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TECHNICAL MEMORANDUM

Numerical Groundwater Modeling to Evaluate the Effect of Artificial Recharge on a Groundwater Pump and Treat System, Former Umatilla Army Depot, Umatilla County, Oregon

To: John Shafer / Umatilla County

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EXP: 5/2024

Attachments: Figures.
Attachment A. Target Well Hydrographs.
Attachment B. Calibration Plots.

Date: December 8, 2023

This technical memorandum (TM), prepared by GSI Water Solutions, Inc. (GSI), summarizes an evaluation of the effect of a proposed artificial recharge project on an existing groundwater contaminant plume that is currently hydraulically controlled by a groundwater pump and treat system at the former Umatilla Army Depot. The evaluation was conducted to support Umatilla County's (the County) Ordnance Gravel Aquifer Recharge Project.

1. Introduction

This section provides an overview of the County's Ordnance Gravel Aquifer Recharge Project (Section 1.1), the groundwater contamination that is located about a mile west of the County's proposed recharge site (Section 1.2), and the purpose and objectives of the groundwater modeling evaluation (Section 1.3).

1.1 Umatilla County's Ordnance Gravel Aquifer Recharge Project

Managed aquifer recharge consists of recharging an aquifer with water for subsequent recovery and, in Oregon, is permitted under the Aquifer Storage and Recovery (ASR) or Artificial Recharge (AR) rules. Umatilla County (the County) is developing a project to recharge the Ordnance Gravel Aquifer at the former Umatilla Army Depot (the Depot) using infiltration basins, and will permit the project under Oregon's AR rules. The project will provide public benefit by augmenting groundwater supply without adverse impacts to threatened and endangered species (note that the Ordnance Gravel Aquifer has been designated as a Critical Groundwater Area by the Oregon Water Resources Department) and reducing elevated concentrations of nitrate in groundwater (the Ordnance Gravel Aquifer is located in a Groundwater Management Area for nitrate).

The permit for AR (called an "AR limited license") is issued by the Oregon Water Resources Department (OWRD) in consultation with the Environmental Protection Agency (EPA), Oregon Department of Environmental

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Quality (DEQ), Oregon Department of Fish and Wildlife (ODFW) and, if applicable, Oregon Health Authority (OHA). The County submitted an AR limited license for the Ordnance Gravel Aquifer recharge project to OWRD on September 9, 2023. The County has applied to initially infiltrate 5,000 acre feet (AF) of Columbia River water to the Ordnance Gravel Aquifer annually. The annual recharge volume may be increased if the performance of the aquifer and infiltration basins indicate additional capacity for recharge.

1.2 Groundwater Contamination at the Depot

A groundwater contaminant plume consisting of the explosives RDX, TNT, and DNT is present at the former Umatilla Army Depot, approximately one mile west of the proposed recharge basins. The contaminated groundwater is being remediated under EPA and DEQ oversight by a pump and treat system that began operating in 1996. Pump and treat systems function by hydraulically capturing contaminated groundwater (i.e., so the contamination cannot migrate to potential environmental receptors) using extraction wells, and treating the contaminated groundwater that is removed from the aquifer. At the former Umatilla Army Depot, the system is comprised of three active extraction wells (see EW-4, EW-5 and EW-6 in Figure 1) and two active infiltration fields that return pumped groundwater to the aquifer (see IF-2 and IF-3 in Figure 1).

DEQ and EPA are requiring that County evaluate the impact of the recharge project on the pump and treat system, and the County has agreed to fund an evaluation as part of the AR limited license application. On December 13, 2022, GSI and the County met with representatives from regulatory agencies (OWRD, DEQ, and EPA) and agreed on the scope for the evaluation (i.e., to develop a numerical groundwater model). This new model would supplement previous analytical modeling evaluations that showed the aquifer recharge project would not impact the pump and treat system.

1.3 Purpose and Objectives of Groundwater Modeling

The purpose of the groundwater modeling evaluation summarized in this TM is to determine the effect of artificial recharge on the groundwater pump and treat system. The objectives of the modeling evaluation are:

(1) Conduct a field investigation to develop site-specific measurements of model input parameters (e.g., hydraulic conductivity, aquifer thickness, etc.)[1].
(2) Conduct a literature review to develop a conceptual hydrogeologic model describing the nature and extent of the aquifer distal from the recharge site.
(3) Construct and calibrate a numerical groundwater flow model using the United States Geological Survey (USGS) modeling code MODFLOW-USG.
(4) Run two model scenarios: (a) hydraulic capture of the plume under current conditions (i.e., no recharge) and (b) hydraulic capture of the plume under future conditions (i.e., recharge). By comparing the results of the model scenarios, impacts of the recharge project can be assessed.

The remainder of this TM is organized into a discussion of groundwater modeling methods (Section 2), groundwater modeling results (Section 3), and evaluation conclusions (Section 4).

2. Groundwater Modeling Assessment Methods

To simulate groundwater flow at the Site for various recharge scenarios, GSI constructed a numerical groundwater flow model using the U.S. Geological Survey's modeling code MODFLOW-USG. The hydrogeologic conceptual model developed by GSI during prior phases of work conducted at the Depot (GSI, 2023a; 2023b),

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[1] The field investigation was conducted in 2022 and is documented in GSI (2023a) and GSI (2023b).

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in addition to the USGS modeling study of the Columbia Plateau Regional Aquifer System (USGS, 2015), provided the foundation for the development of this Model.

2.1 Model Domain and Duration

The model grid consists of 121 rows, 129 columns, and 2 layers of evenly-spaced grid cells measuring 800 by 800 feet. The model covers an area of approximately 230,000 acres, with the Depot located at the center of the model. Figure 1 shows the extent of the model domain and the location of the boundary conditions.

The model divides time into monthly stress periods to vary model fluxes over time (e.g. groundwater pumping; groundwater recharge from agricultural return flows, canal leakage, and precipitation; and groundwater recharge from proposed and existing recharge basins). The model simulates the 5-year period from October 2017 to September 2022 (water years 2018 – 2022).

2.2 Model Properties

Layering

The model is composed of two layers representing the sediments overlying the Columbia River Basalt Group (CRBG)[2]. Layer 1 represents Unconsolidated Sedimentary Deposits, including the Ordnance Gravel Aquifer (Figure 1), and Layer 2 represents the Alkali Canyon Formation. Layer elevations and thicknesses were defined based on land surface elevation data, well log data, and a structural contour map of the top of the Columbia River Basalt Group (Grondin et al., 1995).

Hydraulic Conductivity and Storativity

Hydraulic conductivity describes the ease at which fluid moves through porous media. Hydraulic conductivity in the model was initially set based on published geologic data and available aquifer test data. GSI performed an aquifer test on an Ordnance Gravel Aquifer well in 2023 (GSI, 2023b), which provided initial hydraulic conductivity values for Layer 1 for the Ordnance Gravel Aquifer. Hydraulic conductivity values across the model were then manually modified during calibration to better match the observed groundwater levels in target wells.

Storativity is the volume of groundwater that an aquifer releases or accepts per unit surface area per unit change in head. Effective porosity (i.e., specific yield) and specific storage coefficient values for each model layer were initially set based on published values for various aquifer material types. Similar to hydraulic conductivity, storativity values were adjusted during model calibration to achieve a better match between observed and simulated groundwater elevations.

Table 1. Initial Aquifer Properties.

Hydrogeologic Unit	Initial Storage Value	Initial Hydraulic Conductivity Value
Ordnance Gravel	0.25	5,000 feet/day
Alkali Canyon Formation	0.20	10 feet/day
Other Sediments[1]	0.15	100 feet/day

(1) Other sediments are distal from the recharge site and primarily include thick accumulations of eolian sand and/or fine-grained Missoula Flood Deposits.

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[2] The sediments and CRBG do not appear to be hydraulically connected at the Depot. Therefore, groundwater flow in the CRBG was not simulated by the model.

2.3 Boundary Conditions

A boundary condition is any external influence that adds or removes water from the groundwater system. The model uses the following MODFLOW packages for boundary conditions.

River [RIV] Package

The River Package represents the Umatilla River and the Columbia River. Each RIV cell in the model has a specified head (based on elevation data) and simulates river/aquifer seepage, depending on the head gradient between the river and the groundwater system.

Table 2. RIV Package Input Parameters.

Parameter	Umatilla River	Columbia River
Stage Elevation	268 - 525 feet	266 feet
River Bottom Elevation	260 – 517 feet	257 feet
Conductance	10,000 feet^2/day	$6.4\text{x}10^5$ feet^2/day

Well [WEL] Package

The Well Package simulates flow in a specified model cell that withdraws water from or injects water into the aquifer at a constant rate during a stress period. The additional pumping wells in the immediate vicinity of the Depot were identified by utilizing the OWRD Groundwater Mapping Tool in conjunction with the OWRD Water Rights Information System. Pumping rates identified in the water rights data were divided equally among the associated wells for each water right. Average pumping rates at extraction wells and infiltration fields at the Depot are provided in Table 3[3].

Table 3. Average Pumping and Infiltration Rates in Cubic Feet per Day.

Month	EW-4	EW-5	EW-6	IF-2	IF-3
January	125,031	88,727	38,236	62,999	62,999
February	124,142	103,183	22,040	62,341	62,341
March	122,847	104,148	25,543	26,269	26,269
April	127,955	105,361	31,884	66,300	66,300
May	124,659	106,311	32,367	65,834	65,834
June	117,135	101,582	49,242	66,990	66,990
July	135,798	100,871	28,378	66,262	66,262
August	131,952	108,642	19,965	65,140	65,140
September	135,333	103,994	30,429	67,439	67,439
October	124,203	98,969	35,093	64,566	64,566
November	69,940	82,973	39,098	48,003	48,003
December	125,390	262,143	58,376	111,477	111,477

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[3] In the model, actual rates from 2019 to 2022 were provided to GSI by the Depot and were directly input into the model (rates for 2018 were estimated based on 2019 data).

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All other wells within the Model domain were located based on well density and irrigation maps provided in the Lower Umatilla Basin Groundwater Management Area Hydrogeology report (Grondin et. al., 1995); wells were only added to the model in areas identified as being irrigated by groundwater from the Alluvial Aquifer system. Wells pumping from the Basalt aquifers were not included because the sediments and CRBG do not appear to be hydraulically connected at the Depot and basalt wells would not significantly impact the model results (GSI, 2023c). The Well Package was also used to simulate underflow along the southern edge of the model in both Layer 1 and Layer 2. This value was modified during the calibration process.

Recharge [RCH] Package

The Recharge Package simulates areal recharge to groundwater across the entire model domain, including percolation of precipitation, irrigation return flows, and canal leakage. Rates for these elements of recharge were based on published estimates from Grondin et al. (1995). Artificial recharge from the nearby Ordnance Gravel Aquifer Recharge Project were also included in the Recharge Package.

2.4 Model Calibration

The method of calibration used by the model was the standard "history matching" technique, where model simulated groundwater elevations were compared to measured historical groundwater elevations. Groundwater model calibration is achieved by adjusting input parameters, boundary conditions, and model stresses so that modeled heads and fluxes match measured historical values within an acceptable range of error. The groundwater model is evaluated primarily on the statistical evaluation of residuals (field-observed groundwater elevations minus modeled groundwater elevations) in target wells across the model domain. A total of 13 target wells with 566 monthly averaged ground water elevations were used for calibration. Eight of these target wells are owned by the Oregon Military Department are located within the Depot, in the vicinity of the pump and treat system. Five of the remaining target wells are located immediately adjacent to the Depot, to the south and east. These are monitoring wells with data available via the OWRD online database. The calibration period is from water year 2018 through 2022 with the resulting model calibration statistics shown in Table 4.

Table 4. Groundwater Model Statistics (Water Year).

Statistic	Results
Residual Mean	-0.15 ft
Residual Standard Deviation	1.45 ft
Absolute Residual Mean	1.18 ft
Root Mean Square Error	1.45 ft
Residual Sum of Squares	1,200 ft^2
Minimum Residual	-3.32 ft
Maximum Residual	4.69 ft
Range of Observations	9.58 ft
Scaled Res. Std. Dev.	15.1 %
Scaled Abs. Mean	12.3 %
Scaled RMS	15.2 %
Number of Observations	566

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The absolute error statistics (first four values in Table 4) show that the model residuals are within approximately 1.5 feet with a residual mean indicating that on average the modeled values are only -0.15 feet (indicating a slight over-estimation of water levels) from the measured values. The scaled or relative error statistic is a measure of basin wide calibration where absolute statistics [residual standard deviation, root mean square (RMS), absolute residual mean] are divided by the range of observed groundwater elevations to get a general sense basin wide model performance. The rule of thumb calibration goal is to achieve a relative error of less than 10 percent (ESI, 2000-2020; Spitz and Moreno, 1996), where the relative error is the residual standard deviation (1.45 ft) divided by the range in observed values (9.58 ft). The relative error for the model is 15.1 percent, slightly more than the desired 10 percent rule of thumb.

For context, note that the calibration statistics essentially reflect the immediate vicinity of the Depot wellfield as shown in Figure 1. Due to the closely spaced calibration targets, the calibration statistics do not represent a basin wide model calibration, as such, the relative error rule of thumb of less than 10 percent is not as applicable. In this case, a better calibration focus is on the absolute statistics as previously discussed which show that the model is very well calibrated.

The calibrated hydraulic conductivity values are shown in Table 5. The aerial distribution of hydraulic conductivity zones is shown in Figure 3.

Table 5. Calibrated Aquifer Properties.

Hydrogeologic Unit	Calibrated Storage	Calibrated Hydraulic Conductivity
Unconsolidated Sedimentary Deposits	0.10 – 0.15	90 – 1,990 feet/day
Ordnance Gravel	0.15 – 0.35	1,990 – 9,750 feet/day
Alkali Canyon Formation	0.25	1 - 10 feet/day

Calibration results are further summarized in Attachment A containing the hydrographs of 13 target wells showing model-generated water levels compared to measured levels. Attachment B (Figure B-1) presents a scatter plot of modeled heads versus observed heads. The modeled values plot closely to the 1:1 line and are typically within one standard deviation of the mean. Figure B-2 shows the temporal distribution of residuals over time. The results do not indicate any discernible temporal bias. In general, the measured and model predicted heads compare favorably, and that the model is sufficiently calibrated to use as a tool to assess the proposed artificial recharge.

2.5 Recharge Scenarios

To evaluate potential impacts of artificial recharge on hydraulic capture of the contaminant plume, two scenarios were modeled for the 5-year simulation period corresponding to water years 2018 through 2022. The recharge scenarios that were modeled were as follows:

- **Baseline Scenario.** Simulation of conditions <u>without</u> recharge.
- **Recharge Scenario.** Simulation of future conditions with 5,000 acre-feet per year of recharge at the proposed recharge site, with recharge occurring during the seven months from October to April.

The Baseline Scenario served as the reference condition for evaluating the effects of the County's recharge project on hydraulic capture of the plume. Reverse particle tracking was performed using Mod-PATH3DU for both scenarios to estimate capture zones of the Depot's pump and treat system. A capture zone is the three-dimensional extent of groundwater that is intercepted by an extraction well. Reverse particle tracking involves placing the particles at their final destination (i.e., the extraction well) and tracking their trajectory backwards

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to see where the particles originate from. In this case, 15 particles were evenly placed in a 50-foot radius around each of the three active Depot extraction wells.

3. Modeling Results

Figure 2 shows the modeled capture zones in grey-highlight for the Baseline Scenario (left-hand panel) and the Recharge Scenario (right-hand panel). Model-simulated groundwater elevation contours are shown in orange. The extent of the contaminant plume is shown in yellow, and is from September 2022 isocontours of RDX in groundwater. Individual particle traces are shown by the gray lines. Figure 2 indicates that:

- Hydraulic capture of the contaminant plume at the former Umatilla Army Depot is maintained during recharge facility operation.
- The County's recharge project is predicted to enhance contaminant removal by the pump and treat system. Specifically, there is relatively less groundwater movement from the eastern edge of the contaminant plume to the extraction wells under the Baseline Scenario (note low density of particle traces), which likely explains the existence of the remaining area of contaminated groundwater northeast of extraction well EW-6. Under the Recharge Scenario, the steeper hydraulic gradient caused by the recharge basins increases the groundwater flow through the eastern edge of the plume (note the high density of particle traces), which will enhance removal of contamination northeast of extraction well EW-6.

4. Conclusions

The results of this groundwater modeling evaluation suggest the following:

- The groundwater model is sufficiently calibrated within the Umatilla Depot vicinity and may be utilized for additional analyses relevant to artificial recharge scenarios in the future.
- The County's Ordnance Gravel Aquifer Recharge Project does not negatively affect the groundwater contamination plume; the plume is still captured by the extraction well system.
- The County's Ordnance Gravel Aquifer Recharge Project results in more flow of water between the recharge basin and the extraction wells, and may quicken the cleanup of the easternmost contamination plume.

References

ESI. 2000-2020. Guide to Using Groundwater Vistas, version 8. Environmental Simulations, Inc.

Grondin, Gerald H., Wozniak, Karl C., Nelson, Dennis O., Camacho, Ivan. 1995. *Hydrology, Groundwater Chemistry and Land Uses in the Lower Umatilla Basin Groundwater Management Area*.

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GSI. 2023a. Phase I Subsurface Characterization Results, Umatilla Army Depot, Artificial Recharge Project, Umatilla County, Oregon. March 13.

GSI. 2023b. Phase II Subsurface Characterization Results, Umatilla Army Depot, Artificial Recharge Project, Umatilla County, Oregon. July 10.

GSI. 2023c. *Artificial Recharge (AR) Limited License Application.* Technical Memorandum for Umatilla County – Central Area Artificial Recharge Project. September 9, 2023.

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Spitz, K. and J. Moreno. 1996. A Practical Guide to Groundwater and Solute Transport Modeling. John Wiley & Sons, Inc., New York.

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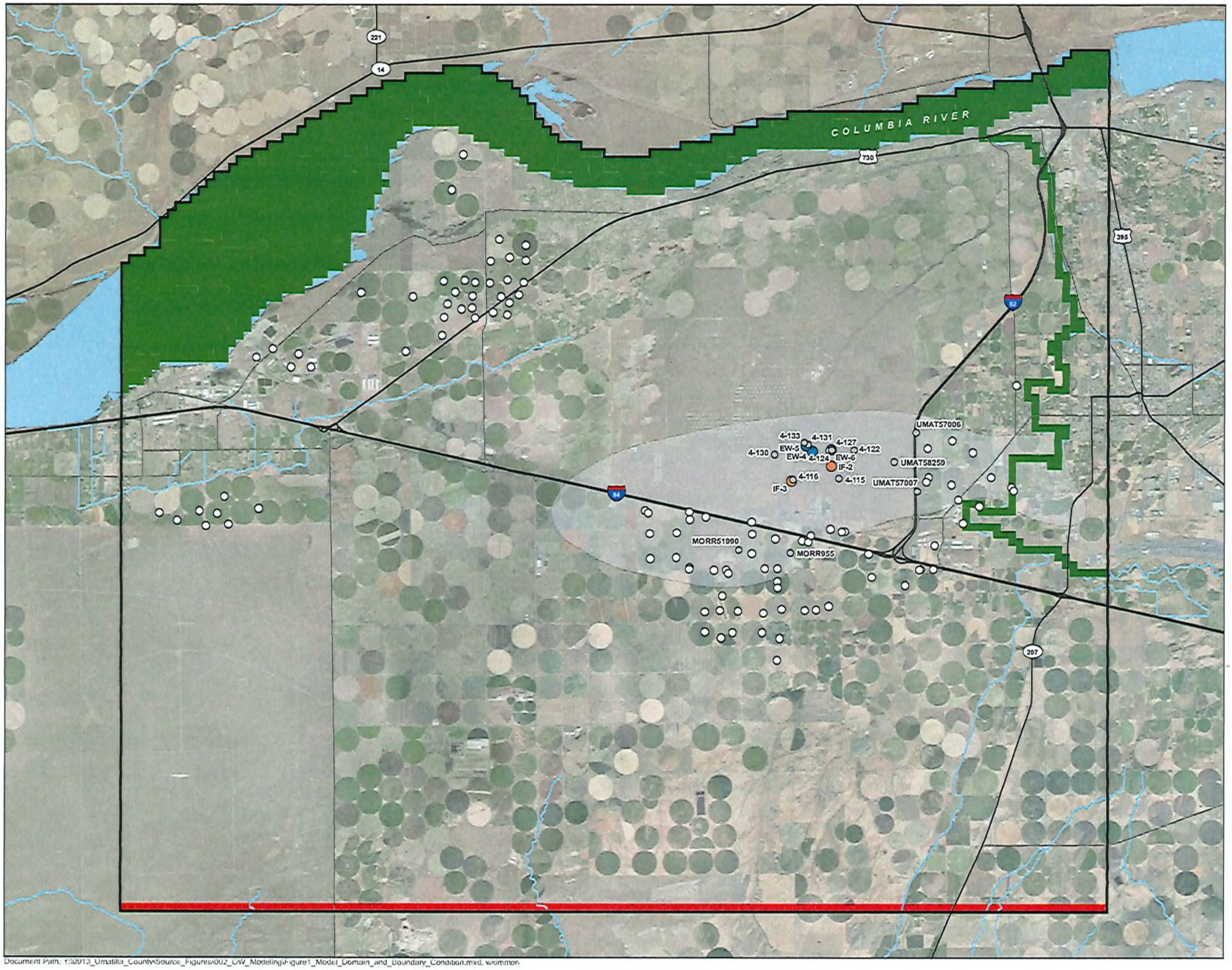
FIGURE 1

Model Domain and Boundary Conditions

Umatilla Army Depot
Groundwater Modeling Evaluation



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LEGEND

- ● Injection Field (Depot)
- ● Extraction Well (Depot)
- ○ Water Elevation Target
- ○ Well Package - Pumping Well
- 🟩 River Package Cell
- 🟥 Well Package – Underflow
- ☐ Active Model Domain
- Extent of Ordnance Gravel Aquifer
- Major Road
- Railroad
- Watercourse
- Waterbody

N

0 5,000 10,000
Feet

Date: November 20, 2023
Data Sources: BLM, ESRI, ODOT, USGS,
Aerial Photo 2020

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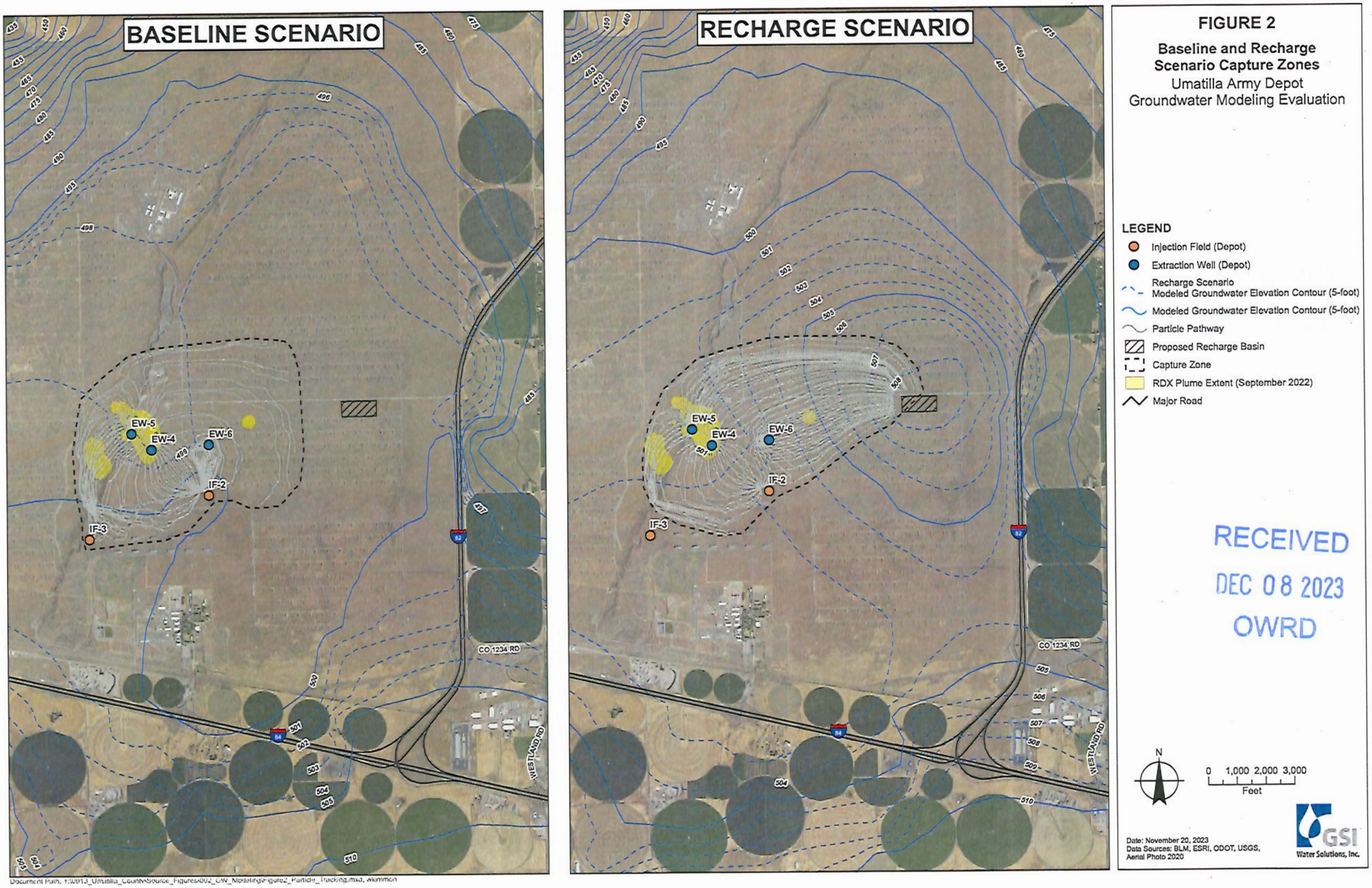
FIGURE 2

Baseline and Recharge Scenario Capture Zones
Umatilla Army Depot
Groundwater Modeling Evaluation



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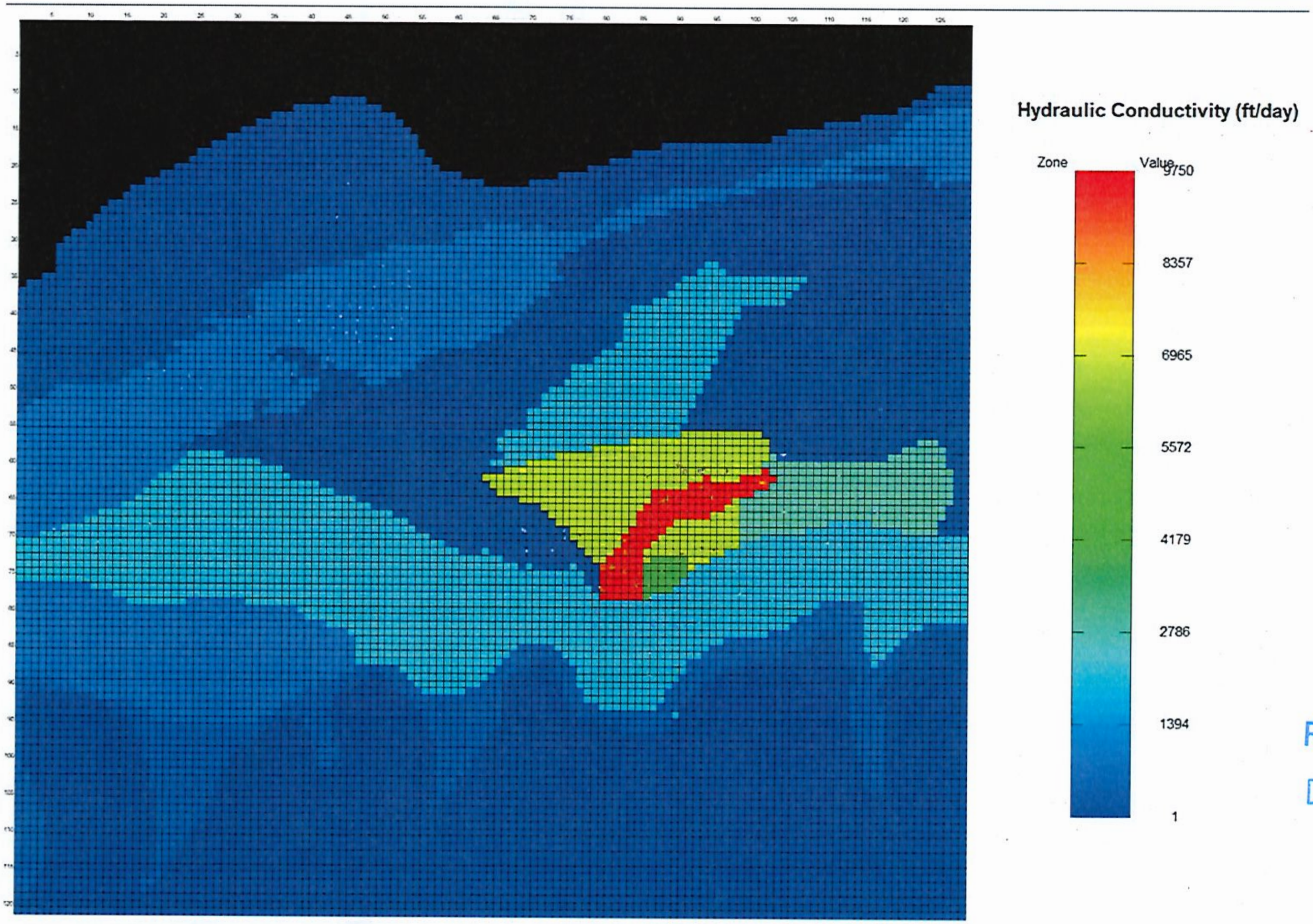

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Figure 3
Hydraulic Conductivity in Layer 1
Umatilla Army Depot Groundwater Modeling Evaluation

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ATTACHMENT A

Target Well Hydrographs

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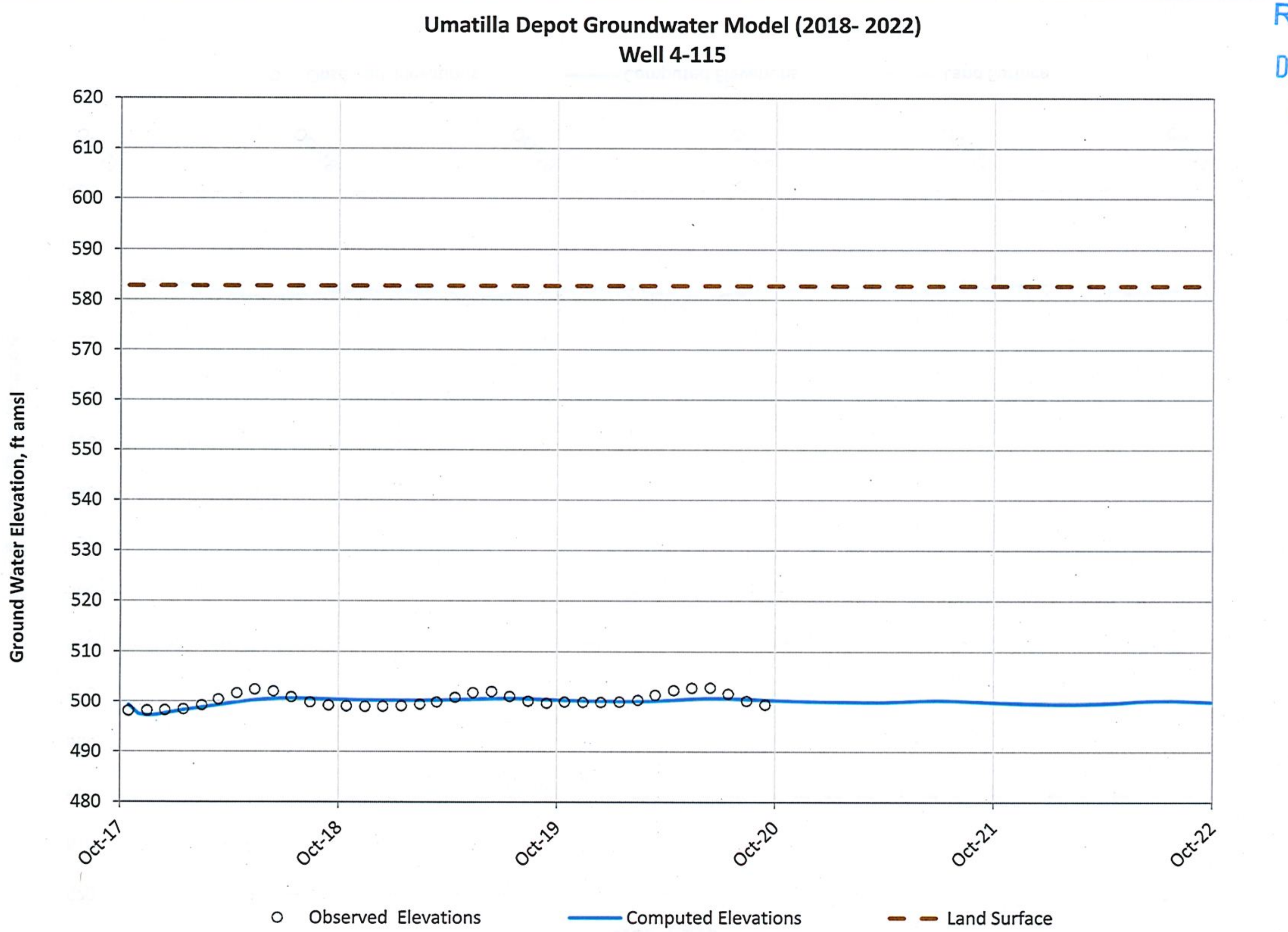

Figure A-1

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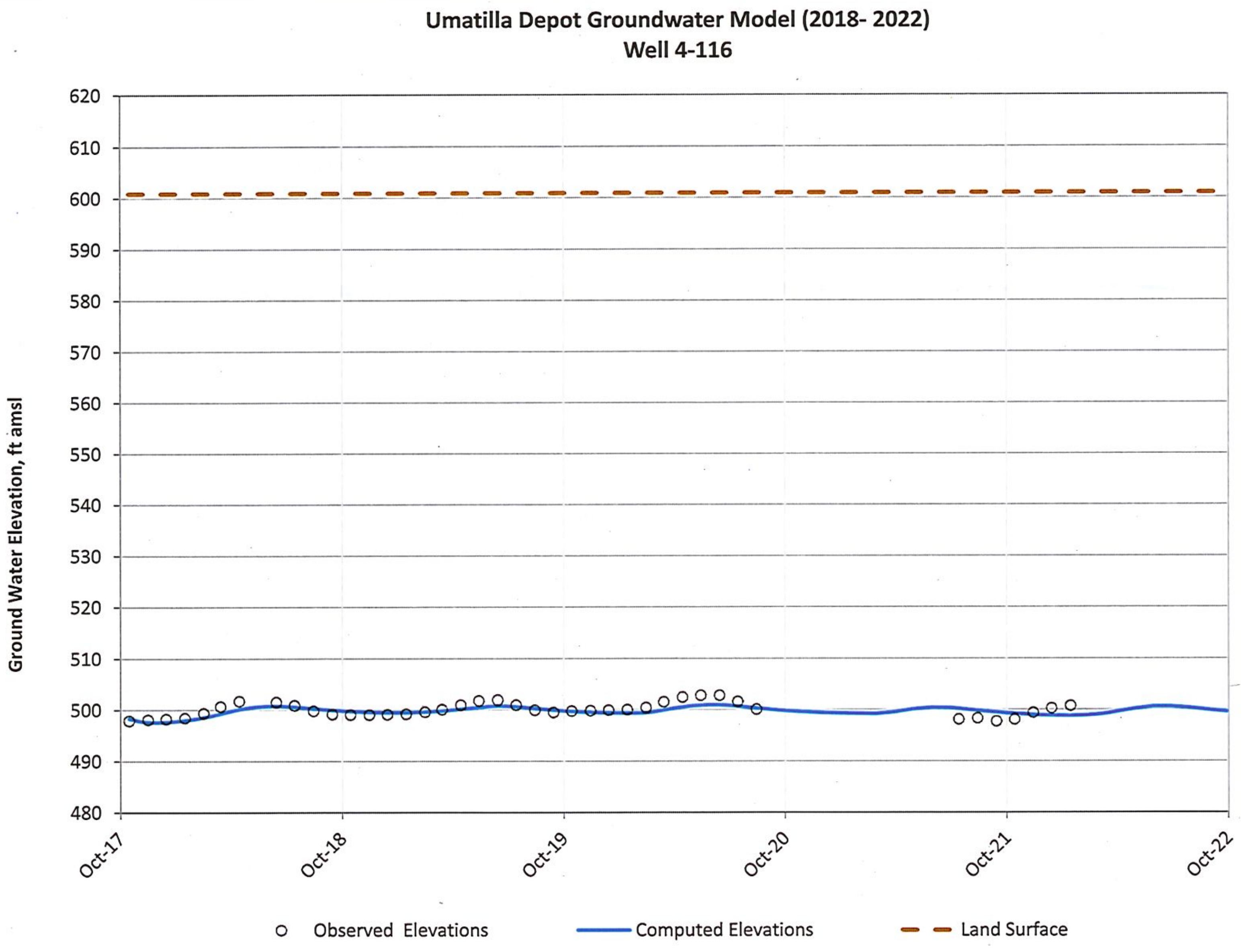

Figure A-2

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Umatilla Depot Groundwater Model (2018- 2022)
Well 4-122

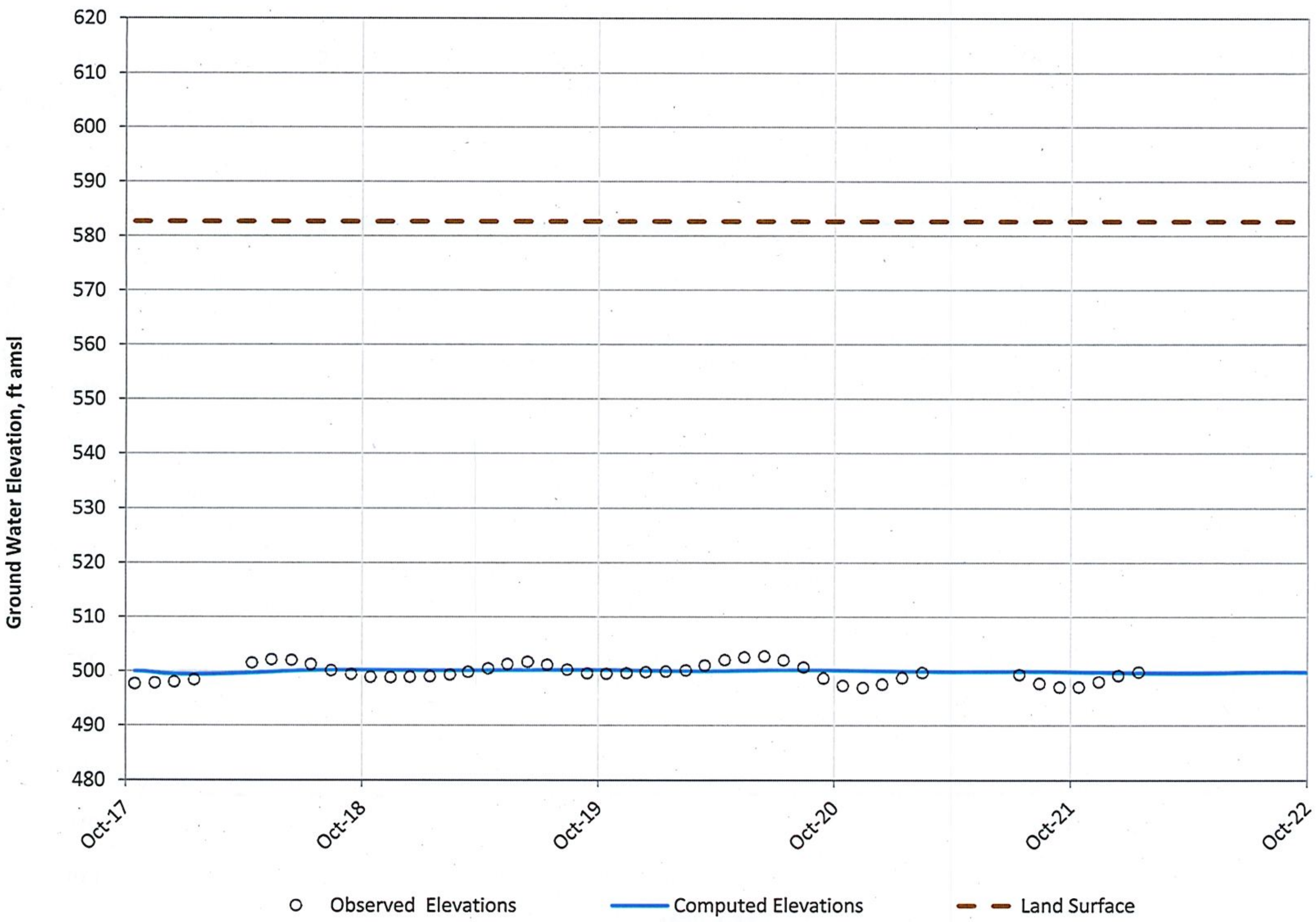

Figure A-3

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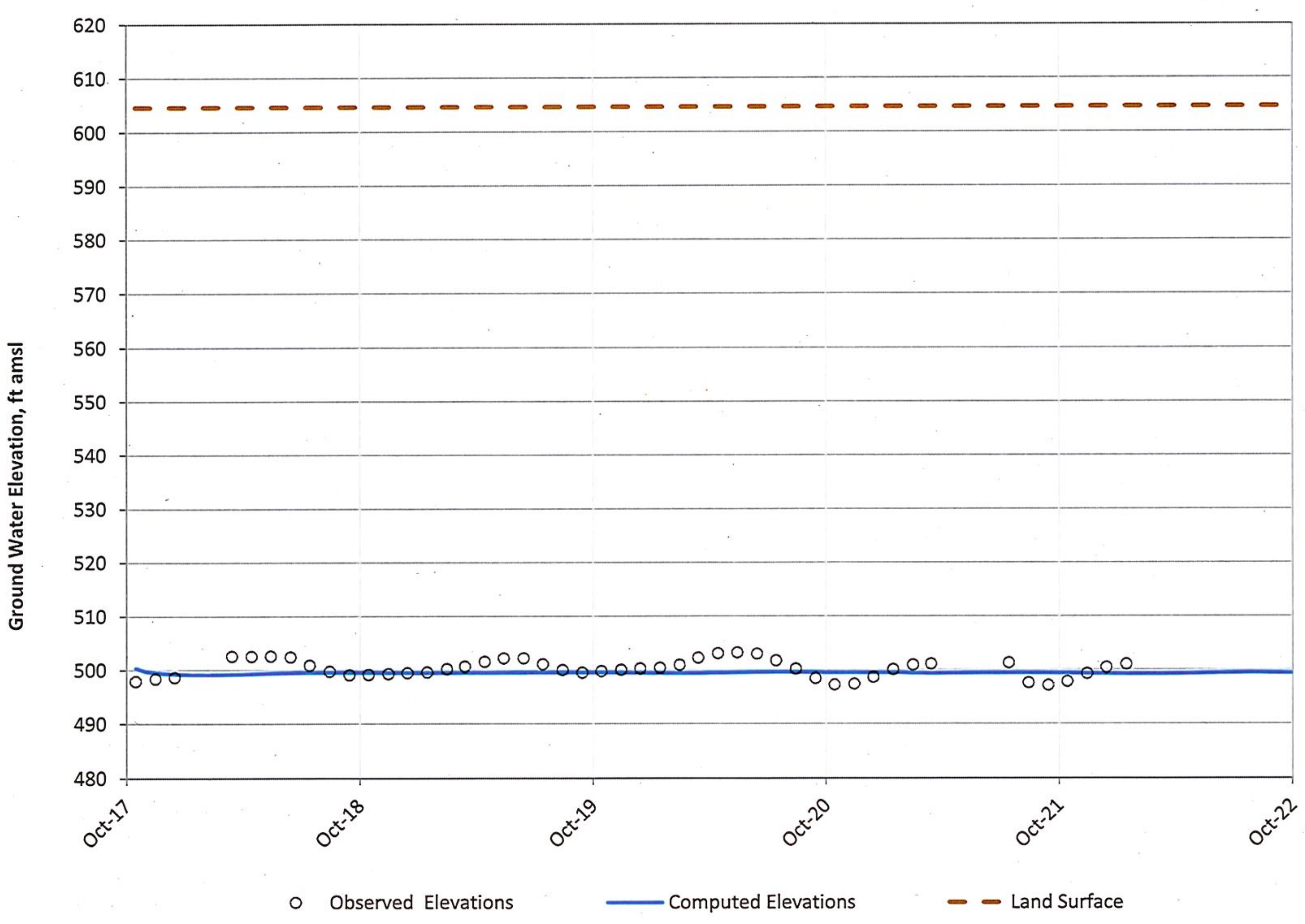

Umatilla Depot Groundwater Model (2018- 2022)
Well 4-124

Figure A-4

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Umatilla Depot Groundwater Model (2018- 2022)
Well 4-127

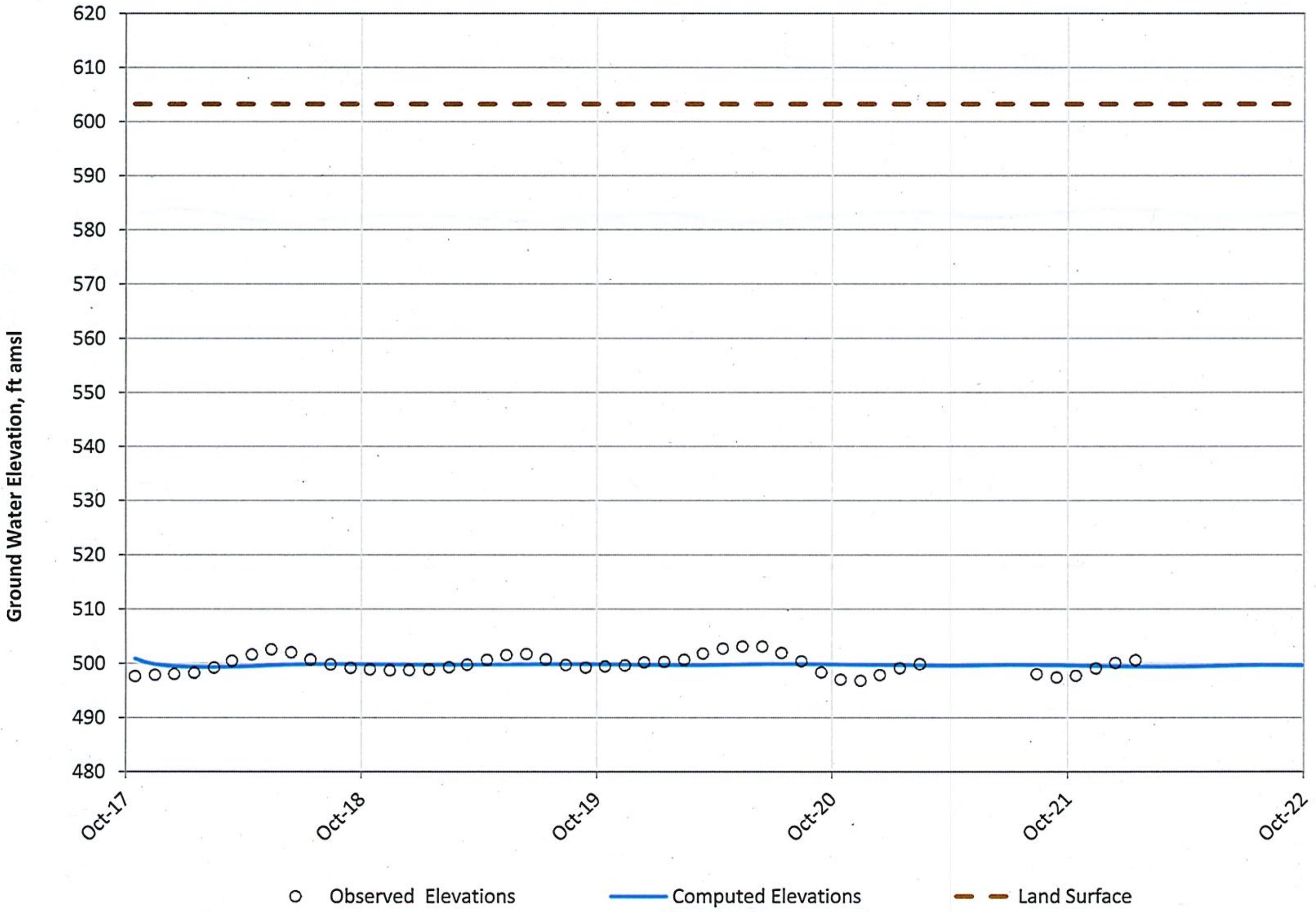

Figure A-5

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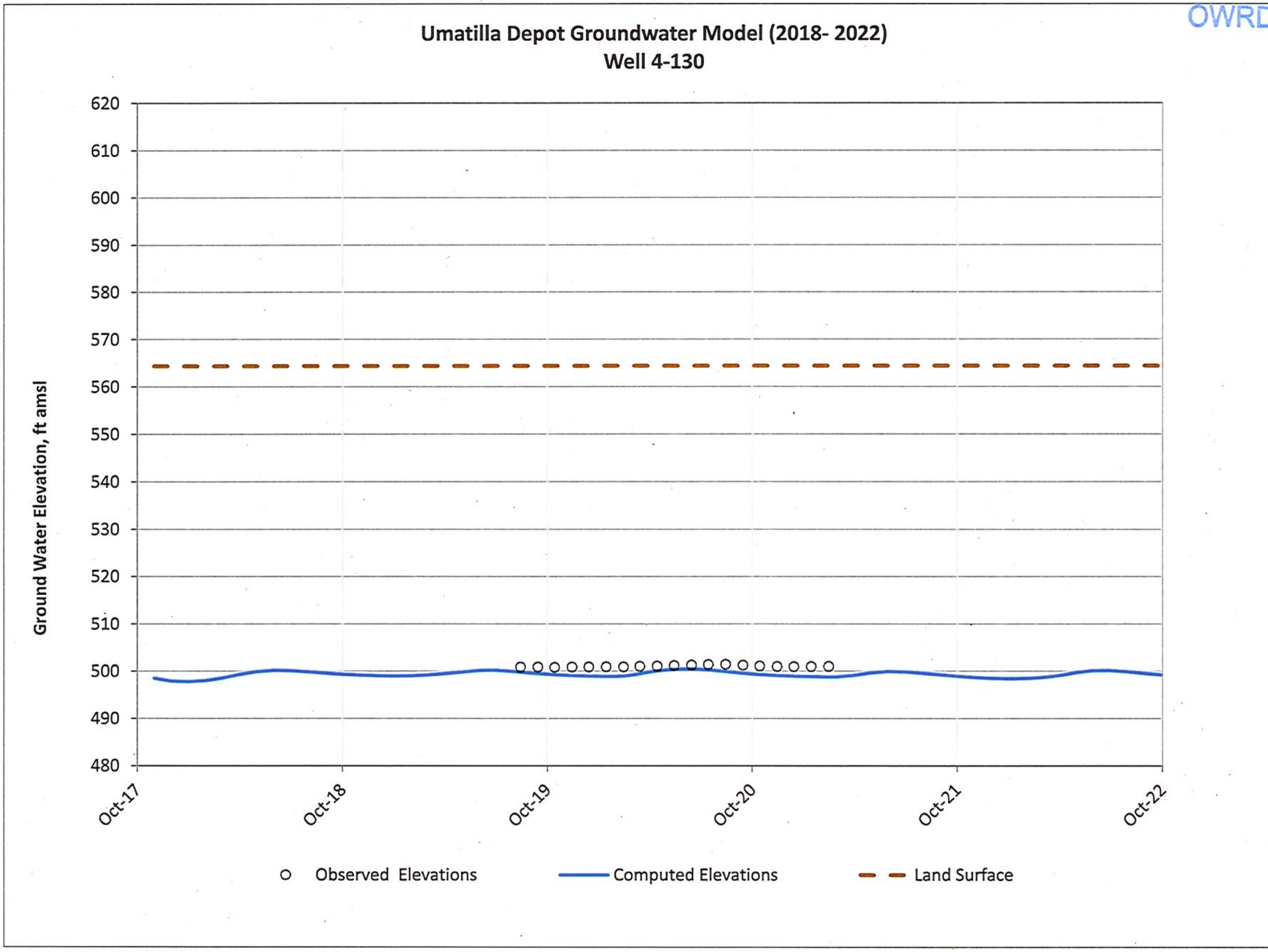

Figure A-6

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Umatilla Depot Groundwater Model (2018- 2022)
Well 4-131

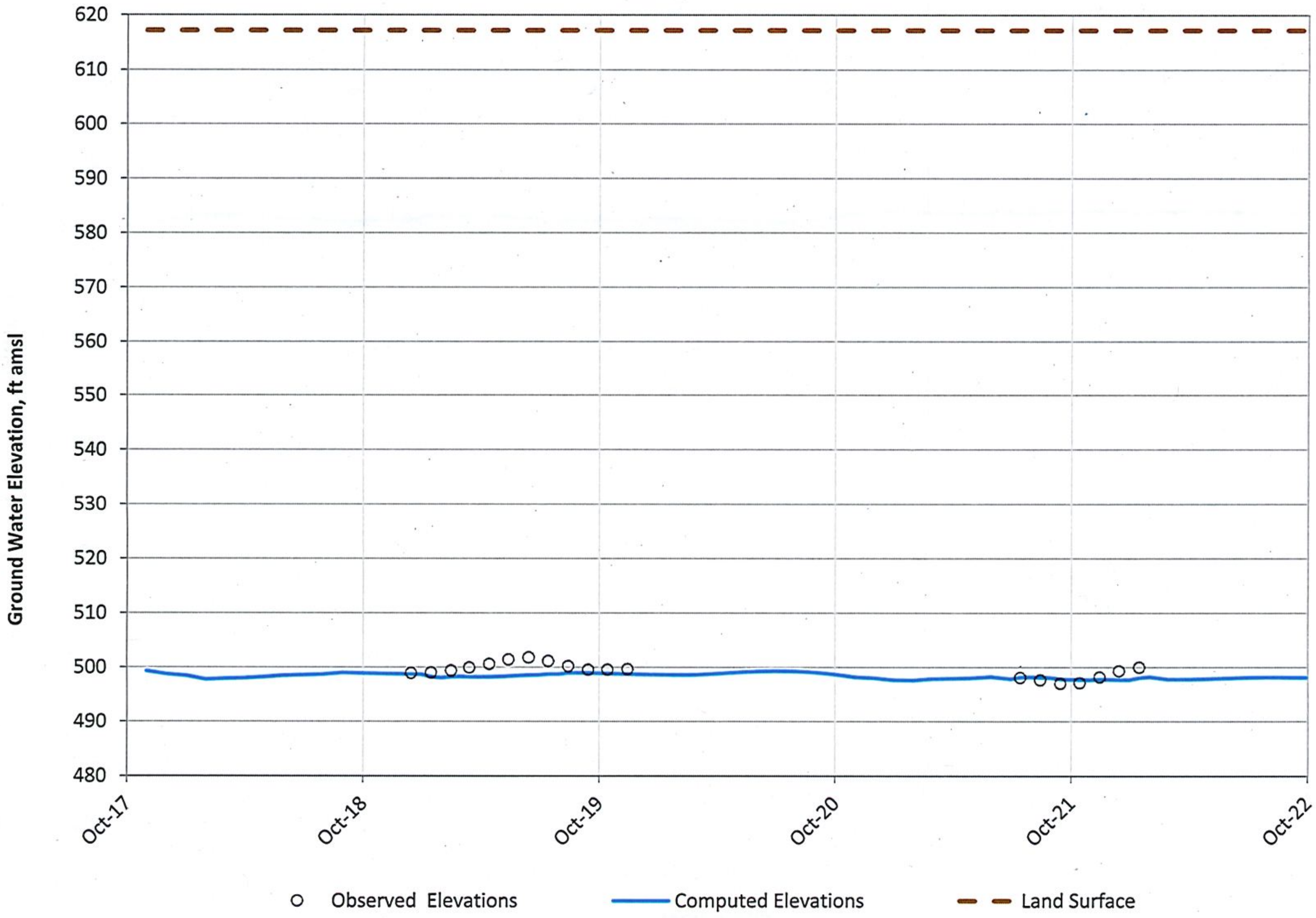

Figure A-7

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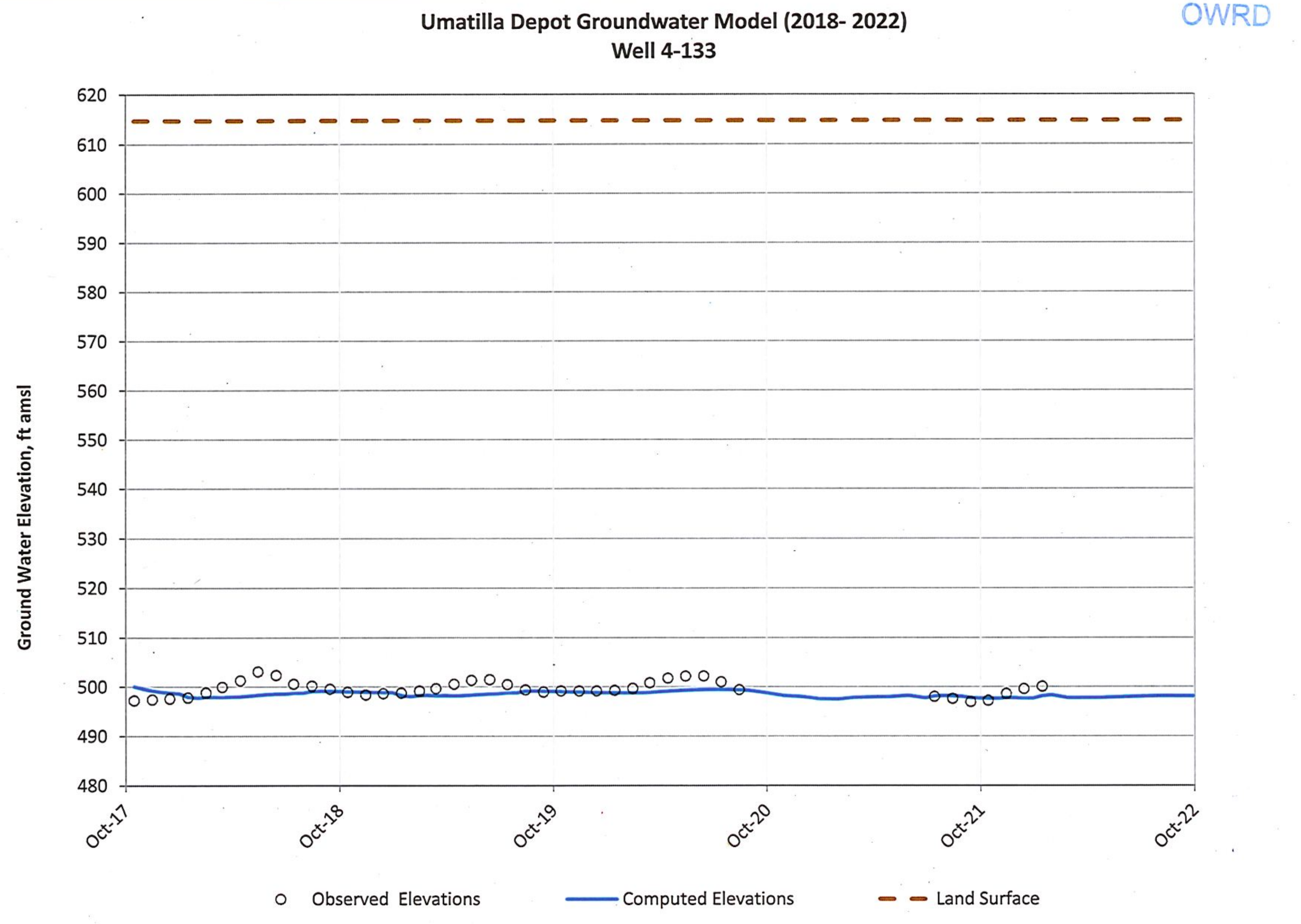

Umatilla Depot Groundwater Model (2018- 2022)
Well 4-133

Figure A-8

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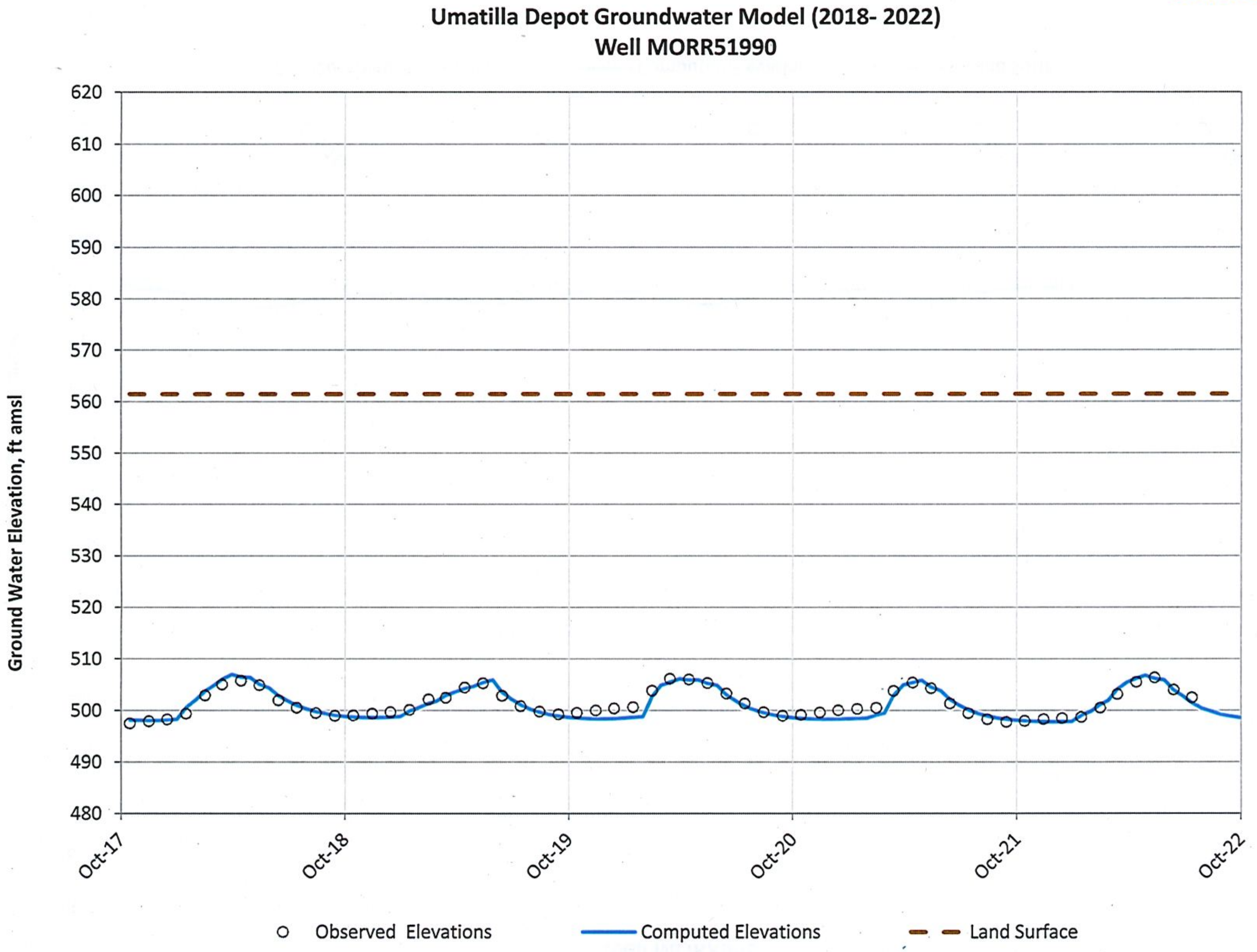

Figure A-9

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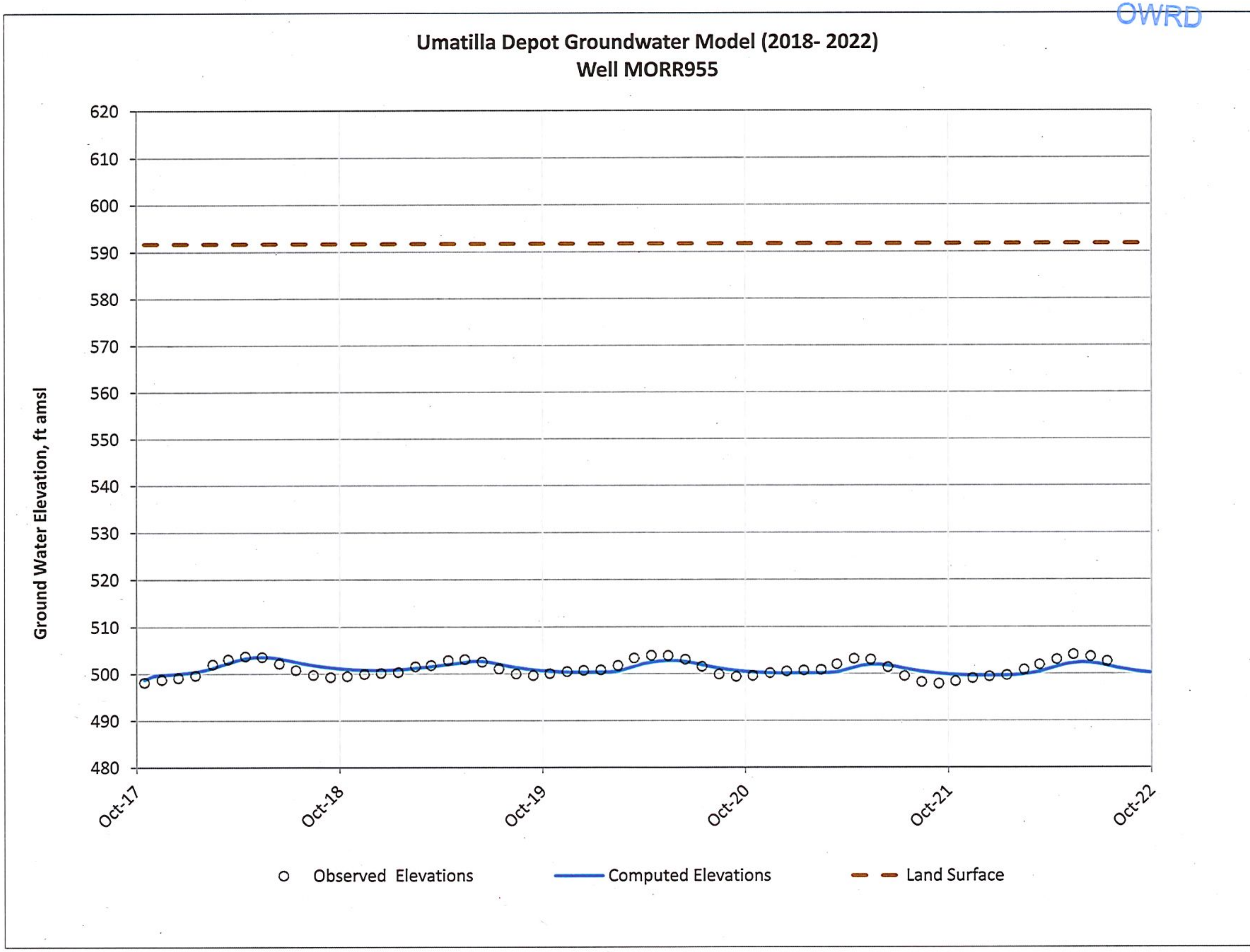

Figure A-10

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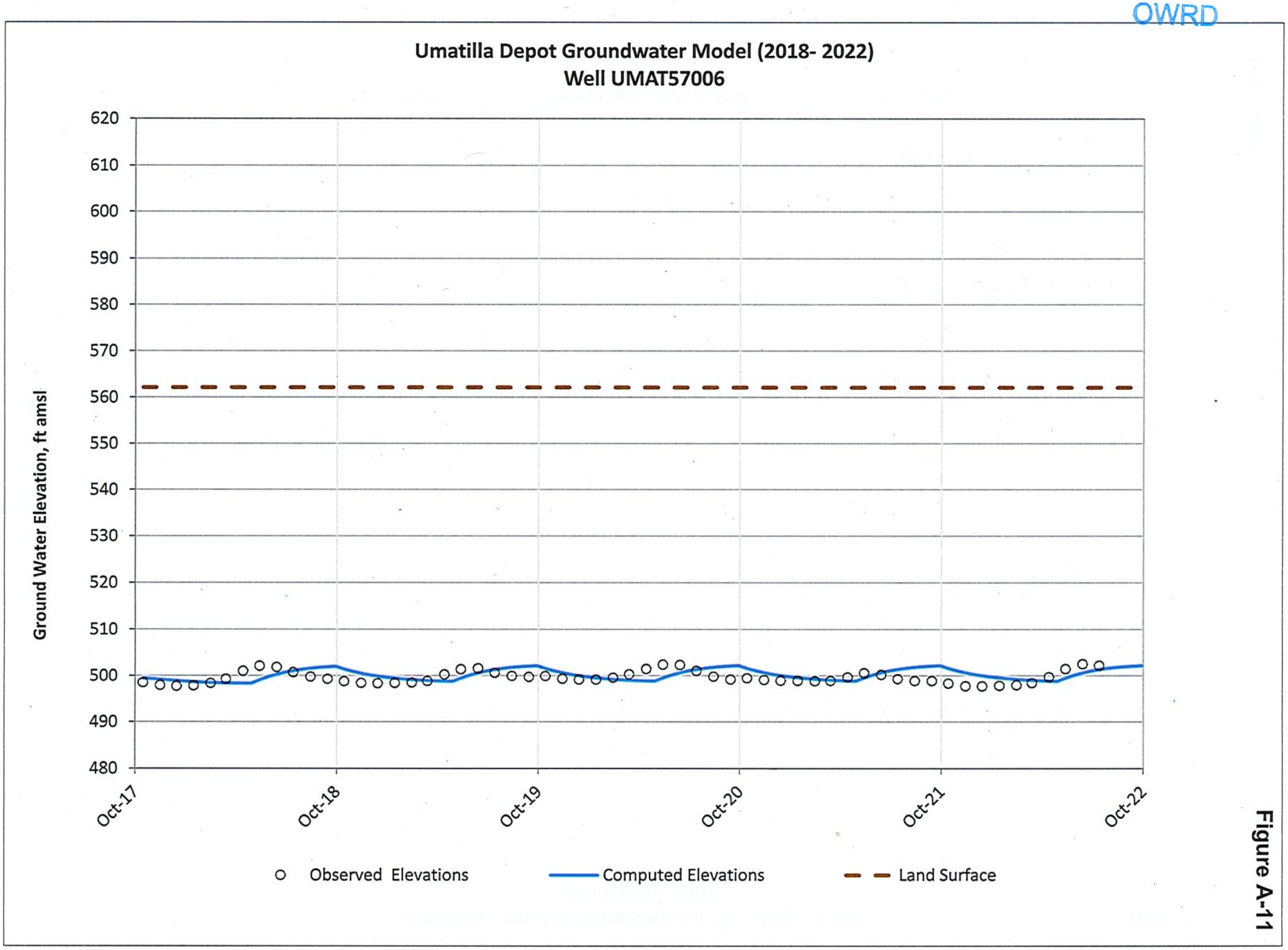

Umatilla Depot Groundwater Model (2018- 2022)
Well UMAT57006

Figure A-11

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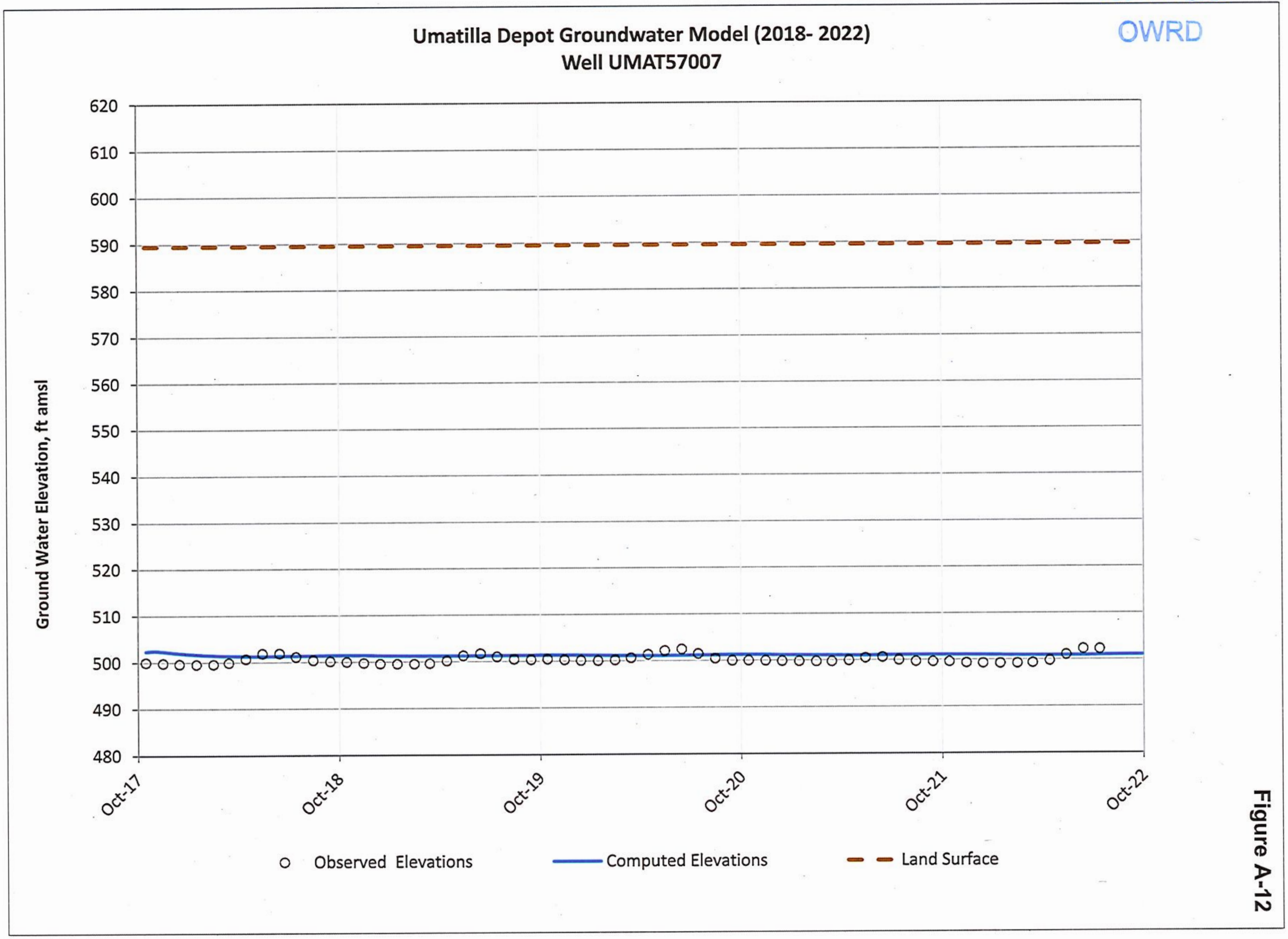

Figure A-12

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Umatilla Depot Groundwater Model (2018- 2022)
Well UMAT58259

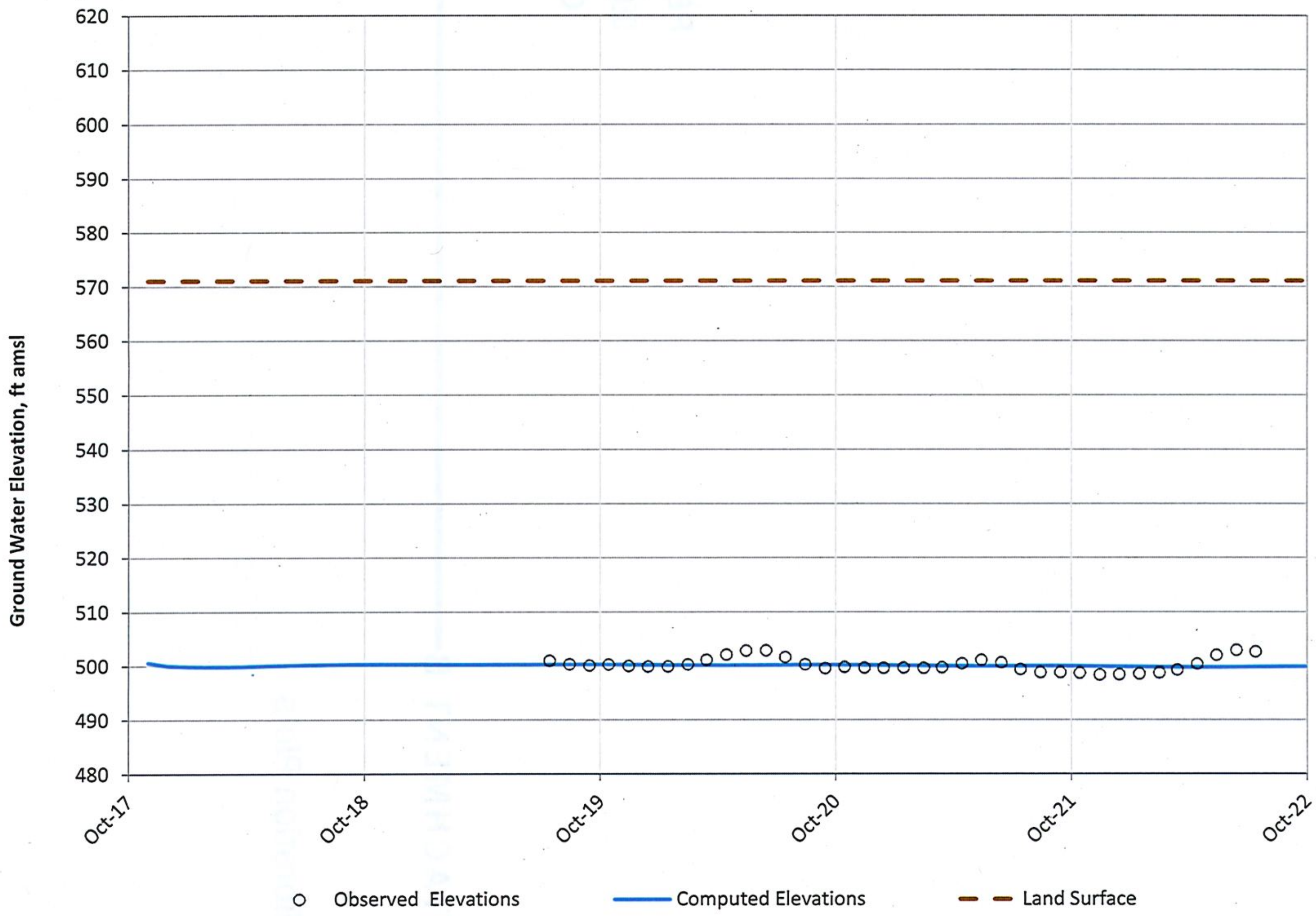

Figure A-13

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ATTACHMENT B

Calibration Plots

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Figure B-1
Calibration Scatter Plot

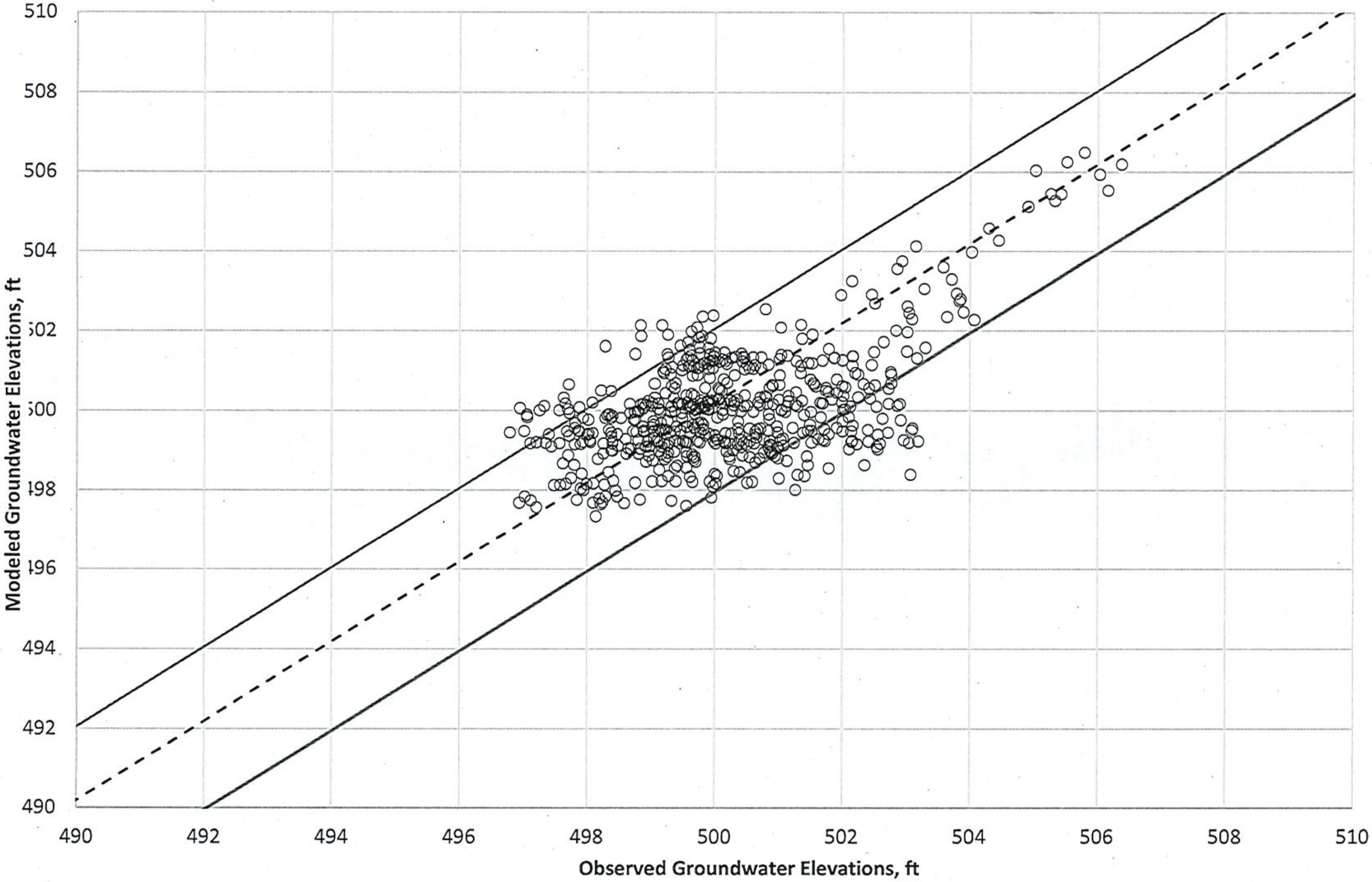

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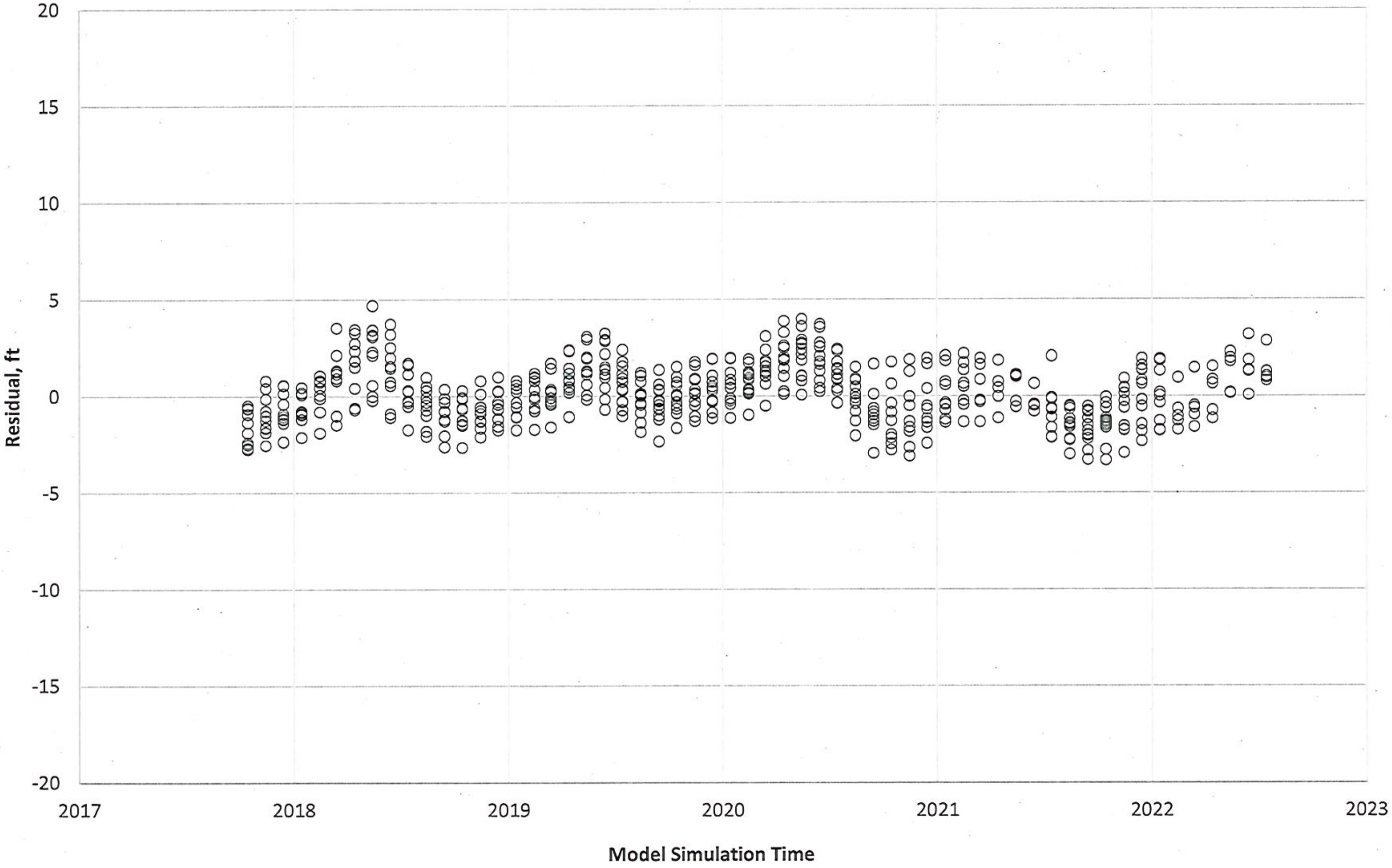
Figure B-2
Residual Distribution



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