Technical Memorandum

To:	Dirk Aaron, General Manager – Clearwater Underground Water Conservation District
From:	Michael Keester, PG
Date:	July 2, 2020
Project:	Update to the Evaluation of District Well Spacing Requirements

A Technical Memorandum dated September 30, 2015 documents an evaluation of the District's well spacing requirements (Keester and Konetchy, 2015). These spacing requirements are defined in Rule 9.5 of the District Rules effective April 1, 2016. This rule sets a minimum tract size, distance from other wells sites, and distance from the property line based on the inside diameter of the column pipe used to discharge water from the well.

Since the evaluation conducted in 2015, the District has collected additional data regarding the hydraulic properties of the managed aquifers. While the District has collected data for each of the aquifers, most of the new information is related to the hydraulic properties of the Lower Trinity Aquifer which makes it the aquifer where we would expect significant changes from the 2015 well spacing evaluation. To address these changes, our evaluation initially focused on the well spacing requirements for the Lower Trinity Aquifer. However, we also updated the methodology from that used in the 2015 evaluation. As such, we deemed it prudent to consider how the methodology changes would affect the spacing analysis of the Middle Trinity as well.

Methodology

Our general methodology follows the same process as the 2015 evaluation with some updates discussed in the following sections. We applied the Theis (1935) analytic model to estimate the effects of pumping. The Theis model uses five parameters to calculate drawdown, namely: pumping rate, pumping time, distance from pumping, aquifer transmissivity, and aquifer storage coefficient. To update the 2015 evaluation, we calculated drawdown at various distances from the pumping well with pumping durations of 1 day, 1 month, and 1 year.

Column Pipe and Pumping Rate

For the pumping rate, we reconsidered the values used in the 2015 evaluation that were associated with each identified column pipe size range in the District rules. We first reviewed published data from Grundfos (2020) regarding the column pipe size associated with pumps rated for various pumping rates. Based on the published data for the submersible pumps, there can be a wide range in the motor horsepower associated with the column pipe size. For example, a 2-inch column pipe could be used with a pump that is driven by a motor with horsepower ranging from 0.75 to 25 depending on the total head (that is, equivalent feet of water above the pump). However, the range of pumping rates assigned to the submersible pumps for each column pipe size is much smaller than the horsepower range.Table 1 provides the range of pumping rates associated with column pipe diameters for various Grundfos submersible pumps.

Table 1. Column pipe diameter associated with pumping rates for Grundfos submersible pump models (Grundfos, 2020).

Column Pipe Diameter (in)	Minimum Pumping Rate (gpm)	Maximum Pumping Rate (gpm)
1	5	7
1.25	10	16
1.5	25	35
2	35	77
3	85	300
4	300	385
6	475	1,100

To estimate a single pumping rate associated with each column pipe diameter, we determined the median pipe flow velocity, based on the pumping rates, associated with the Grundfos submersible pumps. However, as shown in Table 1, the Grundfos submersible pumps only provide guidance for up to a 6-inch diameter column pipe. To calculate pumping rates for larger column pipe sizes, we used the median pipe flow velocity of 6.8 feet per second (fps) determined from all of the Grundfos submersible pump data. However, we observed that for many of the Grudfos pumps the median flow velocity values exceed rule-of-thumb values for the column pipe diameters (The Engineering Toolbox, 2020). Therefore we used a combination of the Grundfos median and rule-of-thumb pipe flow velocity values to estimate pumping rates associated with each column pipe diameter. Table 2 provides the estimated pumping rates associated with the pipe flow velocities.

Table 2. Column pipe diameter and estimated pumping rate associated with pipe flow velocity.

Column Pipe Diameter (in)	Grundfos Median (G.M.) Pipe Flow Velocity (fps)	G.M. Est. Pumping Rate (gpm)	Rule-of-Thumb (R.T.) Pipe Flow Velocity (fps)	R.T. Est. Pumping Rate (gpm)
1	2.0	5	3.5	9
1.25	3.4	13	3.5	13
1.5	6.3	35	3.5	19
2	4.6	46	3.6	35
3	6.8	150	3.8	84
4	9.8	385	4.0	157
6	7.1	625	4.7	415
8	6.8	1,066	5.5	862
10	6.8	1,666	6.5	1,593
12	6.8	2,399	8.5	2,999
14	6.8	3,265	8.5	4,082

The rule-of-thumb pipe flow velocity values are typically lower than the median values associated with the Grundfos submersible pumps. For the column pipe diameter up to 8 inches, we used the pumping rates estimated from the Grundfos data to guide our pumping rate assignment. For the column pipe diameter more than 8 inches, we used the rule-of-thumb pipe flow velocity values to guide our assignment of the pumping rate. Table 3 provides the pumping rates associated with each column pipe diameter we used to update the well spacing evaluation along with the pumping rate associated with the range of column pipe sizes used in the District Rules.

Table 3. Column pipe diameter and assigned pumping rate.

Column Pipe Diameter (in)	Assigned Pumping Rate (gpm)		District Column Pipe Diameter Range (in)	District Range Assigned Pumping Rate (gpm)
1	5		**Up to 2**	45
1.25	10			
1.5	35			
2	45			
3	150		**>2 to 4**	385
4	385			
6	625		**>4 to 6**	625
8	1,000		**>6 to 8**	1,000
10	1,500		**>8 to 10**	1,500
12	3,000		**More than 10***	3,000
14	4,000			

*District Rule 9.5.2 identifies this range as 12-inch or larger

To update the 2015 evaluation, we calculated drawdown after 1 day, 1 month, and 1 year using the method applied in version 1.0 of the District's Drawdown Prediction Tool. The method used by the District's tool applies continuous pumping at the instantaneous rate to predict 1-day drawdown, 15 percent more than the average monthly amount for 30-day drawdown, and the annual amount for 1-Year drawdown (Keester, 2019). The values presented in Table 3 provide the continuous rate for the 1-day drawdown prediction.

For the 30-day drawdown and 1-year drawdown, we assumed an average annual service time of 30 percent for column pipe sizes of 3 inches or more. For a 1-inch column pipe, we set the annual rate at 0.6 acre-feet and for column pipe diameters of 1.25, 1.5, and 2 inches we applied an average annual service time of 1 hour per day. Table 4 provides the estimated pumping volumes associated with each column pipe diameter.

Table 4. Column pipe diameter and estimated production in acre-feet for each time period.

Column Pipe Diameter (in)	1 Day	30 Days	1 Year
1	0.02	0.06	0.60
1.25	0.04	0.06	0.67
1.5	0.15	0.23	2.35
2*	0.20	0.29	3.02
3	0.66	6.96	72.59
4*	1.70	17.85	186.30
6*	2.76	28.98	302.44
8*	4.42	46.37	483.90
10*	6.63	69.56	725.85
12*	13.26	139.12	1,451.71
14	17.68	185.50	1,935.61

*Identifies values that correspond to District defined ranges

Aquifer Hydraulics

The 2015 evaluation relied on transmissivity values as represented in the North Trinity Woodbine Groundwater Availability Model (Kelley and others, 2014). In 2016, the model transmissivity values for the Lower Trinity Aquifer were updated within and near Bell County to better reflect the results from multiple pumping tests (Keester and Konetchy, 2016). These Lower Trinity Aquifer values are also currently being updated to incorporate data from aquifer tests conducted and analyzed since 2016. For this update of the well spacing evaluation, we used the draft updated transmissivity values for the Lower Trinity Aquifer and the TWDB GAM values for the Middle Trinity Aquifer. Table 5 provides the update statistical summary of transmissivity for the two aquifers based on the 17,390 active model cells representing Bell County.

Table 5. Statistical summary of transmissivity values for the Lower Trinity Aquifer in Bell County in square feet per day (ft²/d).

Statistical Measure	Middle Trinity TWDB GAM	Lower Trinity TWDB GAM	Lower Trinity Draft Modified GAM
Minimum	2	278	25
First Quartile	23	427	837
Median	101	512	1,723
Third Quartile	185	717	5,309
Maximum	407	1,220	20,033
Mean	115	593	3,974

For the 2015 evaluation, three storage coefficient values (0.00001, 0.0001, and 0.001) were considered for each aquifer to cover the range of likely values. However, a 30-day aquifer test using the Trinity Oasis well completed in the deep Lower Trinity Aquifer indicated a storage coefficient of 0.00007 to 0.00024 (Yelderman Jr and others, 2020). For this update of the well spacing evaluation, we only used 0.0001 based on the recent aquifer test results that indicate the value is a representative storage coefficient for the Lower Trinity Aquifer. We also used this single value for the Middle Trinity.

Drawdown Estimates

The 2015 evaluation used the 1st quartile, median, and 3rd quartile values of transmissivity to calculate the range of potential drawdown. However, for this update we began by performing the drawdown and spacing calculations for each of the 17,390 active model cells representing Bell County. We then determined the statistical measure from these predicted drawdown results.

In the 2015 evaluation, it was noted that in some cases the calculations were "nonsensical when considered relative to the depth and thickness of the aquifers" (Keester and Konetchy, 2015). To limit the calculation of unrealistic drawdown values, we applied a pumping rate limitation based on an estimate of the specific capacity for the well derived from the aquifer transmissivity. We can estimate the specific capacity for a well in gallons per minute per foot (gpm/ft) from the aquifer transmissivity in gallons per day per foot (gpd/ft) by dividing the transmissivity by 2,000 (Driscoll, 1986). We can then multiply the estimated specific capacity by the available drawdown to determine the maximum pumping rate.

For the available drawdown, we used the difference between the estimated water level at the end of 2019 and the top of the aquifer (Figure 1 illustrates the available drawdown for the Lower Trinity Aquifer). For locations where the available drawdown was more than 200 feet, we capped the available drawdown at 200 feet for calculation of the maximum pumping rate. For example, the estimated transmissivity at a grid cell in western Bell County is 5,152 gpd/ft resulting in a specific capacity of 2.58 gpm/ft which, when multiplied by the estimated available drawdown of 168 feet, results in a maximum pumping rate of 432 gpm. For this particular location, pumping rates associated with column pipe diameters greater than 4 inches were limited to 432 gpm.

Similarly, in some locations in the Middle Trinity Aquifer the calculated available drawdown was less than one foot. In cases where the estimated available drawdown was less than one foot, we assigned a minimum available drawdown value of one foot to that location. For example, a Middle Trinity Aquifer grid cell in western Bell County has an estimated transmissivity value of 765 gpd/ft resulting in a specific capacity of 0.38 gpm/ft. The 2019 estimated water level is at the top of the aquifer resulting in zero feet of available drawdown. However, for conducting the spacing analysis we assigned the location an available drawdown of one foot resulting in a maximum pumping rate of 0.38 gpm which is essentially equal to the one-year pumping rate from a 1-inch column pipe.

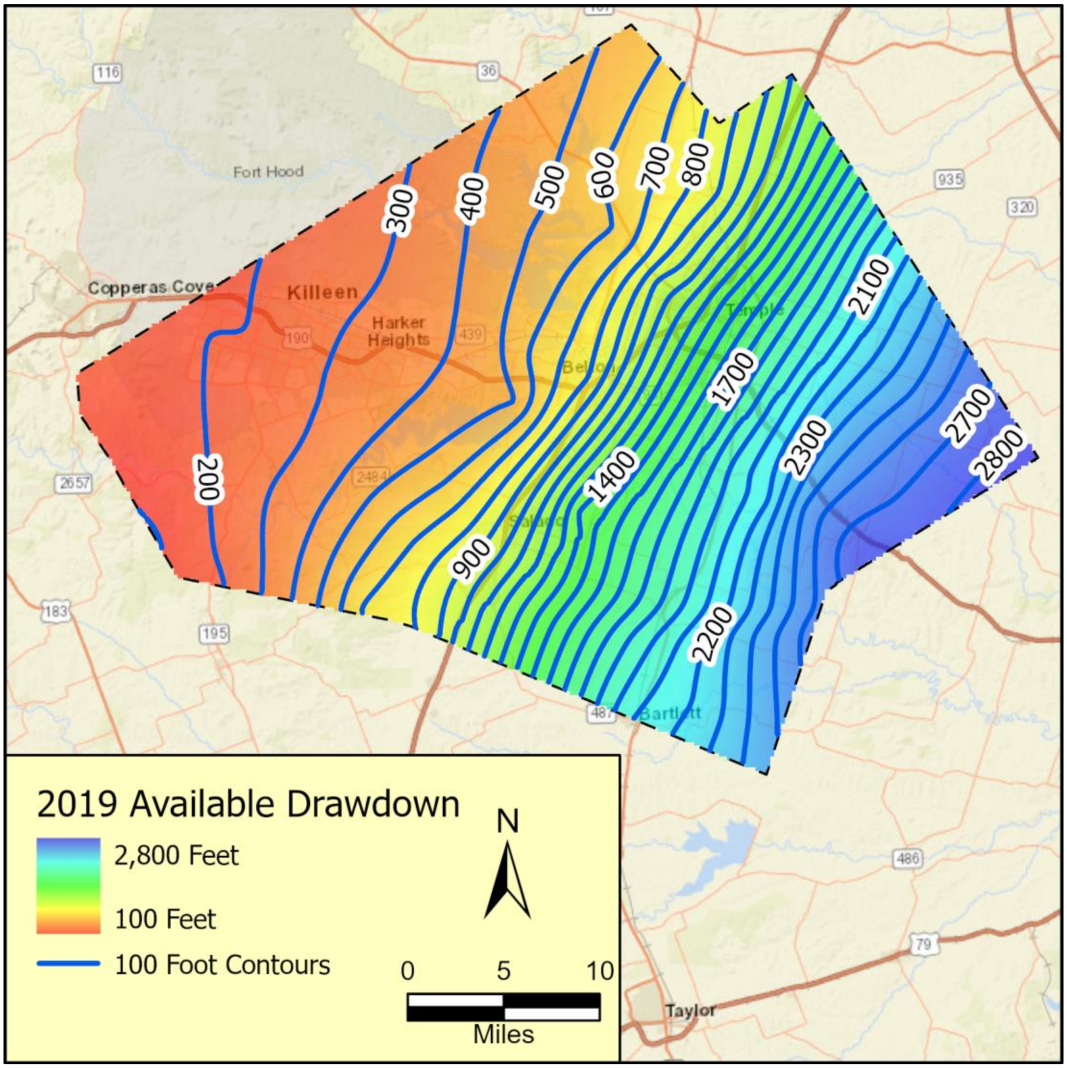

Figure 1. Lower Trinity Aquifer available drawdown at the end of 2019.

Using the pumping rates for each column pipe diameter, or the maximum possible at a grid cell, we calculated the predicted drawdown at the current spacing required between wells. Table 6 and Table 7 provide the first and third quartile predicted drawdown for the Middle Trinity and Lower Trinity, respectively.Table 8 provides the median predicted drawdown for each column pipe diameter range for both aquifers.

Table 6. Middle Trinity — 1st quartile and 3rd quartile predicted drawdown in feet at each column pipe range at the currently required spacing between wells per District Rule 9.5.2. This table updates Table 3 in the 2015 evaluation.

District Column Pipe Diameter Range (in)	1st Quartile Drawdown			3rd Quartile Drawdown		
	1 Day	30 Days	365 Days	1 Day	30 Days	365 Days
Up to 2	21	2	2	40	11	12
>2 to 4	16	48	69	41	71	95
>4 to 6	16	48	76	41	79	105
>6 to 8	16	48	76	41	80	108
>8 to 10	16	48	76	41	80	108
More than 10	16	48	76	41	80	108

Table 7. Lower Trinity — 1st quartile and 3rd quartile predicted drawdown in feet at each column pipe range at the currently required spacing between wells per District Rule 9.5.2. This table updates Table 3 in the 2015 evaluation.

District Column Pipe Diameter Range (in)	1st Quartile Drawdown			3rd Quartile Drawdown		
	1 Day	30 Days	365 Days	1 Day	30 Days	365 Days
Up to 2	1	0	0	6	0	0
>2 to 4	8	4	4	37	22	24
>4 to 6	13	7	7	53	35	39
>6 to 8	21	11	11	60	56	62
>8 to 10	31	16	17	63	79	89
More than 10	49	32	34	69	99	125

Table 8. Median predicted drawdown in feet at each column pipe range at the currently required spacing between wells per District Rule 9.5.2. This table updates Table 4 in the 2015 evaluation.

District Column Pipe Diameter Range (in)	Middle Trinity Median Drawdown			Lower Trinity Median Drawdown		
	1 Day	30 Days	365 Days	1 Day	30 Days	365 Days
Up to 2	29	3	3	3	0	0
>2 to 4	30	60	81	21	11	12
>4 to 6	30	65	90	33	18	20
>6 to 8	30	65	92	48	29	32
>8 to 10	30	65	92	56	44	48
More than 10	30	65	92	61	80	91

For the Middle Trinity Aquifer, the results shown in the previous tables are the same for the larger column pipe diameters. These results indicate that based on our current understanding of the transmissivity of the

Middle Trinity Aquifer, we would not expect wells with a column pipe greater than four inches in diameter and likely would not expect a well with a column pipe greater than two inches. The limitations placed on the calculations to avoid nonsensical results constrains the predicted maximum pumping rates from the Middle Trinity Aquifer to be no more than about 300 gpm throughout the District.

As with the 2015 evaluation, for the Lower Trinity Aquifer we observe a range in the predicted drawdown for each column pipe diameter. For example, review of the statistical measures for predicted drawdown after 365 days indicates a range of more than 100 feet for a well with column pipe diameter more than 2 and up to 4 inches (see Table 9). As Table 9 indicates, except for wells with a small column pipe diameter, the range in potential drawdown after 365 days based on our current understanding of aquifer conditions is considerable.

Table 9. Lower Trinity — Statistical summary of predicted drawdown in feet at each column pipe range at the currently required spacing between wells per District Rule 9.5.2 after 365 days.

Statistical Measure	District Column Pipe Diameter Range (in)					
	Up to 2	>2 to 4	>4 to 6	>6 to 8	>8 to 10	More than 10
Minimum	0	1	2	3	5	10
First Quartile	0	4	7	11	17	34
Median	0	12	20	32	48	91
Third Quartile	0	24	39	62	89	125
Maximum	11	109	115	120	125	133
Mean	0	16	25	40	55	81

As with the 2015 evaluation, we also calculated the spacing to maintain no more than 50 feet of drawdown in an existing well due to production from a new well with each column pipe diameter range. As shown in Table 10, for small column pipe diameters in the Middle Trinity Aquifer, the distance to 50 feet of predicted drawdown does not exceed the current spacing requirement. However, for all other column pipe diamters the first quartile of the predicted distance to 50 feet of drawdown is about three times greater than the current spacing requirement.

For the Lower Trinity Aquifer, the third quartile distance to 50 feet of predicted drawdown from a well with the largest column pipe diameter exceeds one mile after 365 days of production. However, for most other column pipe diameters, the median distance to 50 feet of drawdown is less than the current required spacing between wells and the property line. Table 11 provides the statistical summary fo the distance from a proposed production well to 50 feet of drawdown in the Lower Trinty Aquifer.

Table 10. Middle Trinity — Statistical summary of distance in feet to 50 feet of predicted drawdown at each column pipe range after 365 days (minimum of 1 foot).

Statistical Measure	District Column Pipe Diameter Range (in)					
	Up to 2	>2 to 4	>4 to 6	>6 to 8	>8 to 10	More than 10
Spacing from Wells	100 feet	300 feet				
Spacing from Property Line	50 feet	200 feet	300 feet	350 feet	400 feet	450 feet
Minimum	1	1	1	1	1	1
First Quartile	1	855	972	972	972	972
Median	1	1,474	2,097	2,105	2,105	2,105
Third Quartile	1	2,499	3,553	3,850	3,850	3,850
Maximum	511	4,019	5,121	6,444	6,510	6,510
Mean	11	1,679	2,291	2,439	2,439	2,439

Table 11. Lower Trinity — Statistical summary of distance in feet to 50 feet of predicted drawdown at each column pipe range after 365 days (minimum of 1 foot).

Statistical Measure	District Column Pipe Diameter Range (in)					
	Up to 2	>2 to 4	>4 to 6	>6 to 8	>8 to 10	More than 10
Spacing from Wells	100 feet	300 feet				
Spacing from Property Line	50 feet	200 feet	300 feet	350 feet	400 feet	450 feet
Minimum	1	1	1	1	1	1
First Quartile	1	1	1	1	1	14
Median	1	1	1	10	230	4,186
Third Quartile	1	1	57	866	3,542	8,393
Maximum	1	4,006	5,086	6,468	7,934	11,221
Mean	1	25	173	817	1,929	4,455

To keep predicted drawdown to less than 50 feet, the statistics provided in Table 11 suggest that based on the hydraulic characteristics of the Lower Trinity Aquifer the current spacing requirements are sufficient for wells with a column pipe diameter of 6 inches or less. However, for wells with a proposed column pipe diameter of more than 6 inches the spacing requirement may need to increase. Based on the third quartile of the predicted drawdown values, a reasonable increase in the spacing requirement is 1,320 feet (¼ mile) for wells with a 6 to 8 inch column pipe and 5,280 feet (1 mile) for wells with a column pipe diameter of more than 8 inches.

For the Middle Trinity Aquifer, based on the third quartile of the predicted drawdown values the results shown in Table 10 suggest that the spacing for wells with a column pipe diameter of more than 2 inches up to 4 inches could reasonably be increased to 2,640 feet (½ mile). For wells with a column pipe diameter of more than 4 inches, the spacing could be increased to 5,280 feet (1 mile). For small diameter column pipes (2 inches or less), the third quartile distance to 50 feet of predicted drawdown is very small due to the low pumping rate. However, due to the relatively low productivity of the Middle Trinity we also calculated the distance to 10 feet of drawdown from a well with a small diameter column pipe. While the third quartile for the distance to 10 feet of drawdown is about 250 feet, these values are limited to the far eastern part of Bell County where the Middle Trinity is very deep. The results suggest increasing spacing for wells with a column pipe diameter of 2 inches or less would not be necessary.

Potential Management Areas

The statisical summaries provided above reflect the results for the entire county. Review of the spacing calculations conducted per grid cell reveal a pattern that is reflective of the transmissivity, available drawdown, and estimated production characteristics of the Middle and Lower Trinity aquifers. Figure 2 illustrates the distance to 50 feet of predicted drawdown for a well completed in the Middle Trinity Aquifer with a column pipe diameter of more than 2 inches up to 4 inches. Based on the transmissivity from the TWDB GAM (Kelley and others, 2014) and the estimated available drawdown, the distance to 50 feet of drawdown after one year of pumping is more than 500 feet. That is, in most of Bell County, for a new well completed in the Middle Trinity with a column pipe diameter of 2 to 4 inches, we would expect more than 50 feet of drawdown after 365 days at any existing well within 500 feet of the new well. There is a relatively small area in western Bell County where the distance is less than 100 feet. For the larger column pipe diameters, the distance values in western Bell County are small due to the very low estimated productivity of the aquifer, but as the column pipe diameter decreases the area expands to the northeast as illustrated on Figure 3.

For the Lower Trinity Aquifer, Figure 4 illustrates how spacing requirements could be less in the eastern and northern portions of the District than in western portion. The 100 foot contour line denotes where the calculations indicate a proposed well with an 8-inch diameter column pipe would cause 50 feet of drawdown at a distance of 100 feet. We observe on Figure 4 that to the east of the 100 foot contour the spacing is generally less than 100 feet while to the west of the contour the distance is greater.

Figure 5 and Figure 6 illustrate the calculated spacing for column pipe diameters of more than 8 inches up to 10 inches and more than 10 inches, respectively, in the Lower Trinity Aquifer. These two figures show a similar pattern as Figure 4. In general, these calculations suggest that large capacity wells completed in the Lower Trinty Aquifer should be spaced farther from existing wells in the western portion of the District.

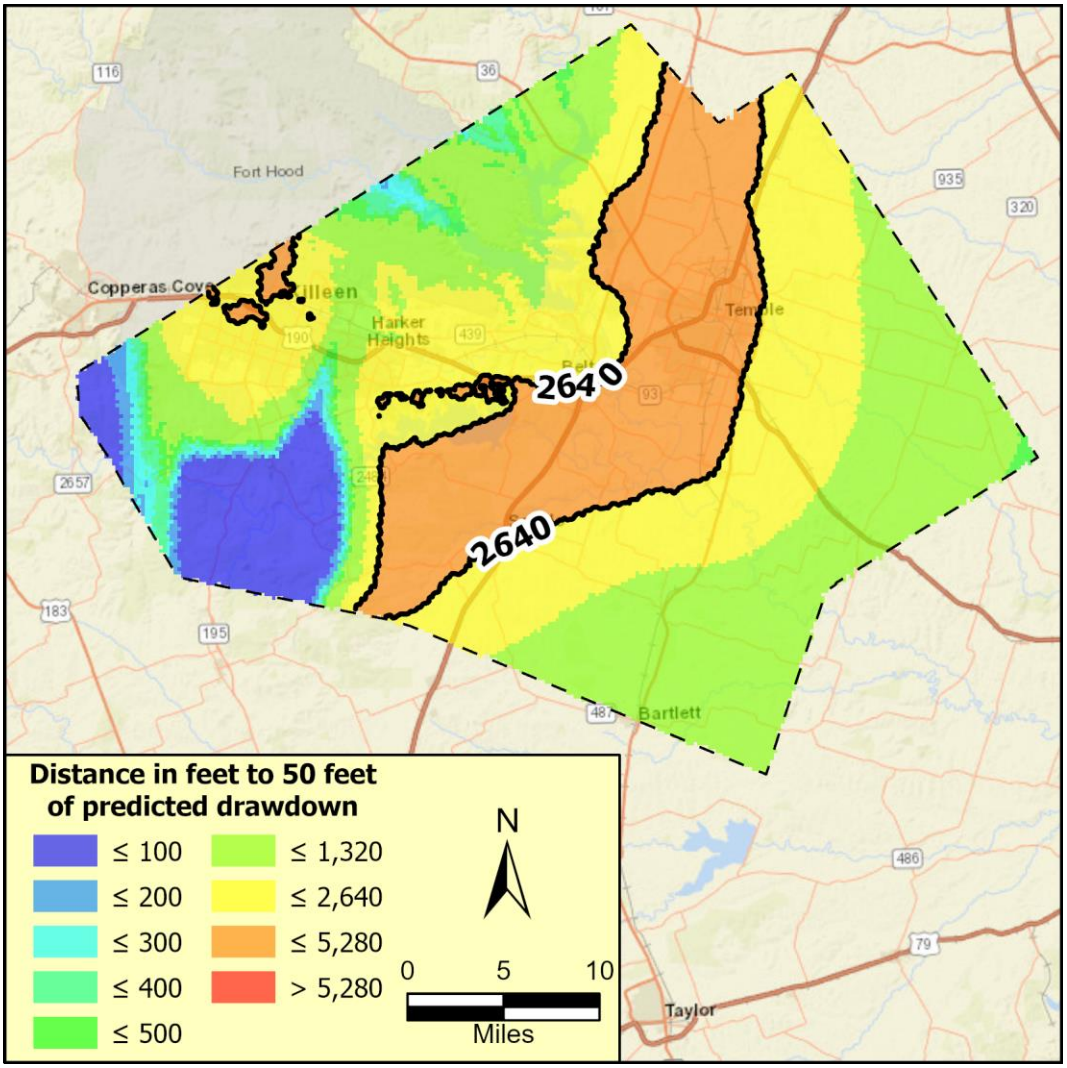

Figure 2. Middle Trinity — Spacing calculations illustrating the distance to 50 feet of predicted drawdown after 365 days of production from a proposed well with a column pipe diameter more than 2 inches up to 4 inches (>2 to 4).

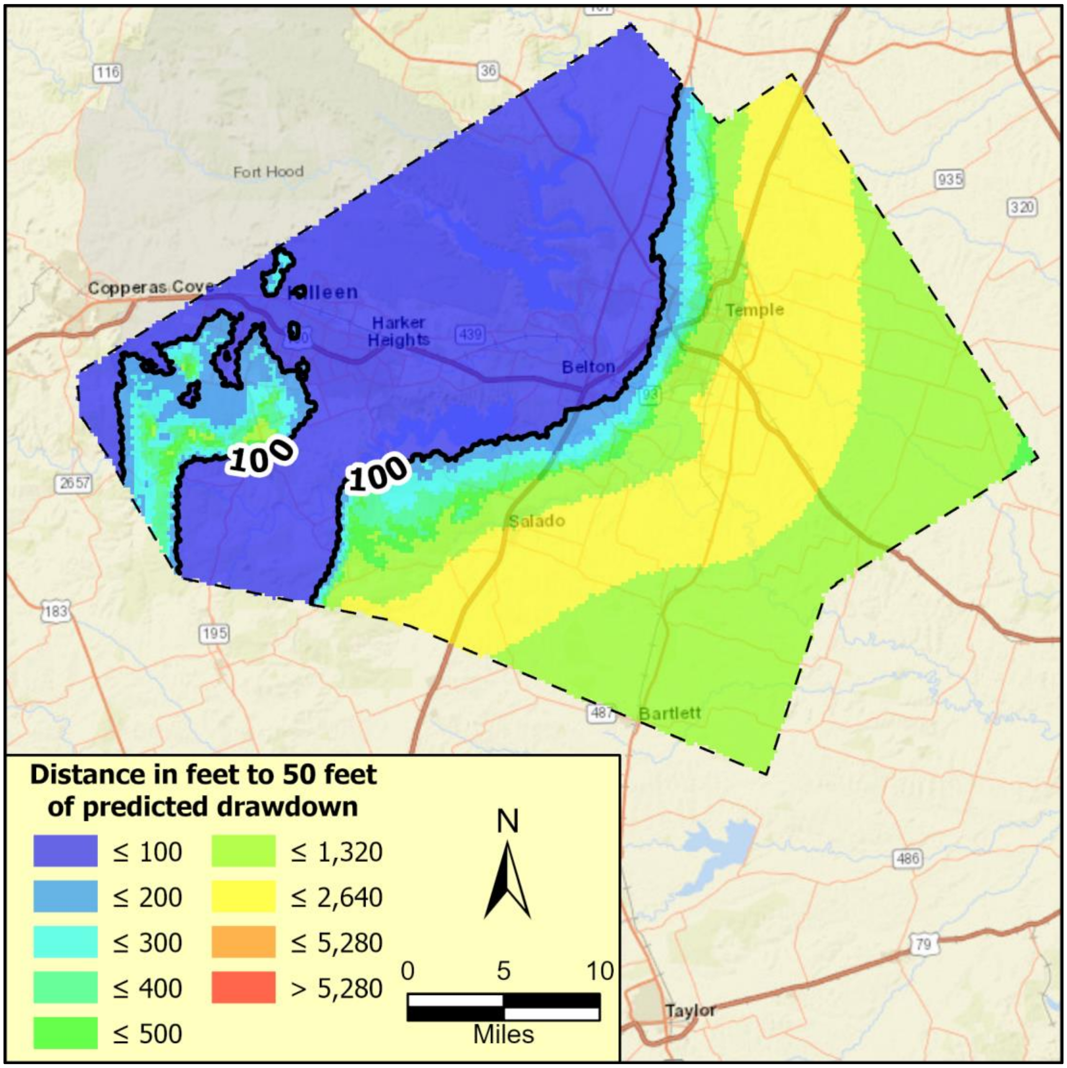

Figure 3. Middle Trinity — Spacing calculations illustrating the distance to 50 feet of predicted drawdown after 365 days of production from a proposed well with a column pipe diameter more than 2 inches up to 3 inches (>2 to 3).

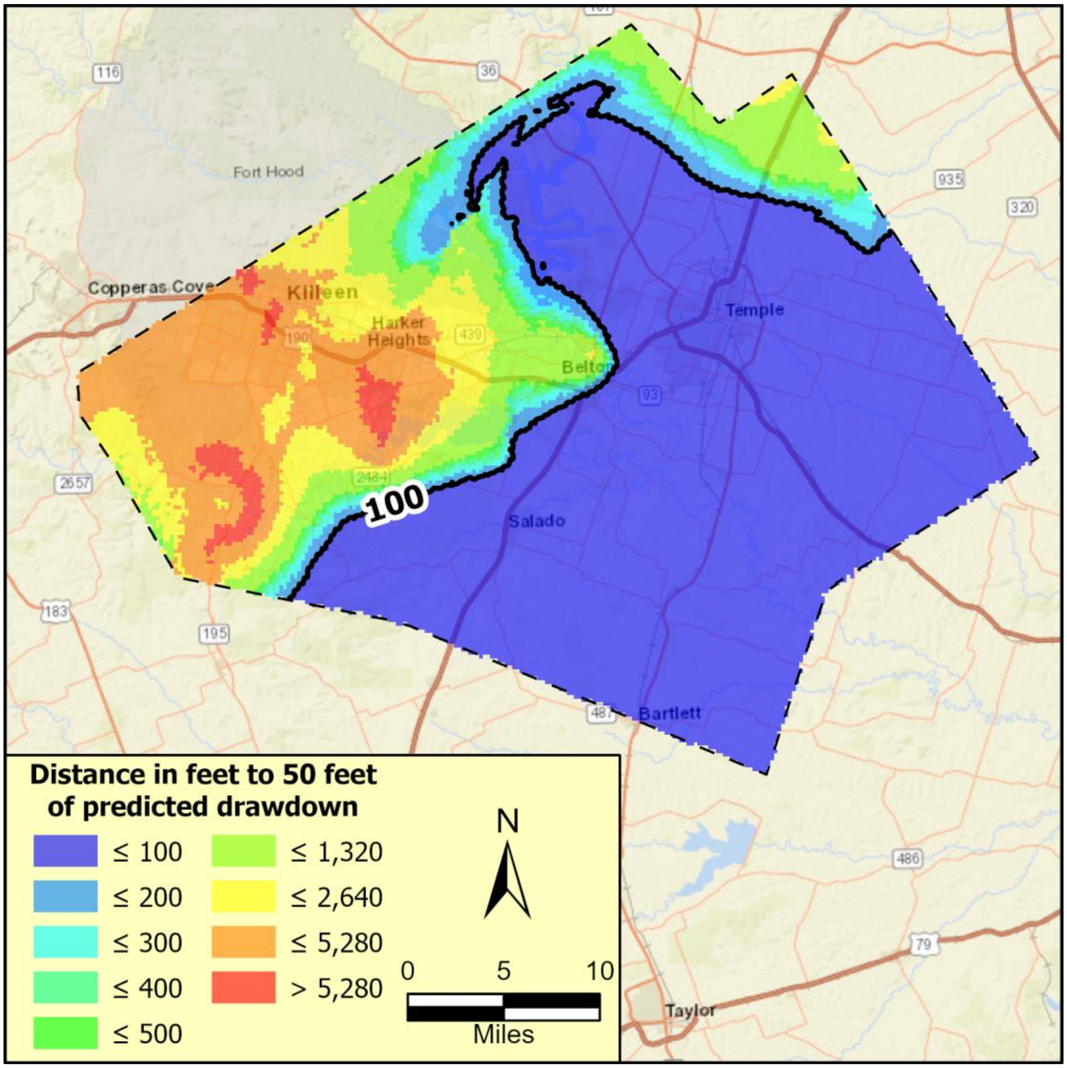

Figure 4. Lower Trinity — Spacing calculations illustrating the distance to 50 feet of predicted drawdown after 365 days of production from a proposed well with a column pipe diameter more than 6 inches up to 8 inches (>6 to 8).

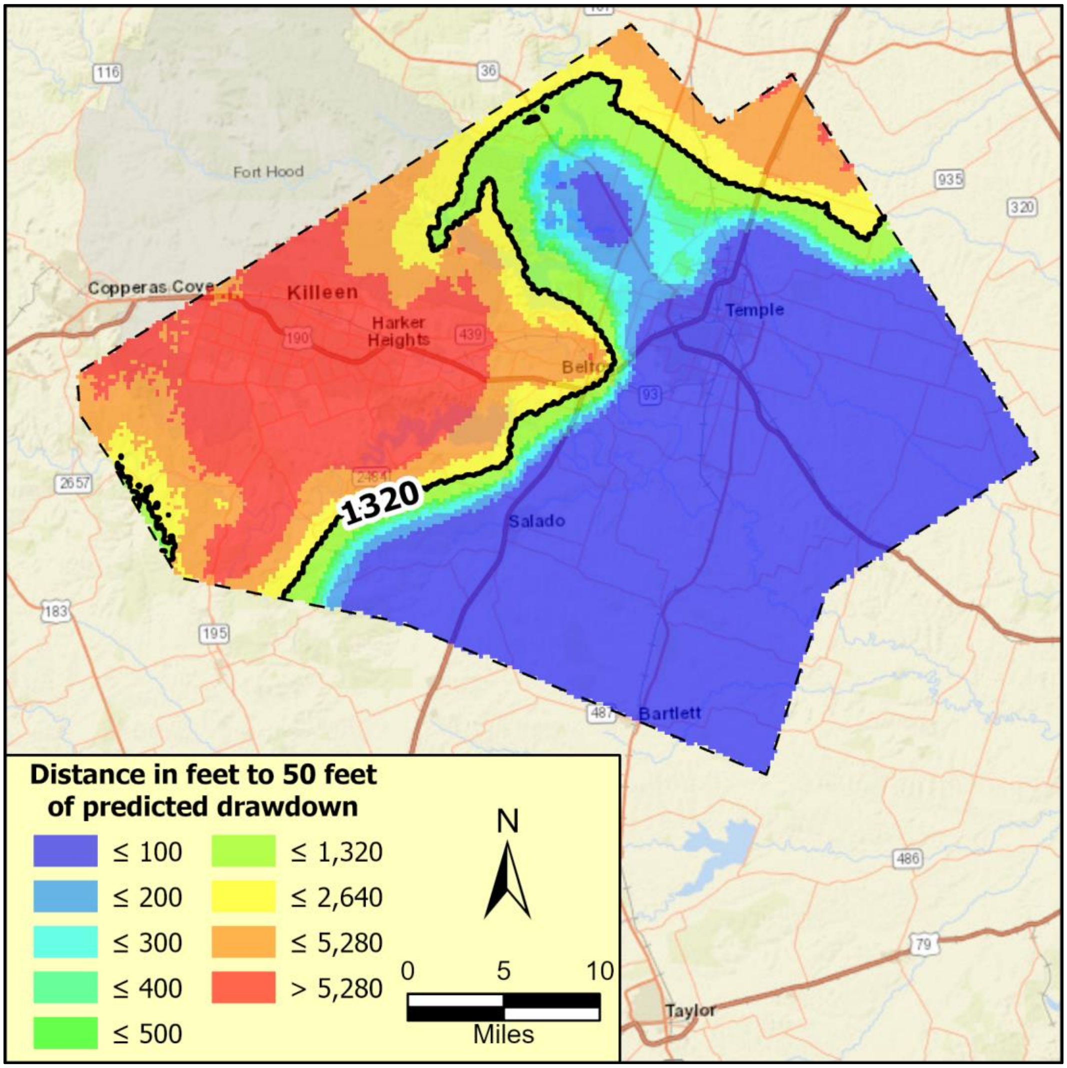

Figure 5. Lower Trinity — Spacing calculations illustrating the distance to 50 feet of predicted drawdown after 365 days of production from a proposed well with a column pipe diameter more than 8 inches up to 10 inches (>8 to 10).

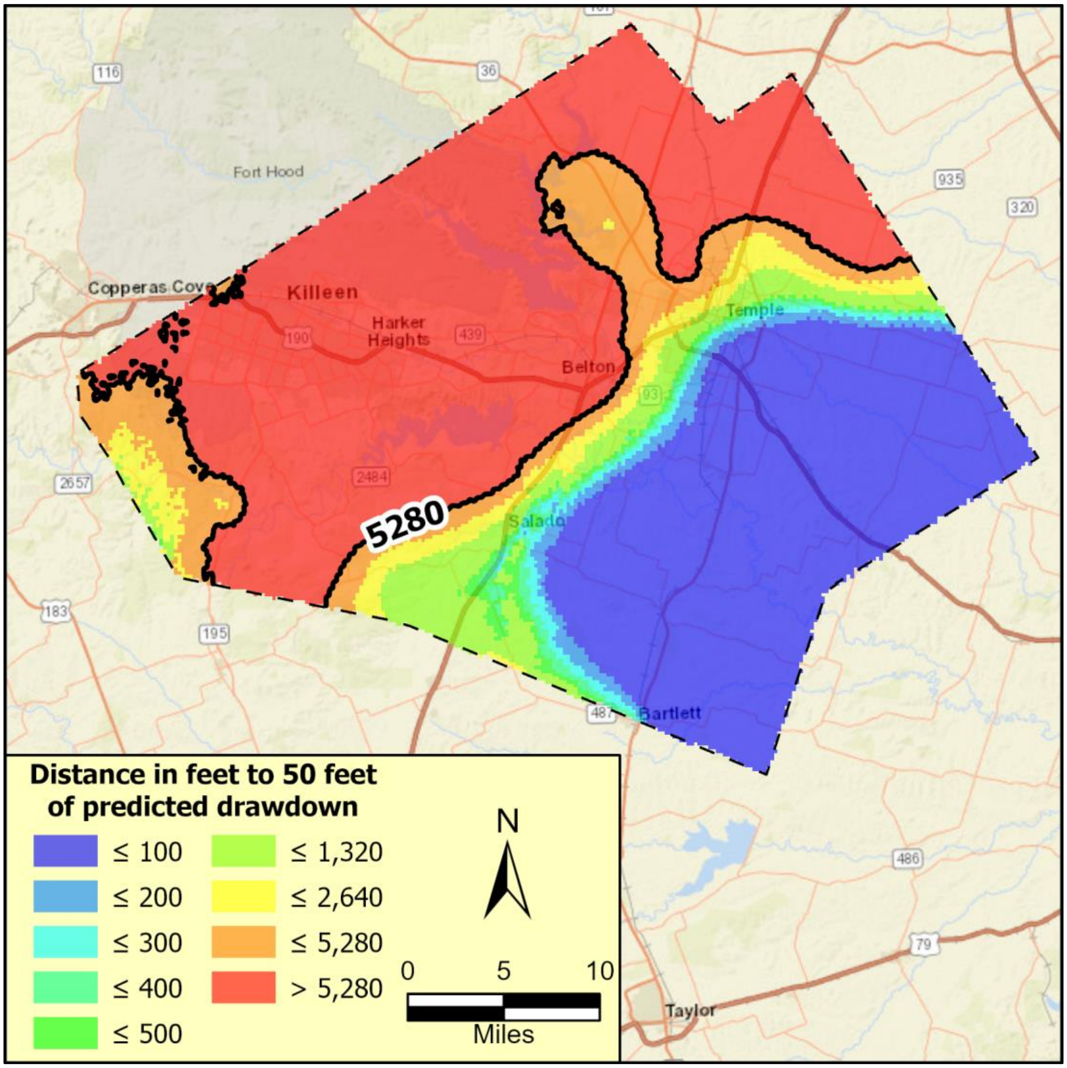

Figure 6. Lower Trinity — Spacing calculations illustrating the distance to 50 feet of predicted drawdown after 365 days of production from a proposed well with a column pipe diameter more than 10 inches.

The spacing calculations using our current understanding of the characteristics of the Middle and Lower Trinity aquifers suggest that assigning management areas is reasonable. For both aquifers, the data and calculation results indicate that two management zones could be defined using the distance to 50 feet of drawdown calculations as a guide. While there are similarities between the calculations for each aquifer, there are some differences that suggest the management zones for each aquifer could not be the same based on our current understanding of the aquifer characteristics.

One option for defining potential management zones could be to utilize our current understanding of the aquifers to delineate the spatial extent of the zones. The zones could then be mapped using the dataset illustrated in the figures above and the delineations could then be communicated through the District's website. A potential drawback to this method is the frequent improvement of our understanding as more data are gathered and assimilated into the datasets. These improvements in our understanding of the aquifers could result in frequent changes to the management zone delineations.

Another option for delineating management zones is to use existing landmarks, such as existing roads and county boundaries, to define the zones. These zones may not exactly reflect our current understanding, but they could be delineated to generally capture distinct differences in the hydrogeologic conditions. An example of a possible delination using existing landmarks of two zones for the Lower Trinity Aquifer based on the results from this evaluation is shown on Figure 7. Similar zones could be delineated for the Middle Trinity Aquifer.

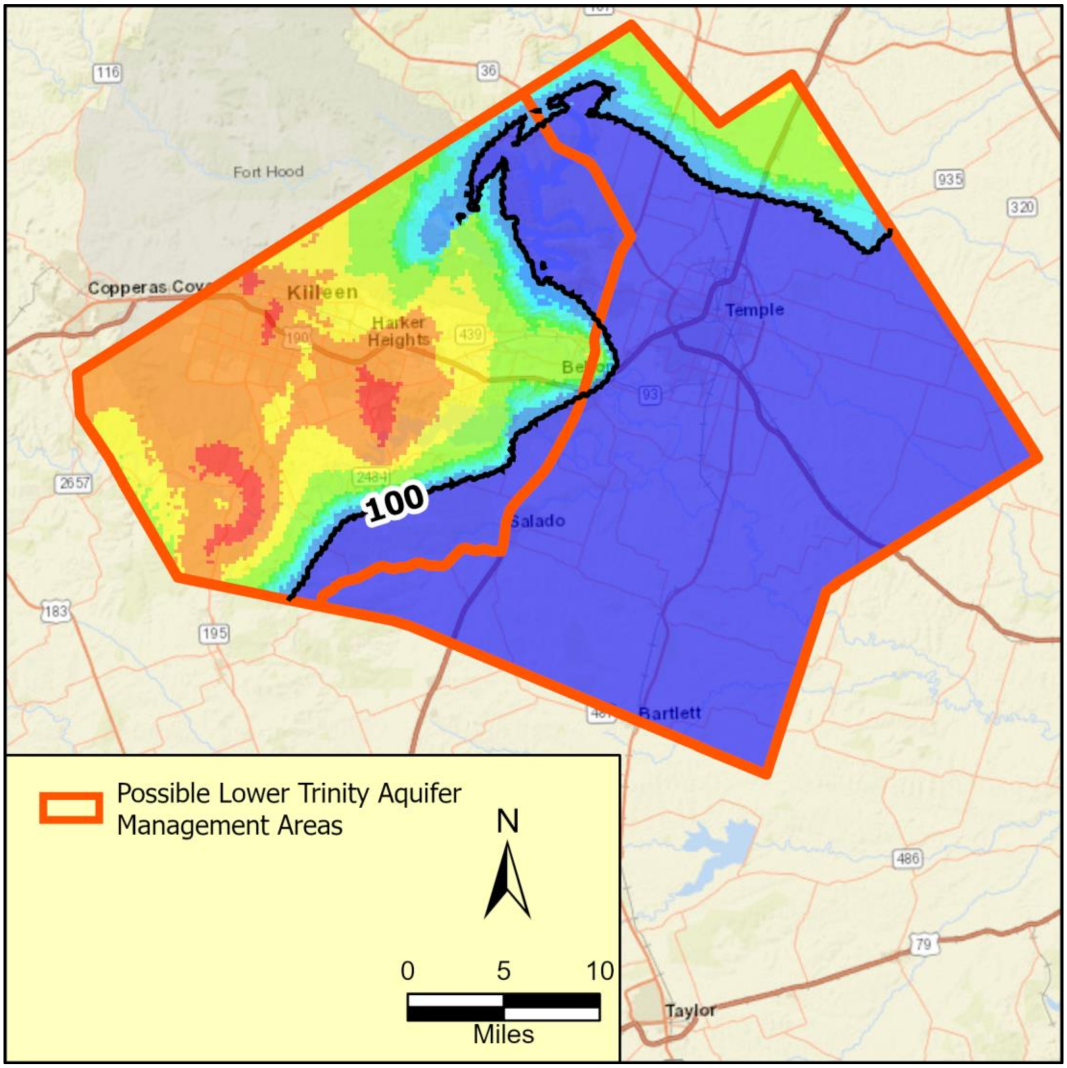

Figure 7. Possible Lower Trinity Aquifer management zone delineation. Figure 4 is the base map for the possible delineation.

Conclusions

With additional hydraulic property data obtained for the Lower Trinity Aquifer, a re-evaluation of the District's well spacing requirements was needed. This evalulation initially focused on the Lower Trinity Aquifer by using the transmissivity and storage coefficient data collected from several pumping tests conducted since the 2015 evaluation of well spacing requirements. For this updated evaluation we applied reasonable constraints on the pumping rates associated with each column pipe size, pumping duration, and available drawdown. With the inclusion of the reasonable constraints on pumping, we also updated the spacing calculations for the Middle Trinity Aquifer.

Results of the analysis suggest that for the Lower Trinity Aquifer the current spacing requirements are sufficient for proposed wells with a column pipe diamter of 6 inches or less to keep predicted drawdown to less than 50 feet at existing wells. For wells with a proposed column pipe diameter of more than 6 inches the spacing requirement may need to increase to limit drawdown to less than 50 feet. A reasonable increase in the spacing requirement is 1,320 feet (¼ mile) for wells with a 6 to 8 inch column pipe and 5,280 feet (1 mile) for wells with a column pipe diameter of more than 8 inches.

For the Middle Trinity Aquifer, the evaluation indicated that we would not expect a well to be completed with a column pipe diameter greater than four inches in diameter and likely would not expect a well with a column pipe greater than two inches. Spacing for wells with a column pipe diameter of more than 2 inches up to 4 inches could reasonably be increased to 2,640 feet (½ mile). If a well were to be completed with a column pipe diameter of more than 4 inches, the spacing could be increased to 5,280 feet (1 mile).

The evaluation of spacing requirements also suggests that at least two management areas for the two aquifers would be reasonable. Lower Trinity Aquifer conditions clearly indicate that spacing requirements, particularly for larger capacity wells, could vary between the eastern and western portions of the District. While the data and results from this analysis are less clear for the Middle Trinity, it may also be reasonable to delineate management zones for the Middle Trinity Aquifer.

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