Shasta Valley Well Failure Discussion

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

11/30/2021

Contents

Introduction **1**

Methods **2**
Shasta Well Data Statistics 2
Well Outage Risk Analysis 3

Results and Discussion **3**
Well Construction Information 4
Estimated Wet Depth to Top of Perforations 13

Conclusion **25**

Introduction

This analysis seeks to determine the number of wells that may be dewatered due to declining groundwater levels. In the Shasta 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 Shasta 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 reconnaisance.

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

Shasta Well Data Statistics

A total of 1148 well logs were analyzed in the Shasta 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 Volcanic Rocks of Shasta Valley (Qvs), Western Cascade Volcanics (Tv), Pleistocene Volcanic Rocks (Qv), Alluvium (Q), Duzel Formation (SOd), with 416, 166, 166, 144, and 79 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, 943 wells out of 1148, or 86% of the available wells, belong to one of the major formations. 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 Shasta Valley wells.

Depth, Obs., Perf. Available?	Well Info Source	No. of Wells
None (location only)	LWA GWO	1
Total Depth Only	LWA GWO	1
Observations Only	DWR	8
Observations Only	LWA GWO	8
Perforation Only	–	0
Observations and Depth	DWR	17
Observations and Depth	LWA GWO	7
Depth, Obs. and Perf.	DWR	13
Depth, Obs. and Perf.	–	0

Table 2: Wells used in Shasta Valley Well Outage Analysis

Bottom Formation	Top of Perforation (Depth in Feet)
Q- Alluvium	166
Qv- Pleistocene Volcanic rocks	144
Qvs- Volcanic rocks of Shasta Valley	416
SOd- Duzel Formation	79
Tv- Western Cascade Volcanics	166

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 Shasta Valley groundwater basin and one-half mile represents the maximum distance of the actual well location from the reported well location. Some areas within the Shasta Valley basin have steeper slopes. There, estimated well elevations may be even less accurate. Clearly, 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 Shasta 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 Shasta 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 Shasta 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 elvation 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 in the Western Cascade Volcanics (Tv) have deeper bottom of perforated intervals relative to other major Shasta Valley domestic well supplying formations. Domestic well top of screens for wells in the Duzel Formation (SOd) are mostly shallower, however some deep screens also exist. The Western Cascade Volcanics (Tv) well screen tops are overall slightly deeper as shown in Figure 3. Domestic, agricultural, and public wells in the Duzel Formation (SOd) all appear to have longer screen lengths than other formations (Figure 4). Geologic Formation plays an important role in determining the top of well screen for domestic and agricultural wells (Figure 8). Relatively shallow top of screen occur among agricultural wells in the Volcanic Rocks of Shasta Valley (Qvs). Some relatively deep domestic wells are present in the Duzel Formation (SOd) and Western Cascade Volcanics (Tv).

Based on pumping test data provided on Well Completion Reports submitted to the Department of Water Resources, agricultural wells in the Pleistocene Volcanic Rocks (Qv) and Volcanic Rocks of Shasta Valley (Qvs) house a greater proportion of higher production wells as shown in Figure 5. In the case of the Pleistocene Volcanic Rocks (Qv) this could be due to a higher proportion of large diameter wells however the distribution of well diameter sizes appear similar among the Alluvium (Q), Volcanic Rocks of Shasta Valley (Qvs), Duzel Formation (SOd), and the Western Cascade Volcanics (Tv) (Figure 6). During pump testing the Pleistocene Volcanic Rocks (Qv) also exhibited lower drawdown than other formations while the Western Cascade Volcanics (Tv) and the Duzel Formation (SOd) both exhibited a relatively high number of large drawdowns during pumping as shwon in Figure 7.

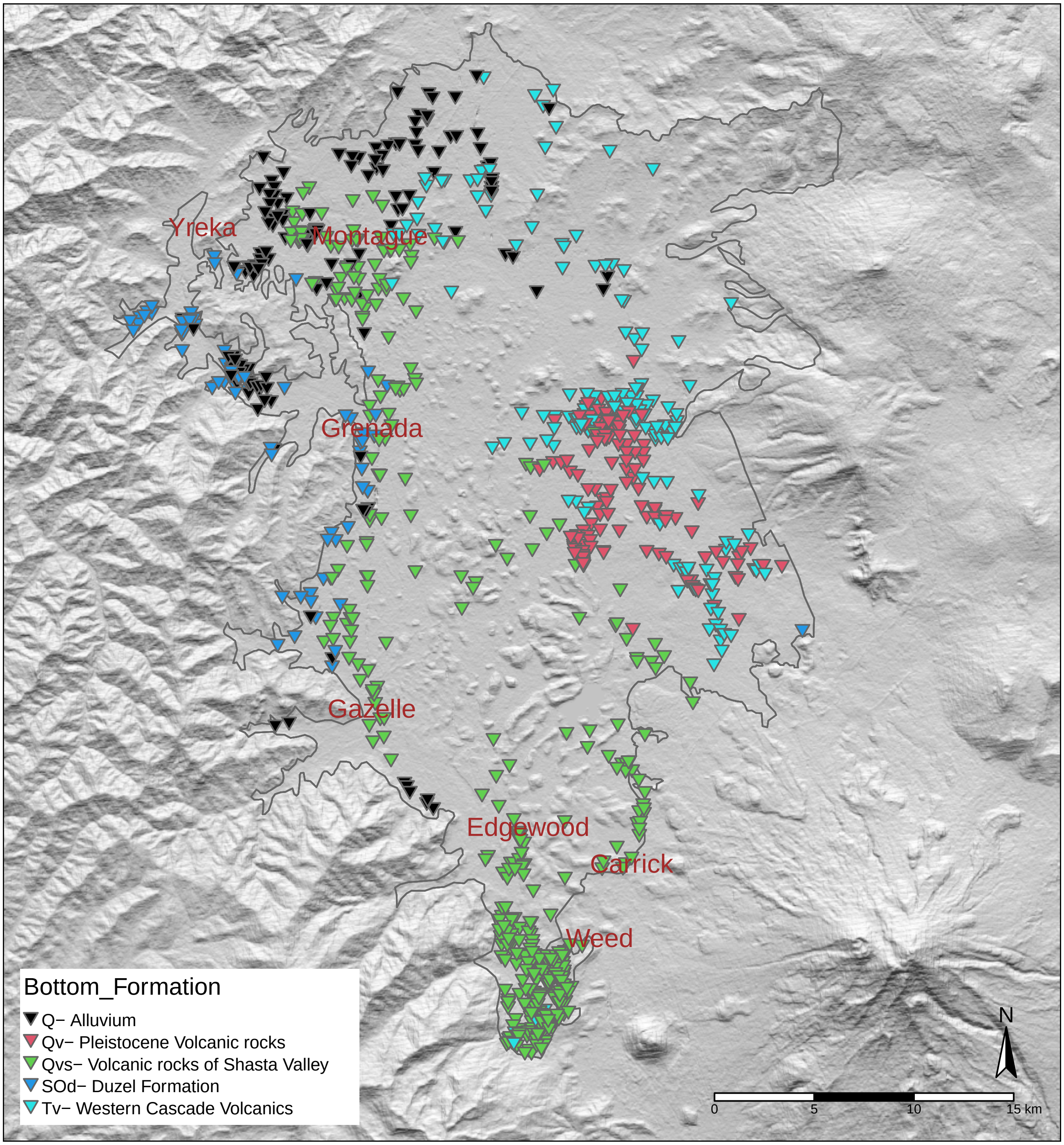

Figure 1: Shasta Valley well map of domestic, public supply, and agricultural wells colored by major formation with locations of water wells are given as colored triangles.

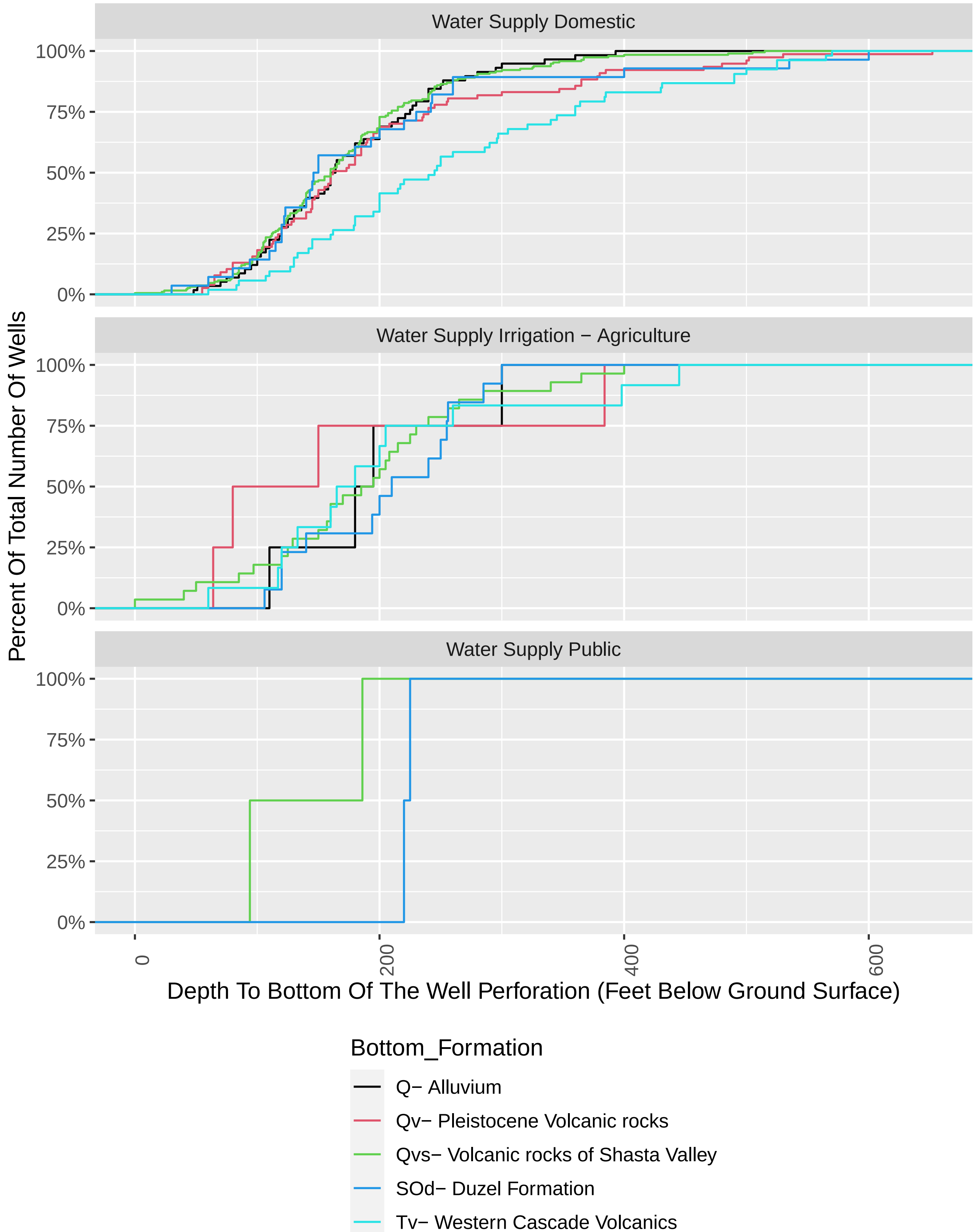

Figure 2: Shasta Valley well perforation bottom. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations. Note that agricultural wells in the Pleistocene Volcanic Rocks have shallower bottom of screens and domestic wells in the Western Cascade Volcanics have deeper bottom of screens.

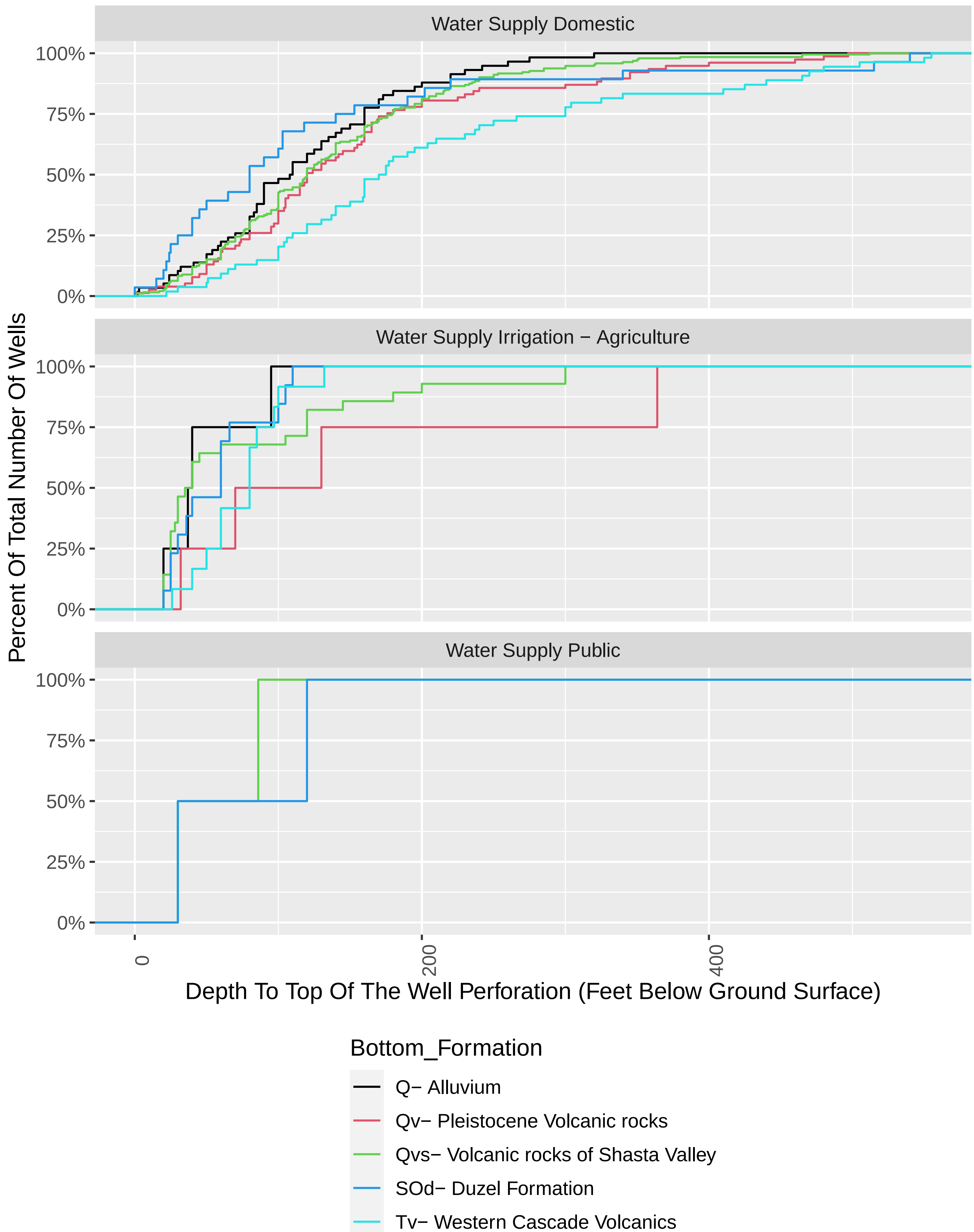

Figure 3: Shasta Valley well perforation top. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.

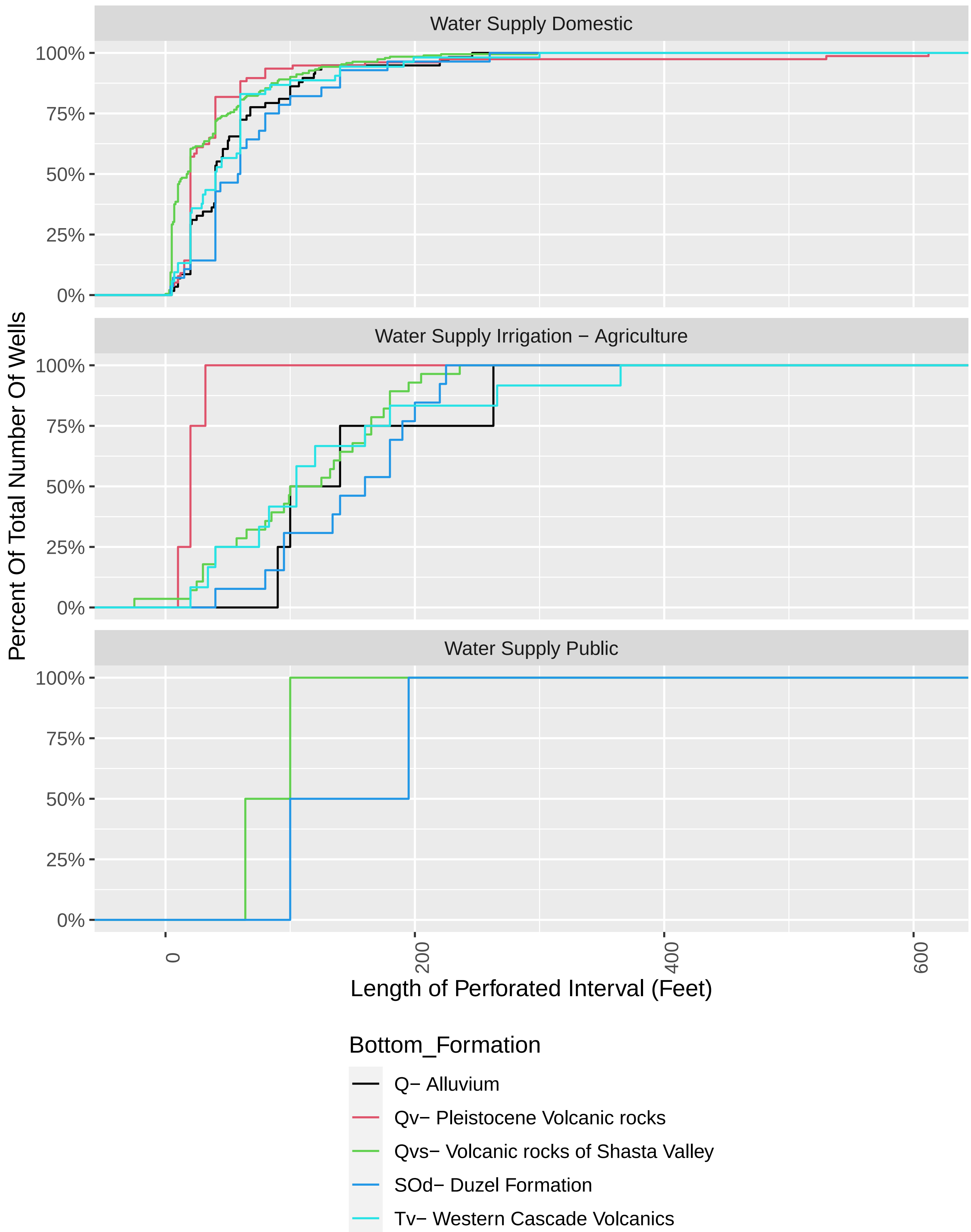

Figure 4: Shasta Valley well perforation length. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations. Irrigation wells in the Pleistocene Volcanic Rocks have an extremely small range of values and are typically short.

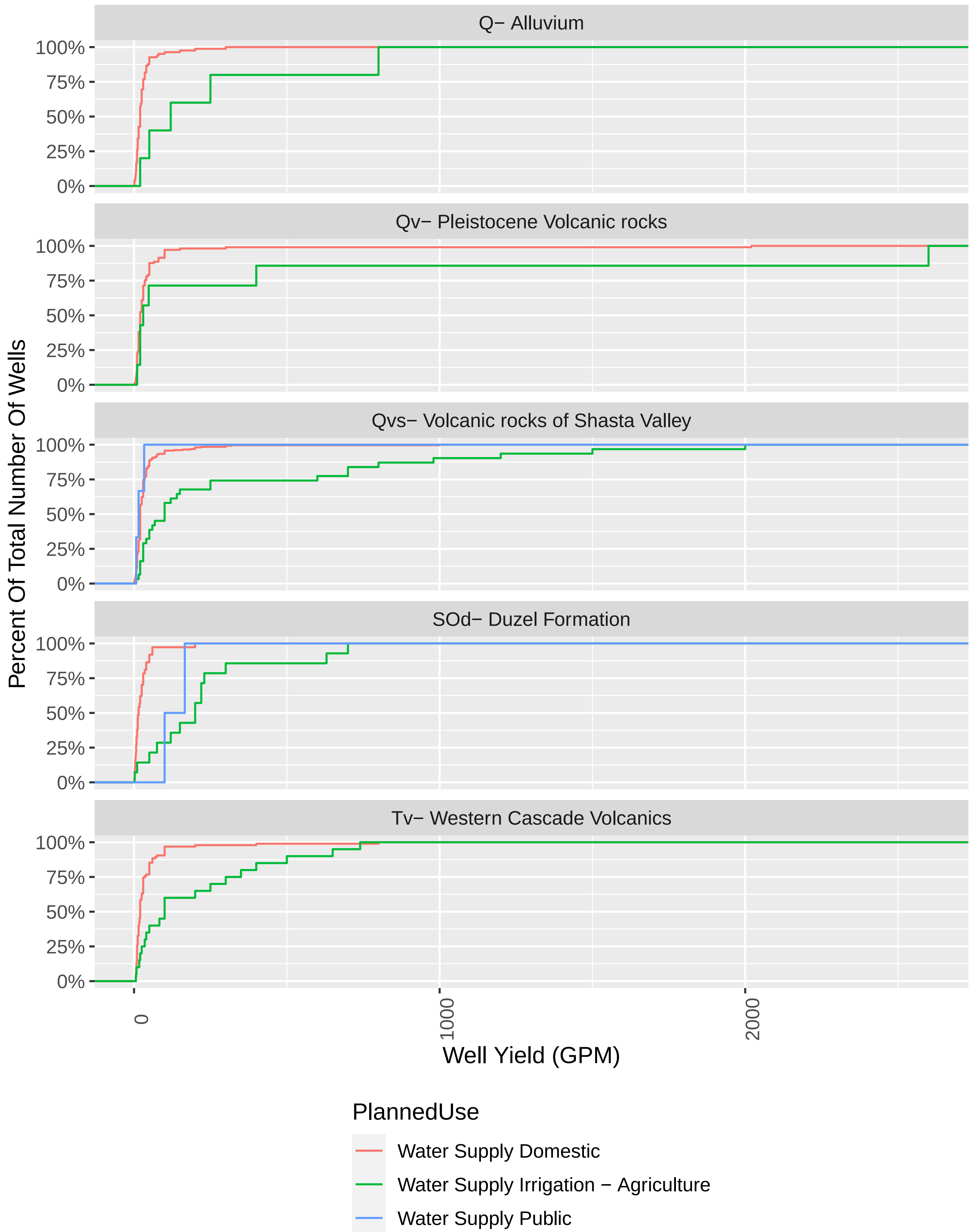

Figure 5: Shasta Valley well yield by formation at the bottom of the well comparing major well types

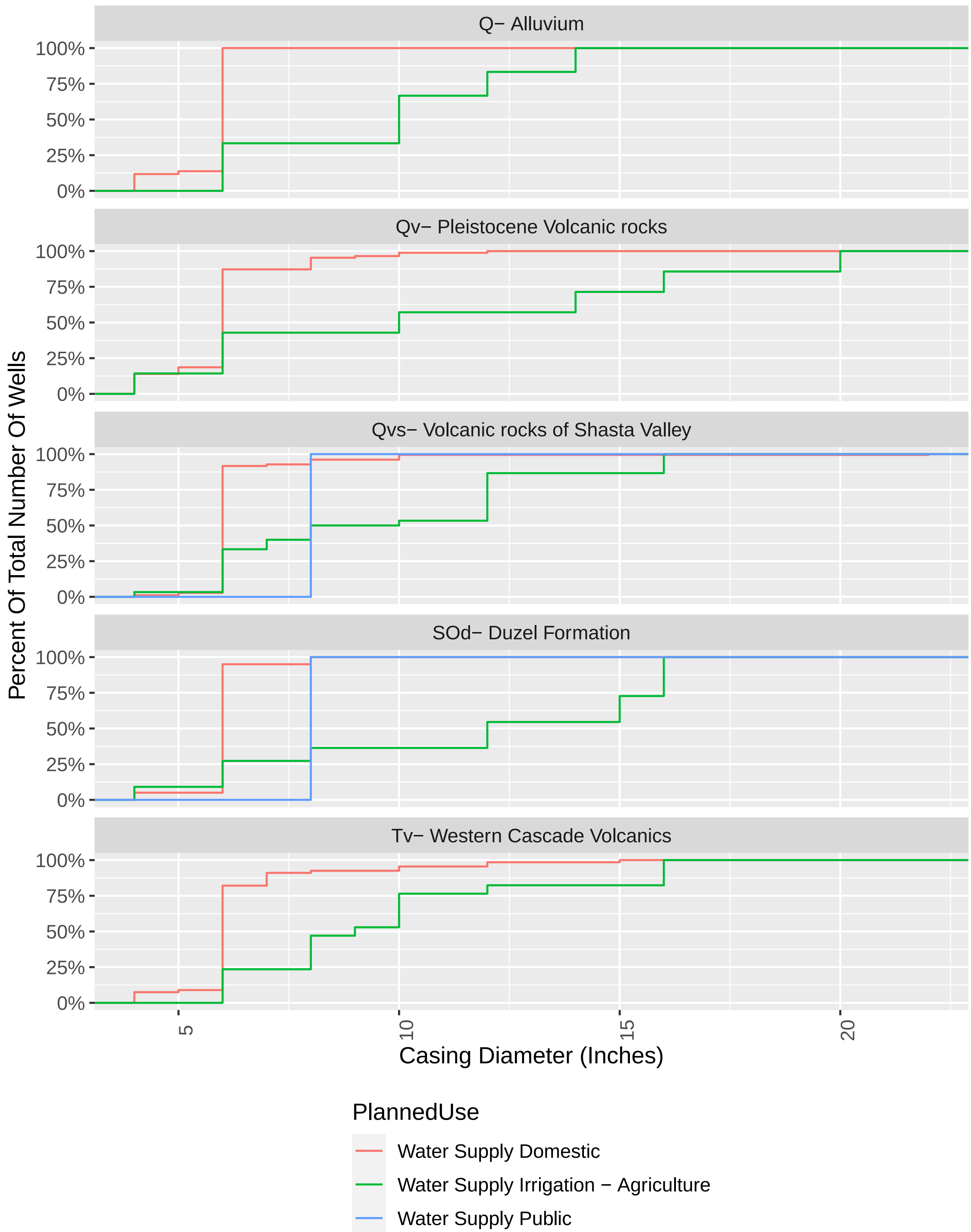

Figure 6: Shasta Valley well casing diameter by formation at the bottom of the well comparing major well types

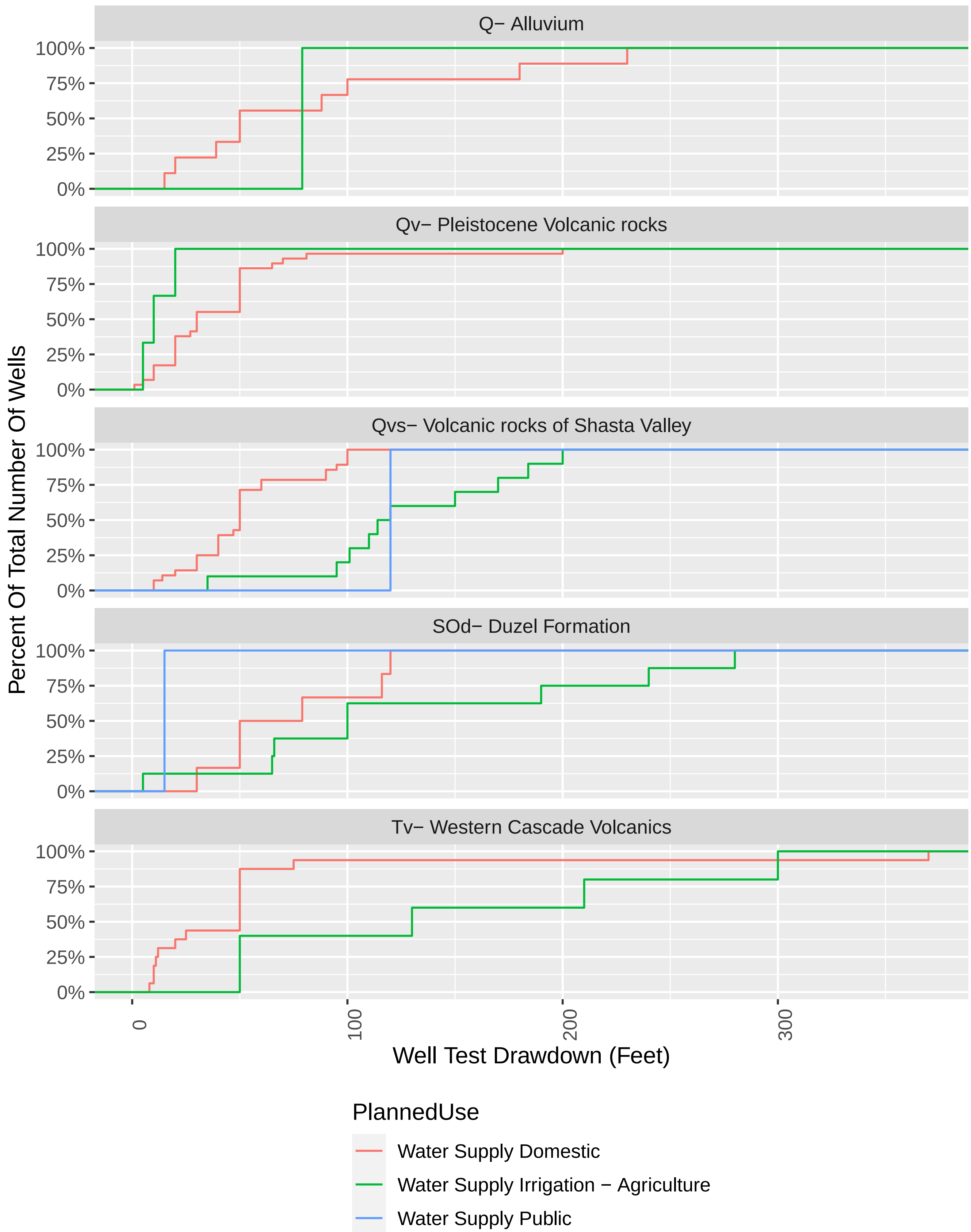

Figure 7: Shasta Valley well test drawdown by formation at the bottom of the well comparing major well types

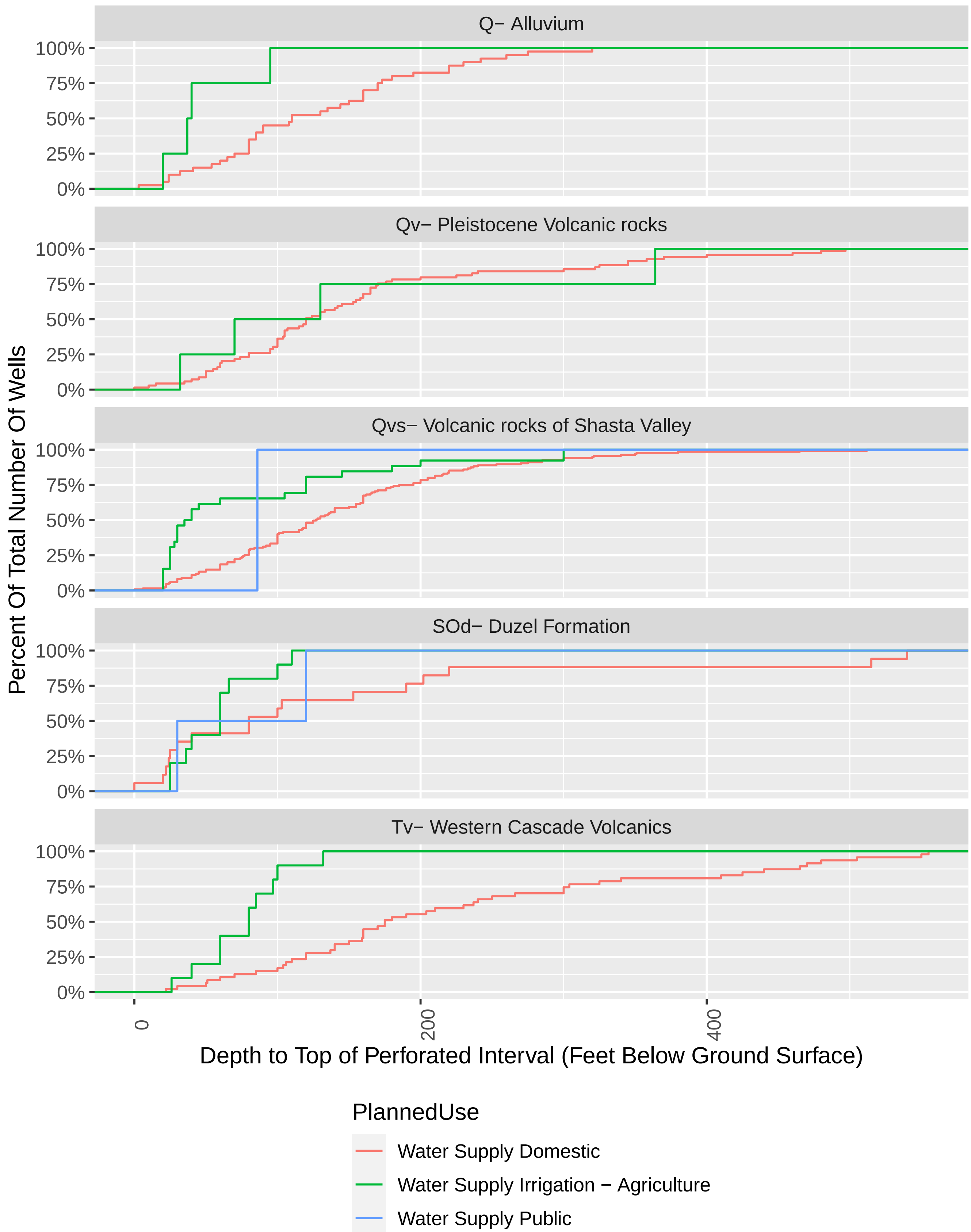

Figure 8: Shasta Valley well top of perforation below ground surface by formation at the bottom of the well comparing major well types

Estimated Wet Depth to Top of Perforations

The interpolated, contoured water table depth in fall of 2015 is shown in Figure 9, 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 Shasta Valley Groundwater Sustainability Plan).

The estimated wet depth to top of perforations is shown in the following map (Figure 10). If the interpolated elevation of the water table was above the top of perforations, the wet depth to top of perforations is positive. If the interpolated water level elevation was below the top of perforations, the difference shown is a negative number, and these wells are color-coded yellow in Figures 10 and 11. About one-quarter of wells have an estimated wet depth to top of perforations that is negative. About half of wells are estimated to have a wet depth to top of perforations of less than 100 feet (but not negative). Slightly more than one-quarter of wells are estimated to have a wet depth to top of perforations of more than 100 feet. The wells most vulnerable to well outage are those with the least (or negative) wet depth to top of perforations. Approximately 93 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 Shasta Valley. The cumulative distribution of the wet depth to top of perforations is shown in Figure 12 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 13. 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 Shasta 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).

When comparing 2015 and 2017 cumulative distributions of wet depth to top of perforations by individual geologic formations, a more differentiated assessment emerges: wells in the Duzel and the Pleistocene volcanic formations show the inverse behavior, with wet depths being shallower in 2015, but deeper in 2017, consistent with the water year type (Figures 14, 15, 16, 17, 18).

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 13 indicates that the slope of the CD is approximately 1.6% to 3% (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 Shasta 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 2% - 3% of Shasta Valley wells are likely to experience well outage for every 10 feet of water level decline below the historically lowest measured water levels.

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 5% to 9% of Shasta Valley wells at risk of well outage, the selection of the minimum threshold poses some risk of at least temporay well outage: about 50-90 wells out of approximately 1,000 wells would be at risk of well outage if water levels lowered to the minimum threshold everywhere in Shasta Valley.

The well outage risk may be unevenly distributed across Shasta Valley (Figures 14, 15, 16, 17, 18): The slopes indicate a lower risk (3%-4%) for wells in the Western Cascade Volcanics and Pleistocene Volcanics, but higher risks elsewhere (up to 11%).

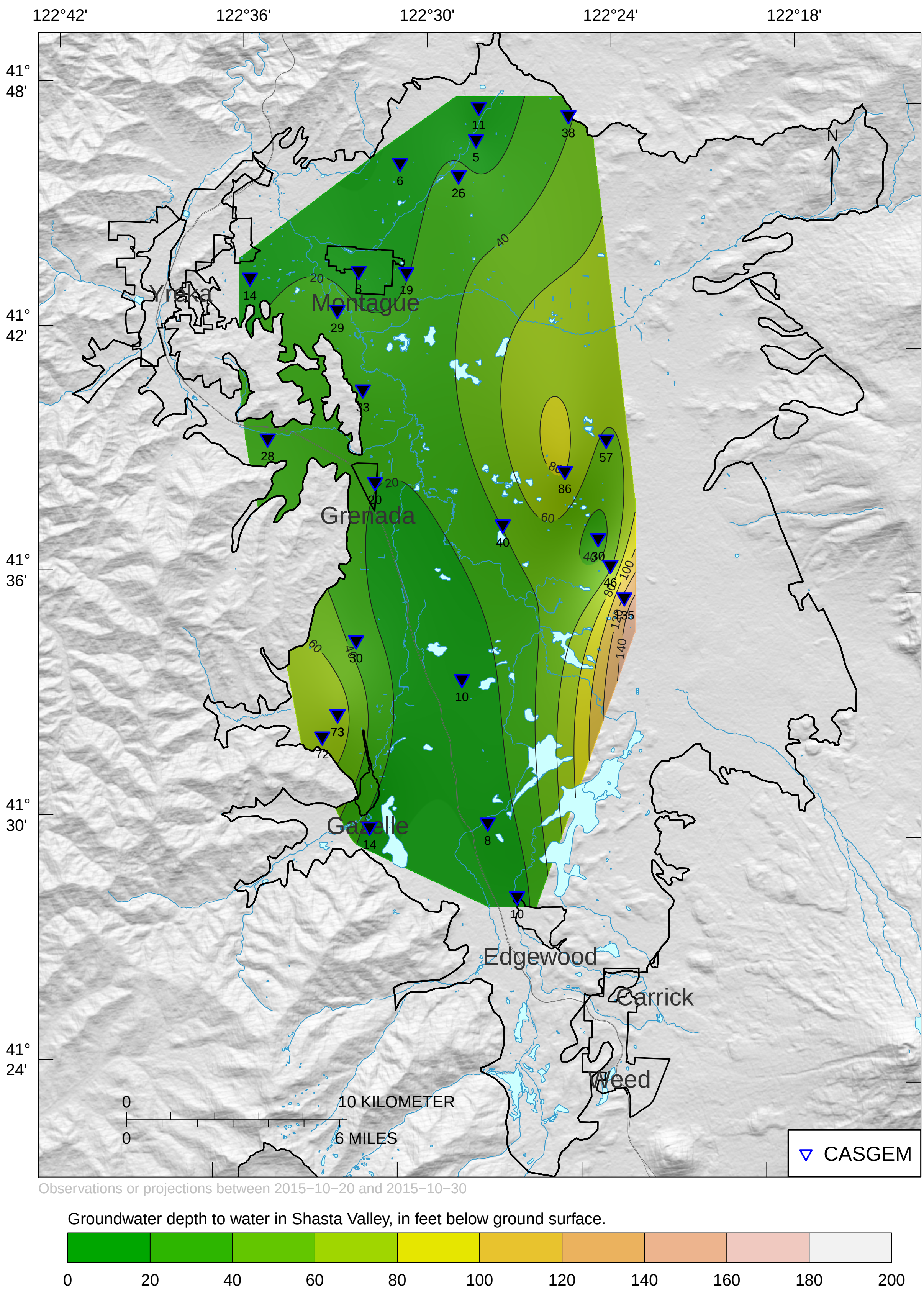

Figure 9: Shasta Valley groundwater elevations reported as approximate depth to groundwater, fall 2015 and well failure estimates based on recent water level observations. Approximate basin-scale groundwater depths are shown.

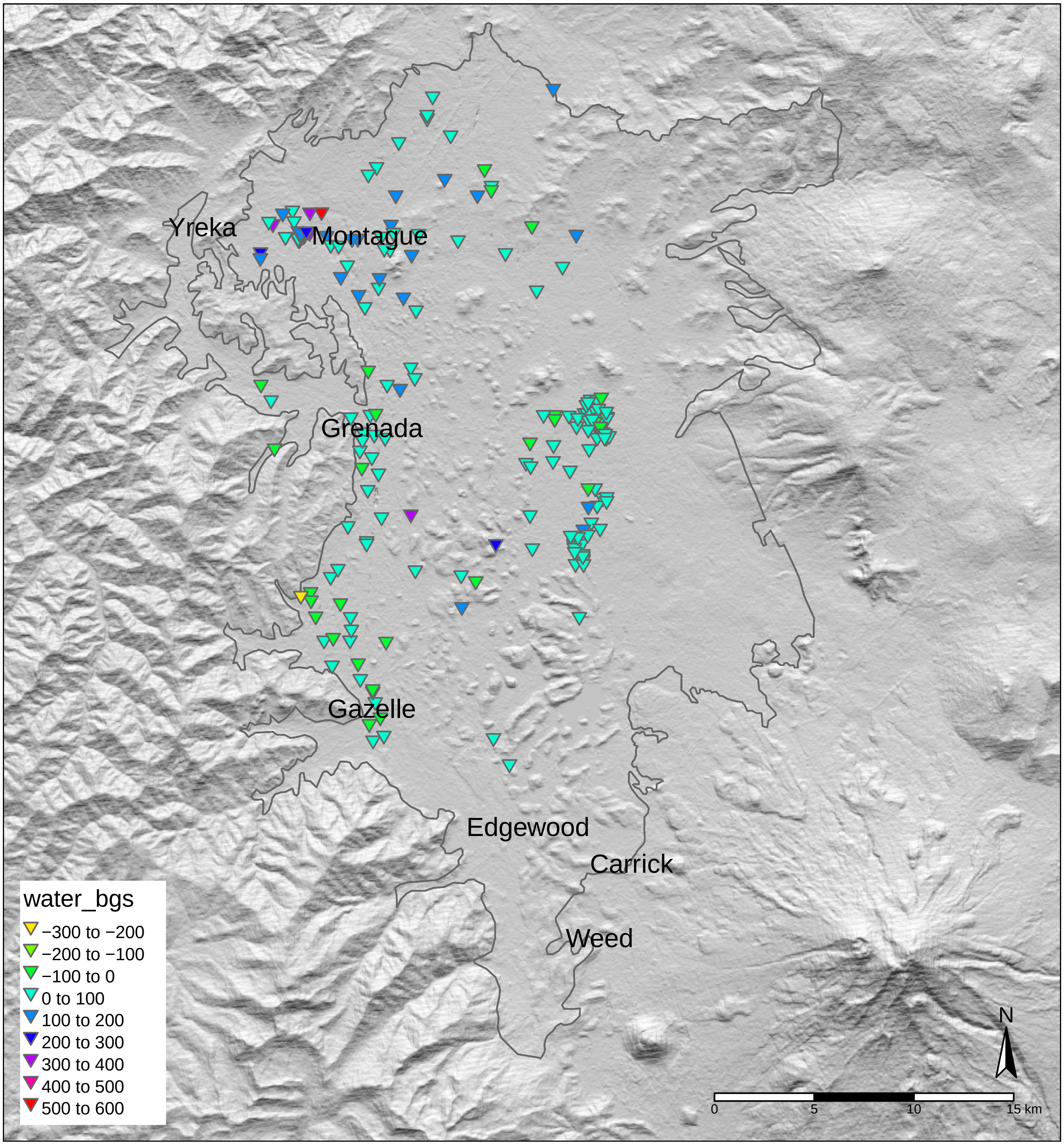

Figure 10: Shasta Valley wet depth to top of perforations based on contoured groundwater elevations, October 2015.

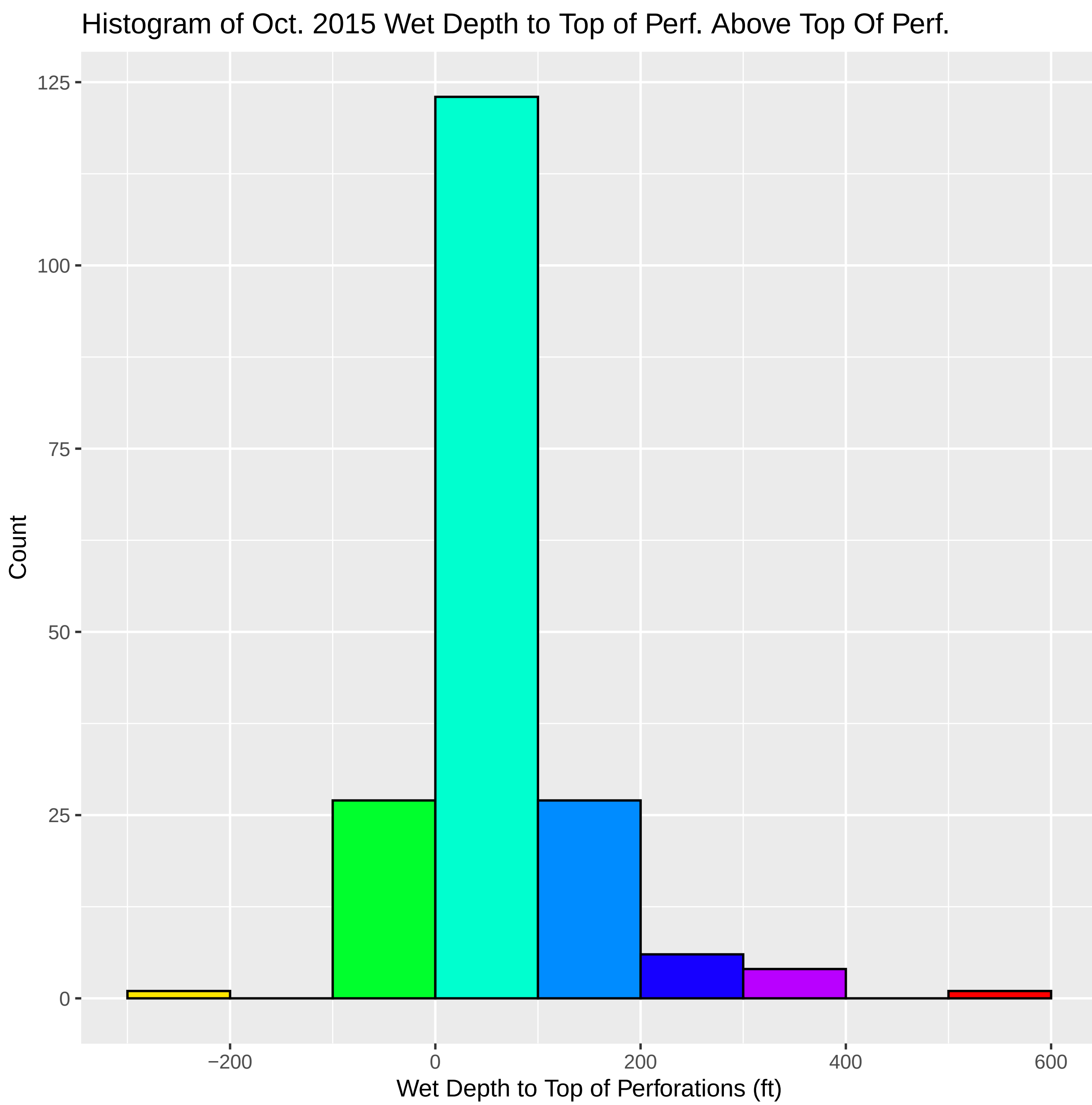

Figure 11: Histogram of wet depth to top of perforations based on contoured groundwater elevations, October 2015.

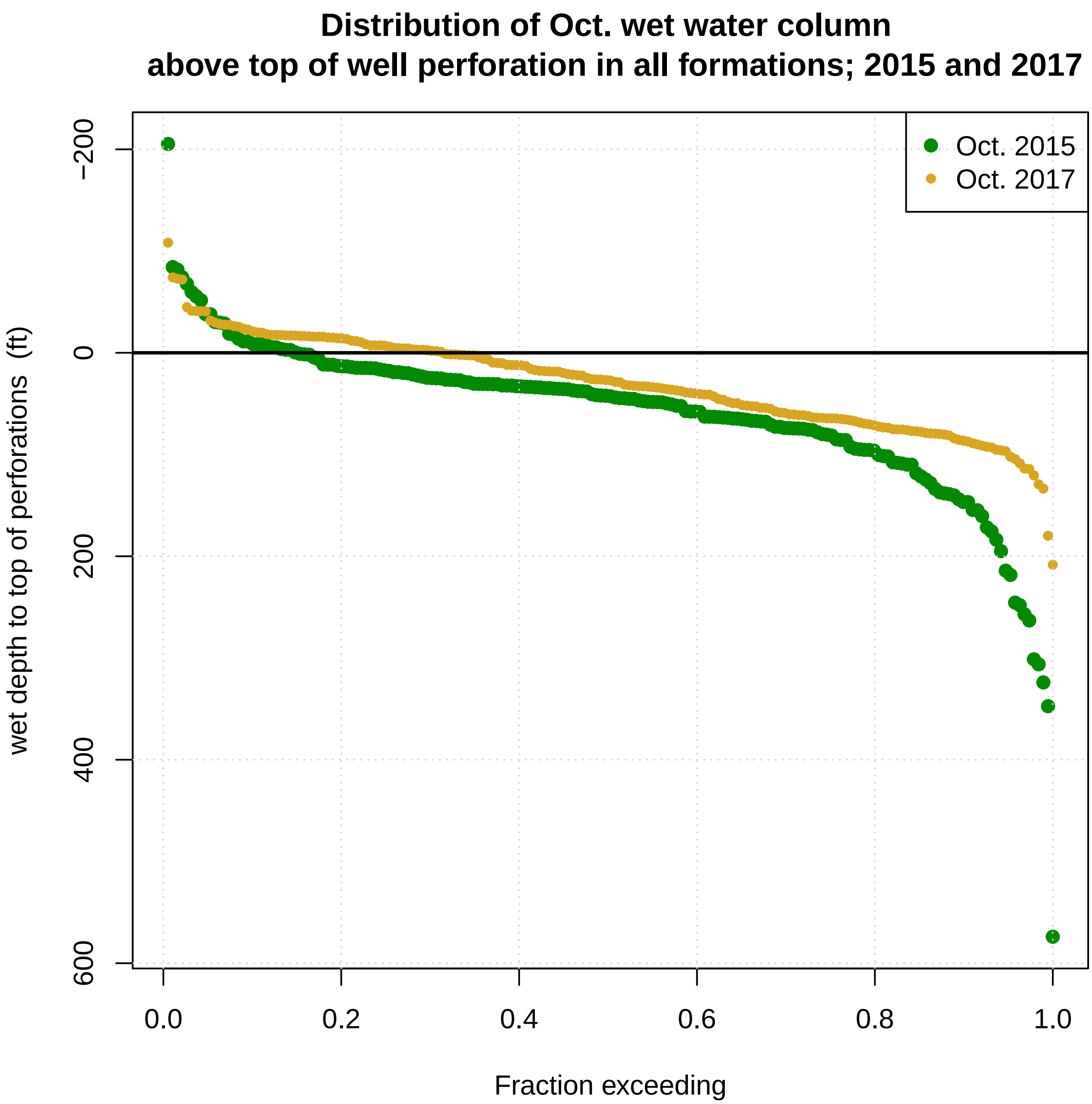

Figure 12: Cumulative distribution function of all well wet depth to top of perforations based on contoured groundwater elevations, Octobers of 2015 and 2017.

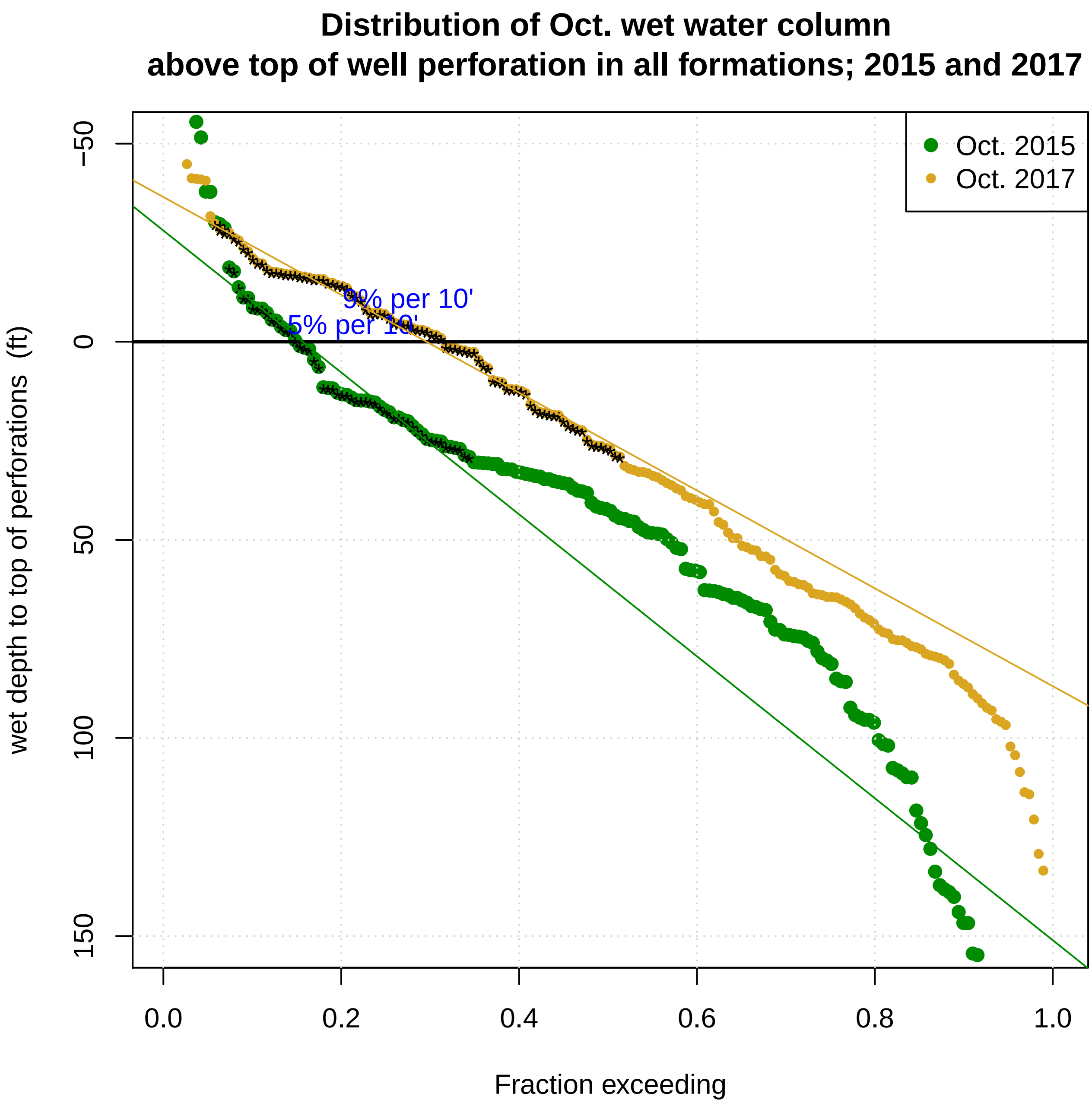

Figure 13: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well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

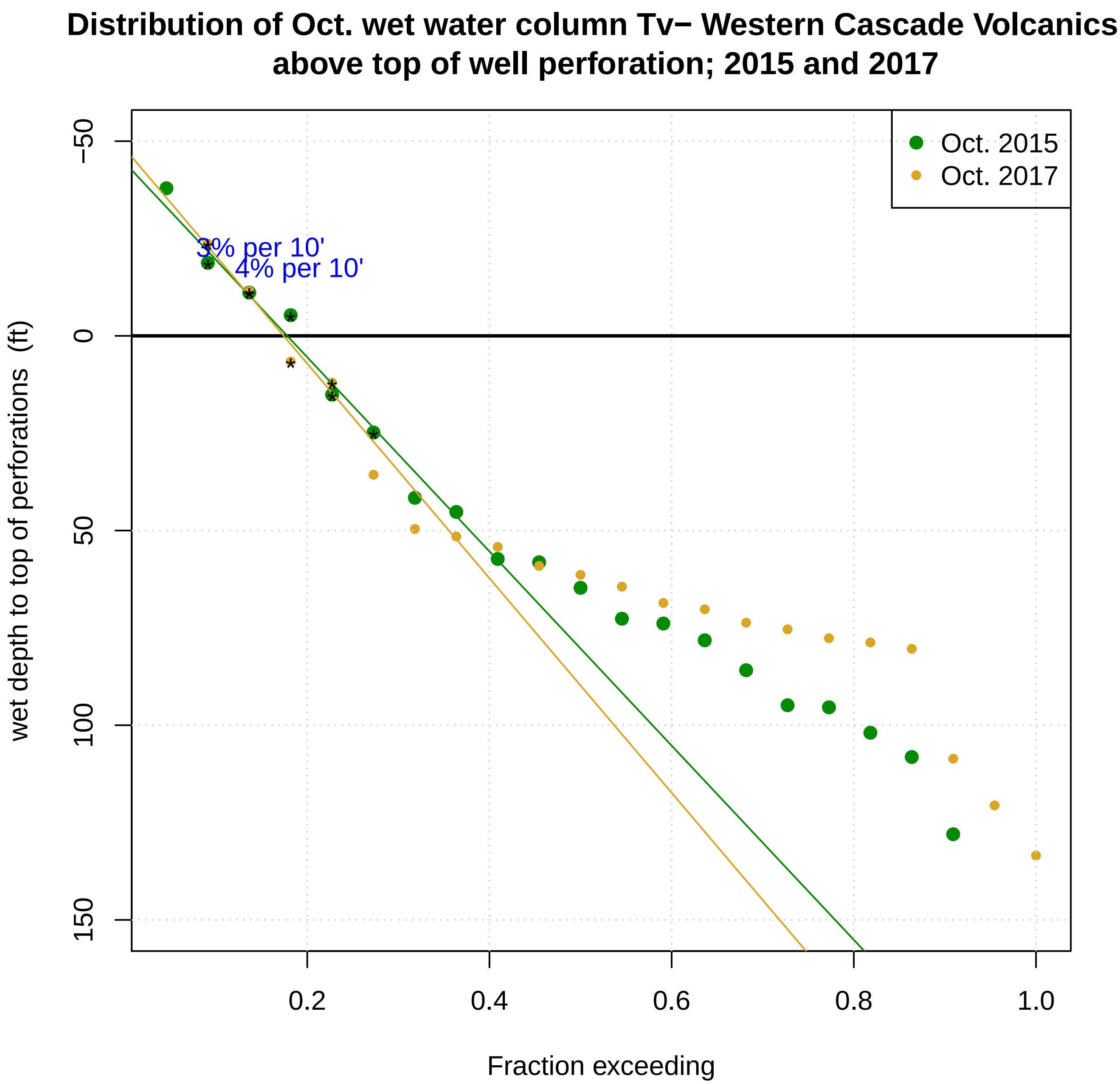

Figure 14: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well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

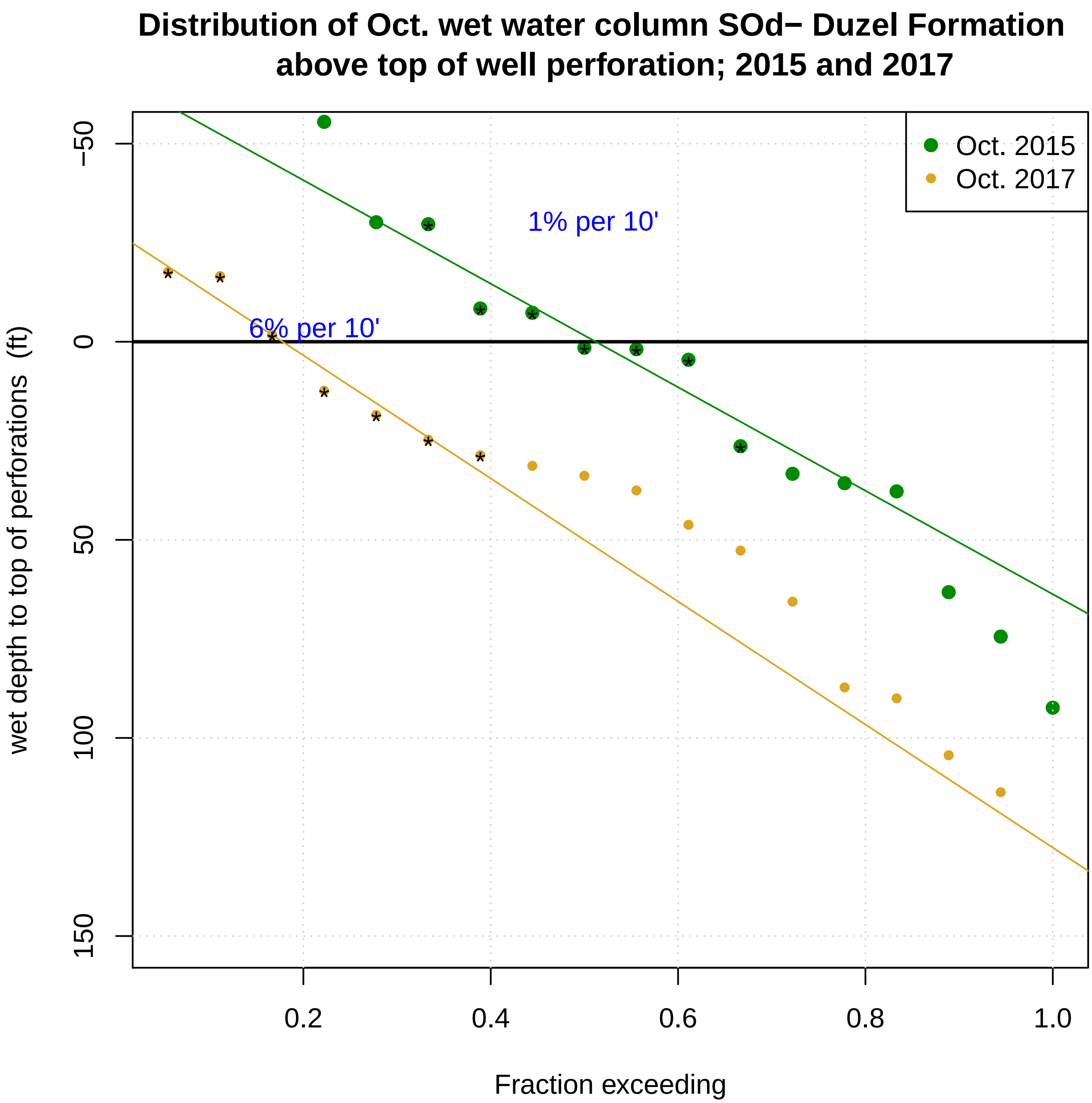

Figure 15: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well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

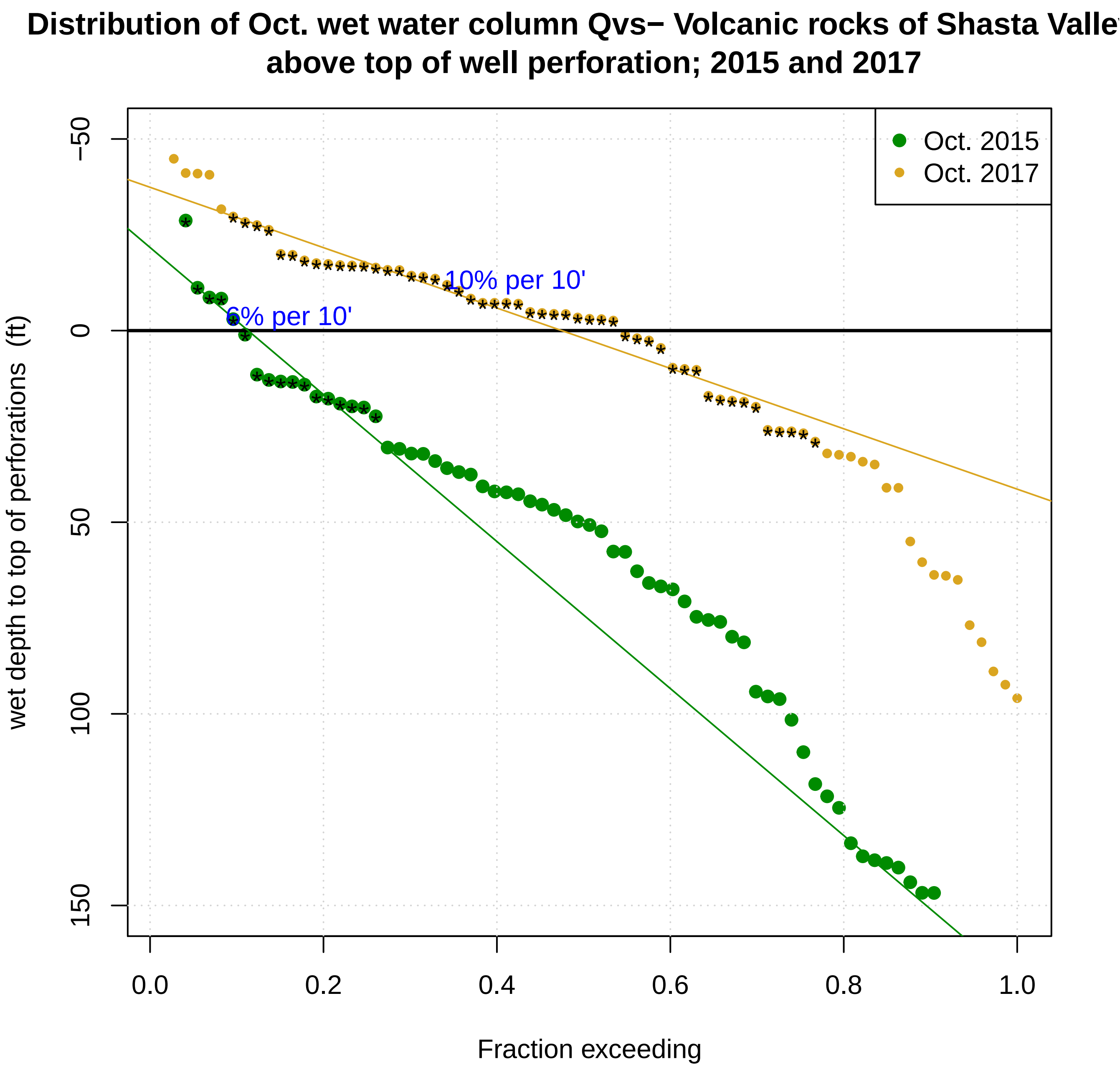

Figure 16: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well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

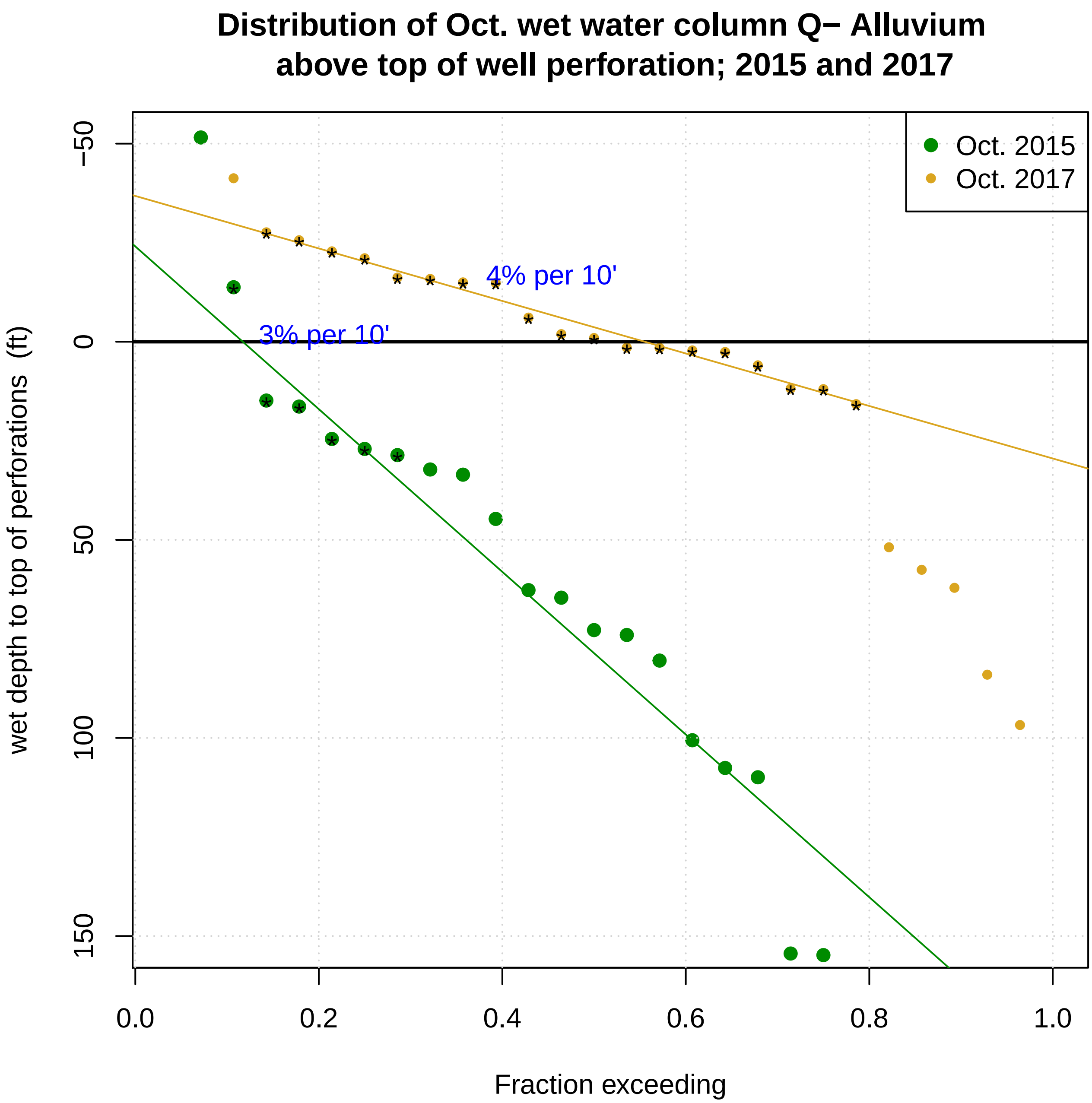

Figure 17: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well 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).

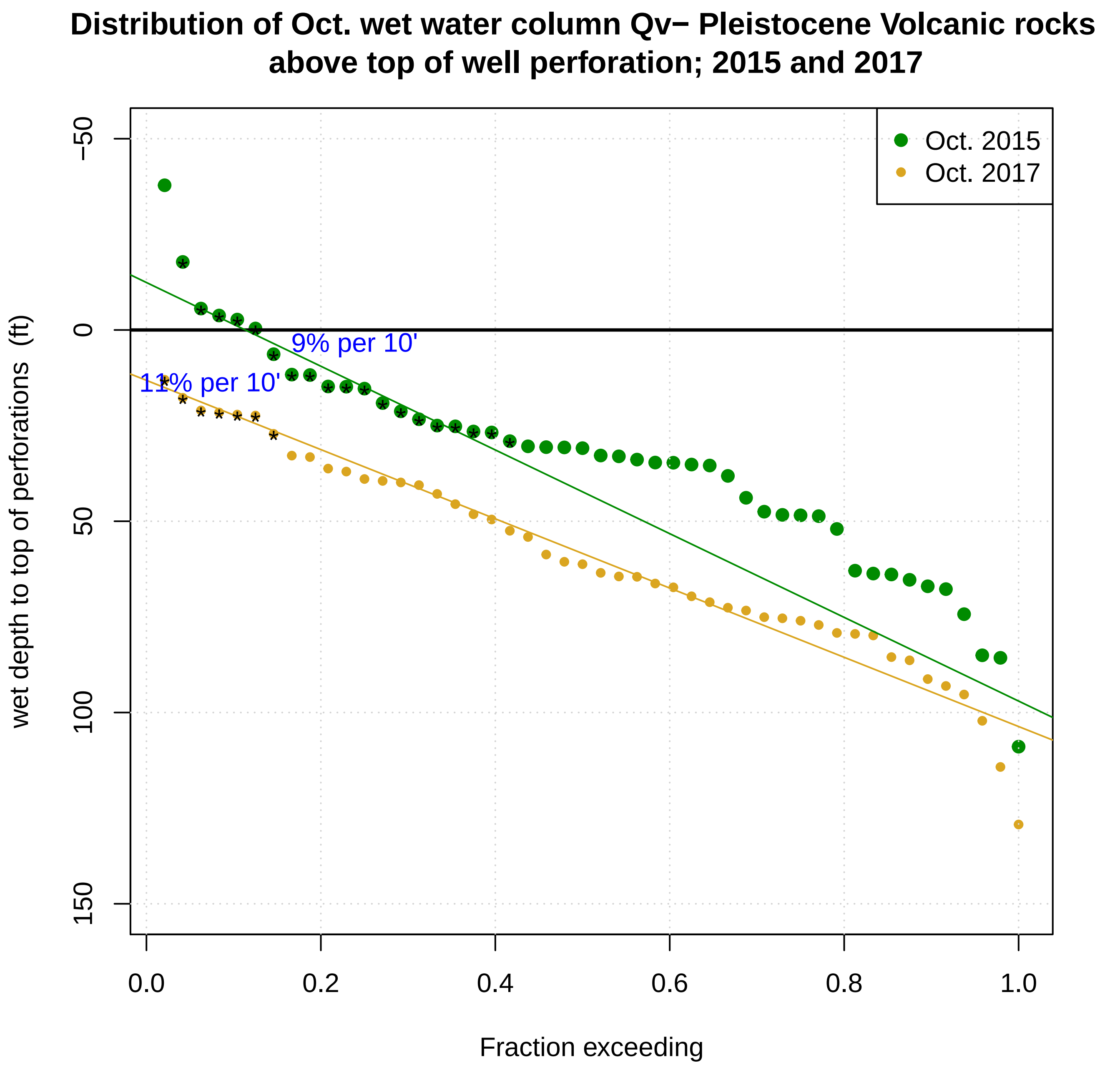

Figure 18: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well 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 Shasta 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 ~25% of wells with top of perforations above the interpolated water level depth (Figure 13) in 2015 (dry year) and 2017 (wet year).

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 Shasta Valley areas, where water depth of groundwater 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 13. 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 13, even a ten foot lowering of the water level - would affect about 5%-9% of wells (50 - 90), if such low water level conditions occurred throughout the Shasta Valley.