Appendix 3-C. Water Level ~~Sustainability~~Sustainable Management Criteria (2024 Revision)

Contents

Groundwater Level SustainableSustainability Management Measurable Criteria

This Appendix provides further background information for Section 3.4.1 Sustainable Management Criteria - Groundwater Elevation in Butte Valley GSP Chapter 3. The following provides additional figures and discussion to sup- plement the main text:

- The hydrographs used to set the minimum thresholds and measurable objectives.
- The process and figures of the well failure analysis.

Please note that drastic updates have been made to this appendix comparing to the 2022 version, where the groundwater level SMCs have been modified and reflected on the updated hydrographs, and the well failure analysis has been updated and reorganized for more in-depth and cohesive evaluations.

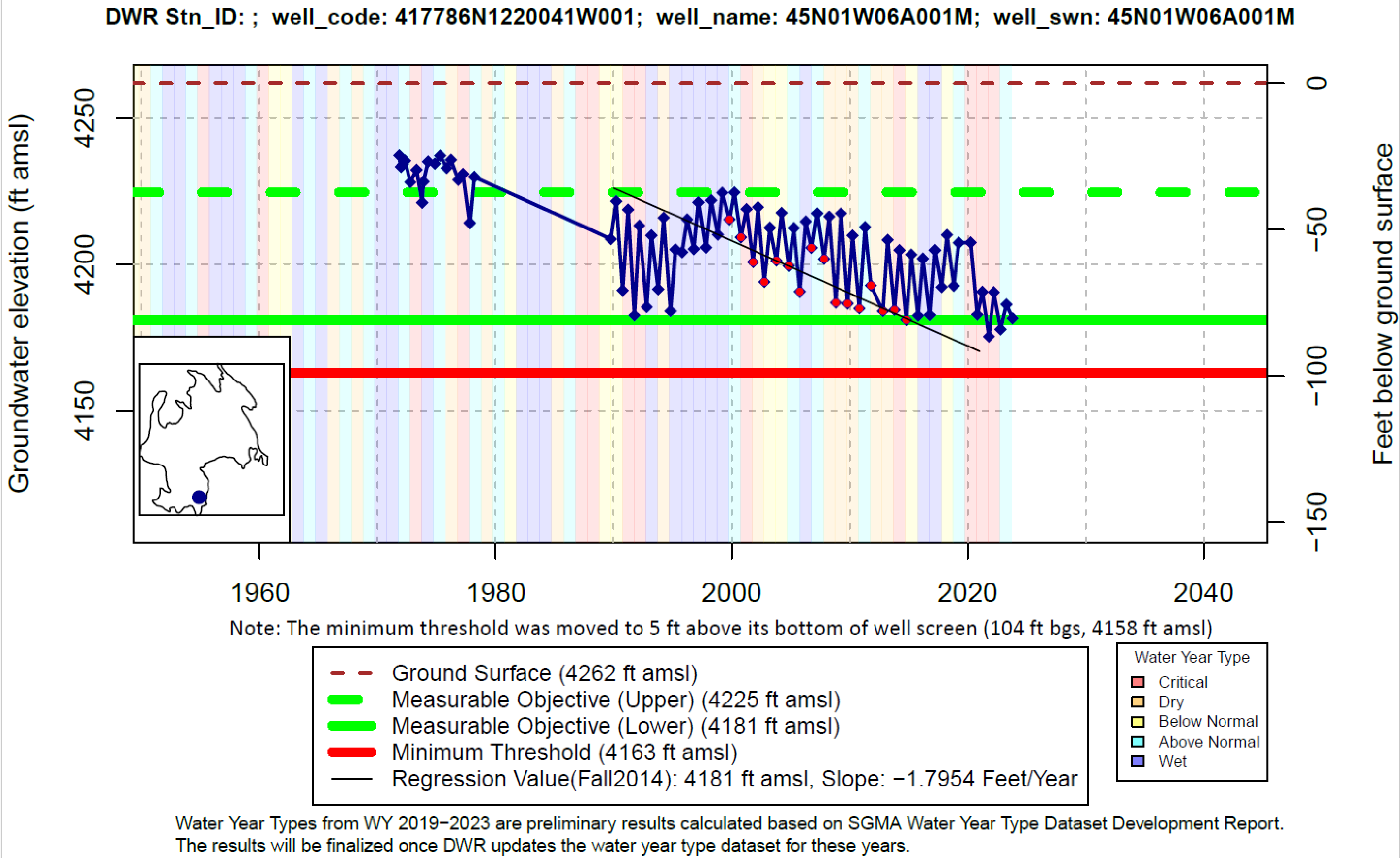
Hydrographs (2024 GSP Revision)

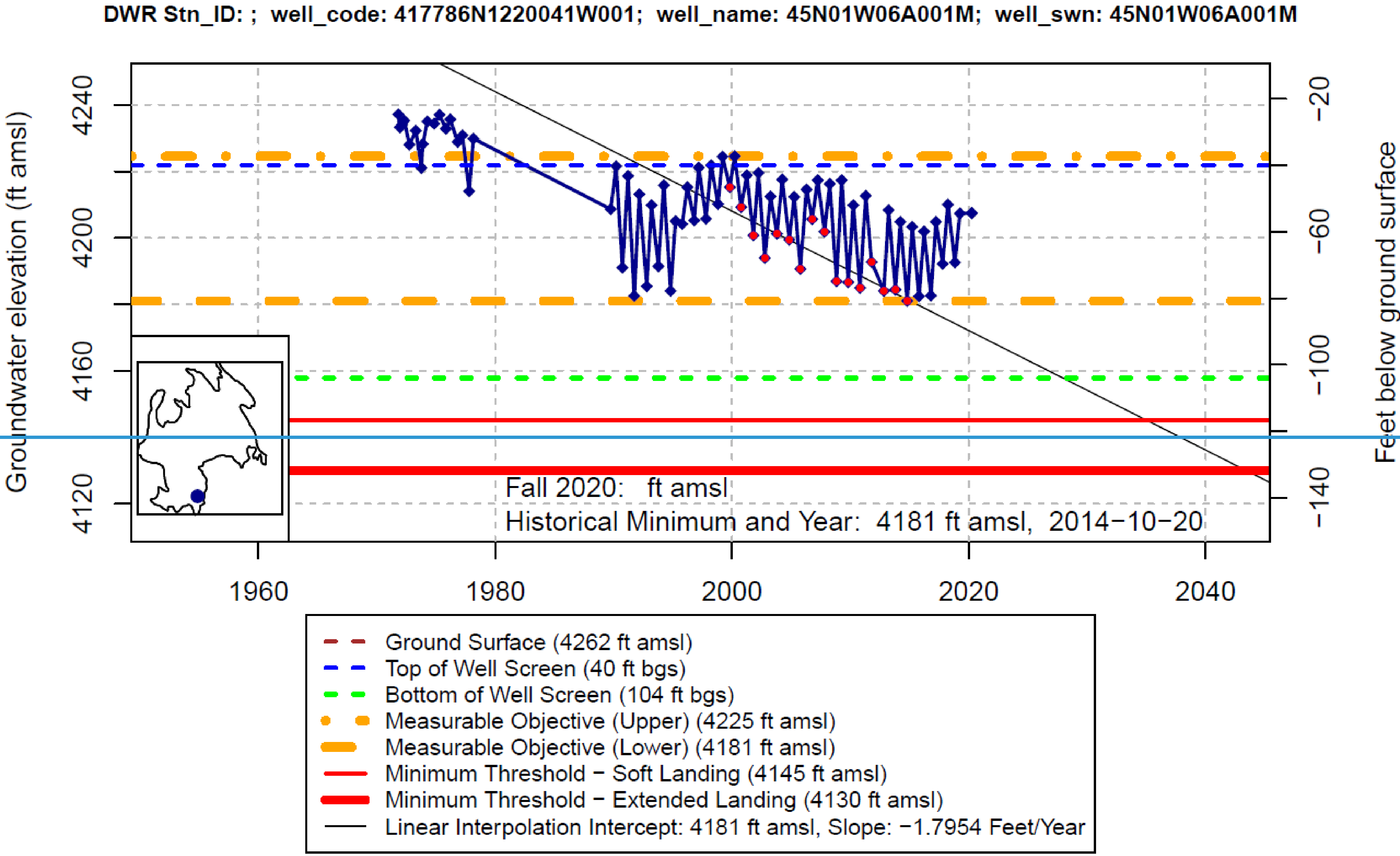
The hydrographs used to set the minimum thresholds and measurable objectives for each representative monitoring point are shown in the following figures. The groundwater level data used in the regression to calculate minimum thresholds have gone through a quality assurance and quality control (QAQC) process that removes data from the analysis for the following reasons:

- Oil or other foreign substances were floating at the groundwater surface inside the well and the data had high uncertainty as a result.
- The well was pumped recently.
- During the minimum threshold process and generation of a regression equation, a data point was deemed an outlier, which may result from the interference of drawdown from nearby wells.

Table 1: Removed groundwater level (WL) data from the regression analysis. The water level is in units of feet above mean sea level (ft amsl).

Well Name	Date	Removed WL	Reason
419451N1218967W001	2000-10-10	4157.23	Oil or foreign substance in casing
417944N1220350W001	2012-10-29	4203.73	Oil or foreign substance in casing
418512N1219183W001	1999-10-26	4208.79	Oil or foreign substance in casing
419451N1218967W001	1999-10-26	4159.73	Oil or foreign substance in casing
418512N1219183W001	2013-10-21	4194.69	Oil or foreign substance in casing
417944N1220350W001	2011-10-18	4189.83	Pumped recently
419755N1219785W001	2014-10-20	4172.7	Oil or foreign substance in casing
419451N1218967W001	2002-10-11	4138.73	Oil or foreign substance in casing
418661N1219587W001	1999-10-26	4204.5	Oil or foreign substance in casing
417789N1220759W001	2011-10-18	4215.01	Oil or foreign substance in casing
418948N1220832W001	2013-10-21	4197.37	Oil or foreign substance in casing
418948N1220832W001	2011-10-18	4197.57	Oil or foreign substance in casing
418948N1220832W001	2009-10-27	4202.07	Oil or foreign substance in casing
418948N1220832W001	1999-10-27	4204.27	Oil or foreign substance in casing
419451N1218967W001	2005-10-10	4153.73	Oil or foreign substance in casing
418661N1219587W001	2013-10-21	4193.7	Oil or foreign substance in casing
418512N1219183W001	2014-10-20	4191.99	Oil or foreign substance in casing
419451N1218967W001	2003-10-20	4139.63	Oil or foreign substance in casing
418948N1220832W001	2007-10-25	4205.57	Oil or foreign substance in casing
418948N1220832W001	2010-10-25	4199.97	Oil or foreign substance in casing
418948N1220832W001	2008-10-30	4205.07	Oil or foreign substance in casing
418948N1220832W001	2006-10-12	4204.87	Oil or foreign substance in casing
418948N1220832W001	2000-10-10	4201.67	Pumping
418948N1220832W001	2012-10-29	4197.97	Oil or foreign substance in casing
418948N1220832W001	2005-10-10	4200.07	Oil or foreign substance in casing
419451N1218967W001	2006-10-12	4149.93	Oil or foreign substance in casing
418948N1220832W001	2002-10-11	4202.37	Oil or foreign substance in casing
418948N1220832W001	2003-10-20	4203.07	Oil or foreign substance in casing
419451N1218967W001	2004-11-02	4136.23	Oil or foreign substance in casing
418948N1220832W001	2004-11-03	4204.37	Oil or foreign substance in casing
418512N1219183W001	2001-10-23	4182.69	Outlier
417789N1220759W001	2006-10-12	4204.81	Outlier


DWR Stn_ID: ; well_code: 417786N1220041W001; well_name: 45N01W06A001M; well_swn: 45N01W06A001M
Groundwater elevation (ft amsl)
Feet below ground surface
4250
4200
4150
0
−50
−100
−150
1960
1980
2000
2020
2040
Note: The minimum threshold was moved to 5 ft above its bottom of well screen (104 ft bgs, 4158 ft amsl)
Ground Surface (4262 ft amsl)
Measurable Objective (Upper) (4225 ft amsl)
Measurable Objective (Lower) (4181 ft amsl)
Minimum Threshold (4163 ft amsl)
Regression Value(Fall2014): 4181 ft amsl, Slope: −1.7954 Feet/Year
Water Year Type
Critical
Dry
Below Normal
Above Normal
Wet
Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.



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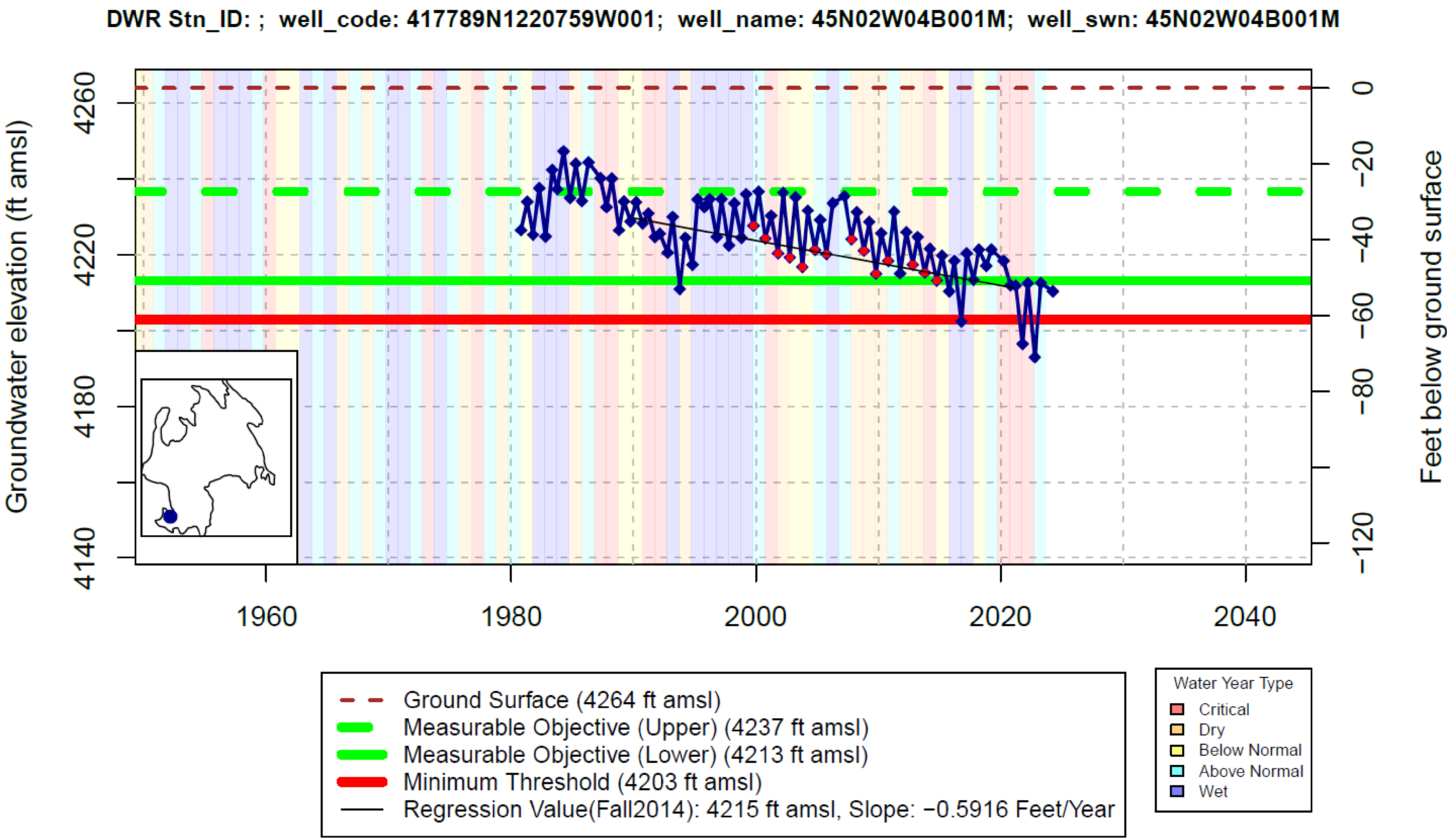
Groundwater elevation (ft amsl)
Feet below ground surface
4240
4200
4160
4120
−20
−60
−100
−140
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4181 ft amsl, 2014−10−20
Ground Surface (4262 ft amsl)
Top of Well Screen (40 ft bgs)
Bottom of Well Screen (104 ft bgs)
Measurable Objective (Upper) (4225 ft amsl)
Measurable Objective (Lower) (4181 ft amsl)
Minimum Threshold − Soft Landing (4145 ft amsl)
Minimum Threshold − Extended Landing (4130 ft amsl)
Linear Interpolation Intercept: 4181 ft amsl, Slope: −1.7954 Feet/Year



Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report. The results will be finalized once DWR updates the water year type dataset for these years.

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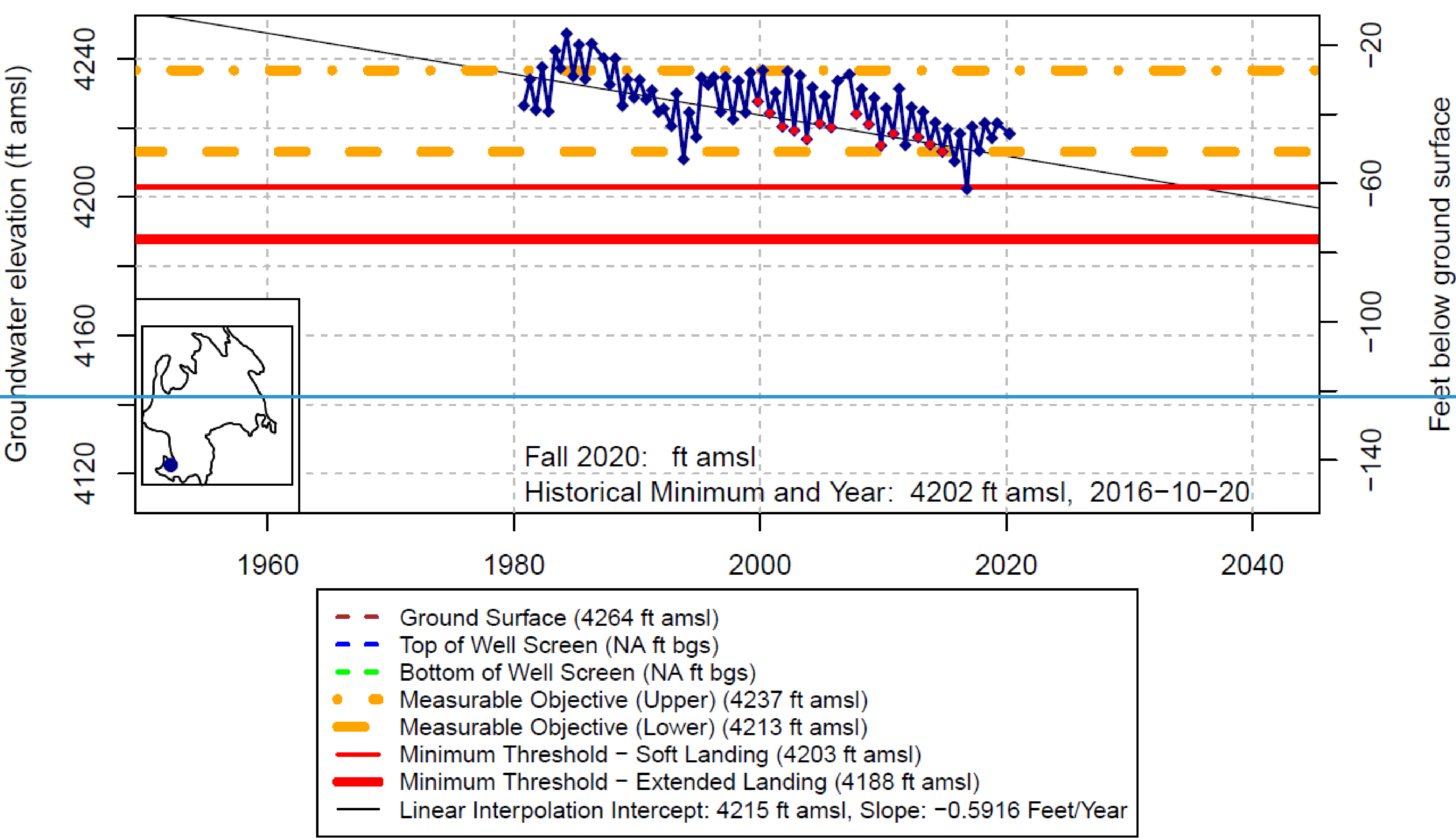
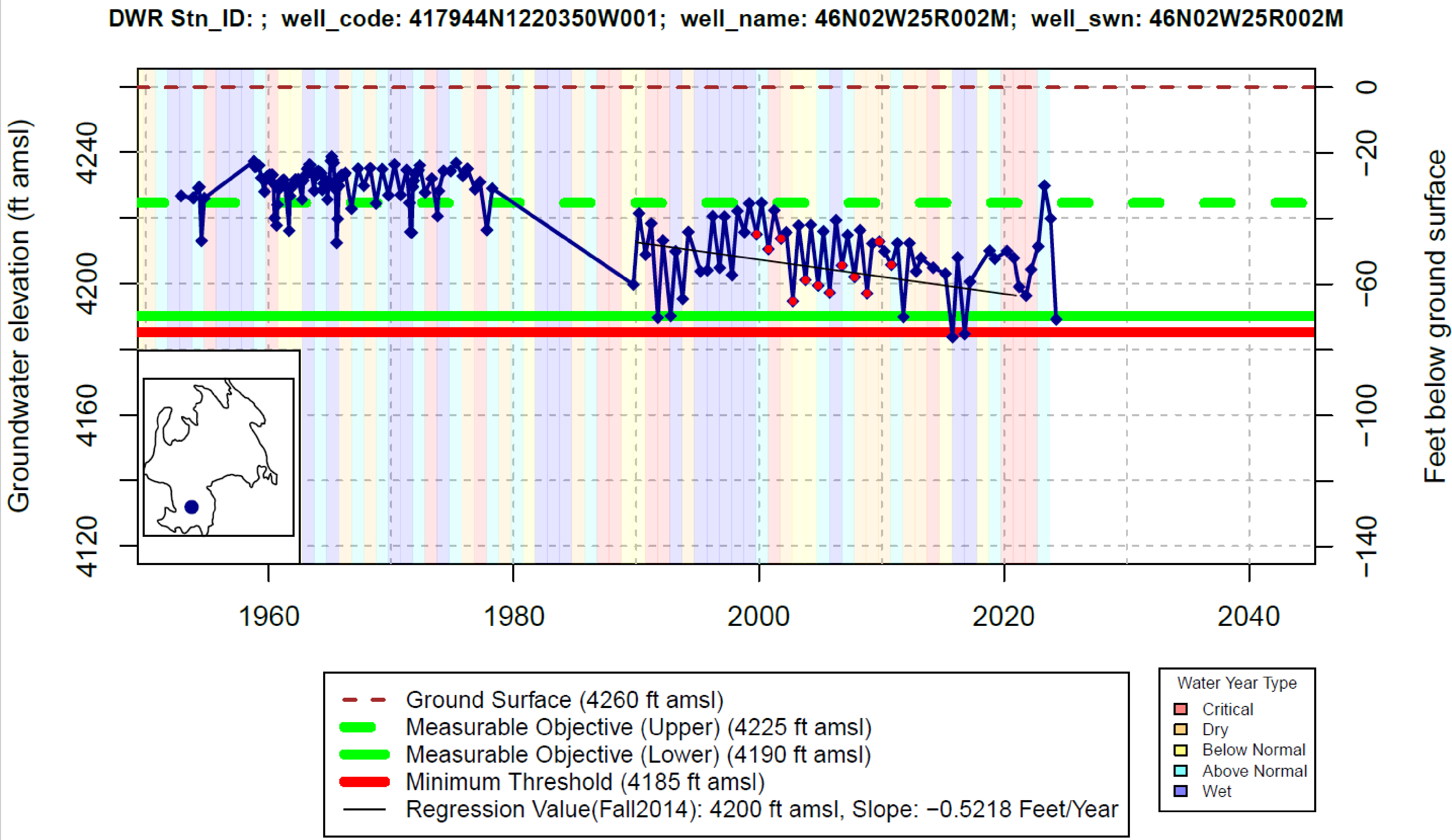
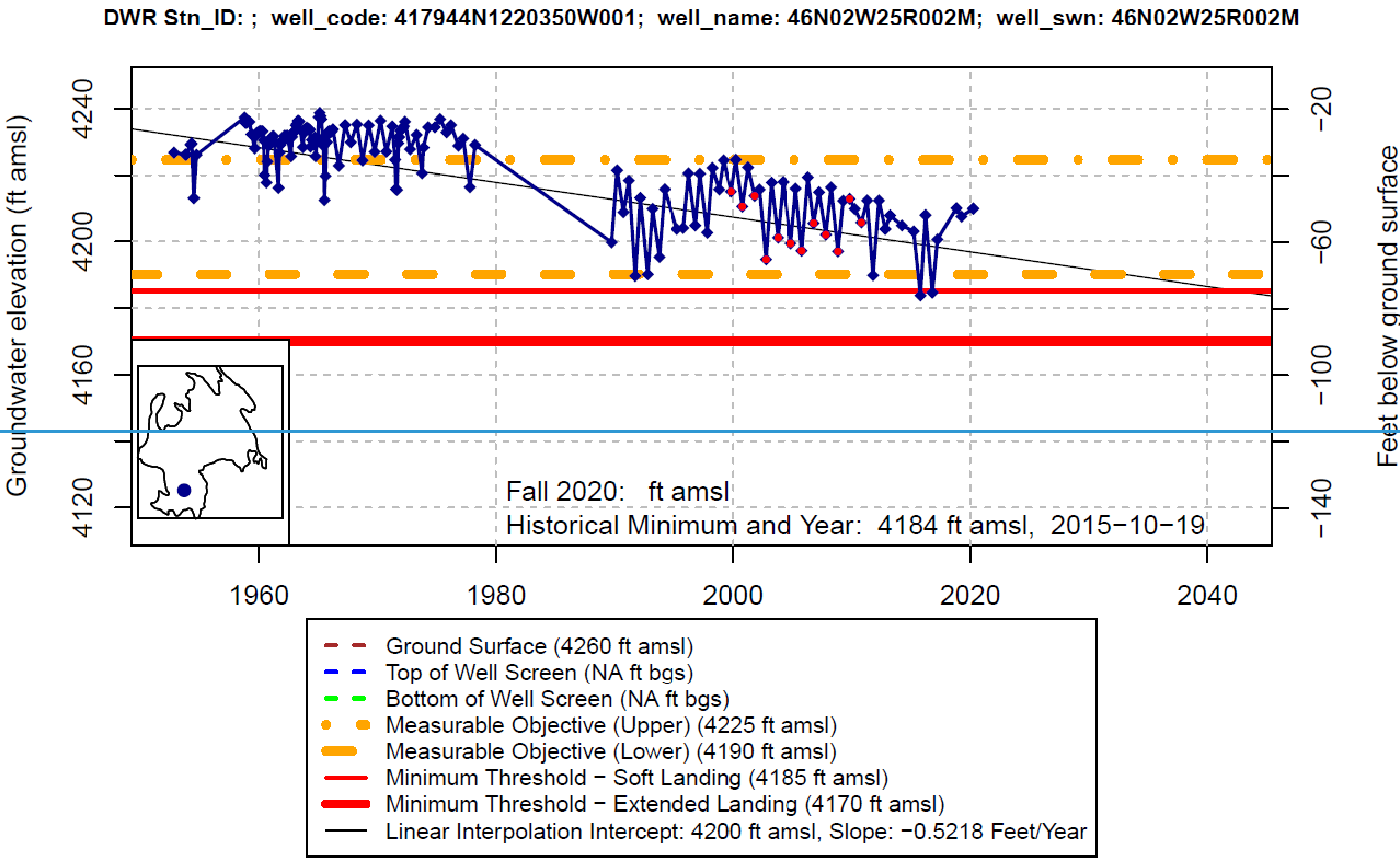




Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report. The results will be finalized once DWR updates the water year type dataset for these years.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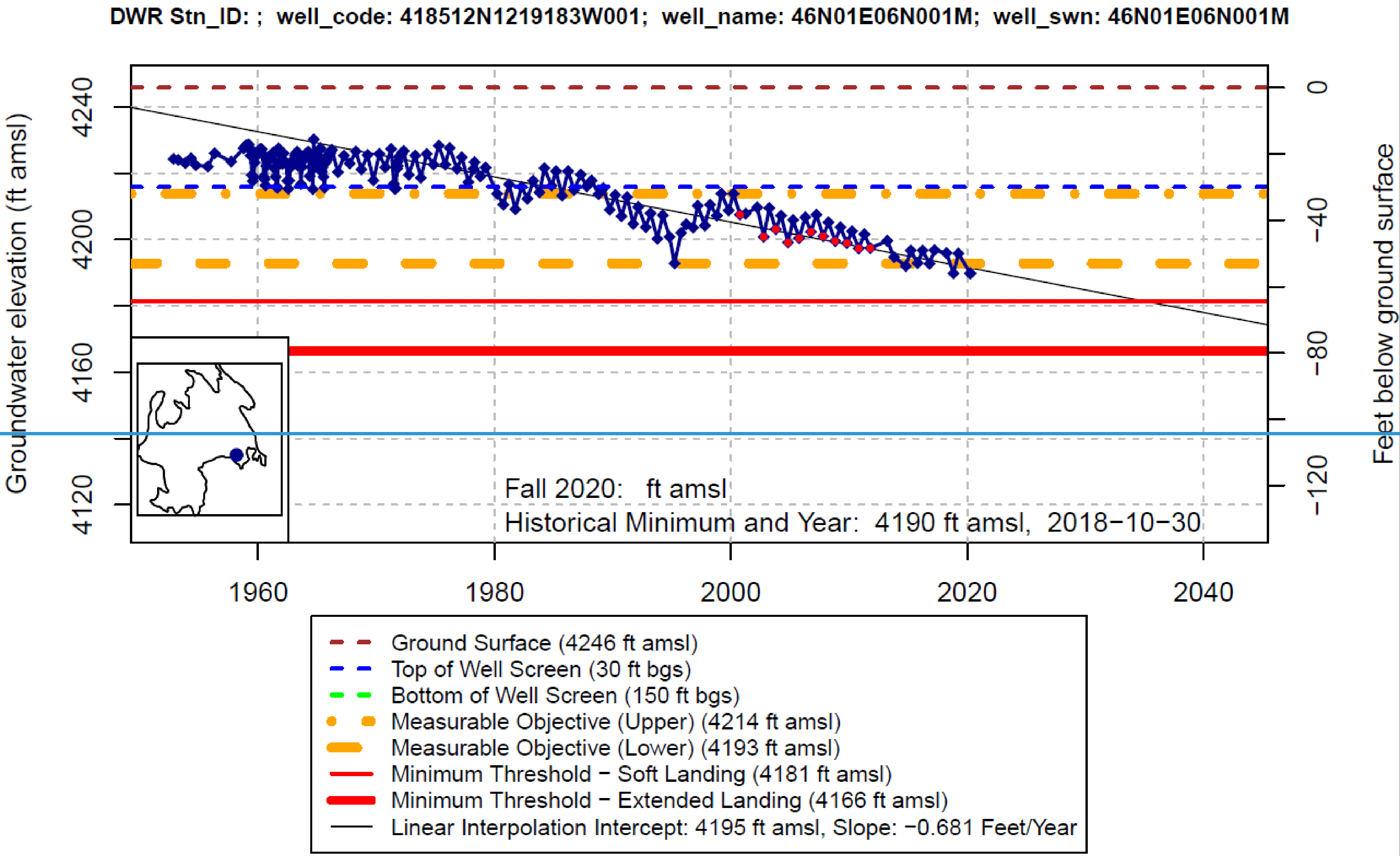
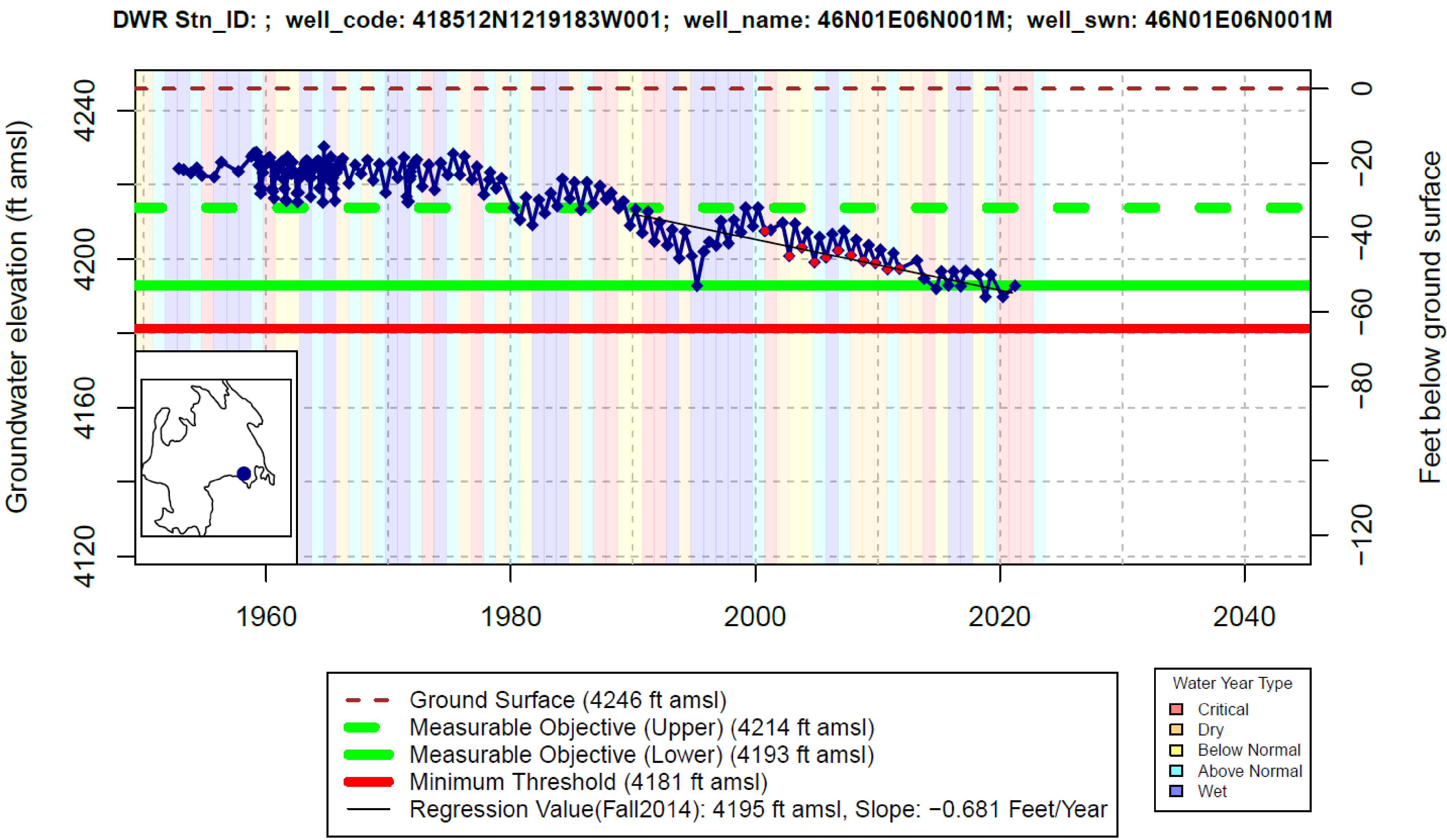
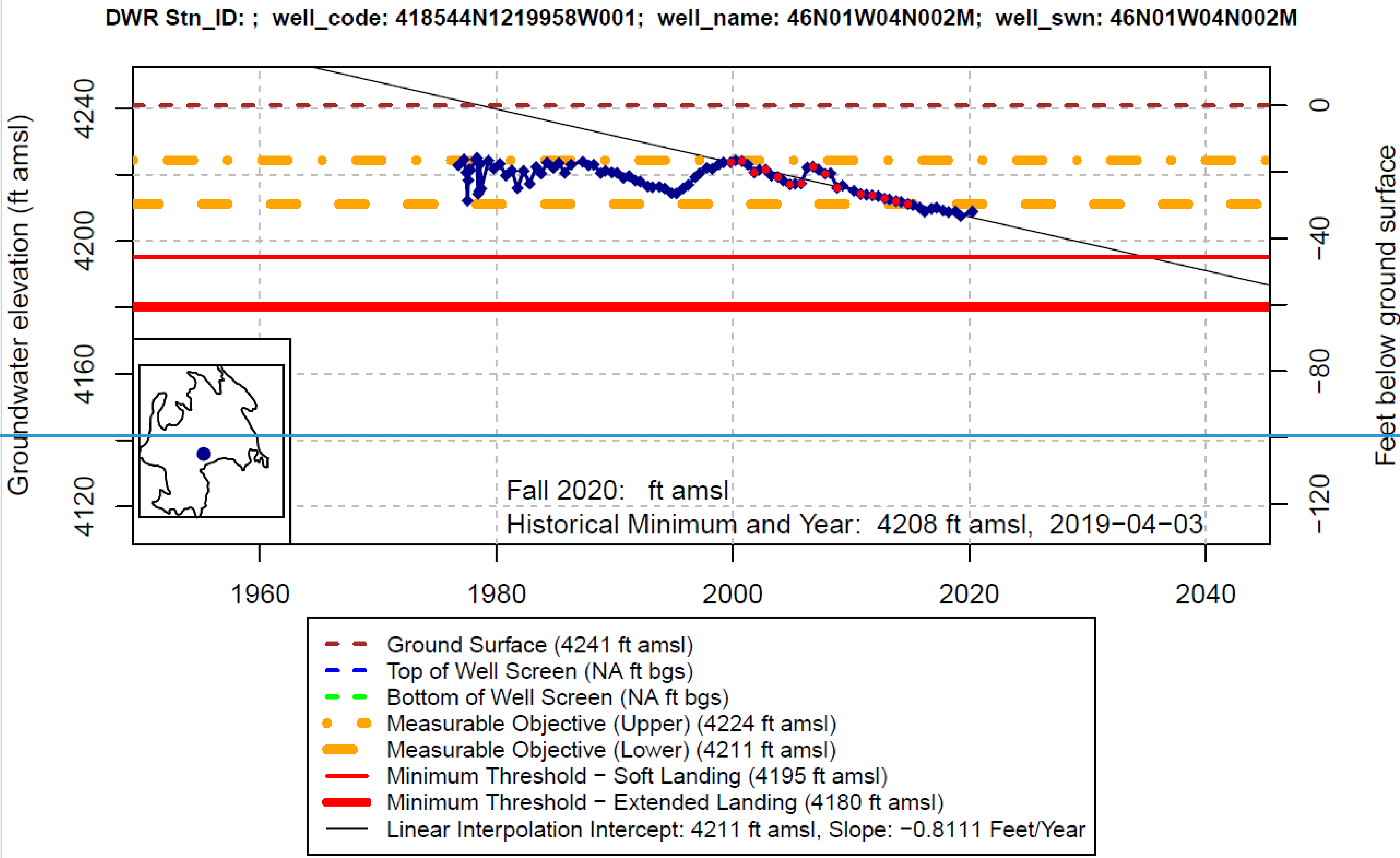
Groundwater elevation (ft amsl)
Feet below ground surface
4240
4200
4160
4120
−20
−60
−100
−140
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4184 ft amsl, 2015−10−19
Ground Surface (4260 ft amsl)
Top of Well Screen (NA ft bgs)
Bottom of Well Screen (NA ft bgs)
Measurable Objective (Upper) (4225 ft amsl)
Measurable Objective (Lower) (4190 ft amsl)
Minimum Threshold − Soft Landing (4185 ft amsl)
Minimum Threshold − Extended Landing (4170 ft amsl)
Linear Interpolation Intercept: 4200 ft amsl, Slope: −0.5218 Feet/Year


DWR Stn_ID: ; well_code: 418512N1219183W001; well_name: 46N01E06N001M; well_swn: 46N01E06N001M
Groundwater elevation (ft amsl)
4120
4160
4200
4240
Feet below ground surface
0
−40
−80
−120
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4190 ft amsl, 2018−10−30
Ground Surface (4246 ft amsl)
Top of Well Screen (30 ft bgs)
Bottom of Well Screen (150 ft bgs)
Measurable Objective (Upper) (4214 ft amsl)
Measurable Objective (Lower) (4193 ft amsl)
Minimum Threshold − Soft Landing (4181 ft amsl)
Minimum Threshold − Extended Landing (4166 ft amsl)
Linear Interpolation Intercept: 4195 ft amsl, Slope: −0.681 Feet/Year



Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.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Groundwater elevation (ft amsl)
Feet below ground surface
4240
4200
4160
4120
0
−40
−80
−120
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4208 ft amsl, 2019−04−03
Ground Surface (4241 ft amsl)
Top of Well Screen (NA ft bgs)
Bottom of Well Screen (NA ft bgs)
Measurable Objective (Upper) (4224 ft amsl)
Measurable Objective (Lower) (4211 ft amsl)
Minimum Threshold − Soft Landing (4195 ft amsl)
Minimum Threshold − Extended Landing (4180 ft amsl)
Linear Interpolation Intercept: 4211 ft amsl, Slope: −0.8111 Feet/Year

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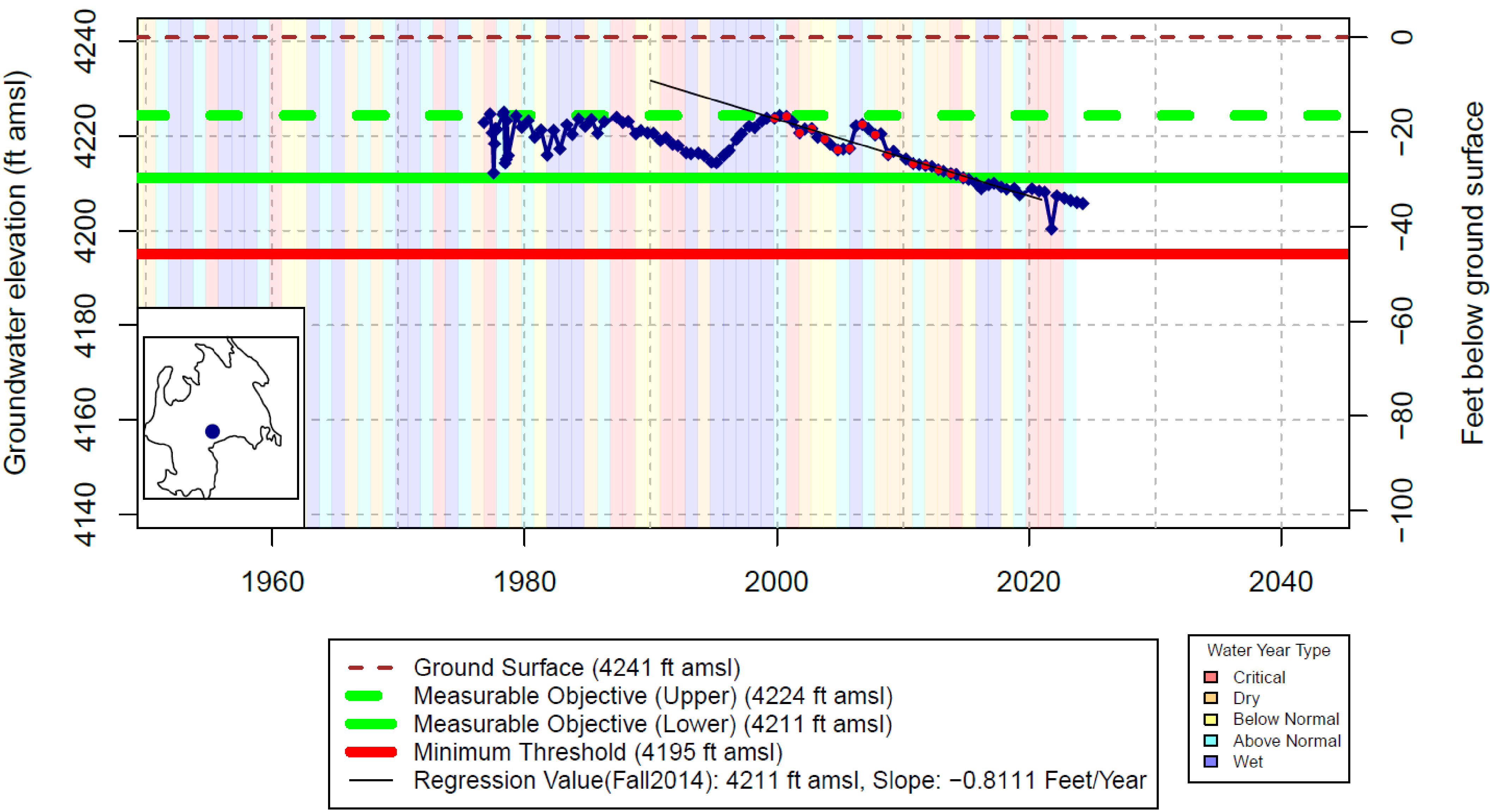
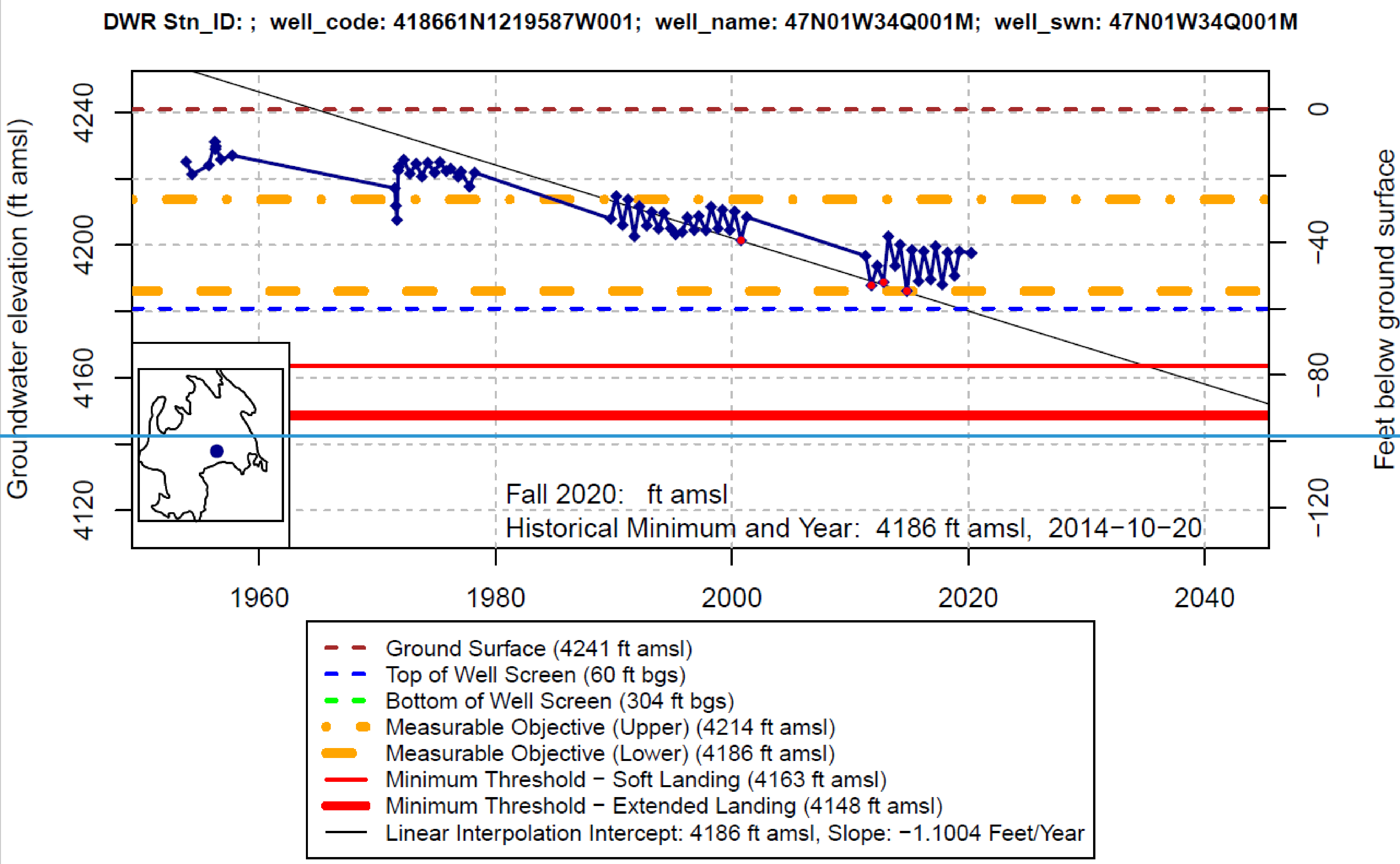
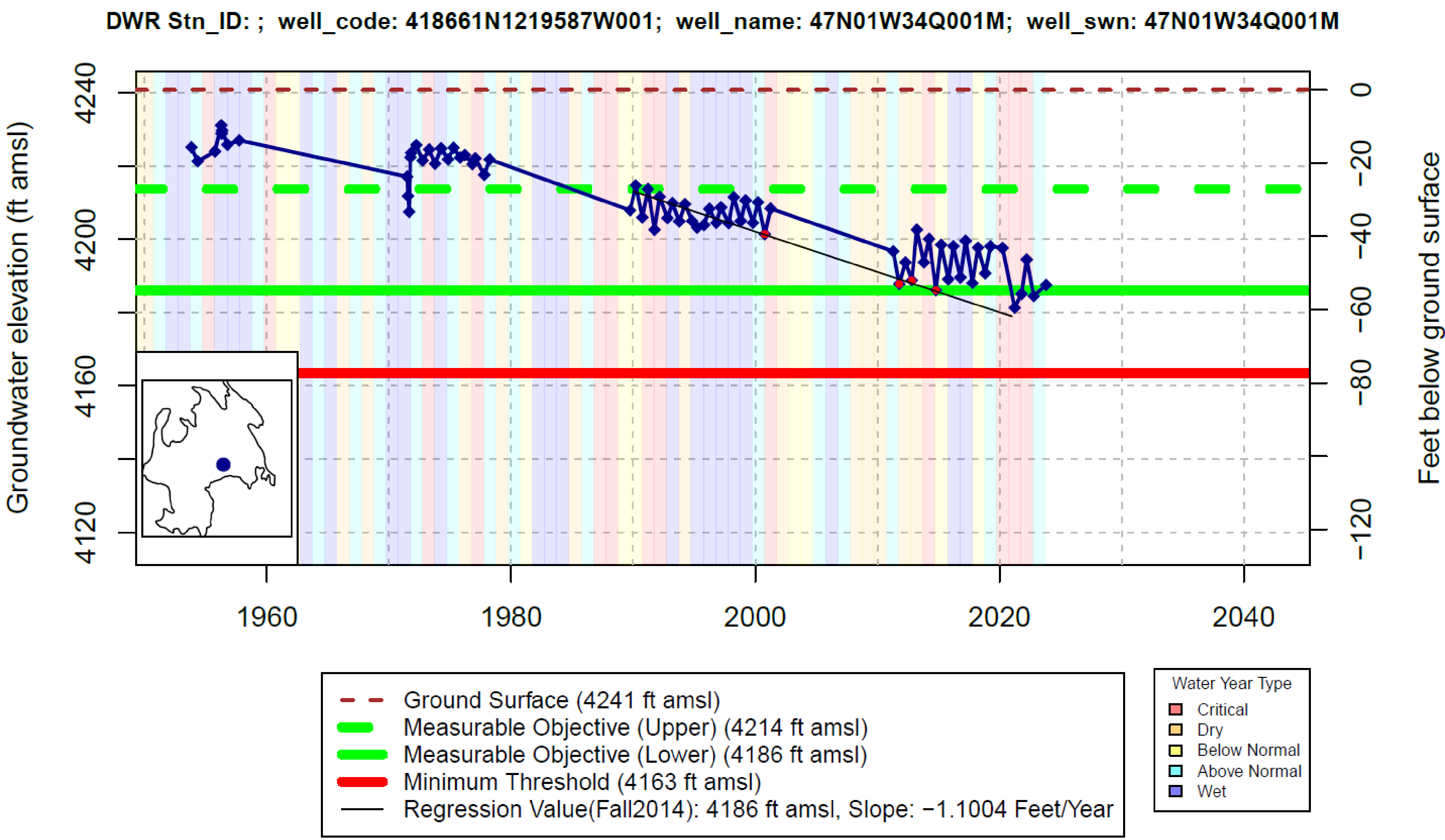


Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.


DWR Stn_ID: ; well_code: 418661N1219587W001; well_name: 47N01W34Q001M; well_swn: 47N01W34Q001M
Groundwater elevation (ft amsl)
Feet below ground surface
4120
4160
4200
4240
0
−40
−80
−120
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4186 ft amsl, 2014−10−20
Ground Surface (4241 ft amsl)
Top of Well Screen (60 ft bgs)
Bottom of Well Screen (304 ft bgs)
Measurable Objective (Upper) (4214 ft amsl)
Measurable Objective (Lower) (4186 ft amsl)
Minimum Threshold − Soft Landing (4163 ft amsl)
Minimum Threshold − Extended Landing (4148 ft amsl)
Linear Interpolation Intercept: 4186 ft amsl, Slope: −1.1004 Feet/Year



Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report. The results will be finalized once DWR updates the water year type dataset for these years.

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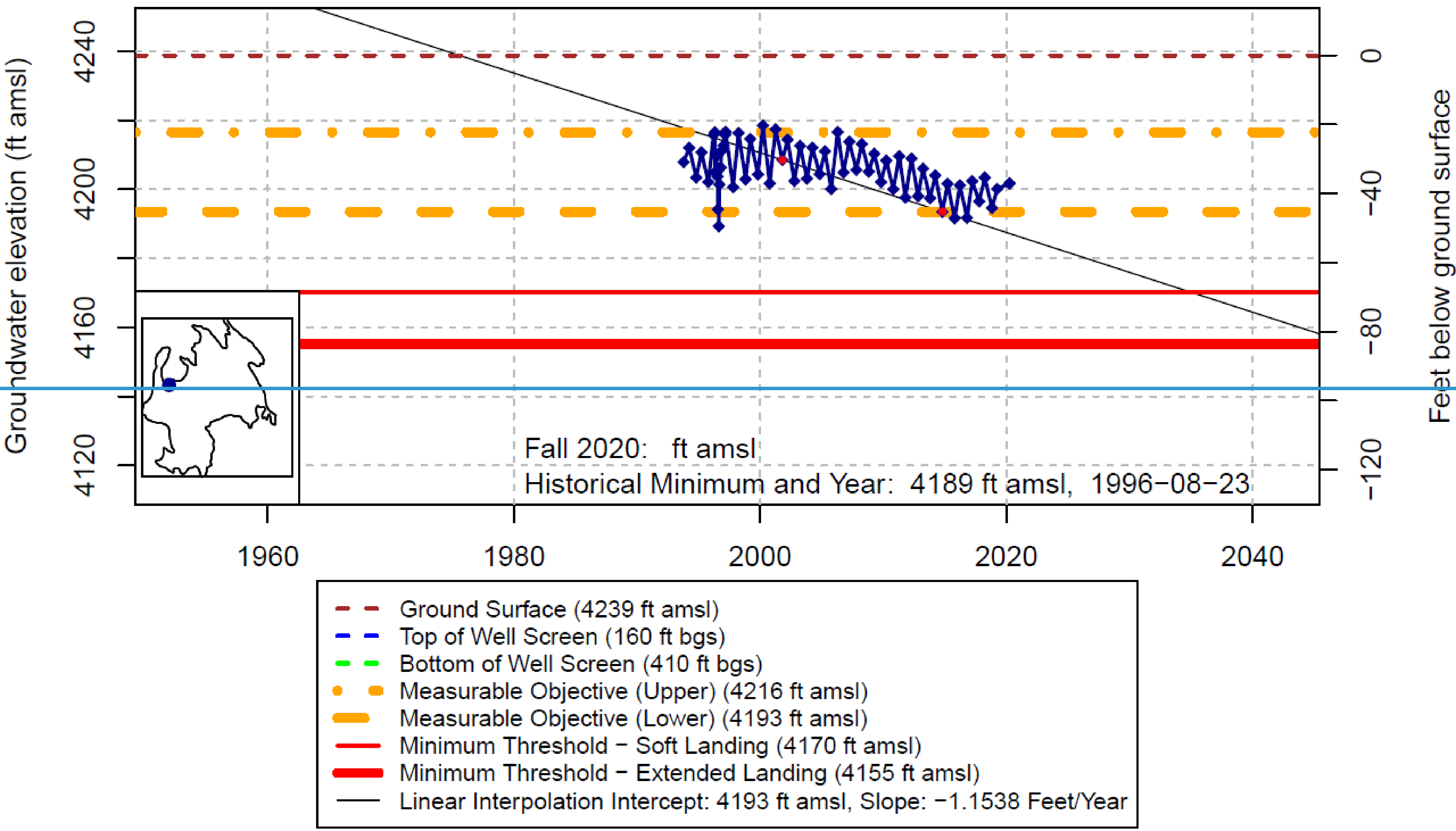
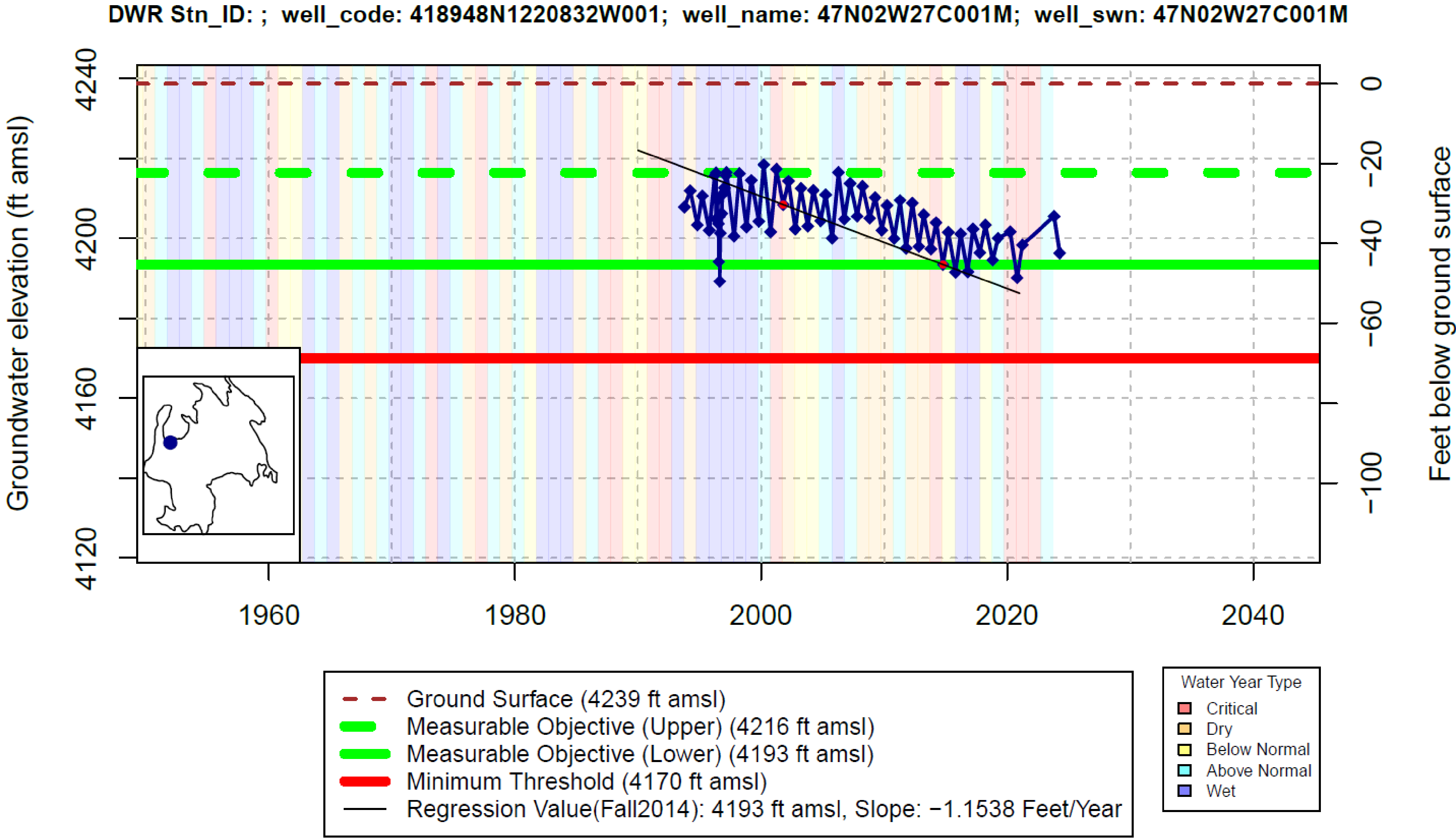
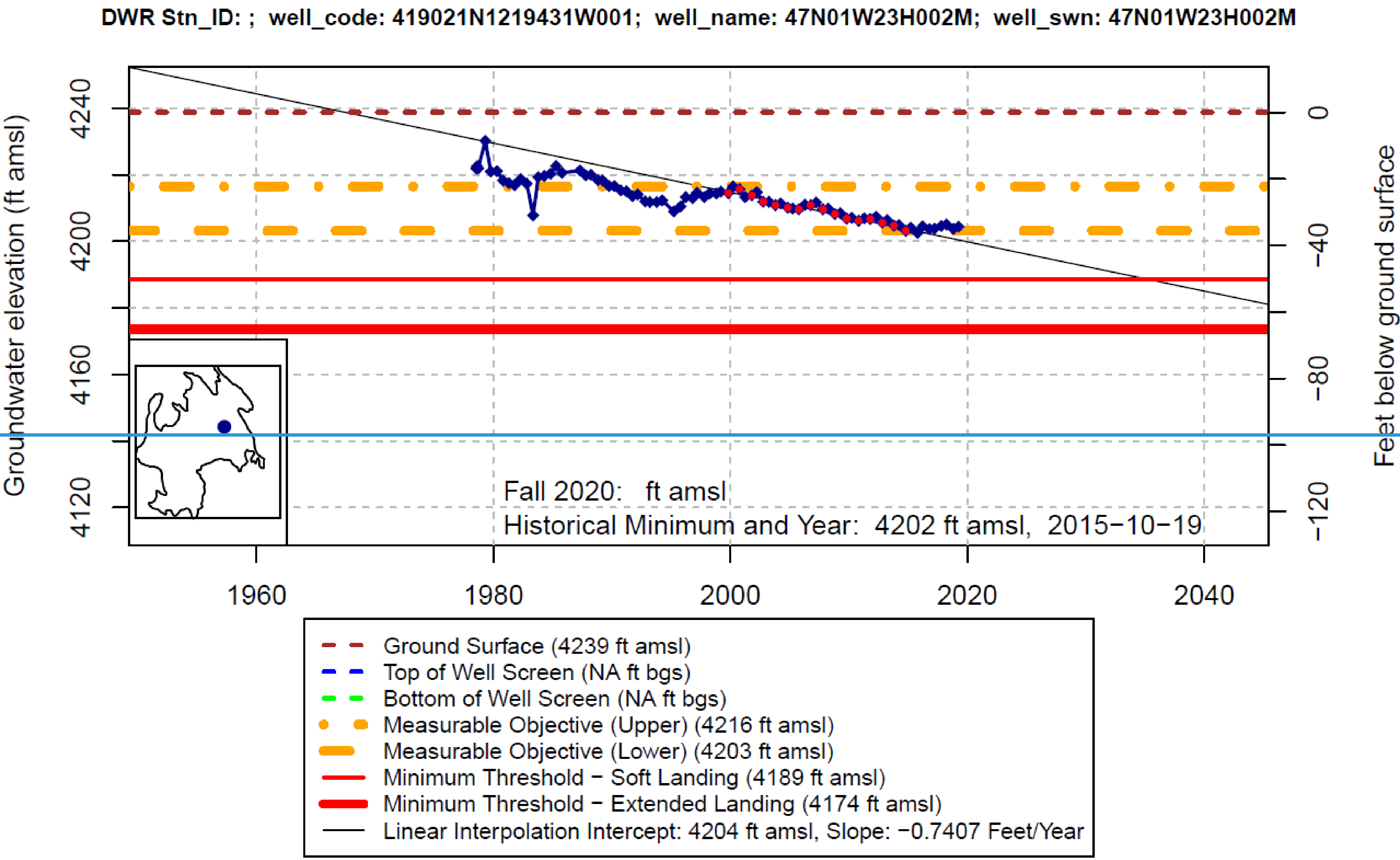
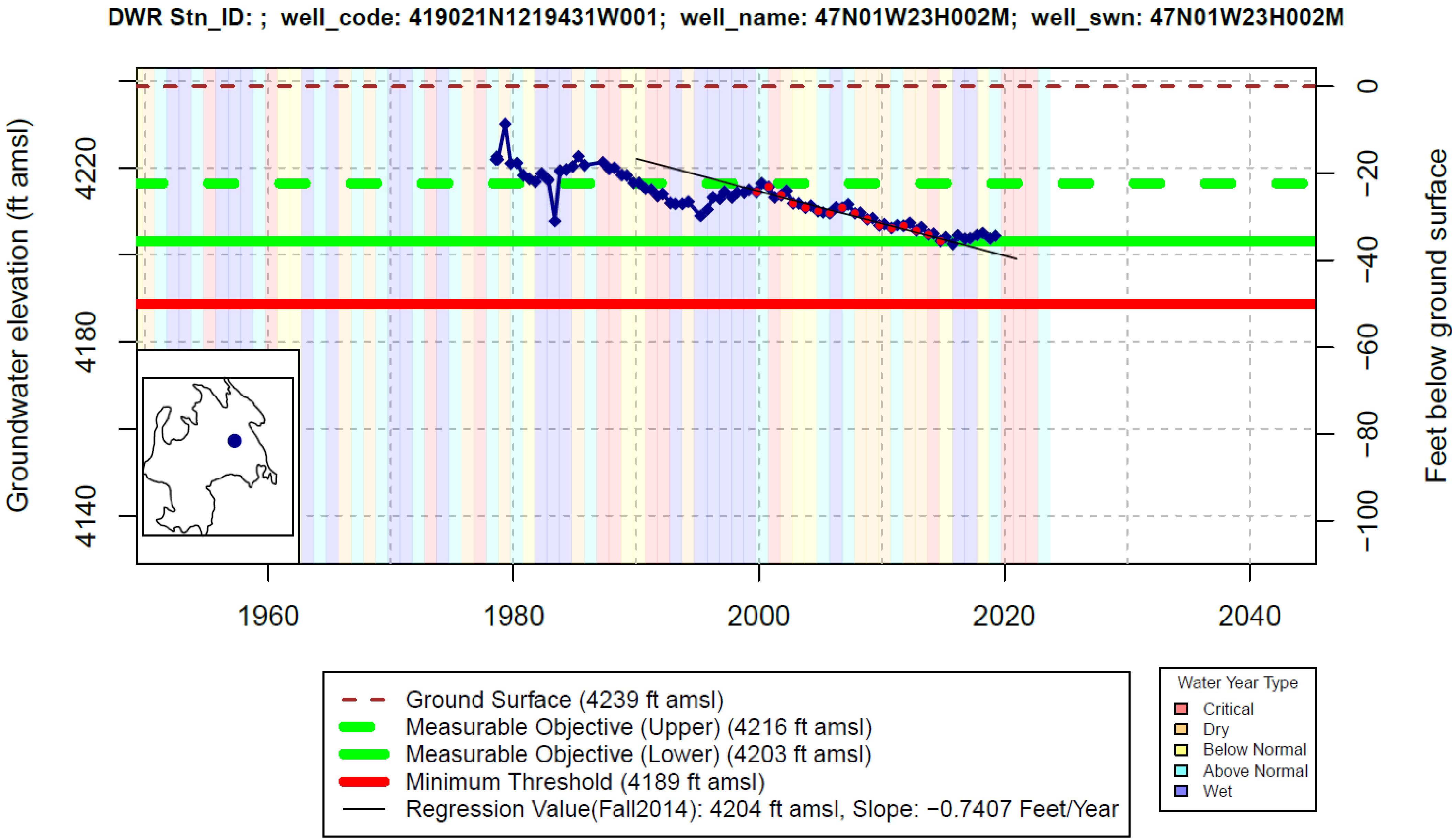




Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report. The results will be finalized once DWR updates the water year type dataset for these years.


DWR Stn_ID: ; well_code: 419021N1219431W001; well_name: 47N01W23H002M; well_swn: 47N01W23H002M
Groundwater elevation (ft amsl)
Feet below ground surface
4120
4160
4200
4240
0
−40
−80
−120
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4202 ft amsl, 2015−10−19
Ground Surface (4239 ft amsl)
Top of Well Screen (NA ft bgs)
Bottom of Well Screen (NA ft bgs)
Measurable Objective (Upper) (4216 ft amsl)
Measurable Objective (Lower) (4203 ft amsl)
Minimum Threshold − Soft Landing (4189 ft amsl)
Minimum Threshold − Extended Landing (4174 ft amsl)
Linear Interpolation Intercept: 4204 ft amsl, Slope: −0.7407 Feet/Year



Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

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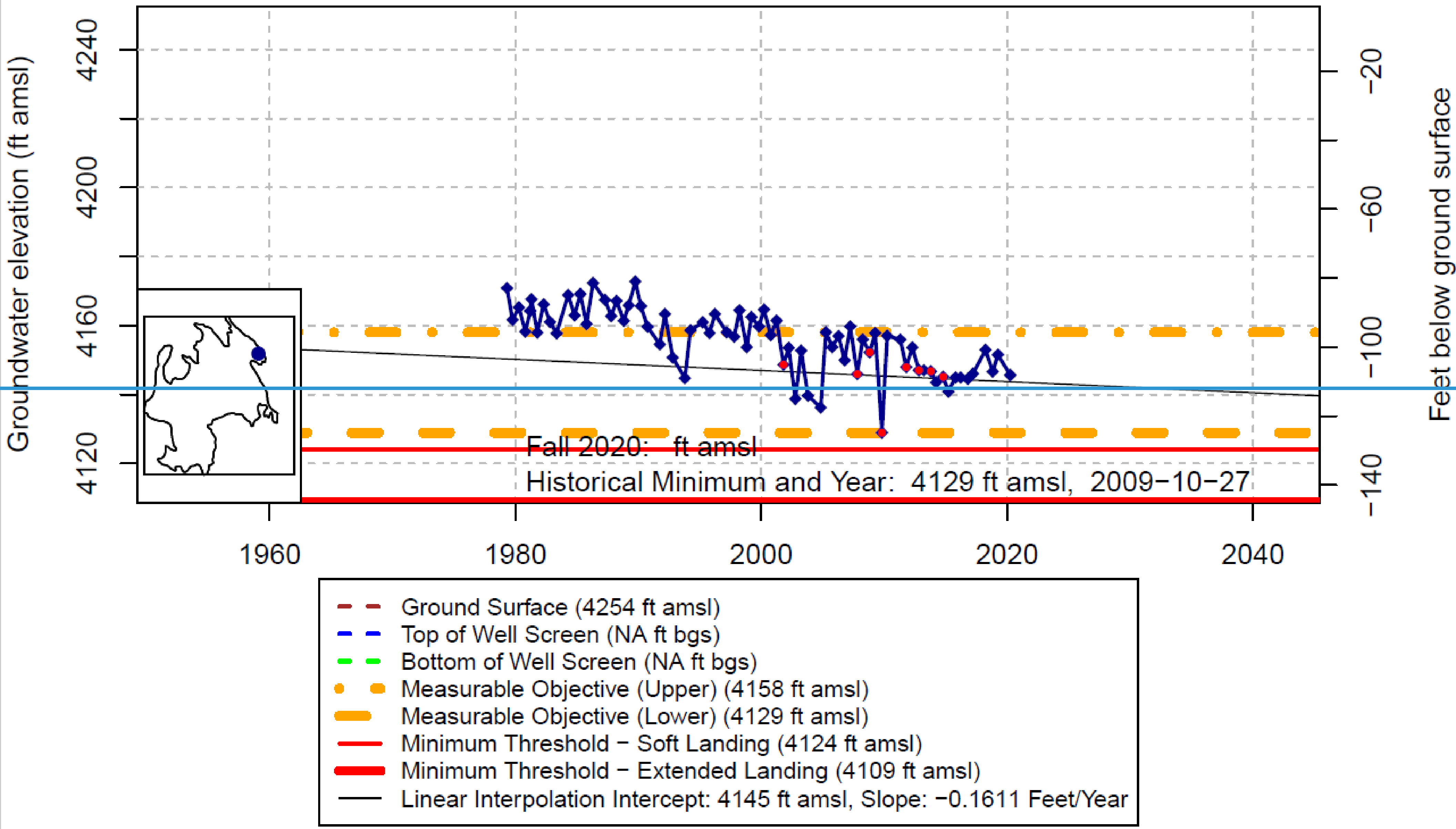
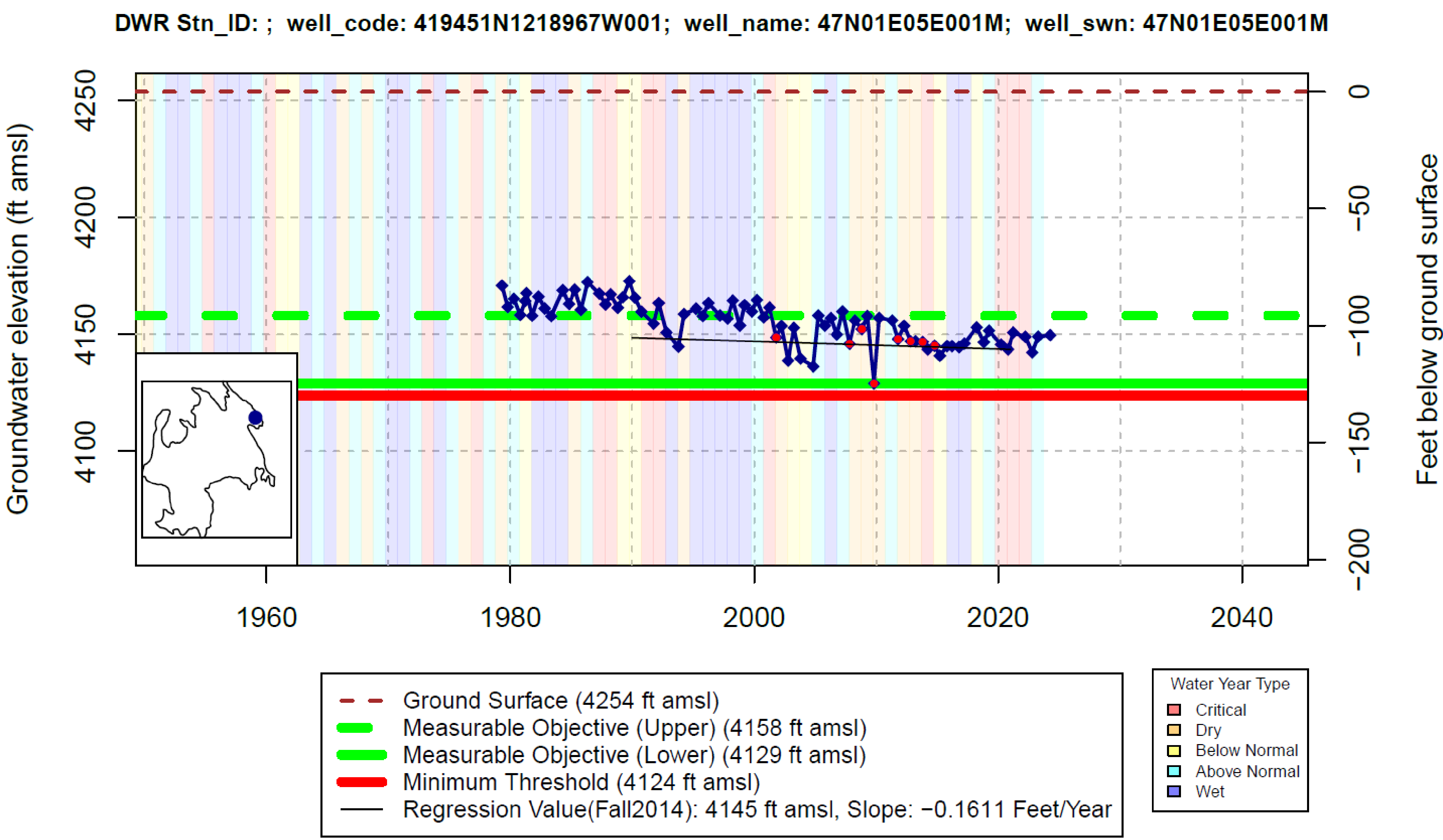
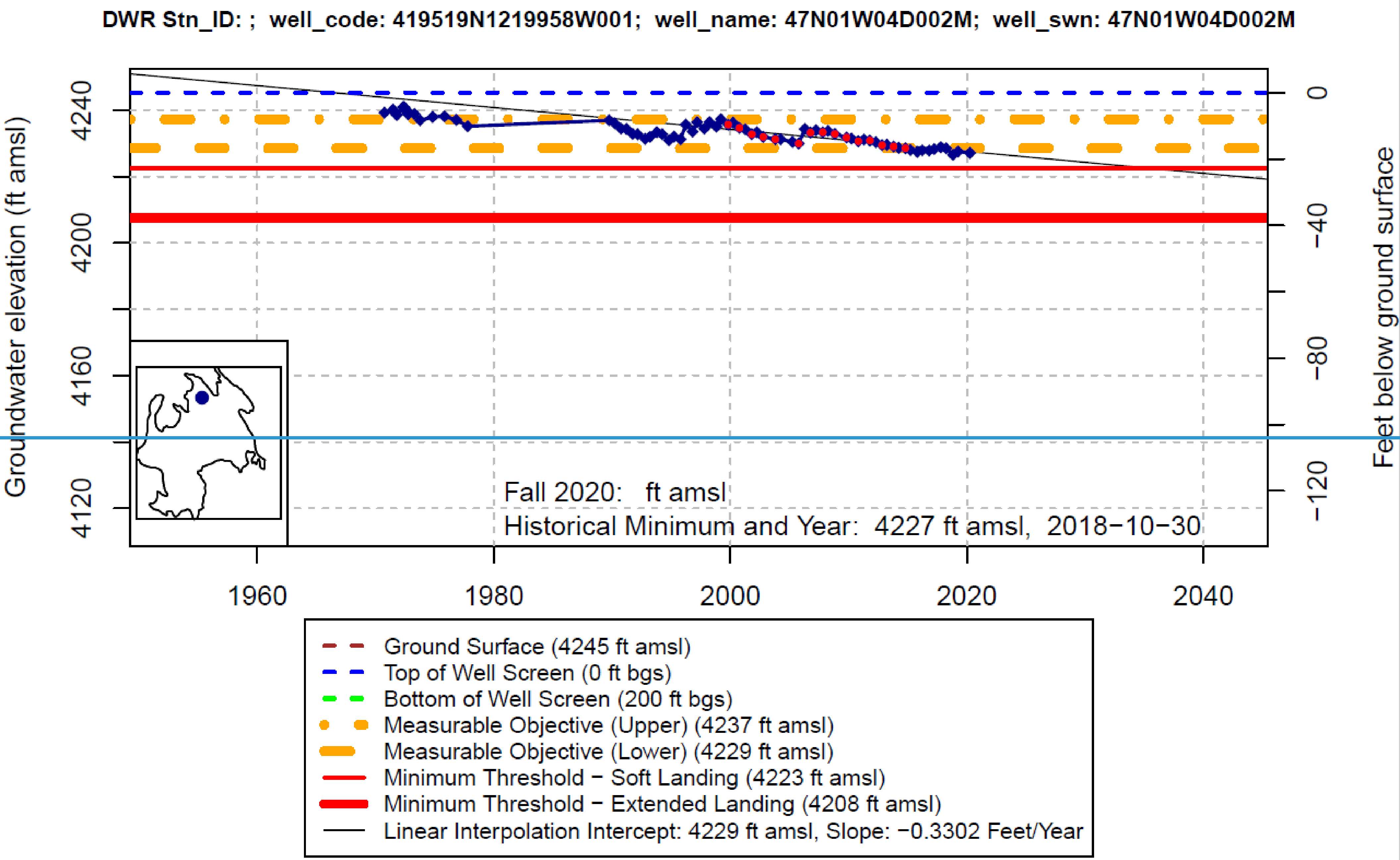


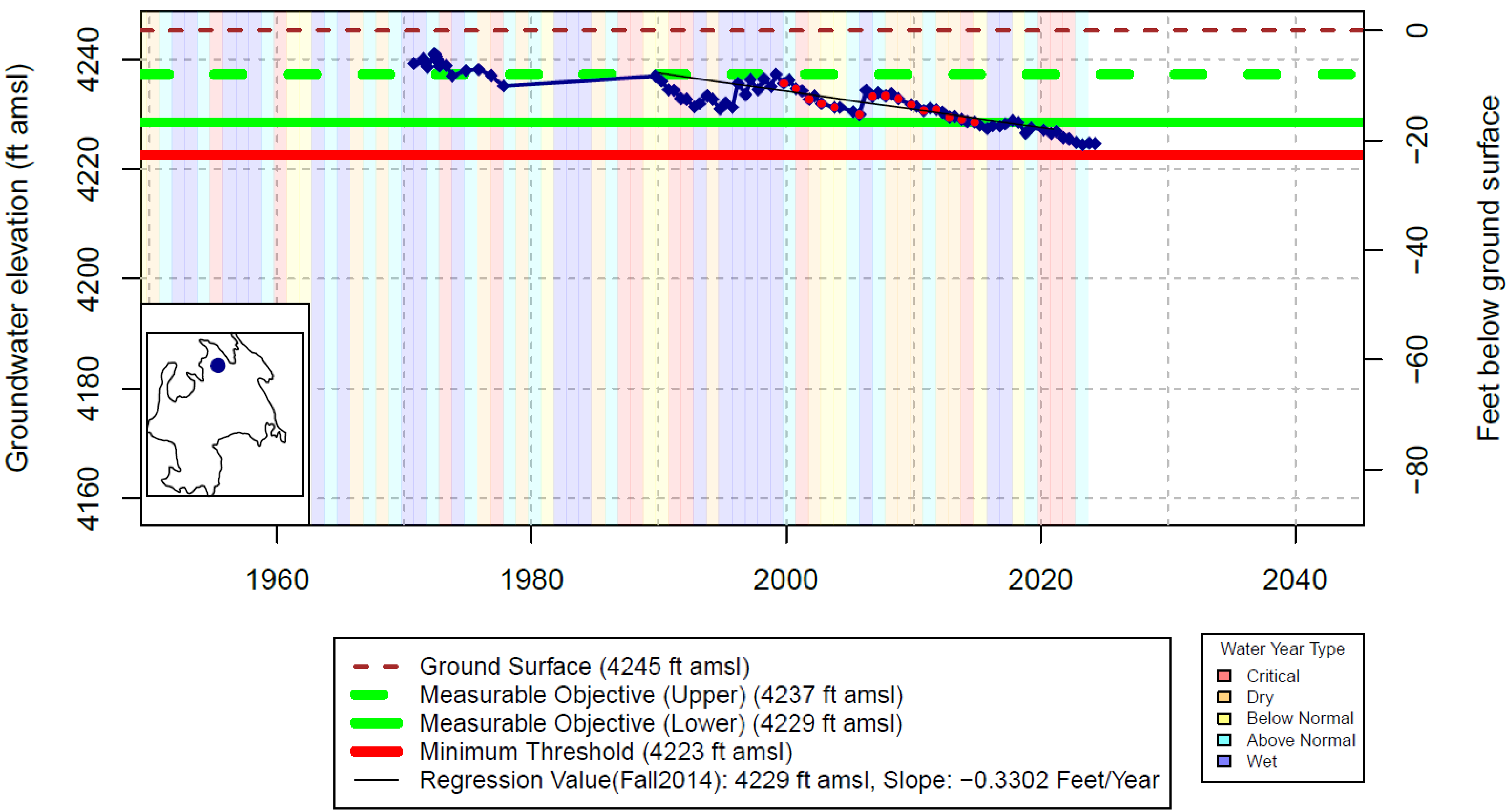


Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

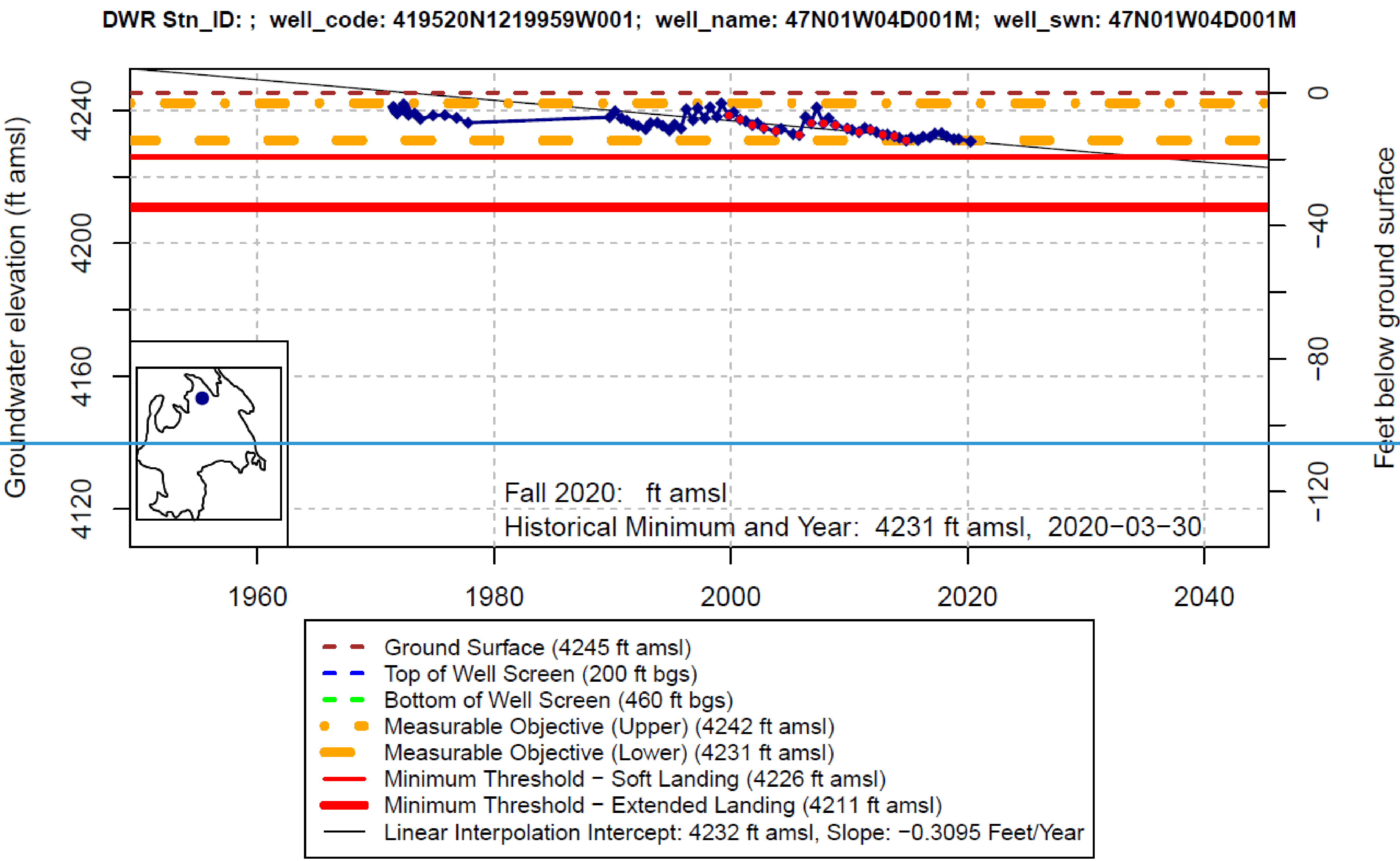


DWR Stn_ID: ; well_code: 419519N1219958W001; well_name: 47N01W04D002M; well_swn: 47N01W04D002M
Groundwater elevation (ft amsl)
Feet below ground surface
4240
4200
4160
4120
0
−40
−80
−120
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4227 ft amsl, 2018−10−30
Ground Surface (4245 ft amsl)
Top of Well Screen (0 ft bgs)
Bottom of Well Screen (200 ft bgs)
Measurable Objective (Upper) (4237 ft amsl)
Measurable Objective (Lower) (4229 ft amsl)
Minimum Threshold − Soft Landing (4223 ft amsl)
Minimum Threshold − Extended Landing (4208 ft amsl)
Linear Interpolation Intercept: 4229 ft amsl, Slope: −0.3302 Feet/Year

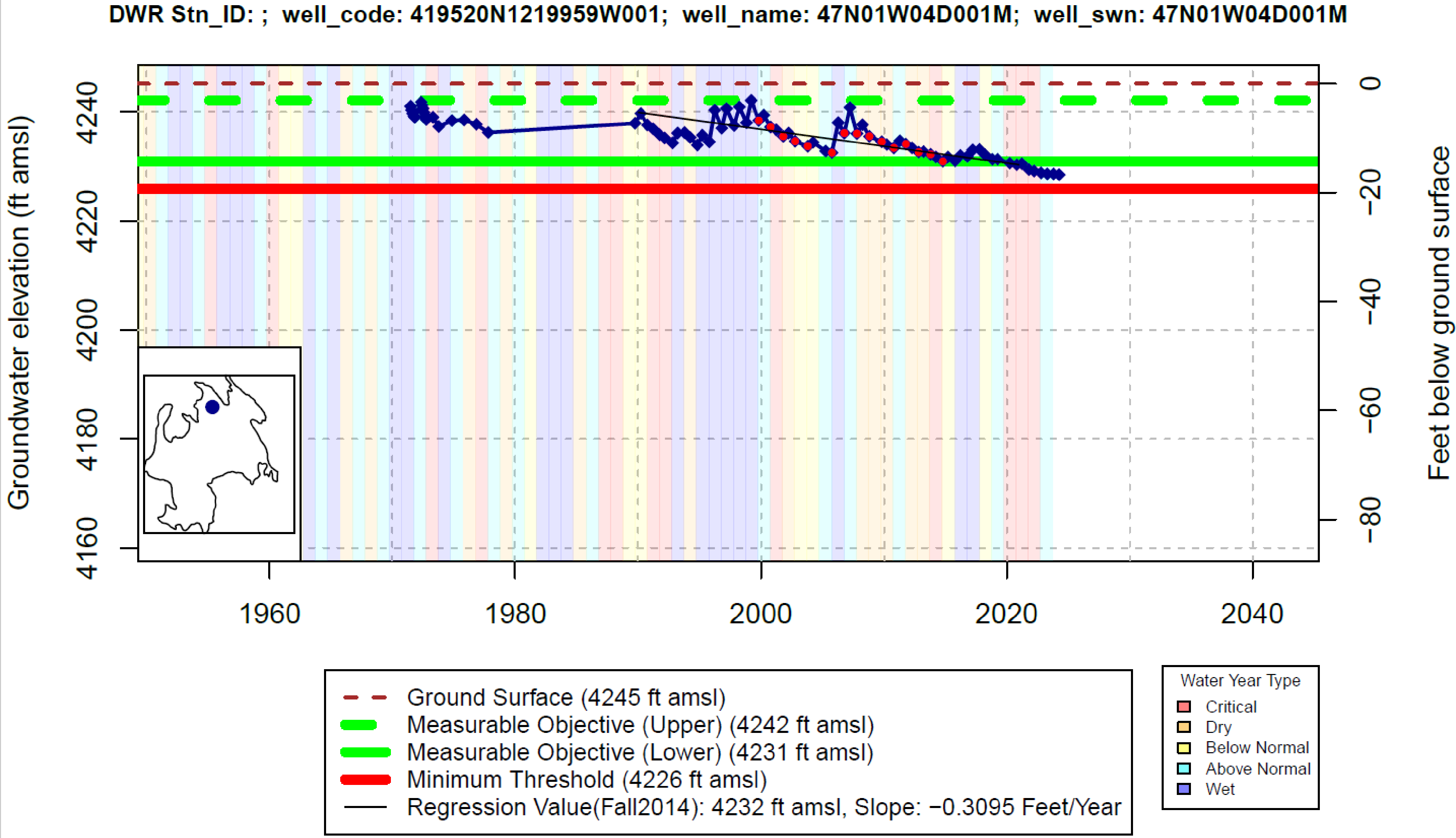
DWR Stn_ID: ; well_code: 419519N1219958W001; well_name: 47N01W04D002M; well_swn: 47N01W04D002M



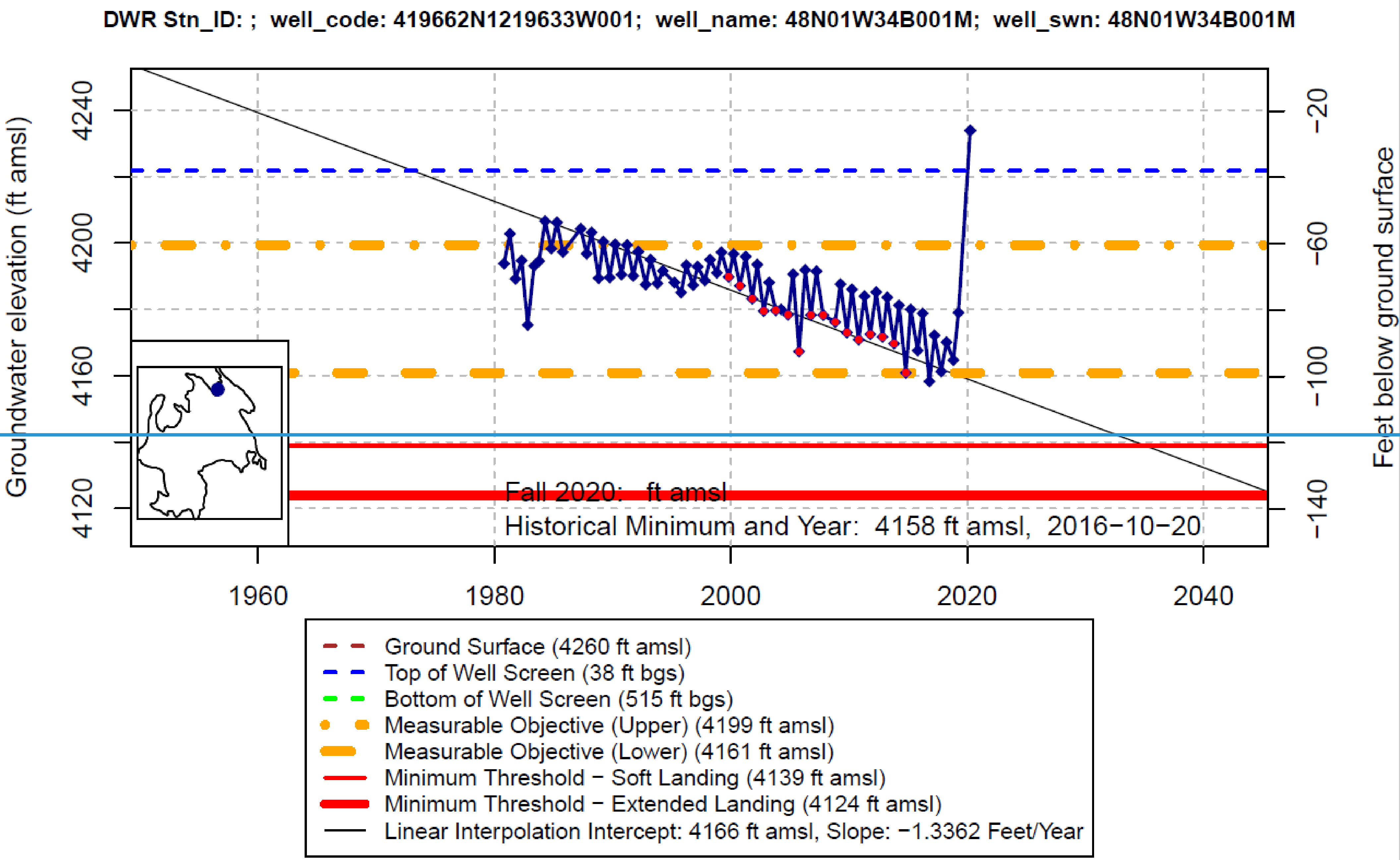
Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.



DWR Stn_ID: ; well_code: 419520N1219959W001; well_name: 47N01W04D001M; well_swn: 47N01W04D001M
Groundwater elevation (ft amsl)
Feet below ground surface
4240
4200
4160
4120
0
−40
−80
−120
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4231 ft amsl, 2020−03−30
Ground Surface (4245 ft amsl)
Top of Well Screen (200 ft bgs)
Bottom of Well Screen (460 ft bgs)
Measurable Objective (Upper) (4242 ft amsl)
Measurable Objective (Lower) (4231 ft amsl)
Minimum Threshold − Soft Landing (4226 ft amsl)
Minimum Threshold − Extended Landing (4211 ft amsl)
Linear Interpolation Intercept: 4232 ft amsl, Slope: −0.3095 Feet/Year



Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report. The results will be finalized once DWR updates the water year type dataset for these years.



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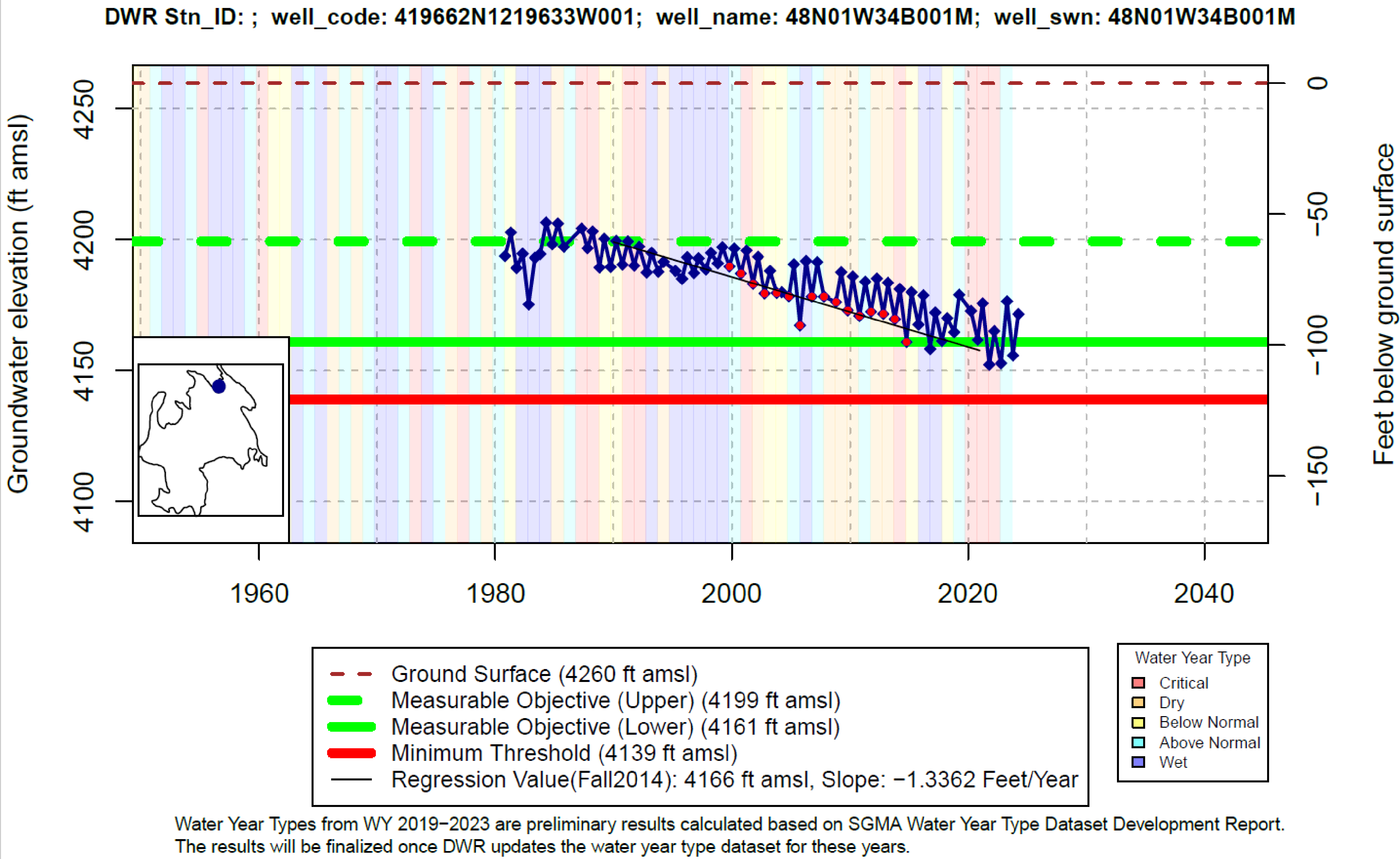
Groundwater elevation (ft amsl)
Feet below ground surface
4120
4160
4200
4240
−20
−60
−100
−140
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4158 ft amsl, 2016−10−20
Ground Surface (4260 ft amsl)
Top of Well Screen (38 ft bgs)
Bottom of Well Screen (515 ft bgs)
Measurable Objective (Upper) (4199 ft amsl)
Measurable Objective (Lower) (4161 ft amsl)
Minimum Threshold − Soft Landing (4139 ft amsl)
Minimum Threshold − Extended Landing (4124 ft amsl)
Linear Interpolation Intercept: 4166 ft amsl, Slope: −1.3362 Feet/Year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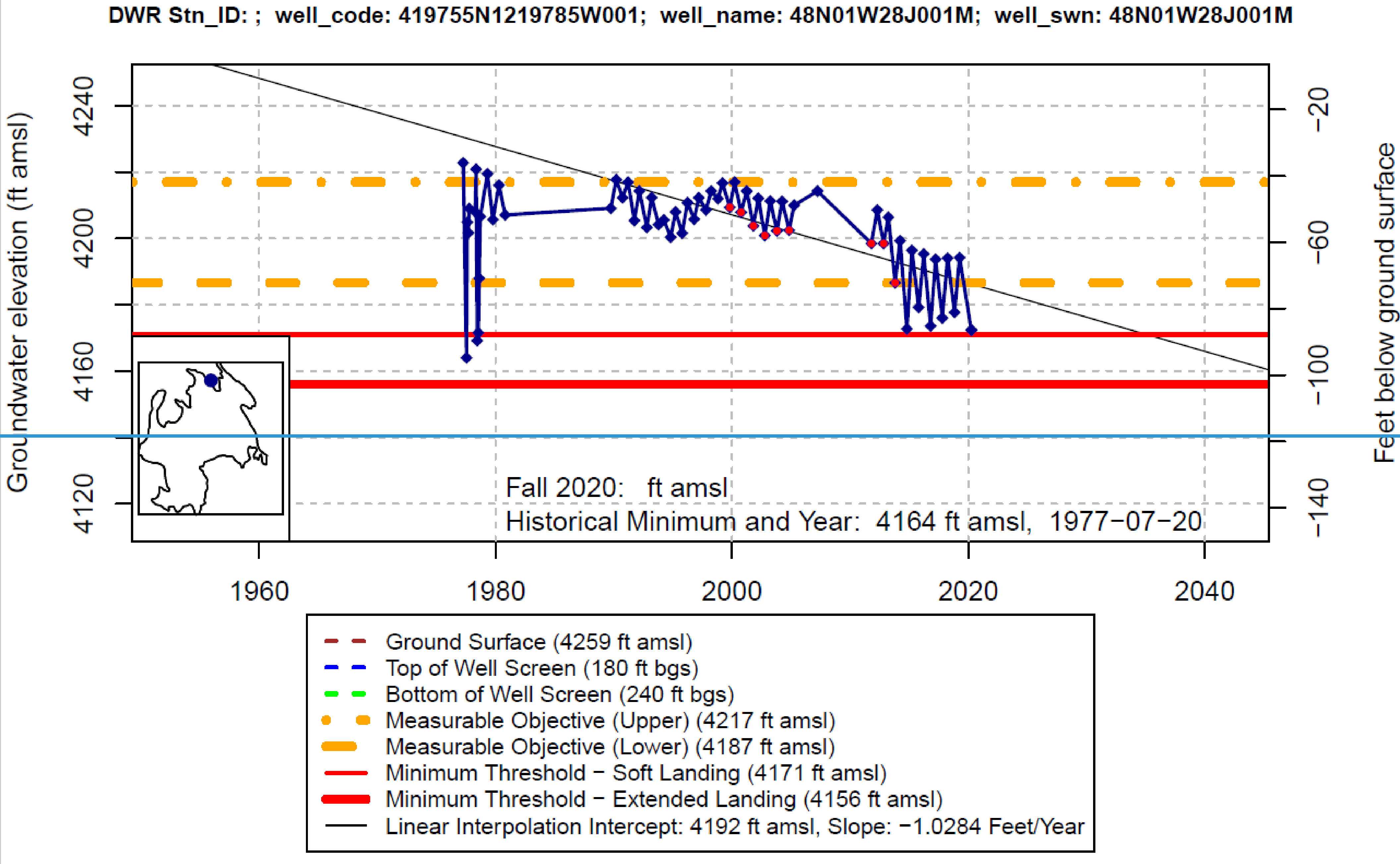
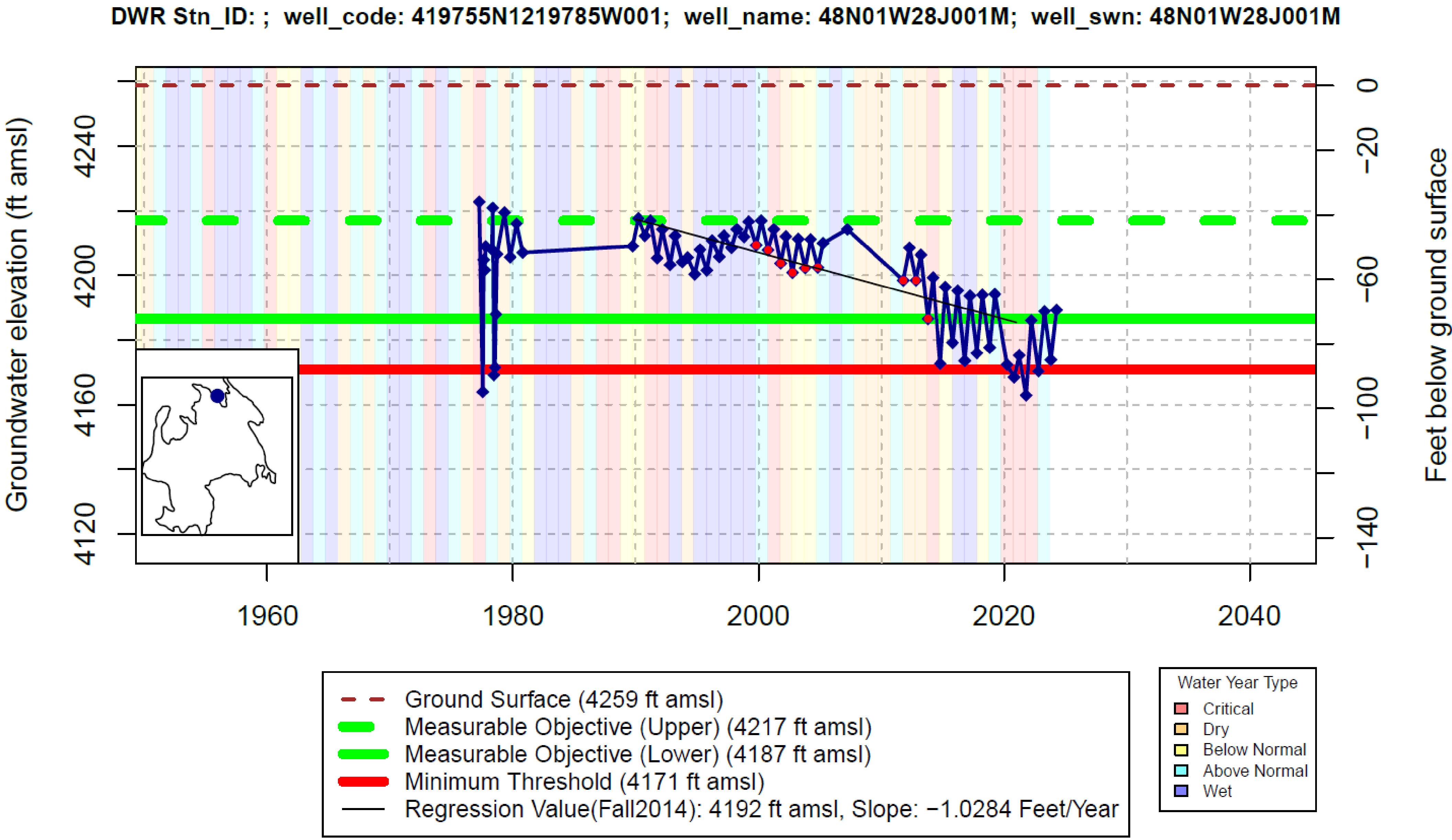
Groundwater elevation (ft amsl)
Feet below ground surface
4100
4150
4200
4250
0
−50
−100
−150
1960
1980
2000
2020
2040
Ground Surface (4260 ft amsl)
Measurable Objective (Upper) (4199 ft amsl)
Measurable Objective (Lower) (4161 ft amsl)
Minimum Threshold (4139 ft amsl)
Regression Value(Fall2014): 4166 ft amsl, Slope: −1.3362 Feet/Year
Water Year Type
Critical
Dry
Below Normal
Above Normal
Wet
Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.


DWR Stn_ID: ; well_code: 419755N1219785W001; well_name: 48N01W28J001M; well_swn: 48N01W28J001M
Groundwater elevation (ft amsl)
Feet below ground surface
4240
4200
4160
4120
−20
−60
−100
−140
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4164 ft amsl, 1977−07−20
Ground Surface (4259 ft amsl)
Top of Well Screen (180 ft bgs)
Bottom of Well Screen (240 ft bgs)
Measurable Objective (Upper) (4217 ft amsl)
Measurable Objective (Lower) (4187 ft amsl)
Minimum Threshold − Soft Landing (4171 ft amsl)
Minimum Threshold − Extended Landing (4156 ft amsl)
Linear Interpolation Intercept: 4192 ft amsl, Slope: −1.0284 Feet/Year



Water Year Types from WY 2019−2023 are preliminary results calculated based on SGMA Water Year Type Dataset Development Report.
The results will be finalized once DWR updates the water year type dataset for these years.

Well Failure Analysis (2024 GSP Revision)

Butte Valley Well Failure Discussion

Helen Zhou
Bill Rice
Dr. Thomas Harter
Larry Walker Associates & UC Davis

6/28/2024
~~11/30/2021~~

Contents

Introduction

This analysis has been performed to determine the number of wells that may be dewatered due to declining groundwater levels. In the Butte Valley, groundwater elevations are highly seasonal. The highest risk of dewatering occurs in the late summer and early fall, when water levels are at their seasonal low.

Ideally, this assessment would involve a comparison of historic and current water levels against well construction details across all or a representative subset of wells in Butte Valley. However, key data limitations inhibit a comparison of well construction details with water levels where they have been measured in wells:

- Well depth, perforated intervals and water level observations have been collected by multiple organizations/agencies.
- The most common datum available for known wells (i.e., wells registered through DWR's Online System for Well Completion Reports, OSWCR) is well depth.
- Ground surface elevations are not commonly available with well construction information. Obtaining ground surface elevation from digital land surface elevation maps at the well location is hampered by the fact that the location of wells is reported by township, range, and section and the exact location within the reported one square-mile section is not readily available.
- Water level information, especially longer time series of such information, is available only for a small subset of monitoring wells, with location accuracy tied to the reported section location (+/- 0.7 miles).
- For most wells associated with water level measurements, the corresponding well construction information is not readily available, making a direct comparison of water level to depth to top of perforation (or to total well depth) impossible without significant further reconnaissance.

Consequently, rather than comparing groundwater elevations with the well depth to top of perforations, this analysis focuses on interpolated groundwater elevation data to assess the aggregated risk of wells not being able to pump water due to low water levels ("well outages"). The risk analysis necessarily utilizes information that is readily available and is therefore limited in its specificity. Future analysis may be able to provide a more refined risk assessment as better information becomes available.

This analysis seeks to determine the number of wells that may be dewatered due to declining groundwater levels. In the Butte Valley, groundwater elevations are highly seasonal. The highest risk of dewatering occurs in the late summer and early fall, when water levels are at their seasonal low.

A thorough assessment would involve a comparison of historic and current water levels against well construction details across all or a representative subset of wells in Butte Valley. However, two key data limitations inhibit a comparison of well construction details with water levels where they have been measured in wells:

- Well depth and perforated intervals, on one hand, and water level observations on the other have been collected by multiple organizations/agencies.

- For most wells associated with water level measurements, the corresponding well construction information is not readily available, making a direct comparison of water levels and depth to top of perforation (or well depth) impossible without significant further reconnaissance.

Consequently, rather than comparing groundwater elevations with depth to top of perforations, this analysis focuses on interpolated groundwater elevation data to assess the aggregated risk of wells not being able to pump water due to low water levels ("well outages"). The risk analysis necessarily utilizes basic information that is readily available and is therefore limited in its specificity. Future analysis may provide a more refined risk assessment.

Methods

2024 Updates to the 2022 GSP Well Failure Discussion

During the original development and this 2024 revision of the Butte Valley GSP, manual review of well logs from OSWCR for more accurate well locations have been performed by technical staff. In reviewing the original GSP, it was found that OSWCR data from within and outside the Bulletin 118 basin boundaries were used for the well record summary in Chapter 2. To augment the well failure analysis in the 2022 GSP, the following improvements and updates were incorporated in this revised well failure analysis:

- OSWCR well records used and computations in this analysis were audited.
- The analysis result of fall 2017 in the original well failure analysis was replaced by the analysis of fall 2023, which reflects the most recent fall conditions.
- Only OSWCR well records in PLSS sections that are fully or partially within the Bulletin 118 basin were included in this analysis. A total of 443 wells with the minimum required construction information were considered for the Basin well failure analysis.
- A review of recently submitted Well Completion Reports was conducted. A summary of wells constructed between 2019 and 2023 and the rationale for excluding the recently constructed wells for the well outage risk analysis is provided in the Results and Discussion section.
- In addition to considering a statistical measure that defines the fraction of well outages per average 10 ft water level decline in the Basin, a direct comparison of interpolated water level against the total well depth was performed. Results are consistent with this statistical measure and provide additional confidence in the estimated number of dry wells (well outages).
- Analysis was performed not only by comparing interpolated water level against the top of the perforation (available for only a small fraction of wells), but also by comparing interpolated water levels against the well depth (available for all of the 443 well records).
- The number of dry wells was determined at the minimum threshold (MT) across the basin, using both methods.

Butte Well Data Statistics

A total of 461 well logs from OSWCR were identified in the Butte Valley Bulletin 118 basin boundary from OSWCR. To determine the wells at risk of dewatering, a total of 443 wells have been identified with total well depth recorded. The remaining 18 records did not identify well depth or have any information about depth or length of screens. These 18 records are likely outdated and could not be used in the analysis.

The 443 wells considered in the analysis were classified by the dominant geologic formation identified at the bottom of the perforated interval during geologic model development. Formations are described in greater detail in the Basin Setting section of the GSP. Major formations and the number of wells identified are the Ql - Lake deposits, QTb - Older volcanic rocks of the “High Cascades”, Qal - Alluvium, and Qb - Butte Valley basalt, with 93, 36, 22, and 16, wells each respectively, summarized in Table 1. Formations with fewer than 10 wells or where the formation was unknown were grouped as “Other (including unknown formation)”.

Wells were also classified and mapped by their planned use (Figure 1 and Figure 2) Only six public wells are found within the basin; one in Dorris, three in Macdoel, and two in the southern part of the basin. Domestic wells are also scattered in the areas of the Basin outside the Butte Valley Wildlife Area and outside the National Grasslands, which occupy the central and southwestern portion of the Basin. The largest number of agricultural wells is found in the southern and eastern portions of the basin. Wells with missing planned use designation occur in and near Dorris, Macdoel, and Mt. Hebron and also are scattered in surrounding rural areas. Domestic wells constitute the largest group of wells (163 of 443), agricultural wells are the second numerous type of wells (148 of 443, in Table 2)

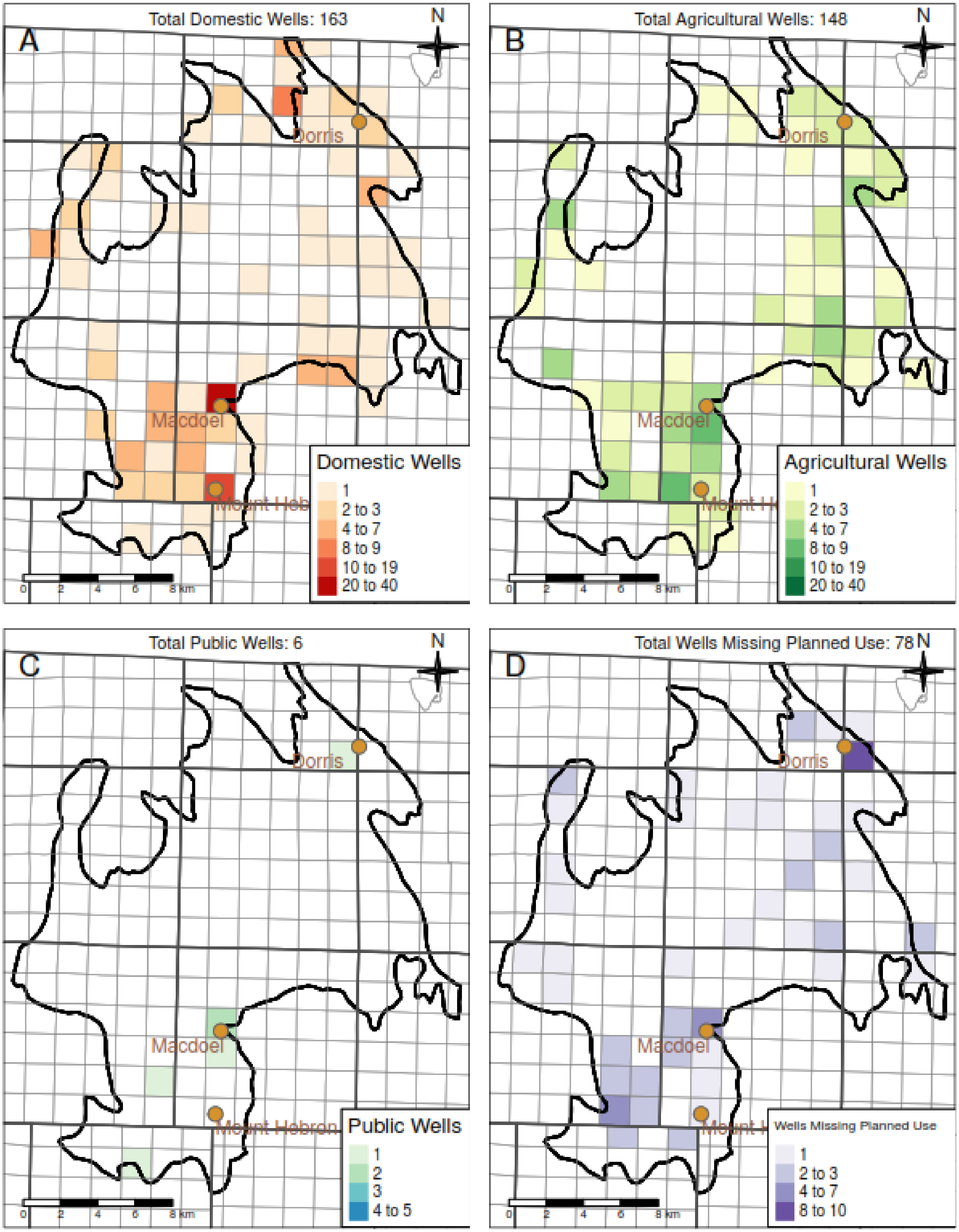


Figure 1: Butte Valley well choropleth maps by planned use from OSWCR.

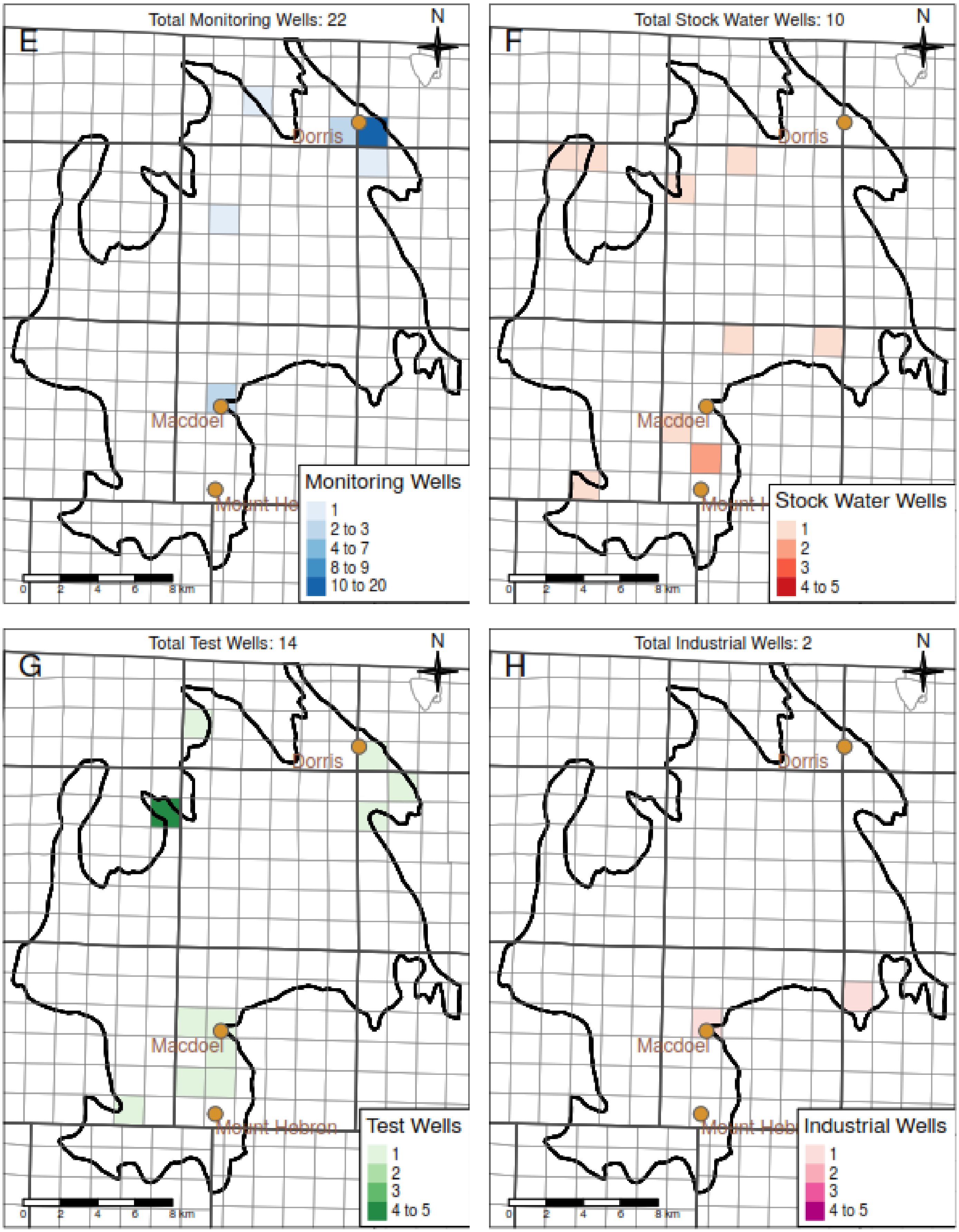


Figure 2: Butte Valley well choropleth maps by planned use from OSWCR (continued).

Table 1: Bottom Formation of Butte Valley Groundwater Basin Wells from OSWCR

Bottom Formation	No. of Wells
QTb - Older volcanic rocks of the "High Cascades"	36
Ql - Lake deposits	93
Qb - Butte Valley basalt	16
Qal - Alluvium	22
Other (including unknown formation)	276

Table 2: Planned Use of Butte Valley Groundwater Basin Wells from OSWCR

Planned Use	No. of Wells
agriculture	148
domestic	163
industrial	2
missing	78
monitoring	22
public	6
stock	10
test well	14

~~A total of 461 well logs were analyzed in the Butte Valley Bulletin 118 basin boundary. These wells were classified by the dominant geologic formation identified at the bottom of the perforated interval during geologic model development. Formations are described in greater detail in the Basin Setting section of the GSP. Major formations and the number of wells identified are the Ql - Lake deposits, QTb - Older volcanic rocks of the "High Cascades", Qal - Alluvium, and Qb - Butte Valley basalt, with 94, 36, 22, and 16, wells each respectively. Formations with fewer than 10 wells or where the formation was unknown were not considered for this analysis due to the sparsity of data. In total, 168 well logs out of 461, or 36 percent of the available wells, belong to one of the major formations and have sufficient data to describe perforation construction. Well locations are shown in Figure 1.~~

~~Paired top of well perforation and water level measurements were not available in most wells. Table 1 shows wells in the California Statewide Groundwater Elevation Monitoring Program (CASGEM) dataset with associated top of perforation data. This data is not sufficiently spatially distributed or representative of well type, depth, and construction to be used alone in establishing well failure risk. Similarly, Table 2 shows the number of wells in each major formation.~~

~~Table 1: Available information for Butte Valley wells.~~

~~Depth, Obs., Perf. Available?~~	~~Well Info Source~~	~~No. of Wells~~
~~None (location only)~~	~~LWA GWO~~	~~95~~
~~Total Depth Only~~	~~LWA GWO~~	~~7~~
~~Observations Only~~	~~Volunteer Monitoring~~	~~24~~
~~Observations Only~~	~~DWR~~	~~9~~
~~Observations Only~~	~~LWA GWO~~	~~4~~
~~Perforation Only~~	~~–~~	~~0~~
~~Observations and Depth~~	~~DWR~~	~~17~~
~~Observations and Depth~~	~~LWA GWO~~	~~8~~
~~Depth, Obs. and Perf.~~	~~DWR~~	~~24~~
~~Depth, Obs. and Perf.~~	~~–~~	~~0~~

Table 2: Wells used in Butte Valley Well Outage Analysis

Bottom Formation	Top of Perforation (Depth in Feet)
Qal - Alluvium	22
Qb - Butte Valley basalt	16
Ql - Lake deposits	94
QTb - Older volcanic rocks of the "High Cascades"	36

Well Outage Risk Analysis

As noted previously, paired top of well perforation elevations and water level measurements were only available in a limited number of wells. For 24 wells, the California Statewide Groundwater Elevation Monitoring Program (CASGEM) provides records of water level, depth to top of screen (perforations) and well depth. For an additional 21 wells, water level and well depth is available in CASGEM (Table 3). The number of these records (45 of 443 wells) is not sufficiently spatially distributed or representative of well type, depth, and construction to be used alone in determining well failure risk. We therefore have utilized alternative methods for well failure analysis.

Due to the limited monitoring wells with water level data and human consumption wells with construction information available, a direct comparison of measured water levels to screened interval or well depth is not currently possible for the majority of Butte Valley consumption wells. Instead, two types of well failure analyses have been performed: a well failure analysis by direct comparison of estimated water level depth with well depth, and a more general trend analysis that considers the slope of the cumulative distribution of estimated wet water column depth. The rationales for and further details of these failure analyses are described in the following subsections.

Table 3: Available information for Butte Valley wells ('observations' refers to water level observations).

Depth, Obs., Perf. Available?	Well Info Source	No. of Wells
None (location only)	DWR TSS Well	1
None (location only)	LWA GWO	115
Total Depth Only	LWA GWO	8
Observations Only	Volunteer Monitoring	34
Observations Only	DWR TSS Well	3
Observations Only	DWR Well Completion	27
Observations Only	DWR	9
Observations Only	LWA GWO	2
Perforation Only	–	0
Observations and Depth	DWR	21
Observations and Depth	LWA GWO	9
Depth, Obs. and Perf.	DWR	24

Uncertainties in Estimating Risk of Well Failure

Absent direct observation of well construction records and water levels, water level elevation at the well location must be estimated from nearby water level observations, incurring an estimation error associated with the interpolation of water level elevations (or depth to water level) at monitored well sites to the hundreds of other well sites across the Basin.

The location of wells is recorded, in most cases, to the center of the PLSS section within which a well is located. While the land elevation at the center of a PLSS section is available from USGS digital elevation maps, and water level elevation or depth can be extrapolated to that exact location, there may be differences in the land elevation, water level elevation, or water level depth between the center of a PLSS section and the actual well location that cannot be accounted for in the spatial extrapolation.

To understand potential errors arising from lack of precise well location records, it is useful to consider the change in land elevation across a section and the change in water level depth across a single PLSS section, relative to the center of the PLSS section:

Much of the Butte Valley floor is essentially flat at elevations between 4226 ft amsl (west of Meiss Lake), 4236 ft amsl (Meiss Lake), 4240-4245 ft amsl (most of the central valley floor west, north, and northeast of MacDoel, south of Dorris), 4250 ft amsl (MacDoel), 4255 ft amsl, Dorris) and 4260 ft amsl (Mt. Hebron). The base of foothills is generally at 4270 ft amsl. For sections entirely contained within the Butte Valley floor, land elevation within a section commonly varies within +/- 5 ft from the section center. However, for sections overlapping with foothill or escarpment slopes, land elevations within a section may be tens or even hundreds of feet different from the section center.

Similar to land elevation, water levels across the floor of the Basin vary only gradually, especially in spring, prior to the pumping season, when local cones of depression have not yet developed. Analyses of water level interpolation across the Basin indicate that the depth to water level changes typically by less than 10 ft per mile (the length of a PLSS section), but can range up to about 20 ft in some years and locations (Figure 5 and Figure 6). In contrast, under foothill or escarpment terrain, depth to water may change as rapidly as land elevations (Figure 5 and Figure 6).

In light of these potential differences in land elevation and water level depth between interpolated data and actual water level, and between the center of a section and the unknown location of a well in that section, the uncertainty about measuring water level elevation above a reported depth to top of perforation, or above a depth to reported depth of well, is on the order of less than 5 ft to 20 ft for wells on the floor of the Basin. For wells in sections that include foothills or escarpments, comparison of estimated water level elevation with well construction information may be associated with errors far exceeding 10 ft.

Additional uncertainties arise from lack of pump placement records and lack of recorded physical limitations to pump placement within the existing well casing, which is a function of geology, well design, pumping rate and other construction details.

Water Level Interpolation

For both types of Well Outage Risk Analysis (direct comparison and trend analysis), three maps of water levels have been constructed: two from measured depth to groundwater, in the fall of 2015 (dry year) and in the fall of 2023 (most recent fall conditions), and one from the MTs at the Representative Monitoring Points (RMPs). The first two water level years have been used to estimate well outages in Butte Valley over the most recent 8 year period and to compare those to reported well outages in the DWR well outage database. The interpolation of MTs was used to predict the number of outages if the water levels reached the MTs at all RMPs simultaneously.

Fall season is considered to be the time period between September 15 - October 31, and the fall low is defined as the maximum depth to groundwater during that time interval. Fall lows are selected for the outage risk analysis to represent the typical low groundwater levels during a year. The interpolated water table depths are most accurate near the locations of the measured wells. The accuracy of estimates deteriorates with distance from a measured well.

Well Outage Risk Analysis by Direct Comparison

Measured water levels for the fall of years of interest and for MTs at the RMPs have been interpolated to the reported location of all wells in the Butte Valley groundwater basin for which construction information is available. This allows for a direct comparison of total well depth against the interpolated water levels, as follows:

```
[reported total depth of well] - [interpolated depth to groundwater at
reported location] = [wet depth to bottom of well]
```

For purposes of this first analysis, we have assumed that a **well outage** (dry well) occurs when the “wet depth to bottom of well” is less than 10 ft.

Considering that some wells may not be able to draw water when only 10 ft of water remain, a more conservative well outage risk criterion was used by comparing the depth to top of perforation and the interpolated water levels at each well, where construction information is available:

```
[reported depth to top of perforation] - [interpolated depth to groundwater
at reported location] = [wet depth to top of perforation]
```

In this conservative evaluation, we assume that a **well outage** occurs when the “interpolated depth to groundwater” is greater than the “depth to top of perforation”, that is, when the “wet depth to top of perforation” is negative, which also means the water table is below the top of perforation.

Note: By using the USGS reported elevation at the reported well location as the reference elevation for both terms on the left-hand-side, the wet depth to top of perforations can also be expressed as:

```
[interpolated water table elevation at reported location] - [reported elevation
of total depth/top of perforation] = [wet depth to total depth/top of perforation]
```

This first analysis may be expanded in the future, with a programmatic effort to better match water level data with well construction information and to obtain better well location information, particularly near the margins of the basin, which are also the areas with the most wells due to the lower flooding risk.

Well Outage Risk Analysis by Wet Depth Trend Analysis

Cumulative distributions have been created for the estimated wet water column depth obtained from the direct comparison method described above. The cumulative distribution values of the wet depth (either above the bottom of the well plus 10 ft, or above the top of the screen) show the fraction of wells that do not exceed the corresponding wet depth in a specific year (or at the MT). The cumulative distribution value at a wet depth of zero indicates the fraction of wells that is likely dry (subject to well outage), which is the same result obtained in the previous direct comparison analysis.

The cumulative distribution provides additional information that is useful considering that there is some uncertainty about the exact depth of the water level at the actual (but unknown) location of the well and about the pump placement requirement: The slope of the cumulative distribution in the shallower range of wet depth indicates the additional number of wells as a fraction of the total number of wells per feet of additional wet depth (or say, percent of total wells per feet of wet depth). The shallower range of wet depths has been quantified as the measures of wet depth between the 5th and 35th percentile of the cumulative distribution function. The slope determined within this range would be a reasonable metric, as the distribution within this range of wet depth has been found to be nearly linear. Additionally, this selection of percentile range not only ensures the shallowest set of wells are considered for well outage risk analysis, but also excludes wells with exceedingly negative wet depths, which may be due to: the well might have been dry for many years, abandoned, or, data errors might have occurred. Furthermore, the 5th to 35th percentile section of the cumulative distribution tends to also be the steepest section, which indicates it is also the range where the majority of wet depths occur (in other words, it has the most wells added to the cumulative distribution function for every 1, 2, 5, 10 ft etc increase in wet depth).

Knowing how many wells have an additional 1, 2, 5, 10 ft etc of wet depth provides a means for estimating the number wells that fall dry as a fraction of the total number of wells for each additional 1, 2, 5, 10 ft etc of water level decline, which is how the concept mentioned above was translated into estimating additional well outages through the linear slope between the 5th to 35 percentile of the cumulative distribution function.

In this analysis, the trend analysis results have been presented as the slope of the cumulative distribution, which is the fraction of total wells in percent per 10 ft increase in wet depth. This number represents an estimate of the percent of wells likely to fall dry per 10 ft of additional water level decline, on average, across the Basin.

Reported Well Outages

For this 2024 well analysis revision, a review of the DWR Dry Well Report database and the findings of 2023 Butte Valley Well Outage Survey have been conducted to further support and validate the findings from the well outage risk estimation for Butte Valley, and to identify potential missing well outages reported for the GSA.

Estimating the elevation datum for each well is based on the USGS reported elevation at the location of the well reported by the respective program agency (mostly DWR). The accuracy of the elevation is estimated to be within 3% of one-half mile, i.e., 80 feet, where 3% represents a general maximum landscape slope within the Butte groundwater basin and one-half mile represents the maximum distance of the actual well location from the reported well location. Some areas within the Butte Valley basin have steeper slopes. There, estimated well elevations may be even less accurate. For comparison of estimated water level elevation with well construction information, not being able to determine elevation of a well at its approximate location with an accuracy much better than 10 feet is potentially very problematic.

Unfortunately, a direct comparison of water levels to screened interval or well depth is not currently possible for the overwhelming majority of Butte Valley wells. A future effort to match water level data with well construction information will help connect some of the wells (from Well Completion Reports) with wells that have recent water level observations. This will provide an aggregated analysis of well outage risk within the network of wells with known water levels.

Instead, the analysis here focuses a) on a review of overall well construction information in Butte Valley and b) a preliminary, highly approximative estimate of the depth of water above the top of well perforations below the water table and its statistical distribution.

This second step relies on comparing the interpolated water level at the reported well location, obtained by mapping measured water levels in Butte Valley, against the elevation of the top of perforations at each well for which construction information is available, at the reported location. The estimate of the elevation of the top of perforations is obtained from the estimated elevation of the well at the reported location and well construction information (depth to top of perforations). The difference between estimated water level elevation and estimated elevation of the top of perforations is herein referred to as the "wet depth to top of perforations":

```
[reported depth to top of perforations] – [interpolated depth to groundwater
at reported location] = [wet depth to top of perforations]
```

Note: By using the USGS reported elevation at the reported well location as the reference elevation for both terms on the left-hand-side, the wet depth to top of perforations can also be expressed as:

```
[interpolated water table elevation at reported location] – [reported elevation
of top of perforations] = [wet depth to top of perforations]
```

For the interpolated depth to water table two maps were constructed from measured depth to groundwater: in the fall of 2015 (dry year) and in the fall of 2017 (wet year). Water level maps were constructed using spline interpolation. The maps of depth to water table were used to digitally determine the interpolated depth to water table at the reported location of each well considered.

Results and Discussion

Well Distribution and Construction Information in Butte Valley

The major planned use of wells of interest for beneficial uses and users of groundwater in Butte Valley are domestic, public, and agricultural water supply wells. In total, 317 out of 443 wells documented in OSWCR fall into these three categories (Figure 1, Figure 2 and Table 2). An analysis of the depth distribution among the 78 wells with "missing" planned use reveals significant similarity to that for domestic wells. For this analysis, the 78 wells are therefore assumed to be domestic wells. The summary of well depth and perforation statistics is presented in Table 4 for these wells. Table 4 shows that for all the OSWCR wells with total well depth available, a majority of them do not have perforation details.

The total completed depths of these wells below ground surface and their associated bottom formation are demonstrated in Figure 3. Of the known formations, domestic wells and "missing" planned use wells are mostly completed in quaternary lake deposits. Most domestic and "missing" planned use wells have depth in the range of 100 ft to 250 ft unless they are completed in the older volcanic rocks (at least 200 ft deep). Shallowest depths of all wells are over 30 ft and deepest wells can be more than 1400 ft.

Agricultural wells have a significantly broader depth distribution than domestic wells. Many newer agricultural wells are 300-500 feet deep while older wells have depths similar to domestic wells. The depth distribution of agricultural wells is similar across geologic formations except in the older volcanic rocks of the High Cascades (QTb) where agricultural wells are less common and are only found at significant depth, typically near the basin boundaries. In the QTb, the agricultural well depths range from about 30 ft to about 1800 ft (Table 4). Additional well construction information can be found in the Supplementary Information.

To understand how a chronic decline in water levels may affect human and natural beneficial uses, the following analysis was performed to evaluate the 247 domestic and public wells from OSWCR in Butte Valley groundwater basin (including "missing" planned use). Their spatial distribution by well formation is presented in Figure 4.

Well logs of newly constructed wells during 2019 and 2023 have been actively reviewed by technical staff for more accurate location information. The preliminary investigation of these wells' construction information indicates that a total of 17 wells were newly installed for domestic and public supply use (14 wells) and agricultural use (3 wells). The new domestic wells have total depths ranging from 80 to 400 ft below ground surface. For the purpose of this analysis, these newly constructed well are not included for the well outage risk analysis, given the need to provide a consistent set of wells for evaluations in 2015 and 2023, and at MT.

Table 4: Summary Statistics of Construction Information by Major Planned Well Use

Planned Use	Statistic	Total Completed Depth (ft bgs)	Top of Perforation (ft bgs)	Bottom of Perforation (ft bgs)	Perforated Length (ft)
agriculture	Min.	29	0	20	8
	1st Qu.	119	46	124	58
	Median	216	71	204	120
	Mean	332	148	317	169
	3rd Qu.	407	154	400	200
	Max.	1818	943	1626	995
	NA count	0	75	75	75
	Percent NA	0	51	51	51
domestic	Min.	32	0	23	4
	1st Qu.	90	38	90	20
	Median	125	62	128	40
	Mean	180	99	173	74
	3rd Qu.	202	128	181	79
	Max.	1450	541	1433	1342
	NA count	0	91	91	91
	Percent NA	0	56	56	56
missing	Min.	29	20	30	2
	1st Qu.	60	31	58	16
	Median	102	47	118	20
	Mean	158	89	131	42
	3rd Qu.	200	120	172	42
	Max.	805	321	341	170
	NA count	0	66	66	66
	Percent NA	0	85	85	85
public	Min.	77	58	78	9
	1st Qu.	111	85	105	20
	Median	143	92	132	20
	Mean	329	119	149	30
	3rd Qu.	241	99	159	40
	Max.	1236	261	270	60
	NA count	0	1	1	1
	Percent NA	0	17	17	17

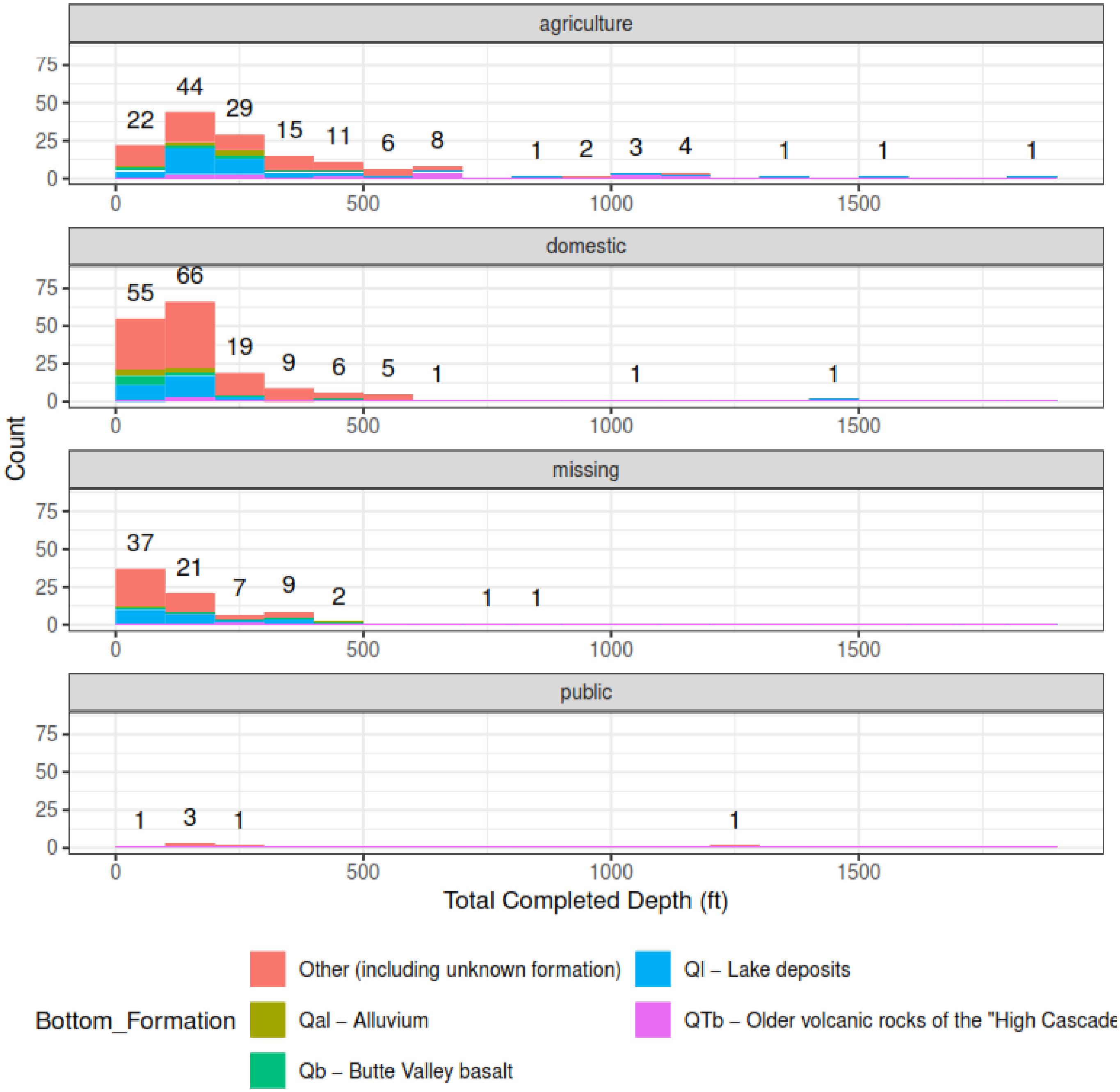


Figure 3: Histogram of Total Completed Depth of Domestic, public supply and agricultural Wells (including the 'missing' planned use wells that were assumed domestic wells in the analysis).

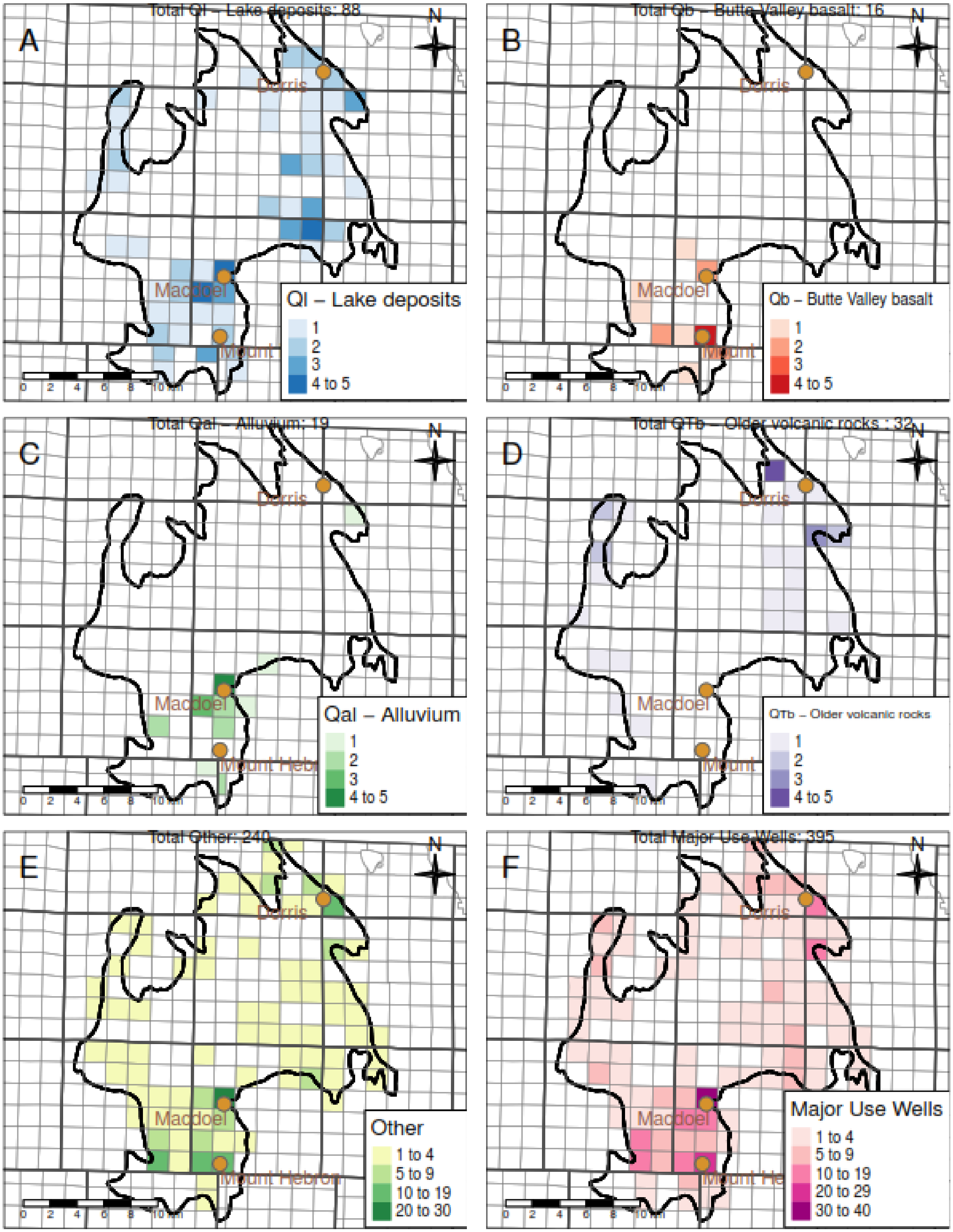


Figure 4: Butte Valley choropleth map of domestic, public supply and agricultural wells by bottom formations.

Well types show different depths to the bottom of the well below ground surface as shown in figure Figure 2. Domestic wells are relatively shallow and vary similarly across various formations. Depths range from less than 100 ft to more than 400 ft. Agricultural wells have a similar depth range to domestic wells (less than 100 ft to over 400 ft), but with most wells deeper within that range than domestic wells. Across formations, agricultural wells follow a similar depth distribution except in the older volcanic rocks of the High Cascades (QTb). In the QTb, the agricultural well depth ranges from about 200 ft to about 1400 ft.

The distribution of depth to the top of the perforated interval follows a similar pattern as well depth: shallow-most top of screens are found in domestic wells, across all formation. A wide range to top of screen is found for agricultural wells in the Older Volcanic Rocks of the High Cascades formation Figure 3. Figure 4 shows the resulting perforation length. Significant differences are observed in the length of agricultural well screens between formations. Agricultural wells in the Older Volcanic Rocks of the High Cascades (QTb) have the broadest range of perforation lengths (50 ft to 1000 ft) and agricultural wells in the Butte Valley Basalt (Qb) have the most narrow range (less than 10 ft to 40 ft). Domestic well screens in alluvium (Qal) and in Butte Valley basalt (Qb) are generally 40 ft or less, and up to 150 ft in lake deposits (Ql) and in older volcanics (QTb)

Few pumping test data provided on Well Completion Reports submitted to the Department of Water Resources show that both domestic wells and public supply wells have low well yields, by design. Agricultural wells tested are generally high production wells with 1000 to 5000 gpm (Figure 5). Agricultural wells have casing diameters of typically 12 to 18 inches. Domestic wells are mostly of smaller (2 to 8 inch) diameter with 10 inch diameter domestic wells in the Butte Valley Basalt (Qb), perhaps owing to miss-classification (Figure 6). During pump testing the Older volcanic rocks of the Older Volcanic Rocks of the High Cascades (QTb) show a narrow range of drawdown between 30 and 60 feet which is deeper than wells completed in the Butte Valley Basalt (Qb). Wells completed in the Lake Deposits (Ql) show a wide range of values between almost no observed drawdown to over 100 feet. Figure 7 summarizes the results of drawdown testing.

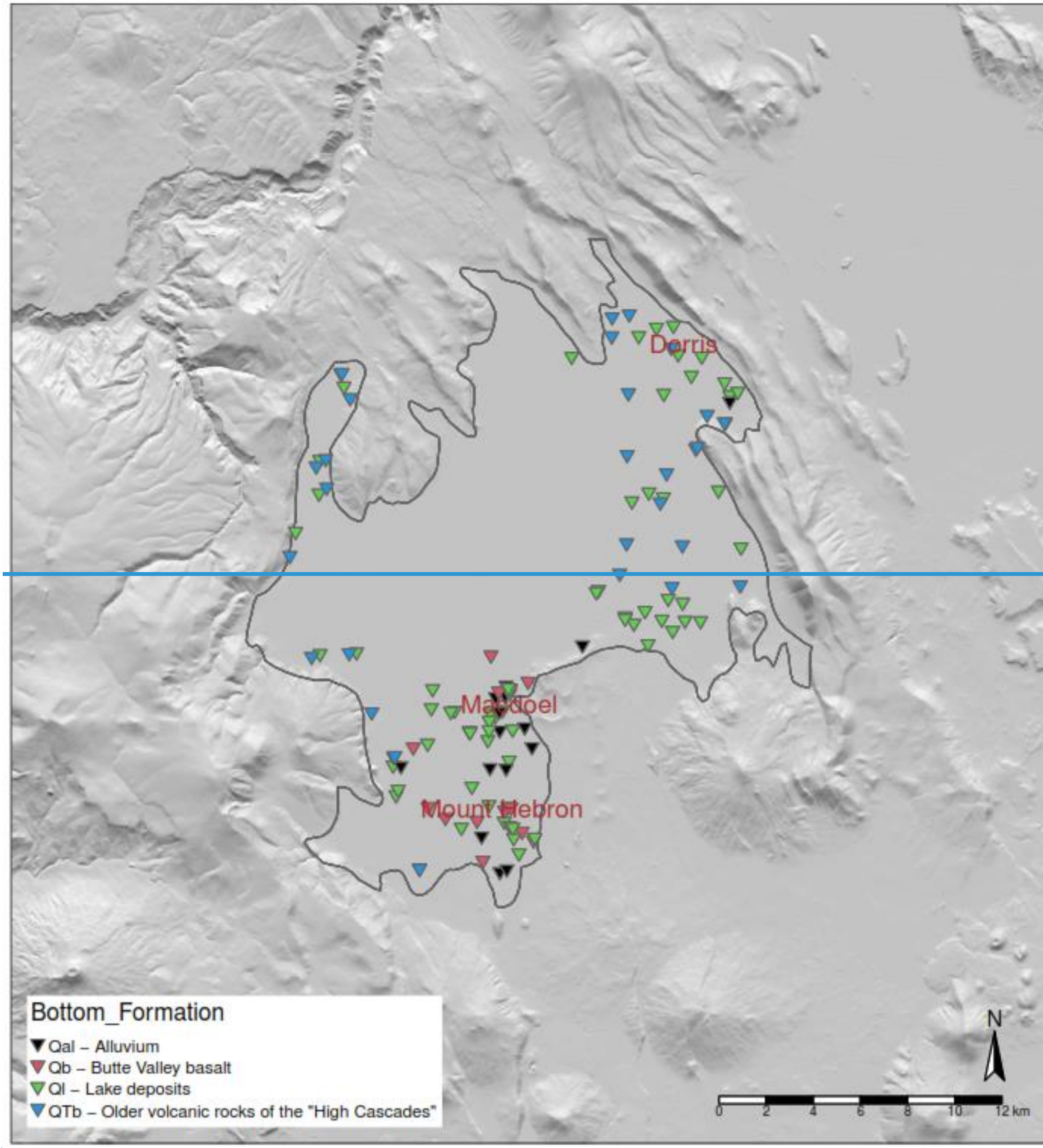
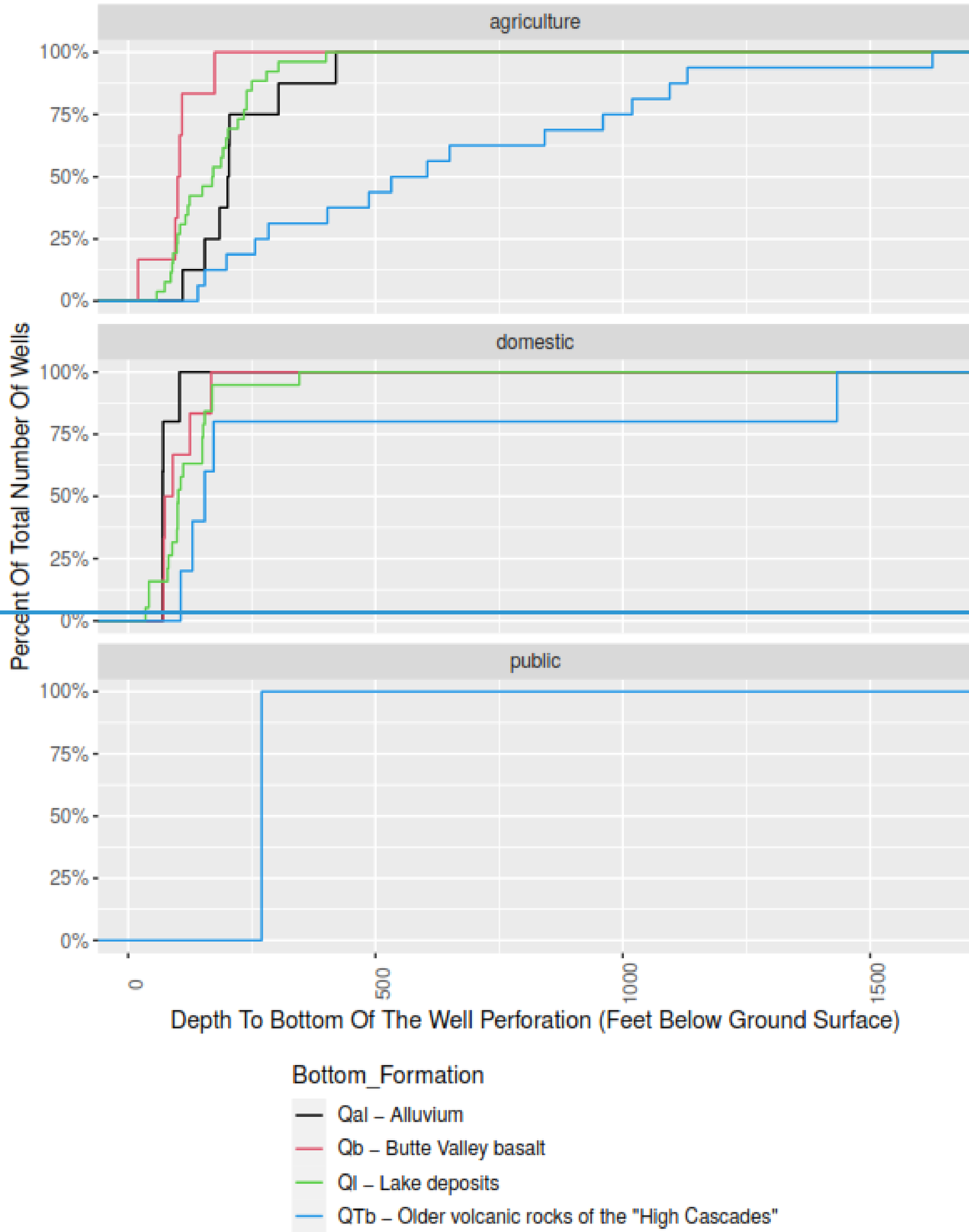
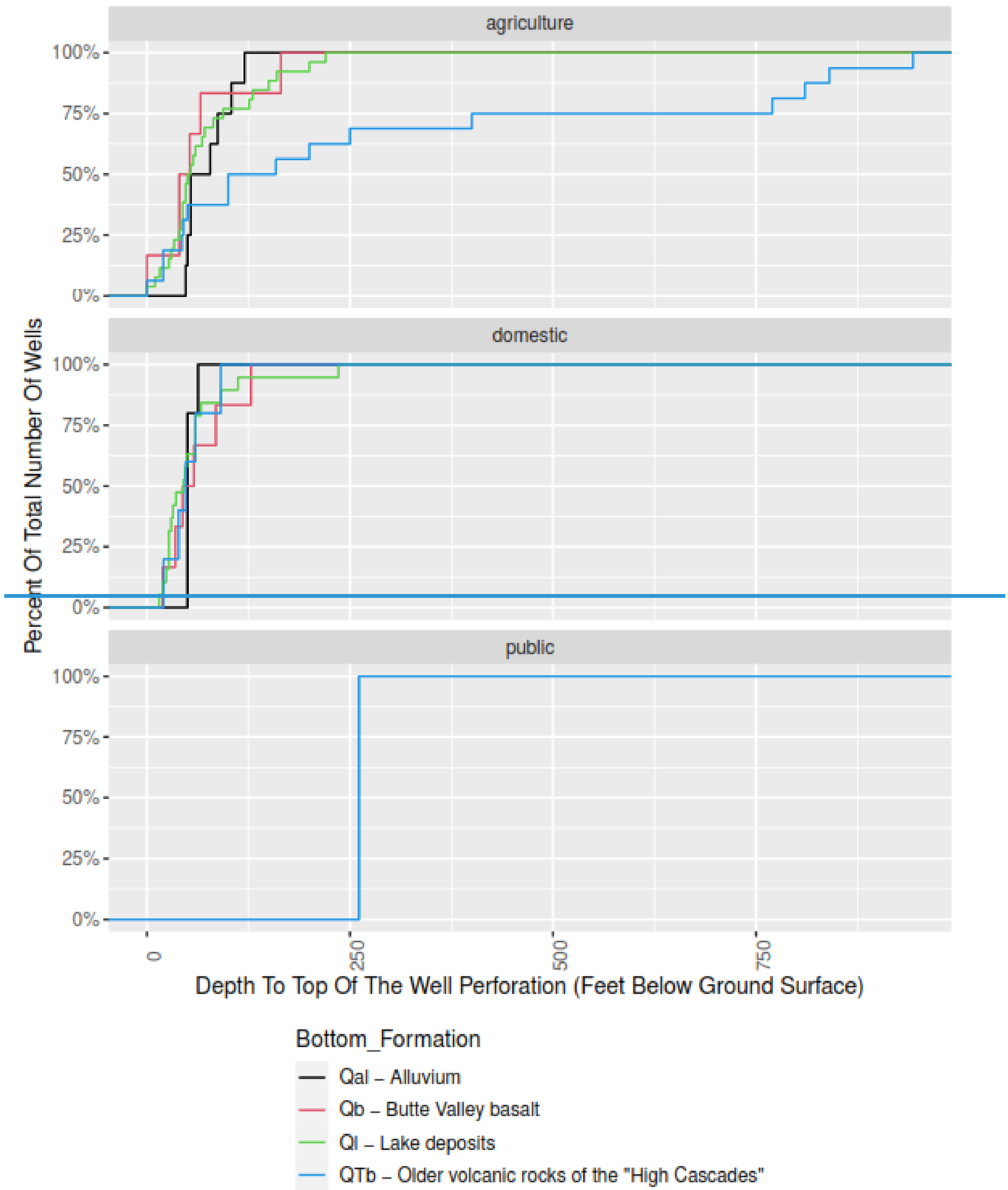


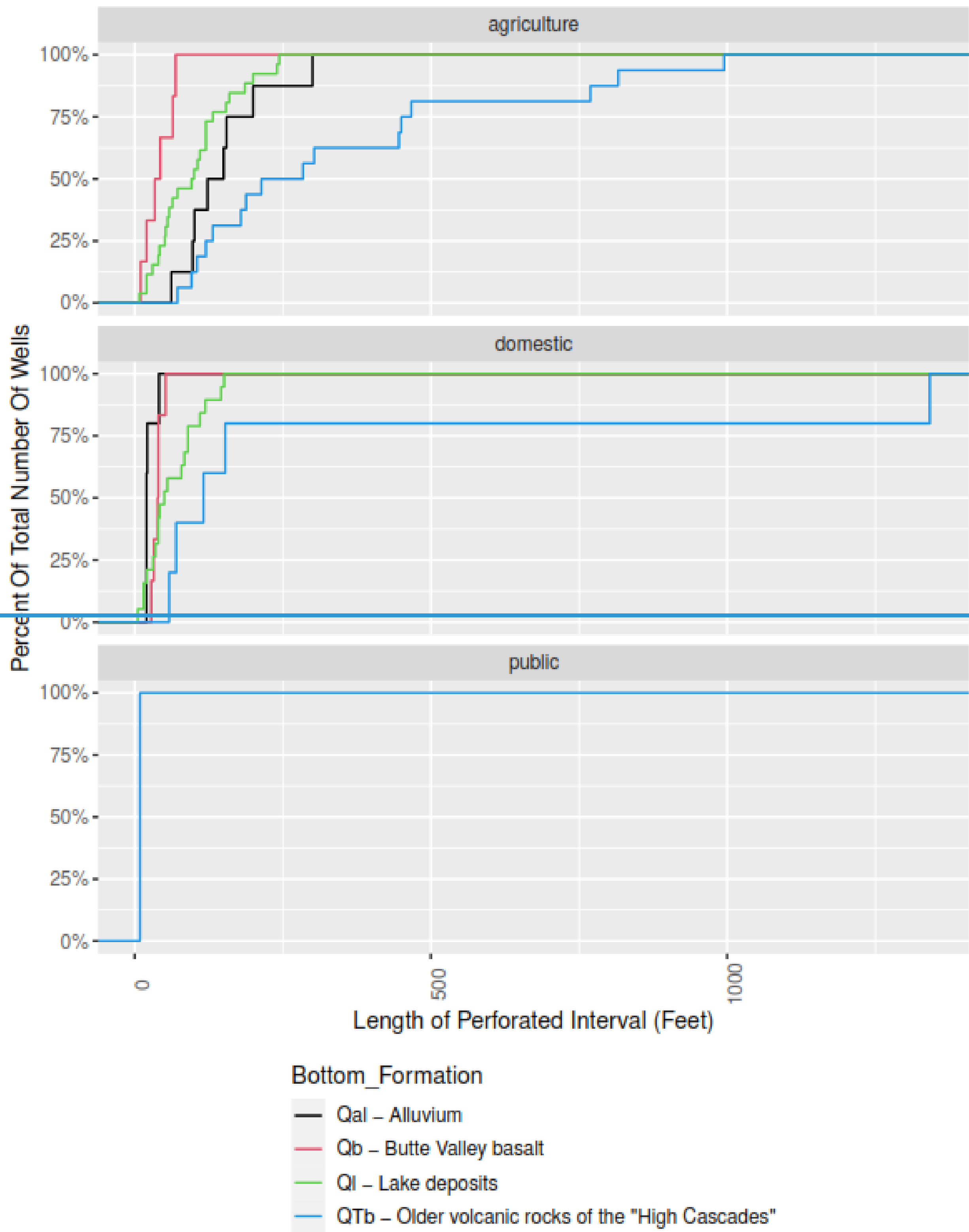
Figure 1: Butte Valley well map of domestic, public supply, and agricultural wells colored by major formation with locations of water wells are given as colored triangles.



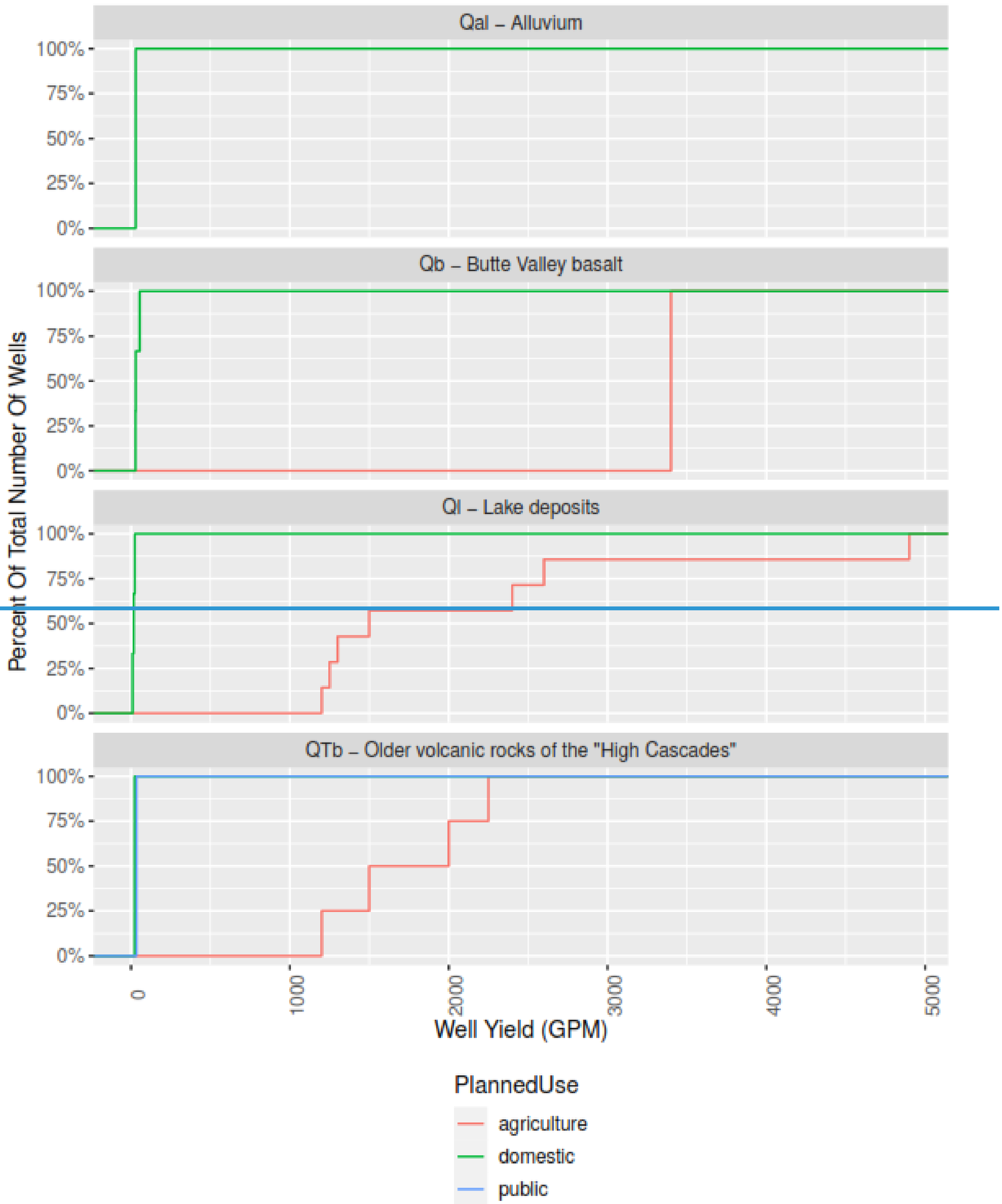
~~Figure 2: Butte Valley well perforation bottom. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.~~



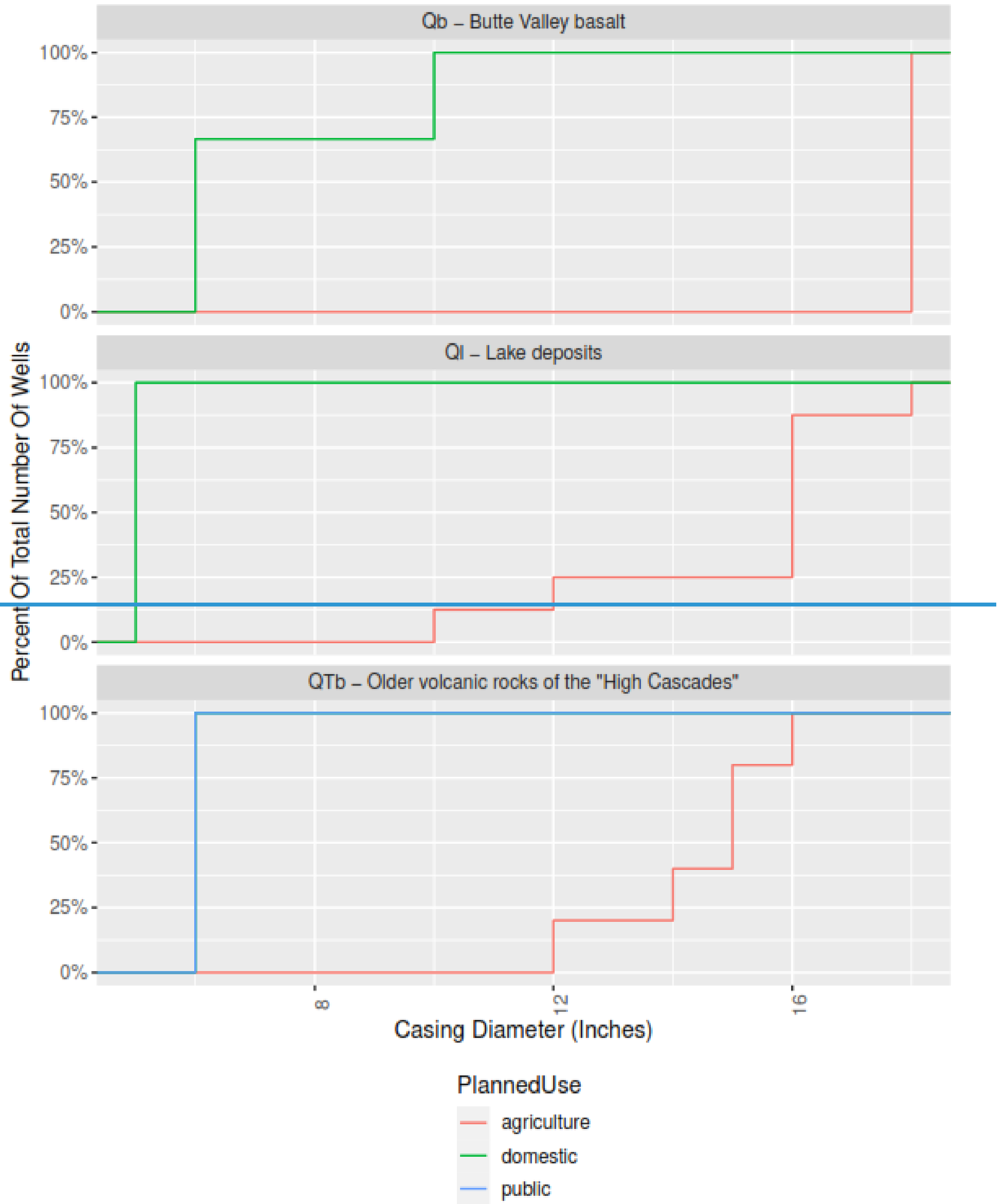
~~Figure 3: Butte Valley well perforation top. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.~~



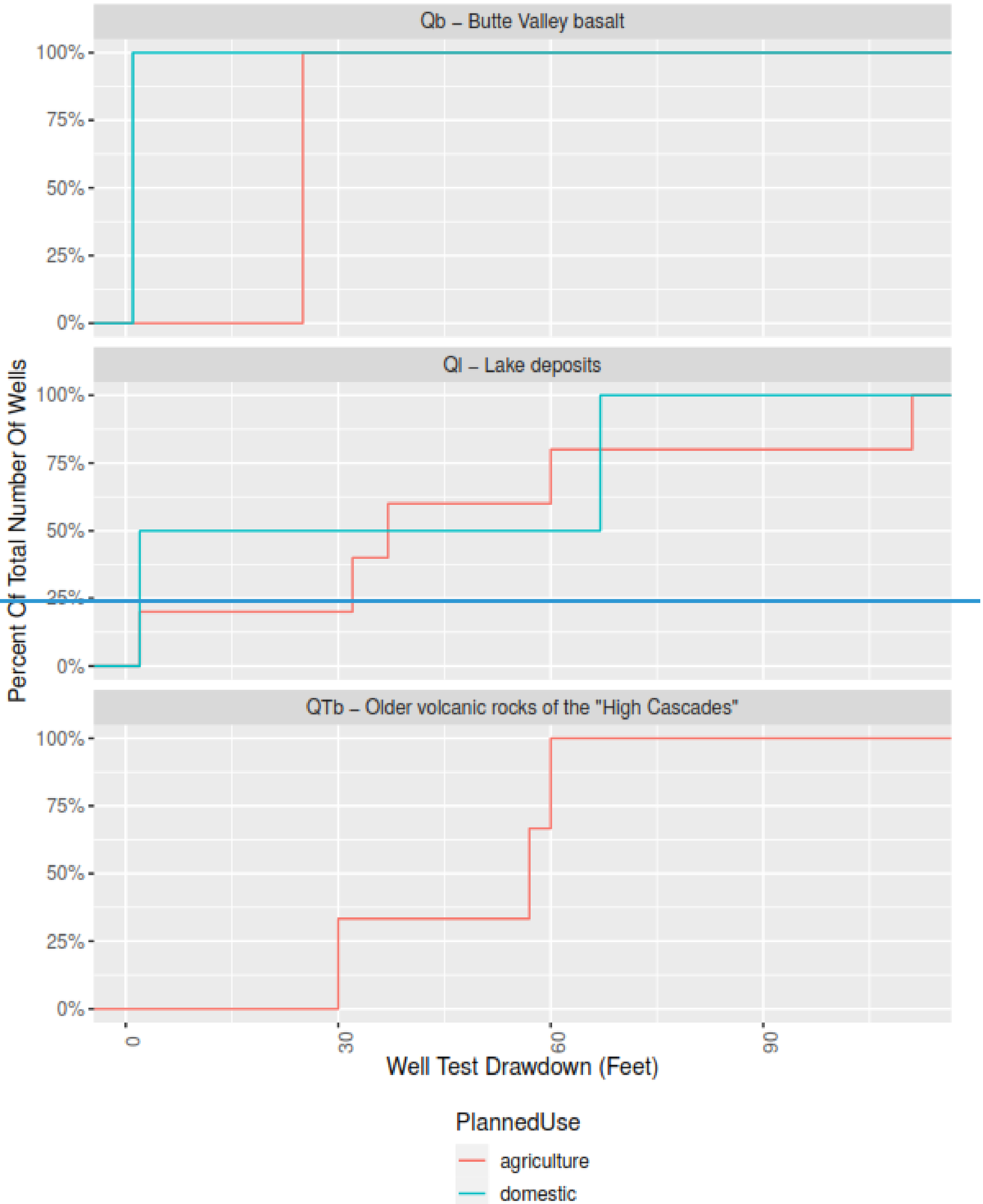
~~Figure 4: Butte Valley well perforation length. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.~~



~~Figure 5: Butte Valley well yield by formation at the bottom of the well comparing major well types~~



~~Figure 6: Butte Valley well casing diameter by formation at the bottom of the well comparing major well types~~



~~Figure 7: Butte Valley well test drawdown by formation at the bottom of the well comparing major well types~~

Well Outage Risk Analysis

Domestic Wells

Estimated Outages by Direct Comparison The interpolated groundwater elevation contours within the Butte Valley B118 boundary are constructed with the best available groundwater level measurements for fall 2015 and 2023, and are presented in Figure 5 and Figure 6, respectively. Histograms of the calculated wet depth to (a) top of perforation and to (b) bottom of well using the reported well information and the interpolated groundwater level at the reported location are presented for fall 2015 and 2023 in Figure 8 and Figure 9, respectively.

When using wet depth to 10 ft above bottom of wells as the criterion for well outage, Figure 8 (right panel) indicates that, in 2015, approximately 19 percent of wells, or 45 out of 241 domestic wells, are estimated to have been experiencing dry conditions (well outage). This may represent older wells that are inactive or abandoned, wells that have been inactive since 2015, and wells that have experienced temporary well failure.

The use of the wet depth to top of perforation as well outage criterion has been done on a much smaller subset of wells (84 out of 241). Nearly half of those wells (40 of 84), meets this alternative well outage criterion in 2015. It is unlikely that nearly half of the domestic wells reported in OSWCR were already dry in 2015. This indicates that the analysis using the wet depth to top of perforation as well outage criterion is limited by the data available for well perforation information in Butte Valley, and possibly many domestic wells may have pumps installed below reported top of perforations.

For the purposes of the well failure analysis, the estimated number of dry wells in 2015 provides a baseline to measure against the estimated additional well outages in a future year (i.e., 2023). The estimated additional well outages between 2015 and 2023 was determined by comparing the number of well outages due to the change of water levels between 2015 and 2023 across the basin.

Using the depth to 10 ft above bottom as the well outage criterion, 14 additional well outages occurred between 2015 and 2023, which is 6% of the total domestic wells analyzed (right panel of Figure 8 and Figure 9). Alternatively, using wet depth to top of perforation as the well outage criterion, an additional 4% of wells were estimated to be at risk for failure between 2015 to 2023 (left panel of Figure 8 and Figure 9). Hence, similar estimates of well failures are obtained from the use of both well outage criteria.

When applying the direct comparison to the water level contour representing MT conditions throughout the Basin (Figure 7), results for the depth to 10 ft above bottom criterion indicate that a water level decline from 2023 conditions (right panel of Figure 9) to MT conditions (right panel of Figure 10) would cause an estimated 14 additional well outages, for a total of 28, or 12% of domestic wells experiencing outage since 2015. The evaluation using wet depth to top of perforation criterion indicates an additional 3% wells at the risk of dewatering from 2023 to MT (6% of wells between 2015 conditions and MT conditions), again, a slightly lower number of well outages than estimated using the first well outage criterion, but essentially confirming the results (Figure 10).

The spatial distribution of the well outages estimated using the 10 ft to well bottom criterion is shown in Figure 11. Most of the 2015-2023 outages are near Dorris, Macdoel, and Mount Hebron, with scattered outages throughout rural areas. Additional outages, were water levels to decline to the MT, would occur mostly in the Mt. Hebron area with additional outages scattered across rural areas.

In summary, 45 domestic wells are estimated to be dry in 2015. From 2015 to 2023, an estimated 10 to 14 additional wells went dry (4-6% of the total domestic wells). From 2023, if levels dropped below MTs, an estimated 8 to 14 additional wells will go dry, bringing the total number of wells going dry, after 2015, at MT conditions, to an estimated 15 to 28 wells (6-12%).

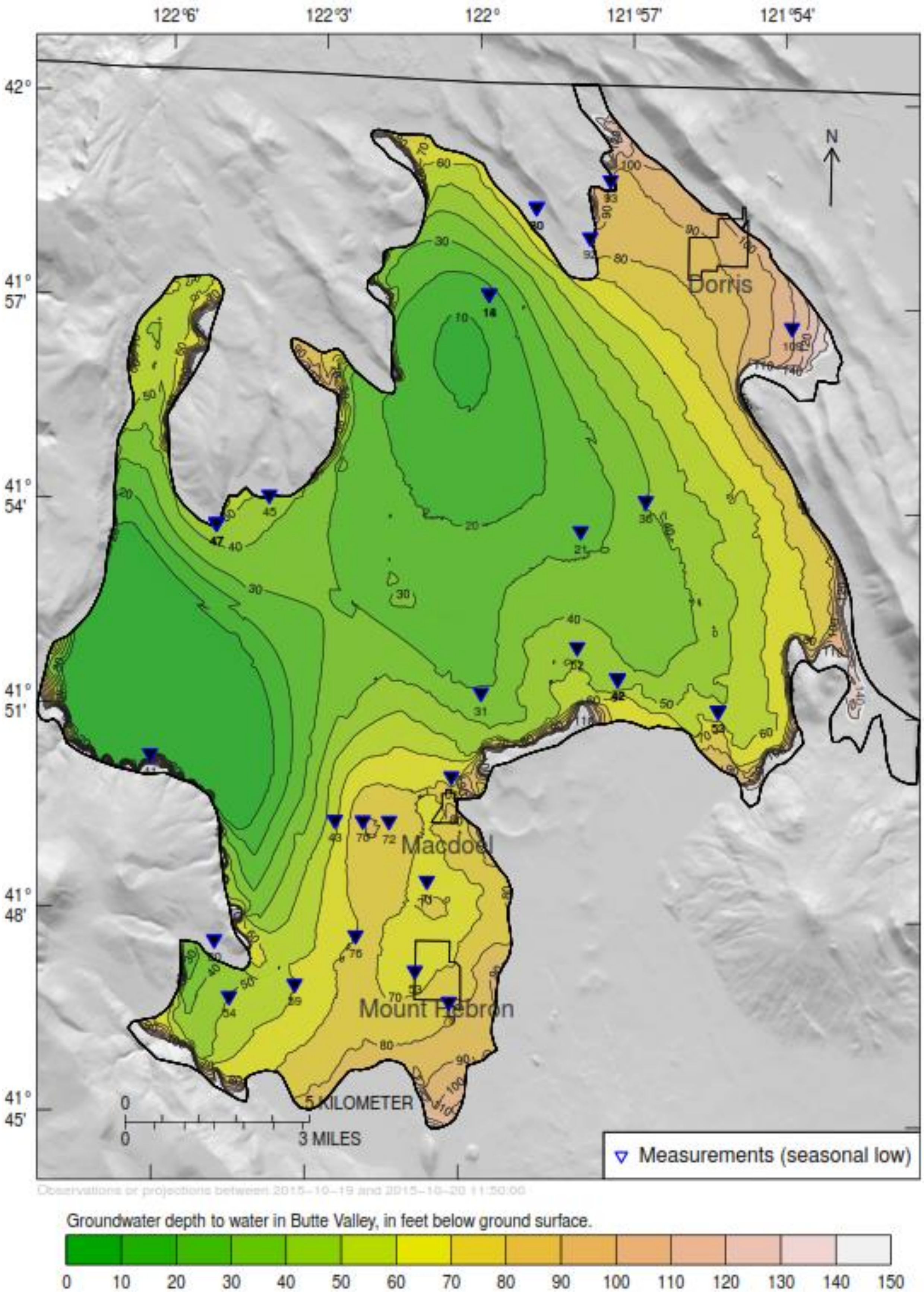


Figure 5: Butte Valley groundwater elevations reported as approximate depth to groundwater, fall low of 2015 and well failure estimates based on recent water level observations. Approximate basin-scale groundwater depths are shown.

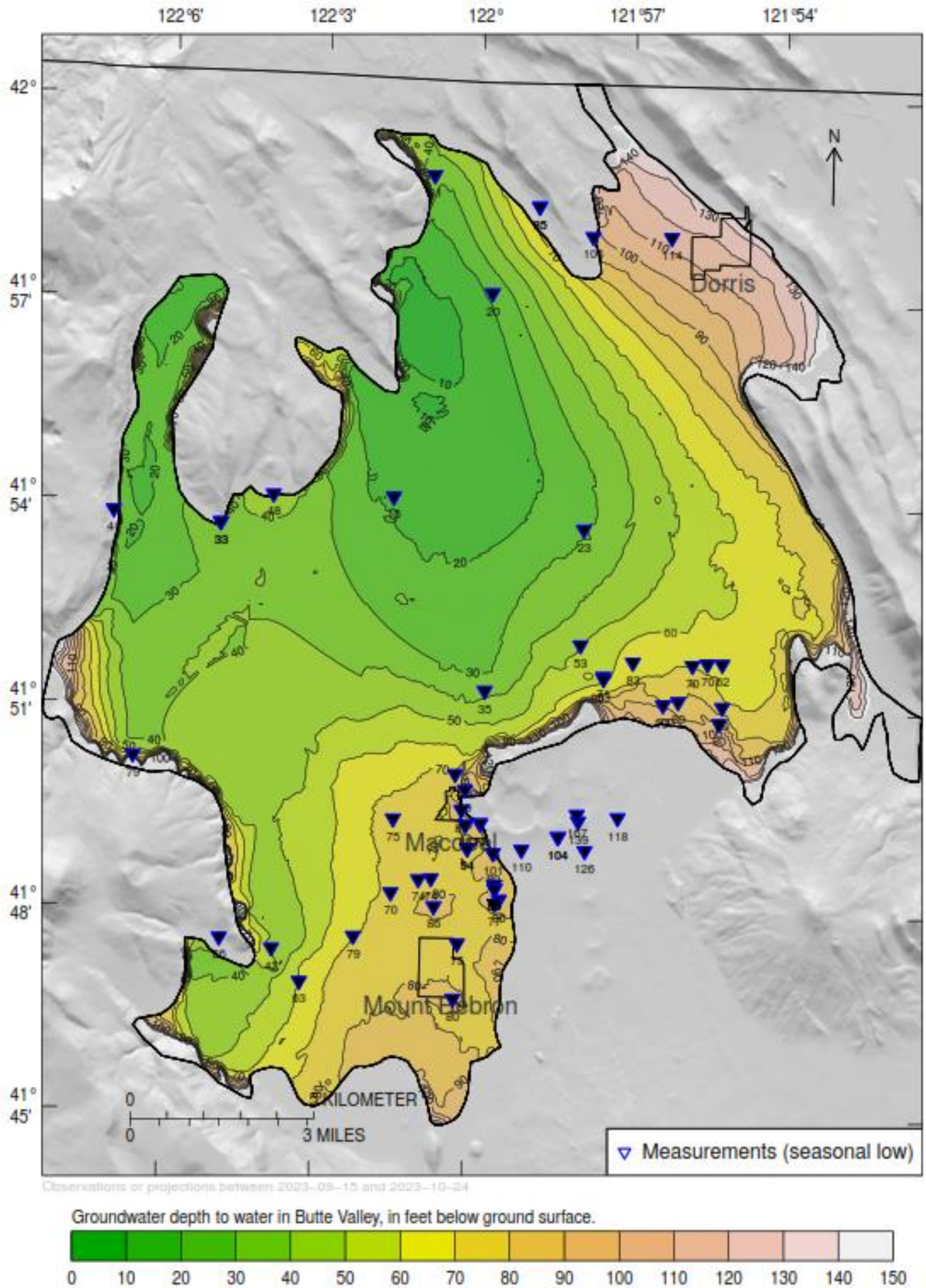


Figure 6: Butte Valley groundwater elevations reported as approximate depth to groundwater, fall low of 2023 and well failure estimates based on recent water level observations. Approximate basin-scale groundwater depths are shown.

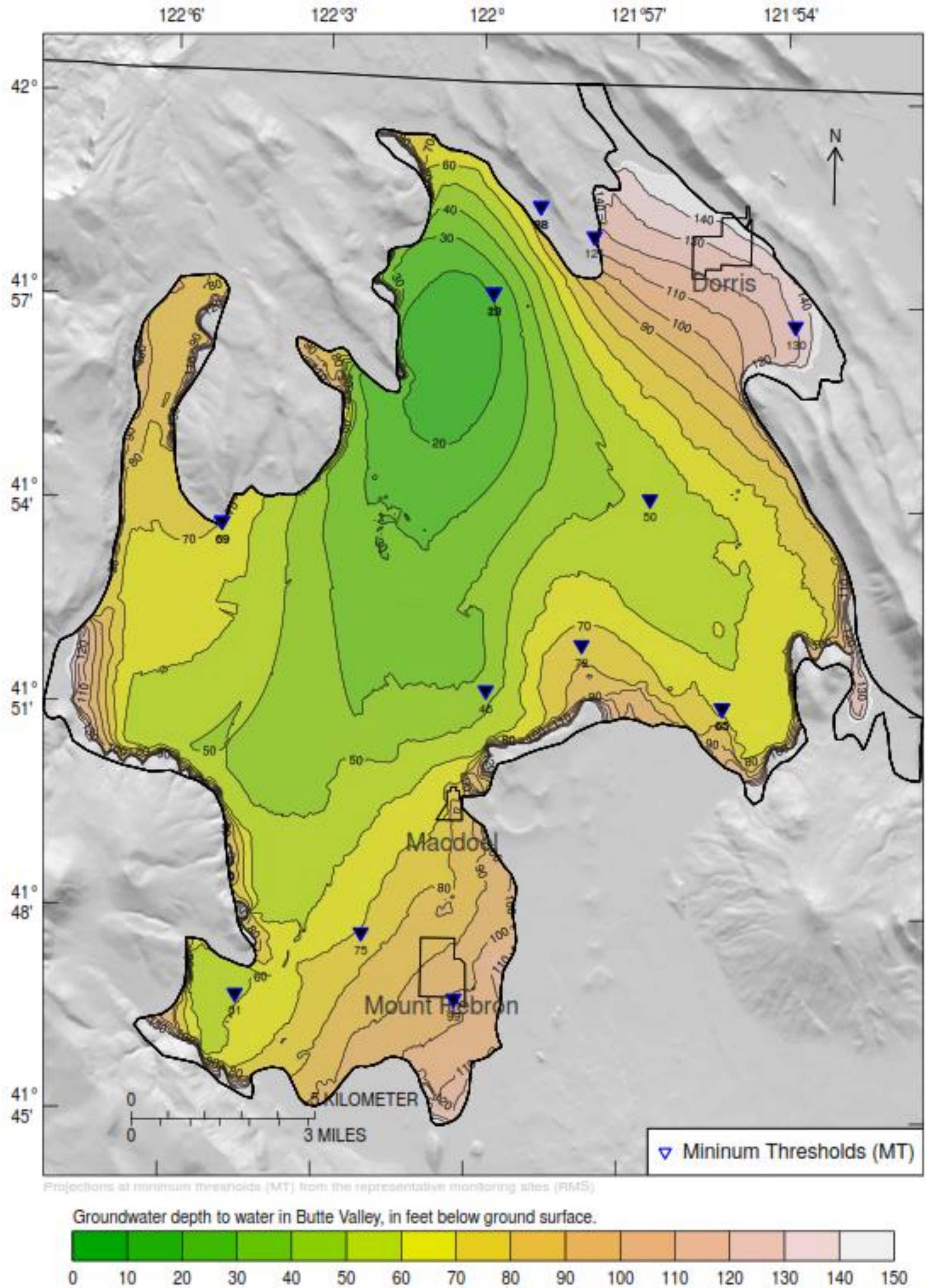


Figure 7: Contour of the predicted Butte Valley groundwater elevations if minimum thresholds were reached at representitive monitoring points. Approximate basin-scale groundwater depths are shown.

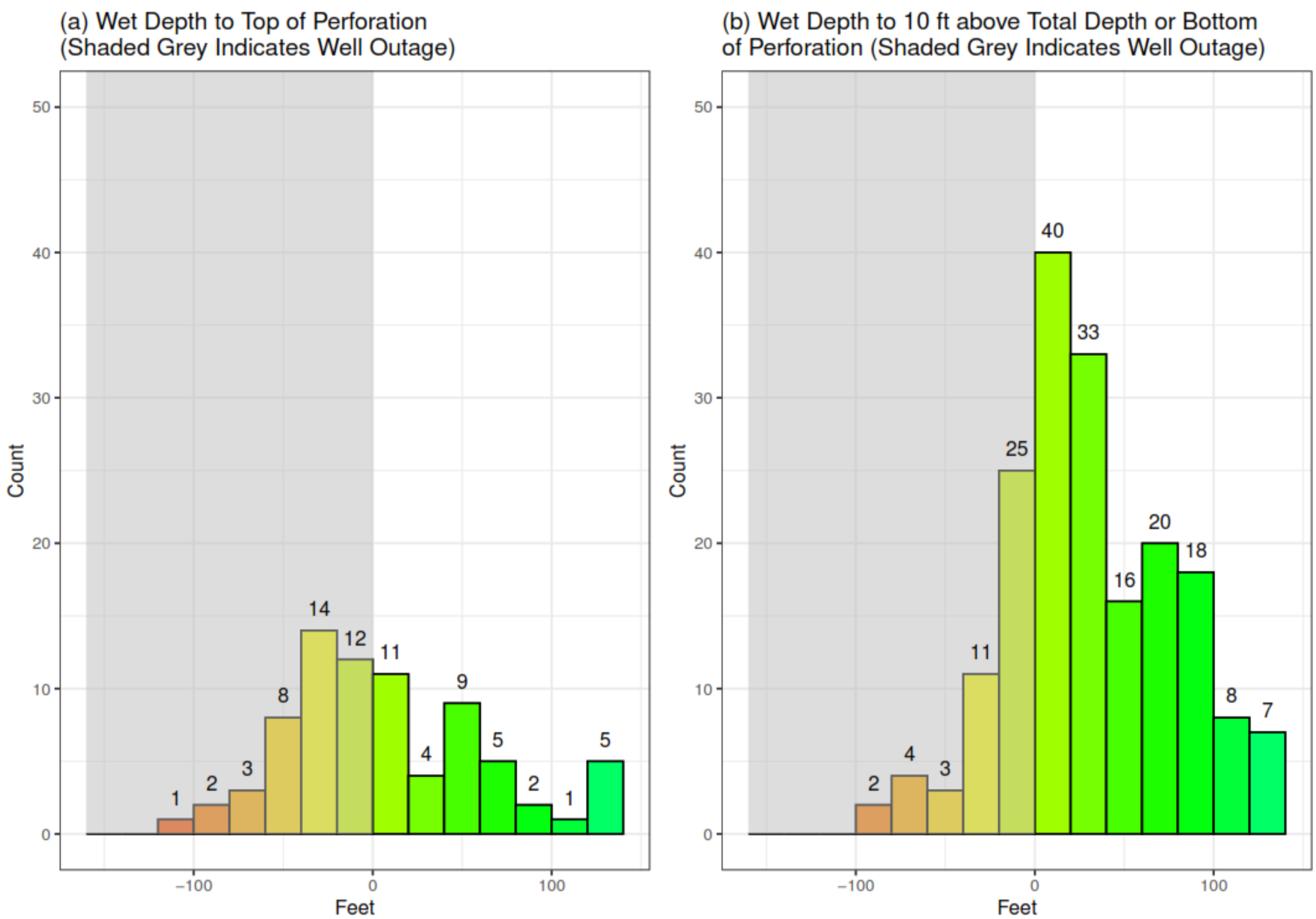


Figure 8: Histogram of wet depth to well perforations for domestic wells based on contoured groundwater elevations, fall 2015. Note: only the wet depths that are negative and less than 140 ft are shown for better illustration. A positive wet depth indicates the water level is above the bottom of well or its top of perforation, indicating the well is relatively deep and not at risk of an outage.

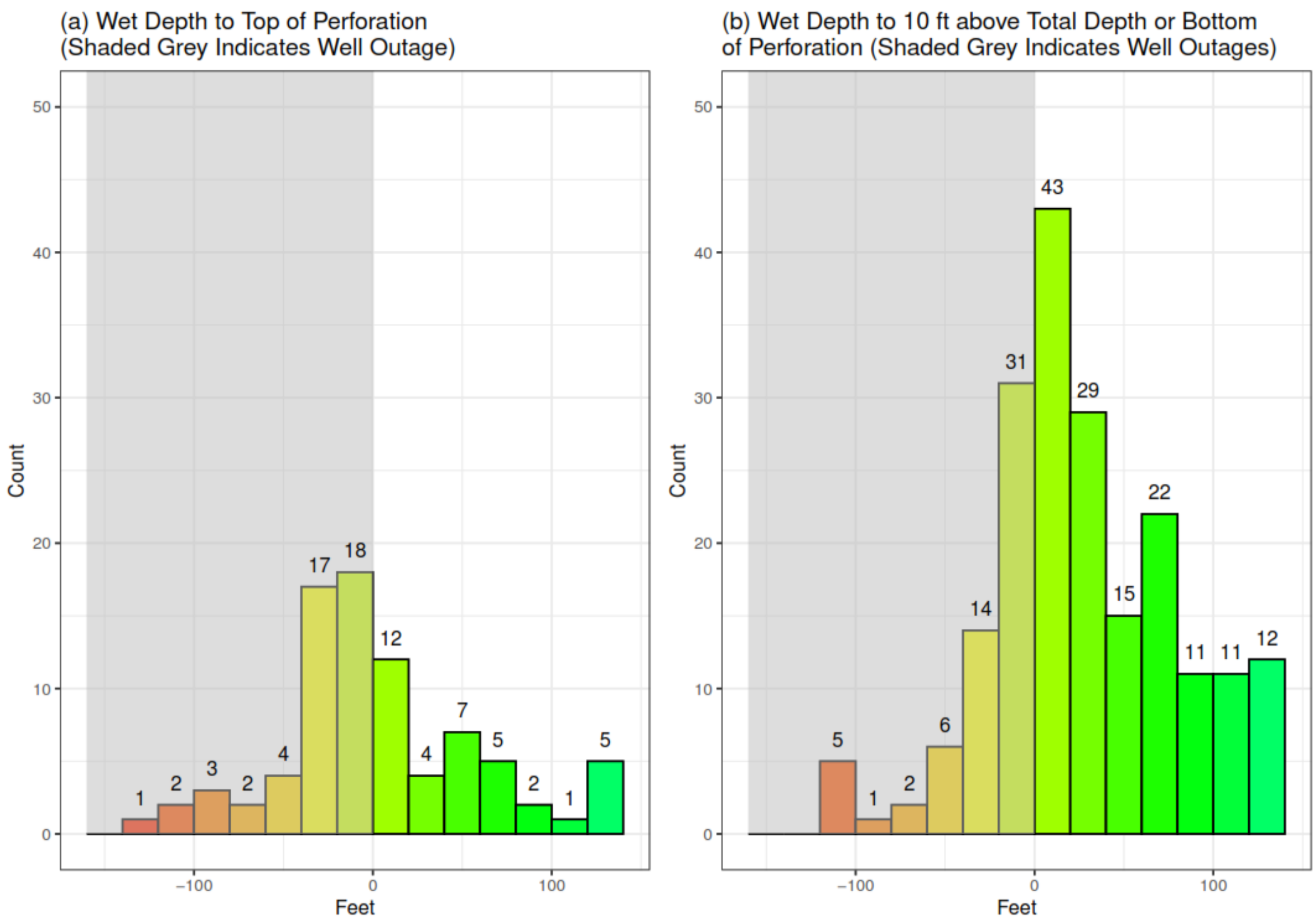


Figure 9: Histogram of wet depth to well perforations for domestic wells based on contoured groundwater elevations, fall 2023. Note: only the wet depths that are negative and less than 140 ft are shown for better illustration. A positive wet depth indicates the water level is above the bottom of well or its top of perforation, indicating the well is relatively deep and not at risk of an outage.

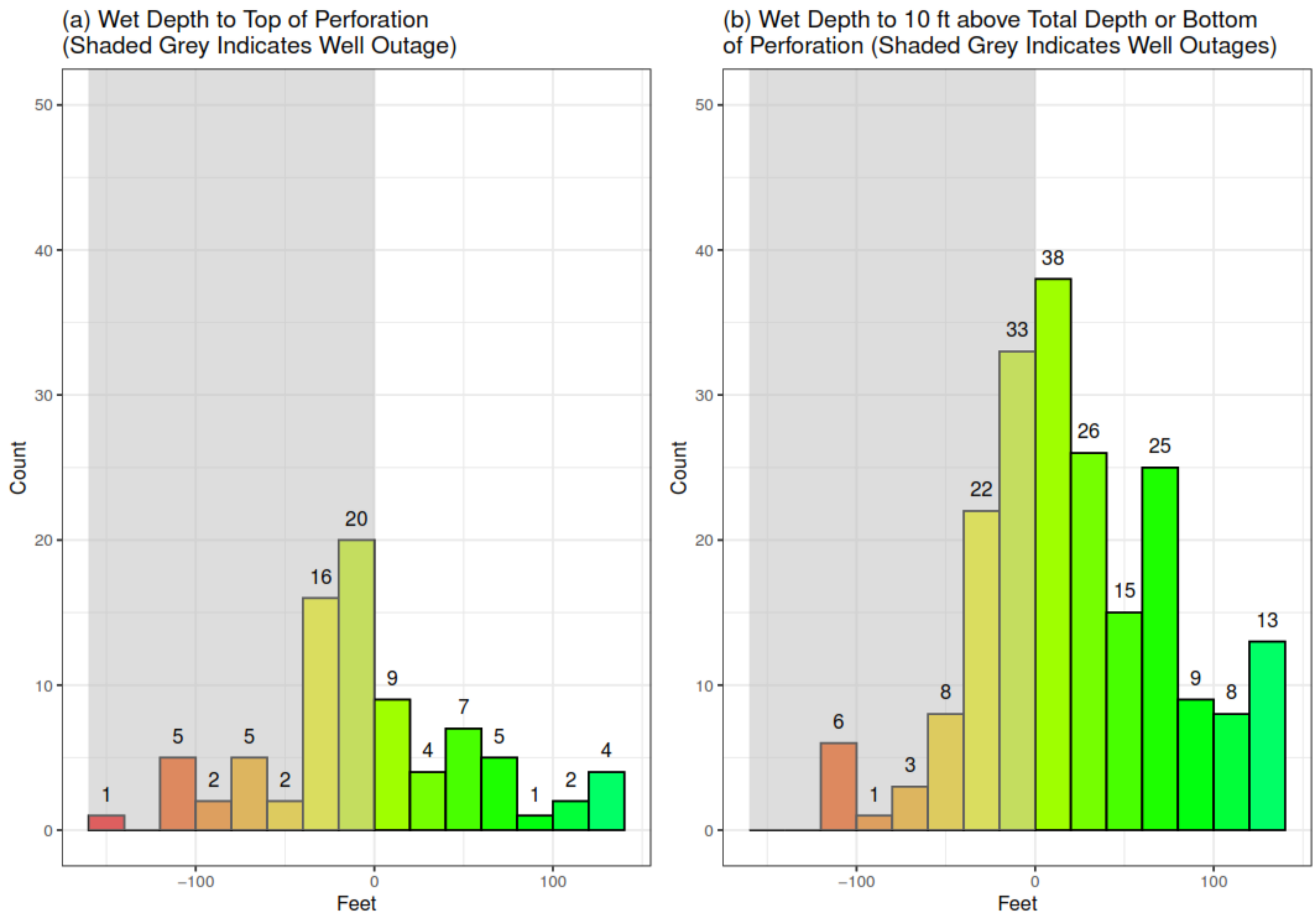


Figure 10: Histogram of wet depth to well perforations for domestic wells based on the predicted contoured groundwater elevations at minimum thresholds. Note: only the wet depths that are negative and less than 140 ft are shown for better illustration. A positive wet depth indicates the water level is above the bottom of well or its top of perforation, indicating the well is relatively deep and not at risk of an outage.

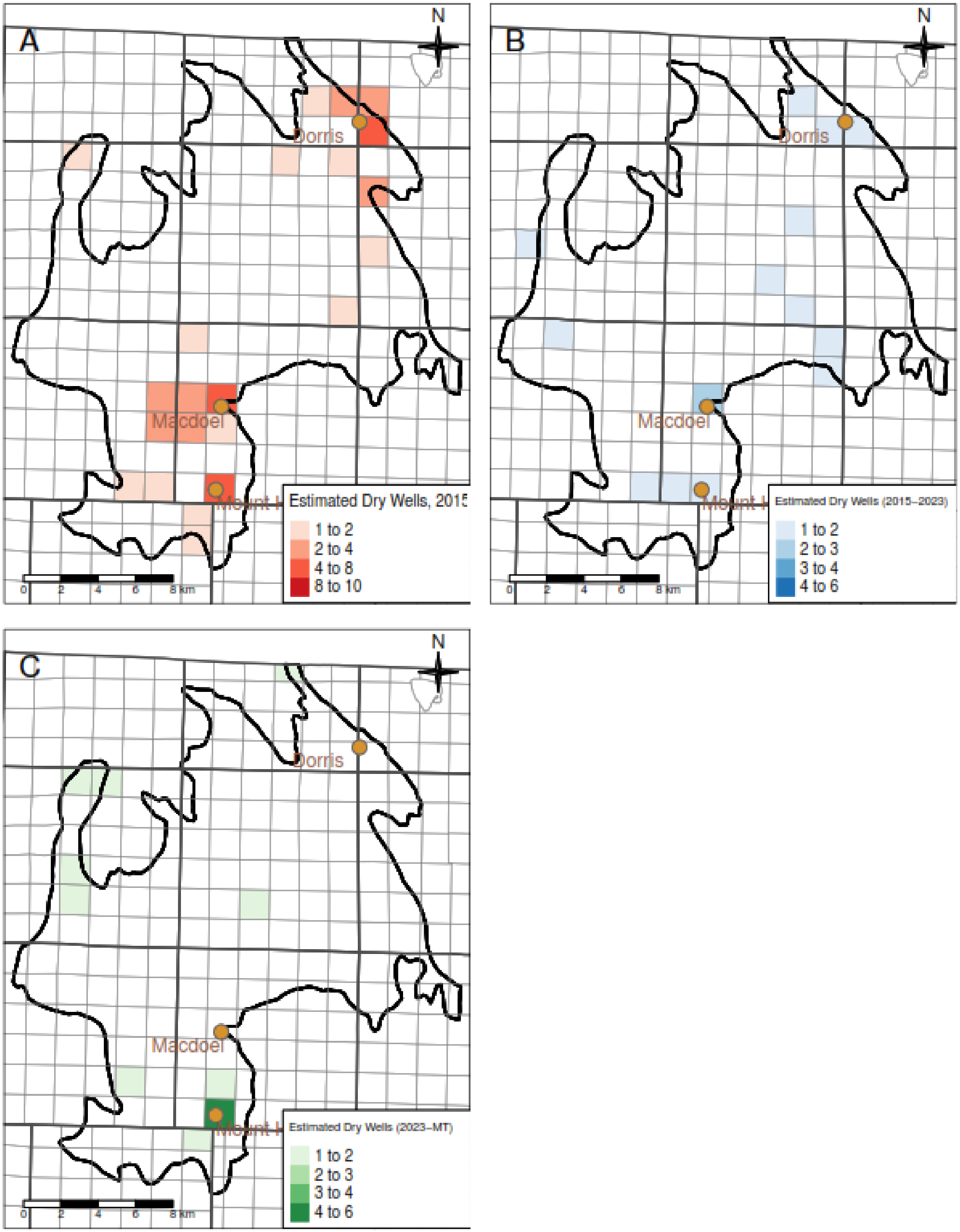


Figure 11: Butte Valley choropleth map of domestic wells indicating the number of estimated well outages in 2015 (panel A), additional well outages from 2015 to 2023 (panel B), and additional well outages from 2023 to MT Triggered across Basin (panel C).

Estimated Outages by Wet Depth Trend Analysis The cumulative distributions of the wet depth to top of perforation and the wet depth to 10 ft above bottom of well are shown in Figure 12 for fall 2015 conditions, fall 2023 conditions, and for MT conditions across the basin. The cumulative distributions of wet depth to top of perforations and wet depth to bottom of well have very similar shapes and show a consistent left shift across the entirety of the distribution. The latter is a result of the fact that water table depth in 2023 is deeper than 2015 across the entire basin. Similarly, MT conditions are deeper than 2023 across the entire basin.

All cumulative distribution functions are relatively flat at their left tail, indicating a few wells with widely spaced negative depths. Once the cumulative distribution functions reach approximately 5% to 10% of wells, the slope steepens to its maximum up to approximately 60% of wells, beyond which it slowly flattens out – fewer and fewer wells are deeper and deeper. The trend analysis takes advantage of the relatively consistent slope in the 5th to 35th percentile range of the cumulative distribution that is also intersecting with the zero wet depth threshold. Since it is the steepest part of the cumulative distribution function, it is also the most conservative estimate, i.e., it provides an upper limit for the estimate of well outages per 10 ft basin-wide decline in water levels.

Importantly, the absolute value of the wet depth of an individual well may have errors of less than +/- 5 ft to as much as +/- 20 ft. To the degree that the average of the error is near 0% (i.e., unbiased), this estimation error does not affect the shape or relative position (on the wet depth axis) of the cumulative distribution function of wet depths. Given the range over which the cumulative distribution function has a nearly consistent slope, the slope value is much less sensitive than the specific estimated wet depth at wells to well outage analysis. If we further assume that the minimum wet depth to either the bottom of the well or to the top of perforations is similar for most domestic wells, then this slope is a relatively robust estimator for the risk for well outages with additional water level decline below historically low values.

Importantly, this approach to estimating well outage risk does not require knowledge of specific well information about pumping bowl elevation relative to the screen location, or about a minimum wet water level depth needed to pump properly. It only assumes that some well outages occur if water levels fall below historic lows and, hence, the selected slope is representative of the one-third of wells at most risk to well outage.

The slope analysis across the two well outage indicators and the three water level conditions indicates that a 10 ft average decline in water levels results in 4% to 6.5% of domestic wells going dry across the Basin.

This slope estimate allows for an estimate of the number of well outages that occur due to a lowering of the water table from the minimum measurable objective (MO, which corresponds to the lowest observed water level between 1991 and 2014) and the MT. The basin-wide average difference between the minimum MO and the MT is 15 ft. The trend analysis suggests that 6% to 10% (per 15 ft, equivalent to the 4% to 6.5% per 10 ft in Figure 12) or (15 to 24) of domestic wells are at risk of well failure between MO conditions and MT conditions.

This result is consistent with the direct comparison method. The consistency of results is due to the similarity of the slope for 2015, 2023 and MT conditions from their cumulative distribution functions, which results in similarity of the intersects of these three regressions with zero wet depth. The trend method is considered slightly more robust due to fitting of the slope to a broader range of wells rather than just considering the difference in the cumulative distribution function specifically at a wet depth of zero.

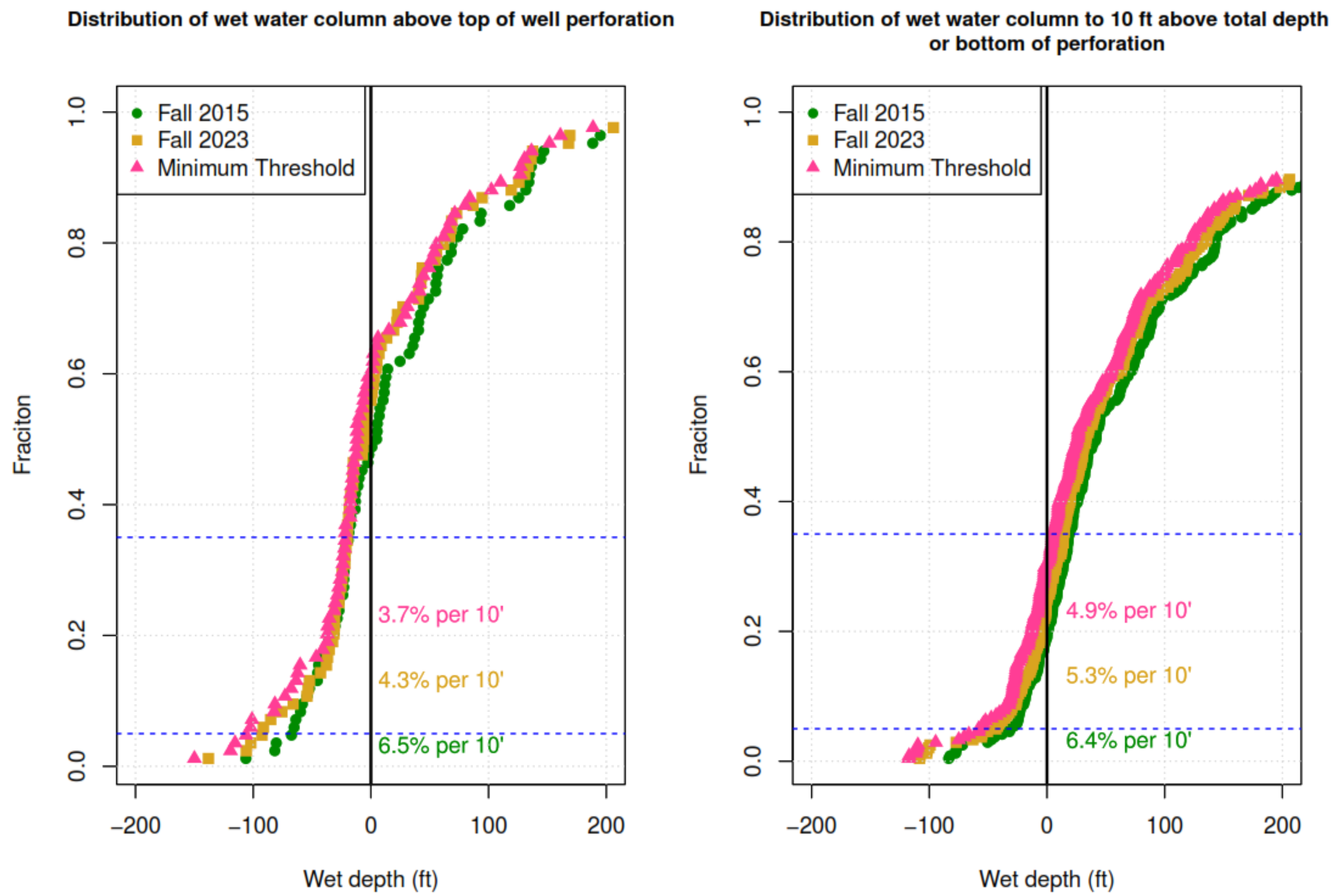


Figure 12: Cumulative distribution function of domestic well wet depth to top of perforations in all formations based on contoured groundwater elevations during Fall of 2015 and 2023, and prediction at mininum thresholds. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (blue dash line). Note: only the wet depths that negative and less than 200 ft are shown for better illustration. A positive wet depth indicates the water level is above the bottom of well or its top of perforation, indicating the well is relatively deep and not at risk of an outage.

Public Wells

An outage analysis has been performed for public wells with the same approach as domestic wells in the previous section. Through the “direct comparison” approach, the public well outage is 0 in 2015, and 0 additional well outages are identified from 2015 to 2023 and to MT. The analysis indicates that public wells in Butte Valley groundwater basin are less likely to experience outage from a chronic lowering groundwater level. The less likelihood of adverse impacts on public wells is because they were constructed with deeper depths compared to other types of wells (see Table 4).

Agricultural Wells

An outage analysis has been performed for agricultural wells with the same approach as domestic wells in the previous section. The percent outage identified through “trend analysis” for agricultural wells falls within the range identified for domestic wells. Through the “direct comparison” approach, the estimated number of agricultural well outages is 7 in 2015 (out of 148 agricultural wells, 5%). 3 additional well outages are estimated from 2015 to 2023. And 7 additional well outages are estimated from 2023 to MT. These results are illustrated in the choropleth maps in Figure 13.

Reported Well Outages

As of June 2024, the DWR Dry Well Report database contains four reports of wells that have gone dry with confirmed locations within the Butte Valley basin. Two of the reported dry wells are within the city of Mt. Hebron. In both wells, the issue was reportedly resolved by lowering the pump bowl. One of the reported dry wells is in the city of Macdoel, and the last dry well is northwest of Dorris. All four wells are domestic wells. The reports were filed with DWR in the summer of 2021 (1 report) and in the spring to fall of 2023 (3 reports).

The 2023 Butte Valley Well Outage Survey was conducted to identify domestic wells needing re-placement or repair in Butte Valley. Twenty survey responses were received across the basin, with 10 reported wells needing repair or replacement, and 8 of the 10 wells being recommended for further actions (i.e., replacement, repair or follow up) based on field inspections after receiving the survey responses. Of the 8 dry or intermittent wells, 7 reported wells are around the Macdoel to Mt. Hebron region, and one is around the City of Dorris. The well outage survey and well repair and replacement are ongoing efforts. Details about the progress has been discussed in Chapter 4.

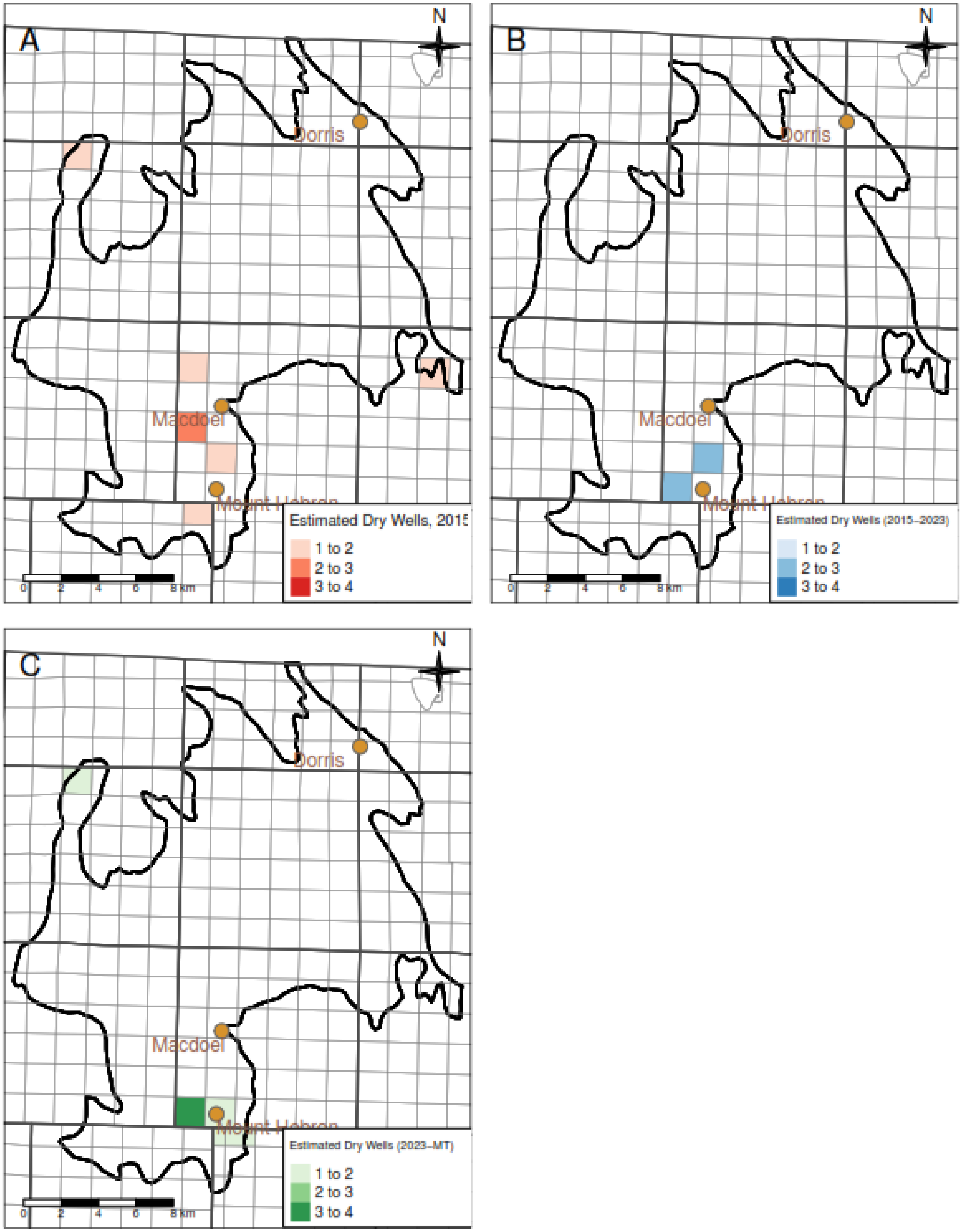


Figure 13: Butte Valley choropleth map of agricultural wells indicating the number of estimated well outages in 2015 (panel A), additional well outages from 2015 to 2023 (panel B), and additional well outages from 2023 to MT Triggered across Basin (panel C).

Estimated Wet Depth to Top of Perforations

The interpolated, contoured water table depth in fall of 2015 is shown in Figure 8, together with the location of those wells with water level measurements that are used for the water table depth interpolation. Estimates of water table depths are most accurate near the locations of the measured wells. The accuracy of estimates deteriorates with distance from a measured well (also see Chapter 2 in the Butte Valley Groundwater Sustainability Plan).

The estimated wet depth to top of perforations is shown in the following map (Figure 9). If the interpolated water level elevation was below the top of perforations, the difference shown is a negative number. These wells are color-coded orange and yellow in Figures 9 and 10. In 2015 (dry year) more than one-half of wells have an estimated wet depth to top of perforations that is negative. About one-third of wells are estimated to have a wet depth to top of perforations of less than 200 feet (but not negative). Few wells have a wet depth to top of perforations of more than 200 feet. The wells most vulnerable to well outage are those with the least (or negative) wet depth to top of perforations. Approximately 98 percent of wells have between negative 100 and positive 200 feet of water predicted above the well perforations.

A negative wet depth to top of perforations may be the result of a real event, e.g., the well is old and has been dry for some time, or the well is pumping from below the top of perforations. A negative wet depth to top of perforations may also be the result of estimation errors:

1) the interpolated water table depth used to estimate wet depth to top of perforations can be associated with significant error, from few feet to few tens of feet, due to limitations of the interpolation algorithm. The algorithm cannot account for localized changes in water table depth, especially in hilly terrains, where depth to water table may change rapidly as a function of terrain and well location.

2) depth to top of perforations is inaccurately reported.

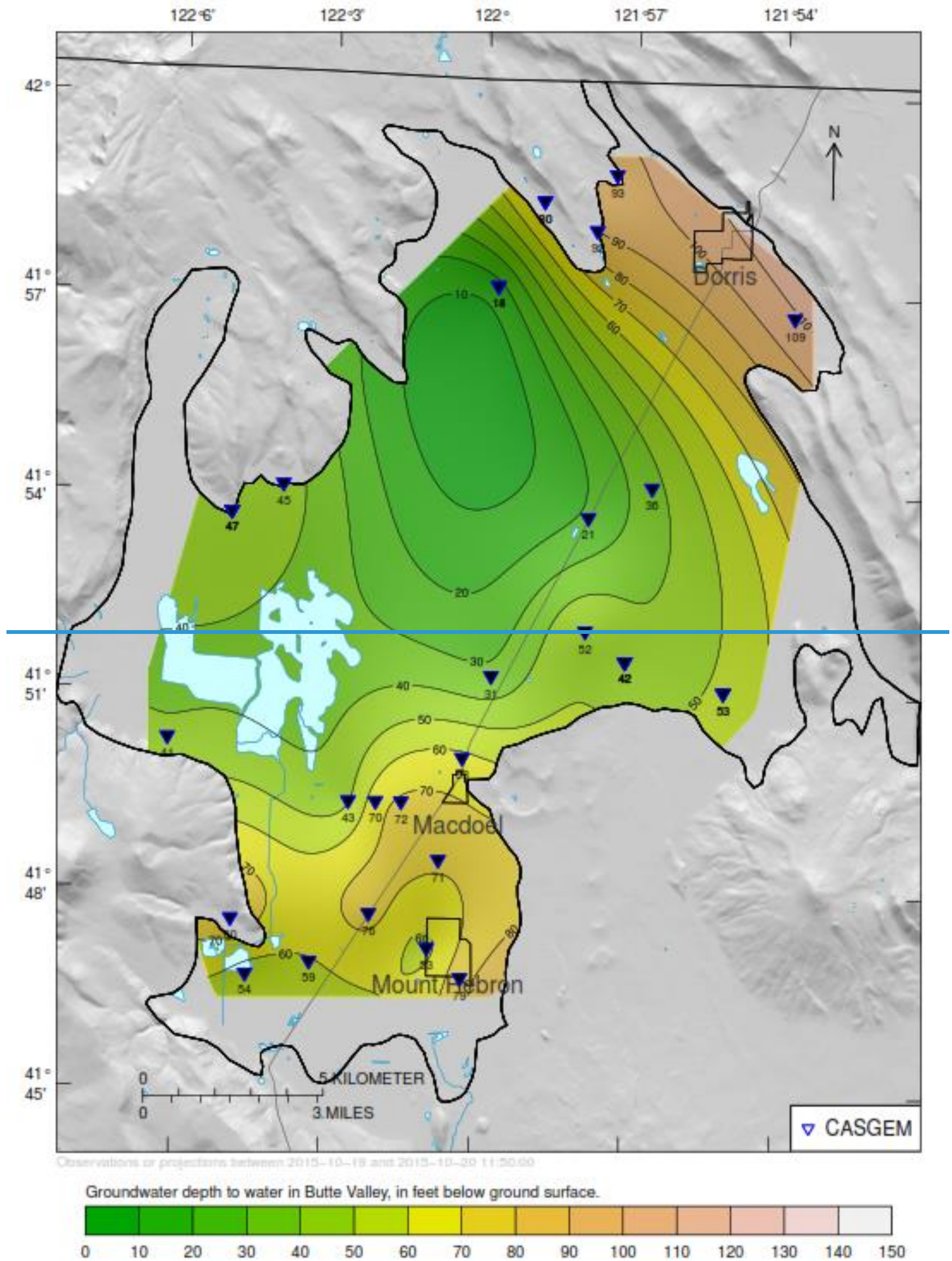
The absolute value of the wet depth to top of perforations is therefore thought to be of poor accuracy. However, its cumulative distribution is indicative of the relative distribution of wet depth to top of perforations across wells in Butte Valley. The cumulative distribution of the wet depth to top of perforations is shown in Figure 11 for both years, 2015 and 2017. A zoomed-in version of this Figure, focused on wet depth to top of perforations from 0 feet to 200 feet is shown in Figure 12. Wet depth to top of perforations are shown for fall 2015, following a dry winter and fall 2017, following a wet winter, for comparison purposes. The cumulative distribution of wet depth to top of perforations indicates that fall 2017 water level conditions actually had less wet depth to top of perforation across many wells in Butte Valley than 2015 (in other words, the brown curve is above - shallower than - the green curve). This is consistent with the observation that water levels in 2015 were higher in many wells than in 2017. The difference between the two years is least where (estimated) wet depth to top of perforations is very shallow or negative. From -20 feet to 80 feet wet depth to top of perforations, the difference between fall of 2015 and fall of 2017 is about 10 - 20 feet (most of wells).

The absolute value of the wet depth to top of perforations is, as indicated, highly uncertain. However, the slopes of the cumulative distributions shown are relatively uniform at either end of the distribution and are therefore much less sensitive to the above listed uncertainties. Figure 12 indicates that the slope of the CD is approximately 3% to 8% (in x-axis direction) per 10 feet (in y-axis direction), for the 5th to 35th percentile of shallowest wells. Hence, this slope is representative for the approximately one-third of Butte Valley wells that have the least estimated wet depth to top of perforations and would be most susceptible to well outages. Given the range over which the slope applies, the slope value is much less sensitive to the specific estimated wet depth to top of perforations at a well. Rather, it applies to all wells with shallow (or negative) values. If we further assume that the minimum wet depth to top of perforations needed for proper pumping is similar for most domestic wells (or most agricultural wells), then the slope can be interpreted as the risk for well outage with additional water level decline below historically low values: the slope indicates that 3% to 8% of Butte Valley wells are likely to experience well outage for every 10 feet of water level decline below the historically lowest measured water levels. Figures 13, 14, 15, and 16 show the cumulative distribution of "wet depth to top of perforations" separately for wells completed in the Lake Deposits, High Cascade Volcanics, the alluvium, and the Butte Valley Basalt, respectively.

Importantly, this approach to estimating well outage risk does not require knowledge of specific well information about pumping bowl elevation relative to the screen location, or about a minimum wet water level depth needed to pump properly. It only assumes that some well outages occur if water levels fall below historic lows and, hence, the selected slope is representative of the one-third of wells at most risk to well outage.

This allows for an estimate of the undesirable result that would occur if water levels declined to the minimum threshold. The average depth difference between the minimum measurable objective (MO, which corresponds to the lowest observed water level between 1991 and 2014) and the soft landing trigger (Chapter 3, Table 1.5) is 15 ft. The approximate number of wells that are at risk of well outage, if water levels across all of the basin fell to the soft landing trigger level is therefore 45 to 120 wells: 3% to 8% of approximately one thousand wells in the Basin fall dry for every ten feet lowering below the minimum MO. That is equivalent to 4.5% to 12% for every 15 feet lowering below the minimum MO. If water levels were to fall to the extended minimum threshold in the basin, which is an additional 15 feet lower at each RMP than the soft landing trigger, the number of well outages would likely double to between 90 and 240 wells.

The well outage risk may be unevenly distributed across Butte Valley (Figures 13, 14, 15, and 16): the slopes indicate a lower risk for wells in the Older Volcanic Rocks of the High Cascade Volcanics, but possibly higher risks elsewhere. However, for individual geologic formations, too few data points exist to make reliable well outage risk estimates.



~~Figure 8: Butte Valley groundwater elevations reported as approximate depth to groundwater, fall 2015 and well failure estimates based on recent water level observations. Approximate basin-scale groundwater depths are shown.~~

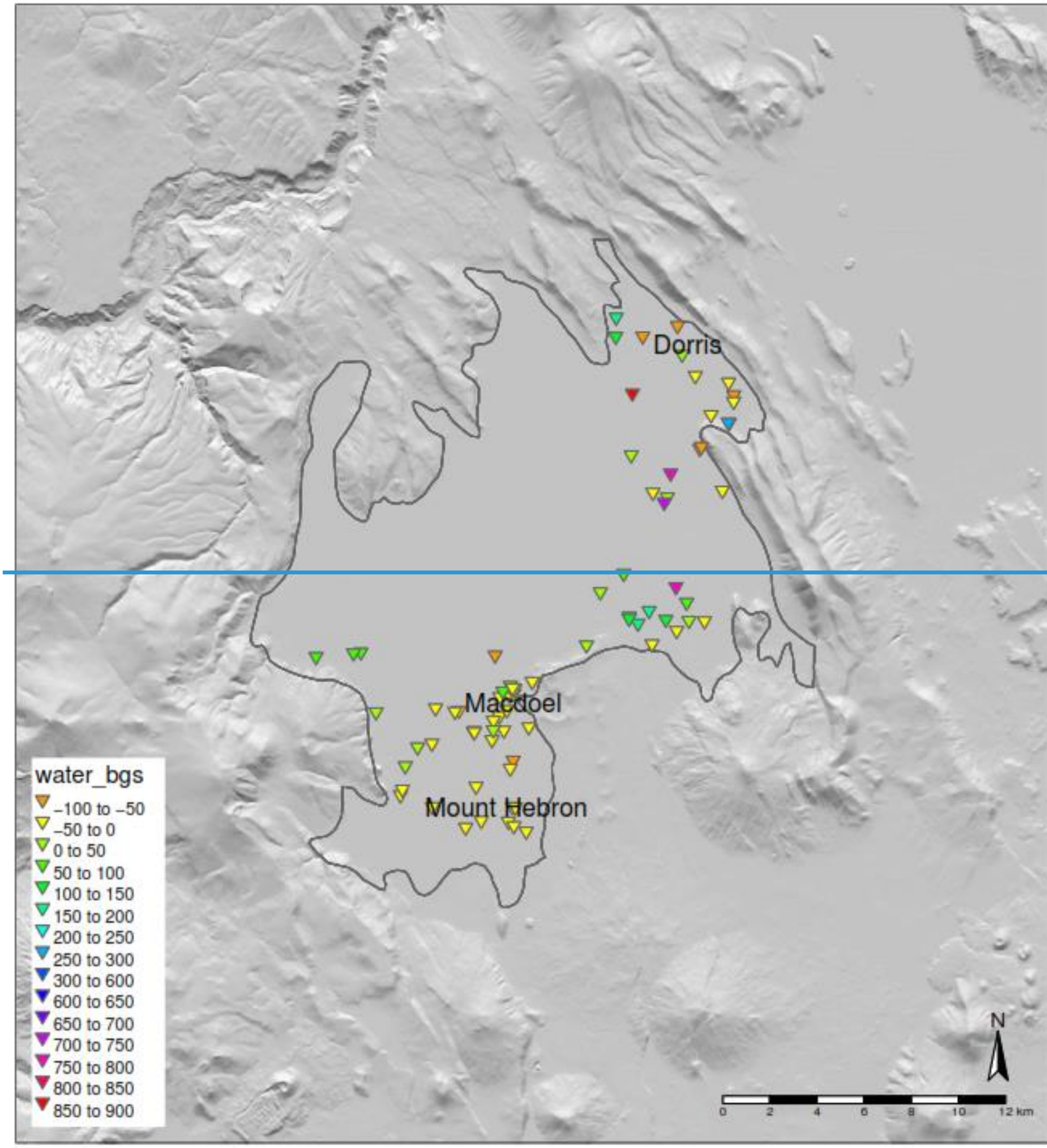
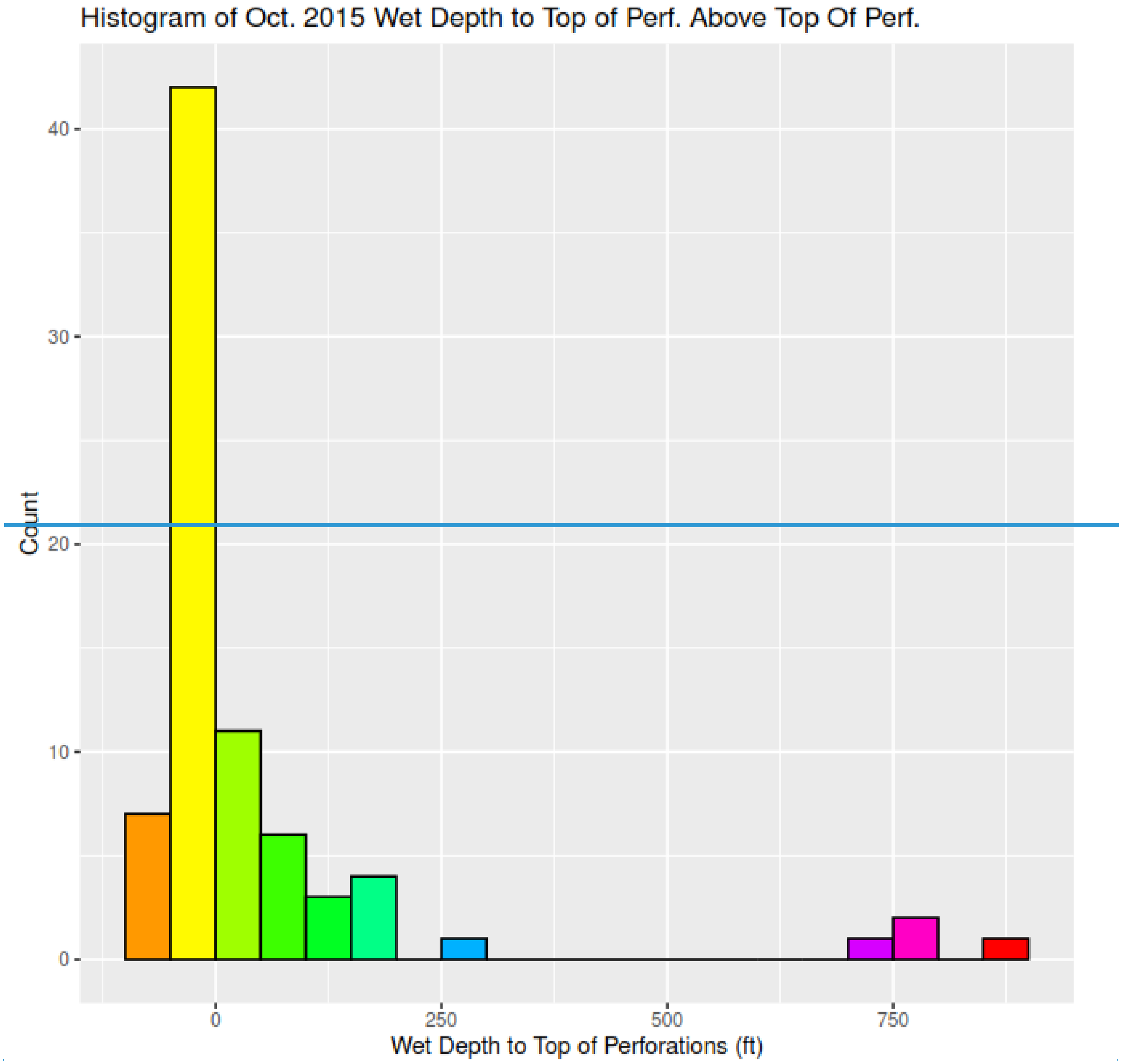
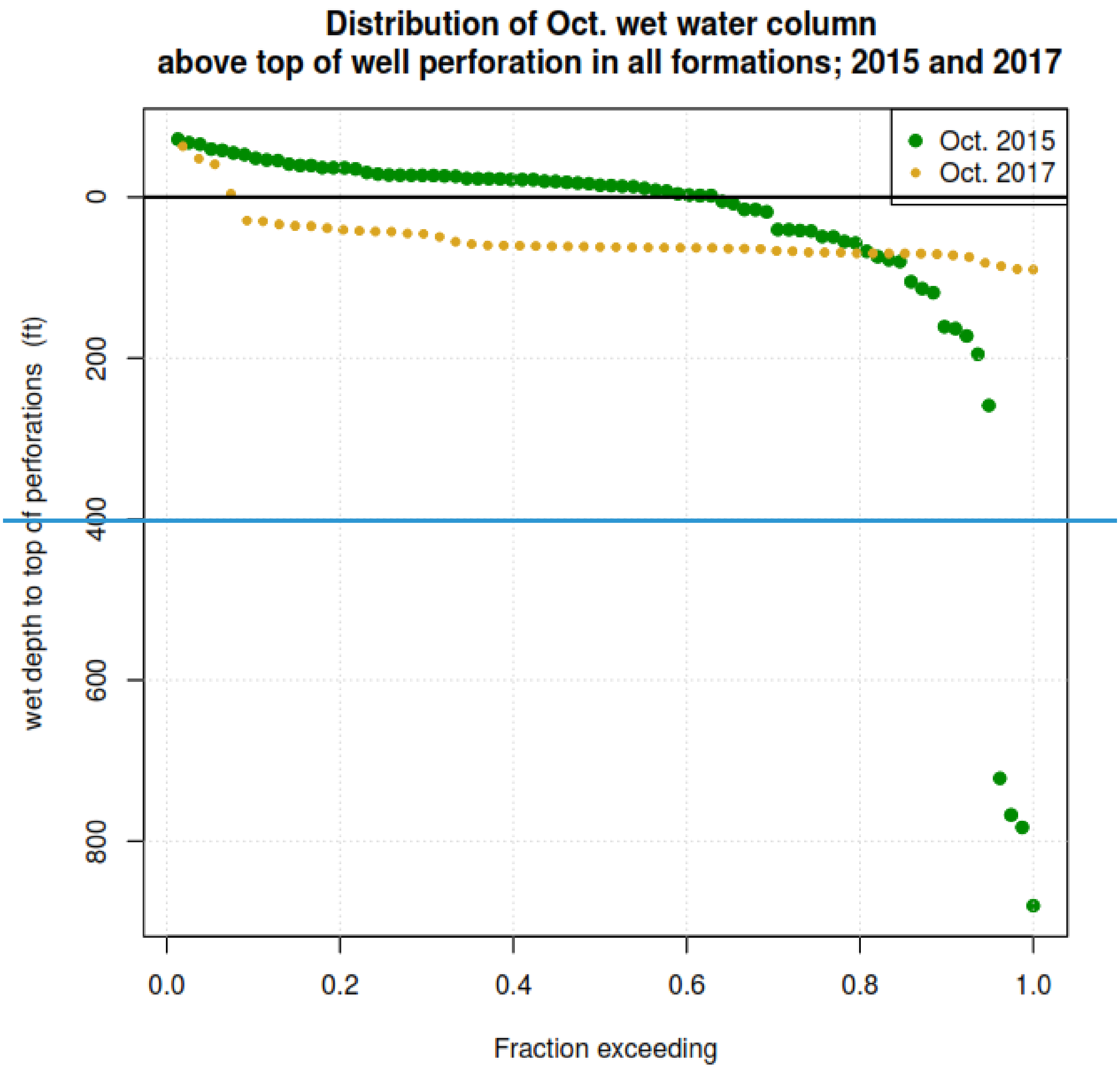


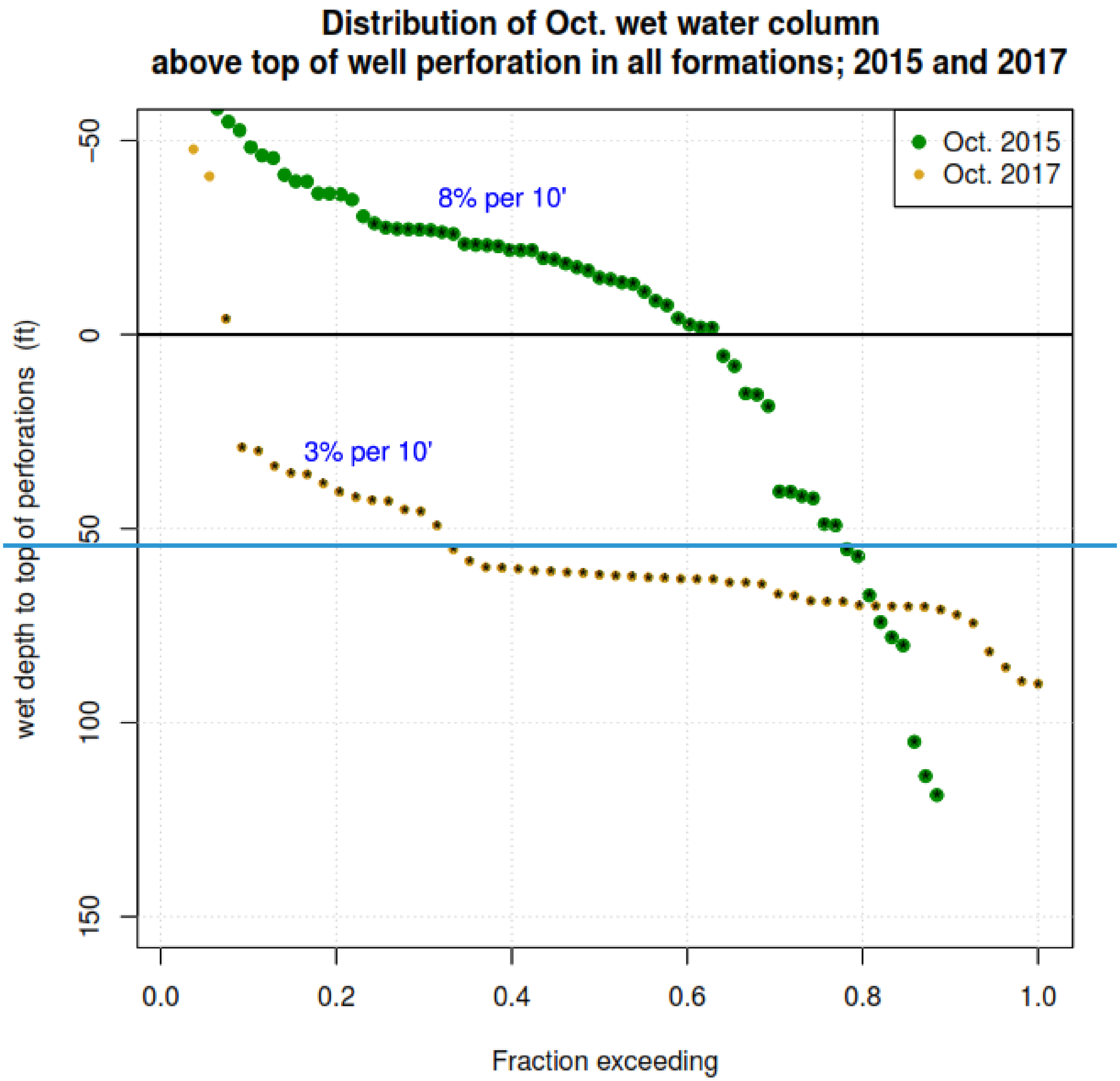
Figure 9: Butte Valley wet depth to top of perforations based on contoured groundwater elevations, October 2015.



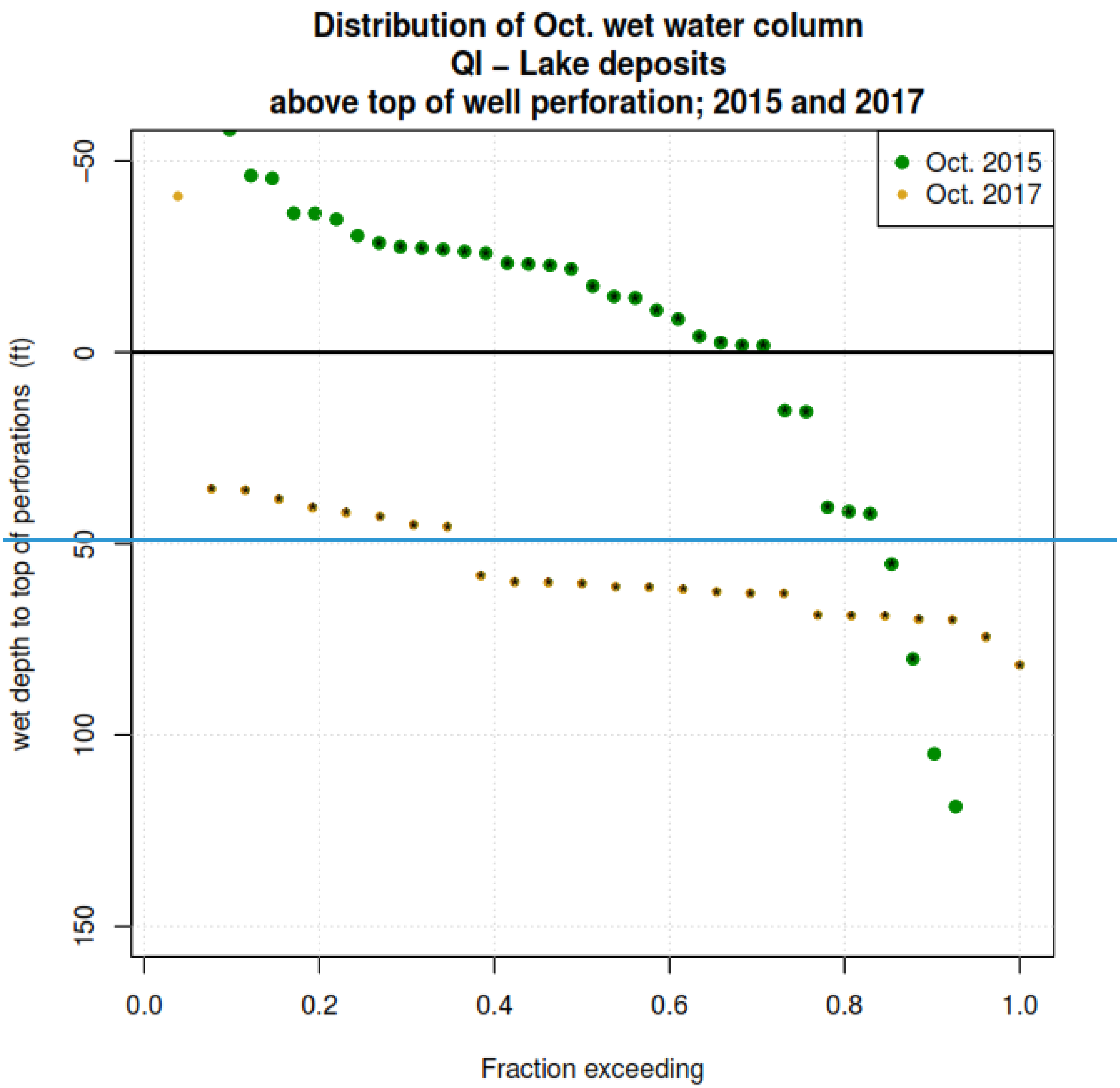
~~Figure 10: Histogram of wet depth to top of perforations based on contoured groundwater elevations, October 2015.~~



~~Figure 11: Cumulative distribution function of all well wet depth to top of perforations based on contoured groundwater elevations, Octobers of 2015 and 2017.~~



~~Figure 12: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well failure slope. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (LINEST function in Excel: 10* LINEST (fraction range, feet range).~~



~~Figure 13: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 100 feet used for interpolating the well failure slope. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (LINEST function in Excel: 10* LINEST (fraction range, feet range).~~

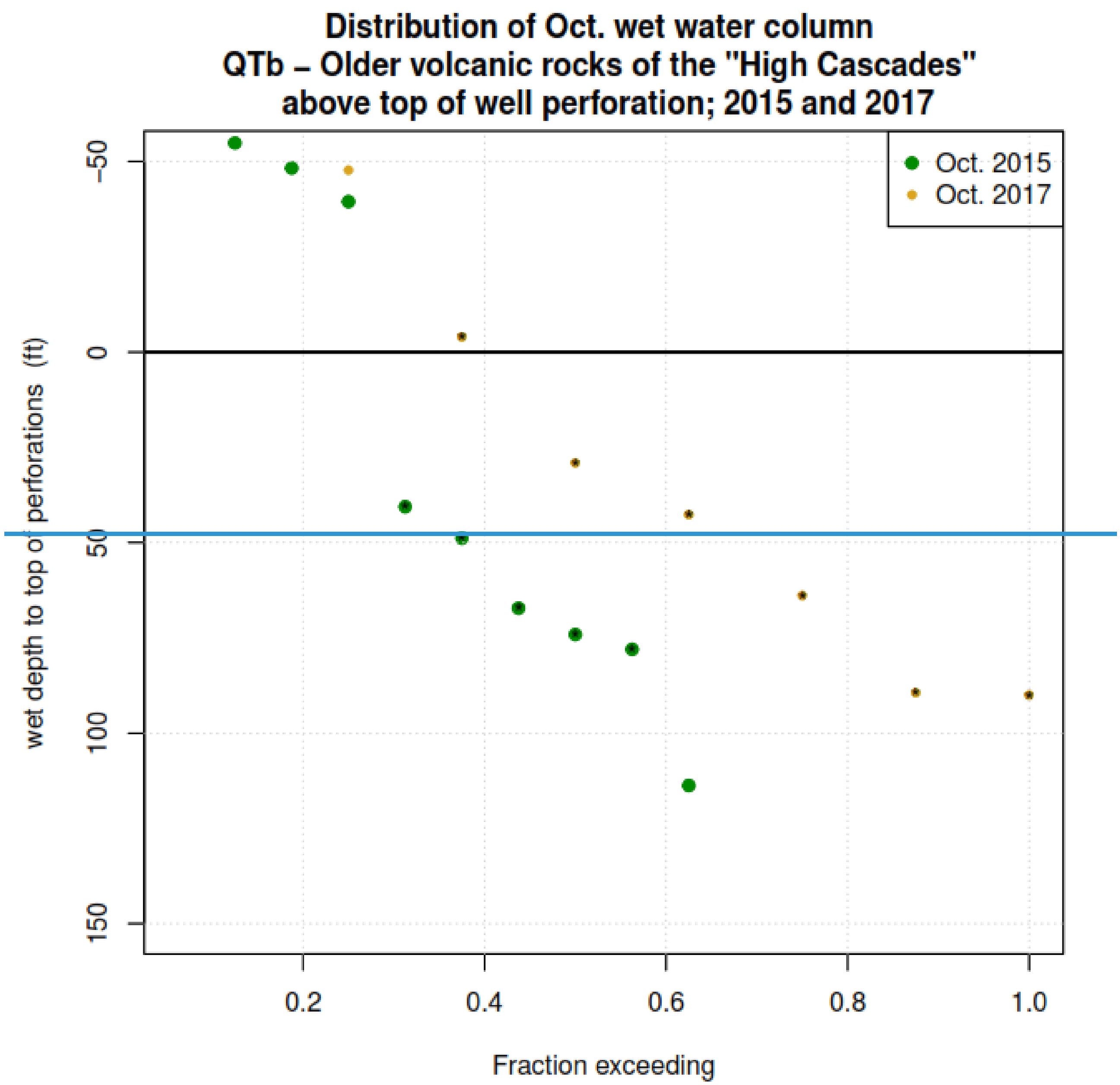
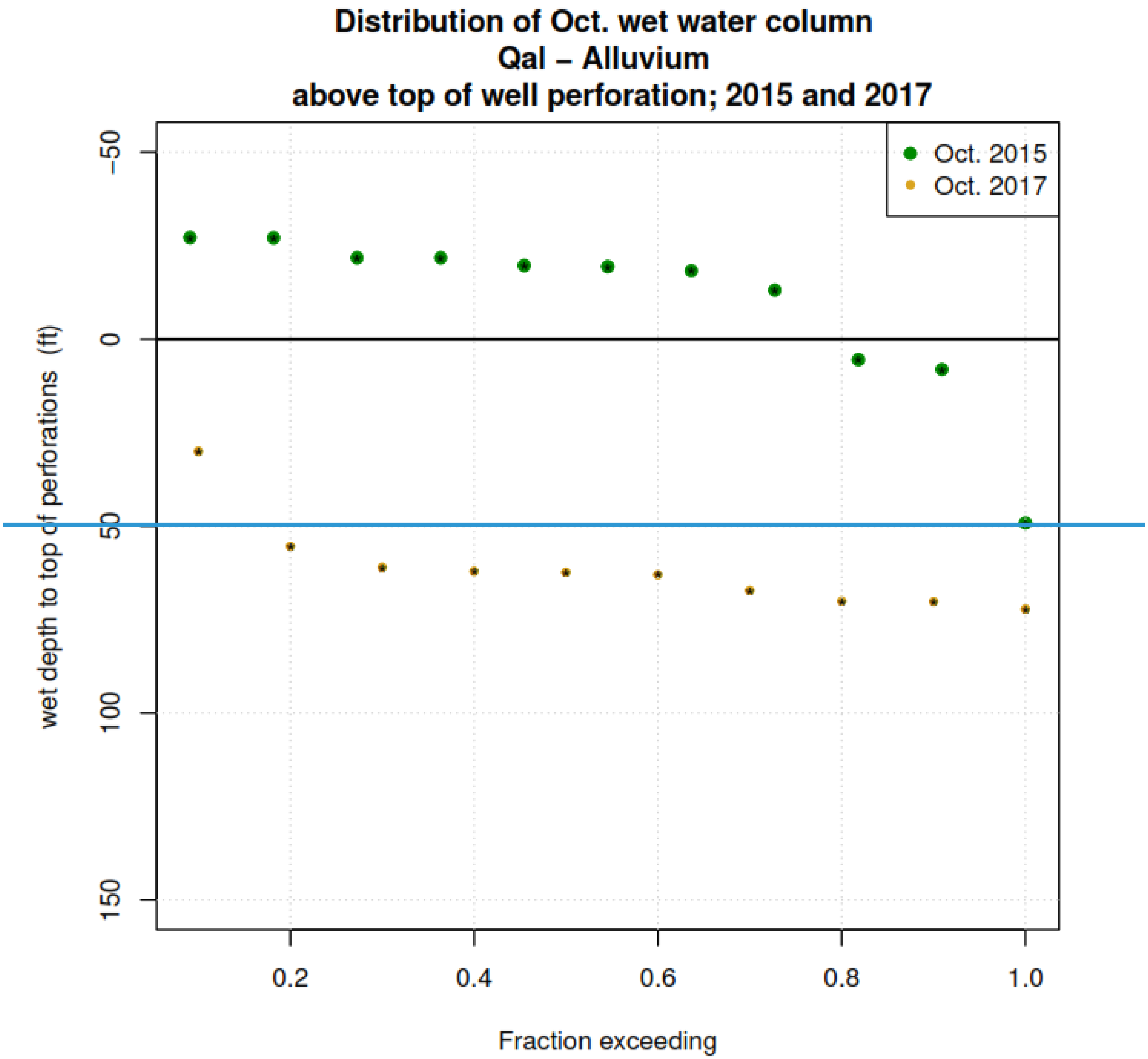
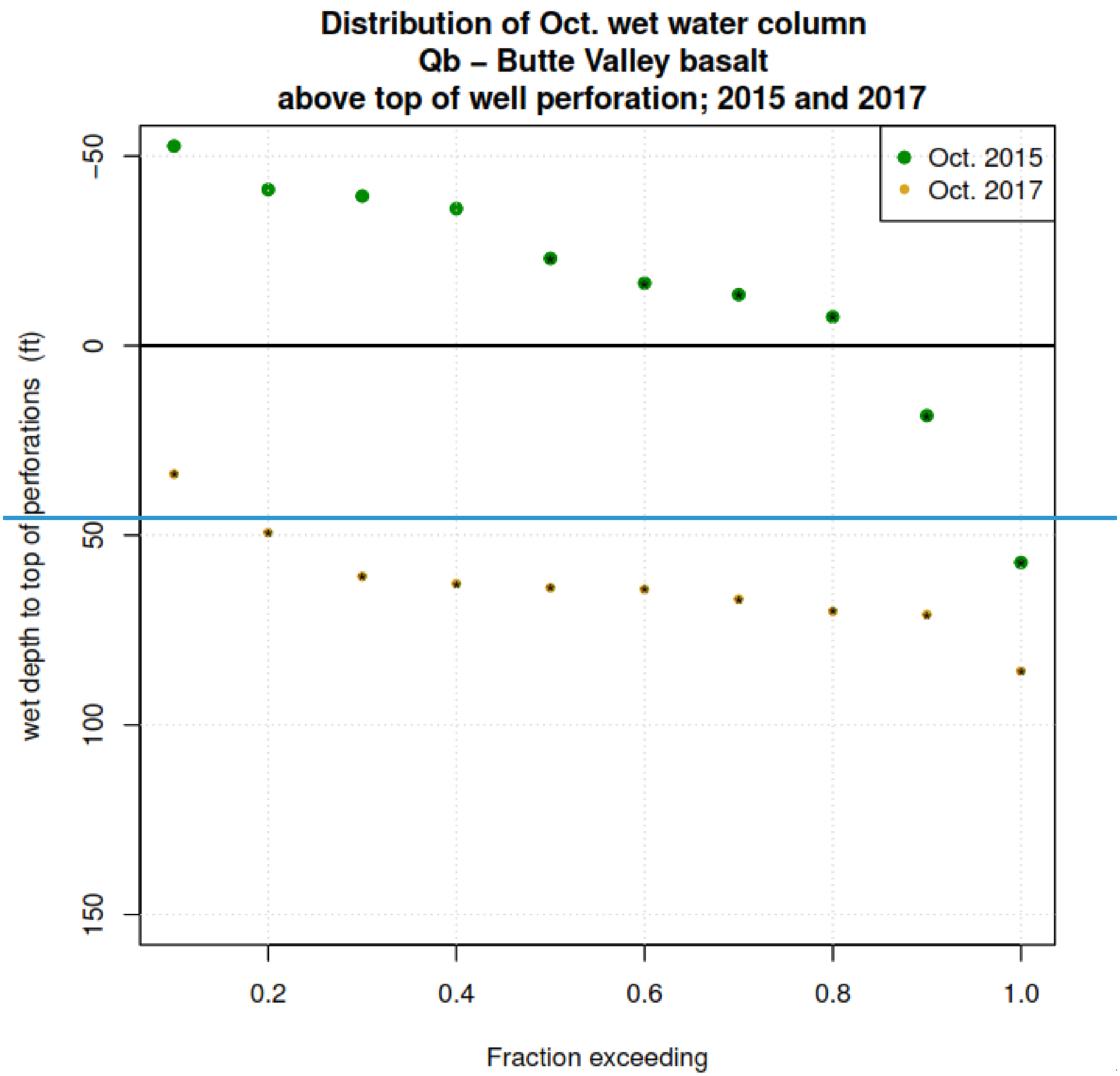


Figure 14: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 100 feet used for interpolating the well failure slope. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (LINEST function in Excel: 10* LINEST (fraction range, feet range).



~~Figure 15: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 100 feet used for interpolating the well failure slope. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (LINEST function in Excel: 10* LINEST (fraction range, feet range).~~



~~Figure 16: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well failure slope. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (LINEST function in Excel: 10* LINEST (fraction range, feet range).~~

Conclusion

We identified three key findings with respect to well outages:

The Majority of wells in the Butte Valley groundwater basin are unlikely to be affected by dewatering. ~~Most wells in Butte Valley have well depths of 50 feet or more below the interpolated groundwater elevations depths of 2015 (at least 65%).~~

Uncertainty affects the quality of the outage analysis~~analysis quality~~.
The analysis has a level of uncertainty due to the lack of information, i.e., wells with both water level measurements and known well construction. Hence, we relied on interpolated water level data, which may be several feet or even tens of feet incorrect in some areas.
~~The analysis is relatively uncertain due to the lack of wells with both water level measurements and known well construction. Hence, we relied on interpolated water level data, which may be several feet or even tens of feet incorrect in some areas. This may be the case regarding the one third of wells with top of perforations above the interpolated water level depth (Figure 12) in 2015 (dry year) and 2017 (wet year) however many of those wells are also in the south east portion of the basin near Macdoel and Mount Hebron where some of the greatest water level declines since the 1980s has occurred. These wells may simply be operating at degraded capacity or are already out of operation seasonally.~~

~~In wells for which the wet depth to top of perforations is negative or exceedingly shallow, either:~~

~~1) the well goes dry in the fall, regardless of water year type, or,~~
~~2) the well pumps from below the top of perforations, or~~
~~3) the depth to water table interpolation is erroneous (most likely in hilly areas), or~~
~~4) well depth is inaccurately reported.~~

~~Due to the uncertainties arising from (3) and (4), we relied instead on the slope of the cumulative distribution of estimated wet water column depth, which is a more stable indicator of how many additional wells fall dry per 10 foot decline in water levels below historically low water levels. We find that:~~

The number of wells affected by groundwater elevations at the Minimum Threshold can be mitigated. ~~is in- significant. A well replacement PMA will further address well outage issues that occur be- low the first trigger level and above the extended minimum threshold.~~
Well outage analyses by direct comparison and by wet depth trend analysis show relatively consistent results of additional well outages. If water levels across the basin fall to the minimum threshold as compared to 2015 conditions, the estimated outage percentages are 6 - 12% of additional wells through direct comparison and 6 - 10% of additional wells through trend analysis. This estimated range falls within the percent mitigatable wells margin set by the GSA (see section 3.4.1.1 Identification of Undesirable Results).

Further, a well replacement PMA (ongoing) and a well mitigation PMA (planning) will be implemented to address well outage issues that occur below the minimum threshold. Details of these two Tier II PMAs are described in Chapter 4.

~~The soft landing trigger is, on average, 15 feet below the lowest measured water level during the 1991 to 2014 period. Based on Figure 12, an estimated 45 to 120 wells out of approximately 1,000 wells (4.5% to 12%) in the Basin may be at risk for well outage if water levels across the basin fall to the soft landing trigger. If water levels across the basin fell to the extended minimum threshold (an additional 15 feet water level decline), twice as many wells, from 9% to 24% of all wells, may be at risk of well outage.~~

Supplementary Information

A detailed characterization of construction information for the domestic, public and agricultural wells can be demonstrated through cumulative distribution plots. The distribution of depth to the top of the perforated interval follows a similar pattern as well depth: shallow-most top of screens are found in domestic wells, across all formations (see Figure 14). Figure 15 shows the distribution of total completed depths, and Figure 16 shows the resulting perforation lengths.

The few pumping test data that have been provided on Well Completion Reports submitted to the Department of Water Resources have shown that both domestic wells and public supply wells have low well yields, by design. As for comparison, agricultural wells tested are generally high production wells with 1000 to 5000 gpm (Figure 17). Agricultural wells have casing diameters of typically 12 to 18 inches, while domestic wells are mostly of smaller (2 to 8 inch) diameter with 10 inch diameter domestic wells in the Butte Valley Basalt (Qb), perhaps owing to miss-classification (Figure 18).

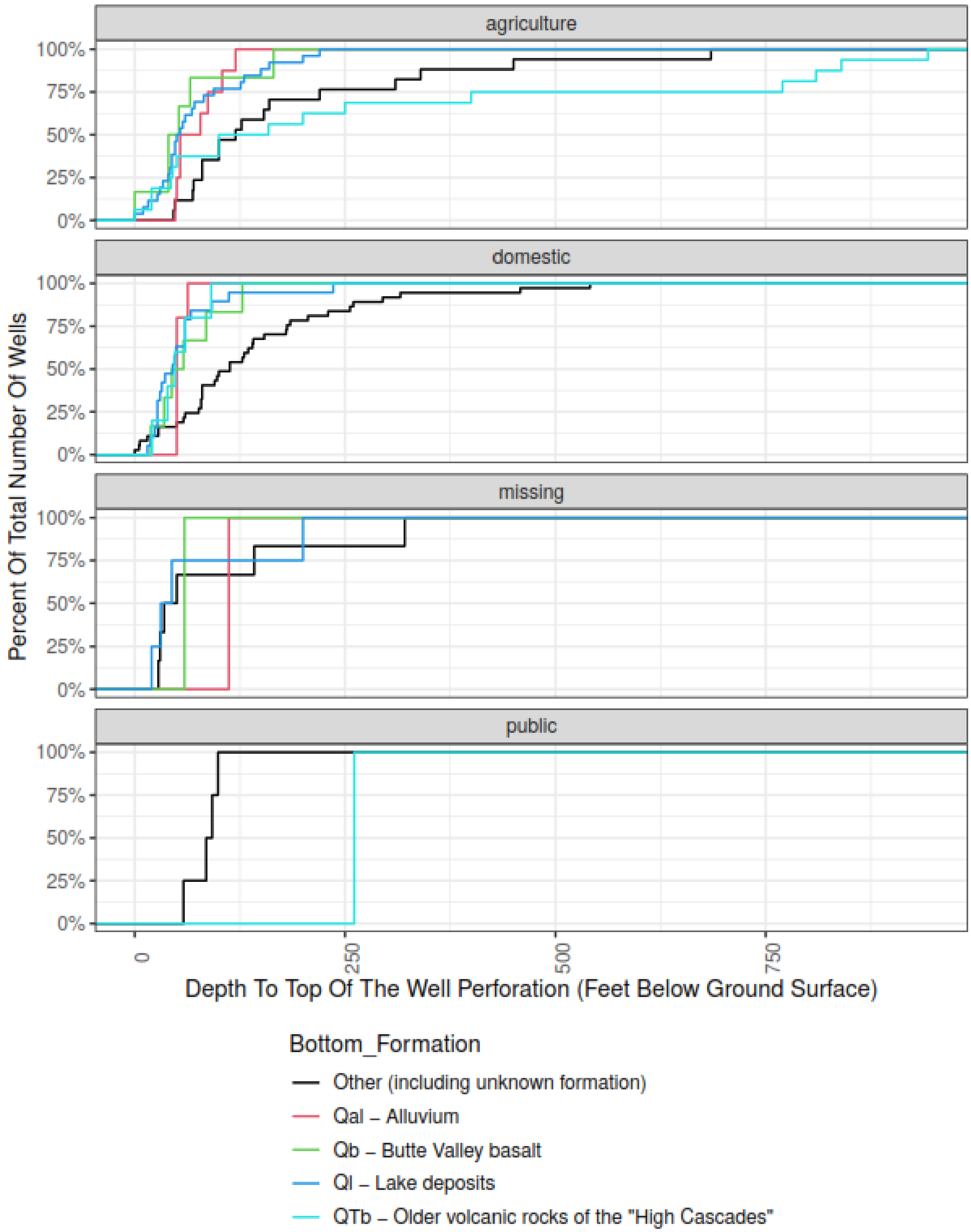


Figure 14: Butte Valley well perforation top. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.

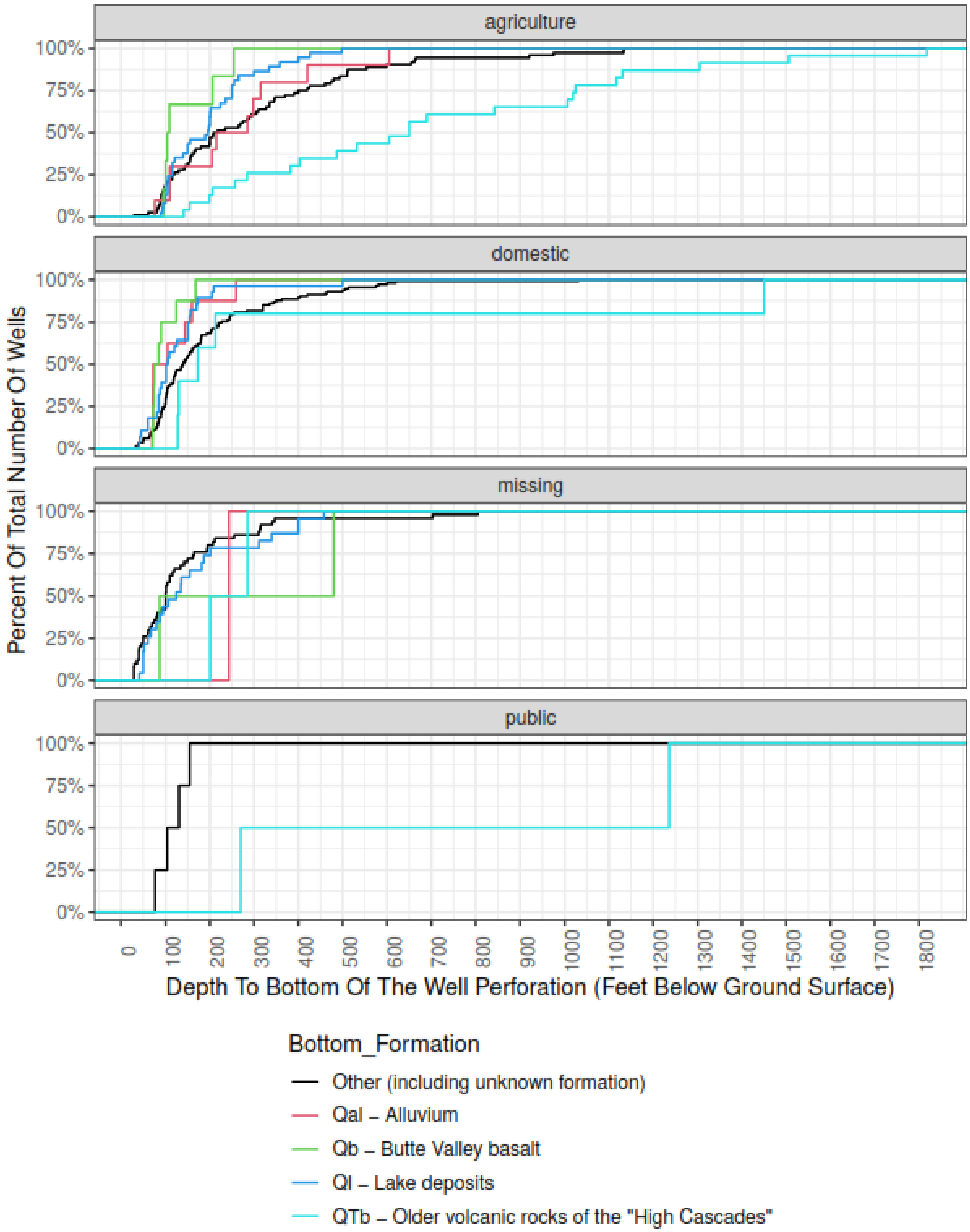


Figure 15: Butte Valley total completed depth for all wells in the valley, including those which have no data on perforated interval. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.

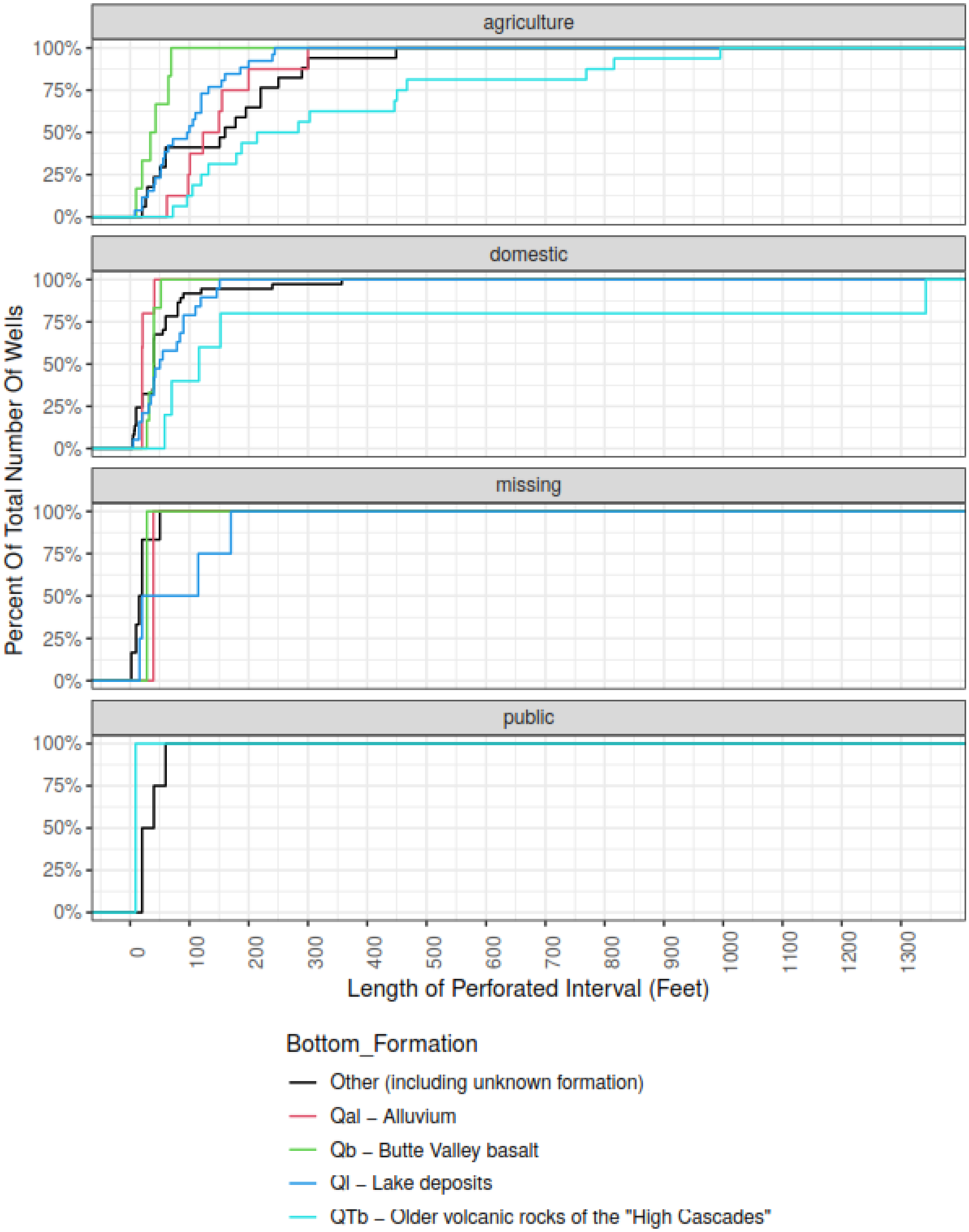


Figure 16: Butte Valley well perforation length. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.

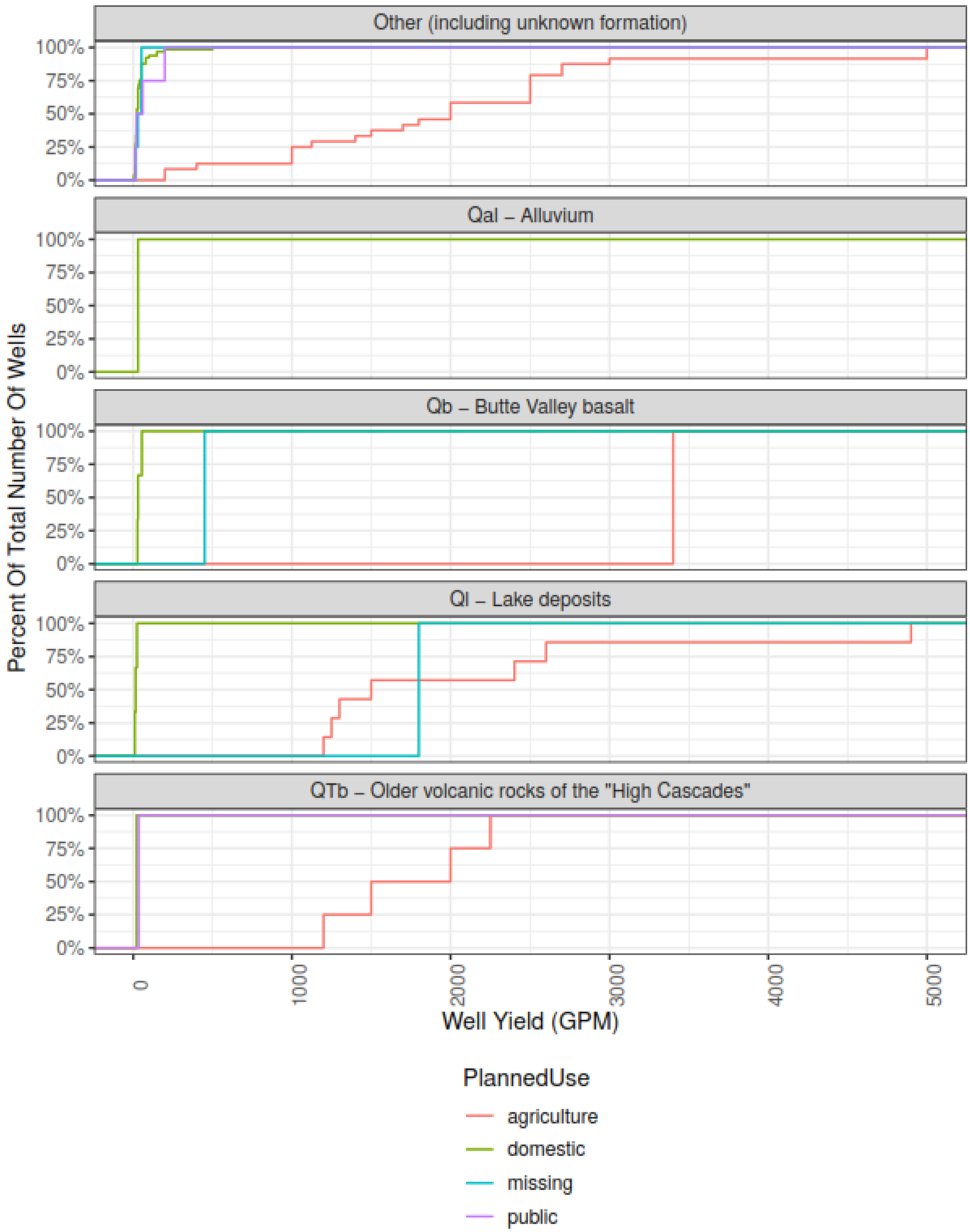


Figure 17: Butte Valley well yield by formation at the bottom of the well for major well types.

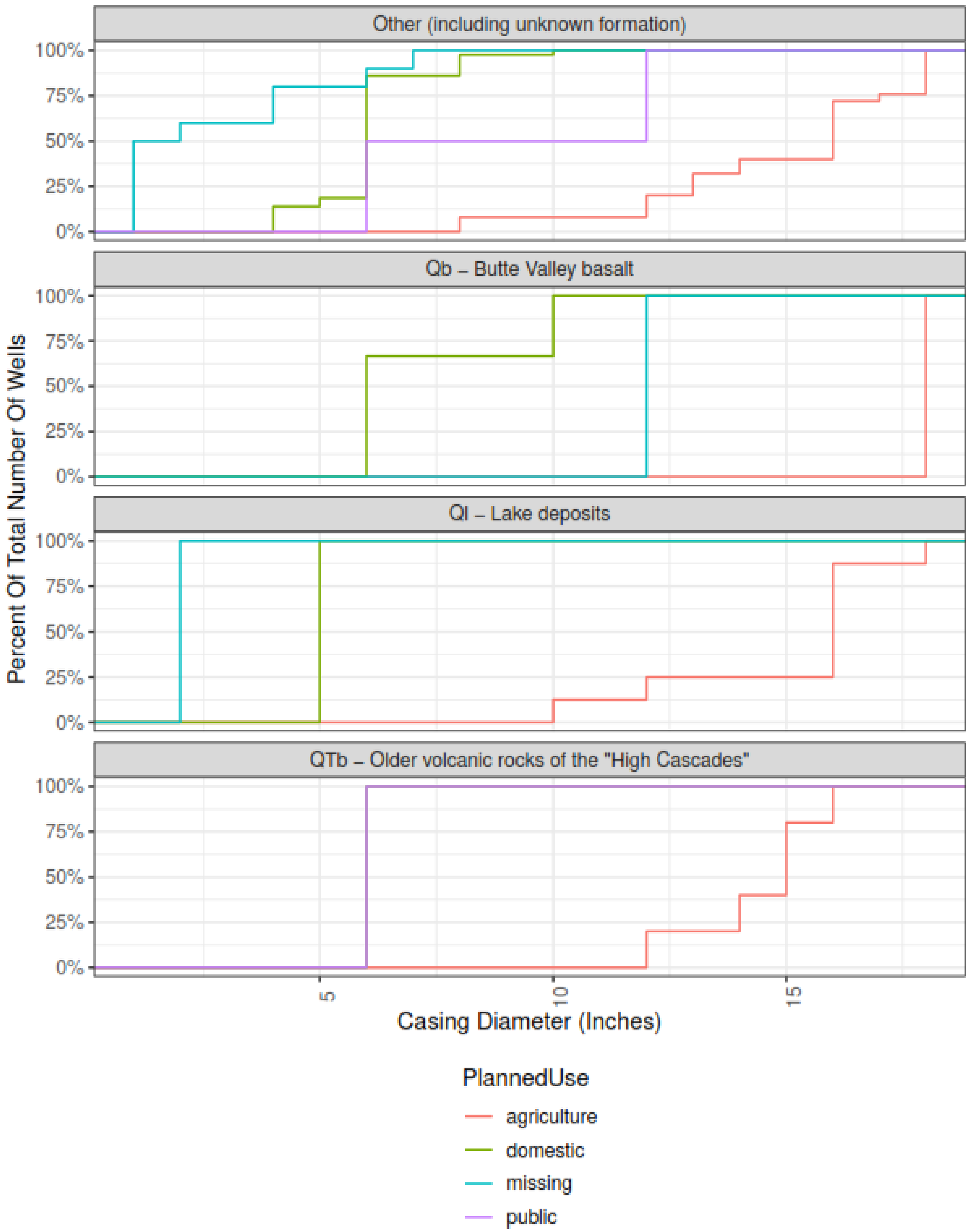


Figure 18: Butte Valley well casing diameter by formation at the bottom of the well for major well types.