Technical Memo 2016-0715
July 2016

Evaluation for Potential Unreasonable Impacts: Needmore Water, LLC, Well D Permit Application

Brian B. Hunt, P.G., and Brian A. Smith, Ph.D., P.G.

Introduction

The Barton Springs/Edwards Aquifer Conservation District's (District) territory was expanded on June 19, 2015 through the passage of H.B. 3405. This act requires all nonexempt, non-Edwards wells to be permitted and the act provides a three-month period to apply for a Temporary Permit, which expired on September 19, 2015. The Temporary Permits provide well owners with an interim authorization to operate a well prior to conversion to a Regular Historical Production Permit. Prior to conversion, the District shall evaluate the proposed production to determine if the amount authorized will cause:

1. A failure to achieve the applicable adopted desired future conditions for the aquifer; or
2. An unreasonable impact on existing wells.

The District has developed rules and policy to address the evaluation of any proposed groundwater production and the potential for causing such impacts. Unreasonable impacts described under factor 2 above have been further defined by District rule to include:

1. well interference related to one or more water wells ceasing to yield water at the ground surface;
2. well interference related to a significant decrease in well yields that results in one or more water wells being unable to obtain either an authorized, historic, or usable volume or rate from a reasonably efficient water well;
3. well interference related to the lowering of water levels below an economically feasible pumping lift or reasonable pump intake level; and
4. the degradation of groundwater quality such that the water is unusable or requires the installation of a treatment system.

The Board-adopted rules further establish a policy related to applications found to have potential for unreasonable impacts. The policy states that:

> *The District seeks to manage total groundwater production on a long-term basis while avoiding the occurrence of unreasonable impacts. The preferred approach to achieve this objective is through an evaluation of the potential for unreasonable impacts using the best available science to anticipate such impacts, monitoring and data collection to measure the actual impacts on the aquifer(s) over time once pumping commences, and prescribed response measures to be triggered by defined aquifer conditions and implemented to avoid unreasonable impacts. Mitigation, if agreed to by the applicant, shall be reserved and implemented only after all reasonable preemptive avoidance measures have been exhausted and shall serve as a contingency for the occurrence of unreasonable impacts that are unanticipated and unavoidable through reasonable measures.*

In application of the adopted rules and policy, the District has conducted a best science evaluation of the Needmore Water, LLC permit request. As part of the evaluation, the Aquifer Science (AS) staff have reviewed the hydrogeologic report (WRGS, 2016) submitted by the applicant, the aquifer test data, and other relevant data and factors. This technical memo presents a summary of the evaluation of the aquifer test and if the potential for unreasonable impacts exists. In addition, this document established compliance levels (water levels) within an index well that will prescribe response measures to be triggered when aquifer conditions exceed those levels. Prescribed measures recommended by staff are described in the special provisions of the proposed Needmore Permit.

Needmore Water, LLC Permit Application

Needmore Water, LLC applied for, and was issued, a Temporary Permit for approximately 180,000,000 gallons per year. Under Part II of the permit application, Needmore has requested authorization for maximum production capacity of a higher volume equivalent to 289,080,000 gallons per year (approximately 887 acre-feet/year; 550 gallons per minute). An evaluation of the aquifer test and the projected potential for unreasonable impacts was performed on the basis of the requested volume.

Needmore Hydrogeologic Report

The report prepared by Wet Rock Groundwater Services, LLC (WRGS, 2016) generally satisfies the goals of the District's Aquifer Test and Hydrogeologic Report Guidelines (dated 2007) by providing data necessary to evaluate: 1) aquifer properties, 2) impacts to wells, and 3) changes in water quality. The aquifer test that was conducted was of excellent quality. **Appendix A** contains detailed technical notes by AS staff on aquifer parameters derived from the 2016 aquifer test.

However, AS staff do not agree with all aspects of the report including some technical opinions, interpretations, and assumptions. The most significant differences in opinion include:

1. **Analytical solutions (Theis).** The WRGS (2016) report generally dismisses the use of analytical solutions such as Theis for making estimates of well interference. This is a long-discussed difference of professional opinion between the WRGS and AS Staff. The Theis equation is a long-established tool within hydrogeology and is the best tool available at this time for making projections of drawdown over time. The WRGS (2016) report states:

   > "The heterogeneic (sic) character of the karst aquifer, in addition to potential disconnects between the Cow Creek Member and other formations, causes traditional methods of estimating drawdown, such as the Modified non-equilibrium equation (Theis equation), to overestimate drawdown."

   A more accurate description of analytical solution results is not that they overestimate drawdown, but that there is inherent uncertainty in the results. Drawdown can result in either an overestimate, or underestimate, of actual conditions. For example, the WRGS (2016) report underestimates drawdown at the observation wells for the test duration. While we understand that WRGS was trying to match drawdown at the pumping well, the goal of the aquifer test was to assess potential for unreasonable impacts including interference with existing wells (see item #2 below).

Repeated criticisms in the report about the use of Theis appears to be focused on the effects of recharge on the Middle Trinity, which the Theis equation does not consider. While this is true, AS staff consider the results from Theis as a scenario similar to a repeat of severe drought (such as the 7-yr drought of record) when little recharge occurs and the ability to capture is constrained. In addition, the Theis equation considers the aquifer infinite, therefore there is an infinite reservoir of water to draw from. —Aquifers are in fact not infinite but have boundaries. Therefore, during drought periods that result in limited recharge and capture constraints, the infinite extent assumption moderates the 'no recharge' assumption in our opinion. Therefore, AS staff consider the source of water as being dominated by changes in storage (depletion) for these types of relatively short-term forecasts, and not dominated by capture. The WRGS (2016) report states at some future point in time the drawdown resulting from the Needmore pumping well will effectively stabilize as a result of capture (inducing recharge, or reducing springflows). This is a true statement—indeed the source of water will change from dominated by storage to dominated by capture at some future time. However, the time period for this to occur is uncertain. AS staff believe that it is likely on the scale of years given the aquifer parameters, distance to such features it would capture (e.g. Jacob's Well), and the age of the water in the area. Indeed, during severe drought conditions, most of the streams and springs would be "capture constrained" since they are generally dry or very low flow (Konikow and Leake, 2014). A numerical model is needed to fully address this issue.

In summary, many of the assumptions listed and discussed in the report are in fact not as limiting as stated. AS staff sum it up quoting Driscoll's (1986) discussion on such assumptions of theoretical models (Theim) where he states, "these assumptions appear to limit severely the use of the equations. In reality however, they do not." AS staff view the use of analytical models (Theis) comparable to the use of numerical models in the Trinity (e.g. Mace et al., 2000; Jones et al., 2011). Results from such tools in the correct context and for certain stated purposes are useful and should be utilized in forecasting.

2. **Estimation of representative aquifer parameters for the study area and lack of evaluation of interference.** While the WRGS (2016) report determined aquifer parameters that appear suitable estimates for an evaluation of drawdown in the immediate vicinity of the pumping well, its estimates result in drawdown that do not match data at observation wells. Accordingly, the parameters are not useful for estimating drawdown at a distance where impacts could occur. The WRGS (2016) report does not explicitly attempt to estimate potential impacts to wells, but AS staff assume by the WRGS (2016) report 's assessment of the relatively minor drawdown, that the professional opinion of WRGS is that little potential exists for unreasonable impacts related to well interference.

3. **Regional Middle Trinity water level trends.** The stability and quick recovery of water levels in the Middle Trinity, including the Cow Creek, as described in the WRGS (2016) report, ignores studies that indicate the contrary. Although no long-term data are available for the immediate vicinity of the Needmore area, numerous studies to the west of Needmore (and where the Trinity is recharged) indicate the Middle Trinity is under stress as a whole. Long-term data indicate the aquifer does not fully recover during wet periods (Hunt and Smith, 2016; Hunt, 2014; Wierman et al., 2010). Indeed, long-term cones of depression are observable on water levels maps for the

Middle Trinity (Hunt and Smith, 2016; Hunt and Smith, 2010) and are precisely the potential impact groundwater conservation districts and groundwater management areas are trying to avoid.

Potential Unreasonable Impacts

The primary goal of this evaluation is to forecast drawdown attributed to the proposed production and associated potential unreasonable impacts related to well interference for existing wells. The impact from pumping on the Desired Future Conditions (DFC) is not addressed in this evaluation, nor are the impacts to springs such as Jacob's Well. Numerical models would be the best tool for such an evaluation, but are not available at this time.

The WRGS (2016) report suggests minimal drawdown over time based on the applicant's analysis of the Needmore Well D pumping data. AS staff estimated aquifer parameters from the data (**Table 1; Appendix A**) and present a range of drawdown from the pumping of Needmore Well D on nearby domestic-supply wells. The focus of this evaluation is on the potential drawdown to a domestic-supply well and a Hays Trinity Groundwater Conservation District monitor well known as the Amos Well. The well is located the Saddle Ridge subdivision located about 2 miles southwest of Needmore Well D (see map **Appendix A**). The Amos Well had a measureable response with recorded drawdown during the aquifer test of about 12 ft. AS staff reasonably assume that the water level response to pumping in the Amos Well is representative of wells in the northern area of Saddle Ridge subdivision.

Using the aquifer parameters derived from the aquifer test (**Table 1**; **Appendix A**), the AS staff estimate the additional drawdown from the Needmore pumping over time in **Figure 1**. For the evaluation, AS staff choose drawdown from pumping during a 7-year period. This period was chosen to be representative of a severe drought when little recharge occurs, and capture is constrained. The results of the estimated drawdown at the Amos Well due to Needmore pumping is about 75 ft after 7 years (**Figure 1**).

In order to estimate the potential for unreasonable impact from the Needmore pumping, the full range of water-level variability in the area of influence must be considered and accounted for in the evaluation (**Table 2**). This includes an accounting of projected drawdown attributed to factors independent of the proposed production including drought variability and existing and future local pumping (**Table 2**). Combined with this existing water level variability of 50 ft (**Table 2**), the total projected drawdown (76 ft) is about 126 ft. The estimated additional drawdown from the Needmore pumping could lower the water level (heads) below the top of the Middle Trinity Aquifer in the Saddle Ridge area. The additional drawdown also puts the water level within 20 feet of the pump in the Amos well.

Table 1. Parameter estimates used in drawdown scenarios

Parameter	*Value*	*Comment*
Transmissivity	814 ft2/d	average for Amos
Storativity	2.6e-5	average for Amos
Thickness	350 ft	Cow Creek and Lower Glen Rose
Distance	10,300 ft	From pumping to Amos Well
Pumping	540 gpm	Assumes 24/7

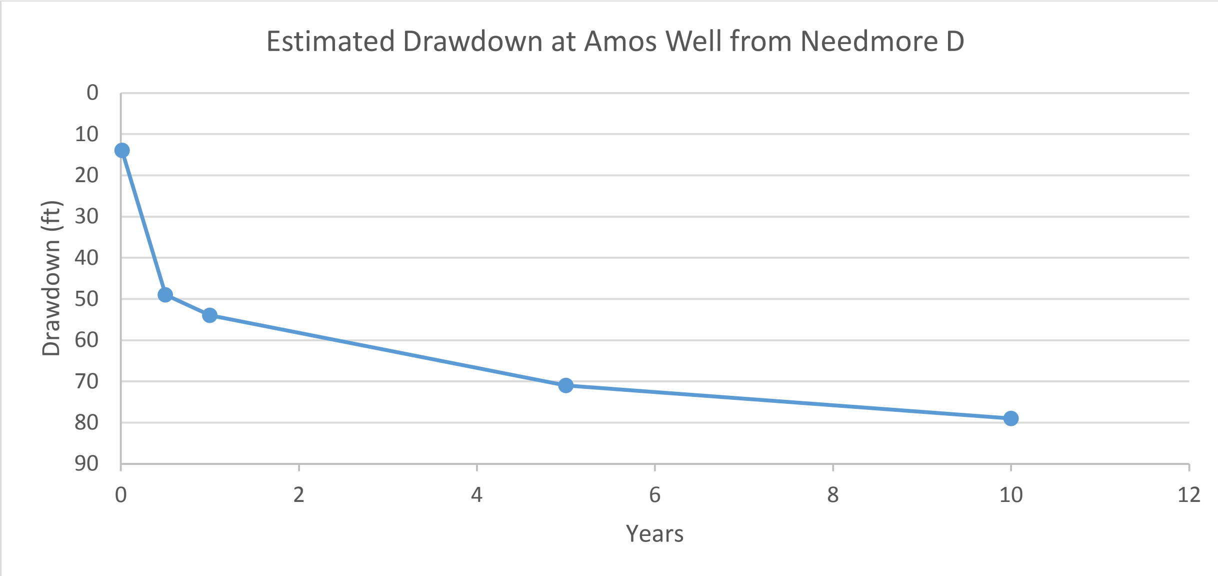


Figure 1. Graphical presentation of drawdown versus time from the Needmore pumping alone at the Amos observation well (assuming Table 1 parameters). Note most of the drawdown occurs within the first year.

Table 2. Existing drawdown or water level variability estimates in the vicinity of the Amos well prior to Needmore pumping

Source	*Value (ft)*	*Comment*
Drought	42	Derived from the Ruby Ranch Westbay Well (Cow Creek Zone)
Present local interference	4	Nearby domestic and the Amos well
Future local interference	2	Domestic wells
Uncertainty	2	Buffer for estimates above
Total:	50	

Findings: Potential Unreasonable Impacts

After considering existing water level variability, the projected effects of drawdown from the Needmore pumping would cause some wells to cease to yield water at the ground surface or cause the lowering of water levels below a reasonable pump intake level.

A conservative assessment of the data, and using the best available science and methods, leads us to conclude that <u>there is a potential for unreasonable impacts due to the full production of this permit over time.</u>

Proposed Compliance Levels and Potential Permit Conditions

Although AS staff determine that there is the potential for unreasonable impacts, there is always uncertainty with any forecasting or modeling. AS staff fully recognize and appreciate uncertainties in using analytical models for forecasting, and accordingly, our approach is to constrain model results with data moving forward. Pursuant to District policy, AS staff recommends special provisions to the permit requiring 1) ongoing monitoring and data collection to measure the actual impacts to the aquifer over time once pumping commences and, 2) prescribed response measures indexed to defined compliance levels and a dedicated index well.

Table 3 presents a summary of the specific compliance levels derived for the Amos Well. **Figure 2** is a graphical representation of the Amos Index Well and the corresponding compliance levels. Compliance levels were set after considering natural water level variability (Table 2; 50 ft) and also the observed short-term operational effects of pumping from the Needmore Well (~15 ft). Thus, this allows for up to about 65 ft of variability below the average water level before crossing the first compliance level threshold. **Figure 3** is a conceptual diagram showing how each compliance level is distributed over depth and time.

Recommended special provisions to the permit will reference the compliance levels established in this document and are only briefly presented in Table 3.

Table 3: Summary of specific compliance levels in the Amos monitor well

Compliance Level	Description	depth to water (ft)	Note	Permit Action
1	Evaluation	525	Approximate top of Middle Trinity Aquifer as determined from geophysical logs.	District will conduct an evaluation of data to assess the actual impacts of pumping.
2	Avoidance Measures	550	This level is the mid-point between level 1 and 3 and is a sentinel level to begin curtailment measures in order to delay or abate further drawdown.	Temporary curtailment of 20% off the baseline curtailment rate (BCR).
3	Maximum Drawdown Allowable	575	This level accounts for the drawdown from the Needmore Well D pumping for 1 year (~50 ft), after accounting for 65 feet of variability	Temporary curtailment of 40% off the baseline curtailment rate (BCR).
4	Unreasonable Impact to Existing Wells	580	This level is deemed a reasonable pump intake level and below this level an unreasonable impact occurs to the Amos Well, and likely surrounding wells.	Temporary curtailment of 100% off the baseline curtailment rate (BCR)

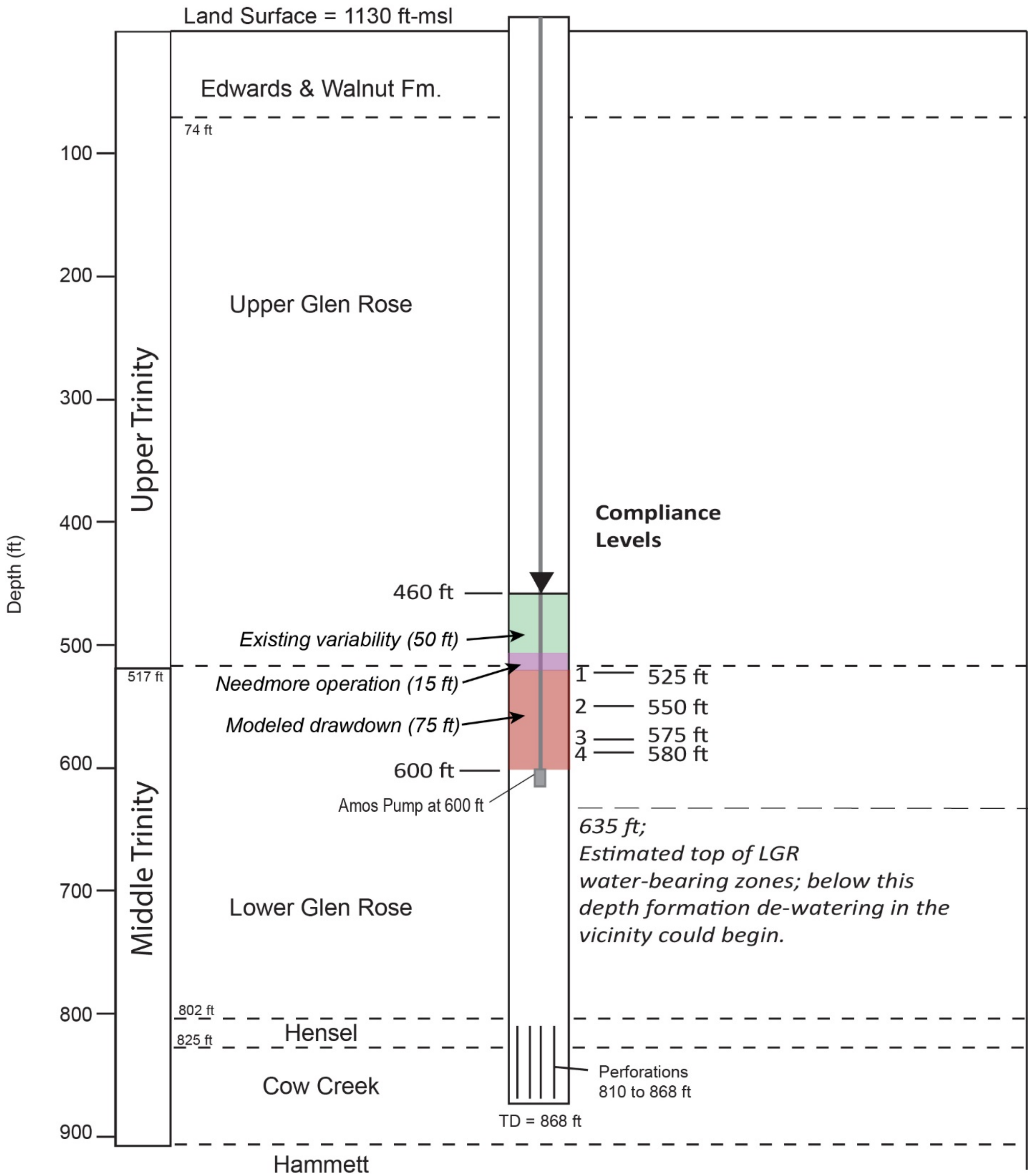


Figure 2. Potential Index Well Diagram and Compliance Levels

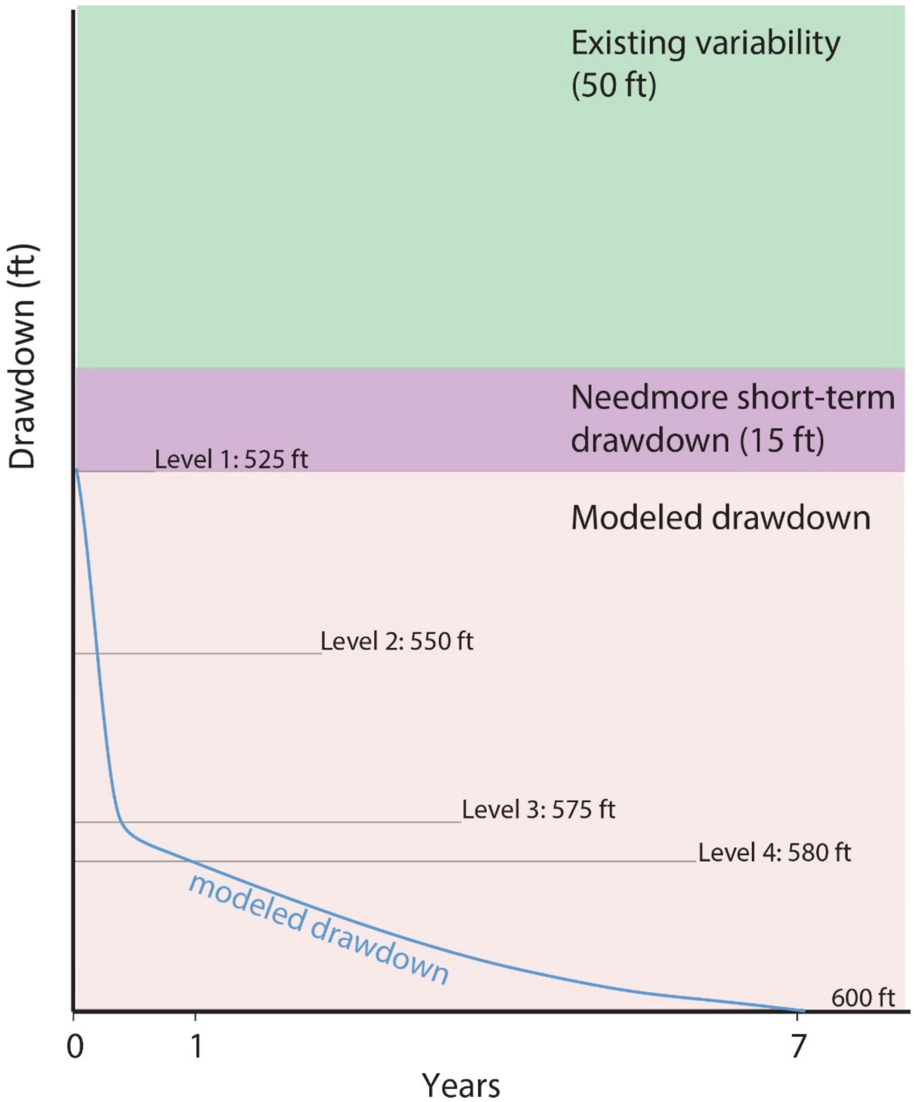


Figure 3. Drawdown vs Time indicating compliance levels.

References

Driscoll, Fletcher R., 1986, Groundwater and Wells. Second Edition. Johnson Screens, St. Paul, Minnesota. Pp. 1089.

Hunt, B.B. and B.A. Smith, 2016, Desired Future Condition Monitoring of the Middle Trinity Aquifer, Groundwater Management Area 9, Central Texas. BSEACD Technical Note Technical 2016—0415, April 2016, 9 p.

Hunt, B.B., and B.A. Smith, 2010, Spring 2009 Potentiometric Map of the Middle trinity Aquifer in Groundwater Management Area 9, Central Texas: Barton Springs Edwards Aquifer Conservation District Report of Investigations 2010-0501, 26 p.

Hunt, Brian B., 2013, An Approach to Monitoring Compliance with the "Desired Future Condition" of the Texas Hill Country Trinity Aquifer. Geological Society of America Abstracts with Programs. Vol. 45, No. 3, p. 70.

Jones, I.C., R. Anaya, and S.C. Wade, 2011, Groundwater Availability Model: Hill Country Portion of the Trinity Aquifer of Texas: Texas Water Development Board Report 377, June 2011, 165 p.

Konikow, L.F. and S.A. Leake, 2014, Depletion and Capture: Revisiting "The Source of Water Derived from Wells": Groundwater Vol. 52, pages 100-111.

Kruseman, G.P., and N.A. de Ridder, 1991, Analysis and Evaluation of Pump Test Data, Second Edition, ILRI, Netherlands. Pp. 377

Mace, R., A. Chowdhury, R. Anaya, and S. Way, 2000, Groundwater Availability of the Trinity Aquifer, Hill Country Area, Texas: Numerical Simulations through 2050: Texas Water Development Board, 172 p.

Theis, C.V., Brown, R.H., and Myers, R.R., 1963, Estimating the transmissibility of aquifers from the specific capacity of wells: methods of determining permeability, transmissivity, and drawdown, in U.S. Geological Survey Water-Supply Paper, No. 1464, 693 p.

Wetrock, 2016, Hydrogeologic Report of the Needmore Water, LLC Well D: Report of Findings WRGS 16-004, March 2016, 46 p, + appendices

Wierman, D.A., A.S. Broun, and B.B. Hunt (Eds), 2010, Hydrogeologic Atlas of the Hill Country Trinity Aquifer, Blanco, Hays, and Travis Counties, Central Texas: Preparted by the Hays-Trinity , Barton/Springs Edwards Aquifer, and Blanco Pedernales Groundwater Conservation Districts, July 2010, 17 plates+DVD.

Appendix A

Summary Notes of January 2016 Aquifer Test and Parameter Estimation, Needmore Water LLC, Well D, Hays County

Aquifer Science Staff

2/23/16

Summary of Aquifer Test

WRGS conducted an aquifer test for the Needmore Ranch "Well D" in January 2015 according to District rules and guidelines. Under H.B. 3405, Needmore Water LLC are asking for (887 ac-ft/yr) 289 MGY for agricultural use. The purpose of this document is to summarize the aquifer test and the estimation of aquifer parameters.

Table 1 summarizes the wells in the study completed in the Middle Trinity (including the Cow Creek). Another shallow Upper Glen Rose well (Caboose observation well) was monitored and showed no response to the pumping, and is not included herein.

Table A-1. Aquifer Test Summary

Well Name	*Type*	*Pump depth*	*Date Aquifer Test*	*Static WL used in Eval (DTW-ft)*	*Duration*	*Yield (gpm)*	*Max. drawdown (ft)**
Needmore D_PW	Pumping		1/25/16 10:20 AM	272.91	Pumping: 5.03 days (120.7 hrs) Recovery:	544	35.3
Catfish Pond_OW	Needmore Observation			407.13			15.8
Amos_OW	HTGCD Observation	600		459.70			14.4
Top of Hill_OW	Needmore Observation			319.78			6.1

**Per WRGS*

Table A-2. Well Information

Well Name	***Tracking No.***	***Ddlat***	***Ddlong***	***Distance (mi) from PW***	***Radial Distance (ft)***	***Date drilled***	***MP***	***LSD (ft-msl)***	***Borehole dia (in)***	***Depth _total ft***	***Casing dia (in)***	***Depth casing (ft)***	***completion***
Needmore D_PW		29.970225	-98.034223	0	0	01-Jan-16	2.5	936	9.875	800	8.63	600	open
Catfish Pond_OW		29.970017	-98.052244	1.1	5808		1.8	1070			6.25	475	open
Amos_OW		29.961129	-98.065213	1.95	10296			1132			5		
Top of Hill_OW	148941	29.990911	-98.033147	1.43	7550	02-Dec-05	2.0	995	8	1100	5	700	open

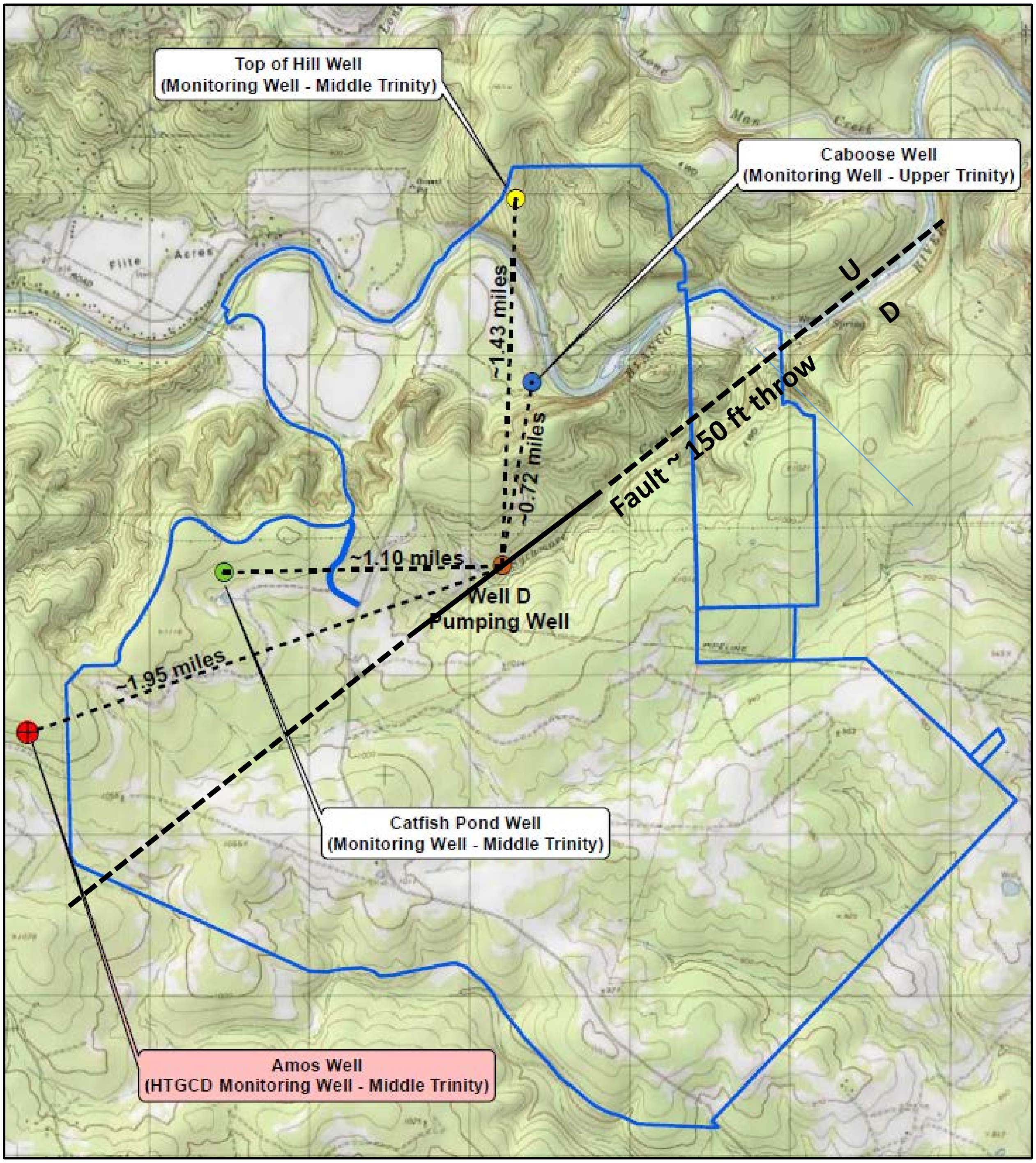


Figure A-1. Location map of the Needmore Ranch and wells in the study (basemap modified from WRGS). Note the fault that is mapped and confirmed in the field by BSEACD staff. The well is located on the fault, however the production zone is on the up-thrown side of the fault.

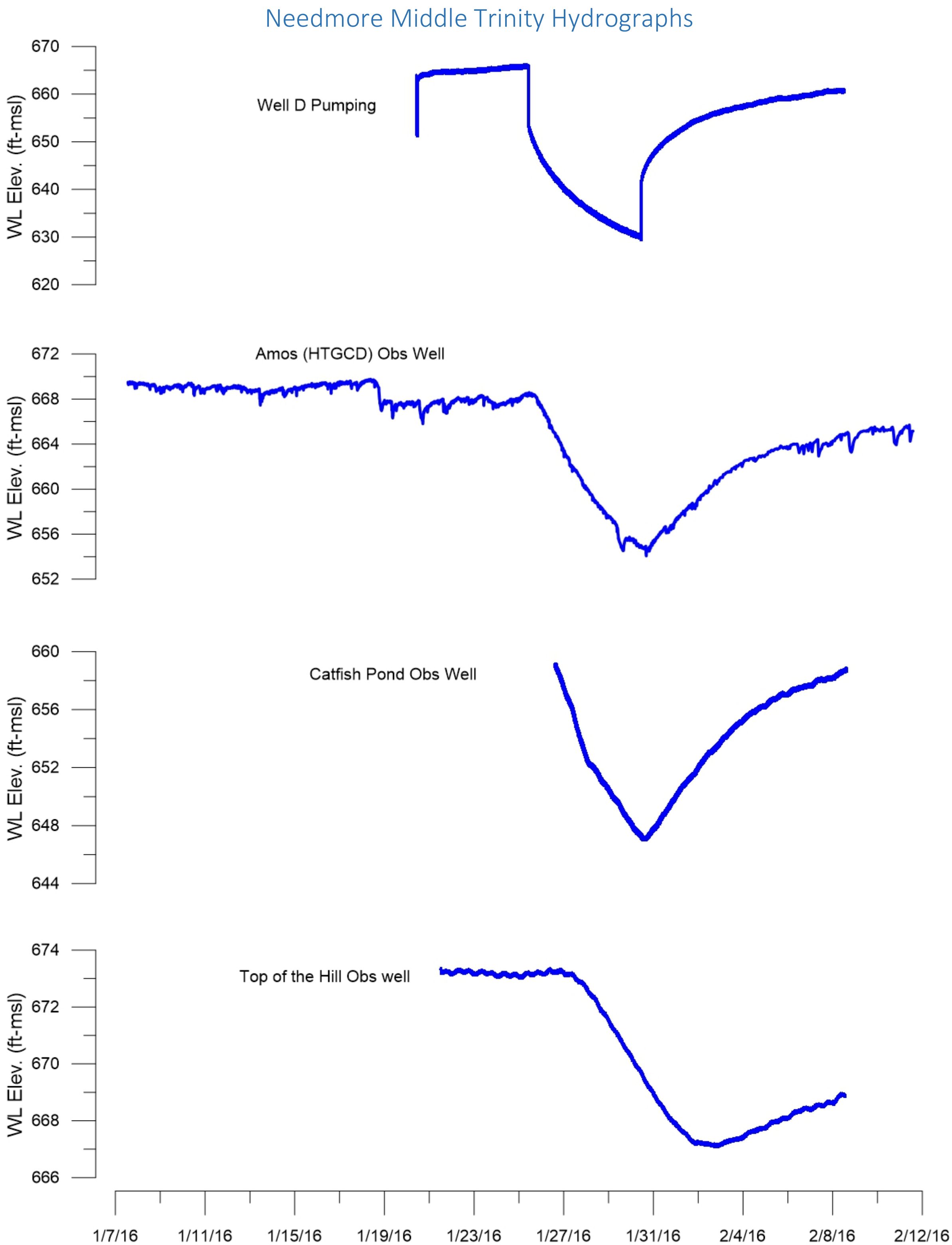


Figure A-2. Hydrograph from transducer data for all Middle Trinity wells.

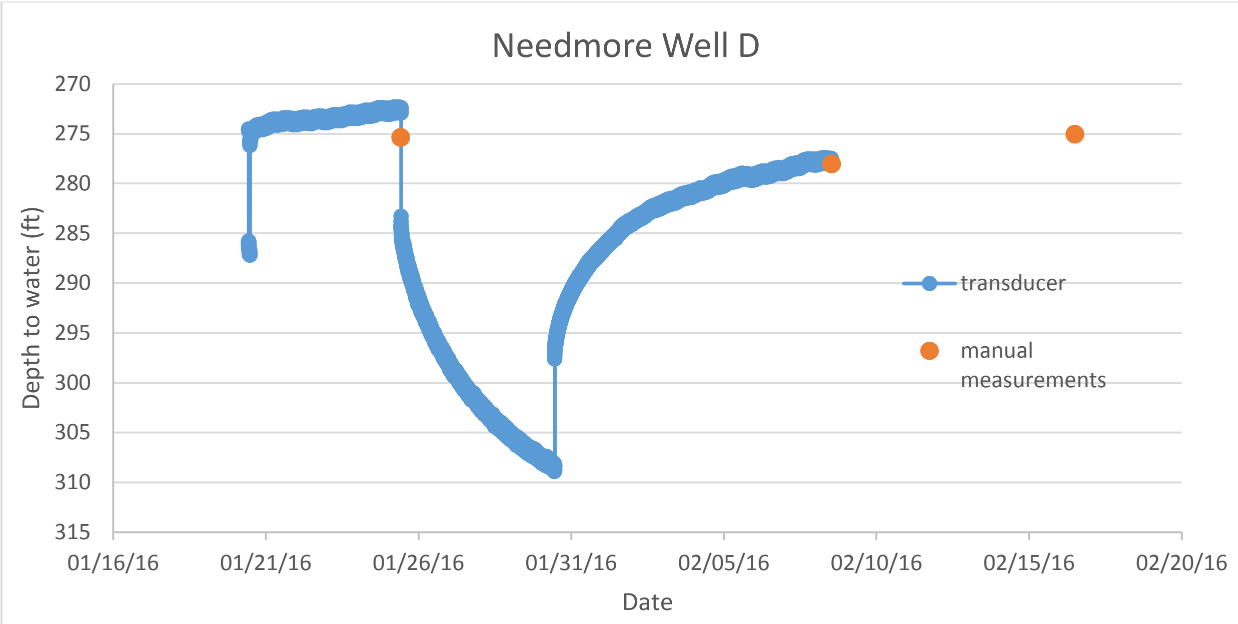


Figure A-3. Hydrograph of the Needmore D pumping well transducer and manual data. Water levels were rising from pre-test of pump on 1/20/16 when test started on 1/25/16. Note that a "pumping level" or psuedo-steady state was not reached before the end of the pumping phase. Maximum drawdown was 35 feet at the end of the test. Water levels reached 86% recovery after 14 days (when transducer was taken out), and 94% after 22 days of recovery and last measurement on 2/16/16.

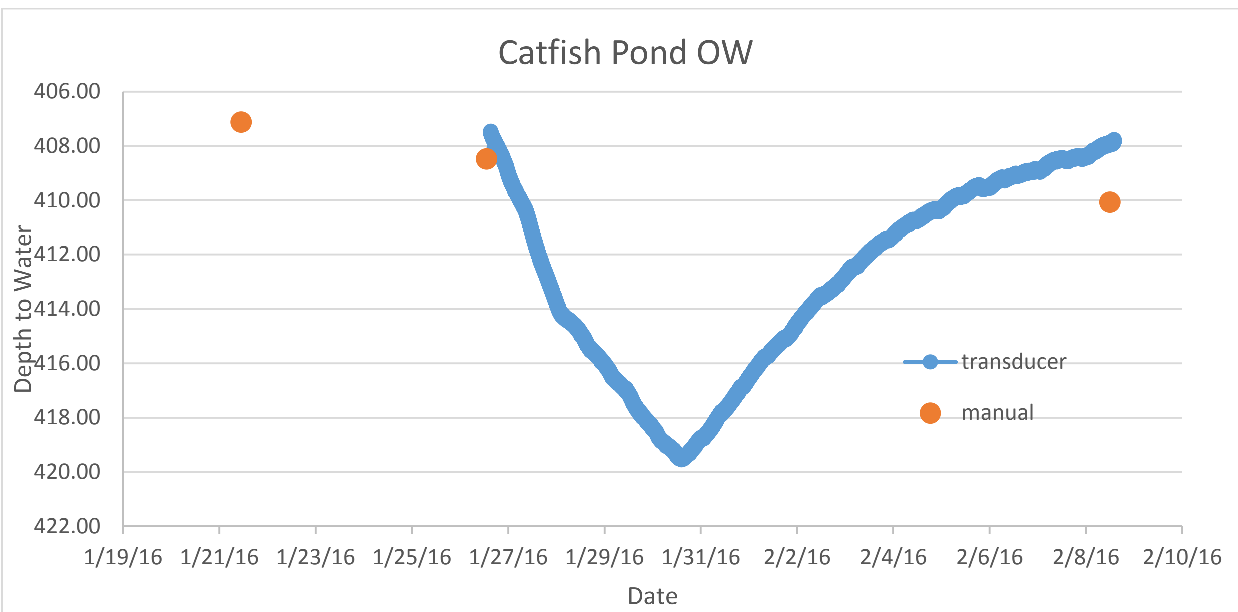


Figure A-4. Hydrograph of the Catfish Observation Well transducer and manual data. An error in the placement of the transducer resulted in missing early-time data. Note there is 0.7 ft discrepancy in the manual measurements and the transducer data on 1/26/16. There is about a 2.0 ft discrepancy in the manual measurements and transducer data on 2/8/16. Source of the error is unknown but it could be double subtractions of a measurement point. Maximum drawdown during the test was 16 feet. Water levels reached 90% recovery after 13 days with last measurement on 2/8/16.

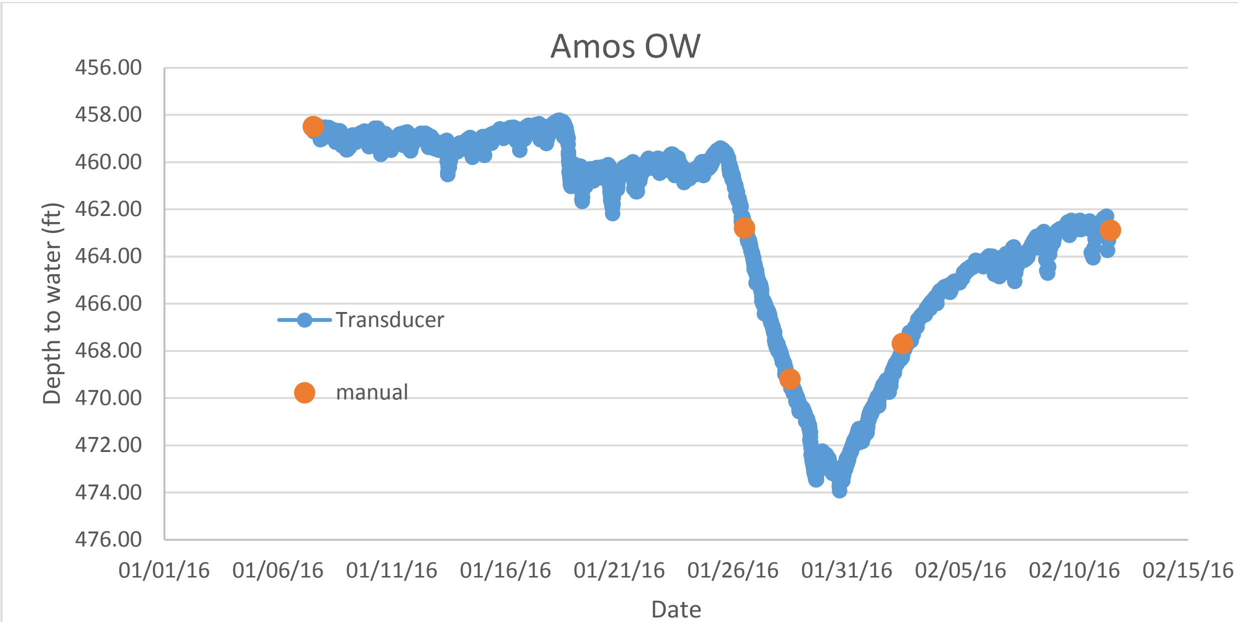


Figure A-5. Hydrograph of the HTGCD Amos Observation well transducer and manual data. Some local well interference creates the small variations of up to about 2 ft. Pre-test water level trends are relatively flat. Maxium drawdown was about 13 feet. Water levels reached 77% recovery after 13 days with last measurement on 2/11/16.

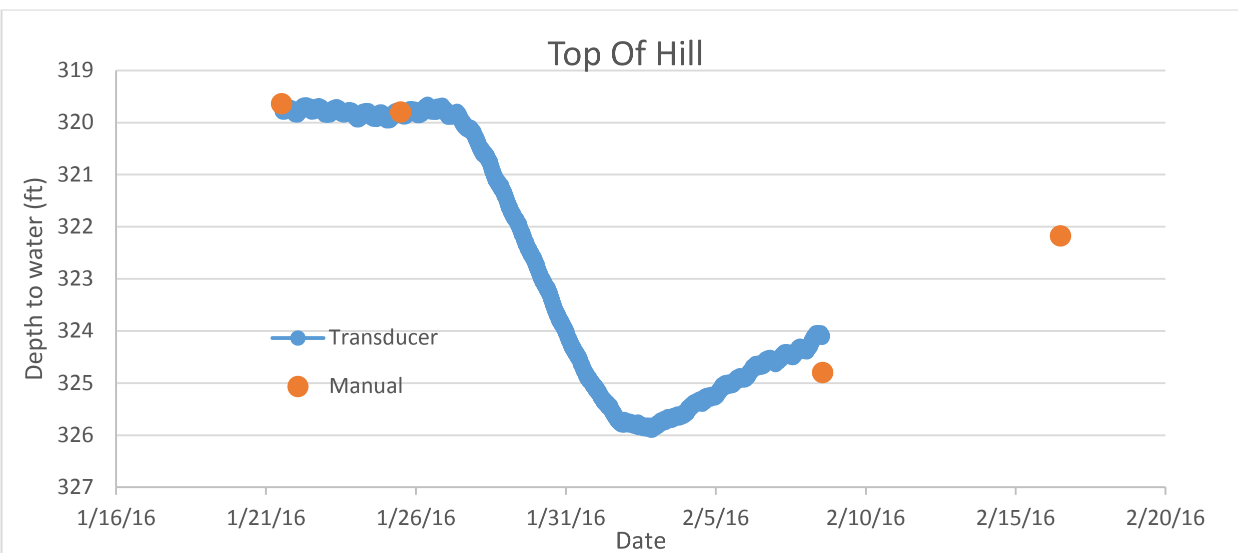


Figure A-6. Hydrograph of the Top of the HIll Observation Well transducer and manual data. Note there is 0.7 ft discrepancy in the manual measurement and the transducer data on 2/8/16. Source could be instrument drift or manual measurement error. Pre-test water level trends are relatively flat. Maximum drawdown was about 6 feet. Water levels reached 60% recovery after 22 days and last measurement on 2/16/16.

Parameter Estimates

(Note all values below are draft and subject to more technical review.)

Table A-3 summarizes two estimates of Transmissivity from specific capacity data, including empirical (Mace, 2001) and analytical (Theis et. al, 1963; Cooper-Jacob). **Figure 7** shows the Cooper-Jacob analytical solution using the change in head over one log-cyle of time. **Tables 4-7** summarize the parameters from various analytical solutions using Aqtesolv software (except where indicated).

Table 3. Empirical and Analytical estimates of Transmissivity from specific capacity (15.4 gpm/ft) of the pumping well Needmore D.

Method--Transmissivity	Value (ft2/d)	units
Empirical (Mace, 2001)	2,068	Developed for fractured Glen Rose and Cow Creek
Analytical (Theis 1963)	5,751	Interactive spreadsheet described in Mace, 2001.
Analytical (Driscoll, 1986)	4,120	
Analytical (Cooper-Jacob)	976	
average	***3,229***	

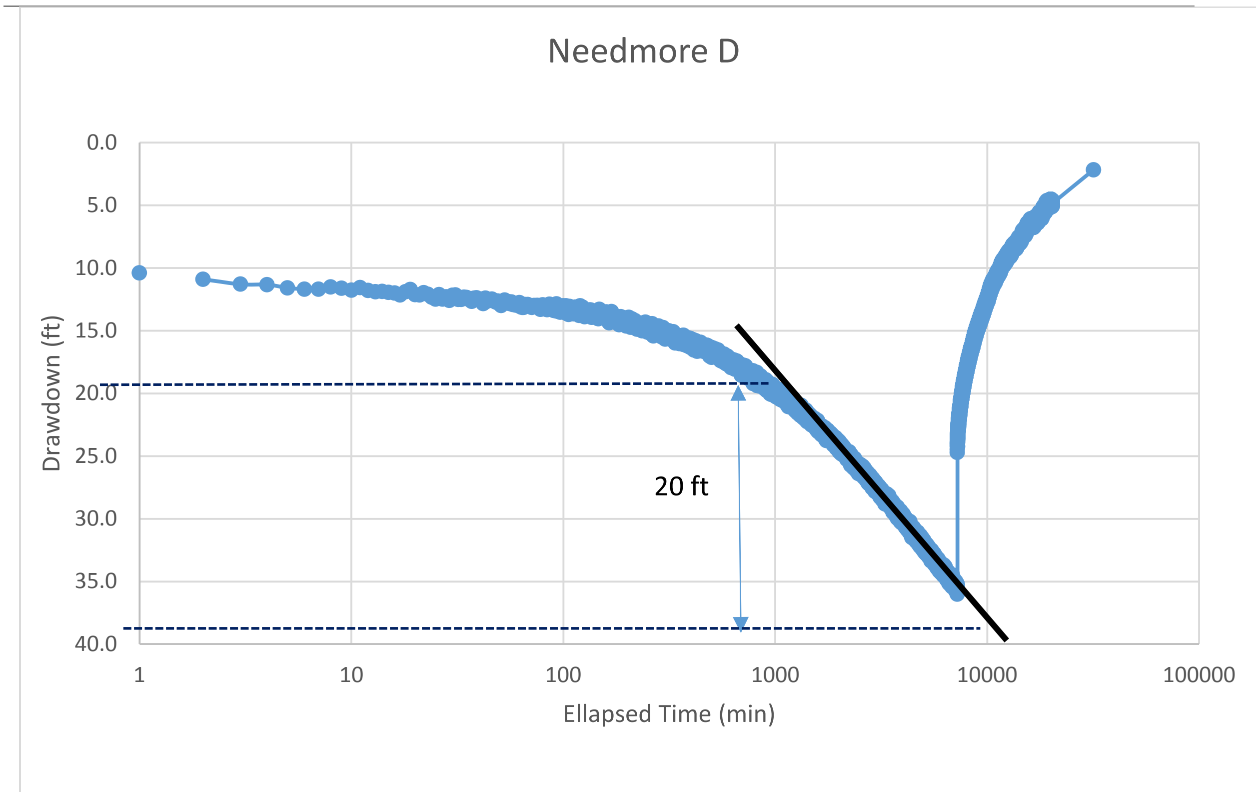


Figure A-7. Cooper-Jacob analytical method to estimate Transmissivity.

Table A-4. Needmore Pumping Well D Parameter Estimation from analytical solutions

Method	Result (T, ft^2/d)	Storativity	Comment
Theis	774	n/a	partial penetration
Theis Recovery	617	n/a	
Cooper-Jacob	855	n/a	
Papadopulos-Cooper	737	n/a	Wellbore storage
Dougherty-Babu	737	n/a	Wellbore storage, partial penetration
average	744		

1 gpd/ft = 0.13 ft2/d
1 ft2/d = 7.48 gpd/ft

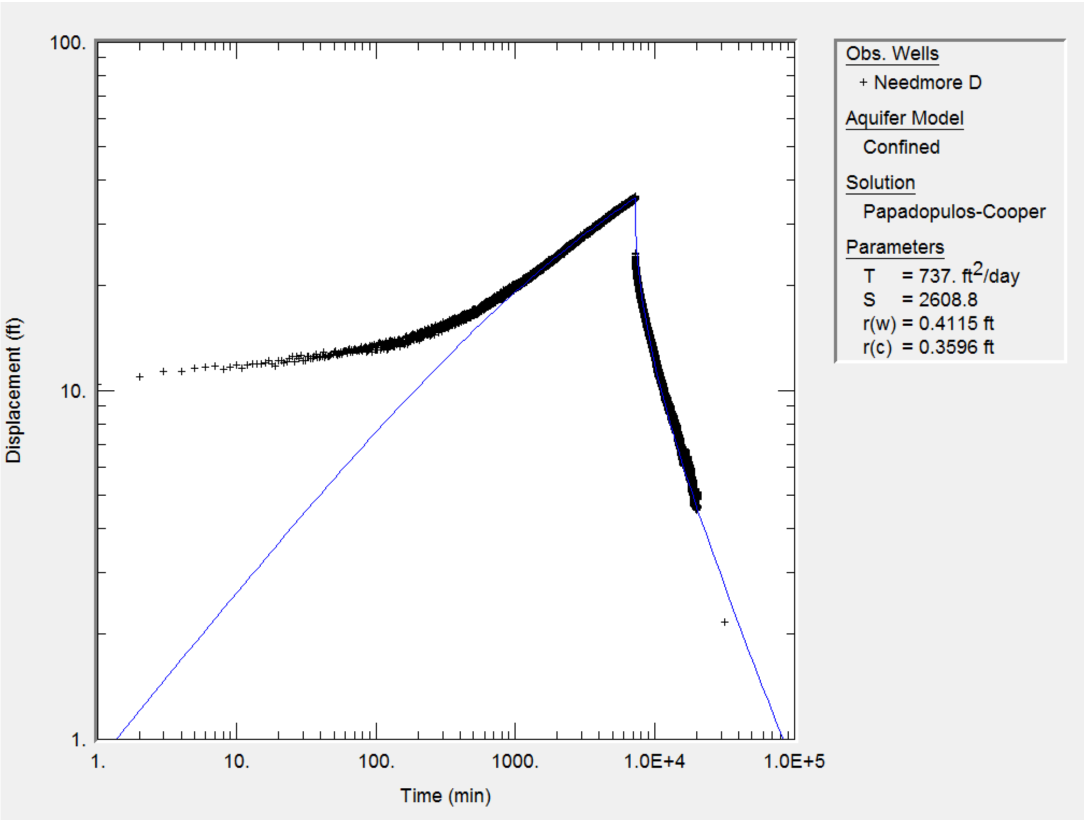


Figure A-8. Selected Aqtesolv solution and curve match for Needmore D pumping well. Note the early time suggests well bore storage effects.

Table A-5. Catfish Pond Observation Well Parameter Estimation

Method	Result (T, ft^2/d)	Storativity	Comment
Theis	921	9.8e-5	
Theis/Agarwal	557	8.0e-5	recovery
Theis Recovery	850	n/a	
Cooper-Jacob	837	8.1e-5	
Papadopulos-Cooper	895	9.8e-5	
Dougherty-Babu	896	1.0e-4	
average	*826*	*9.14e-5*	

1 gpd/ft = 0.13 ft2/d
1 ft2/d = 7.48 gpd/ft

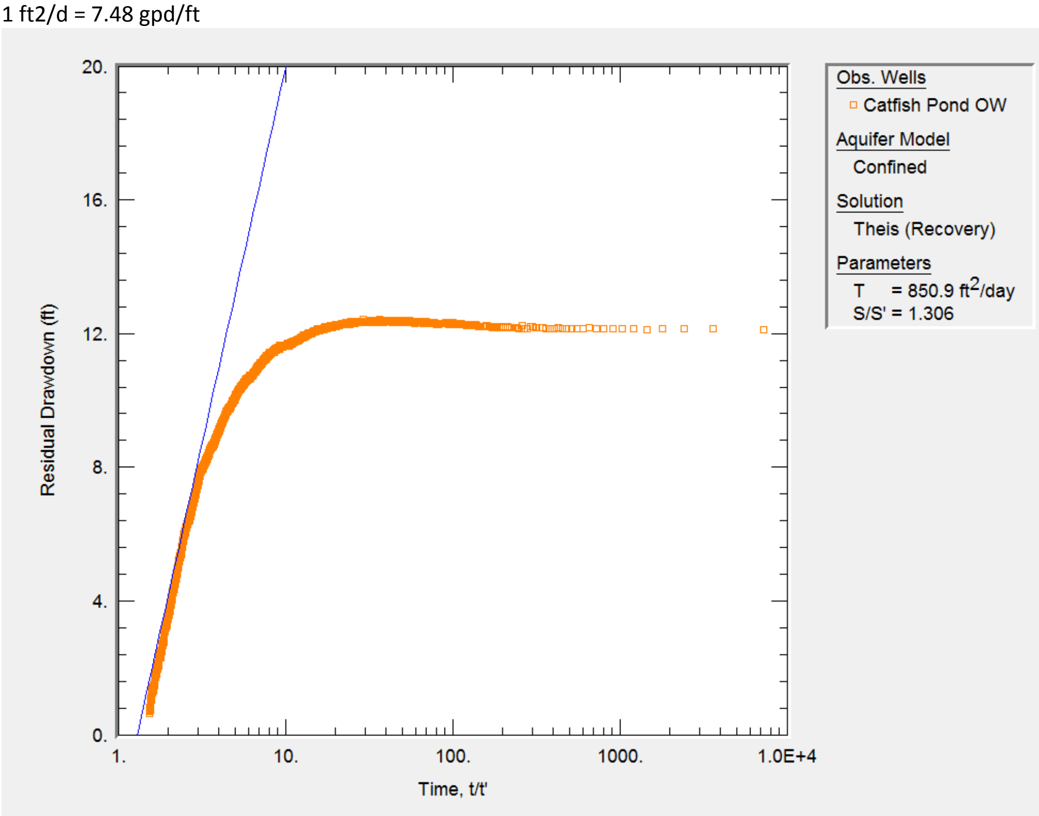


Figure A-9. Selected Aqtesolv solution and curve match for Catfish Pond Observation Well.

Table A-6. Amos HTGCD Observation Well Parameter Estimation

Method	Result (T, ft^2/d)	Storativity	Comment
Theis	834	2.7e-5	
Theis/Agarwal	585	3.1e-5	
Theis Recovery	945	n/a	
Cooper-Jacob	1,186	2.0e-5	
Papadopulos-Cooper	813	2.7e-5	
Dougherty-Babu	824	2.4e-5	

MLU-single layer	*823*	*2.3e-5*	*MLU software*
MLU-multi layer	*500*	*2.7e-5*	*MLU software*
average	*814*	*2.6e-5*	

1 gpd/ft = 0.13 ft2/d
1 ft2/d = 7.48 gpd/ft

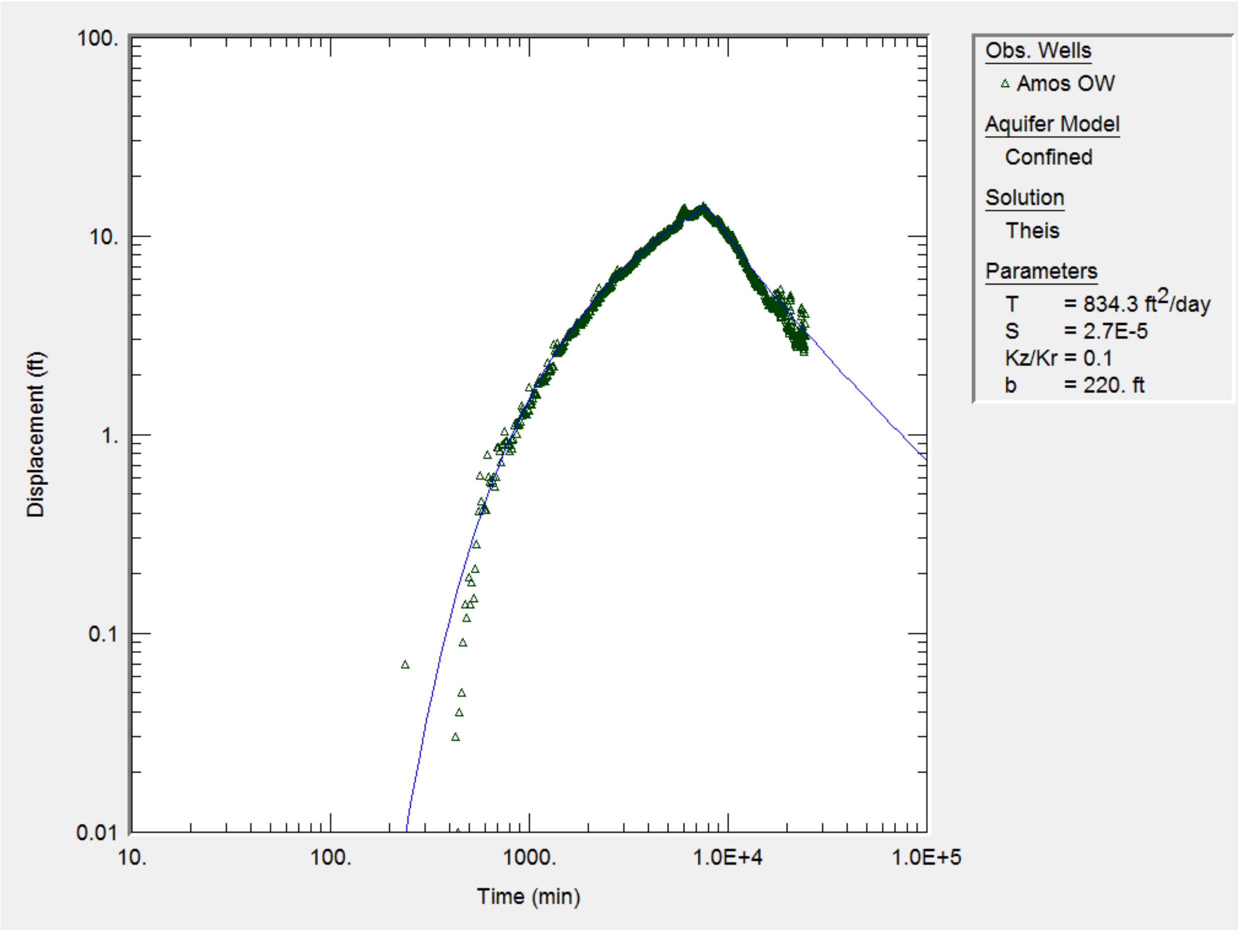


Figure A-10. Selected Aqtesolv solution and curve match for Amos Observation Well.

Table A-7. Top of the Hill Observation Well Parameter Estimation

Method	Result (T, ft^2/d)	Storativity	Comment
Theis	504	1.8e-4	
Theis Recovery	1838	n/a	
Cooper-Jacob	1366	1.5e-4	
Papadopulos-Cooper	438	1.7e-4	
Dougherty-Babu	494	1.4e-4	
MLU-single layer	*509*	*1.8e-4*	*MLU software*
MLU-multi layer	*358*	*1.4e-4*	*MLU software*
average	*786*	*1.6e-4*	

1 gpd/ft = 0.13 ft2/d
1 ft2/d = 7.48 gpd/ft

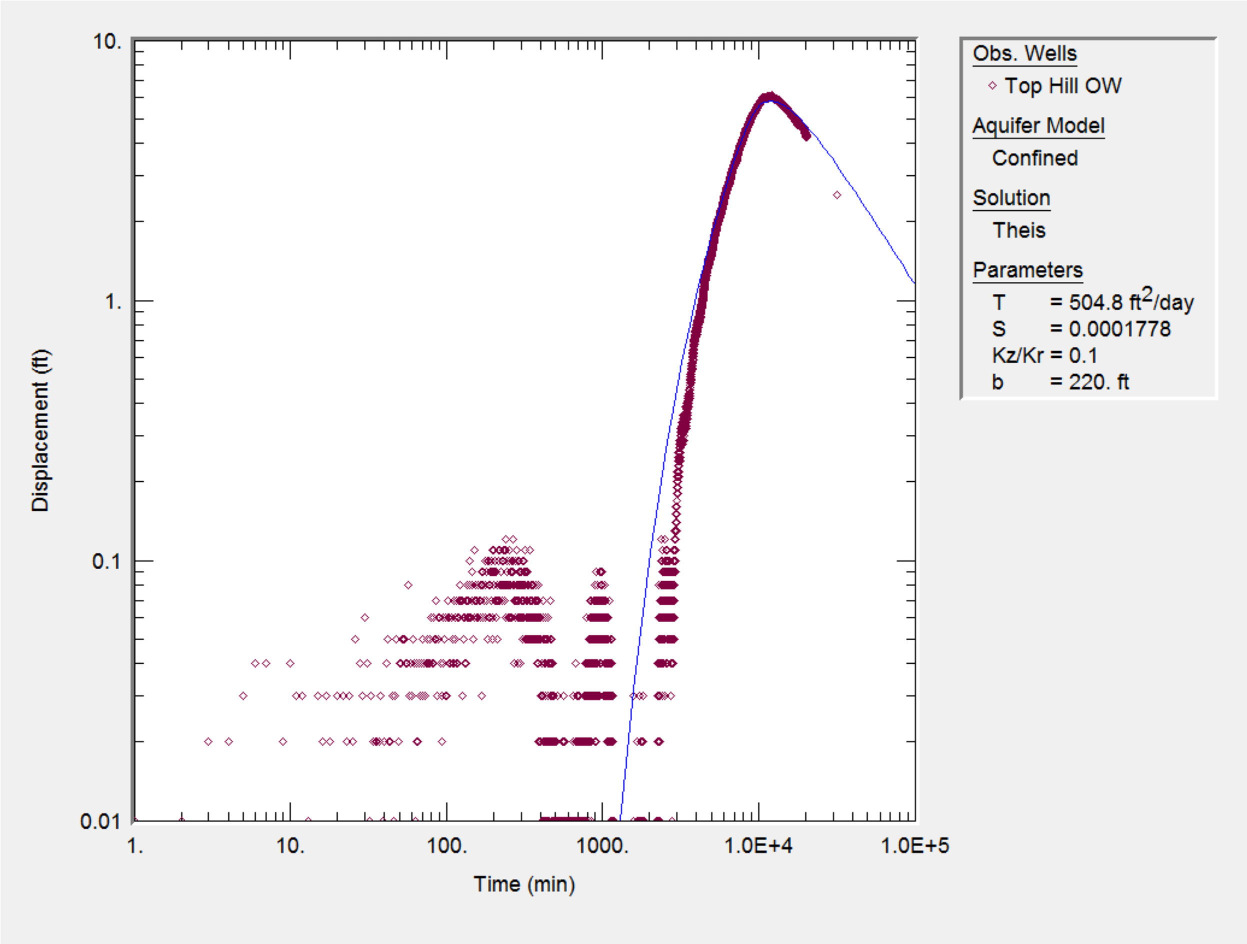
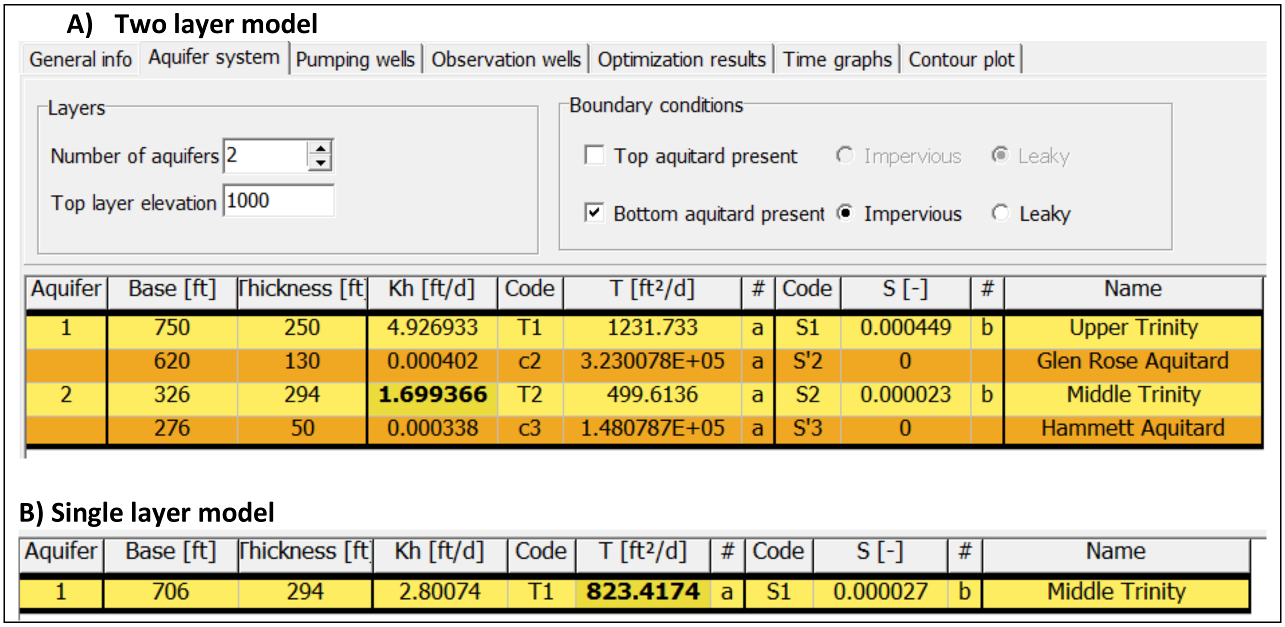


Figure A-11. Selected Aqtesolv solution and curve match for Top of Hill Observation Well.

MLU Software

MLU (Multi-Layer Unsteady state; http://www.microfem.com/products/mlu.html) software is another analytical solution to estimate aquifer parameters, but in layered aquifer systems. The benefit to MLU is that the layered stratigraphy and aquifer parameters can be used to test conceptual models and potentially provide a better fit to data that other analytical solutions that do not consider layered hydrostratigraphy.

For this evaluation, a two aquifer system with two aquitards (limits of the freeware) were created for testing. MLU was calibrated to the Amos Well and the Hill Top Well, independently **(Figures 12-15)**. Similar to Aqtesolv, the model would not calibrate with multiple observation wells together, owing to the anisotropy and heterogeneity of the aquifer.



A) Two layer model

General info | Aquifer system | Pumping wells | Observation wells | Optimization results | Time graphs | Contour plot

Layers

Number of aquifers 2

Top layer elevation 1000

Boundary conditions

Top aquitard present — Impervious — Leaky

Bottom aquitard present — Impervious — Leaky

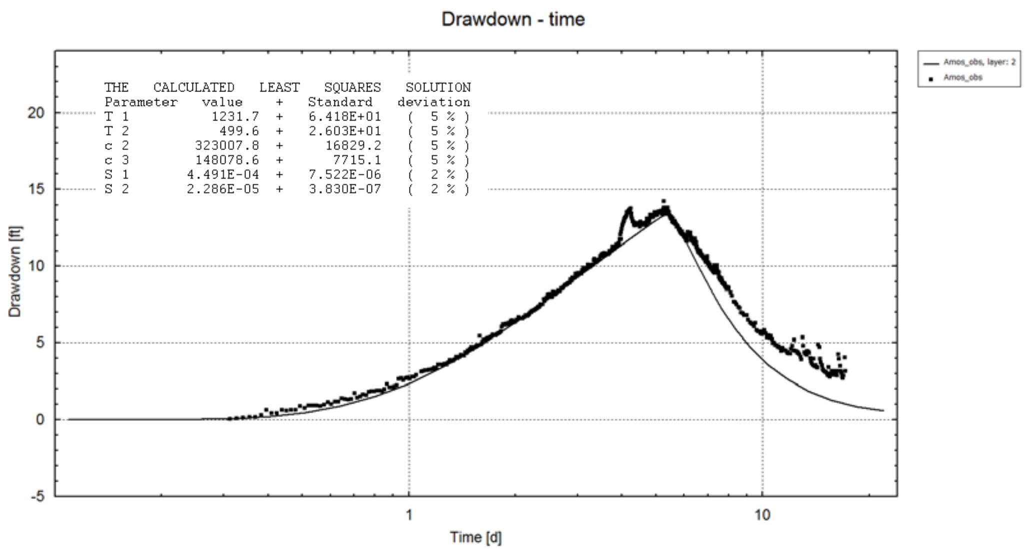
Aquifer	Base [ft]	Thickness [ft]	Kh [ft/d]	Code	T [ft²/d]	#	Code	S [-]	#	Name
1	750	250	4.926933	T1	1231.733	a	S1	0.000449	b	Upper Trinity
	620	130	0.000402	c2	3.230078E+05	a	S'2	0		Glen Rose Aquitard
2	326	294	**1.699366**	T2	499.6136	a	S2	0.000023	b	Middle Trinity
	276	50	0.000338	c3	1.480787E+05	a	S'3	0		Hammett Aquitard

B) Single layer model

Aquifer	Base [ft]	Thickness [ft]	Kh [ft/d]	Code	T [ft²/d]	#	Code	S [-]	#	Name
1	706	294	2.80074	T1	**823.4174**	a	S1	0.000027	b	Middle Trinity

Figure A-12. MLU conceptual models that returned the best-fit of the data to the Amos Well considering two aquifers and two aquitards (upper) and only one aquifer (lower). Note that the value under T (ft2/d) in the aquitard is actually a conductance value. A) contains a conceptual model with two aquifers that has a good fit. B) Contains a conceptual model with only 1 layer that has the best fit of the data.

A) Two aquifer model



B) Single-layer model

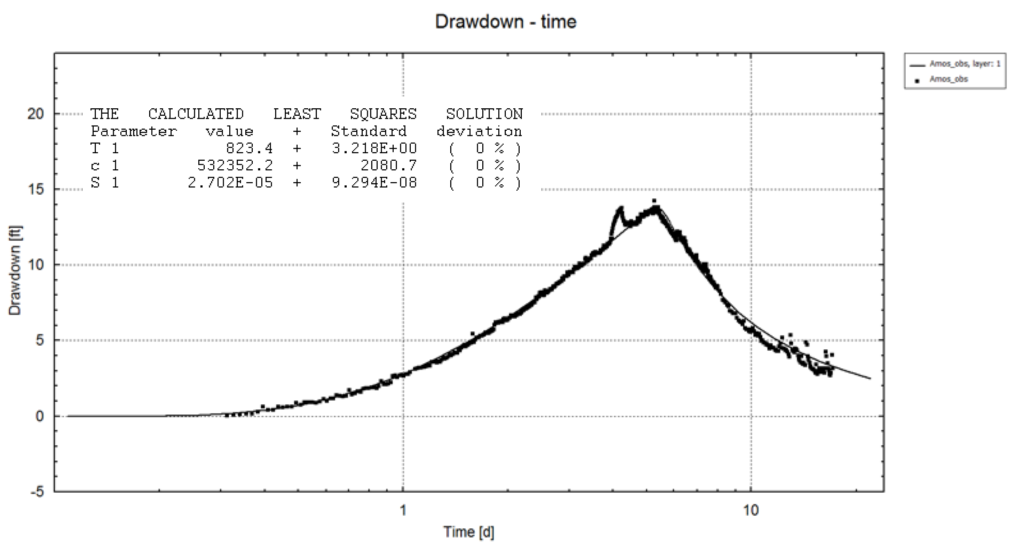


Figure A-13. MLU time-drawdown graph for the Amos OW showing data and model output. A) results from with two aquifers, B) results with just one aquifer, and has a better fit.

A) Two Aquifer model

Aquifer	Base [ft]	Thickness [ft]	Kh [ft/d]	Code	T [ft²/d]	#	Code	S [-]	#	Name
1	750	250	3.533548	T1	883.3869	a	S1	0.002882	b	Upper Trinity
	620	130	0.000561	c2	2.31658E+05	a	S'2	0		Glen Rose Aquitard
2	326	294	1.218768	T2	358.3179	a	S2	0.000147	b	Middle Trinity
	276	50	0.000471	c3	1.062005E+05	a	S'3	0		Hammett Aquitard

B) One aquifer model

Aquifer	Base [ft]	Thickness [ft]	Kh [ft/d]	Code	T [ft²/d]	#	Code	S [-]	#	Name
1	706	294	1.729687	T1	**508.5281**	a	S1	0.000179	b	Middle Trinity

Figure A-14. MLU conceptual models that returned the best-fit of the data to the Hill Top Well considering A) two aquifers and two aquitards, and B) one aquifer. Note that the value under T (ft2/d) in the aquitard is actually a conductance value. The upper figure with two aquifers had a good fit. However, the second conceptual model had the same good fit.

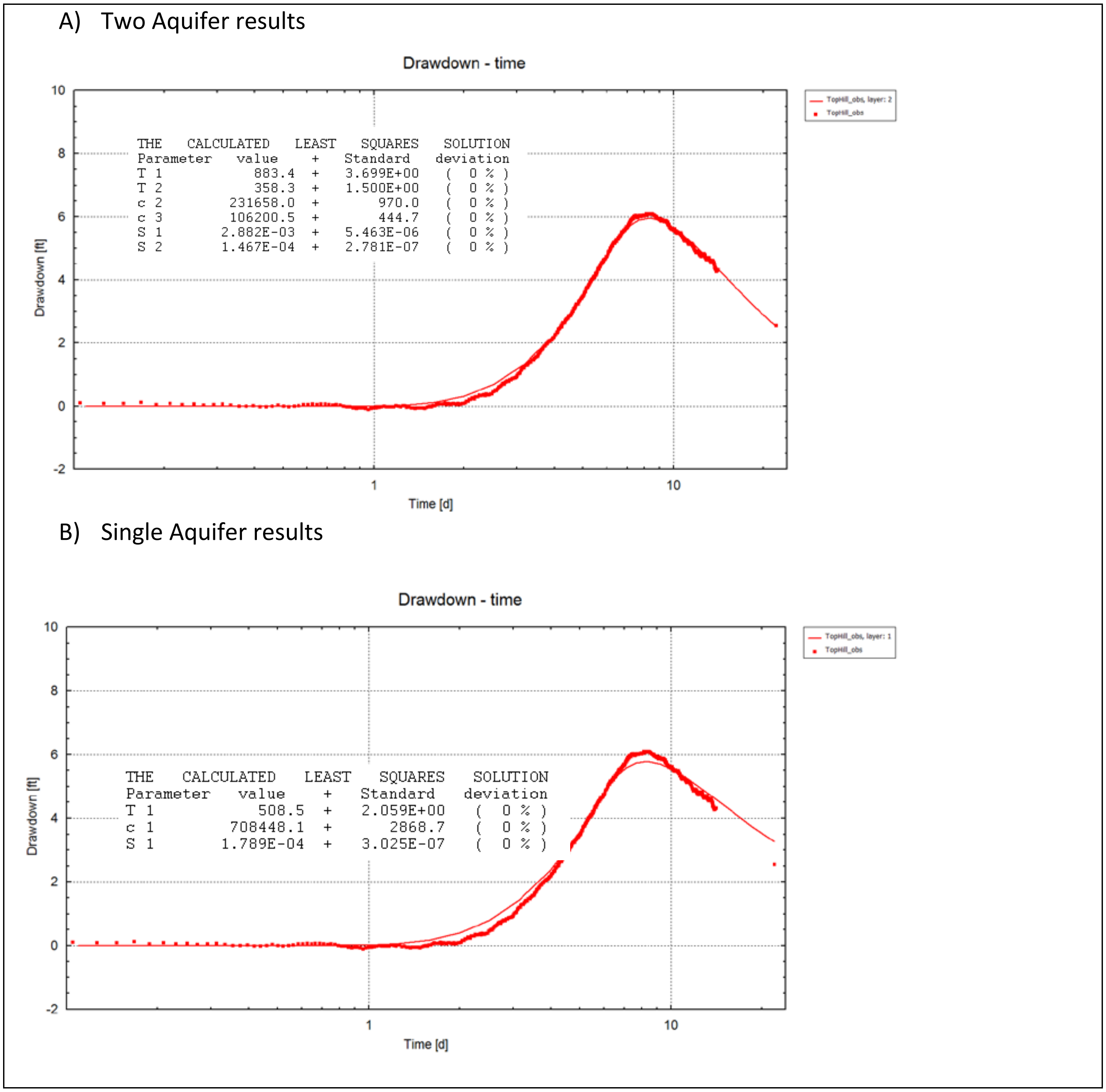


Figure A-15. MLU time-drawdown graphs for the Hill Top OW showing data and model output. The upper figure is with two aquifers, the lower is with just one aquifer—they both had equal statistical fit of the data. However, the multi-layer (A) figure visually matches the late-time better than the single layer.

Discussion and Conclusions

Analytical estimates of transmissivity using various analytical solutions in Aqutesolv and MLU were consistent among the pumping well and all three observation wells. However, estimates of transmissivity from specific capacity were elevated when compared to analytical solutions in Aqtesolv and MLU.

Along strike of the Needmore Well D, and parallel to the fault zone, the observation wells responded quicker and with a larger magnitude to pumping than the Hill Top Well updip and normal to the fault zone. Wells along strike appear to have higher transmissivity and lower storativity values compared to the updip Hill Top Observation Well.

The MLU program provided similar results as the analystical solutions of Aqtesolv. However, MLU demonstrated that to fit the data, leaky or layered aquifer systems are not needed for a test of this duration. In other words, for this test, the Middle Trinity Aquifer does not appear to derive significant amounts of water from the overlying Upper Trinity Aquifer. Supporting this was the fact that the Caboose Upper Trinity Observation Well monitored for this test did not register any response to the pumping.

Only the discrepancy between manual measurements and transducer data (noted above), and the lack of early-time data in the Catfish Observation Well were problems with the data from this test. However, those issues do not appear to signifcantly affect these evaluations and parameter estimations.

Two aspects of the well response to pumping deserve further investigation as to understanding the response in terms of long-term implications, if any:

1. The lack of pseudo-steady state or pumping level reached by the Needmore D Well and therefore the observation wells.
2. Very slow to incomplete recovery of the pumping and observation wells.

The aquifer test conducted by WRGS was done according to BSEACD guidelines and the District was consulted and involved in all aspects of the test. The data collected for the test was of good quality and allows a relatively straight-forward parameter estimation. **Table 8** contains a summary of the average values of parameter for each well, and the overall average value.

Table A-8. Summary of average aquifer parameters

Well	*Average Transmissivity (ft2/d)*	*Storativity*
Needmore D_PW	744	n/a
Catfish OW	*826*	*9.14e-5*
Amos OW	*814*	*2.6e-5*
Hill Top OW	*786*	*1.6e-4*
Average	793	9.25e-5

References

(Incomplete)

Mace, R., 2001, Estimating Transmissivity Using Specific-Capacity Data, Geological Circular 01-2, Bureau of Economic Geology, University of Texas at Austin, 44 p.

Theis, C.V., Brown, R.H., and Myers, R.R., 1963, Estimating the transmissibility of aquifers from the specific capacity of wells: methods of determining permeability, transmissivity, and drawdown, in U.S. Geological Survey Water-Supply Paper, No. 1464, 693 p.