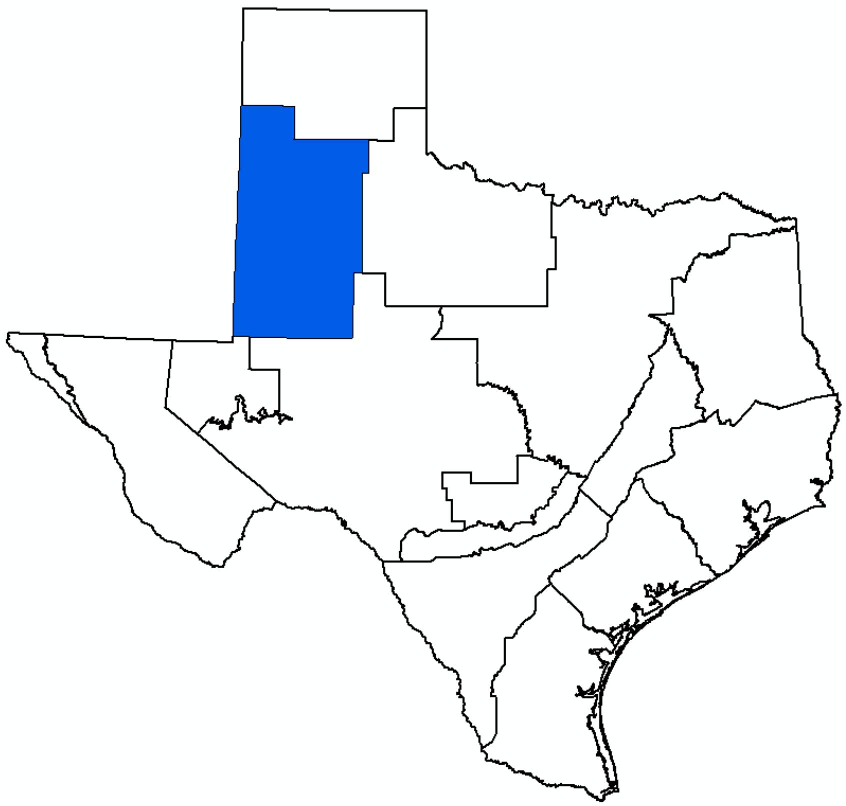
Explanatory Report
For Desired Future Conditions (Final)
Ogallala, Edwards-Trinity (High Plains), and Dockum Aquifers
Groundwater Management Area 2



William R. Hutchison, Ph.D., P.E., P.G.
Independent Groundwater Consultant
9305 Jamaica Beach
Jamaica Beach, TX 77554
512-745-0599
billhutch@texasgw.com

November 1, 2016

Explanatory Report for Desired Future Condition (Final)
Ogallala, Edwards-Trinity (High Plains), and Dockum Aquifers for
Groundwater Management Area 2

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:

William R. Hutchison, Ph.D., P.E. (96287), P.G. (286)

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

STATE OF TEXAS
WILLIAM RAY HUTCHISON
96287
LICENSED
PROFESSIONAL ENGINEER

William R Hutchison
11/1/16

STATE OF TEXAS
WILLIAM R. HUTCHISON
GEOLOGY
286
LICENSED
PROFESSIONAL GEOSCIENTIST

William R Hutchison
11/1/16

Table of Contents

List of Figures

List of Tables

List of Appendices

1.0 Groundwater Management Area 2

Groundwater Management Area 2 is one of sixteen groundwater management areas in Texas, and covers a large portion of the southern plains portion of west Texas (Figure 1).

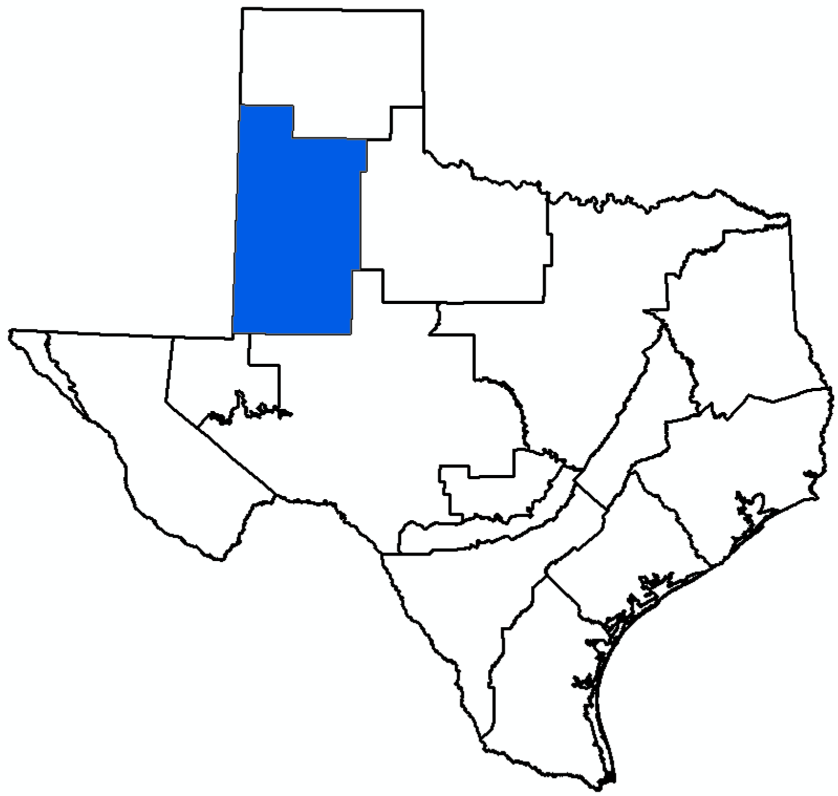


Figure 1. Groundwater Management Area 2

Groundwater Management Area 2 covers all or part of the following counties: Andrews, Bailey, Borden, Briscoe, Castro, Cochran, Crosby, Dawson, Deaf Smith, Floyd, Gaines, Garza, Hale, Hockley, Howard, Lamb, Lubbock, Lynn, Martin, Parmer, Swisher, Terry, and Yoakum (Figure 2).

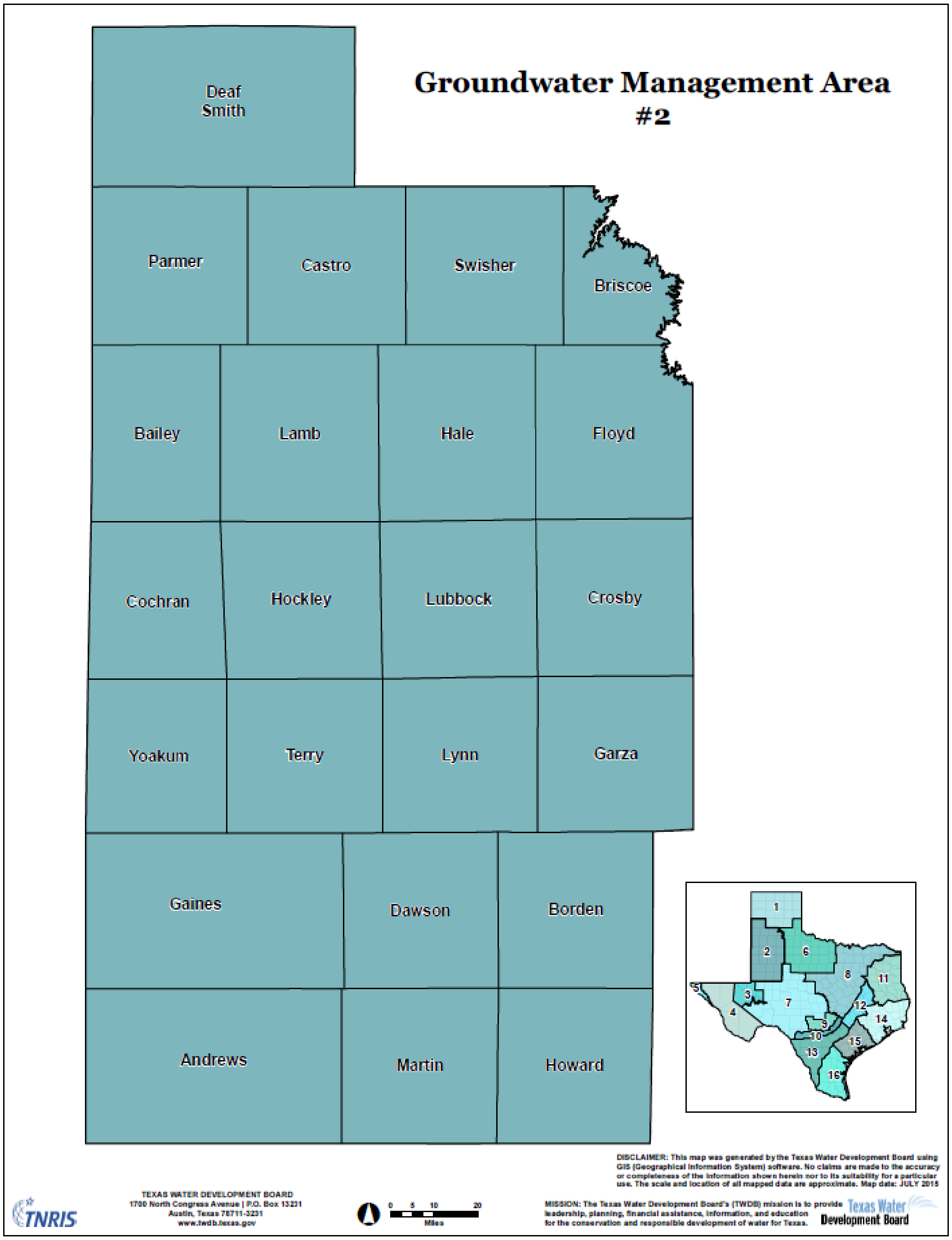


Figure 2. GMA 2 Counties (from TWDB)

There are seven groundwater conservation districts in Groundwater Management Area 2: Garza UWCD, High Plains UWCD No. 1, Llano Estacado UWCD, Mesa UWCD, Permian Basin, UWCD, Sandy Land UWCD, and South Plains UWCD.

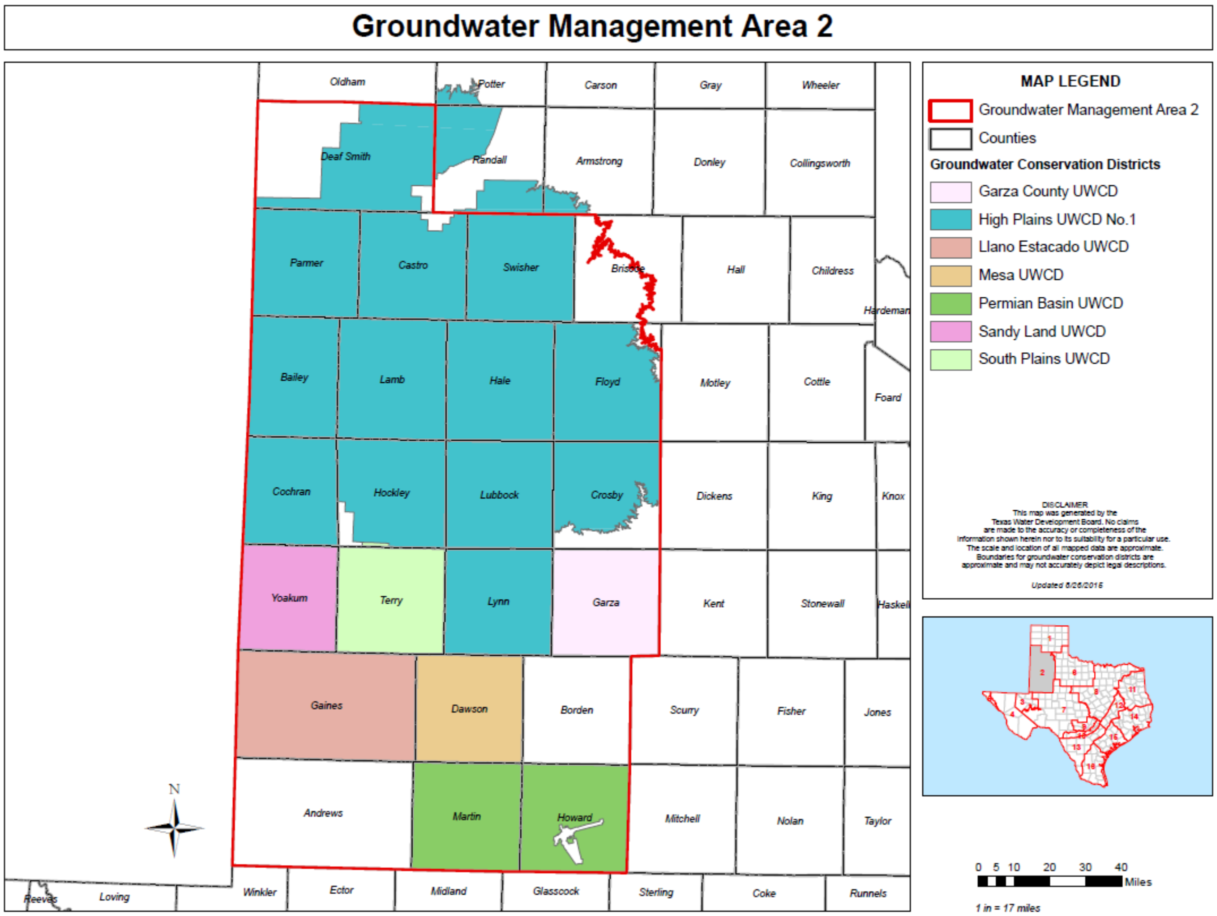


Figure 3. Groundwater Conservation Districts in GMA 2 (from TWDB)

2.0 Proposed Desired Future Condition

2.1 Background

In GMA 2, the Ogallala Aquifer and the underlying Edwards-Trinity (High Plains) Aquifer are managed together. Historic pumping has caused groundwater level declines to the point that individual well pumping rates in many areas of the Ogallala Aquifer have been reduced. In the future, pumping is expected to continue primarily for irrigation, and pumping rates will continue to decline as groundwater levels drop further. Water conservation techniques and irrigation technologies have advanced over the years, and are expected to improve in the future to mitigate the economic effects of lower well production.

In GMA 2, groundwater from the Dockum Aquifer has been pumped to relatively small amounts, largely due to poor water quality. However, increased pumping from the Dockum Aquifer is expected in the future as envisioned in the 2016 Region O Plan.

The Texas Water Code and the Texas Water Development Board require that desired future conditions be a quantified condition of the aquifer in the future. The desired future condition cannot be expressed in terms of how much can be pumped from an aquifer. In GMA 2, the continued declines in groundwater levels in the Ogallala Aquifer will result in reductions in pumping rates. Thus, the drawdown that will occur in the future and the pumping rates that will decline in the future are linked.

Once a desired future condition is adopted by the groundwater conservation districts in GMA 2, the Texas Water Development Board will use the new groundwater availability model to estimate the pumping that will achieve the desired future condition, or the modeled available groundwater (MAG).

2.2 2010 Desired Future Conditions

In 2010, GMA 2 adopted desired future conditions for the Ogallala and Edwards-Trinity (High Plains) aquifers that reflected the concept of managed decline of groundwater levels. In the High Plains UWCD area, the DFC was 50 percent of storage remaining after 50 years (50/50), and in the other areas of GMA 2, the DFC was expressed as a decadal decline rate. In the High Plains UWCD area, pumping was adjusted in the GAM simulations to hit 50 percent storage remaining in each county of the district. Although this approach treated every county within the district equally, it ignored the inherent variability of the aquifer in terms of saturated thickness and hydraulic conductivity. Future pumping in some High Plains UWCD counties was reduced to match the 50/50 goal, while other High Plains UWCD counties had artificial increases in simulated pumping above historic amounts simply to reach the 50/50 goal.

The adopted DFC within High Plains UWCD could be viewed as somewhat arbitrary in that a specific reduction in groundwater levels was selected without the ability to fully understand the relationship between declining groundwater levels and reduced pumping rates. The decision to adopt these DFCs was, to a degree, based on the limitations of the Groundwater Availability Model that was then used. The DFC was also based on a concept where equality in outcome was a higher consideration than a management approach that first considered the hydraulic characteristics of the aquifer, the hydraulics of pumping wells in an unconfined aquifer where groundwater levels are dropping, and the associated economics of pumping groundwater for irrigation in an area where groundwater levels are dropping.

2.3 Proposed Desired Future Conditions

The resolution adopting the desired future conditions is presented as Appendix A.

2.3.1 Ogallala and Edwards-Trinity (High Plains)

The proposed desired future condition for the Ogallala and Edwards-Trinity (High Plains) aquifers is average drawdown of between 23 and 27 feet for all of GMA 2. The drawdown is calculated from the end of 2012 conditions to the year 2070.

The drawdown is expressed as a range due to the link between future pumping and future rainfall. As documented in GMA 2 Technical Memorandum 15-01 and GMA 2 Technical Memorandum 16-01, historic pumping is higher in dry years than in wet years. Since most of the water use in GMA 2 from the Ogallala Aquifer is for irrigation, producers pump more groundwater in dry years than in normal or wet years. The simulations assumed that initial pumping rates in the future would be between 100 percent and 150 percent of 2012 pumping rates. Essentially, in average or wet years, initial annual pumping would be approximately the same as 2012 pumping rates. In dry years, initial annual pumping rates could be as high as 150 percent of 2012 pumping rates based on the variation of pumping rates in the recent past.

Figure 4 presents the pumping results from the simulation for Scenario 8 from GMA 2 Technical Memorandum 15-01, and Scenario 16 from GMA 2 Technical Memorandum 16-01, and Figure 5 presents the drawdown associated with Scenarios 8 and 16. Scenario 8 assumes initial future pumping rates are 100 percent of 2012 pumping rates (average and wet conditions), and Scenario 10 assumes initial future pumping rates are 150 percent of 2012 pumping rates (dry conditions). Please note that by about 2045, the total pumping is expected to be about the same.

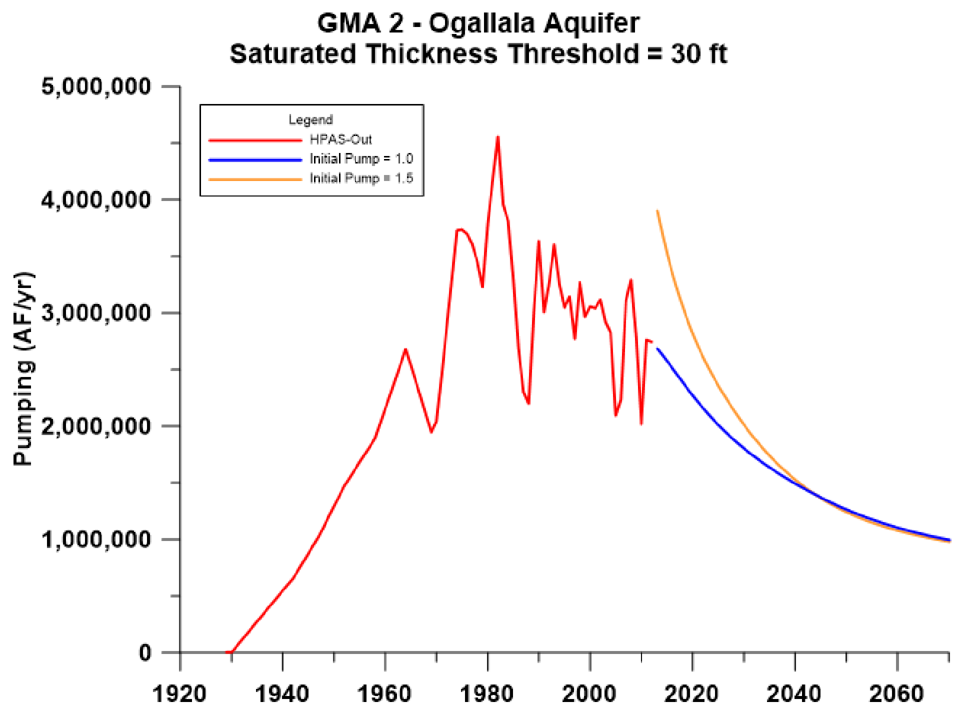


Figure 4. Historic and Simulated Future Pumping – Ogallala and Edwards-Trinity (High Plains) Aquifers in GMA 2

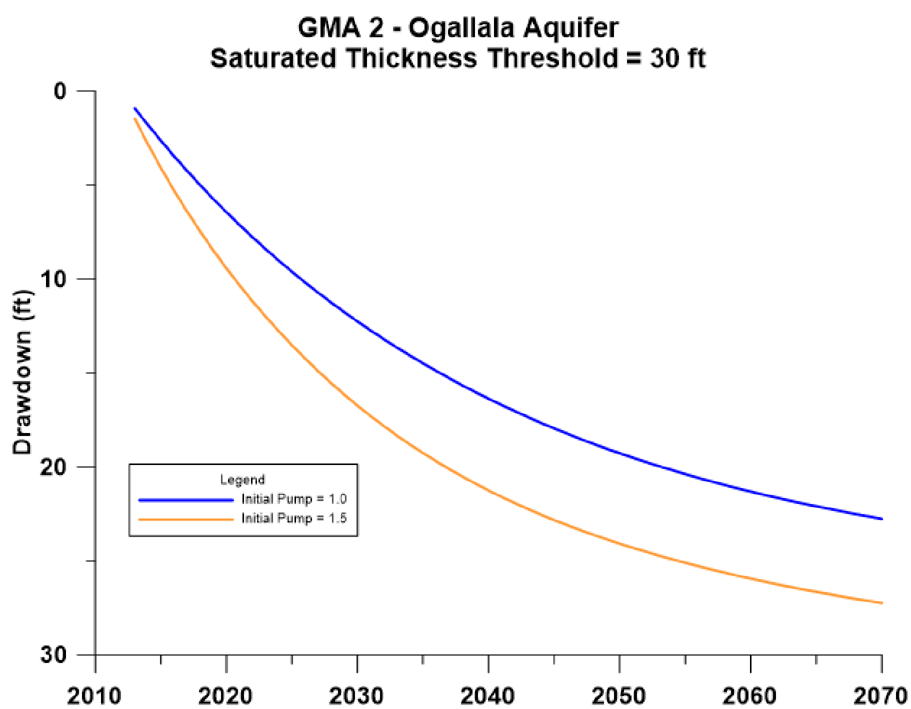


Figure 5. Simulated Average Drawdown – Ogallala and Edwards-Trinity (High Plains) Aquifers in GMA 2

2.3.2 Dockum Aquifer

The proposed desired future condition for the Dockum Aquifer is average drawdown of 27 feet for all of GMA 2. The drawdown is calculated from the end of 2012 conditions to the year 2070, and is based on Scenario 16 as documented in GMA 2 Technical Memorandum 16-01.

The average drawdown was calculated over the entire extent of the modeled area (not just the official aquifer boundary as defined by TWDB). Much of the area of the Dockum Aquifer in GMA 2 is brackish groundwater with salinity of over 3,000 mg/l total dissolved solids. Typically, TWDB does not recognize these areas as part of the official aquifer boundary. However, the groundwater conservation districts in GMA 2 have included these areas and expect that this resource will be developed in the future.

Historic and simulated future pumping from the Dockum Aquifer is presented in Figure 6, and the simulated drawdown associated with the simulated future pumping is presented in Figure 7.

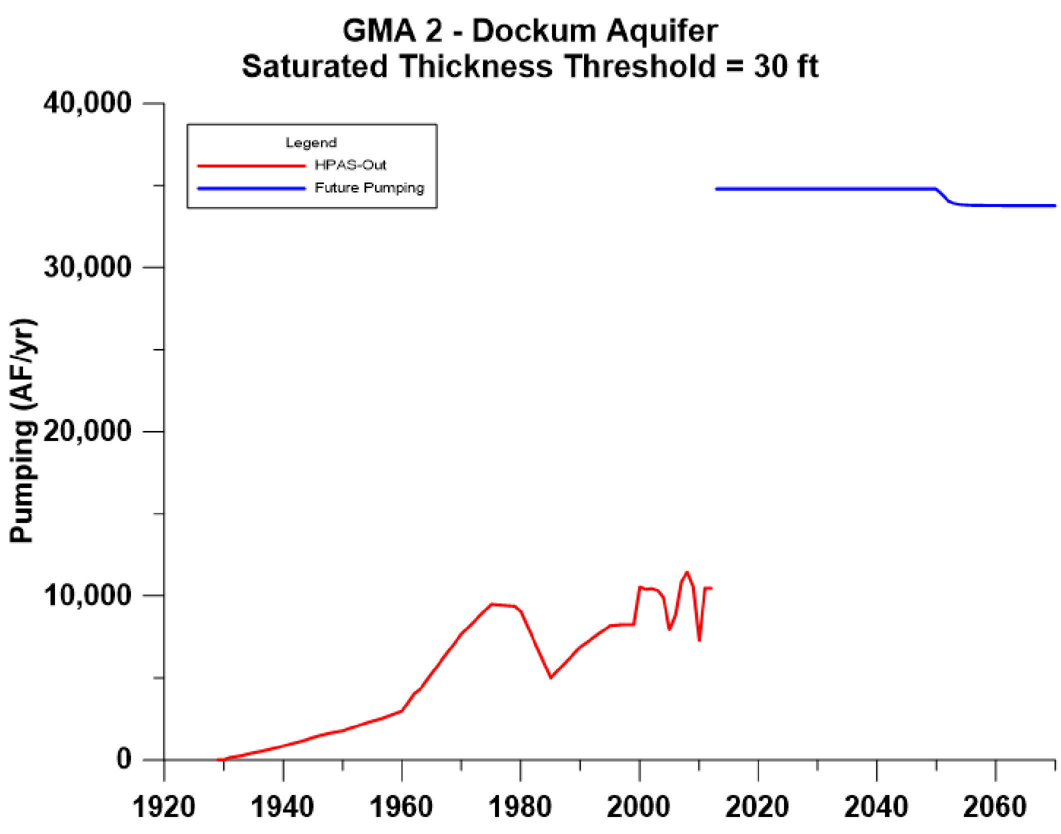


Figure 6. Historic and Simulated Future Pumping - Dockum Aquifer in GMA 2

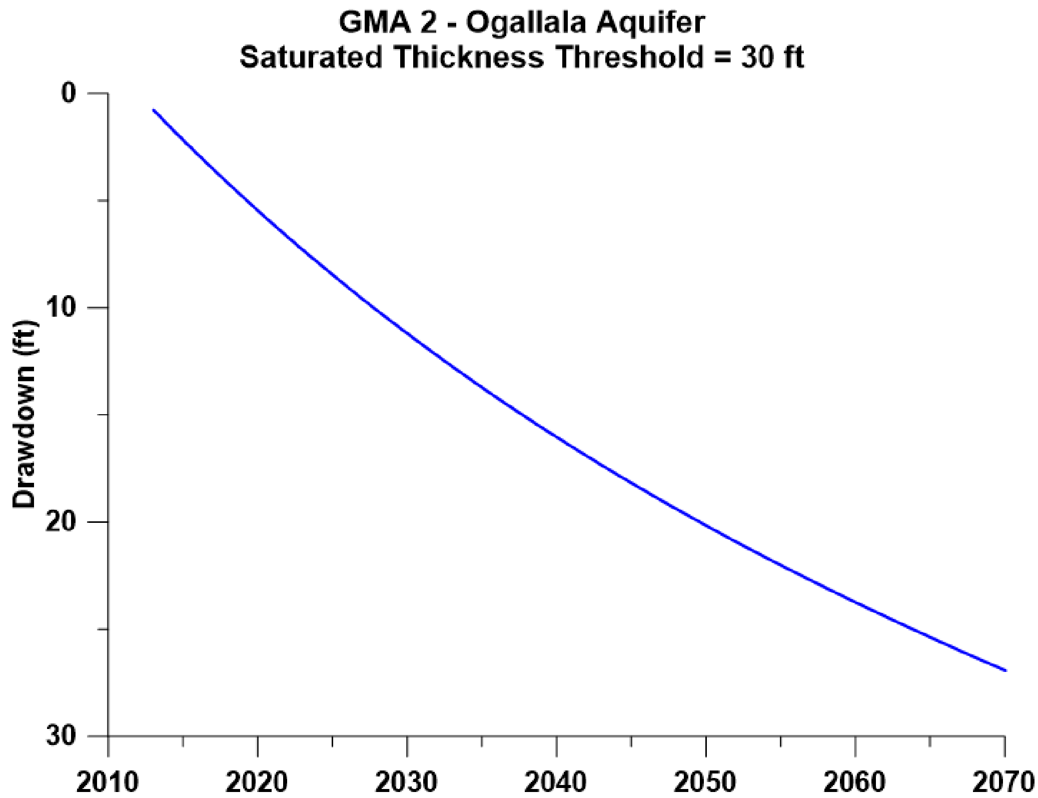


Figure 7. Simulated Average Drawdown - Dockum Aquifer in GMA 2

3.0 Policy Justification

As developed more fully in this report, the desired future condition was adopted after considering:

- Aquifer uses and conditions within Groundwater Management Area 2
- Water supply needs and water management strategies included in the 2012 State Water Plan
- Hydrologic conditions within Groundwater Management Area 2 including total estimated recoverable storage, average annual recharge, inflows, and discharge
- Other environmental impacts, including spring flow and other interactions between groundwater and surface water
- The impact on subsidence
- Socioeconomic impacts reasonably expected to occur
- The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 2 in groundwater as recognized under Texas Water Code Section 36.002
- The feasibility of achieving the desired future condition
- Other information

In addition, the desired future condition provides a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging, and prevention of water of groundwater in Groundwater Management Area 2.

As discussed earlier, the DFC that was adopted for the High Plains UWCD area of GMA 2 for the Ogallala Aquifer in 2010 was based on a concept where equality in outcome was emphasized more than a management approach that considered the hydraulic characteristics of the aquifer, the hydraulics of pumping wells in an unconfined aquifer where groundwater levels are dropping, and the associated economics of pumping groundwater for irrigation in an area where groundwater levels are dropping. The DFC that is described in this explanatory report puts more emphasis on aquifer hydraulics, economics, and property rights than were considered before, at least in High Plains UWCD area of GMA 2 for the Ogallala Aquifer.

4.0 Technical Justification

The desired future conditions were developed based, in part, on simulations of alternative scenarios of future pumping using the new Groundwater Availability Model (GAM) of the Ogallala, Edwards-Trinity (High Plains) and Dockum aquifers (Deeds and Jigmond, 2015). This model utilizes a recently released finite-difference code by the US Geological Survey that dynamically simulates the effect of declining groundwater levels on well production rates. Consequently, this model was used to evaluate the expected pumping rate declines in GMA 2 in the future under a wide variety of alternatives.

The new Groundwater Availability Model report was released in August 2015 (Deeds and Jigmond, 2015), and the files were made available by the TWDB in November 2015. GMA 2 completed 15 alternative simulations to understand the relationship between declining groundwater levels and reduced pumping rates. This analysis was documented in three technical memoranda (Hutchison, 2015a, 2015b, and 2015c). Based on the review of the results of Scenario 1 to 15, GMA 2 directed that a final simulation be completed (Scenario 16) as follows:

- GMA 2 requested that initial (beginning of 2013) Ogallala pumping be set to 150 percent of 2012 pumping and set the saturated thickness threshold to 30 feet to be consistent with the value used during the calibration period of the model. This essentially corresponds to the approach taken in Scenario 10 in GMA 2 Technical Memorandum 15-01. GMA 2 representatives also asked that results from the Ogallala and Edwards-Trinity (High Plains) aquifers be combined. This corresponds to layers 1 and 2 of the GAM in GMA 2. The DFC that was adopted for GMA 2 in 2010 combines the two aquifers, and the aquifers are managed as a single unit.

- Initial (2013) pumping for the Edwards-Trinity (High Plains) was set to either 150 percent of 2012 pumping or on the historic maximum depending on county. Scenario 10 used a consistent 150 percent of 2012 pumping, but historic pumping was higher in earlier years. GMA 2 representatives requested that pumping in those counties correspond to the historic maximum.

- Pumping in the Dockum Aquifer was also set to either 150 percent of 2012 pumping or historic maximum. In addition, areas with no historic pumping were assigned pumping. These counties typically fall outside the official TWDB boundaries of the Dockum Aquifer, but were included in the model.

The results for Scenario 16 are documented in Hutchison (2016). In reality, pumping withdrawals vary according to rainfall. This is observed in the model calibration plots, where cyclical patterns of withdrawal are evident. The range of expected pumping in the development of the desired future condition accounts for uncertainty and timing of drought periods.

As discussed in the documentation for Scenario 16, development of DFCs on a county scale based on the GAM is inappropriate based on a review of the results for several counties. The GAM provides reasonable results on a regional scale (i.e. GMA 2). Thus, the limitations of the GAM were used and acknowledged in the development of these proposed DFCs.

5.0 Factor Consideration

Section 36.108(d) of the Texas Water Code requires that groundwater conservation districts include documentation of how nine listed factors were considered prior to proposing a desired future condition, and how the proposed desired future condition impact each factor. This section of the explanatory report summarizes the information that the groundwater conservation districts used in its deliberations and discussions.

5.1 Aquifer Uses and Conditions

For the purposes of the development of a desired future condition, the groundwater conservation districts in Groundwater Management Area 2 considered the following in the category of aquifer uses (i.e. pumping):

- Estimates of 1930 to 2012 input and output pumping from the GAM (Deeds and Jigmond, 2015)
- Estimates of pumping from 1980 and 1984 to 2013 from the TWDB groundwater pumping database
- Current modeled available groundwater for 2010 to 2060
- Estimates of pumping from the initial predictive simulation that was completed for GMA 1 as part of the contract to develop the GAM for 2013 to 2070

These estimates were summarized, presented and discussed at the April 29, 2015 meeting of GMA 2. The estimates associated with the GAM (historic and future) were based on the preliminary model, and much of the discussion was preparing comments for the draft model.

The discussion of these estimates also included comparing the historic pumping to the current modeled available groundwater, and how the new GAM was capable of better simulating the expected continued declines in pumping rates associated with declining groundwater levels in the Ogallala Aquifer. Finally, the discussion reviewed the inherent problems of establishing a 50/50 DFC given the historic aquifer uses, expected future uses, and aquifer conditions across GMA 2.

The presentation that was used during the April 29, 2015 meeting is included in this explanatory report as Appendix B.

5.2 Water Supply Needs and Water Management Strategies

The 2016 Region O Plan lists recommended water management strategies, some of which are for local groundwater development. The underlying basis for the proposed DFC is that pumping in the Ogallala Aquifer would increase to 150 percent of estimated 2012 pumping in 2013. The elevated level of 2012 pumping represents a scenario of increased usage during drought conditions. Future reductions in pumping through 2070 would be as a result of declining groundwater levels and the associated change in the hydraulics of pumping wells.

The recommended strategies are generally relatively small amounts of increased groundwater pumping in the Ogallala of up to about 2,600 AF/yr (most are a few hundred acre-feet per year). The Ogallala DFC is consistent with these strategies.

The recommended strategies also include the development of brackish groundwater. The Dockum DFC explicitly included increased pumping for the Dockum to accommodate these strategies, including areas of the Dockum that are not currently within the official boundaries of the Dockum Aquifer (as defined by TWDB) due to poor water quality.

5.3 Hydrologic Conditions within Groundwater Management Area 2

As required by statute, the groundwater conservation districts in Groundwater Management Area 2 considered total estimated recoverable storage, average annual recharge, inflows, and discharge prior to adopting a proposed desired future condition.

5.3.1 Total Estimated Recoverable Storage (TERS)

As required by statute, the Texas Water Development Board provided the groundwater conservation districts in Groundwater Management Area 2 with estimates of total recoverable storage (Kohlrenken and others, 2013). The report is included as Appendix C.

The TWDB storage estimates were developed based on the hydrogeologic framework and aquifer parameters of the old GAMs. The release of the new GAM (Deeds and Jigmond, 2015) postdated the report. In working with storage volumes in the simulation results, the new GAM was used.

It is also noteworthy that the TERS estimates were taken from the last year of model calibration. For the Ogallala and Edwards-Trinity (High Plains), the TERS calculation was year 2000. The Dockum TERS estimates are based on 1997 data.

5.3.2 Average Annual Recharge, Inflows and Discharge

The average groundwater budget for Groundwater Management Area 2 for the Ogallala and Edwards-Trinity (High Plains) aquifers based on the calibrated GAM (Deeds and Jigmond, 2015) for the historic period 1930 to 2012 alongside the groundwater budget for the proposed DFC from 2013 to 2070 is summarized in Table 1.

The average groundwater budget for Groundwater Management Area 2 for the Dockum Aquifer based on the calibrated GAM (Deeds and Jigmond, 2015) for the historic period 1930 to 2012 alongside the groundwater budget for the proposed DFC from 2013 to 2070 is summarized in Table 2.

Time-series plots of each component of the water budget for all years are presented in Hutchison (2016), the documentation for Scenario 16 upon which the DFCs are based. These graphs provide context to the changes in each component over time and as a result of changes to pumping.

Table 1. Groundwater Budget for the Ogallala and Edwards-Trinity (High Plains) Aquifers in Groundwater Management Area 2

Inflow Component	1930 to 2012 Average Flow (AF/yr)	2013 to 2070 Average Flow Under the DFC (AF/yr)
Recharge from Precipitation	334,028	679,308
Inflow from Surface Water	48,907	94,752
Inflow from New Mexico	9,261	12,385
Inflow from GMA 1		2,283
Inflow from GMA 6		491
Vertical Inflow from Dockum		10,959
Total Inflow	392,196	800,178

Outflow Component	1930 to 2012 Average Flow (AF/yr)	2013 to 2070 Average Flow Under the Proposed DFC (AF/yr)
Pumping	2,234,585	1,794,502
Springs	53,678	34,857
Evapotranspiration	17,022	8,832
Outflow to GMA 1	9,907	
Outflow to GMA 3	210	208
Outflow to GMA 6	4,504	
Outflow to GMA 7	1,757	2,432
Vertical Outflow to Dockum	3,955	
Total Outflow	2,325,618	1,840,832

Inflow - Outflow	-1,933,421	-1,040,654
Storage Change from Model	-1,933,422	-1,040,654
Model Error	1	0

Table 2. Groundwater Budget for the Dockum Aquifer in Groundwater Management Area 2

Inflow Component	1930 to 2012 Average Flow (AF/yr)	2013 to 2070 Average Flow (AF/yr)
Recharge from Precipitation	14,097	19,982
Vertical Inflow from Ogallala	3,955	
Total Inflow	18,052	19,982

Outflow Component	1930 to 2012 Average Flow (AF/yr)	2013 to 2070 Average Flow (AF/yr)
Pumping	5,442	34,485
Springs	4,337	4,774
Discharge to Surface Water	12,612	14,830
Evapotranspiration	6,307	7,293
Outflow to New Mexico	258	289
Outflow to GMA 1	1,817	1,848
Outflow to GMA 3	64	65
Outflow to GMA 6	1,447	1,031
Outflow to GMA 7	640	673
Vertical Outflow to Ogallala		10,959
Total Outflow	32,924	76,249

Inflow - Outflow	-14,872	-56,266
STOR	-14,871	-56,263
Model Error	-1	-3

5.4 Other Environmental Impacts, Including Spring Flow and Other Interactions between Groundwater and Surface Water

The evaluation of all water budget components was discussed in Section 5.3.2 above.

5.5 Subsidence

Subsidence has not been an issue historically in these aquifers in GMA 2.

5.6 Socioeconomic Impacts

Texas Tech and Texas AgriLife Extension Services published a report in 2011 that assessed the economics of proposed groundwater management strategies in Groundwater Management Area 2 (Weinheimer and others, 2011). This report stated that the declining saturated thickness would result in 33 percent fewer irrigated acres over the next 50 years as the region converts to dryland production. The study also found that the aggregate economic impacts from the selected water management policies implemented by the districts will have "very little negative impact relative to the baseline scenario".

Please note that this conclusion was based on the 2010 DFC, which included a 50/50 concept for the High Plains UWCD area of GMA 2. It was noted in the report that it was possible that individual farms could be impacted by the "proposed strategies", especially those with very high wells yields and the ability to apply irrigation water over a long period of time.

The areas that would be impacted include those where pumping is artificially and arbitrarily limited to achieve an equal 50/50 condition across the entire area. The concept of equal outcomes was specifically rejected as part of the development of the proposed DFC for the Ogallala discussed in this explanatory report. The new DFC implicitly recognizes the variability of the aquifer (e.g. saturated thickness and well yields), and recognizes that differences in pumping in various areas of GMA 2 are, in part, the result of the economics of pumping groundwater for beneficial use.

Thus, the limited economic impacts found in Weinheimer and others (2011) are substantially eliminated by this proposed DFC.

5.7 Impact on Private Property Rights

The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 2 in groundwater are recognized under Texas Water Code Section 36.002.

The DFC is consistent with protecting property rights. As discussed in the socioeconomic impacts discussion in Section 5.6, under the 50/50 concept, Weinheimer and others (2015) found a limited condition where there could be impacts as the result of the imposition of an equal outcome management concept. The DFC has eliminated that concern since the DFC implicitly recognizes that the aquifer conditions vary across the region, and that property rights are best protected when the pumping is limited only by the physics of groundwater flow and by the economics of pumping groundwater for a beneficial use.

5.8 Feasibility of Achieving the Desired Future Condition

Groundwater levels are routinely monitored by the districts and by the TWDB in GMA 2. Evaluating the monitoring data is a routine task for the districts, and the comparison of these data with the model results that were used to develop the DFCs is covered in each district's management plan. These comparisons will be useful to guide the update of the DFCs that are required every five years.

5.9 Other Information

GMA 2 did not consider any other information in developing the DFCs.

6.0 Discussion of Other Desired Future Conditions Considered

During the development of the proposed DFCs, a total of sixteen GAM simulations were evaluated and considered. As described earlier, the initial fifteen simulations were used to develop Scenario 16, which was the basis for the proposed DFC.

Also considered was continuation of a 50/50 concept. However, as described in more detail above, this approach was rejected in favor of proposed DFCs that implicitly considered aquifer conditions and aquifer variability, economics of pumping groundwater in light of declining groundwater levels, and property rights over an arbitrary approach that emphasizes equal outcomes on a county scale.

7.0 Discussion of Other Recommendations

Public comments were invited and each district held a public hearing on the proposed desired future condition as follows:

Groundwater Conservation District	Date of Public Hearing	Number of Comments Received
Garza County UWCD	July 12, 2016	None
High Plains Water District	June 14, 2016 (Amarillo) and July 12, 2016 (Lubbock)	1 oral (in Lubbock), 1 written
Llano Estacado UWCD	July 14, 2016	None
Mesa UWCD	August 17, 2016	None
Permian Basin UWCD	June 16, 2016	None
Sandy Land UWCD	June 8, 2016	None
South Plains UWCD	July 5, 2016	None

The one oral comment received at the High Plains Water District meeting in Lubbock simply was to express appreciation in the approach in developing the proposed desired future condition.

The one written comment received from James Adams was essentially a comment on property rights and the constitutionality of groundwater regulation. This comment was not specifically on the proposed desired future condition beyond the assertion that any such process "abolishes the private character of the land by converting the private use of the land to state agency purposes of preserving the aquifer".

As developed in this explanatory report, the desired future condition actually moves away from the previous desired future conditions which contemplated arbitrary restrictions of pumping in some areas in order to achieve equal outcomes (i.e. 50/50) on a county scale.

The new desired future condition approached the issue from a practical and more business-like approach by leveraging the features of the new Groundwater Availability Model. The results showed the ineffectiveness of pumping restrictions in the context of pumping rates in the year 2070. The analysis showed that whether pumping increases in the short term or is arbitrarily reduced in the near future through regulation, the declining water levels that have been observed over the past several decades would continue, and result in reduced pumping rates.

8.0 References

Deeds, N.E. and Jigmond, M., 2015. Numerical Model Report for the High Plains Aquifer System Groundwater Availability Model. Prepared by INTERA Incorporated for Texas Water Development Board, 640p.

Hutchison, W.R., 2015a. Ogallala Aquifer: Initial Predictive Simulations. GMA 2 Technical Memorandum 15-01, Draft 1, Prepared for Groundwater Management Area 2. December 22, 2015, 61p.

Hutchison, W.R., 2015a. Ogallala Aquifer: Initial Predictive Simulations. GMA 2 Technical Memorandum 15-01, Draft 1, Prepared for Groundwater Management Area 2. December 22, 2015, 61p.

Hutchison, W.R., 2015b. Edwards-Trinity (High Plains) Aquifer: Initial Predictive Simulations. GMA 2 Technical Memorandum 15-02, Draft 1, Prepared for Groundwater Management Area 2. December 22, 2015, 26p.

Hutchison, W.R., 2015c. Dockum Aquifer: Initial Predictive Simulations. GMA 2 Technical Memorandum 15-03, Draft 1, Prepared for Groundwater Management Area 2. December 22, 2015, 27p.

Kohlrenken, W., Boghici, R., and Jones, I., 2013, GAM Task 13-026: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 2. Texas Water Development Board, Groundwater Resources Division, Groundwater Availability Modeling Section, September 19, 2013, 26p.

Weinheimer, J. Johnson, P., Johnson, J, Guerrero, B., and Amosson, S., 2011. Economic Assessment of Proposed Groundwater Management Strategies in Groundwater Management Area 2. Final Report submitted 8/31/2011, Department of Agricultural and Applied Economics, Texas Tech University and Texas AgriLife Extension Service, 73p.

Appendix A

Desired Future Conditions Resolution

Groundwater Management Area 2
Resolution 16-01

Desired Future Conditions for the Ogallala, Edwards-Trinity (High Plains), and Dockum Aquifers in Groundwater Management Area 2

WHEREAS, Groundwater Conservation Districts (GCDs) located within or partially within Groundwater Management Area 2 (GMA 2) are required under Chapter 36.108, Texas Water Code to conduct joint planning and designate the Desired Future Conditions of aquifers within GMA 2 and;

WHEREAS, the Board Presidents or their Designated Representatives of GCDs in GMA 2 have met in various meetings and conducted joint planning in accordance with §36.108, Texas Water Code since September 2010; and

WHEREAS, the GMA 2 committee has received and considered Groundwater Availability Model runs and other technical advice regarding local aquifers, hydrology, geology, recharge characteristics, the nine factors set forth in §36.108(d) of the Texas Water Code, local groundwater demands and usage, population projections, total water supply and quality of water supply available from all aquifers within the respective GCDs, regional water plan water management strategies, ground and surface water interactions, that affect groundwater conditions through the year 2070; and

WHEREAS, the member GCDs of GMA 2, having given proper and timely notice, held an open meeting on April 19, 2016 at the offices of the Mesa Underground Water Conservation District located at 212 N Ave G, Lamesa, Texas, to vote to adopt proposed Desired Future Conditions for the Ogallala, Edwards-Trinity (High Plains), and Dockum aquifers within the boundaries of GMA 2; and

WHEREAS, the member GCDs in which the Ogallala, Edwards-Trinity (High Plains), and Dockum aquifers are relevant for joint planning purposes held open meetings within each said district between June 8, 2016 and August 17, 2016 to take public comment on the proposed DFCs for that district; and

WHEREAS on this day of October 19, 2016, at an open meeting duly noticed and held in accordance with law at Brownfield City Hall located at 201 W. Broadway, Brownfield, Texas, the GCDs within GMA 2, having considered at this meeting comments submitted to the individual districts during the comment period and at this meeting, have voted, __ districts in favor, __ districts opposed, to adopt the following DFCs for in the following counties and districts through the year 2070 as follows:

- The desired future condition for the Ogallala and Edwards-Trinity (High Plains) aquifers is average drawdown of between 23 and 27 feet for all of GMA 2. The drawdown is calculated from the end of 2012 conditions to the year 2070. The drawdown is expressed as a range due to the link between future pumping and future rainfall. As documented in GMA 2 Technical Memorandum 15-01 and GMA 2 Technical Memorandum 16-01, historic pumping is higher in dry years than in wet years. Since most of the water use in

GMA 2 from the Ogallala Aquifer is for irrigation, producers pump more groundwater in dry years than in normal or wet years. The simulations assumed that initial pumping rates in the future would be between 100 percent and 150 percent of 2012 pumping rates. Essentially, in average or wet years, initial annual pumping would be approximately the same as 2012 pumping rates. In dry years, initial annual pumping rates could be as high as 150 percent of 2012 pumping rates based on the variation of pumping rates in the recent past.

- The desired future condition for the Dockum Aquifer is average drawdown of 27 feet for all of GMA 2. The drawdown is calculated from the end of 2012 conditions to the year 2070, and is based on Scenario 16 as documented in GMA 2 Technical Memorandum 16-01.

NOW THEREFORE BE IT RESOLVED, that Groundwater Management Area 2 does hereby document, record, and confirm the above-described Desired Future Conditions for the Ogallala, Edwards-Trinity (High Plains), and Dockum Aquifer which were adopted by vote of the following Designated Representatives of Groundwater Conservation Districts present and voting on October 19, 2016:

for Garza County UWCD

for High Plains UWCD #1

for Llano Estacado UWCD

for Mesa UWCD

Donna Springer
for Permian Basin UWCD

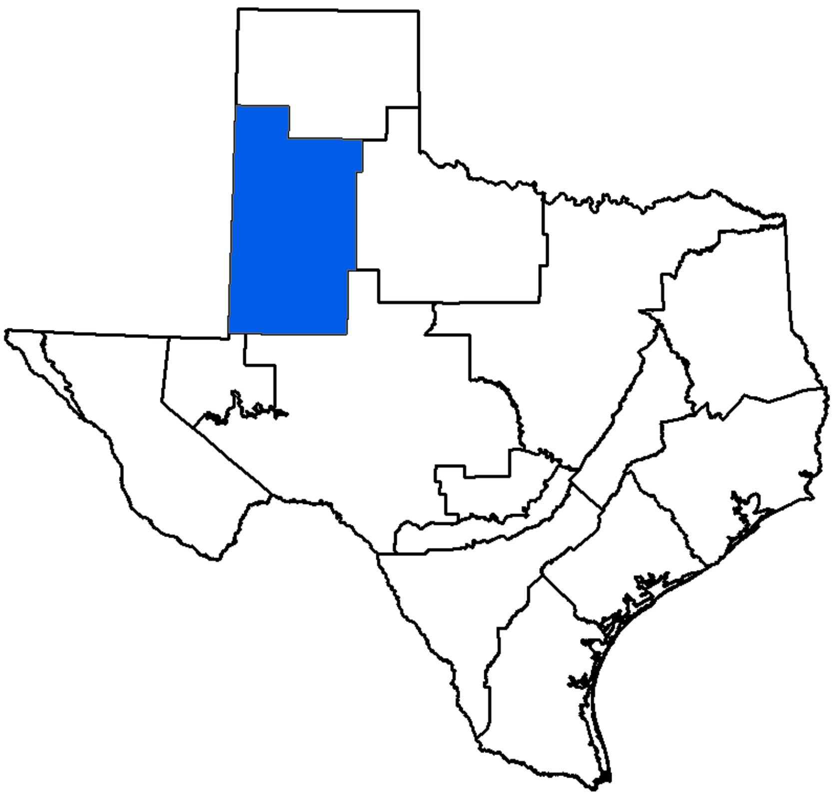
for Sandy Land UWCD

for South Plains UWCD

Appendix B

GMA 2 PowerPoint for April 29, 2015
Groundwater Use Estimates

Review of Draft High Plains Aquifer System (HPAS) Groundwater Availability Model (GAM)



Bill Hutchison, Ph.D., P.E., P.G.

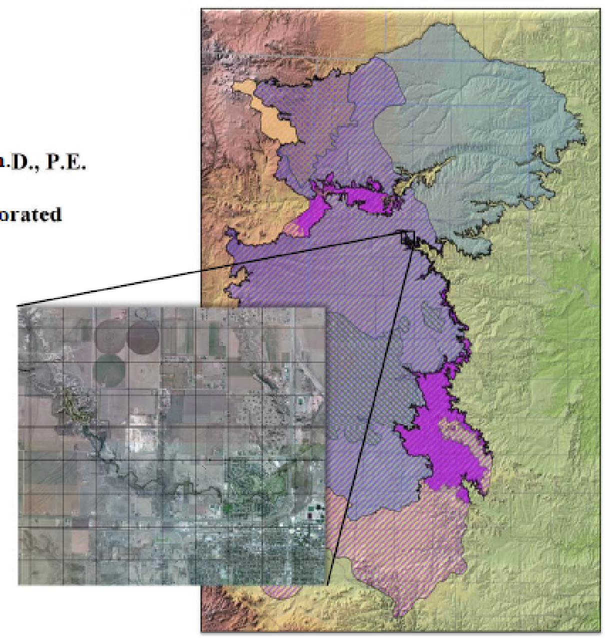
GMA 2 Meeting

April 29, 2015

Draft Model

- SAF 3 Meeting in Amarillo on February 18, 2015
- Report downloaded April 3, 2015
- Model Files downloaded April 4, 2015
- Deadline to comment is May 6, 2015

Draft Numerical Model Report for the High Plains Aquifer System Groundwater Availability Model



Prepared by

Neil E. Deeds, Ph.D., P.E.
Marius Jigmond
INTERA Incorporated

Prepared for:

Texas Water Development Board
P.O. Box 13231, Capitol Station
Austin, Texas 78711-3231

Texas Water Development Board

March 2015

Topics

- Review draft model in context of DFC development
  - Specific yield
  - Recharge
  - Pumping
- Administrative/Invoicing Discussion
- Next steps for GMA 2

Specific Yield

- Specific yield has a big influence on storage calculations
- At February 18, 2015 SAF meeting, specific yield had not been a calibration parameter
  – “Did not feel it was justified, since no new measurement were available”
- Draft report states that some specific yield values had been modified

Specific Yield in Draft Report

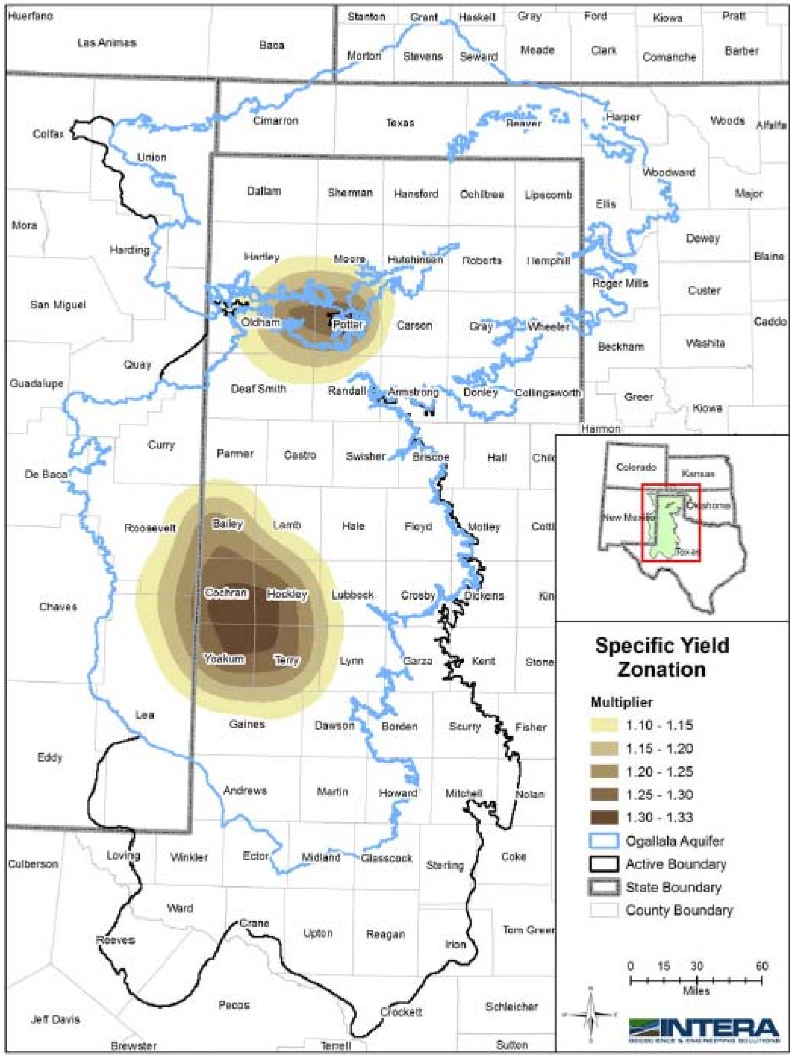


Figure 2.4.6 Specific yield calibration zone.

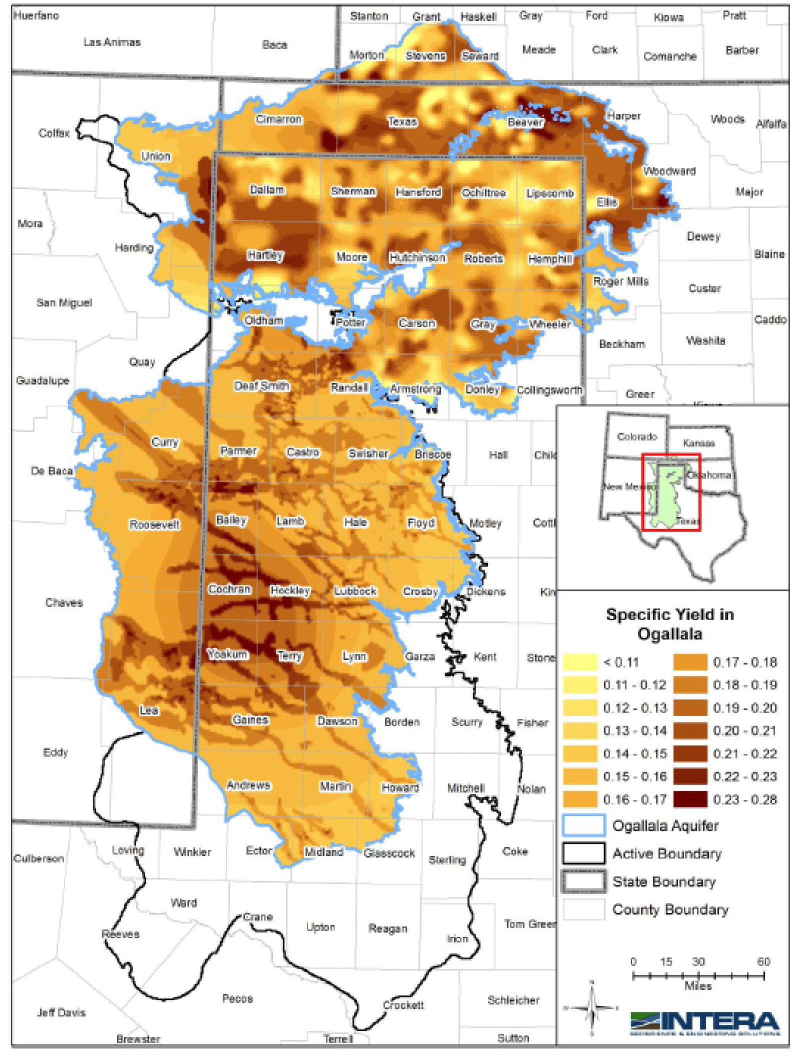


Figure 3.1.9 Calibrated specific yield in the Ogallala Aquifer.

Recharge

- Assumed constant recharge every year (1930 to 2012)
- Recharge includes irrigation return flow in southern portion of model
  - County-by-county “breakthrough” curves (Fig 4.4.15 of Conceptual Model report

From Conceptual Model Report

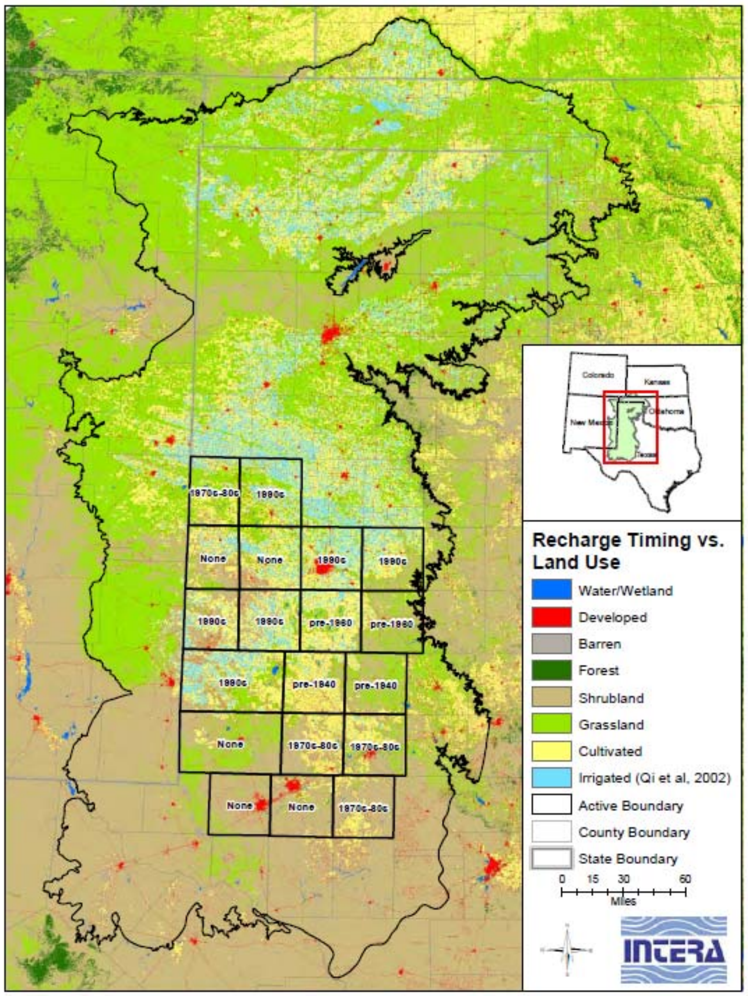
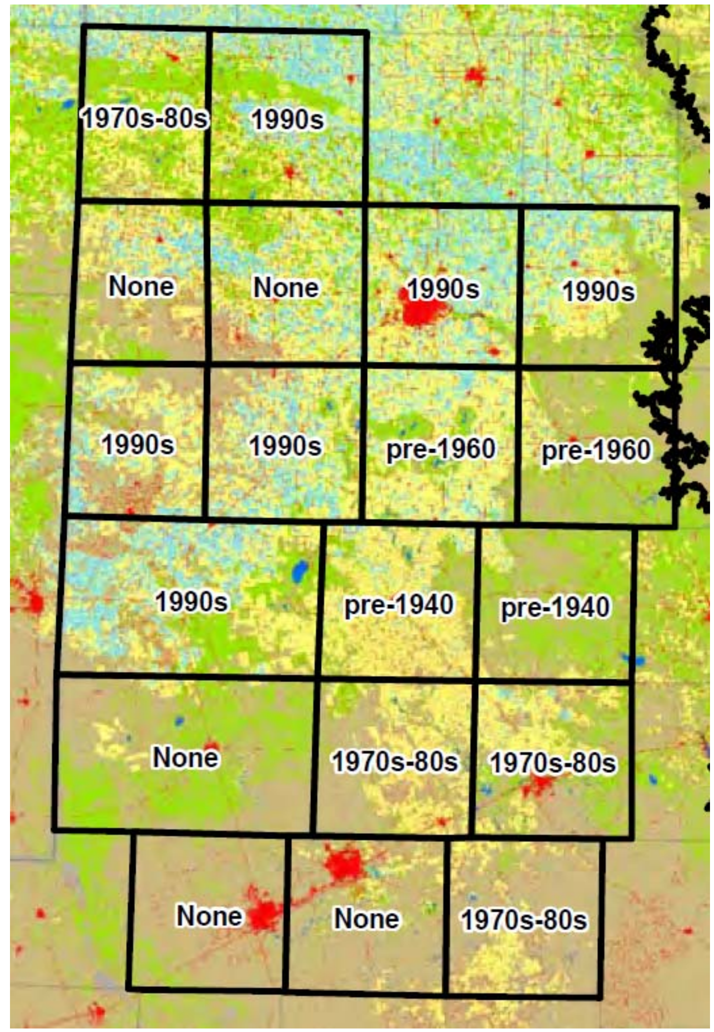


Figure 4.4.15 Timing of recharge compared to land use in southern Ogallala.



Steady State and Transient Recharge

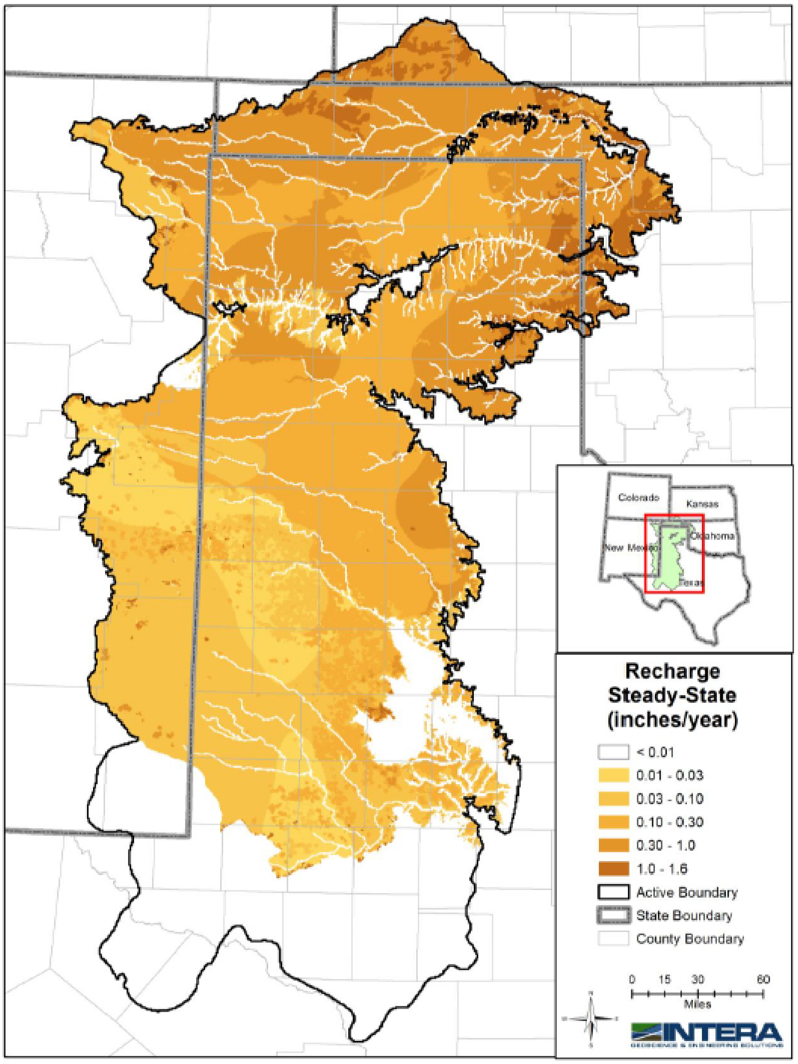


Figure 3.1.13 Calibrated predevelopment (steady-state stress period) recharge distribution.

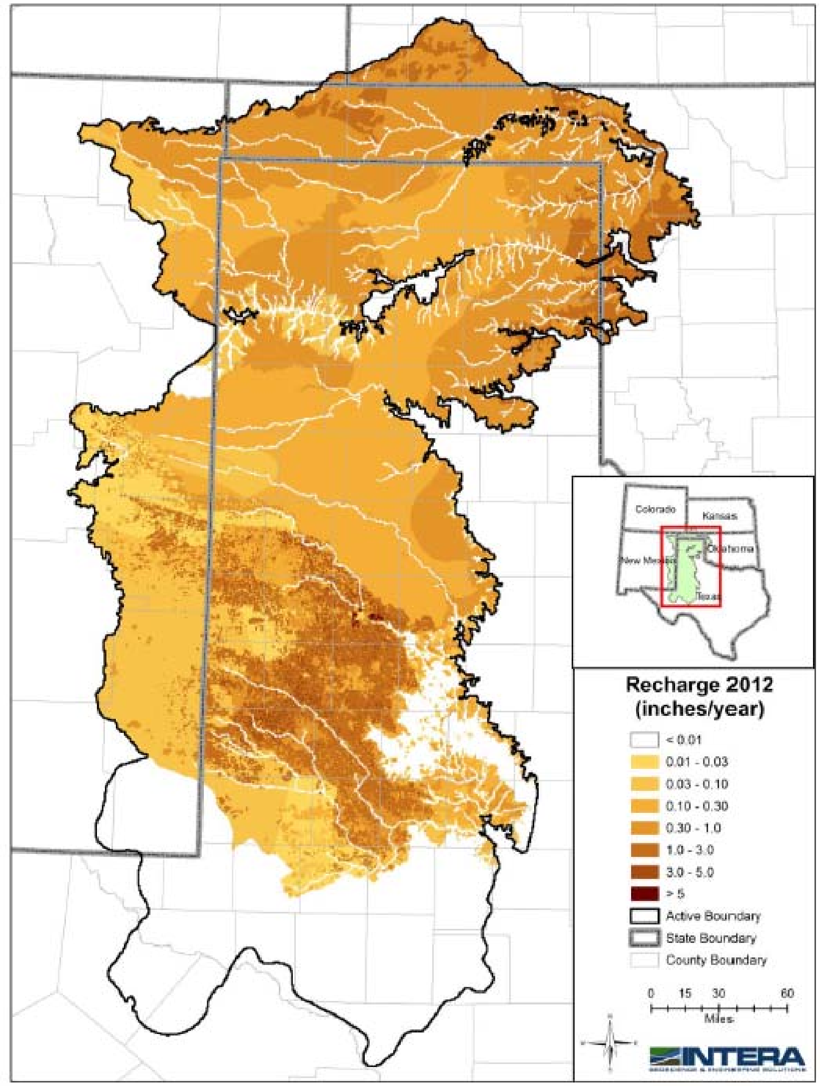
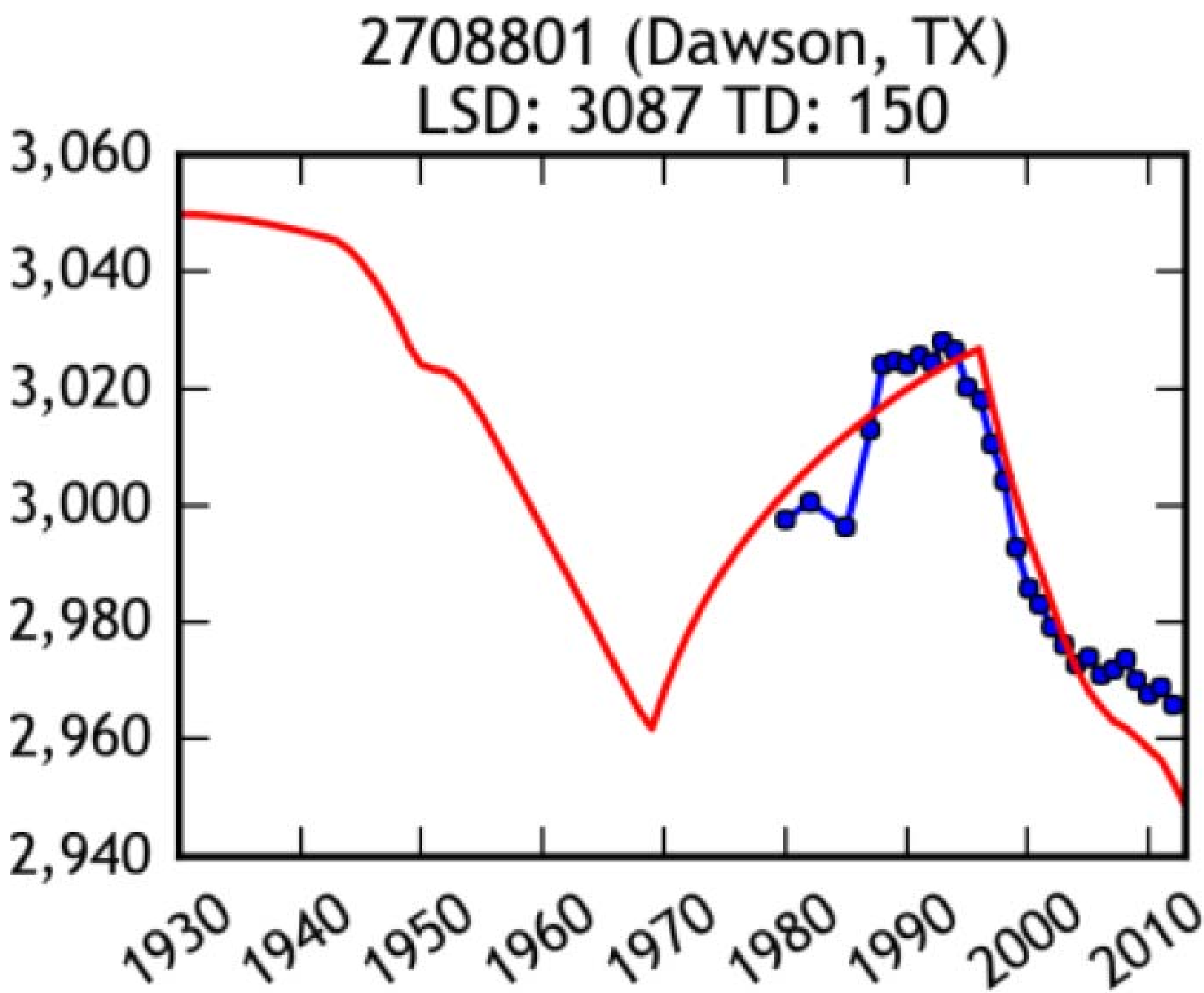
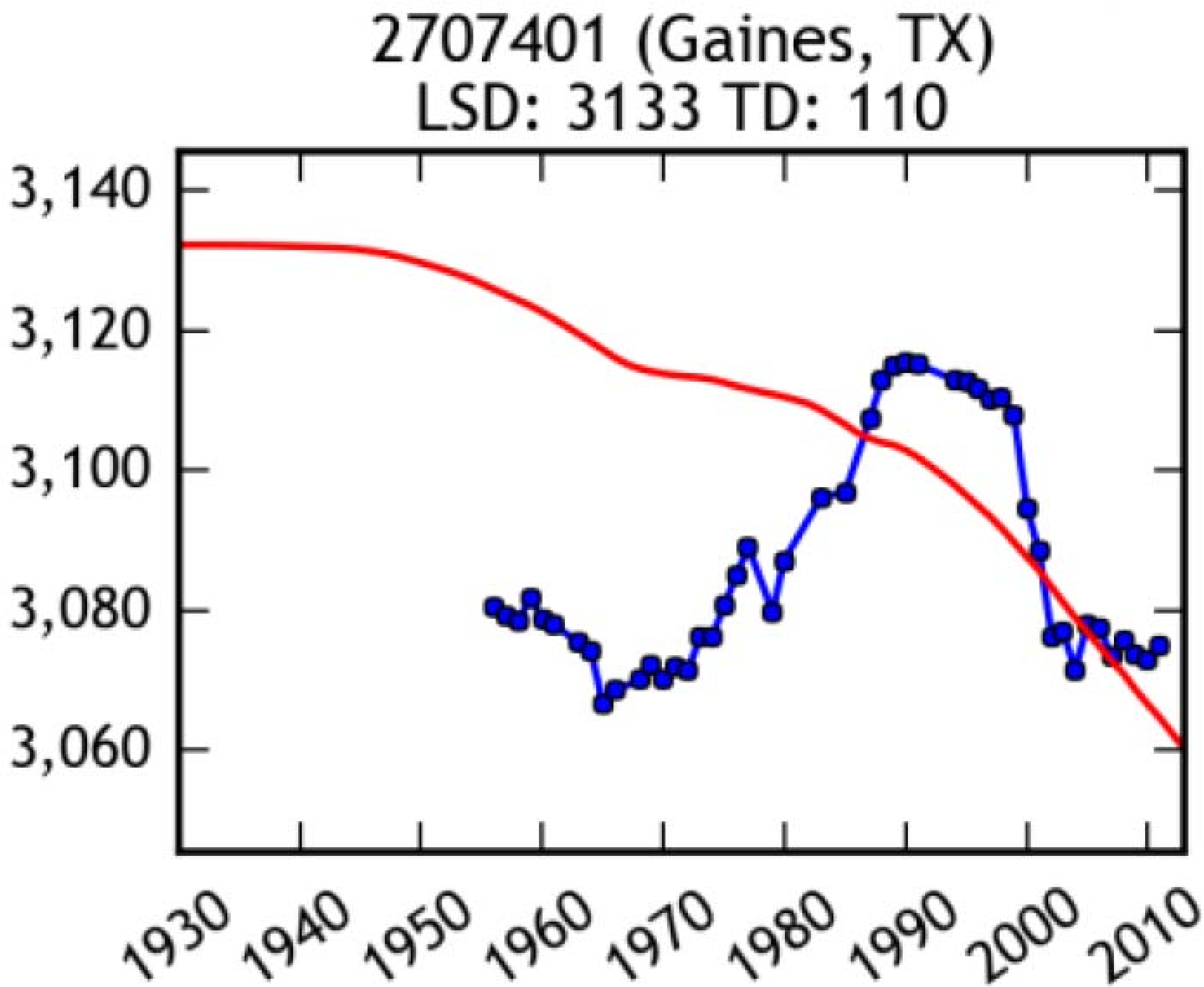


Figure 3.1.14 Calibrated transient recharge distribution in year 2012 (stress period 84).


2708801 (Dawson, TX)
LSD: 3087 TD: 150
3,060
3,040
3,020
3,000
2,980
2,960
2,940
1930
1940
1950
1960
1970
1980
1990
2000
2010


2707401 (Gaines, TX)
LSD: 3133 TD: 110
3,140
3,120
3,100
3,080
3,060
1930
1940
1950
1960
1970
1980
1990
2000
2010

Pumping

- Draft report documents methods to select pumping locations well
- Conceptual model documents pumping amounts
  - Previous model(s)
  - TWDB water use survey data

Initial Intera Simulation for GMA 1

- Received PowerPoint from Jason Coleman on April 24, 2015
- Included summary results for GMA 2
  - Assumed 50/50 for all aquifers (ETHP combined with Ogallala
  - Summaries of results are presented in context of historic pumping and current MAGs

Summary of Run Requirements

	Aquifer							
Region	Ogallala	Rita Blanca	ETHP	Dockum	Reference Start Year	Reference End Year	Simulation End Year	Decline Type
NPGCD: West	40/50	Historical Fraction of Dallam Ogallala pumping rate	n/a	50/50 (available drawdown)	2016	2065	2070	linear
NPGCD: East	2015 Pumping + 100K AFY	n/a	n/a	n/a	2016	2065	2070	linear
HCUWCD	80/50	n/a	n/a	n/a	2016	2065	2070	linear
PGCD	50/50	n/a	n/a	50/50 (available drawdown)	2016	2065	2070	1.25%
HPWD	50/50	n/a	Combine thickness with Ogallala	50/50 (available drawdown)	2016	2065	2070	exponential
non-HPWD South	50/50	n/a	Combine thickness with Ogallala	50/50 (available drawdown)	2016	2065	2070	exponential

Ogallala Aquifer (Layer 1 of HPAS)

- TWDB – groundwater pumping estimates (1980, 1984-2012) from water use surveys
- HPAS
  - Input pumping
  - Output pumping
- Current MAG
- Intera Scenario 1

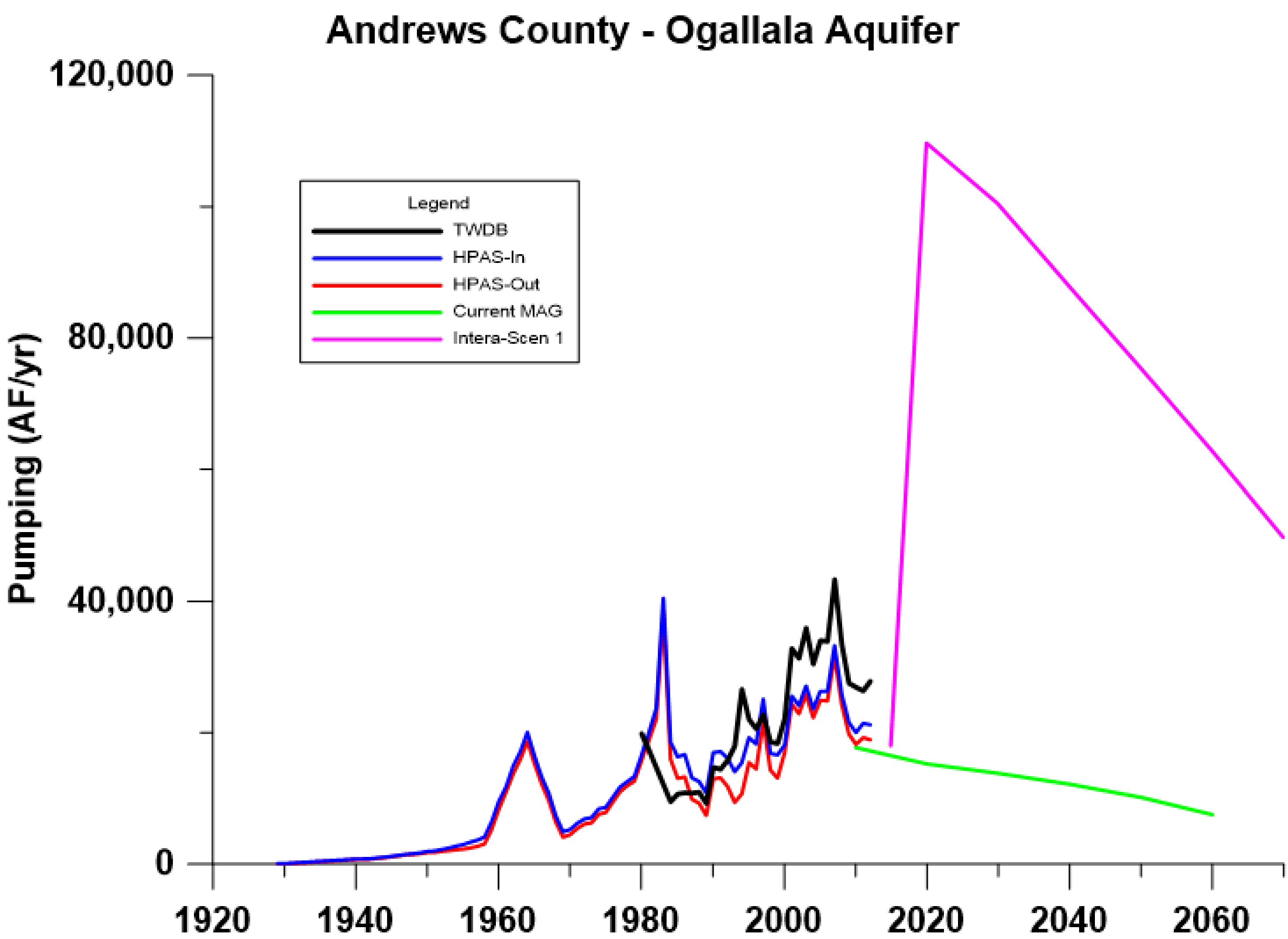
Ogallala Aquifer: GMA2 Counties

Ogallala	Available Groundwater							Average Drawdown					
County	2015	2020	2030	2040	2050	2060	2070	2020	2030	2040	2050	2060	2070
Bailey	76,446	163,279	85,113	50,247	31,428	22,811	19,496	8	16	20	22	23	23
Castro	197,417	105,713	88,569	77,100	67,862	60,059	53,187	5	14	22	28	34	38
Cochran	65,992	426,880	35,867	13,685	13,423	13,789	14,122	24	37	37	37	36	36
Crosby	122,013	91,502	81,522	72,895	65,722	58,880	53,002	6	16	24	32	38	44
DeafSmith	159,557	123,717	111,903	100,209	89,206	78,649	69,203	3	9	14	18	21	24
Floyd	124,639	124,983	105,703	93,207	82,976	73,134	63,894	7	19	29	37	45	51
Hale	244,065	99,739	75,503	62,172	53,347	45,949	39,395	4	11	16	20	24	26
Hockley	139,163	233,942	22,936	24,177	25,344	26,352	27,253	22	22	21	20	19	19
Lamb	215,118	186,773	114,571	79,334	58,524	46,199	39,964	7	16	20	23	24	25
Lubbock	121,364	283,775	121,778	75,354	56,303	46,869	45,745	13	24	26	27	27	26
Lynn	77,720	272,634	38,566	35,979	36,631	37,394	38,277	23	25	24	23	22	21
Parmer	140,154	81,350	69,169	59,844	52,074	43,918	37,353	3	9	13	17	20	22
Swisher	115,702	76,831	64,180	49,956	36,402	27,687	22,379	3	8	12	14	16	17
Andrews	18,042	109,705	100,488	87,913	75,503	62,903	49,764	4	13	20	26	30	34
Borden	4,732	21,404	8,191	4,567	3,490	2,931	2,607	11	24	29	32	33	33
Briscoe	28,314	18,219	12,980	9,501	6,891	5,658	4,945	1	3	5	5	6	6
Dawson	119,547	171,695	160,960	140,411	120,910	105,301	91,619	8	22	33	41	48	53
Gaines	230,441	326,140	205,688	133,063	93,878	69,405	58,277	7	17	23	26	27	27
Garza	14,204	19,340	14,350	11,067	8,376	6,368	4,993	5	13	18	22	23	23
Howard	12,646	48,908	45,350	39,616	32,921	26,586	22,755	3	8	12	14	16	17
Martin	41,993	104,485	101,430	94,723	87,195	78,964	70,614	5	13	20	26	31	35
Terry	185,777	264,932	45,802	50,046	52,811	54,754	56,298	25	24	23	21	20	19
Yoakum	123,488	271,231	24,313	23,008	23,340	23,865	24,366	23	25	24	24	23	23

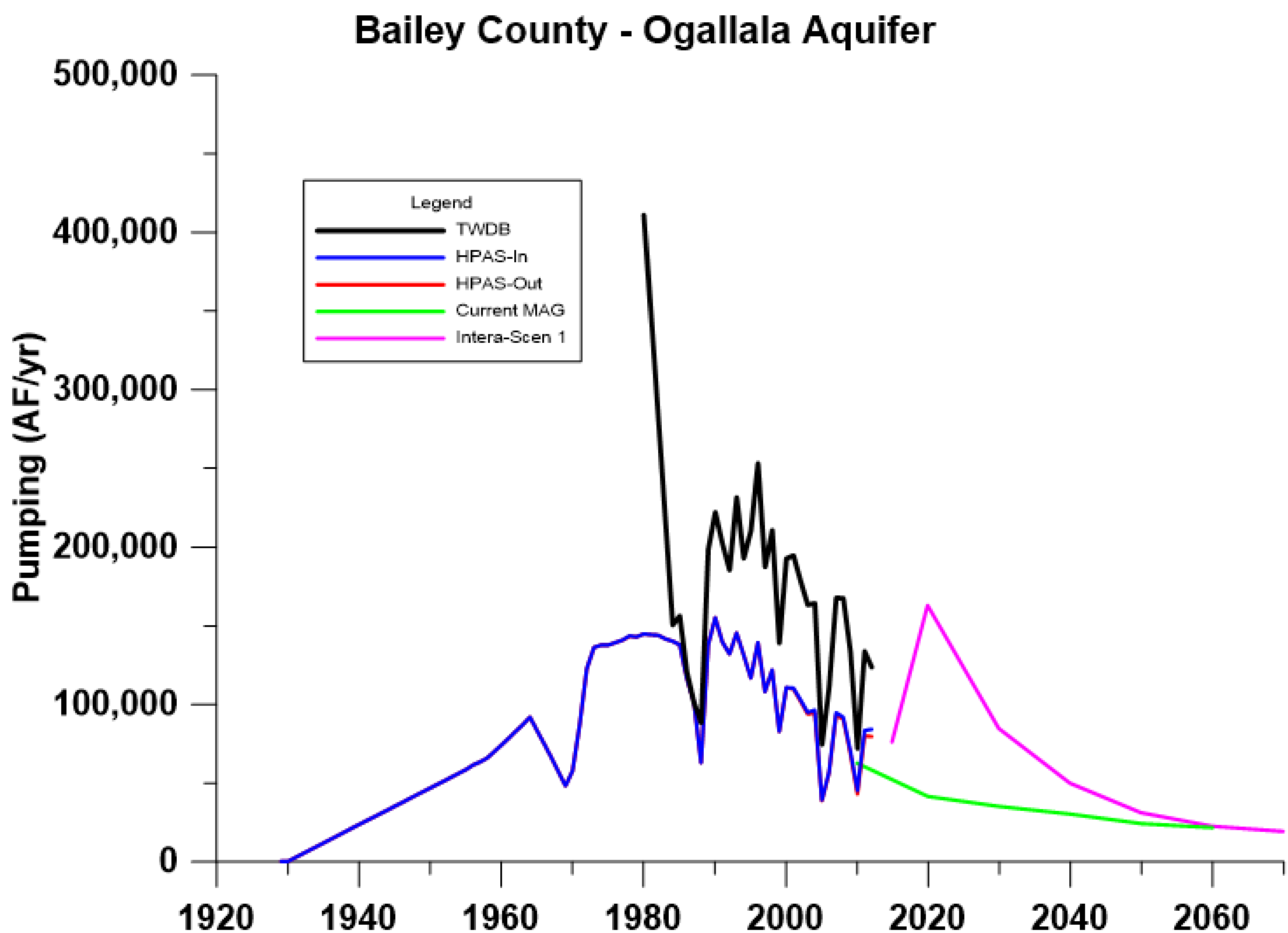
Note: 2015 rate is based on the historical model (using the rate from 2012), and is provided for comparison to predicted available groundwater. The rate may be a few percent less than was input due to some wells located in areas of small saturated thickness (where rates get scaled back.)

Ogallala Aquifer: GMA2 Counties

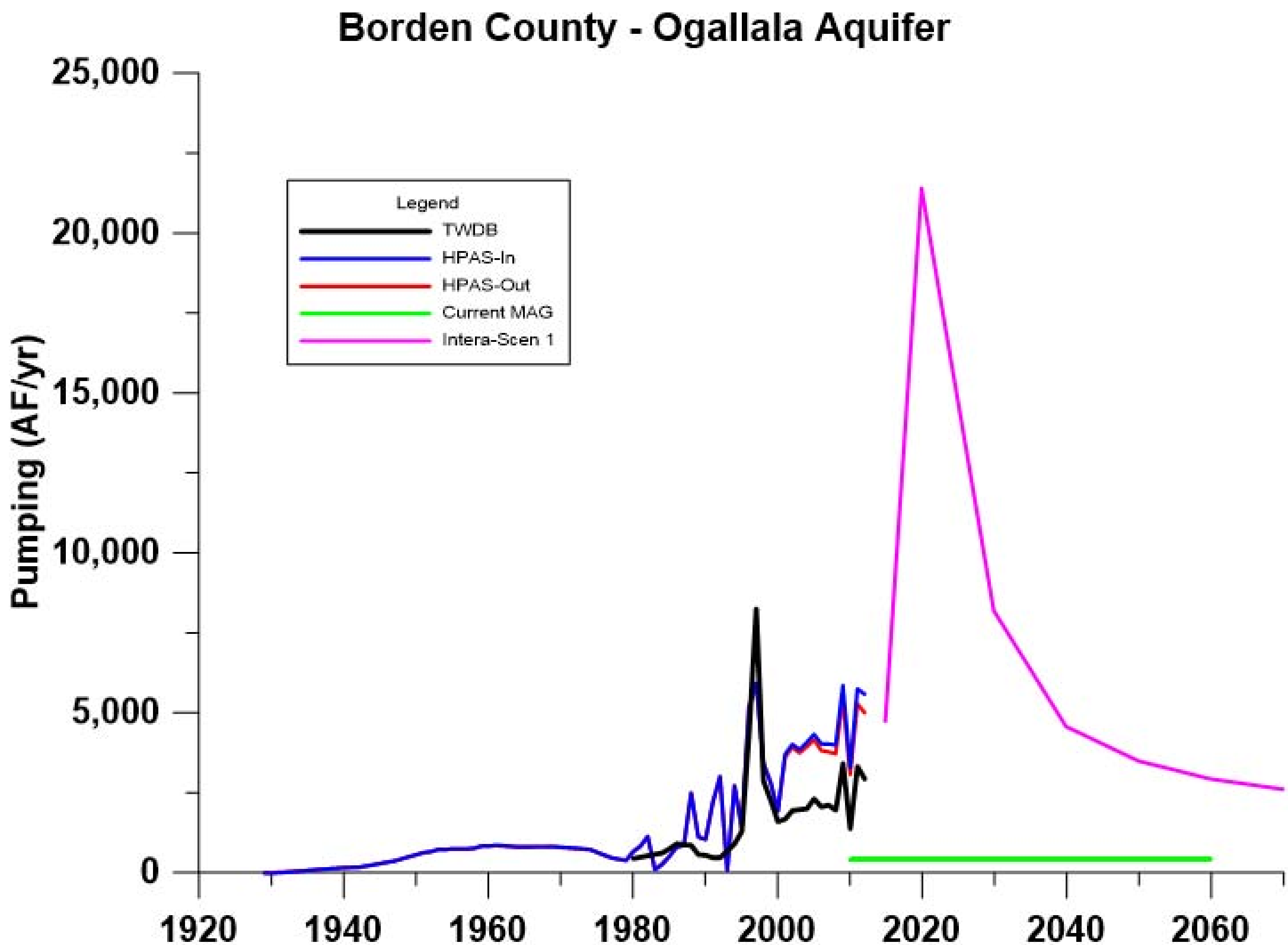
Ogallala	Groundwater In Storage (af)							Fraction Remaining from 2015					
County	**2015**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2065**
Bailey	3,864,356	3,080,301	2,165,096	1,771,204	1,607,218	1,556,427	1,558,135	0.80	0.56	0.46	0.42	0.40	0.40
Castro	6,977,848	6,457,866	5,562,837	4,814,776	4,176,142	3,630,679	3,255,878	0.93	0.80	0.69	0.60	0.52	0.49
Cochran	5,090,626	2,701,464	1,326,444	1,347,413	1,379,512	1,392,838	1,402,413	0.53	0.26	0.26	0.27	0.27	0.27
Crosby	5,443,055	5,071,769	4,408,043	3,834,266	3,335,887	2,906,403	2,658,283	0.93	0.81	0.70	0.61	0.53	0.50
DeafSmith	7,307,655	6,811,208	5,890,792	5,097,415	4,421,905	3,856,180	3,497,978	0.93	0.81	0.70	0.61	0.53	0.49
Floyd	7,033,278	6,408,777	5,403,576	4,575,099	3,874,767	3,285,011	2,937,904	0.91	0.77	0.65	0.55	0.47	0.43
Hale	4,724,424	4,295,695	3,631,555	3,127,892	2,726,409	2,402,000	2,200,658	0.91	0.77	0.66	0.58	0.51	0.48
Hockley	4,228,093	1,687,549	1,647,101	1,787,566	1,896,166	1,988,317	2,072,183	0.40	0.39	0.42	0.45	0.47	0.48
Lamb	5,325,912	4,535,368	3,485,585	2,963,464	2,679,946	2,549,369	2,502,412	0.85	0.65	0.56	0.50	0.48	0.47
Lubbock	4,397,210	3,125,040	2,064,408	1,805,962	1,756,530	1,789,247	1,851,394	0.71	0.47	0.41	0.40	0.41	0.41
Lynn	3,763,196	1,524,236	1,374,315	1,467,764	1,530,556	1,587,061	1,642,574	0.41	0.37	0.39	0.41	0.42	0.43
Parmer	4,189,492	3,883,919	3,334,337	2,887,876	2,526,435	2,246,586	2,071,124	0.93	0.80	0.69	0.60	0.54	0.51
Swisher	3,650,411	3,372,727	2,890,541	2,533,863	2,306,496	2,166,999	2,080,851	0.92	0.79	0.69	0.63	0.59	0.58
Andrews	8,009,644	7,469,275	6,484,165	5,643,281	4,940,928	4,368,447	4,094,218	0.93	0.81	0.70	0.62	0.55	0.52
Borden	376,681	266,963	157,888	124,263	108,145	100,397	98,172	0.71	0.42	0.33	0.29	0.27	0.26
Briscoe	895,070	844,782	762,852	716,562	686,560	664,909	647,783	0.94	0.85	0.80	0.77	0.74	0.73
Dawson	7,468,865	6,722,384	5,470,354	4,474,859	3,705,875	3,106,708	2,849,270	0.90	0.73	0.60	0.50	0.42	0.38
Gaines	7,935,674	6,688,808	4,962,775	4,108,706	3,621,582	3,368,116	3,281,980	0.84	0.63	0.52	0.46	0.42	0.42
Garza	584,766	501,451	384,822	307,855	261,547	239,768	238,347	0.86	0.66	0.53	0.45	0.41	0.40
Howard	2,135,140	1,971,210	1,707,670	1,502,334	1,360,937	1,278,844	1,249,433	0.92	0.80	0.70	0.64	0.60	0.59
Martin	6,356,287	5,917,868	5,142,395	4,483,141	3,928,646	3,469,437	3,239,730	0.93	0.81	0.71	0.62	0.55	0.51
Terry	4,508,024	1,693,395	1,789,305	1,985,048	2,129,478	2,246,368	2,345,280	0.38	0.40	0.44	0.47	0.50	0.51
Yoakum	4,099,710	1,718,228	1,496,535	1,578,422	1,643,692	1,697,918	1,744,616	0.42	0.37	0.39	0.40	0.41	0.42



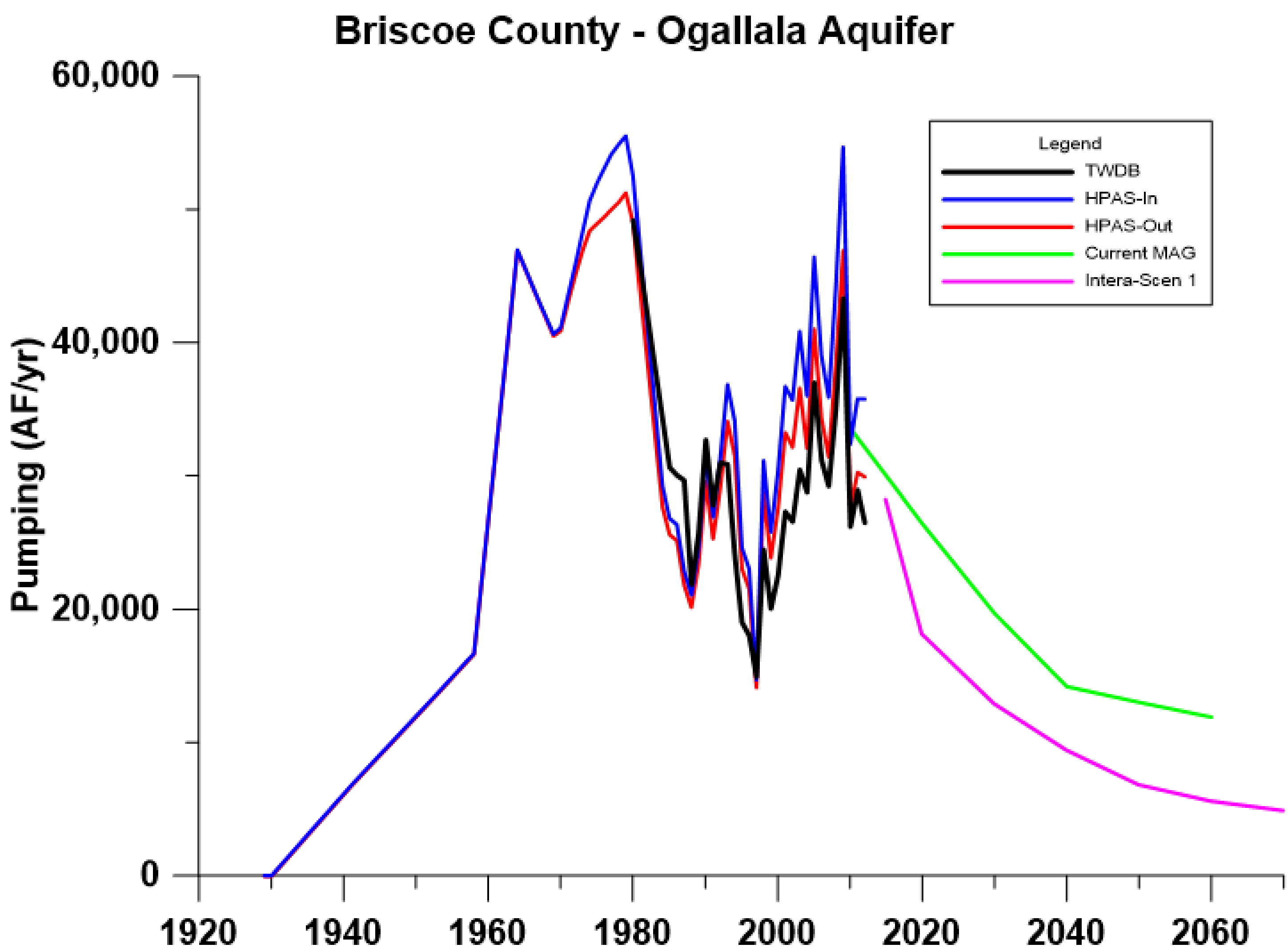
Andrews County - Ogallala Aquifer
Pumping (AF/yr)
120,000
80,000
40,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1



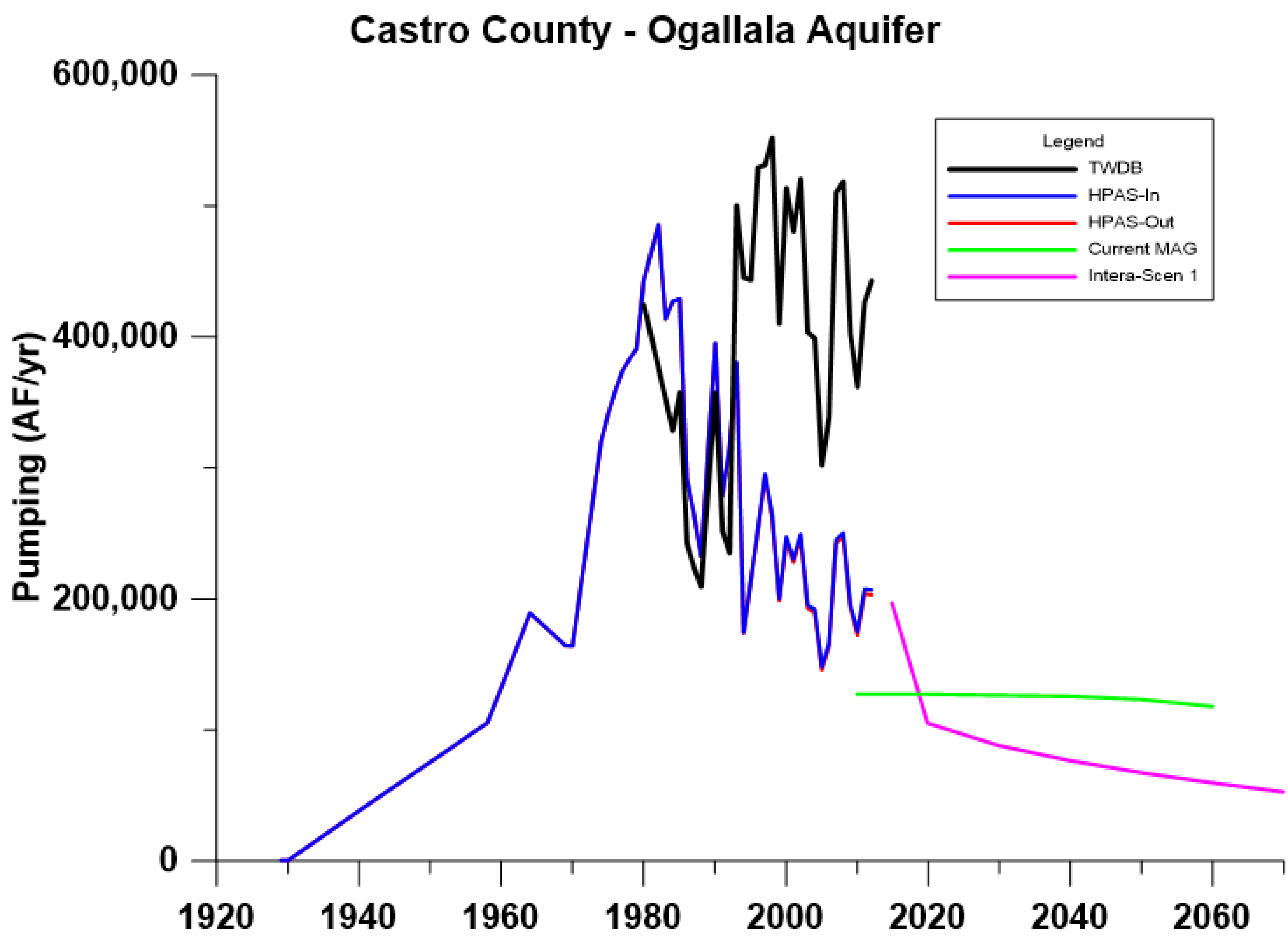
Bailey County - Ogallala Aquifer
Pumping (AF/yr)
500,000
400,000
300,000
200,000
100,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1



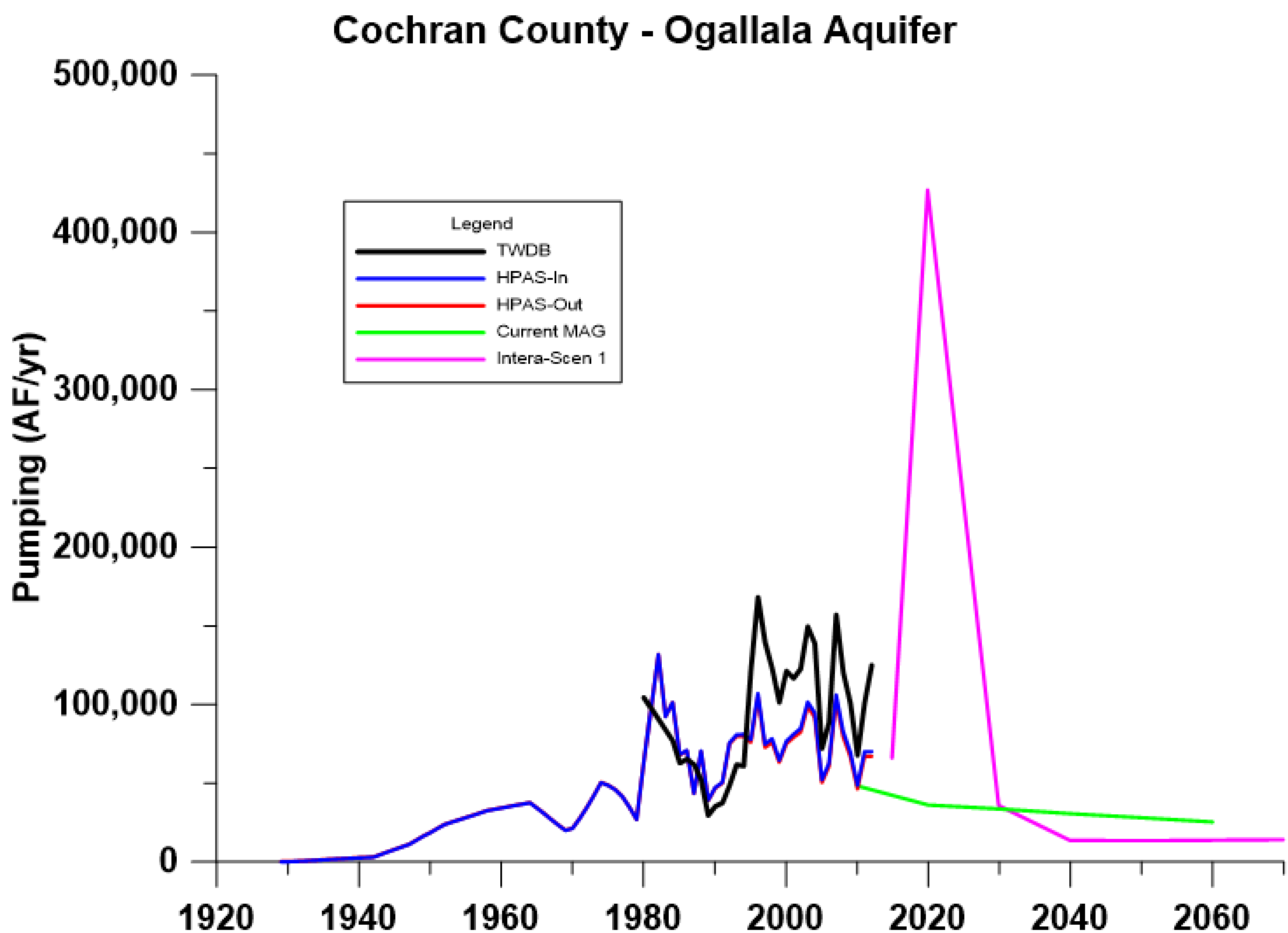
Borden County - Ogallala Aquifer
Pumping (AF/yr)
25,000
20,000
15,000
10,000
5,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1



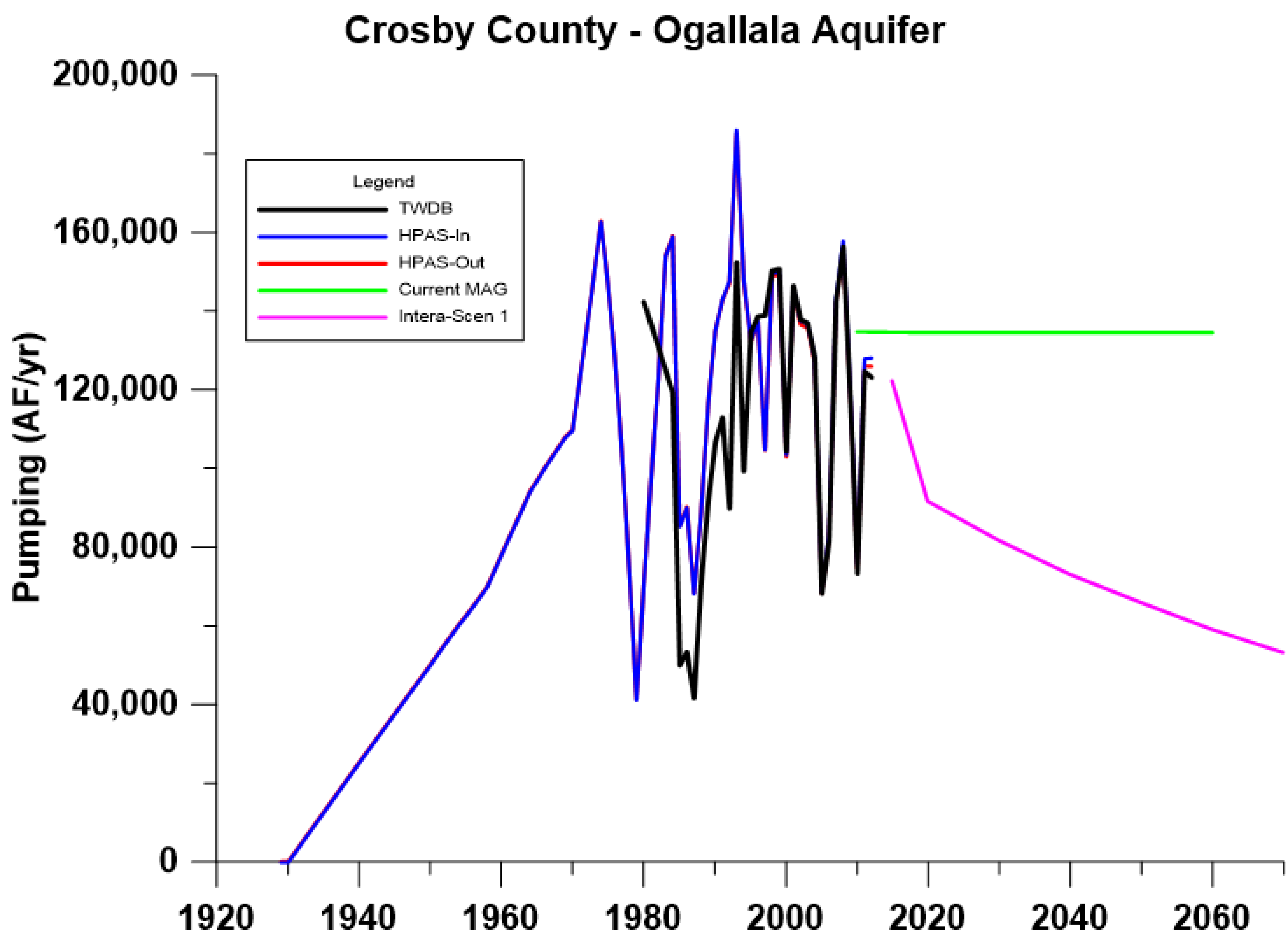
Briscoe County - Ogallala Aquifer
Pumping (AF/yr)
60,000
40,000
20,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1



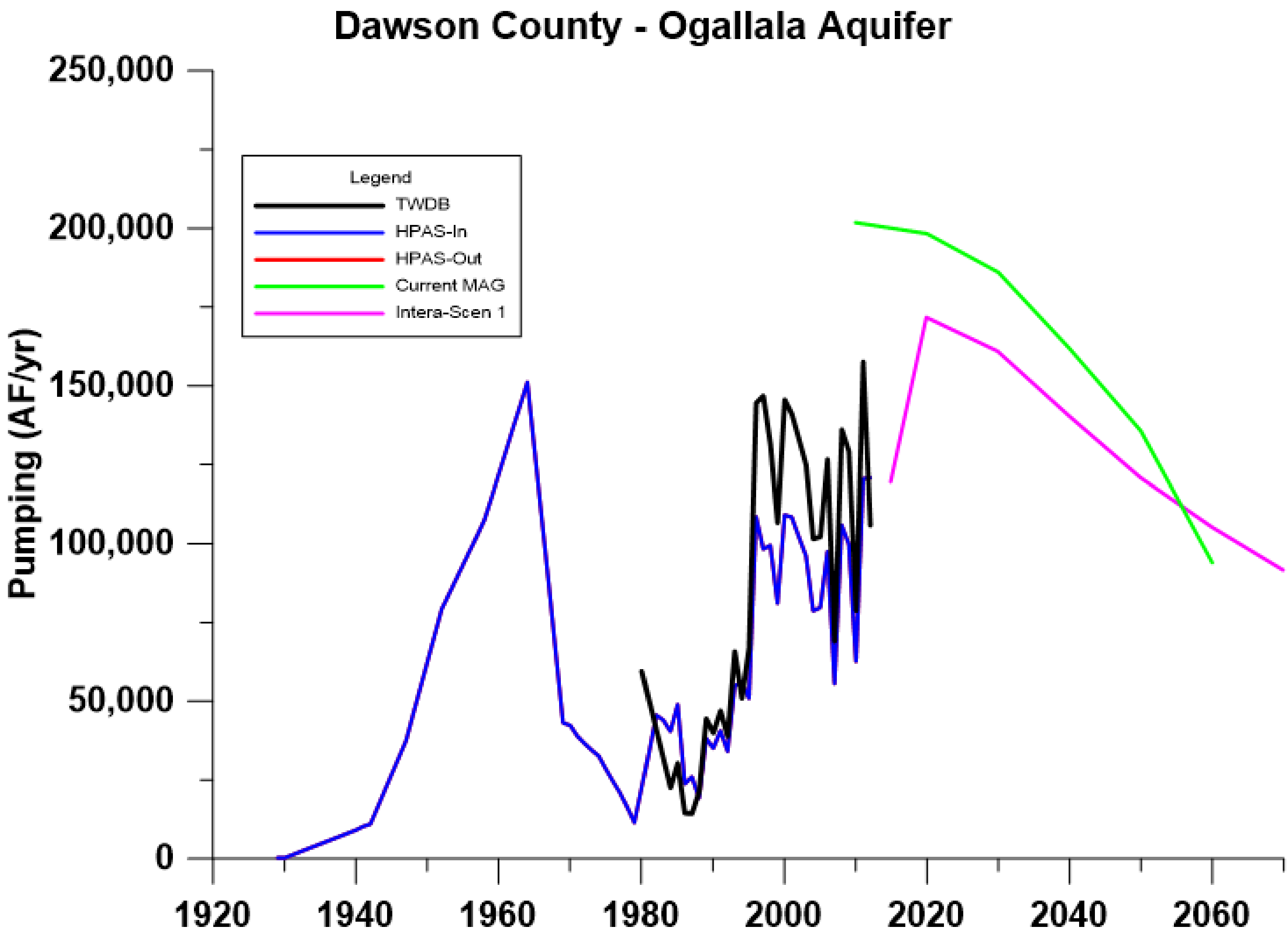
Castro County - Ogallala Aquifer
Pumping (AF/yr)
600,000
400,000
200,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1



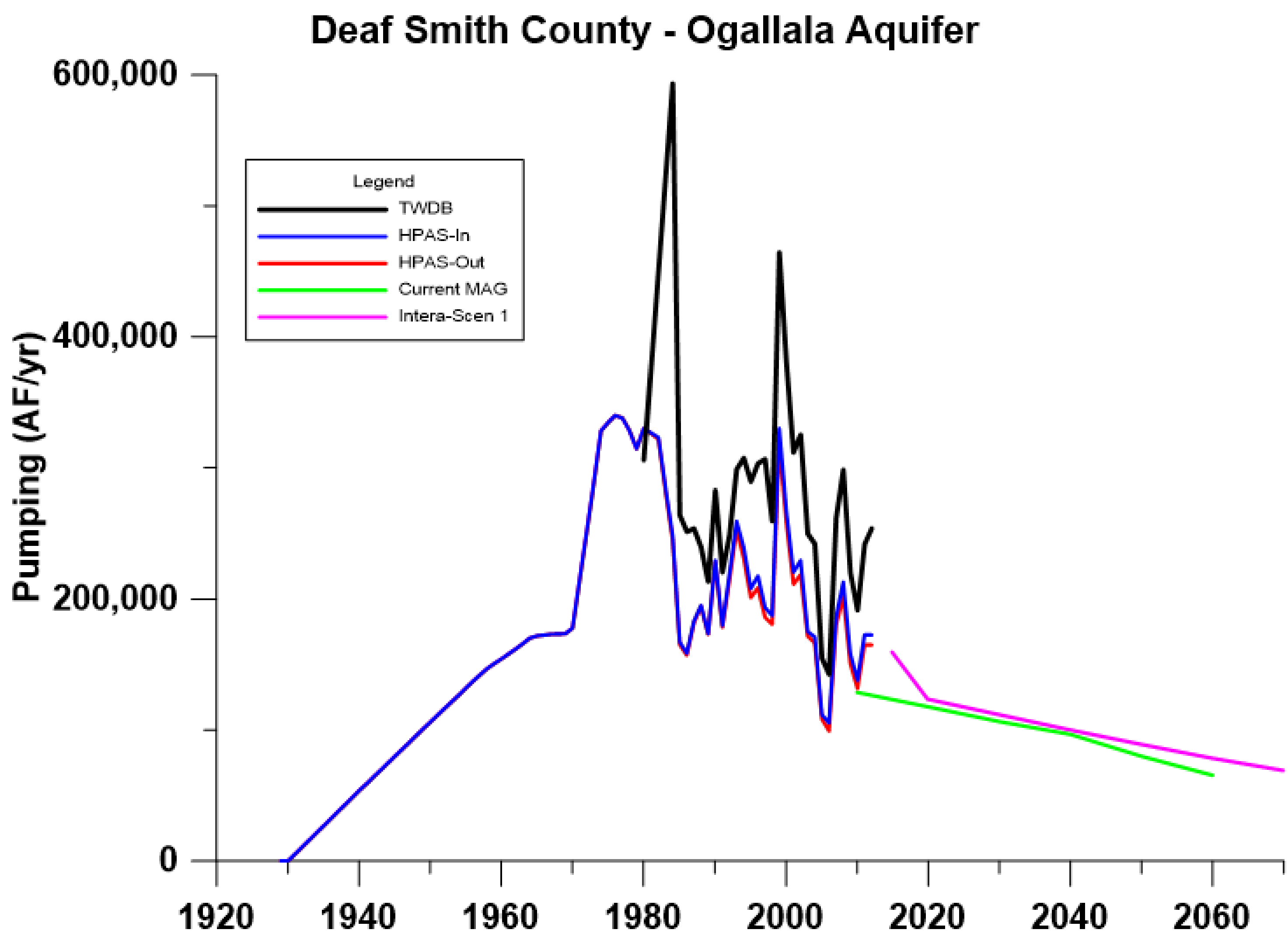
Cochran County - Ogallala Aquifer
Pumping (AF/yr)
500,000
400,000
300,000
200,000
100,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1



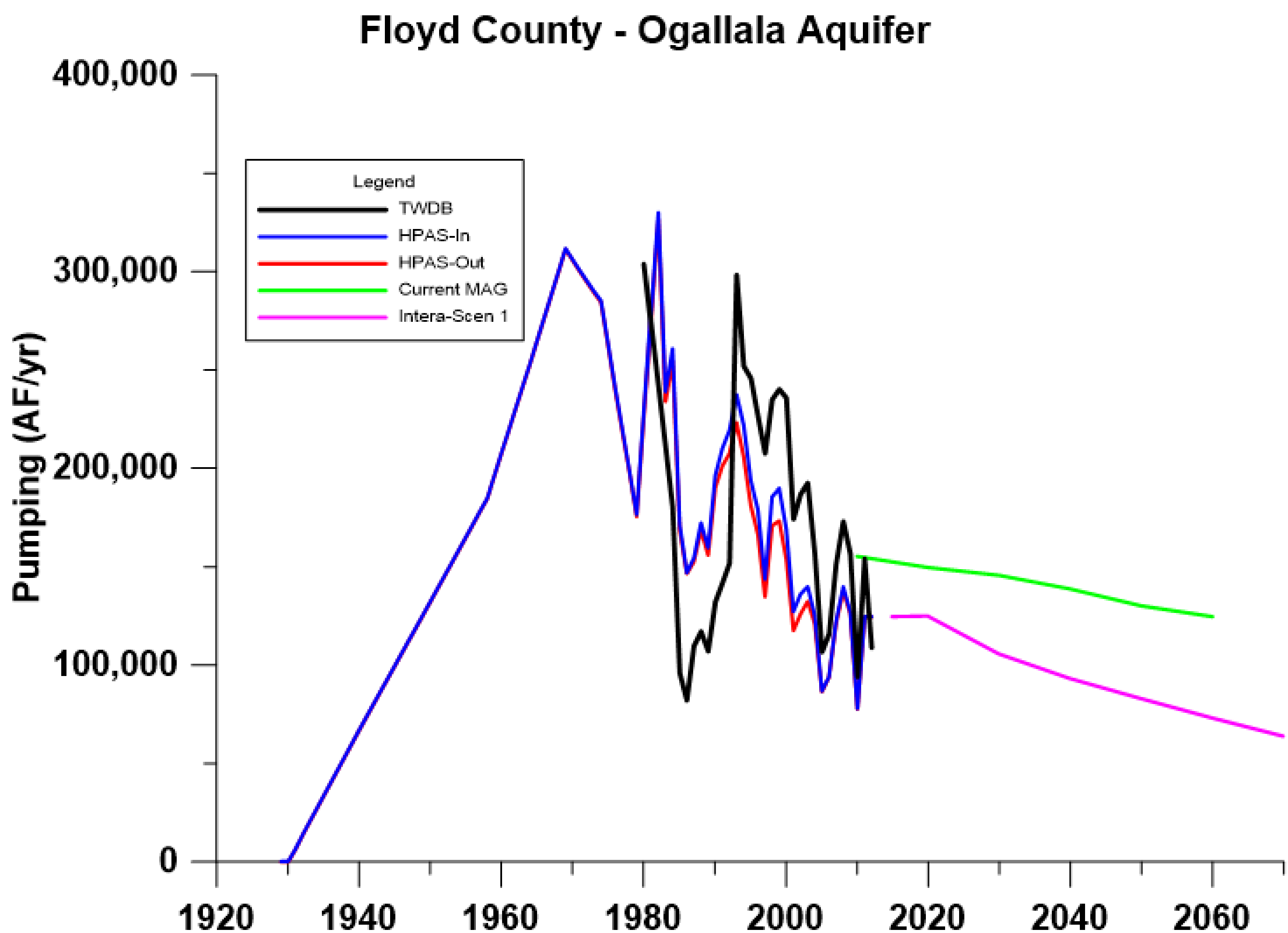
Crosby County - Ogallala Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1
Pumping (AF/yr)
200,000
160,000
120,000
80,000
40,000
0
1920
1940
1960
1980
2000
2020
2040
2060

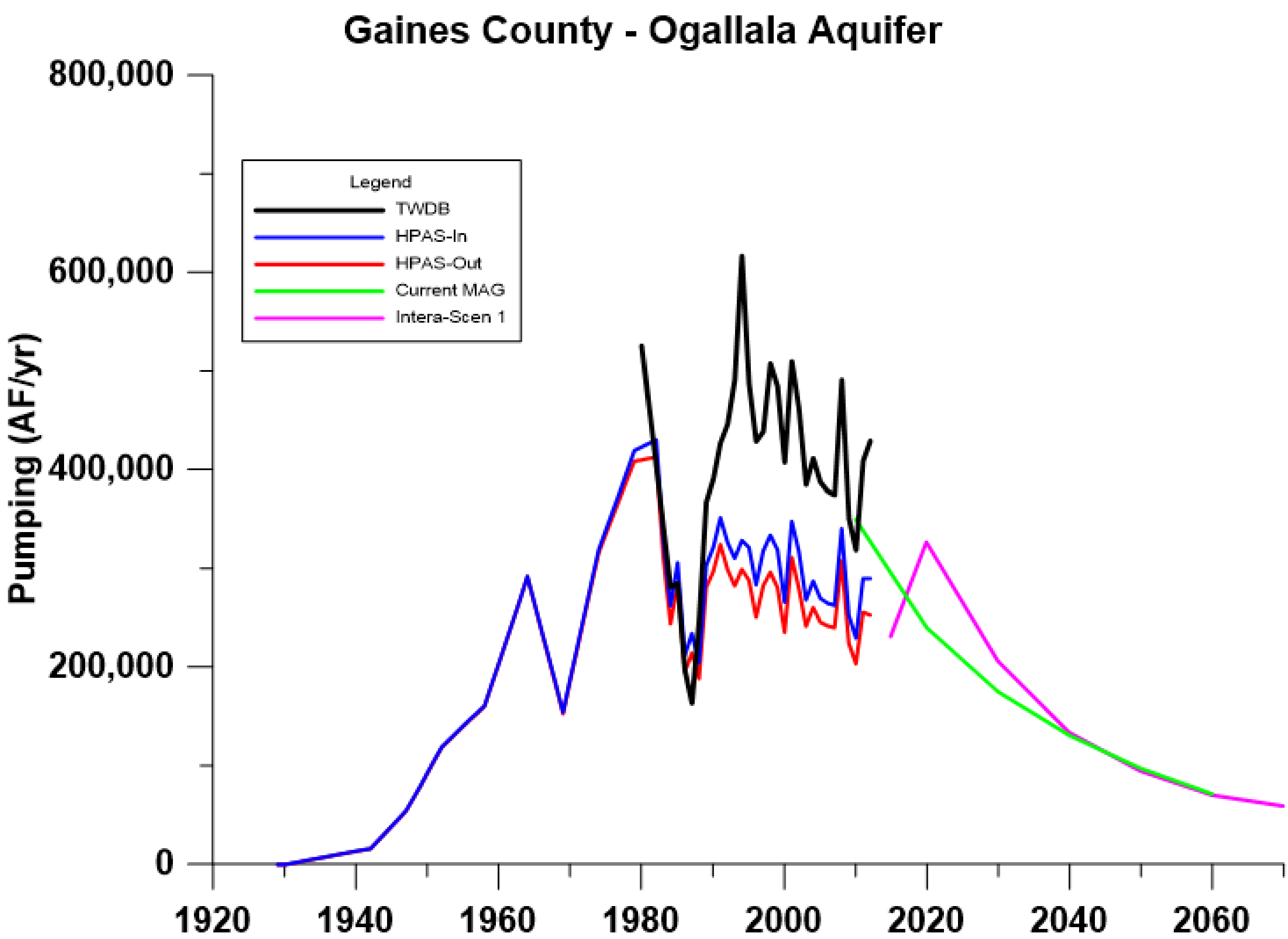


Dawson County - Ogallala Aquifer
Pumping (AF/yr)
250,000
200,000
150,000
100,000
50,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1

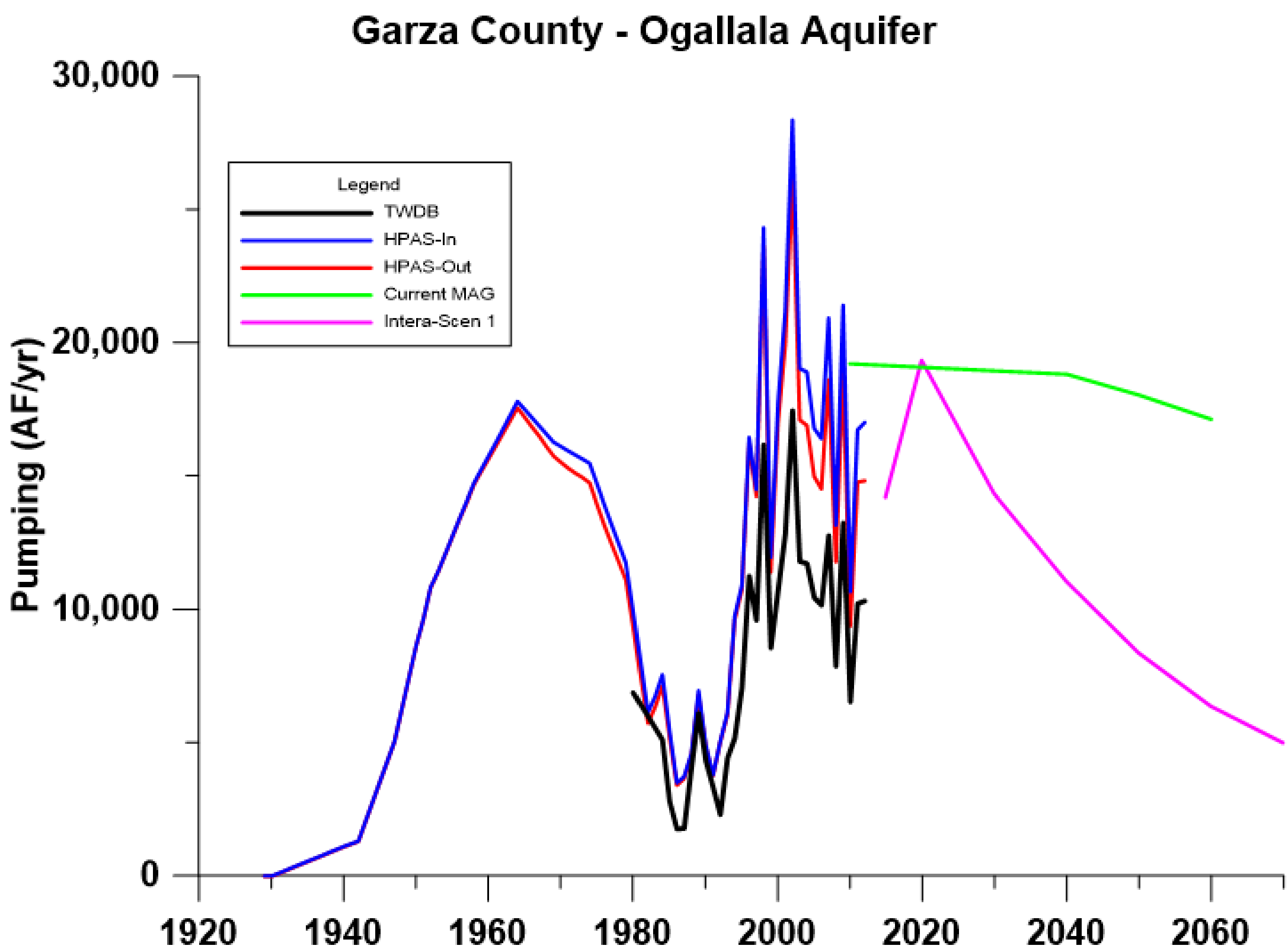


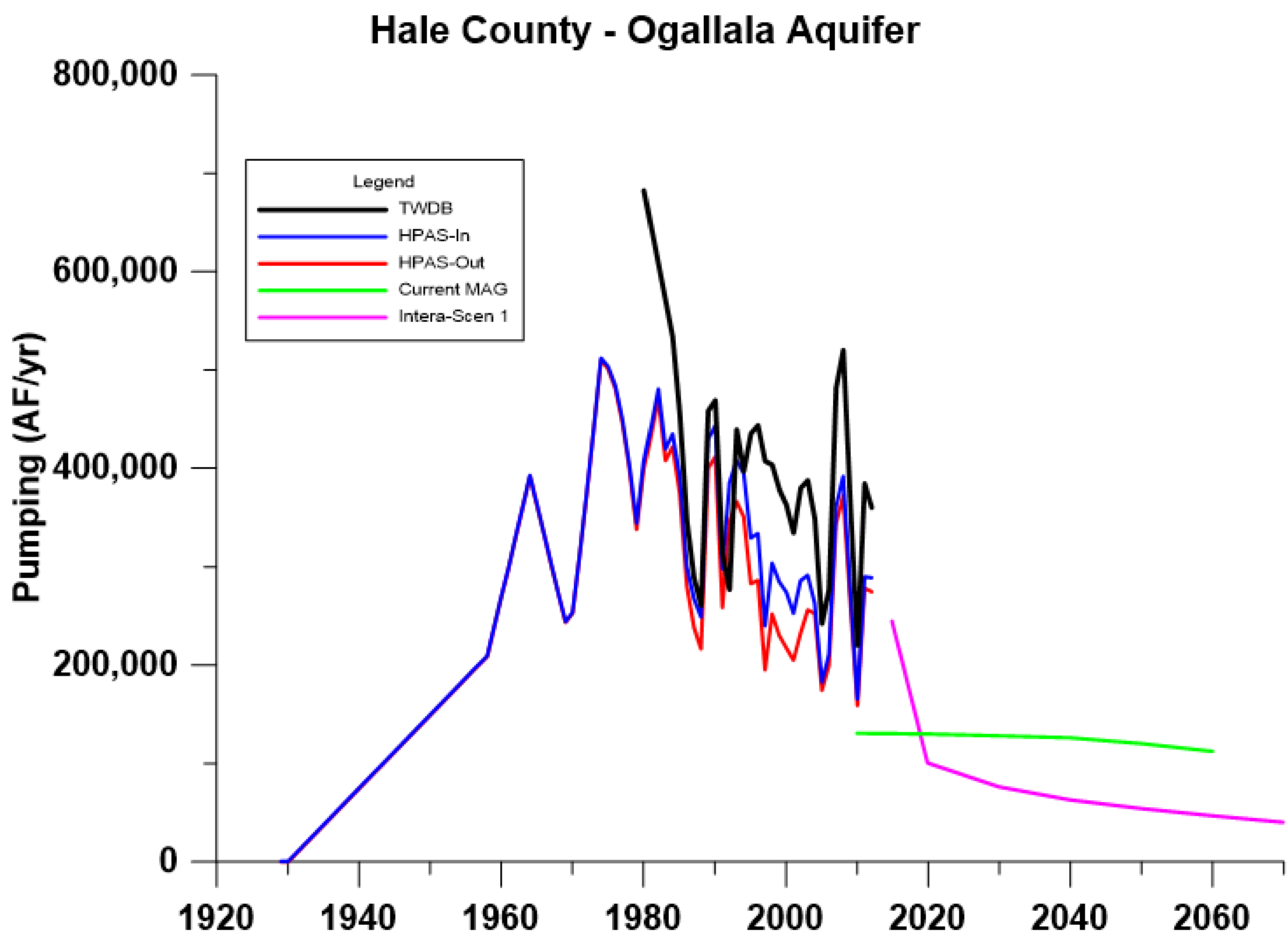
Deaf Smith County - Ogallala Aquifer
Pumping (AF/yr)
600,000
400,000
200,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1


Floyd County - Ogallala Aquifer
Pumping (AF/yr)
400,000
300,000
200,000
100,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1

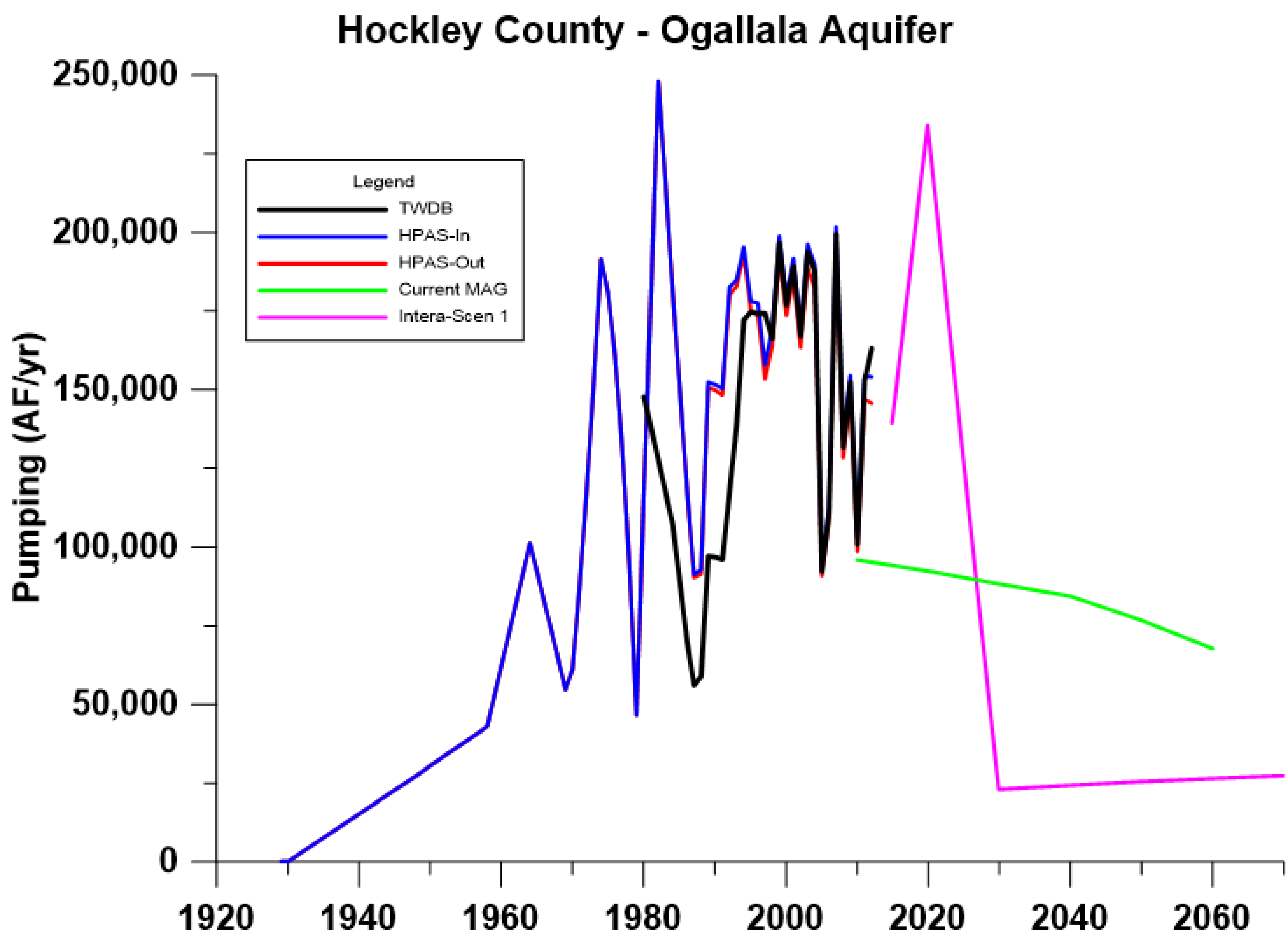


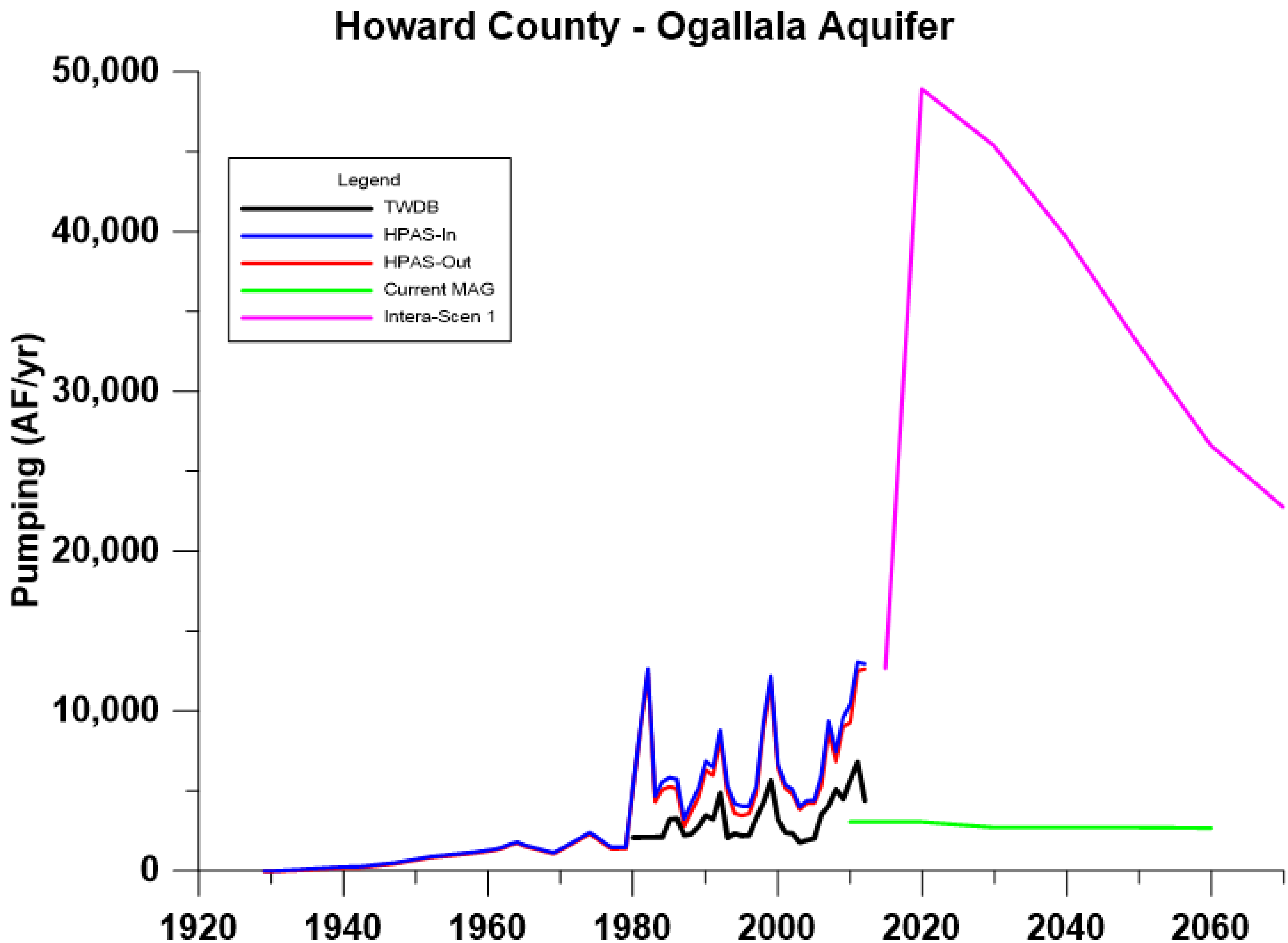
Gaines County - Ogallala Aquifer
Pumping (AF/yr)
800,000
600,000
400,000
200,000
0
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1
1920
1940
1960
1980
2000
2020
2040
2060


Garza County - Ogallala Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1
Pumping (AF/yr)
30,000
20,000
10,000
0
1920
1940
1960
1980
2000
2020
2040
2060

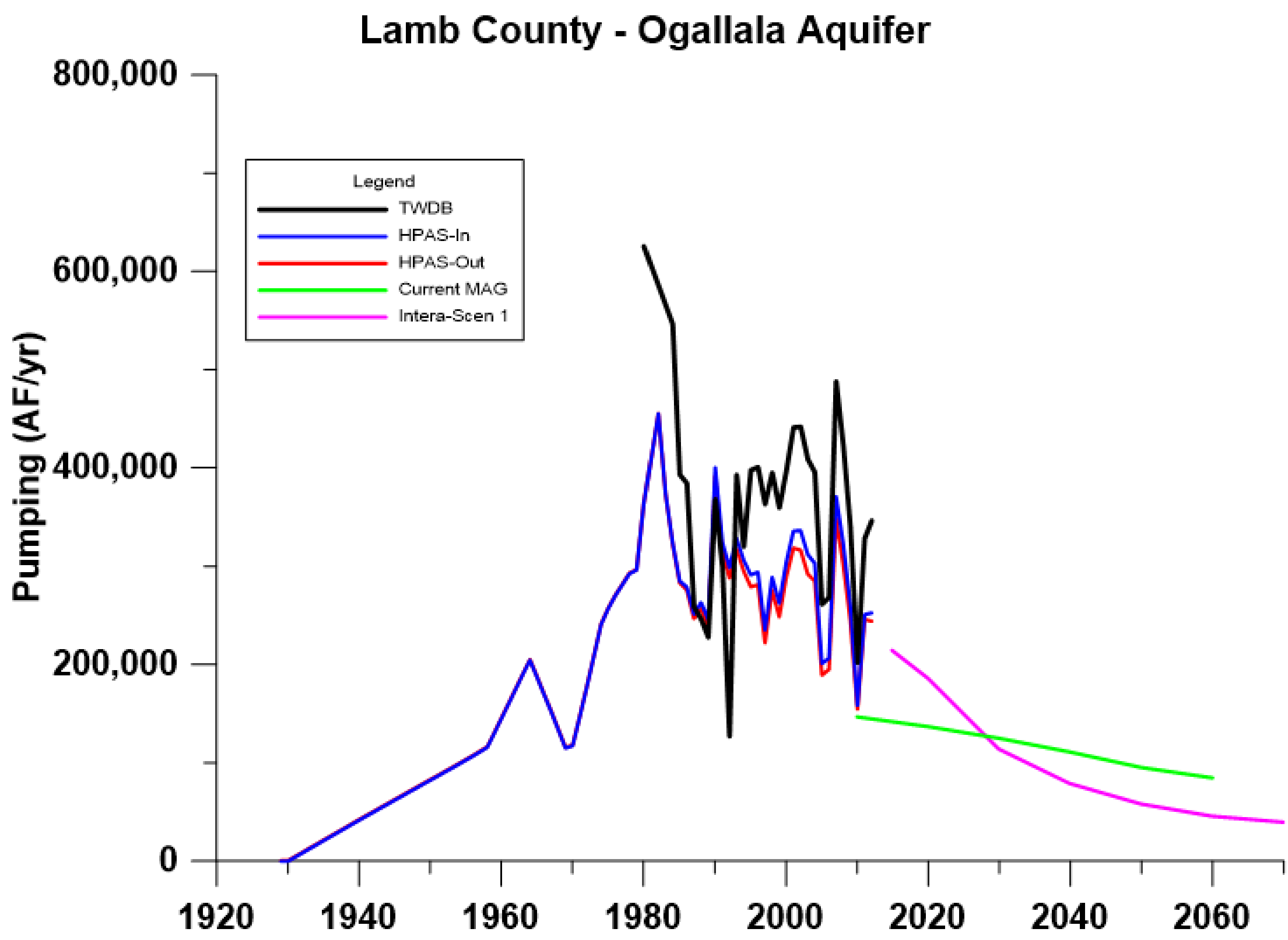


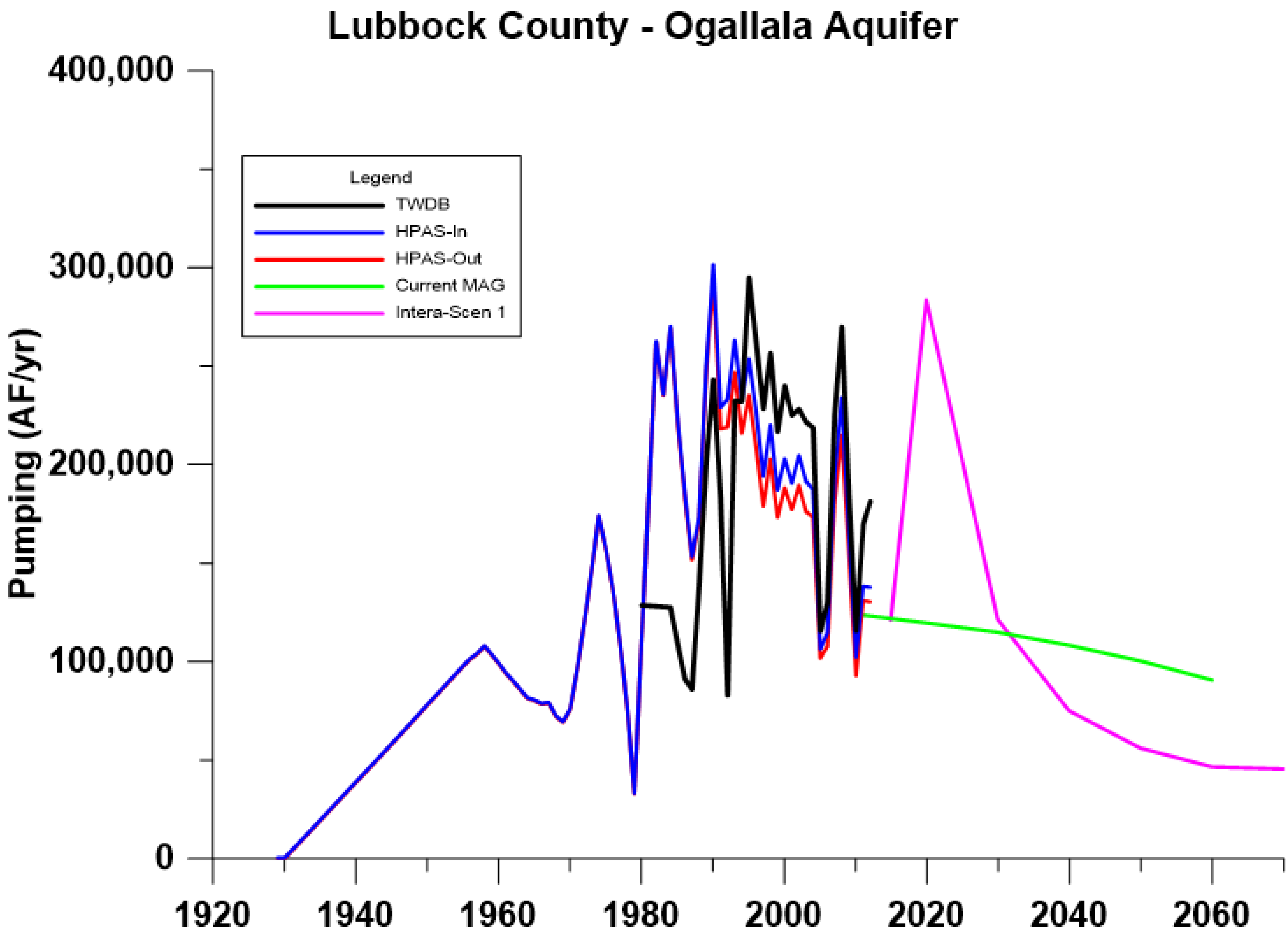
Hale County - Ogallala Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1
Pumping (AF/yr)
800,000
600,000
400,000
200,000
0
1920
1940
1960
1980
2000
2020
2040
2060


Hockley County - Ogallala Aquifer
Pumping (AF/yr)
250,000
200,000
150,000
100,000
50,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1

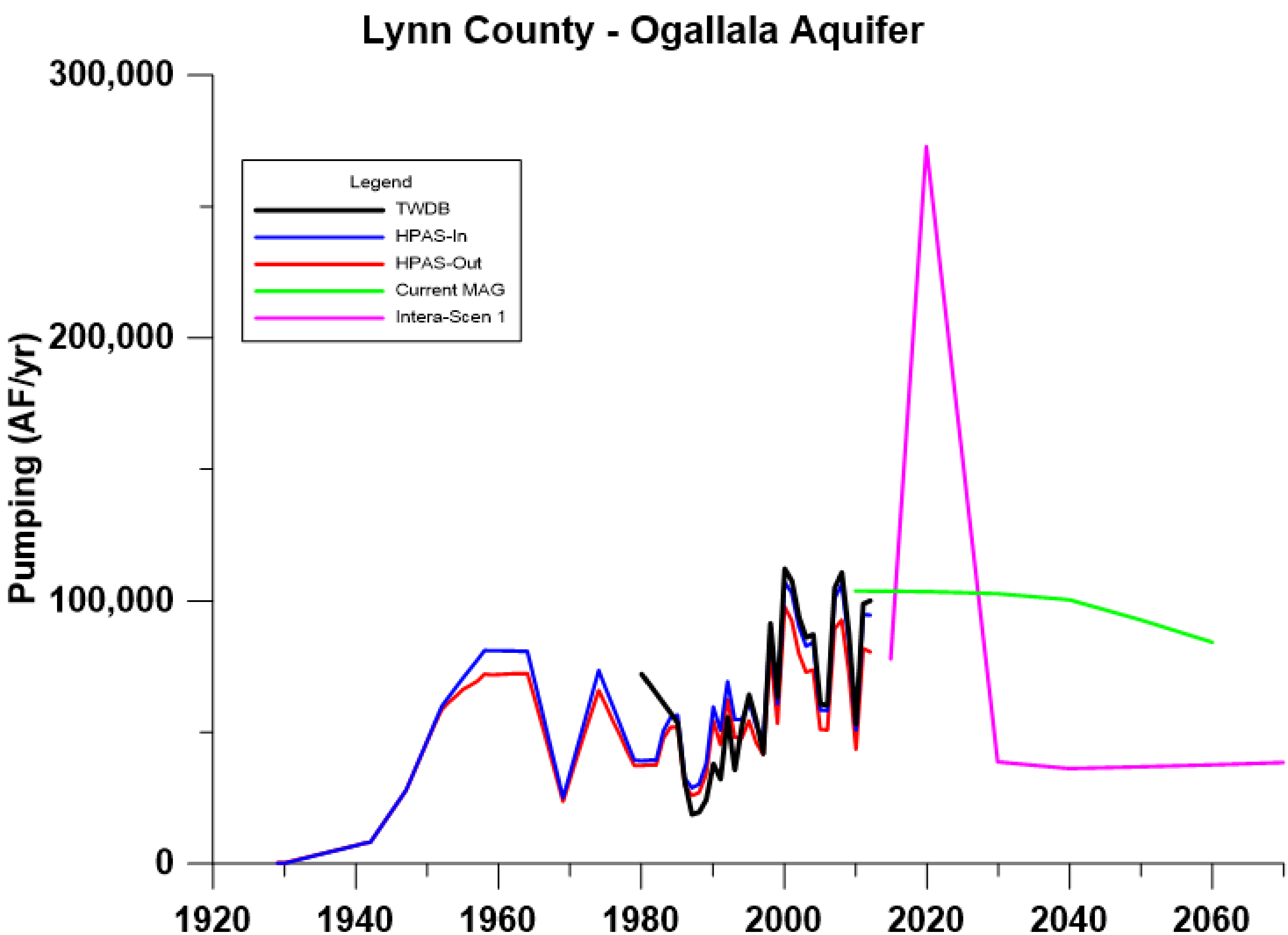


Howard County - Ogallala Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1
Pumping (AF/yr)
50,000
40,000
30,000
20,000
10,000
0
1920
1940
1960
1980
2000
2020
2040
2060

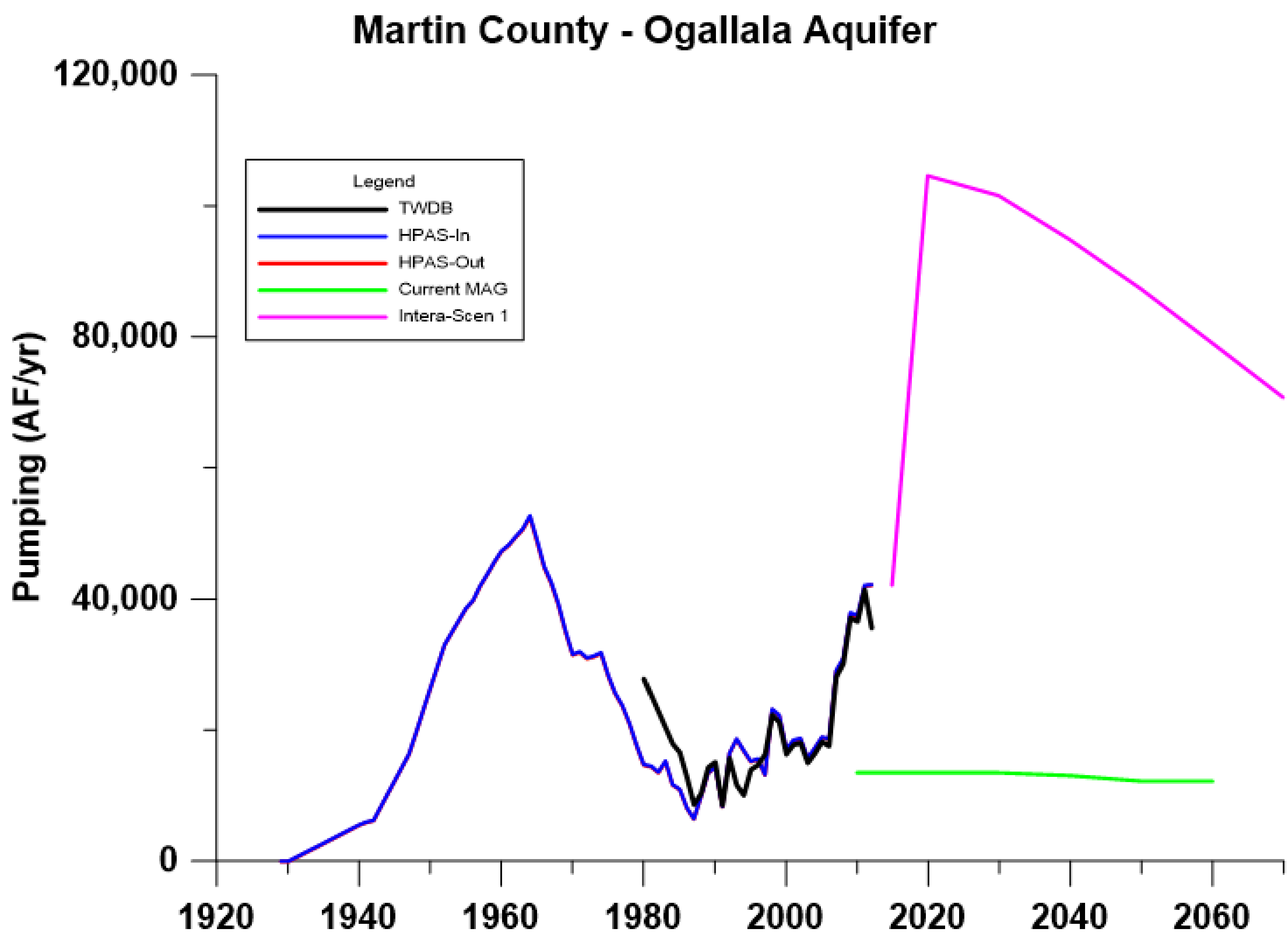

Lamb County - Ogallala Aquifer
800,000
600,000
400,000
200,000
0
Pumping (AF/yr)
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1
1920
1940
1960
1980
2000
2020
2040
2060



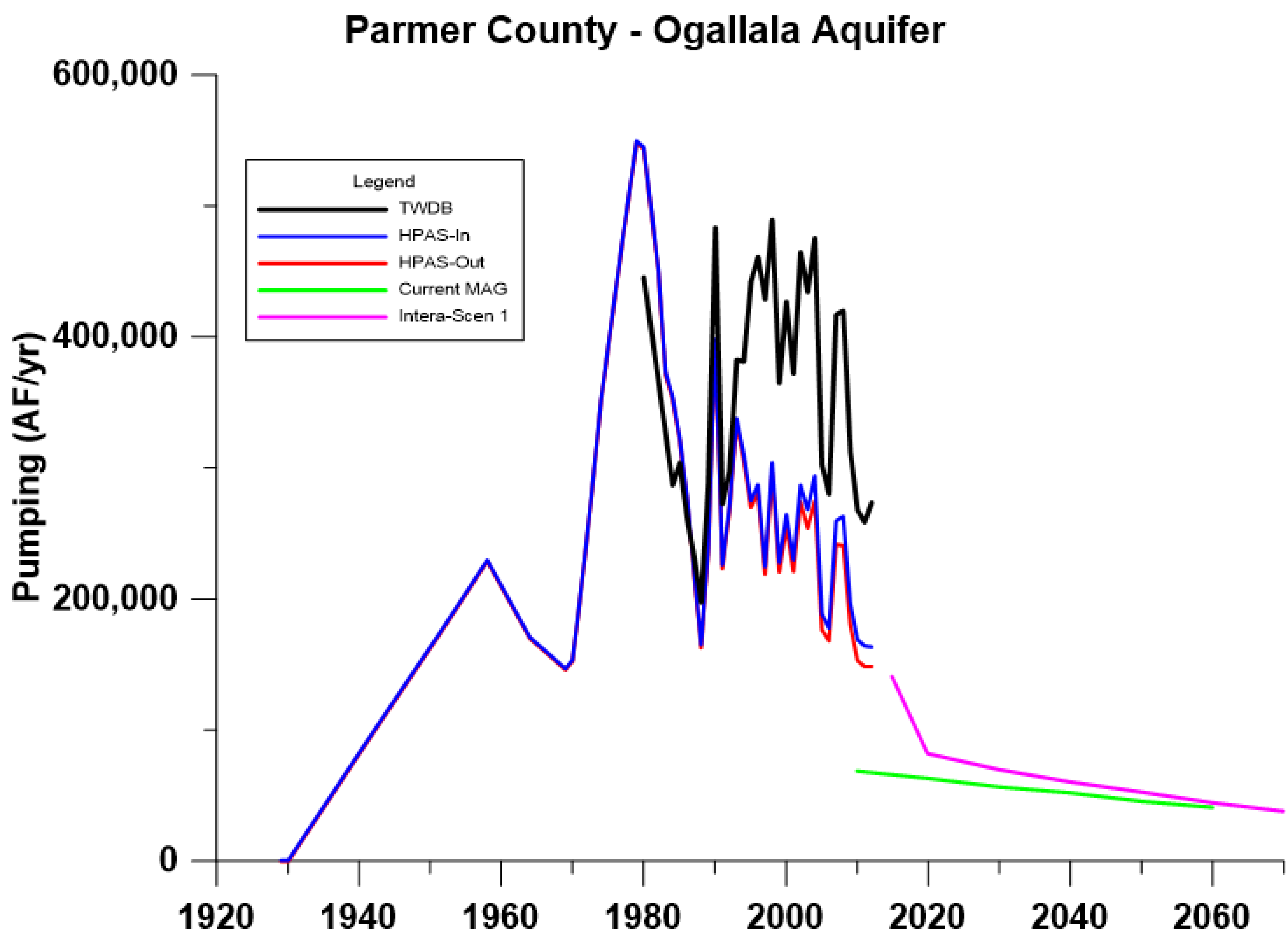
Lubbock County - Ogallala Aquifer
Pumping (AF/yr)
400,000
300,000
200,000
100,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1



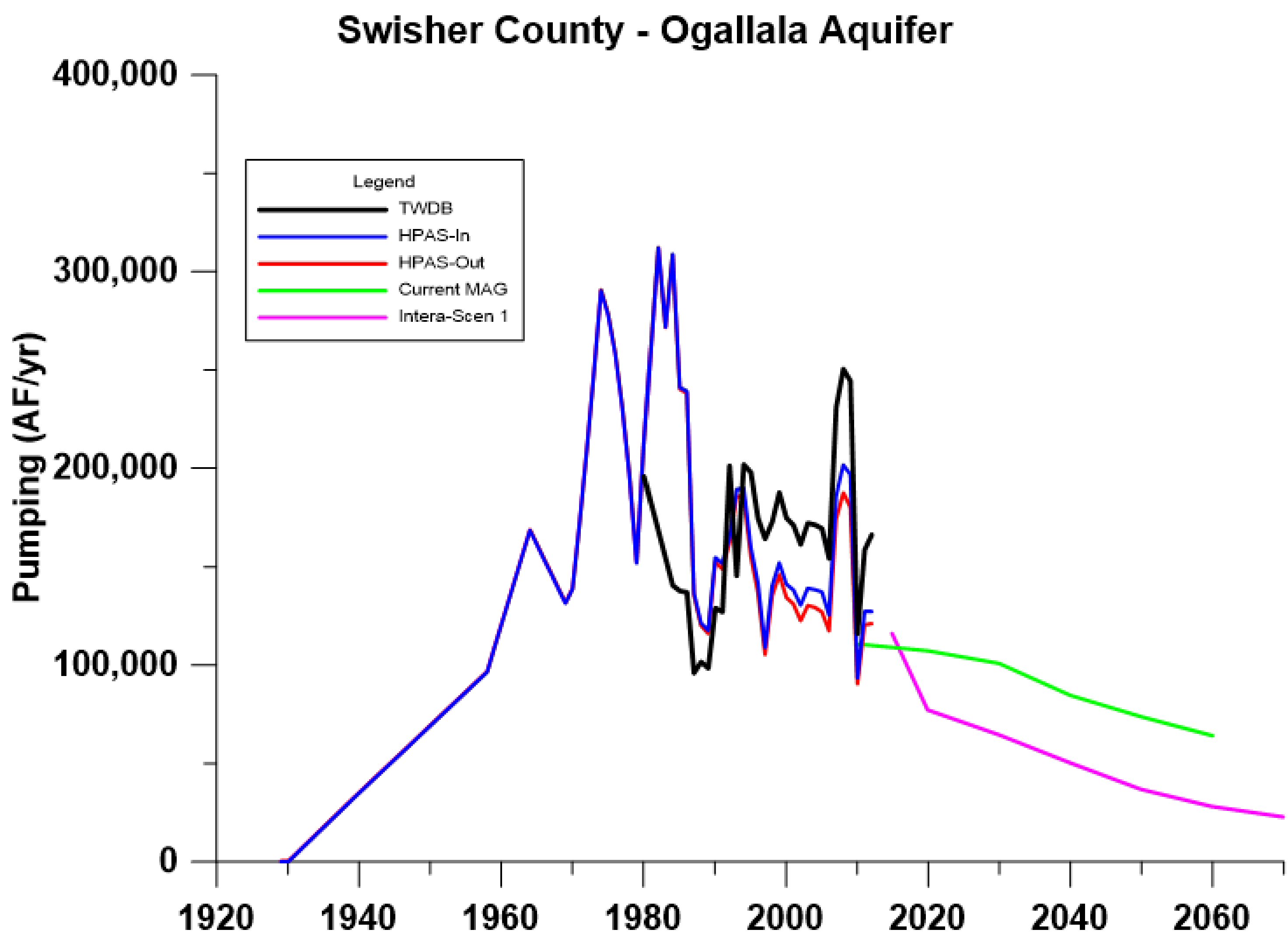
Lynn County - Ogallala Aquifer
Pumping (AF/yr)
300,000
200,000
100,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1



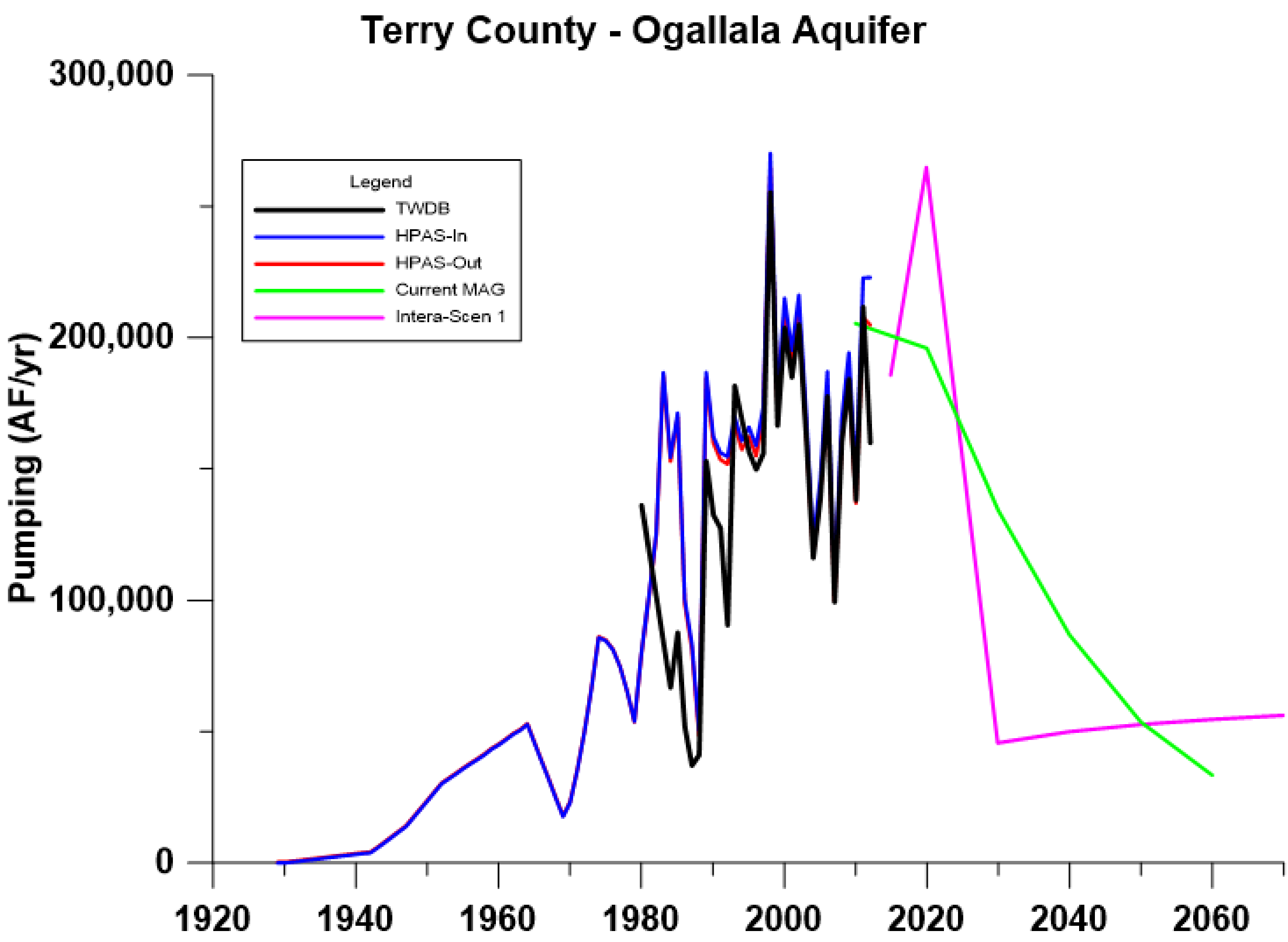
Martin County - Ogallala Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1
Pumping (AF/yr)
120,000
80,000
40,000
0
1920
1940
1960
1980
2000
2020
2040
2060



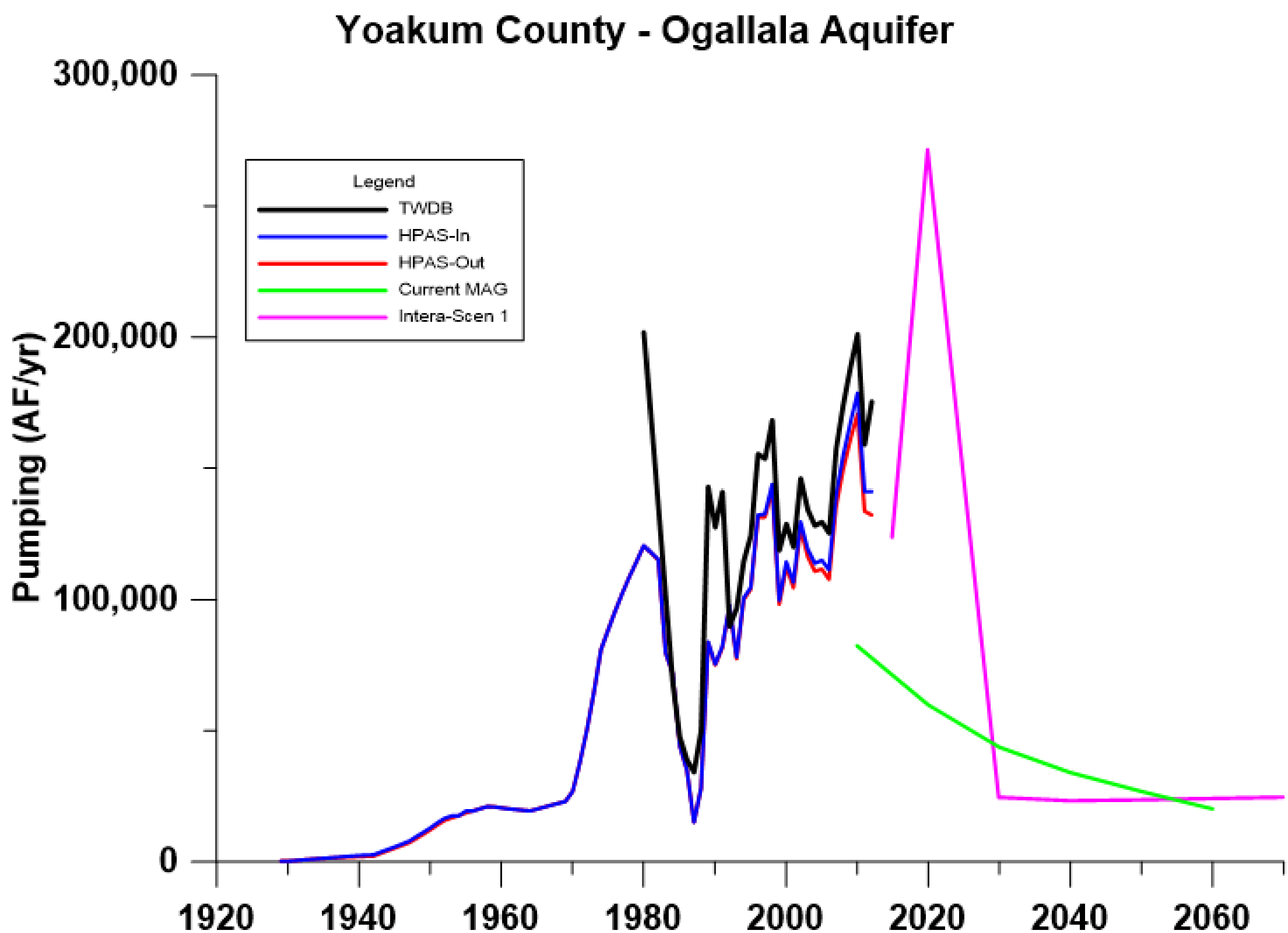
Parmer County - Ogallala Aquifer
Pumping (AF/yr)
600,000
400,000
200,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1



Swisher County - Ogallala Aquifer
Pumping (AF/yr)
400,000
300,000
200,000
100,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1



Terry County - Ogallala Aquifer
Pumping (AF/yr)
300,000
200,000
100,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1


Yoakum County - Ogallala Aquifer
Pumping (AF/yr)
300,000
200,000
100,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Intera-Scen 1

Ogallala Aquifer Summary

- TWDB and HPAS comparison
  - Sometimes agree, sometimes different
  - HPAS estimates are likely more accurate (constrained estimates)
- Intera Scenario 1 pumping
  - Often have large increase in 2020, then sharp decline
  - Sometimes higher than current MAG, sometimes lower

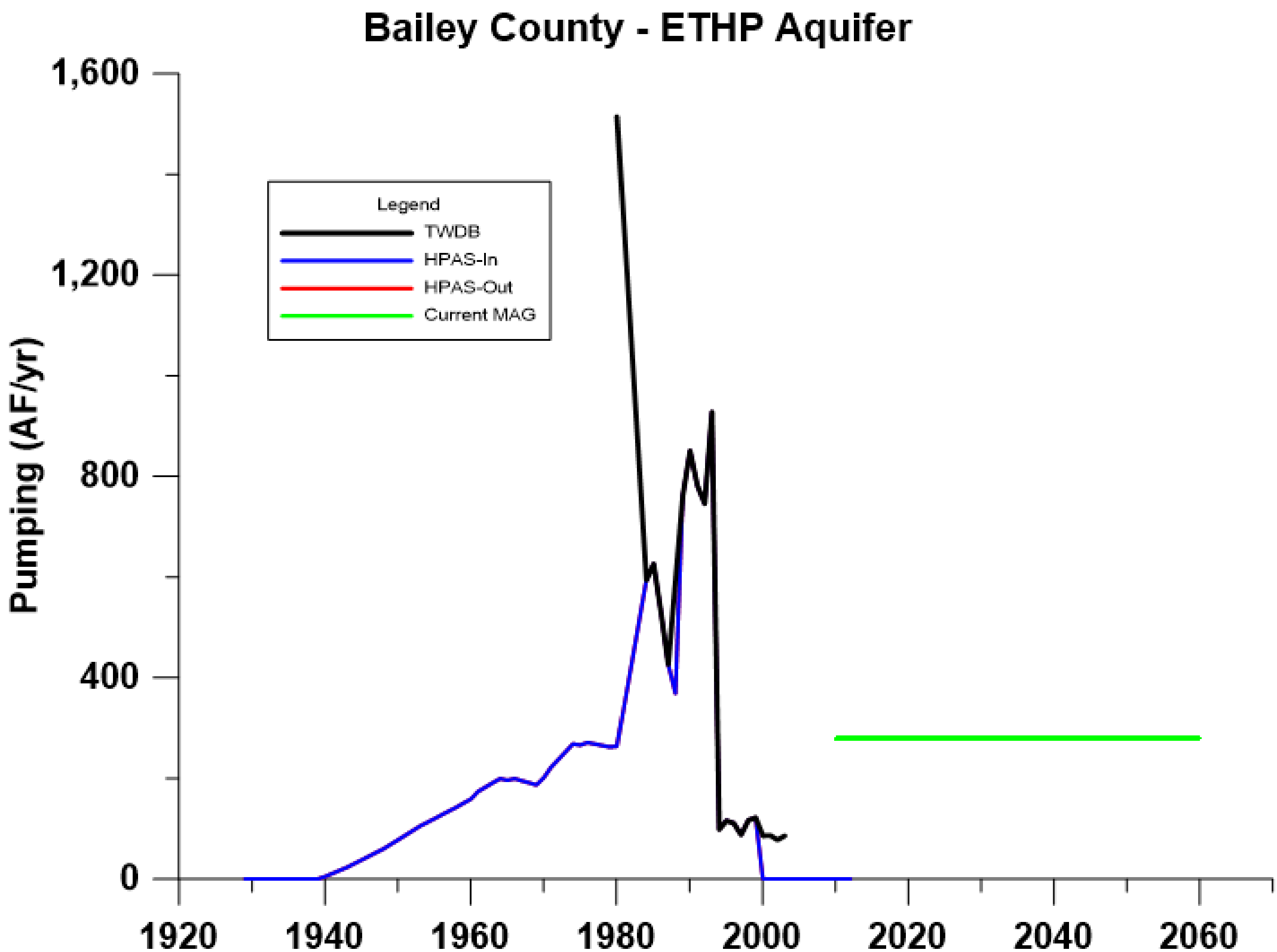
Edwards-Trinity (High Plains) Aquifer (Layer 2 of southern portion of HPAS)

- TWDB – groundwater pumping estimates (1980, 1984-2012) from water use surveys
- HPAS
  - Input pumping
  - Output pumping
- Current MAG
- Did not include Intera results
- Only included counties with TWDB estimates

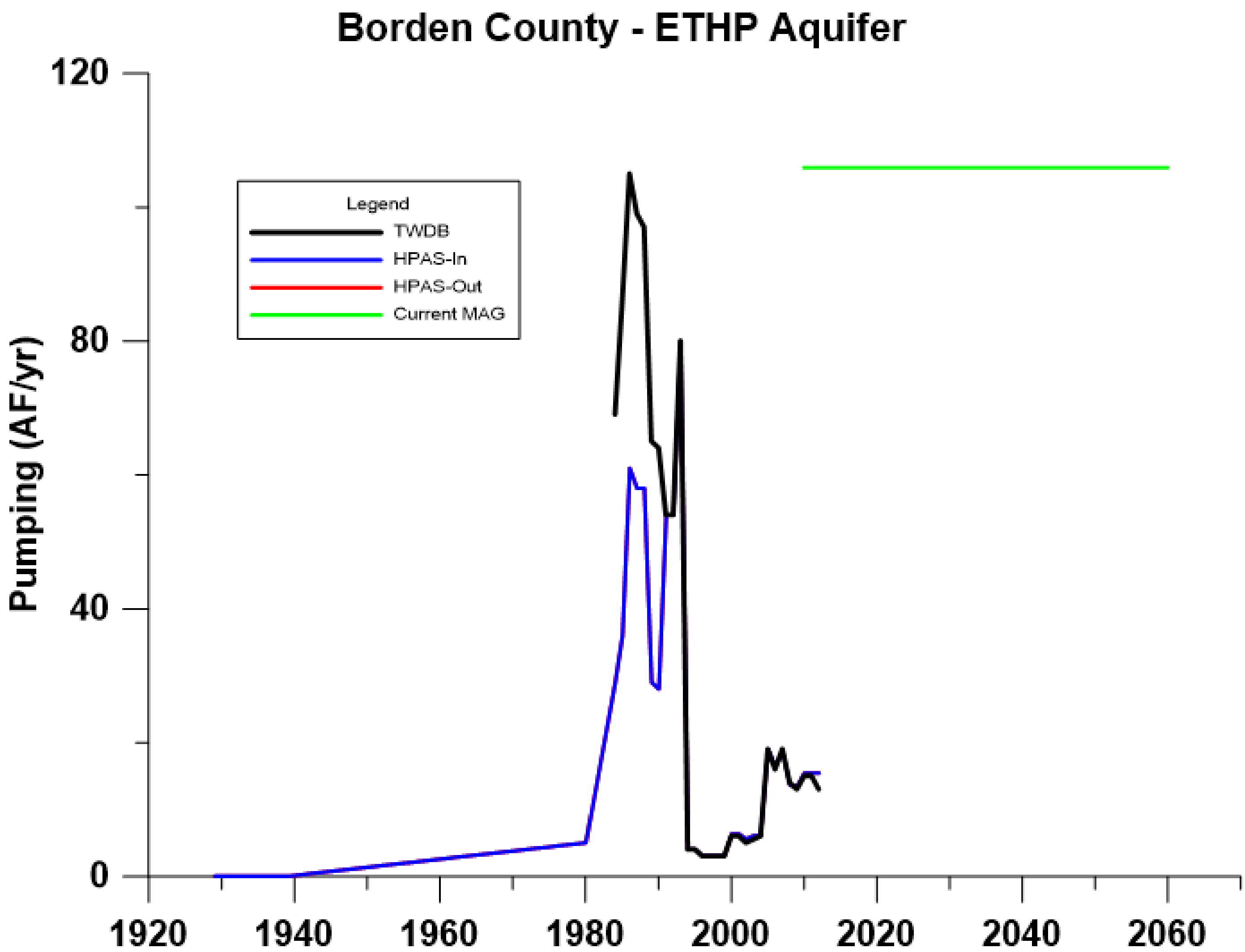
Edwards Trinity (High Plains) Aquifer: GMA2 Counties

ETHP	Available Groundwater							Average Drawdown					
County	2015	2020	2030	2040	2050	2060	2070	2020	2030	2040	2050	2060	2070
Bailey	-	5,796	25,167	33,224	30,483	24,055	16,437	10	21	34	45	53	57
Cochran	19	24,631	139,407	125,329	97,352	71,094	50,007	34	62	91	112	126	135
Floyd	-	12,797	10,268	10,346	10,862	10,718	10,687	25	37	47	56	64	72
Hale	7,307	3,782	3,638	3,242	2,818	2,508	2,288	2	5	9	12	14	15
Hockley	83	180,680	263,626	178,536	113,973	47,680	13,271	44	96	132	154	165	166
Lamb	-	5,382	14,062	22,296	20,782	17,874	15,258	17	30	47	62	73	82
Lubbock	972	23,364	57,345	62,366	58,157	50,345	35,323	27	48	66	78	86	89
Lynn	1,136	108,959	223,628	164,113	117,453	69,427	25,693	21	67	101	123	135	137
Borden	15	6,509	6,210	7,059	7,051	6,250	5,623	13	26	38	50	59	66
Dawson	2,146	8,386	7,574	7,695	8,210	9,239	10,129	16	33	47	57	66	72
Gaines	12,224	39,895	54,478	76,288	83,323	79,962	71,330	18	32	42	50	55	58
Garza	183	7,692	5,081	3,864	2,845	2,268	1,956	26	36	43	47	48	48
Terry	41	273,145	296,466	196,310	124,738	61,816	12,349	45	104	144	169	182	184
Yoakum	6	136,609	226,741	160,655	109,104	59,173	25,135	28	74	109	131	144	148

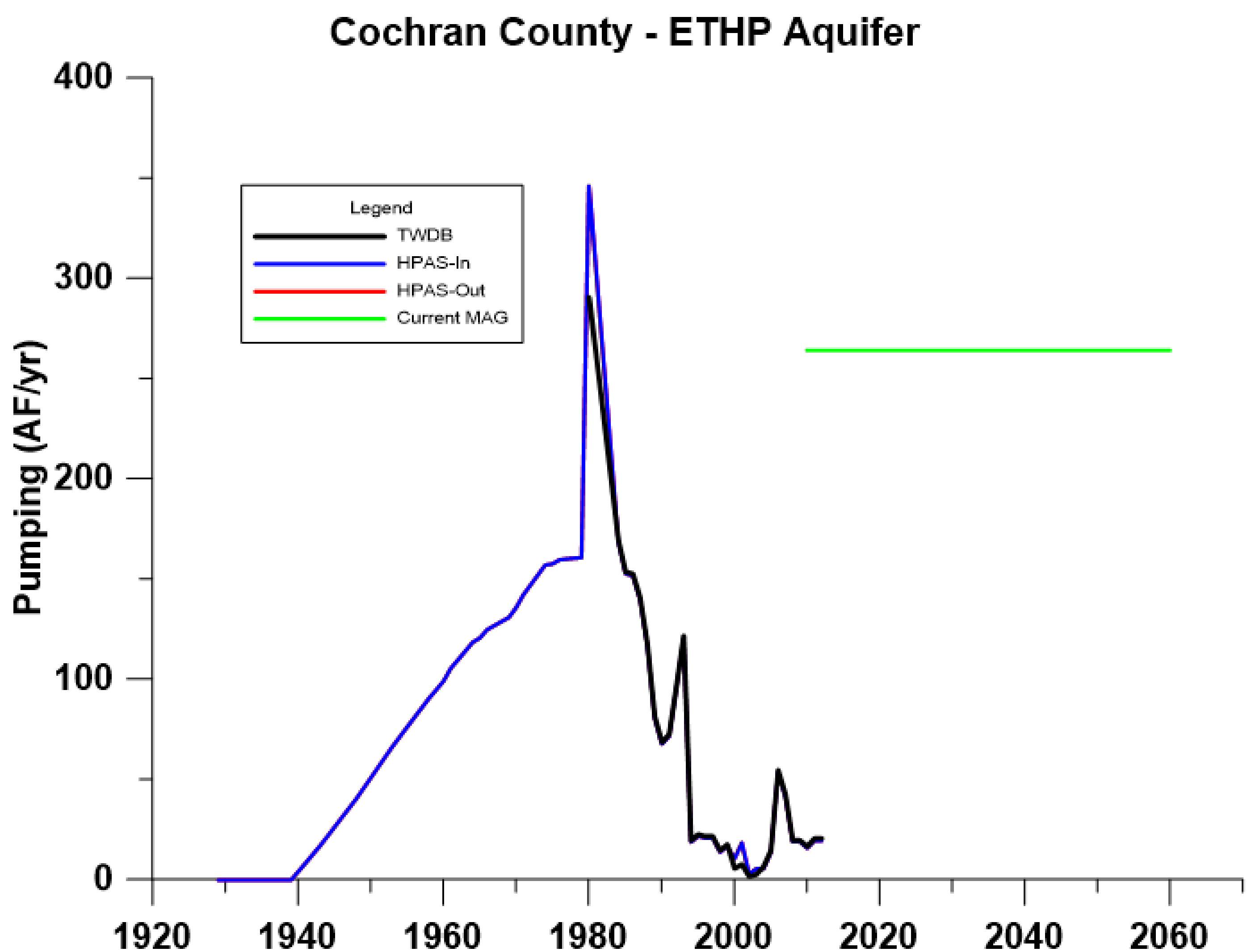
Note: The very high rates that occur are due to simulated desaturation of the ETHP, when target water levels are below the top of the ETHP. This type of storage change under desaturation of a confined aquifer is not a well-studied phenomenon, and we should treat these results with caution.

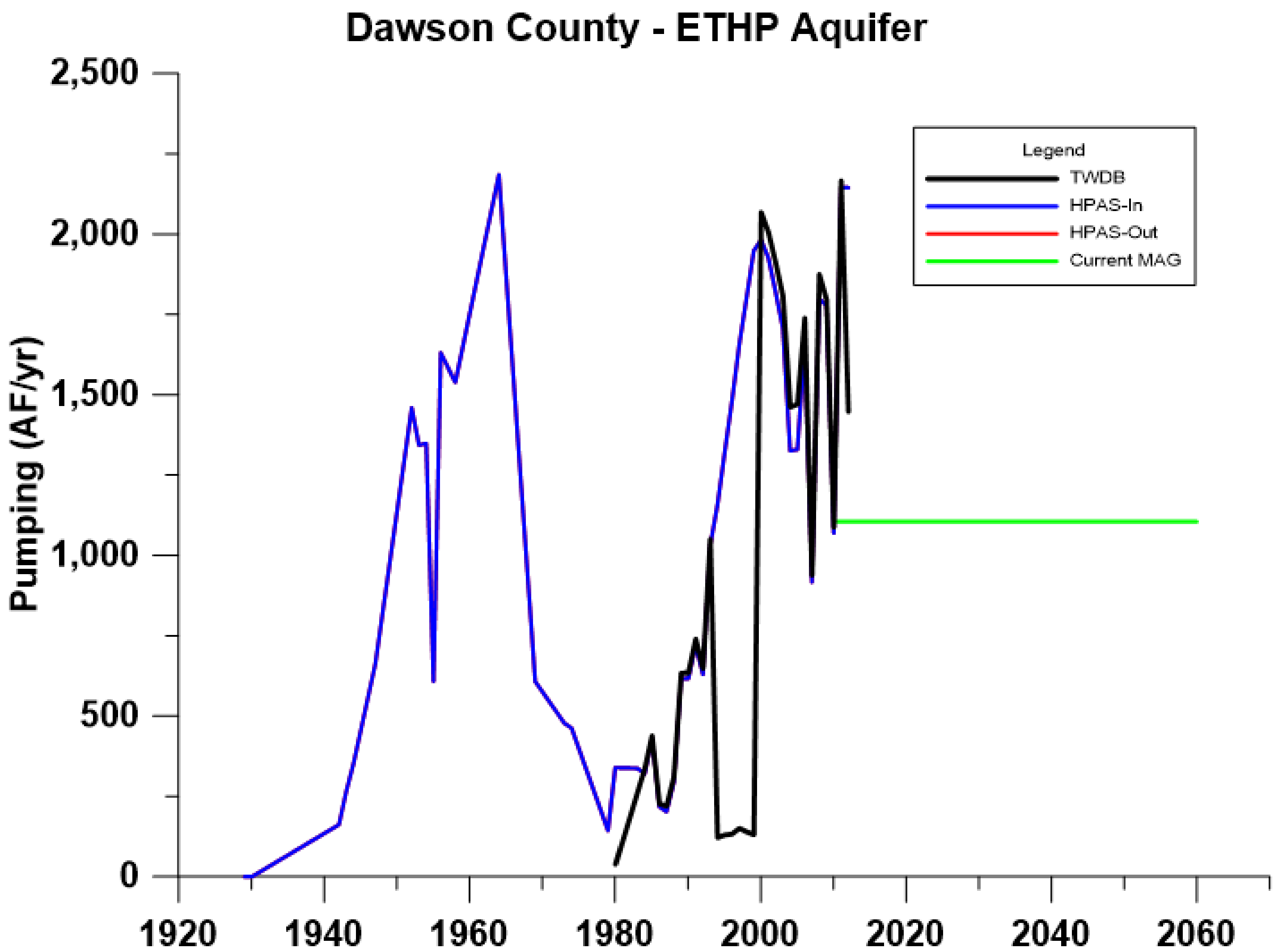


Bailey County - ETHP Aquifer
Pumping (AF/yr)
1,600
1,200
800
400
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG

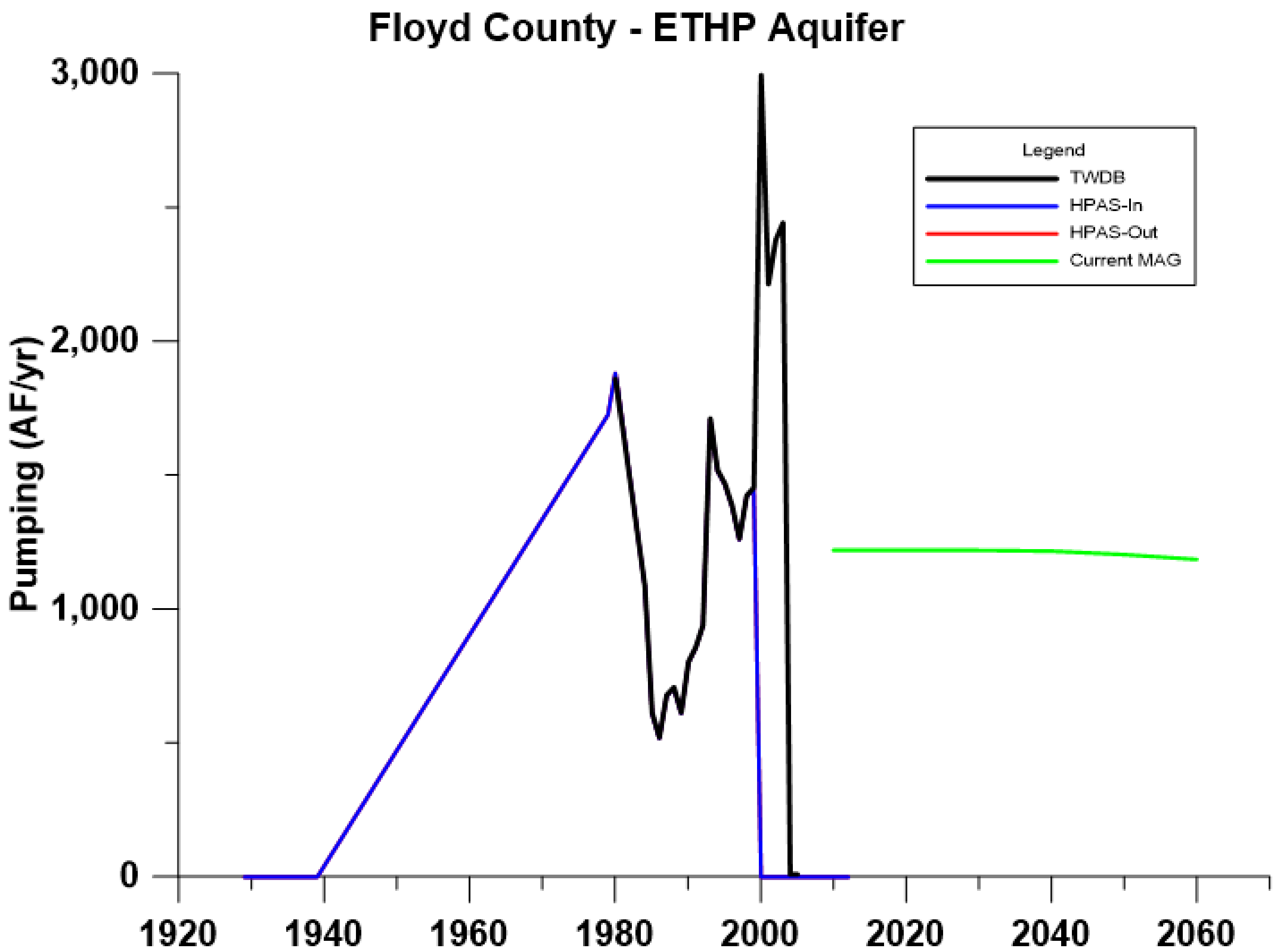


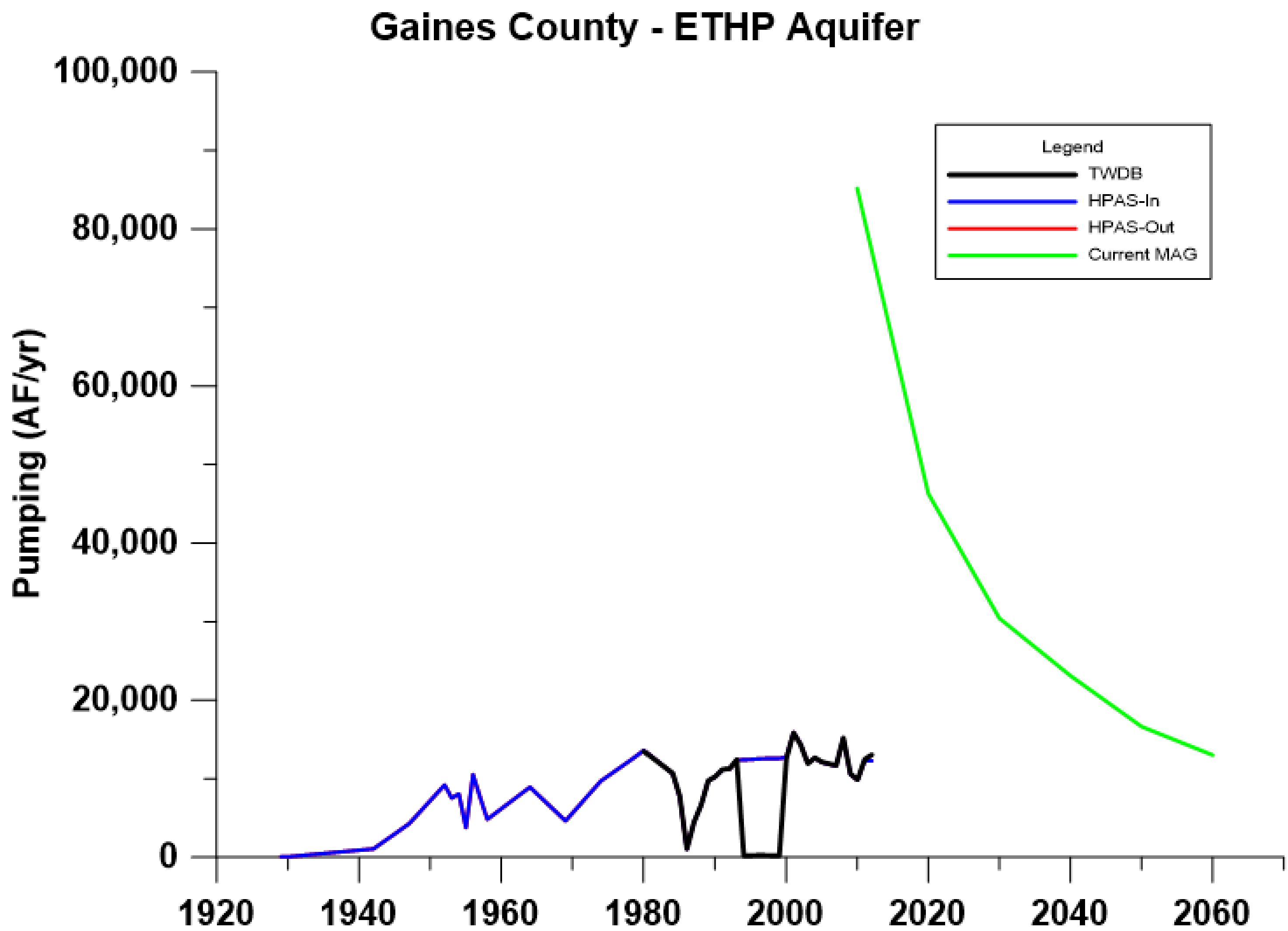
Borden County - ETHP Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Pumping (AF/yr)
120
80
40
0
1920
1940
1960
1980
2000
2020
2040
2060


Cochran County - ETHP Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Pumping (AF/yr)
400
300
200
100
0
1920
1940
1960
1980
2000
2020
2040
2060

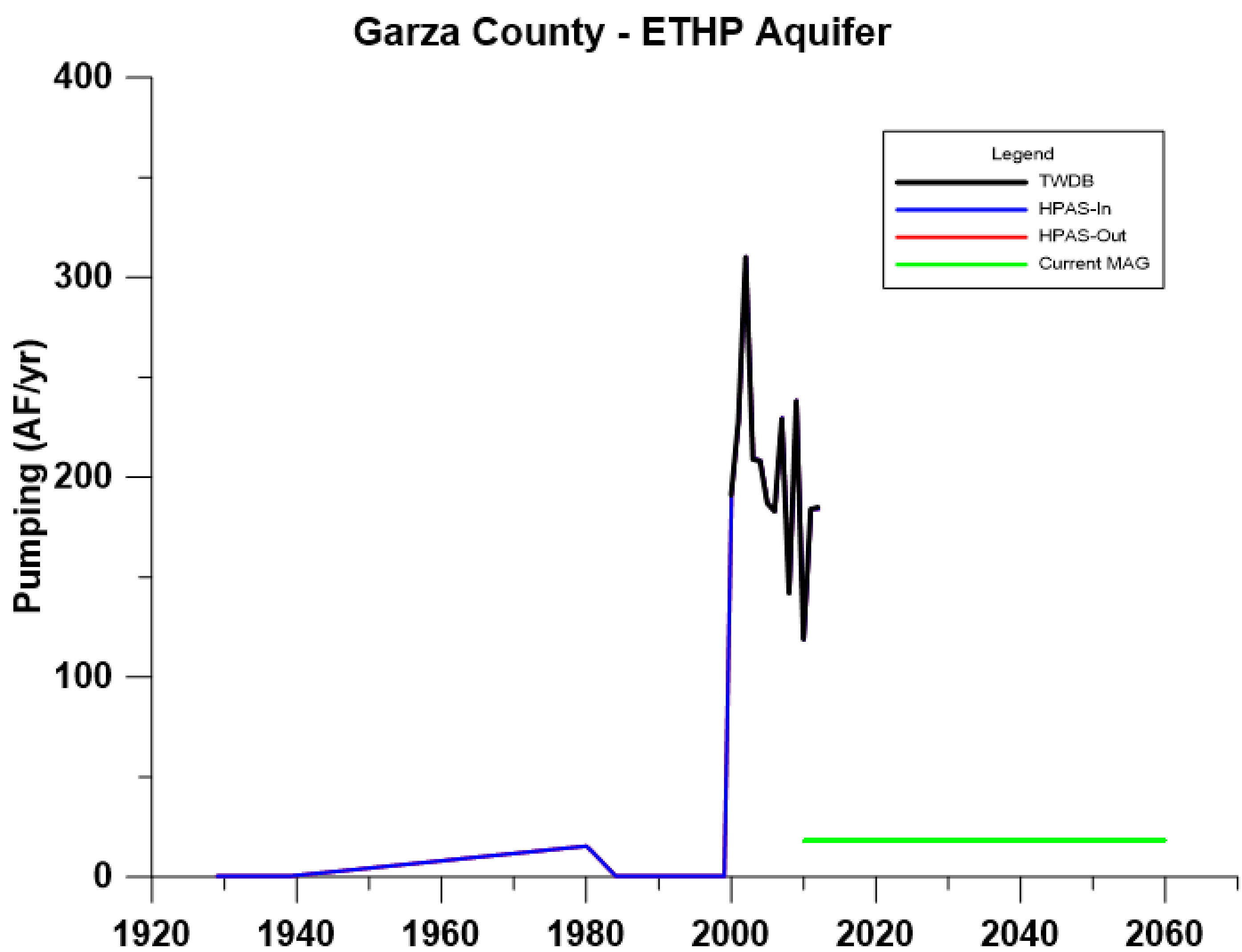


Dawson County - ETHP Aquifer
Pumping (AF/yr)
0
500
1,000
1,500
2,000
2,500
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG

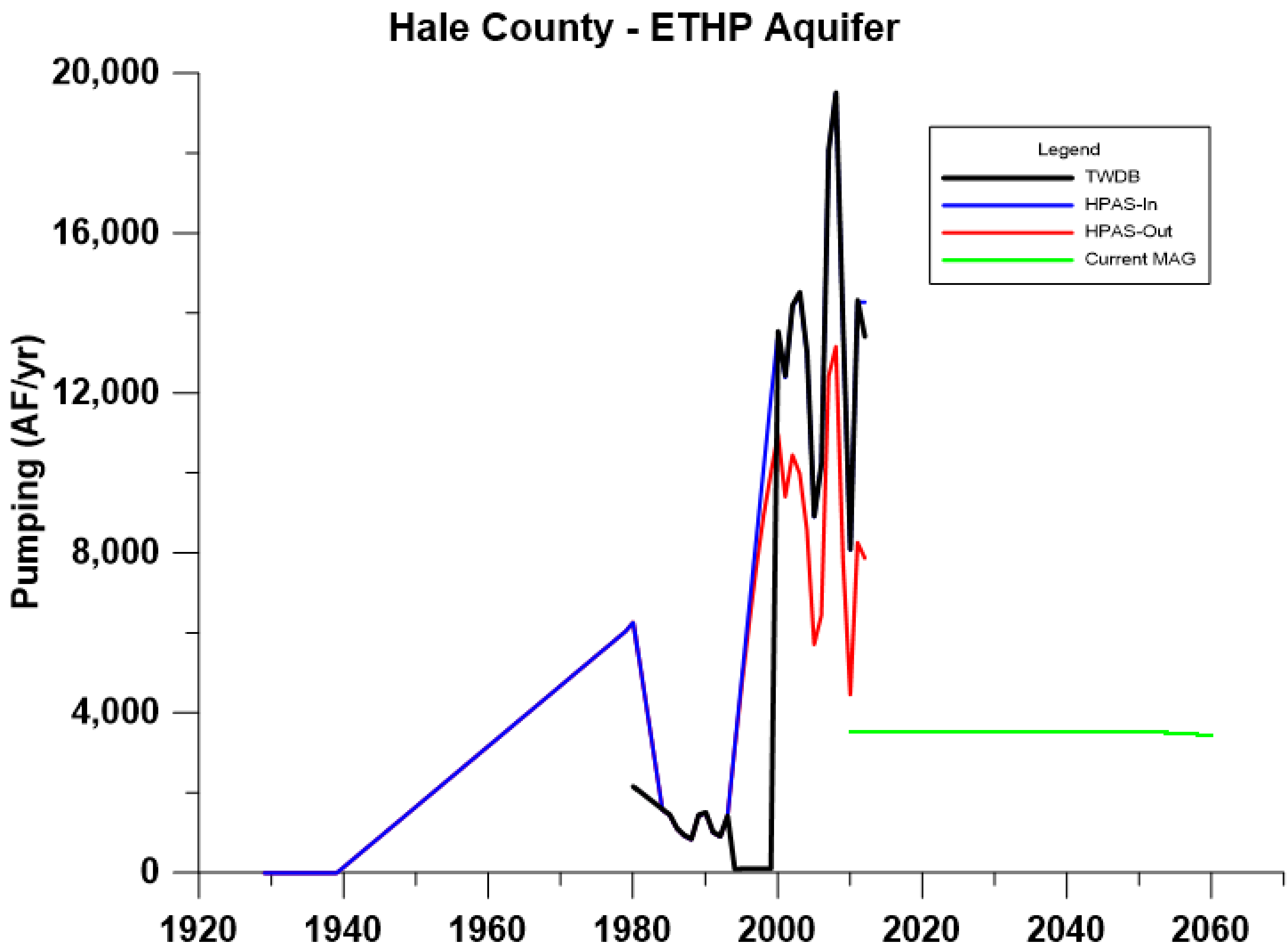

Floyd County - ETHP Aquifer
Pumping (AF/yr)
3,000
2,000
1,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG

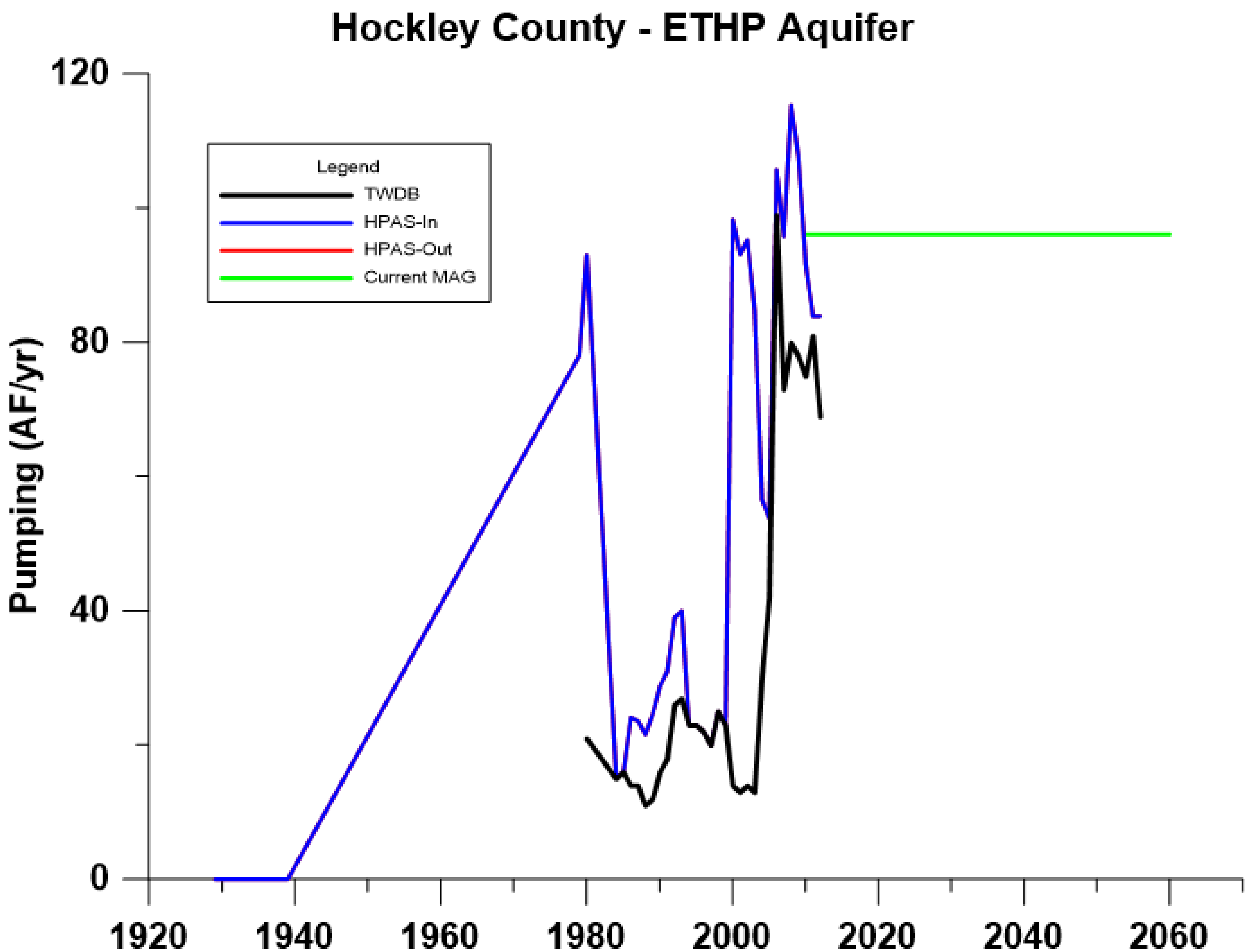


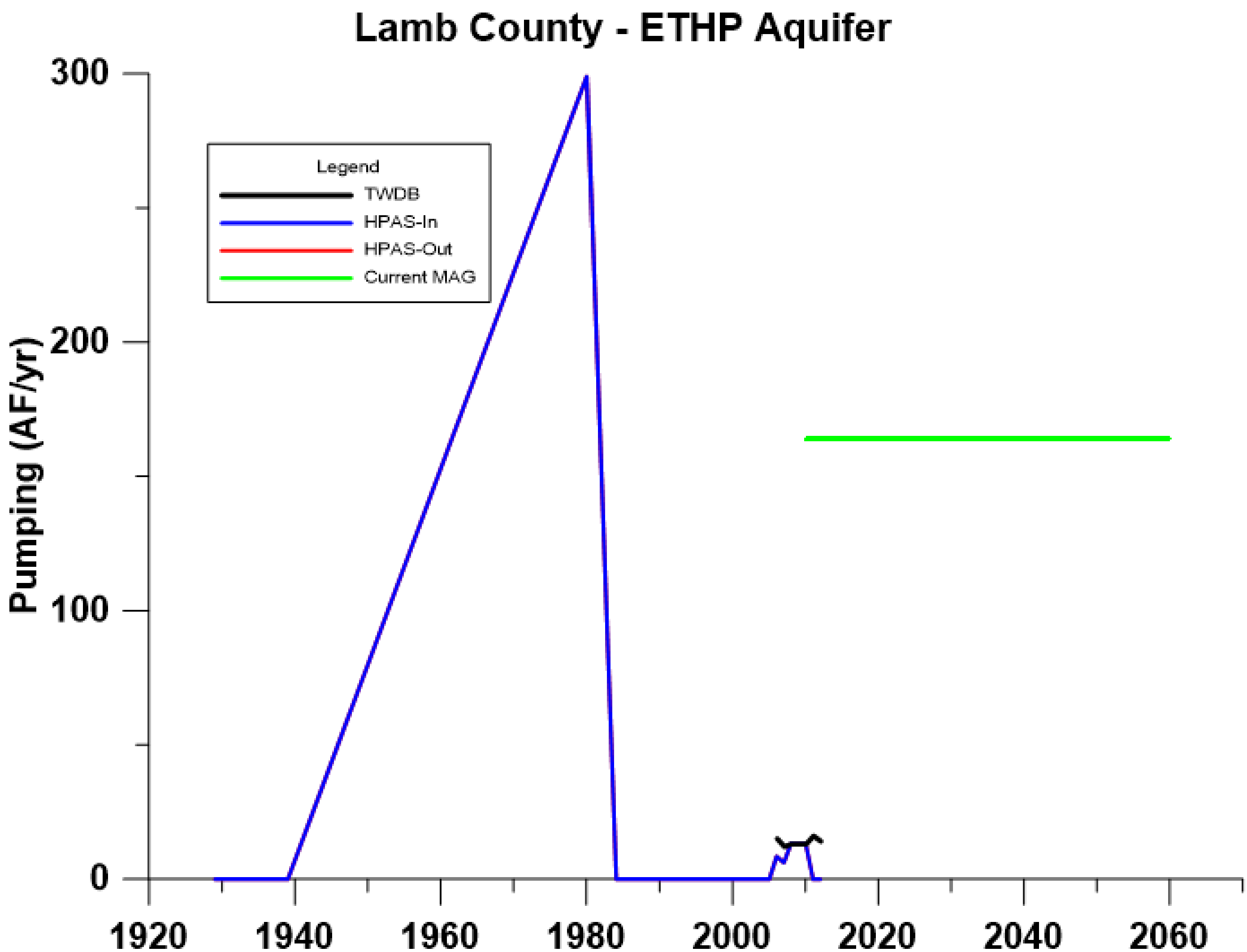
Gaines County - ETHP Aquifer
Pumping (AF/yr)
100,000
80,000
60,000
40,000
20,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG

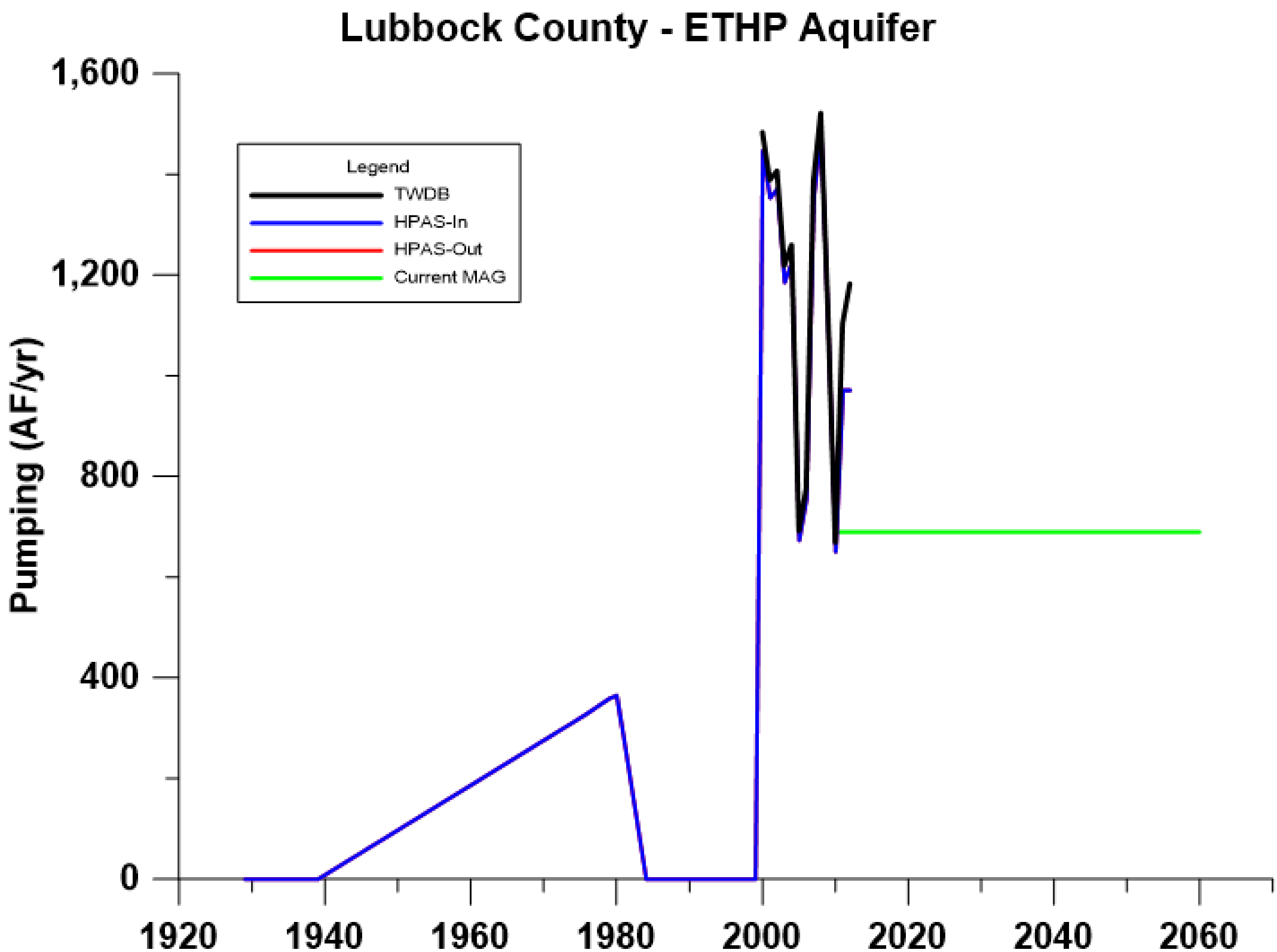


Garza County - ETHP Aquifer
Pumping (AF/yr)
400
300
200
100
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG

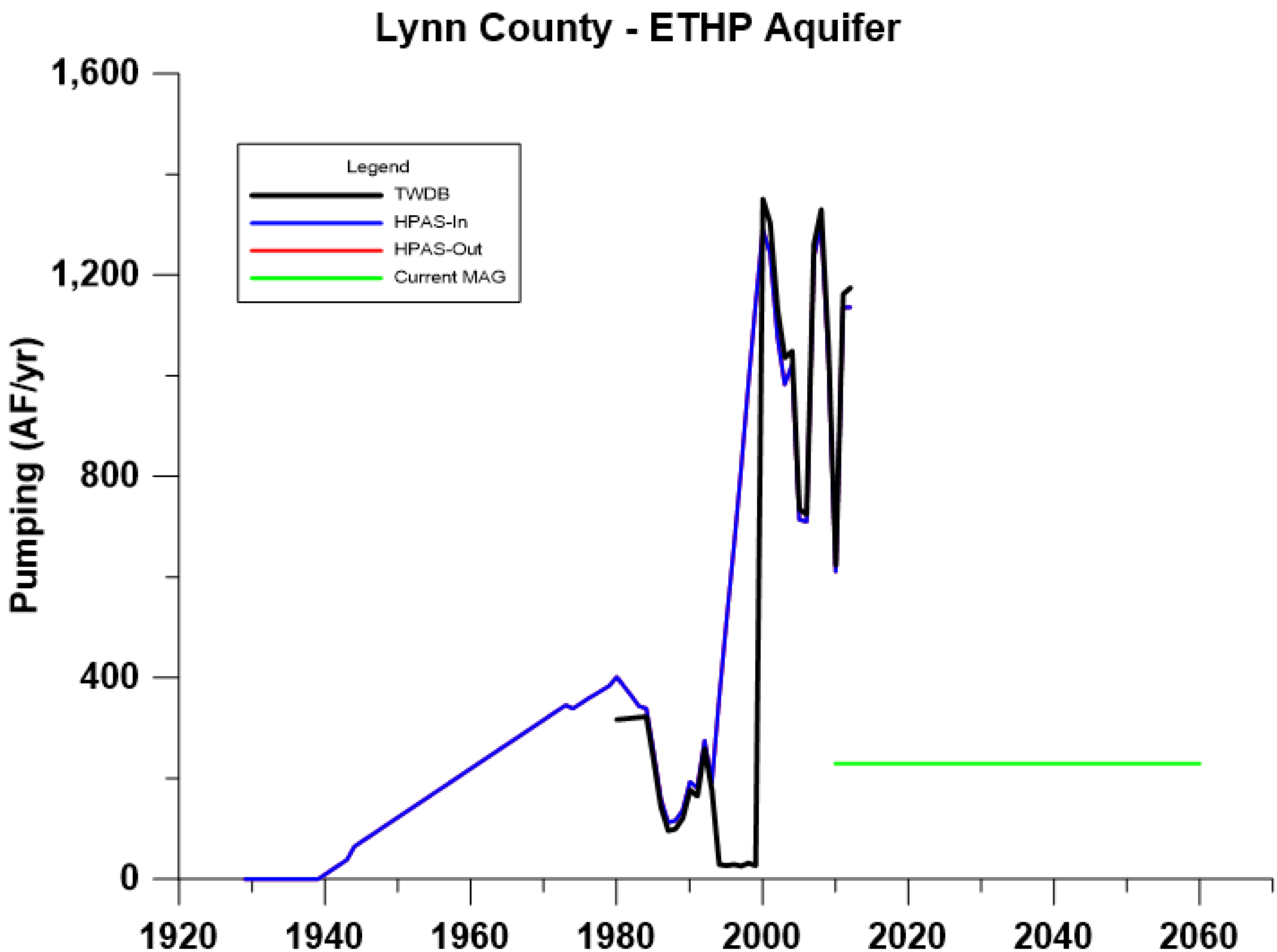

Hale County - ETHP Aquifer
Pumping (AF/yr)
20,000
16,000
12,000
8,000
4,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG


Hockley County - ETHP Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Pumping (AF/yr)
120
80
40
0
1920
1940
1960
1980
2000
2020
2040
2060

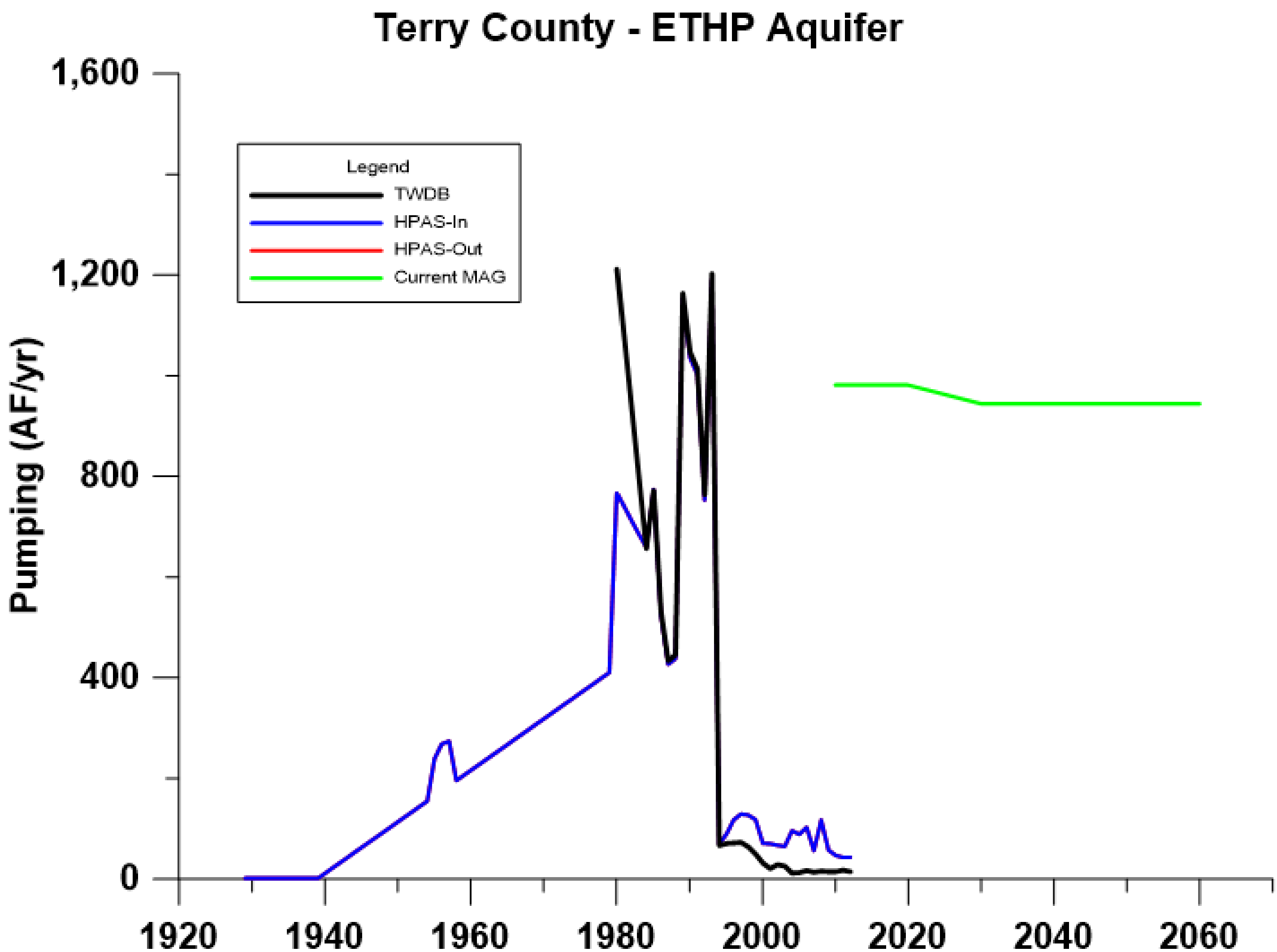

Lamb County - ETHP Aquifer
Pumping (AF/yr)
300
200
100
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG



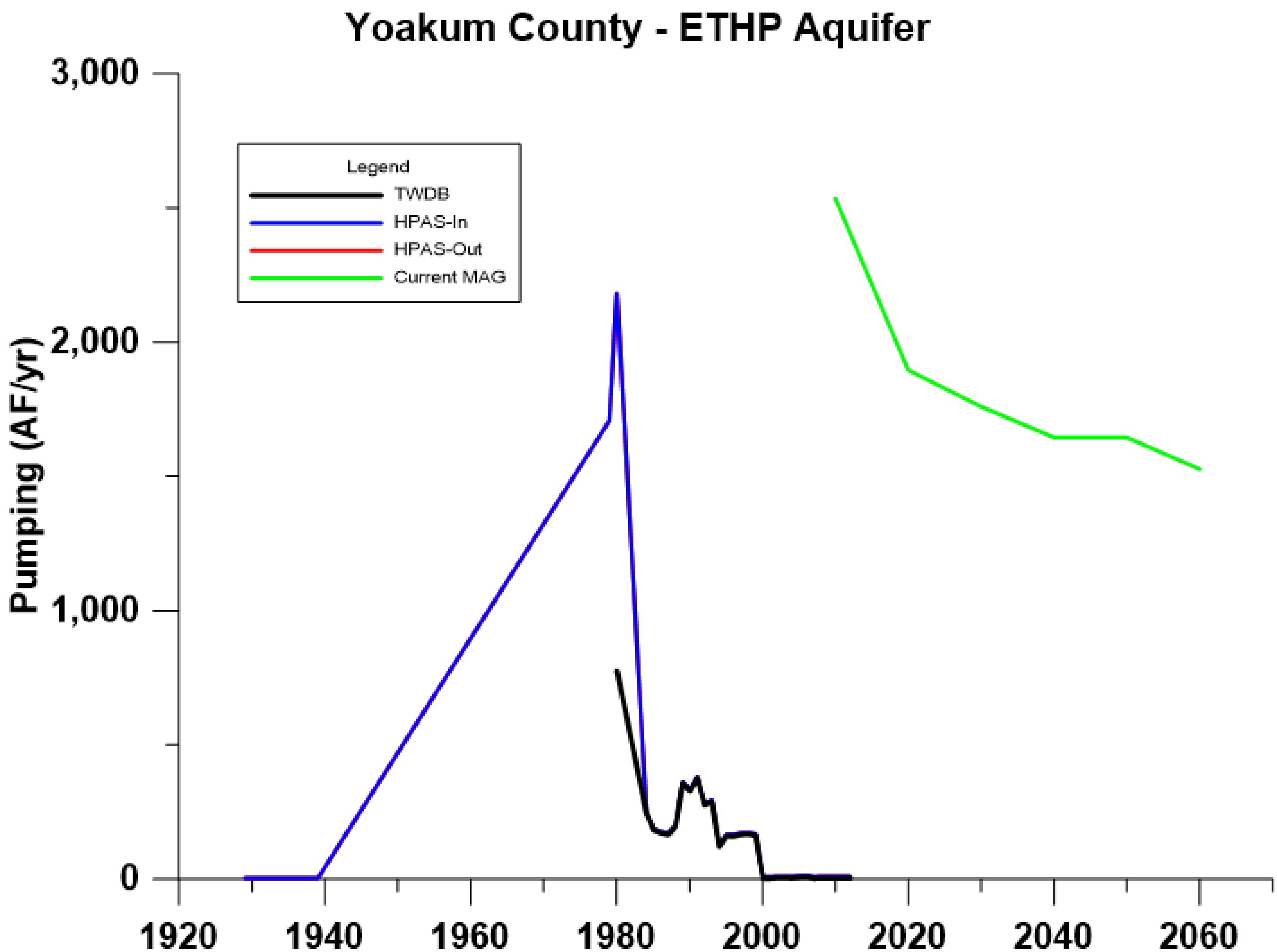
Lubbock County - ETHP Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
1,600
1,200
800
400
0
Pumping (AF/yr)
1920
1940
1960
1980
2000
2020
2040
2060



Lynn County - ETHP Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Pumping (AF/yr)
1,600
1,200
800
400
0
1920
1940
1960
1980
2000
2020
2040
2060



Terry County - ETHP Aquifer
1,600
1,200
800
400
0
Pumping (AF/yr)
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
1920
1940
1960
1980
2000
2020
2040
2060



Yoakum County - ETHP Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Pumping (AF/yr)
3,000
2,000
1,000
0
1920
1940
1960
1980
2000
2020
2040
2060

ETHP Summary

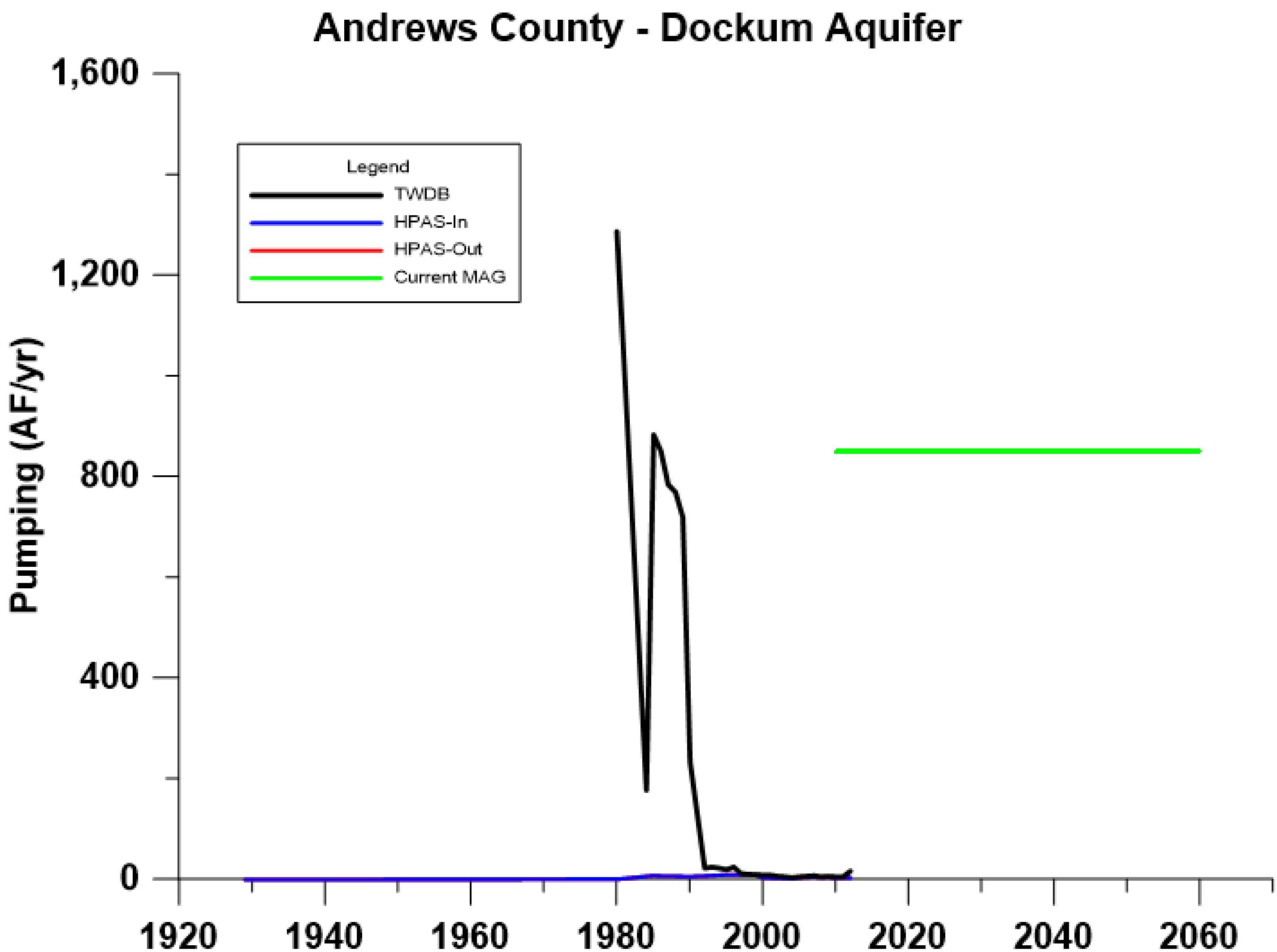
- HPAS estimates generally consistent with TWDB estimates
- Current MAGs are not consistent with historic pumping (sometimes much higher, sometimes much lower)
  - Old model estimates of historic pumping may not have been based on TWDB historic data?
- Intera scenario combined thickness with Ogallala and sought 50/50
- Need to use historic data as starting point and consider range of increases and decreases

Dockum Aquifer (Layers 3 and 4 of HPAS)

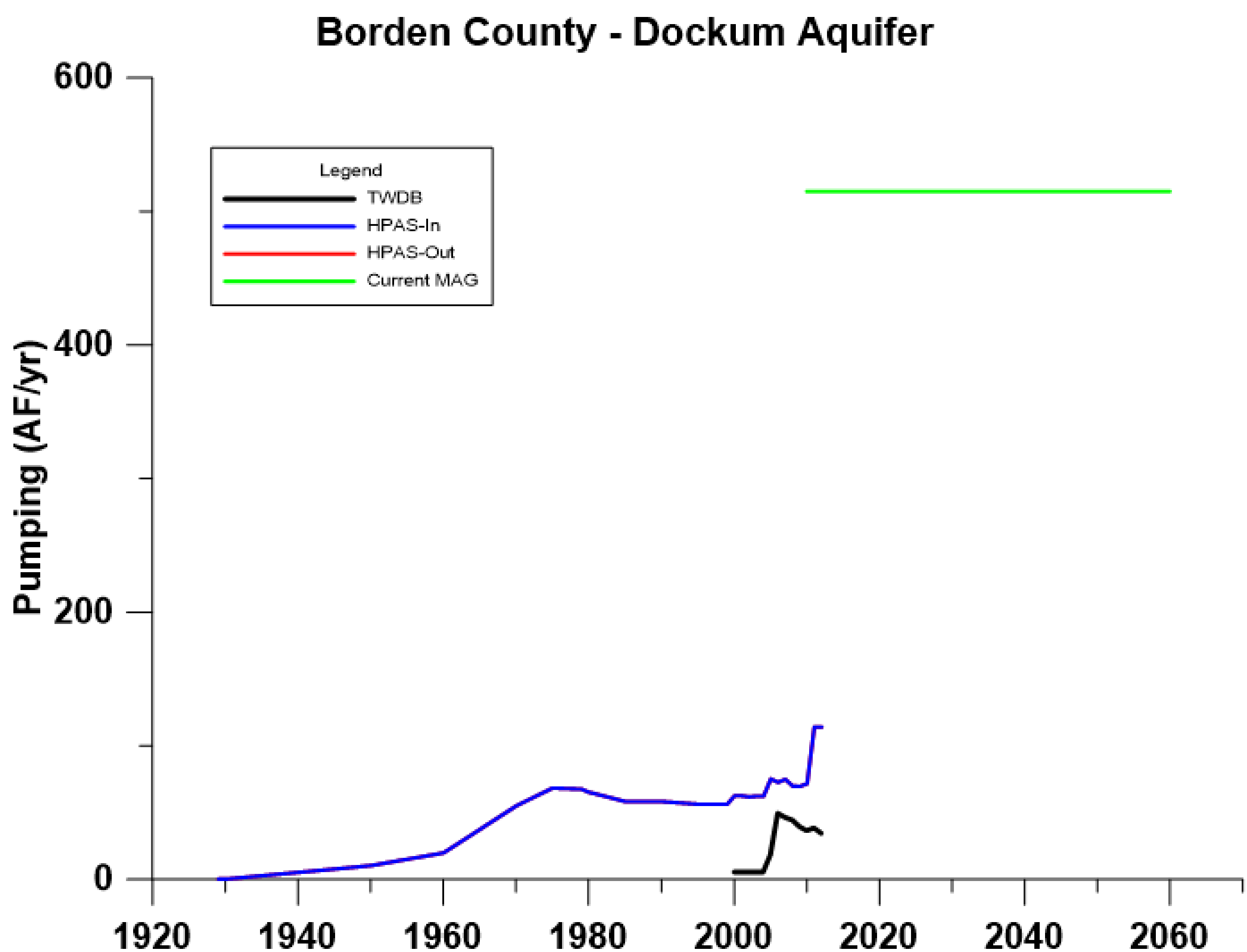
- TWDB – groundwater pumping estimates (1980, 1984-2012) from water use surveys
- HPAS
  - Input pumping
  - Output pumping
- Current MAG
- Did not include Intera results
- Only included counties with TWDB estimates

Dockum Aquifer: GMA2 Counties

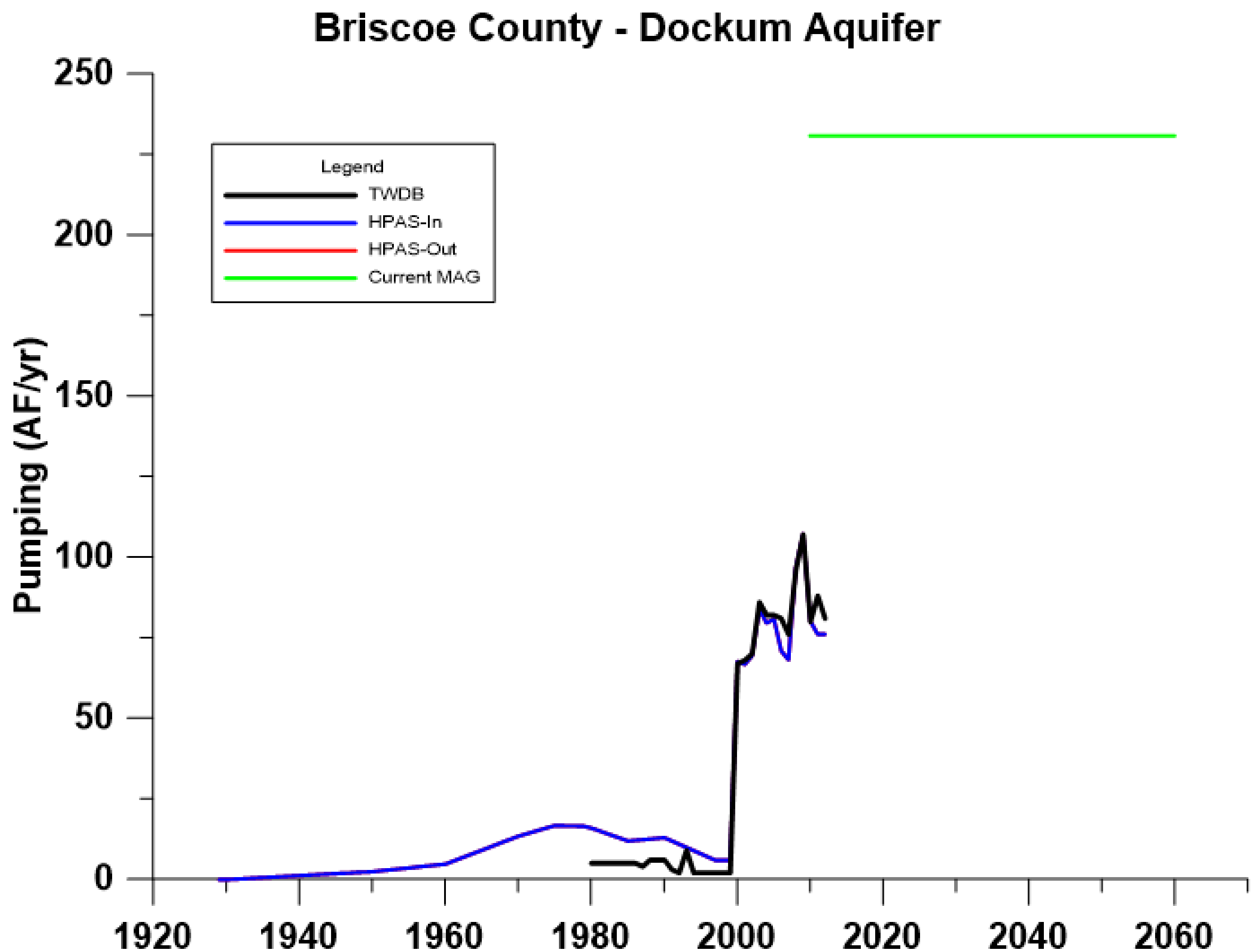
Dockum	Available Groundwater							Average Drawdown					
County	2015	2020	2030	2040	2050	2060	2070	2020	2030	2040	2050	2060	2070
Bailey	-	35,087	31,540	28,160	25,301	22,661	20,440	58	164	256	337	406	467
Castro	322	14,427	12,971	11,649	10,564	9,571	8,754	28	80	124	163	197	227
Cochran	-	41,403	36,801	32,571	29,017	25,761	23,029	70	196	306	402	485	558
Crosby	2,930	60,865	60,087	56,495	52,709	48,706	45,083	7	21	32	43	52	60
DeafSmith	2,100	20,461	20,104	19,251	18,344	17,382	16,545	14	39	61	81	98	112
Floyd	2,450	13,896	16,755	17,300	17,378	17,243	17,071	8	23	37	48	58	67
Hale	129	10,138	9,214	8,335	7,627	6,987	6,451	20	57	90	118	143	165
Hockley	27	39,838	35,385	31,208	27,695	24,487	21,796	53	149	233	306	370	425
Lamb	-	29,348	26,151	23,157	20,652	18,366	16,458	41	114	179	235	283	326
Lubbock	3	16,808	15,047	13,376	11,983	10,718	9,674	27	77	120	158	191	219
Lynn	81	24,999	22,666	20,365	18,378	16,526	14,967	31	88	138	181	219	251
Parmer	-	21,490	19,557	17,601	15,932	14,377	13,066	38	107	167	219	265	304
Swisher	1,177	5,228	6,590	7,288	7,772	8,061	8,259	9	24	38	51	62	71
Andrews	3	36,285	32,971	29,620	26,702	23,969	21,654	31	87	136	180	218	251
Borden	113	724,601	641,085	564,818	500,593	442,197	393,094	40	113	177	233	281	324
Briscoe	76	15,155	18,706	19,647	19,692	19,360	18,767	2	7	11	15	20	24
Dawson	2	22,479	20,306	18,121	16,218	14,441	12,933	29	82	128	169	205	236
Gaines	-	61,590	56,314	50,554	45,357	40,420	36,182	47	133	209	277	336	388
Garza	190	303,805	273,486	243,548	217,825	194,111	173,899	17	49	77	101	123	142
Howard	413	230,343	214,382	194,605	176,805	159,628	144,636	14	41	65	86	105	122
Martin	322	17,792	16,285	14,635	13,200	11,869	10,755	23	66	104	137	166	191
Terry	-	47,669	42,277	37,293	33,079	29,208	25,947	59	167	261	343	414	477
Yoakum	-	47,554	42,422	37,607	33,507	29,718	26,513	67	190	297	390	472	543



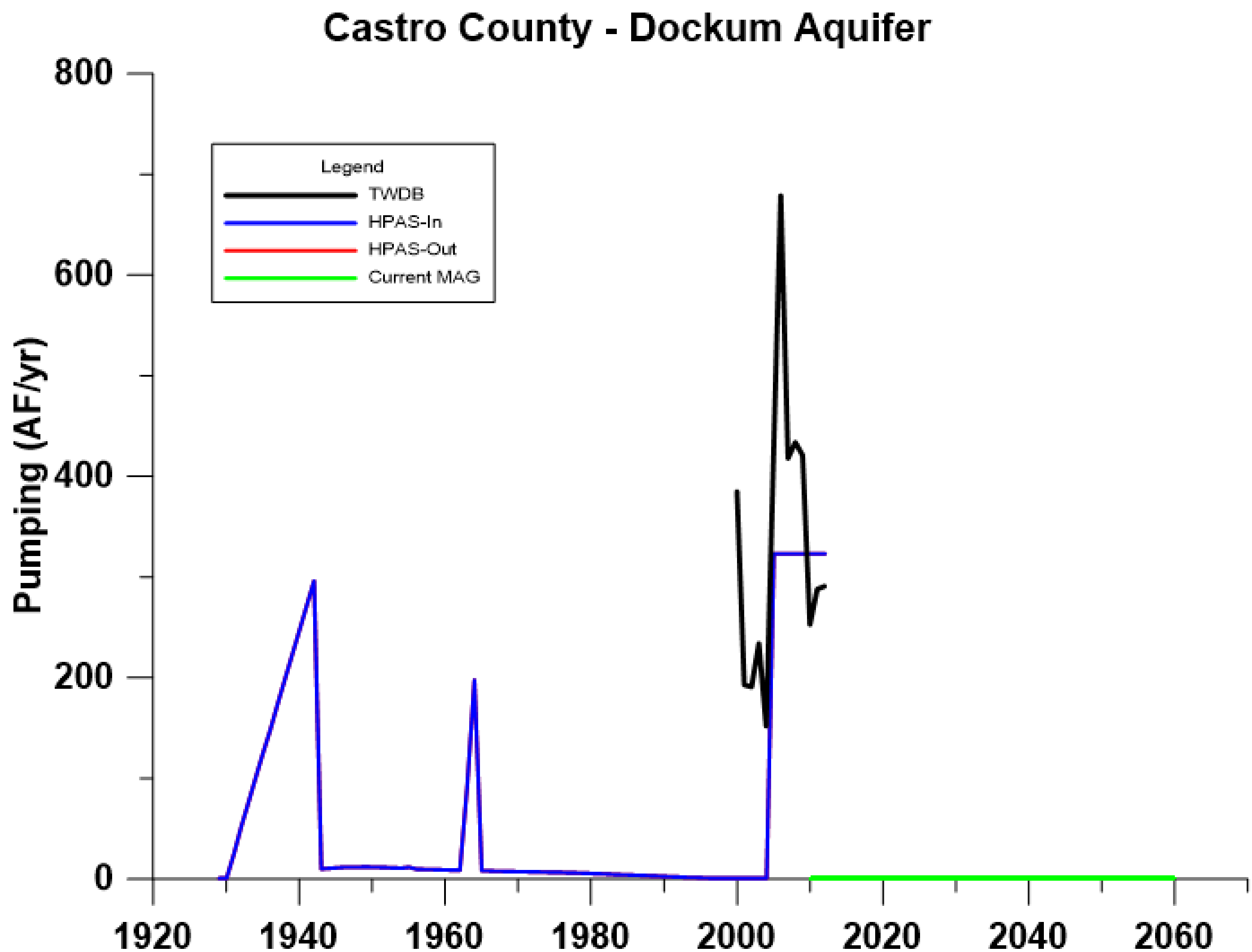
Andrews County - Dockum Aquifer
Pumping (AF/yr)
1,600
1,200
800
400
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG



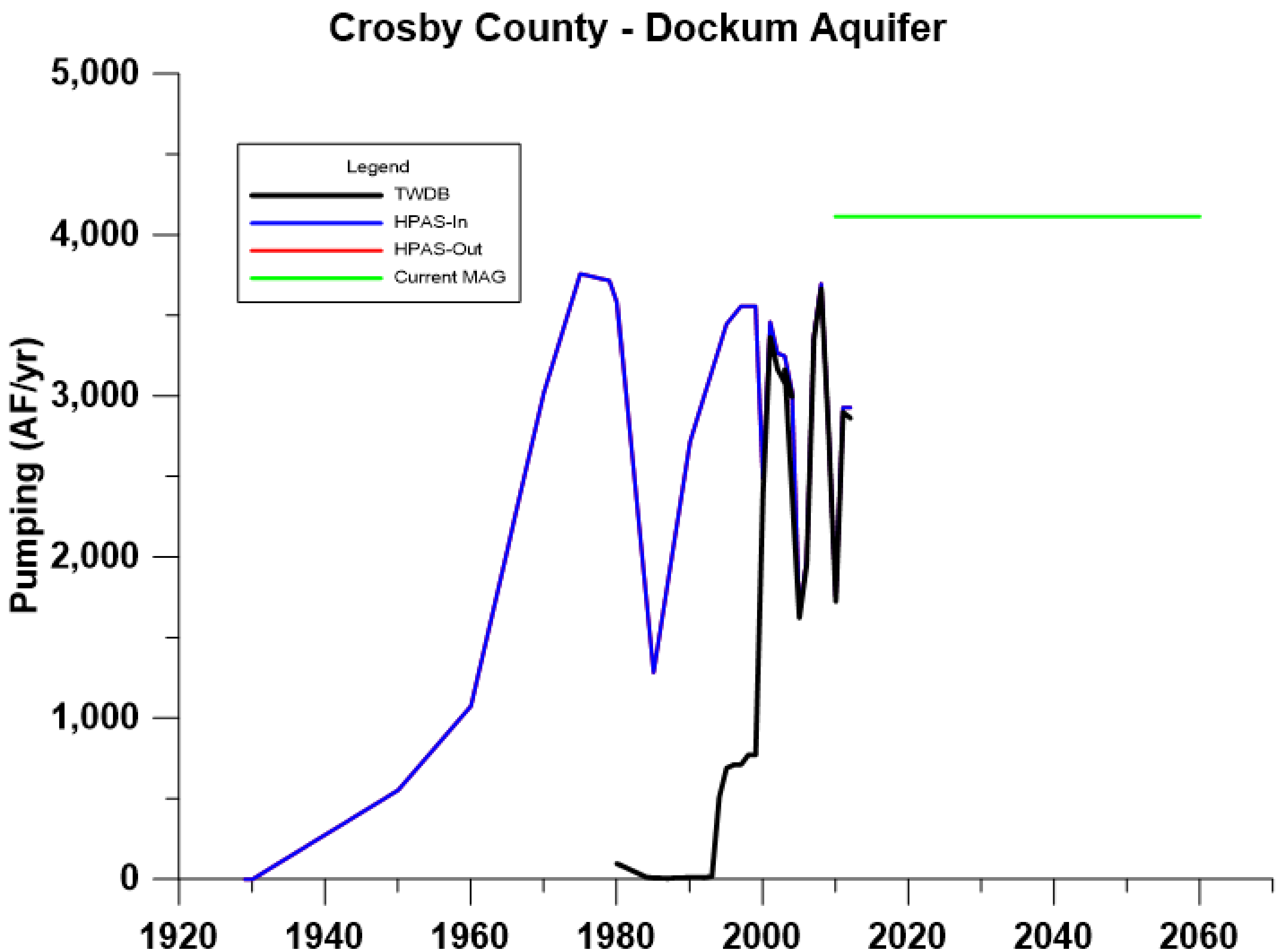
Borden County - Dockum Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Pumping (AF/yr)
600
400
200
0
1920
1940
1960
1980
2000
2020
2040
2060



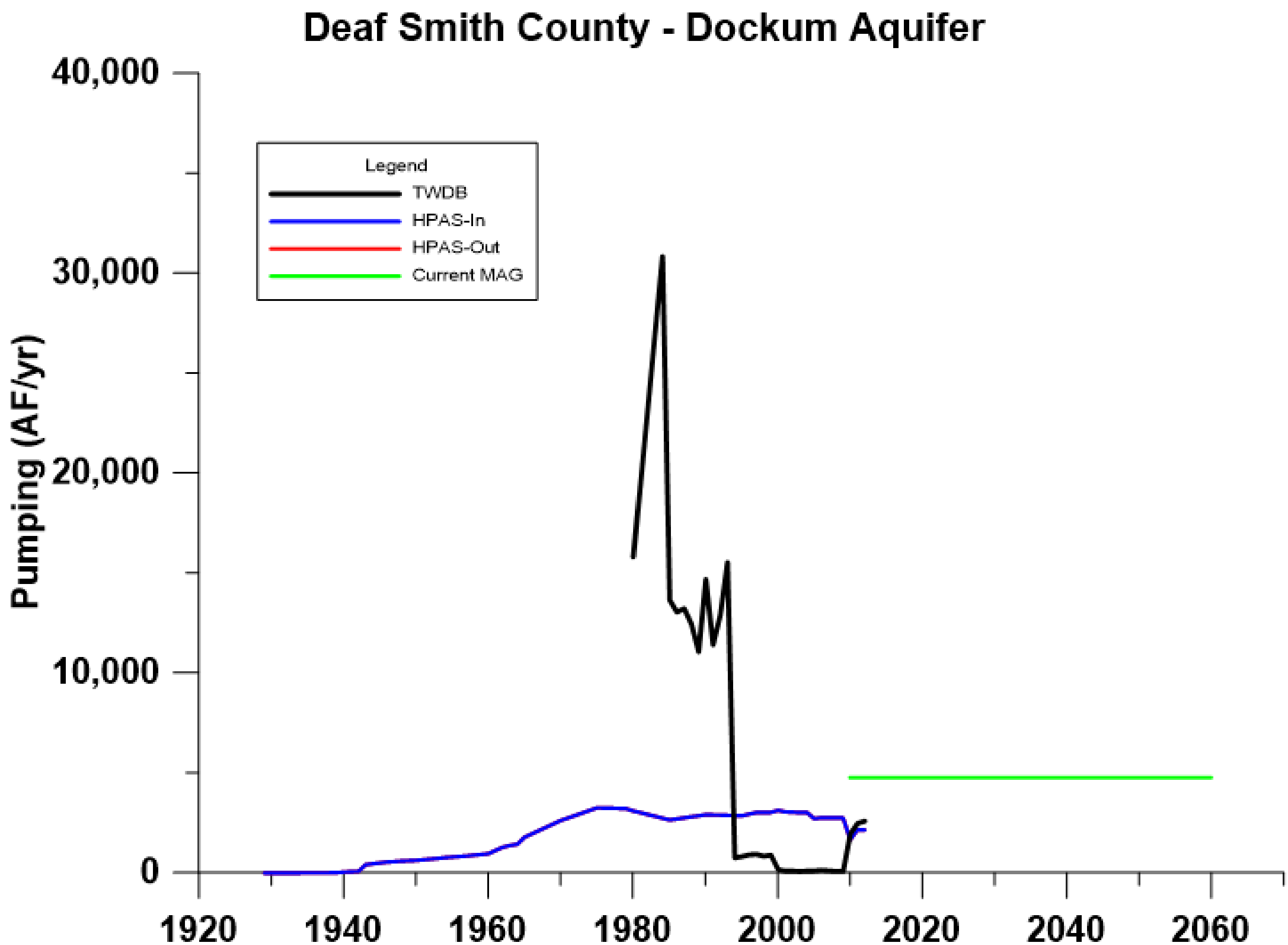
Briscoe County - Dockum Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Pumping (AF/yr)
250
200
150
100
50
0
1920
1940
1960
1980
2000
2020
2040
2060



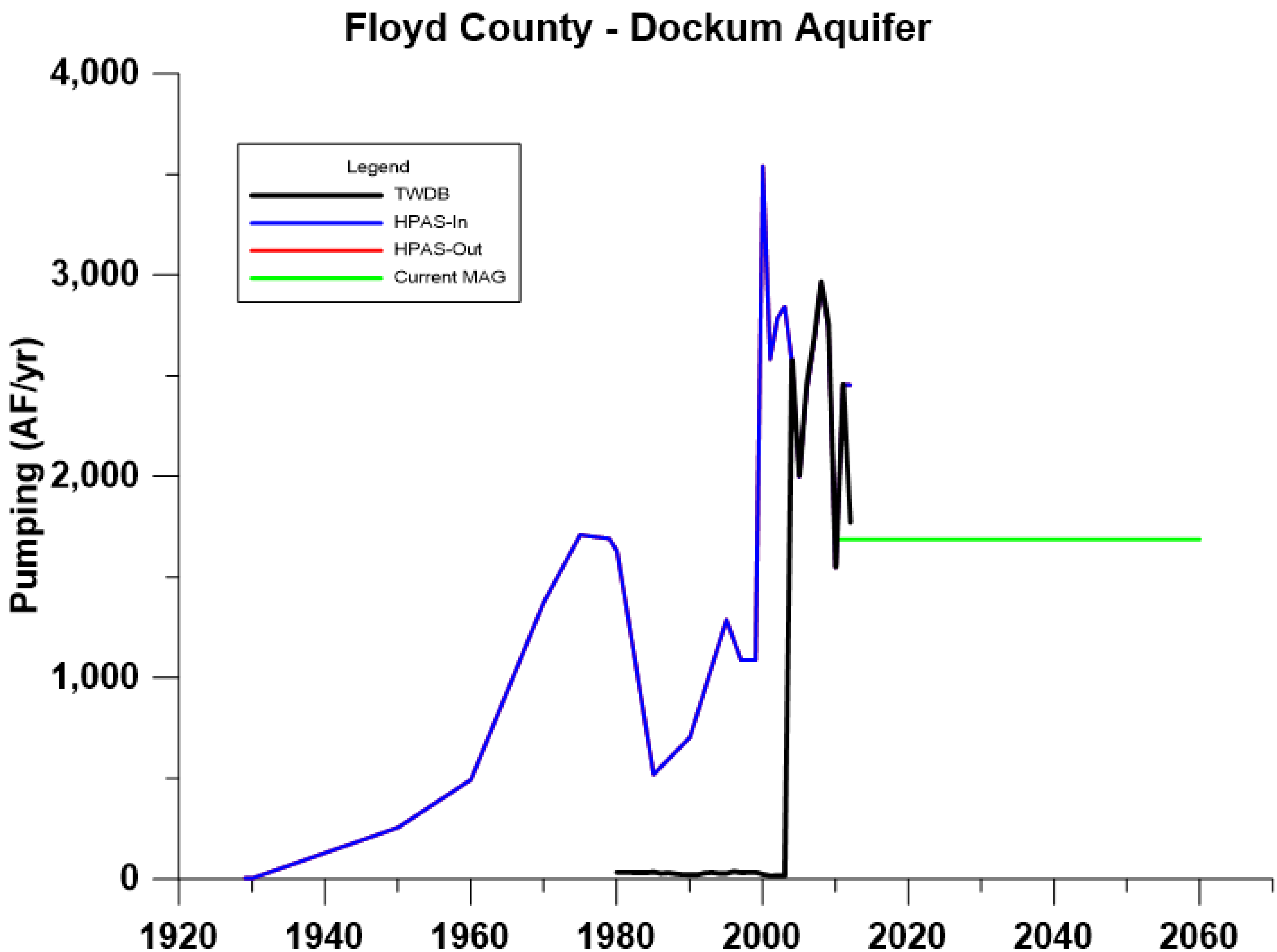
Castro County - Dockum Aquifer
Pumping (AF/yr)
0
200
400
600
800
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG



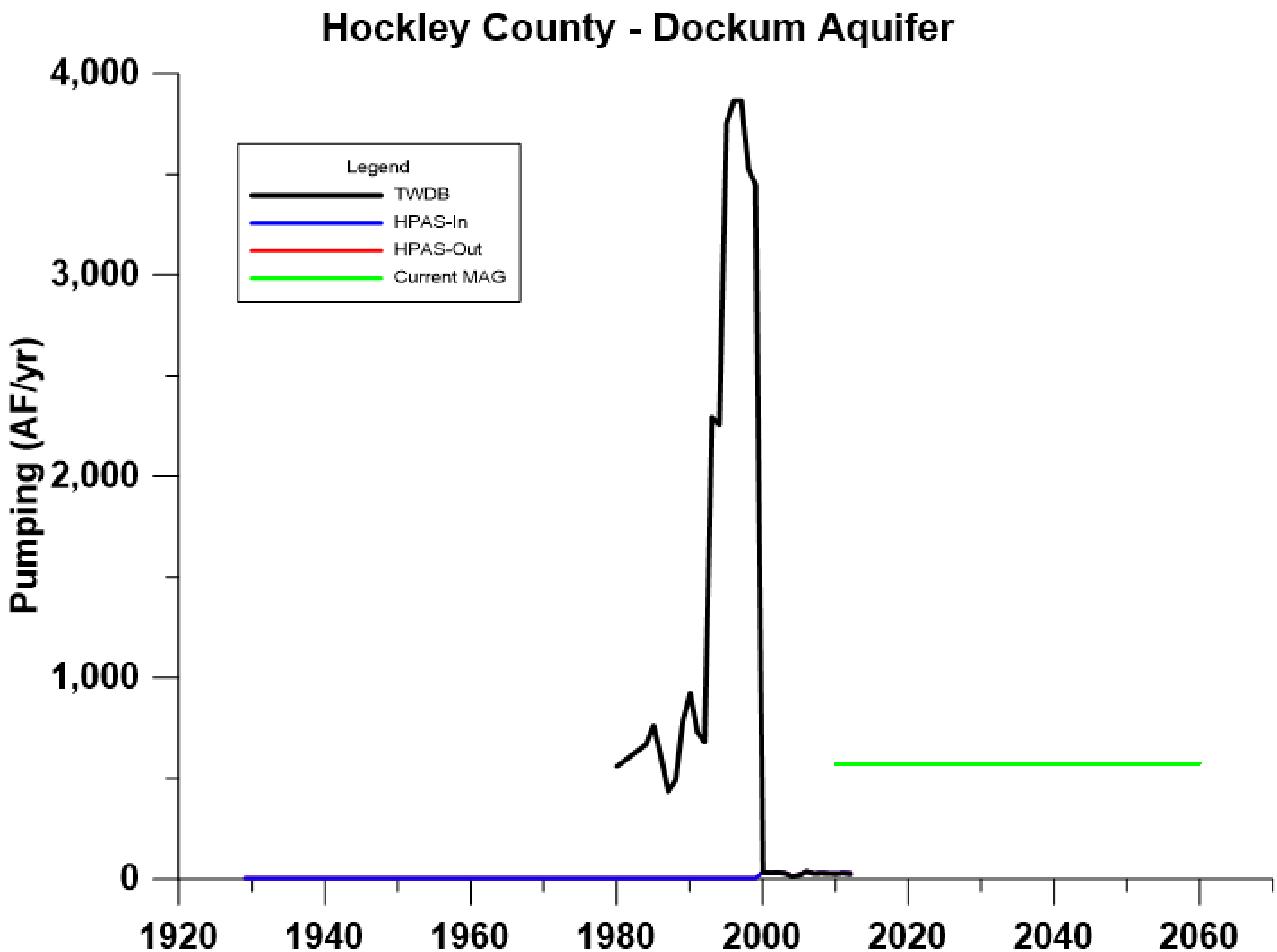
Crosby County - Dockum Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Pumping (AF/yr)
5,000
4,000
3,000
2,000
1,000
0
1920
1940
1960
1980
2000
2020
2040
2060



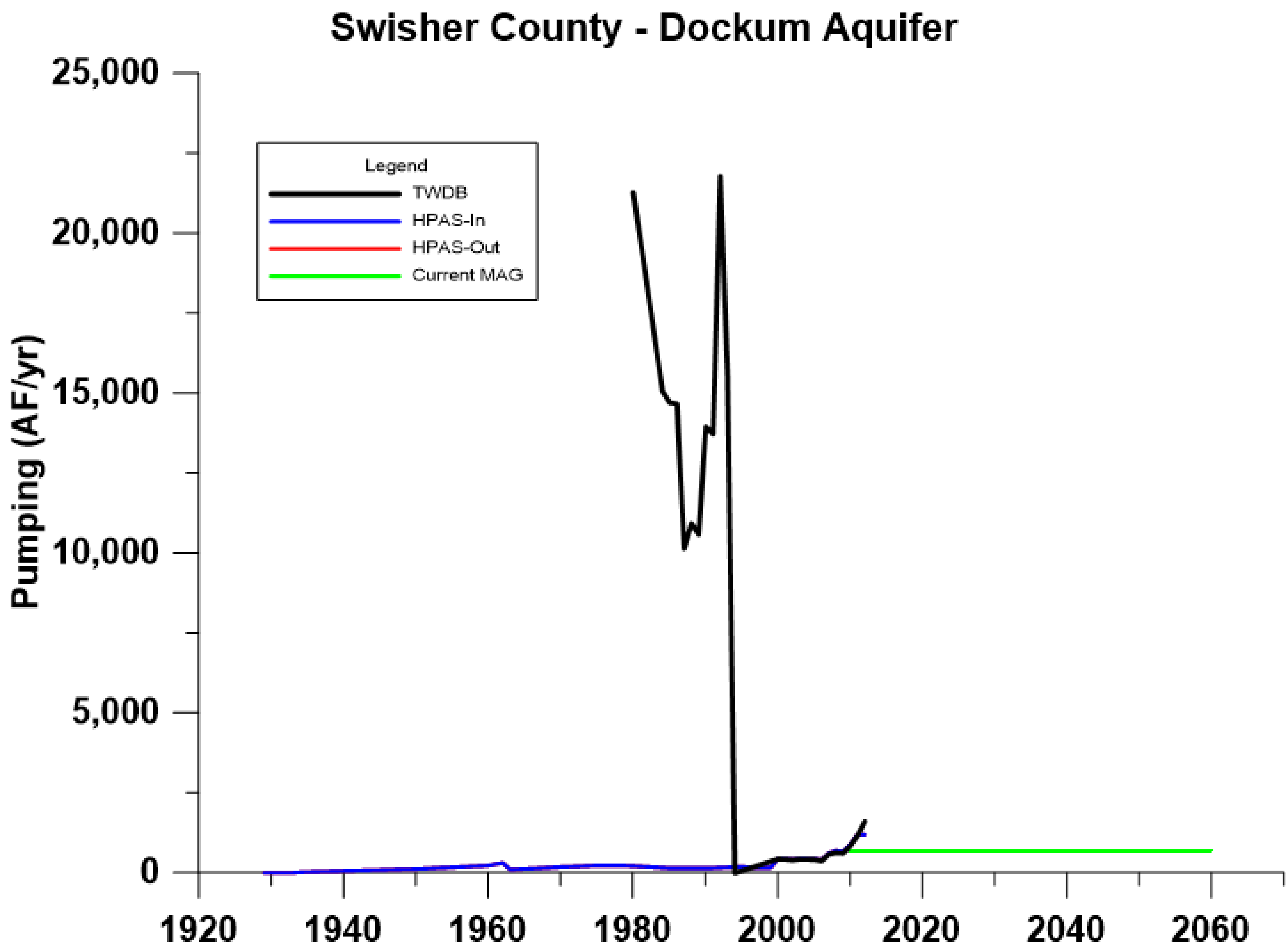
Deaf Smith County - Dockum Aquifer
Pumping (AF/yr)
40,000
30,000
20,000
10,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG



Floyd County - Dockum Aquifer
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG
Pumping (AF/yr)
4,000
3,000
2,000
1,000
0
1920
1940
1960
1980
2000
2020
2040
2060



Hockley County - Dockum Aquifer
Pumping (AF/yr)
4,000
3,000
2,000
1,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG



Swisher County - Dockum Aquifer
Pumping (AF/yr)
25,000
20,000
15,000
10,000
5,000
0
1920
1940
1960
1980
2000
2020
2040
2060
Legend
TWDB
HPAS-In
HPAS-Out
Current MAG

Dockum Summary

- HPAS estimates not always consistent with TWDB estimates
- Current MAGs are not consistent with historic pumping (sometimes much higher, sometimes much lower)
  - Old model estimates of historic pumping may not have been based on TWDB historic data?
- Intera scenario sought 50/50 (?)
- Need to use historic data as starting point and consider range of increases and decreases

Administrative/Invoicing Discussion

- Proposal dated September 15, 2014
  - Three phases proposed
  - Firm cost estimate for Phase 1 (complete with comment letter)
  - Range of costs for Phase 2 and 3
  - Discuss initial task of Phase 2
- Confirm contact and email addresses for invoice
- Provide estimate of first invoice to each GCD

Invoice Breakdown

District	Address	Contact	Email	Allocation (%)	Approximate Invoice
High Plains	2930 Ave. Q Lubbock, TX 79411	Jason Coleman	jason.coleman@hpwd.com	62.41	5,616.85
Llano Estacado	200 SE Ave. C Seminole, TX 79360	Lori Barnes	leuwcdlb@gmail.com	7.80	702.11
Mesa	Box 497 Lamesa, TX 79331	Harvey Everheart	harvey.everheart@gmail.com	4.95	445.81
Permian Basin	Box 1314 Stanton, TX 79782	Leatrice Adams	permianbasin@sbcglobal.net	8.72	784.43
Sandy Land	Box 130 Plains, TX 79355	Amber Blount	amber@sandylandwater.com	8.22	739.39
South Plains	Box 986 Brownfield, TX 79316	Lindy Harris	lindy@spuwcd.org	7.90	711.43
			Totals	100	9,000.00

Activities Completed for GMA 2

- GMA 2 meeting on January 23, 2015
- HPAS SAF meeting on February 18, 2015
  - 1/3 of travel cost and time
- Reviewed model report and files
- Compiled model pumping data and TWDB pumping estimate data
- Reviewed Intera PowerPoint, and integrated it into pumping estimate graphs
- GMA 2 meeting today
  - 1/2 travel cost

Next Steps

- Proposal of September 15, 2014 covered 3 phases:
  - Initial data gathering, DFC strategy, and HPAS review (done as of May 6 with comment letter)
  - Technical assistance in developing Proposed DFC (deadline is May 1, 2016)
  - Technical assistance after Proposed DFC is adopted

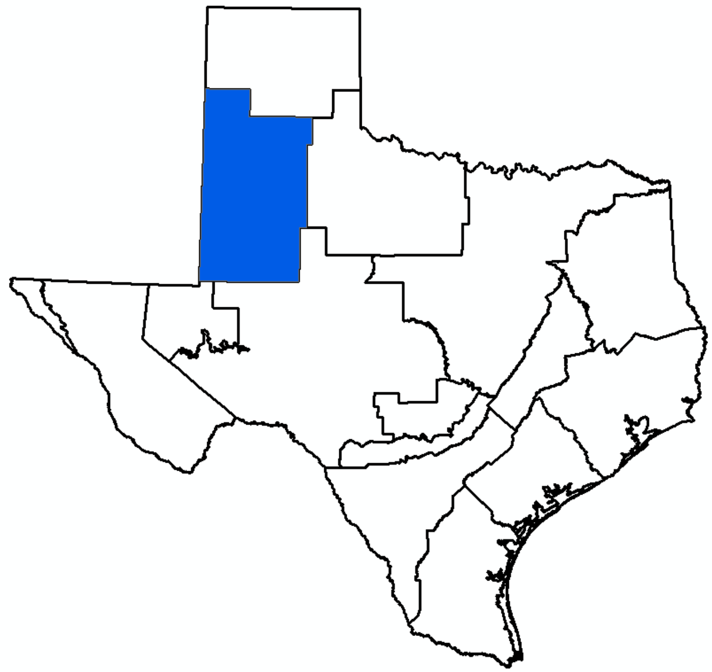
Technical Assistance in Developing Proposed DFC

- Initial cost estimate was $20,000 to $40,000
  - Attend GMA 2 meetings
  - Completing model runs
  - Complete work associated with nine factors
  - Prepare draft explanatory report

Recommended Initial Model Runs

- Complete initial model runs based on physics of system (reduced pumping based on saturated thickness for Ogallala)
  - Use GMA 1 model files for GMA 1 area
  - Use 2012 rates (Ogallala) and/or historic high rates (other aquifers)
  - Vary initial pumping rates and reduction factor (Ogallala)
  - Increases/decrease initial rates for ETHP and Dockum
- Share files with TWDB/Intera by June 1, 2015
- Prepare a technical memorandum by June 26, 2015
- Meeting in July to discuss results and plan next steps
  - Possible SAF meeting in coordination with GMA 2 meeting?
- Cost to complete: not-to-exceed $9,000

Questions and Discussion



Bill Hutchison
512-745-0599
billhutch@texasgw.com

Appendix C

TWDB GAM Task 13-026
Total Estimated Recoverable Storage for GMA 2

GAM Task 13-026: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 2

by William Kohlrenken, Radu Boghici, P.G., and Ian Jones, Ph.D., P.G.
Texas Water Development Board
Groundwater Resources Division
Groundwater Availability Modeling Section
(512) 463-8279[1]
September 19, 2013

STATE OF TEXAS
CYNTHIA K. RIDGEWAY
GEOLOGY
No. 471
LICENSED
PROFESSIONAL GEOSCIENTIST
9/19/13

STATE OF TEXAS
IAN C. JONES
GEOLOGY
No. 477
LICENSED
PROFESSIONAL GEOSCIENTIST
9/19/2013

STATE OF TEXAS
RADU BOGHICI
GEOLOGY
No. 482
LICENSED
PROFESSIONAL GEOSCIENTIST
9/19/2013

Cynthia K. Ridgeway is the Manager of the Groundwater Availability Modeling Section and is responsible for oversight of work performed by William Kohlrenken under her direct supervision. The seals appearing on this document were authorized by Cynthia K. Ridgeway, P.G. 471, Ian C. Jones, P.G. 477, and Radu Boghici, P.G. 482 on September 19, 2013.

The total estimated recoverable storage in this report was calculated as follows: the Dockum Aquifer, Edwards-Trinity (High Plains), and Ogallala aquifers (William Kohlrenken); the Seymour Aquifer (Radu Boghici); and the Edwards-Trinity (Plateau) and Pecos Valley aquifers (Ian Jones).

[1] This is the office telephone number for William Kohlrenken

This page is intentionally blank

GAM TASK 13-026: TOTAL ESTIMATED RECOVERABLE STORAGE FOR AQUIFERS IN GROUNDWATER MANAGEMENT AREA 2

by William Kohlrenken, Radu Boghici, P.G., and Ian Jones, Ph.D., P.G.
Texas Water Development Board
Groundwater Resources Division
Groundwater Availability Modeling Section
(512) 463-8279[2]
September 19, 2013

EXECUTIVE SUMMARY:

Texas Water Code, § 36.108 (d) (Texas Water Code, 2011) states that, before voting on the proposed desired future conditions for a relevant aquifer within a groundwater management area, the groundwater conservation districts shall consider the total estimated recoverable storage as provided by the executive administrator of the Texas Water Development Board (TWDB) along with other factors listed in §36.108 (d). Texas Administrative Code Rule §356.10 (Texas Administrative Code, 2011) defines the total estimated recoverable storage as the estimated amount of groundwater within an aquifer that accounts for recovery scenarios that range between 25 percent and 75 percent of the porosity-adjusted aquifer volume.

This report discusses the methods, assumptions, and results of analyses to estimate the total recoverable storage for the Dockum, Edwards-Trinity (High Plains), Edwards-Trinity (Plateau), Ogallala, Seymour, and Pecos Valley aquifers within Groundwater Management Area 2. Tables 1 through 12 summarize the total estimated recoverable storage required by the statute. Figures 2 through 7 indicate the extent of the groundwater availability models used to estimate the total recoverable storage.

DEFINITION OF TOTAL ESTIMATED RECOVERABLE STORAGE:

The total estimated recoverable storage is defined as the estimated amount of groundwater within an aquifer that accounts for recovery scenarios that range between 25 percent and 75

[2] This is the office telephone number for William Kohlrenken

percent of the porosity-adjusted aquifer volume. In other words, we assume that between 25 and 75 percent of groundwater held within an aquifer can be removed by pumping.

The total recoverable storage was estimated for the portion of each aquifer within Groundwater Management Area 2 that lies within the official lateral aquifer boundaries as delineated by George and others (2011). Total estimated recoverable storage values may include a mixture of water quality types, including fresh, brackish, and saline groundwater, because the available data and the existing groundwater availability models do not permit the differentiation of different water quality types. These values do not take into account the effects of land surface subsidence, degradation of water quality, or any changes to surface water-groundwater interaction as the result of extracting groundwater from the aquifer.

METHODS:

To estimate the total recoverable storage of an aquifer, we first calculated the total storage in an aquifer within the official aquifer boundary in the groundwater management area. The total storage is the volume of groundwater that can be removed by completely draining the aquifer.

Aquifers can be either unconfined or confined (Figure 1). A well screened in an unconfined aquifer will have a water level equal to the water level in the aquifer outside the well. Thus, unconfined aquifers have water levels within the aquifers. A confined aquifer is bounded by low permeable geologic units at the top and bottom, and the aquifer is under hydraulic pressure above the ambient atmospheric pressure. The water level at a well screened in a confined aquifer will be above the top of the aquifer. As a result, calculation of total storage is also different between unconfined and confined aquifers. For an unconfined aquifer, the total storage is equal to the volume of groundwater that makes the water level fall to the aquifer bottom. For a confined aquifer, the total storage contains two parts. The first part is the groundwater released from the aquifer when the water level falls from above the top of the aquifer to the top of the aquifer. The reduction of hydraulic pressure in the aquifer by pumping causes expansion of groundwater and deformation of aquifer solids. The aquifer is still fully saturated to this point. The second part, just like unconfined aquifer, is the groundwater released from the aquifer when the water level falls from the top to the bottom of the aquifer. Given the same aquifer area and water level drop, the amount of water released in the second part is much greater than the first part. The difference is quantified by two parameters: storativity related to confined aquifer and specific yield related to unconfined aquifer. For example, storativity values range from 10^{-5} to 10^{-3} for most confined aquifers, while the specific yield values can be 0.01 to 0.3 for most unconfined aquifers. The equations for calculating the total storage are presented below:

- for unconfined aquifers

$$Total\ Storage\ = V_{drained} = Area \times S_y \times (Water\ Level - Bottom)$$

- for confined aquifers

$$Total\ Storage\ = V_{confined} + V_{drained}$$

  - confined part

$$V_{confined} = \ Area \times [\ S \times (Water\ Level - Top)]$$

or

$$V_{confined} = \ Area \times [\ S_s\ \times (\mathrm{Top} - \mathrm{Bottom}) \times (Water\ Level - Top)]$$

  - unconfined part

$$V_{drained} = \ Area \times \left[S_y \times (Top - Bottom)\right]$$

where:

- $V_{drained}$ = storage volume due to water draining from the formation (acre-feet)
- $V_{confined}$ = storage volume due to elastic properties of the aquifer and water(acre-feet)
- *Area* = area of aquifer (acre)
- *Water Level* = groundwater elevation (feet above mean sea level)
- *Top* = elevation of aquifer top (feet above mean sea level)
- *Bottom* = elevation of aquifer bottom (feet above mean sea level)
- S_y = specific yield (no units)
- S_s = specific storage (1/feet)
- S = storativity or storage coefficient (no units)

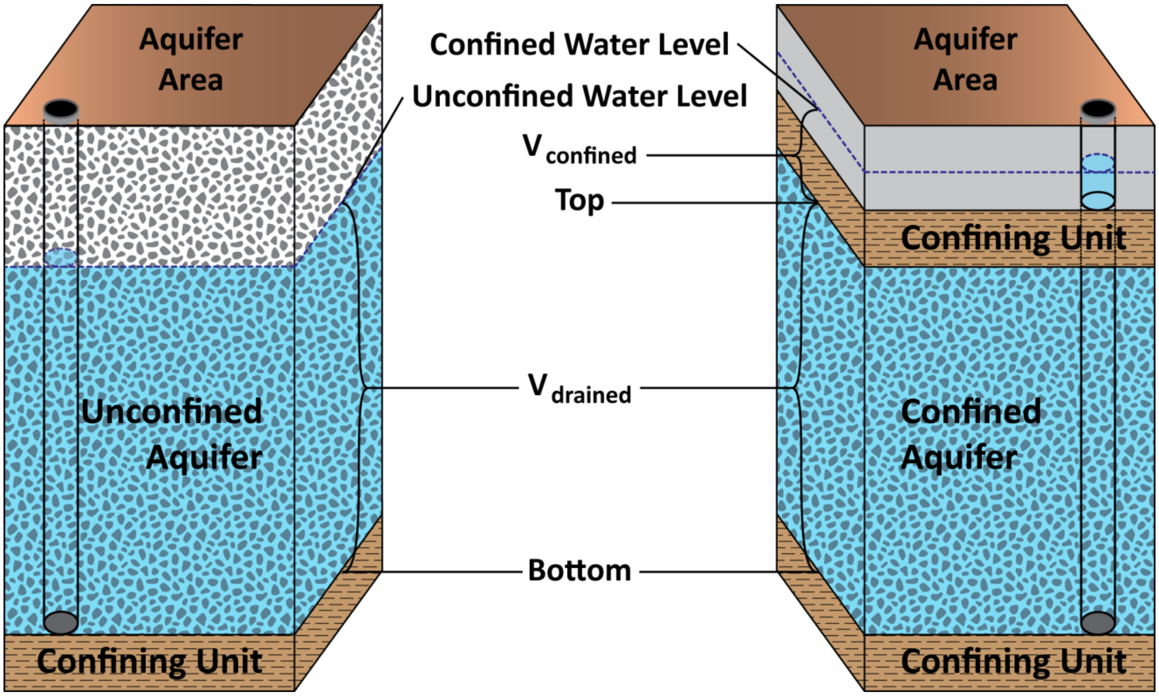


FIGURE 1. SCHEMATIC GRAPH SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

As presented in the equations, calculation of the total storage requires data, such as aquifer top, aquifer bottom, aquifer storage properties, and water level. For the Dockum, Edwards-Trinity (High Plains), Edwards-Trinity (Plateau), Ogallala, and Seymour aquifers in Groundwater Management Area 2, we extracted this information from existing groundwater availability model input and output files on a cell-by-cell basis. This information was contained in model input and output files on a cell-by-cell basis. In the absence of groundwater availability model(s), the total storage will be calculated using other approaches.

Python scripts and a FORTRAN-90 program were developed and used to expedite the storage calculation. The total recoverable storage was calculated as the product of the total storage and an estimated factor ranging from 25 percent to 75 percent.

The following methodology was used to estimate total recoverable storage for parts of the Pecos Valley and Edwards-Trinity (Plateau) aquifers in Groundwater Management Area 2 that were not included in the 1-layered alternative groundwater flow model covering these aquifers (Hutchison and others, 2011). The excluded parts of the respective aquifers are relatively thin, mostly located along the margins of the respective aquifers in the western part of the model.

Recoverable storage in areas outside of the model but within the official aquifer boundaries is estimated by first establishing a relationship between aquifer thickness and saturated thickness. Where aquifer thickness is the difference between the elevations of the aquifer top and base, and saturated thickness is the difference between the water table and aquifer base elevations. In each of the three aquifers included in this model there is a generally linear relationship between aquifer thickness and saturated thickness. In the Pecos Valley Aquifer, the ratio between saturated thickness and aquifer thickness is approximately 0.8, while in the Edwards-Trinity (Plateau) and Trinity aquifers, it is 0.9 and 0.6, respectively. Saturated thickness in the non-modeled areas is estimated using these ratios.

The three aquifers—Pecos Valley and Edwards-Trinity (Plateau) aquifers, and the Hill Country portion of the Trinity Aquifer—are assumed to be unconfined. Consequently, storage in each model cell representing parts of the respective aquifers excluded from the groundwater flow model is estimated using the following equation:

$$Total\ Storage = V_{drained} = Area \times S_y \times H_{sat}$$

where:

- $V_{drained}$ = storage volume due to water draining from the formation (acre-feet)
- $Area$ = area of aquifer (acre)
- S_y = specific yield (no units)
- H_{sat} = estimated saturated thickness (feet)

Storage volumes estimated using this method were added to the storage volumes from the remainder of the modeled area to estimate the total recoverable storage for the entire aquifer.

PARAMETERS AND ASSUMPTIONS:

Dockum Aquifer

- We used version 1.01 of the groundwater availability model for the Dockum Aquifer to estimate the total recoverable storage. See Ewing and others (2008) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes three layers which generally represent the younger geologic units overlying the Dockum Aquifer (Layer 1), the upper portion of the Dockum Aquifer (Layer 2), and the lower portion of the Dockum Aquifer (Layer 3).
- Of the three layers, total estimated recoverable storage was determined and combined for layers representing the Dockum Aquifer (layers 2 and 3).
- The down-dip boundary of the Dockum Aquifer in this model was set to approximately coincide with the extent of the available geologic data, well beyond any active portion (groundwater use) of the aquifer (Ewing and others, 2008). Consequently, the model extends into zones of brackish and saline groundwater. The official extent of the Dockum Aquifer was used to exclude this area (George and others, 2011).

Southern portion of the Ogallala Aquifer and Edwards-Trinity (High Plains) Aquifer

- We used version 2.01 of the groundwater availability model to estimate the total recoverable storages of the southern portion of the Ogallala and Edwards-Trinity (High Plains) aquifers. This model is an expansion on and update to the previously developed groundwater availability model for the southern portion of the Ogallala Aquifer described in Blandford and others (2003). See Blandford and others (2008) and Blandford and others (2003) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes 4 layers which represent the southern portion of the Ogallala (Layer 1) and the Edwards-Trinity (High Plains) (primarily Edwards, Comanche Peak, and Antlers Sand formations; layers 2-4).

- Of the four layers, total estimated recoverable storage was determined for the Ogallala Aquifer (Layer 1) and Edwards-Trinity (High Plains) Aquifer (layers 2-4) in Groundwater Management Area 2.

Edwards-Trinity (Plateau) and Pecos Valley aquifers

- We used alternative groundwater flow model for the Edwards-Trinity (Plateau) Aquifer. See Hutchison and Others (2011) for assumptions and limitations of the alternative numerical groundwater flow model.
- This 1-layer groundwater flow model simulates groundwater flow through the Pecos Valley and Edwards-Trinity (Plateau) aquifers, and the Hill Country portion of the Trinity Aquifer.
- In this model, where the Pecos Valley and Edwards-Trinity (Plateau) aquifer overlap, total storage is assigned to the Pecos Valley Aquifer.

Seymour Aquifer

- We used version 1.01 of the groundwater availability model for the Seymour and Blaine aquifers. See Ewing and others (2004) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes two layers, representing the Seymour (Layer 1) and Blaine (Layer 2) aquifers. In areas where the Blaine Aquifer does not exist the model roughly replicates the various Permian units located in the study area.
- Of the two layers, total estimated recoverable storage was determined using the cells in the model that represent the Seymour Aquifer in Layer 1.

RESULTS:

Tables 1 through 12 summarize the total estimated recoverable storage required by statute. The county and groundwater conservation district total estimates are rounded to two significant figures. Figures 2 through 7 indicate the extent of the groundwater availability models in Groundwater Management Area 2 for the Dockum, Edwards-Trinity (High Plains), Edwards-Trinity (Plateau), Ogallala, Seymour, and Pecos Valley aquifers from which the storage information was extracted.

TABLE 1. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE DOCKUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 2. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Andrews	220,000,000	55,000,000	165,000,000
Borden	7,600,000	1,900,000	5,700,000
Briscoe	18,000,000	4,500,000	13,500,000
Castro	7,000,000	1,750,000	5,250,000
Crosby	30,000,000	7,500,000	22,500,000
Deaf Smith	130,000,000	32,500,000	97,500,000
Floyd	40,000,000	10,000,000	30,000,000
Gaines	200,000,000	50,000,000	150,000,000
Garza	4,900,000	1,225,000	3,675,000
Hale	16,000,000	4,000,000	12,000,000
Howard	22,000,000	5,500,000	16,500,000
Martin	11,000,000	2,750,000	8,250,000
Parmer	30,000,000	7,500,000	22,500,000
Swisher	66,000,000	16,500,000	49,500,000
Total	**802,500,000**	**200,625,000**	**601,875,000**

TABLE 2. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD)[3] FOR THE DOCKUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 2. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Garza County UWCD[4]	4,900,000	1,225,000	3,675,000
High Plains UWCD No.1	250,000,000	62,500,000	187,500,000
Llano Estacado UWCD	200,000,000	50,000,000	150,000,000
Permian Basin UWCD	32,000,000	8,000,000	24,000,000
No District	310,000,000	77,500,000	232,500,000
Total	**796,900,000**	**199,225,000**	**597,675,000**

[3] The total estimated recoverable storages by groundwater conservation district and county aquifer may not be the same because the numbers have been rounded to two significant figures.
[4] UWCD is the abbreviation for Underground Water Conservation District.

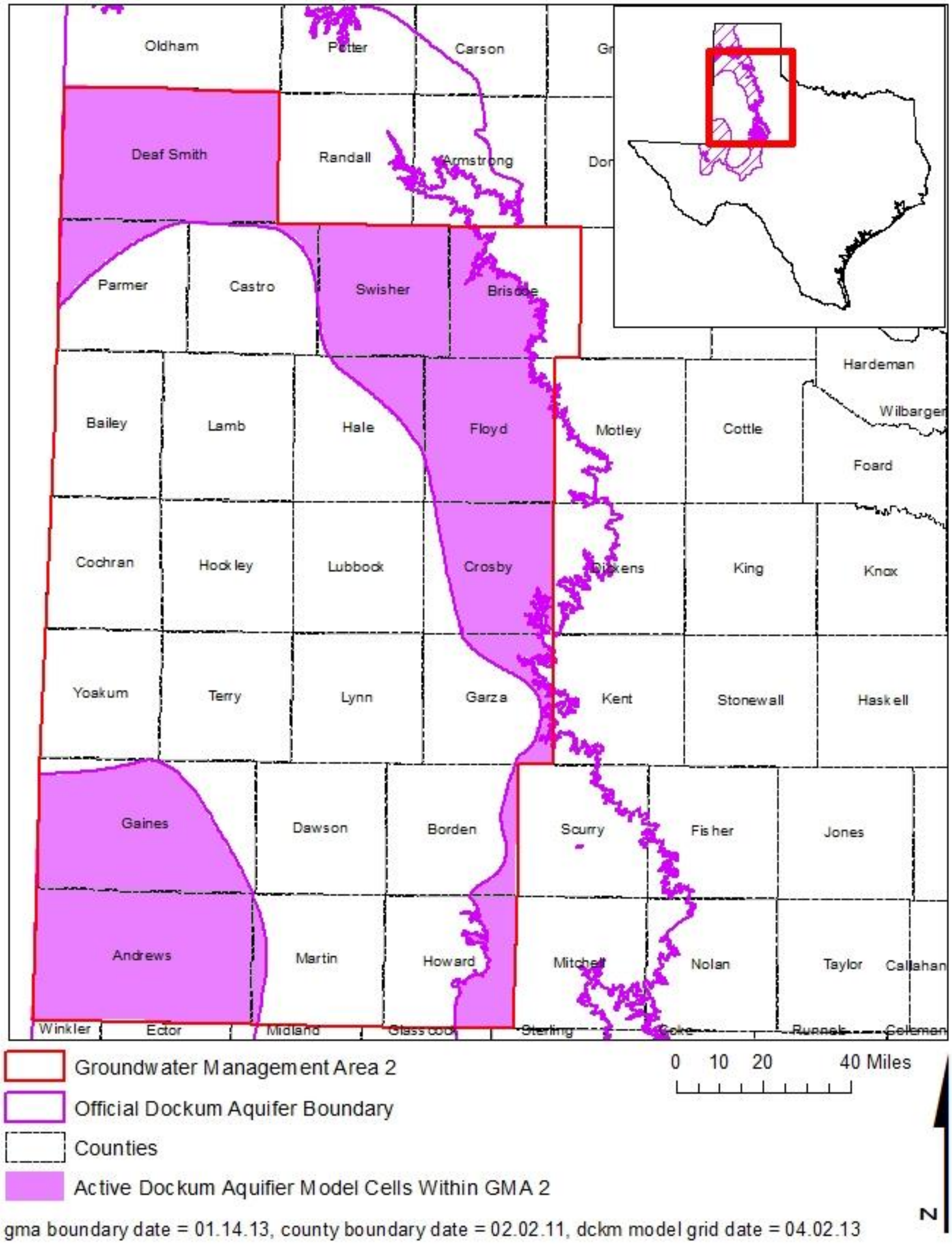


FIGURE 2. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL OF THE DOCKUM AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 1 AND 2) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 2.

TABLE 3. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE EDWARDS-TRINITY (HIGH PLAINS) AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 2. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Bailey	690,000	172,500	517,500
Borden	1,600,000	400,000	1,200,000
Cochran	1,700,000	425,000	1,275,000
Dawson	1,000,000	250,000	750,000
Floyd	730,000	182,500	547,500
Gaines	3,100,000	775,000	2,325,000
Garza	120,000	30,000	90,000
Hale	870,000	217,500	652,500
Hockley	2,200,000	550,000	1,650,000
Lamb	500,000	125,000	375,000
Lubbock	2,000,000	500,000	1,500,000
Lynn	3,400,000	850,000	2,550,000
Terry	3,300,000	825,000	2,475,000
Yoakum	2,500,000	625,000	1,875,000
Total	**23,710,000**	**5,927,500**	**17,782,500**

TABLE 4. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD)[5] FOR THE EDWARDS-TRINITY (HIGH PLAINS) AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 2. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Garza County UWCD[6]	120,000	30,000	90,000
High Plains UWCD No.1	12,000,000	3,000,000	9,000,000
Llano Estacado UWCD	3,100,000	775,000	2,325,000
Mesa UWCD	1,000,000	250,000	750,000
Sandy Land UWCD	2,500,000	625,000	1,875,000
South Plains UWCD	3,300,000	825,000	2,475,000
No District	1,700,000	425,000	1,275,000
Total	**23,720,000**	**5,930,000**	**17,790,000**

[5] The total estimated recoverable storages by groundwater conservation district and county aquifer may not be the same because the numbers have been rounded to two significant figures.
[6] UWCD is the abbreviation for Underground Water Conservation District.

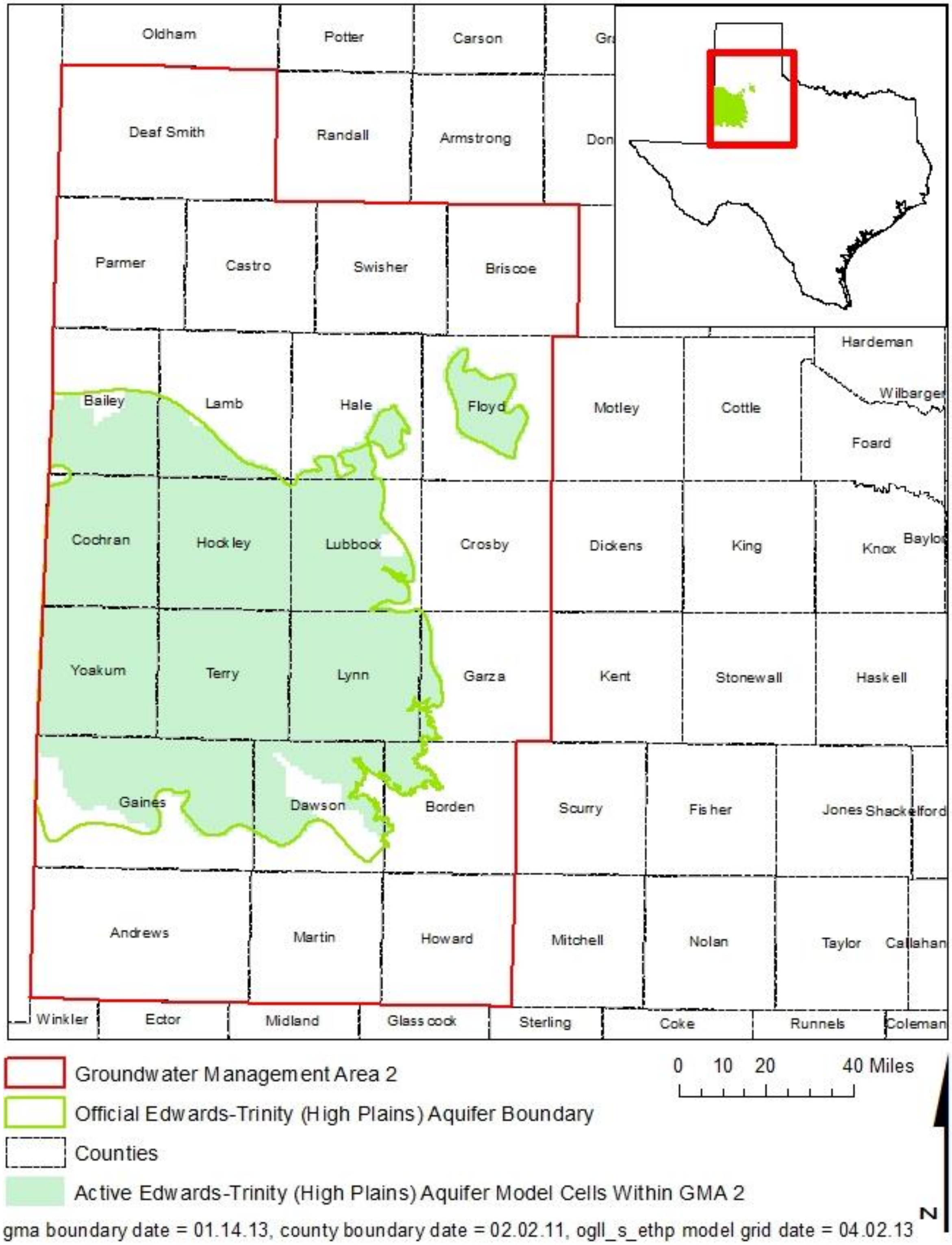


FIGURE 3. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE EDWARDS-TRINITY (HIGH PLAINS) AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 3 AND 4) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 2.

TABLE 5. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE EDWARDS-TRINITY (PLATEAU) AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 2. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Andrews	32,000	8,000	24,000
Howard	61,000	15,250	45,750
Martin	49,000	12,250	36,750
Total	**142,000**	**35,500**	**106,500**

TABLE 6. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD) FOR THE EDWARDS-TRINITY (PLATEAU) AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 2. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Permian Basin UWCD[7]	95,000	23,750	71,250
No District	47,000	11,750	35,250
Total	**142,000**	**35,500**	**106,500**

[7] UWCD is the abbreviation for Underground Water Conservation District.

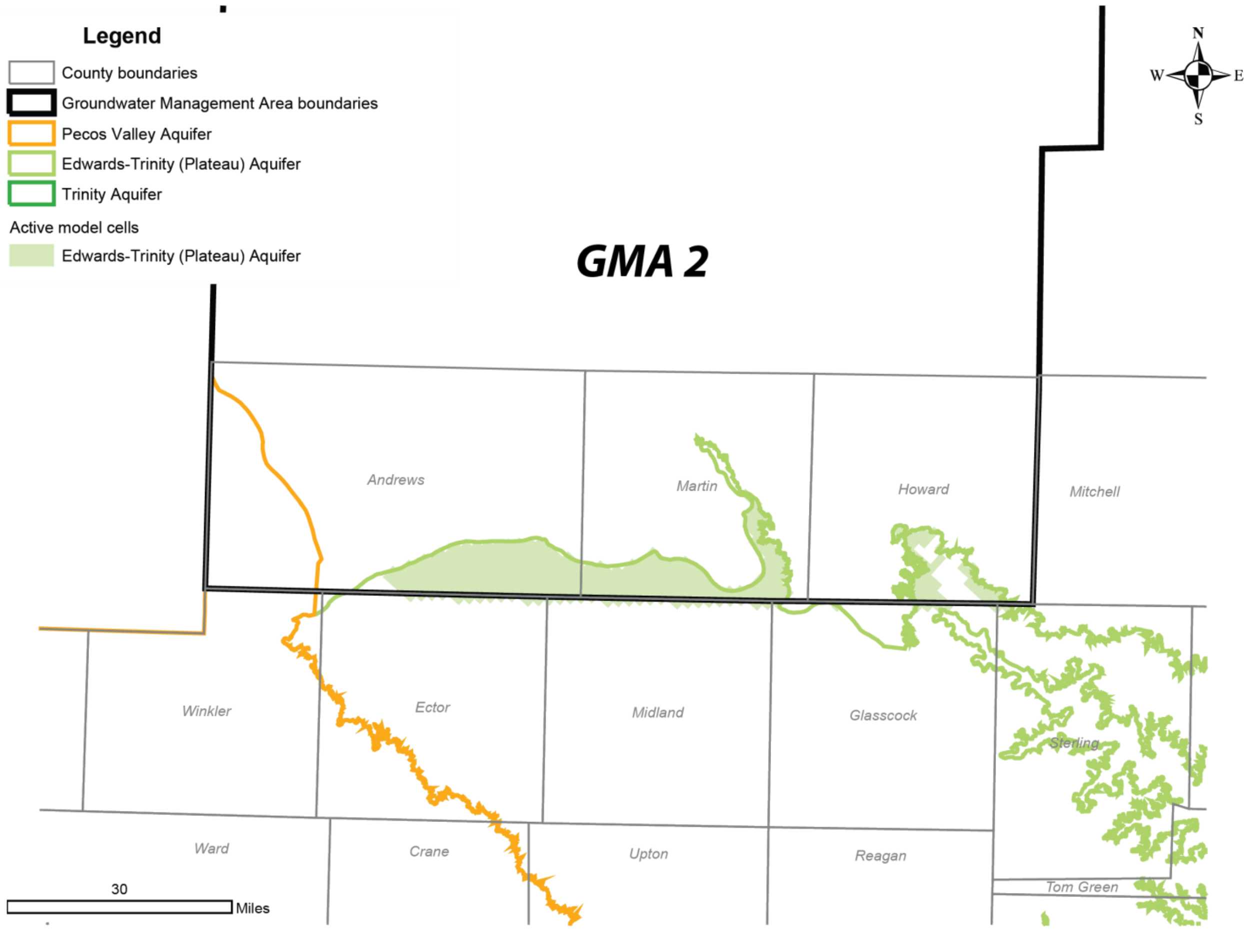


FIGURE 4. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE EDWARDS-TRINITY (PLATEAU) AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 5 AND 6) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 2.

TABLE 7. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE OGALLALA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 2. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Andrews	5,400,000	1,350,000	4,050,000
Bailey	2,900,000	725,000	2,175,000
Borden	310,000	77,500	232,500
Briscoe	2,100,000	525,000	1,575,000
Castro	9,500,000	2,375,000	7,125,000
Cochran	2,900,000	725,000	2,175,000
Crosby	12,000,000	3,000,000	9,000,000
Dawson	7,400,000	1,850,000	5,550,000
Deaf Smith	8,300,000	2,075,000	6,225,000
Floyd	12,000,000	3,000,000	9,000,000
Gaines	11,000,000	2,750,000	8,250,000
Garza	1,100,000	275,000	825,000
Hale	9,500,000	2,375,000	7,125,000
Hockley	5,900,000	1,475,000	4,425,000
Howard	2,300,000	575,000	1,725,000
Lamb	8,600,000	2,150,000	6,450,000
Lubbock	7,000,000	1,750,000	5,250,000
Lynn	5,000,000	1,250,000	3,750,000
Martin	7,100,000	1,775,000	5,325,000
Parmer	3,900,000	975,000	2,925,000
Swisher	7,600,000	1,900,000	5,700,000
Terry	5,200,000	1,300,000	3,900,000
Yoakum	2,200,000	550,000	1,650,000
Total	**139,210,000**	**34,802,500**	**104,407,500**

TABLE 8. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD)[8] FOR THE OGALLALA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 2. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Garza County UWCD[9]	1,100,000	275,000	825,000
High Plains UWCD No.1	90,000,000	22,500,000	67,500,000
Llano Estacado UWCD	11,000,000	2,750,000	8,250,000
Mesa UWCD	7,400,000	1,850,000	5,550,000
Permian Basin UWCD	9,300,000	2,325,000	6,975,000
Sandy Land UWCD	2,200,000	550,000	1,650,000
South Plains UWCD	5,300,000	1,325,000	3,975,000
No District	12,000,000	3,000,000	9,000,000
Total	**138,300,000**	**34,575,000**	**103,725,000**

[8] The total estimated recoverable storages by groundwater conservation district and county aquifer may not be the same because the numbers have been rounded to two significant figures.
[9] UWCD is the abbreviation for Underground Water Conservation District.

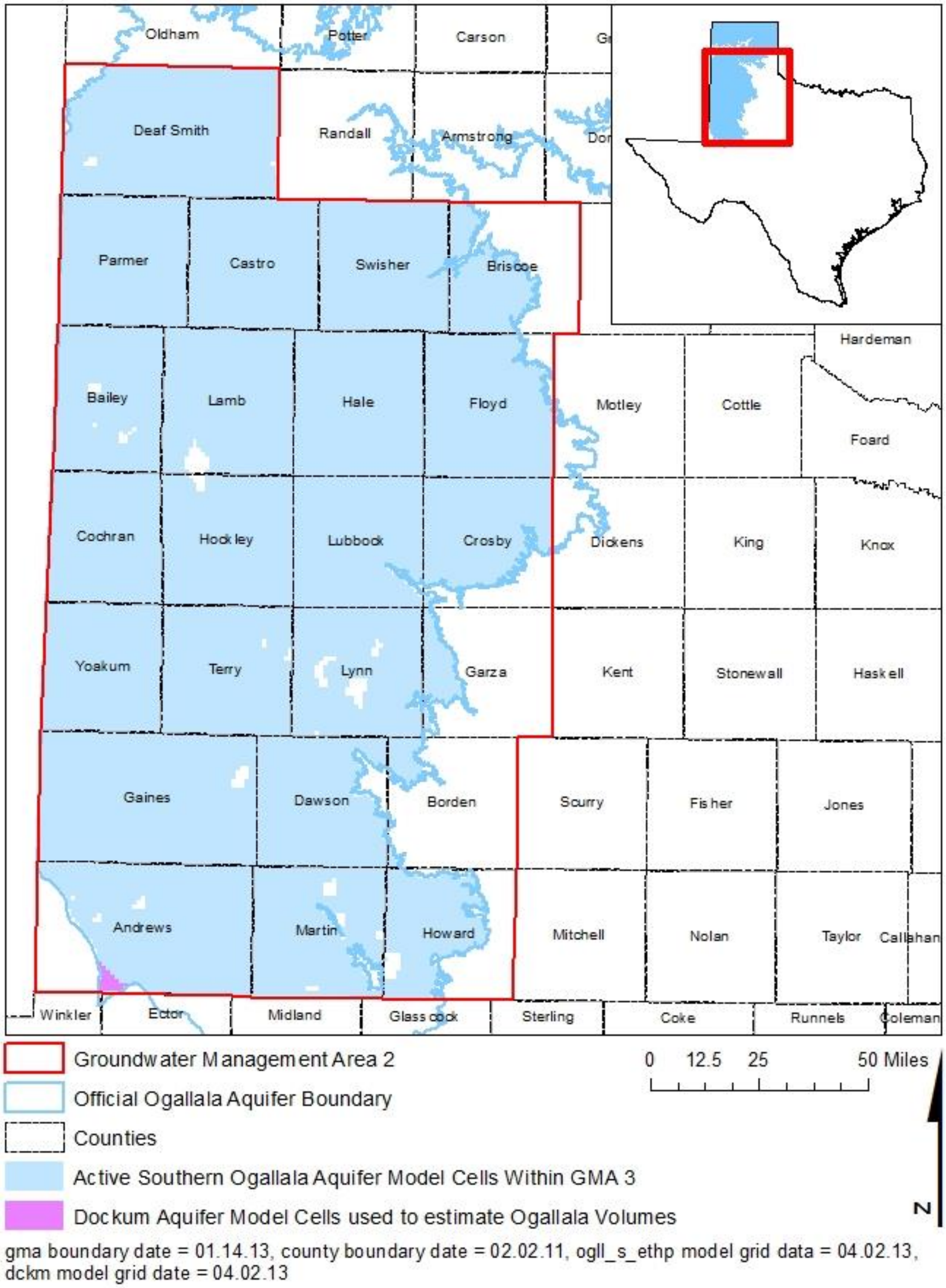


FIGURE 5. EXTENT OF THE GROUNDWATER AVAILABILITY MODELS FOR THE SOUTHERN PORTION OF THE OGALLALA AQUIFER AND DOCKUM AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 7 AND 8) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 2.

TABLE 9. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE SEYMOUR AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 2. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Briscoe	57,000	14,250	42,750
Total	**57,000**	**14,250**	**42,750**

TABLE 10. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD) FOR THE SEYMOUR AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 2. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
No District	57,000	14,250	42,750
Total	**57,000**	**14,250**	**42,750**

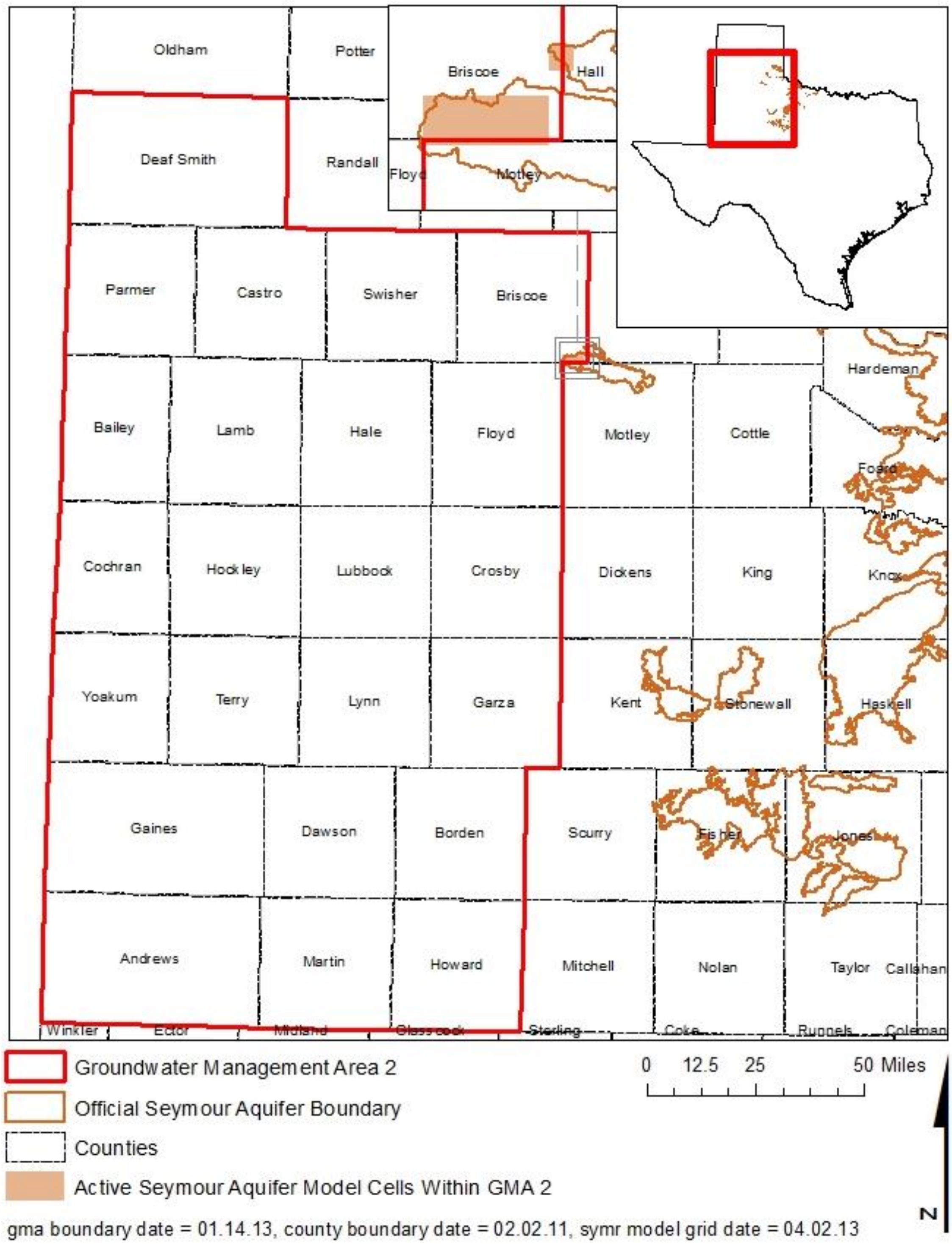


FIGURE 6. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL OF THE SEYMOUR AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 9 AND 10) WITHIN GROUNDWATER MANAGEMENT AREA 2.

TABLE 11. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE PECOS VALLEY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 2. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Andrews	2,000,000	500,000	1,500,000
Total	**2,000,000**	**500,000**	**1,500,000**

TABLE 12. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD) FOR THE PECOS VALLEY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 2. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
No District	2,000,000	500,000	1,500,000
Total	**2,000,000**	**500,000**	**1,500,000**

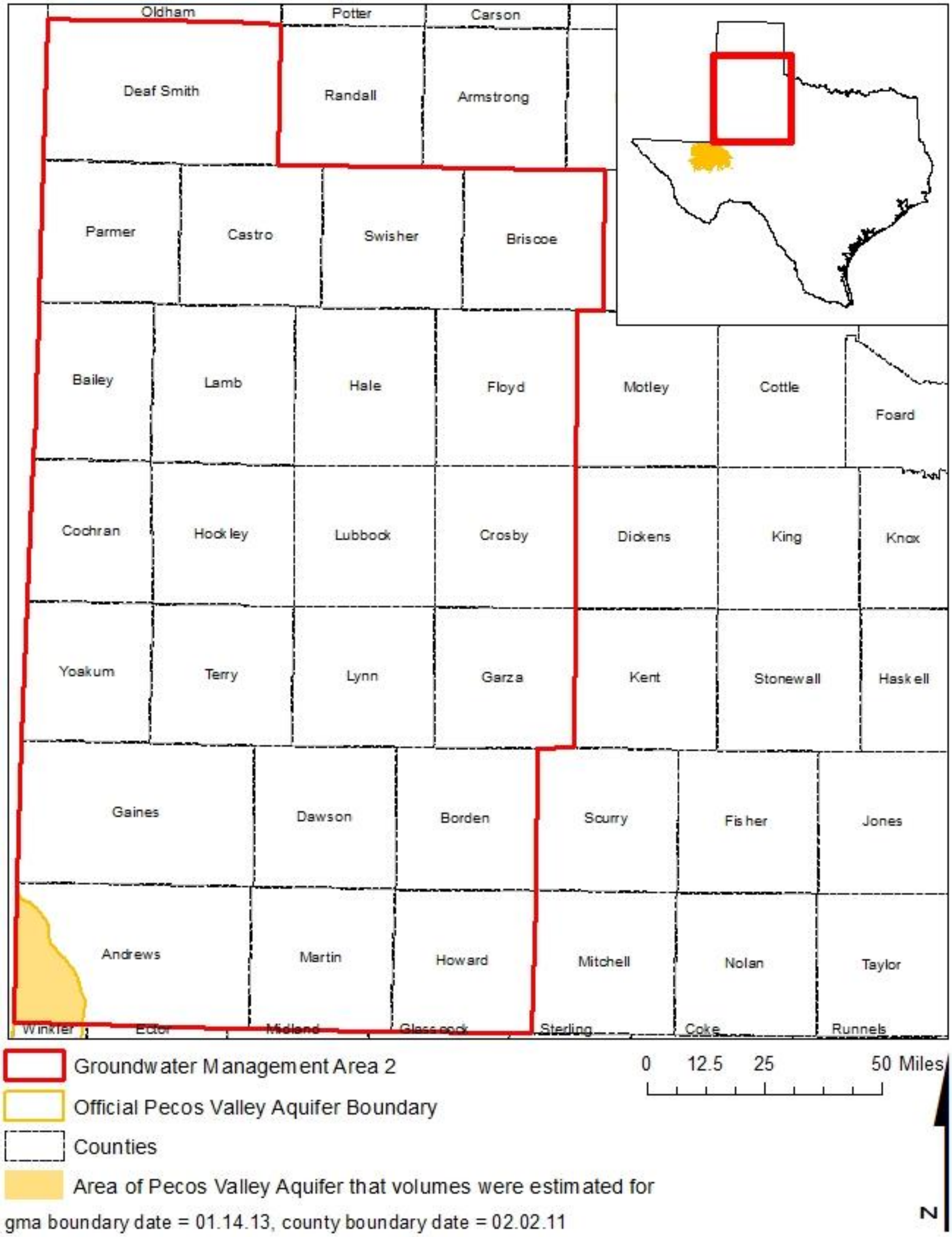


FIGURE 7. AREA OF THE PECOS VALLEY AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 11 AND 12) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 2.

LIMITATIONS

The groundwater models used in completing this analysis are the best available scientific tools that can be used to meet the stated objective(s). To the extent that this analysis will be used for planning purposes and/or regulatory purposes related to pumping in the past and into the future, it is important to recognize the assumptions and limitations associated with the use of the results. In reviewing the use of models in environmental regulatory decision making, the National Research Council (2007) noted:

> *"Models will always be constrained by computational limitations, assumptions, and knowledge gaps. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Scientific advances will never make it possible to build a perfect model that accounts for every aspect of reality or to prove that a given model is correct in all respects for a particular regulatory application. These characteristics make evaluation of a regulatory model more complex than solely a comparison of measurement data with model results."*

Because the application of the groundwater model was designed to address regional scale questions, the results are most effective on a regional scale. The TWDB makes no warranties or representations relating to the actual conditions of any aquifer at a particular location or at a particular time.

REFERENCES:

Blandford, T.N., Blazer, D.J., Calhoun, K.C., Dutton, A.R., Naing, T., Reedy, R.C., and Scanlon, B.R., 2003, Groundwater availability of the southern Ogallala aquifer in Texas and New Mexico—Numerical simulations through 2050: Final report prepared for the Texas Water Development Board by Daniel B. Stephens & Associates, Inc., 158 p., http://www.twdb.texas.gov/groundwater/models/gam/ogll_s/OGLL_S_Full_Report.pdf.

Blandford, T.N., Kuchanur, M., Standen, A., Ruggiero, R., Calhoun, K.C., Kirby, P., and Shah, G., 2008, Groundwater availability model of the Edwards-Trinity (High Plains) Aquifer in Texas and New Mexico: Final report prepared for the Texas Water Development Board by Daniel B. Stephens & Associates, Inc., 176 p., http://www.twdb.texas.gov/groundwater/models/gam/ethp/ETHP_Model_Report.pdf.

Ewing, J.E., Jones, T.L., Pickens, J.F., Chastain-Howley, A., Dean, K.E., Spear, A.A., 2004, Groundwater availability model for the Seymour Aquifer: Final report prepared for the

Texas Water Development Board by INTERA, Inc., 533 p., http://www.twdb.texas.gov/groundwater/models/gam/symr/SYMR_Model_Report.pdf.

Ewing, J.E., Jones, T.L., Yan, T., Vreugdenhil, A.M., Fryar, D.G., Pickens, J.F., Gordon, K., Nicot, J.P., Scanlon, B.R., Ashworth, J.B., and Beach, J., 2008, Groundwater Availability Model for the Dockum Aquifer – Final Report: contract report to the Texas Water Development Board, 510 p., http://www.twdb.texas.gov/groundwater/models/gam/dckm/DCKM_Model_Report.pdf.

George, P. G., Mace, R. E., and Petrossian, R, 2011, Aquifers of Texas, Texas Water Development Board Report 380, http://www.twdb.texas.gov/groundwater/aquifer/index.asp

Hutchison, W. R., Jones, I. C., and Anaya, R., 2011, Update of the Groundwater Availability Model for the Edwards-Trinity (Plateau) and Pecos Valley Aquifers of Texas: Unpublished report, Texas Water Development Board, 60 p., http://www.twdb.texas.gov/groundwater/models/alt/eddt_p_2011/ETP_PV_One_Layer_Model.pdf

National Research Council, 2007, Models in Environmental Regulatory Decision Making Committee on Models in the Regulatory Decision Process, National Academies Press, Washington D.C., 287 p., http://www.nap.edu/catalog.php?record_id=11972.

Texas Administrative Code, 2011, http://info.sos.state.tx.us/pls/pub/readtac$ext.viewtac

Texas Water Code, 2011, http://www.statutes.legis.state.tx.us/docs/WA/pdf/WA.36.pdf