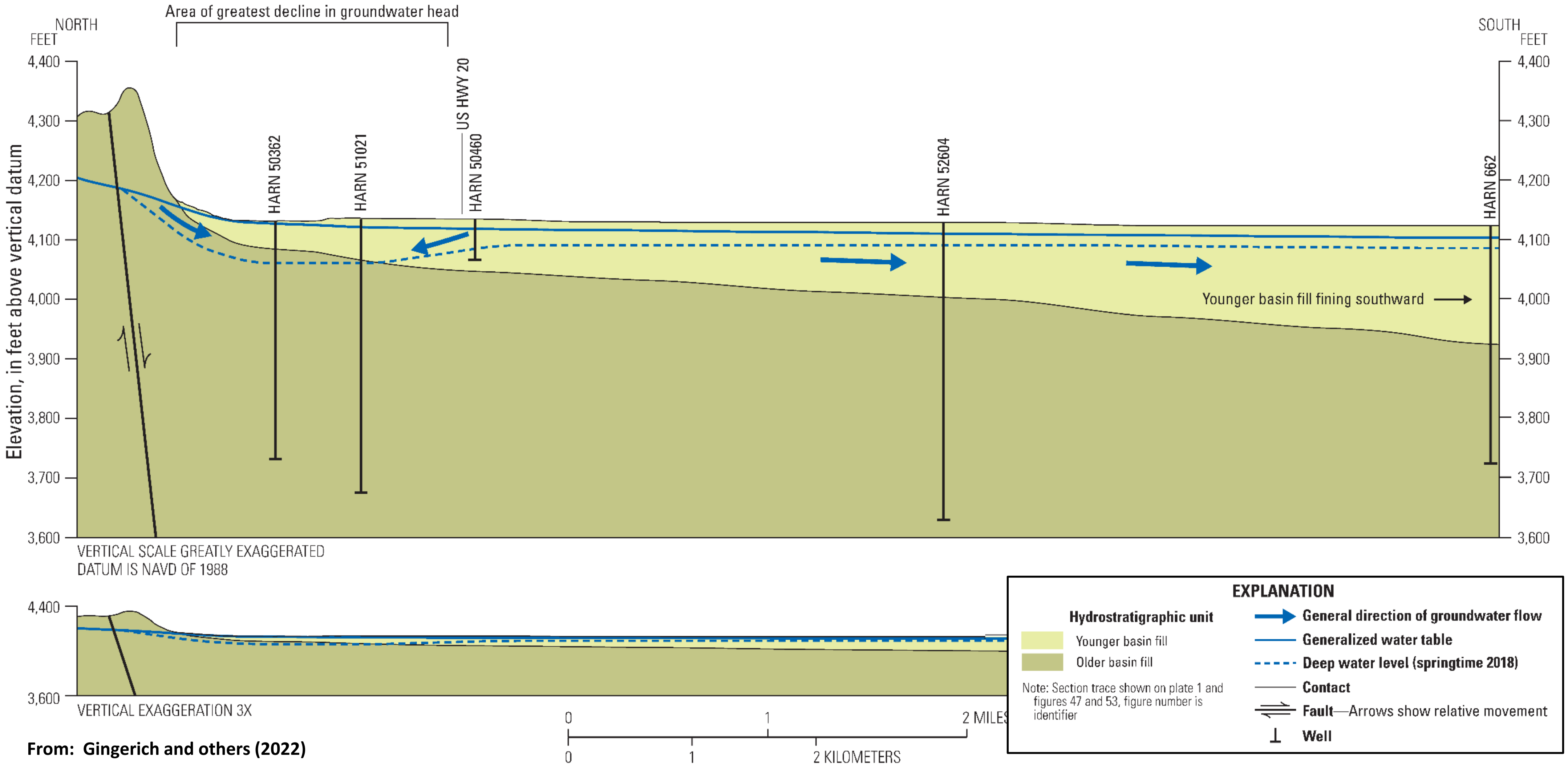
- **Understanding groundwater flow within the basin**
  - **Flat gradient vs. steeper gradient areas**
- **Understanding groundwater response to pumping**
  - **Cones of depression vs. area-wide decline**
- **Water budget within the basin**
  - **Controls on recharge and discharge**

Hydrostratigraphy: Weaver Springs



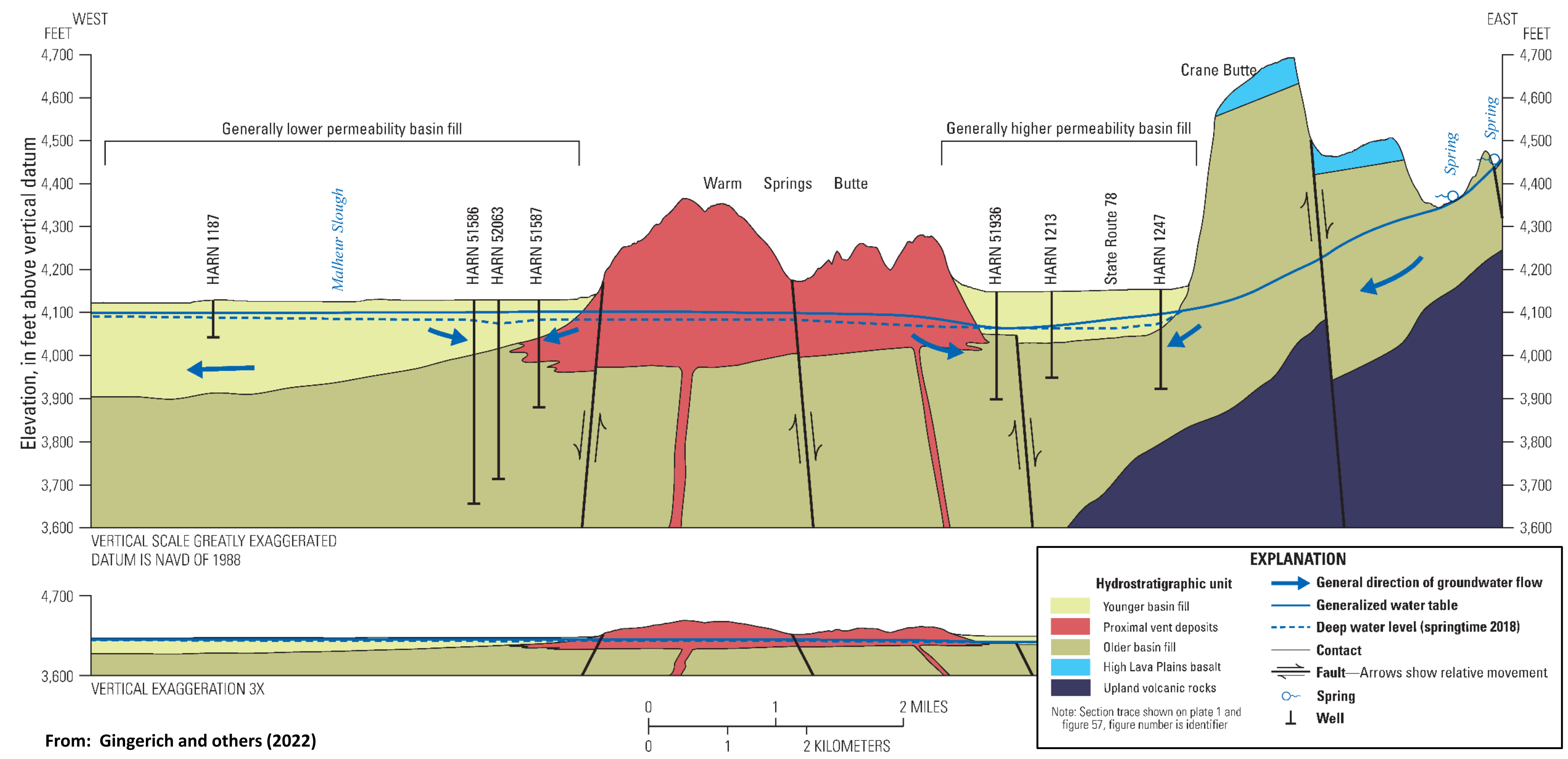
From: Gingerich and others (2022)

Hydrostratigraphy: North Harney Valley



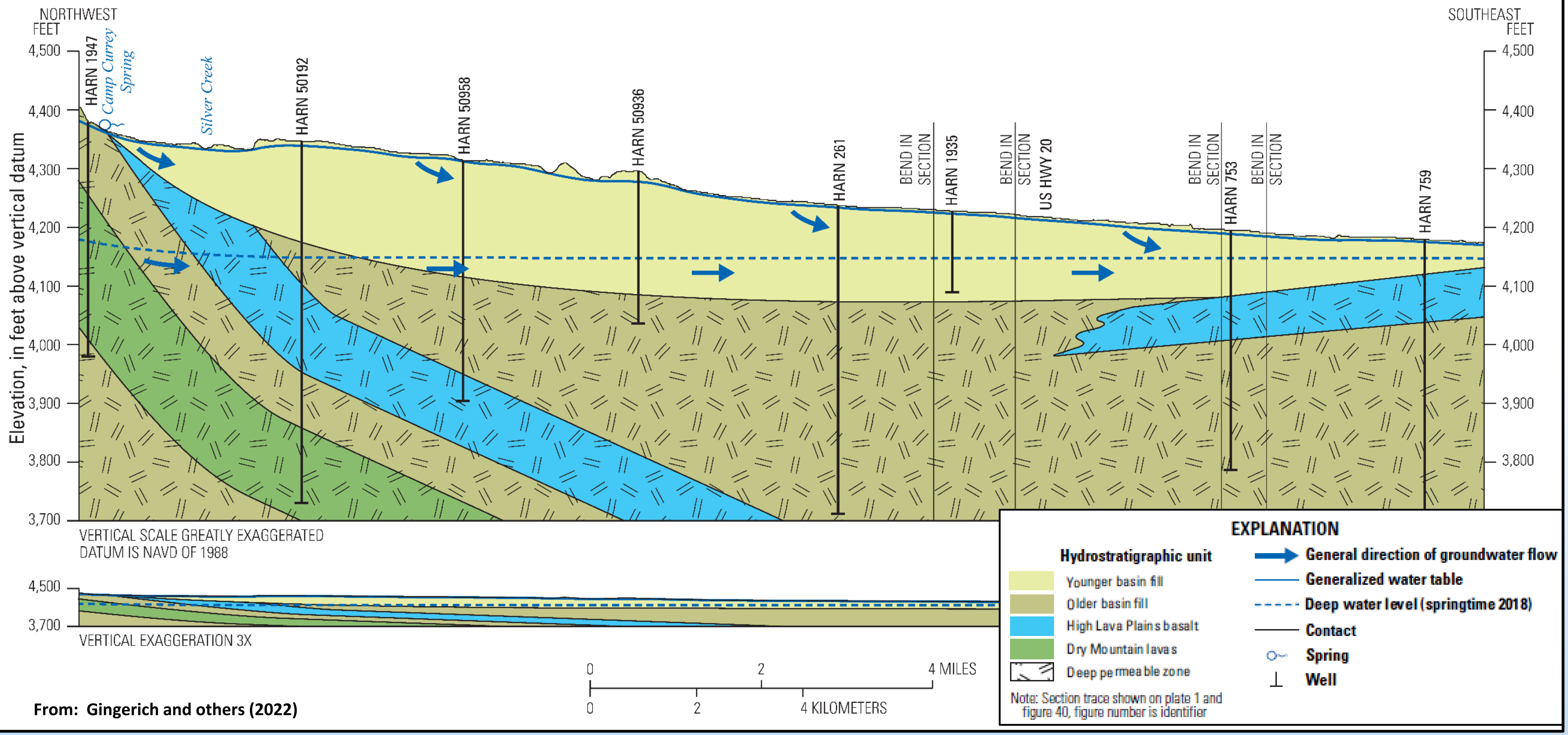
From: Gingerich and others (2022)

Hydrostratigraphy: Crane Vicinity



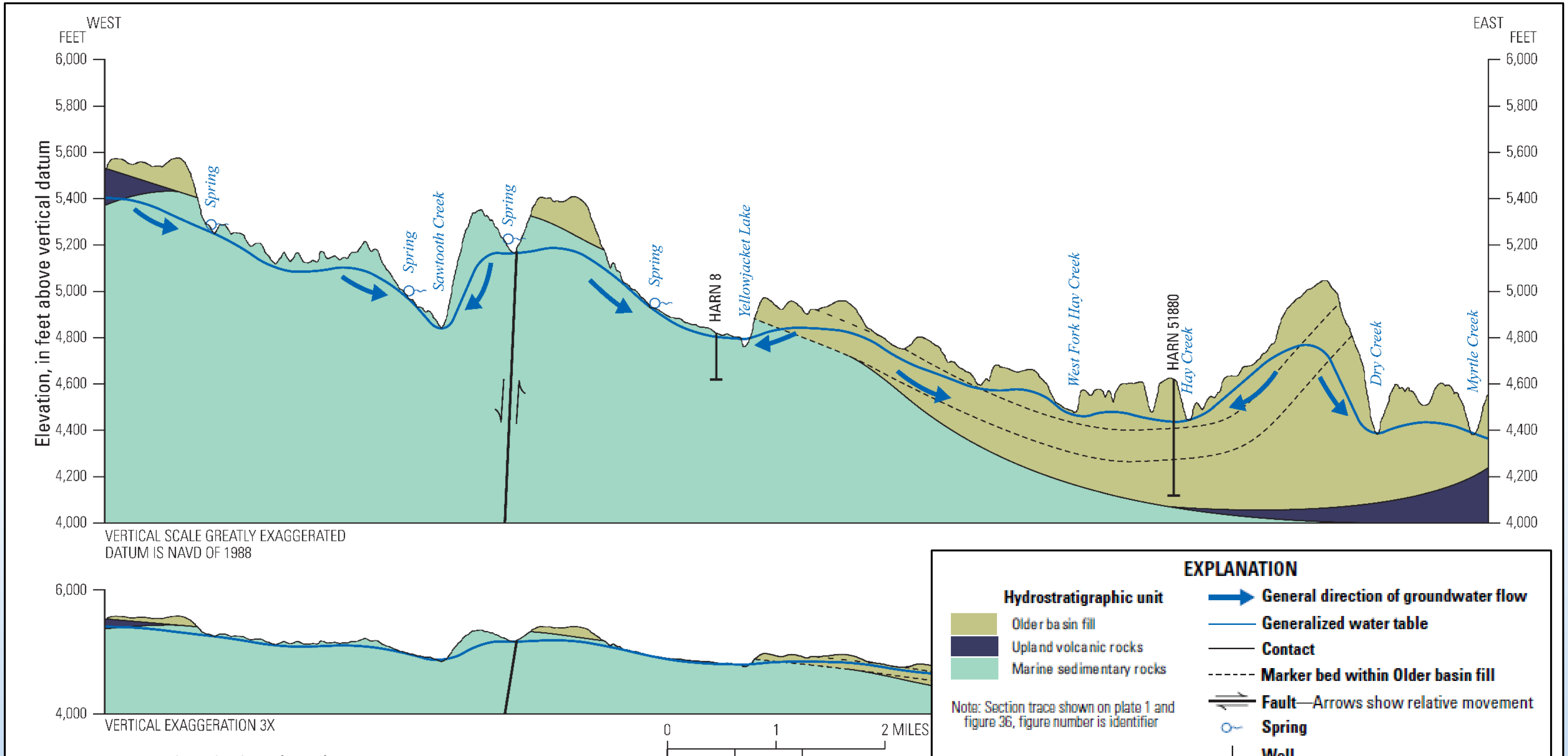
From: Gingerich and others (2022)

Hydrostratigraphy: Silver Creek



From: Gingerich and others (2022)

Hydrostratigraphy: North Uplands



From: Gingerich and others (2022)

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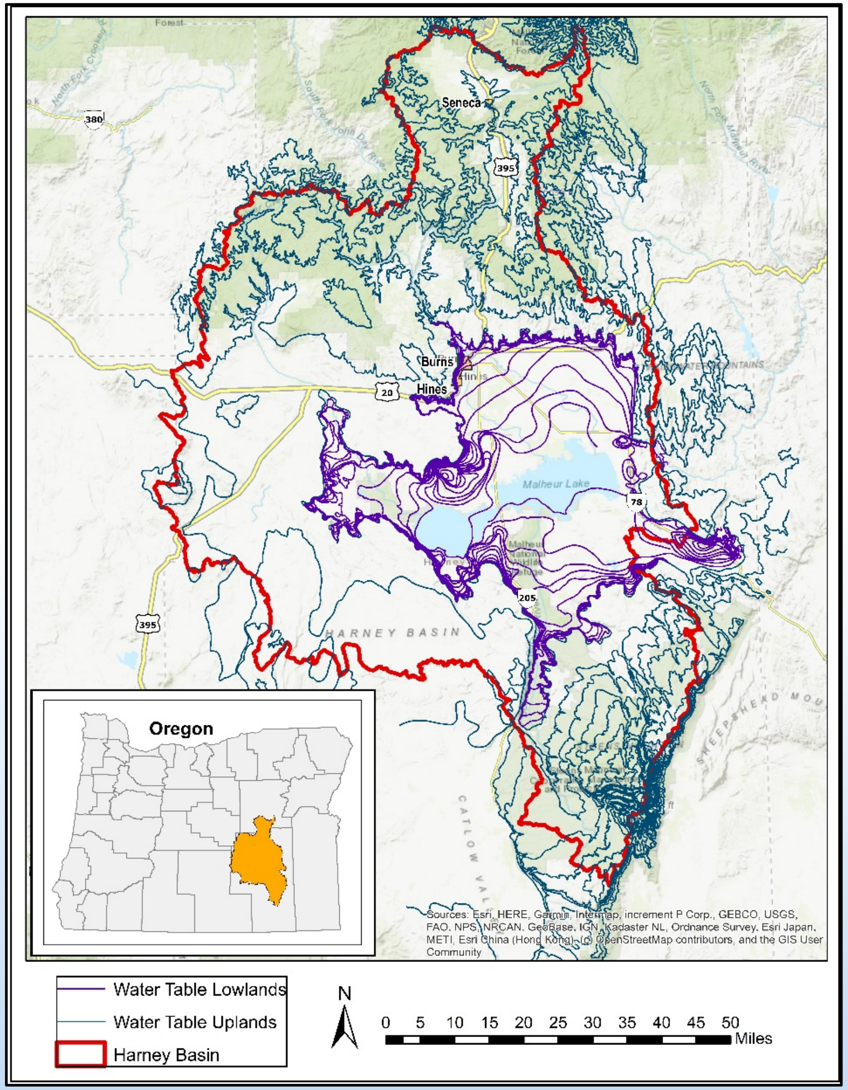
Study Takeaway #3



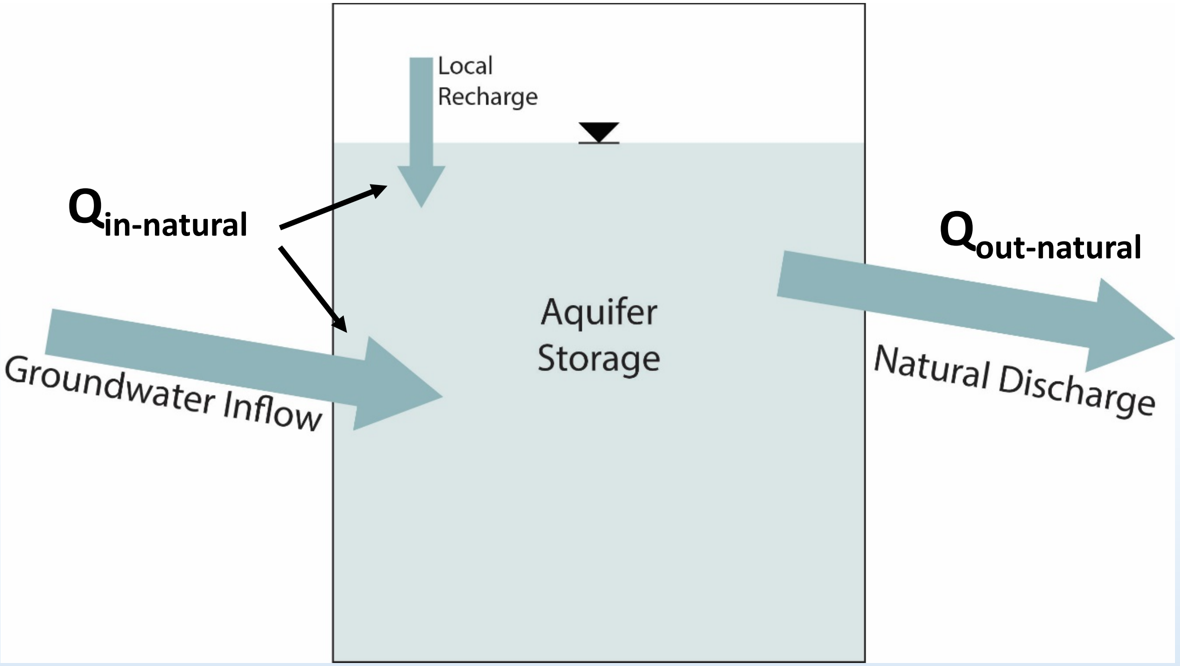
Study Takeaway #3:

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

Groundwater Budget Concepts

Pre-Development



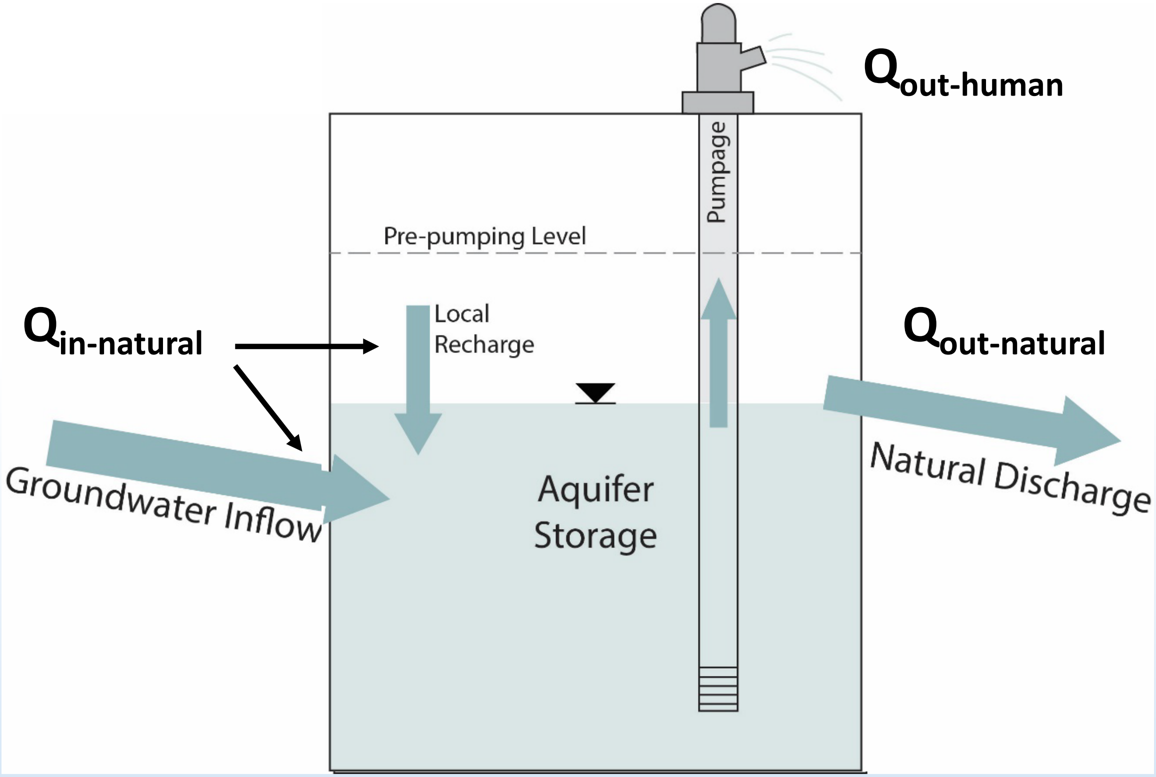
$Q_{in\text{-}natural} = Q_{out\text{-}natural}$

Pre-Development

- **Dynamic equilibrium (inflow = outflow)**
- **Natural inflow to groundwater includes:**
  - **Precipitation**
  - **Surface water loss to subsurface**
  - **Groundwater inflow from neighbor area**
- **Natural groundwater outflow includes:**
  - **Groundwater outflow to surface water**
  - **Evaporation**
  - **Plant transpiration**
  - **Groundwater outflow to neighbor area**
- **Groundwater levels are steady long-term but can have short-term variability**
- **"Stored" water is not static but moves from inflow to outflow**

Groundwater Budget Concepts

Post-Development



$Q_{in\text{-}natural} = Q_{out\text{-}natural} + Q_{out\text{-}human}$ **(new equilibrium)**

or

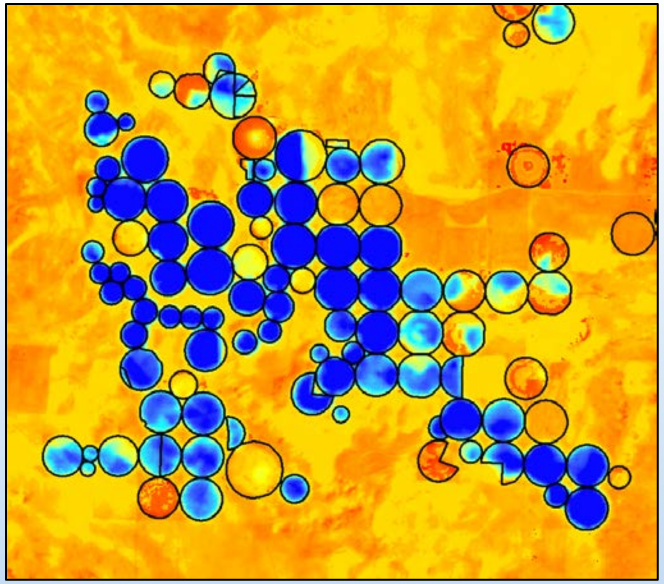
$Q_{in\text{-}natural} < Q_{out\text{-}natural} + Q_{out\text{-}human}$ **(disequilibrium)**

Post-Development

- **Human groundwater development causes changes**
  - **Human outflow added to groundwater system**
  - **Natural groundwater inflow may increase**
  - **Natural groundwater outflow often decreases**
  - **Groundwater "storage" often changes seen as new lower stable groundwater levels or ongoing groundwater level decline**
- **New equilibrium:**
  - **When inflow and new total outflow equal**
  - **Possibly new lower, stable groundwater levels**
  - **Possibly new lower natural groundwater outflow**
- **Disequilibrium:**
  - **When new total outflow exceeds inflow**
  - **Possibly ongoing decrease in groundwater level and/or decrease in natural groundwater outflow**

Harney Basin Water Budget Data Sources

Eddy Covariance Station



Satellite Imagery

Harney Basin Water Budget Data Sources

- Climate data (multiple sources)
- Soil data
- Land cover data
- Satellite imagery and Eddy covariance stations
- Flow measurements (published, unpublished, study)
- Water and plant chemistry (study sampling-analyses)
- OWRD water right data
- OHA community (public facility) water system data
- OWRD well construction data
- Water use (pumpage) reported to OWRD
- Published water use indices (various uses & sources)

Data Sources, Analyses, and Results Detailed in

- Beamer and Hoskinson (2021), Grondin (2021)
- Garcia and others (2022), Gingerich and others (2022)

Harney Basin Upland GW Budget

Upland Groundwater Recharge & Discharge (acre-feet/year)

Adapted from: Garcia and others (2022)

Component	Annual mean by region (acre-feet)			
	North	South	West	Harney Basin
Upland Recharge				
Precipitation and snowmelt	86,000	157,000	45,000	288,000
Total Upland Recharge	**86,000**	**157,000**	**45,000**	**288,000**
Upland Discharge				
Stream base flow	75,000	125,000	25,000	225,000
Springs[1]	2,000	12,000	22	14,000
Groundwater flow to lowlands	9,000	20,000	20,000	49,000
Total Upland Discharge	**86,000**	**157,000**	**45,000**	**288,000**
Recharge minus Discharge	**0**	**0**	**0**	**0**

[1]Estimates represent discharges unaccounted for in base-flow estimates and include current and historical spring discharge measurements

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Harney Basin Lowland GW Recharge

Lowland Groundwater Recharge (acre-feet/year)

Adapted from: Garcia and others (2022)

Lowland Recharge	Mean annual recharge by region (acre-feet)			
	North	South	West	Harney Basin
Sources				
Groundwater inflow from uplands	9,000	20,000	20,000	49,000
Streams and floodwater (natural) [1,2]	40,000	900	18,000	59,000
Malheur and Harney Lakes[1]	47	—	160	210
Surface water (irrigation) [1]	24,000	26,000	7,300	57,000
Sub-Total	**73,000**	**47,000**	**45,000**	**165,000**
Groundwater pumpage reinfiltration				
Groundwater irrigation and non-irrigation use[3]	4,800	1,200	2,200	8,200
Total Lowland Recharge (all sources)	**78,000**	**48,000**	**47,000**	**173,000**

[1]Includes a portion of upland runoff and base flow.

[2]In the southern region, recharge from streams and floodwater is mostly accounted for in irrigated areas, and channel losses are assumed to be equally offset by base-flow gains between Frenchglen and Diamond Lane.

[3]Estimate is basin wide, but 99.9 percent occurs either within the lowland boundary or within two miles outside of the lowland boundary.

Harney Basin Lowland GW Discharge

Lowland Groundwater Discharge (acre-feet/year)

Adapted from: Garcia and others (2022)

Lowland Discharge	Mean annual discharge by region (acre-feet)			
	North	South	West	Harney Basin
Natural Discharge				
Springs[1], Evapotranspiration[2], Seepage to lakes	64,000	28,900	35,000	127,900
Groundwater outflow to Malheur River Basin	NA	3,100	NA	3,100
Sub-Total (natural discharge)	**64,000**	**32,000**	**35,000**	**131,000**
Groundwater pumpage discharge				
Irrigation pumpage[3]	81,000	22,000	42,000	145,000
Non-irrigation pumpage[3]	6,100	470	400	7,000
Sub-Total (pumpage discharge)	**87,000**	**22,000**	**43,000**	**152,000**
Total Lowland Discharge (all components)	**151,000**	**54,000**	**78,000**	**283,000**
Total Lowland Recharge minus Discharge	**-73,000**	**-6,000**	**-31,000**	**-110,000**

Note: Summation discrepancies solely from rounding of component estimates

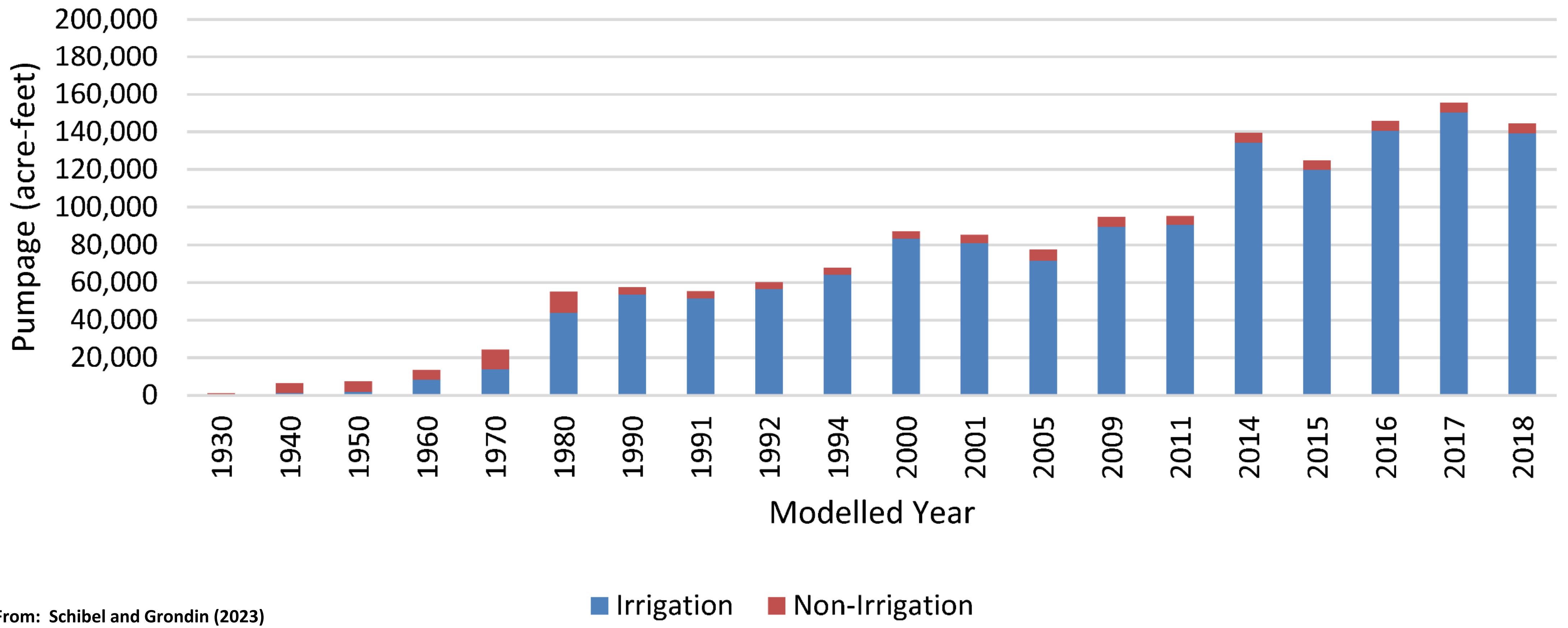
[1]Mean of measurements made during 1907–80

[2]ET_{GW} from non-irrigated areas and spring-irrigated agriculture. Includes ET_{GW} of spring discharge

[3]Estimate is basin wide, but 99.9 percent occurs either within the lowland boundary or within two miles outside of the lowland boundary.

Harney Basin GW Pumpage

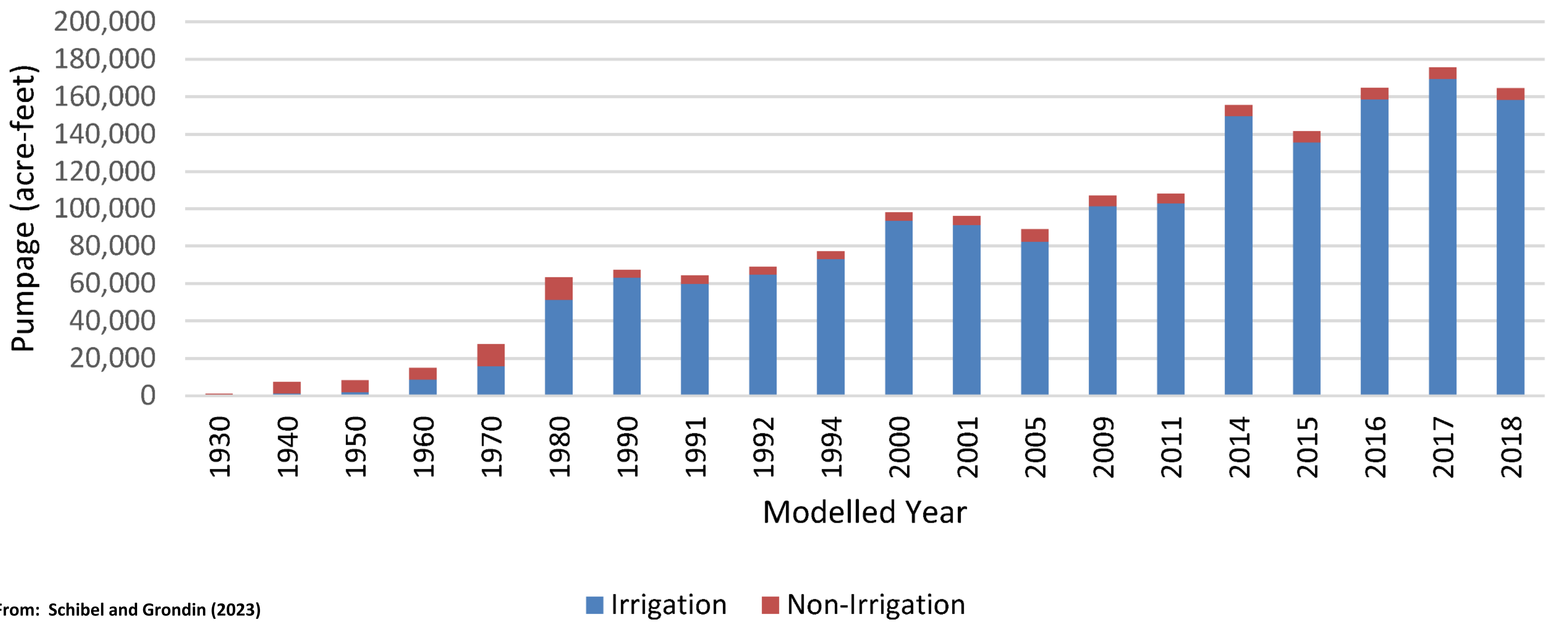
Estimated Groundwater Pumpage in the Harney Basin GHVGAC (1930-2018)
(acre-feet/year)



From: Schibel and Grondin (2023)

Harney Basin GW Pumpage

Estimated Groundwater Pumpage for the Entire GW Model Area (1930-2018) (acre-feet/year)



From: Schibel and Grondin (2023)

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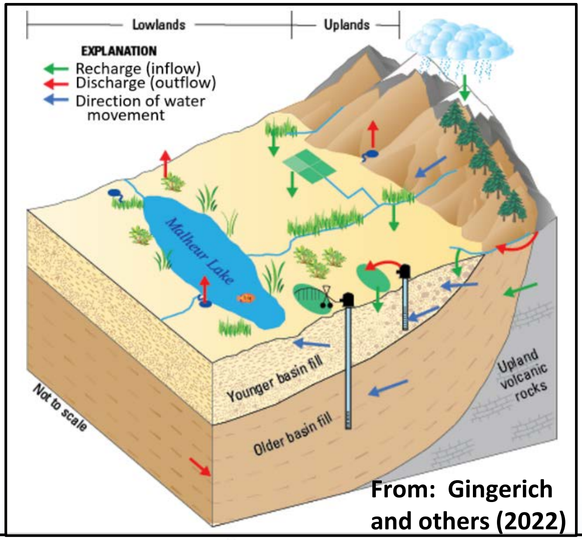
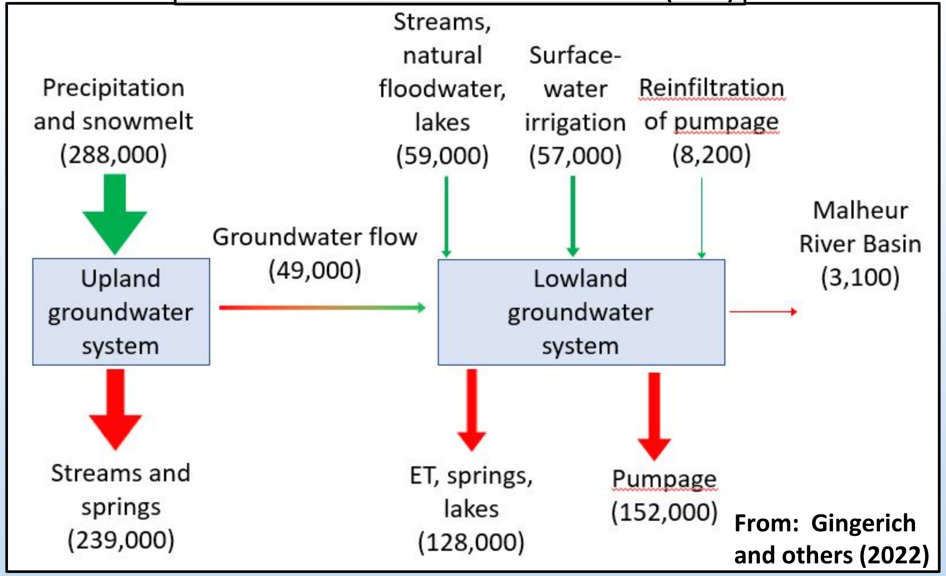
Study Takeaway #4



From: Gingerich and others (2022)



From: Gingerich and others (2022)

Study Takeaway #4:
Harney Basin Groundwater Budget Balances in the Uplands and Does Not Balance in the Lowlands

- **Upland groundwater budget:**
  - **Minimally affected by groundwater development**
  - **Generally represents the natural system**
- **Lowland groundwater budget:**
  - **Accounts for most groundwater development**
  - **Is out of balance by about -110,000 acre-feet/year**
  - **Imbalance is primarily seen as groundwater removed from storage with 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**

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Groundwater Study Key Takeaways

Key Takeaways

1. **Most Harney Basin groundwater is ancient (recharged 5,000 to 30,000 years ago), and 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 system, a continuum**

4. **Harney Basin groundwater budget balances in the uplands; it does not balance in the lowlands (deficit of 110,000 acre-feet/year)**

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Thank You

References and Related Reports

- Beamer, J.P., and Hoskinson, M.D., 2021, Historical irrigation water use and groundwater pumpage estimates in the Harney Basin, Oregon, 1991–2018: Oregon Water Resources Department Open File Report 2021–02, 53 p. [Also available at https://www.oregon.gov/owrd/wrdreports/OWRD_OFR_2021-02_Harney_Basin_METRIC_Irrigation_Use_Report.pdf.]

- Boschmann, D.E., 2021, Generalized geologic compilation map of the Harney Basin: Oregon Water Resources Department Open File Report 2021–01, 57 p. [Also available at https://www.oregon.gov/owrd/wrdreports/OFR_2021-01_report.pdf.]

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- Garcia, C.A., Corson-Dosch, N.T., Beamer, J.P., Gingerich, S.B., Grondin, G.H., Overstreet, B.T., Haynes, J.V., and Hoskinson, M.D., 2022, Hydrologic budget of the Harney Basin groundwater system, Oregon: U.S. Geological Survey Scientific Investigations Report 2021–5128, 140 p. [Also available at https://doi.org/10.3133/sir20215128.]

- Garcia, C.A., Haynes, J.V., Overstreet, B., and Corson-Dosch, N., 2021, Supplemental data—Hydrologic budget of the Harney Basin groundwater system, Oregon: U.S. Geological Survey data release. [Also available at https://doi.org/10.5066/P9QABFML.]

- Gingerich, S.B., Johnson, H.M., Boschmann, D.E., Grondin, G.H., and Garcia, C.A., 2021, Contour data-set of the potentiometric surfaces of shallow and deep groundwater-level altitudes in Harney Basin, Oregon, February–March 2018: U.S. Geological Survey data release. [Also available at https://doi.org/10.5066/P9ZJTZUV.]

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References and Related Reports (cont.)

- Gingerich, S.B., Garcia, C.A., and Johnson, H.M., 2022, Groundwater resources of the Harney Basin, southeastern Oregon: U. S. Geological Survey Fact Sheet 2022-3052, 6 p. https://doi.org/10.3133/fs20223052.

- Gingerich, S.B., Johnson, H.M., Boschmann, D.E., Grondin, G.H., and Garcia, C.A., 2022, Groundwater resources of the Harney Basin, Oregon: U.S. Geological Survey Scientific Investigations Report 2021–5103, 116 p. [Also available at https://doi.org/10.3133/sir20215103.]

- Gingerich, S.B., Johnson, H.M., Boschmann, D.E., Grondin, G.H., Garcia, C.A., and Schibel, H.J., 2022, Location information, discharge, and water-quality data for selected wells, springs, and streams in the Harney Basin, Oregon: U.S. Geological Survey data release. [Also available at https://doi.org/10.5066/P9J0FE5M.]

- Grondin, G.H., 2021, Methods and results for estimating groundwater pumped, returned, and consumed for nonirrigation uses in the Harney Basin, Oregon: Oregon Water Resources Department Open File Report 2021–03, 28 p. [Also available at https://www.oregon.gov/owrd/wrdreports/OWRD_OFR_2021-003_Harney_Basin_non_irrigation_GW_use_report_stamped.pdf.]

- Grondin, G.H., Boschmann, D.E., Barnett, H.J., and Scandella, B.P., 2021, Methods and results for estimating the hydraulic characteristics of the subsurface materials in the Harney Basin, Oregon: Oregon Water Resources Department Open File Report 2021–04, 63 p. [Also available at https://www.oregon.gov/owrd/wrdreports/OFR_2021-04_Harney_Basin_subsurface_hydraulic_properties.pdf.]

- Schibel, H.J. and Grondin, G.H., 2023, Methods and results for estimating 1930-2018 well pumpage in the Harney Basin, Oregon: Oregon Water Resources Department Open File Report 2023–01, 72 p. [Also available at https://www.oregon.gov/owrd/programs/GWWL/GW/HarneyBasinStudy/Pages/default.aspx]