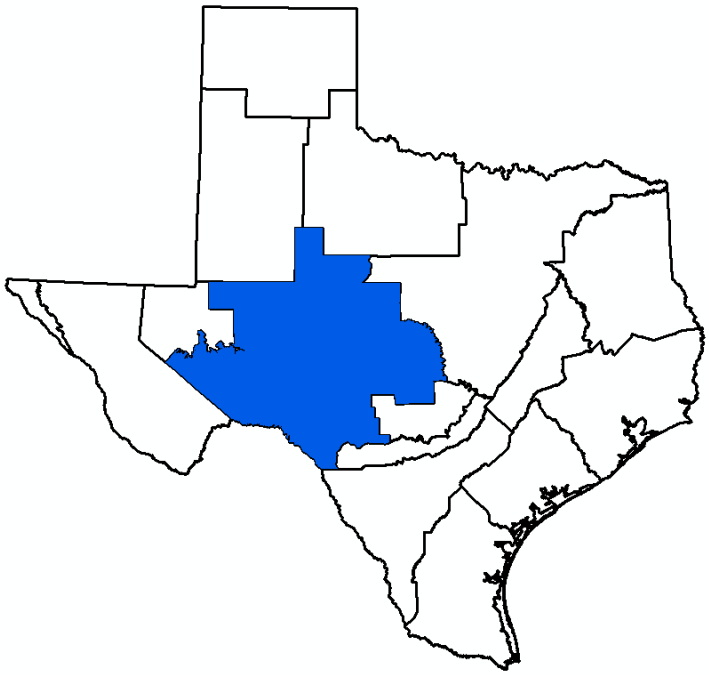
GMA 7 Technical Memorandum 21-01 - Final

Quantitative Assessment of Impacts: Conversion of Historic Groundwater Pumping from Irrigation Use to Municipal Use in Management Zone 1 of the Middle Pecos Groundwater Conservation District



Prepared for:
Groundwater Management Area 7

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August 28, 2021

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Geoscientist and Engineering Seal

This report documents the work and supervision of work of the following licensed Texas Professional Geoscientist and licensed Texas Professional Engineers:

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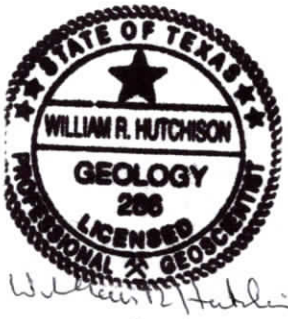
Dr. Hutchison completed the analyses and model simulations described in this report, and was the principal author of the final report.

8/28/2021



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1.0 Introduction

1.1 Background

The groundwater conservation districts in Groundwater Management Area 7 proposed desired future conditions for the Edwards-Trinity (Plateau) Aquifer (and other aquifers) at their meeting of March 18, 2021. After the meeting, the Groundwater Management Area 7 coordinator sent each groundwater conservation district the proposed desired future conditions, which began a 90-day public comment period. During the public comment period, each groundwater conservation district held a public hearing and received written comments.

Belding Farms provided written comments to Middle Pecos Groundwater Conservation District in a letter dated June 4, 2021, which was an updated version of a letter sent on February 2, 2021. Mr. Ryan Reed, representing Belding Farms/Cockrell Investments, provided oral comments at the Middle Pecos Groundwater Conservation District public hearing on June 15, 2021. Finally, Belding Farms provided additional written comments in a letter to Middle Pecos Groundwater Conservation District dated June 17, 2021.

The June 4, 2021 letter stated that, since the adoption of the 2016 desired future conditions, "a permit has been granted which would allow the export of water from the MPGCD for municipal use". Further, the letter stated that "groundwater production for municipal purposes can have different pumping patterns as compared with agricultural uses". The stated concern in the letter is that the "differences can have significant effects on localized groundwater availability and reliability, and to the anticipated aquifer recovery rate". Finally, the comment concluded that "we anticipate these impacts to be most pronounced during high water use demands typical of the summer months".

The June 4, 2021 letter also characterized the modeling that has been completed as "flawed, lacks specificity in identifying the changes in pumping cycles on a monthly basis, and is not representative of the impacts seen during actual pumping".

At the public hearing, Mr. Reed requested that a quantitative assessment be completed to evaluate how pumping of about 28,000 AF/yr of water on a municipal schedule would affect the proposed desired future conditions.

1.2 Scope of Analyses

The issue raised by Mr. Reed refers to the Fort Stockton Holdings operating permit that was approved by the Middle Pecos Groundwater Conservation District in 2017. This operating permit authorizes pumping 28,400 AF/yr for agricultural, municipal, or industrial use and the groundwater can be exported outside of Pecos County. As part of approval process for the operating permit, Fort Stockton Holdings reduced their Historic and Existing Use permit by the same amount (28,400 AF/yr). Thus, the total permitted pumping for Fort Stockton Holdings (and other wells within Management Zone 1) remained the same. Thus, the stated concern revolves around the potential impact of changing the timing of the pumping from an irrigation season to a "municipal"

schedule. Potentially, this could mean pumping anytime during the year rather than only during the irrigation season. In Pecos County, the irrigation season can extend from February or March to September or October depending on several factors (crop type, rainfall, etc.).

The timing of "municipal" pumping in the operating permit is not as clear, because the permit only provides limitations on annual production. It is possible that the pumping would represent a baseline supply and pumping could be constant each month (January to December). It is also possible that the pumping would be highest in the typical peak municipal demand period (June to September), and the pumping would represent a peaking supply. In general, pumping for municipal use during the summer would have similar effects as pumping for irrigation since the timing of the pumping would be similar, but concentrating the pumping over a few months at the end of the irrigation season would have greater impacts than if the pumping was spread out over the entire irrigation season. At the current time, there is no specific "municipal" schedule associated with the Fort Stockton Holdings operating permit.

Many of the comments are misplaced regarding the scope and purpose of joint planning and the development of desired future conditions. Some of the specificity that is requested is generally outside the scope of joint planning given the size of the area involved and the time frame of the planning period. It must be emphasized that the joint planning process is a "planning process" that has different goals and objectives than "management" activities or groundwater pumping "regulation".

Specifically, in the June 4, 2021 letter at the bottom of page 4, there is a statement that requests an analysis that links the desired future conditions (that are defined as an average drawdown over the GMA 7 portion of Pecos County, an area of over 3,000 square miles over a 60-year period), to the "establishment of a summer threshold". The special permit conditions in the Fort Stockton Holdings operating permit that established a series of winter and summer thresholds in 11 individual monitoring wells. Pumping reductions are specifically tied to the winter thresholds. No such pumping reduction requirements are in the special permit conditions for not meeting summer thresholds. The lack of pumping reductions associated with the summer threshold in the operating permit has been an issue of concern for Belding Farms since 2017 when the permit was approved.

Although the joint planning process and the establishment of desired future conditions is a planning activity by GMA 7, and many of the issues raised in the comments are more properly considered management or regulatory activities by Middle Pecos GCD, this technical memorandum addresses the modeling-related comments.

1.3 Organization of Technical Memorandum

The technical memorandum is organized as follows:

- Section 2 presents a summary of findings and conclusions
- Section 3 documents the pumping capacities and permit limits of the 25 wells in the Fort Stockton Holdings operating permit.

- Section 4 documents an analysis of groundwater levels in 24 Belding Farms wells. The stated concern since 2017 of Belding Farms is the ability of the Belding Farms wells to maintain production during the irrigation season. The data for these wells was previously provided to Middle Pecos Groundwater Conservation District in 2018. Middle Pecos Groundwater Conservation District previously completed a review of these data (Hutchison, 2018).
- Section 5 presents a summary of the two groundwater models used in these analyses.
- Section 6 summarizes results of four simulations that were completed using the Groundwater Availability Model used in the joint planning process in GMA 7. The results are applicable when addressing comments related to the impacts of seasonal pumping on the desired future conditions.
- Section 7 summarizes four initial simulations that were completed using the Western Pecos County groundwater model, which is more appropriate to use when addressing comments that are related to specific issues in Management Zone 1 and in individual wells. Results of these simulations are reported as drawdowns in individual Belding Farms wells.
- Section 8 summarizes four baseline simulations (two with no pumping from the FSH operating permit wells and two with pumping on an irrigation schedule) and eight simulations that consider the shift of 28,400 AF/yr of agricultural pumping to alternative municipal pumping schedules and evaluates the impacts on Belding Farms wells.

2.0 Summary of Findings and Conclusions

FSH Operating Permit Wells: Based on operating permit limits, there is significant variability in the installed capacity of the 25 FSH wells. Each well has its own installed capacity and annual production limits. Assuming 24-hour per day production at the listed capacities, 12 wells can pump their annual limit in less than four months, but nine wells require over six months to reach their annual limit.

Belding Farms Wells Groundwater Data: Minimum groundwater elevations (maximum depth to water) in the Belding Farms wells typically occur at the end of the irrigation season. An analysis of data provided by Belding Farms in 2018 shows that the most frequent month with minimum groundwater elevations is August.

GAM Simulations: The Groundwater Availability Model for the Edwards-Trinity (Plateau) Aquifer (GAM) is the model used in the joint planning process that leads to the development of desired future conditions. Simulations using the GAM quantitatively demonstrated that there is no substantial difference in predicted average drawdown in the GMA 7 portion of Pecos County and in Management Zone 1 over a 60-year period when using annual stress periods, monthly stress periods with constant pumping, and monthly stress periods using different patterns of seasonal pumping.

Initial WPC Model Simulations: Simulations with alternative patterns of seasonal pumping using the Western Pecos County Groundwater Model (WPC Model) quantified the changes in monthly groundwater elevations at 22 well sites associated with Belding Farms wells. The simulated interannual fluctuations in simulated groundwater elevation from these simulations are consistent with groundwater drawdown data provided by Belding Farms in 2018. Thus, it was concluded that the WPC could be used to simulate alternative schedules of municipal pumping from the FSH Operating Permit wells and evaluate the impacts on Belding Farms wells.

Alternative Municipal Pumping Simulations with WPC Model: Simulations with alternative patterns of seasonal pumping and alternative operations of FSH operating permit wells quantified the changes in monthly groundwater elevations at 22 well sites associated with Belding Farms wells. The significant findings and conclusions are:

- If the FSH operating permit wells were not pumped at all, the interannual variation in groundwater elevations in the Belding Farms well would be between 9 and 16 feet, depending on the length of the irrigation season.

- The interannual variation in groundwater elevations in the Belding Farms wells under scenarios where all wells in Management Zone 1 are operating on an irrigation schedule is between about 20 and 29 feet, depending on the length of the irrigation season.

- As noted above, the current installed pump capacity and per well limits associated with each FSH operating permit well means that 12 wells can pump

the full annual permit limit in less than 4 months, but nine wells must be pumped for over six months to achieve the full permit limit. Under the installed pump capacity and current annual production limits in the operating permit, the interannual variation in the groundwater elevations of the Belding Farms wells is between about 22 and 27 feet, depending on the length of the irrigation season.

- If the constraint of installed pump capacity and the current annual production limits (on a per well basis) for the FSH operating permit were relaxed and the full amount of permitted annual pumping could be extracted in four months, the interannual variation in the groundwater elevations in the Belding Farms wells is about 31 feet.

- If the constraint of installed pump capacity and the current annual production limits (on a per well basis) for the FSH operating permit were relaxed and the full amount of permitted annual pumping could be extracted in three months, the interannual variation in the groundwater elevations in the Belding Farms wells is about 33 feet.

Summary Conclusion: Under current installed capacity and annual production limits of each well in the FSH Operating Permit, the results of simulating pumping on a municipal schedule demonstrate that impacts to the Belding Wells are nearly identical to simulated impacts to the Belding Wells when FSH Operating Permit wells are operated on an irrigation schedule. The current permit conditions require adherence to the current pump capacity and annual production limits of each well. Simulations that assumed relaxation of these limits (i.e. all FSH Operating Permit pumping over a three- or four-month period) did result in higher impacts to Belding Farms wells, but did not impact long-term drawdown, which is a groundwater planning issue.

Groundwater Management and Regulation Issues: The significance of the additional impacts associated with concentrated pumping of FSH Operating Permit wells over a three- or four-month period are unknown. However, understanding the significance are more properly groundwater management and groundwater regulation issues, not groundwater planning process issues. Additional data and a more robust analytical exercise with a more appropriate model would be needed to assess the significance of these simulated impacts. Currently, there has been no request submitted to modify the installed pump capacity and/or the annual limits of individual wells, so there is no urgent need to evaluate the significance further. However, this analysis does provide some background if such a request is made in the future. Any such request would be made to the Middle Pecos Groundwater Conservation District (not Groundwater Management Area 7). Such a request would be analyzed by and would be approved by the Middle Pecos Groundwater Conservation District as part of its groundwater management and groundwater regulation activities.

3.0 Fort Stockton Holdings Wells in Operating Permit

Table 1 summarizes data taken from the Fort Stockton Holdings operating permit application for the 25 wells in the permit. Data include the well name, well coordinates, elevation, aquifer, permit limit (in AF/yr) and the peak production rate of the well (in gallons per minute). Table 1 also includes columns that show the results of the following calculations:

- Peak rate of production in AF/month and in AF/day. These values were calculated assuming operation at peak rate 24 hours per day.
- The number of months to reach annual permit limits when pumping at the peak rate (assumed a 30-day month) and the number of days to each annual permit limits when pumping at the peak rate.

Table 1. Summary of FSH Wells in Operating Permit

From Appendix B-1 of Permit Application							Calculated Values Based on Peak Rate of Production and Annual Permit Limits			
Well	Longitude	Latitude	Elevation (feet AMSL)	Aquifer	Operating Permit (AF/yr)	Peak Rate of Production (gpm)	Peak Rate of Production (AF/30 day month)	Peak Rate of Production (AF/day)	Months at Peak Rate to Reach Annual Permit Limit	Days at Max Rate to Reach Annual Limit
C-1	-103.0287	30.89099	3,005	Edwards	849	2,000	265.15	8.84	3.20	96.06
C-2	-103.0314	30.89109	3,006	Edwards	1,273	3,000	397.73	13.26	3.20	96.02
C-3	-103.0346	30.89126	3,008	Edwards	1,273	3,000	397.73	13.26	3.20	96.02
C-4	-103.0258	30.88655	3,006	Edwards	849	2,000	265.15	8.84	3.20	96.06
M-1	-103.0261	30.757445	3,293	Edwards	2,129	2,200	291.67	9.72	7.30	218.98
M-2	-103.0262	30.764695	3,279	Edwards	1,419	1,500	198.86	6.63	7.14	214.07
M-3	-103.0262	30.768281	3,277	Edwards	2,149	2,200	291.67	9.72	7.37	221.04
M-4	-103.0261	30.779308	3,262	Edwards	1,758	1,800	238.64	7.95	7.37	221.01
M-5	-103.0077	30.792598	3,238	Edwards	1,328	2,200	291.67	9.72	4.55	136.59
M-6	-103.006	30.792928	3,231	Edwards	1,727	2,000	265.15	8.84	6.51	195.40
M-7	-103.0064	30.794657	3,213	Edwards	1,727	2,000	265.15	8.84	6.51	195.40
M-8	-102.9936	30.800244	3,195	Edwards	928	1,000	132.58	4.42	7.00	209.99
M-9	-103.0262	30.772017	3,282	Edwards	332	800	106.06	3.54	3.13	93.91
NC-2	-102.9637	30.899027	2,981	unknown	212	500	66.29	2.21	3.20	95.95
S-1	-103.0435	30.815876	3,152	Edwards	458	1,400	185.61	6.19	2.47	74.03
S-2	-103.0438	30.823565	3,144	Edwards	1,352	1,800	238.64	7.95	5.67	169.97
S-4	-103.0135	30.827628	3,141	Edwards-Trinity	1,839	2,100	278.41	9.28	6.61	198.16
S-6	-103.0435	30.830453	3,121	Edwards	424	1,000	132.58	4.42	3.20	95.95
S-11	-103.0259	30.83056	3,128	Edwards-Trinity	1,381	2,500	331.44	11.05	4.17	125.00
S-13	-103.0172	30.830579	3,131	Edwards	920	1,800	238.64	7.95	3.86	115.66
S-18	-103.0103	30.859055	3,066	Edwards	406	1,000	132.58	4.42	3.06	91.87
S-19	-103.0218	30.859023	3,074	Edwards-Trinity	406	1,200	159.09	5.30	2.55	76.56
S-20	-103.0218	30.860309	3,064	Edwards	406	1,400	185.61	6.19	2.19	65.62
S-26	-103.0372	30.85887	3,077	Edwards	1,318	2,000	265.15	8.84	4.97	149.12
S-32	-103.0351	30.858848	3,088	Edwards	1,537	1,650	218.75	7.29	7.03	210.79
Totals					**28,400**	**44,050**	**5,840**			

Please note that the installed capacity of the wells and the annual permit limits suggest that it takes several months operating at full capacity to pump the annual limit of the operating permit. Twelve of the wells can reach the full limit in less than 4 months. However, nine wells require over six months of pumping to reach the operating permit limit.

4.0 Annual Minimum Depth to Water in 24 Belding Farms Wells

The data provided to Middle Pecos Groundwater Conservation District by Belding Farms for 24 of their wells in 2018 were analyzed to find the annual minimum depth to water reading for each year and for each well. The FORTRAN program *minmo.exe* was written for this purpose. All files associated with this analysis using a Google Drive folder that can be accessed at:

https://drive.google.com/drive/folders/15UanCjnyORvf9YgG72uEJQO0i7tlMnrT?usp=sharing

The program reads the file *BeldingStaticDTW.csv* (which was extracted from the data provided by Belding Farms in 2018). The program then finds the minimum depth to water for each well in each year and fills an array with the month number.

The program then writes the results to an output file named *minmo.dat*. This file was imported into Excel and saved as *BeldingMinMoCount.xlsx* for further processing. Each row of the file *minmo.dat* is a year and each column is a well. The month with the minimum depth to water is written to *minmo.dat*. If there are no data for a well in a particular year, the default value is -999. The first tab of *BeldingMinMoCount.xlsx* is the data from *minmo.dat.* The -999 values are removed from the results. The second tab of *BeldingMinMoCount.xlsx* is a summary that presents a monthly count of the minimum values.

There are 440 well-year results in the *minmo.dat* tab, and the *Summary* tab shows that August has the most minimum depth-to-water values. Figure 1 summarizes the data in the *Summary* tab. Thus, August is the month with the most minimum depth-to-water data. September has the next most, and July is slightly less than September.

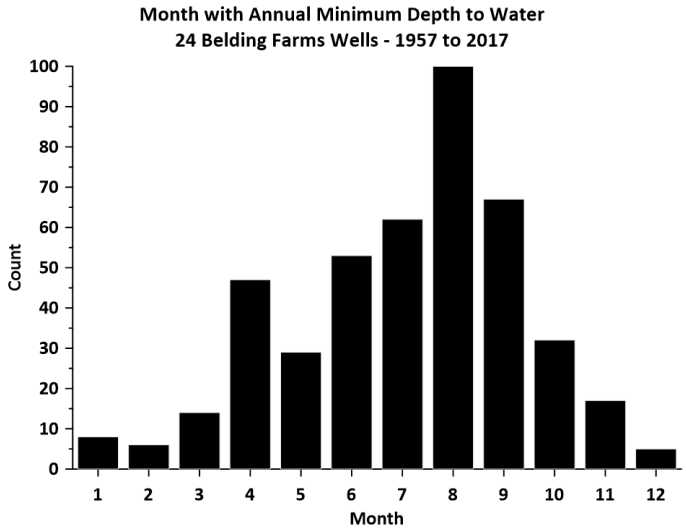

Figure 1. Month with Annual Minimum Depth to Water

There are instances in the Belding data where depth to water data were not collected in every month. Therefore, this analysis can only be considered cursory. However, the results demonstrate that the lowest groundwater levels each year tend to occur at the end of the irrigation season.

5.0 Groundwater Model Summary Descriptions

Two groundwater models were used for this effort:

- The alternative Groundwater Availability Model for the Edwards-Trinity (Plateau) Aquifer, also known as the one-layer model (Hutchison and others, 2011), has been used in the joint planning process since 2010. The model fully covers Pecos County and has one square mile grid cells (640 acres). The model calibration period was 1931 to 2005, with annual stress periods.
- The Western Pecos County Groundwater Model (WPC Model), documented in Harden and others (2011), and was reviewed by Hutchison (2017). The focus of the model development and calibration was the Leon-Belding Area (i.e. Management Zone 1). The model does not cover the full extent of Pecos County, but does fully cover Management Zone 1 as defined by the Middle Pecos Groundwater Conservation District. The model has grid cells that are 2,000 ft by 2,000 ft (about 91 acres or about 0.14 square miles). The model calibration period was 1945 to 2010, with annual stress periods.

5.1 Comparison of Pumping – Calibration Periods

The groundwater pumping from the two model were compared as follows:

- Figure 2 presents the pumping comparison in Management Zone 1,
- Figure 3 presents the pumping comparison for the Fort Stockton Holdings (FSH) wells associated with the operating permit, and
- Figure 3 presents the pumping comparison for the Belding Farm wells.

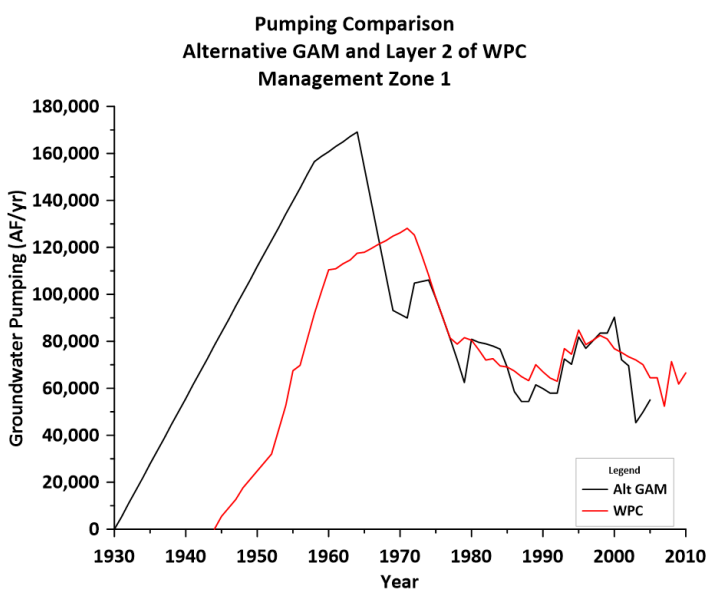

Figure 2. Pumping Comparison - Management Zone 1

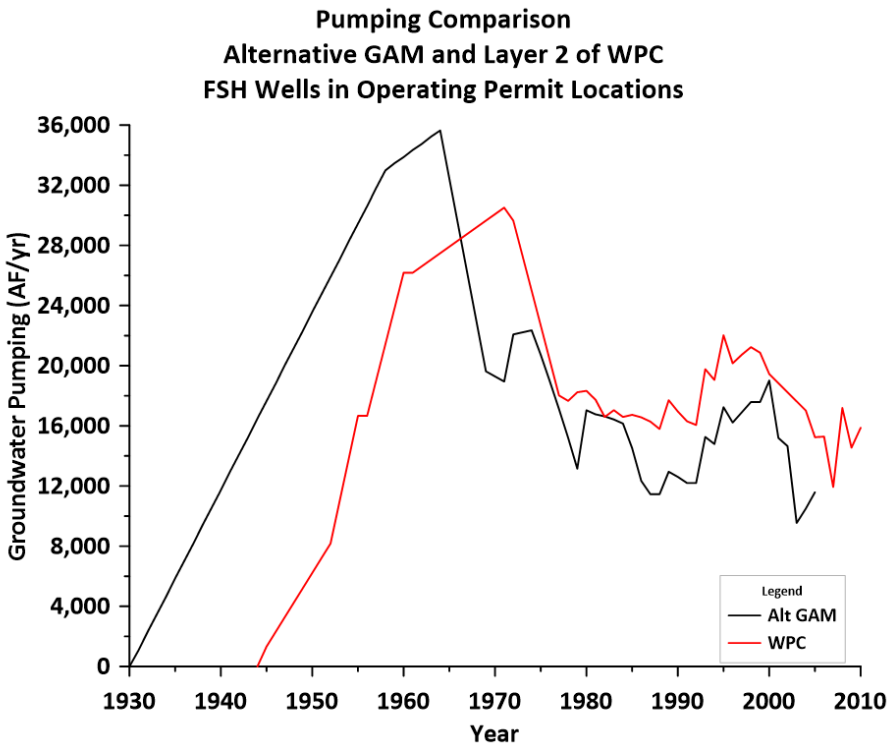

Figure 3. Pumping Comparison - FSH Operating Permit Wells

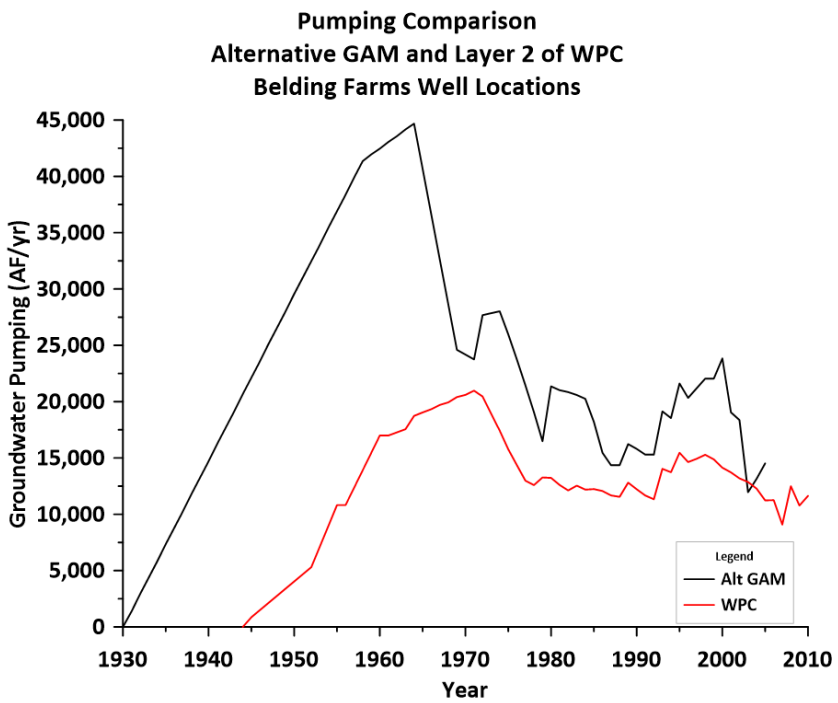

Figure 4. Pumping Comparison - Belding Farms Wells

Please note that both models have similar pumping estimates in Management Zone 1 after the mid-1970s. In general, the Alternative GAM has slightly lower estimates of pumping in the FSH Operating permit wells than the WPC Model. Also, the Alternative GAM has slightly higher estimates of pumping in the Belding Farms wells than the WPC Model.

During development of the desired future conditions starting in 2010, several simulations have been completed using the Alternative GAM. The assumed pumping for the GMA 7 portion of Pecos County is 117,309 AF/yr, and the pumping from Management Zone 1 is 74,134 AF/yr.

The WPC Model was used in a series of evaluations by Hutchison (2017) that used pumping in 2010 (the last year of the calibration period) as the baseline. In the WPC Model in the current Management Zone 1, pumping was 66,561 AF/yr in layer 2 (Edwards) and 6,474 AF/yr in layer 3 (Trinity), for a total Edwards-Trinity pumping of 73,035 AF/yr, which is reasonably close to the GAM estimate of 74,134 AF/yr. Pumping from the FSH wells associated with the operating permit in 2010 was 15,869 AF/yr for layer 2 (Edwards) and 450 AF/yr for layer 3 (Trinity), for a total Edwards-Trinity pumping of 16,319 AF/yr. This total is less than the 28,400 AF/yr associated with the operating permit. As developed further below, the pumping from the FSH wells was modified for simulations using the WPC Model as part of this analysis.

6.0 Simulations with the Alternative GAM

As detailed below, the Alternative GAM was used to complete simulations that quantitatively demonstrated that there is no substantial difference in predicted drawdown over a 60-year period when using annual stress periods, monthly stress periods with constant pumping, and monthly stress periods using different patterns of seasonal pumping.

6.1 Annual Stress Periods

The alternative GAM was used as part of the development of the desired future conditions in 2010 and 2016. The proposed desired future conditions in 2021 are the same as the final desired future conditions in 2016 (Hutchison, 2018b and Hutchison 2018c). In the GMA 7 portion of Pecos County, the desired future condition is expressed as 14 feet of drawdown from 2011 to 2070. The associated pumping in Pecos County (i.e. the modeled available groundwater) is 117,309 AF/yr. All files associated with the base run using a Google Drive folder that can be accessed at:

https://drive.google.com/drive/folders/11Qsqqdo6A6me38XPbdKKTonhMm_JPcho?usp=sharing

For purposes of this analysis, the average drawdown in Management Zone 1 was calculated from 2011 to 2070, and the pumping in Management Zone 1 was also calculated. These were accomplished with a FORTRAN post-processor *postprocann.exe* (also included in the above Google Drive link). Average drawdown in Management Zone 1 from 2011 to 2070 is 45 feet, and pumping is 74,134 AF/yr.

The issue raised in the Belding Farms comments cannot be answered with an annual model. The desired future conditions for GMA 7 were set from 2011 to 2070, and it was assumed that interannual variations were not relevant given the length of the planning period and objectives of the joint planning process. However, in response to the comment and given the nature of the expected change in a significant amount of Management Zone 1 pumping from agricultural to a mix of agricultural and municipal, a preliminary conversion of the alternative GAM to a monthly model was needed to provide preliminary answers to the questions that have been raised. An updated model that is currently in development will use monthly stress periods, at least for recent years, and will be used to address these groundwater management issues more directly and more robustly in the future.

6.2 Monthly Stress Periods – Base Case (Constant Pumping Rate)

The model input files were modified to run the simulation using monthly stress periods. For this base run, average annual rates of pumping and constant rates of recharge were maintained to demonstrate that the average drawdowns do not change using monthly stress periods or annual stress periods. All other input files were modified to handle the monthly stress periods. All files associated with this base run of the monthly stress period alternative GAM can be accessed at:

https://drive.google.com/drive/folders/16jQtUdSRbKl2AIrmfBb_XzbELXRxpCPx?usp=sharing

Average drawdown and pumping were extracted from model results using a FORTRAN post-processor *postprocann.exe* (also included in the above Google Drive link).

For the GMA 7 portion of Pecos County, average drawdown was calculated as 14 feet (13.62 feet for the monthly base model versus 13.67 feet for the annual model). Pumping for all of Pecos County was calculated as 240,206 AF/yr for the monthly base model (as compared with 240,208 AF/yr for the annual model). These differences are attributable to rounding error and are not significant for the purposes of this analysis.

Average drawdown in Management Zone 1 from 2011 to 2070 is using the monthly base model was calculated as 45 feet (45.40 feet for the monthly base model versus 45.33 feet for the annual model) and pumping from the monthly base model is 74,131 AF/yr (as compared to 74,134 for the annual model). As with the GMA 7 portion of Pecos County, these differences are attributable to rounding error and are not significant for the purposes of this analysis.

Based on these results, the change to monthly stress periods results in essentially the same drawdown for the GMA 7 portion of Pecos County and Management Zone 1 as the annual stress period simulation. The base monthly simulation did not change any assumptions relative to the simulated rate of pumping and recharge, just specified them at a constant monthly rate that changes each year rather than at annual rate that changes each year. The objective for this simulation was to test the model code relative to rounding error and other components of the simulated groundwater system.

6.3 Monthly Stress Periods with Seasonal Pumping

Three alternative seasonal pumping simulations were completed:

- Pumping from January to June, no pumping from July to December (6 months on, 6 months off, establish a baseline based on equal pumping and equal recovery time for end of year comparison).
- No pumping from January to March, pumping from April to September, no pumping from October to December (6 months on, 6 months off, agricultural pumping pattern)
- No pumping from January to February, pumping from March to October, no pumping from November to December (8 months on, 4 months off, agricultural pumping pattern)

All files for these simulations, including a pre-processor that was written to develop input pumping files (*ScenWel.exe*) and a post-processor that was written to extract pumping and drawdown results (*MonthlyScenPostProc.exe*) can be accessed at:

https://drive.google.com/drive/folders/1pfQ1wO6HeouqtH3DfiqO1t_VZ4p19BDJ?usp=sharing

6.3.1 January to June Pumping Scenario

As discussed above, the monthly simulation where pumping was held constant throughout the year was completed to quantitatively demonstrate that the average drawdowns do not change using

monthly stress periods or annual stress periods. Similarly, this simulation was completed to quantitatively demonstrate that doubling the monthly rate of pumping for six months followed by six months of no pumping would results in essentially the same drawdowns as a constant monthly pumping or as a simulation that used annual stress periods. This pattern is clearly not realistic in terms of an irrigation season but was an important intermediate analytical step to interpret the results of the other two seasonal pumping scenarios.

6.3.2 April to September Pumping Scenario

This scenario has the same rates of pumping as the January to June pumping scenario (double the average annual rate of pumping) but assumes a six-month irrigation season. When evaluating end-of-year groundwater elevations or end-of-year drawdowns (i.e. end of December), this scenario does not have a full six-month recovery period as in the January to June scenario. Thus, this scenario provides a means to quantitatively evaluate differences in end-of-year drawdown without the benefit of a full six months of recovery.

6.3.3 March to October Pumping Scenario

This pumping scenario assumes pumping for eight months and four months of recovery. The pumping rate is 1.5 times the annual average rate (i.e. evenly distributed over the eight months). This is a more realistic scenario as the irrigation season is generally considered to be about eight months with some variation due to crop type and weather. This scenario provides a means to quantitatively evaluate differences in end-of-year drawdown over a short period of recovery (two months).

6.3.4 Summary of Seasonal Pumping Results

Table 2 presents a summary of results from the simulation using the GAM with annual stress periods (i.e. the basis for the desired future condition in 2016 and proposed desired future condition for 2021), and the results of the four simulations using the GAM with monthly stress periods as developed above.

Table 2. Summary of GAM Simulations - Drawdown and Pumping

	Scenario				
	Annual Stress Periods	Monthly Stress Periods			
		Constant Monthly Pumping	Pumping from Janaury to June	Pumping from April to September	Pumping from March to October
GMA 7 Portion of Pecos County					
Drawdown from 2011 to 2070 (ft)	13.67	13.62	13.27	13.65	13.74
Annual Range of Drawdown in 2011 (ft)	N/A	0.34	1.27	1.63	1.23
Annual Range of Drawdown in 2070 (ft)	N/A	0.18	1.34	1.54	1.11
Pumping (AF/yr)	117,309	117,308	116,347	117,633	118,114
Management Zone 1 in Pecos County					
Drawdown from 2011 to 2070 (ft)	45.33	45.40	44.65	45.56	45.85
Annual Range of Drawdown in 2011 (ft)	N/A	0.74	1.09	1.35	1.17
Annual Range of Drawdown in 2070 (ft)	N/A	0.64	1.05	1.29	1.10
Pumping (AF/yr)	74,134	74,131	73,525	74,337	74,640

Please note that there is some rounding error associated with converting the average annual rate of pumping to a seasonal rate of pumping for indivudal months due to the different number of days in each month. However, there is only minimal difference in the calculated drawdowns in the GMA 7 portion of Pecos County and in Management Zone 1 in Pecos County.

The results also include the difference in the maximum and minimum drawdowns in 2011 and 2070 for the GMA 7 portion of Pecos County and Management Zone 1 in Pecos County. For the constant pumping scenario, the interannual variation is the same as the average annual decline in groundwater elevation. For example, in the GMA 7 portion of Pecos County, the average drawdown from 2011 to 2070 is 13.67 feet. Over a 60-year period, this converts to an average annual rate of 0.23 ft/yr. As shown in Table 2, the 2011 rate of decline is 0.34, and the 2070 rate is 0.18. These results provide a baseline to compare the annual change associated with the seasonal pumping results.

Note that, for all scenarios, the interannual variation in average drawdown is less than 2 feet. However, at the end of the planning period (2070) drawdowns in all scenarios are essentially the same. Thus, the scenario with eight months of pumping (March to October) and only two months of recovery results in essentially the same drawdown as the other scenarios where recovery times are longer (i.e. three months or six months).

Please recall that the desired future conditions are expressed without the decimal places (i.e. rounded to the nearest foot). These results demonstrate that the differences in drawdown associated among the different seasonal pumping scenarios are within that rounding standard. It must be emphasized that although these analyses are quantiatiative, some of the assumptions are not particulely realistic (i.e. constant recharge throughout the year). Also, all pumping was assumed to be seasonal as defined by the scenario. Clearly, not all pumping would follow this pattern. The scenarios were designed to evaluate the assumption of seasonal pumping in contrast to the average annual pumping assumption in the annual GAM simulation that are the basis for the desired future conditions. By assuming all pumping as seasonal in the monthly simulations, it provides the best opportunity to evaluate the interannual variation in average drawdown over large areas. The results suggest that, for GMA 7, the assumptions of average annual pumping rates and annual stress periods are appropriate for planning purposes and development of desired future conditions.

With respect to the consitency of the desired future conditions with the FSH Operating Permit conditions, Figure 5 (appears as Figure 2 in the MPGCD Management Plan) compares the desired future condition drawdown at each of the 11 monitoring wells with two of the thresholds for each well (Historic Minimum Winter Depth to Water -10 feet and Historic Winter Minimum Depth to Water +5 feet). Please note that the blue data points represent the groundwater elevation where pumping cutbacks begin for each well. The red dots represent the groundwater elevation where a shut-down in non-historic groundwater pumping would be required, thus providing an opportunity for groundwater elevation recovery. The black line represents one-to-one line between the DFC depth to water at each well and the threshold depth to water in each well. The data points generally fall just above or just below the black line demonstrating that the thresholds are consistent with the DFC.

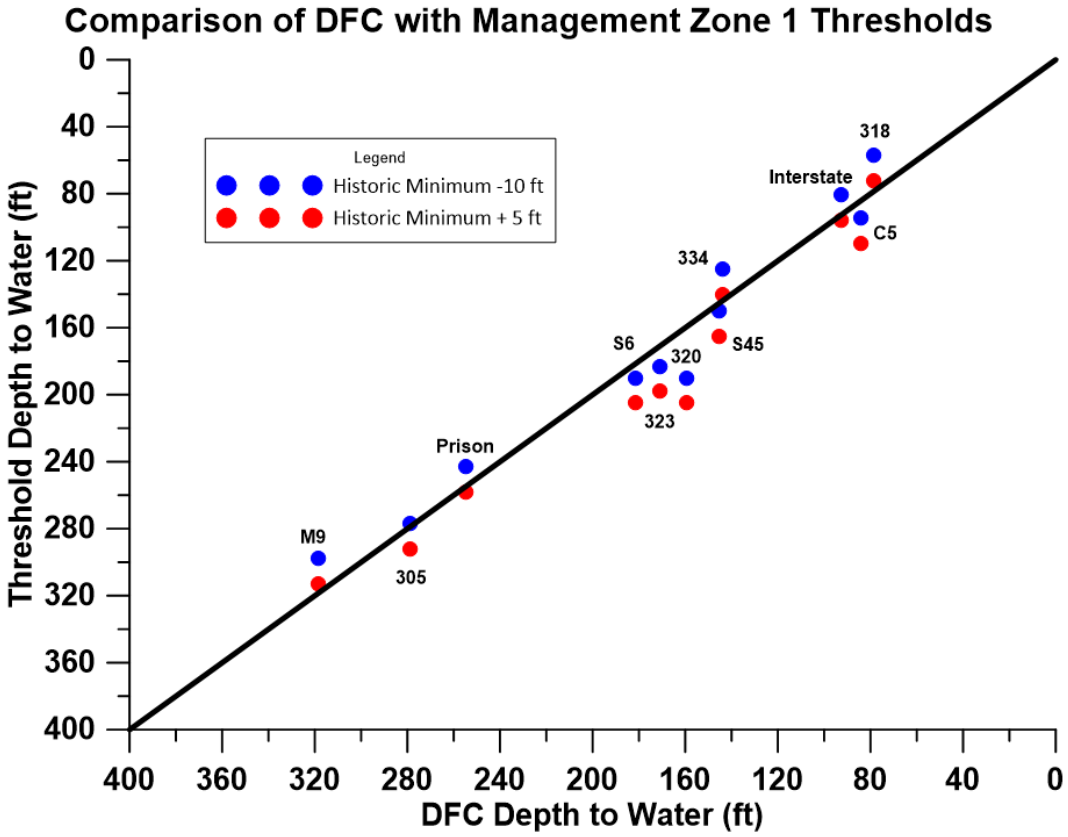

Figure 5. Comparison of DFC with Management Zone 1 Thresholds

7.0 Simulations with the Western Pecos County (WPC) Model

The simulations with the GAM presented above quantiatively demonstrated that the use of the GAM with monthly stress periods and alternative patterns of seasonal pumping provide consistent results with the simulations with annual stress periods that were used to develop desired future conditions. Consequently, it can be concluded that the use of the annual stress periods in the Alternative GAM to calculate average drawdowns in Pecos County for planning purposes is appropriate despite its inability to simulate seasonal pumping. Furthermore, the winter thresholds in the FSH Operating Permit are consistent with the desired future conditons.

The comments received from Belding Farms and the ongoing discussions between MPGCD and Belding Farms suggest that the real issue is not long term average drawdowns (i.e. desired future conditions), but the potential impacts of converting 28,400 AF/yr of agricultural pumping to municipal use. More directly, the issue is the potential impact on Belding Farms wells. The GAM is not the best analytical tool for such an analysis due to its coarse discretization (i.e. one square mile grid cells) and calibration focus over the entire GMA 3/GMA 7 area. The Western Pecos Model (WPC Model) was developed and calibrated specifically for the Leon-Belding area (i.e. Management Zone 1), and is used for additional simulations documented in this section.

As part of the review of the WPC Model (Hutchison, 2017), 55 simulations were completed that evaluated the sensitivity of pumping to average drawdown in the old Management Zone 1 and spring flow at Comanche Springs. The base case for the the effort used pumping from the last stress period of the calibration period (2010):

- Pumping in 2010, as assumed by the WPC Model in the current Management Zone 1, was 66,561 AF/yr in layer 2 (Edwards) and 6,474 AF/yr in layer 3 (Trinity), for a total Edwards-Trinity pumping of 73,035 AF/yr. This total is reasinably close to the GAM estimate of 74,134 AF/yr.
- Pumping from the FSH wells associated with the operating permit in 2010 was 15,869 AF/yr for layer 2 (Edwards) and 450 AF/yr for layer 3 (Trinity), for a total Edwards-Trinity pumping of 16,319 AF/yr. This total is less than the 28,400 AF/yr associated with the operating permit.

Initial simulations were completed that were similar to the GAM simulations described above. These were completed in order to evaluate the drawdown variation at specific Belding Farms well locations drawdown under the following scenarios:

- Annual stress periods using the model files from the base case of Hutchison (2017)
- Monthly stress period simulation using constant rate pumping based on base case of Hutchison (2017), or the same pumping rate as the base case
- Monthly stress period simulation with 6 months of pumping and 6 months of recovery (April to Septmber pumping), or double the pumping rate as the base case
- Monthly stress period simulation with 8 months of pumping and 4 months of recovery (March to October pumping), or 1.5 times the pumping rate as the base case

7.1 Annual Stress Periods

This simulation was the same as the base case documented in Hutchison (2017). All model files are available at:

https://drive.google.com/drive/folders/11g5bMhruMTm9uABmb31C3zp3Vaz-wtIX?usp=sharing

As noted above, pumping was held constant in all years (2011 to 2070) using pumping from the calibrated model in 2010. In the current Management Zone 1, pumping was 66,561 AF/yr in layer 2 (Edwards) and 6,474 AF/yr in layer 3 (Trinity), for a total Edwards-Trinity pumping of 73,035 AF/yr. This total is reasinably close to the GAM estimate of 74,134 AF/yr.

Pumping from the FSH wells associated with the operating permit in 2010 was 15,869 AF/yr for layer 2 (Edwards) and 450 AF/yr for layer 3 (Trinity), for a total Edwards-Trinity pumping of 16,319 AF/yr. This total is less than the 28,400 AF/yr associated with the operating permit.

Ouput from the model was used in a post-processor named *gethds.exe* that writes groundwater elevation and drawdown for each of the Belding Farm wells and a summary file with the drawdown for each well at the end of the simulation (2070). The post processor, source code and all output files are also available from the above link.

7.2 Monthly Stress Periods, Constant Pumping

The model input files of the WPC Model were modified to run the simulation using monthly stress periods. However, for this base run, average annual rates of pumping and constant rates of recharge were maintained to demonstrate so that that the average drawdowns do not change using monthly stress periods or annual stress periods. All other input files were modified to handle the monthly stress periods. The output control file was modified to only write cell by cell output at the end of each year rather than the end of each month due to model file size constraints. All files associated with this base run of the monthly stress period alternative GAM can be accessed at:

https://drive.google.com/drive/folders/1fQ22hD-CUkt-g7YL-xaJ4JhDlfrr5Any?usp=sharing

A post-processor named *gethds.exe* extracted results from the model output files to obtain groundwater elevation and drawdown results for each of the Belding Farm wells and a summary file with the drawdown for each well at the end of the simulation (2070). In addition, the post processor calculates the difference between the maximum drawdown each year and the minimum drawdown each year for each well site. This “interannual variation” or “amplitude” is useful to understand the seasonal variation in groundwater elevations based on the assumptions of the particular analysis. The post processor, source code and all output files are also available from the above link.

7.3 Monthly Stress Periods, April to September Pumping

This simulation assumed that all pumping occurs from April to September. Thus, the rate of constant monthly pumping for each cell from April to September was doubled, and pumping from October to March was set to zero. Pumping for this simulation was developed with the pre-processor *ScenWel.exe*. All other input files for this simulation were the same as the constant monthly pumping scenario. The output control file was modified to only write cell by cell output at the end of each year rather than the end of each month due to model file constraints. All files associated with this base run of the monthly stress period alternative GAM can be accessed at:

https://drive.google.com/drive/folders/18IUjEl270vYY6S43-2Iv1MZBx9iIN9jd?usp=sharing

A post-processor named *gethds.exe* extracted results from the model output files to obtain groundwater elevation and drawdown results for each of the Belding Farm wells and a summary file with the drawdown for each well at the end of the simulation (2070). In addition, the post processor calculates the difference between the maximum drawdown each year and the minimum drawdown each year for each well site. This "interannual variation" or "amplitude" is useful to understand the seasonal variation in groundwater elevations based on the assumptions of the particular analysis. The post processor, source code and all output files are also available from the above link.

7.4 Monthly Stress Periods, March to October Pumping

This simulation assumed that all pumping occurs from March to October. Thus, the rate of constant monthly pumping for each cell from March to October was multiplied by 1.5 and pumping from November to February was set to zero. Pumping for this simulation was developed with the pre-processor *ScenWel.exe*. All other input files for this simulation were the same as the constant monthly pumping scenario. The output control file was modified to only write cell by cell output at the end of each year rather than the end of each month due to model file constraints. All files associated with this base run of the monthly stress period alternative GAM can be accessed at:

https://drive.google.com/drive/folders/1KDzIMEb7O29iPsDIMEJ9lw8m-3lF3VzY?usp=sharing

A post-processor named *gethds.exe* extracted results from the model output files to obtain groundwater elevation and drawdown results for each of the Belding Farm wells and a summary file with the drawdown for each well at the end of the simulation (2070). In addition, the post processor calculates the difference between the maximum drawdown each year and the minimum drawdown each year for each well site. This "interannual variation" or "amplitude" is useful to understand the seasonal variation in groundwater elevations based on the assumptions of the particular analysis. The post processor, source code and all output files are also available from the above link.

7.5 Simulation Results

7.5.1 Hydrographs of Well B-7 Drawdown

Results from these simulations were focused on drawdown in individual Belding Farms wells. Results for each well were saved in individual files which are available at the links provided above. An example is Well B-7.

Figure 6 presents the drawdown results from the annual stress period simulation and the monthly stress period simulation using constant pumping. The black data points represent the annual stress period simulation results and the red line represents the results from the constant monthly pumping simulation. There is no discernable difference between these sets of results in the hydrograph.

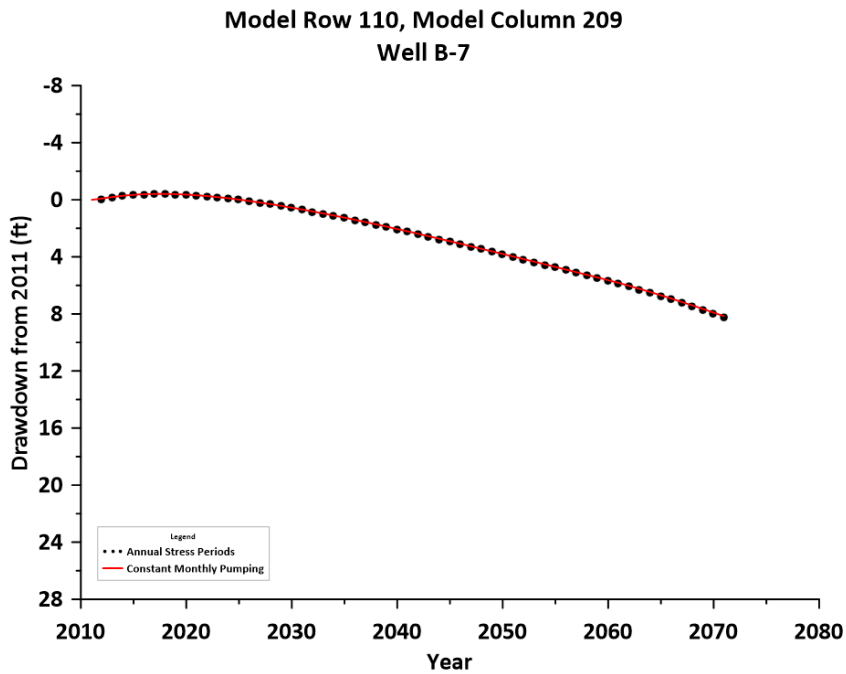

Figure 6. Well B-7 Drawdown Hydrograph - Annual Stress Period and Constant Monthly Pumping Simulations

Figure 7 presents the drawdown results from the annual stress period simulation and the monthly stress period simulation assuming pumping only from April to September. The red line represents the monthly stress period-constant pumping simulation results and the blue line represents the monthly stress period-April to September pumping simulation results. Please note that the simulation results show the seaasonal increase and decrease in groundwater elevation due to the seasonal cycle of pumping and recovery. The interannual variation or amplitude of the seasonal fluctuation exceeds 25 feet in this well. Also, please note that the model represents static groundwater levels, not pumping groundwater levels. Typcially, pumping water levels are lower

than static groundwater levels as demonstrated in the Belding Farms data that was reviewed by Hutchison (2018).

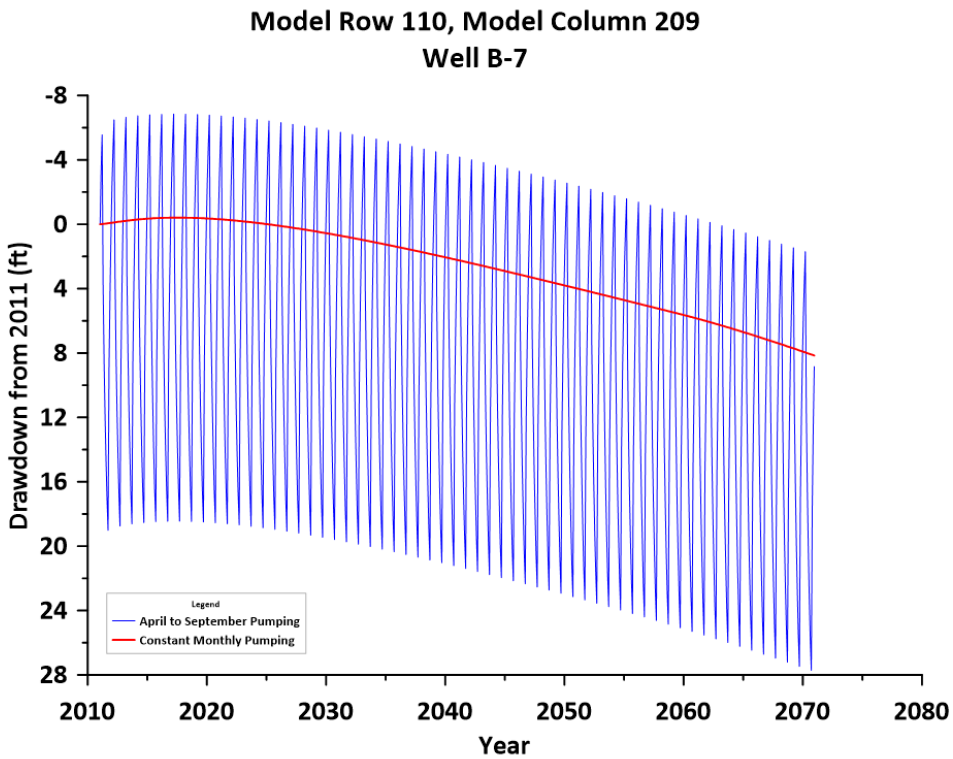

Figure 7. Well B-7 Drawdown Hydrograph - Annual Stress Period and April to September Pumping Simulations

Figure 8 presents the drawdown results from the annual stress period simulation and the monthly stress period simulation assuming pumping only from March to October. The red line represents the monthly stress period-constant pumping simulation results and the green line represents the monthly results of the March to October pumping simulation.

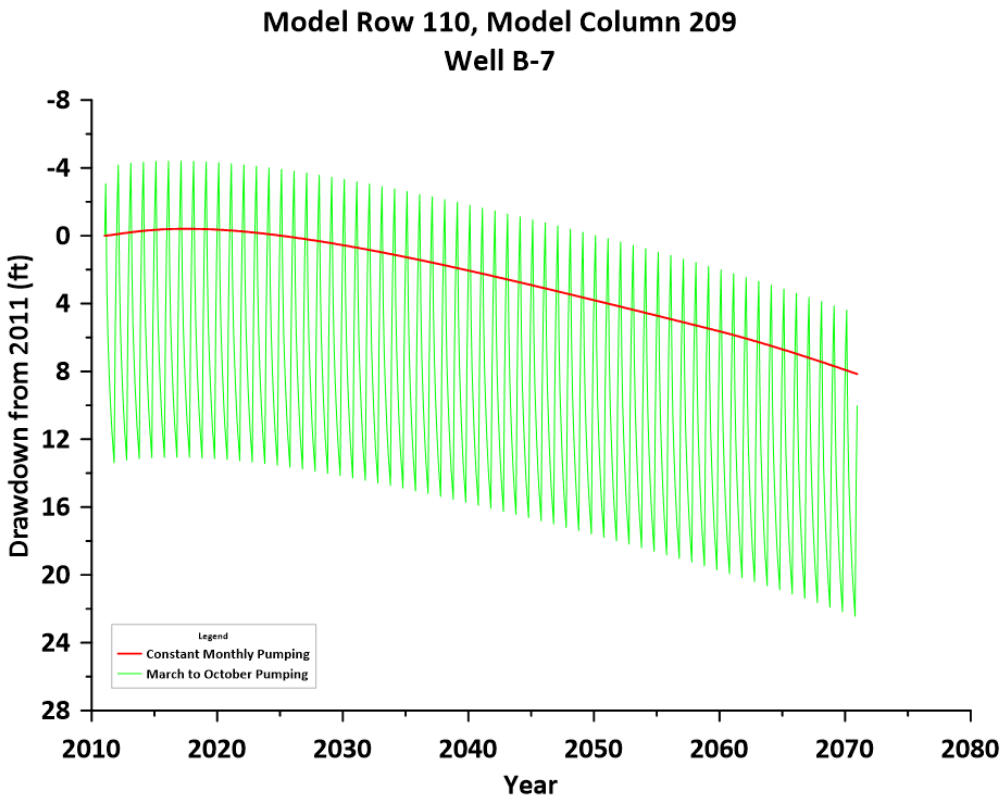

Figure 8. Well B-7 Drawdown Hydrograph - Annual Stress Period and March to April Pumping Simulations

Please note that the March to October results show a seasonal increase and decrease in groundwater elevation due to the cycle of pumping and recovery, but not to the extent as the April to September fluctuations. The interannual variation or amplitude of the seasonal fluctuation exceeds 15 feet in this well as compared to greater than 25 feet fluctuation in the April to September results previously shown in Figure 7. This is due to the higher rates of pumping in the April to September simulation (twice the average annual rate for six months) as compared to the March to October simulations (1.5 times the average annual rate for eight months).

Also, please note that the model represents static groundwater levels, not pumping groundwater levels. Typcially, pumping water levels are lower than static groundwater levels as demonstrated in the Belding Farms data that was reviewed by Hutchison (2018).

The example hydrographs are useful to visualize the differences in results between the simulations, but a more quantitative analysis of the results is provided below using all the Belding Farm well sites.

7.5.2 Summary of 2011 to 2070 Drawdown

Table 3 summarizes drawdown from 2011 to 2070 at 23 locations of Belding Farms wells. Please note that some of the three of the model cells contain two Belding Farms wells, and one cell contains three Belding Farms wells. Model row and column are provided for reference.
The fourth column is labeled "Annual Stress Period", and represents the drawdown from 2011 to 2070 for the base run of Hutchison (2017). The results of the monthly stress period simulations are presented in the next three columns. The final three columns are the difference between the annual stress period simulation drawdown and the individual monthly stress period simulations drawdown results. The final row represent the averages for each column, which are convenient to provide a basis for discussion.

Table 3. Summary of WPC Model Simulation Drawdowns in Belding Farms Wells

Well Number(s)	Model Row	Model Column	Drawdown - 2011 to 2070 (ft)				Monthly Stress Period Simulation Drawdown Difference from Annual Simulation (ft)		
			Annual Stress Period	Monthly Stress Periods					
				Constant	Apr-Sept	Mar-Oct	Constant	Apr-Sept	Mar-Oct
B1-B25	116	213	8.41	8.35	9.18	10.19	-0.06	0.77	1.78
B2	114	211	8.34	8.28	9.06	10.14	-0.06	0.72	1.80
B3	113	211	8.29	8.23	8.96	10.06	-0.06	0.67	1.77
B4	115	209	8.42	8.36	9.32	10.35	-0.06	0.90	1.93
B5	113	210	8.31	8.25	9.03	10.13	-0.06	0.72	1.82
B6	111	214	8.05	7.99	8.74	9.83	-0.06	0.69	1.78
B7	110	209	8.22	8.16	8.84	10.03	-0.06	0.62	1.81
B8-B17	110	210	8.17	8.11	8.76	9.95	-0.06	0.59	1.78
B9-B14	116	210	8.46	8.40	9.35	10.36	-0.06	0.89	1.90
B10	114	214	8.26	8.20	8.98	10.01	-0.06	0.72	1.75
B11	115	214	8.32	8.26	9.07	10.09	-0.06	0.75	1.77
B12	114	213	8.29	8.23	8.98	10.04	-0.06	0.69	1.75
B13	115	211	8.40	8.33	9.17	10.21	-0.07	0.77	1.81
B18	107	214	7.71	7.65	8.57	9.65	-0.06	0.86	1.94
B19	106	215	7.54	7.47	8.59	9.58	-0.07	1.05	2.04
B20	118	212	8.53	8.46	9.44	10.40	-0.07	0.91	1.87
B21	117	213	8.47	8.41	9.28	10.27	-0.06	0.81	1.80
B22	111	213	8.10	8.03	8.73	9.85	-0.07	0.63	1.75
B23	115	212	8.37	8.31	9.11	10.16	-0.06	0.74	1.79
B24	113	214	8.20	8.14	8.89	9.94	-0.06	0.69	1.74
B26	112	212	8.20	8.14	8.82	9.95	-0.06	0.62	1.75
B27	116	209	8.47	8.41	9.43	10.43	-0.06	0.96	1.96
B28-B29-B30	105	207	8.11	8.04	8.72	9.95	-0.07	0.61	1.84
Average			**8.25**	**8.18**	**9.00**	**10.07**	**-0.06**	**0.76**	**1.82**

Please note average drawdown for these 23 sites for the annual simulation and constant monthly simulation are within 0.1 feet (8.25 ft vs. 8.18 ft). However, the April to September simulation has a drawdown that is almost a foot less than the annual stress period simulation. The March to October drawdown is almost 2 feet lower than the annual stress period simulation. These differences are due to the timing of the "end of the year" drawdown calculation and the length of recovery from the seasonal pumping.

The April to September pumping recovers from October to March, but the drawdown in this table is calculated at the end of December, only four months into the six month recovery period. The

March to October pumping recovers from November to February. This means that the "end of the year" drawdown is calculated only two months into a four month recovery period.

The FSH operating permit thresholds do not consider "end of year" as winter groundwater elevations, but the winter maximum (whenever it occurs). The winter maximum groundwater elevations and the end of the year groundwater elevations were evaluated in Hutchison (2018) for this reason. Consequently, the differences between the drawdowns in Table 3 are not considered significant.

Also please recall from the example hydrograph of Well B-7 that the groundwater levels will rise above the annual average groundwater level in non-pumping periods and then fall below the annual average groundwater level during pumping periods. This fluctuation is well documented in the monitoring data in wells monitored by MPGCD. This fluctuation is analyzed below.

7.5.3 Interannual Variation in Groundwater Levels

Table 4 summarizes the interannual variation in 2011 and 2070 for the three monthly stress period simulations. For each well, the interannual variation is calculated as the maximum drawdown in a specific year minus the minimum drawdown in that same year. The results for 2011 are presented in the fourth, fifth, and sixth columns. The results for 2070 are presented in the seventh, eighth, and ninth columns. The final row represent the averages for each column, which are convenient to provide a basis for discussion.

Table 4. Summary of Interannual Variation in Groundwater Levels in Belding Farms Wells

Well Number(s)	Model Row	Model Column	Annual Maximum Drawdown minus Annual Minimum Drawdown (ft)					
			2011			2070		
			Constant	Apr-Sept	Mar-Oct	Constant	Apr-Sept	Mar-Oct
B1-B25	116	213	0.07	22.08	14.88	0.23	23.35	16.22
B2	114	211	0.08	22.66	15.22	0.23	23.96	16.63
B3	113	211	0.08	23.06	15.47	0.23	24.39	16.93
B4	115	209	0.08	21.20	14.17	0.23	22.42	15.50
B5	113	210	0.08	22.90	15.35	0.23	24.22	16.79
B6	111	214	0.08	22.40	15.02	0.23	23.70	16.45
B7	110	209	0.09	24.58	16.46	0.23	26.02	18.05
B8-B17	110	210	0.08	24.04	16.08	0.23	25.45	17.65
B9-B14	116	210	0.07	21.21	14.21	0.23	22.43	15.52
B10	114	214	0.07	22.60	15.23	0.23	23.90	16.62
B11	115	214	0.07	22.14	14.91	0.23	23.41	16.27
B12	114	213	0.07	22.58	15.19	0.23	23.88	16.59
B13	115	211	0.07	22.19	14.91	0.23	23.46	16.28
B18	107	214	0.09	20.19	13.41	0.23	21.39	14.76
B19	106	215	0.09	18.25	12.08	0.23	19.32	13.29
B20	118	212	0.07	20.30	13.62	0.23	21.49	14.87
B21	117	213	0.07	22.28	15.05	0.23	23.56	16.39
B22	111	213	0.08	22.86	15.32	0.23	24.19	16.79
B23	115	212	0.07	22.39	15.06	0.23	23.68	16.44
B24	113	214	0.08	23.06	15.54	0.23	24.38	16.96
B26	112	212	0.08	23.18	15.54	0.23	24.52	17.02
B27	116	209	0.08	20.59	13.76	0.23	21.78	15.03
B28-B29-B30	105	207	0.10	25.83	17.30	0.24	27.38	19.01
Average			**0.08**	**22.29**	**14.95**	**0.23**	**23.58**	**16.35**

Please note that the interannual variation in the constant monthly pumping columns for 2011 and 2070 are 0.08 ft and 0.23 ft, respectively. The annual drawdown average from Table 3 above is 8.25 feet, which is about 0.12 ft/yr. Thus, the 2011 value is below the annual average rate of decline and the 2070 value is above the annual average rate of decline. Thus, the constant pumping scenario results represent the long-term rate of decline since there is no seasonal variation associated with this simulation.

The April to September simulation fluctuation is greater than the March to October fluctuation:

- In 2011, April to September is about 22 ft and March to October is about 15 ft
- in 2070, April to September is about 24 ft and March to October is about 16 ft

This is because the pumping rate in the April to September simulation is double the average annual rate and the pumping rate in the March to October is 1.5 times the average annual rate. Pumping is more concentrated in the six month period (April to September) than it is in the eight month period (March to October). Thus, the higher seasonal variation would be expected in the scenario with the shorter pumping period.

These interannual simulation results are analogous to the results in Hutchison (2018) in evaluating the Belding Farms well drawdown data. Hutchison (2018) evaluated drawdown two ways based on the way Belding Farms records their data: 1) the difference between the static groundwater elevation and pumping groundwater elevation in the same month (informally called monthly drawdown) and 2) the difference between the winter maximum groundwater elevation and the pumping groundwater elevation for each month that year (informally called annual drawdown).

The results in Table 4 represent the difference between the winter maximum static groundwater elevation and the summer minimum static groundwater elevation in each year. The groundwater model only considers static groundwater levels, not pumping groundwater levels. It is expected, therefore, that these results would be less than the "annual" drawdowns in each well in Appendix D of Hutchison (2017). For convenient reference Appendix D of Hutchison (2018) is presented in this Technical Memorandum as Appendix A.

Please note that "annual drawdown" in hydrographs of Appendix A generally ranges between 20 and 50 feet, which, given the different definitions used in this analysis (static groundwater levels versus pumping groundwater levels) suggests that the WPC groundwater model is providing reasonable seasonal fluctuation results, despite the approximate way these simulations simulate monthly conditions (i.e. not a calibrated monthly model).

8.0 WPC Model Simulations with Alternative FSH Operating Permit Pumping Schedules

The simulations in the previous section demonstrated that the WPC Model can be used to analyze seasonal groundwater variations in the Bedling Farms wells resulting from seasonal pumping changes despite the limitations associated with converting a model that was developed and calibrated using annual stress periods. This conclusion is based on comparing the annual variation results with actual data from Belding Farms wells presented in Appendix A.

The simulations summarized in this section include:

- Four simulations that establish baselines (two with no pumping in the FSH Operating Permit wells and two with pumping in the FSH Operating Permit wells on an irrigation schedule), and
- Eight simulations that implent alternative "municipal" pumping schedules for the FSH Operating Permit wells while keeping all other wells in the model domain on an irrigation schedule (alternatively April to September or March to October).

The objective of these scenarios was to provide a basis for comparison to assess the potential for impacts to the Belding Farms wells as a result of changing the pattern of pumping by comparing the results to the results of the baseline scenarios.

All files associated with these simulations can be accessed at this link:

https://drive.google.com/drive/folders/1pmbxVpXcAUqqD_oxWzk56x76rxs9v3g9?usp=sharing

Based on the results of the WPC simulations presented above, it is evidient that there is no need to simulate 60 years to obtain meaningful results relative to the objectives of this effort. Interannual variation changed only slightly between the first year and 65th year of the simulations. Thus, these simulation were run for a 10-year period using monthly stress periods.

8.1 Scenario Summary

A total of 12 scenarios were developed. Scenarios 1 to 4 were used to establish baseline conditions, and Scenarios 5 to 12 evaluated alternatives "municipal" pumping schedules for the FSH Operating Permit wells while keeping all other wells in the model domain on an irrigation schedule:

- Scenarios 1 and 2 assumed that the FSH Operating Permit wells are not pumped, and all other wells in the model domain are pumped on an irrigation schedule. Scenario 1 assumed that the irrigation season runs from April to September. Scenario 2 assumed that the irrigation season runs from March to October.
- Scenarios 3 and 4 assumed that all wells within the model domain (including the FSH Operating Permit wells) are pumped on an irrigation schedule. Scenario 3 assumed that

the irrigation season runs from April to September. Scenario 4 assumed that the irrigation season runs from March to October. Additonal details of assumptions in the specification of the pumping rate of the FSH Operating Permit wells are provided below.

- Scenarios 5 and 6 assumed that the FSH Operating Permit wells are pumped at a constant rate from January to December, simulating a municipal base supply. Scenario 5 assumed that all other pumping in the model domain occurs from April to September. Scenario 6 assumed that all other pumping in the model domain occurs from March to October. Additonal details of assumptions in the specification of the pumping rate of the FSH Operating Permit wells are provided below.
- Scenarios 7 and 8 assumed that the FSH Operating Permit wells are pumped based on a schedule that was constrained by the installed pump capacity and the annual permit limit for each well. Consequently, some wells were operated for less than four months, and some were operated for more than six months, but all pumping from these wells occurred from February to September. Details are provided below. All other pumping in the model domain occurred in April to September (Scenario 7) and March to October (Scenario 8).
- Scenarios 9 and 10 assumed that the FSH Operating Permit wells are pumped based on a schedule that was constrained by the installed pump capacity and the annual permit limit for each well. Consequently, some wells were operated for less than four months, and some were operated for more than six months, but all pumping from these wells occurred from March to October. Details are provided below. All other pumping in the model domain occurred from April to September (Scenario 9) and March to October (Scenario 10).
- Scenario 11 assumed that there was a relaxation of the permit limits associated with per well installed capacity limits to the point that all FSH Operating Permit pumping could occur in four months (June to September). All other pumping in the model domain occurred from April to September.
- Scenario 12 assumed that there was a relaxation of the permit limits associated with per well installed capacity limits to the point that all FSH Operating Permit pumping could occur in three months (July to September). All other pumping in the model domain occurred from April to September.

Groundwater pumping input for use in the simulations were developed using a pre-processor written for this effort (*ScenWelMuni.exe*). The source code, input files and output files for this pre-processor are included in the link provided above. As noted in the scenario summary above, the treatment of FSH Operating Permit wells and all other wells in the model domain were developed differently. Documentation of the development is provided below.

8.2 Development of non-FSH Operating Permit Well Pumping Input

Annual pumping for all non-FSH Operating Permit wells in the model domain was assumed equal to the 2010 pumping from the calibrated WPC Model as discussed in the previous section of this Technical Memorandum. A total of 1,364 non-FSH Operating Permit wells in the model domain were simulated in these scenarios.

As described in the previous section, pumping rates were doubled for all scenarios that assumed all non-FSH Operating Permit wells were pumped from April to September (Scenarios 1, 3, 5, 7, 9, 11 and 12), and pumping rates were multipled by 1.5 for all scenarios that assumed that all non FSH Operating Permit wells were pumped from March to October (Scenarios 2, 4, 6, 8, and 10).

8.3 Development of FSH Operating Permit Well Pumping Input

8.3.1 Scenarios with No FSH Operating Permit Well Pumping (1 and 2)

Scenarios 1 and 2 were developed to provide a baseline, and pumping for the FSH Operating Permit wells was set to zero for these scenarios.

8.3.2 Scenarios based on Average Annual Rates (3 to 6 and 11 to 12)

The pumping rates associated with the WPC Model in 2010 (Hutchison, 2017) that were used in the previous set of simulations described above were removed for these simulations. For the FSH Operating Permit wells, pumping rates for Scenarios 3 to 6 and Scenarios 11 and 12 were based on the annual operating permit limits for the 25 individual wells previosuly presented in Table 1. This annual total in AF/yr was converted to an average annual rate expressed in cubic feet per day (the units used in MODFLOW input files). This represents an average annual rate of pumping. Use of this average annual rate for these scenarios was as follows:

- For Scenario 3: the average annual rate was doubled to simulate pumping over 6 months (April to September).
- For Scenario 4, the average annual rate was multiplied by 1.5 to simulate pumping over 8 months (March to October).
- Scenarios 5 and 6: the average annual rate was used because the to simulate a constant rate of pumping from January to December.
- Scenario 11: the average annual rate was multiplied by 3 to simulate pumping over 4 months (June to September).
- Scenario 12: the average annual rate was multiplied by 4 to simulated pumping over 3 months (July to September).

These assumed rates are not entirely consistent with the permit conditions related to both installed capacity and annual permit production limits. Strict adherence to both of the conditions was simulated in Scenarios 7 to 10 as developed below.

8.3.3 Scenarios Constrained by Intalled Pump Capacity and Annual Limits (7 to 10)

Based on the insalled pump capacity and the production limits associated with each well (previously presented in Table 1), two sets of municipal pumping scnenarios were developed: one set with pumping from February to September (Scenarios 7 and 8), and one set with pumping from March to October (Scenarios 9 and 10). The development of these scenarios was completed using

Excel spreasheets that can be accessed in the link provided above (*FSHOperatingPermitWells-FebtoSep.xlsx* and *FSHOperatingPemitWells-MartoOct.xlsx*).

The last column in Table 1 (previously presented) is the number of days of pumping to reach the maximum limit based on the installed pump capacity, assuming continuous operation. This is Column K in the spreadsheet labeled The tab named *"Timing"* in the spreadsheets. Table 5 summarizes the number of days of pumping in each well for Scenarios 7 and 8 for each month to reach the annual production limit based on installed pump capacity. For this simulation, all pumps are turned on with the intention of reaching the annual limit on September 30. The companion table for Scenarios 9 and 10 assumes that the maximum limit would be reached on October 31.

For example, based on the installed capacity of Well C-1, continuous pumping would result in reaching the annual permit limit in about 96 days. In order to evaluate the maximum impact on end of September groundwater elevations, it was assumed that the well would operate for a little over 4 days in June, and then operate continuously in July, August, and September. The total in the right hand column can then be compared to verify that the number of days of pumping matches the calcuated days in the second column of the table.

Another example is M-1. Based on the installed capacity of this well, continuous pumping would result in reaching the annual permit limit in about 219 days. In order to evaluate the maximum impact on end of September groundwater elevations, it was assumed that the well would operate for just under 5 days in February, and then operate continuously from March to September.

Table 5. Scenario 7 - Number of Days of Pumping in Each FSH Well

Well Number	Days at Max Rate to Reach Annual Limit	Days Each month at Maximum Pumping								
		Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total
C-1	96.06					4.06	31.00	31.00	30.00	96.06
C-2	96.02					4.02	31.00	31.00	30.00	96.02
C-3	96.02					4.02	31.00	31.00	30.00	96.02
C-4	96.06					4.06	31.00	31.00	30.00	96.06
M-1	218.98	4.98	31.00	30.00	31.00	30.00	31.00	31.00	30.00	218.98
M-2	214.07	0.07	31.00	30.00	31.00	30.00	31.00	31.00	30.00	214.07
M-3	221.04	7.04	31.00	30.00	31.00	30.00	31.00	31.00	30.00	221.04
M-4	221.01	7.01	31.00	30.00	31.00	30.00	31.00	31.00	30.00	221.01
M-5	136.59				14.59	30.00	31.00	31.00	30.00	136.59
M-6	195.40		12.40	30.00	31.00	30.00	31.00	31.00	30.00	195.40
M-7	195.40		12.40	30.00	31.00	30.00	31.00	31.00	30.00	195.40
M-8	209.99		26.99	30.00	31.00	30.00	31.00	31.00	30.00	209.99
M-9	93.91					1.91	31.00	31.00	30.00	93.91
NC-2	95.95					3.95	31.00	31.00	30.00	95.95
S-1	74.03						13.03	31.00	30.00	74.03
S-2	169.97			16.97	31.00	30.00	31.00	31.00	30.00	169.97
S-4	198.16		15.16	30.00	31.00	30.00	31.00	31.00	30.00	198.16
S-6	95.95					3.95	31.00	31.00	30.00	95.95
S-11	125.00				3.00	30.00	31.00	31.00	30.00	125.00
S-13	115.66					23.66	31.00	31.00	30.00	115.66
S-18	91.87						30.87	31.00	30.00	91.87
S-19	76.56						15.56	31.00	30.00	76.56
S-20	65.62						4.62	31.00	30.00	65.62
S-26	149.12				27.12	30.00	31.00	31.00	30.00	149.12
S-32	210.79		27.79	30.00	31.00	30.00	31.00	31.00	30.00	210.79

Using the number of days shown in Table 5 and the installed capacity pumping rate, the actual pumping for each month for Scenarios 7 and 8 is presented in Table 6 in acre-feet per month. This is found in the "*AF mo*" tab in the spreadsheets. Please note that for this scenario, the highest monthly total is in August, because August has 31 days and September has 30 days, even though pumping in both months is at the maximum rates for each well. Maximum pumping occurs in July, August and September. Less than maximum pumping occurs from February to June as noted in Table 6. A similar "*AF mo*" tab is in the spreasheet associated with Scenarios 9 and 10.

Table 6. Scenario 7 - Pumping (AF/month)

Well Number	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total
C-1	0	0	0	0	36	274	274	265	849
C-2	0	0	0	0	53	411	411	398	1,273
C-3	0	0	0	0	53	411	411	398	1,273
C-4	0	0	0	0	36	274	274	265	849
M-1	48	301	292	301	292	301	301	292	2,129
M-2	0	205	199	205	199	205	205	199	1,419
M-3	68	301	292	301	292	301	301	292	2,149
M-4	56	247	239	247	239	247	247	239	1,758
M-5	0	0	0	142	292	301	301	292	1,328
M-6	0	110	265	274	265	274	274	265	1,727
M-7	0	110	265	274	265	274	274	265	1,727
M-8	0	119	133	137	133	137	137	133	928
M-9	0	0	0	0	7	110	110	106	332
NC-2	0	0	0	0	9	68	68	66	212
S-1	0	0	0	0	0	81	192	186	458
S-2	0	0	135	247	239	247	247	239	1,352
S-4	0	141	278	288	278	288	288	278	1,839
S-6	0	0	0	0	17	137	137	133	424
S-11	0	0	0	33	331	342	342	331	1,381
S-13	0	0	0	0	188	247	247	239	920
S-18	0	0	0	0	0	136	137	133	406
S-19	0	0	0	0	0	83	164	159	406
S-20	0	0	0	0	0	29	192	186	406
S-26	0	0	0	240	265	274	274	265	1,318
S-32	0	203	219	226	219	226	226	219	1,537
Total	**173**	**1,737**	**2,316**	**2,915**	**3,707**	**5,678**	**6,035**	**5,840**	**28,400**

The final step in developing the pumping input files is to convert the input pumping to cubic feet per day. The spreadsheet tab labeled "*cfd*" contains the calculations for these conversions.

Table 7 summarizes the input pumping assumptions associated with each scenario.

Table 7. Summary of Scenario Pumping Input

Scenario Number	Scenario Type	Non-FSH Operating Permit Wells		FSH Operating Permit Wells	
		Time Period of Pumping	Average Annual Pumping Rate Multiplier	Time Period of Pumping	Average Annual Pumping Rate Multiplier
1	No FSH Pumping	Apr to Sep	2.0	None	0.0
2		Mar to Oct	1.5	None	0.0
3	FSH as Irrigation Wells	Apr to Sep	2.0	Apr to Sep	2.0
4		Mar to Oct	1.5	Mar to Oct	1.5
5	FSH as Baseline Municipal Source	Apr to Sep	2.0	Jan to Dec	1.0
6		Mar to Oct	1.5	Jan to Dec	1.0
7	FSH as Peak Municipal Pumping	Apr to Sep	2.0	Feb to Sep	***See Note Below***
8		Mar to Oct	1.5	Feb to Sep	***See Note Below***
9		Apr to Sep	2.0	Mar to Oct	***See Note Below***
10		Mar to Oct	1.5	Mar to Oct	***See Note Below***
11		Apr to Sep	2.0	Jun to Sep	3.0
12		Apr to Sep	2.0	Jul to Sep	4.0

Note: Pumping not based on rate multipier, but based on Spreadsheet Calculations as documented in text

8.4 Simulation Results

Results from these simulations were focused on drawdown in individual Belding Farms wells. Results for each well were saved in individual files which are accessible at the links provided above. Results for drawdown, interannual variation in groundwater elevation, and pumping are also accessible at the links provided above.

8.4.1 Output Pumping Results

Total pumping in Management Zone 1 and pumping from the FSH Operating Permit wells was extracted from the cell by cell model output to verify the proper input pumping values as outlined above.

FSH Operating permit pumping was zero in Scenarios 1 and 2, and about 28,400 AF/yr in Scenarios 3 to 12. Small variations attributed to round error were present, but deemed insignifcant for purposes of this analysis.

Total pumping in Management Zone 1 included all FSH Operating Permit wells. The total pumping was about 60,000 AF/yr in Scenarios 1 and 2 (FSH Operating Permit wells were off), and about 88,000 AF/yr in Scenarios 3 to 12. Along with the small variations attributable to rounding error, there was also some decline in Management Zone 1 pumping that appears to be due to reduction in pumping due to dry cells. The reduction was about 600 AF for the 10-year simulation in all scenarios, and was not considered significant.

Files associated with the extraction of pumping were written by the post-proccessor *getpumpmuni.exe*. The source code, executables and output files are accessible in the link provided earlier.

8.4.2 Hydrographs of Well B-7 Drawdown

Results for each well are accessible in the link provided above, and the results are all similar. Hydrographs of Well B-7 for three of the scenarios are provided below to illustrate the interpretation of the results.

Figure 9 presents a comparison of the drawdown in Well B-7 for Scenarios 3 and 7. Please recall that Scenario 3 represents all wells pumping on an irrigation schedule that runs from April to September, and Scenario 7 represents the scenario where non-Operating Permit wells pump on an April to September irrigation schedule and FSH Operating Permit wells pumping on a schedule that is constrained by the pumping capacity and annual limits on each well as noted in Table 6 previously presented.

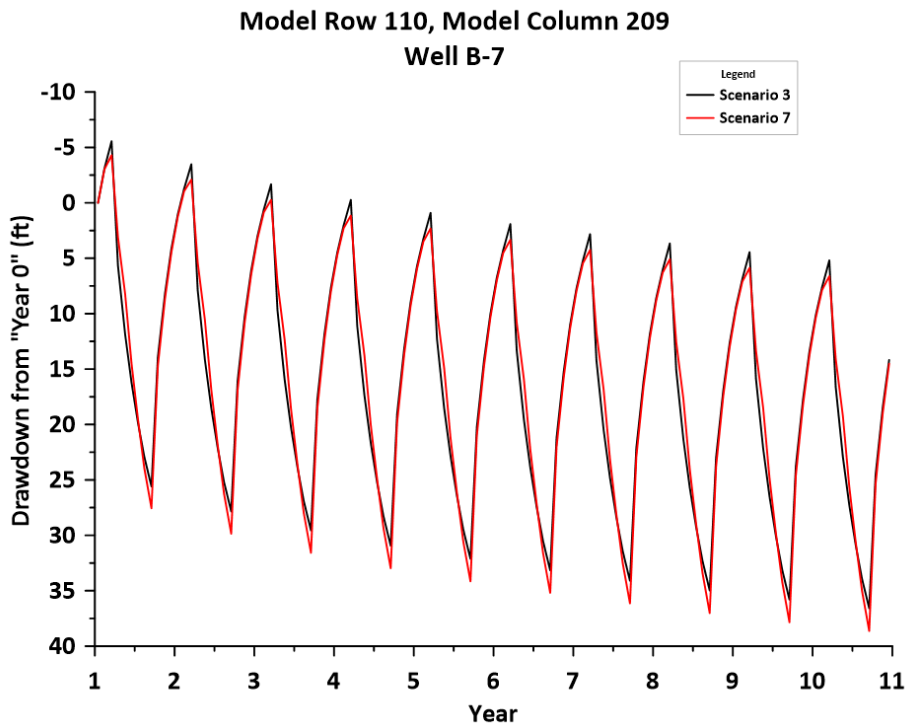

Figure 9. Well B-7 Drawdown Hydrograph - Scenarios 3 and 7

The general trend of reduced drawdown over time is evident, as well as an interannual cycle of drawdown and recovery. The drawdown trend is more pronounced in these simulations as compared to the earlier simulations because the overall pumping in higher. Please recall that the FSH Operating Permit wells in 2010 (the final year for the calibration period of the WPC Model) was about 16,300 AF/yr. Because the pumping for these simulations assumed pumping of 28,400 AF/yr, and there was no reduction in the pumping in the rest of Management Zone 1 to achieve a total of about 77,000 AF/yr, total pumping for Management Zone 1 was assumed to be about 88,000 AF/yr for these simulations, with the exception of Scenarios 1 and 2 that assumed no pumping from the FSH Operating Permit wells.

Please note that the interannual variationin groundwater elevation due to seasonal pumping is evident. The winter recovery in Scenario 3 is slightly higher than in Scenario 7 due to the nine wells that pumping in February and March in Scenario 7 that are off in Scenario 3. The maximum drawdown at the end of September is slightly higher in Scenario 7 than it is in Scenario 3 due to the higher rate of pumping in Scenario 7 associated with the nine wells that start operating in later June and are at full pumping during July, August and Septmber in Scenario 7. Scenario 3 has constant pumping in all months from April to September. However, the differences in the winter recovery levels between the two scenarios and the differences in the end-of-September groundwater levels are not signficant.

Based on this comparison, there is no significant difference between the groundwater levels in this well between the two scenarios where FSH Operating Permit wells are alternatively operated on an irrigation schedule and on an aggressive municipal schedule that maximizes production in July, August, and September consistent with the current permit conditions related to installed pump capacity and annual production limits for each well.

While Scenario 7 was constrained by current well capacities as listed in the permit, Scenario 12 represents a hypothetical assumption that the all FSH Operating Permit wells could produce their full annual permit limit in 3 months. This hypothetical assumption is inconsistent with the permit conditions, but the results are instructive to gain a better understanding of the potential impacts of concentrating pumping over a relatively short period of time. Comparison hydrographs of Scenario 3 and Scenario 12 is presented in Figure 10.

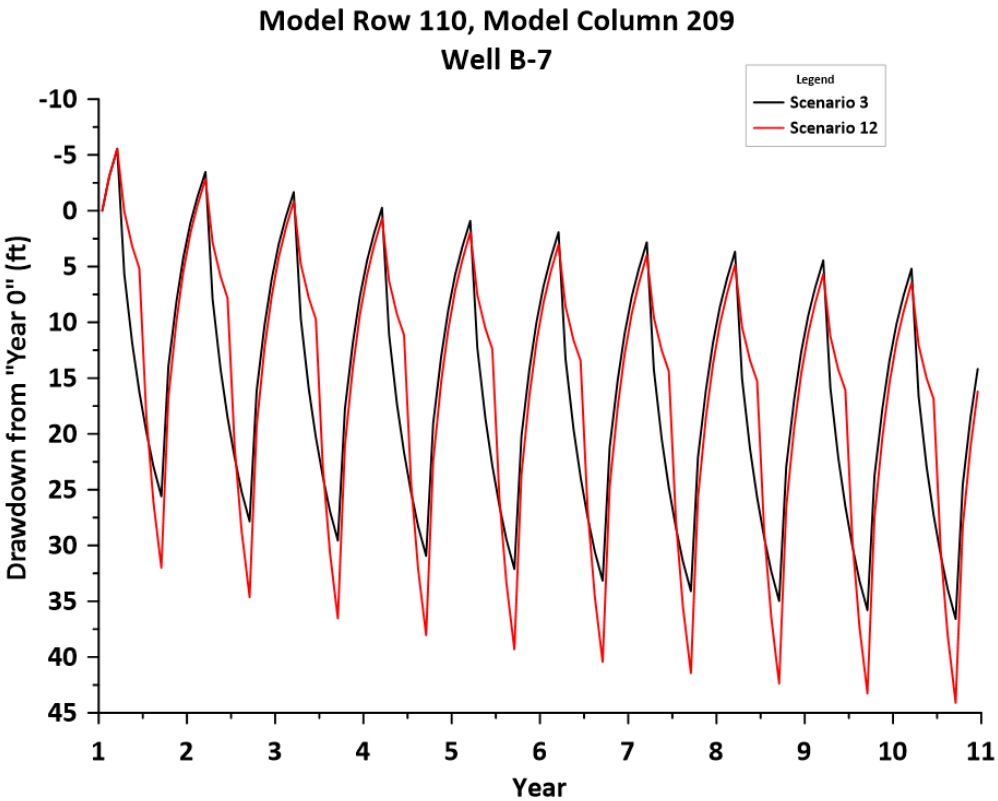

Figure 10. Well B-7 Drawdown Hydrograph - Scenarios 3 and 12

Please note the distinctive increase in Scenario 12 drawdown each July when the FSH Operating Permit wells start the three-month pumping cycle. Also, please note that the Scenario 12 end-of-September maximum drawdown is nearly 10 feet greater than the Scenario 3 end-of-September maximum drawdown. This is slightly greater than the difference between Scenario 3 and Scenario 12 end-of-September maximum drawdown.

8.4.3 Summary Results of Drawdown and Interannual Variation

The results were extracted from the model head save file using a post-processor *gethdsmuni.exe.* The source code, executable, and output files associated with this post-processor are accessible at the link provided above.

Table 8 summarizes the average simulated drawdown, simulated average interannual variation in Year 1, and the simulated average interannual vairation in Year 10 for the Belding Farms wells for each scenario.

Table 8. Summary of Simulated Average Drawdown and Interannual Variation for Belding Farms Wells

Scenario Number	Scenario Type	Average of Belding Famrs Wells		
		Drawdown (ft)	Interannual Variation (ft)	
			Year 1	Year 10
1	No FSH Pumping	-15.63	13.60	15.78
2		-14.99	8.49	10.76
3	FSH as Irrigation Wells	14.18	28.44	28.51
4		15.32	20.37	19.86
5	FSH as Baseline Municipal Source	13.93	18.31	17.78
6		14.62	13.63	12.51
7	FSH as Peak Municipal Pumping	14.36	27.39	27.35
8		15.04	22.21	21.90
9		15.83	26.66	26.28
10		16.52	22.65	21.72
11		15.27	31.14	31.07
12		16.11	33.31	33.17

Please note that in Scenarios 1 and 2 (no FSH Operating Permit well pumping), there is a overall recovery in groundwater elevations during the simulation period and interannual variation is relatively small. This is due to an overall reduction in pumping because FSH Operating Permit wells are off. Total pumping in Management Zone 1 in the scenario is about 60,000 AF/yr as compared to all other scenarios where the total pumping in Management Zone 1 is about 88,000 AF/yr.

The results of Scenario 3 and 4 represent a baseline because all pumping in the model domain is on an irrigation schedule (April to September in Scenario 3 and March to October in Scenario 4). Please note that the interannual variation is lower in the Scenario 4 than in Scenario 3 because the pumping in Scenario 4 is spread out over 8 months rather than 6 months in Scenario 3.

The simulated average interannual variation in Scenarios 5 and 6 is less than the irrigation pumping season baselines (Scenarios 3 and 4) because FSH Operating Permit well pumping is spread out over a 12 month period, thus reducing the drawdown and recovery associated with seasonal pumping for a significant portion of the total pumping in the model domain (about 28,000 AF/yr out of a total of about 88,000 AF/yr).

The simulated average interannual variation in Scenarios 7 and 9 are similar because the FSH Operating Permit well pumping is over the same time period (February to September), while all other pumping in Scenario 7 is between April and September (6 months) and other pumping in Scenario 9 is between March and October (8 months). Similarly, the simulated interannual variation in Scenarios 8 and 10 are simillar because the FSH Operating well pumping is over the same time period (March to October).

The simulated average interannual variation in Scenarios 11 and 12 is highest of all the scenarios because the FSH Operating Permit wells pumping in concentrated over a four month period

(Scenario 11) and a three month period (Scenario 12). As discussed above, this scenario is not consistent with the terms of the permit, but was completed to gain a better understanding of the potential impacts of concentrating pumping over a relatively short period of time.

8.5 Discussion of Results

Under current installed capacity and annual production limits of each well in the FSH Operating Permit, the results of simulating pumping on a municipal schedule demonstrate that impacts to the Belding Wells are nearly identical to simulated impacts to the Belding Wells when FSH Operating Permit wells are operated on an irrigation schedule. The current permit conditions require adherence to the current pump capacity and annual production limits of each well. Simulations that assumed relaxation of these limits (i.e. all FSH Operating Permit pumping over a three- or four-month period) did result in higher impacts to Belding Farms wells, but did not impact long-term drawdown, which is a groundwater planning issue.

The significance of the additional impacts associated with concentrated pumping of FSH Operating Permit wells over a three- or four-month period are unknown. However, understanding the significance is more properly groundwater management and groundwater regulation issues, not groundwater planning process issues. Additional data and a more robust analytical exercise with a more appropriate model would be needed to assess the significance of these simulated impacts. Currently, there are no plans to modify the installed pump capacity and/or the annual limits of individual wells, so there is no urgent need to evaluate the significance further. However, this analysis does provide some background if such a request is made in the future. Any such request would be made to the Middle Pecos Groundwater Conservation District (not Groundwater Management Area 7). Such a request would be analyzed by and would be approved by the Middle Pecos Groundwater Conservation District as part of its groundwater management and groundwater regulation activities.

9.0 References

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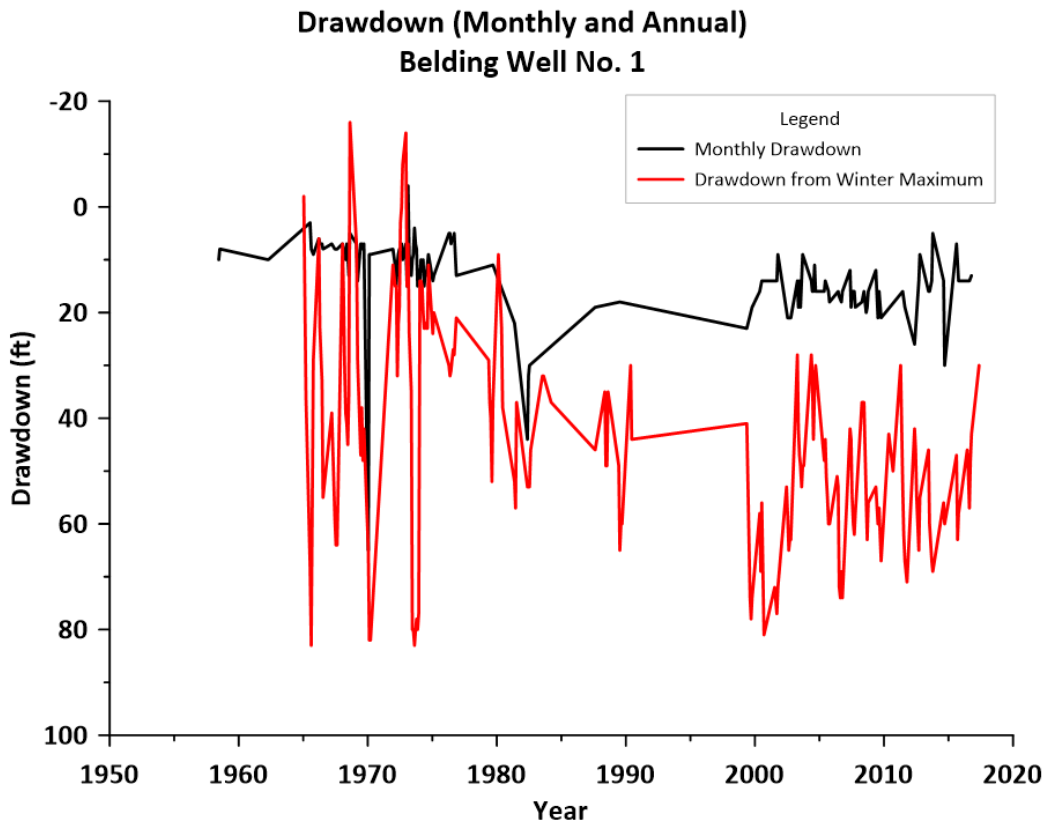
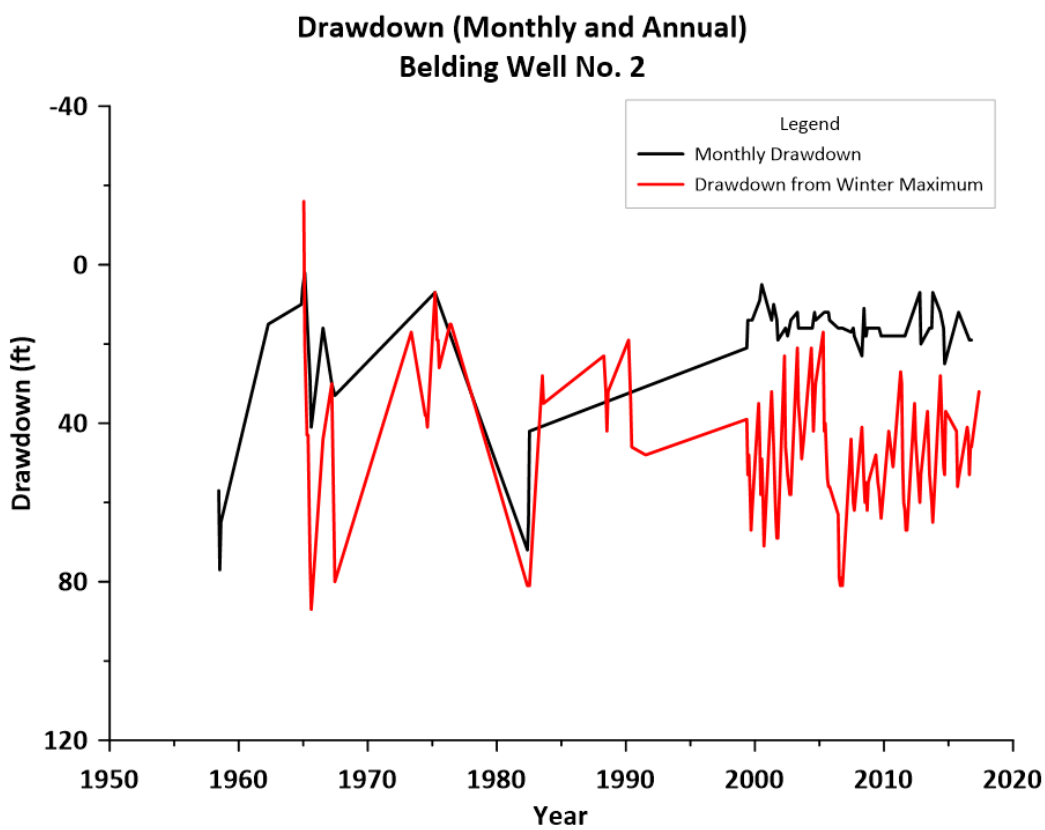
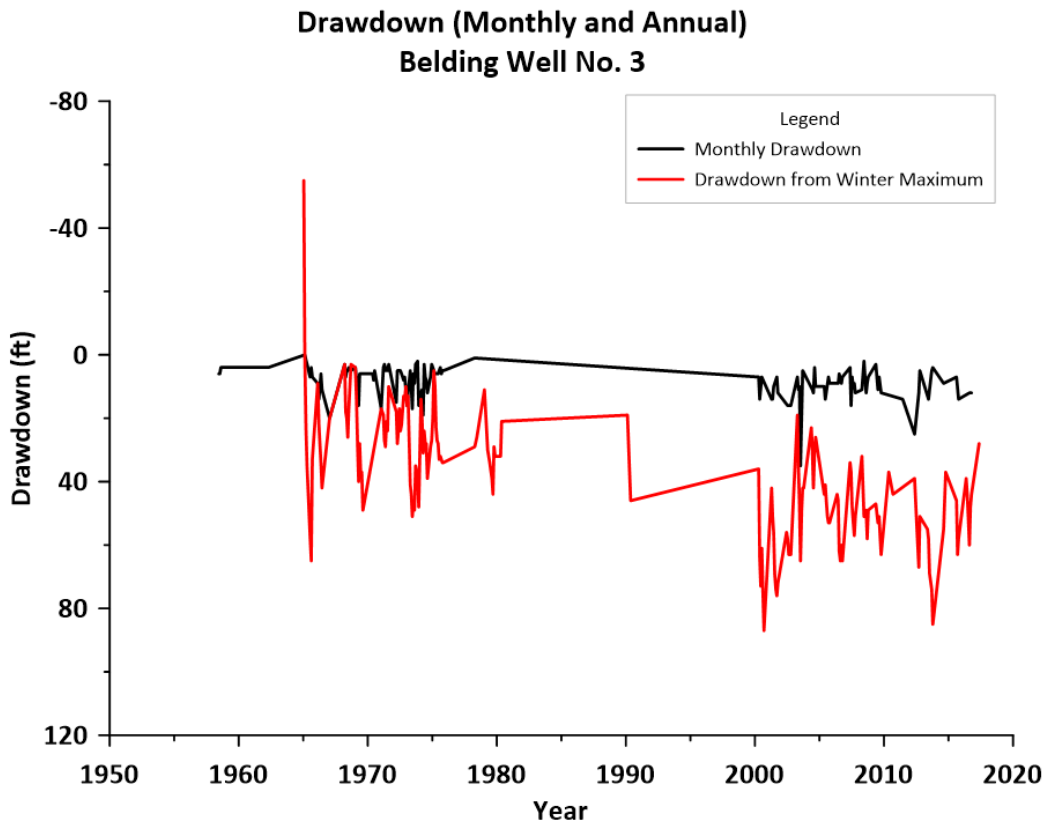
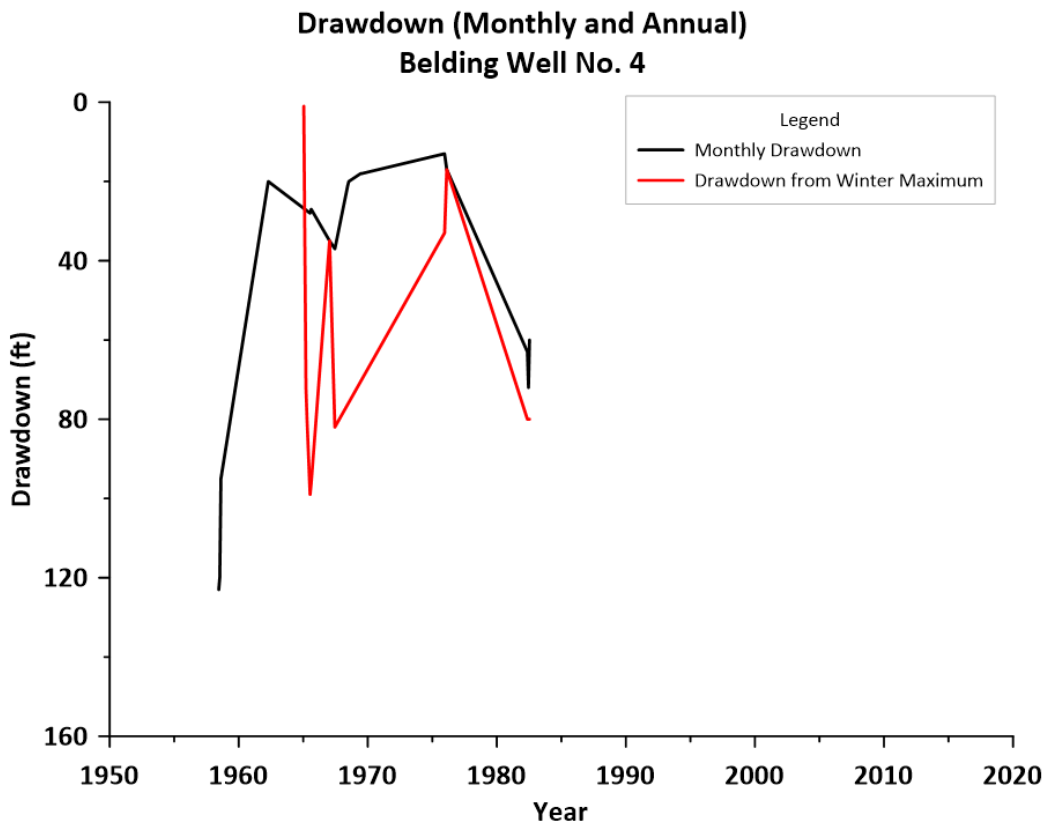
Appendix A

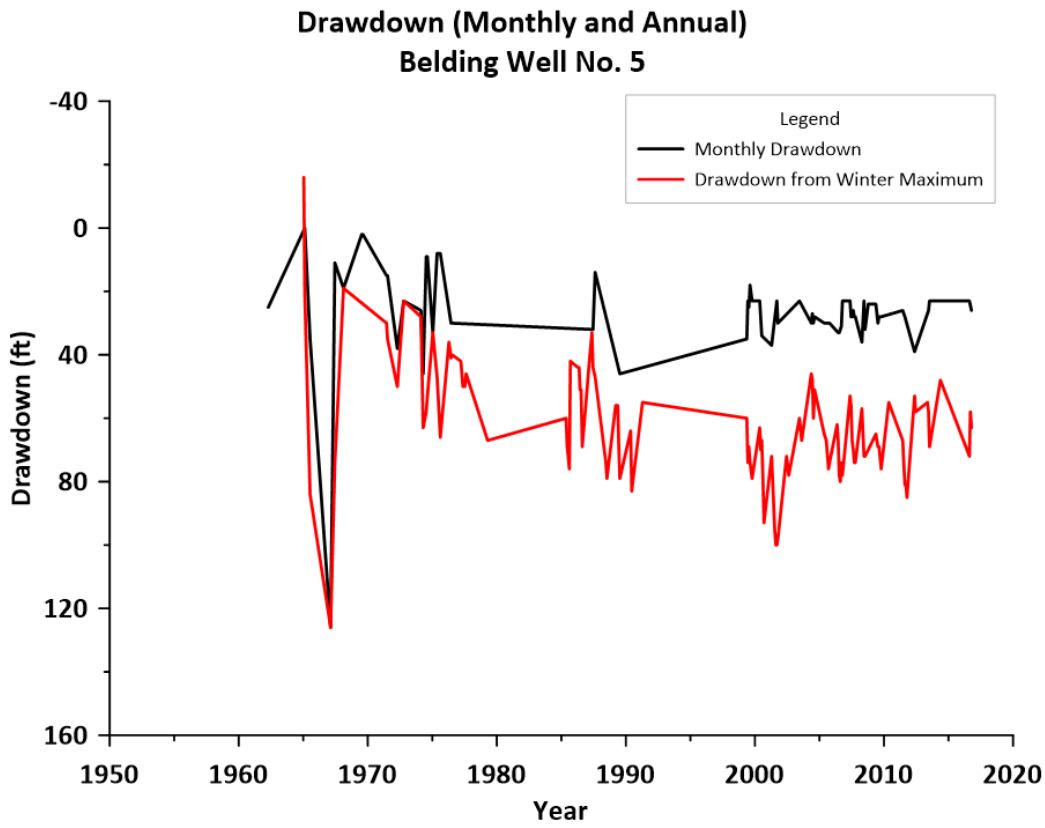
Belding Farms Drawdown Hydrographs

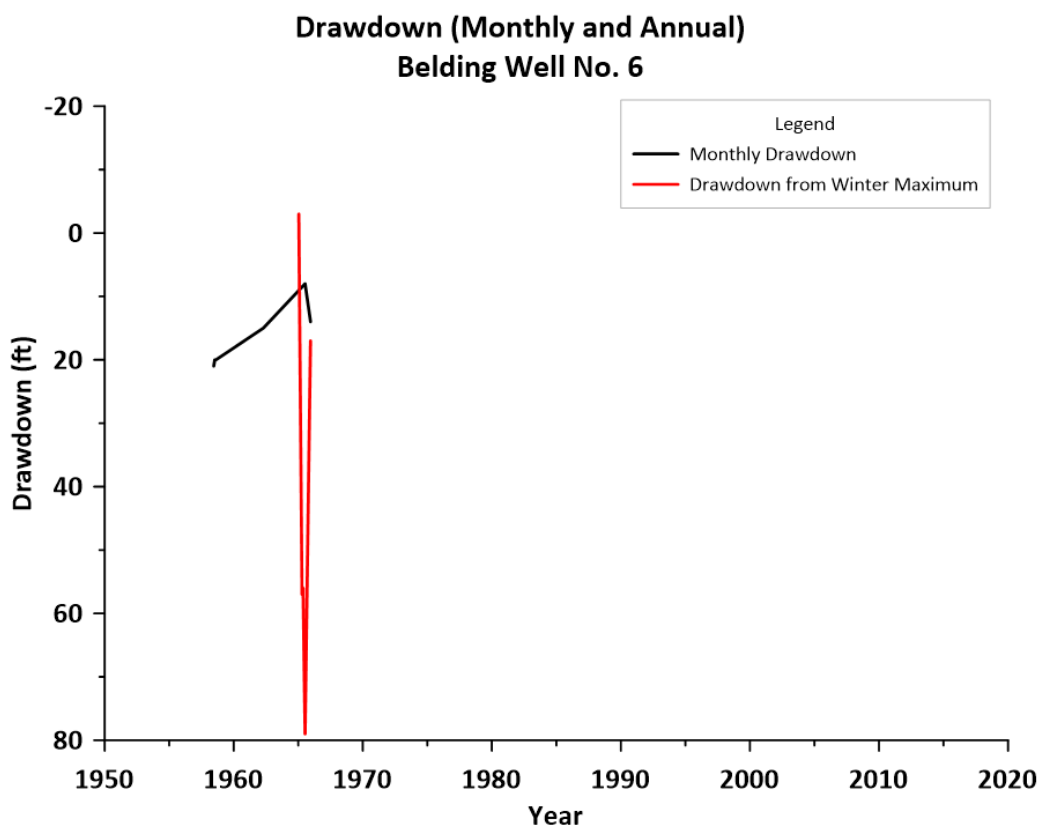

Drawdown (Monthly and Annual)
Belding Well No. 1
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-20
0
20
40
60
80
100
1950
1960
1970
1980
1990
2000
2010
2020
Year

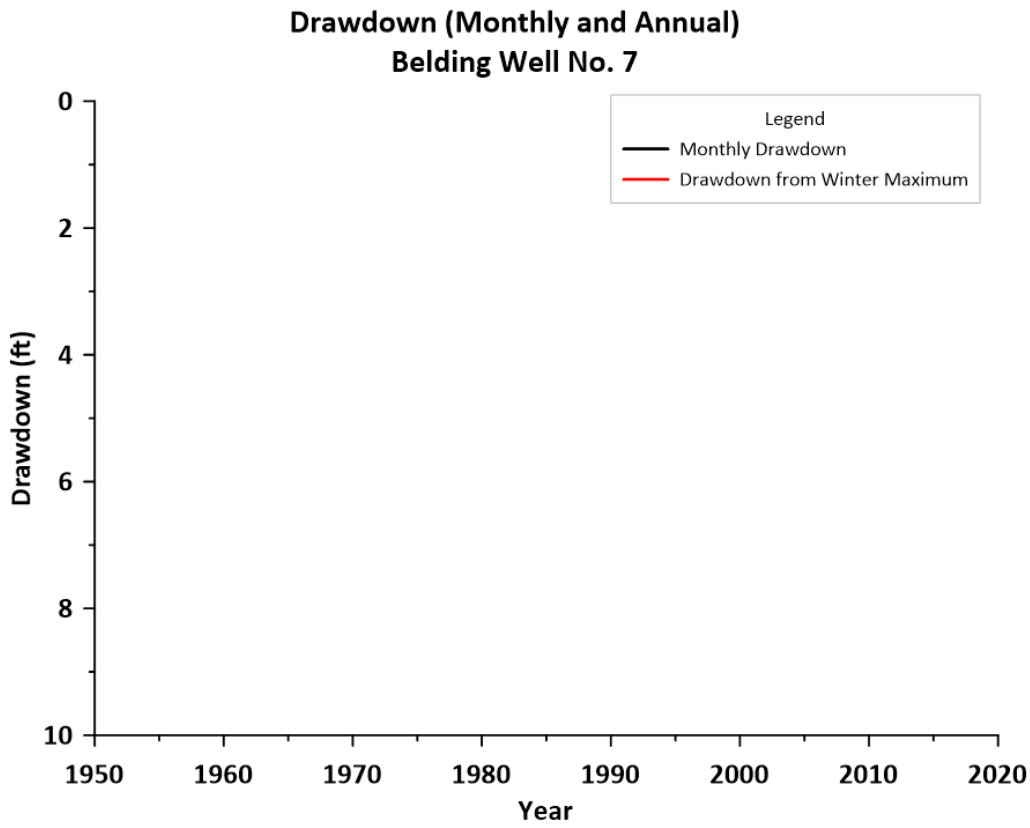

Drawdown (Monthly and Annual)
Belding Well No. 2
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-40
0
40
80
120
1950
1960
1970
1980
1990
2000
2010
2020
Year

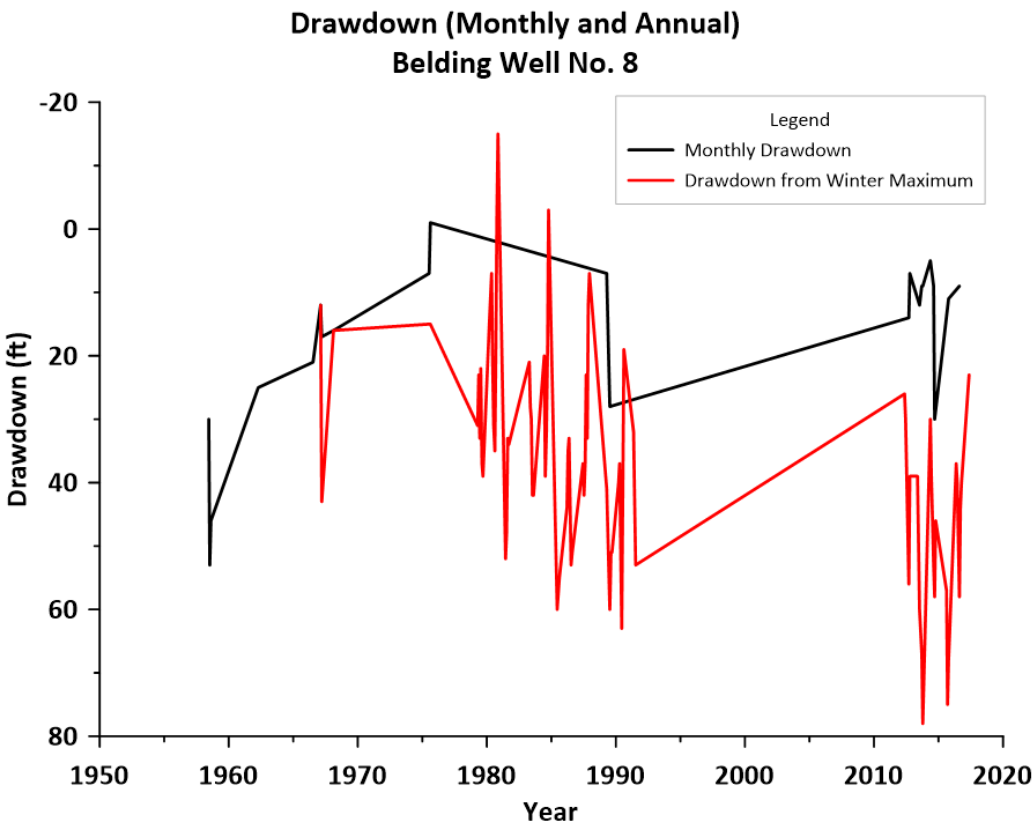

Drawdown (Monthly and Annual)
Belding Well No. 3
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-80
-40
0
40
80
120
1950
1960
1970
1980
1990
2000
2010
2020
Year

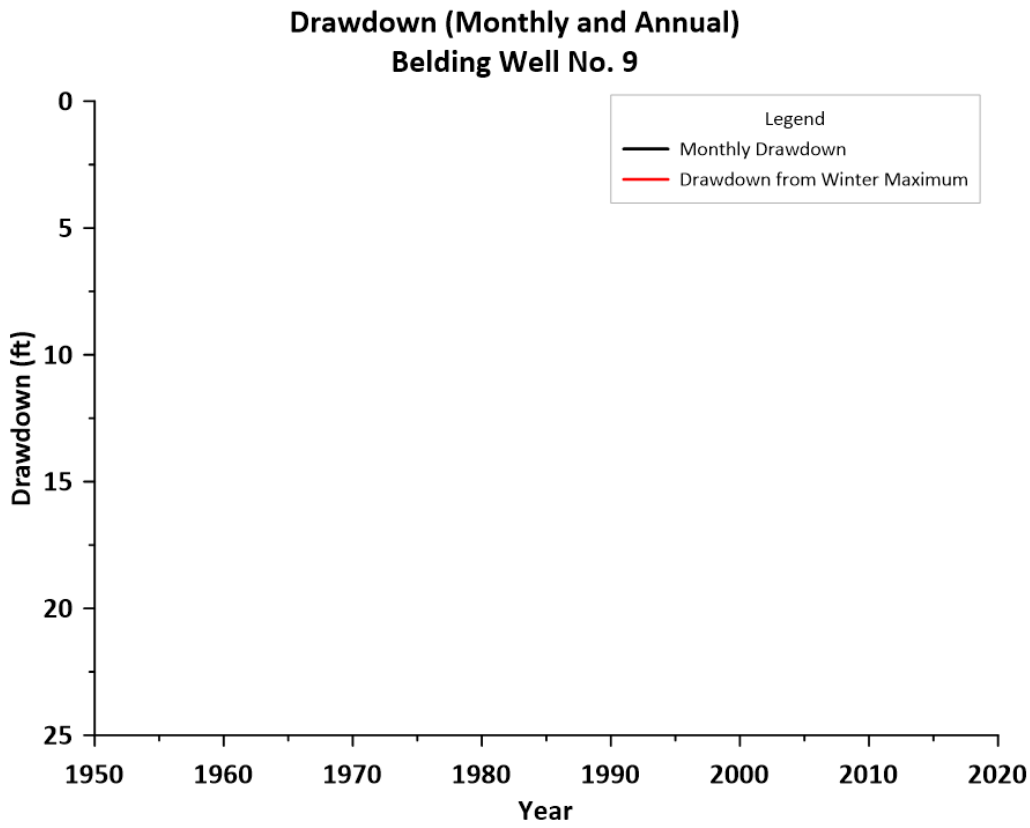

Drawdown (Monthly and Annual)
Belding Well No. 4
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
0
40
80
120
160
1950
1960
1970
1980
1990
2000
2010
2020
Year

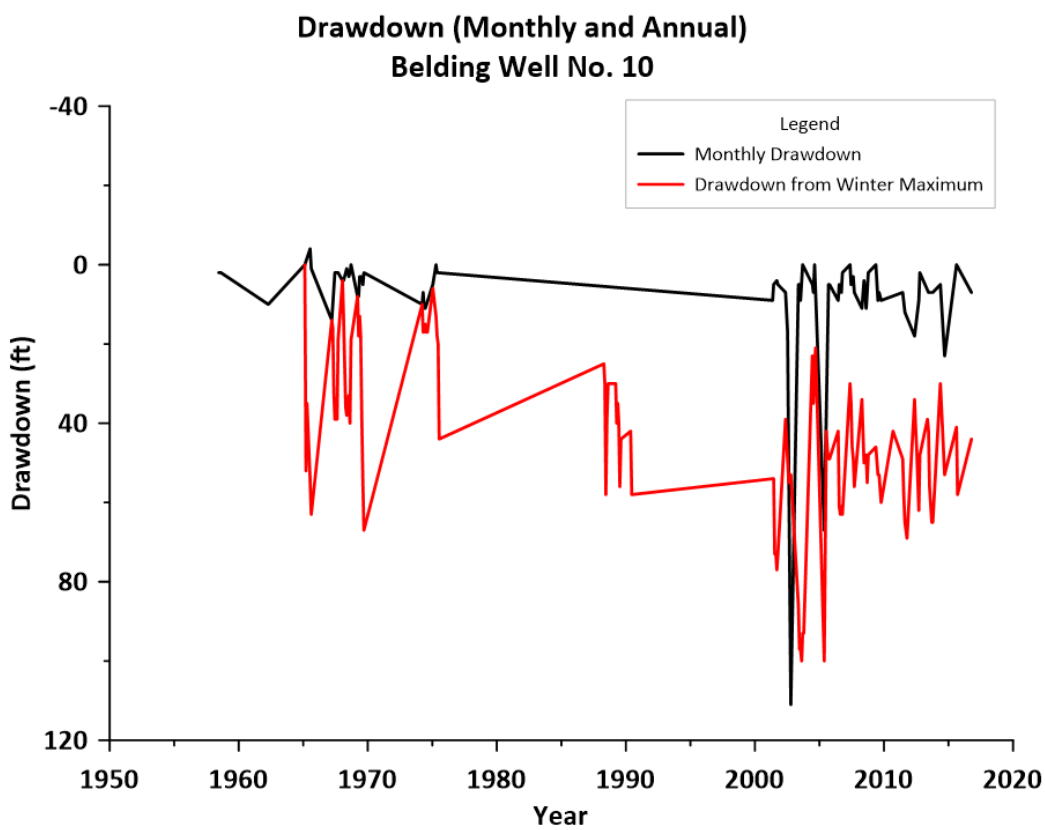

Drawdown (Monthly and Annual)
Belding Well No. 5
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-40
0
40
80
120
160
1950
1960
1970
1980
1990
2000
2010
2020
Year

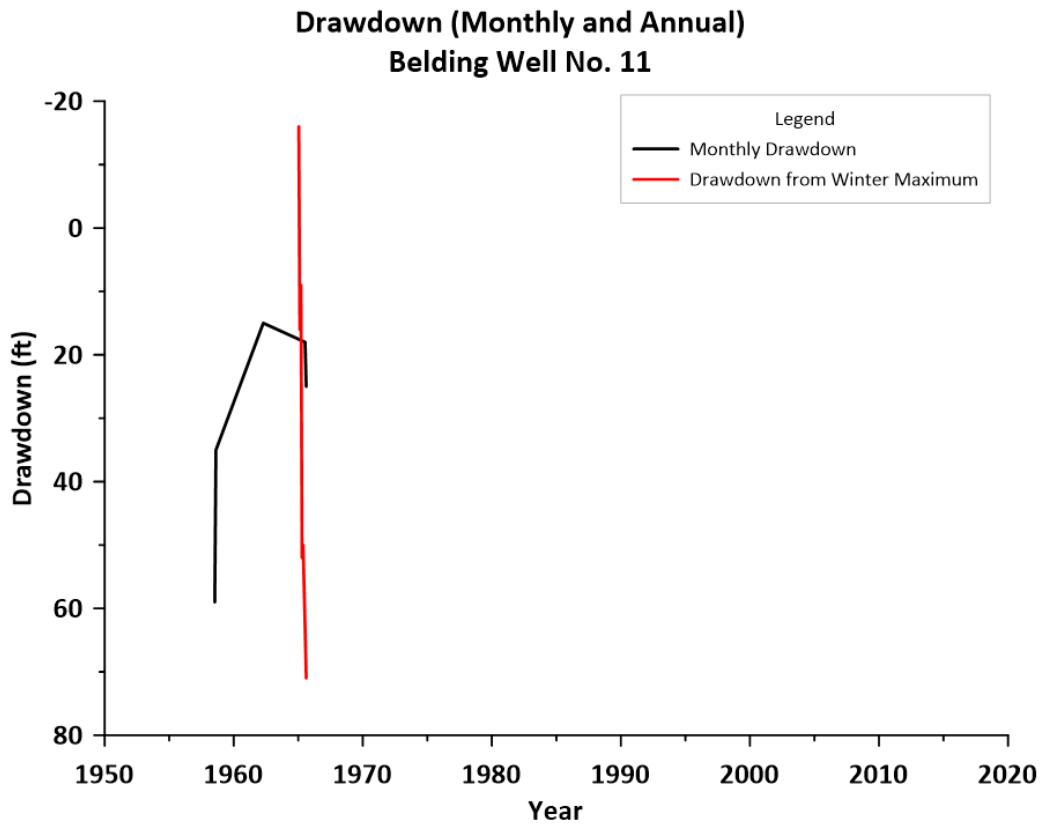

Drawdown (Monthly and Annual)
Belding Well No. 6
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-20
0
20
40
60
80
1950
1960
1970
1980
1990
2000
2010
2020
Year

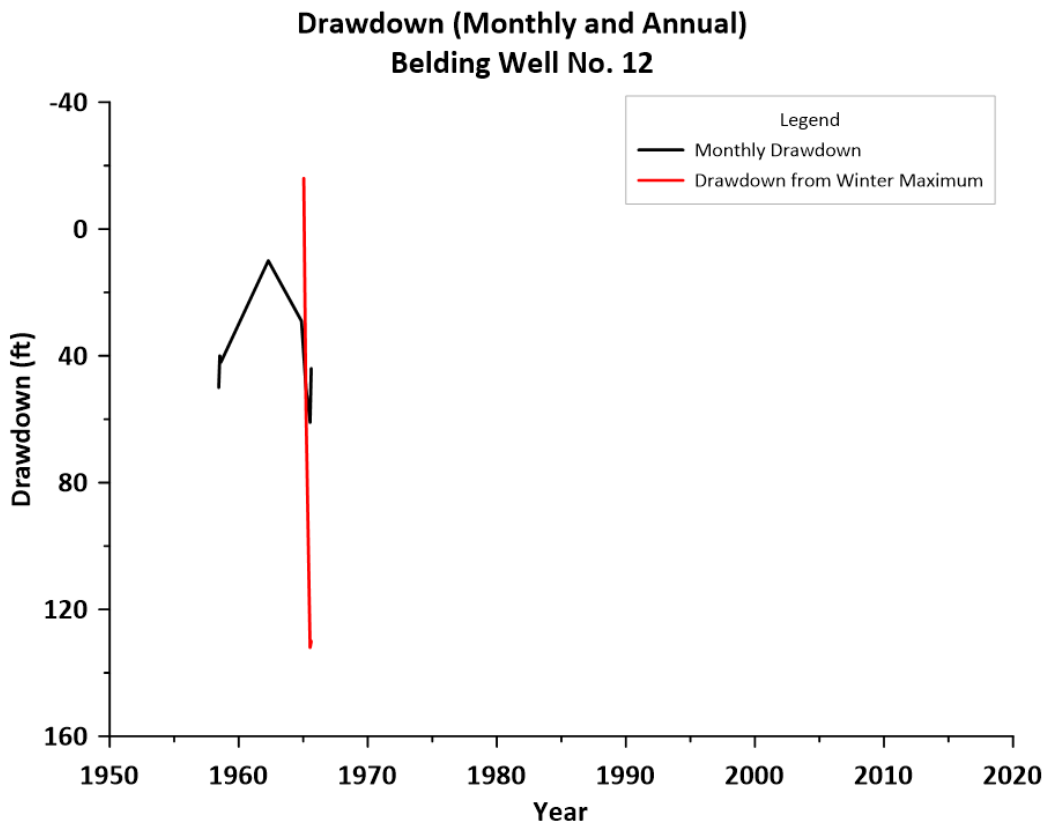

Drawdown (Monthly and Annual)
Belding Well No. 7
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
0
2
4
6
8
10
1950
1960
1970
1980
1990
2000
2010
2020
Year

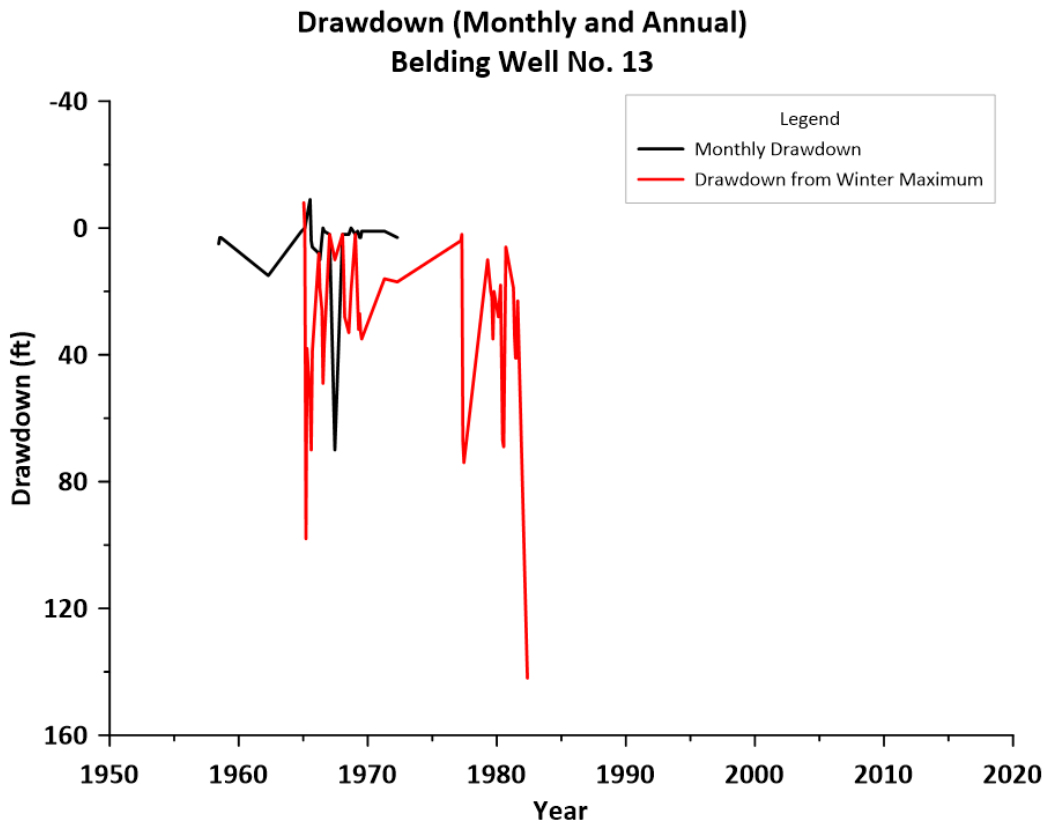

Drawdown (Monthly and Annual)
Belding Well No. 8
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-20
0
20
40
60
80
1950
1960
1970
1980
1990
2000
2010
2020
Year

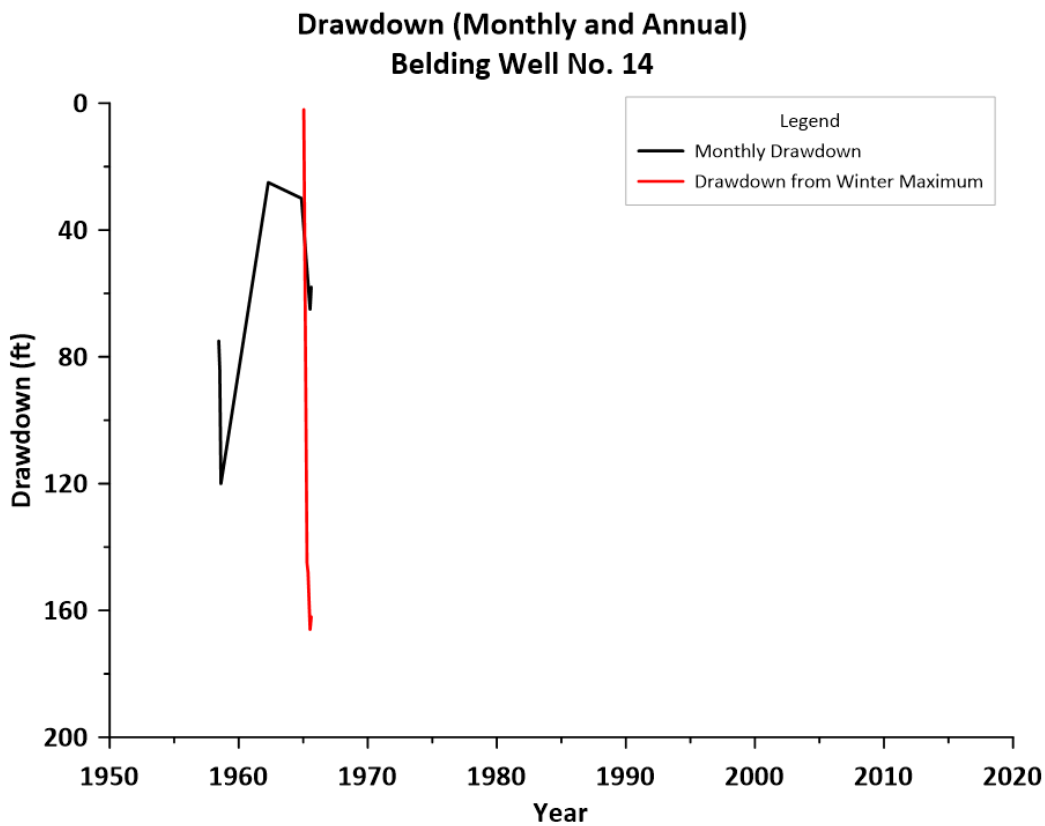

Drawdown (Monthly and Annual)
Belding Well No. 9
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
0
5
10
15
20
25
1950
1960
1970
1980
1990
2000
2010
2020
Year

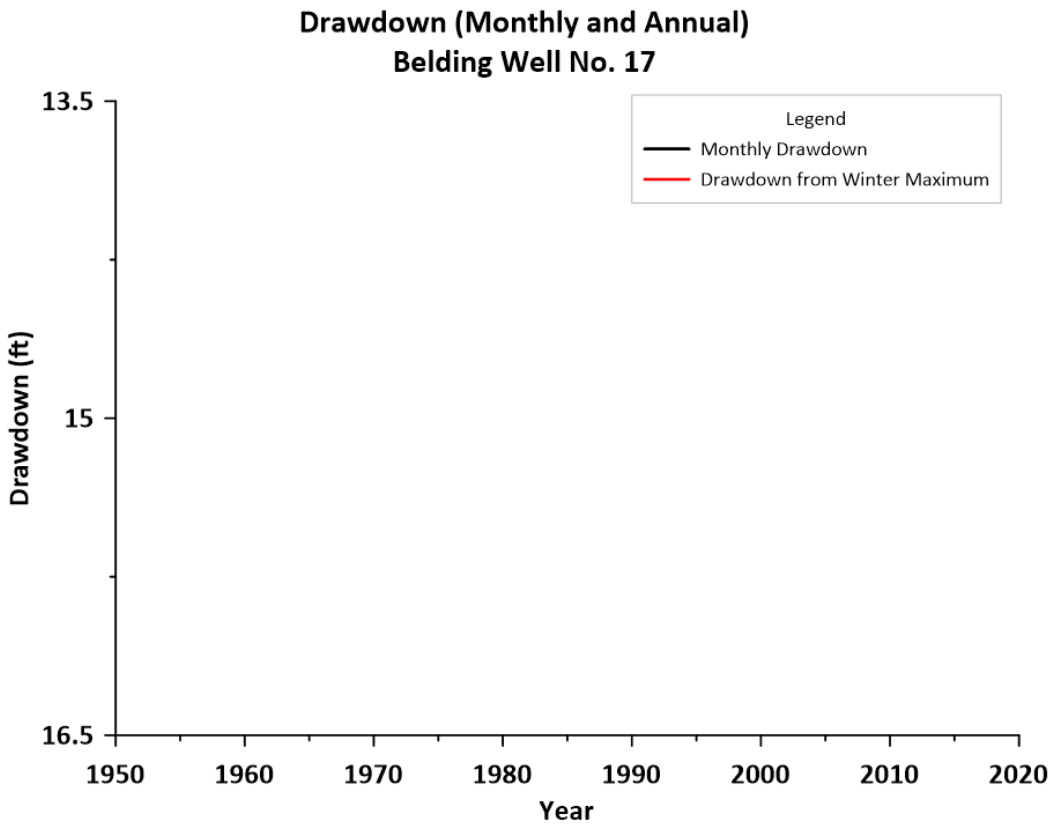

Drawdown (Monthly and Annual)
Belding Well No. 10
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-40
0
40
80
120
1950
1960
1970
1980
1990
2000
2010
2020
Year

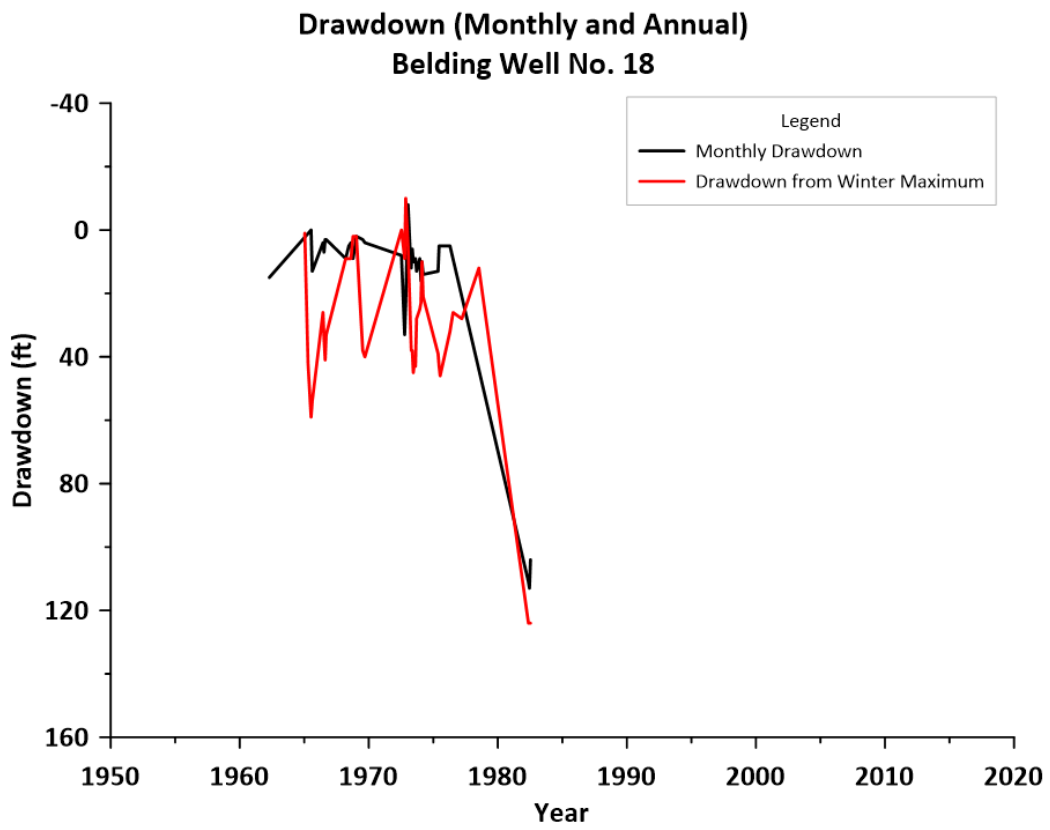

Drawdown (Monthly and Annual)
Belding Well No. 11
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-20
0
20
40
60
80
1950
1960
1970
1980
1990
2000
2010
2020
Year

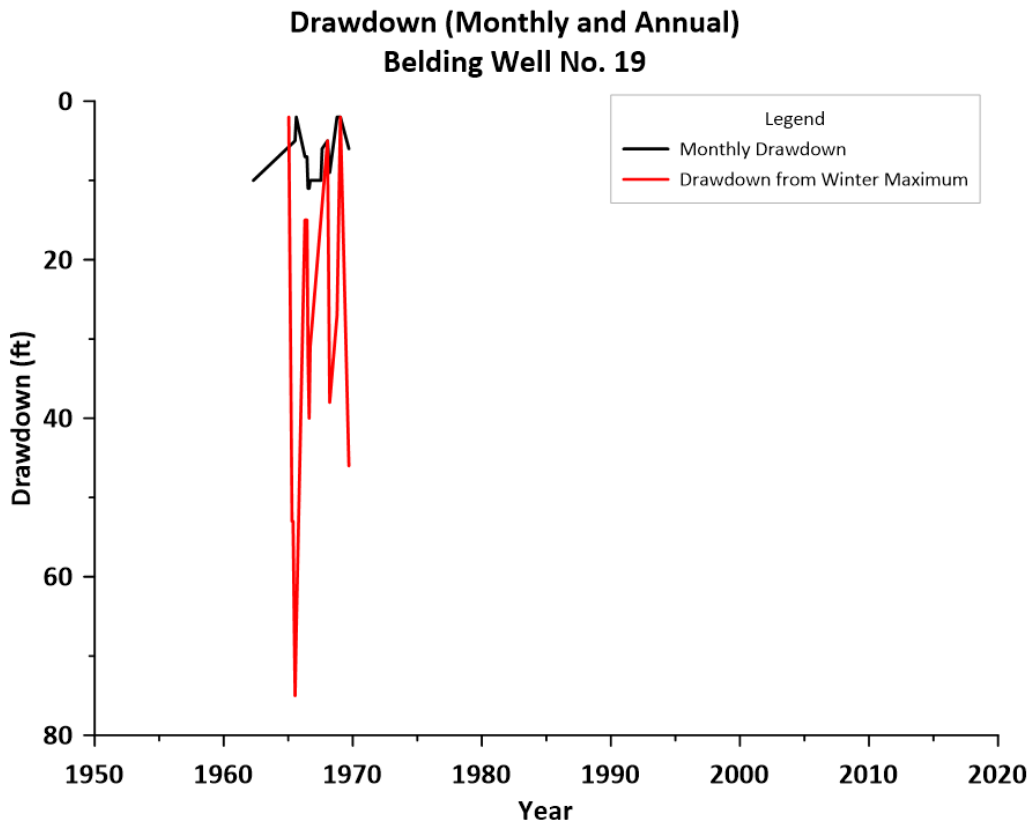

Drawdown (Monthly and Annual)
Belding Well No. 12
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-40
0
40
80
120
160
1950
1960
1970
1980
1990
2000
2010
2020
Year

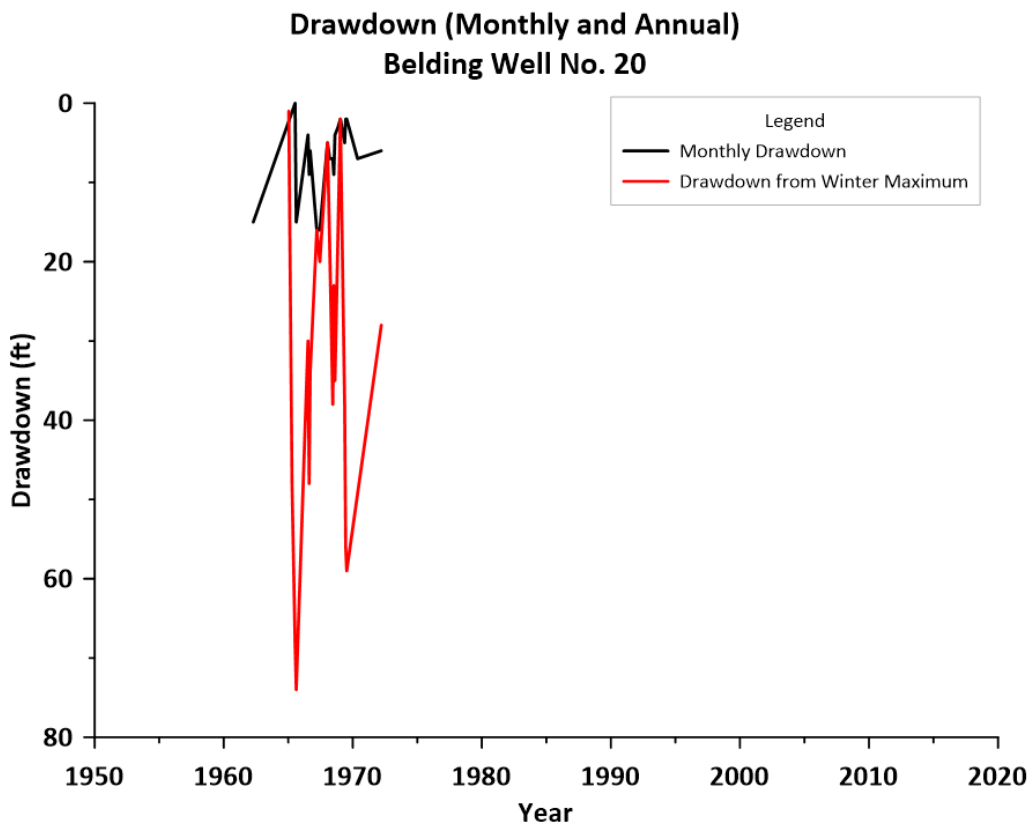

Drawdown (Monthly and Annual)
Belding Well No. 13
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-40
0
40
80
120
160
1950
1960
1970
1980
1990
2000
2010
2020
Year

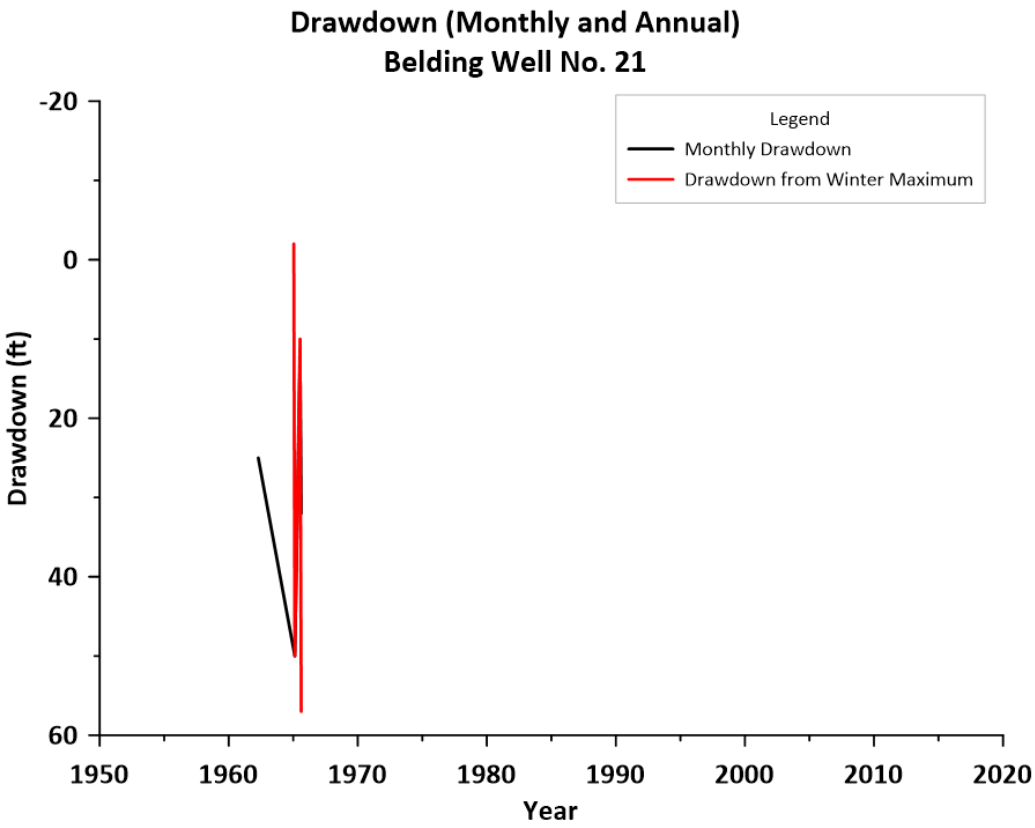

Drawdown (Monthly and Annual)
Belding Well No. 14
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
0
40
80
120
160
200
1950
1960
1970
1980
1990
2000
2010
2020
Year

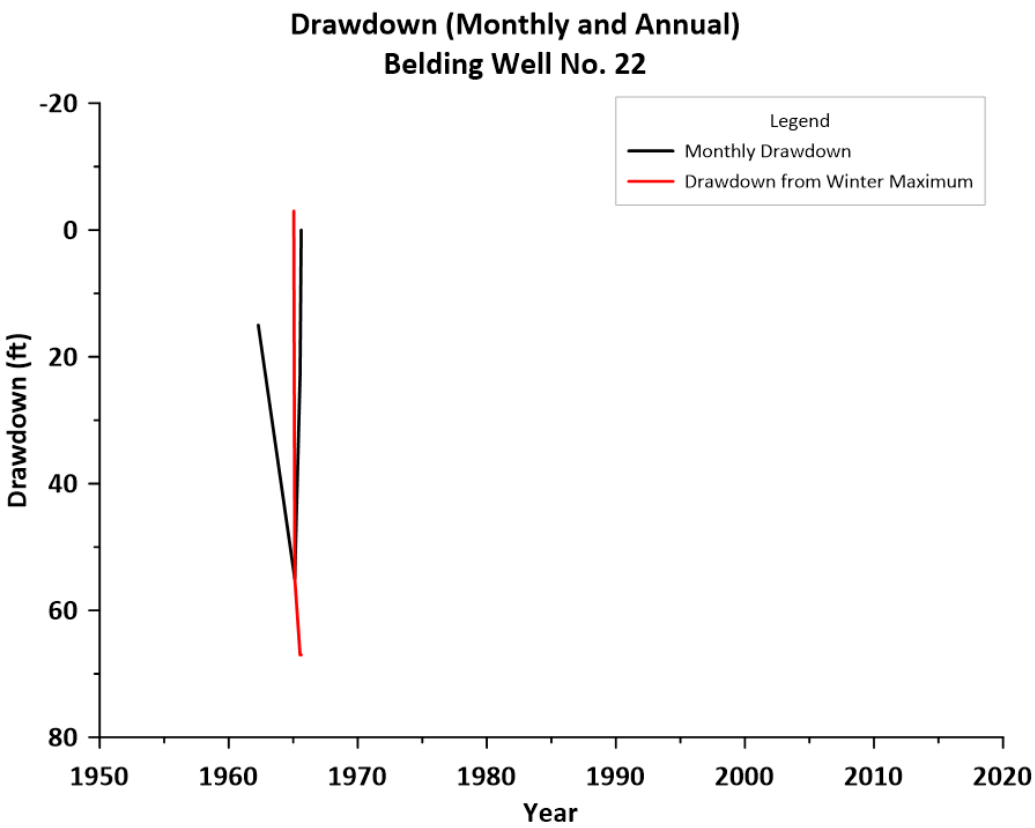

Drawdown (Monthly and Annual)
Belding Well No. 17
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
13.5
15
16.5
1950
1960
1970
1980
1990
2000
2010
2020
Year

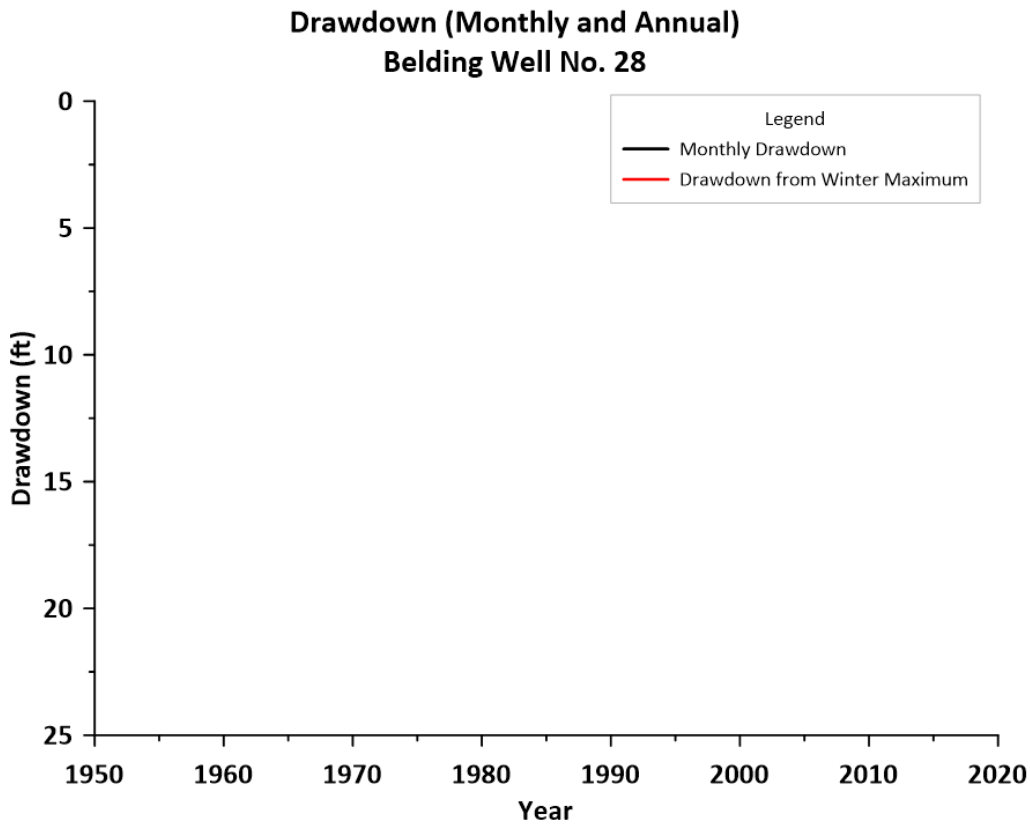

Drawdown (Monthly and Annual)
Belding Well No. 18
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-40
0
40
80
120
160
1950
1960
1970
1980
1990
2000
2010
2020
Year

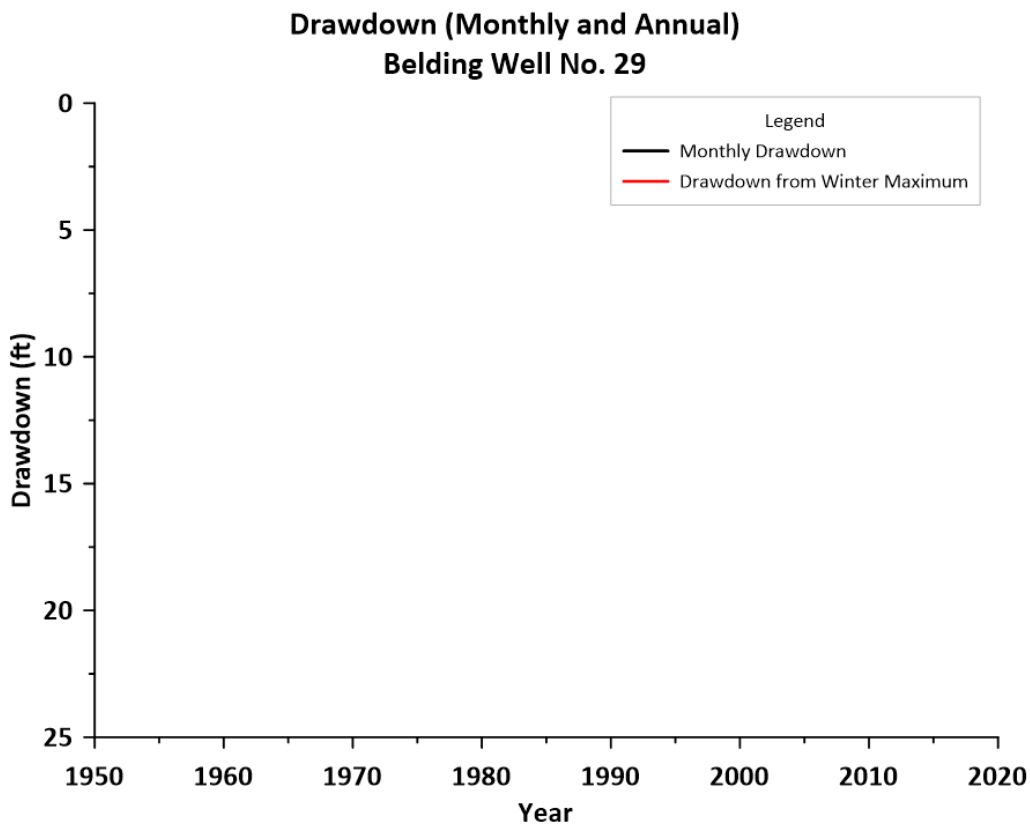

Drawdown (Monthly and Annual)
Belding Well No. 19
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
0
20
40
60
80
1950
1960
1970
1980
1990
2000
2010
2020
Year

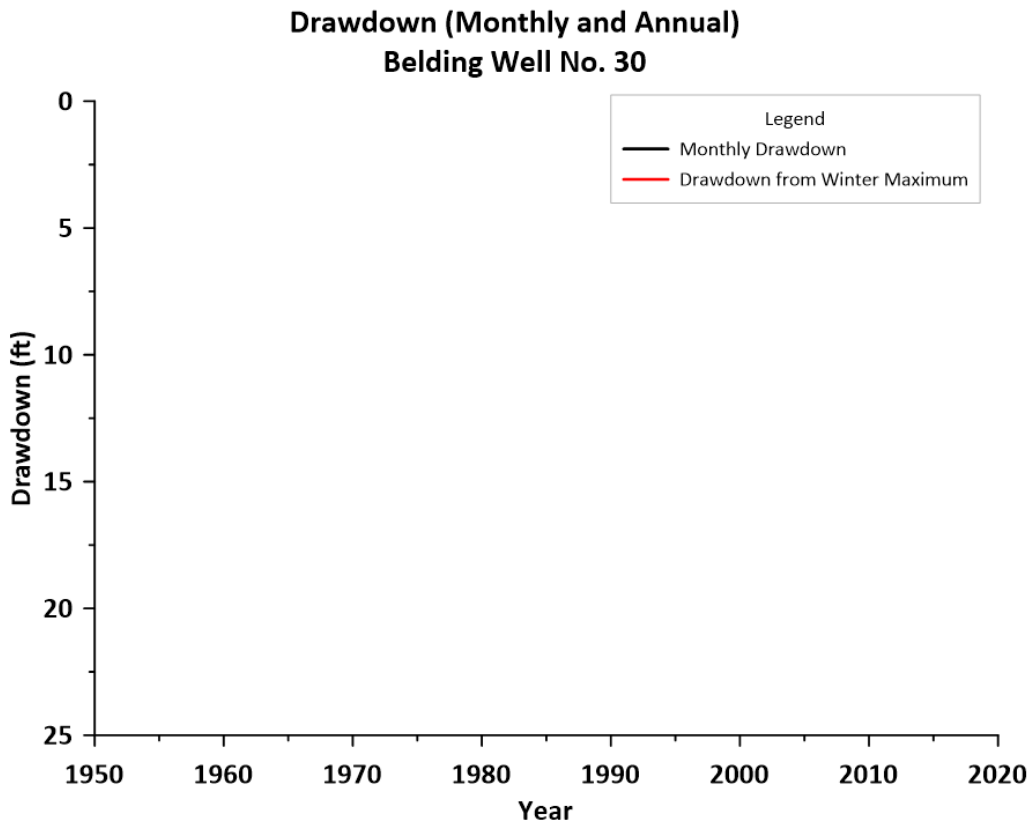

Drawdown (Monthly and Annual)
Belding Well No. 20
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
0
20
40
60
80
1950
1960
1970
1980
1990
2000
2010
2020
Year


Drawdown (Monthly and Annual)
Belding Well No. 21
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-20
0
20
40
60
1950
1960
1970
1980
1990
2000
2010
2020
Year


Drawdown (Monthly and Annual)
Belding Well No. 22
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
-20
0
20
40
60
80
1950
1960
1970
1980
1990
2000
2010
2020
Year


Drawdown (Monthly and Annual)
Belding Well No. 28
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
0
5
10
15
20
25
1950
1960
1970
1980
1990
2000
2010
2020
Year


Drawdown (Monthly and Annual)
Belding Well No. 29
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
0
5
10
15
20
25
1950
1960
1970
1980
1990
2000
2010
2020
Year


Drawdown (Monthly and Annual)
Belding Well No. 30
Legend
Monthly Drawdown
Drawdown from Winter Maximum
Drawdown (ft)
0
5
10
15
20
25
1950
1960
1970
1980
1990
2000
2010
2020
Year