Memorandum

To: OWRD Groundwater Allocation Rulemaking Team

From: Ben Scandella, Groundwater Data Chief

Date: DRAFT 12/11/2023

Regarding: Analysis of Oregon wells correlated with precipitation

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Summary

The Department is in the process of updating its rules for issuing new groundwater permits, and the proposed new rules include a new definition for Reasonably Stable Groundwater Levels. This proposed definition attempts to balance multiple policy objectives, including characterizing groundwater levels as Reasonably Stable as long as they remain within the range of observed variability consistent with long-term stability. This memo evaluates two aspects of this variability relevant to the proposed definition: the magnitudes of water level cycles and the rates of decline calculated using the proposed definition. Those two attributes are evaluated using data from wells with longer-term water level records that are correlated with precipitation and that show limited long-term declines.

The observed attributes vary between wells but do not show obvious dependence on location. This memo characterizes their statewide distributions statistically. These distributions may be combined with policy objectives, like the percentage of precipitation-correlated wells whose behavior should be characterized as Reasonably Stable, to determine appropriate thresholds in the proposed definition. The determination of appropriate thresholds may also consider impacts of additional groundwater level declines, which are not addressed in this memo.

Contents

Introduction

The proposed definition of Reasonably Stable Groundwater Levels balances multiple policy objectives, including characterizing groundwater levels as Reasonably Stable as long as they remain within the range of variability consistent with long-term stability. The range of water levels that fluctuate around a value that remains constant over long time periods has been termed the "dynamically stable range" (Gleeson *et al.*, 2020). Groundwater use may be considered renewable if water levels are expected to remain within this range or to recover to within this range over a timescale for human planning (Cuthbert *et al.*, 2023). The dynamically stable range does not include expected drawdown at a new dynamic equilibrium that may be established following the full capture of surface water by increased groundwater pumping. So, even if water level declines cease at a new, lower level, this does not constitute renewable use of groundwater unless the duration of the expected use is short enough that water levels are expected to recover back to within the dynamically stable range.

The following memo characterizes the dynamically stable range using water level data in wells that show limited long-term declines over an extended period of record. It further focuses on wells with behavior correlated with regional precipitation, which is a major driver of significant groundwater level fluctuations that have the potential to remain stable over the long run. Water levels in most groundwater reservoirs in Oregon rise and fall due to natural variability in precipitation and consequent groundwater recharge, and these natural fluctuations are often amplified by anthropogenic activities. In some settings, persistent groundwater pumping causes water levels to decline, but in others, the additional pumping is offset by capture of surface water that allows water levels to remain stable over the long run.

Even if the water level record remains stable over decades, these sources of variability have the potential to cause findings of "Reasonably Stable Groundwater Levels" to oscillate between true and false in the intervening years. Such oscillations between Reasonably Stable and not could create significant uncertainty and conflict between applicants for water rights under the Prior Appropriation system, because a later applicant could be issued a permit when an earlier applicant was denied due to water levels not being Reasonable Stable. Some instances of this undesirable situation are unavoidable with a rule-based definition of Reasonably Stable. The lack of a mechanistic understanding of *why* groundwater levels are declining limits the ability of any rule to predict whether observed declines are part of a natural cycle that is expected to recover, or whether they are the beginning of a new system state characterized by ongoing declines. In the absence of such understanding, the thresholds in rule may set such that the vast majority of wells that show long-term stability would remain Reasonably Stable throughout their entire period of record, and that the other wells would be classified as Reasonably Stable over the vast majority of their record. The relevant question then becomes how to characterize the magnitude of variability in groundwater levels among these wells. That is the topic of this memo.

Methods

Identification of Precipitation-Correlated Wells

The set of wells analyzed was restricted to those where declines are limited to less than 0.5 feet per year over the period of record. Sensitivity analysis to this threshold is presented below. This restriction was taken as an indication that the influence of groundwater pumping was limited enough to remain consistent with reasonable stability. So long as long-term declines are below this limit, even water level fluctuations amplified by anthropogenic activity are valid for inclusion in this analysis as representative of the dynamically stable range. Nonetheless, in order to better represent long-term stability, water level records were "detrended" by removing the least-squares best-fit linear trend. This detrending was performed before evaluation of the correlation with water levels and of the characteristic magnitude and rate.

Water levels were compared against precipitation in each NOAA Climatic Division (9 in Oregon) containing each well. Precipitation was averaged with a backward-looking moving-average window with durations of 2 through 10 years, reflecting the range of typical recharge times in Oregon. Wells were included in the analysis set if they were sufficiently correlated with precipitation averaged over any of these averaging windows (Figure 1 through Figure 6). Wells were required to be correlated with precipitation using a Pearson's correlation coefficient $R^2 >= 0.2$ with $R > 0$. This threshold is discussed in the following section, "Selection of and Sensitivity to Analysis Parameters". A selection of hydrographs paired with precipitation records among included wells is displayed in Figure 1 through Figure 6.

Each well required at least 25 years of annual high measurements to be included in this analysis in order to ensure the robustness of the correlation with precipitation. This minimum also increased the likelihood of sampling multiple cycles of precipitation response. A sensitivity analysis is shown below.

Evaluation of Characteristic Total Decline and Rate of Decline in Each Well

The characteristic magnitude of total decline for each well was calculated as the maximum decline among years in the record for that well. Each year's Annual High Water Level was compared against the shallowest preceding Annual High, which was assumed for the purposes of this analysis to represent the Department's best estimate of the pre-development water level. Representing each well using the maximum decline over the period of record sometimes led to declines that were not broadly representative of the majority of the record. For example, well SHER 340 is correlated with precipitation, but the strong dip in the early 1990s is not representative of the bulk of the well's variability (Figure 4). The maximum total decline and rate are therefore inflated in this record.

Likewise, the characteristic rate of water level decline within each well was calculated as the maximum rate of decline quantified using the form of the proposed rate test among all years with preceding data spanning at least 10 years within a given well. That is, for each year under evaluation, the rate was the minimum rate of decline among trends using data over immediately preceding averaging periods from 5 to 20 years. While the proposed definition requires only 5 years of data, the requirement for 10 years in this analysis reflects the fact that interannual precipitation variability in Oregon is dominated by decadal fluctuations (Abatzoglou *et al.*, 2014). The selection of and sensitivity to this initial span are discussed in the following section, "Minimum Initial Period of Data Collection for Rate Test Evaluation."

The results of the rate test as in the proposed definition were compared against the results of the Mann-Kendall test for monotonic declines (Figure 17 and Figure 18). The Mann-Kendall test has been widely used for evaluating trends in environmental data (Helsel *et al.*, 2020), but it assumes that measurements are independent and not serially correlated (Yue *et al.*, 2002). Annual High Water Level measurements are typically strongly serially correlated, and this violation of a core assumption of the test biases the results toward detecting declines when they may not be present (Yue and Wang, 2002). Corrections are available but require expert judgment to be applied in each case (Yue and Wang, 2004). The proposed form of the rate test was developed because it is relatively easy to implement without advanced statistical software, and because the comparison against a maximum decline rate adds flexibility and facilitates transparent discussion about the limits of detection by the rate test. However, the comparison between it and the Mann-Kendall test provides perspective on the sensitivity and robustness of the proposed definition at different threshold rates. Significance levels of 0.1, 0.01, and 0.001 were tested, bracketing the standard value of 0.05. The significance level alpha 0.05 for a one-tailed test means that the test required less than a 5% probability that an observed trend could have been generated from a stable trend, in order for the test to classify the trend as declining.

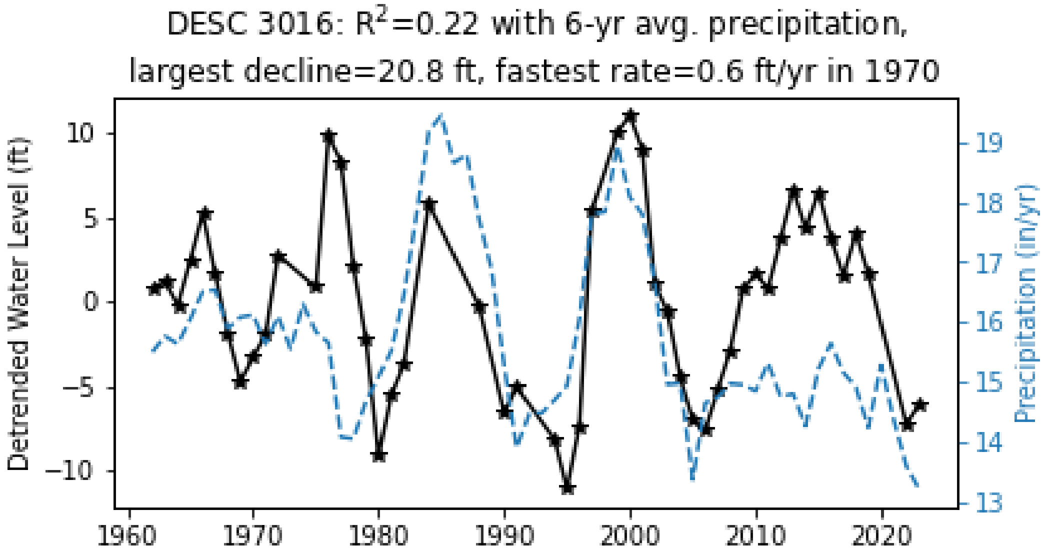

Figure 1: Hydrograph for well DESC 3016 with detrended Annual High Water Levels (solid black line, left axis) correlated (R^2 = 0.22) with 6-year moving-average precipitation (dashed blue line, right y-axis). The range of water levels after detrending = 20.8 feet, and the fastest rate of decline calculated with the proposed definition is 0.6 feet per year in 1970. Among years with preceding data spanning at least 10 years, the steepest decline was 0.3 feet per year in 1995.

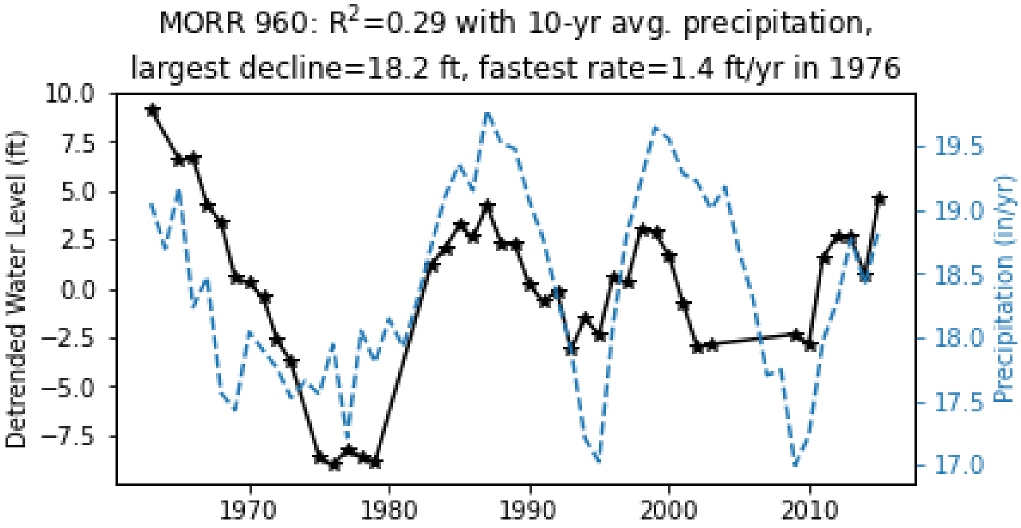

Figure 2: Hydrograph for well MORR 960 with detrended Annual High Water Levels (solid black line, left axis) correlated (R^2 = 0.29) with 10-year moving-average precipitation (dashed blue line, right y-axis). The range of water levels after detrending = 18.2 feet, and the fastest rate of decline calculated with the proposed definition is 1.4 feet per year in 1976, near the bottom of the initial declining trend measured in this well.

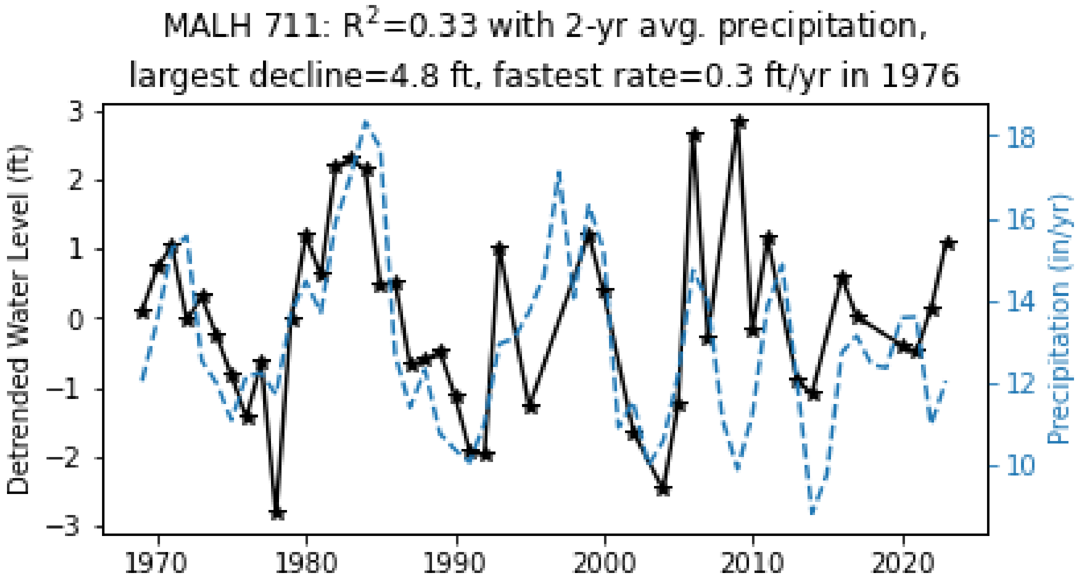

Figure 3: Hydrograph for well MALH 711 with detrended Annual High Water Levels (solid black line, left axis) correlated (R^2 = 0.33) with 2-year moving-average precipitation (dashed blue line, right y-axis). The range of water levels after detrending = 4.8 feet, and the fastest rate of decline calculated with the proposed definition is 0.3 feet per year in 1976. Among years with preceding data spanning at least 10 years, the steepest decline was 0.1 feet per year in 1979.

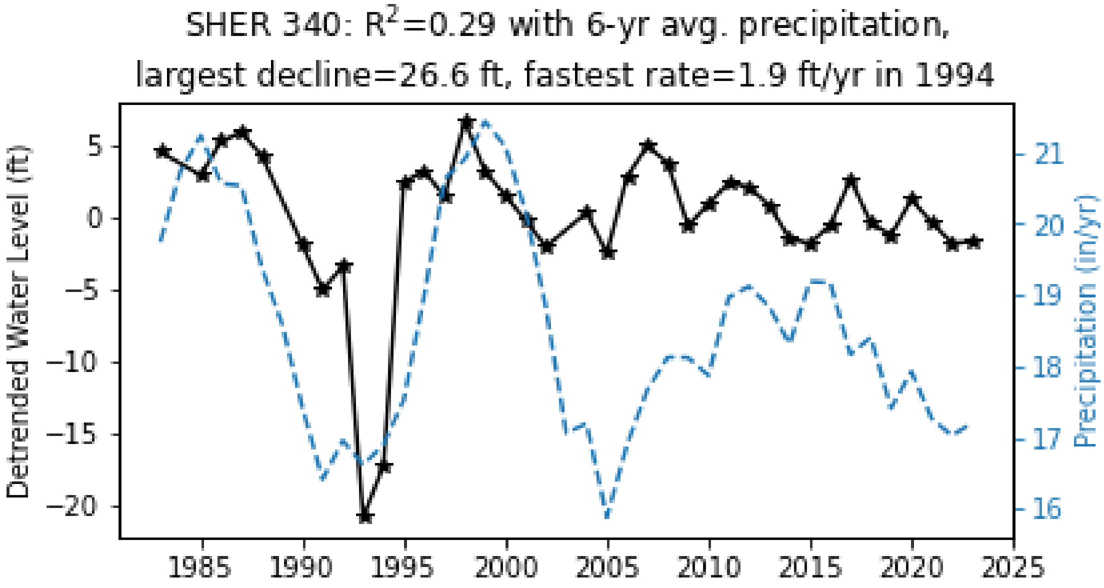

Figure 4: Hydrograph of well SHER 340 with detrended Annual High Water Levels (solid black line, left axis) correlated (R^2 = 0.20) with 6-year moving-average precipitation (dashed blue line, right y-axis). The range of water levels after detrending = 26.6 feet, and the fastest rate of decline calculated with the proposed definition is 1.9 feet per year in 1994.

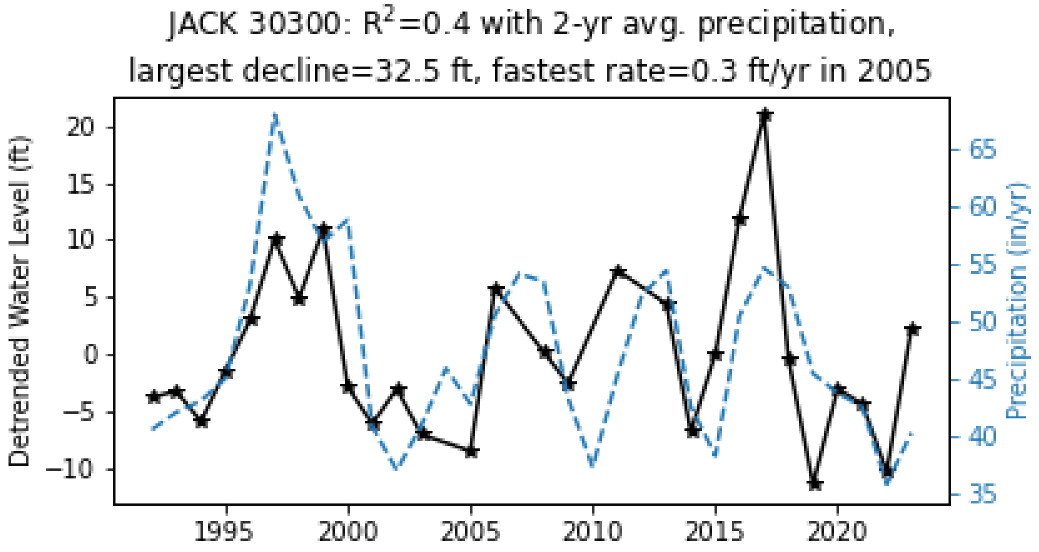

Figure 5: Hydrograph for well JACK 30300 with detrended Annual High Water Levels (solid black line, left axis) correlated (R^2 = 0.40) with 2-year moving-average precipitation (dashed blue line, right y-axis). The range of water levels after detrending = 32.5 feet, and the fastest rate of decline calculated with the proposed definition is 0.3 feet per year in 2005.

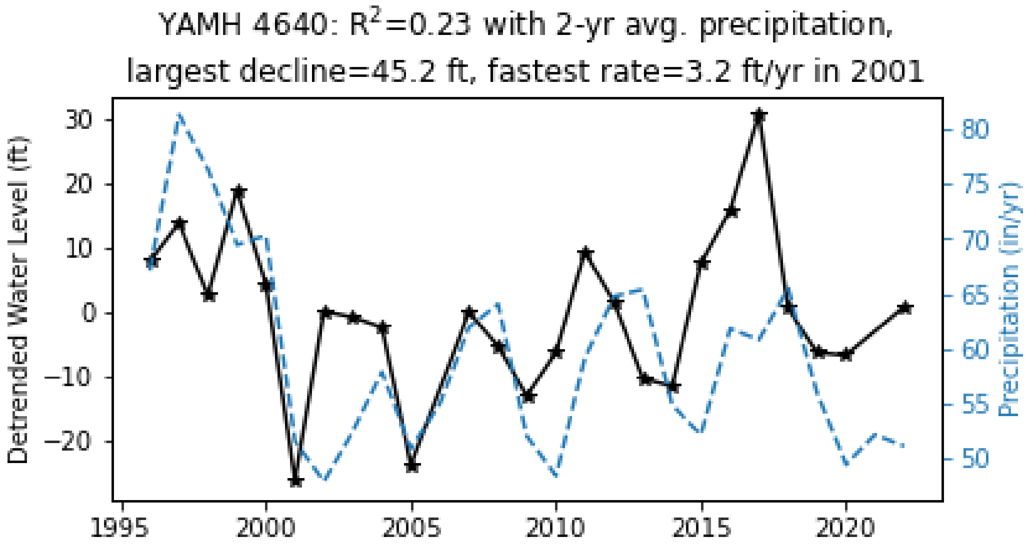

Figure 6: Hydrograph for well YAMH 4640 with detrended Annual High Water Levels (solid black line, left axis) correlated (R^2 = 0.23) with 2-year moving-average precipitation (dashed blue line, right y-axis). The range of water levels after detrending = 45.2 feet, and the fastest rate of decline calculated with the proposed definition is 3.2 feet per year in 2001. Among years with preceding data spanning at least 10 years, the steepest decline was 0.8 feet per year in 2009.

Clustering of Similar Wells

Applying this test to a collection of 9,397 wells with Annual High Water Levels in the Department's Groundwater Information System, 234 wells had the appropriate qualifications (Figure 7). Those wells spanned the state, but they also showed enhanced density in some regions of the state, especially in portions of the Willamette and Klamath basins. This over-representation was in tension with the intent of this analysis: to characterize statewide variability with the distribution of values measured in individual wells.

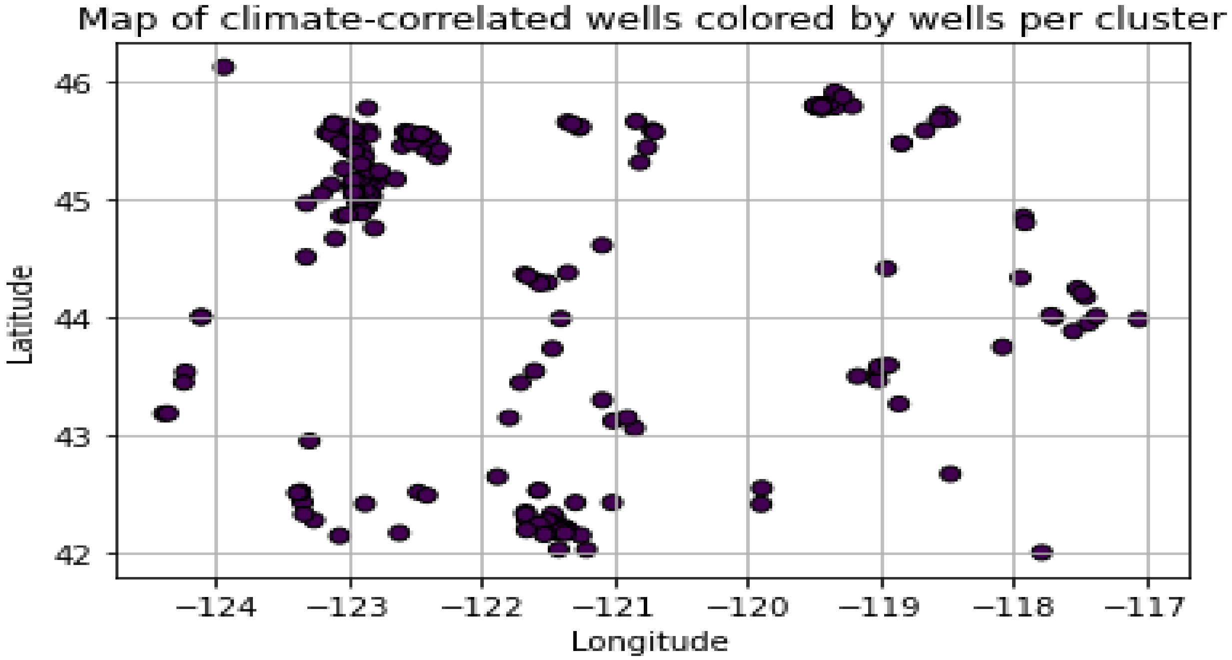

Figure 7: Map of 234 wells with appropriate qualifications for inclusion in the analysis of precipitation-correlated variability in water levels. This map will be replaced by a proper one.

This spatial sampling bias was mitigated by clustering wells that were nearby and showed similar relevant properties. Wells were clustered using single-linkage agglomerative clustering. That means a well is added to an existing cluster if it meets all of the following criteria with respect to any other member of the cluster:

- Located within 10 miles, or within 25 miles if the well is known to be a basalt well (due to their much larger hydraulic diffusivity).
- Water level total declines agree within 30% of the mean value between the pair. A percentage threshold was used rather than an absolute value because the distribution of well-specific maximum decline magnitudes is roughly exponential (Figure 14). Sensitivity analysis to the 30% minimum is presented below in the section, “Maximum Percent Difference in Characteristic Magnitude of Decline Between Similar wells.”
- The wells potentially access the same aquifer. Aquifer compatibility could be established through any of the following methods:
    - If both wells have been identified to access the same aquifer in the Groundwater Information System.
    - If either of the wells only had an aquifer *system* selected and not a specific aquifer, and the wells are in the same aquifer system.
    - The aquifer and aquifer system for either of the wells has not been selected.

Single-linkage clustering was used instead of complete-linkage clustering because wells along a gradient of elevation within the same aquifer may respond to hydraulic forcing with a gradient of magnitudes. Other clustering methods may also be useful but were not investigated.

Applying the above method grouped the 234 wells into 106 distinct clusters (Figure 8). Of these clusters, 59 had only a single well, 28 had more than 1 well, 5 had at least 10 wells, 2 had at least 20, and the largest cluster had 24 wells. Values of water level range and characteristic rate of decline were averaged among wells within each cluster using the mean value.

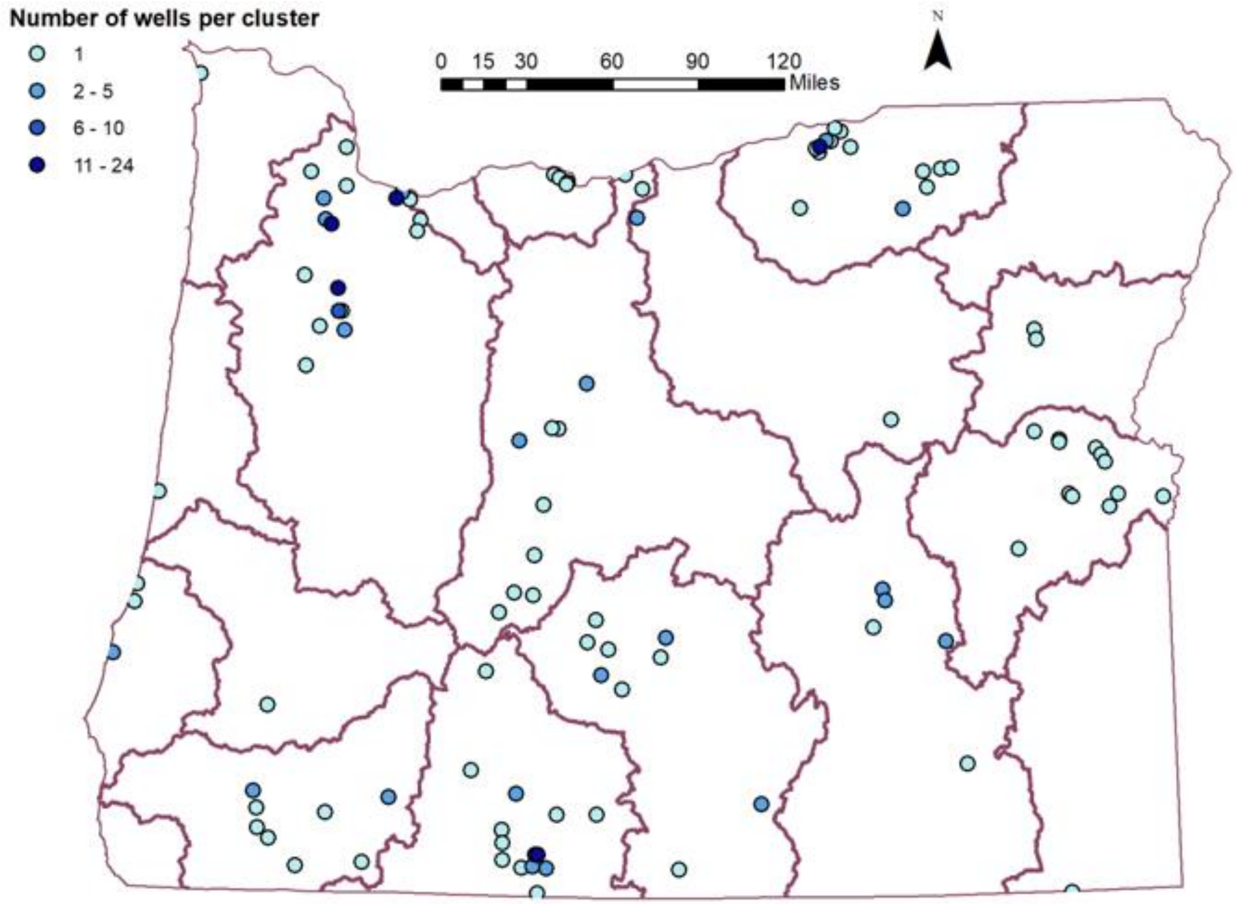

Figure 8: Map of 106 precipitation-correlated clusters, colored by number of wells per cluster.

Selection of and Sensitivity to Analysis Parameters

This analysis depends on empirical parameters to appropriately identify wells correlated with long-term precipitation cycles and with limited influence of pumping. The most sensitive of parameters include the minimum degree of correlation with regional precipitation, the minimum number of Annual High Water Levels, the maximum long-term rate of decline, the minimum percent difference in total decline between cluster members, and the initial span of data required to evaluate the rate test. The particular parameter values were selected manually using professional judgement on review of (1) hydrographs from wells determined to be precipitation-driven or not, and (2) sensitivity of the results and sample size to the parameter values. Below is presented a discussion of these selections, along with a sensitivity analysis of the results to changing each parameter's values (Figure 9 through Figure 13).

Minimum Coefficient of Determination (R^2)

A primary filter on inclusion of wells is the requirement that they be sufficiently correlated with the regional precipitation record. The criterion for "sufficiently correlated" was empirically determined as the maximum value of coefficient of determination ($R^2 = 0.2$) that still includes a well with known strong climatic influence, DESC 3016 (Figure 1). Higher minimum values would have ensured more significant correlations, but the number of qualifying well clusters decreased roughly linearly to nearly 0 by $R^2 = 0.5$ (Figure 9, bottom). The sensitivity of the results to the minimum coefficient of determination are shown in Figure 9. The upper subfigure shows how the distribution of water level declines (as characterized by the 50th, 67th, 80th, and 90th percentile values) display a rough local minimum around $R^2 = 0.2$. The 90th percentile decline increases to roughly 30 feet at $R^2 = 0$ and $R^2 = 0.35$. between 0.1 and 0.25. Above 0.35, the 90th percentile decline reduces to roughly 20 feet.

The middle subfigure shows how the characteristic rates of decline retain stable distributions for minimum R^2 values between approximately 0.1 and 0.25. Above this, the tested percentiles vary inconsistently, which can be attributed in part to the rapidly shrinking set of well clusters with increasing coefficient of determination.

Minimum Number of Annual Water Level Measurements

The 90th percentile water level total decline varies between approximately 20 and 30 feet in response to minimum number of Annual High Water Level measurements between 10 and 40 (Figure 10). Results are roughly consistent (insensitive to this parameter) in the range from 20 to 35 measurements. Meanwhile, the 90th percentile rate of decline are more consistent in the range from 12 to 25 measurements, and the other percentiles increase over the same range. Above 25 measurements, the lower percentiles remain roughly constant while the 90th percentile varies between 0.5 and 0.7. The minimum of 25 that was used to generate the final results (Figure 14 through Figure 16), shown in the dashed vertical line, was selected for balance of relatively large sample size (with a lower minimum) and fewer precipitation-correlated wells that also appear to be influenced by other factors. An example of such a well is shown in Figure 4.

Maximum Long-Term Rate of Decline

The 90th percentile water level range varies between approximately 20 and 30 feet in response to maximum rates of decline between 0 and 1 feet per year (Figure 11). It is relatively insensitive for limits between 0.2 and 0.8 feet per year. As the maximum allowed decline is reduced, fewer wells meet the limitations, with as few as 20 with a maximum rate of 0 feet per year.

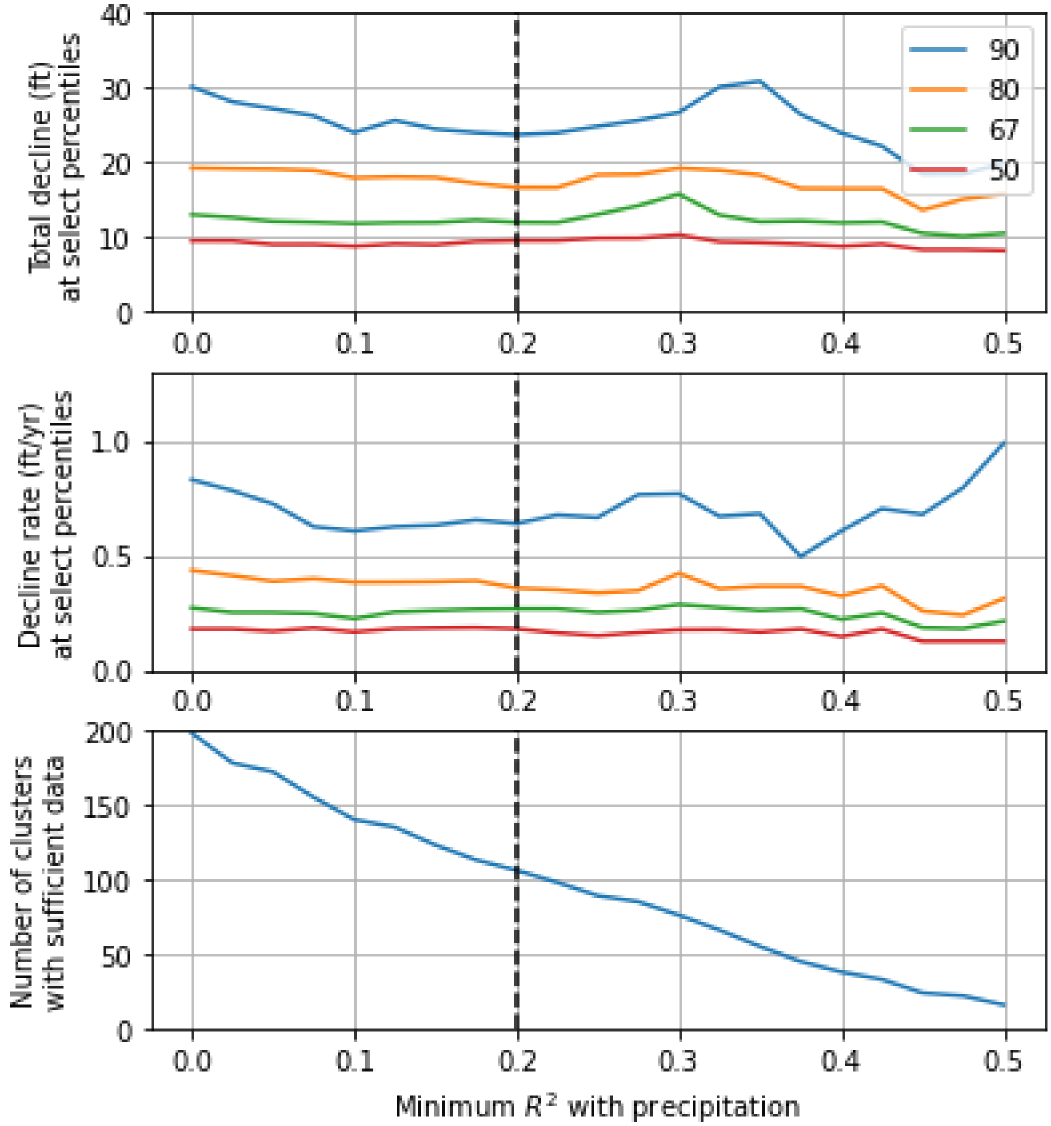

Figure 9: Sensitivity of results to minimum Pearson's correlation coefficient R2. Top: water level range at 50th, 67th, 80th, and 90th percentiles (line colors indicated in legend) among clusters of qualifying wells. Middle: characteristic of decline at 50th, 67th, 80th, and 90th percentiles. Bottom: number of clusters with sufficient data given the threshold displayed in the x-axis. The vertical dashed line in all subfigures represents the final threshold of 0.2.

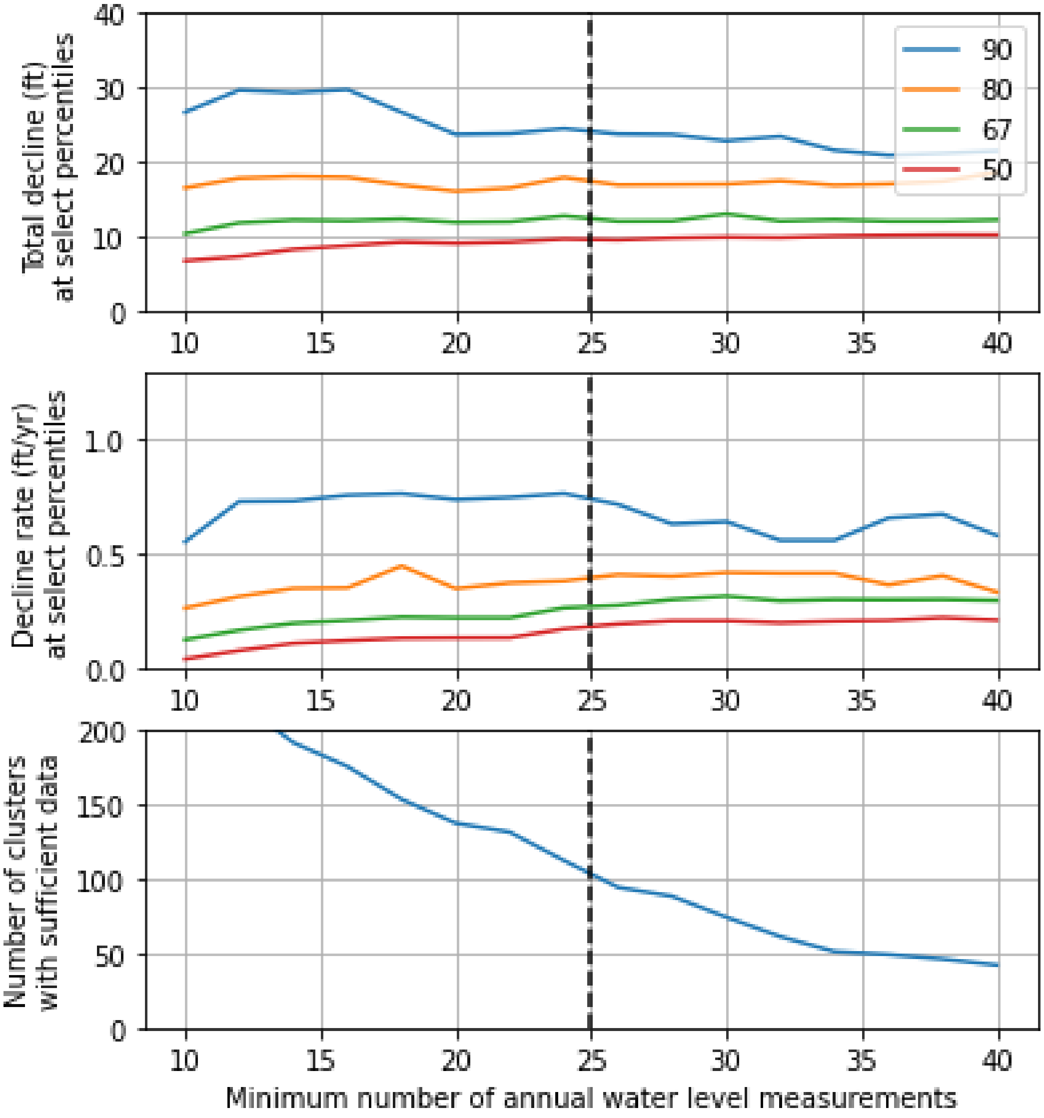

Figure 10: Sensitivity of results to minimum number of Annual High Water Levels. Top: water level range 50th, 67th, 80th, and 90th percentiles among clusters of qualifying wells. Middle: characteristic rate of decline at 50th, 67th, 80th, and 90th percentiles. Bottom: number of clusters with sufficient data given the threshold displayed in the x-axis. The vertical dashed line in all subfigures represents the final threshold of 25 measurements.

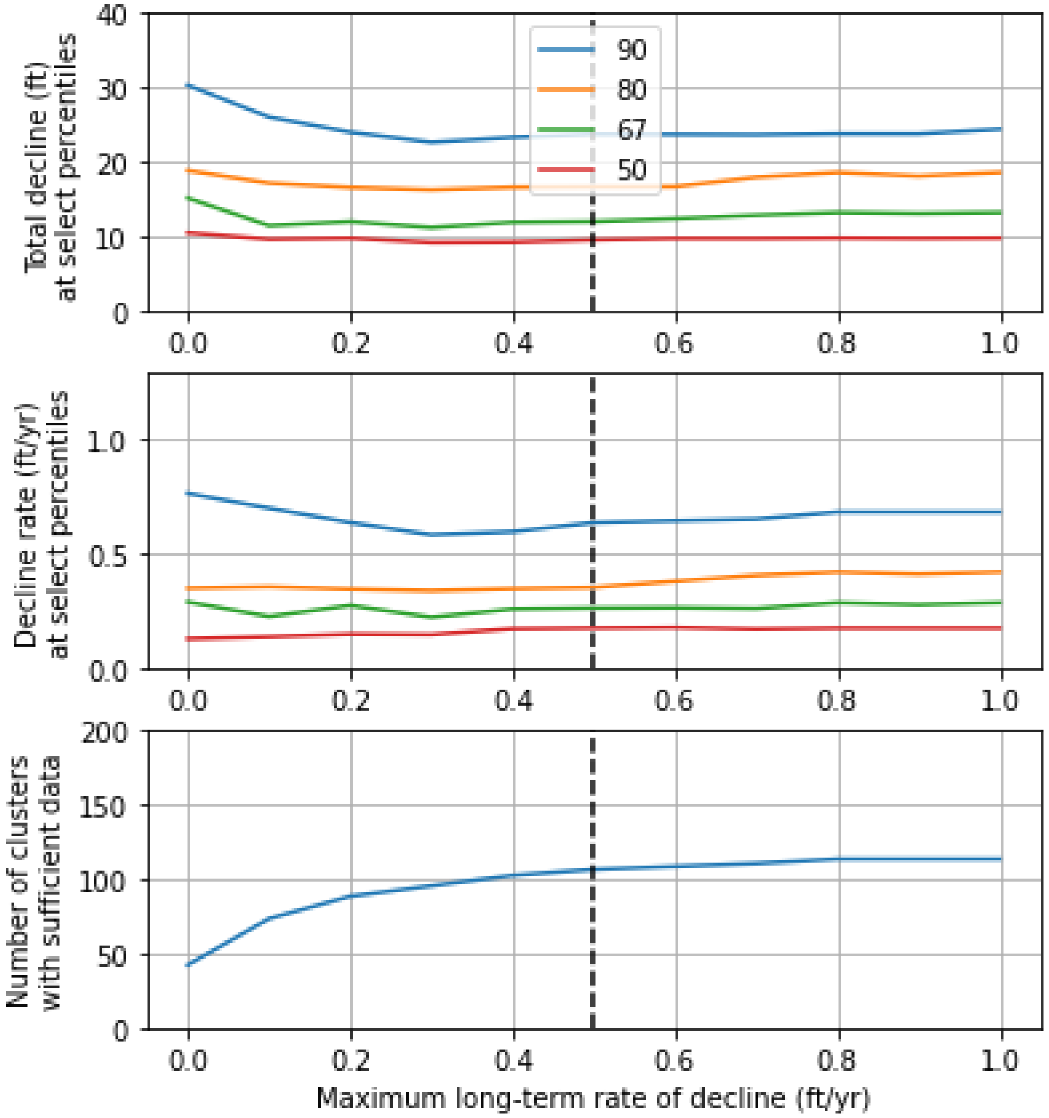

Figure 11: Sensitivity of results to maximum long-term rate of decline (feet per year, x-axis). Top: water level range at 50th, 67th, 80th, and 90th percentiles among clusters of qualifying wells. Middle: characteristic rate of decline at 50th, 67th, 80th, and 90th percentiles. Bottom: number of clusters with sufficient data given the threshold displayed in the x-axis. The vertical dashed line in all subfigures represents the final threshold of 0.5 feet per year.

Maximum Percent Difference in Characteristic Magnitude of Decline Between Similar wells

Decline magnitudes are roughly exponentially distributed (Figure 14), so any sampling from that distribution should be by percent instead of by absolute value in order to avoid distorting it. Thus, when clustering wells to limit spatial sampling bias, similarity was determined using a percentage agreement rather than an absolute value (feet). The results were relatively insensitive to the maximum percent difference, except that the number of clusters decreased strongly with larger values (Figure 12).

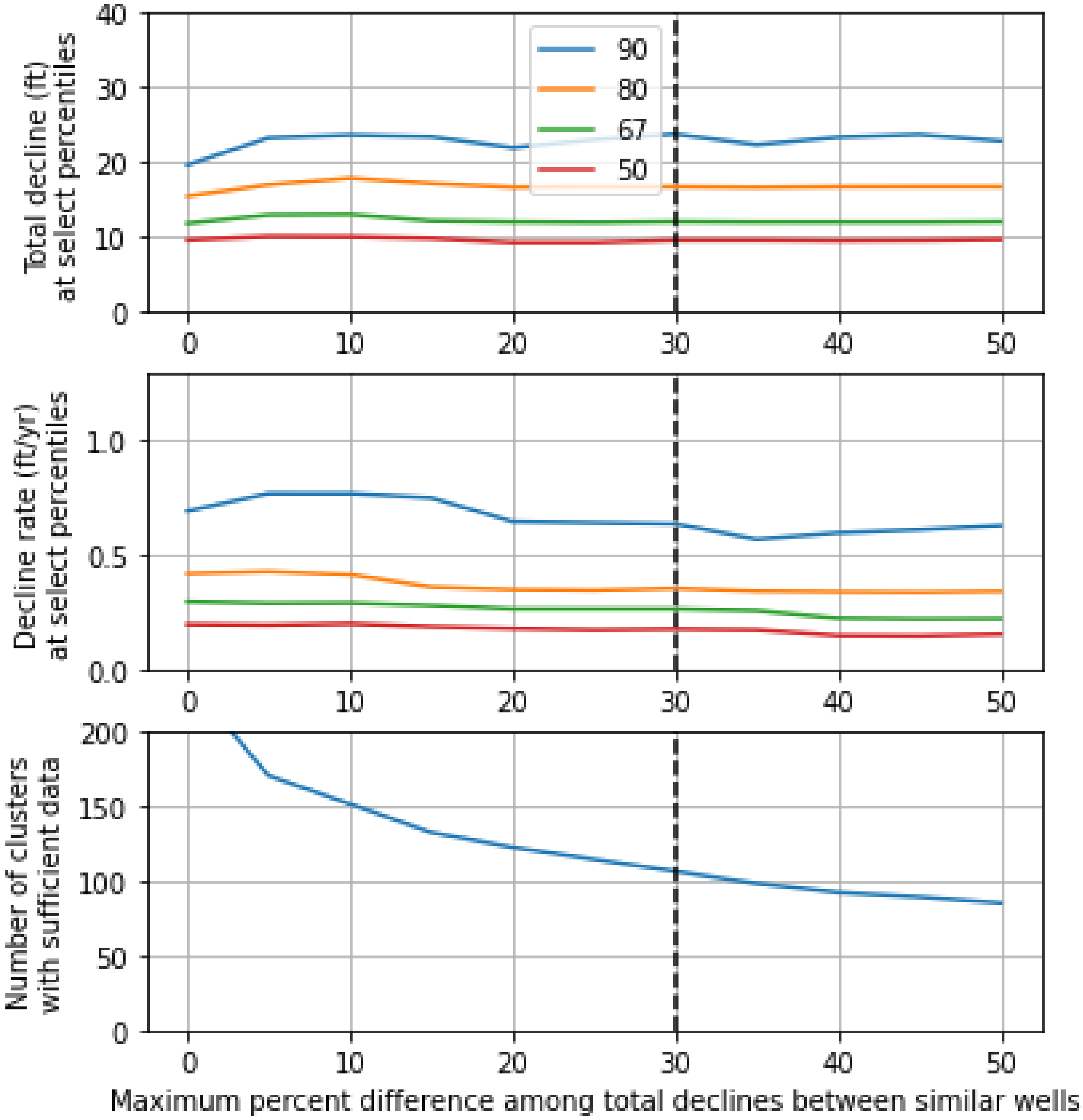

Figure 12: Sensitivity to the maximum percent difference between total declines allowed for wells characterized as similar (eligible to join the same cluster). This parameter had a large influence on the resulting number of clusters but not other results. The vertical dashed line in all subfigures represents the final threshold of 30%.

Minimum Initial Period of Data Collection for Rate Test Evaluation

The proposed definition of the rate test is intended to allow wells to remain Reasonably Stable across roughly decadal periods of the primary interannual variability in precipitation observed in Oregon (Gannett *et al.*, 2001; Abatzoglou *et al.*, 2014). The rate test selects the slowest rate of decline among those measured over any averaging window between 5 and 20 years leading up to the year being evaluated. This definition is therefore most able to remain Reasonably Stable when a full 20 years of data are available for comparison with a given measurement. However, in an area without sufficient data, applicants for water rights may wish to receive a determination of stability with fewer than 20 years of data collection. Breaks in data collection also mean that data are rarely available in all consecutive preceding years. The proposed rule accommodates these interests by requiring a span of 5 years before the rate test to be evaluated. However, in the context of this statewide evaluation of rates of decline in wells correlated with precipitation, it is not obvious that 5 years is the minimum span of data that should exist before the rate test is evaluated.

Instead, the analysis below requires that preceding data collection span a period of 10 years before the rate test may be applied. Following are rationale for this choice and a sensitivity analysis of the results. The intent of the threshold of the rate test is to balance sensitivity to the onset of rapid declines against robustness to the roughly decadal precipitation cycles in Oregon. Each well in this analysis is a sample of the statewide variability, and the test should be able to be applied to a full cycle's worth of data. Because the cycles typically last 10 years, the test requires roughly 10 years to operate as intended in Oregon. With fewer than 10 years of data, wells may coincidentally begin being measured during a declining limb of a cycle, and after only 5 years, the slowest average rate may be evaluated only over declining data without the benefit of any preceding deeper measurements. This situation is exemplified in well YAMH 4640 (Figure 6), which began measurement in the mid-1990s near the peak of cycles in precipitation and water levels. The first measurement eligible for analysis according to rule, in 2001, is at the trough of this cycle, and the best-fit preceding rate is 3.2 feet per year. This would then be the maximum rate of decline measured in that well. Requiring preceding data to span 10 years instead of 5 reduces the steepest decline rate to 0.8 feet per year in 2009.

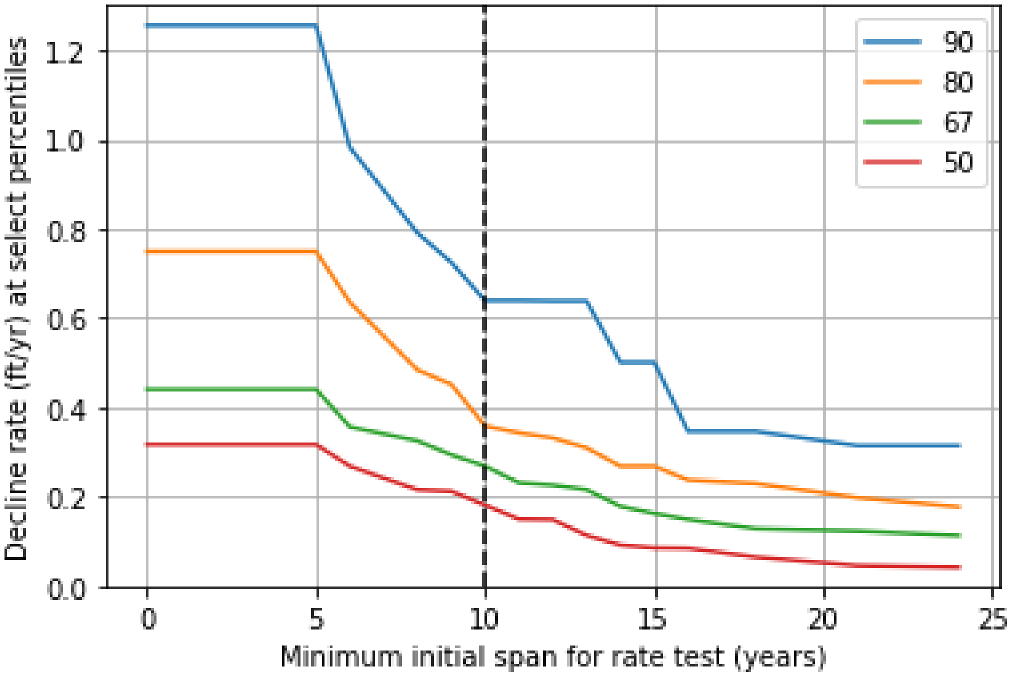

Figure 13: Sensitivity of rate of decline to minimum initial span of data before the rate test is applied.

One could go further to argue that this statewide analysis should be carried out only when preceding data span a full 20 years, in order to fully leverage the smoothing enabled by the form of the rate test. I suggest that 10 years is a suitable compromise between the 5 years required in rule and the 20-year maximum allowed. The sensitivity of the distribution of measured rates according to the rate test (Figure 13) suggests that 10-13 years is a relatively stable range of initial periods to enforce for evaluating the rate test. The 90th percentile rate is most sensitive and is treated as representative. It begins stable and above 1.2 feet per year from 0 through 5 years, reflecting the 5-year minimum in rule. Between 5 and 10 years, the 90th percentile declines rapidly to 0.64 feet per year, which is interpreted to reflect primarily the inclusion of water level measurements spanning a full cycle. From 10 through 13 years of minimum span, the 90th percentile remains constant, reinforcing the idea that more complete capturing of a full initial decadal cycle is the dominant effect in this regime compared with either longer-period cycles or a general increase in options for smoothing against more preceding measurements. This smoothing likely does play a role in reducing the 90th percentile between 13 and 16 years, as well as in reducing the lower percentiles tested in Figure 13 throughout the range from 5 through 20 years. Above roughly 16 years, all percentiles become relatively stable, reflecting diminishing returns from additional smoothing.

Results and Discussion

Total Decline from Pre-development Level

The statewide distribution of water level ranges in well clusters varies from 2 feet to 41 feet (Figure 14). The distribution is roughly concave between the 50th and 100th percentiles, such that the portion of wells represented by an additional increment of range decreases with increasing range. Among this upper half of observed ranges, select percentiles are indicated as dashed lines in Figure 14: the 50th percentile (10 feet), 67th (12 feet), 80th (17 feet) and 90th (24 feet).

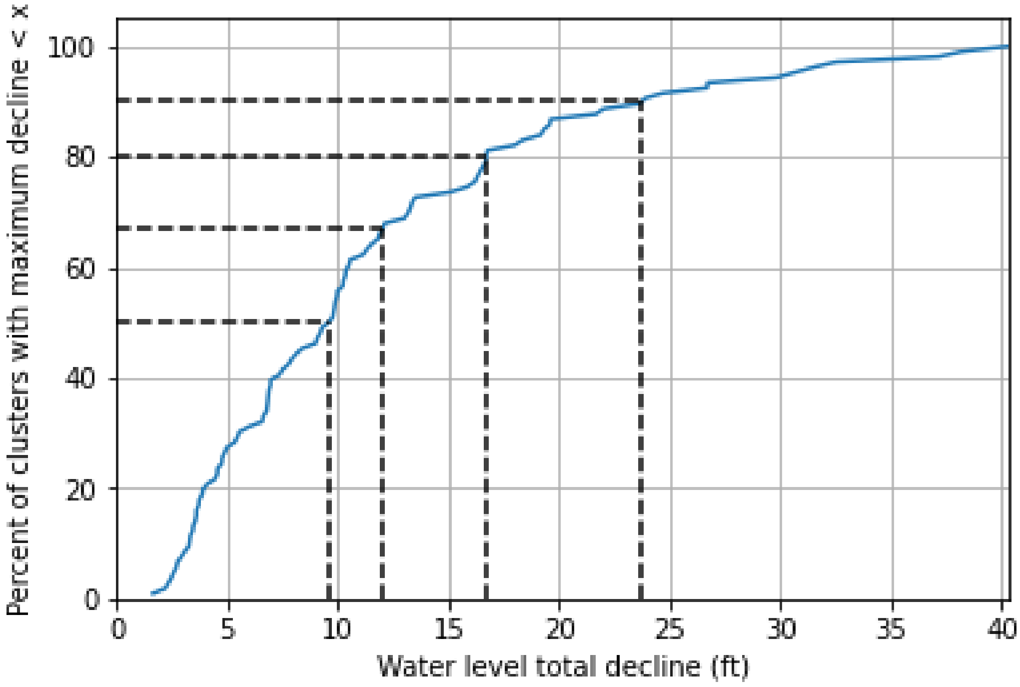

Figure 14: Cumulative distribution of well-specific maximum water level declines in detrended water level records correlated with regional precipitation. The total number of wells analyzed is 234 wells, which were grouped into 106 distinct clusters. Dashed lines indicate the rates corresponding to the 50th, 67th, 80th, and 90th percentiles, which are approximately 10, 12, 17, and 24 feet, respectively.

The well clusters included in Figure 14 are distributed across the state according to the map shown in Figure 15. This map shows that well clusters exceed the proposed threshold in many basins, and there is no discernable spatial trend.

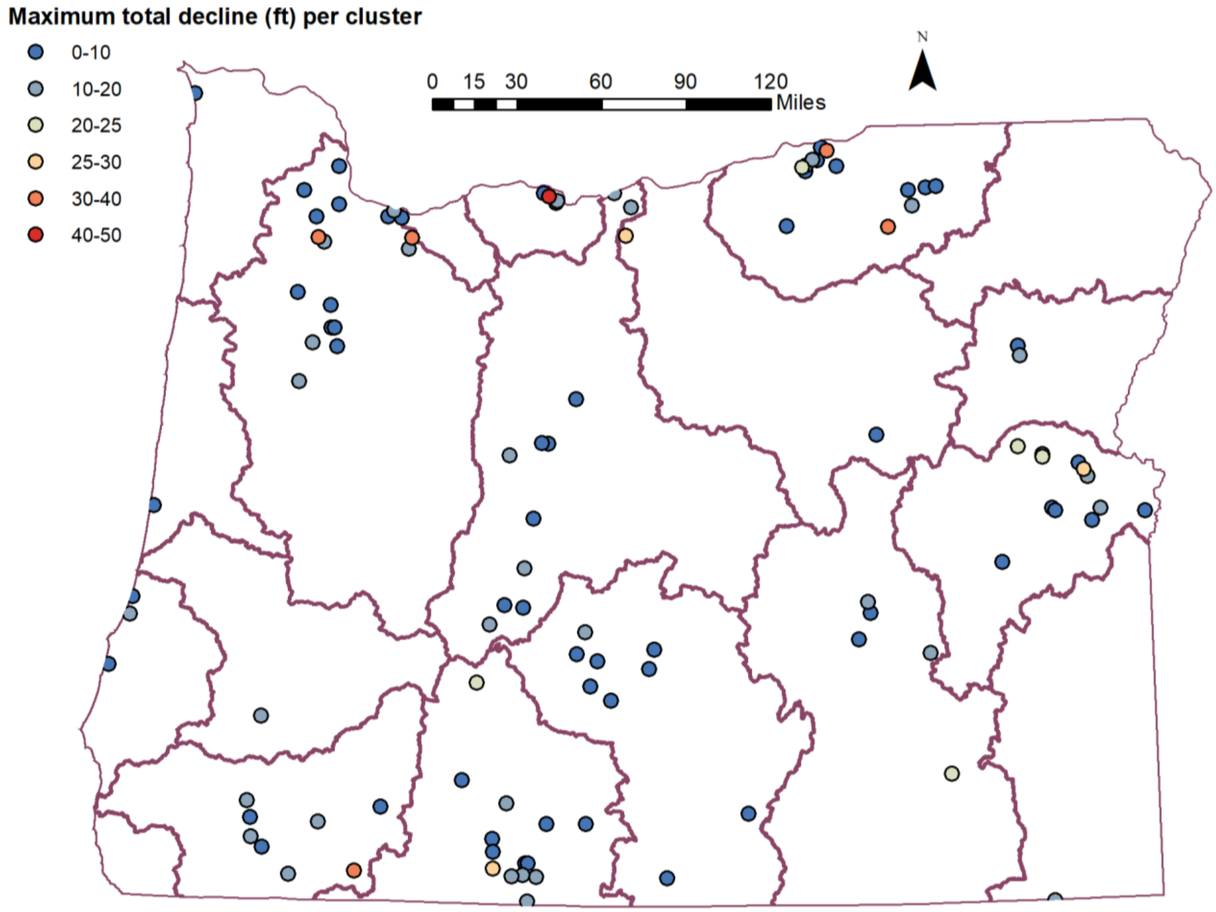

Figure 15: Map of 106 precipitation-correlated clusters colored by characteristic water level range (feet). The color scale is warm (yellow to red) for ranges greater than 25 feet and cool (green to blue) for ranges less than 25 feet.

The results shown in Figure 14 are relevant because they indicate the probability that a well influenced primarily by precipitation (and with limited long-term declines) would always remain Reasonably Stable, avoiding any oscillations in reasonable stability. Such oscillations are undesirable for the Department and for water rights applicants, but some instances of oscillation are an inevitable feature of any rule-based definition of Reasonably Stable Groundwater Levels in the context of both climatic and anthropogenic influences. Given that inevitability, it is also worth evaluating the proposed definition from another relevant perspective: the portion of time that a precipitation-correlated well would remain reasonably stable. This portion of time is typically higher than the portion of precipitation-correlated wells that are *always* Reasonably Stable, because even wells that decline to deeper than the allowable maximum total decline may rebound back into the realm of Reasonable Stability.

A sensitivity analysis of the portion of time is presented in Figure 16. That figure shows how the percent of time that the total decline test would be passed (characteristic decline magnitude is less than the allowed decline) depends on the maximum allowed decline (x-axis). The upper, blue line shows the mean percentage of time among all well clusters, including those that pass the total decline test over their entire period of record. This result is analogous to the one presented in Figure 14, and the percentage of time (Figure 16) is larger than the percent of wells always within the maximum (Figure 14) for all thresholds. With a total decline of less than 25 feet, the clusters pass the total decline test an average of 99% of the time. Even among the wells that do exceed the maximum allowed decline at some point in their period of record (orange line in Figure 16), the total decline is less than 25 feet over 86% of the time.

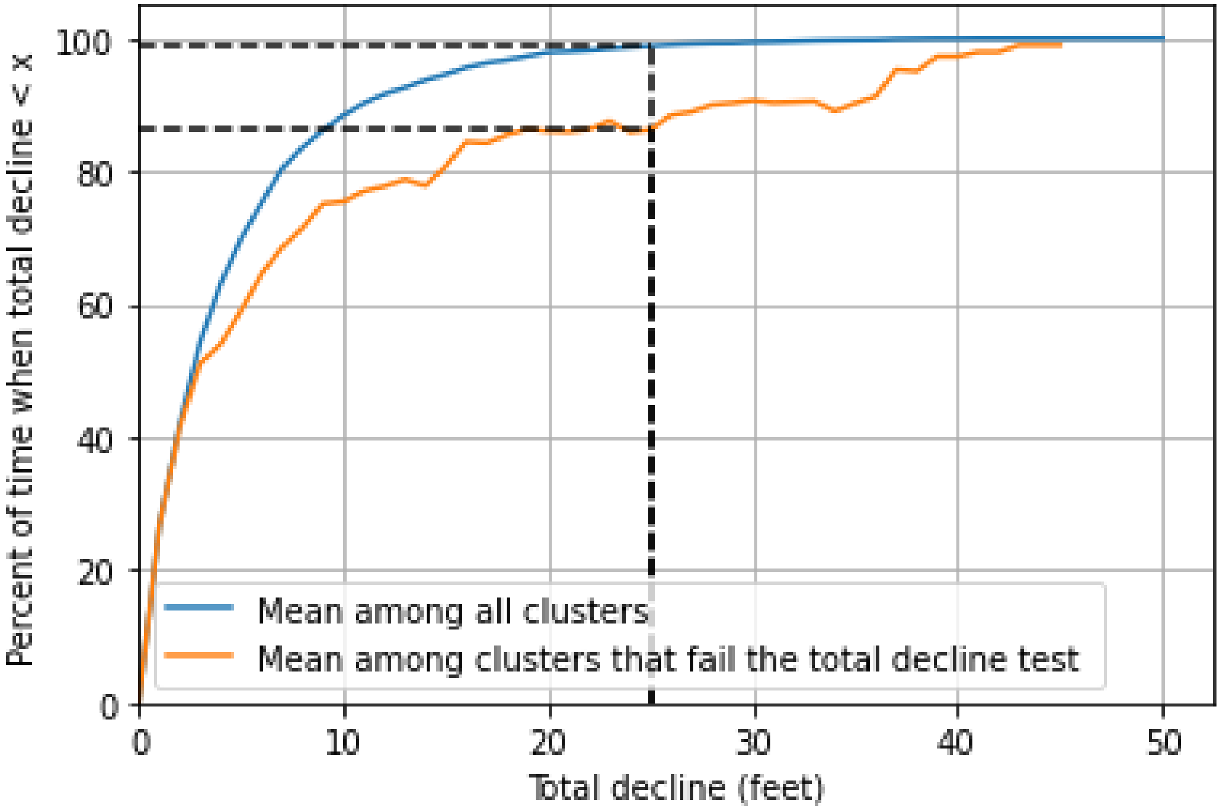

Figure 16: Sensitivity of the percent of time that the total decline test would be passed (decline from highest known less than the maximum allowed) as a function of the maximum characteristic total decline (x-axis) for a cluster. The blue line shows the mean percentage of time within the limit among all well clusters. The orange line shows the percent of time within the limit among well clusters that exceed the limit at some point. The black dashed lines indicate the percentages of time associated with a threshold of 25 feet: 99% over all well clusters, and 86% over those that fail the decline test at some point (have a maximum decline over 25 feet).

Distribution of Rates of Decline

The rate test in the proposed definition attempts to detect consistent declines of a significant magnitude while retaining Reasonable Stability across cycles up to 20 years in duration. To do so, it evaluates the slowest rate of decline among averaging windows of width 5 to 20 years leading up to the year being evaluated. It then compares that "test rate" against a threshold defining a significant rate of decline. Here, I characterize the range of rates of decline observed in the same detrended, precipitation-correlated water level records used in the preceding analysis. For each well, the "test rate" is evaluated in each year with sufficient data. The well's characteristic test rate is then taken as the fastest rate of decline among all valid years. As noted above, valid years are restricted in this analysis to those with a data point measured at least 10 years before. The distribution of well-specific test rates is then collected statewide in order to understand the portion of precipitation-correlated wells that would remain reasonably stable under a given maximum allowed (significant) rate of decline (Figure 17).

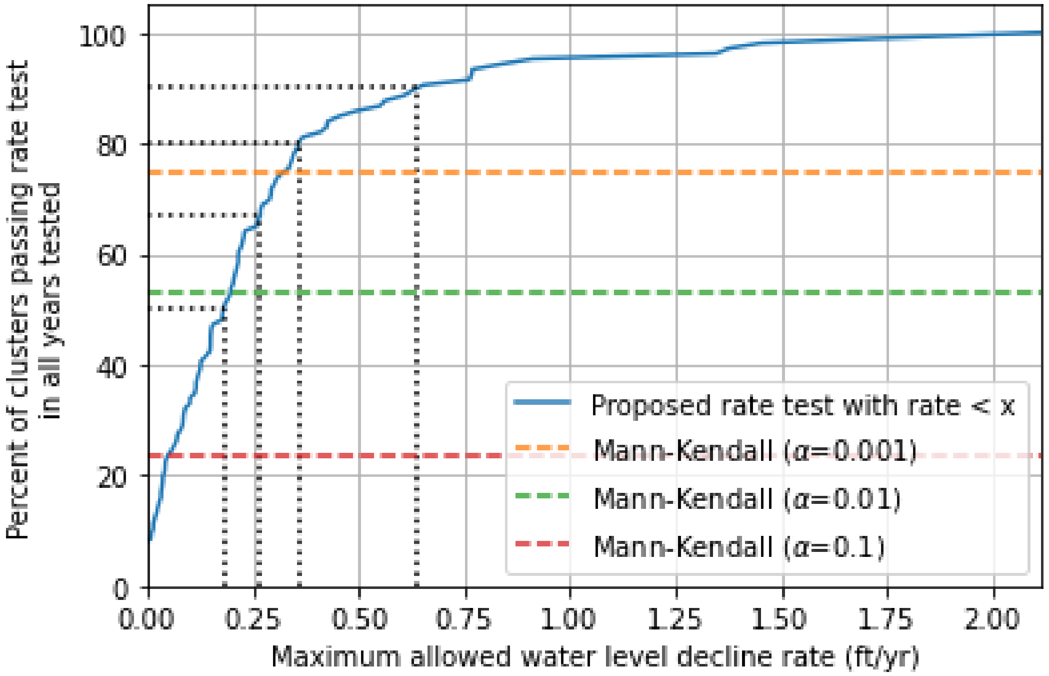

Figure 17: Characteristic rates of decline among wells statewide. Blue line: cumulative distribution of characteristic rates according to the proposed definition. The characteristic rate for each well was calculated as the maximum rate among all years that could be tested using the proposed definition with a minimum period of 10 years since the first measurement on that well. Black dotted lines indicate the rates corresponding to the 50th, 67th, 80th, and 90th percentiles, which are approximately 0.2, 0.3, 0.4, and 0.6 feet per year, respectively. Orange, green, and red dashed lines: percent of precipitation-correlated clusters that remained "not declining" over the same portion of each well's record, according to the Mann-Kendall test with the values of one-tailed significance levels alpha. Percent of clusters for alpha = 0.1, 0.01, and 0.001 are 24, 53, and 75 percent, respectively.

The percentage of clusters that pass the rate test over the entire tested period of record increases with larger rates (Figure 17). The median rate (among clusters) that encompasses the tested rates in each cluster is 0.2 feet per year, and the 90th percentile is 0.6 feet per year. Because of the restriction requiring a span of at least 10 years for evaluating the rate test, larger percents of wells would exceed these thresholds during the first 5 years that the rate was eligible to be tested according to the proposed rule. With only 5 years of data collection, the 90th percentile among clusters increases to 1.3 feet per year (Figure 13). However, these failures of the rate test would be expected to resolve with a few years of additional data collection in order to sample over a full decadal climate cycle.

In addition, the 90th percentile rate of 0.6 feet per year is significantly more tolerant of the decline in this analysis than the more common Mann-Kendall test. That test found only 35% of clusters passing the rate test at the standard significance level of alpha = 0.05. Even decreasing alpha to an extremely low value of 0.001 (making the test much less sensitive to declines) only increases the percent of clusters that remain “not declining” over the tested period of record to 75 percent of clusters. Thus, the proposed rate test offers transparency, simplicity, and robustness to cyclical declines compared with the Mann-Kendall test.

The Department is interested not only in the percent of wells that remain Reasonably Stable over a tested period of record, but also the percent of time that wells tend to remain reasonably stable. The former question is stricter and addresses the potential for any oscillations in the finding of Reasonably Stable, while the latter is practically important for establishing the overall consistency of a test with an expectation of finding water level fluctuations Reasonably Stable among the set evaluated here. The percent of time that water levels pass the proposed rate test as a function of the rate threshold is shown in Figure 18. In contrast with Figure 17, Figure 18 was generated without the 10-year minimum data span restriction, in order to more fully evaluate the impact of the rate limit on the period of record. The percentage of time increases from 79% to 100% as the rate maximum increases from 0 to 2 feet per year. At the rate of 0.7 feet per year, clusters pass the test over 97% of the time. This is larger than the percent passage (85%) by the Mann-Kendall test at standard alpha = 0.05. Among wells that fail the test at some point, the percent of time passing is smaller than the average including all clusters but still high. At the rate of 0.7 feet per year, these clusters still pass the test 90% of the time. By comparison, the Mann-Kendall test passes only 79% of the time. Thus, both in terms of the percent of well clusters and the percent of time over period of record, the proposed rate test with thresholds of 0.5 to 0.7 feet per year is more robust to the oscillations evaluated in this study.

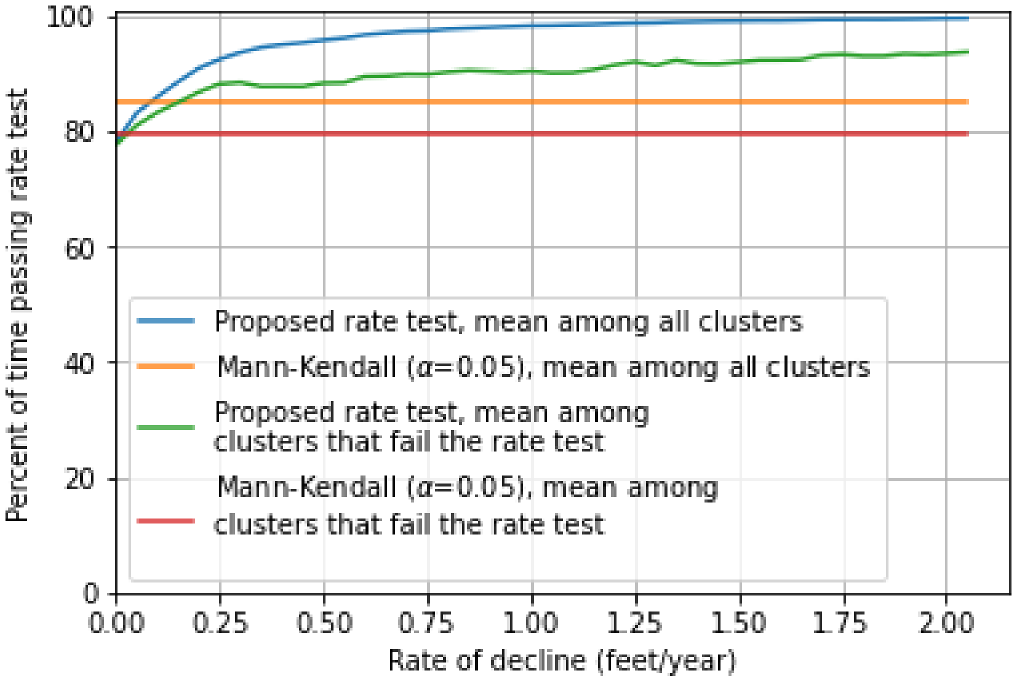

Figure 18: Percent of time that water levels pass the proposed rate test (blue and green) and are not declining according to the Mann-Kendall test (orange and yellow). For the proposed rate test, the percent of time depends on the maximum allowed rate of decline (x-axis), while the nonparametric Mann-Kendall test does not. The blue and orange lines show the mean percent of time among all wells, which addresses the overall robustness of these tests to the decline rates observed in the sample wells. Meanwhile, the green and red lines show the percent of time among wells that fail their respective rate tests during at least part of their records. These lines focus on wells that would fail their respective tests for stability at some point and indicate the portion of time that they nonetheless indicate a lack of declines. For generating this figure, the 10-year minimum span of data was dropped so that the 5-year minimum written into the proposed rule was the active restriction.

Text of Proposed Definitions

The following two definitions are proposed to be added to OAR 690-008:

(1) “**Annual High Water Level**” in a groundwater reservoir or part thereof means the highest elevation (shallowest depth) static groundwater level that exists in a year.

(9) “**Reasonably Stable Groundwater Levels**” means:

(a) The Annual High Water Levels as measured at one or more representative wells in a groundwater reservoir or part thereof:

(A) indicate no decline or an average rate of decline of less than XX feet per year over any immediately preceding averaging period with duration between 5 and 20 years. Four Annual High Water Levels are required to calculate the rate of change, and at least one of these must have been measured between 5 and 20 years before the year under evaluation. If either of these conditions is not met, then data are insufficient to perform this test, and the Department will presume that water levels are not reasonably stable; and

(B) compared with the pre-development static water level, have not declined or have declined by less than YY feet.

(b) Water level data must be available in the year under evaluation to perform the tests in (a). However, in the absence of current data, a finding of reasonable stability may be presumed to persist for a maximum of 5 years beyond the most recent Annual High Water Level.

(c) If groundwater has not yet been extracted or authorized for extraction from the groundwater reservoir, then water levels may be presumed to be reasonably stable.

(d) The limits in part (a) of this definition may be superseded by limits defined in a basin program rule adopted pursuant to the Commission’s authority in ORS 536.300 and 536.310.

(e) This definition does not apply to Critical Groundwater Areas designated under OAR 690-0010.

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