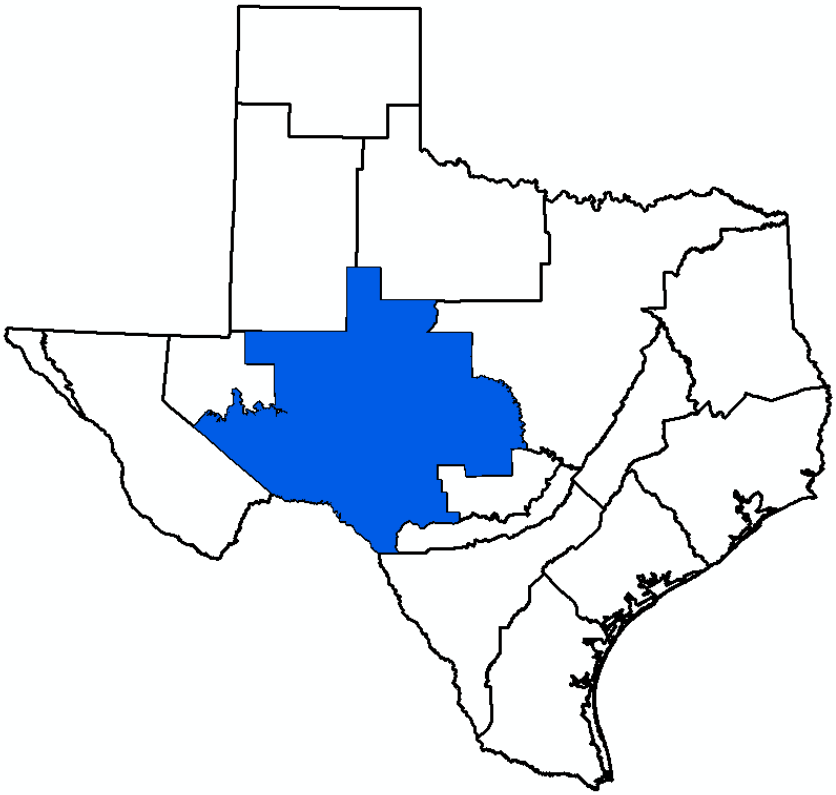
GMA 7 Technical Memorandum 16-02
Draft 1

Llano Uplift Aquifers:
Initial Predictive Simulations with Draft Llano Uplift GAM



Prepared for:
Groundwater Management Area 7

Prepared by:
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Jamaica Beach, TX 77554
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March 13, 2016

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1.0 Introduction and Objective

This technical memorandum documents initial simulations using the recently released draft numerical model of the minor aquifers of the Llano Uplift region (Marble Falls, Ellenburger-San Saba, and hickory (Shi and others, 2016). The model is still considered a draft. If changes are made to the model after review of comments, any simulation that formed the basis of a proposed DFC would have to be updated.

Because the DFCs that were developed in 2010 were based on analytical water budget methods, these runs are particularly significant in that it is the first time that a rigorous evaluation of the relationship between pumping and drawdown can be made. In addition, the model was used to simulate the start-up of the City of San Angelo wells in the Hickory Aquifer.

2.0 Description of Simulations

Simulations were run for 60 years (2011 to 2070). Model files for the scenarios were taken from the calibrated model, and modified for purposes of the simulation. Table 1 summarizes how predictive simulation files were developed.

Table 1. Summary of Input Files for Simulations

File Type	File Name	Changes from Calibrated Model
BAS	lupred01.bas	External ibound arrays and starting head arrays. Now reads external files of starting heads taken from last stress period of calibrated model (2010)
SMS	llano-uplift.sms	No change
DISU	lupred01.dis	Changed number of stress periods to 60
OC	lupred01.oc	Changed number of stress periods to 60
GHB	lupred01.ghb	Changed number of stress periods to 60
RCH	luavgrech.rch	Cell-by-cell average from the calibrated model to achieve "average" recharge for simulation
WEL	scenXX.wel	Specific pumping file for each scenario (described below)
RIV	lu2010riv.riv	Used last stress period of calibrated model for all 60 stress periods
DRN	lu2010drn.drn	Used last stress period of calibrated model for all 60 stress periods
LPF	llano-uplift.lpf	No change

A base case was developed using the historic pumping from the calibrated model. The default was to use 2010 pumping (the final stress period). Table 2 summarizes how pumping in specific counties was assigned. The basic objective of this was to use recent historic maximum pumping in areas of GMA 7 that were relevant for purposes of joint planning (i.e. DFCs were developed and MAGs were calculated in 2010).

Table 2. Initial Pumping Basis (Year of Maximum Pumping)

Aquifer	County	Maximum Pumping Year	Stress Period
Marble Falls	San Saba	2000	21
Ellenburger-San Saba	Gillespie	2008	29
Ellenburger-San Saba	Kimble	2008	29
Ellenburger-San Saba	Mason	2008	29
Ellenburger-San Saba	McCulloch	2008	29
Ellenburger-San Saba	Menard	2008	29
Ellenburger-San Saba	San Saba	2008	29
Hickory	Concho	2005	26
Hickory	Gillespie	2008	29
Hickory	Kimble	2008	29
Hickory	Llano	2006	27
Hickory	Mason	1999	20
Hickory	McCulloch	2006	27
Hickory	Menard	2006	27
Hickory	San Saba	2004	25

In addition to the historic maximum pumping as a base case for simulated pumping, 15 City of San Angelo Wells were included and assumed to pump for the entire simulation at a rate of 12,000 AF/yr.

The San Angelo well locations and pumping rates were provided by Mr. James Beach of LBG-Guyton Associates. A summary of the locations in terms of the model grid are as shown in Table 3.

The scenarios were developed to evaluate how changed pumping affects drawdown. Scenario 3 was the base case. Scenarios 1 and 2 evaluated reduced pumping (except the San Angelo wells), and Scenarios 4 and 5 evaluated increased pumping (except the San Angelo wells) as follows:

- Scenario 1 = 50 percent of base case pumping
- Scenario 2 = 75 percent of base case pumping
- Scenario 3 = 100 percent of base case pumping (see Table 2)
- Scenario 4 = 125 percent of base case pumping
- Scenario 5 = 150 percent of base case pumping

Again, it must be emphasized that in all scenarios, the 12,000 AF/yr of pumping from the 15 San Angelo wells remained the same.

Table 3. Model Grid Locations for San Angelo Wells

Well	Row	Column	Node
WSW-1	279	138	1749314
WSW-2	276	153	1747661
WSW-3	273	150	1745990
WSW-4	275	147	1747099
WSW-5	278	150	1748770
WSW-6	270	147	1744319
WSW-7	272	144	1745428
WSW-8	275	141	1747093
WSW-9	283	132	1751532
WSW-12	283	138	1751538
WSW-13	283	144	1751544
WSW-14	286	141	1753209
WSW-17	289	138	1754874
WSW-20	289	132	1754868
WSW-22	279	142	1749318

3.0 Simulation Results

Pumping and drawdown results for the five scenarios are presented below in Table 4, and in hydrograph form in Appendix A.

Table 4. Summary of Pumping and Drawdown - Scenarios 1 to 5

Aquifer	County	2011 to 2070 Pumping (AF/yr)				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Marble Falls	San Saba	2,172	3,257	4,343	5,429	6,515
Ellenburger-San Saba	Gillespie	3,231	4,847	6,463	8,078	9,694
Ellenburger-San Saba	Kimble	267	401	535	669	802
Ellenburger-San Saba	Mason	1,932	2,898	3,863	4,829	5,795
Ellenburger-San Saba	McCulloch	2,246	3,369	4,492	5,615	6,738
Ellenburger-San Saba	Menard	155	232	309	387	464
Ellenburger-San Saba	SanSaba	4,195	6,293	8,391	10,488	12,586
Hickory	Concho	13	20	27	34	40
Hickory	Gillespie	907	1,360	1,814	2,267	2,721
Hickory	Kimble	83	124	165	207	248
Hickory	Llano	1,011	1,516	2,021	2,526	3,032
Hickory	Mason	7,533	11,299	15,066	18,832	22,599
Hickory	McCulloch	17,034	20,751	24,468	28,185	31,902
Hickory	Menard	2,562	2,644	2,725	2,806	2,887
Hickory	SanSaba	3,875	5,813	7,751	9,688	11,626

Aquifer	County	2010 to 2070 Average Drawdown (ft)				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Marble Falls	San Saba	-3	2	7	12	17
Ellenburger-San Saba	Gillespie	-6	1	8	15	22
Ellenburger-San Saba	Kimble	6	12	18	24	30
Ellenburger-San Saba	Mason	0	7	14	20	27
Ellenburger-San Saba	McCulloch	12	20	29	37	46
Ellenburger-San Saba	Menard	27	36	46	55	65
Ellenburger-San Saba	SanSaba	-3	1	5	9	13
Hickory	Concho	21	37	53	69	86
Hickory	Gillespie	-5	2	9	16	23
Hickory	Kimble	6	12	18	24	30
Hickory	Llano	2	5	8	10	13
Hickory	Mason	1	9	17	25	33
Hickory	McCulloch	11	20	29	38	47
Hickory	Menard	27	37	46	55	65
Hickory	SanSaba	-2	2	6	10	14

4.0 Next Steps

Preliminary evaluation of water budget results was completed, but not finalized in summary tables or graphs. Since this is the initial predictive runs using this new model, the objective of the water budget evaluation was to ensure that the model results were consistent with the conceptual model, and that the model was providing meaningful results. This was especially important since the model uses the unstructured grid code, and the traditional layering limitations have been removed (i.e. no need to have "dummy layers" or "pass-through" layers to simulated the connection between, for example layers 3 and 5). All preliminary evaluations showed the efficacy of the modeling code to properly simulate the movement of water in the complex geologic framework. More detail on the water budget will be developed once a scenario is selected as the basis for a DFC.

Results of the initial simulations will be discussed at the March 17, 2016 GMA 7 meeting, and at the Board of Directors meeting of the Hickory UWCD on April 14, 2016.

5.0 References

Shi, J., Boghici, R., Kohlrenken, W., and Hutchison, W.R., 2016. Draft Numerical Model Report: Minor Aquifers of the Llano Uplift Region of Texas (Marble Falls, Ellenburger-San Saba, and Hickory). Texas Water Development Board, draft report, February 16, 2016, 403p.

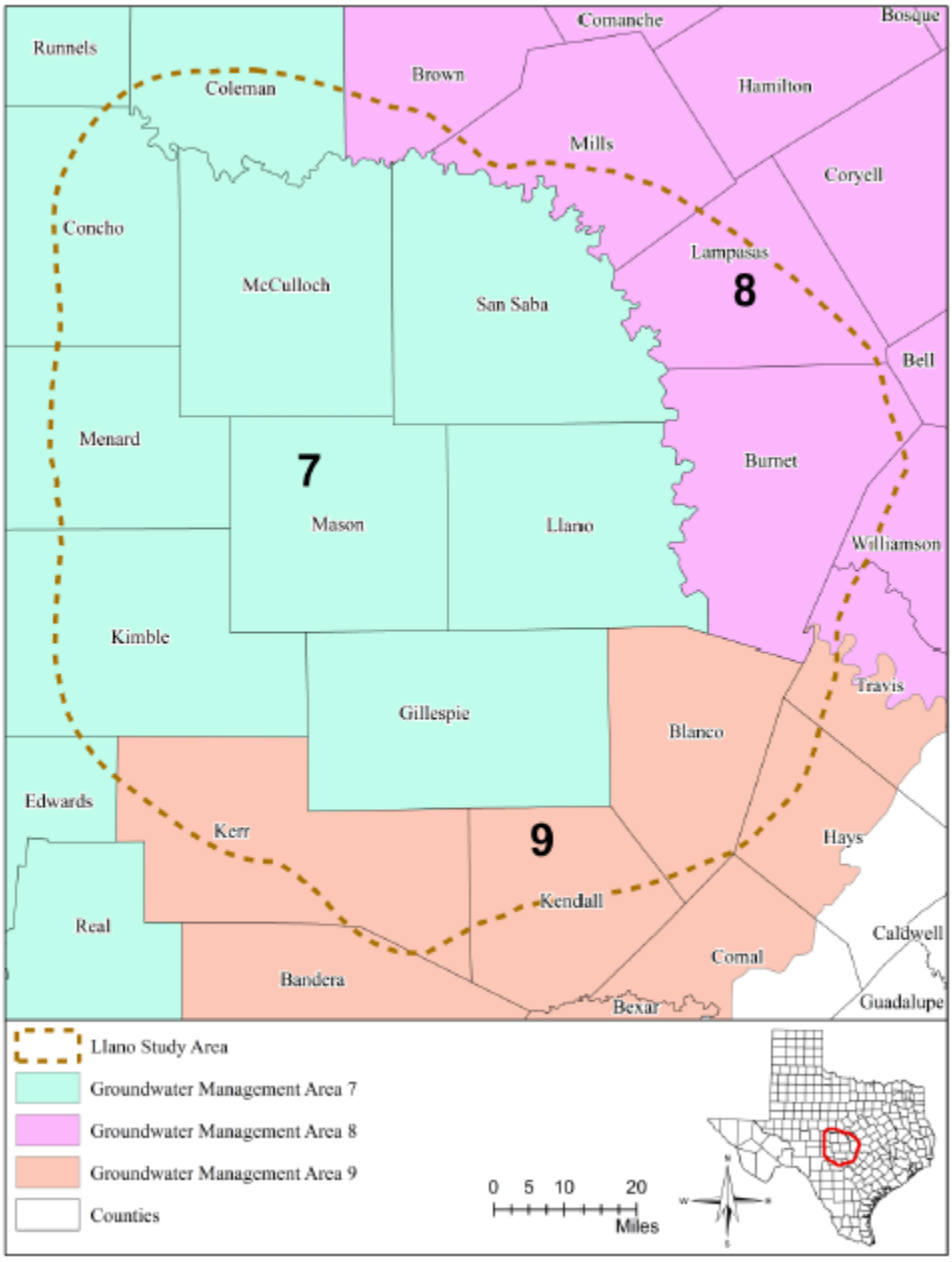
Appendix A

Hydrographs of Pumping and Drawdown

Marble Falls Aquifer

Ellenburger-San Saba Aquifer

Hickory Aquifer


Runnels
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Brown
Comanche
Bosque
Hamilton
Mills
Coryell
Concho
McCulloch
San Saba
Lampasas
8
Bell
Menard
7
Mason
Llano
Burnet
Williamson
Kimble
Gillespie
Blanco
Travis
Edwards
Kerr
9
Hays
Kendall
Real
Caldwell
Comal
Bandera
Bexar
Guadalupe
Llano Study Area
Groundwater Management Area 7
Groundwater Management Area 8
Groundwater Management Area 9
Counties
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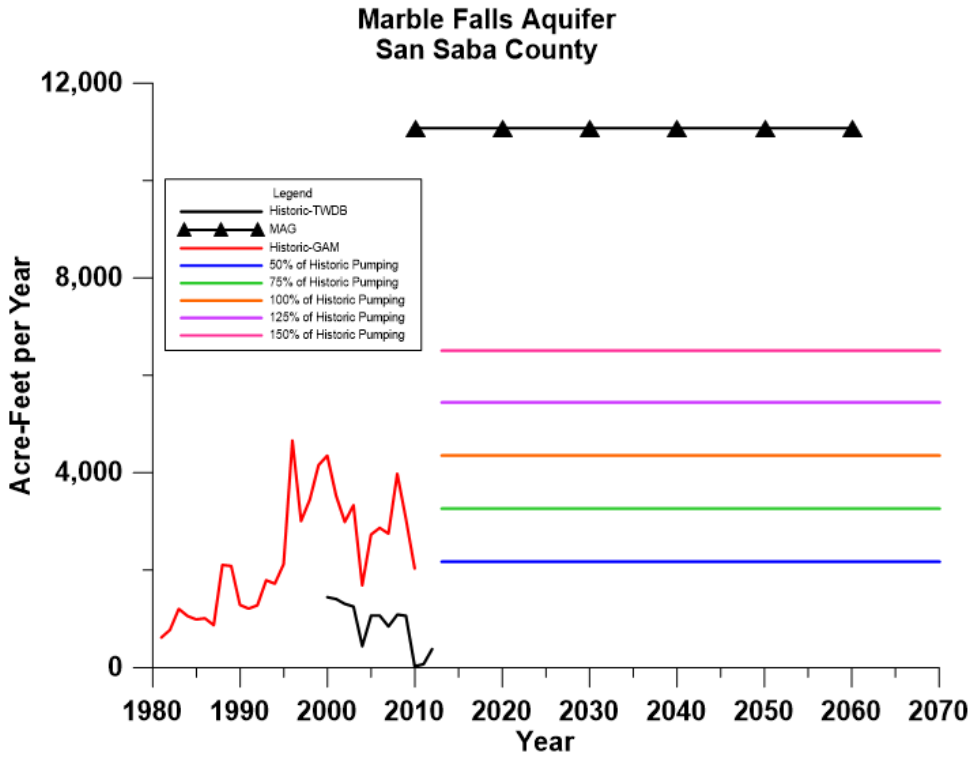
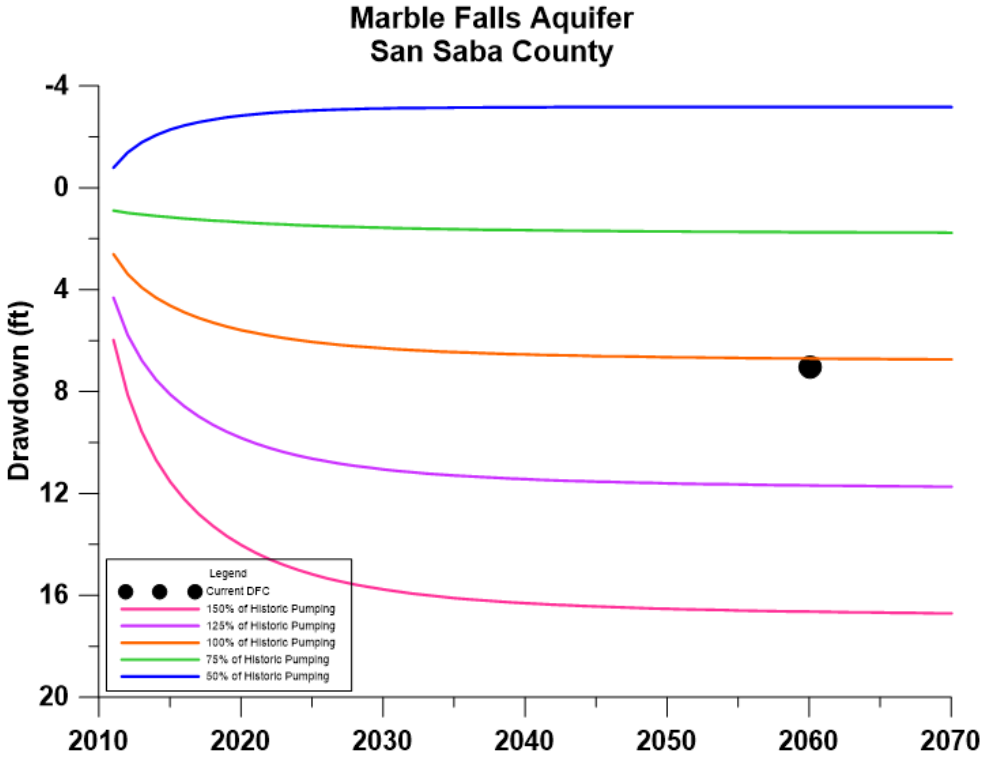
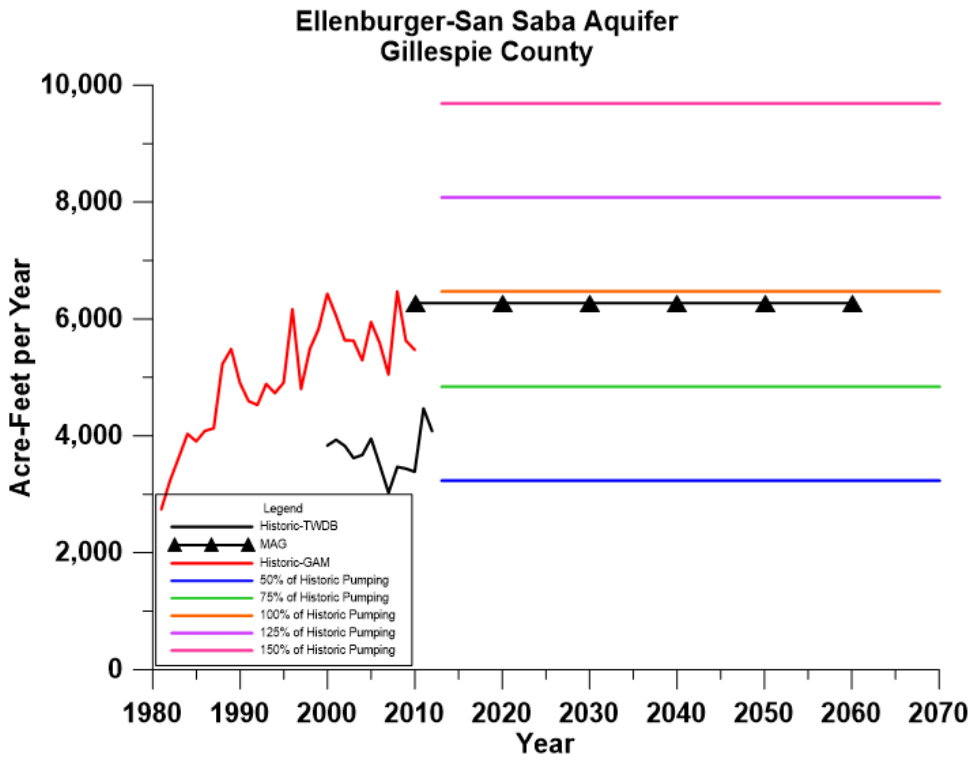
Miles


Marble Falls Aquifer
San Saba County
12,000
8,000
4,000
0
Acre-Feet per Year
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year
Legend
Historic-TWDB
MAG
Historic-GAM
50% of Historic Pumping
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping


Marble Falls Aquifer
San Saba County
-4
0
4
8
12
16
20
Drawdown (ft)
2010
2020
2030
2040
2050
2060
2070
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping


Ellenburger-San Saba Aquifer
Gillespie County
Acre-Feet per Year
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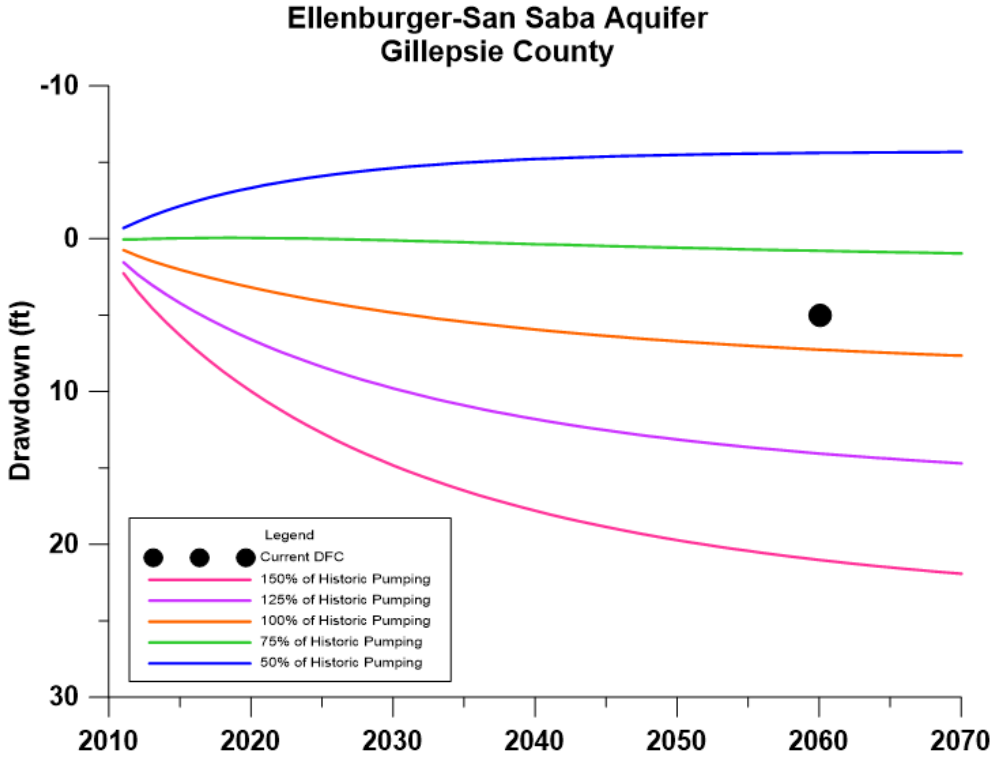
8,000
6,000
4,000
2,000
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year
Legend
Historic-TWDB
MAG
Historic-GAM
50% of Historic Pumping
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping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Gillepsie County
Drawdown (ft)
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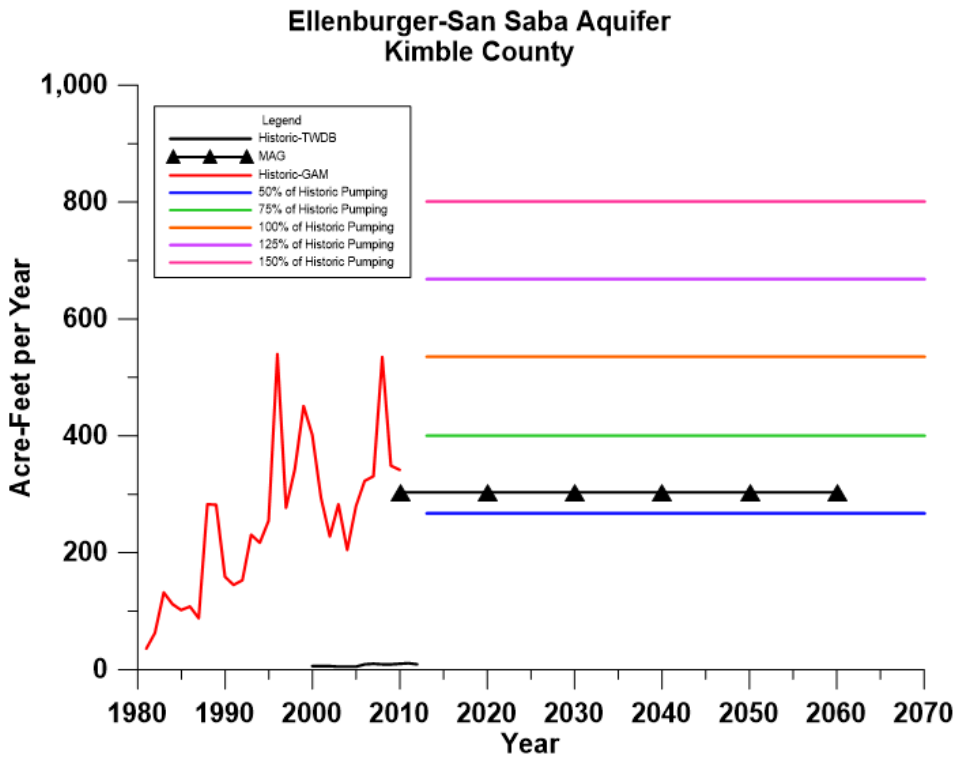
0
10
20
30
2010
2020
2030
2040
2050
2060
2070
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping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Kimble County
Legend
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MAG
Historic-GAM
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75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping
Acre-Feet per Year
1,000
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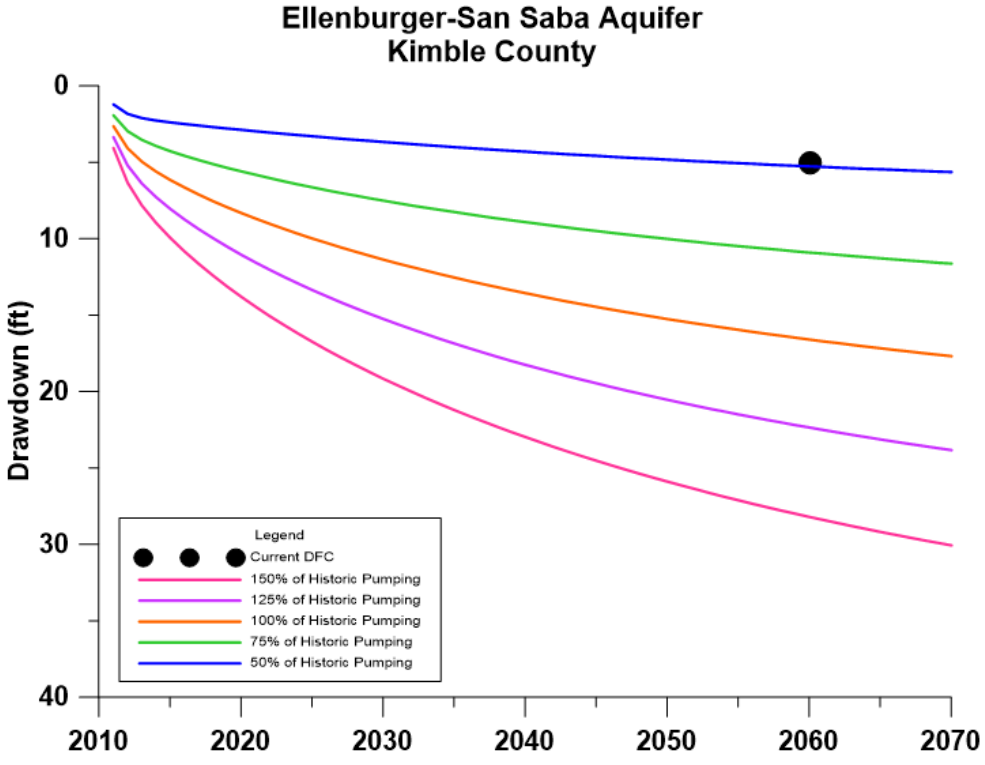
600
400
200
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year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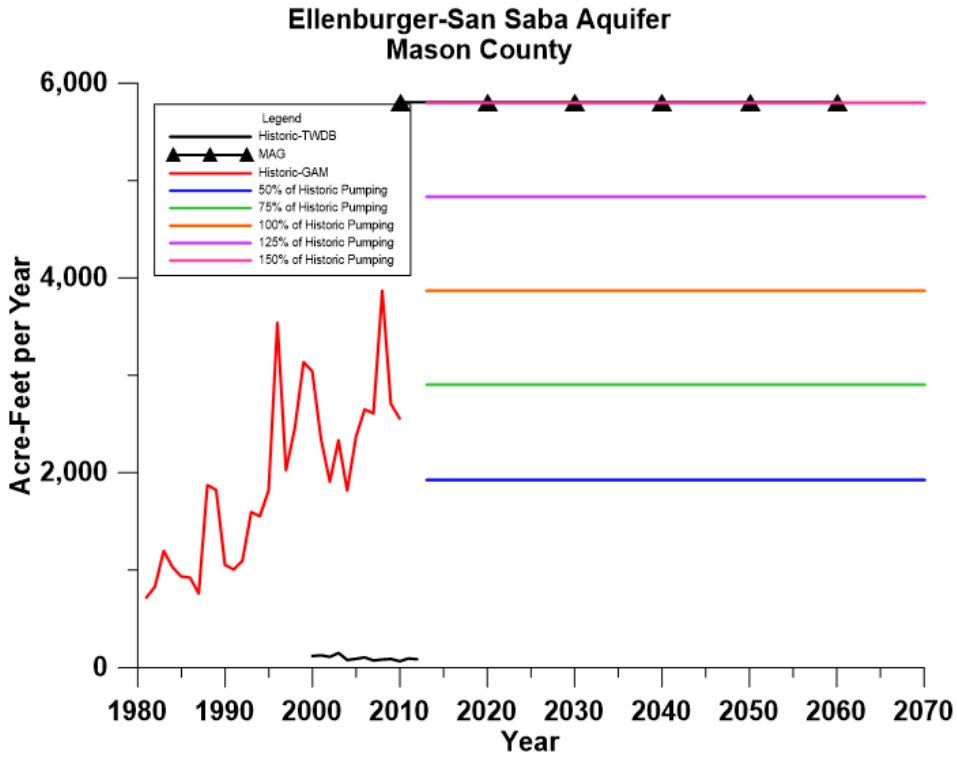
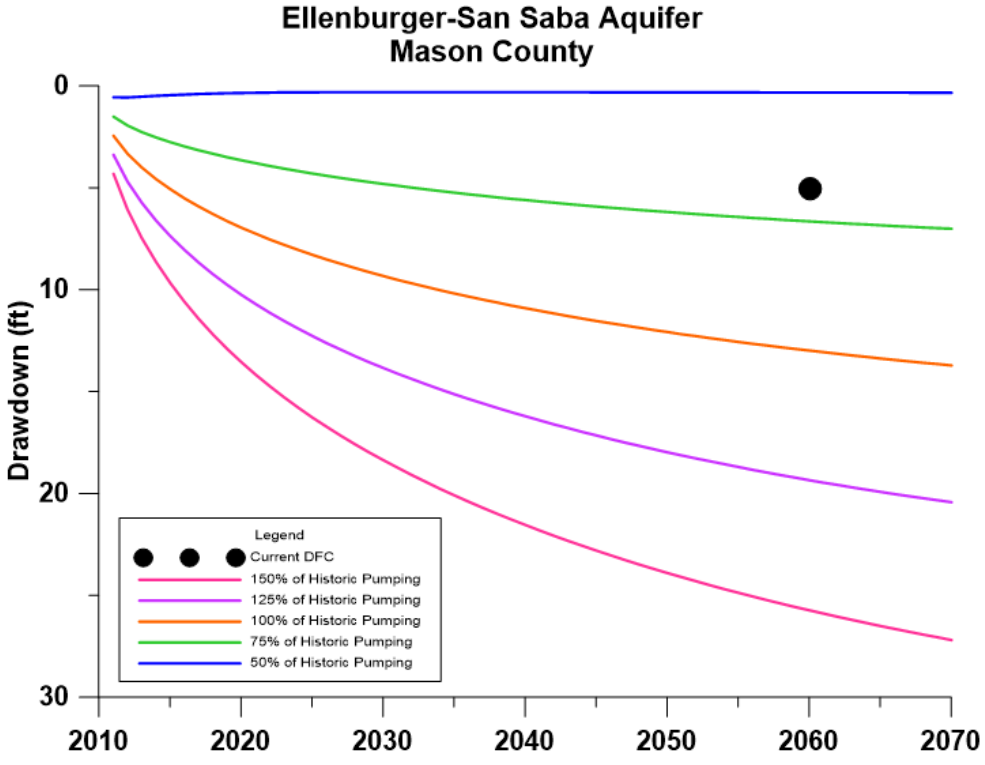
Kimble County
Drawdown (ft)
0
10
20
30
40
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping
2010
2020
2030
2040
2050
2060
2070


Ellenburger-San Saba Aquifer
Mason County
Legend
Historic-TWDB
MAG
Historic-GAM
50% of Historic Pumping
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping
Acre-Feet per Year
6,000
4,000
2,000
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year


Ellenburger-San Saba Aquifer
Mason County
Drawdown (ft)
0
10
20
30
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping
2010
2020
2030
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2050
2060
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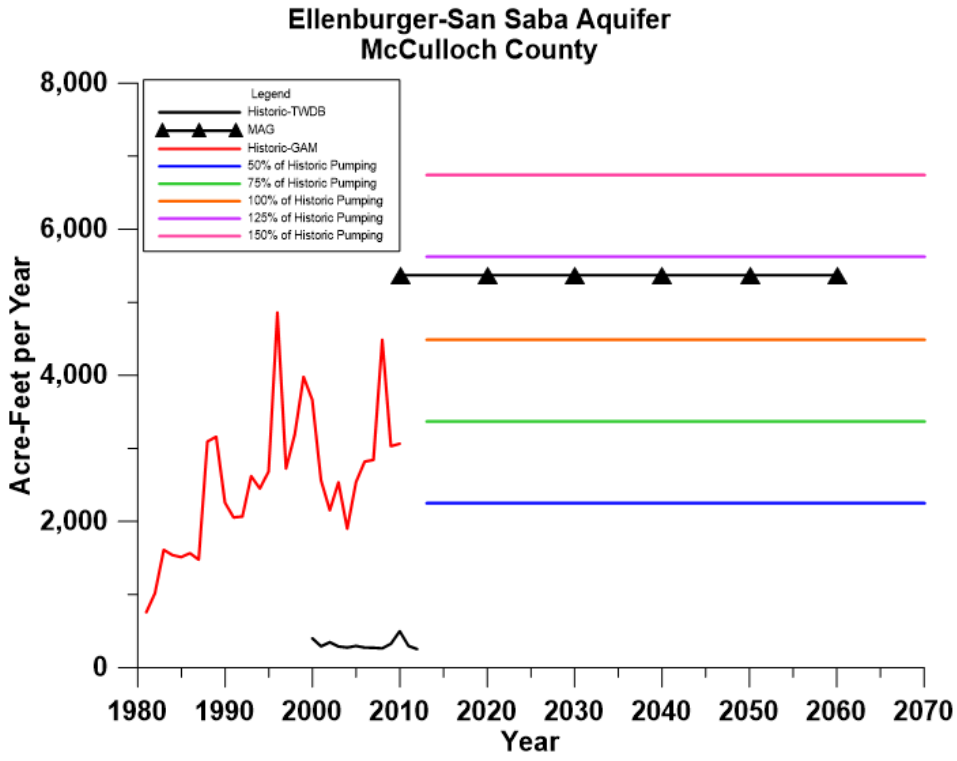
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McCulloch County
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Historic-GAM
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75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping
Acre-Feet per Year
8,000
6,000
4,000
2,000
0
1980
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2030
2040
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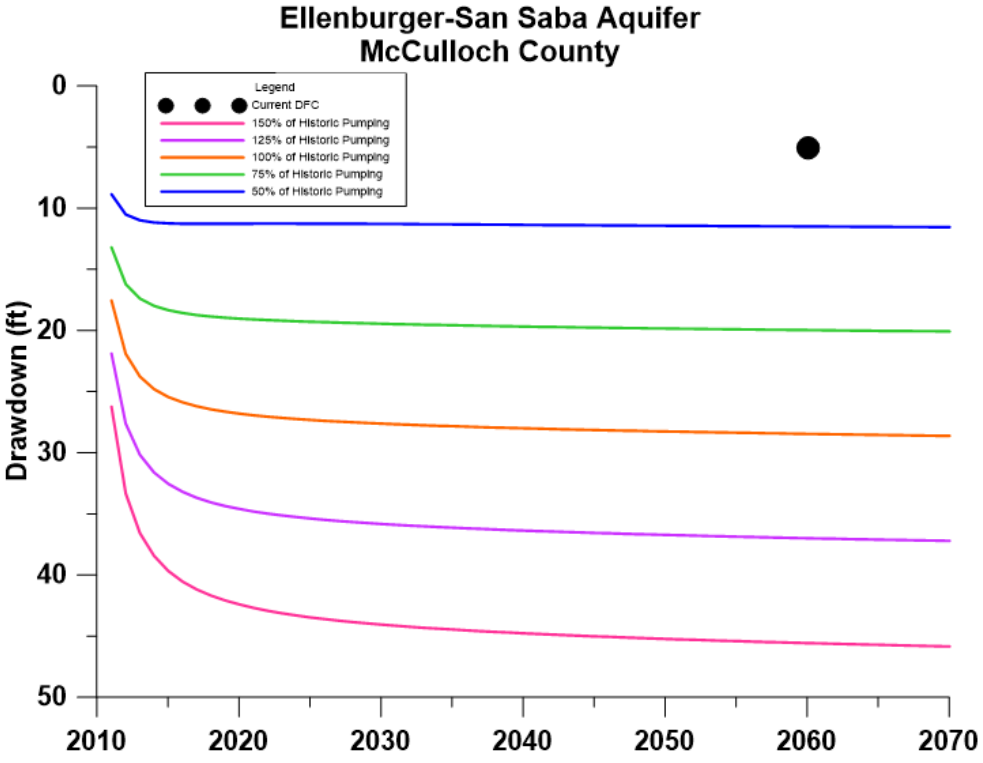
2060
2070
Year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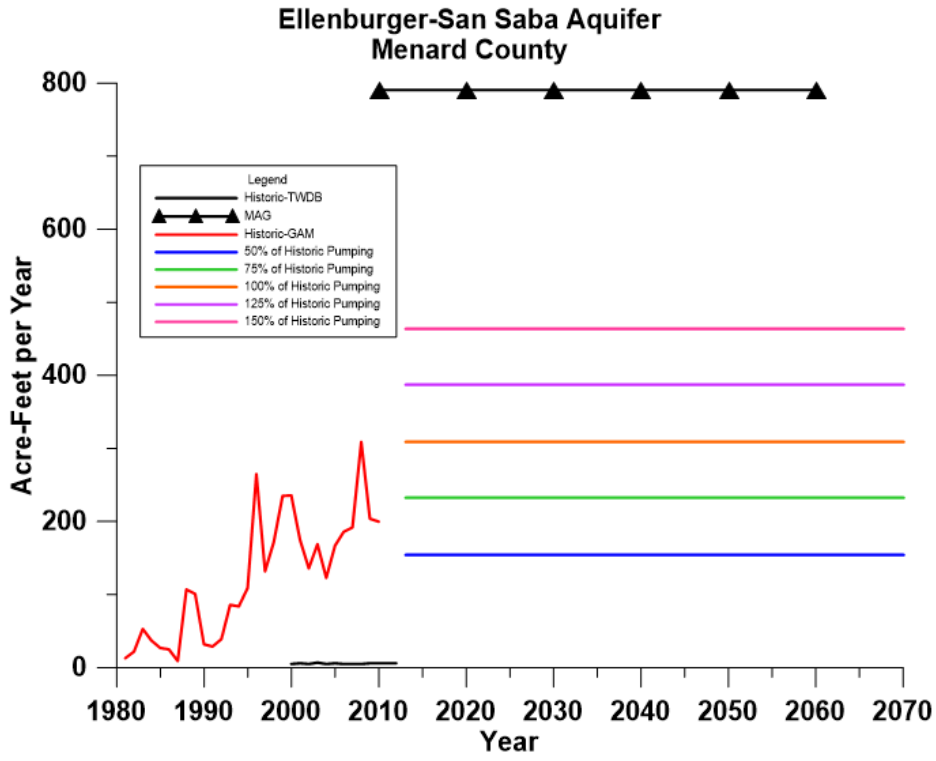
McCulloch County
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping
Drawdown (ft)
0
10
20
30
40
50
2010
2020
2030
2040
2050
2060
2070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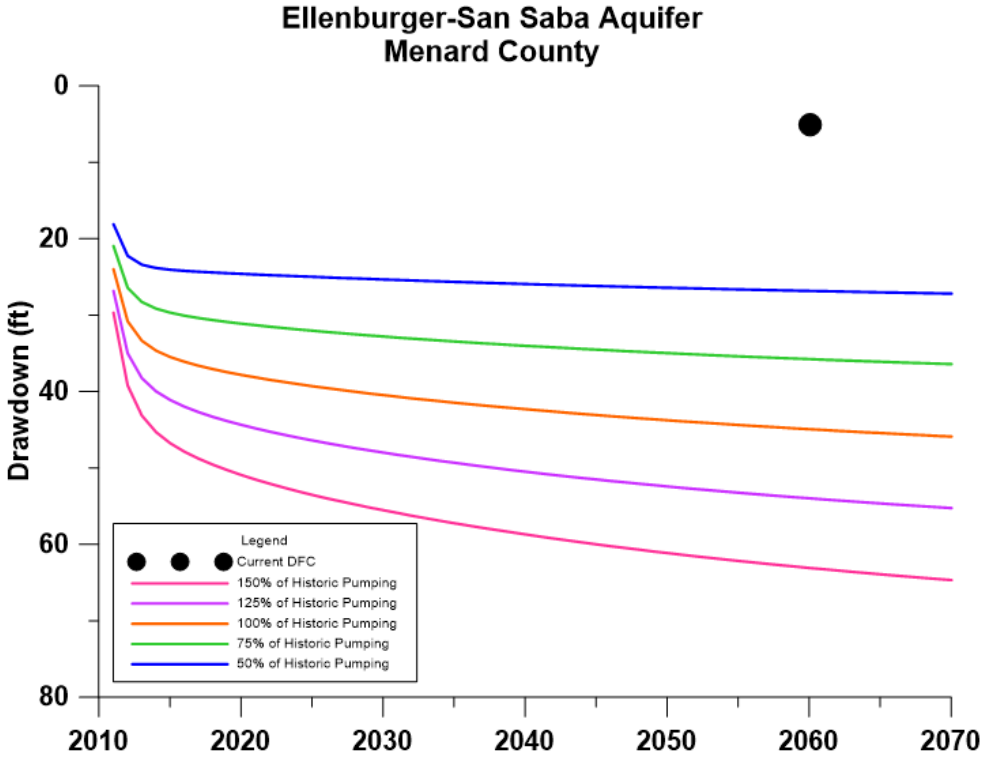
Menard County
Acre-Feet per Year
800
600
400
200
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year
Legend
Historic-TWDB
MAG
Historic-GAM
50% of Historic Pumping
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping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Menard County
Drawdown (ft)
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20
40
60
80
2010
2020
2030
2040
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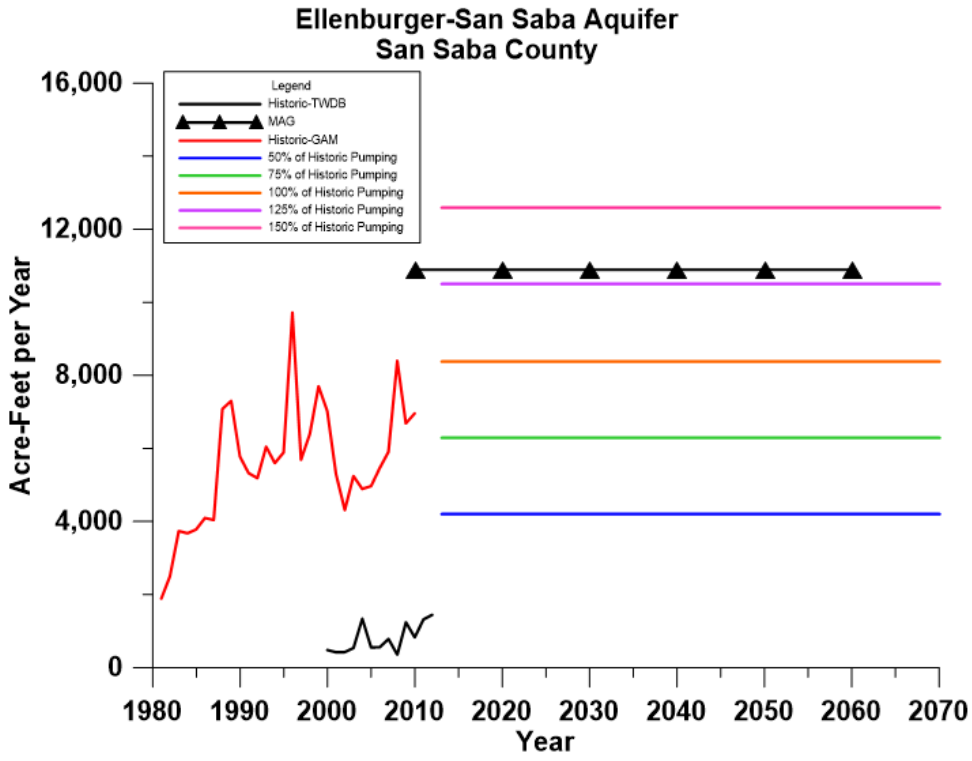
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping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San Saba County
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MAG
Historic-GAM
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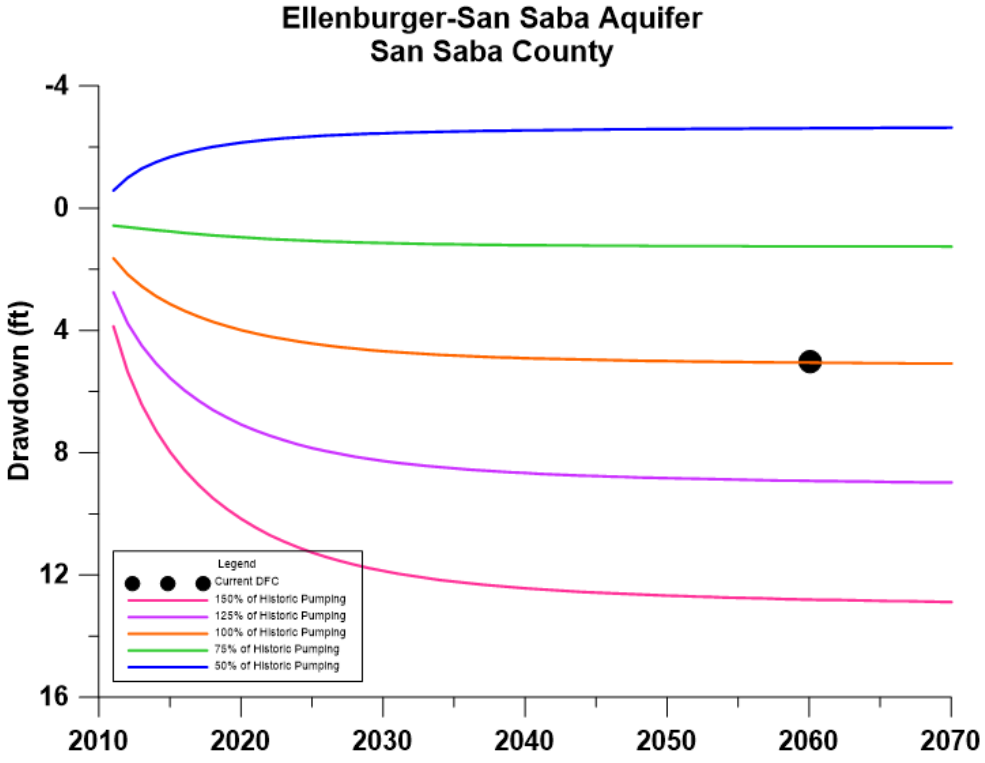
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping
Acre-Feet per Year
16,000
12,000
8,000
4,000
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year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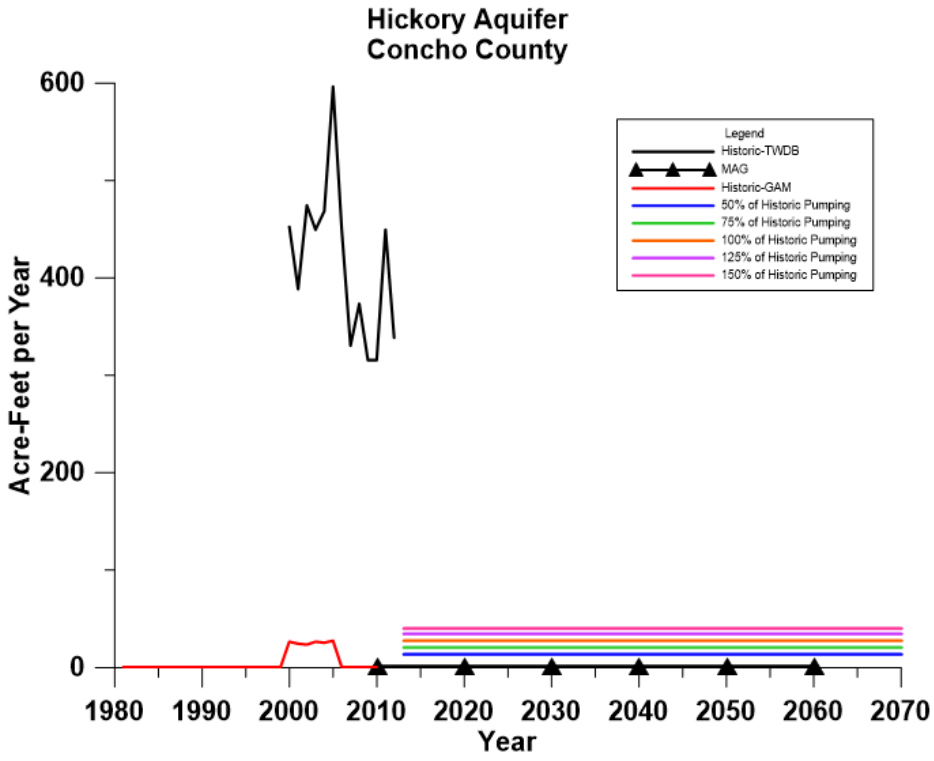
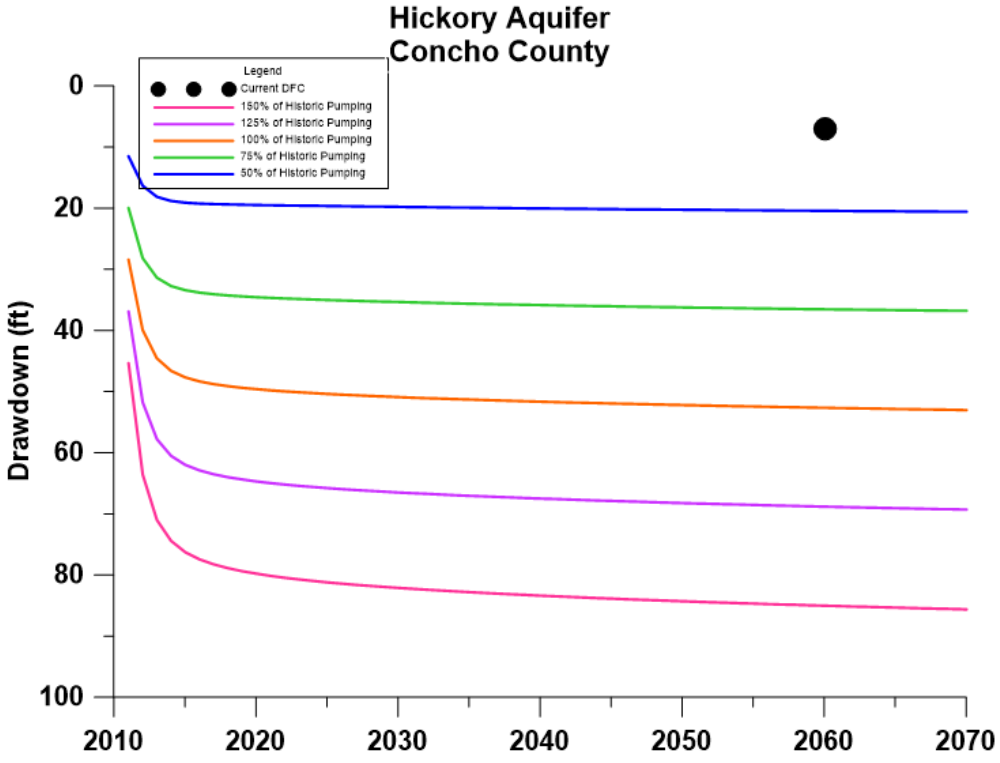
San Saba County
Drawdown (ft)
-4
0
4
8
12
16
2010
2020
2030
2040
2050
2060
2070
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping


Hickory Aquifer
Concho County
Acre-Feet per Year
600
400
200
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year
Legend
Historic-TWDB
MAG
Historic-GAM
50% of Historic Pumping
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping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Concho County
Drawdown (ft)
0
20
40
60
80
100
2010
2020
2030
2040
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Legend
Current DFC
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100% of Historic Pumping
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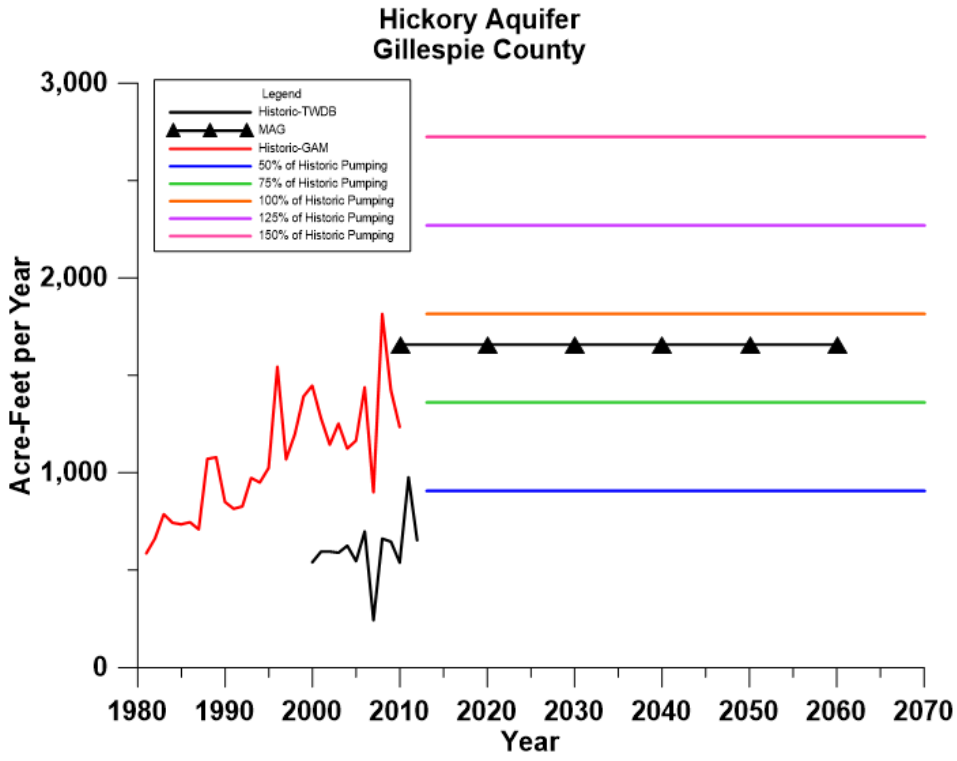
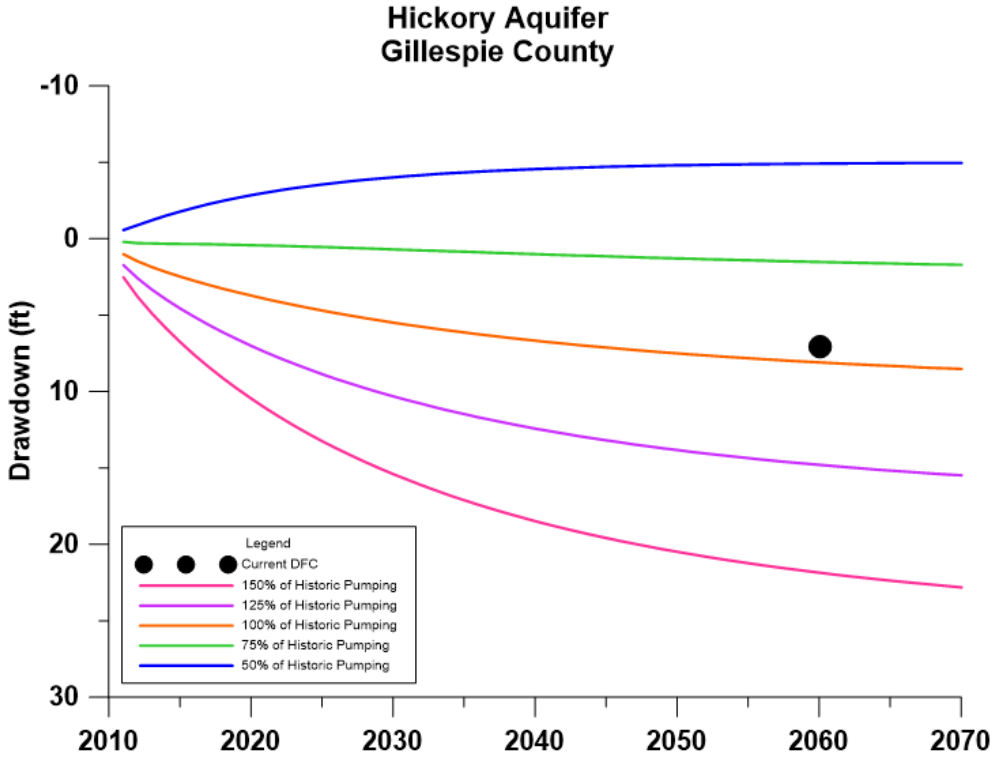
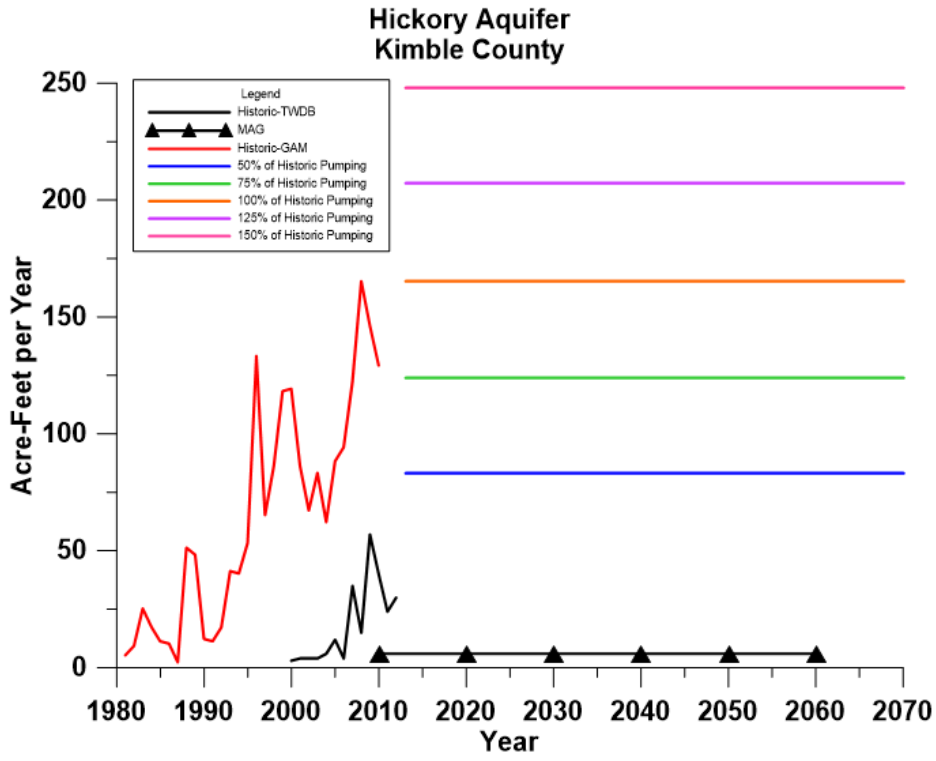
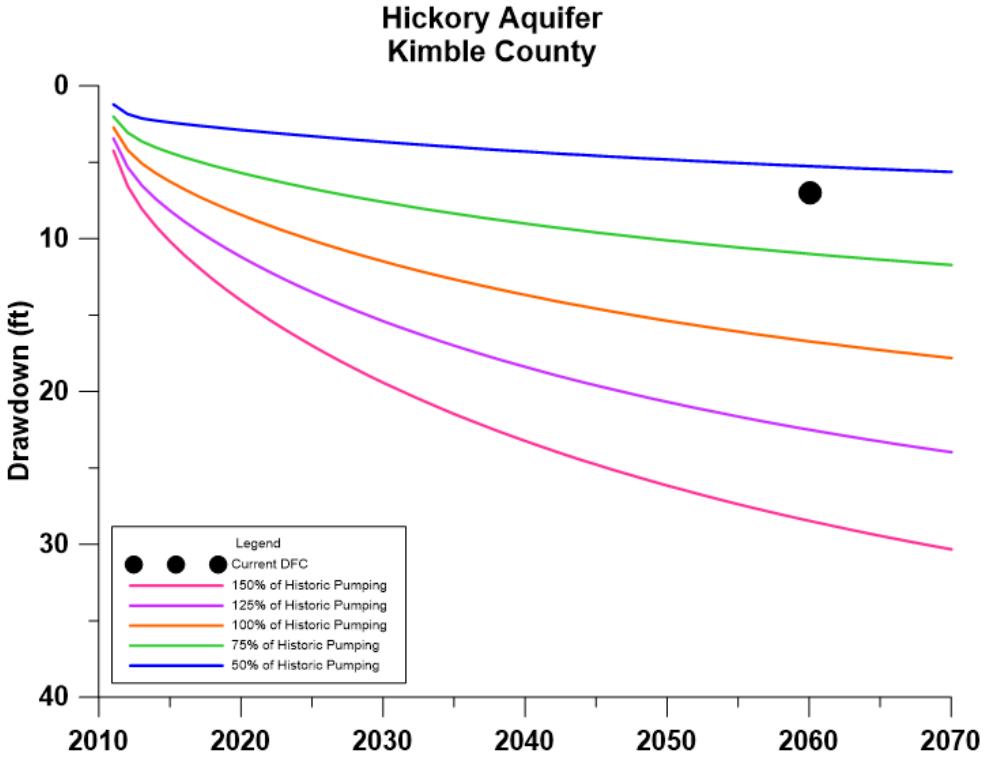
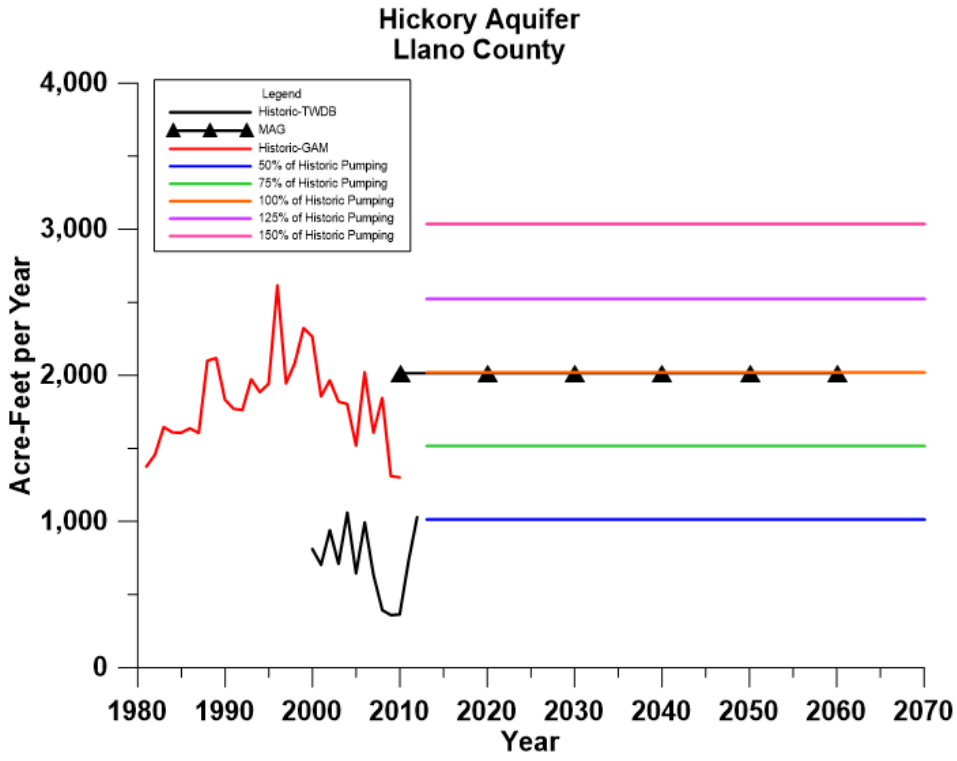
50% of Historic Pumping

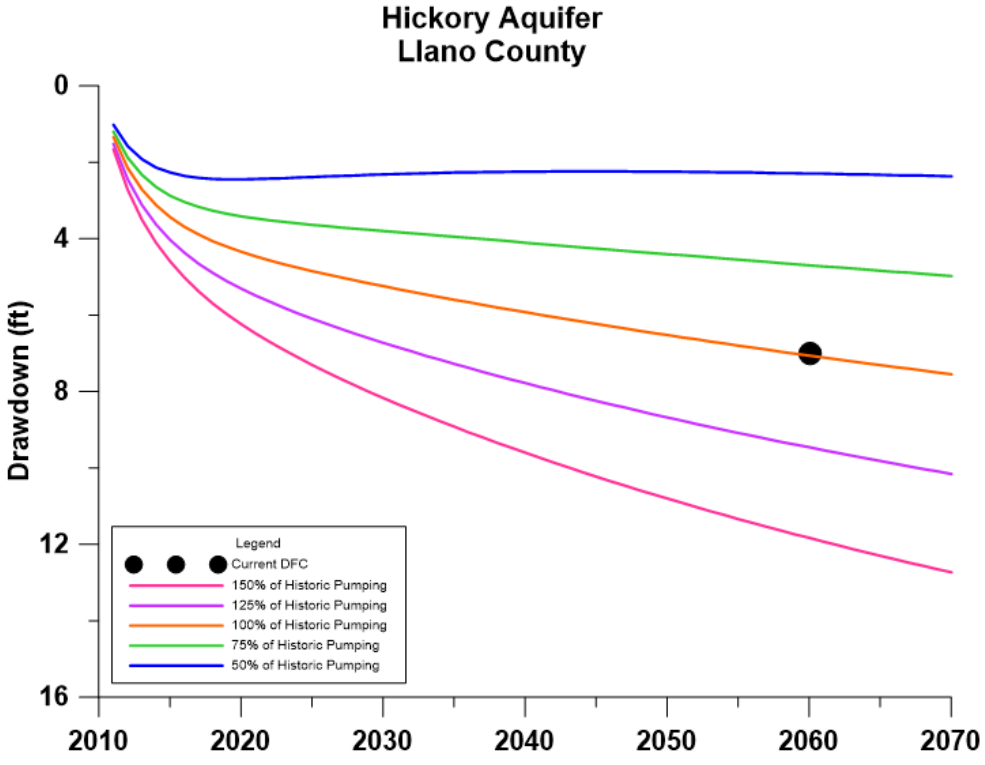

Hickory Aquifer
Gillespie County
Legend
Historic-TWDB
MAG
Historic-GAM
50% of Historic Pumping
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping
Acre-Feet per Year
3,000
2,000
1,000
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year

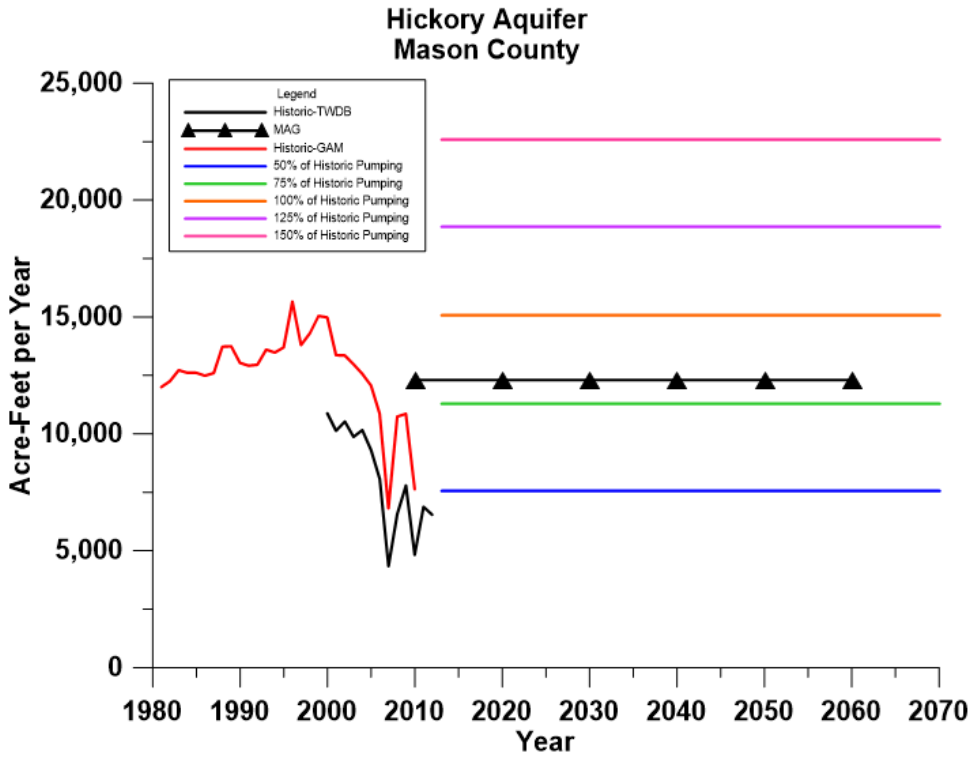

Hickory Aquifer
Gillespie County
Drawdown (ft)
-10
0
10
20
30
2010
2020
2030
2040
2050
2060
2070
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping

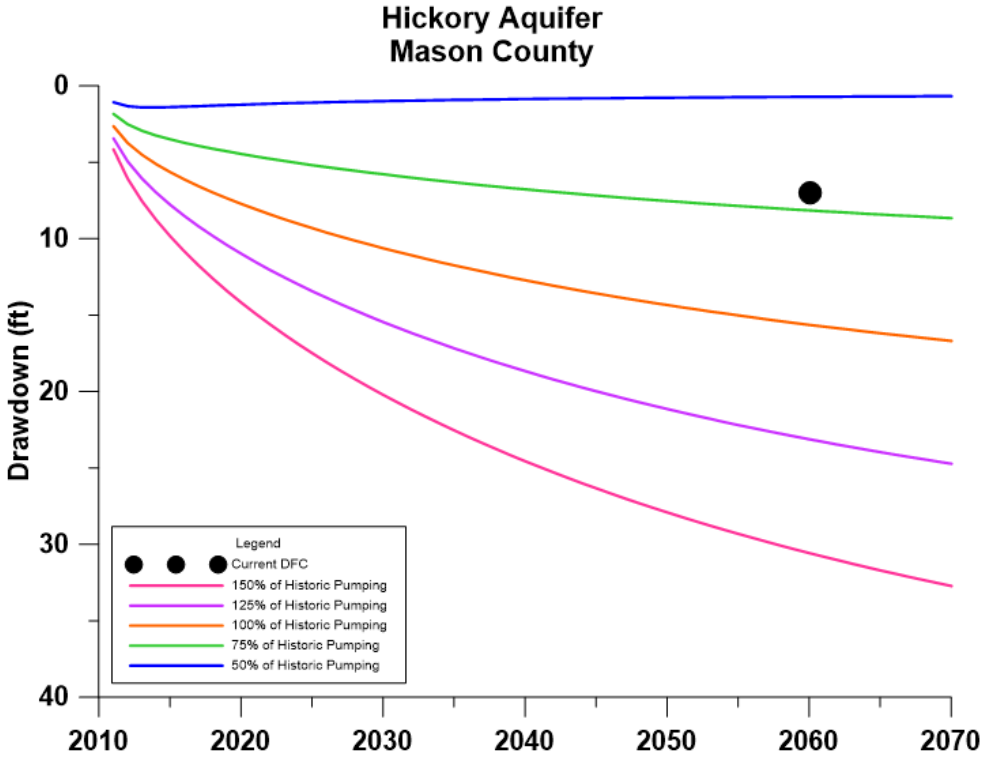

Hickory Aquifer
Kimble County
Legend
Historic-TWDB
MAG
Historic-GAM
50% of Historic Pumping
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping
Acre-Feet per Year
250
200
150
100
50
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year

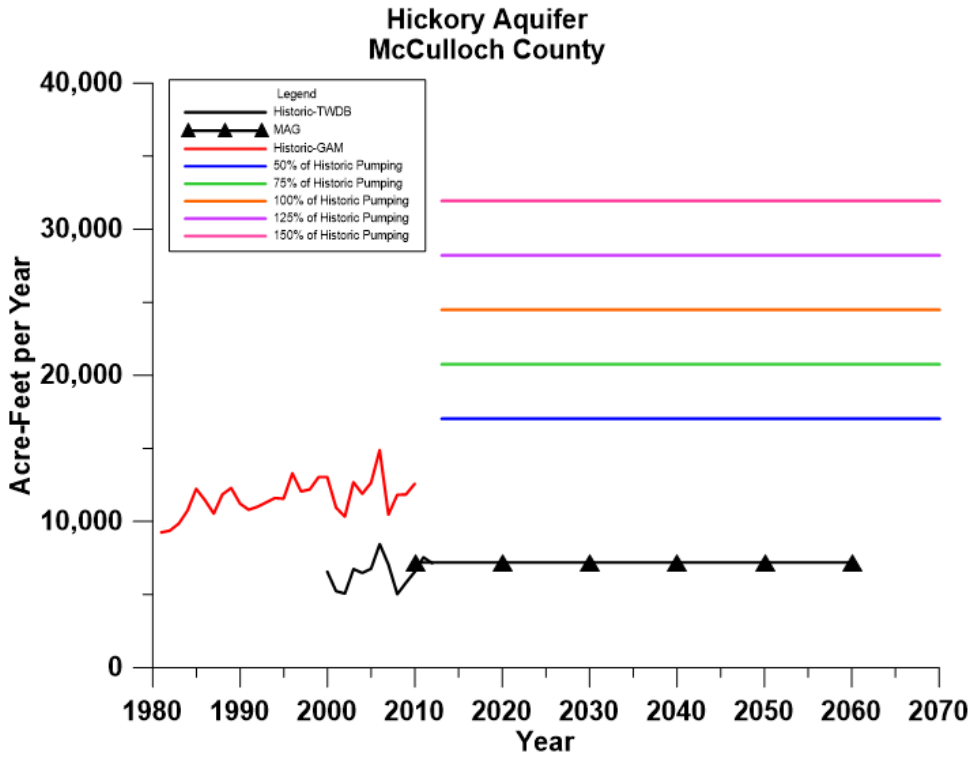

Hickory Aquifer
Kimble County
Drawdown (ft)
0
10
20
30
40
2010
2020
2030
2040
2050
2060
2070
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping

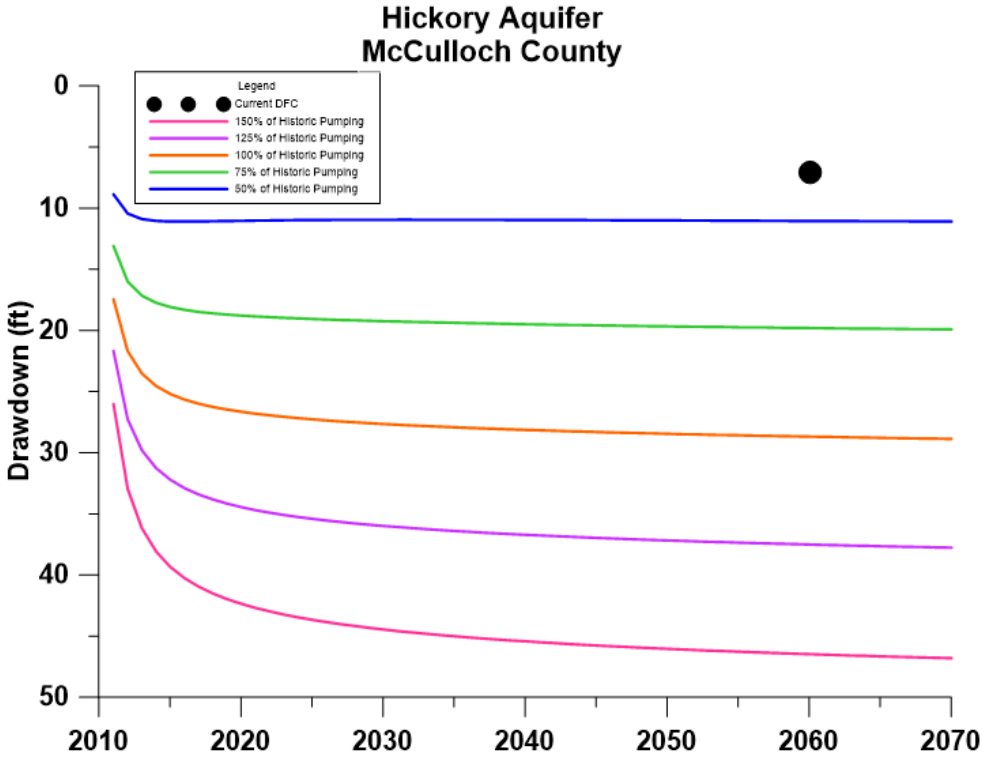

Hickory Aquifer
Llano County
Legend
Historic-TWDB
MAG
Historic-GAM
50% of Historic Pumping
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping
Acre-Feet per Year
4,000
3,000
2,000
1,000
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year

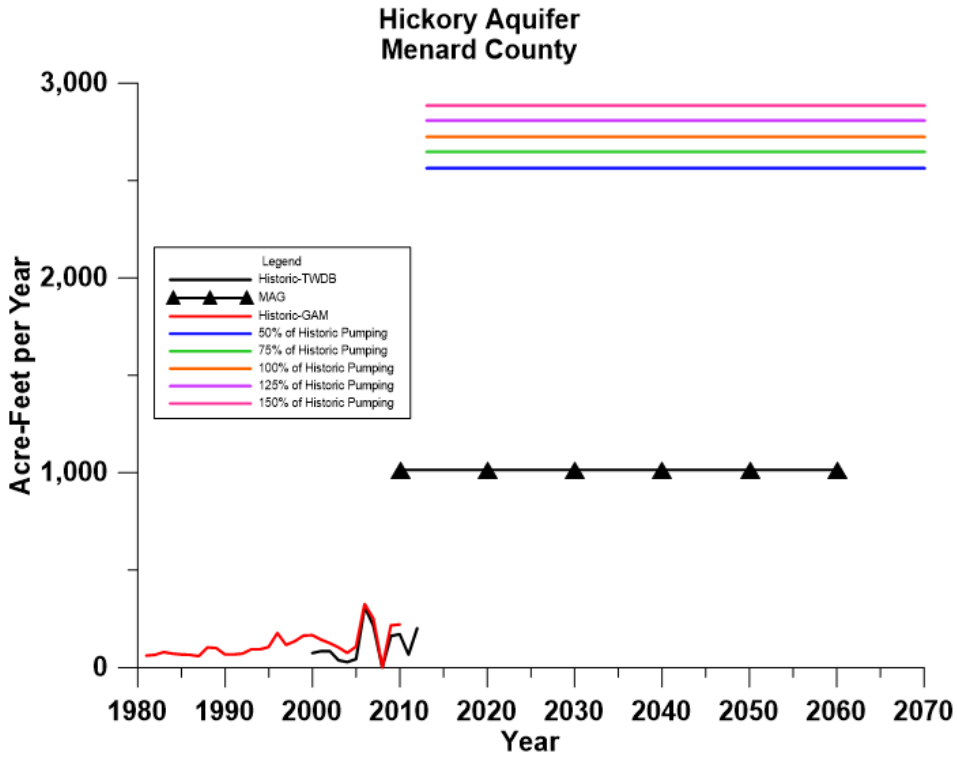

Hickory Aquifer
Llano County
Drawdown (ft)
0
4
8
12
16
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping
2010
2020
2030
2040
2050
2060
2070

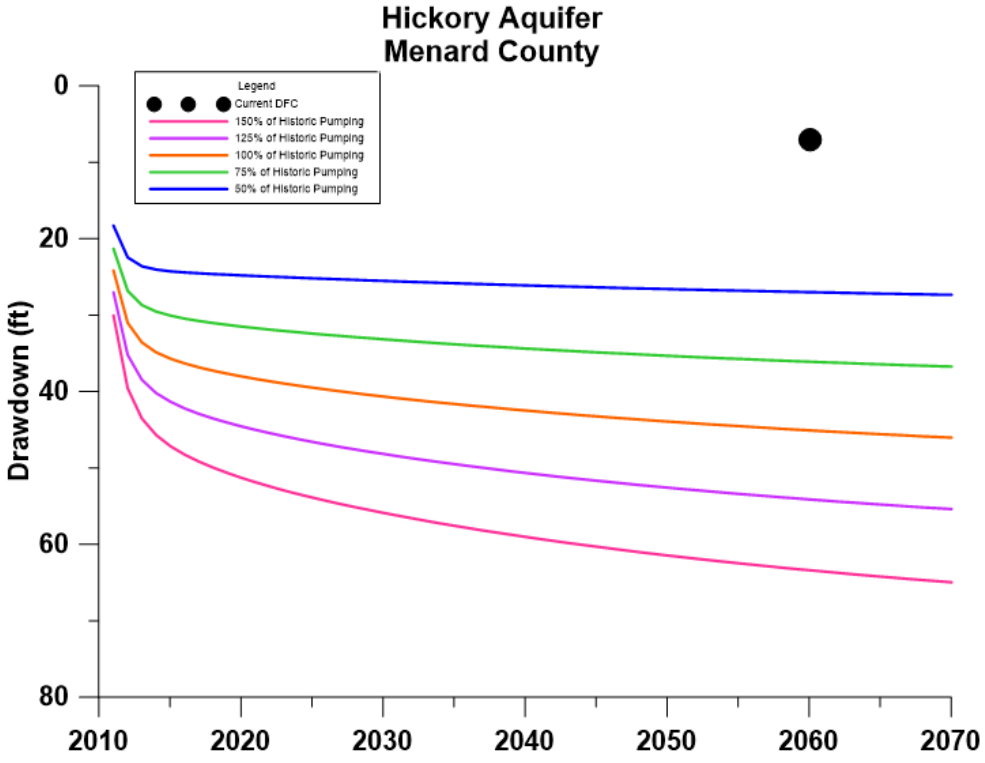

Hickory Aquifer
Mason County
Legend
Historic-TWDB
MAG
Historic-GAM
50% of Historic Pumping
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping
Acre-Feet per Year
25,000
20,000
15,000
10,000
5,000
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year

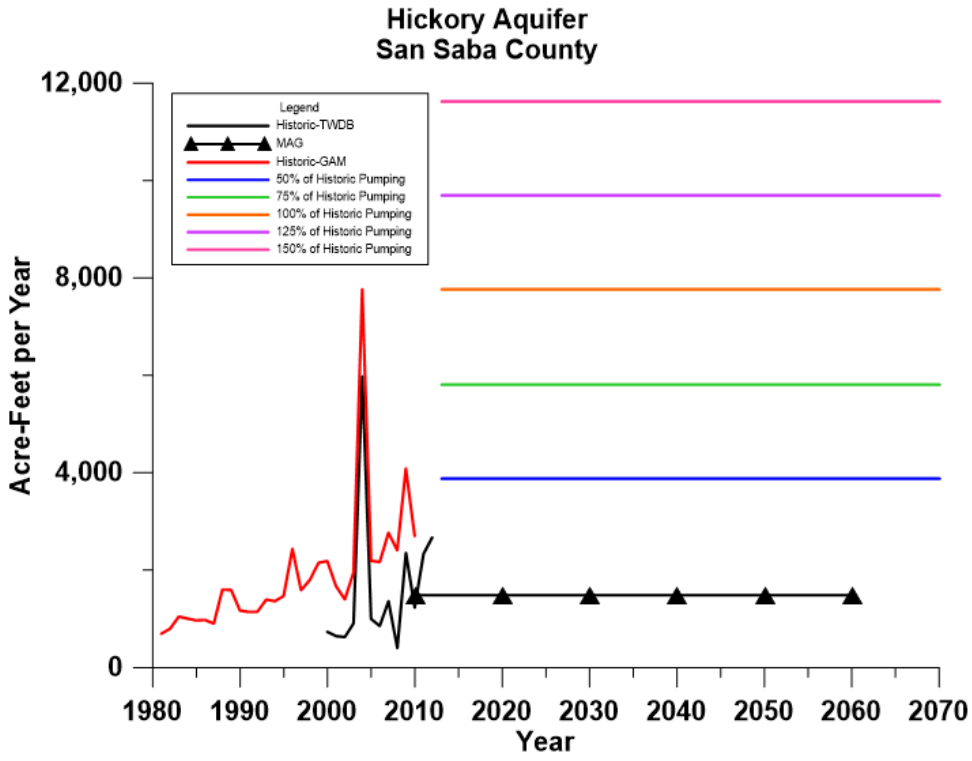

Hickory Aquifer
Mason County
Drawdown (ft)
0
10
20
30
40
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping
2010
2020
2030
2040
2050
2060
2070

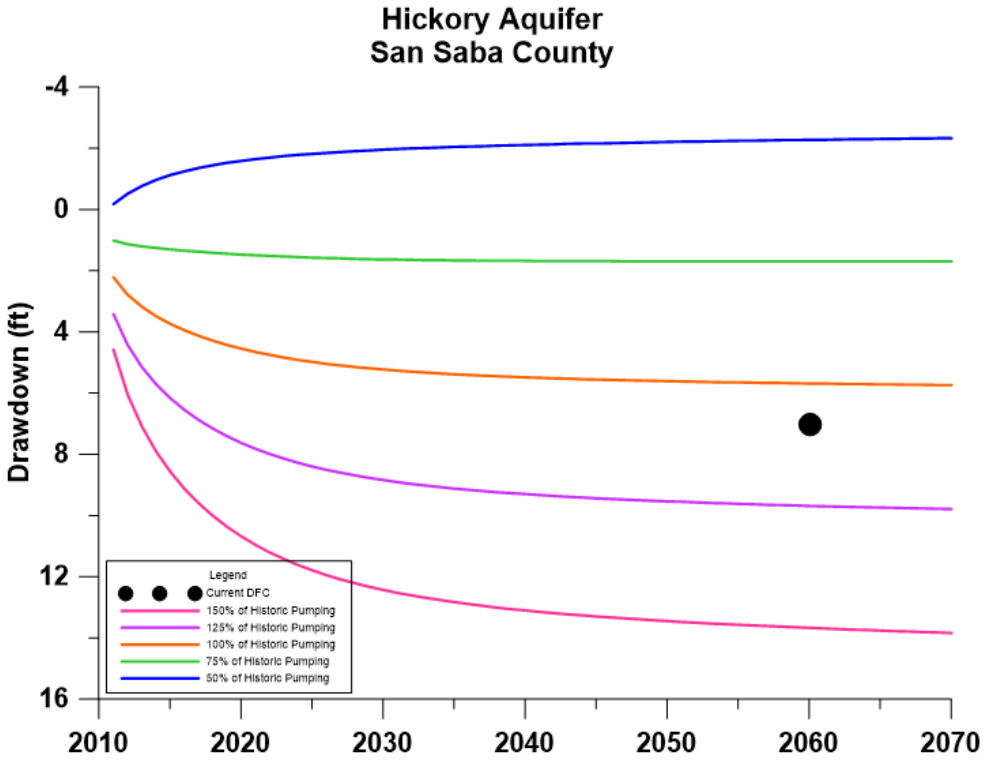

Hickory Aquifer
McCulloch County
Legend
Historic-TWDB
MAG
Historic-GAM
50% of Historic Pumping
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping
Acre-Feet per Year
40,000
30,000
20,000
10,000
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year


Hickory Aquifer
McCulloch County
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping
Drawdown (ft)
0
10
20
30
40
50
2010
2020
2030
2040
2050
2060
2070


Hickory Aquifer
Menard County
3,000
2,000
1,000
0
Acre-Feet per Year
Legend
Historic-TWDB
MAG
Historic-GAM
50% of Historic Pumping
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year


Hickory Aquifer
Menard County
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping
0
20
40
60
80
Drawdown (ft)
2010
2020
2030
2040
2050
2060
2070


Hickory Aquifer
San Saba County
Legend
Historic-TWDB
MAG
Historic-GAM
50% of Historic Pumping
75% of Historic Pumping
100% of Historic Pumping
125% of Historic Pumping
150% of Historic Pumping
Acre-Feet per Year
12,000
8,000
4,000
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year


Hickory Aquifer
San Saba County
Drawdown (ft)
-4
0
4
8
12
16
Legend
Current DFC
150% of Historic Pumping
125% of Historic Pumping
100% of Historic Pumping
75% of Historic Pumping
50% of Historic Pumping
2010
2020
2030
2040
2050
2060
2070