Updates to the MODFLOW Groundwater Model of the San Antonio Segment of the Edwards Aquifer

Presented by

Jim Winterle

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EAA Modeling Team:
Angang “Al” Liu
Ned Troshanov
Andi Zhang
Jim Winterle

EDWARDS AQUIFER AUTHORITY

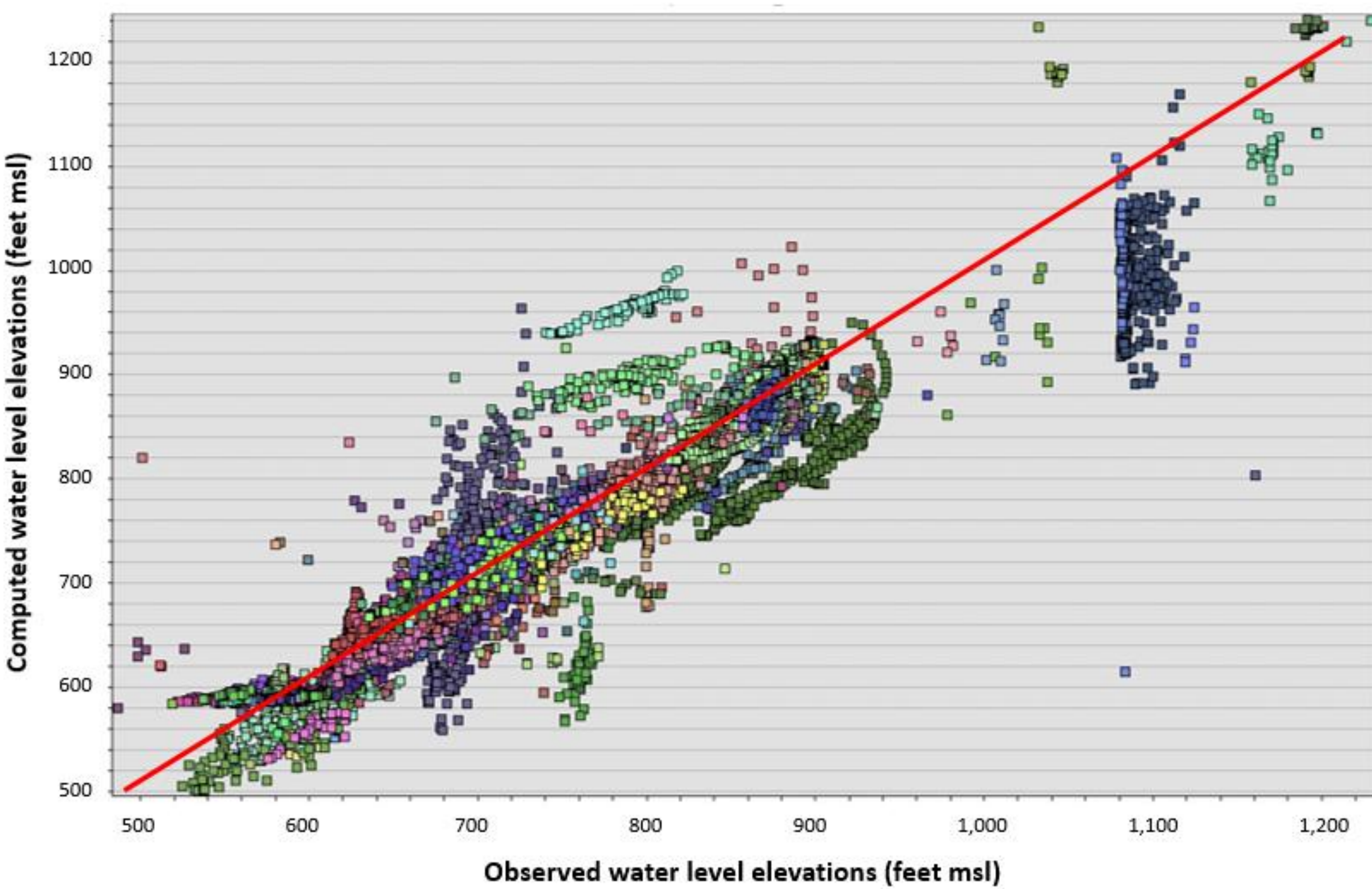
Background

- The goal of the MODFLOW model in the Phase II EAHCP process is to examine spring flow protection measures and inform any refinements that need to be made to those measures
- The EAA model represents a multi-year update of a 2004 model produced by Lindgren et al. (2004)
- The EAA completed updates and solicited feedback from a Groundwater Model Advisory Panel (GMAP) in March 2017
- A report documenting parameterization, calibration, and validation was also reviewed by GMAP members and ready for publication

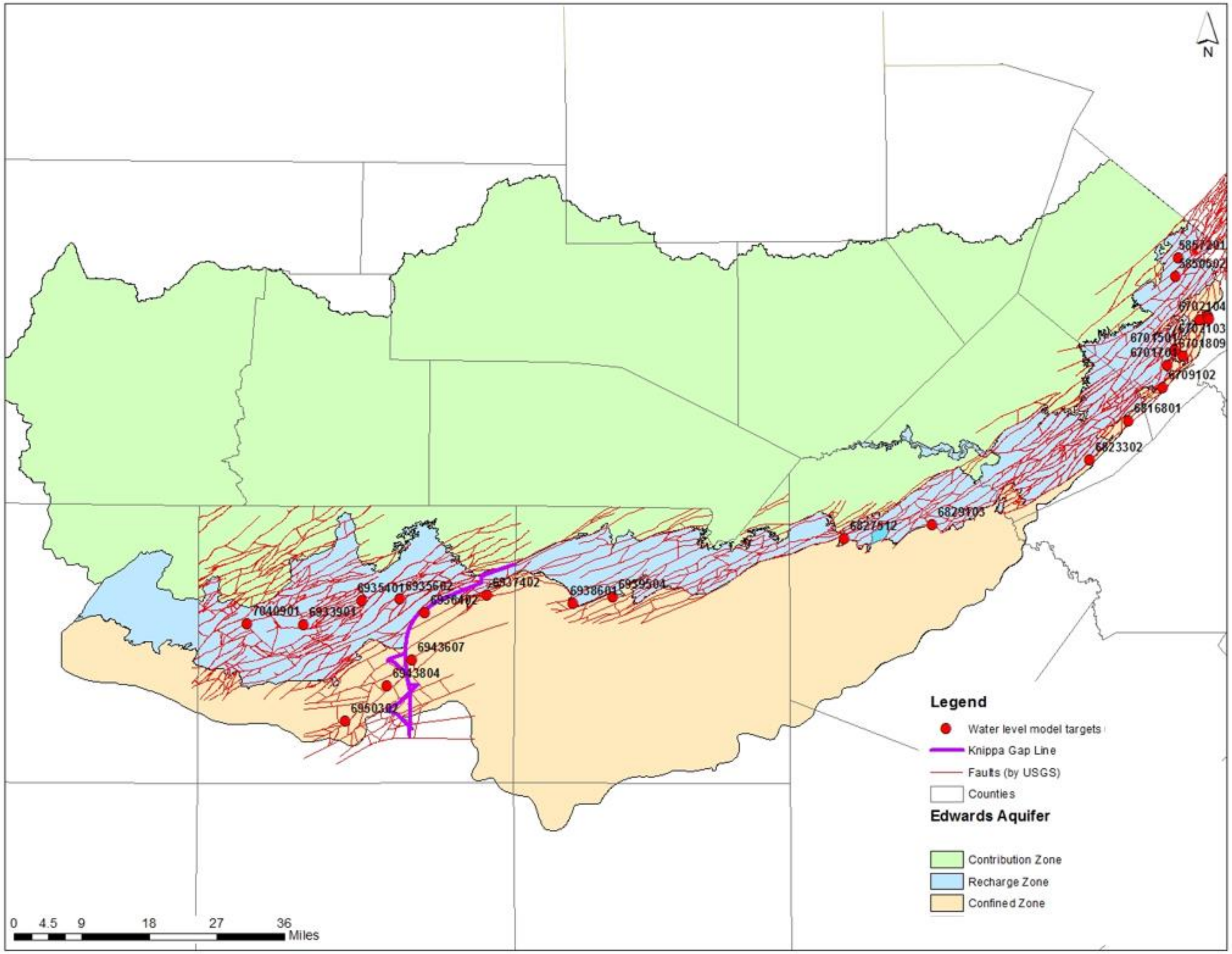
In-Depth Review of Original MODFLOW Model: "Functionality and Verification Analyses"

- Original model calibrated to data from period 1947—2000
- Functionality Analysis conducted to compare original model simulation results to observation data not used in the original calibration
- Verification Analysis ran original model forward for years 2001—2009 to evaluate how well model predicts water levels and spring flows for a period it was not calibrated to
- Results of these analyses informed model updates

Simulated vs. Observed Water Levels for Functionality Test of 2004 Model



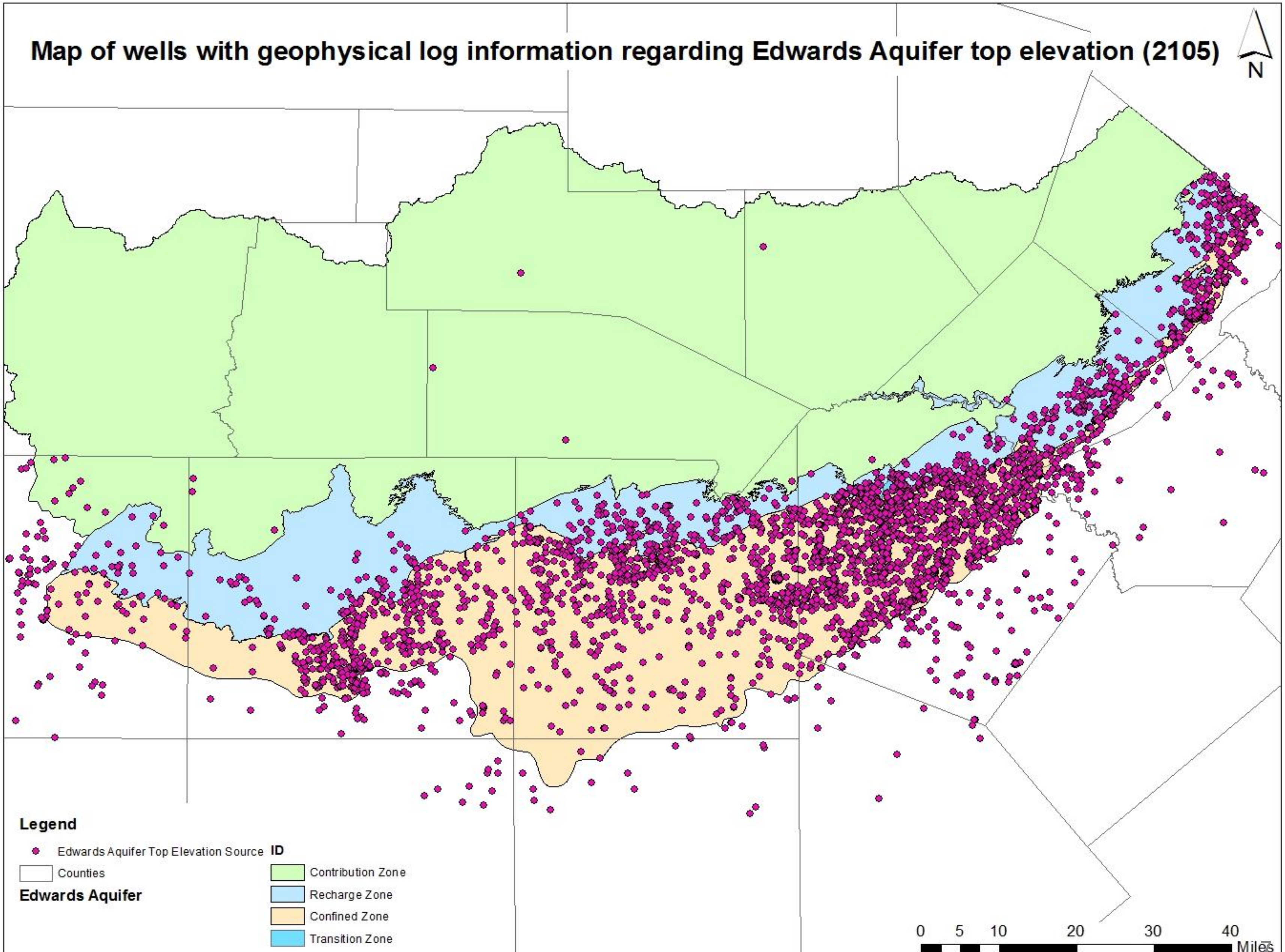
Locations of Wells with Largest Errors in Functionality Test

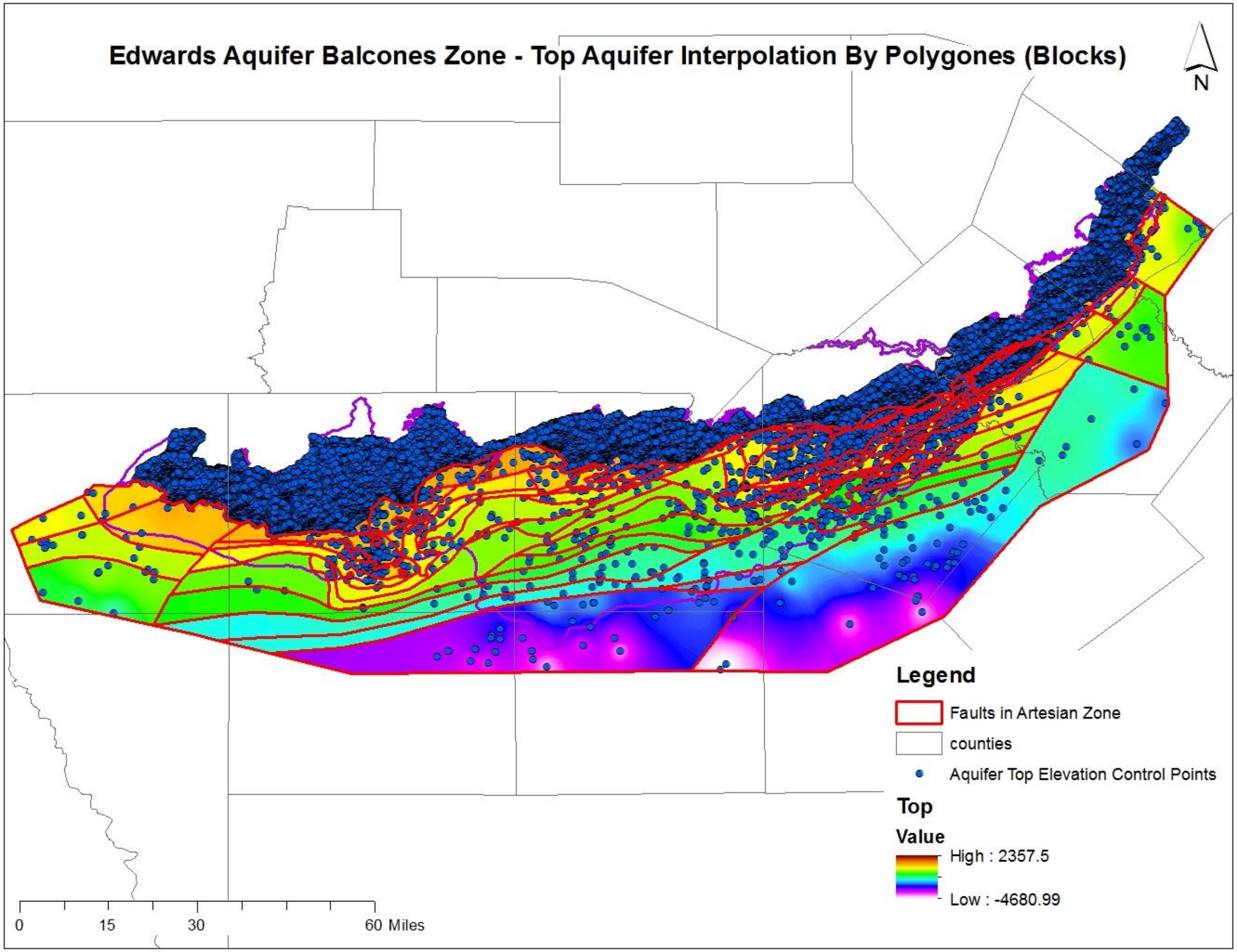


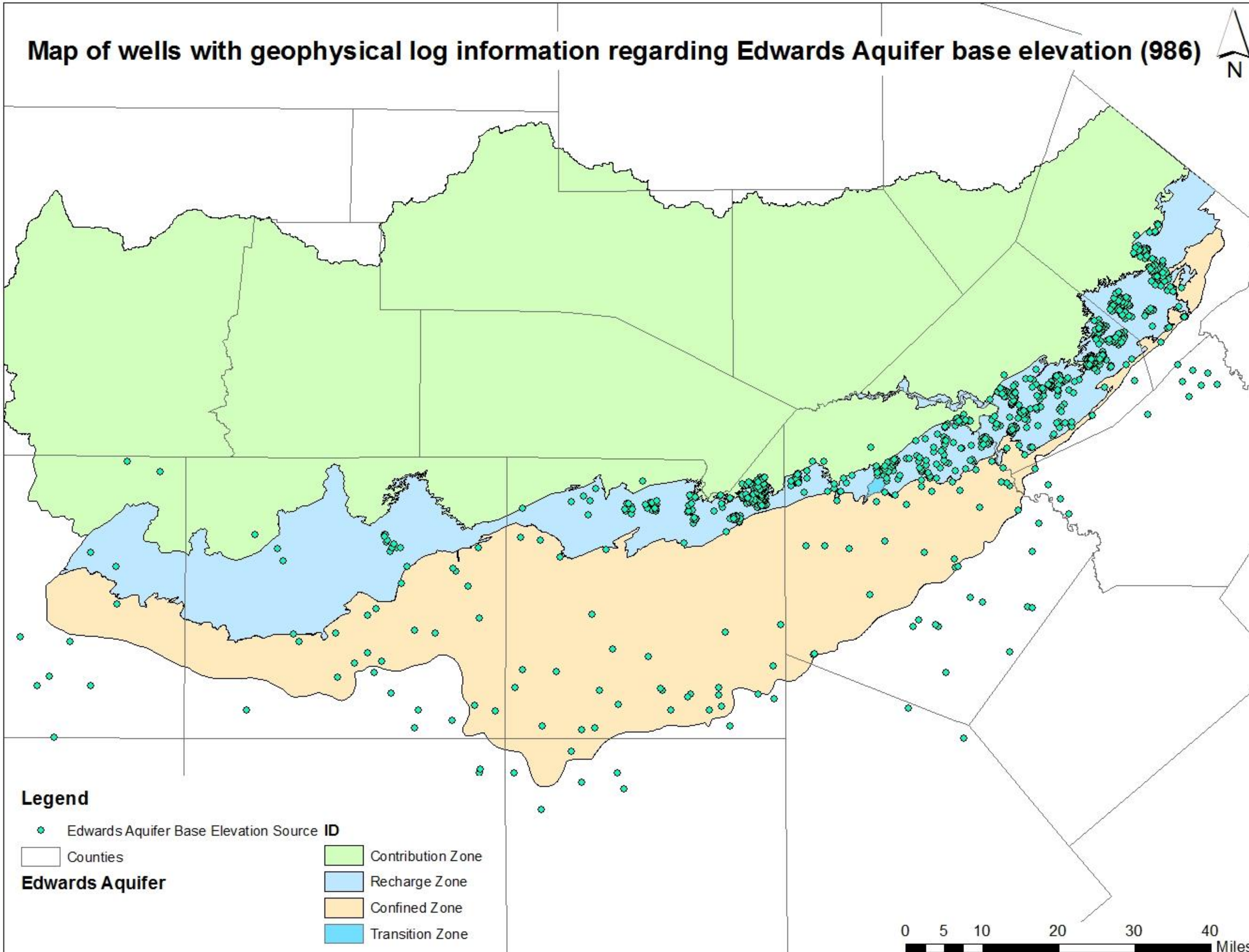
Model Update and Recalibration

Major changes from original model include:

- Removed Barton Spring segment
- New tops and bottom layer elevation model
- Hydraulic conductivity zones modified to remove explicit conduits
- Added HFB flow barriers to represent Knippa Gap and Haby's Crossing fault zone
- Known locations of wells and annual pumping totals
- Added two new spring locations to represent Hueco Springs and subsurface discharge in Leona River basin
- Increase rate of interformational flow in norther Bexar County


Map of wells with geophysical log information regarding Edwards Aquifer top elevation (2105)
N
Legend
Edwards Aquifer Top Elevation Source
Counties
Edwards Aquifer
ID
Contribution Zone
Recharge Zone
Confined Zone
Transition Zone
0 5 10 20 30 40
Miles

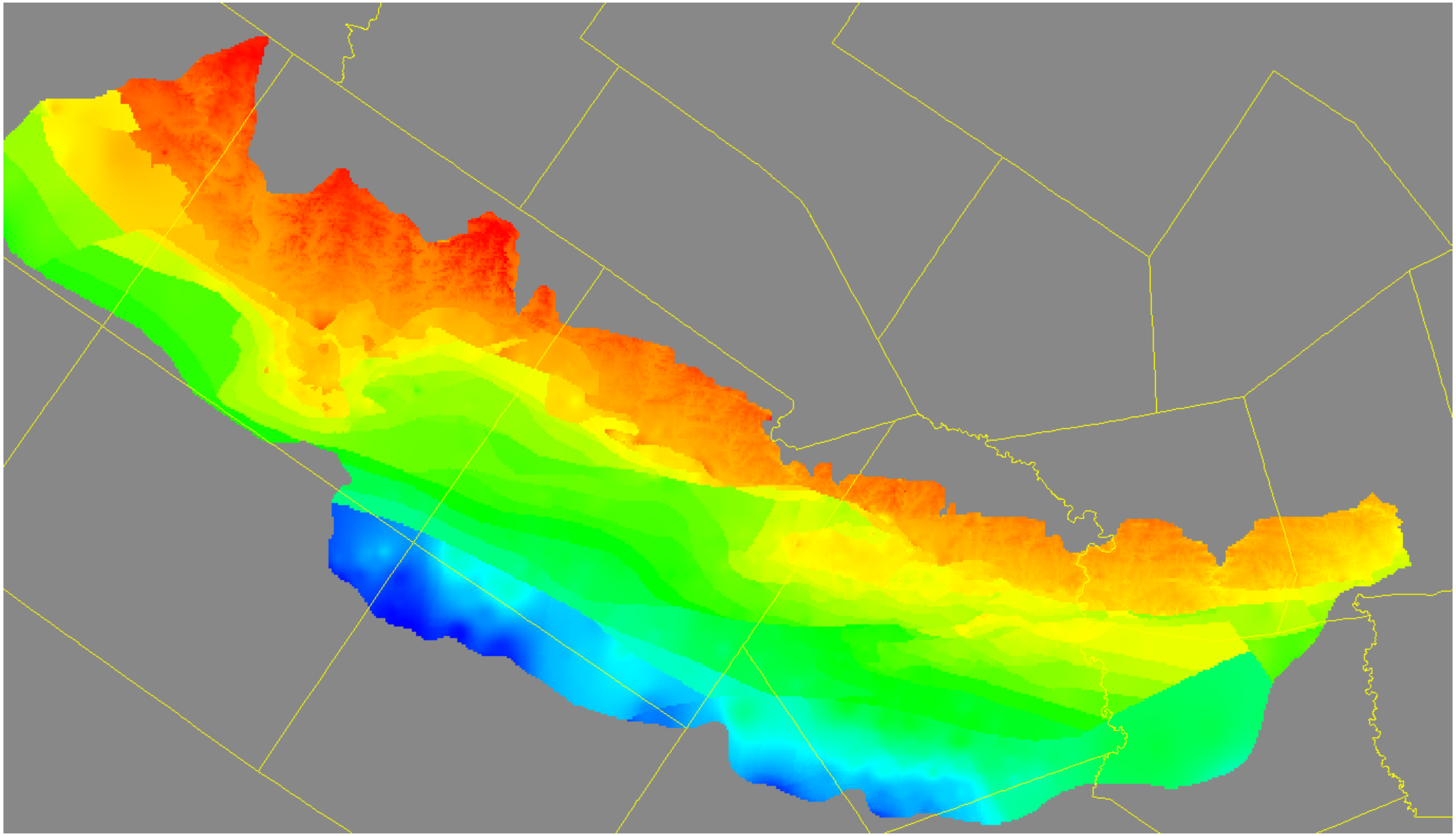

Edwards Aquifer Balcones Zone - Top Aquifer Interpolation By Polygones (Blocks)
N
Legend
Faults in Artesian Zone
counties
Aquifer Top Elevation Control Points
Top
Value
High : 2357.5
Low : -4680.99
0
15
30
60 Miles



Map of wells with geophysical log information regarding Edwards Aquifer base elevation (986)
N
Legend
Edwards Aquifer Base Elevation Source ID
Counties
Edwards Aquifer
Contribution Zone
Recharge Zone
Confined Zone
Transition Zone
0 5 10 20 30 40
Miles

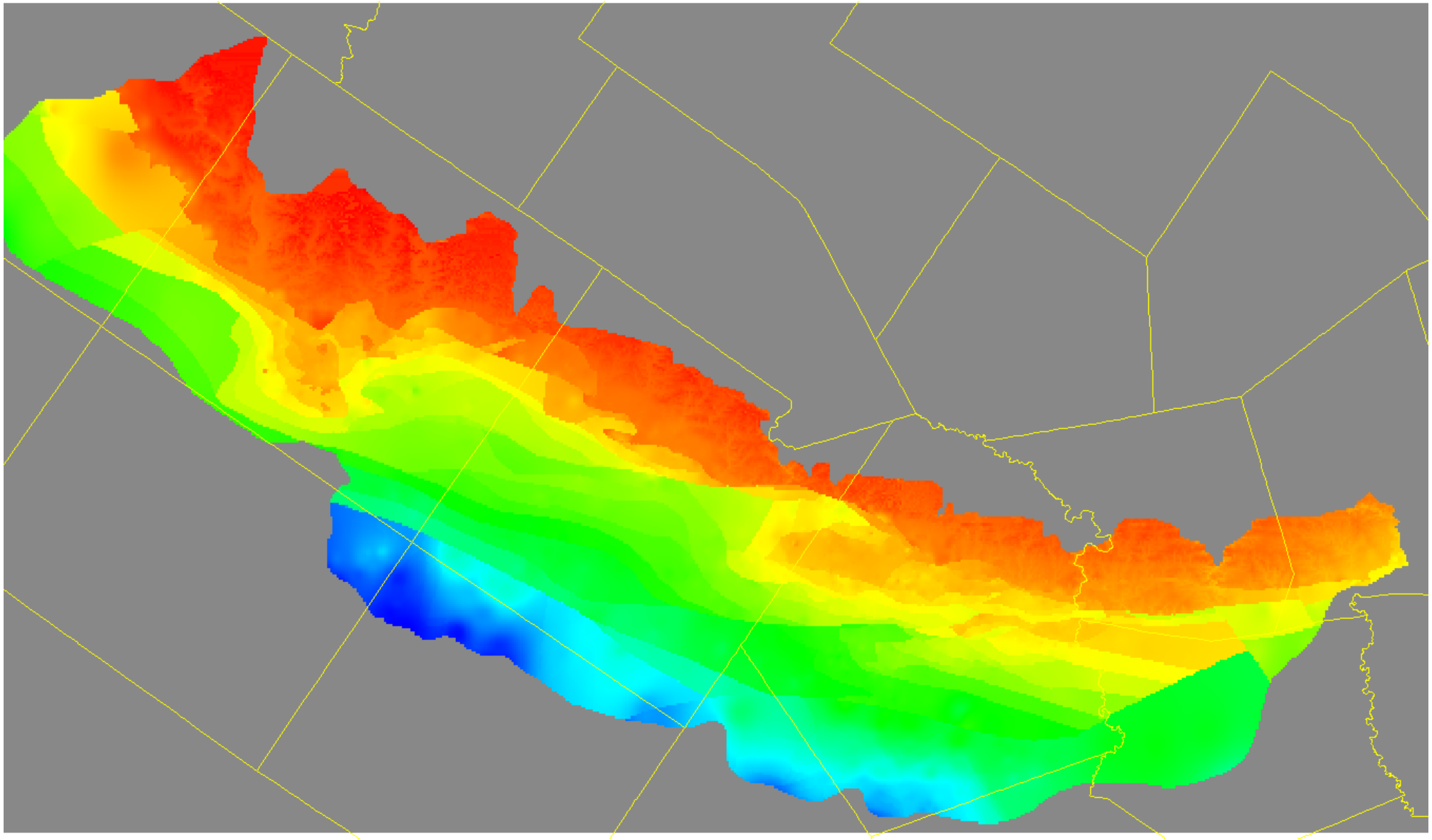
Updated Model Top Elevation

Contour of Simulated Model Top Elevation (Range from -4064 (blue) to 2018 ft (red) above msl)



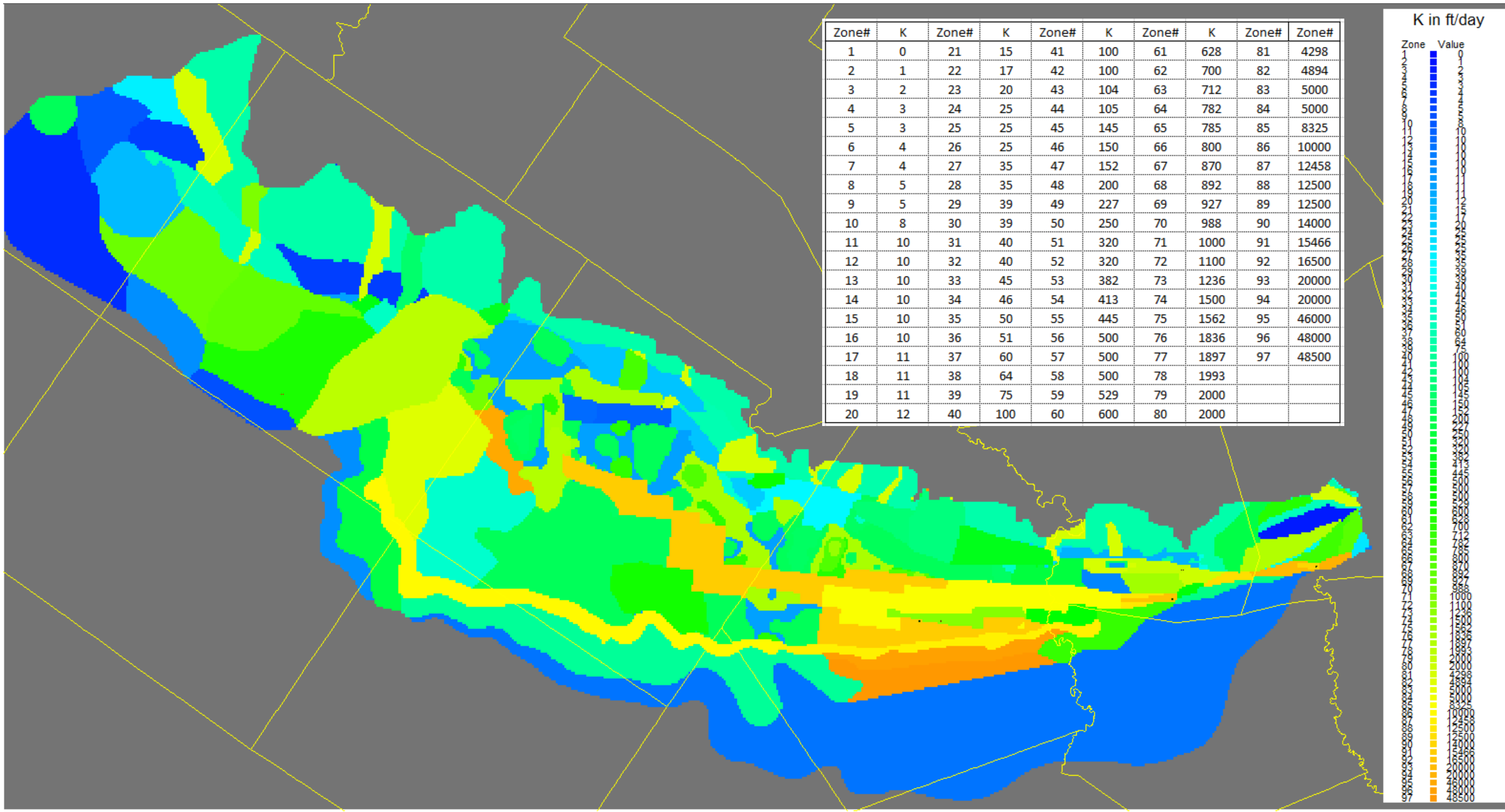
Updated Model Bottom Elevation

Contour of Simulated Model Bottom Elevation (Range from -5000 (blue) to 1114 ft (red) above msl)



Hydraulic Conductivity Zones

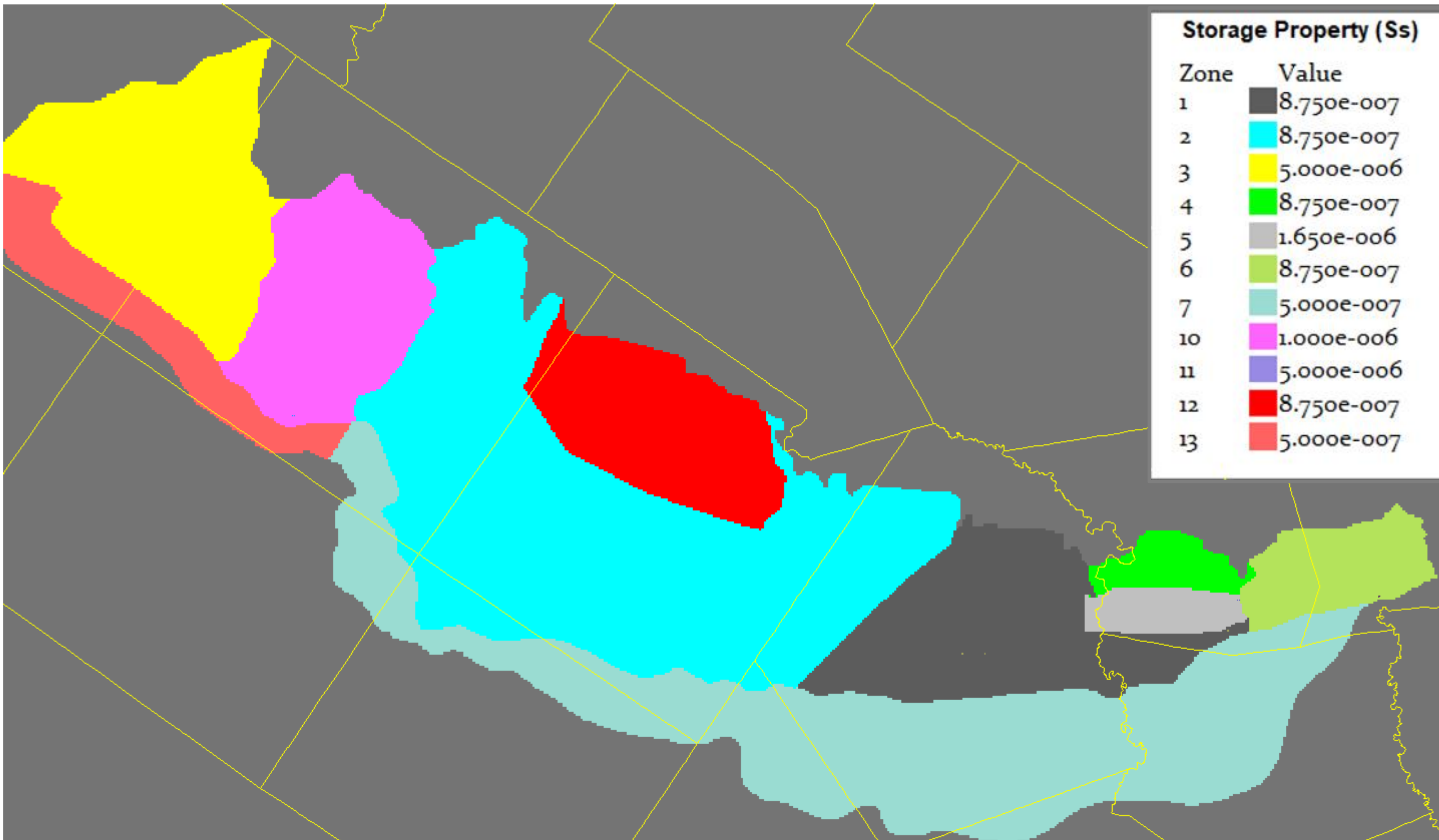
Simulated Distribution of Hydraulic Conductivity, Ranging from 1 ft/day (dark blue) to 48,500 ft/day (orange)



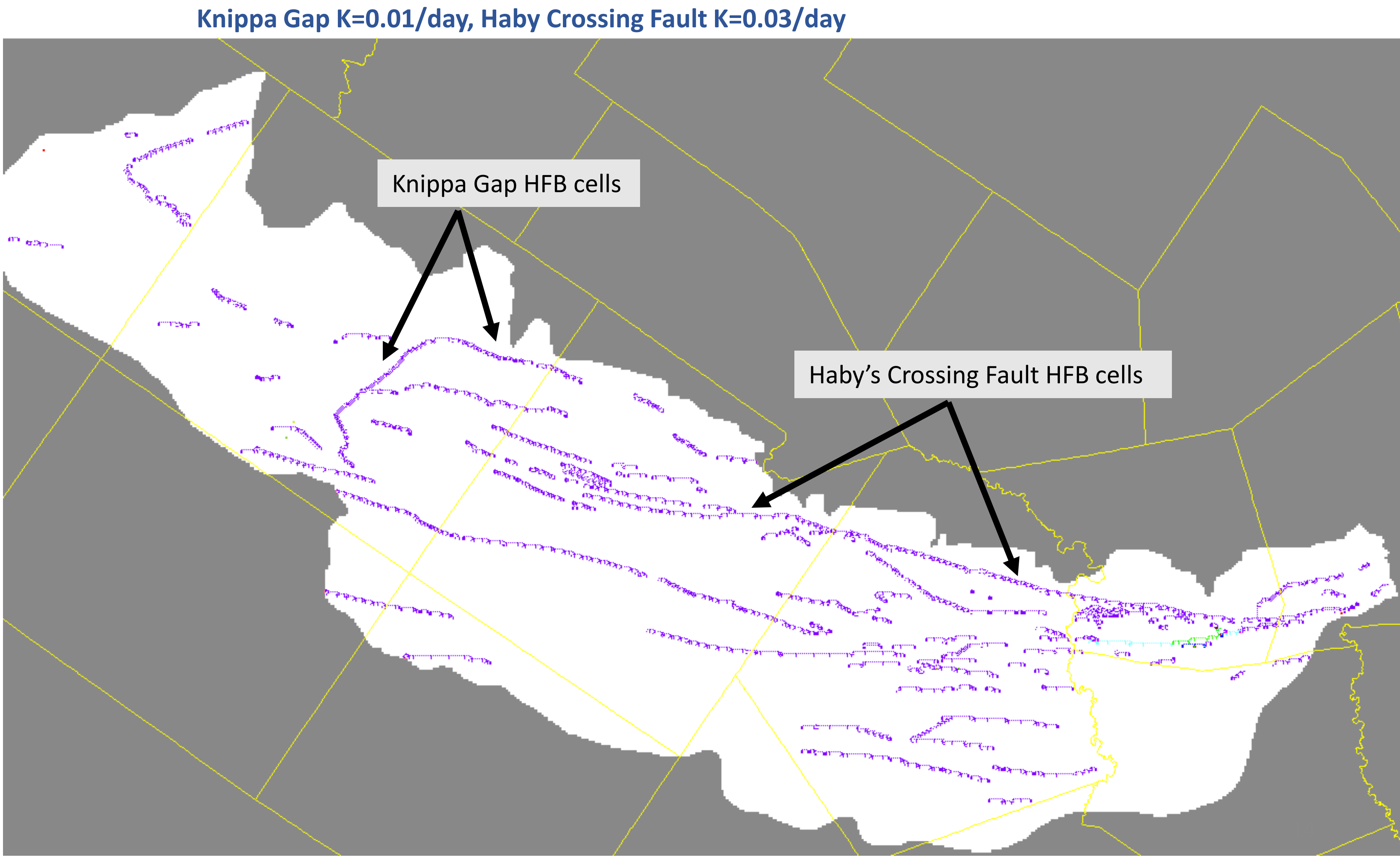
Zone#	K	Zone#	K	Zone#	K	Zone#	K	Zone#	Zone#
1	0	21	15	41	100	61	628	81	4298
2	1	22	17	42	100	62	700	82	4894
3	2	23	20	43	104	63	712	83	5000
4	3	24	25	44	105	64	782	84	5000
5	3	25	25	45	145	65	785	85	8325
6	4	26	25	46	150	66	800	86	10000
7	4	27	35	47	152	67	870	87	12458
8	5	28	35	48	200	68	892	88	12500
9	5	29	39	49	227	69	927	89	12500
10	8	30	39	50	250	70	988	90	14000
11	10	31	40	51	320	71	1000	91	15466
12	10	32	40	52	320	72	1100	92	16500
13	10	33	45	53	382	73	1236	93	20000
14	10	34	46	54	413	74	1500	94	20000
15	10	35	50	55	445	75	1562	95	46000
16	10	36	51	56	500	76	1836	96	48000
17	11	37	60	57	500	77	1897	97	48500
18	11	38	64	58	500	78	1993		
19	11	39	75	59	529	79	2000		
20	12	40	100	60	600	80	2000		

Storage Parameter Zones

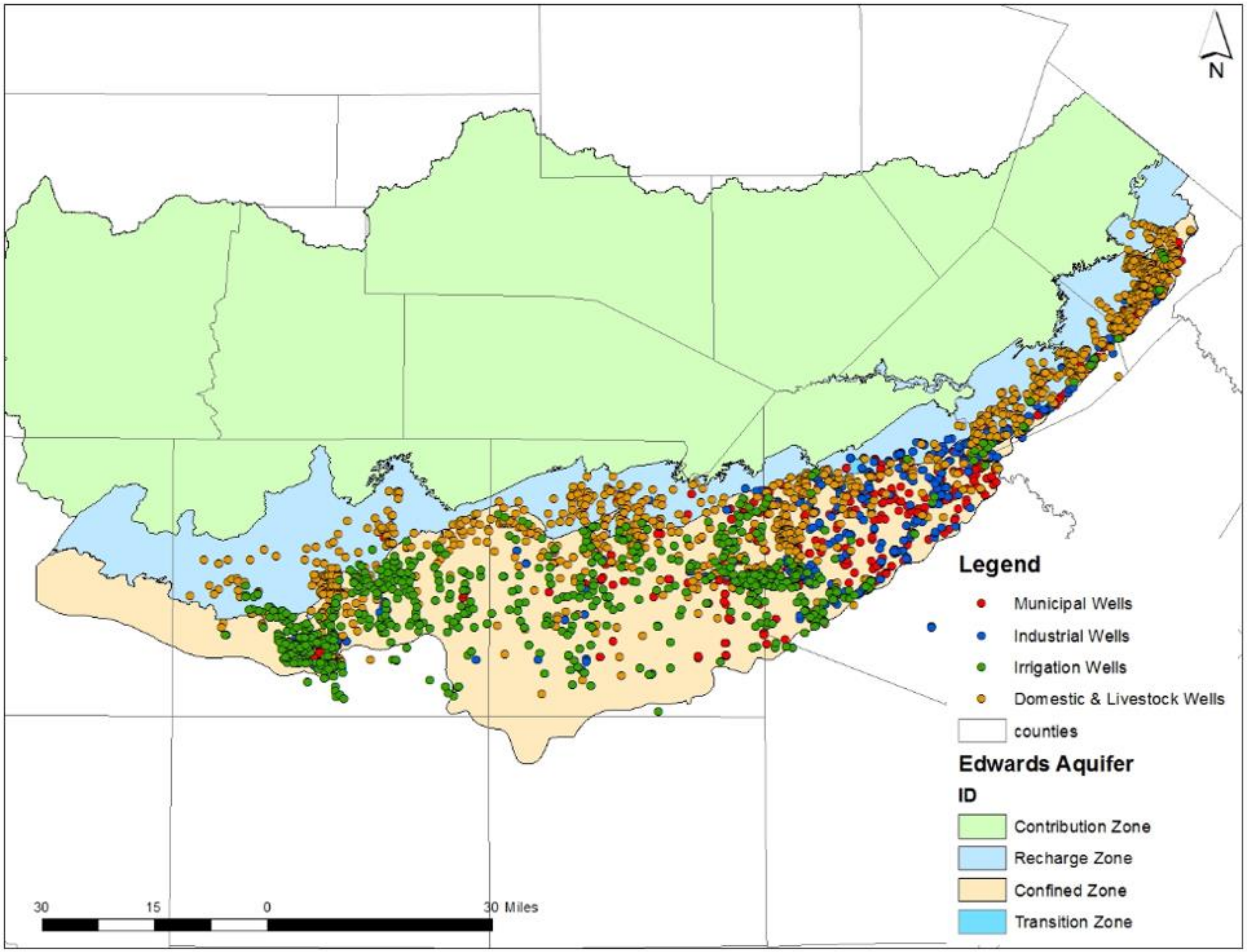
Specific Storage (Ss) 5.00E-06 to 5.00E-07 d^{-1} (same as original 2004 model)
Specific Yield (Sy) 1.00E-03 to 2.12E-01 (5.00E-03 to 1.50E-01 in 2004 model)



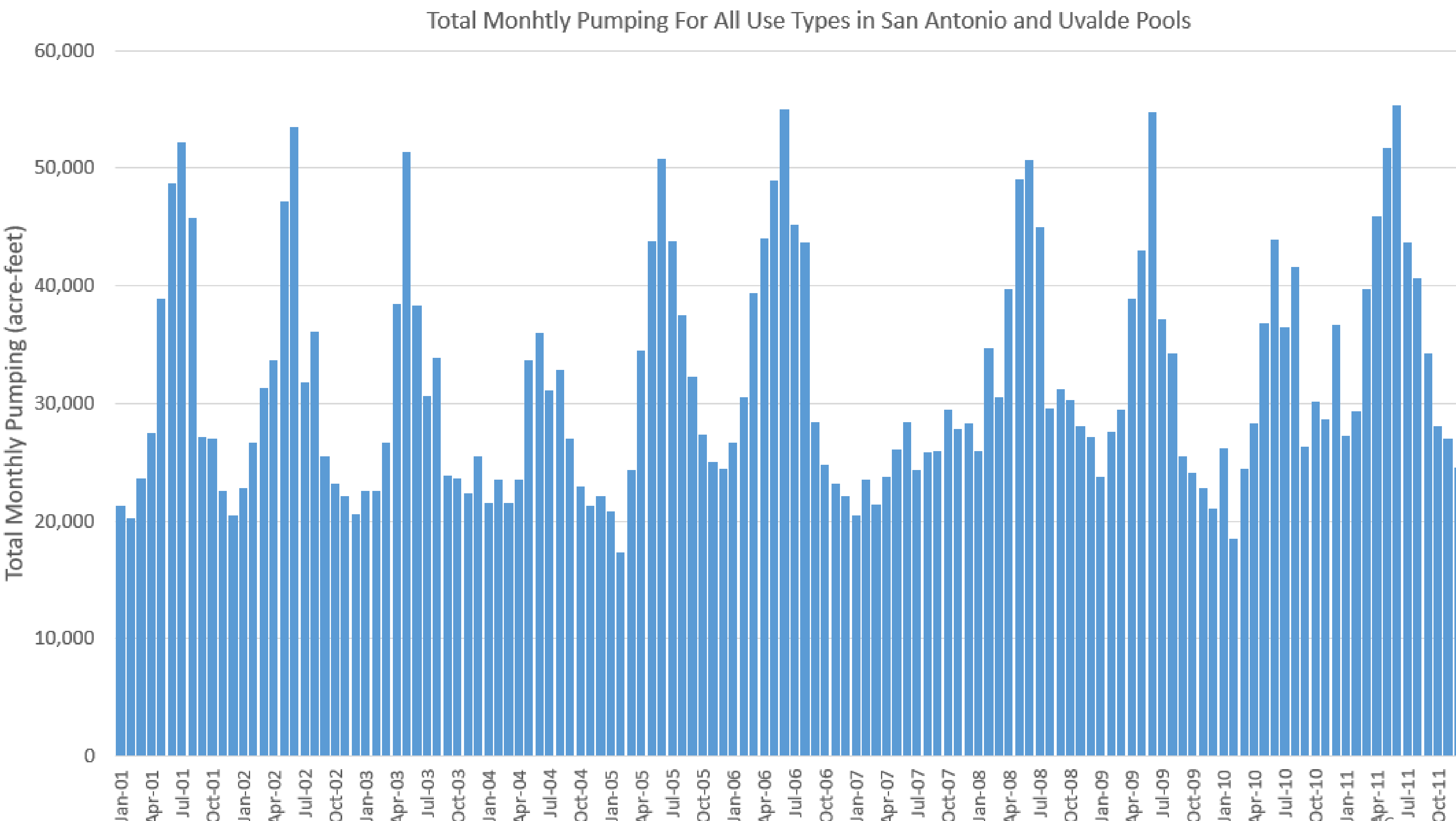
Horizontal Flow Barriers



Pumping Locations and Type of Use

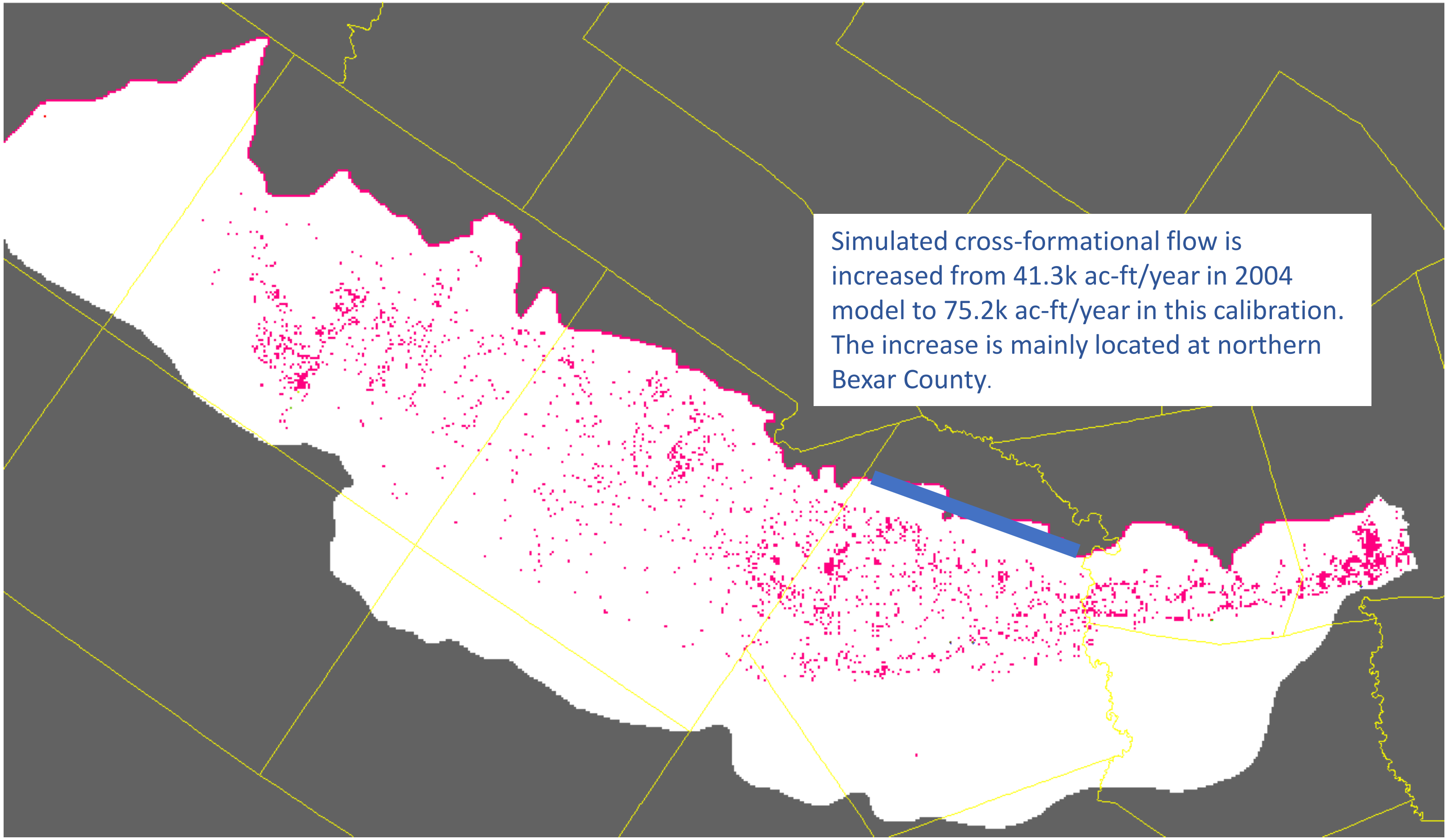


Monthly Pumping Rates Estimated for Each Location

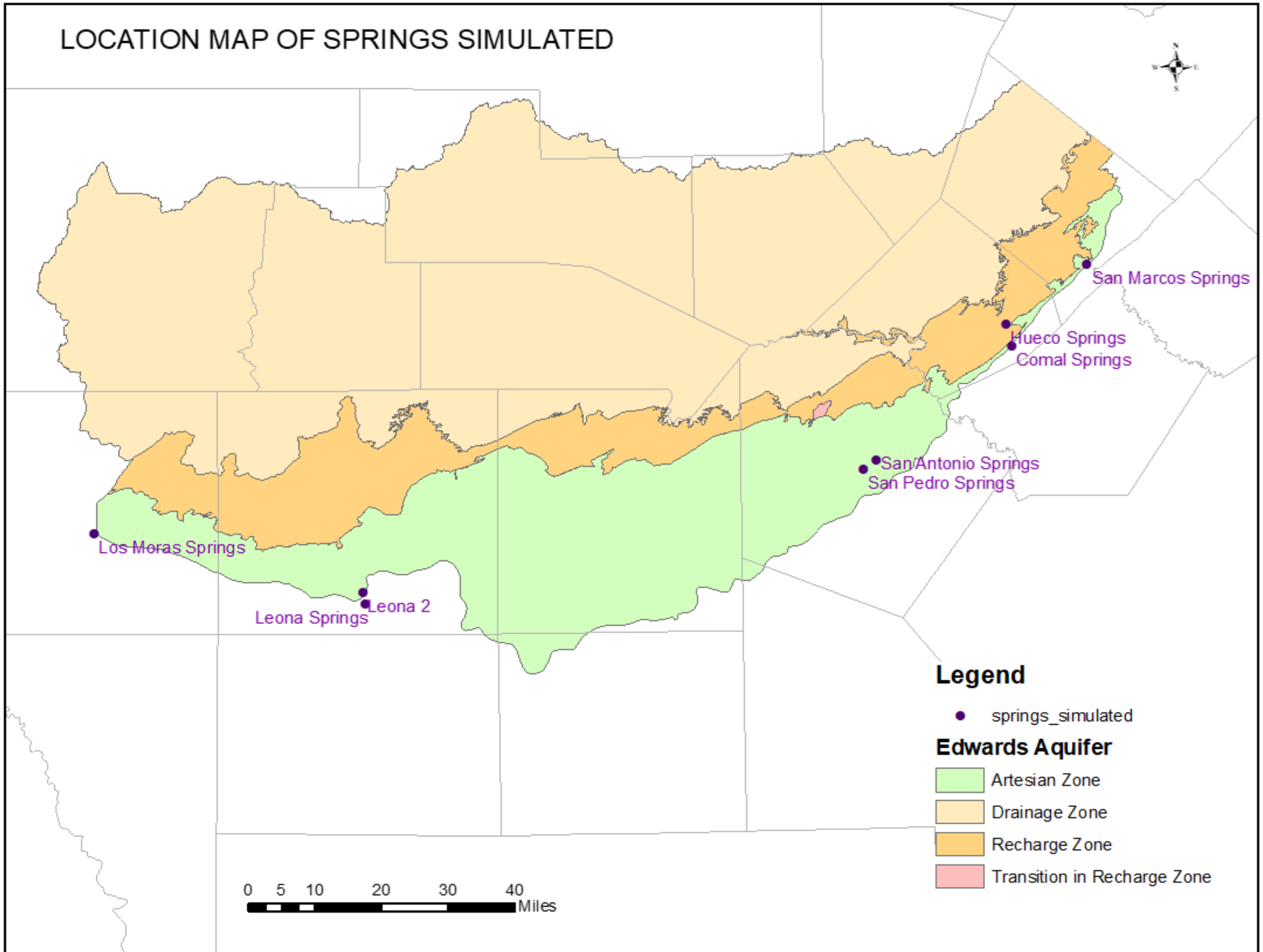


Pumping well locations

Injection wells used to represent cross-formational boundary flow from Trinity aquifer to the north



Modeled Springflow Locations



Modifications to USGS recharge estimates based on same method developed by Lindgren et al. for the original model

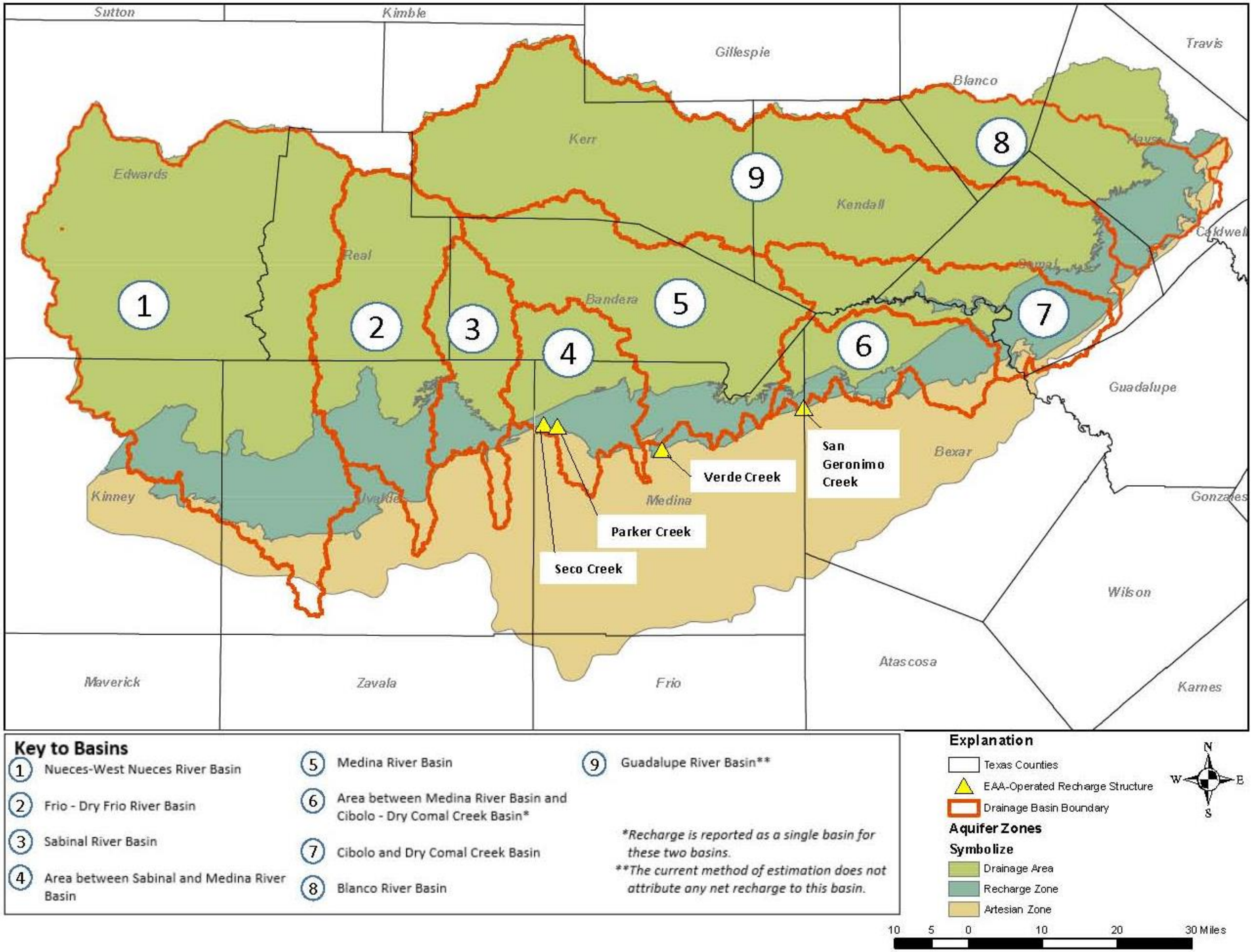
- Recharge to the Cibolo and Dry Comal Creek watershed area is reduced by a factor of 0.5 for all monthly stress periods

- In years when the USGS aquifer-wide total annual recharge estimate exceeds 1.4 million acre-feet, recharge to all basins is multiplied by a factor of 0.8 for all stress periods during that year, after applying the above corrections. In the updated model, this reduction was applied to years 2002, 2004, and 2007

- Recharge to Nueces-West Nueces River watershed was increased by a factor of 1.048 for all monthly stress periods

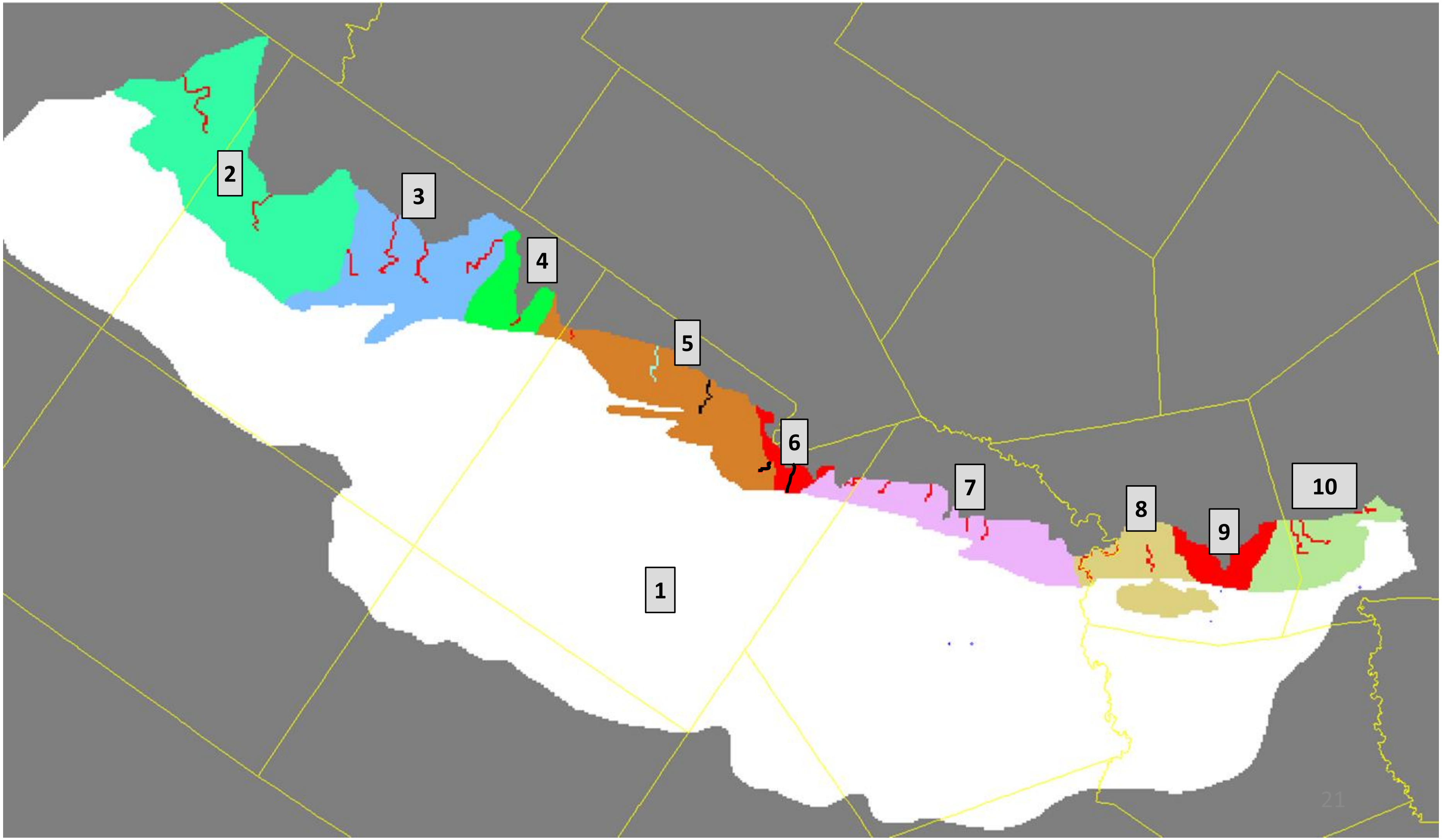
- Recharge to Frio – Dry Frio watershed area was increased by a factor of 1.011 for all monthly stress periods.

Recharge estimates start with USGS estimates for 8 watershed areas Guadalupe watershed (9) not estimated by USGS



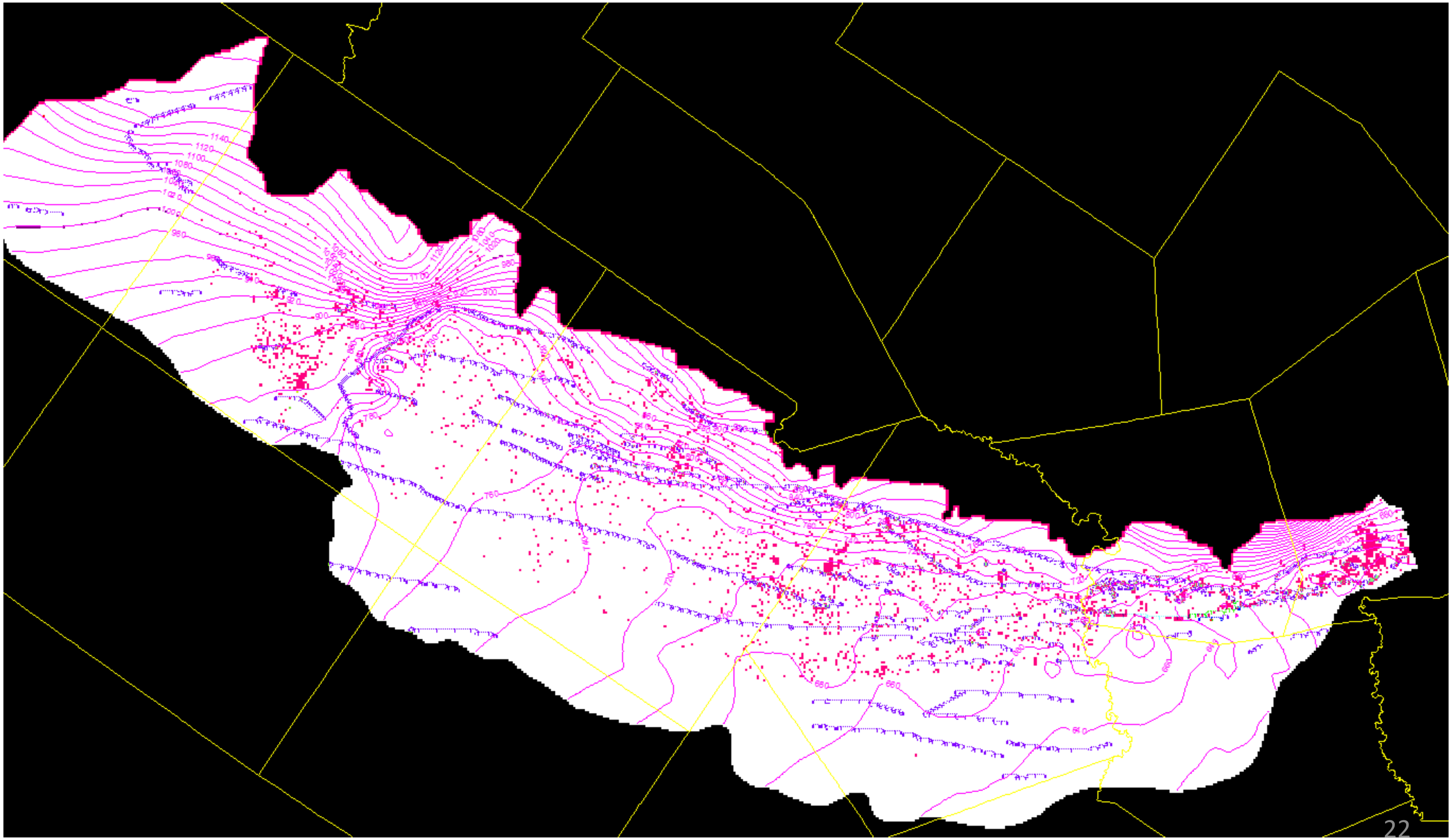
Distribution of Recharge

15% assigned as distributed recharge in nine watershed zones
85% assigned to 23 stream segments
Only distributed recharge in Guadalupe River basin, based on average rates for adjacent basins



Initial Condition for Hydraulic Heads

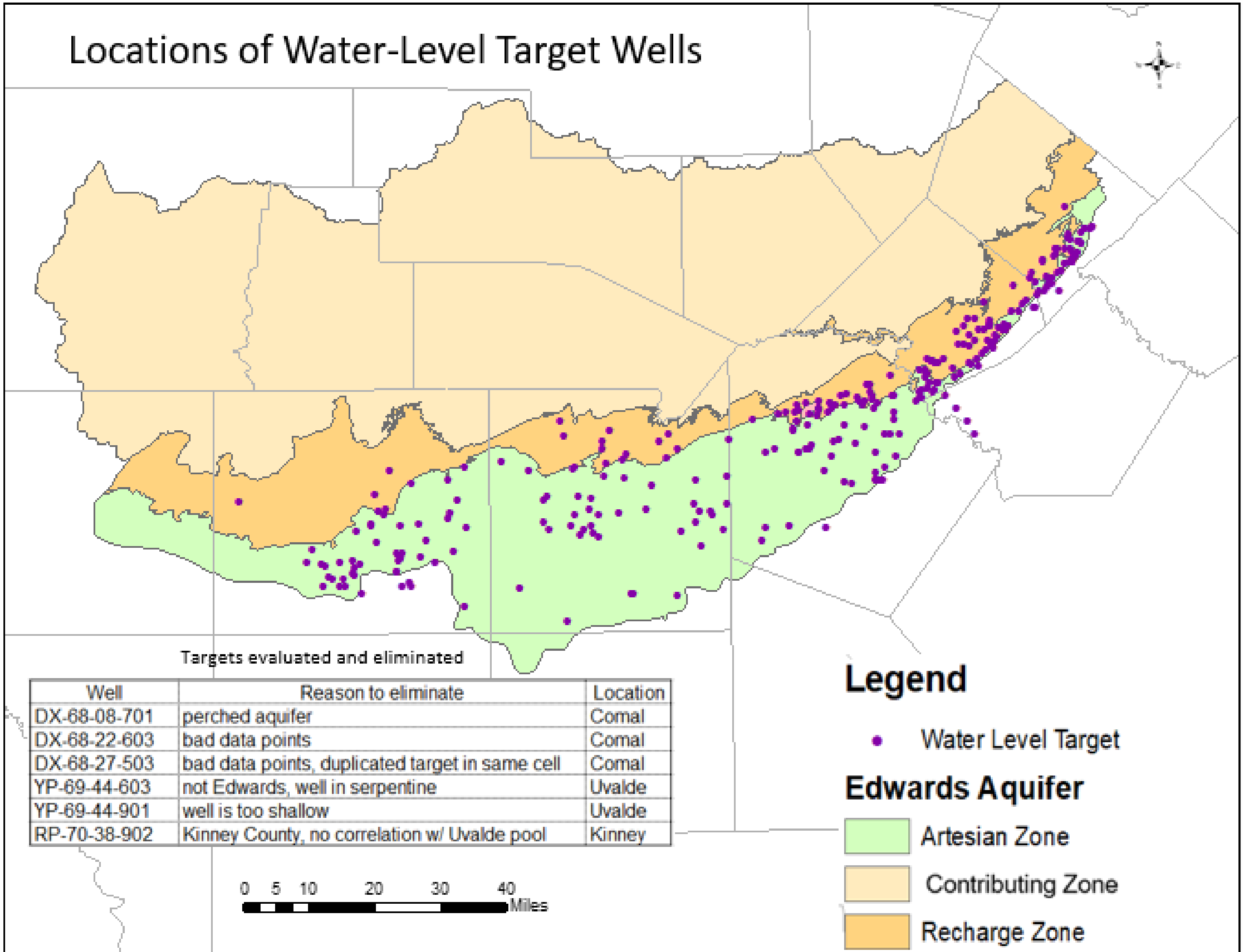
Contour of Initial Head Data for End of December 2000



Model Calibration

- Parameters varied during calibration:
  - The shape, and assigned hydraulic conductivity of 96 delineated hydraulic conductivity zones
  - Specific yield of the 12 storage zones
  - Hydraulic characteristic parameter for the HFB locations representing the Haby's Crossing fault and Knippa Gap area
  - Drain elevation and conductance parameters for the drain cells representing spring discharge locations, and
  - Boundary inflow rates representing interformational flow across the northern model boundary
- January 2001 through December 2011 calibration period—132 monthly time steps

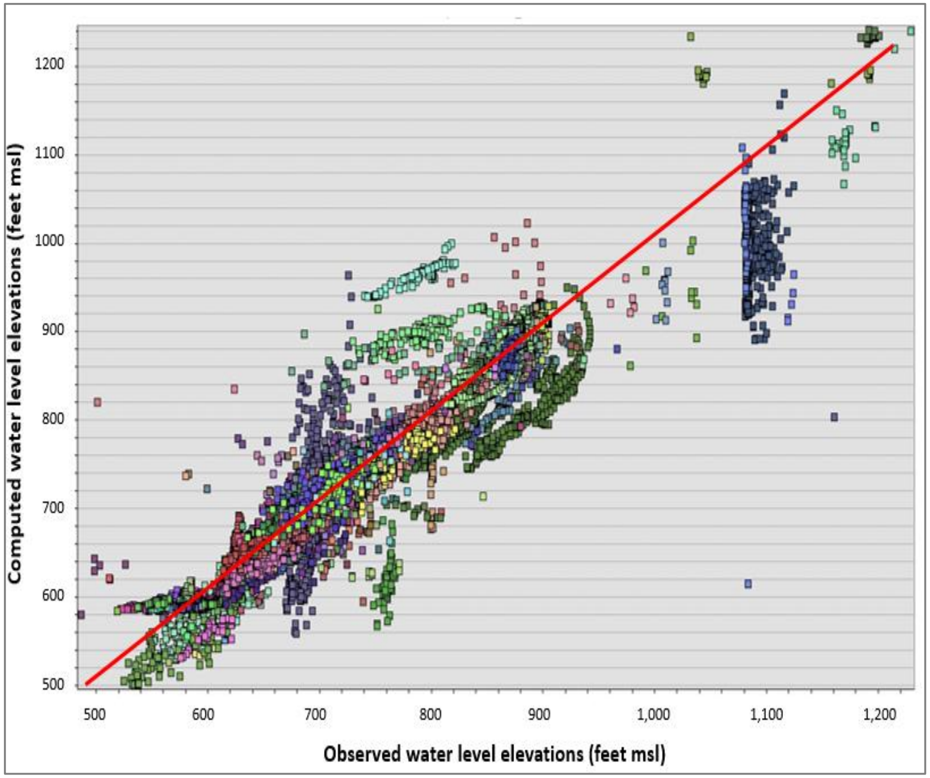
Water-Level Observation Locations



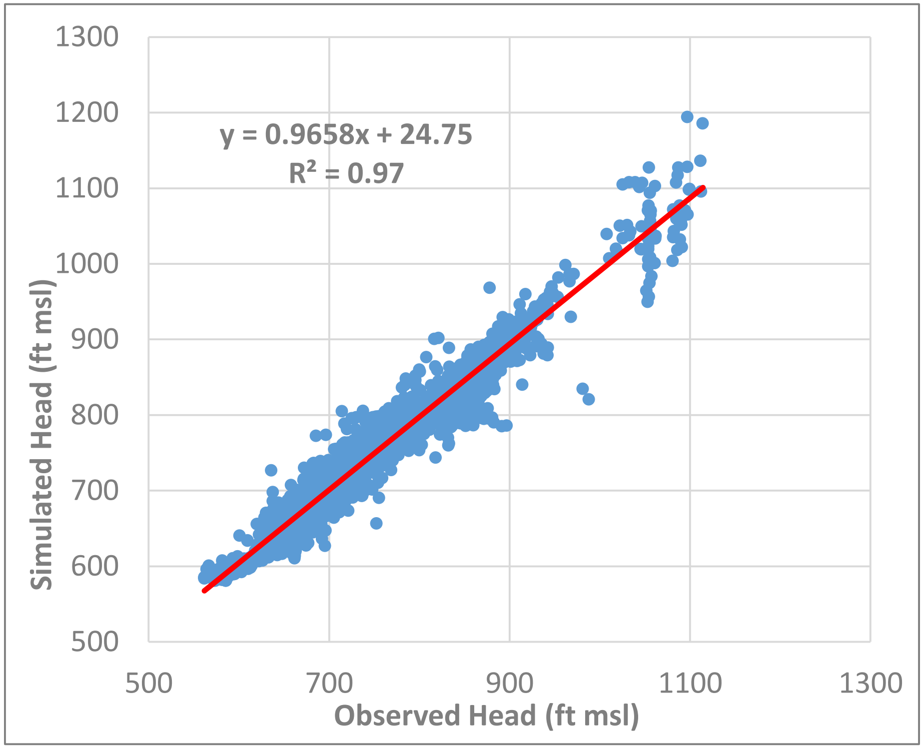
Targets evaluated and eliminated

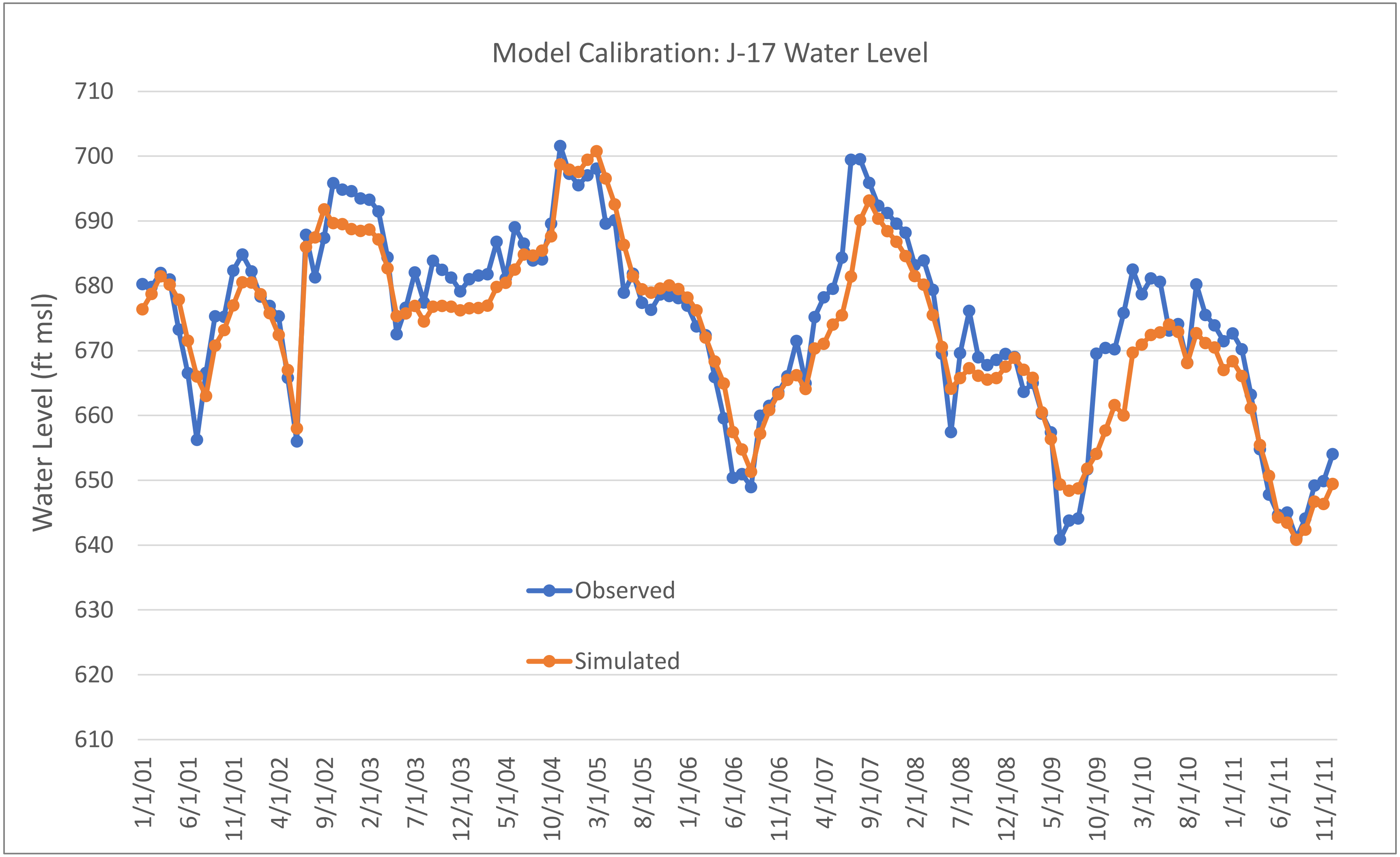
Well	Reason to eliminate	Location
DX-68-08-701	perched aquifer	Comal
DX-68-22-603	bad data points	Comal
DX-68-27-503	bad data points, duplicated target in same cell	Comal
YP-69-44-603	not Edwards, well in serpentine	Uvalde
YP-69-44-901	well is too shallow	Uvalde
RP-70-38-902	Kinney County, no correlation w/ Uvalde pool	Kinney

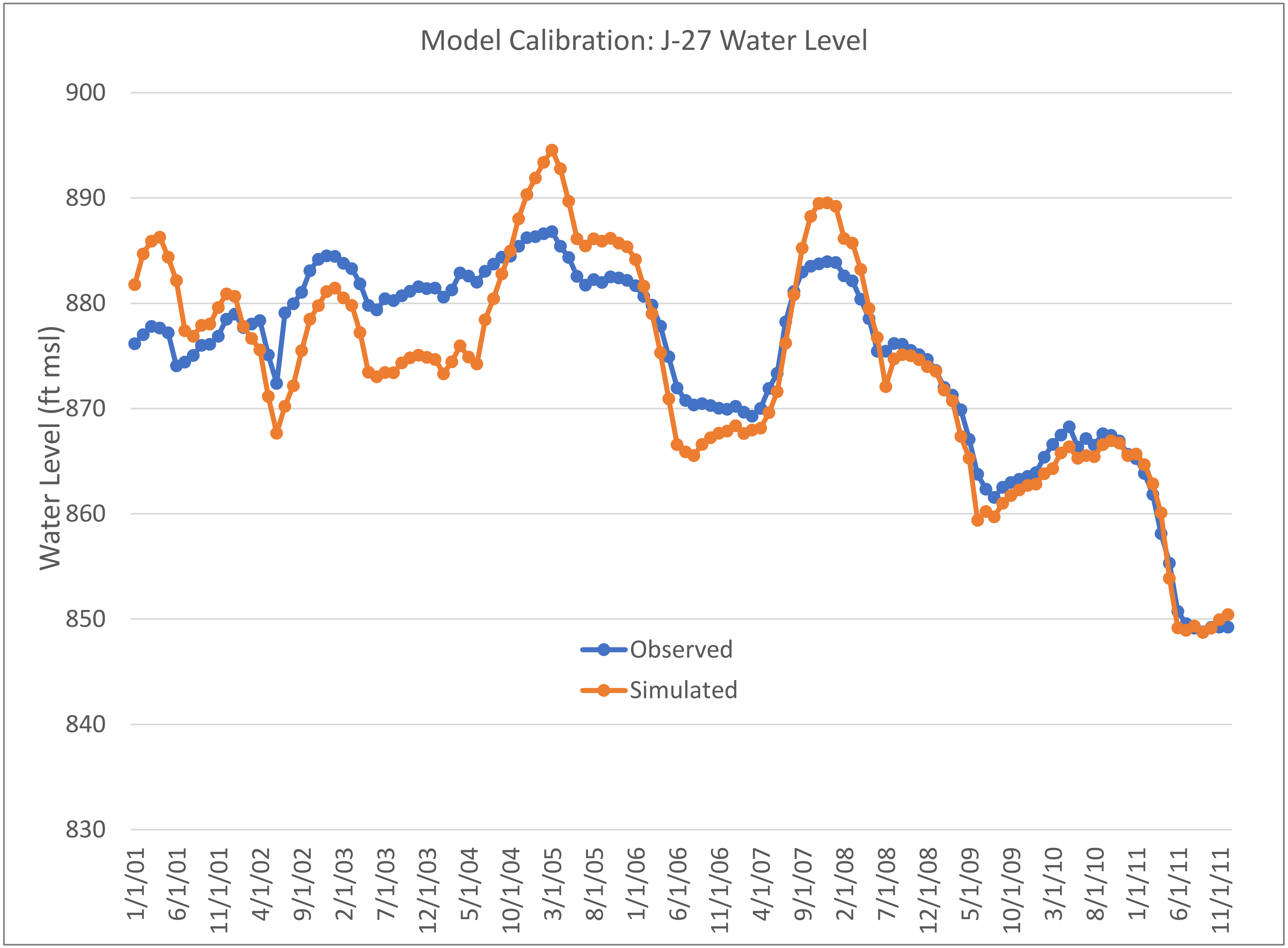
Original Model 1947-2000

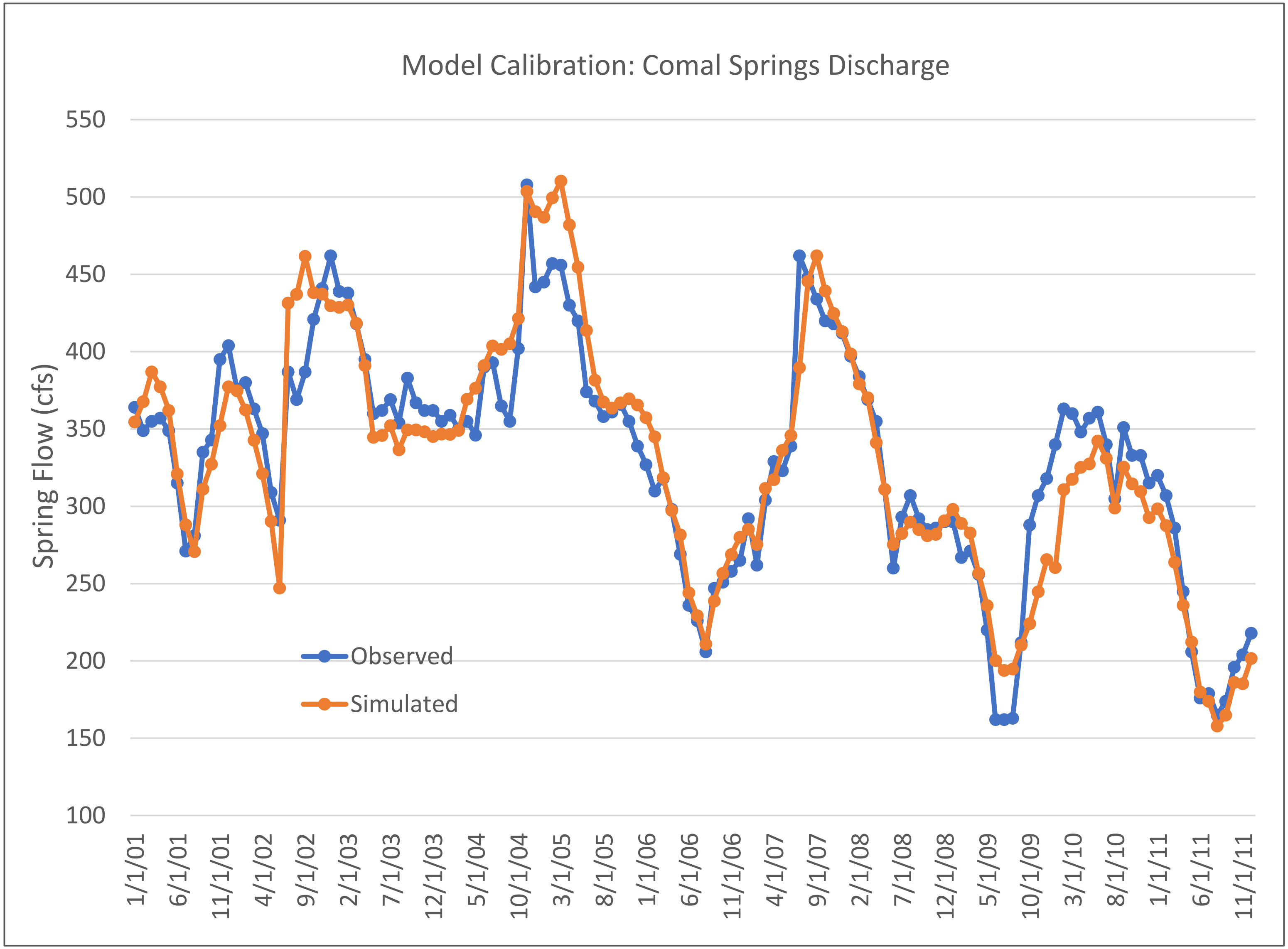


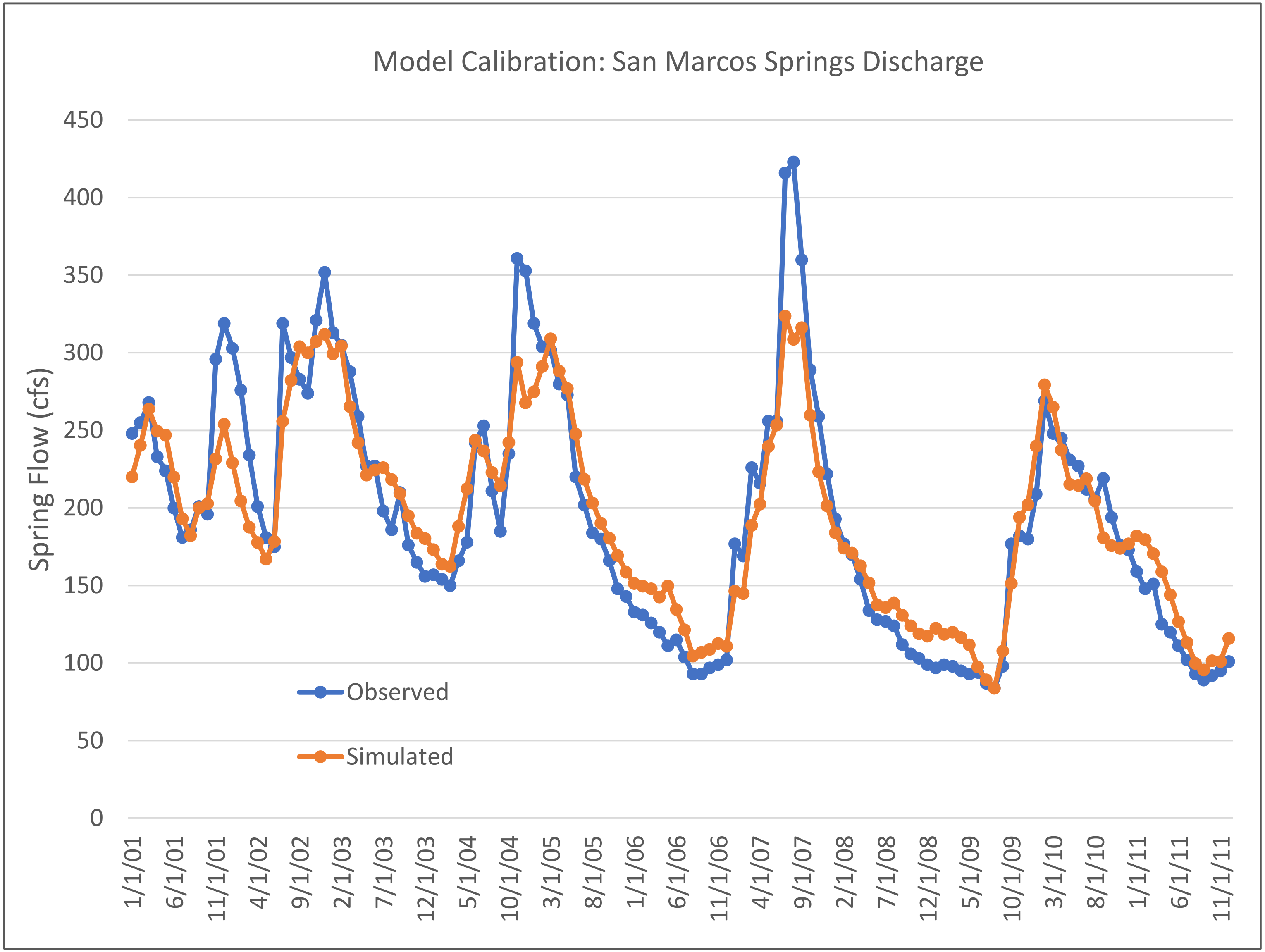
Updated Model 2001-2011

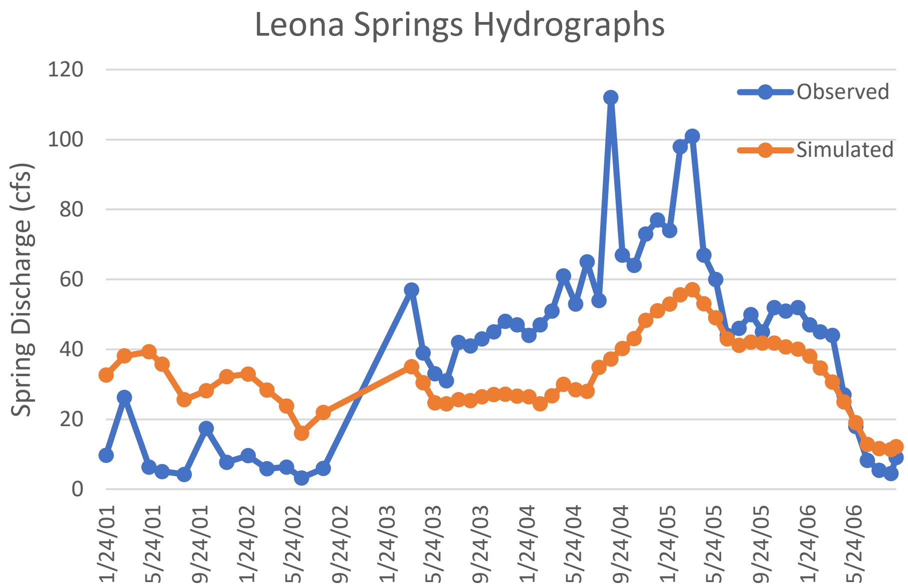


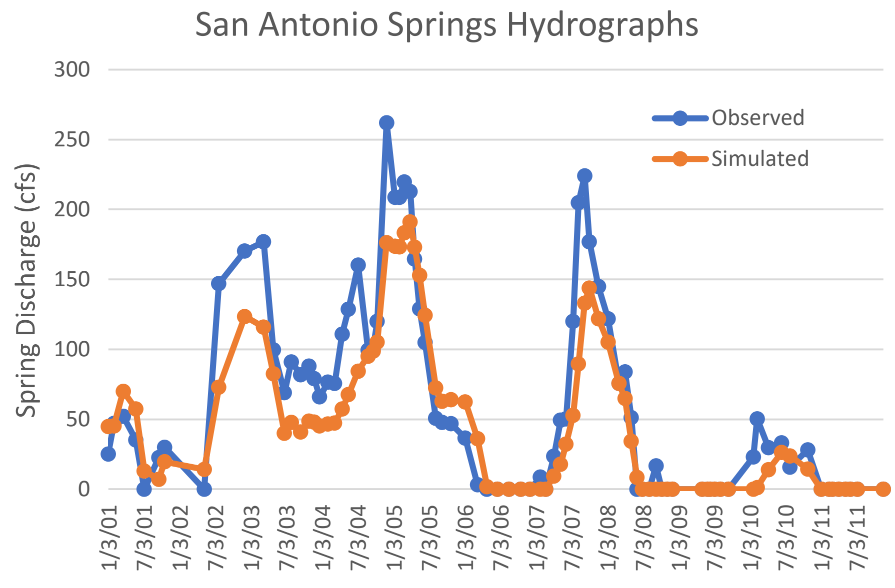

Model Calibration: J-17 Water Level
Water Level (ft msl)
710
700
690
680
670
660
650
640
630
620
610
1/1/01
6/1/01
11/1/01
4/1/02
9/1/02
2/1/03
7/1/03
12/1/03
5/1/04
10/1/04
3/1/05
8/1/05
1/1/06
6/1/06
11/1/06
4/1/07
9/1/07
2/1/08
7/1/08
12/1/08
5/1/09
10/1/09
3/1/10
8/1/10
1/1/11
6/1/11
11/1/11
Observed
Simulated

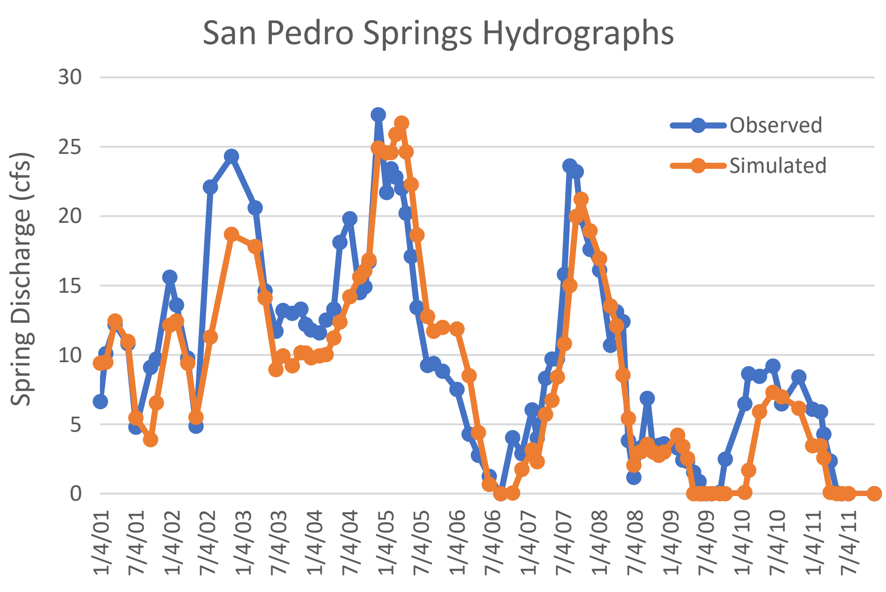

Model Calibration: J-27 Water Level
900
890
880
870
860
850
840
830
Water Level (ft msl)
Observed
Simulated
1/1/01
6/1/01
11/1/01
4/1/02
9/1/02
2/1/03
7/1/03
12/1/03
5/1/04
10/1/04
3/1/05
8/1/05
1/1/06
6/1/06
11/1/06
4/1/07
9/1/07
2/1/08
7/1/08
12/1/08
5/1/09
10/1/09
3/1/10
8/1/10
1/1/11
6/1/11
11/1/11

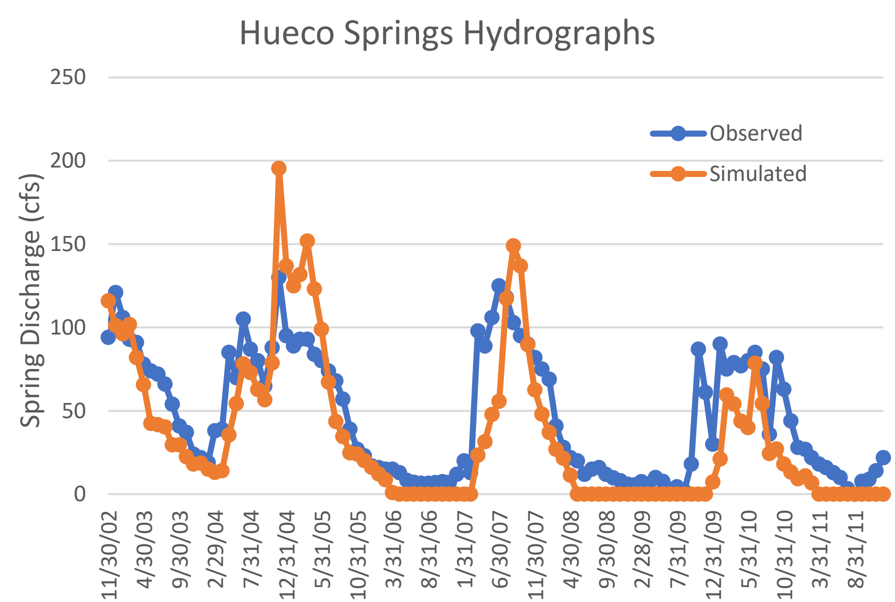

Model Calibration: Comal Springs Discharge
Spring Flow (cfs)
550
500
450
400
350
300
250
200
150
100
1/1/01
6/1/01
11/1/01
4/1/02
9/1/02
2/1/03
7/1/03
12/1/03
5/1/04
10/1/04
3/1/05
8/1/05
1/1/06
6/1/06
11/1/06
4/1/07
9/1/07
2/1/08
7/1/08
12/1/08
5/1/09
10/1/09
3/1/10
8/1/10
1/1/11
6/1/11
11/1/11
Observed
Simulated


Model Calibration: San Marcos Springs Discharge
Spring Flow (cfs)
450
400
350
300
250
200
150
100
50
0
1/1/01
6/1/01
11/1/01
4/1/02
9/1/02
2/1/03
7/1/03
12/1/03
5/1/04
10/1/04
3/1/05
8/1/05
1/1/06
6/1/06
11/1/06
4/1/07
9/1/07
2/1/08
7/1/08
12/1/08
5/1/09
10/1/09
3/1/10
8/1/10
1/1/11
6/1/11
11/1/11
Observed
Simulated


Leona Springs Hydrographs
Spring Discharge (cfs)
0
20
40
60
80
100
120
1/24/01
5/24/01
9/24/01
1/24/02
5/24/02
9/24/02
1/24/03
5/24/03
9/24/03
1/24/04
5/24/04
9/24/04
1/24/05
5/24/05
9/24/05
1/24/06
5/24/06
Observed
Simulated


San Antonio Springs Hydrographs
Spring Discharge (cfs)
0
50
100
150
200
250
300
1/3/01
7/3/01
1/3/02
7/3/02
1/3/03
7/3/03
1/3/04
7/3/04
1/3/05
7/3/05
1/3/06
7/3/06
1/3/07
7/3/07
1/3/08
7/3/08
1/3/09
7/3/09
1/3/10
7/3/10
1/3/11
7/3/11
Observed
Simulated


San Pedro Springs Hydrographs
Spring Discharge (cfs)
0
5
10
15
20
25
30
1/4/01
7/4/01
1/4/02
7/4/02
1/4/03
7/4/03
1/4/04
7/4/04
1/4/05
7/4/05
1/4/06
7/4/06
1/4/07
7/4/07
1/4/08
7/4/08
1/4/09
7/4/09
1/4/10
7/4/10
1/4/11
7/4/11
Observed
Simulated


Hueco Springs Hydrographs
Spring Discharge (cfs)
0
50
100
150
200
250
11/30/02
4/30/03
9/30/03
2/29/04
7/31/04
12/31/04
5/31/05
10/31/05
3/31/06
8/31/06
1/31/07
6/30/07
11/30/07
4/30/08
9/30/08
2/28/09
7/31/09
12/31/09
5/31/10
10/31/10
3/31/11
8/31/11
Observed
Simulated

HYDRAULIC HEAD CALIBRATION STATISTICS

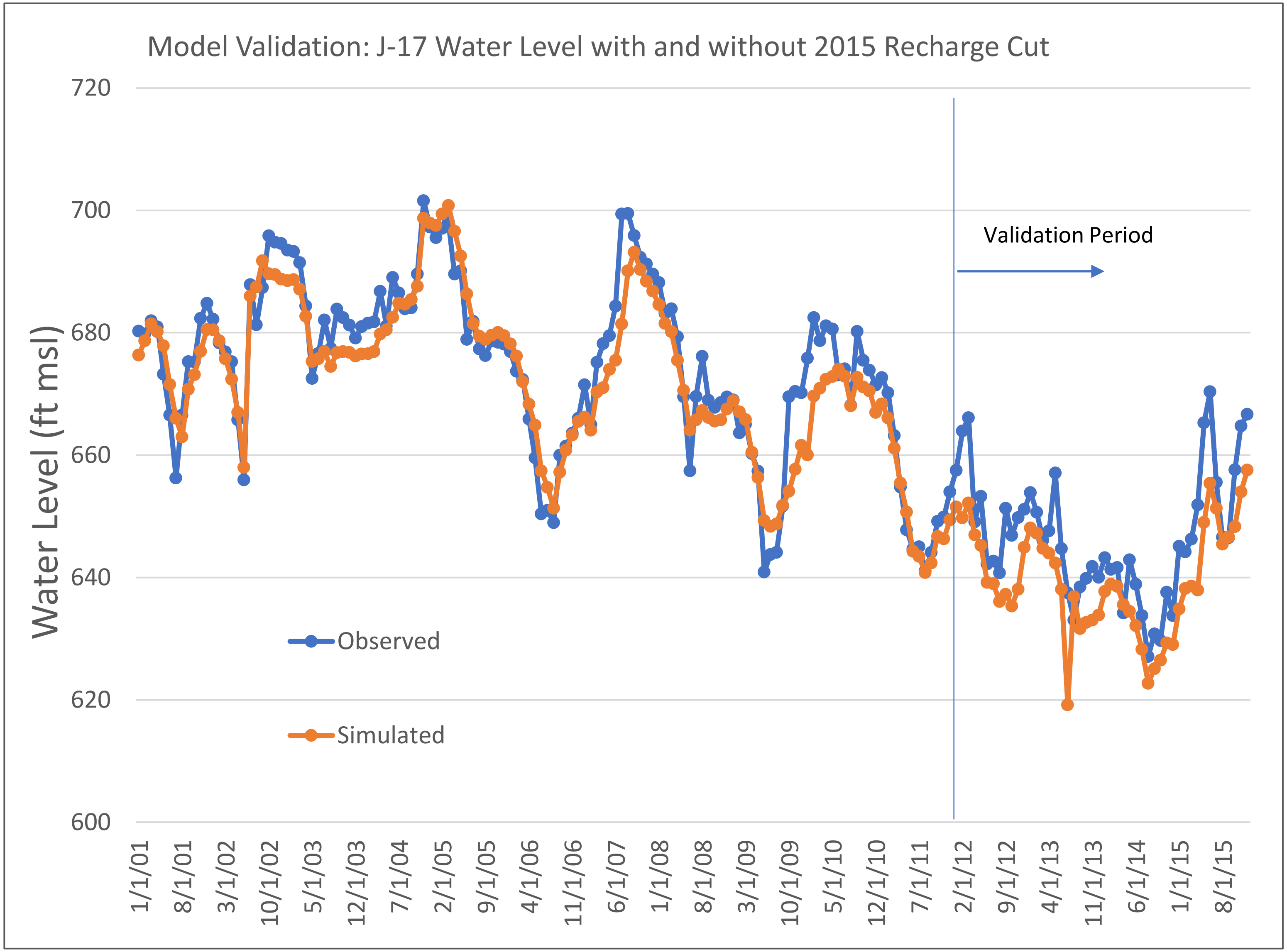
Error Statistic	Proposed Criterion	Original 2004 Model	Updated Model
Mean Error, all observations	≤ 2.0 ft	**−14.4 ft**	**−0.45 ft**
Mean Absolute Error, all observations	≤ 20 ft	**25.7 ft**	**11.7 ft**
Root-Mean-Square (RMS) Error, all observations	≤ 25 ft	**38.4 ft**	**17.0 ft**
RMS-Error to Range-of-Observations Ratio	≤ 10%	**5.1%**	**3.1%**
J-17 Mean Error	≤ 2.0 ft	**3.9 ft**	**1.9 ft**
J-17 RMS Error	≤ 7.0 ft	**7.9 ft**	**5.0 ft**
J-17 Maximum Absolute Error	≤ 30 ft	**10.3 ft**	**18 ft**
J-27 Mean Error	≤ 1.3 ft	**−31.0 ft**	**0.7 ft**
J-27 RMS Error	≤ 5.0 ft	**30.7 ft**	**4.0 ft**
J-27 Maximum Absolute Error	≤ 20 ft	**46.8 ft**	**8.9 ft**

SPRING TARGETS CALIBRATION SUMMARY

Error Statistic	Proposed Criterion	Original 2004 Model	Updated Model
Comal Springs Mean Error	≤ 3.0 cfs	14.9 cfs	0.4 cfs
Comal Springs RMS Error	≤ 50 cfs	37.9 cfs	26.2 cfs
Comal Springs Cumulative Error	≤ 3%	4.0 %	0.12%
Comal Springs Maximum Absolute Error	≤ 150 cfs	139 cfs	79.7 cfs
San Marcos Springs Mean Error	≤ 3 cfs	43.6 cfs	0.8 cfs
San Marcos Springs RMS Error	≤ 35 cfs	62 cfs	28.0 cfs
San Marcos Springs Cumulative Error	≤ 3%	22%	0.4%
San Marcos Springs Maximum Absolute Error	≤ 150 cfs	134 cfs	114.3 cfs

Model Validation Test

- Model run forward for a period that was not used in the calibration: January 2012—December 2015
- 48 additional monthly time steps
- Specifically suggested in NAS 2
- Includes lowest water levels observed during the 2008—2014 drought and recovery from drought in 2015


Model Validation: J-17 Water Level with and without 2015 Recharge Cut
720
700
680
660
640
620
600
Water Level (ft msl)
Validation Period
Observed
Simulated
1/1/01
8/1/01
3/1/02
10/1/02
5/1/03
12/1/03
7/1/04
2/1/05
9/1/05
4/1/06
11/1/06
6/1/07
1/1/08
8/1/08
3/1/09
10/1/09
5/1/10
12/1/10
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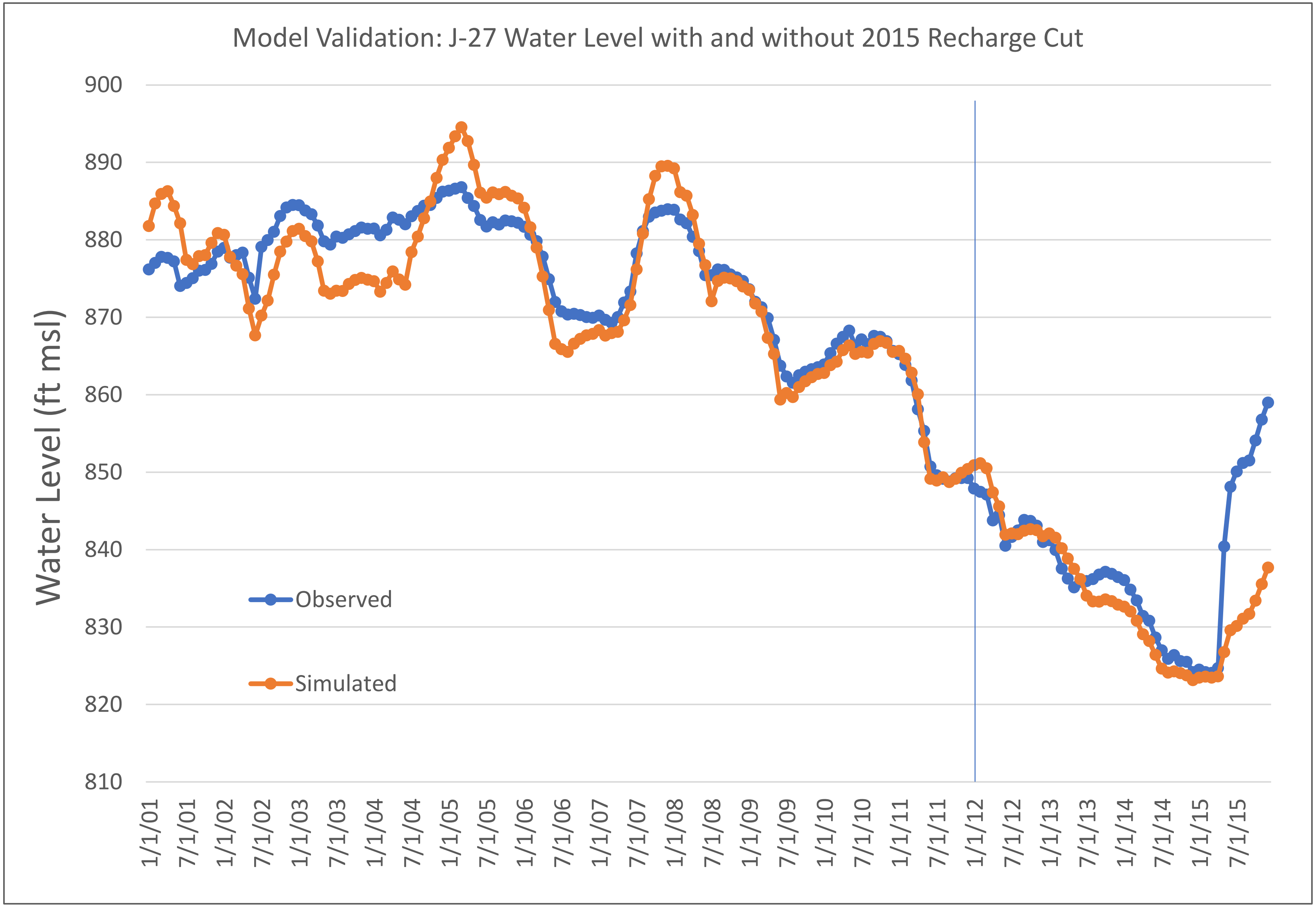
6/1/14
1/1/15
8/1/15



Model Validation: J-27 Water Level with and without 2015 Recharge Cut
Water Level (ft msl)
900
890
880
870
860
850
840
830
820
810
Observed
Simulated
1/1/01
7/1/01
1/1/02
7/1/02
1/1/03
7/1/03
1/1/04
7/1/04
1/1/05
7/1/05
1/1/06
7/1/06
1/1/07
7/1/07
1/1/08
7/1/08
1/1/09
7/1/09
1/1/10
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1/1/11
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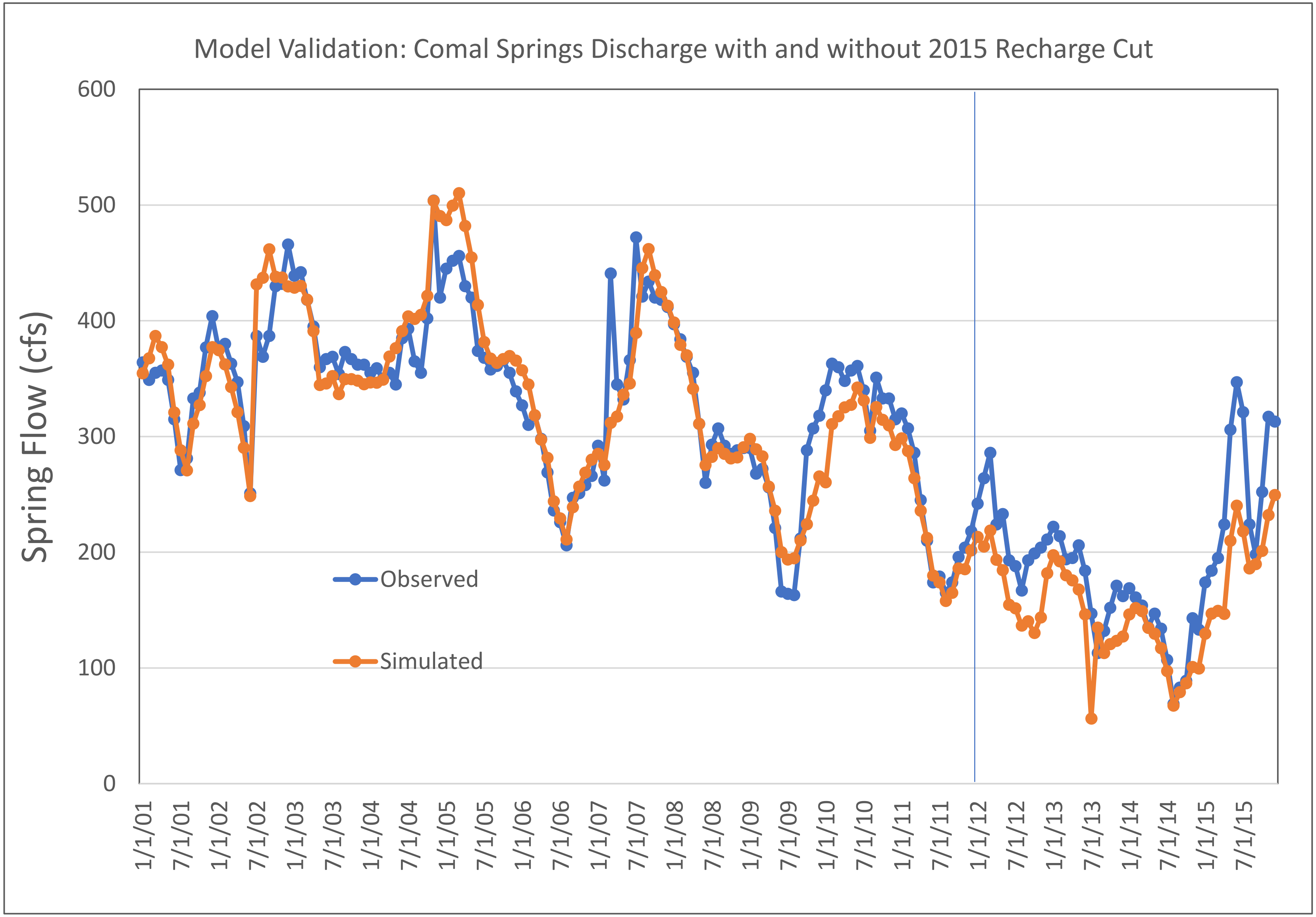
1/1/15
7/1/15



Model Validation: Comal Springs Discharge with and without 2015 Recharge Cut
Spring Flow (cfs)
600
500
400
300
200
100
0
Observed
Simulated
1/1/01
7/1/01
1/1/02
7/1/02
1/1/03
7/1/03
1/1/04
7/1/04
1/1/05
7/1/05
1/1/06
7/1/06
1/1/07
7/1/07
1/1/08
7/1/08
1/1/09
7/1/09
1/1/10
7/1/10
1/1/11
7/1/11
1/1/12
7/1/12
1/1/13
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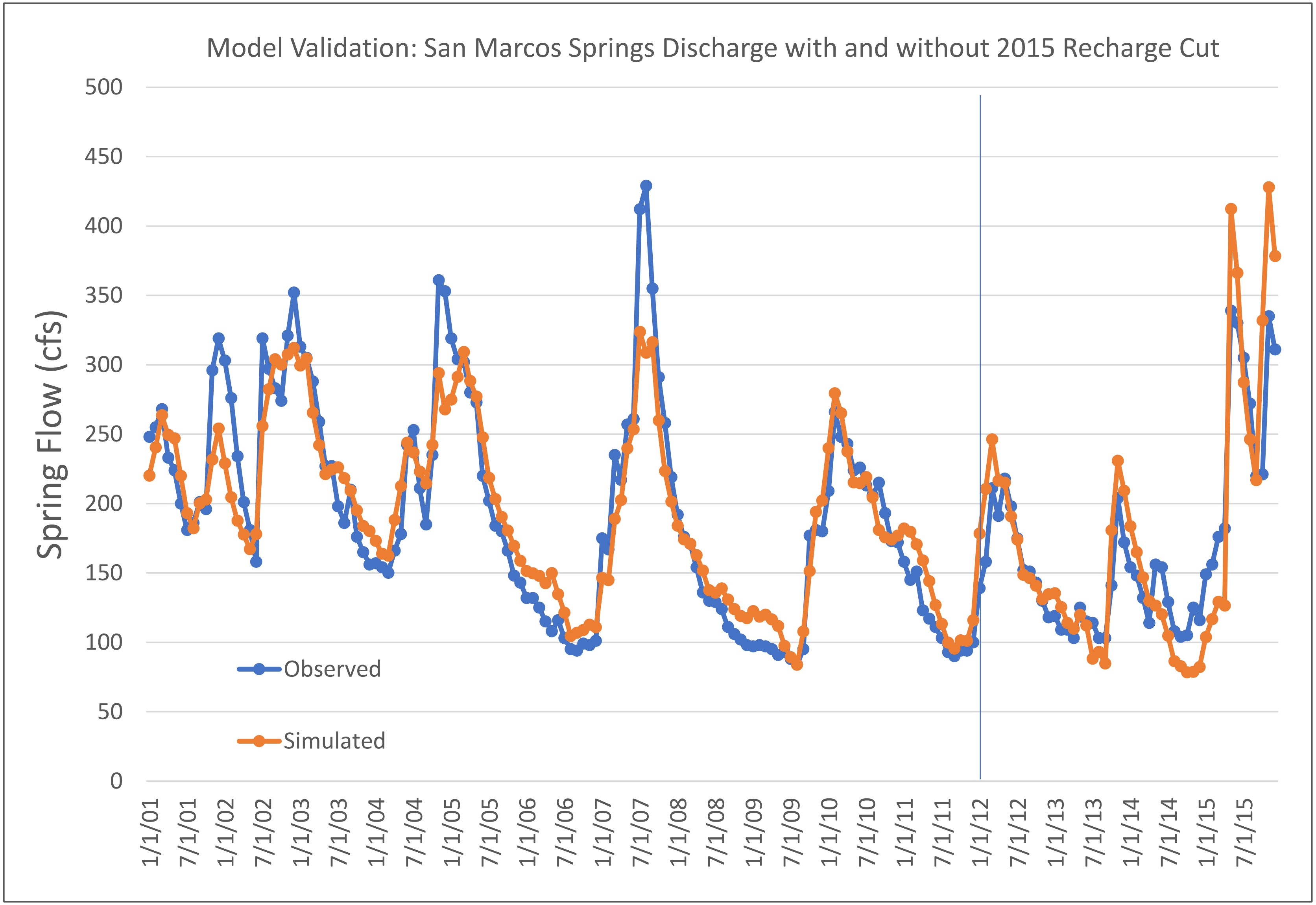
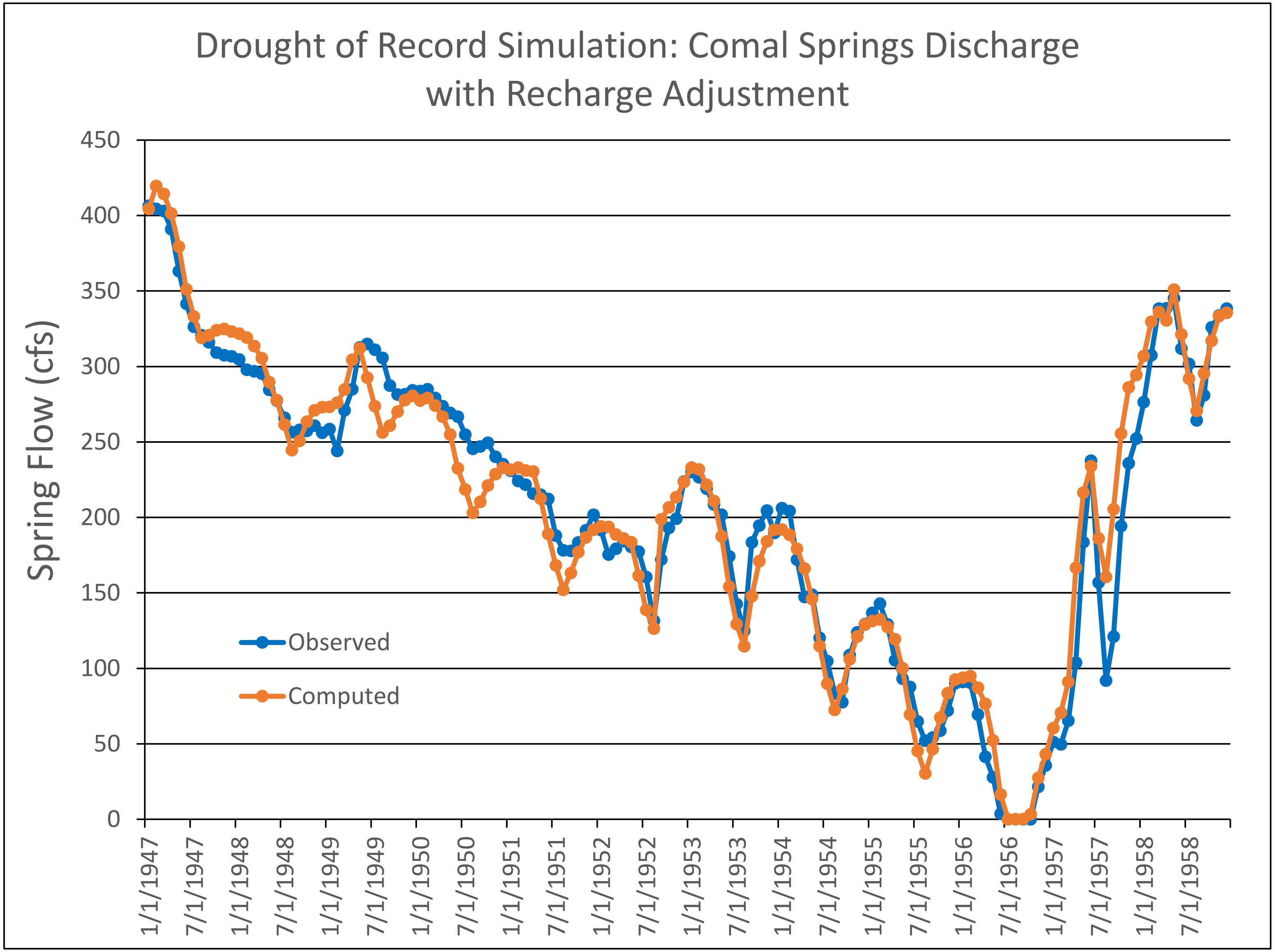
1/1/14
7/1/14
1/1/15
7/1/15



Model Validation: San Marcos Springs Discharge with and without 2015 Recharge Cut
Spring Flow (cfs)
500
450
400
350
300
250
200
150
100
50
0
Observed
Simulated
1/1/01
7/1/01
1/1/02
7/1/02
1/1/03
7/1/03
1/1/04
7/1/04
1/1/05
7/1/05
1/1/06
7/1/06
1/1/07
7/1/07
1/1/08
7/1/08
1/1/09
7/1/09
1/1/10
7/1/10
1/1/11
7/1/11
1/1/12
7/1/12
1/1/13
7/1/13
1/1/14
7/1/14
1/1/15
7/1/15

Drought-of-Record Simulations

- Set up drought-of-record scenario using pumping and recharge estimates for the period of January 1947 through December 1958 to use for HCP Adaptive Management evaluations
- Model goal for DOR scenario is to closely match observed spring flows—especially minimum flows observed during 1956
- No changes made to calibrated model parameters
- Small adjustment made to recharge near San Marcos springs to better match observed spring flows



Drought of Record Simulation: Comal Springs Discharge
with Recharge Adjustment
Spring Flow (cfs)
450
400
350
300
250
200
150
100
50
0
Observed
Computed
1/1/1947
7/1/1947
1/1/1948
7/1/1948
1/1/1949
7/1/1949
1/1/1950
7/1/1950
1/1/1951
7/1/1951
1/1/1952
7/1/1952
1/1/1953
7/1/1953
1/1/1954
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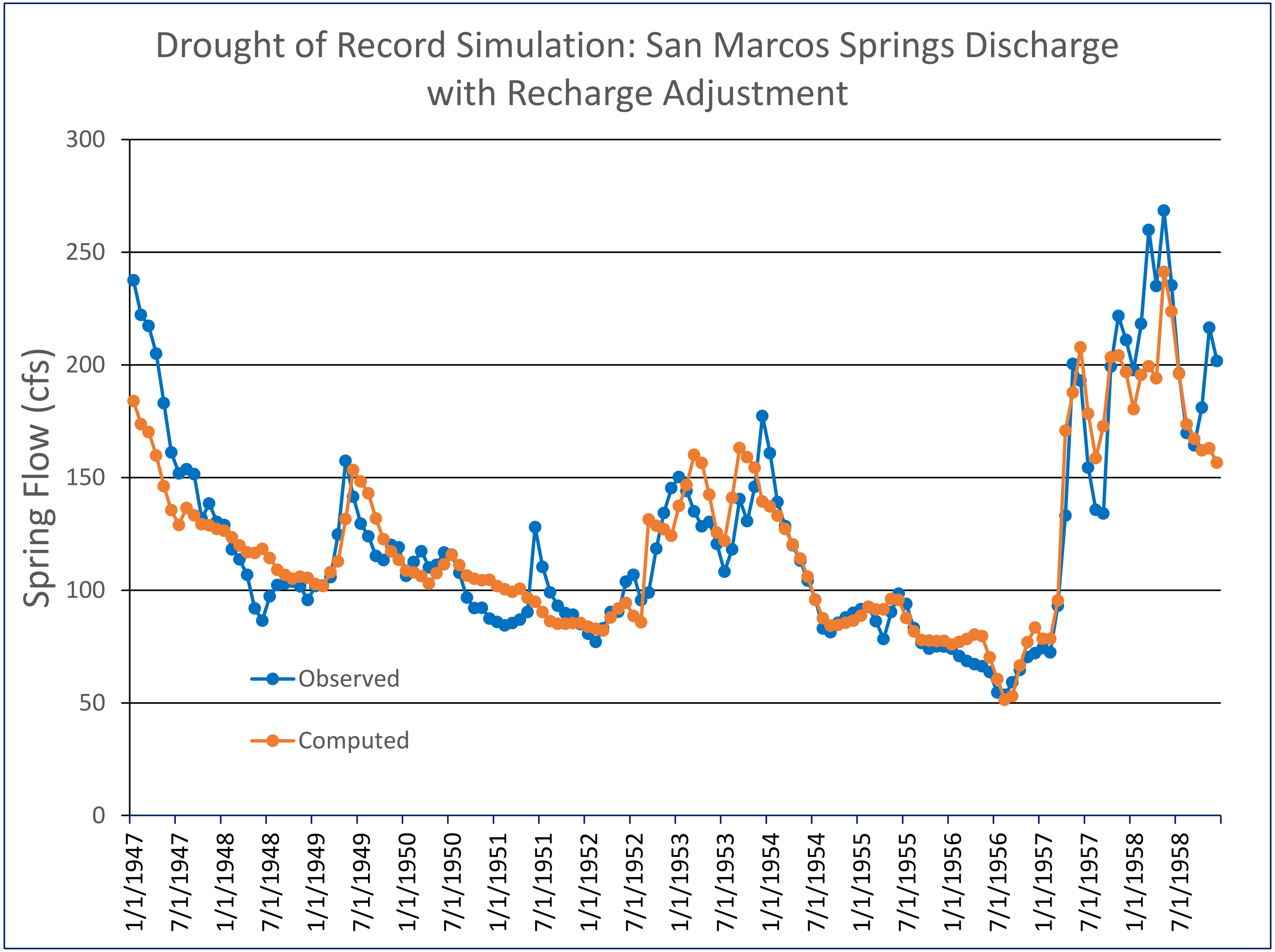
1/1/1958
7/1/1958


Drought of Record Simulation: San Marcos Springs Discharge
with Recharge Adjustment
Spring Flow (cfs)
300
250
200
150
100
50
0
Observed
Computed
1/1/1947
7/1/1947
1/1/1948
7/1/1948
1/1/1949
7/1/1949
1/1/1950
7/1/1950
1/1/1951
7/1/1951
1/1/1952
7/1/1952
1/1/1953
7/1/1953
1/1/1954
7/1/1954
1/1/1955
7/1/1955
1/1/1956
7/1/1956
1/1/1957
7/1/1957
1/1/1958
7/1/1958

Repeat HDR (2011) “Bottom-Up Analysis with Updated Model

- Original 2004 MODFLOW Model used to demonstrate effectiveness of conservation measures to preserve spring flows

BOTTOM-UP Program

Layer 4	Layer 3 + Stage V Emergency Reductions
Layer 3	Layer 2 + SAWS ASR with Trade-Off Option
Layer 2	Layer 1 + Municipal Conservation Measures
Layer 1	Voluntary Irrigation Suspension Program Option

Source: HDR, Inc. (2011)

Evaluation of Water Management Programs and Alternatives for Springflow Protection of Endangered Species at Comal and San Marcos Springs

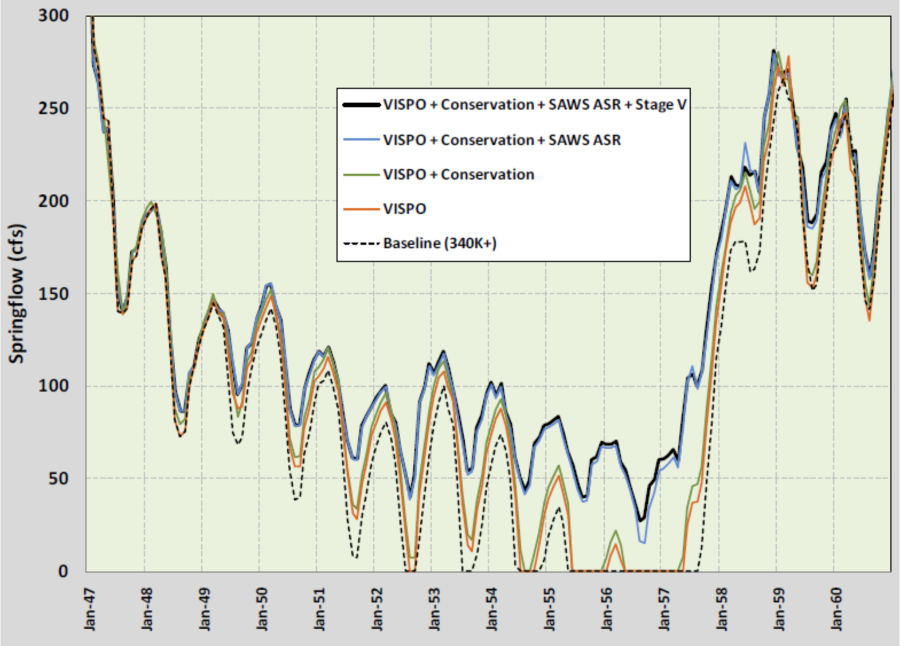
Prepared for:
Edwards Aquifer
Recovery Implementation Program
(EARIP)

Prepared by:
Todd Engineers
HDR Engineering, Inc.
Westward Environmental, Inc.

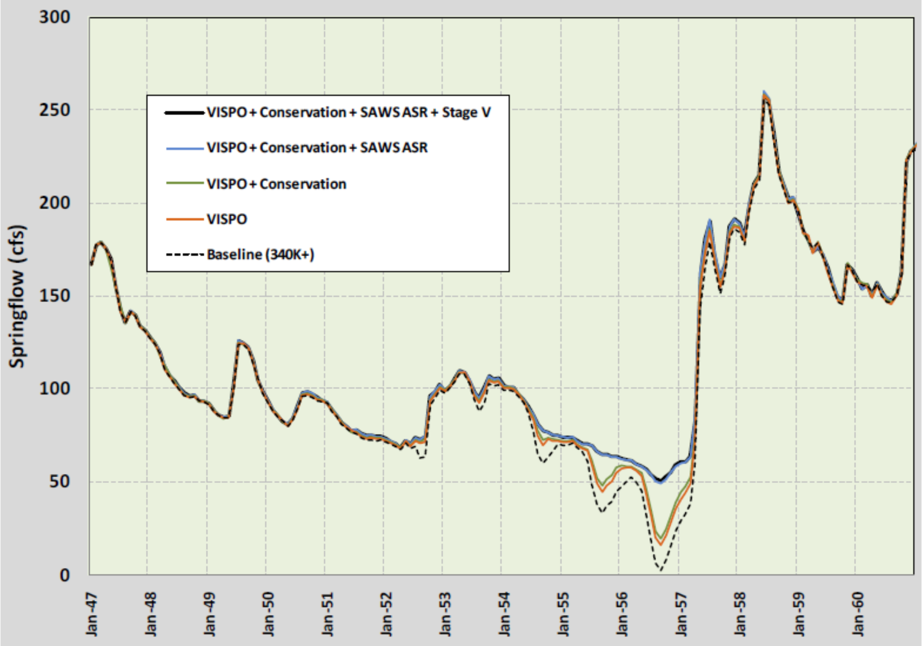
October 2011

Original Bottom-Up Results

Comal Springs minimum flow: 27 cfs in August 1956



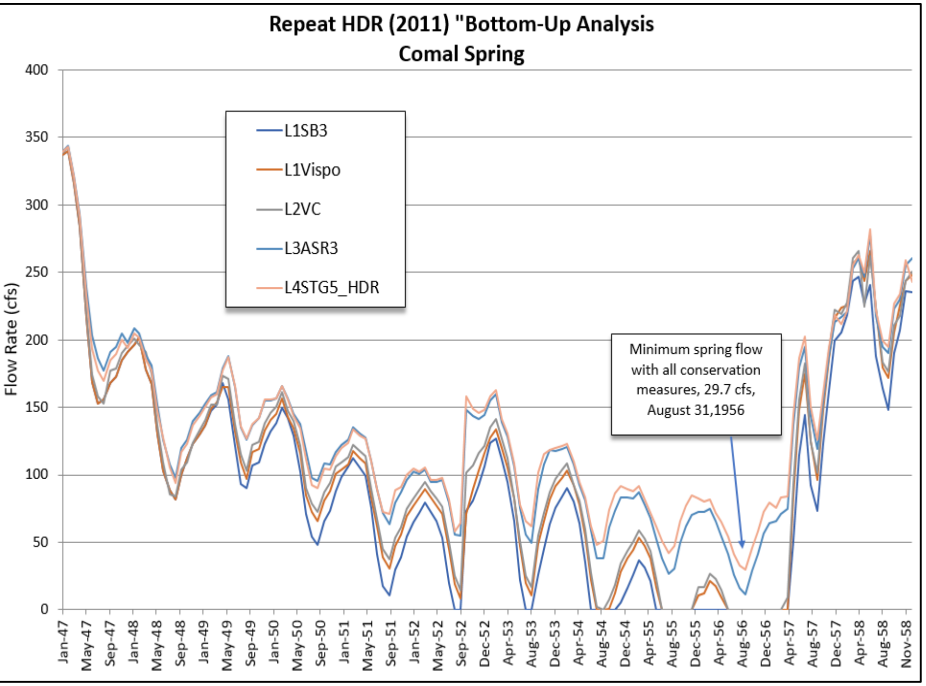
San Marcos Springs minimum flow: 51 cfs in August 1956



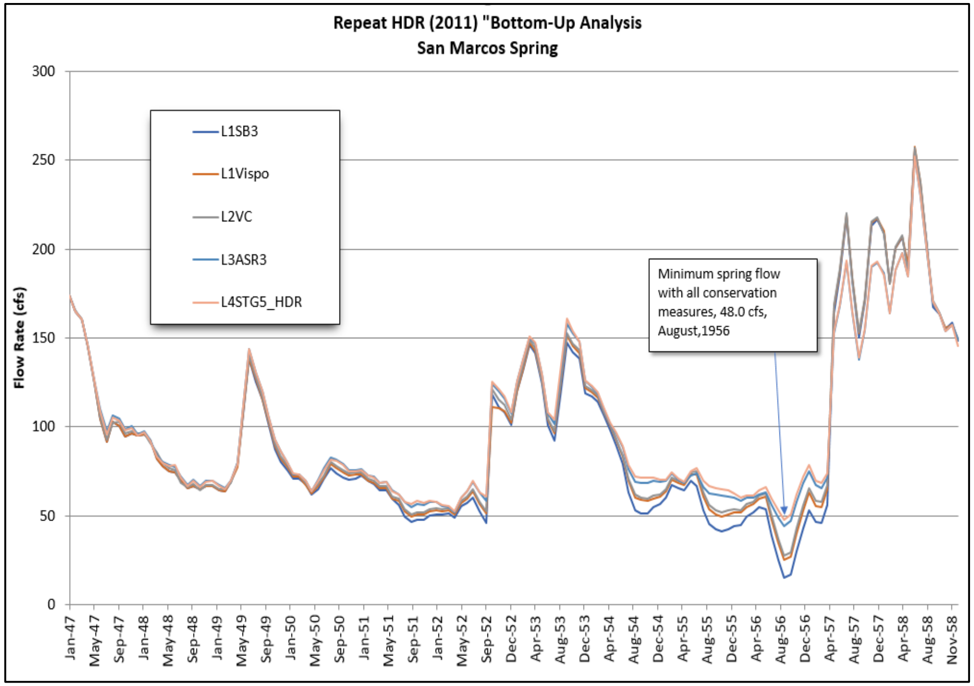
Source: HDR, Inc. (2011)

Updated model Bottom-Up Results

Comal Springs minimum flow:
29.7 cfs in August 1956



San Marcos Springs minimum flow: 48 cfs in August 1956



Next Steps

- Publish Model Update Report by December 2017
- Use model to support HCP Adaptive Management
  - Repeat HDR (2011) bottom-up analysis with new assumptions regarding ASR leases and triggers

Next Steps

- Uncertainty analysis using PEST++ inverse parameter estimation software
  - Collaboration with USGS’ Austin Office using their high-performance computer cluster and parallel processing methods
  - Evaluate uncertainty in hydraulic parameters and recharge quantity distribution
  - Simultaneous inversion to both the 2001—2015 period and the 1947—1958 drought-of-record period
  - Expected completion by March 2019

Questions?