Appendix 3-C. Water Level Sustainability Management Criteria

Contents

Groundwater Level Sustainability Measurable Criteria

This Appendix provides further background information for Section 3.4.1 Sustainable Management Criteria - Groundwater Elevation. The following provides additional figures and discussion to supplement the main text:

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

Hydrographs

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

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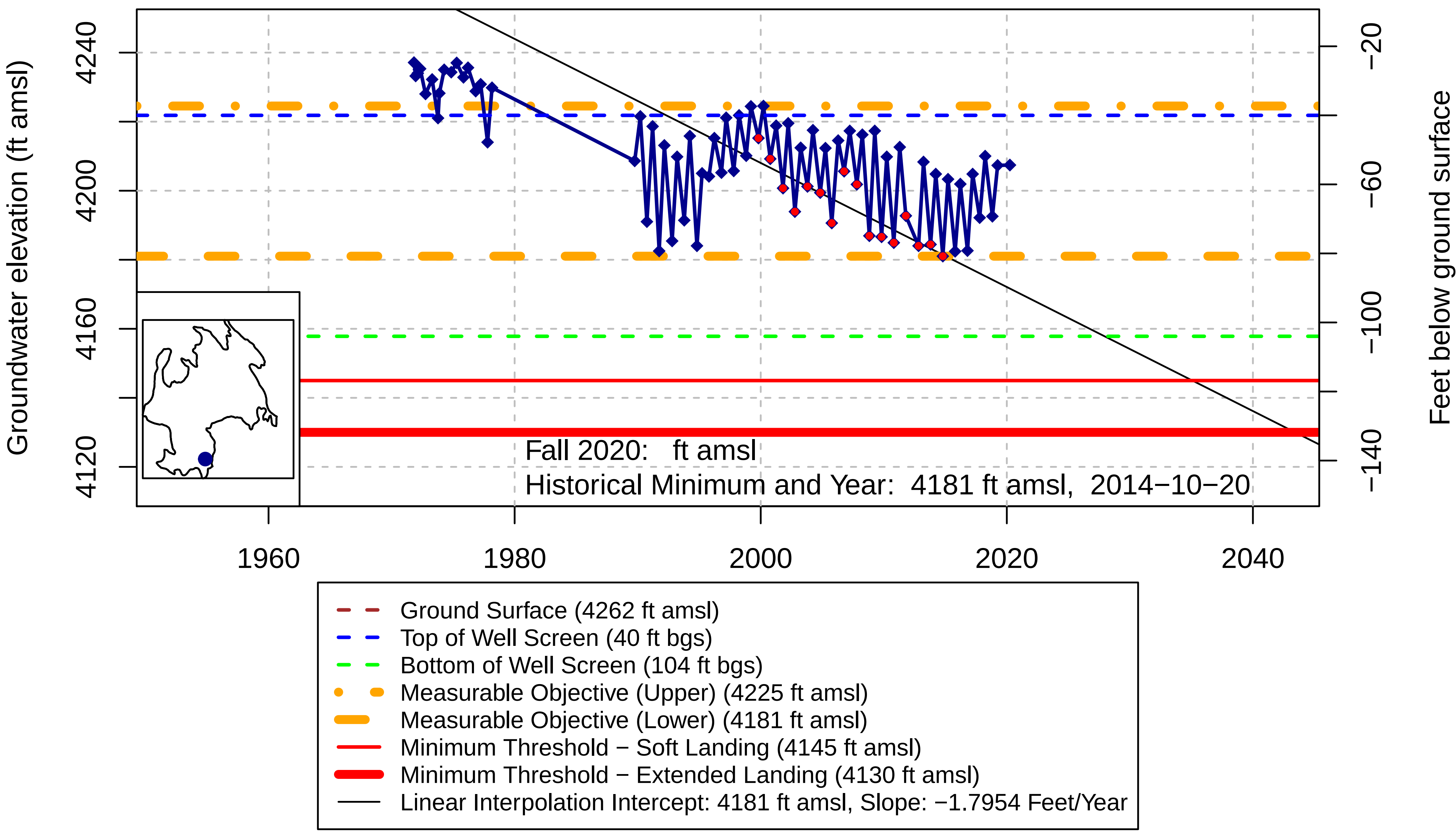

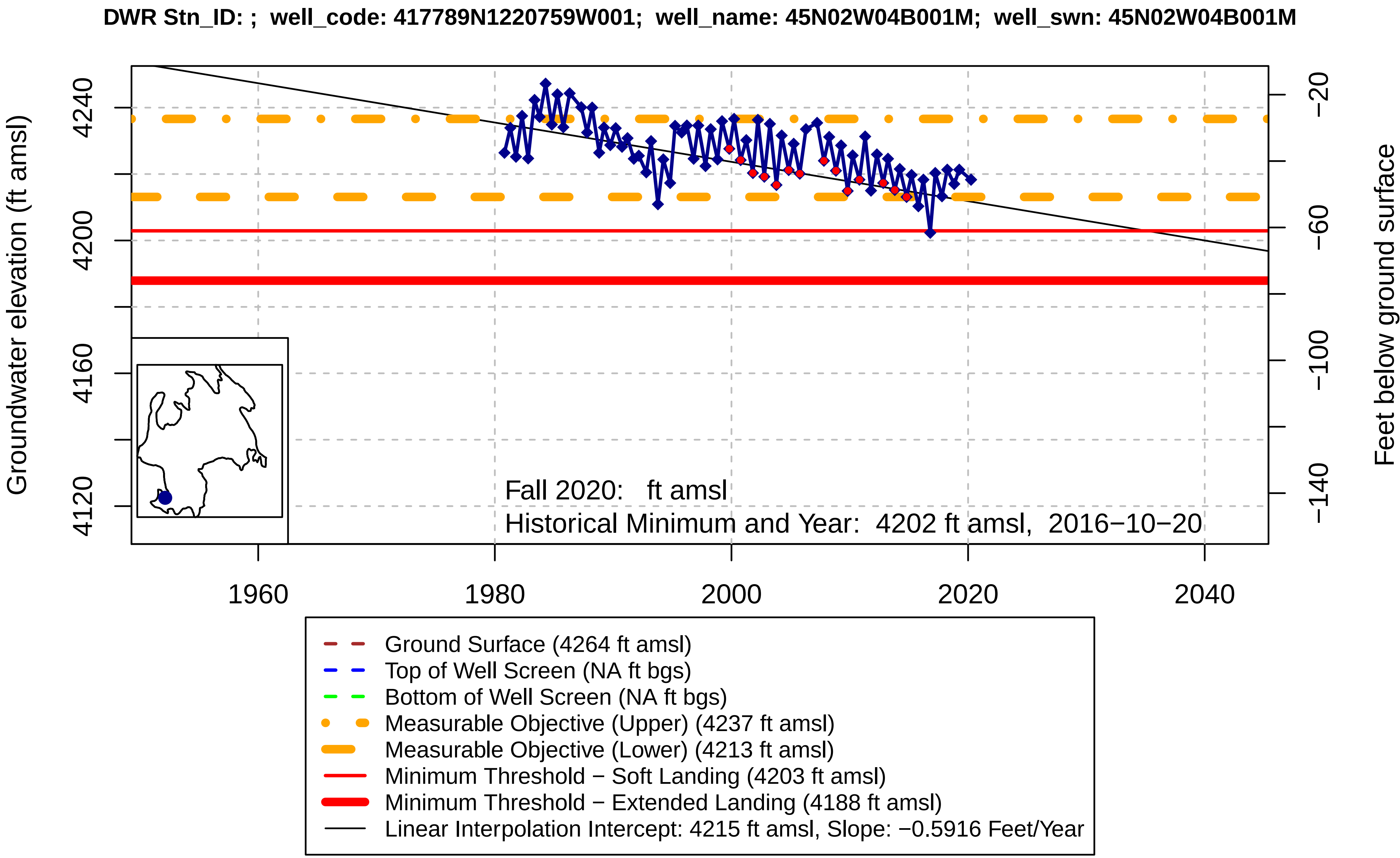
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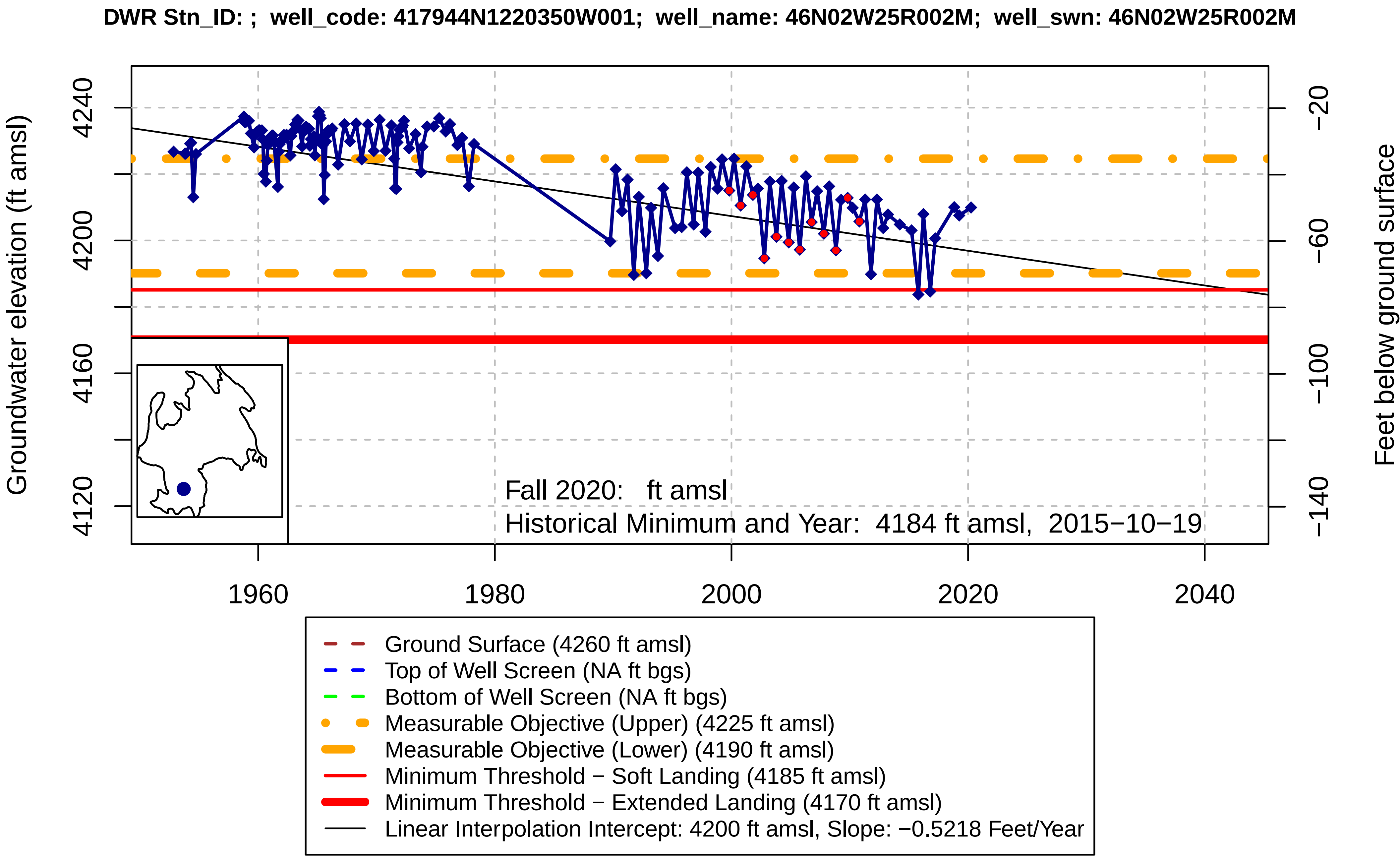
Groundwater elevation (ft amsl)
Feet below ground surface
4120
4160
4200
4240
−20
−60
−100
−140
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4202 ft amsl, 2016−10−20
Ground Surface (4264 ft amsl)
Top of Well Screen (NA ft bgs)
Bottom of Well Screen (NA ft bgs)
Measurable Objective (Upper) (4237 ft amsl)
Measurable Objective (Lower) (4213 ft amsl)
Minimum Threshold − Soft Landing (4203 ft amsl)
Minimum Threshold − Extended Landing (4188 ft amsl)
Linear Interpolation Intercept: 4215 ft amsl, Slope: −0.5916 Feet/Year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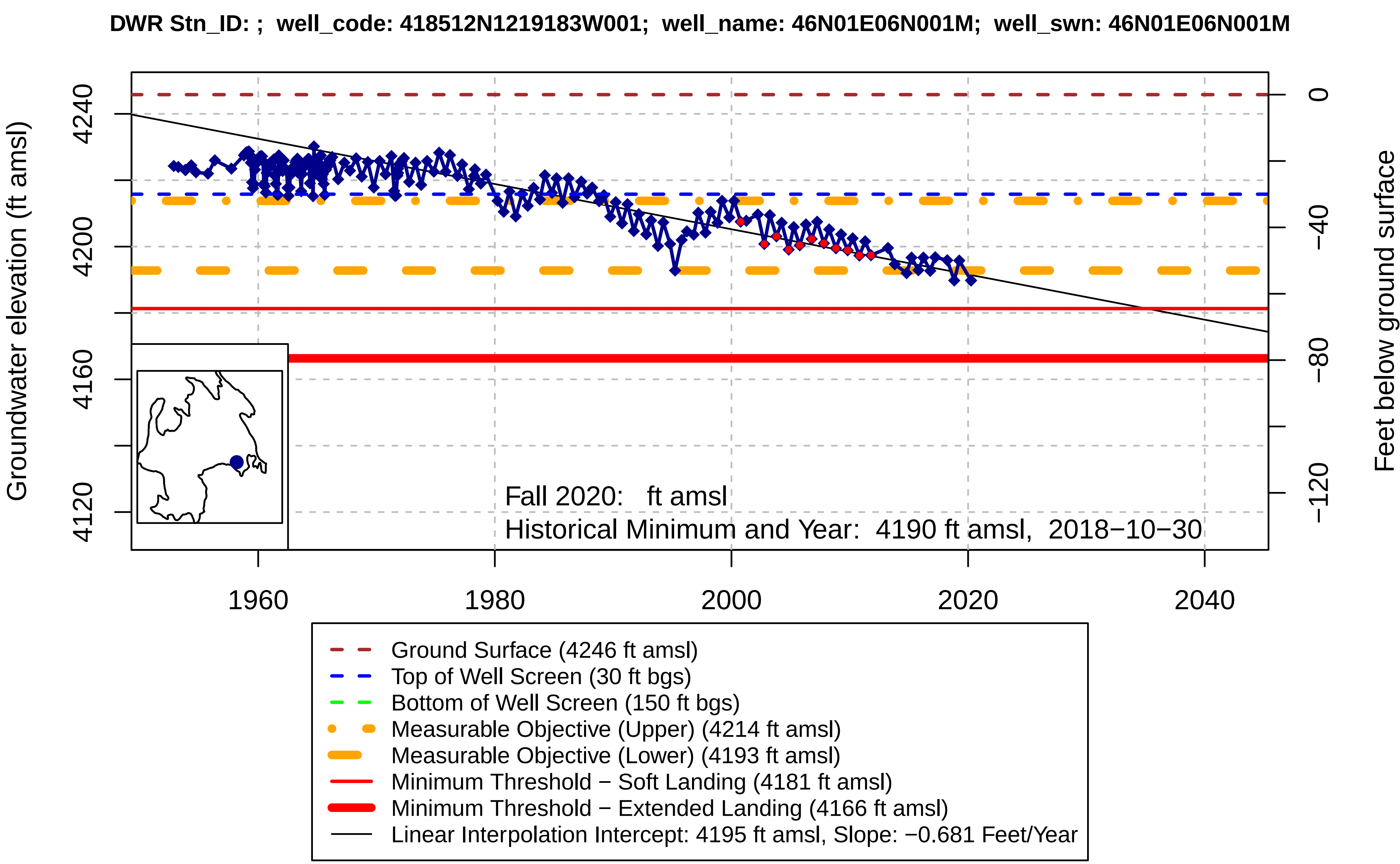
Feet below ground surface
4120
4160
4200
4240
−20
−60
−100
−140
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4184 ft amsl, 2015−10−19
Ground Surface (4260 ft amsl)
Top of Well Screen (NA ft bgs)
Bottom of Well Screen (NA ft bgs)
Measurable Objective (Upper) (4225 ft amsl)
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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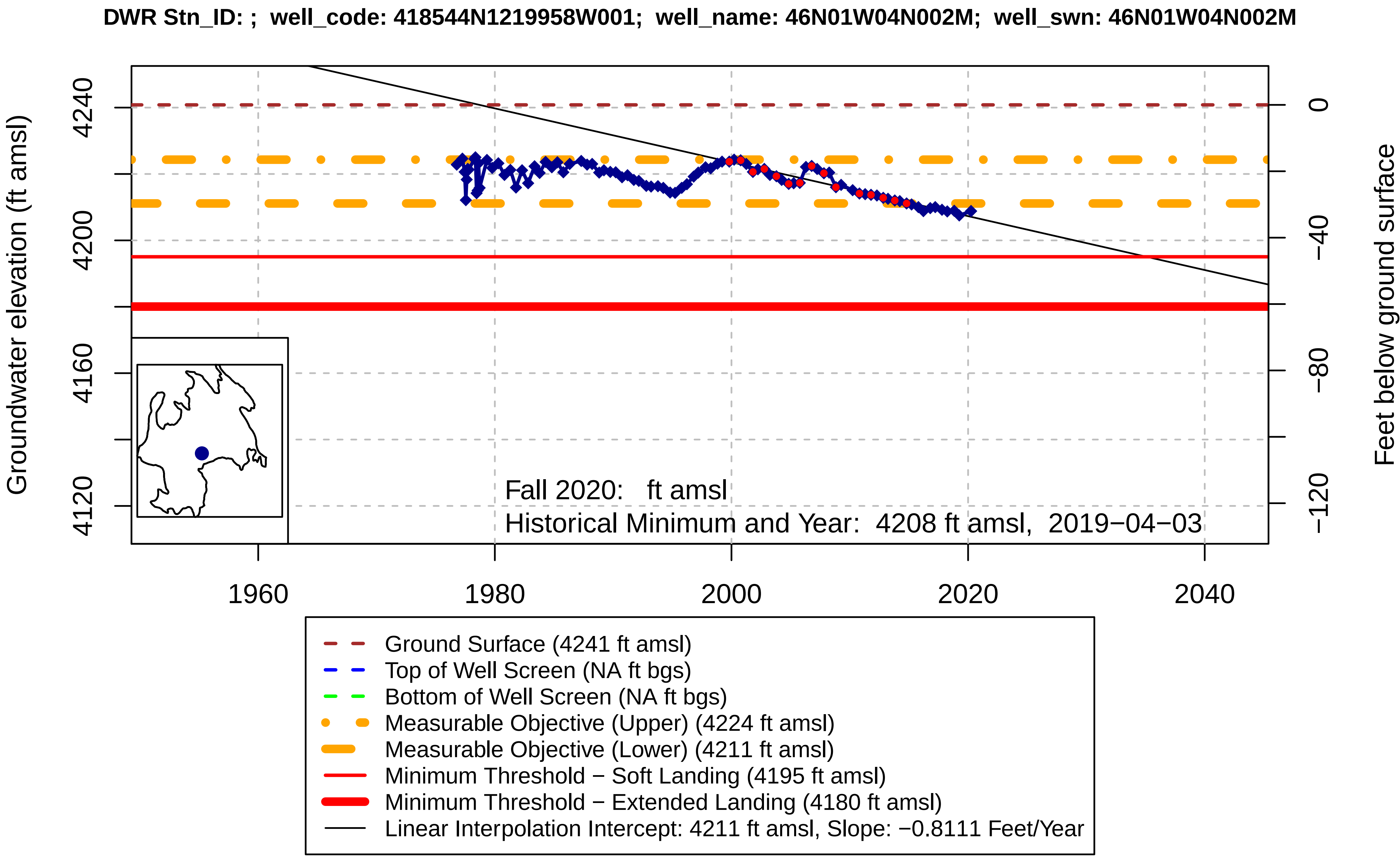
Groundwater elevation (ft amsl)
Feet below ground surface
4240
4200
4160
4120
0
−40
−80
−120
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4190 ft amsl, 2018−10−30
Ground Surface (4246 ft amsl)
Top of Well Screen (30 ft bgs)
Bottom of Well Screen (150 ft bgs)
Measurable Objective (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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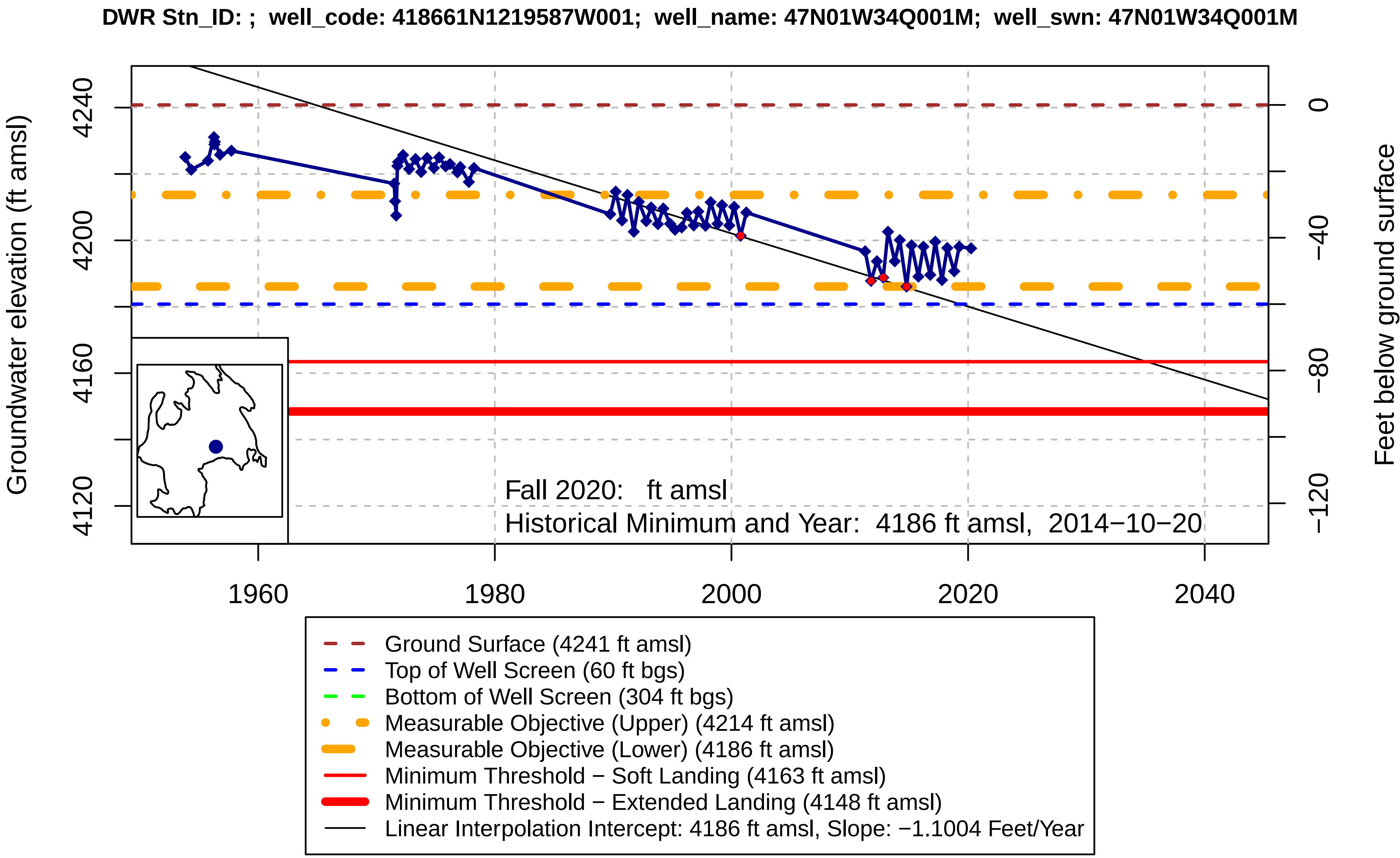
Groundwater elevation (ft amsl)
Feet below ground surface
4120
4160
4200
4240
0
−40
−80
−120
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4208 ft amsl, 2019−04−03
Ground Surface (4241 ft amsl)
Top of Well Screen (NA ft bgs)
Bottom of Well Screen (NA ft bgs)
Measurable Objective (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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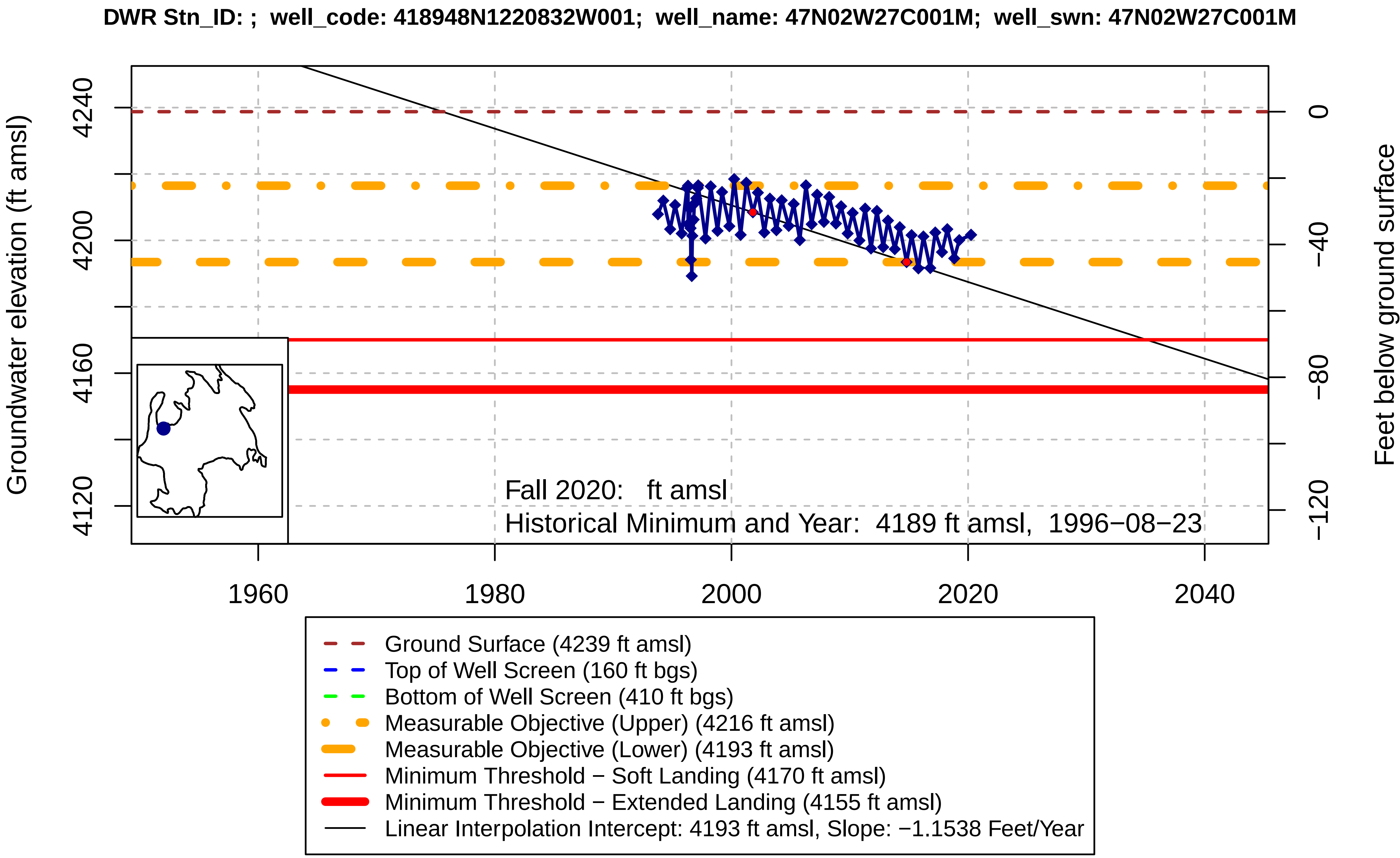
Groundwater elevation (ft amsl)
Feet below ground surface
4120
4160
4200
4240
0
−40
−80
−120
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4186 ft amsl, 2014−10−20
Ground Surface (4241 ft amsl)
Top of Well Screen (60 ft bgs)
Bottom of Well Screen (304 ft bgs)
Measurable Objective (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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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: 4189 ft amsl, 1996−08−23
Ground Surface (4239 ft amsl)
Top of Well Screen (160 ft bgs)
Bottom of Well Screen (410 ft bgs)
Measurable Objective (Upper) (4216 ft amsl)
Measurable Objective (Lower) (4193 ft amsl)
Minimum Threshold − Soft Landing (4170 ft amsl)
Minimum Threshold − Extended Landing (4155 ft amsl)
Linear Interpolation Intercept: 4193 ft amsl, Slope: −1.1538 Feet/Year

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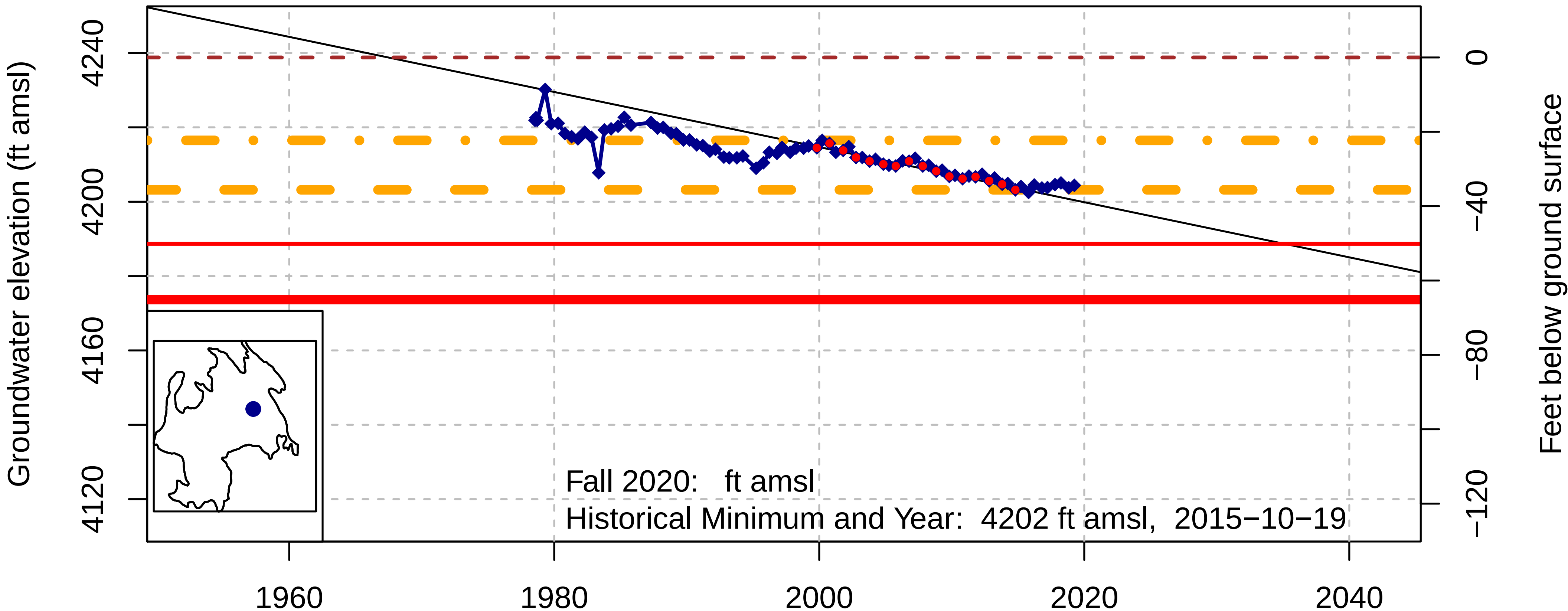
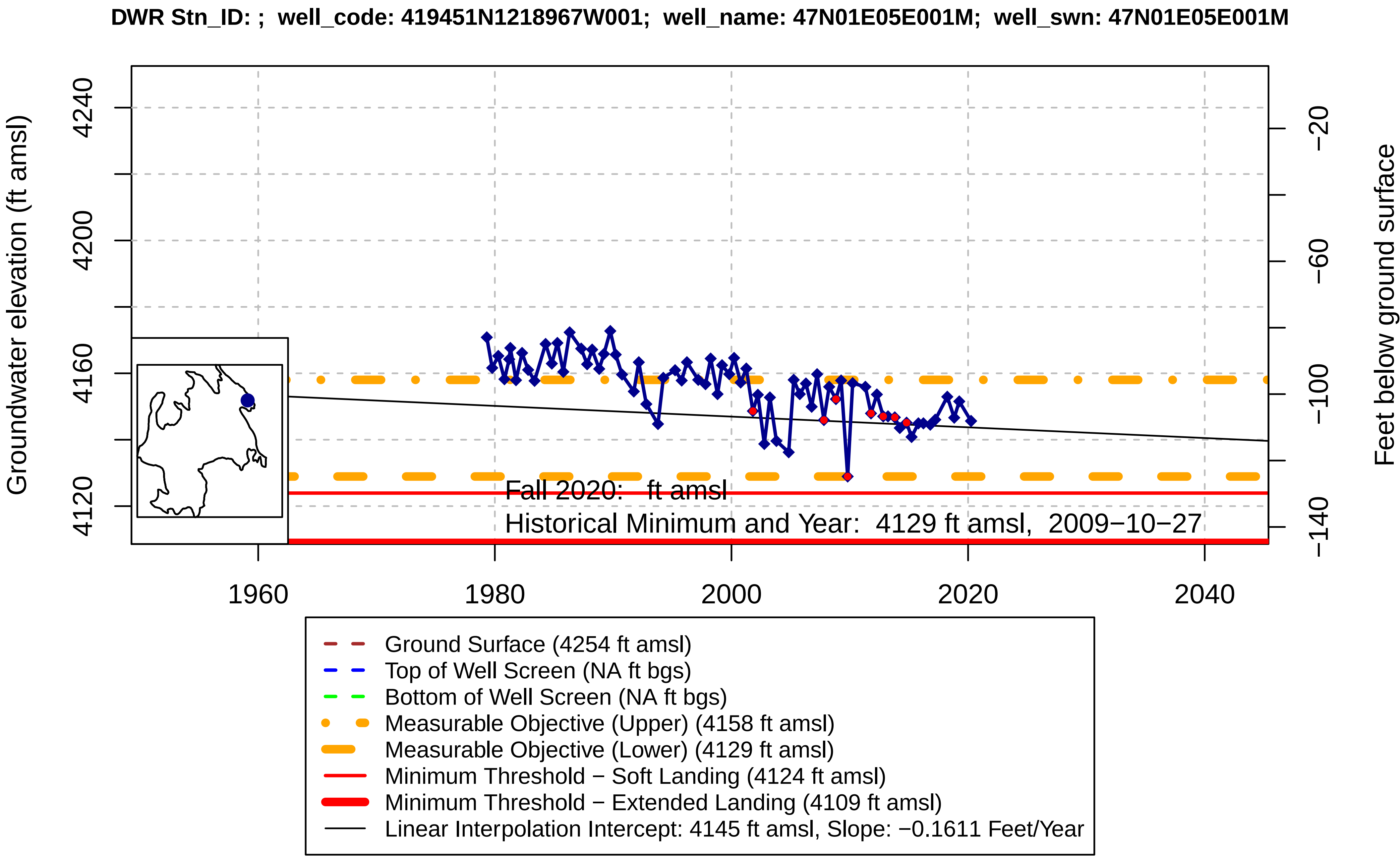


- Ground Surface (4239 ft amsl)
- Top of Well Screen (NA ft bgs)
- Bottom of Well Screen (NA ft bgs)
- Measurable Objective (Upper) (4216 ft amsl)
- Measurable Objective (Lower) (4203 ft amsl)
- Minimum Threshold − Soft Landing (4189 ft amsl)
- Minimum Threshold − Extended Landing (4174 ft amsl)
- Linear Interpolation Intercept: 4204 ft amsl, Slope: −0.7407 Feet/Year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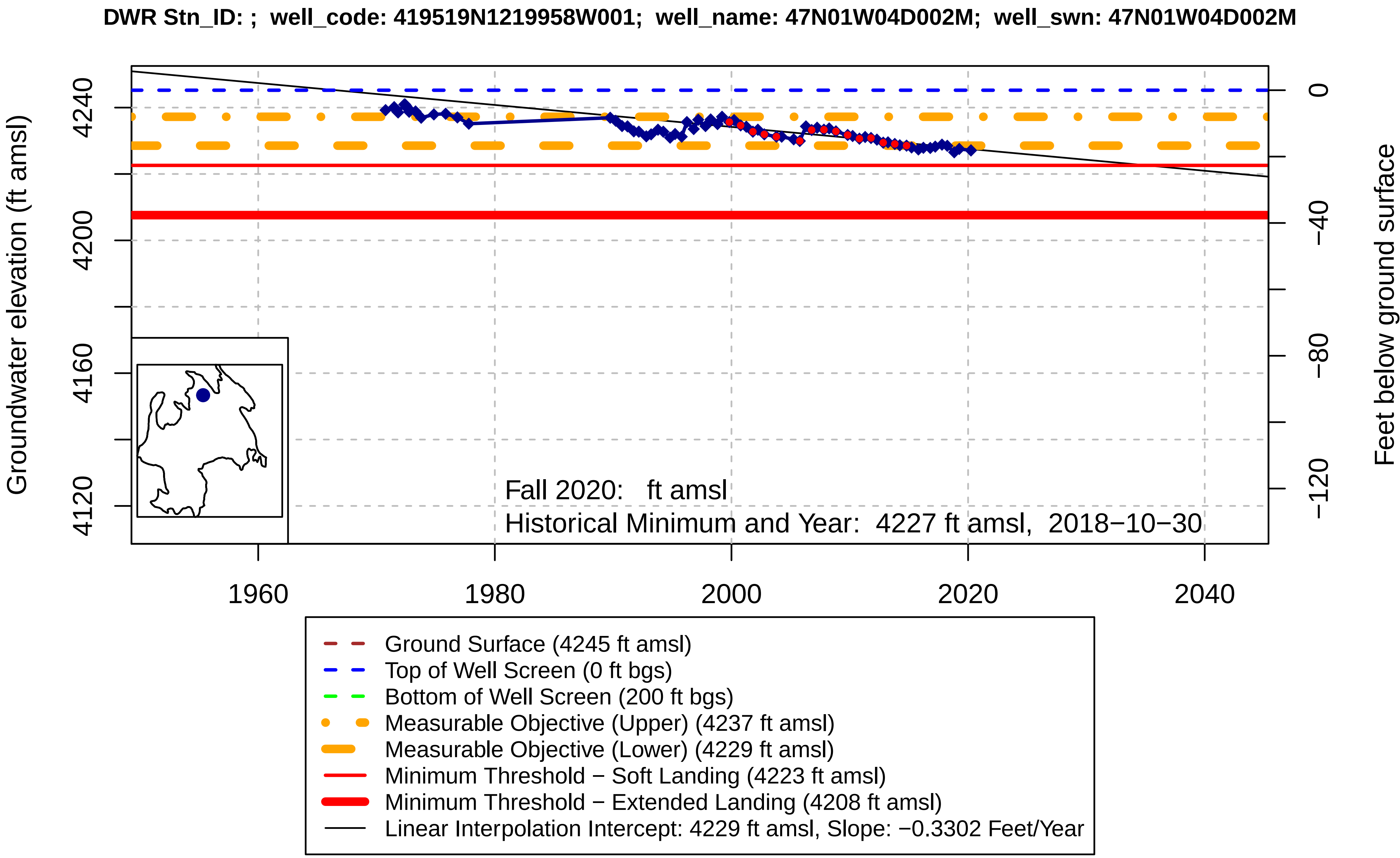
Groundwater elevation (ft amsl)
4120
4160
4200
4240
Feet below ground surface
−20
−60
−100
−140
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4129 ft amsl, 2009−10−27
Ground Surface (4254 ft amsl)
Top of Well Screen (NA ft bgs)
Bottom of Well Screen (NA ft bgs)
Measurable Objective (Upper) (4158 ft amsl)
Measurable Objective (Lower) (4129 ft amsl)
Minimum Threshold − Soft Landing (4124 ft amsl)
Minimum Threshold − Extended Landing (4109 ft amsl)
Linear Interpolation Intercept: 4145 ft amsl, Slope: −0.1611 Feet/Year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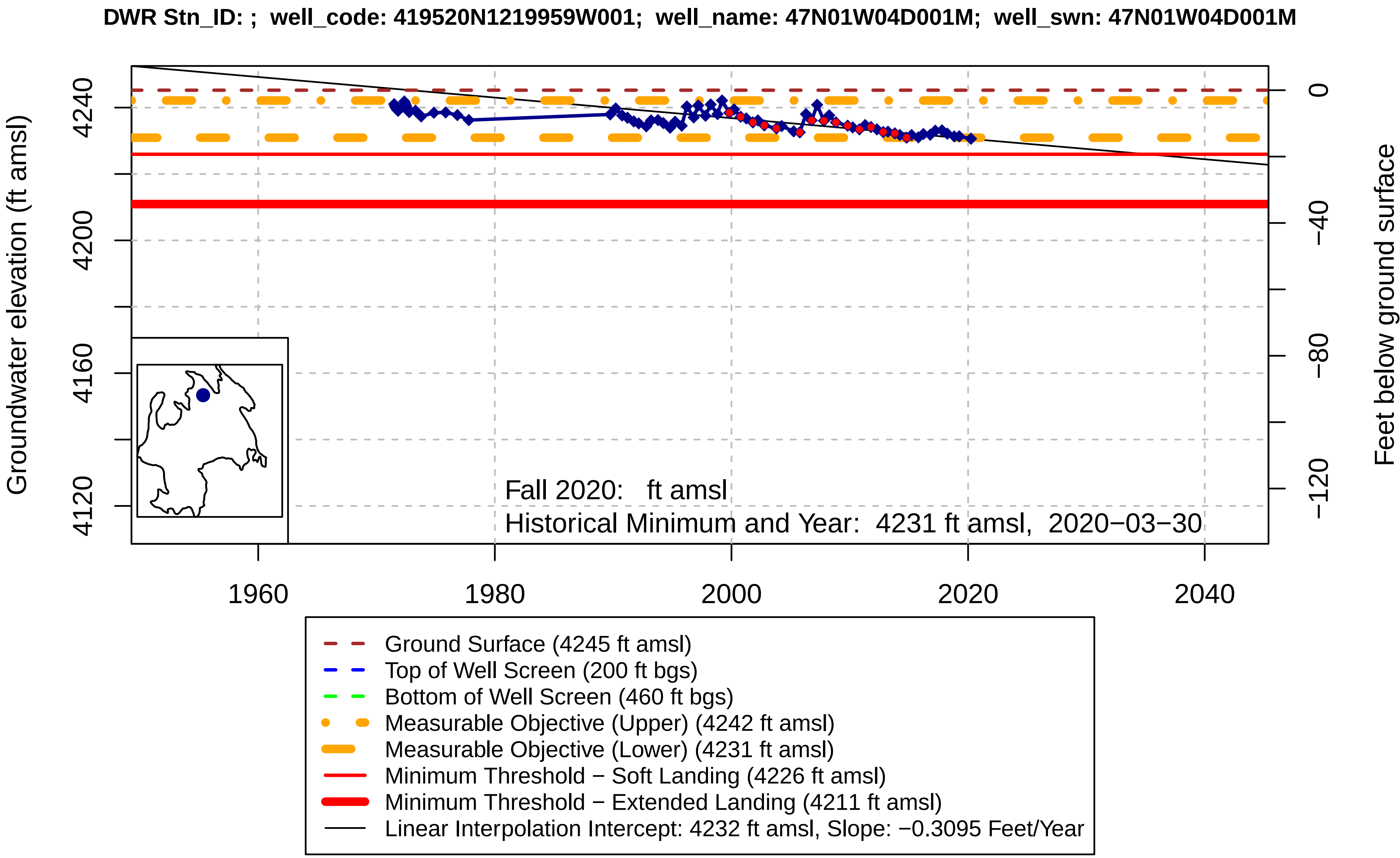
Groundwater elevation (ft amsl)
Feet below ground surface
4120
4160
4200
4240
0
−40
−80
−120
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4227 ft amsl, 2018−10−30
Ground Surface (4245 ft amsl)
Top of Well Screen (0 ft bgs)
Bottom of Well Screen (200 ft bgs)
Measurable Objective (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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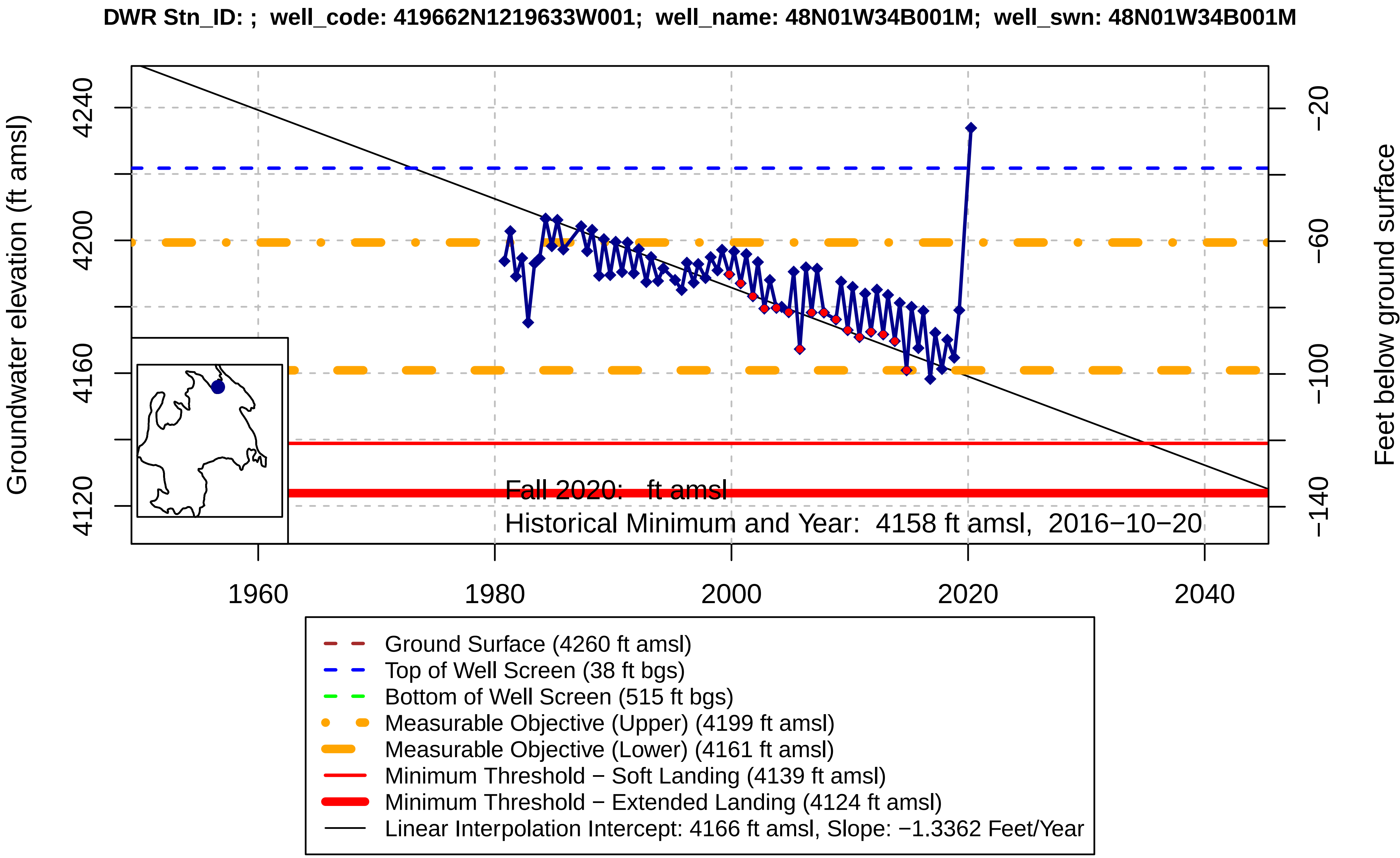
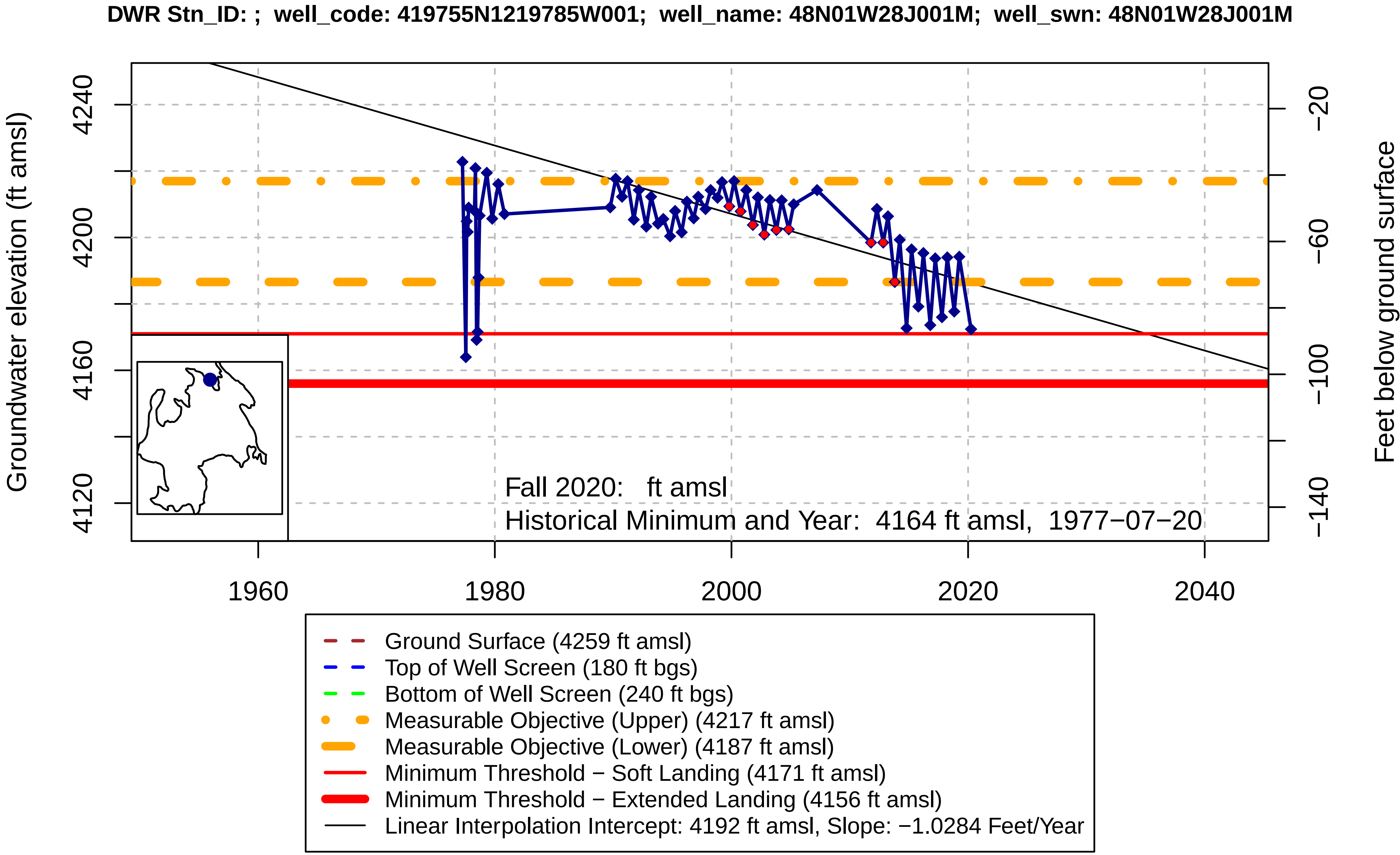
Groundwater elevation (ft amsl)
Feet below ground surface
4120
4160
4200
4240
0
−40
−80
−120
1960
1980
2000
2020
2040
Fall 2020: ft amsl
Historical Minimum and Year: 4231 ft amsl, 2020−03−30
Ground Surface (4245 ft amsl)
Top of Well Screen (200 ft bgs)
Bottom of Well Screen (460 ft bgs)
Measurable Objective (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



DWR Stn_ID: ; well_code: 419662N1219633W001; well_name: 48N01W34B001M; well_swn: 48N01W34B001M
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


DWR Stn_ID: ; well_code: 419755N1219785W001; well_name: 48N01W28J001M; well_swn: 48N01W28J001M
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: 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

Well Failure Analysis

Butte Valley Well Failure Discussion

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Dr. Thomas Harter
Larry Walker Associates & UC Davis

11/30/2021

Contents

Introduction

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

Butte Well Data Statistics

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	82
Total Depth Only	LWA GWO	7
Observations Only	Volunteer Monitoring	24
Observations Only	DWR	9
Observations Only	LWA GWO	10
Perforation Only	–	0
Observations and Depth	DWR	17
Observations and Depth	LWA GWO	23
Depth, Obs. and Perf.	DWR	23
Depth, Obs. and Perf.	LWA GWO	26
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

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 Construction Information

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 400ft. 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 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 upt 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. 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.

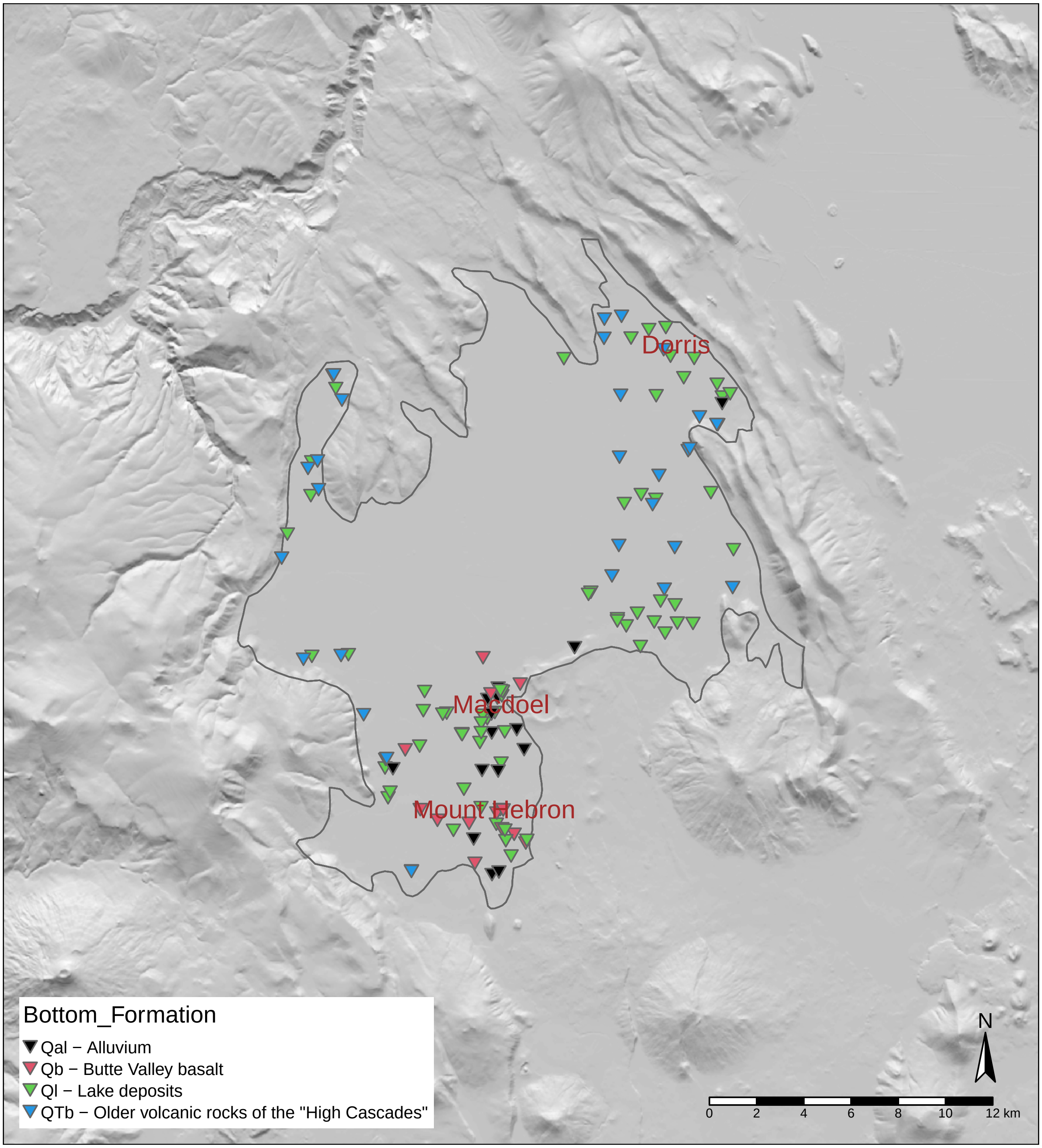

Figure 1: Butte Valley well map of domestic, public supply, and agricultural wells colored by major formation with locations of water wells are given as colored triangles.

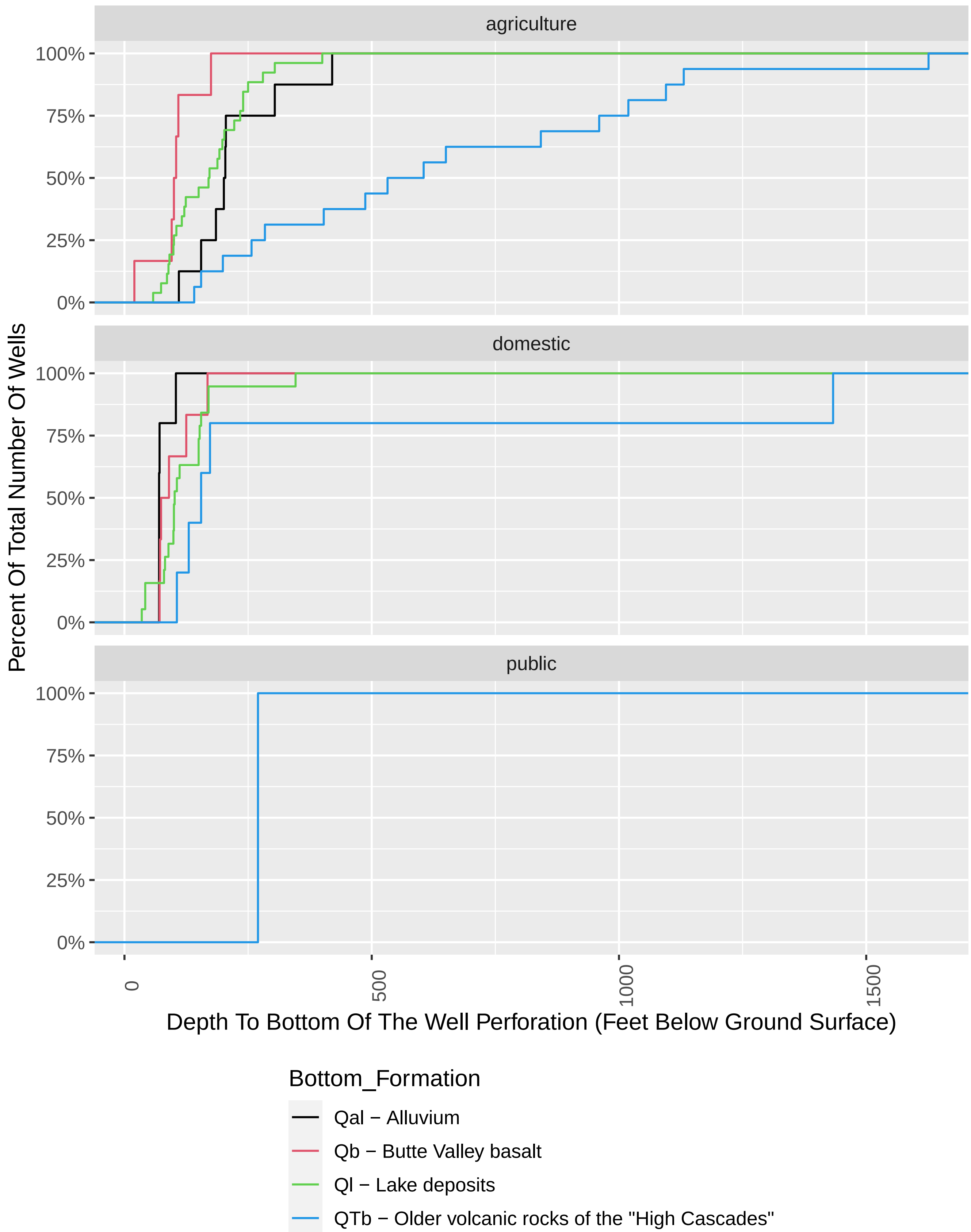

Figure 2: Butte Valley well perforation bottom. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.

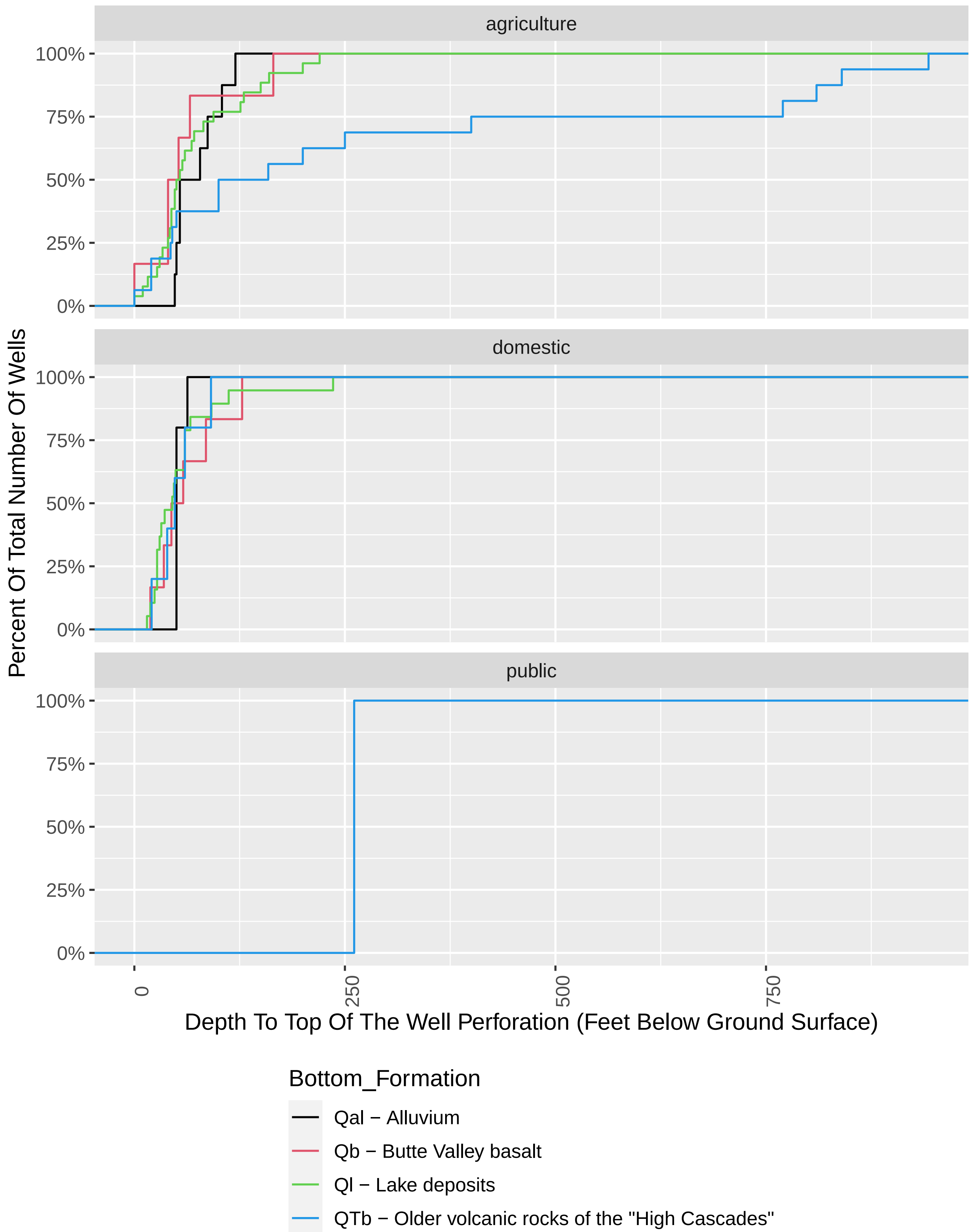

Figure 3: Butte Valley well perforation top. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.

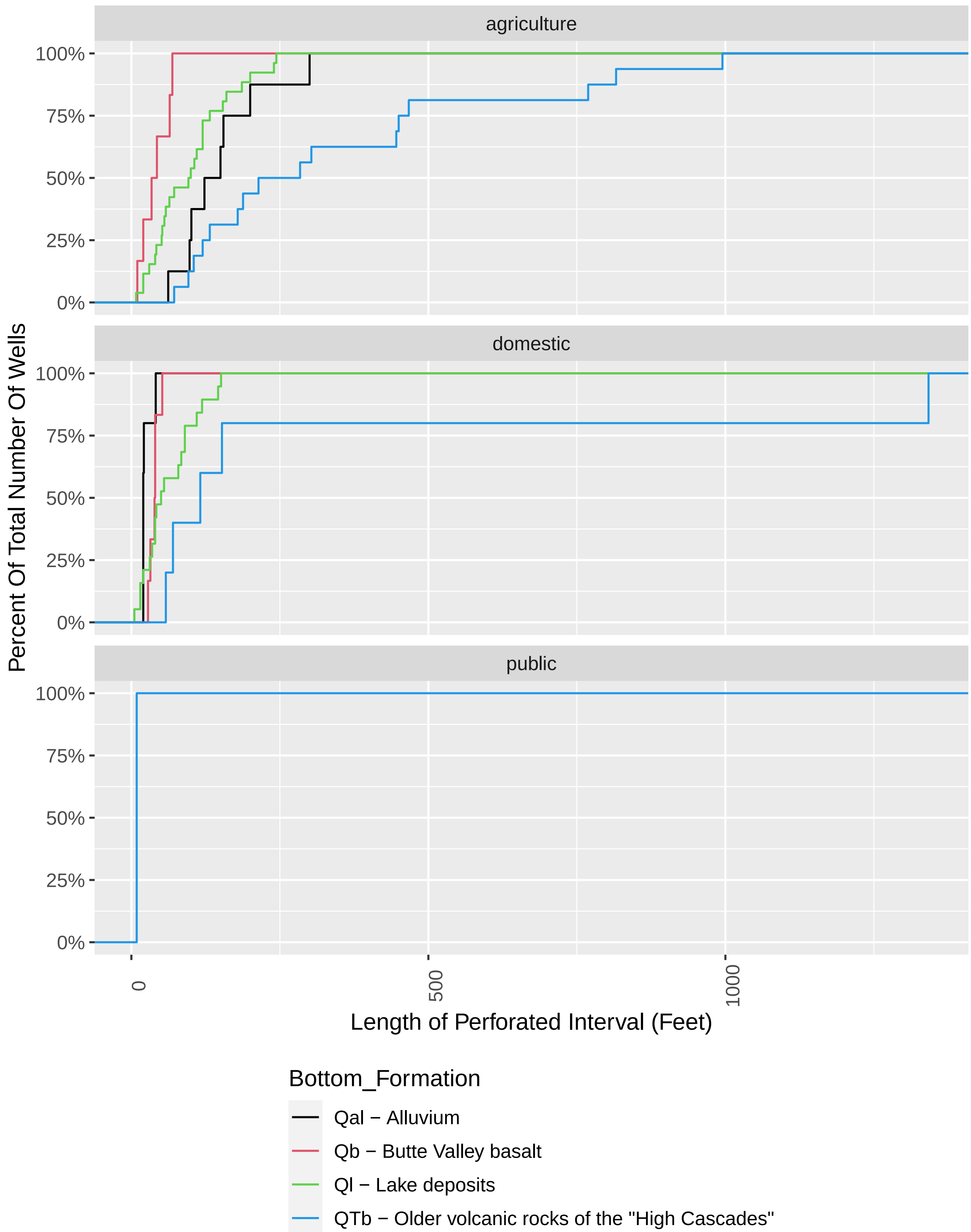

Figure 4: Butte Valley well perforation length. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.

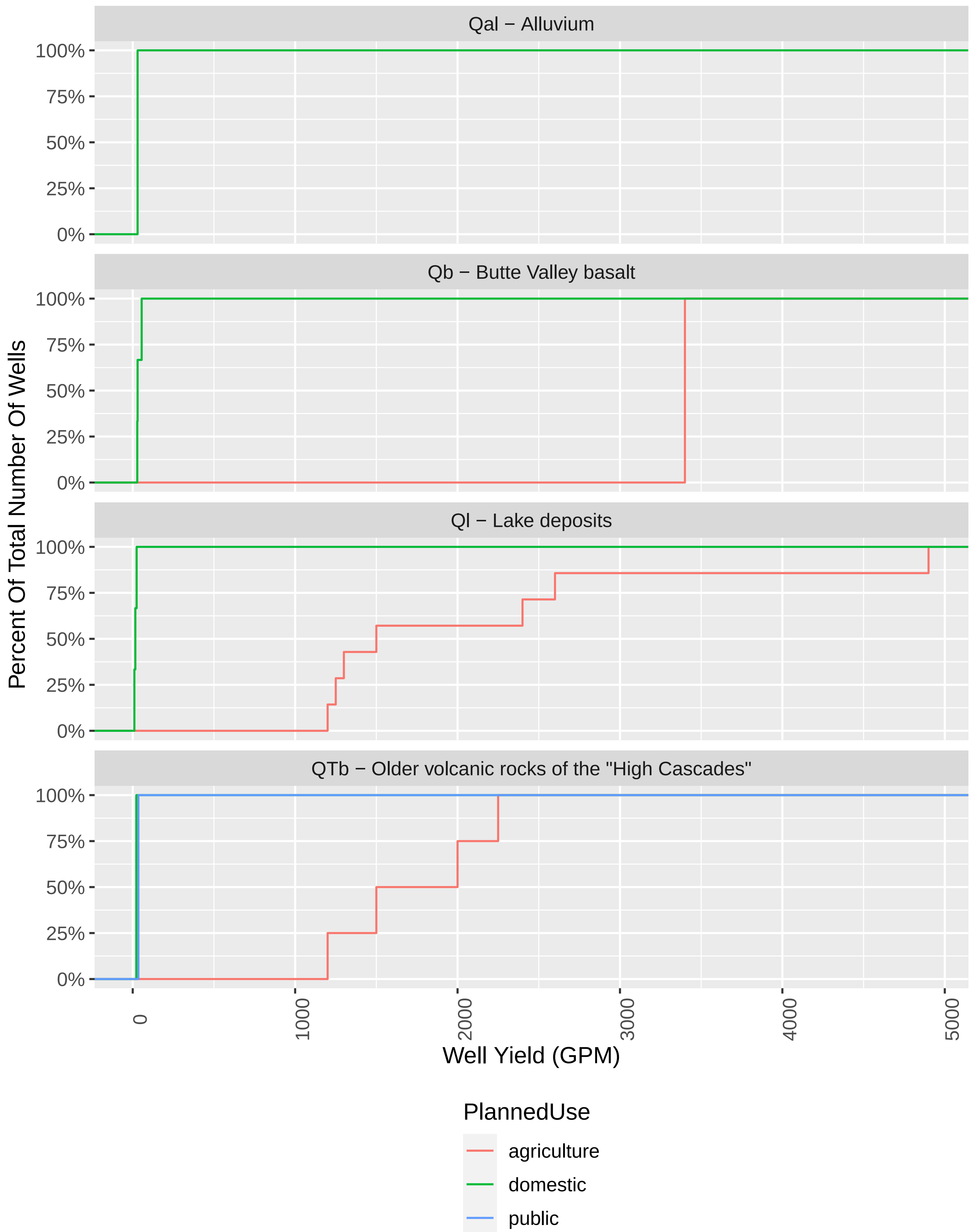

Figure 5: Butte Valley well yield by formation at the bottom of the well comparing major well types

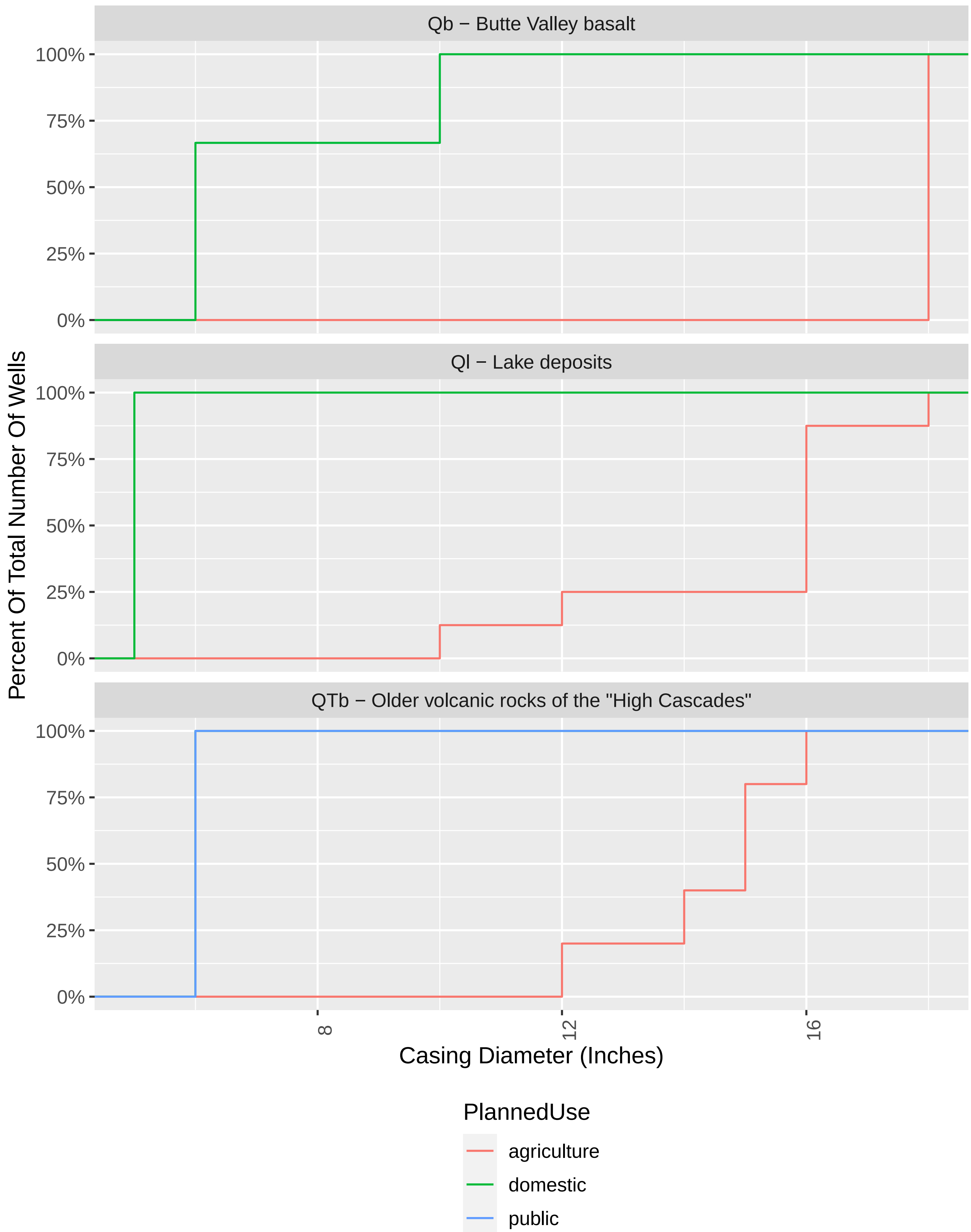

Figure 6: Butte Valley well casing diameter by formation at the bottom of the well comparing major well types

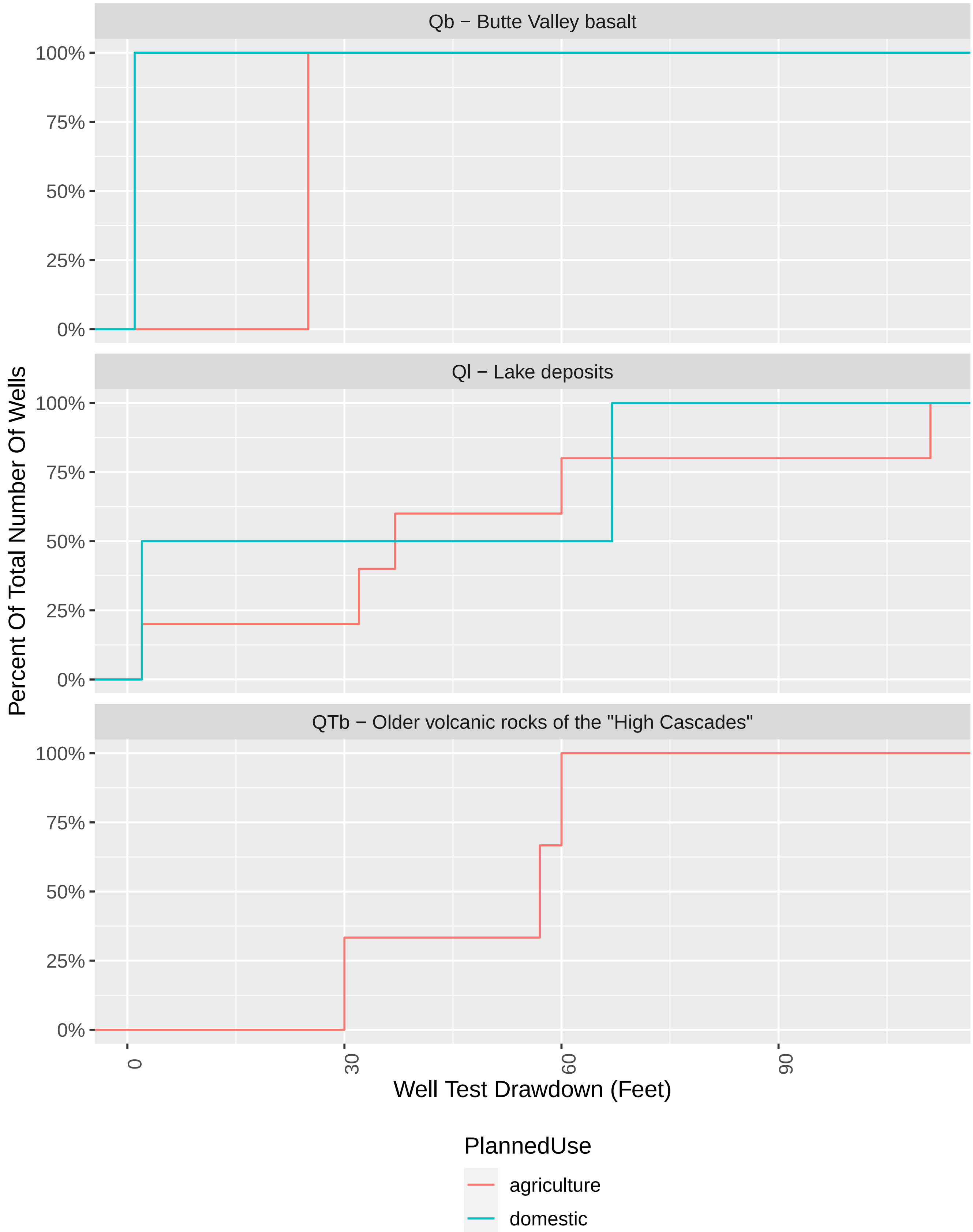

Figure 7: Butte Valley well test drawdown by formation at the bottom of the well comparing major well types

Estimated Wet Depth to Top of Perforations

The interpolated, contoured water table depth in fall of 2015 is shown in 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 4% to 17% (in x-axis direction) per 10 feet (in y-axis direction), for the range of wet depth to top of perforations from -30 feet to 30 feet. 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) in the Lake Deposits (Ql) formation, 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 2% - 31% 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. Figure 15 shows potential well outages in the Alluvium (Qal) formation, the most sensitive to well outages in our analysis.

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 depth to water level at the minimum threshold is defined as 110% of the deepest depth to water level observed, but never more than 10 ft below the deepest observed water level. In most areas of the groundwater basin, the deepest depth to the water level observed over time is less than 100 feet (see above), hence the minimum threshold in most areas would allow 3 to 8 feet, at most 10 feet of additional lowering of water levels. Given that a 10 foot decline puts about 3% to 8% of Butte Valley wells at risk of well outage, the selection of the minimum threshold poses some risk of at least temporary well outage: about 30-80 wells out of approximately 1,000 wells would be at risk of well outage if water levels lowered to the minimum threshold everywhere in Butte Valley.

The well outage risk may be unevenly distributed across Butte Valley (Figures 13, 14, 15, and 16): The slopes indicate a lower risk (2%-4%) for wells in the Older Volcanic Rocks of the High Cascade Volcanics, but higher risks elsewhere (up to 31%).

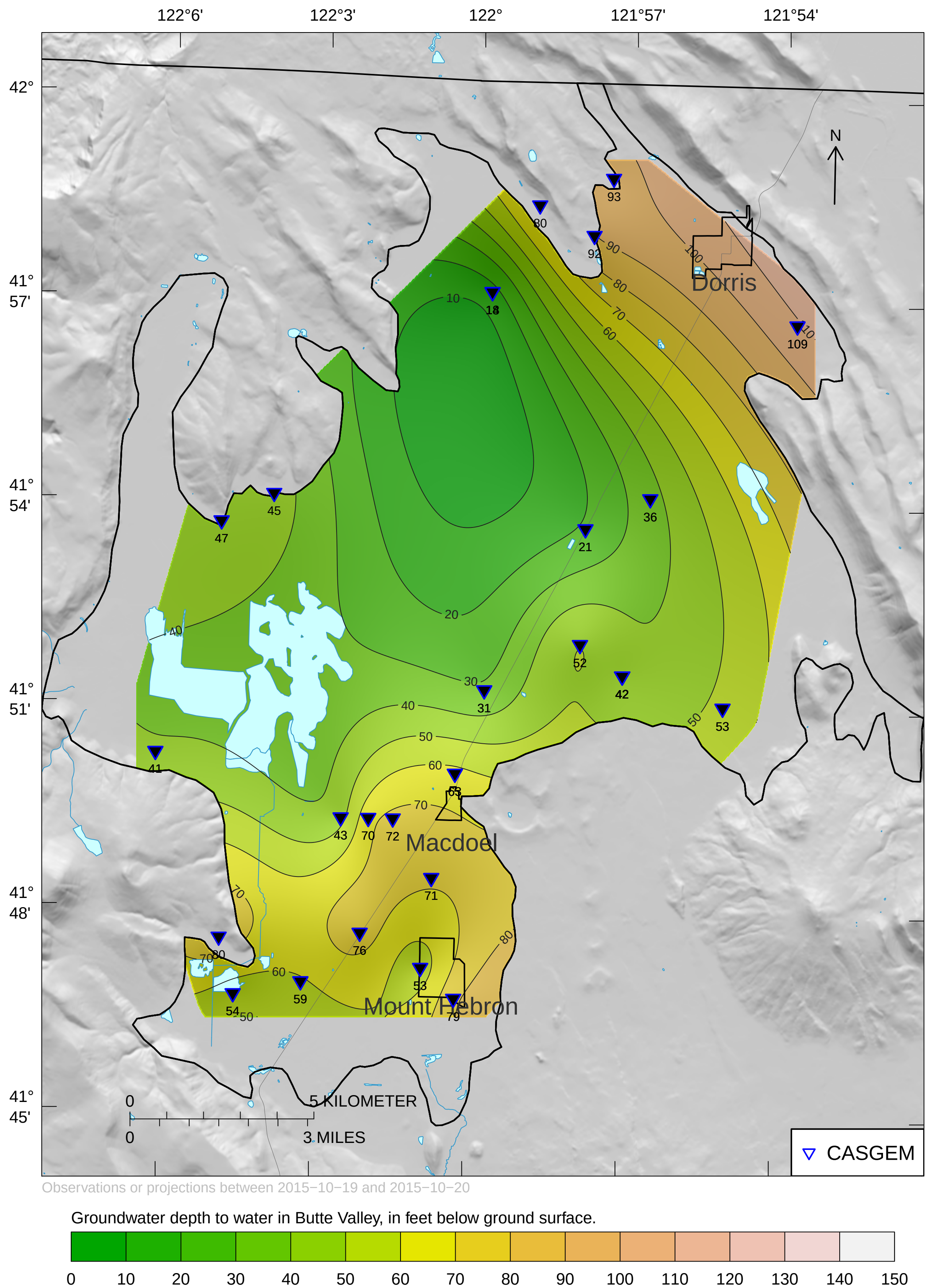

Figure 8: Butte Valley groundwater elevations reported as approximate depth to groundwater, fall 2015 and well failure estimates based on recent water level observations. Approximate basin-scale groundwater depths are shown.

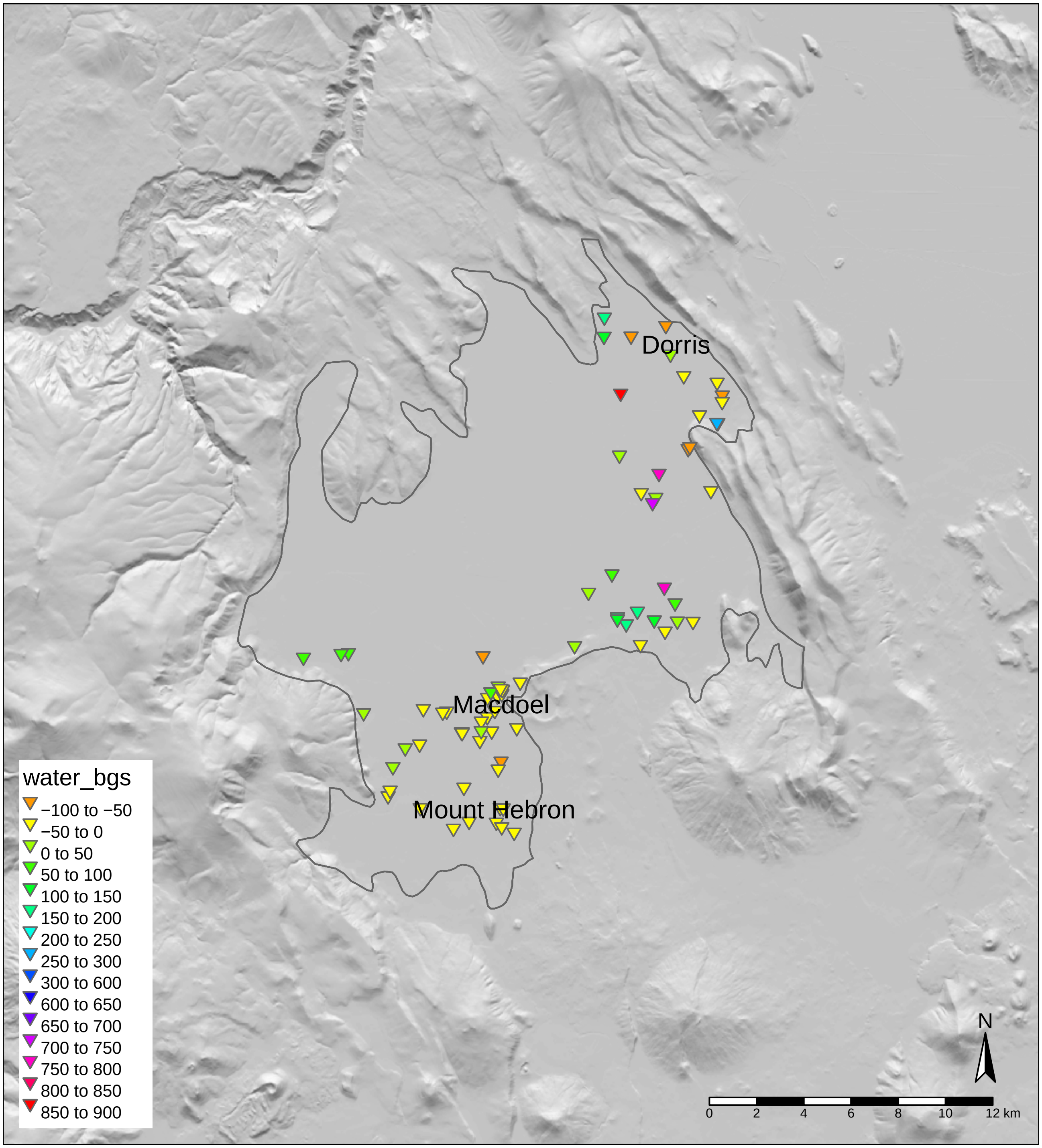

Figure 9: Butte Valley wet depth to top of perforations based on contoured groundwater elevations, October 2015.

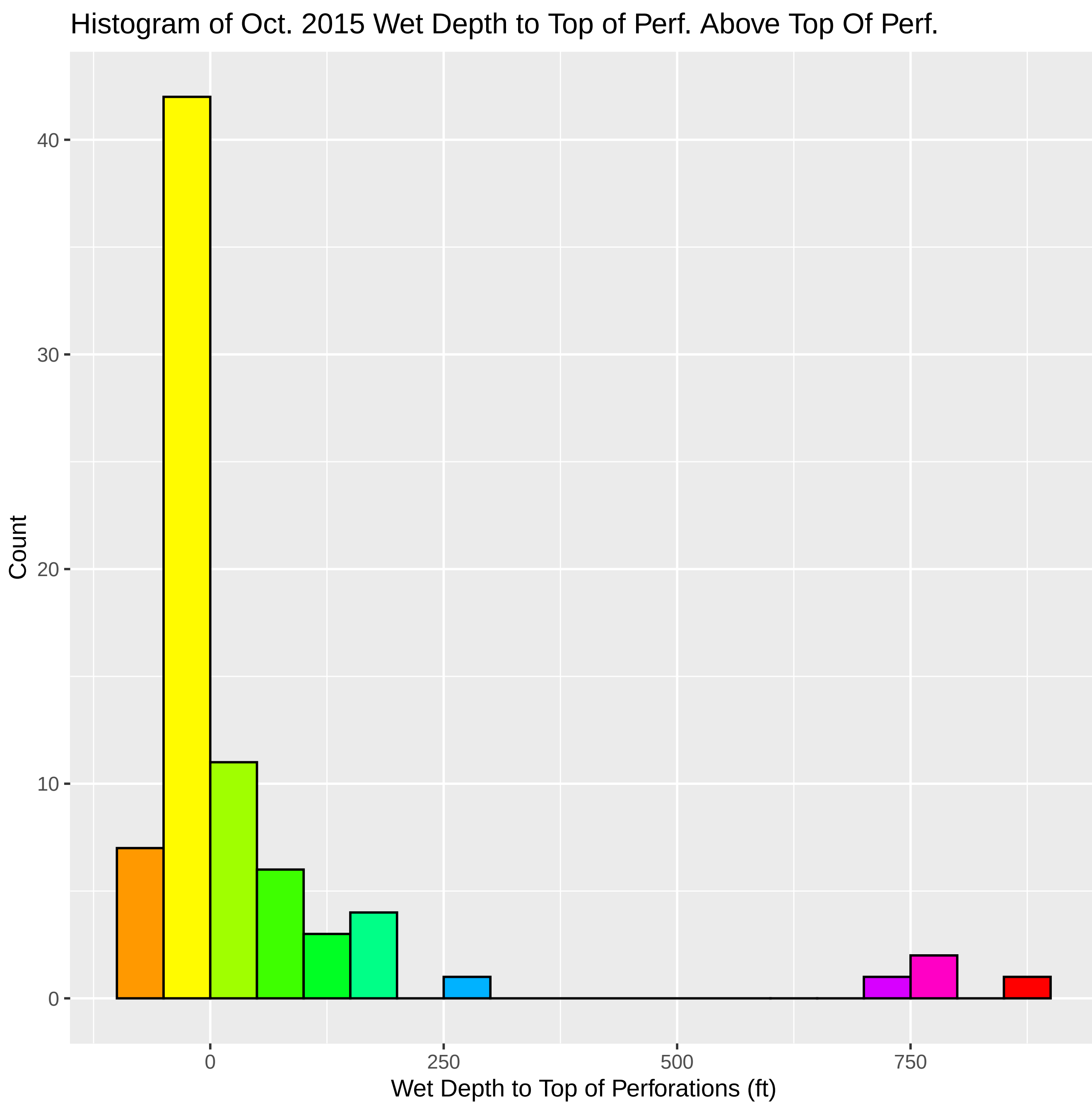

Figure 10: Histogram of wet depth to top of perforations based on contoured groundwater elevations, October 2015.

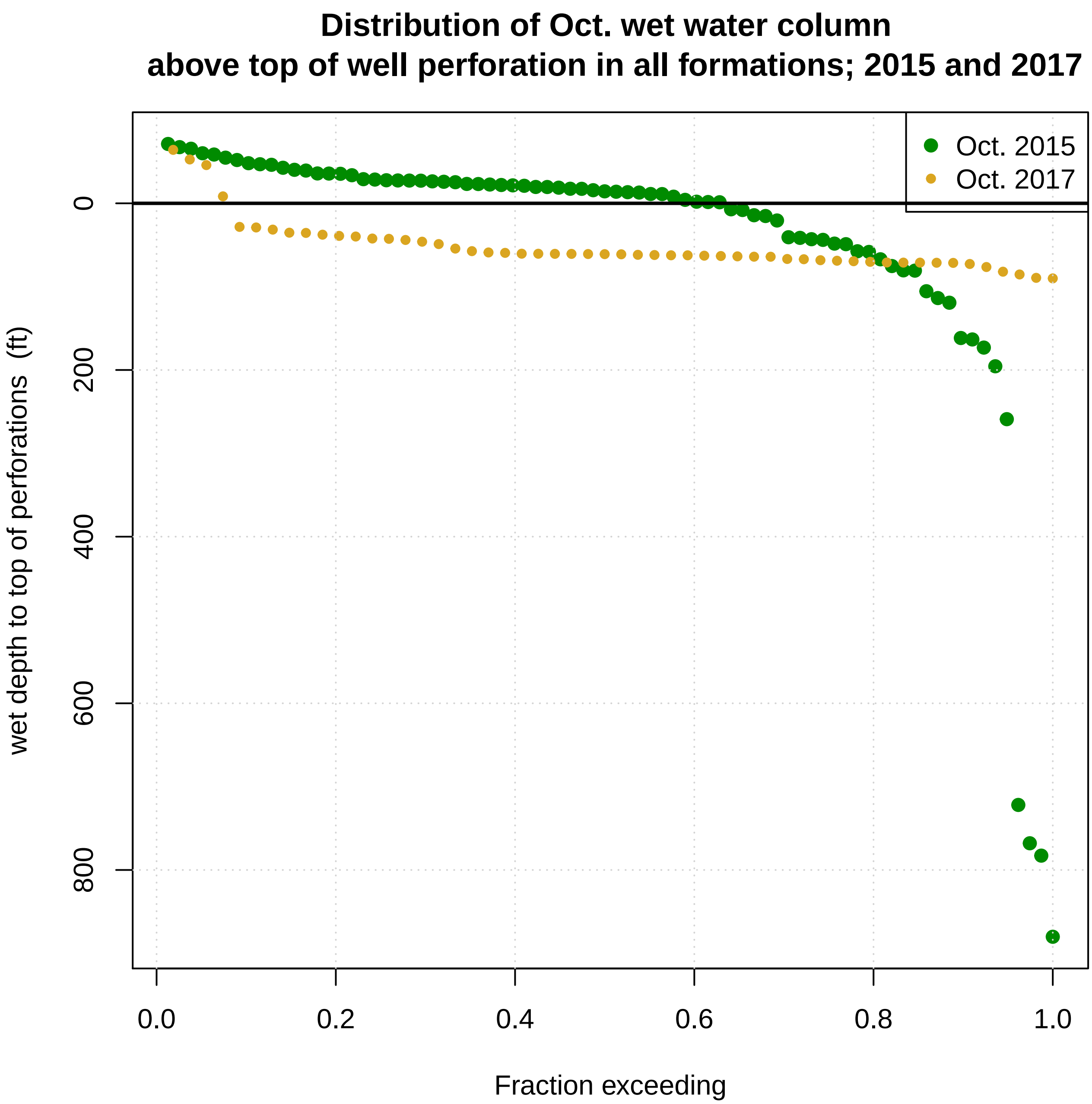

Figure 11: Cumulative distribution function of all well wet depth to top of perforations based on contoured groundwater elevations, Octobers of 2015 and 2017.

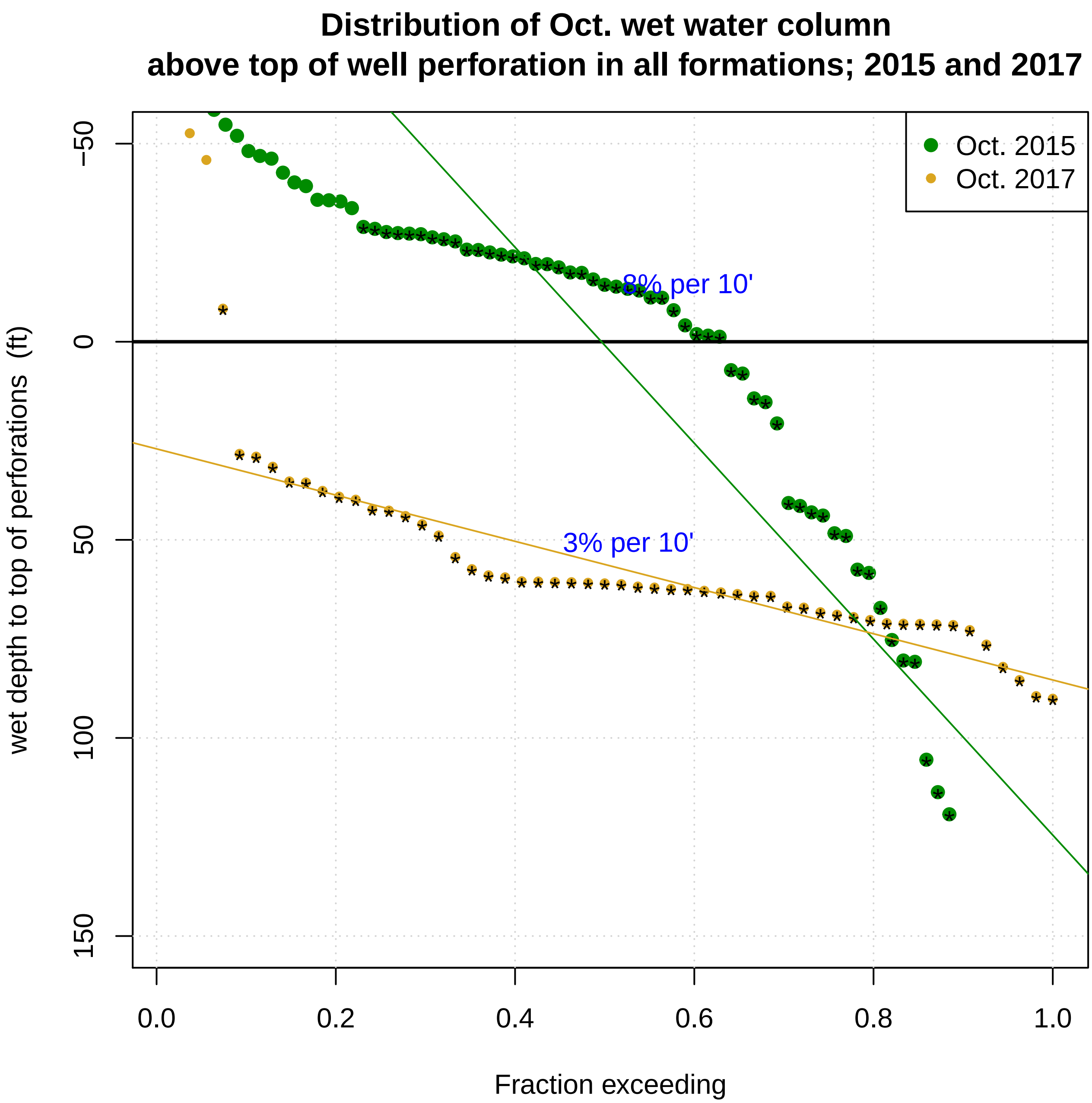

Figure 12: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well 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).

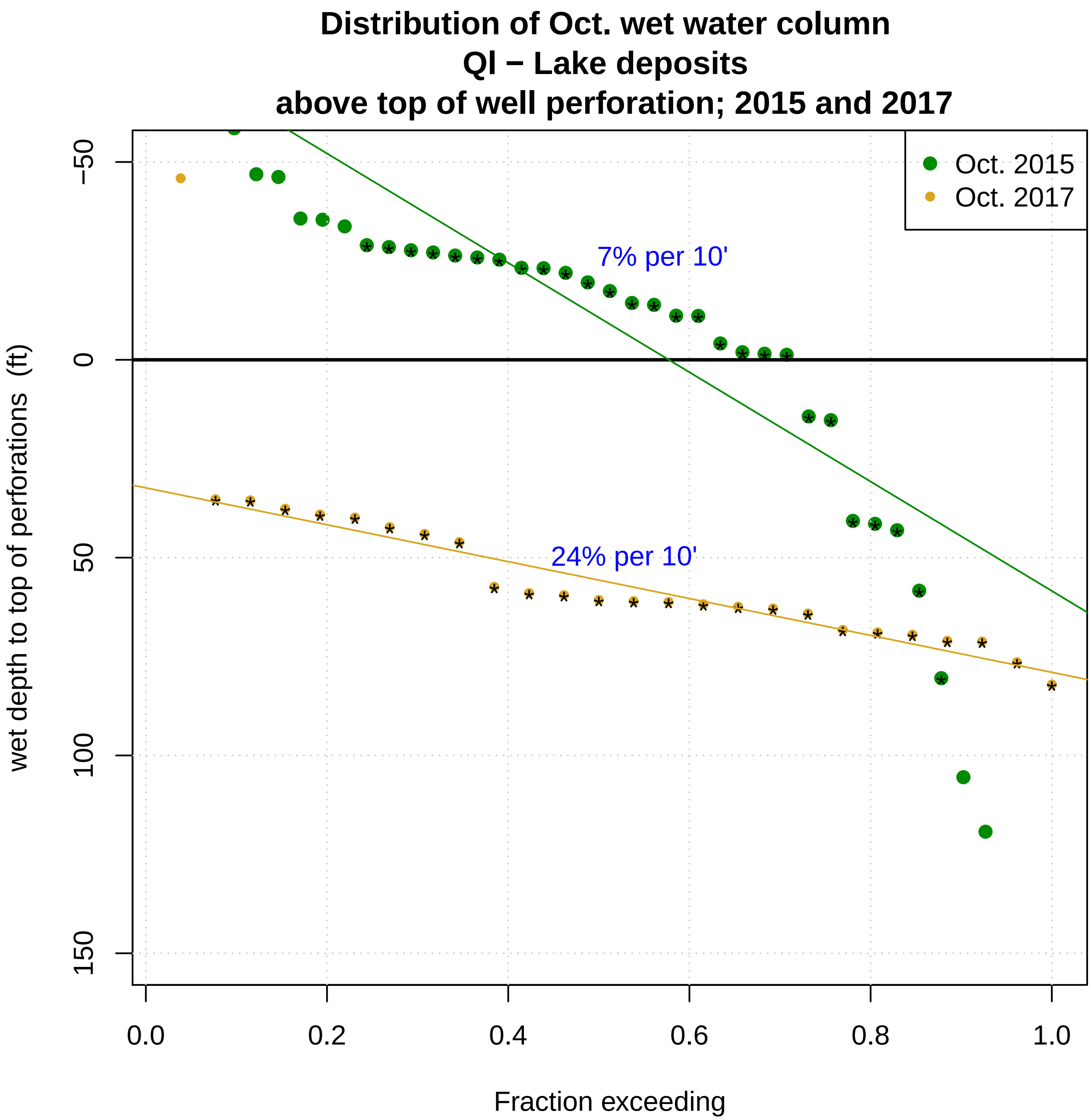

Figure 13: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 100 feet used for interpolating the well 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).

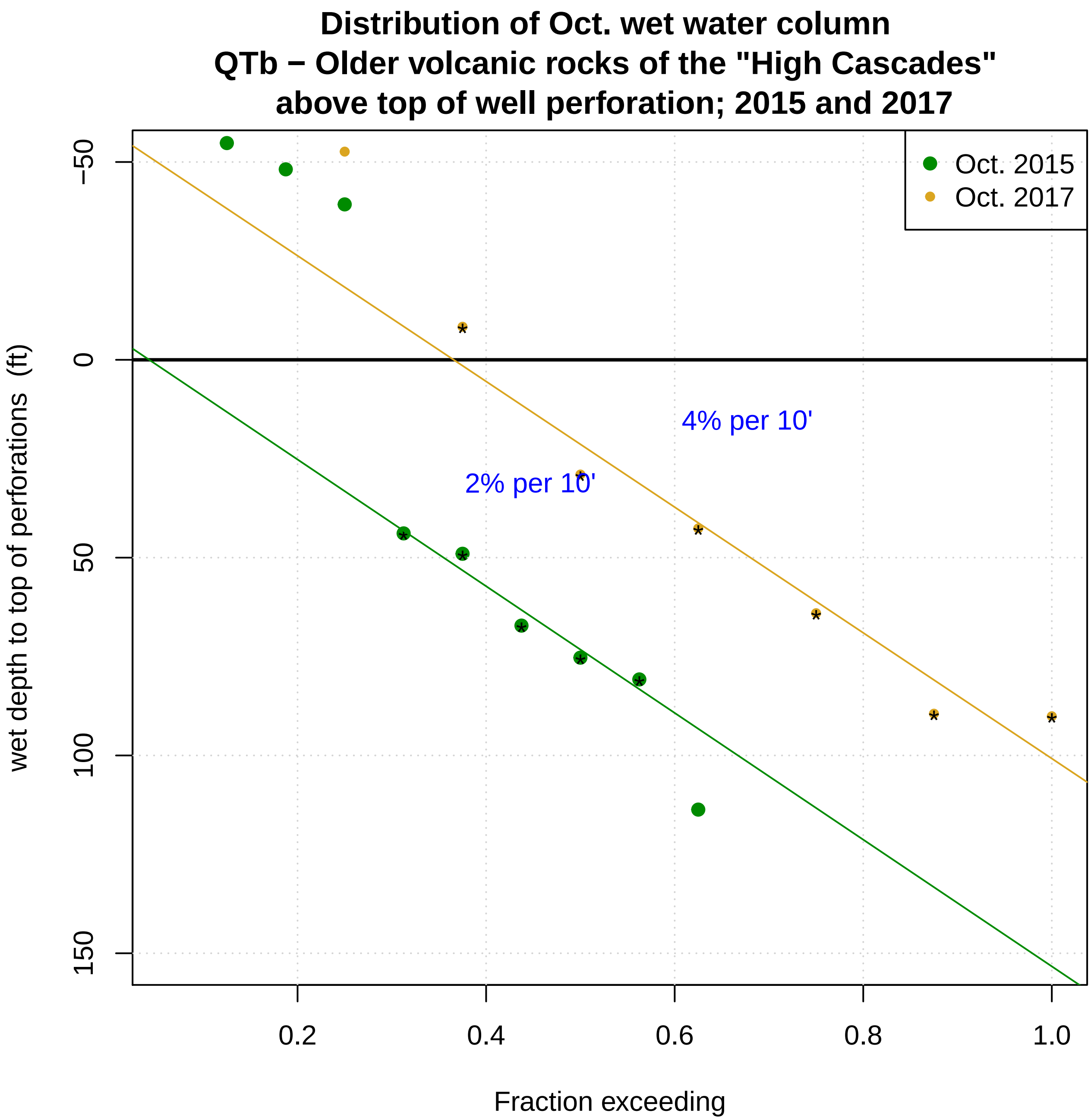

Figure 14: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 100 feet used for interpolating the well 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).

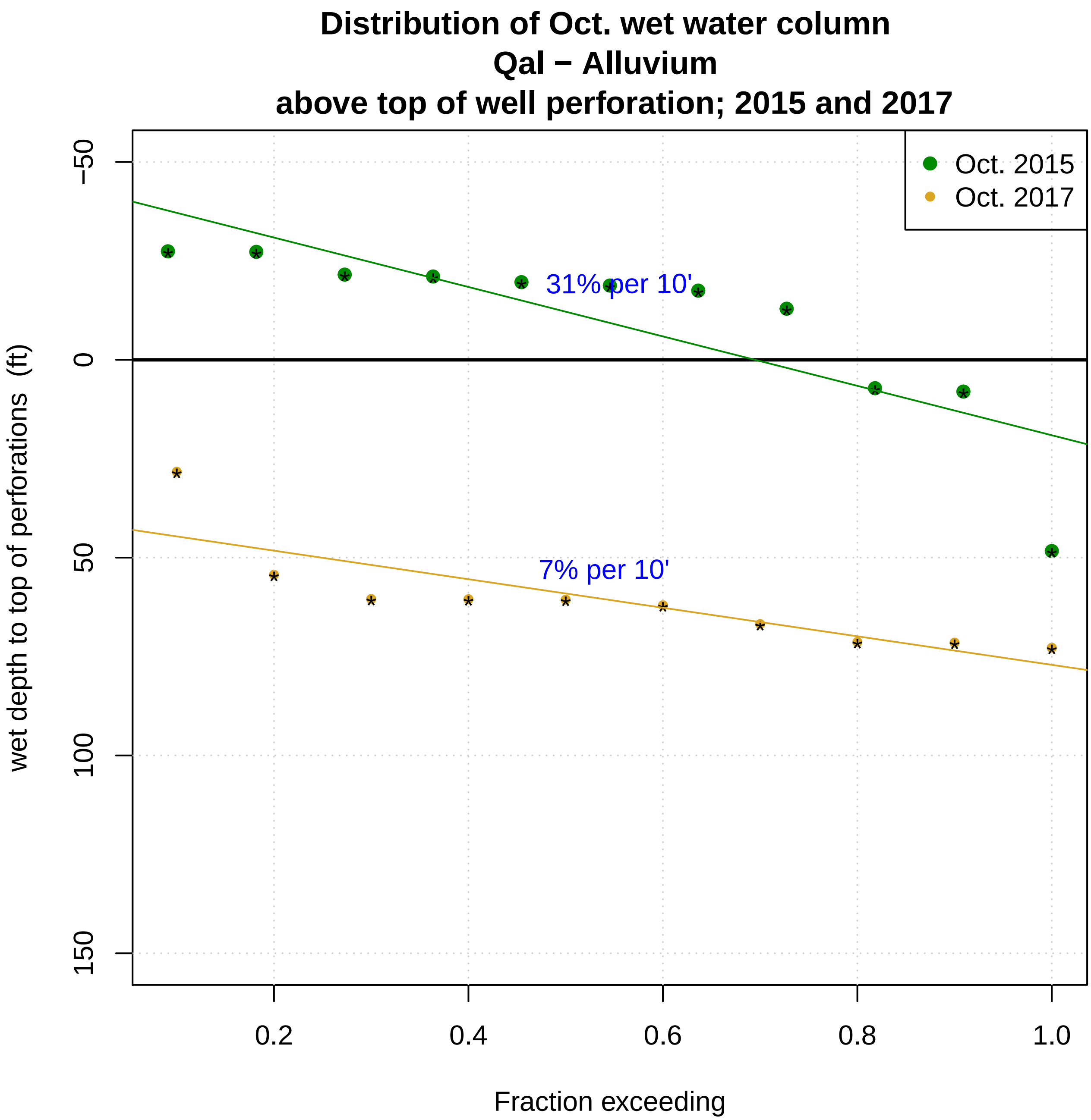

Figure 15: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 100 feet used for interpolating the well 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).

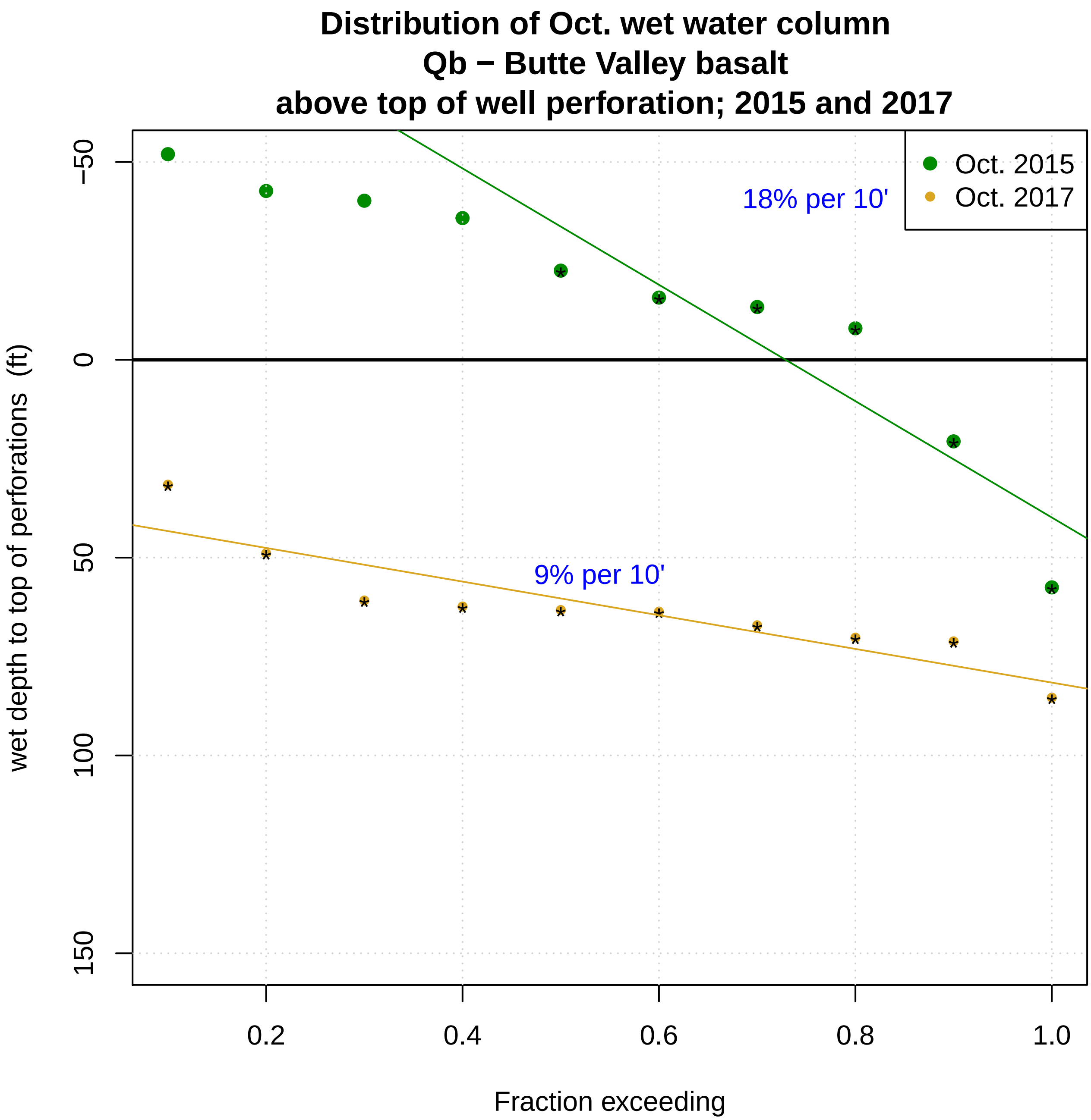

Figure 16: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well 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:

Majority of wells 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 analysis quality. 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 is probably very small. The minimum threshold is 10% lower than the minimum measured depth to the water table (see Chapter 3). In most Butte Valley areas, where depth to the water table is less than 70 feet, water levels at the minimum threshold would be less than 7 feet lower than at their historic low. A small number of wells would be affected by that, as shown in Figure 12. Considering Table 6 Chapter 3, the minimum threshold is at most 10 ft below the historically deepest measured water level. This much lowering to the MT would occur only in wells that already have a depth to water of 100 feet or more. Based on Figure 12, a ten foot lowering of the water level would affect about 3%-8% of wells (30 - 80 wells), if such low water level conditions occurred throughout the Butte Valley.