Groundwater Availability Modeling (GAM) for the Dockum Aquifer

Stakeholders Advisory Forum 3

Model Calibration Results

June 4, 2008

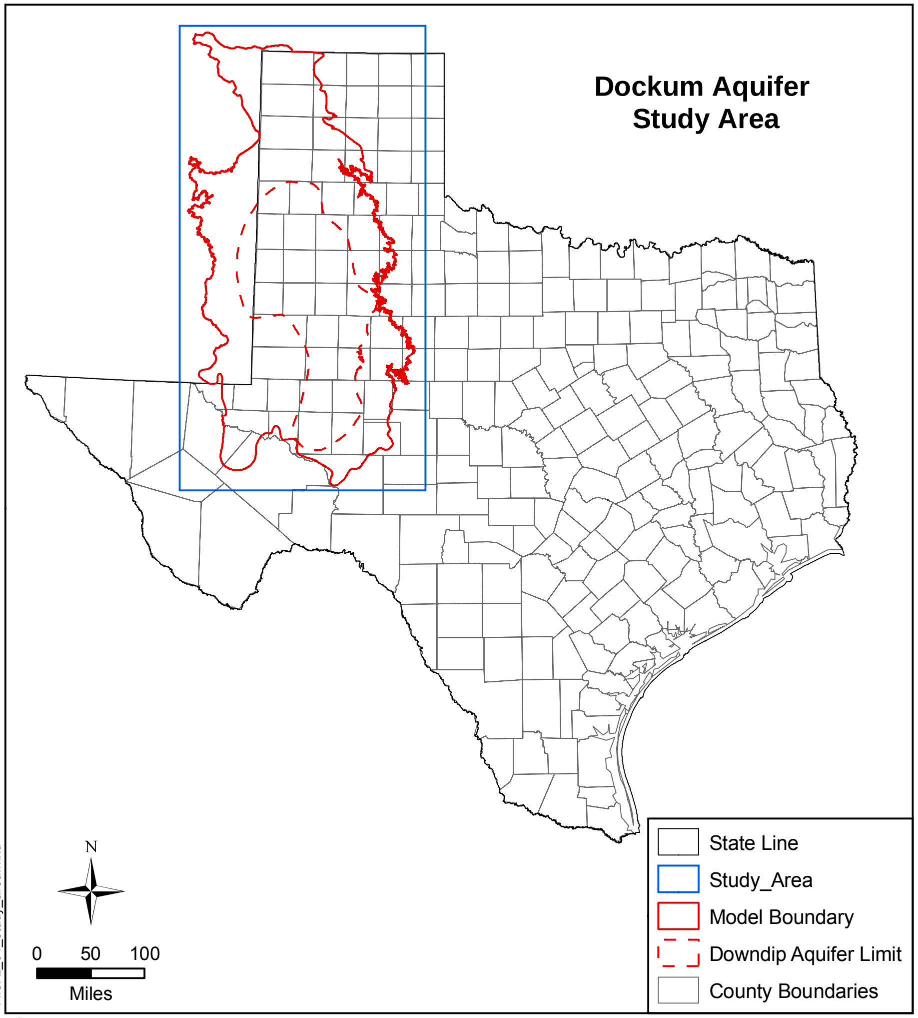
Outline

- Aquifer Review
- Model Design
- Conceptual Model
- Model Implementation
- Model Calibration
- Model Results
- Model Conclusions
- Model Limitations
- GAM Schedule

Aquifer Review

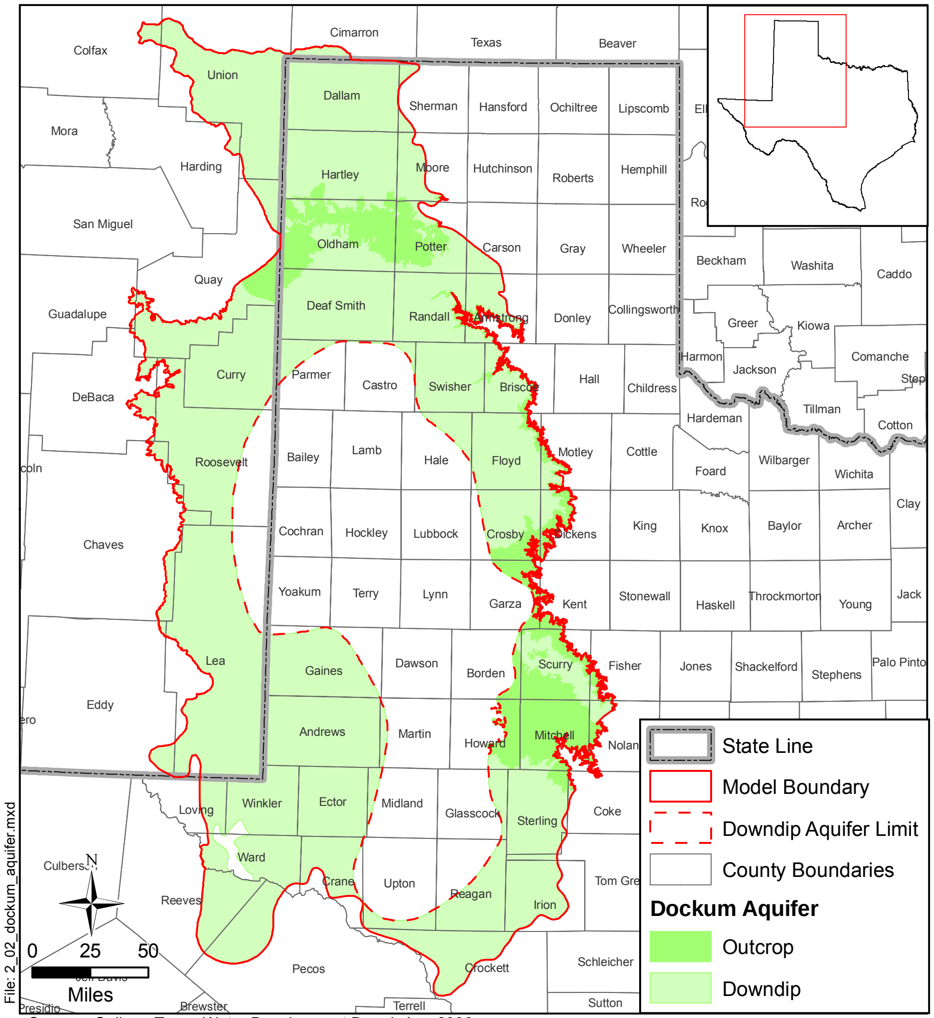
Aquifer Location

Study Area



Source: N/A

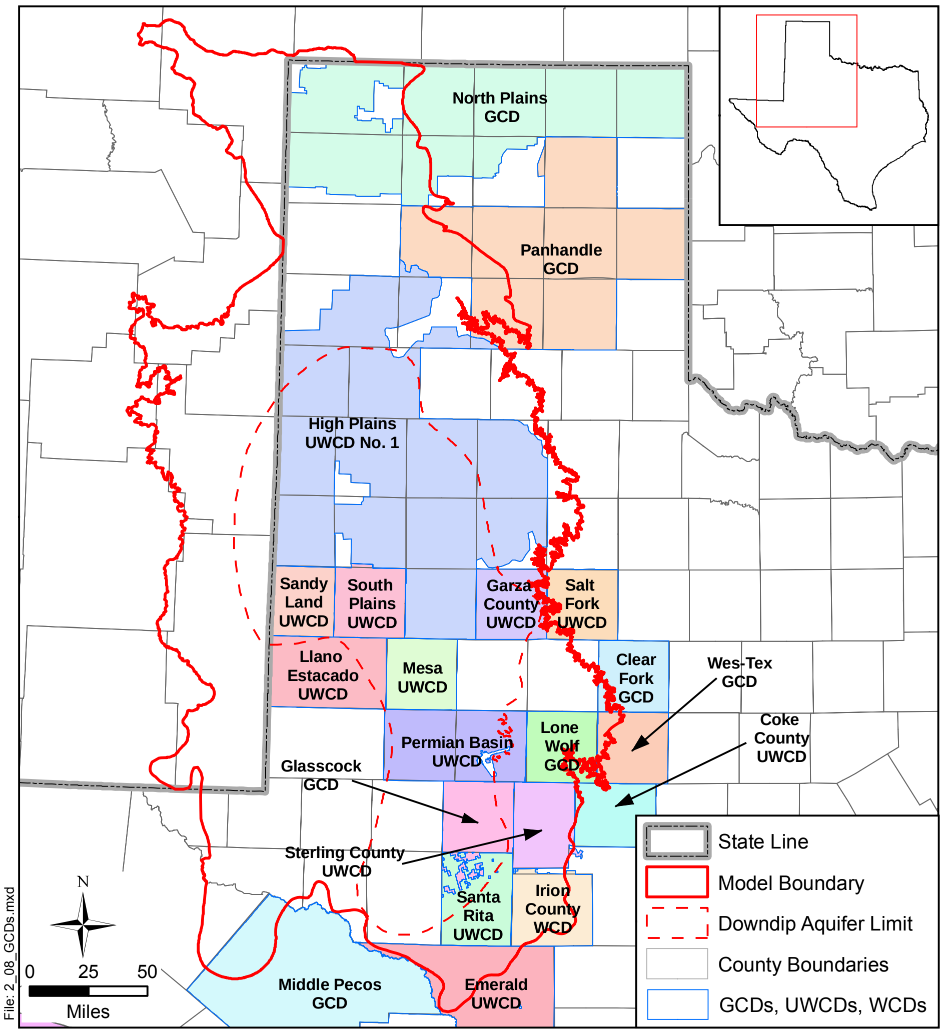
Model Domain



Source: Online: Texas Water Development Board, Aug 2006

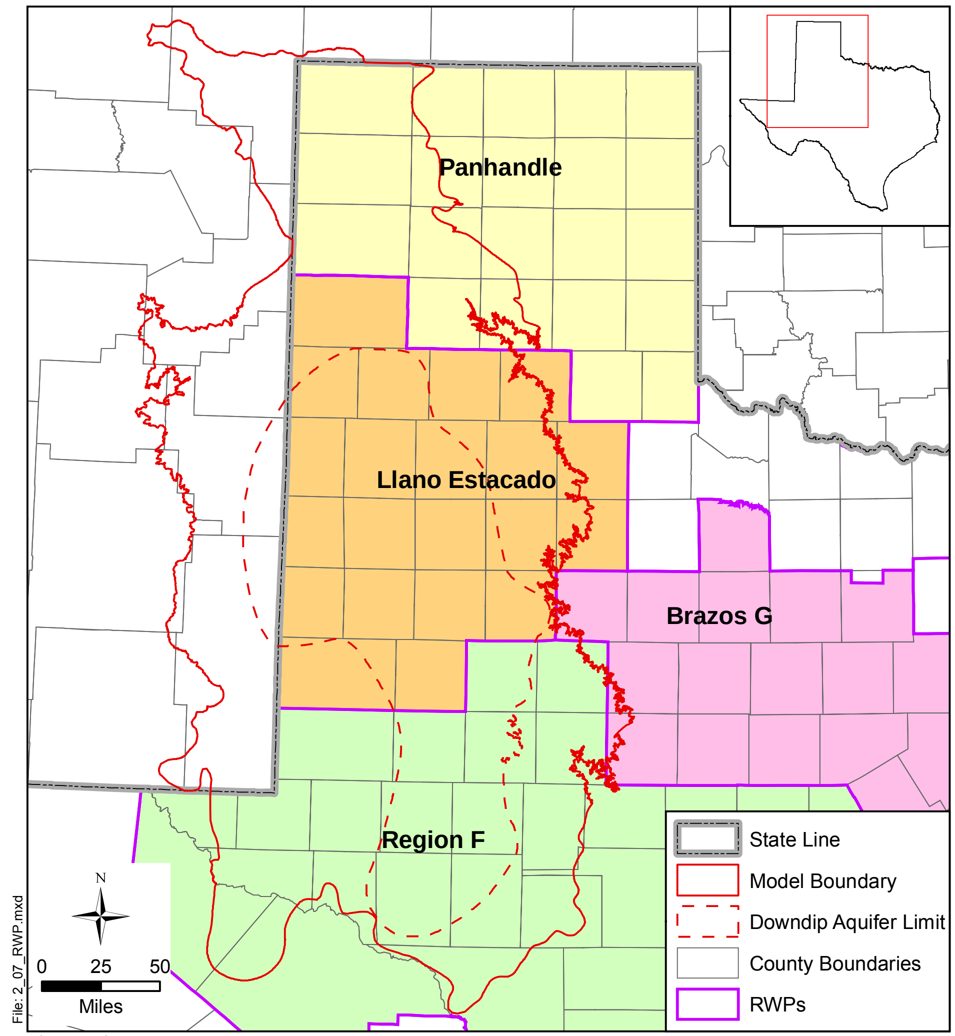
Aquifer Location

Groundwater Conservation Districts



Source: Online: Texas Water Development Board, June 2006.

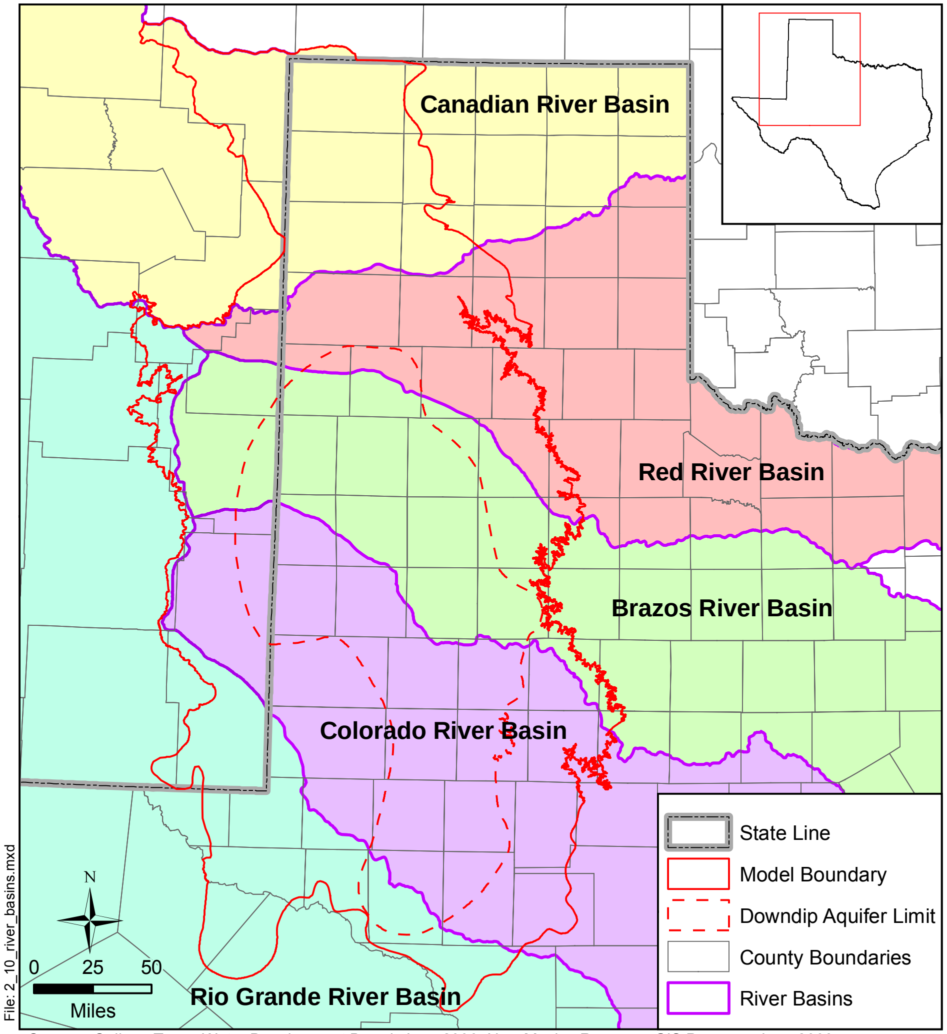
Regional Water Planning Groups



Source: Online: Texas Water Development Board, June 2006

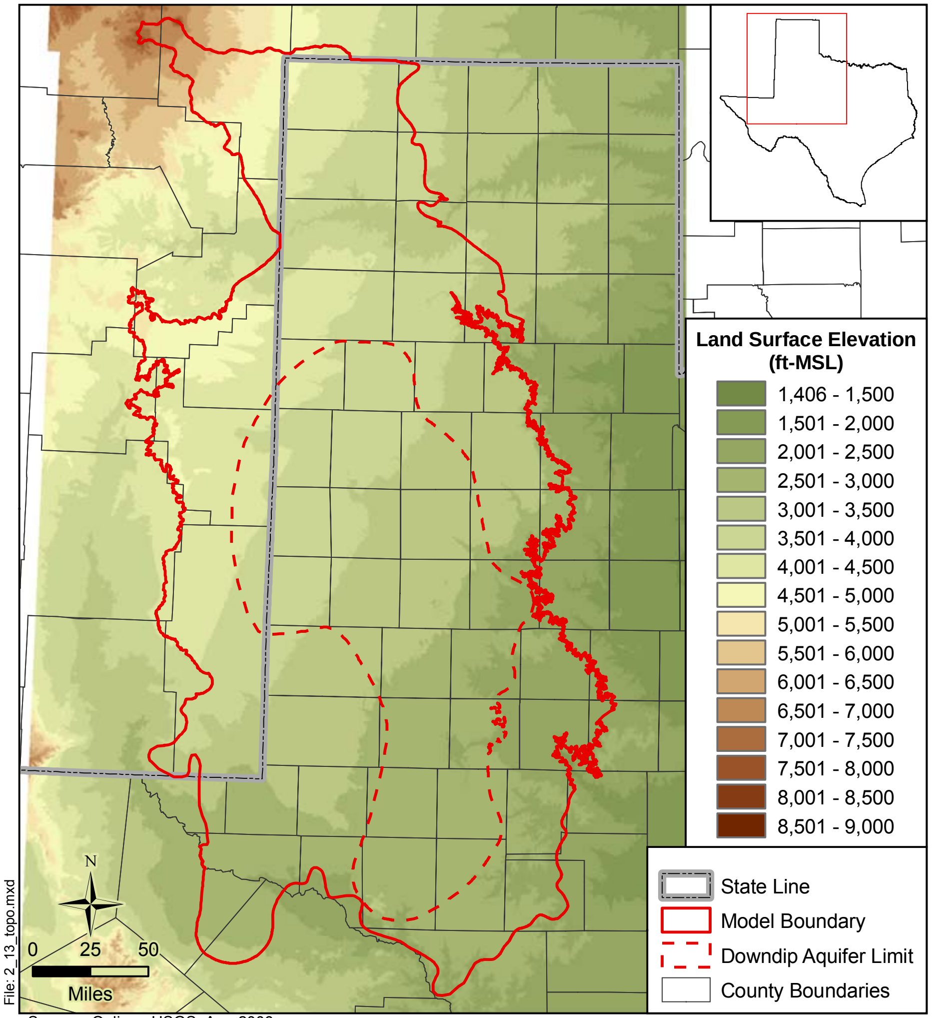
River Basins and Topography

Major River Basins



Source: Online: Texas Water Development Board, June 2006; New Mexico Resource GIS Program, June 2006

Topography



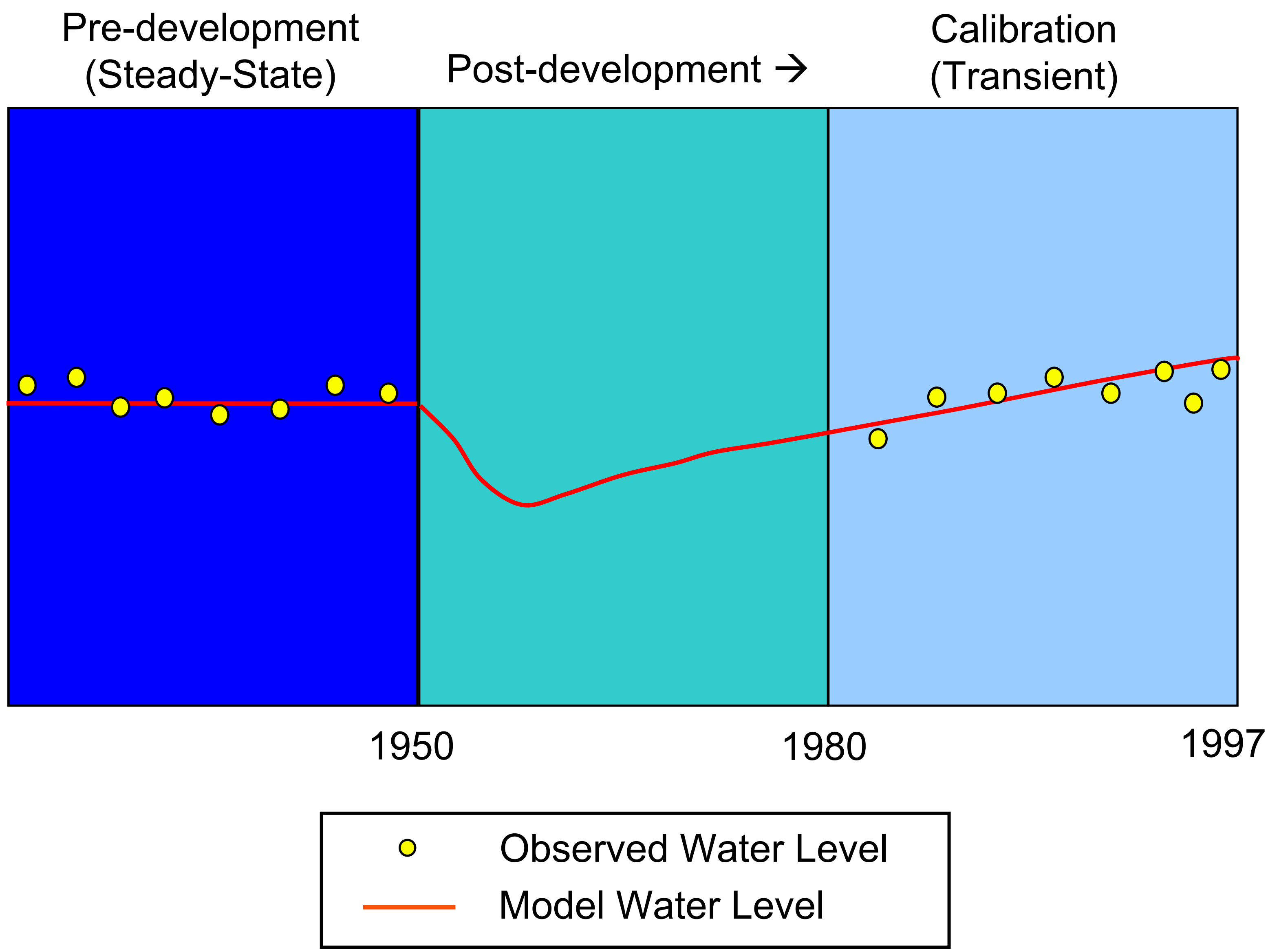
Source: Online: USGS, Aug 2006

Model Design

Modeling Protocol

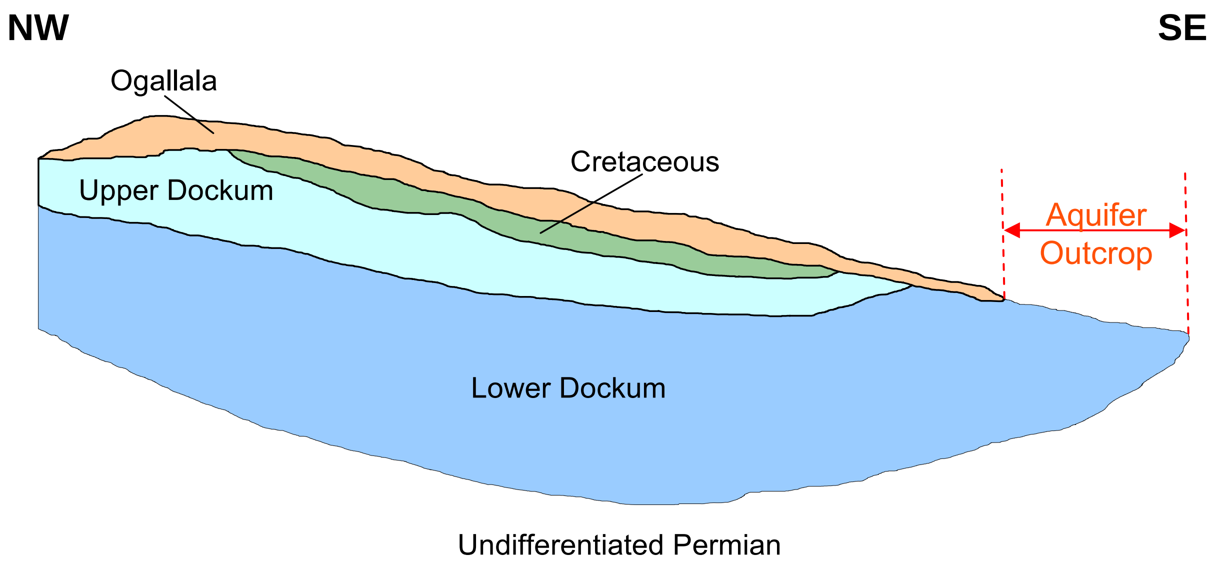
- Compile and Analyze Field and Literature Data
- Develop a Conceptual Model
- Model Design
- Calibrate the Model
- Use the Model for Predictive Purposes

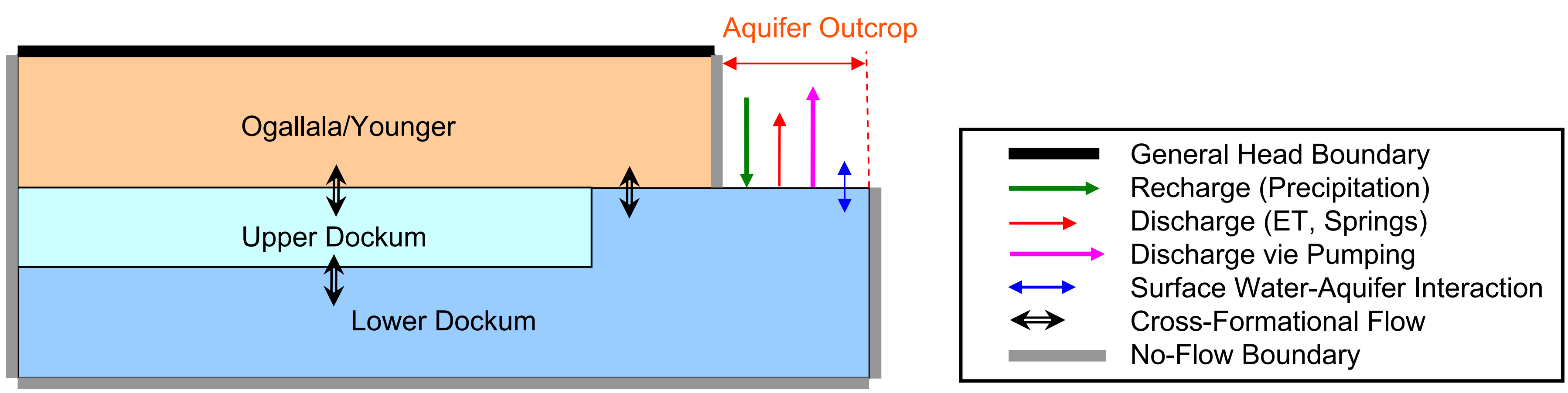
Schematic of Modeling Periods



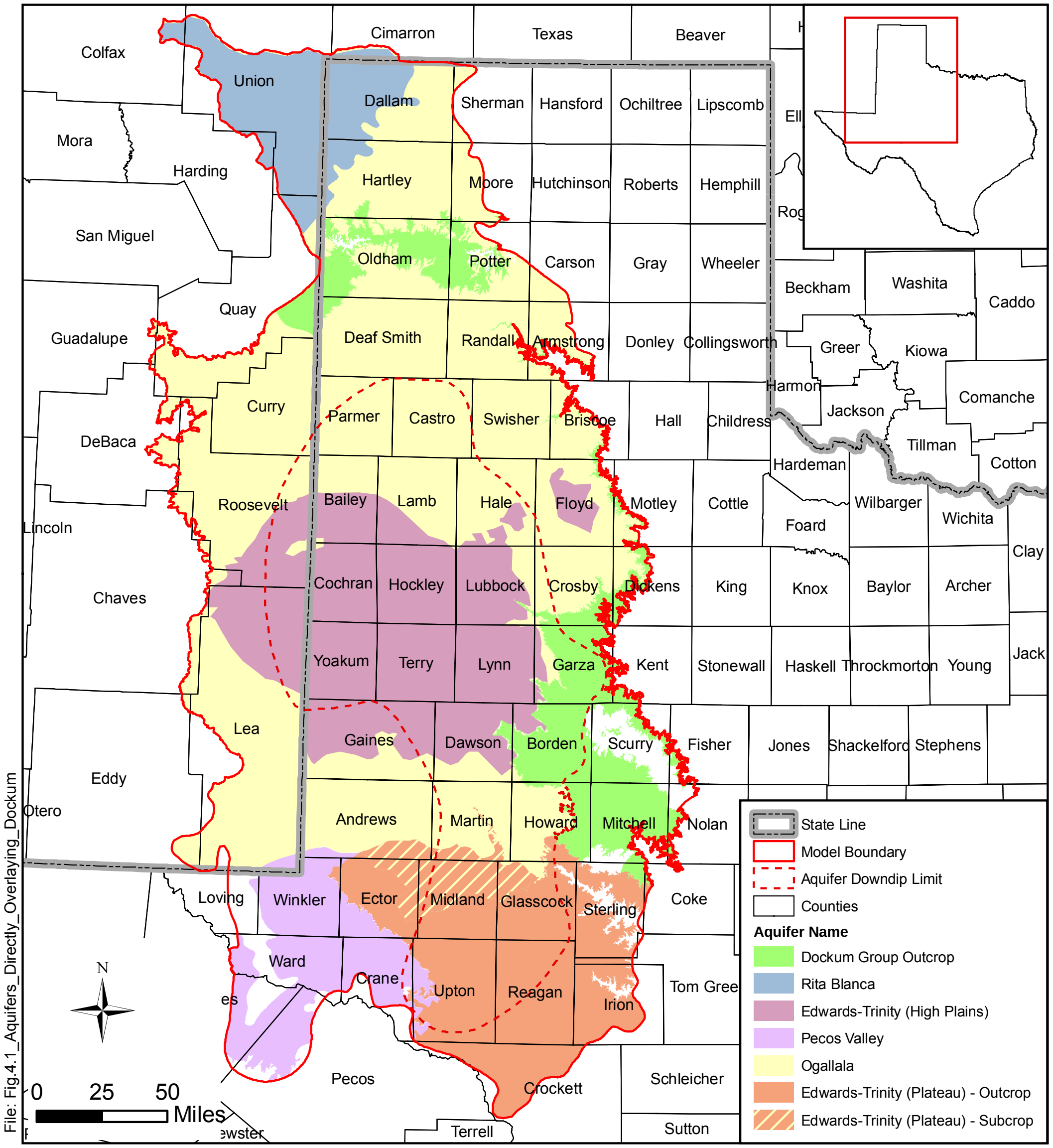
Conceptual Model

Conceptualization of Groundwater Flow





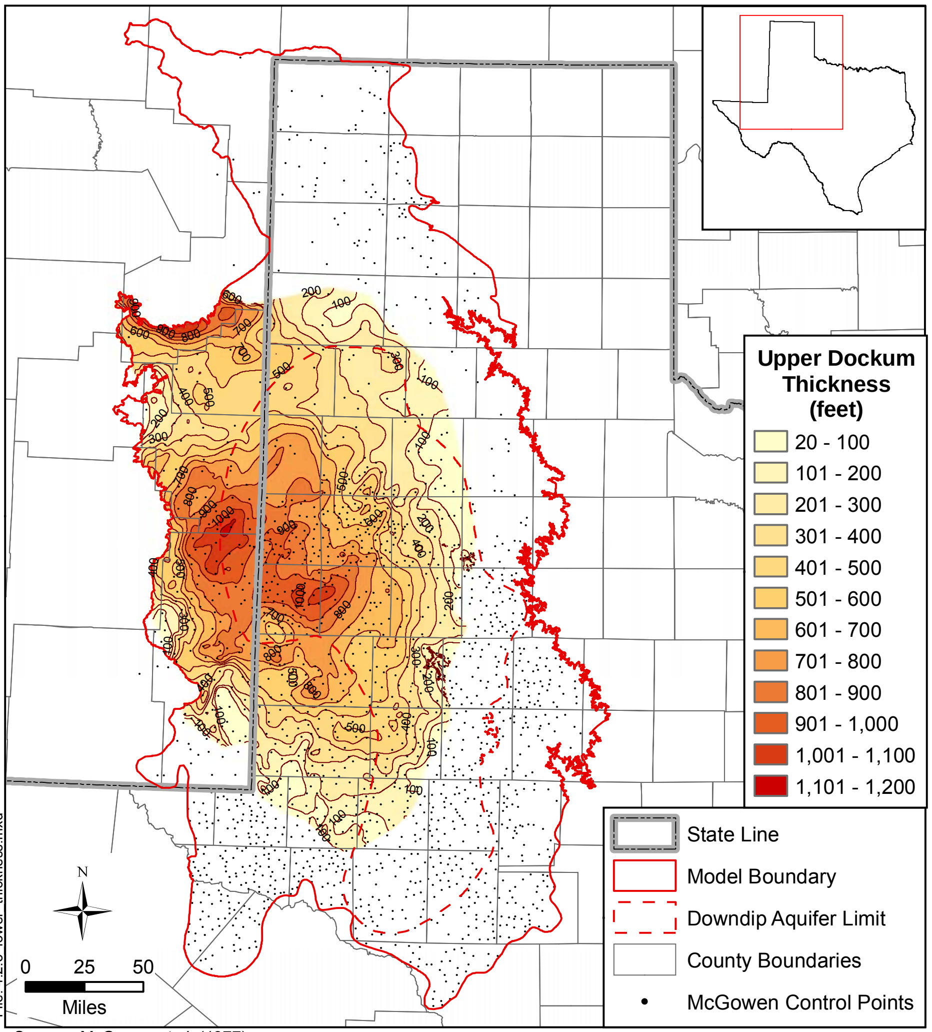
Aquifer Directly Overlying the Dockum



Source: Adapted from Texas Water Development Board, Dec 2006

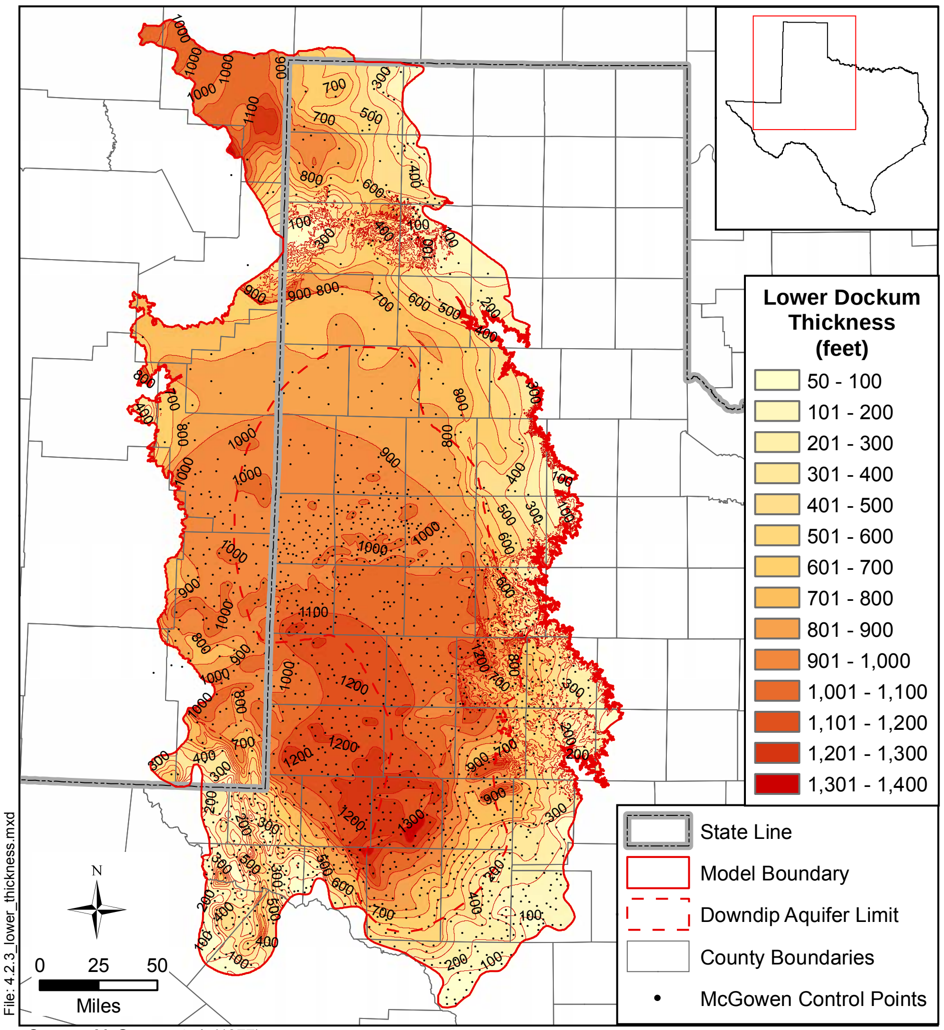
Dockum Thickness

Upper Dockum



Source: McGowen et al. (1977)

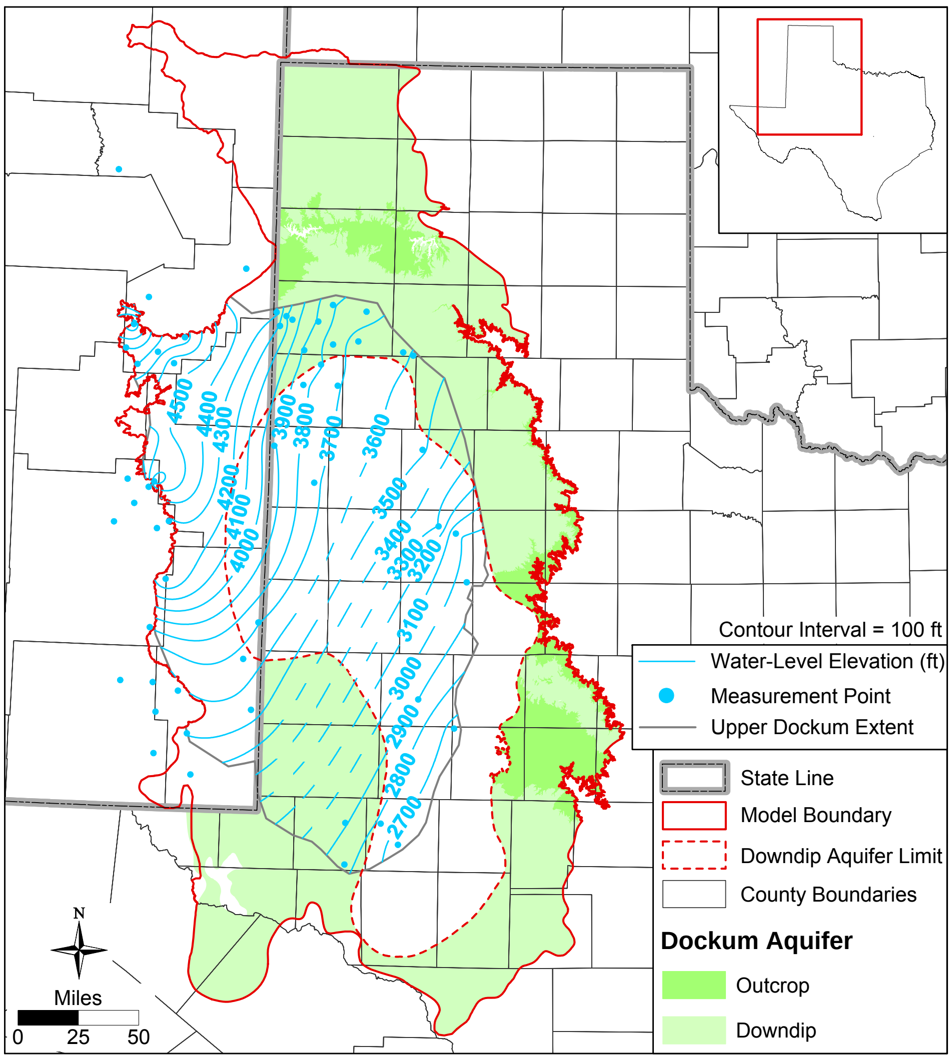
Lower Dockum



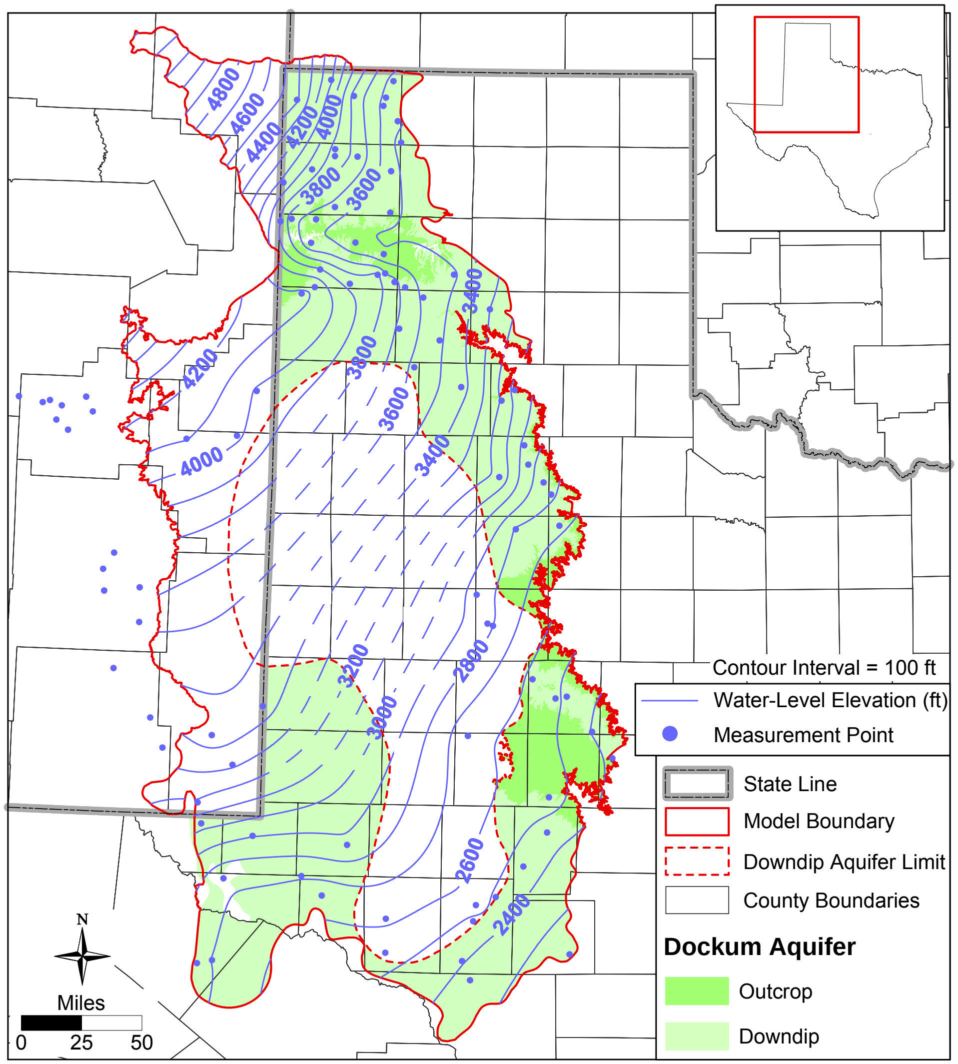
Source: McGowen et al. (1977)

Predevelopment Water-Level Elevations

Upper Dockum

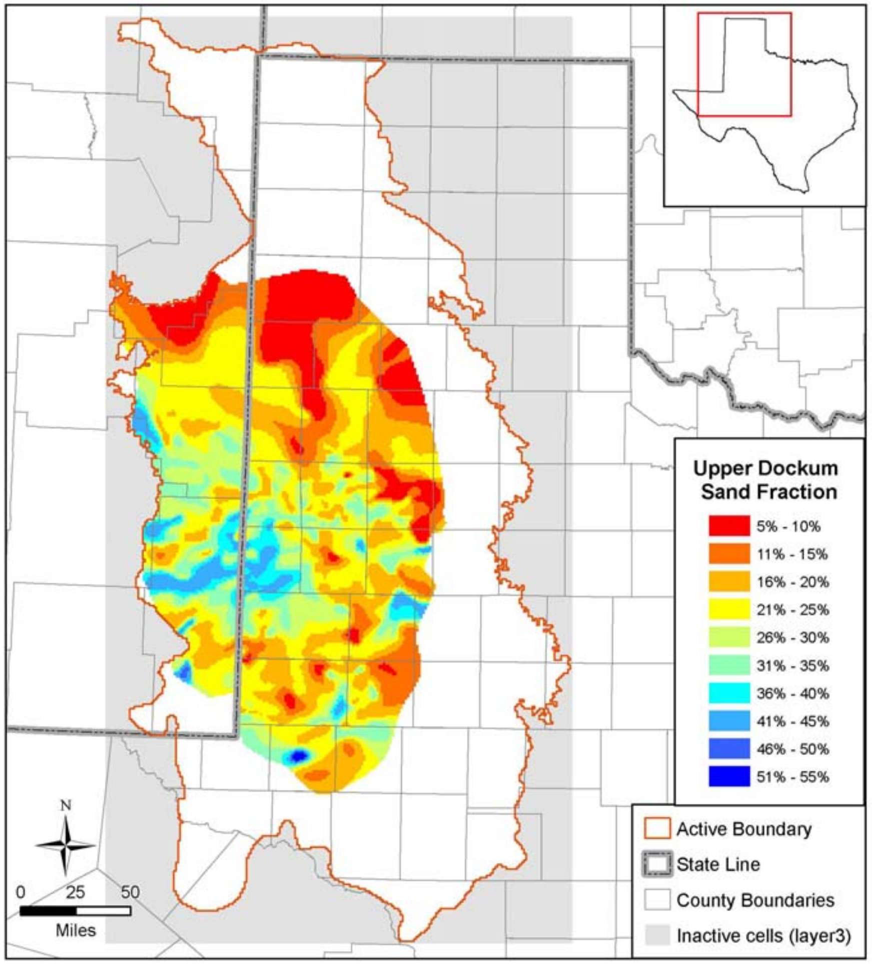


Lower Dockum

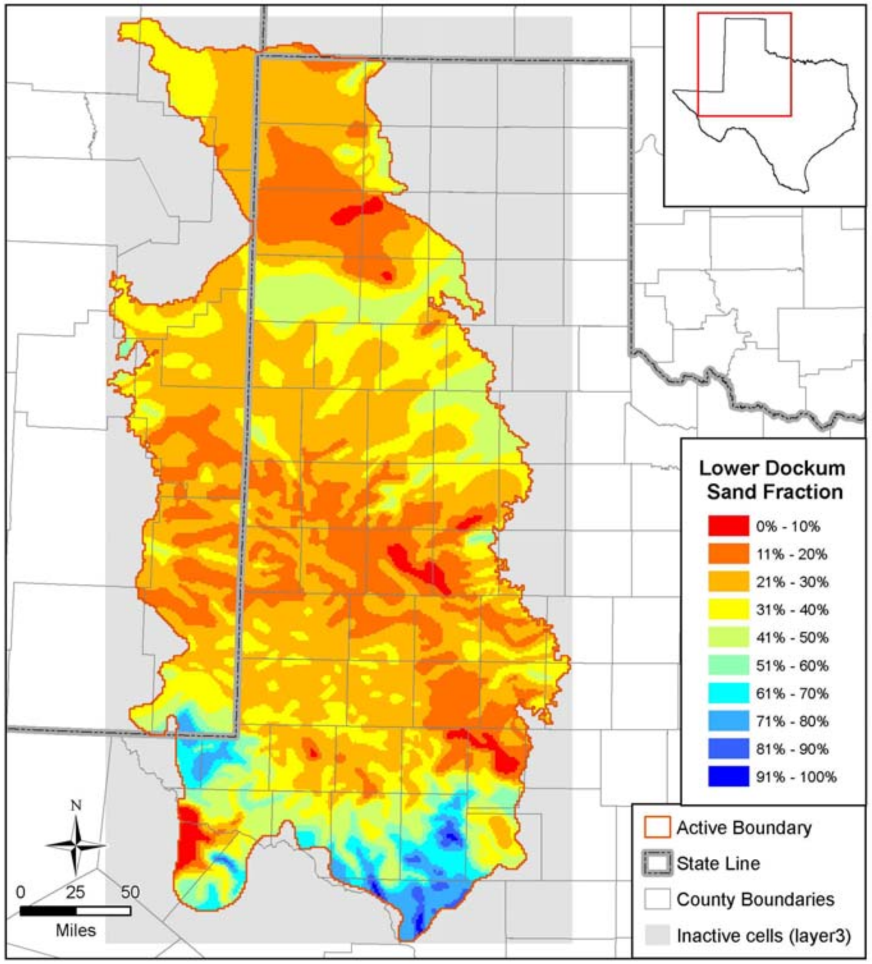


Sand Fraction

Upper Dockum

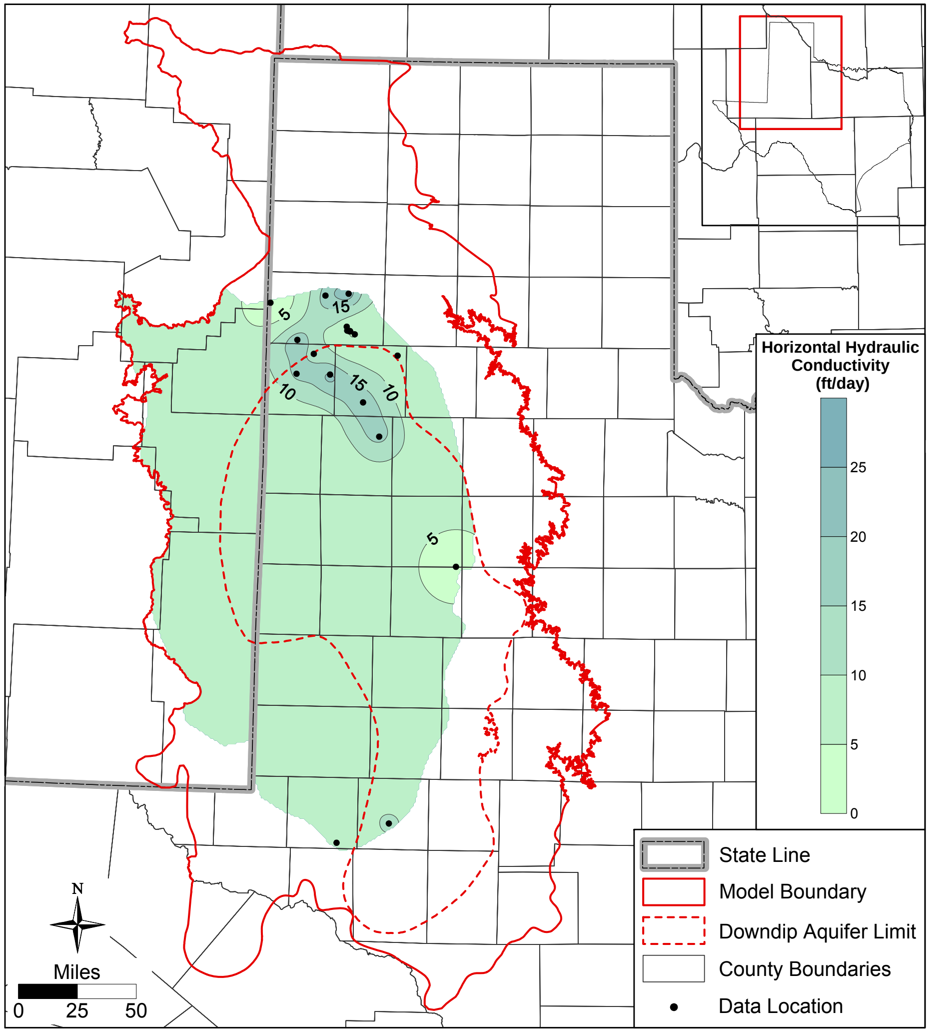


Lower Dockum

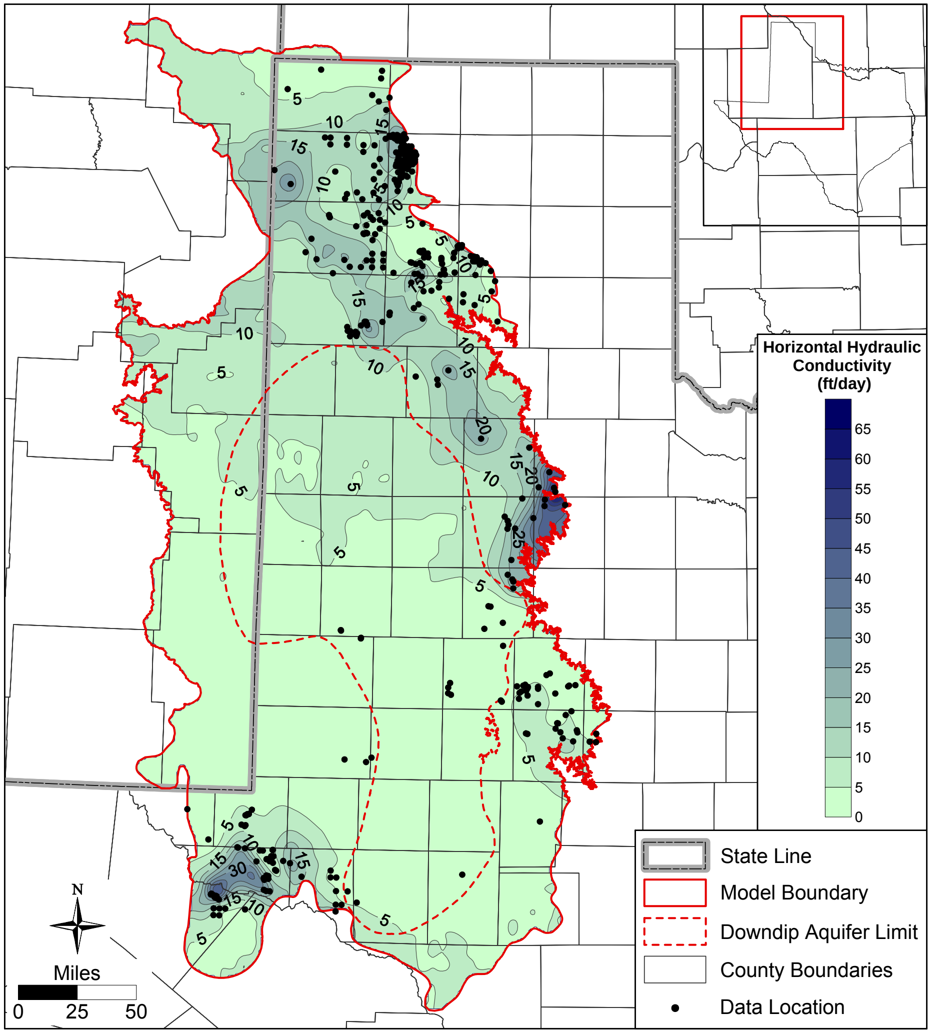


Horizontal Sand Hydraulic Conductivity

Upper Dockum



Lower Dockum



Conceptual Model of Groundwater Flow

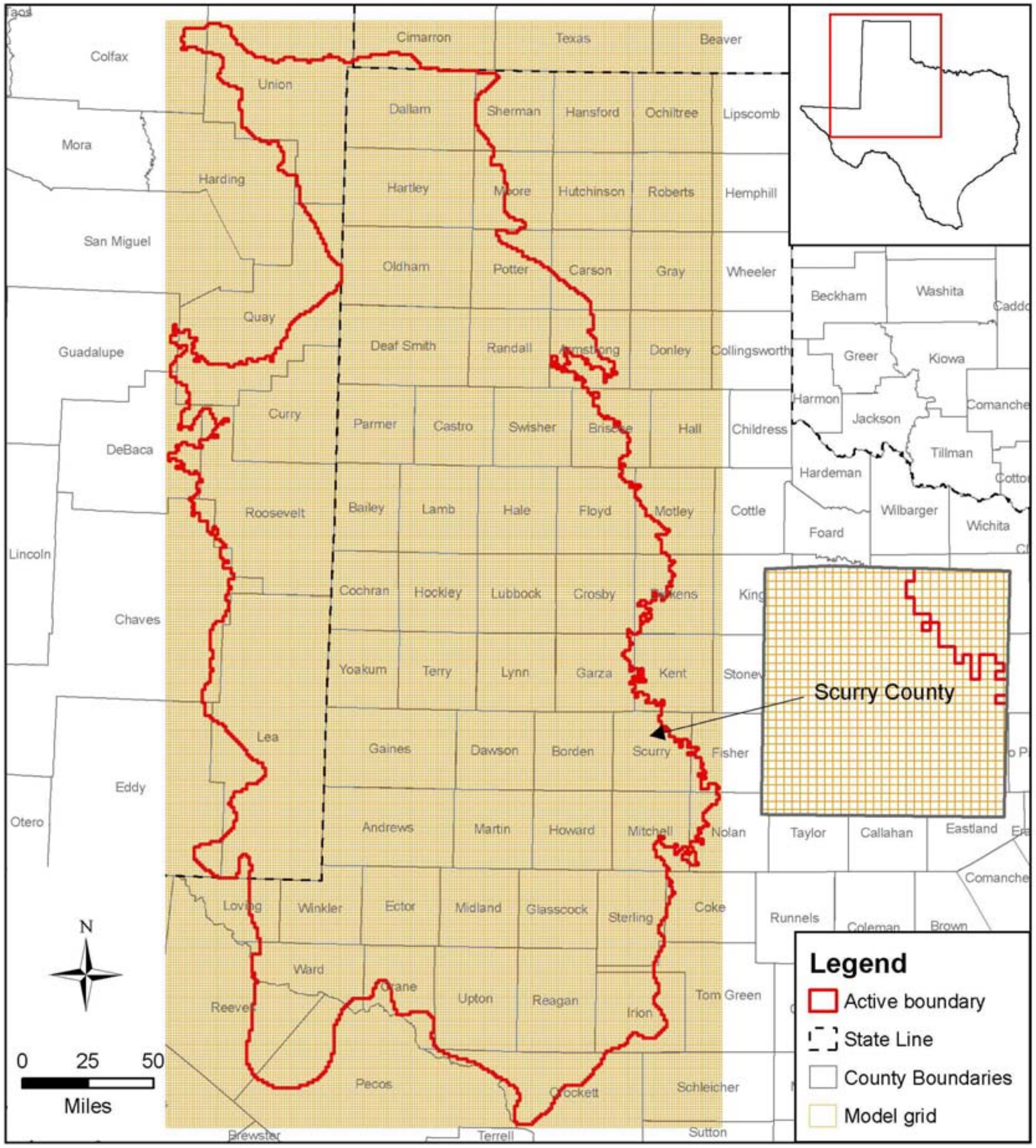
- Outcrop Areas
  - Recharge by precipitation and stream loss
  - Discharges to springs and streams and by ET
- Subcrop with TDS < 5,000 mg/L
  - Portion of Dockum Group defined as an aquifer
  - Only lower Dockum present
  - Fresh water enters via cross-formational flow from overlying Ogallala and Pecos Valley aquifers
  - Flow is towards the Canadian River in the northern portion of the model area
  - Flow is towards the southeast along the eastern side of the model area and discharge to springs or overlying formations
  - Flow is likely towards the trough in southwestern portion of model area

Conceptual Model of Groundwater Flow

- Subcrop with TDS > 5,000 mg/L
  - Correspond to the portion of the Dockum Group not defined as an aquifer
  - Upper and lower Dockum present
  - Little movement of groundwater into or out of the deeper parts of the depositional basin
  - No or insignificant displacement of connate water by meteoric water
  - Connate water from recharge in eastern New Mexico prior to Pleistocene time when Pecos River valley was eroded
  - Movement of water out of the deeper parts of the basin is restricted by the high fluid density of the groundwater
  - Very little cross-formational flow from overlying aquifers due to the high mudstone content in the upper Dockum

Model Implementation

Model Grid



1 square mile grid blocks
212 columns
422 rows
3 layers
150,548 active cells

Stress Periods

period	time	type	length
1	pre-development	ss	
2	1950-1959	tr	10 yrs
3	1960-1969	tr	10 yrs
4	1970-1974	tr	5 yrs
5	1975	tr	1 yr
.	.	.	.
.	.	.	.
.	.	.	.
27	1997	tr	1 yr

Hydraulic Properties - Dockum

- **K_H based on sand hydraulic conductivity and sand fraction:**

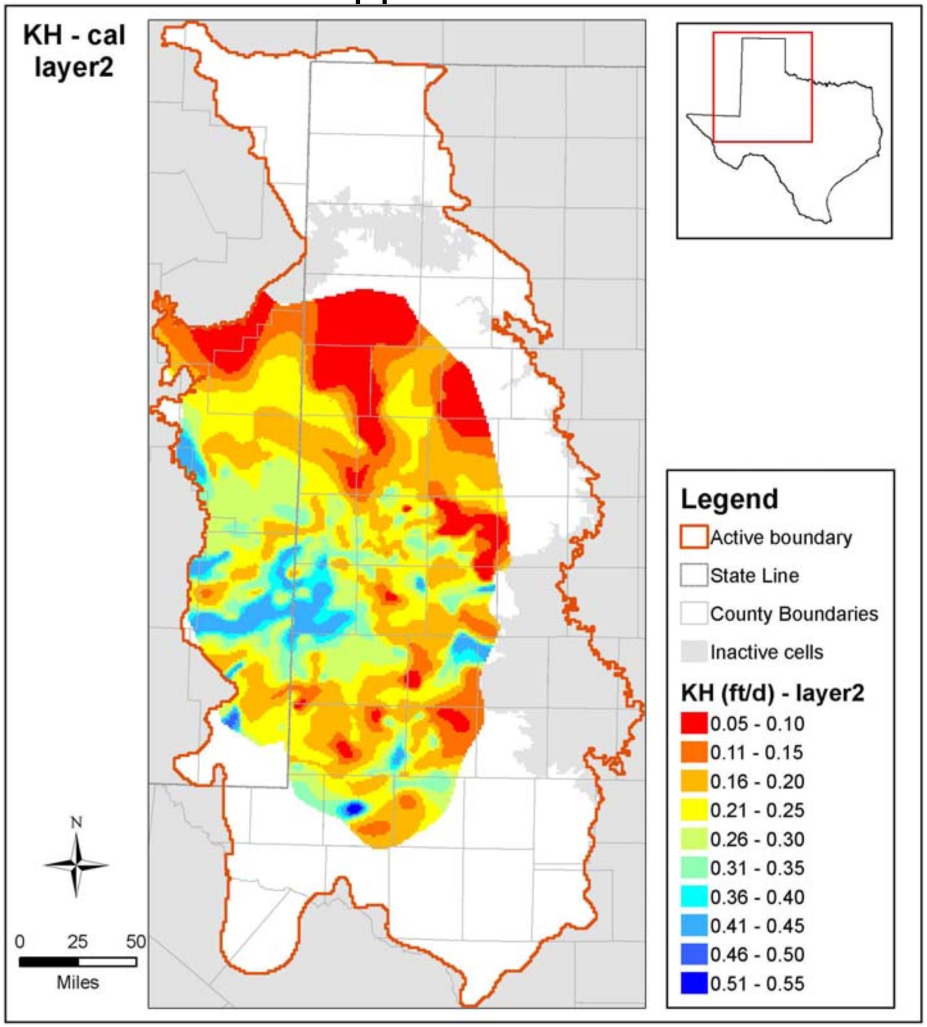
$$K_H = SF \cdot K_{sand}$$

- **K_v calculated as harmonic mean of sand and clay conductivities:**

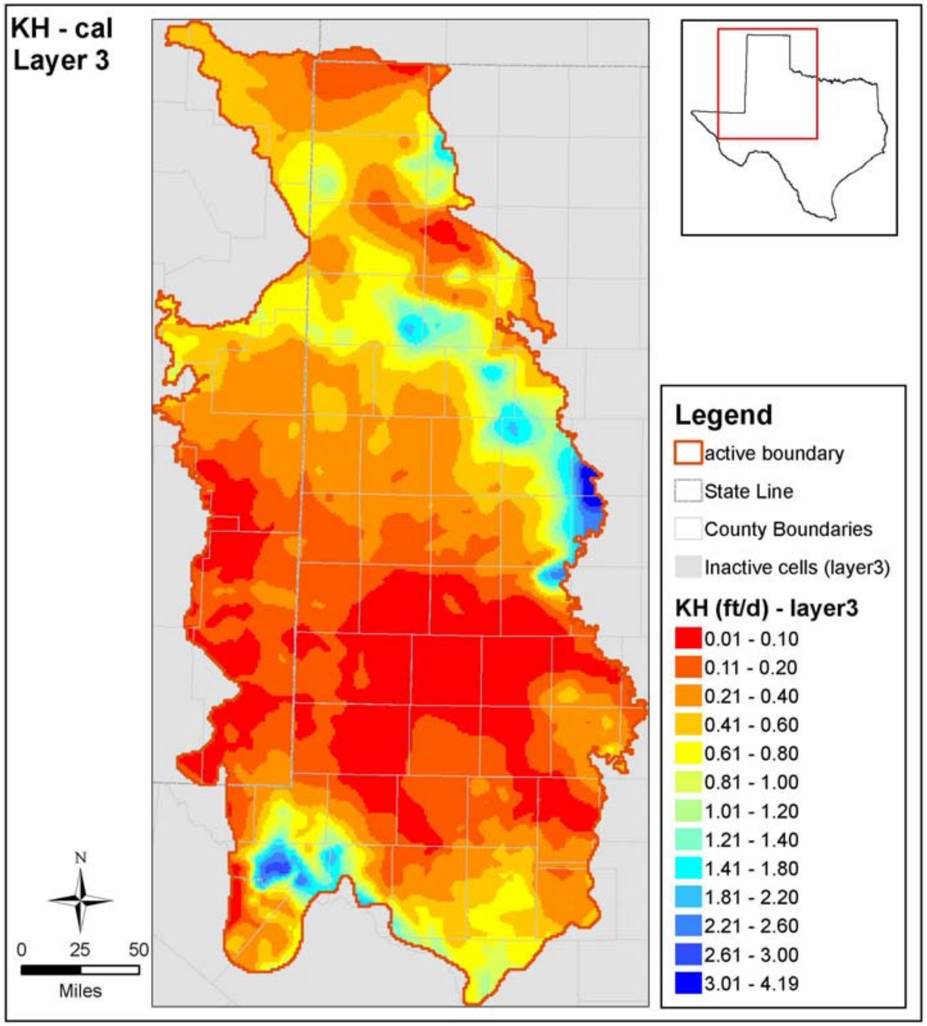
$$K_V = \frac{1}{\frac{SF}{K_{sand}} + \frac{1-SF}{K_{clay}}}$$

Horizontal Hydraulic Conductivity – K_H

Upper Dockum

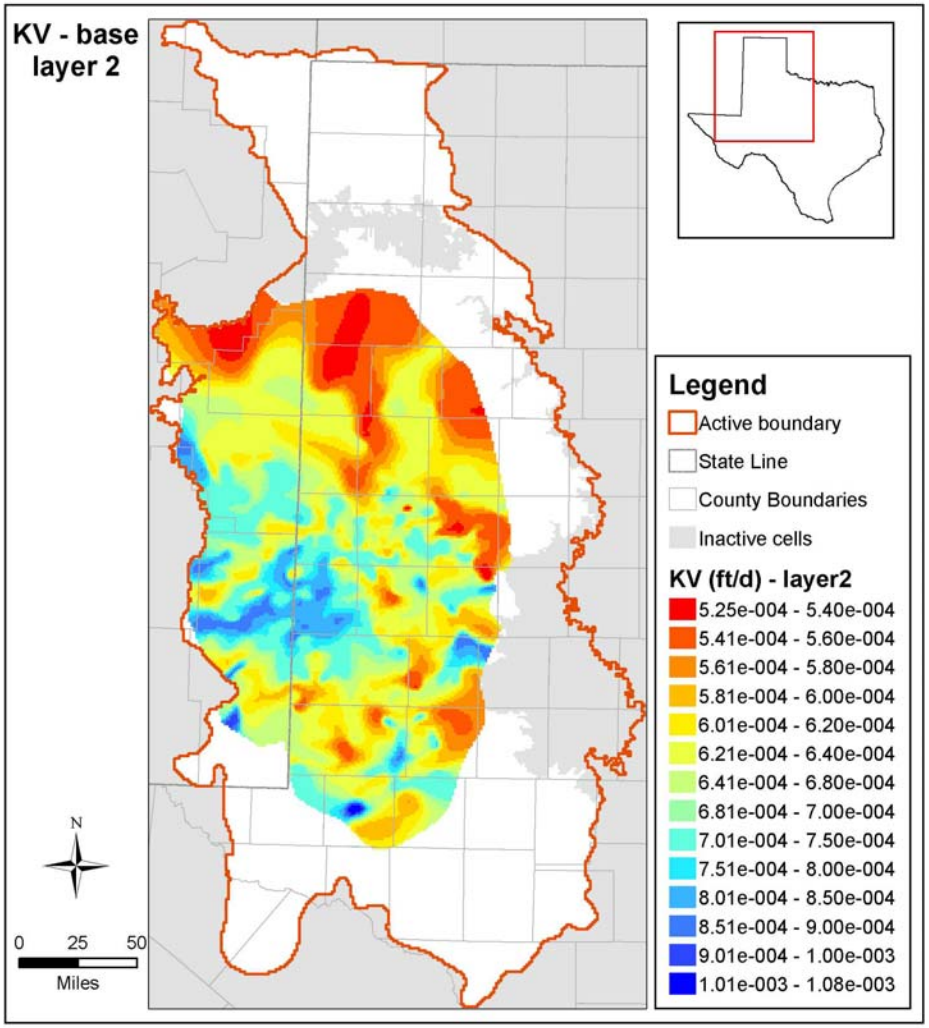


Lower Dockum

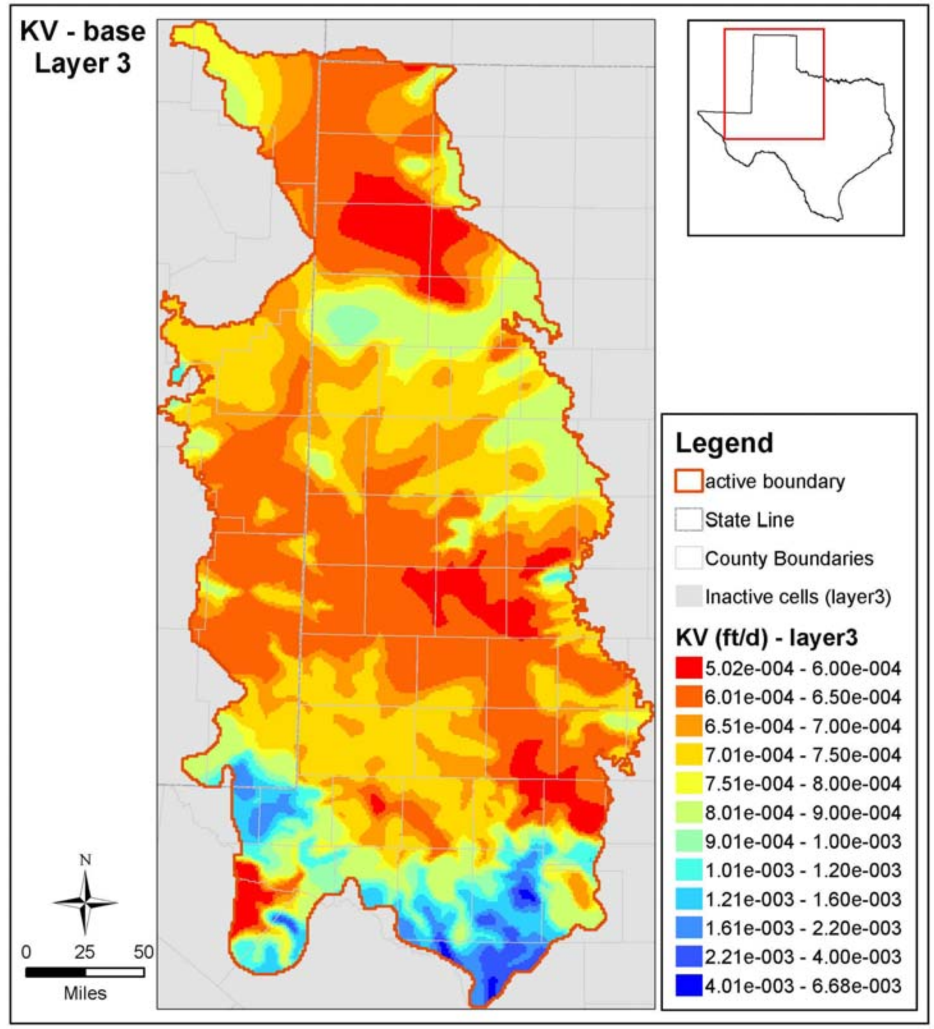


Vertical Hydraulic Conductivity – K_V

Upper Dockum



Lower Dockum



Storage Parameters

- Specific Storage coefficient for upper and lower dockum aquifers are calculated using equation:

  $S_s = SF*S_{s\text{-}sand}+(1-SF)*S_{s\text{-}clay}$

  where:

  SF– sand fraction

  $S_{s\text{-}sand}$ – sand specific storage : $3E\text{-}6\ ft^{-1}$

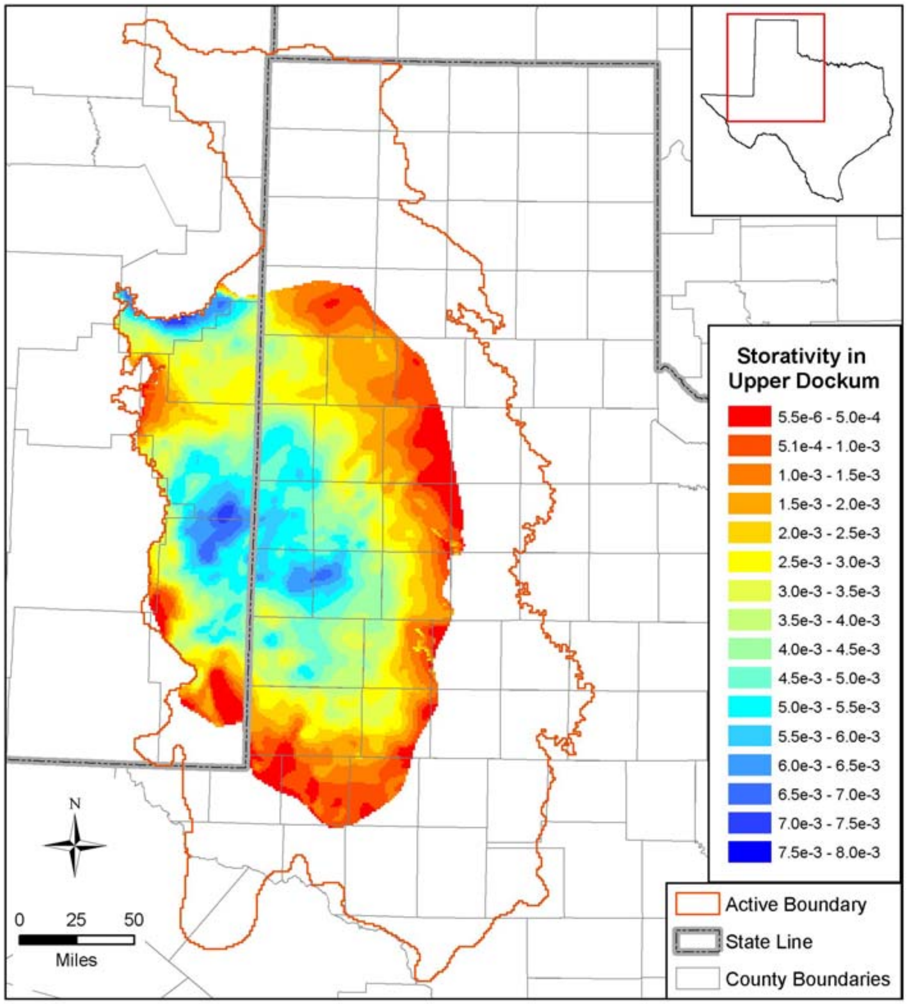
  $S_{s\text{-}clay}$ – clay specific storage : $7.5E\text{-}6\ ft^{-1}$

  $S_{s\text{-}min}$ – water specific storage : $1.3E\text{-}6\ ft^{-1}$
- Storativity product of specific storage and aquifer thickness
- Specific yield set to literature value in absence of data

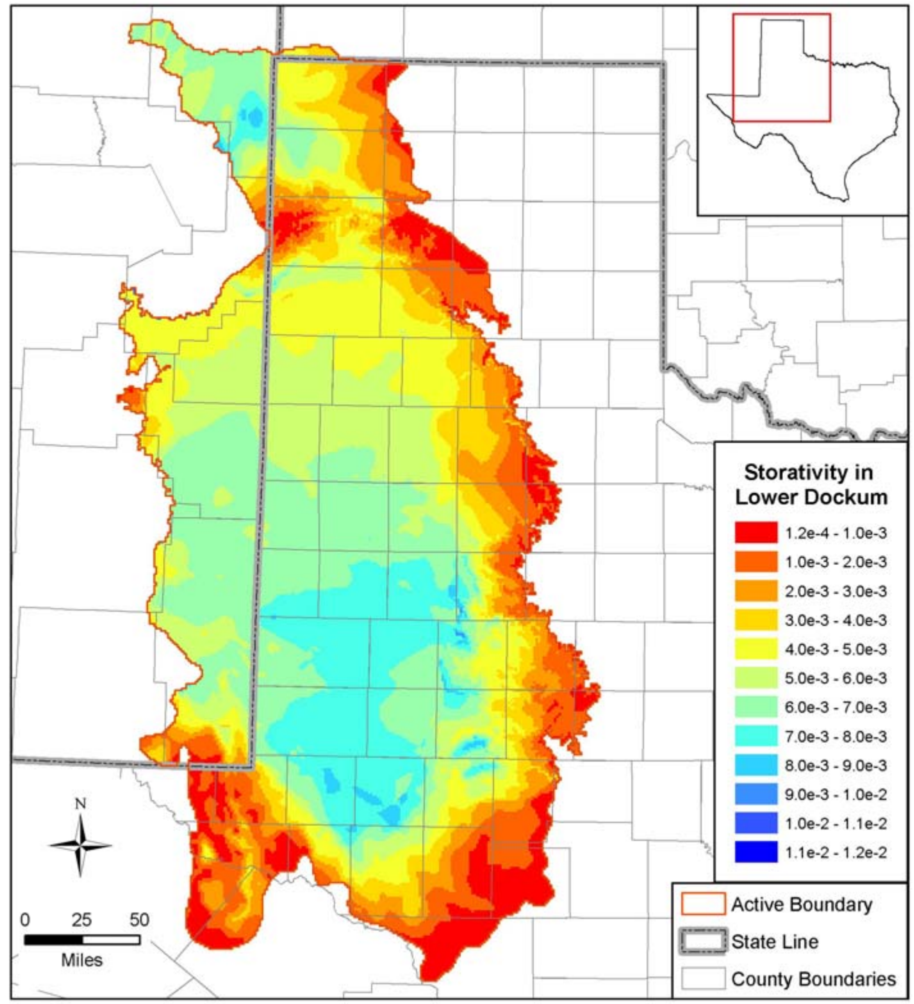
  0.15

Storativity

Upper Dockum



Lower Dockum



Recharge Rate Estimates

County/Area	Land use	Aquifer	Recharge (in/yr)	Technique	Reference
Dockum Aquifer – Colorado River outcrop area					
All of the Colorado River outcrop area - Predevelopment	Grassland and shrubland	Dockum	0.08	SZ chloride mass balance	This report
Sandy areas (Nolan and eastern Mitchell counties) - Predevelopment	Grassland and shrubland	Dockum	0.22	SZ chloride mass balance	This report
All of the Colorado River outcrop area		Dockum	0.08 to 0.2	UZ numerical modeling	Scanlon et al. (2003)
Western Scurry and Mitchell counties	Grassland and shrubland	Dockum	<0.01	SZ chloride mass balance	This report
Scurry County - Predevelopment		Dockum	0.02 to 0.04	Water budget on playas	This report
All of the Colorado River Outcrop area - Postdevelopment		Dockum	2.2	regional water level rise	This report
Sandy areas (Nolan and eastern Mitchell counties) - Postdevelopment	Cropland	Dockum	Geom. Average = 1.7 Median = 1.6 Range = 0 to 4.3	linear water level rises in individual wells	This report

County/Area	Land use	Aquifer	Recharge (inch/yr)	Technique	Reference
Dockum Aquifer – Canadian River outcrop area					
All of the Canadian River outcrop area- Predevelopment and Postdevelopment	Grassland and shrubland	Dockum	0.17	SZ chloride mass balance	This report
All of the Canadian River outcrop area		Dockum	<0.08	UZ numerical modeling	Scanlon et al. (2003)
Dockum Aquifer – high TDS outcrop area					
Howard, Borden and Garza counties - Predevelopment	Grassland and shrubland	Dockum	<0.01	SZ chloride mass balance	This report

Predevelopment Recharge

- **Recharge was estimated on limited points (80) using:**

$$R = P \frac{Cl_P}{Cl_{GW}}$$

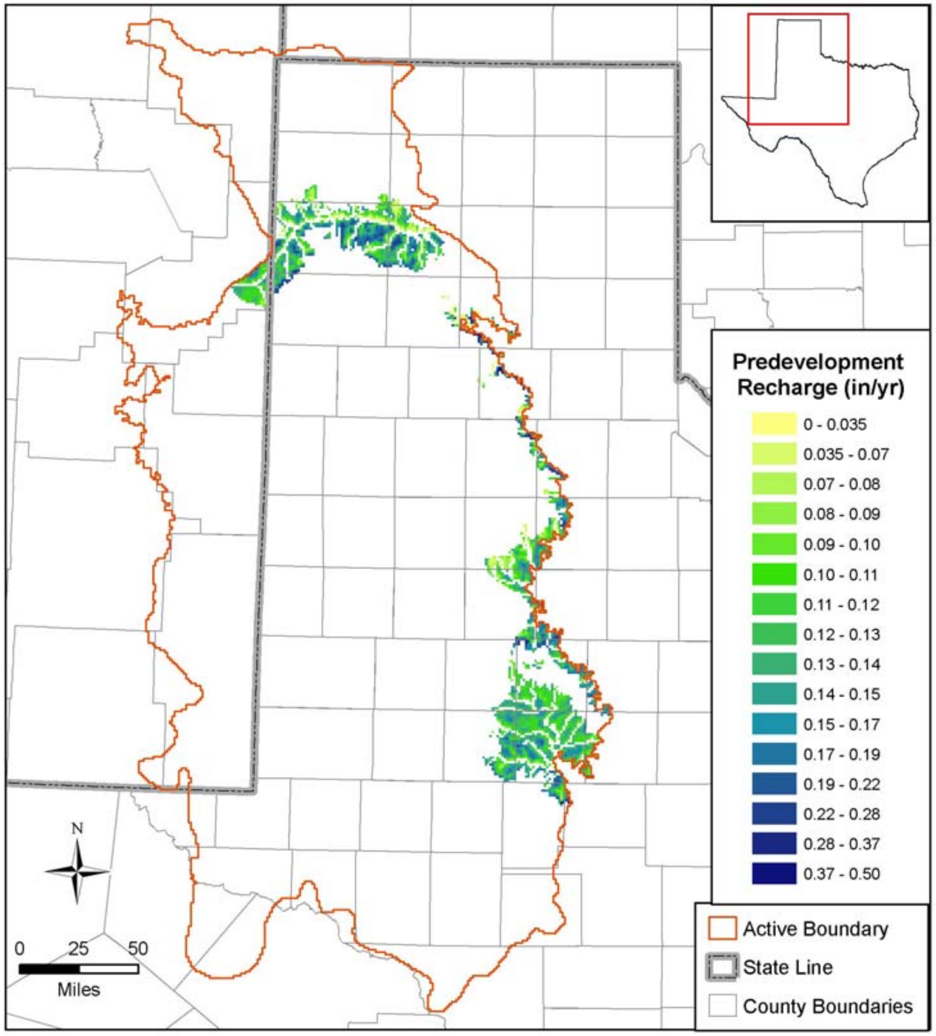
- **The correlation of estimated recharge to physical parameters was tested, however, no obvious correlation was found**
- **A significance analysis (t-test) was conducted to determine whether average recharge rates should be divided into regions; no significant difference existed**
- **Recharge rates were weighted as a power function of the local topography and normalized to conserve total recharge**
- **Power coefficient adjusted until maximum recharge rate was reasonable (~0.5 in/yr)**

Modern Recharge

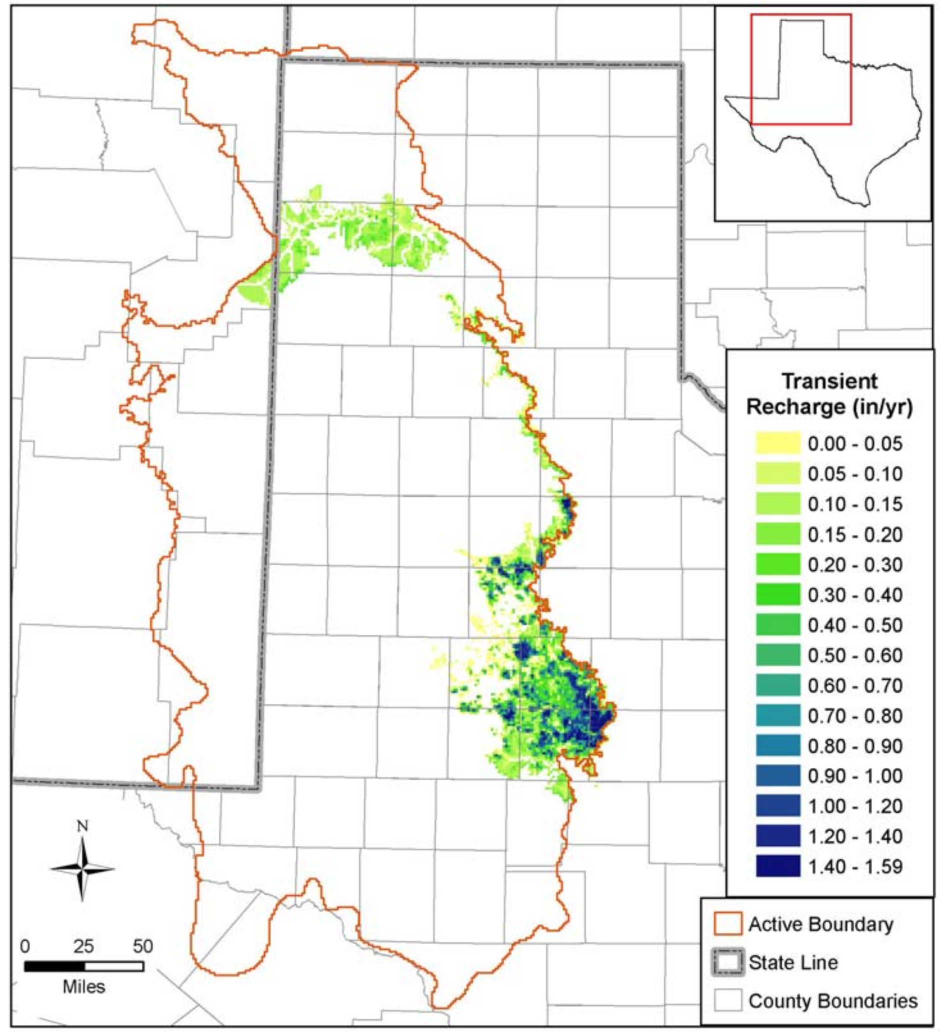
- **Analysis of regional water-level rise was conducted**
  - Colorado River outcrop rise indicates 2.2 in/yr effective recharge
  - Canadian River outcrop indicates no appreciable rise
  - includes recovery, stream loss, land-use impacts, return flow
- **For non-pumped, interstream wells with linear water table rise:**
  - Recharge = $\Delta h / Sy \Delta t$ where median = 1.6 in/yr
  - Already have 0.15 in/yr historical recharge
- **Added 1.45 in/yr to cropland areas**
  - Only added within Colorado River outcrop
  - Added to cells by percent cropland within cell

Recharge Distribution

Predevelopment



Modern

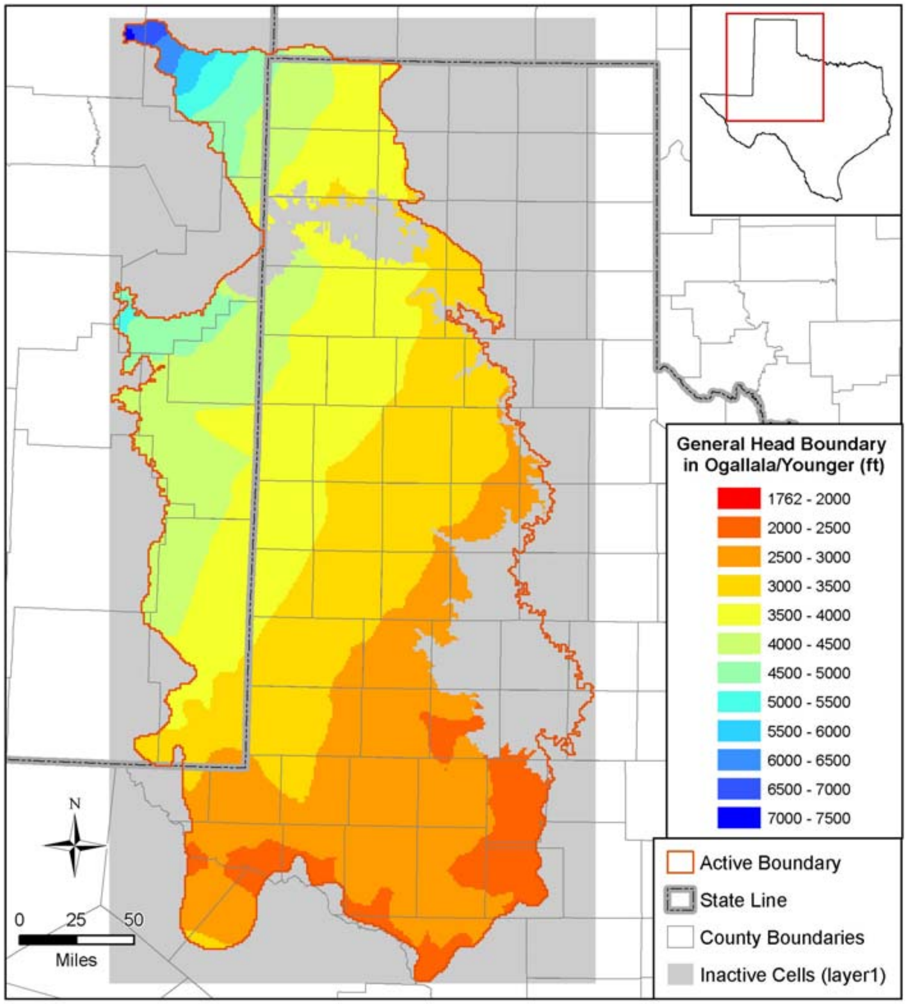


General Head Boundary

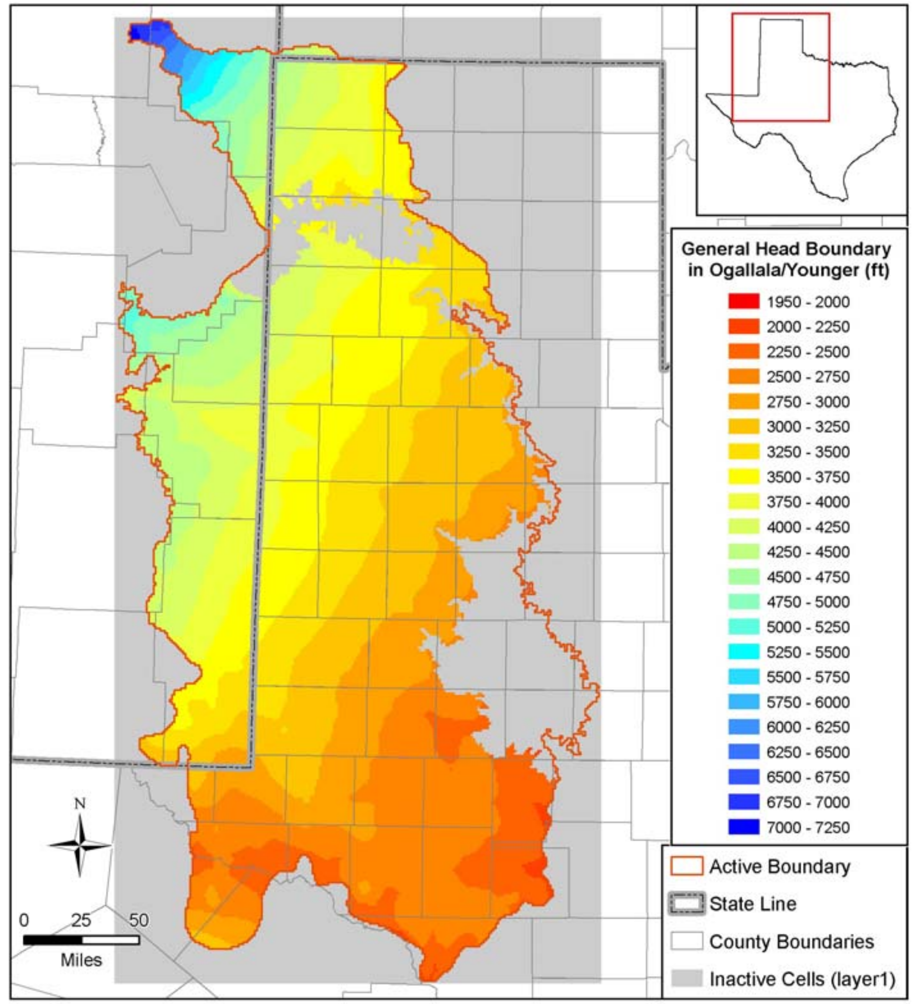
- Used to represent impact of the overlying aquifers
- Pre-development heads based on observed data
- Transient heads based on drawdown from Southern Ogallala GAM simulations
- GHB Conductances large → Dockum properties are primary limiter to flow

General Head Boundary

Predevelopment

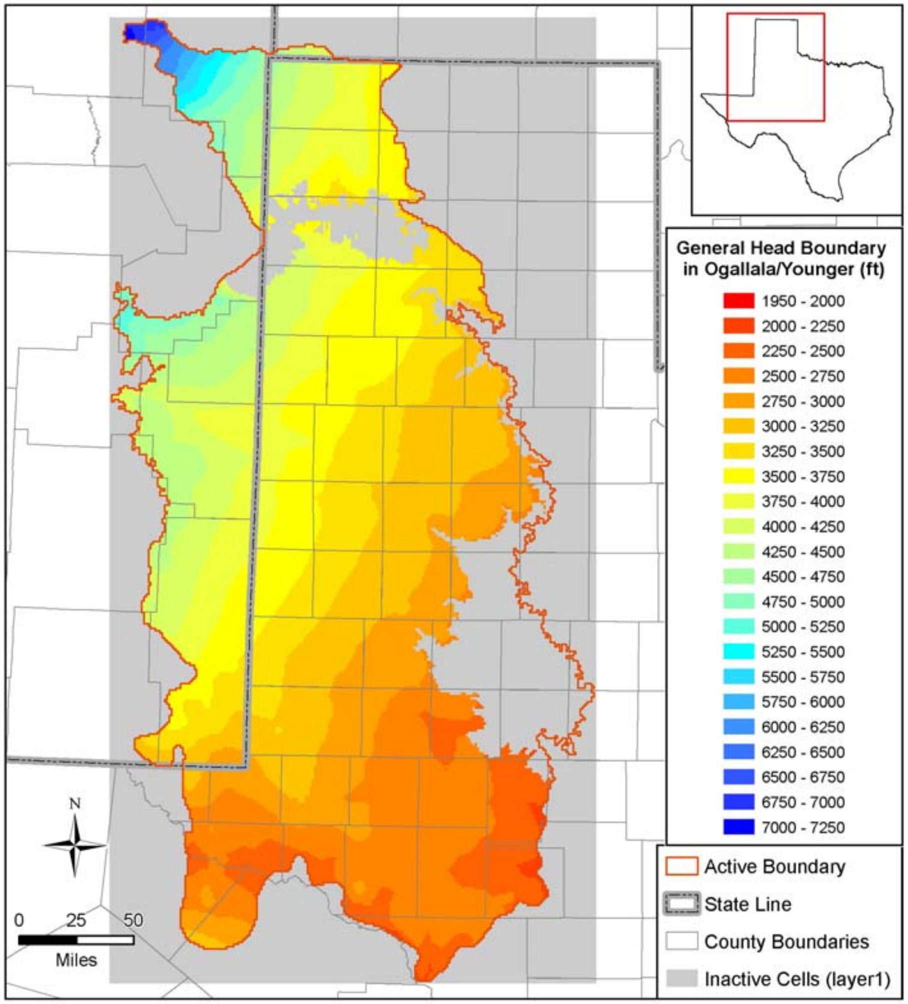


1980

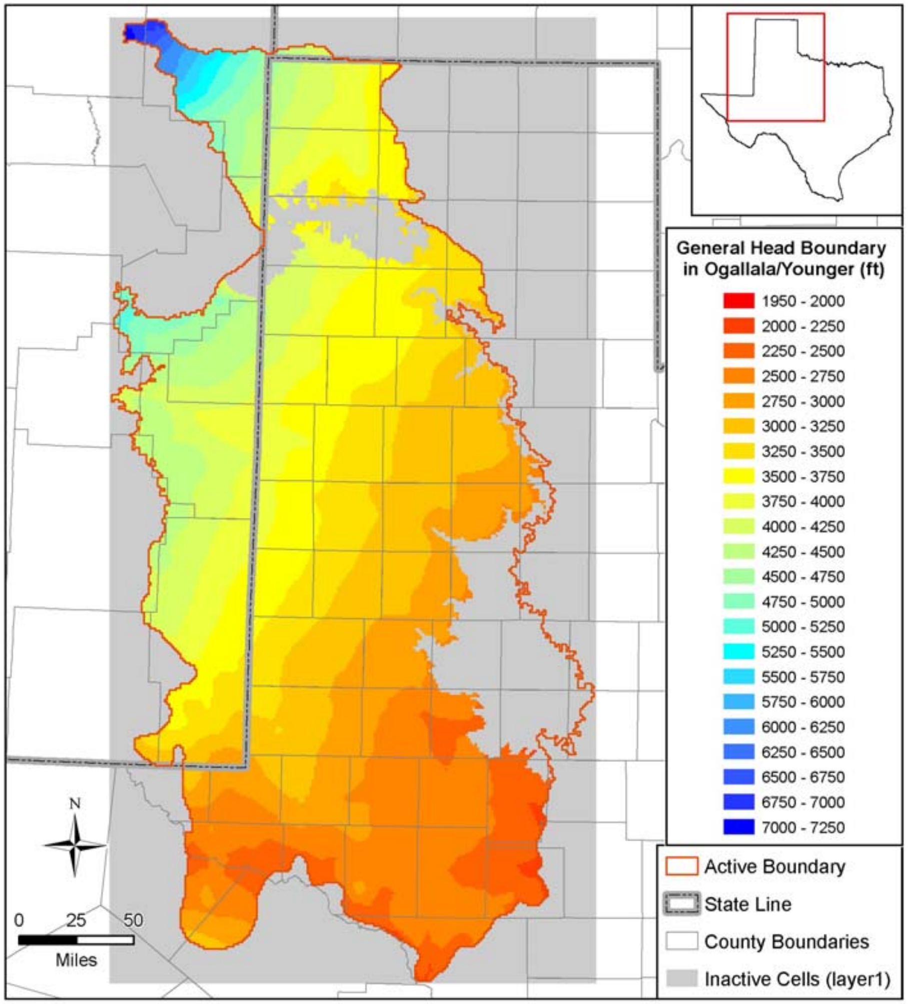


General Head Boundary

1990



1997

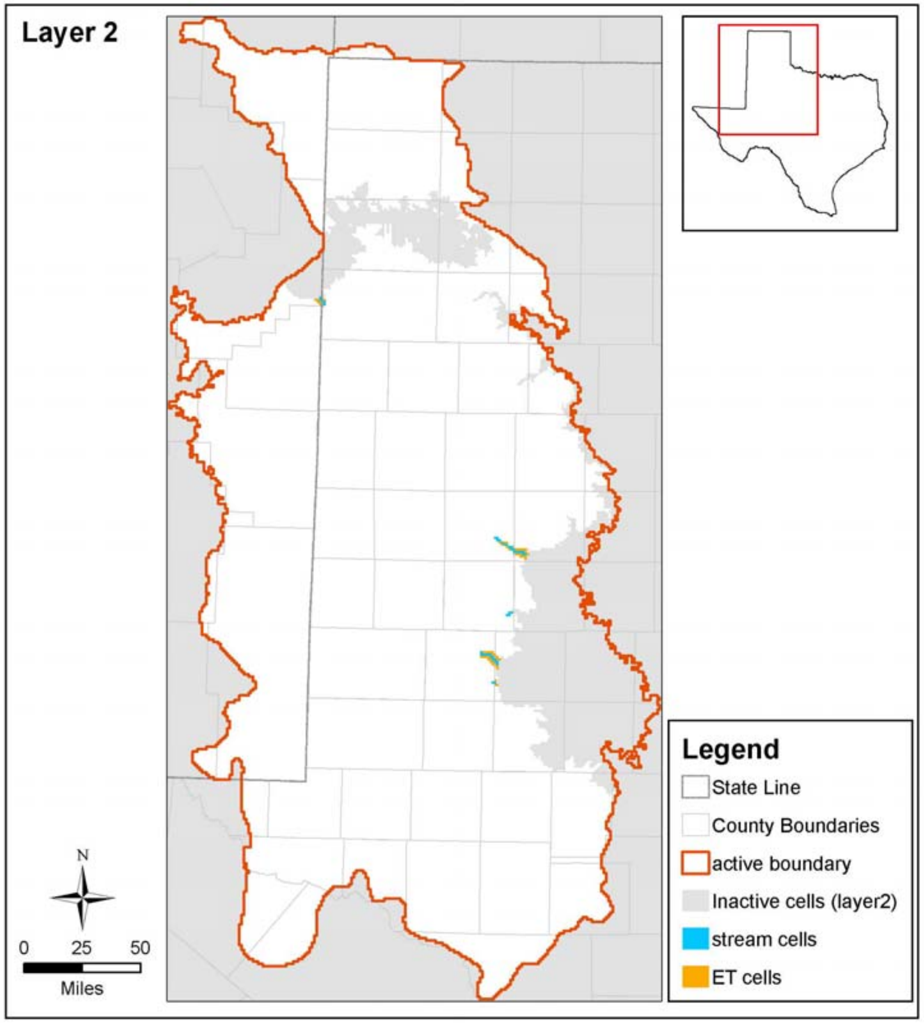


Surface Water Boundary Conditions

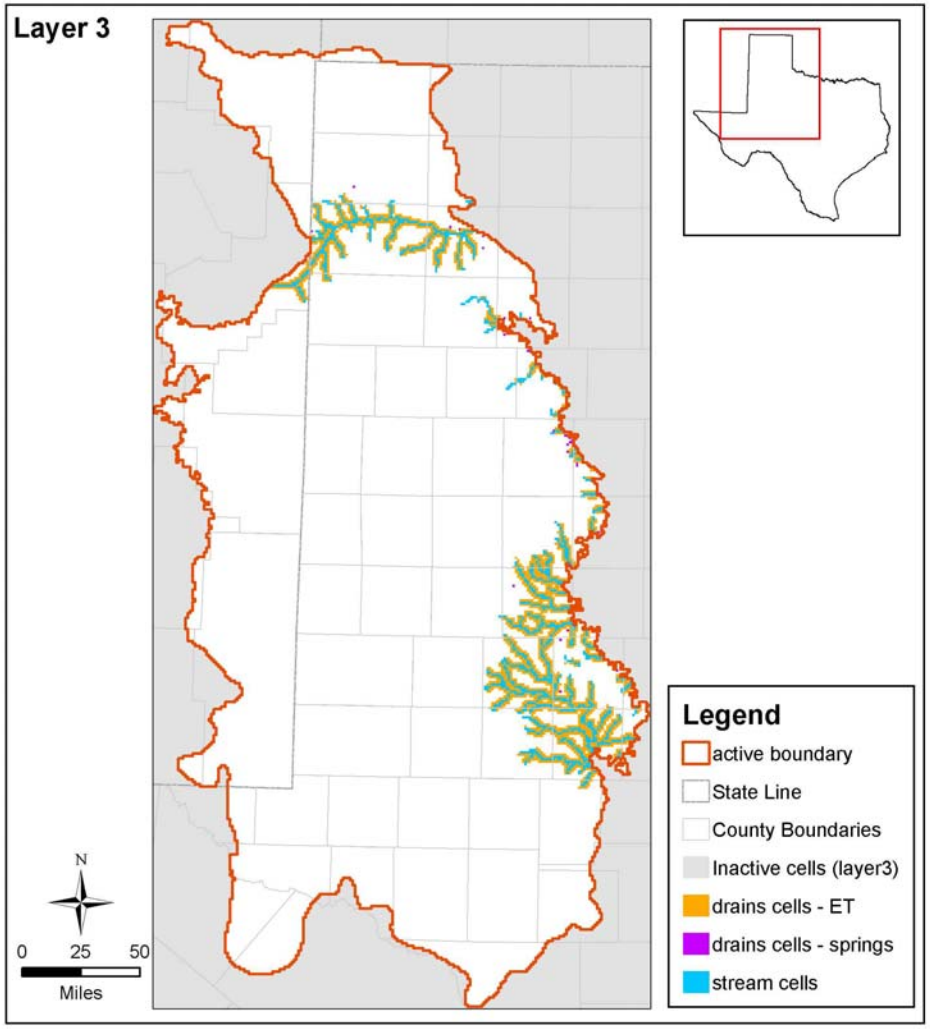
- **Streams represented by STR package**
  - Stream geometry (length, slope, width) from RF1 dataset
  - Streamflow from RF1 mean flow
  - Streambed conductance calibration parameter
- **Springs represented by DRN package**
  - Drain elevations based on literature
  - Conductance calibration paramter
- **Evapotranspiration represented by DRN package**
  - Attempt to use EVT package following Scanlon et al. 2005 resulted in convergence problems associated with EVT package
  - Drain elevation set to root extinction depth
  - Conductance large and flows compared with ET_{max}

Surface Water Boundary Conditions

Upper Dockum

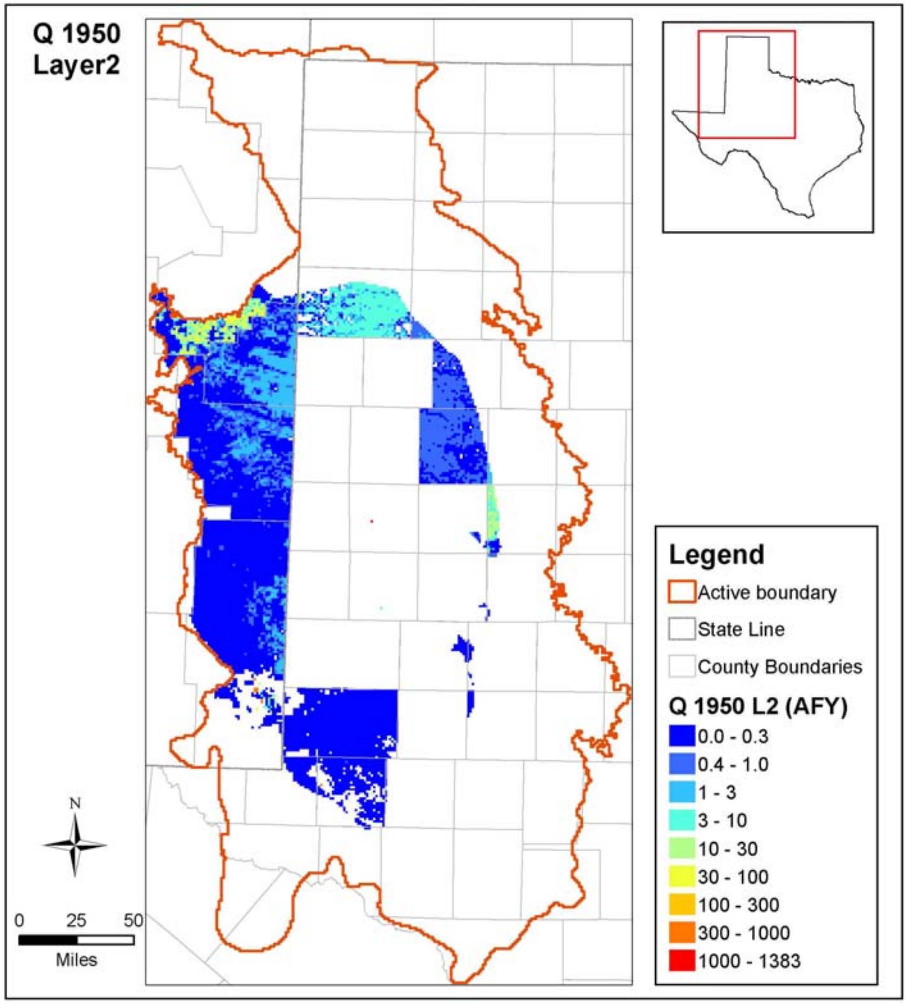


Lower Dockum

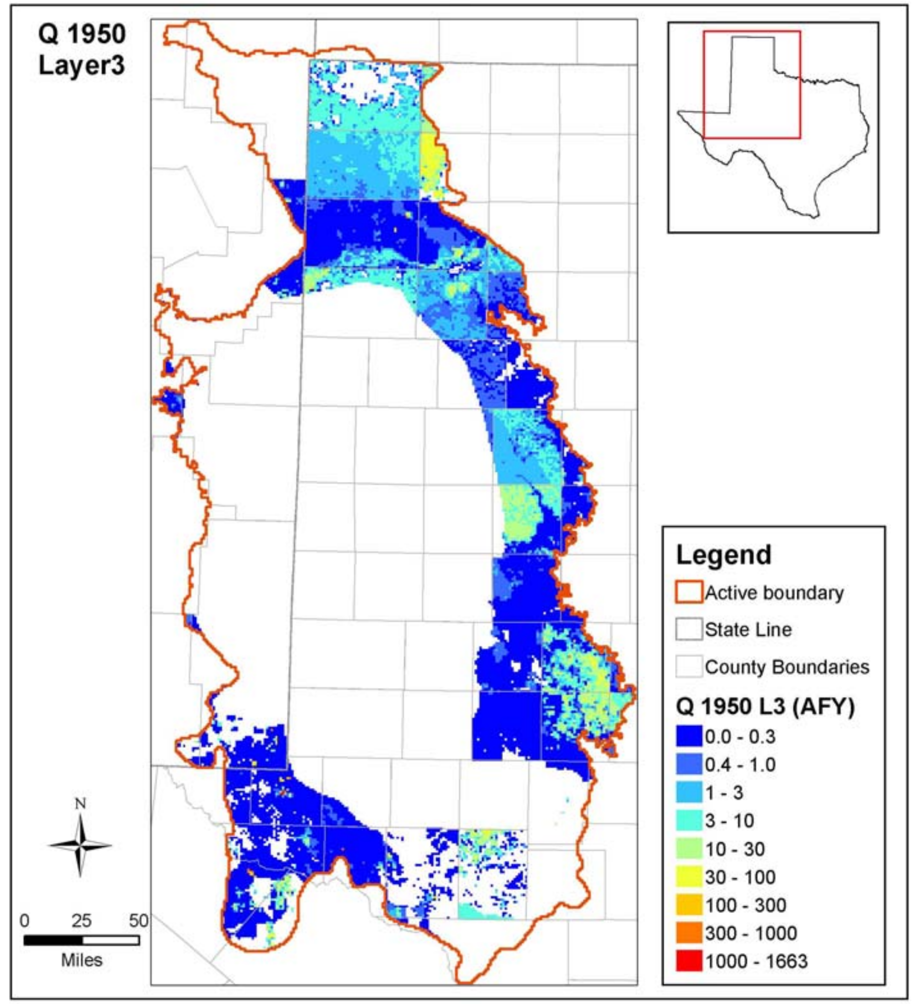


Pumping – 1950

Upper Dockum

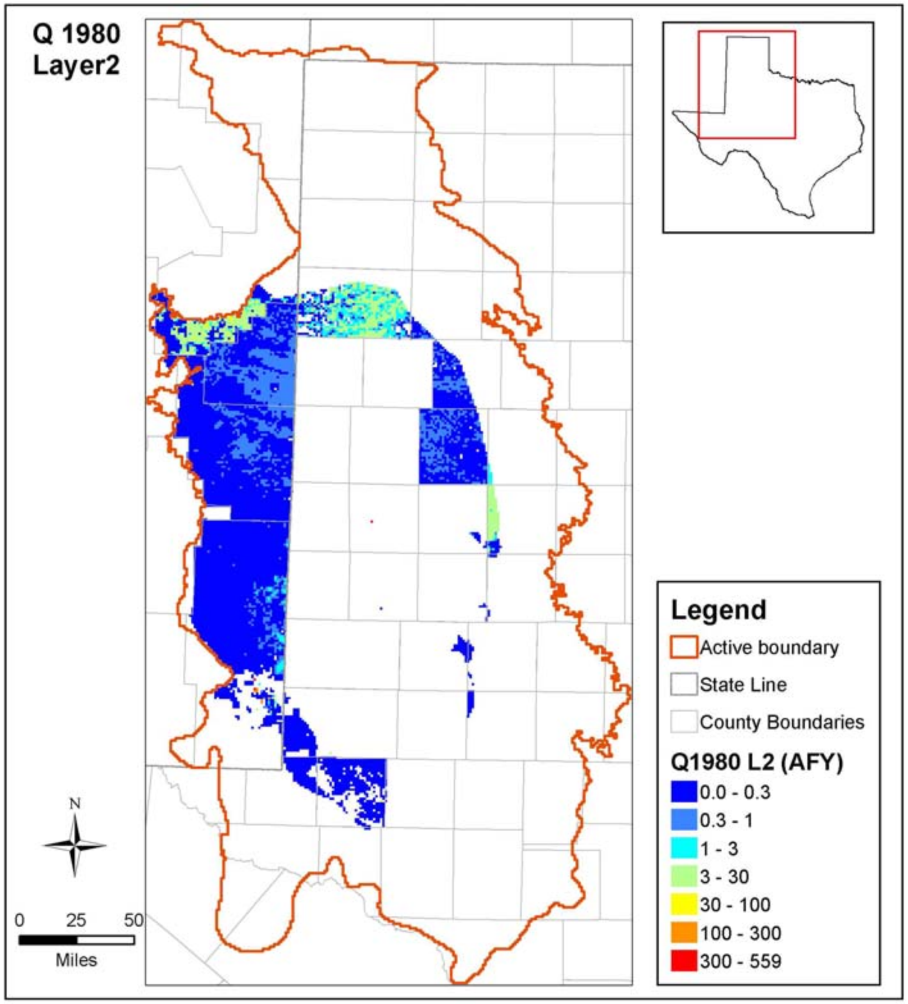


Lower Dockum

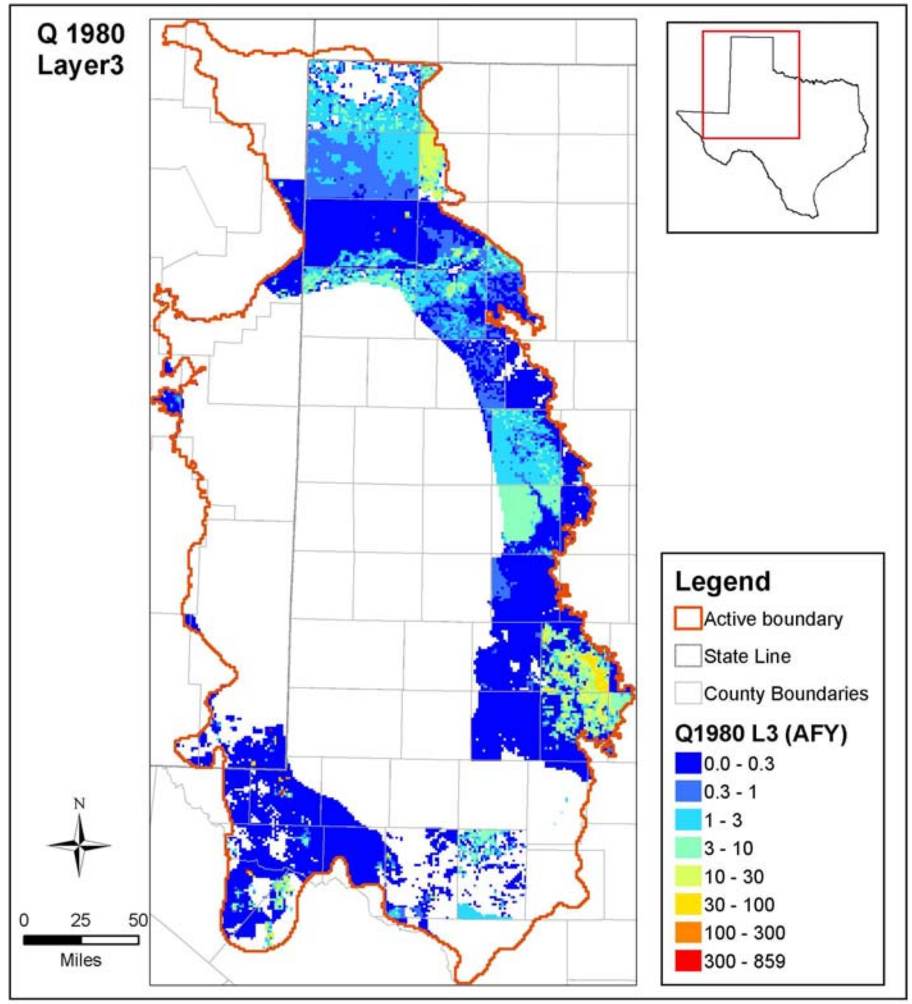


Pumping – 1980

Upper Dockum

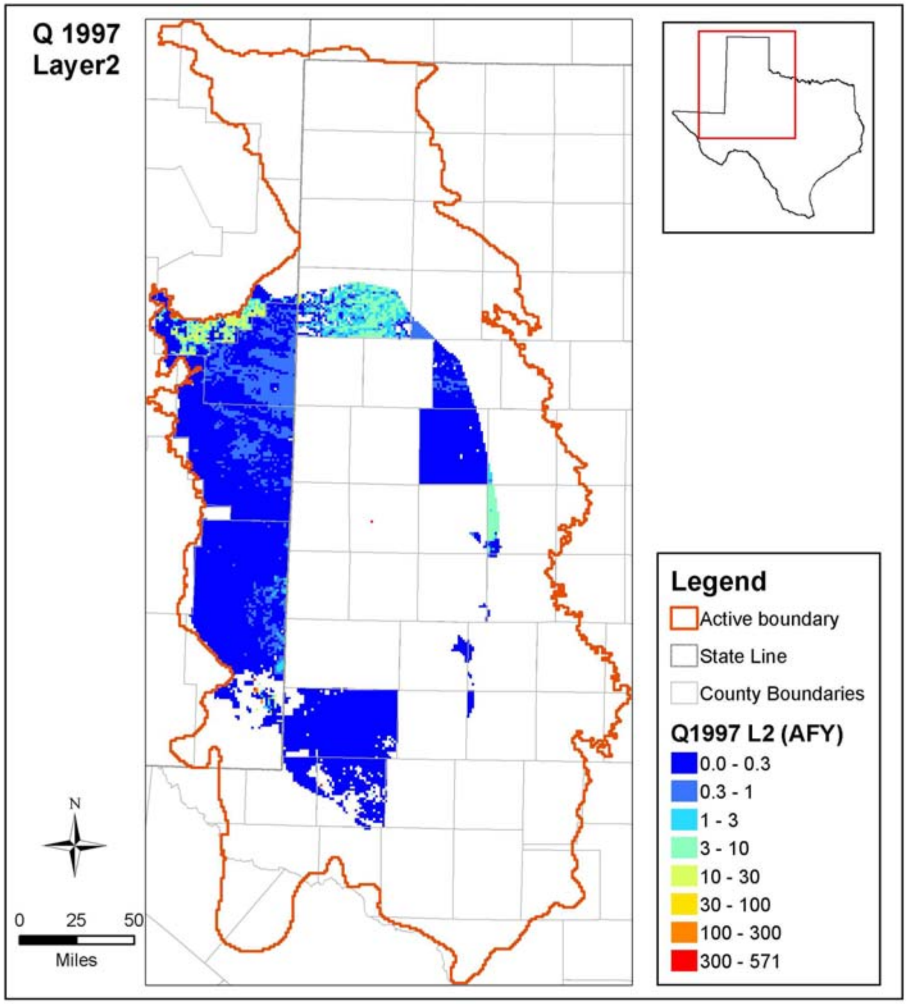


Lower Dockum

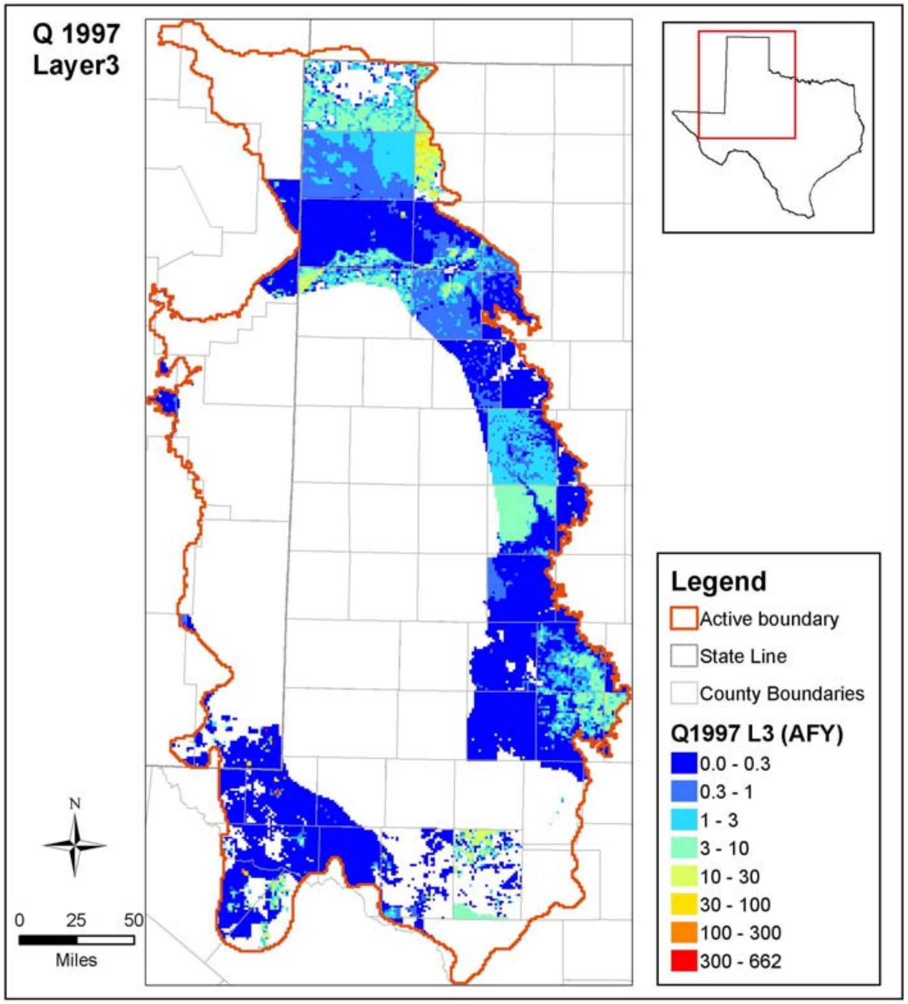


Pumping – 1997

Upper Dockum

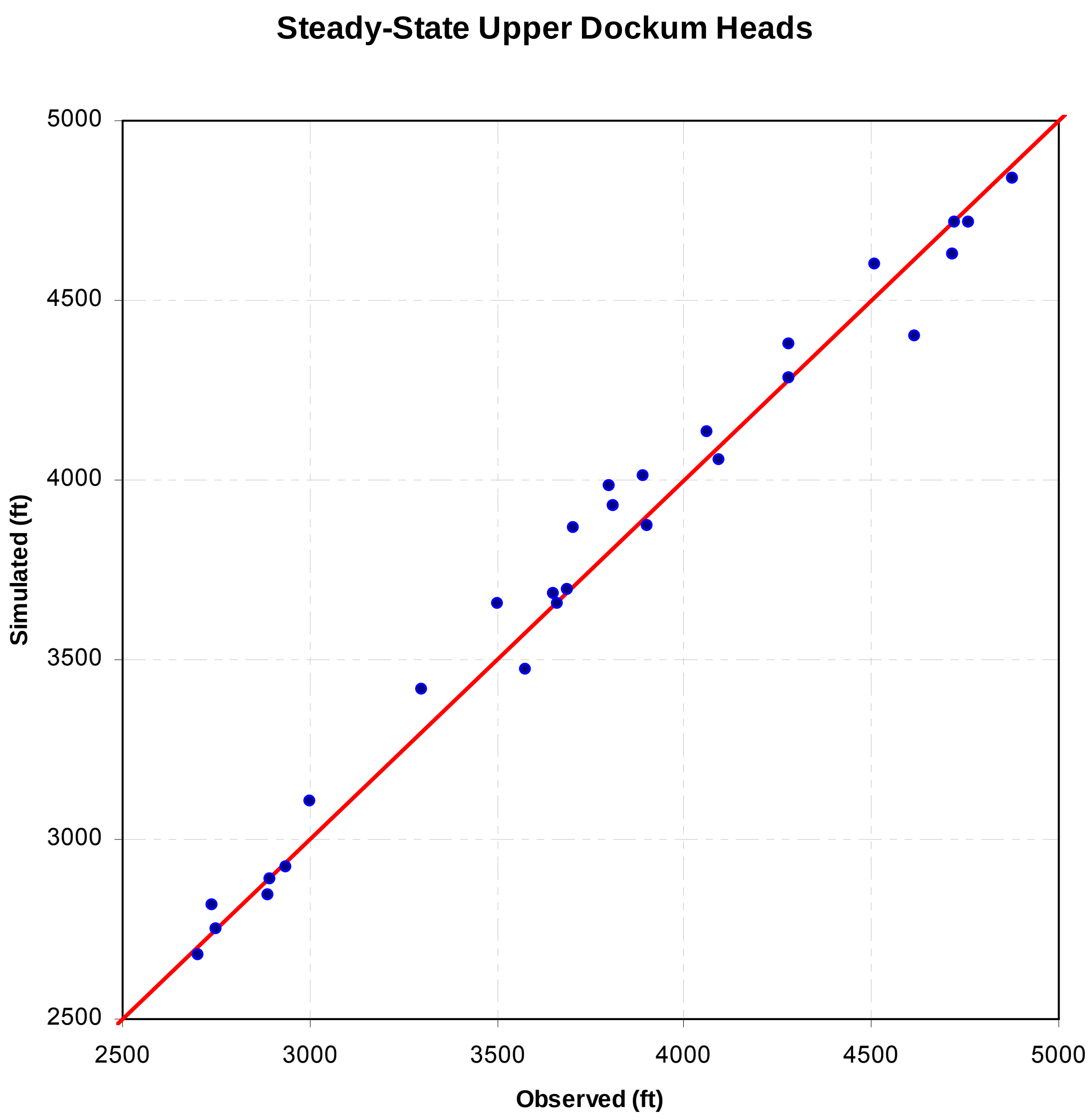


Lower Dockum



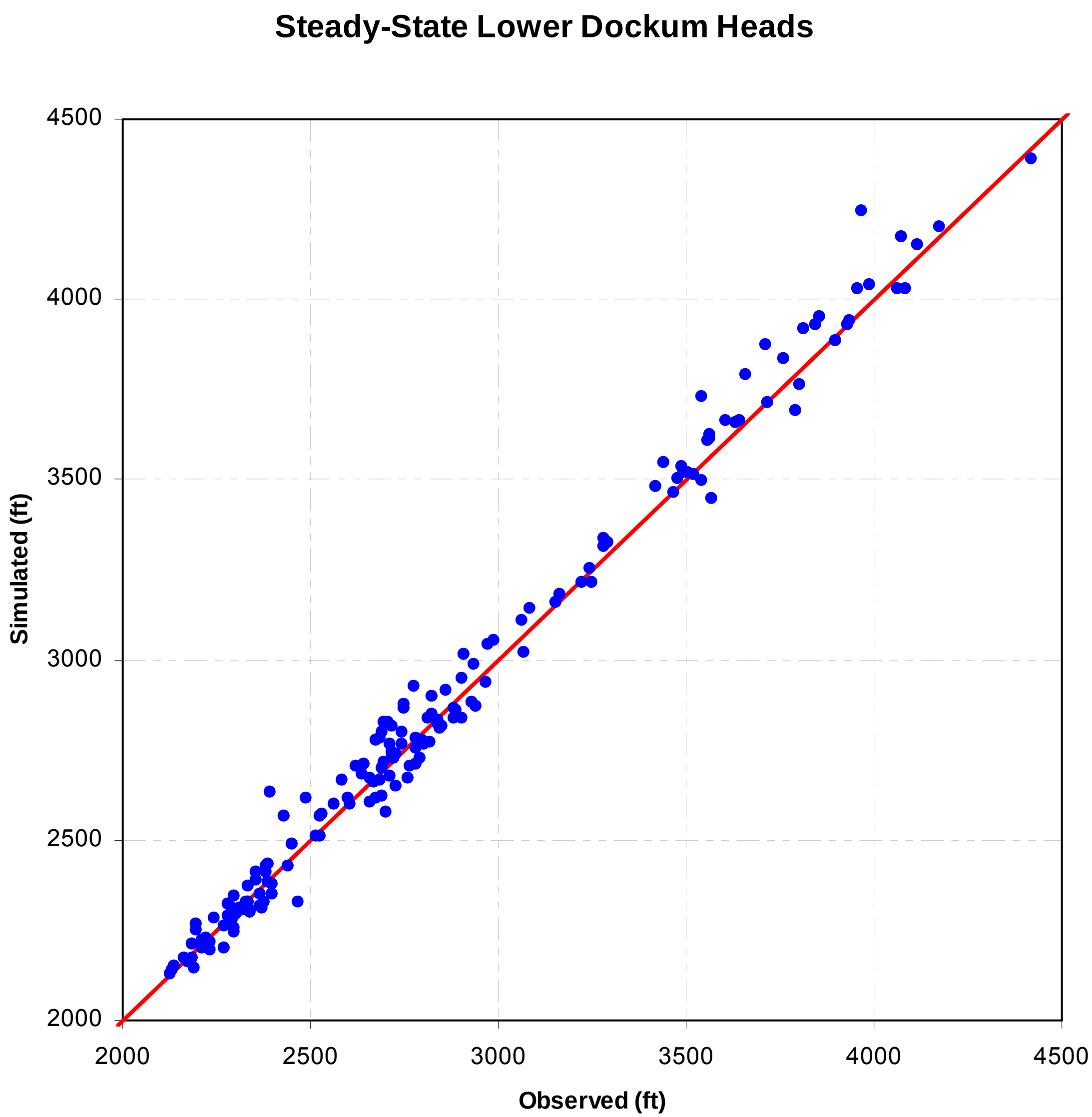
Model Calibration

Upper Dockum Calibration – Predevelopment



RMSE	100.0 ft
MAE	77.0 ft
ME	15.0 ft
Min E	-223.4 ft
Max E	185.6 ft
Range	2403.6 ft
RMSE/Range	4.16%
MAE/Range	3.20%
ME/Range	0.62%

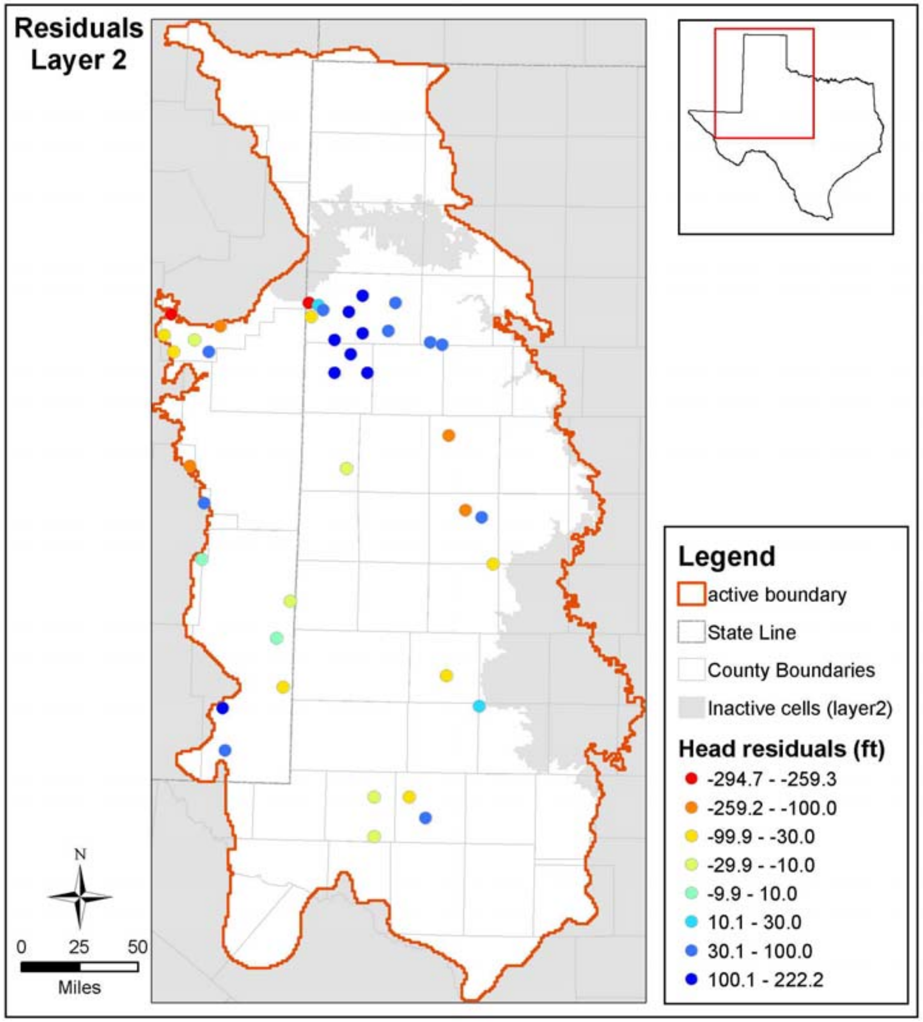
Lower Dockum Calibration – Predevelopment



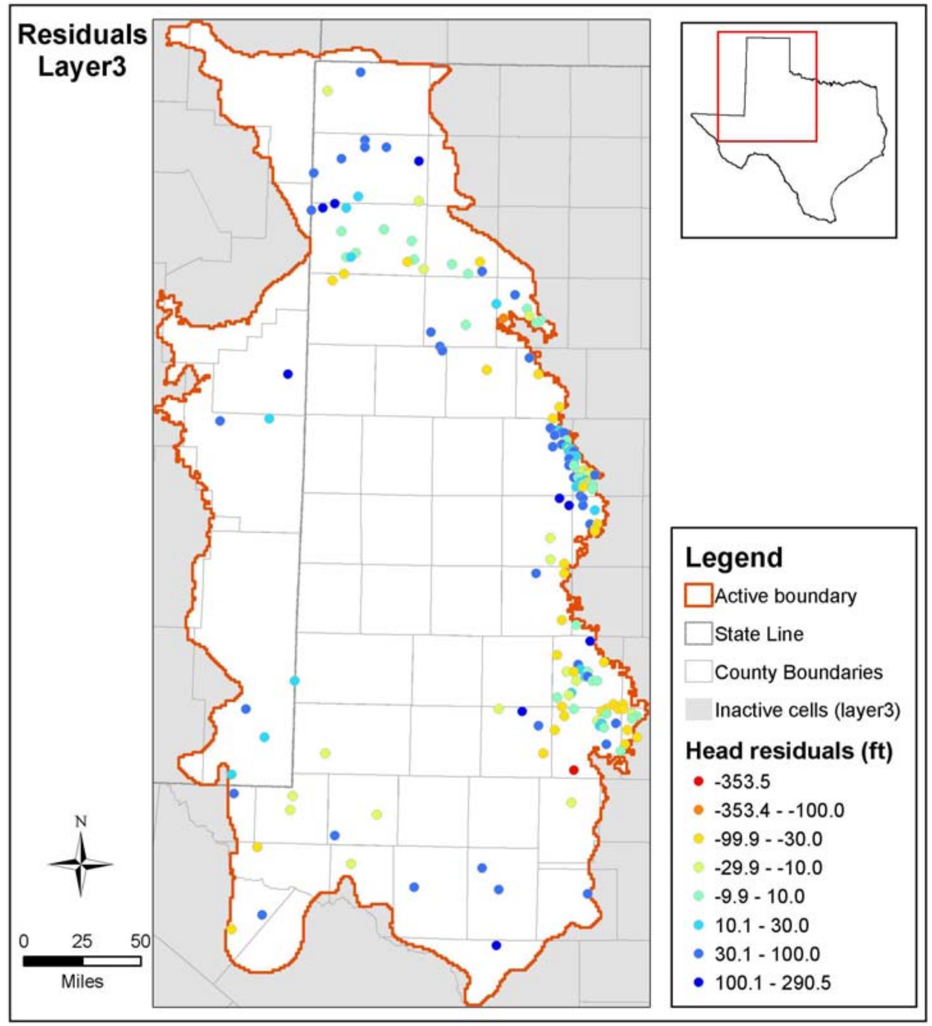
RMSE	65.1 ft
MAE	48.4 ft
ME	15.1 ft
Min E	-136.7 ft
Max E	273.8 ft
Range	2288.5 ft
RMSE/Range	2.84%
MAE/Range	2.12%
ME/Range	0.66%

Predevelopment Head Residuals

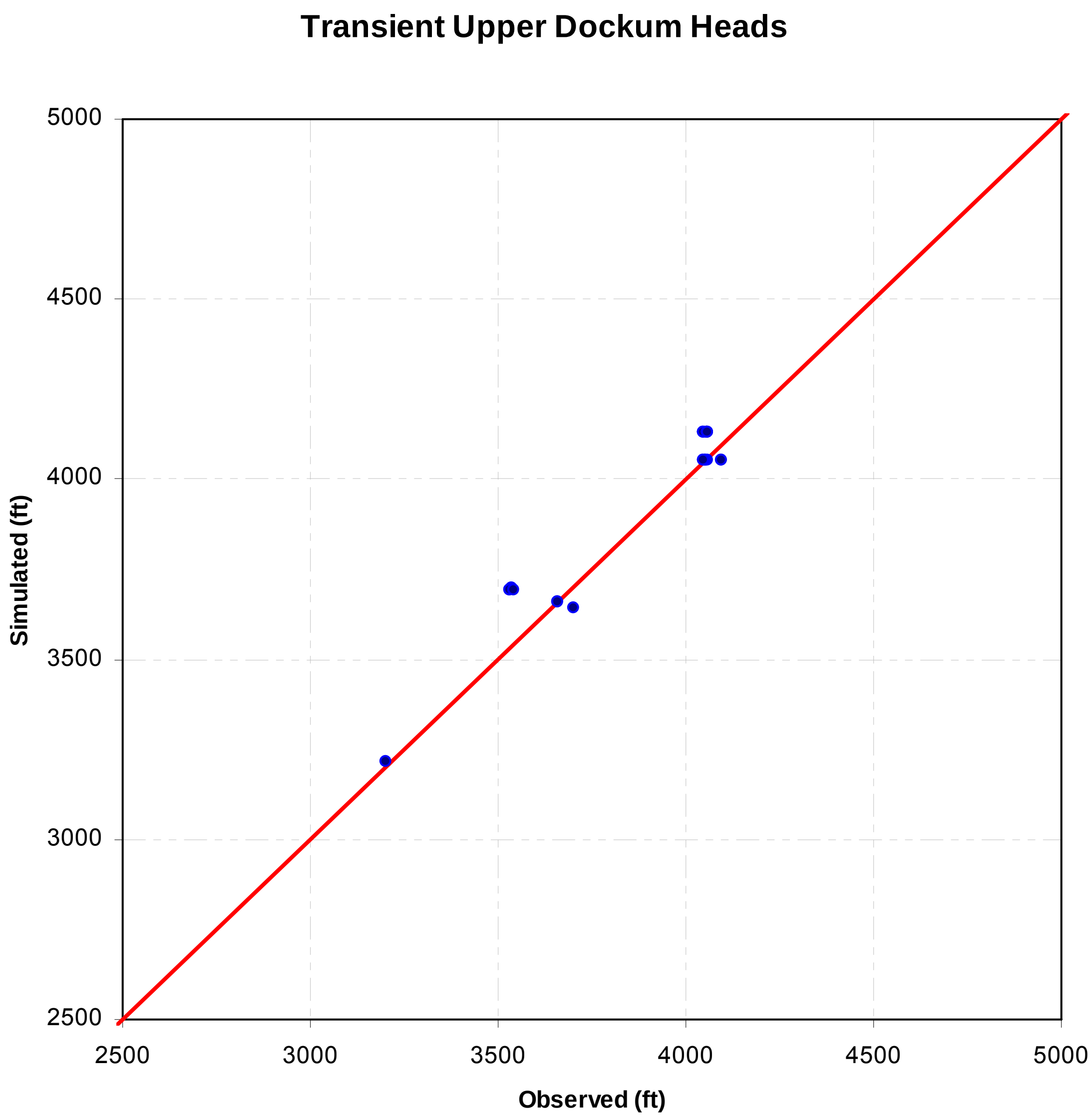
Upper Dockum



Lower Dockum

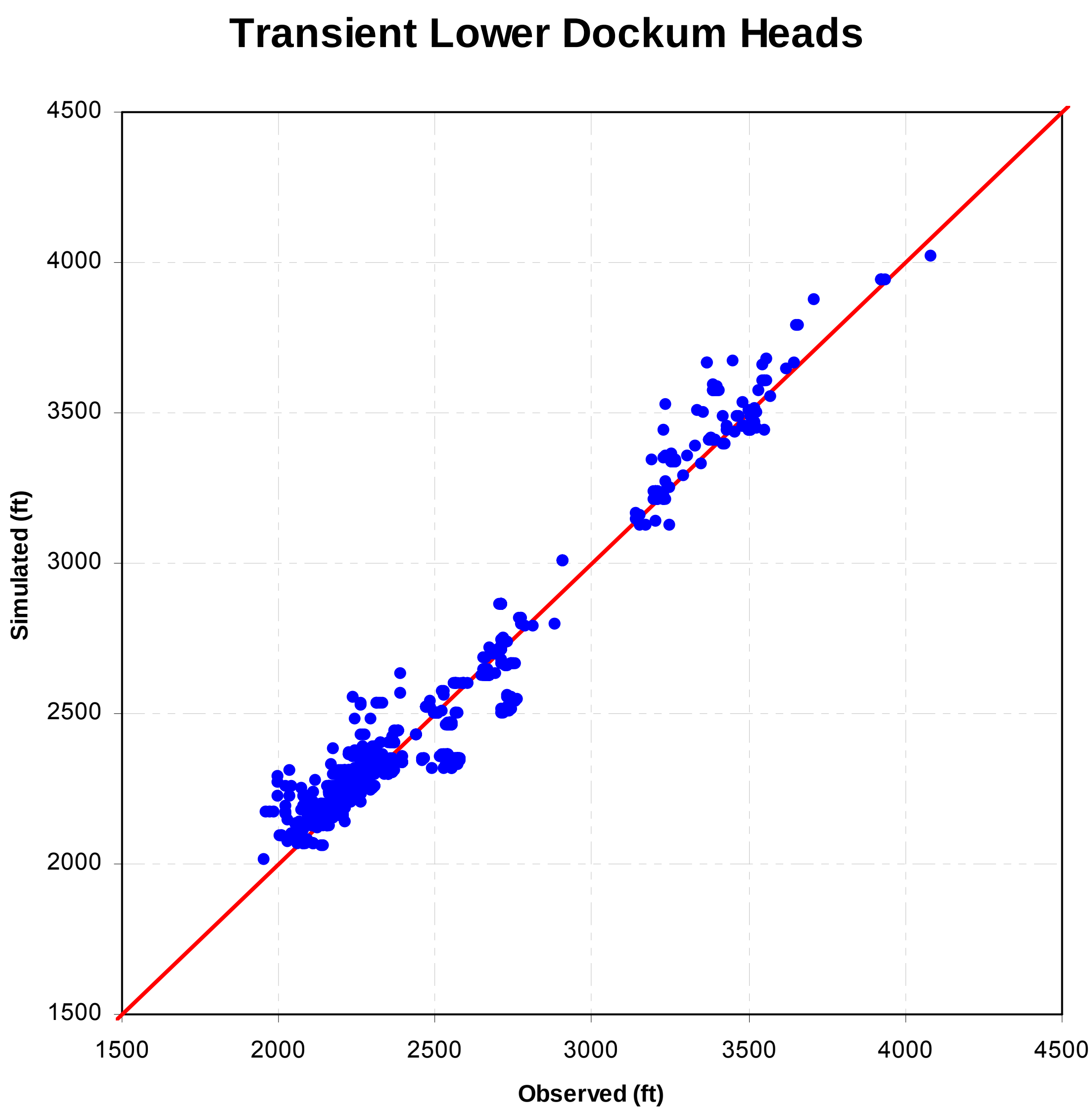


Upper Dockum Calibration – Transient



RMSE	80.3 ft
MAE	60.3 ft
ME	46.8 ft
Min E	-60.3 ft
Max E	164.0 ft
Range	2403.6 ft
RMSE/Range	3.34%
MAE/Range	2.51%
ME/Range	1.95%

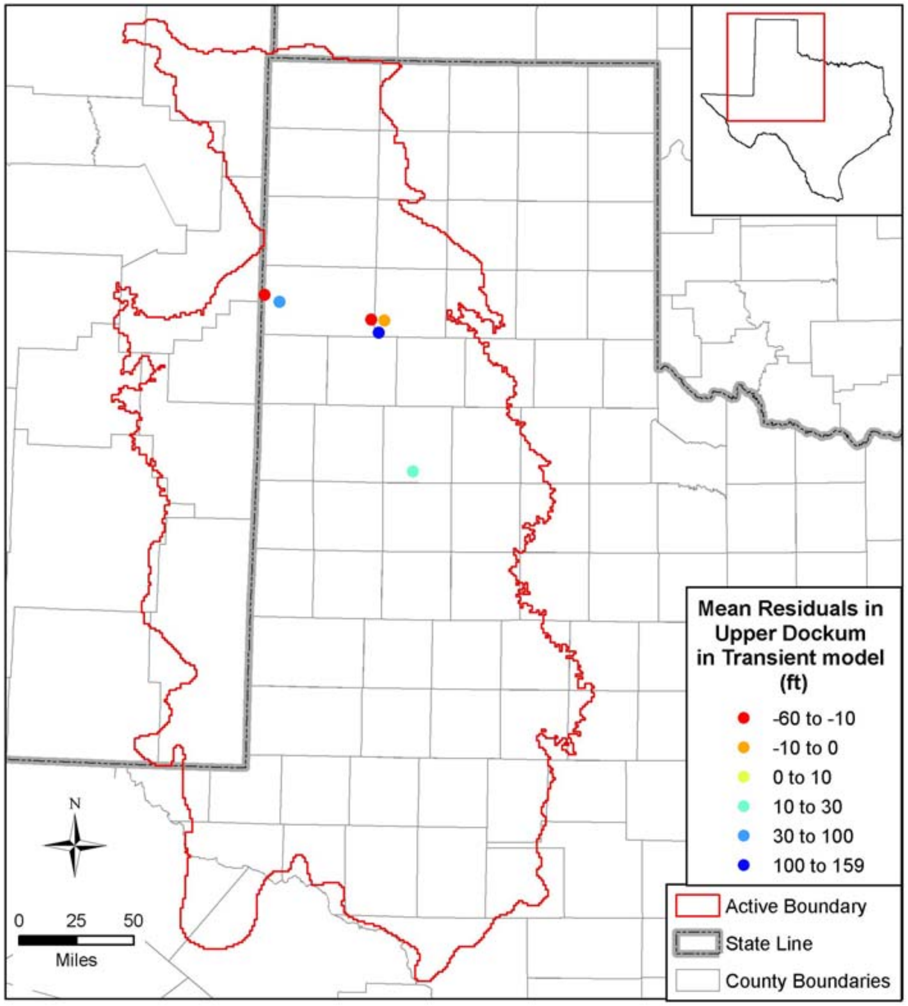
Lower Dockum Calibration – Transient



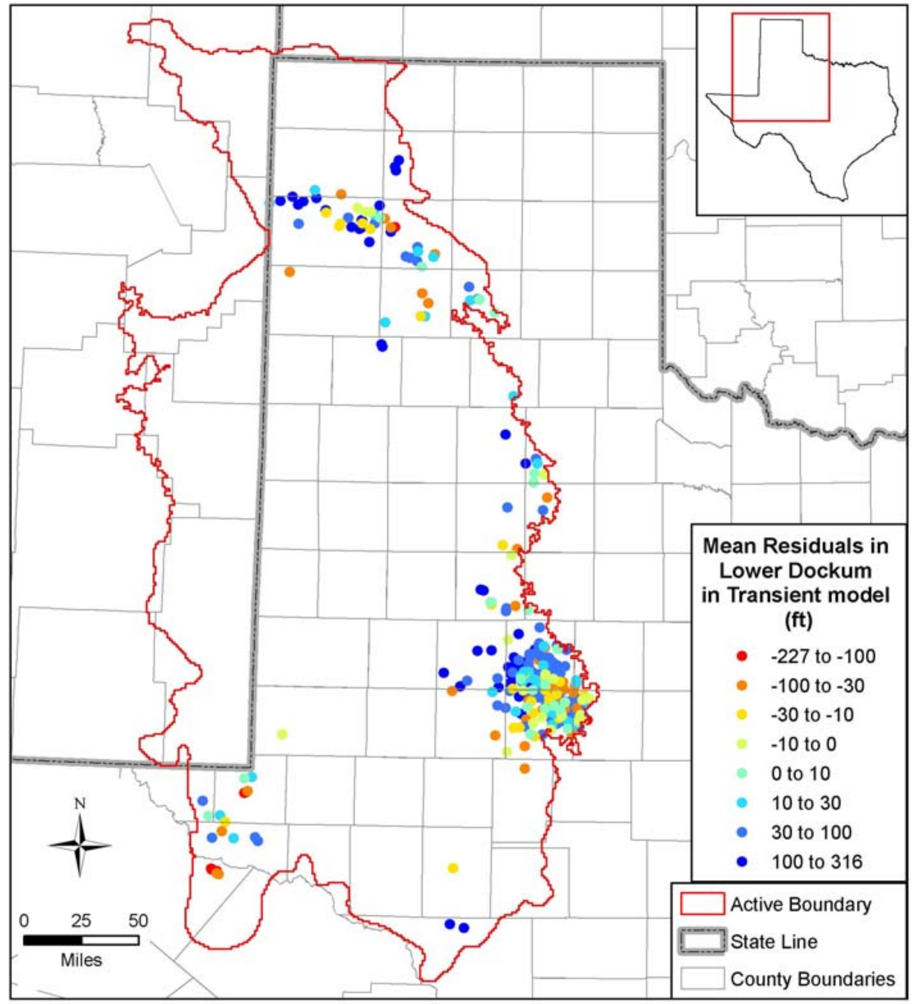
RMSE	94.3 ft
MAE	65.6 ft
ME	0.1 ft
Min E	-243.6 ft
Max E	316.2 ft
Range	2288.5 ft
RMSE/Range	4.12%
MAE/Range	2.87%
ME/Range	0.01%

Transient Mean Residuals in Dockum

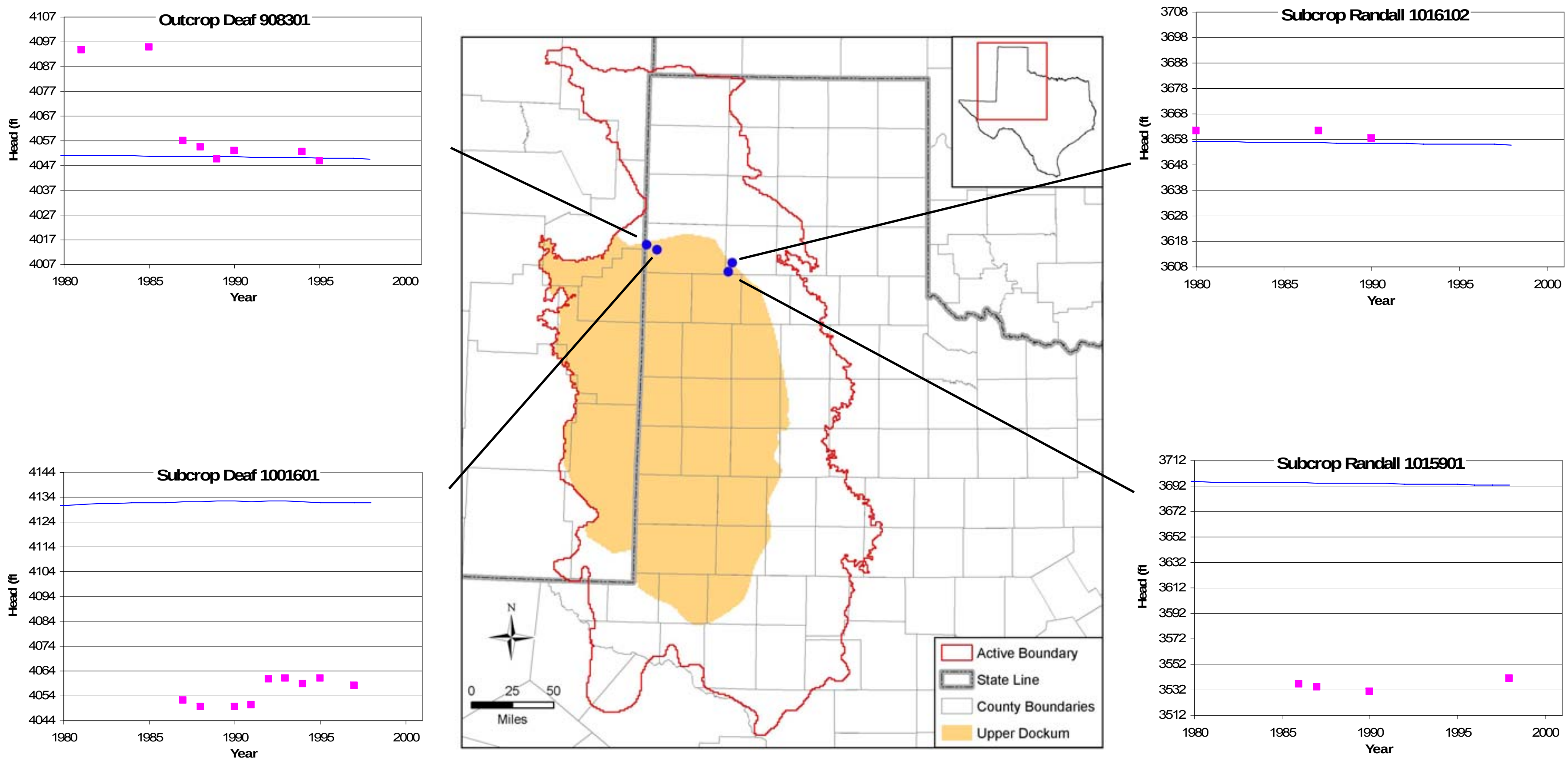
Upper Dockum



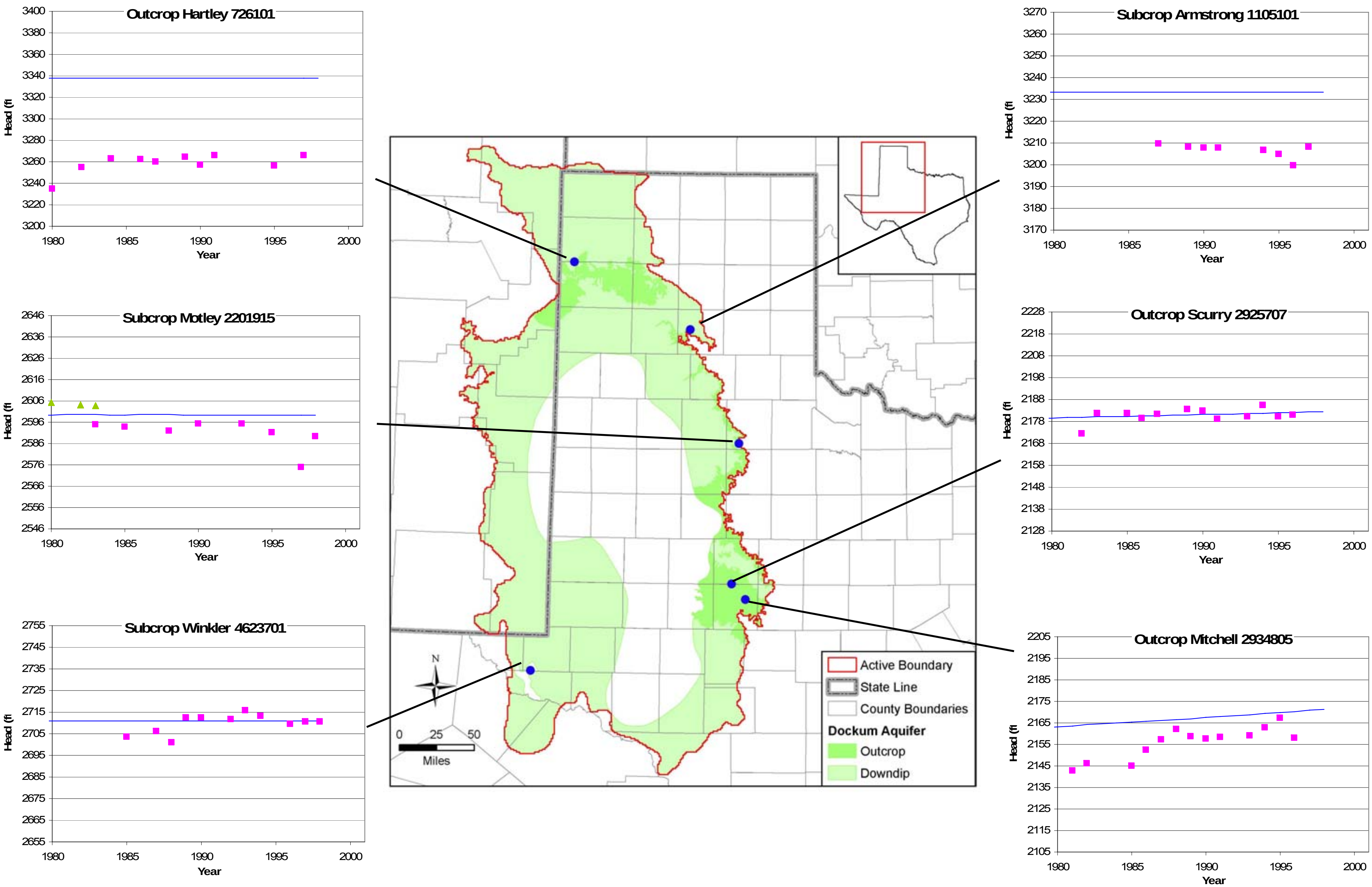
Lower Dockum



Upper Dockum Hydrographs

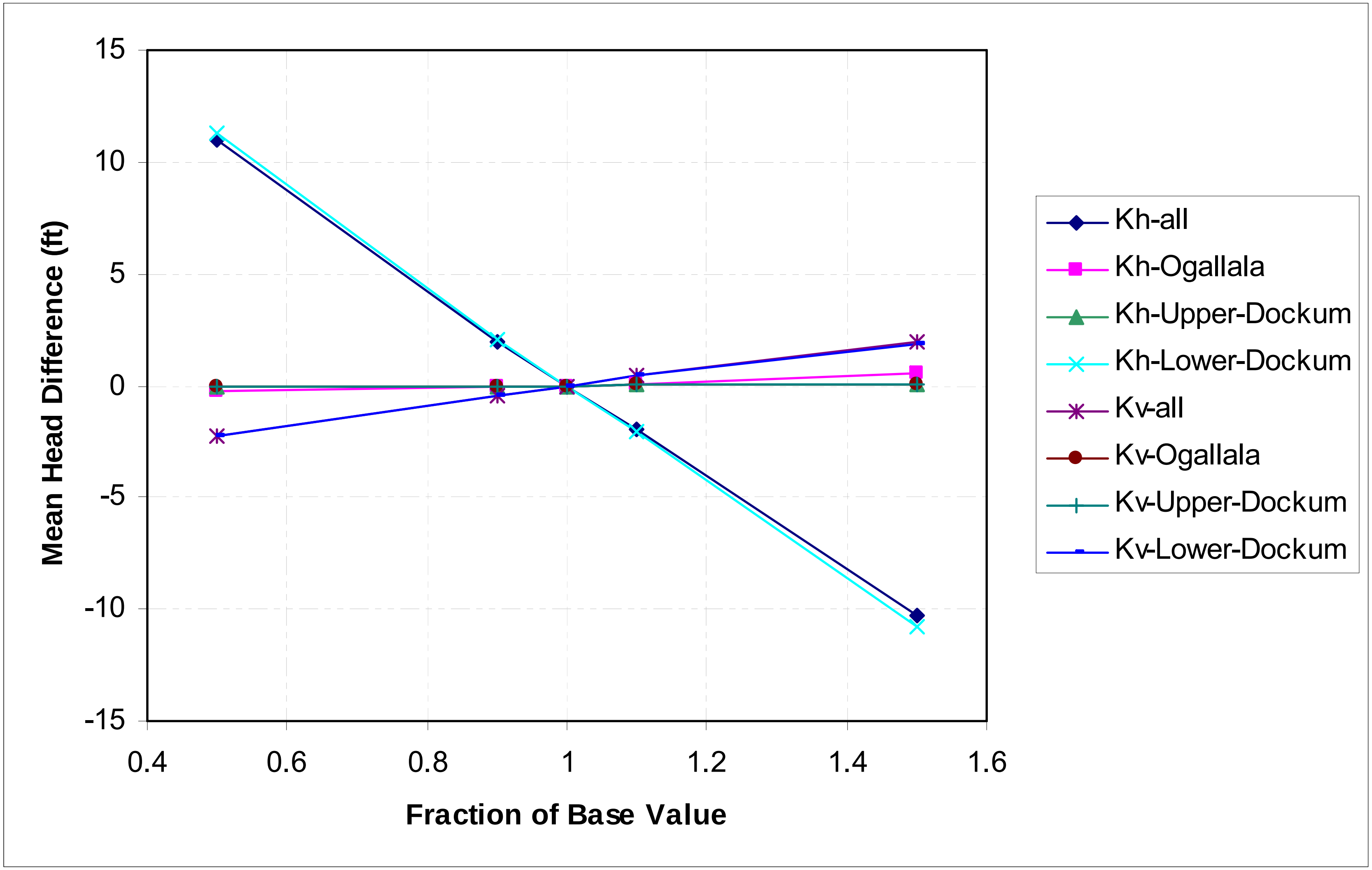


Lower Dockum Hydrographs



Sensitivity Analysis

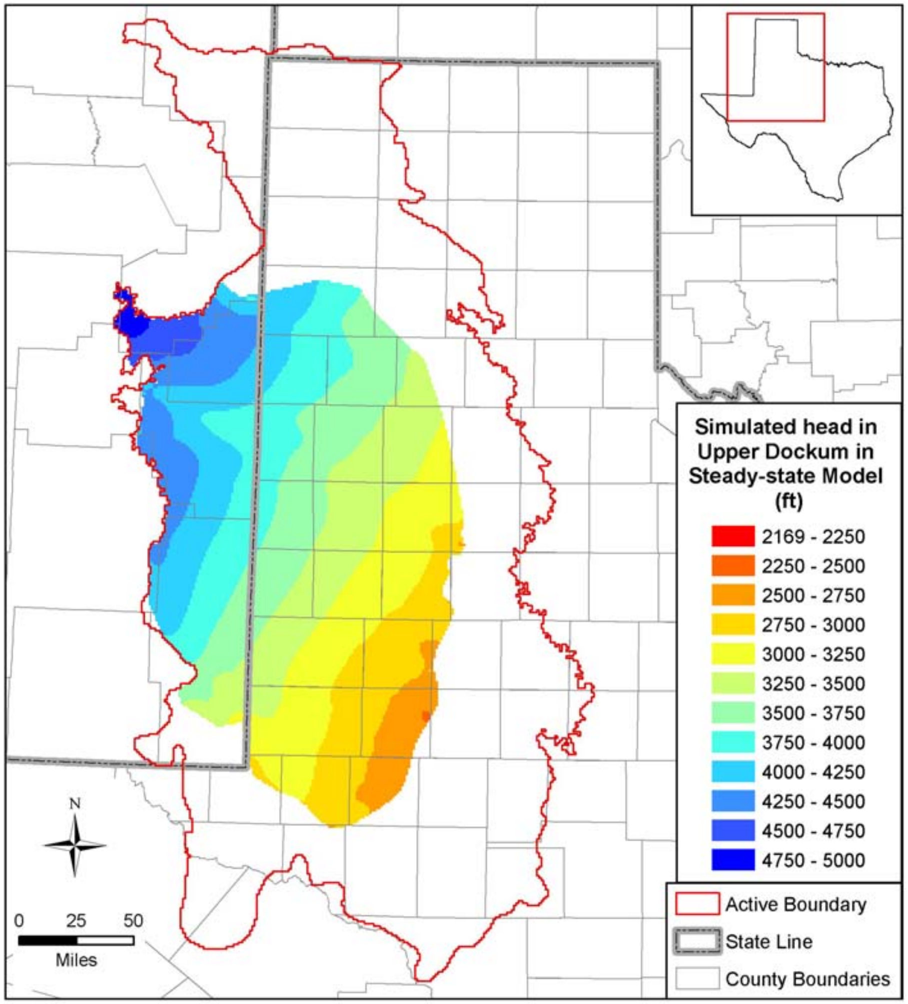
Example: Effect of Hydraulic Parameters on Lower Dockum Heads



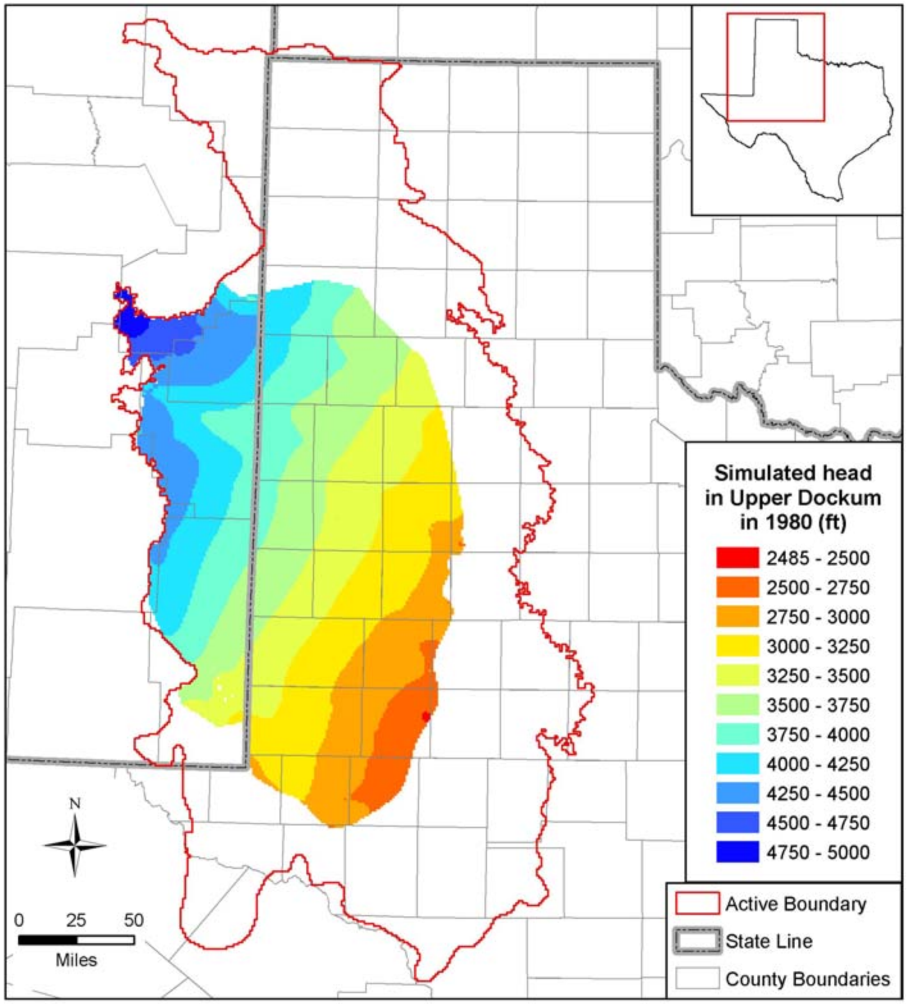
Transient Model Results

Simulated Head in Upper Dockum

Predevelopment

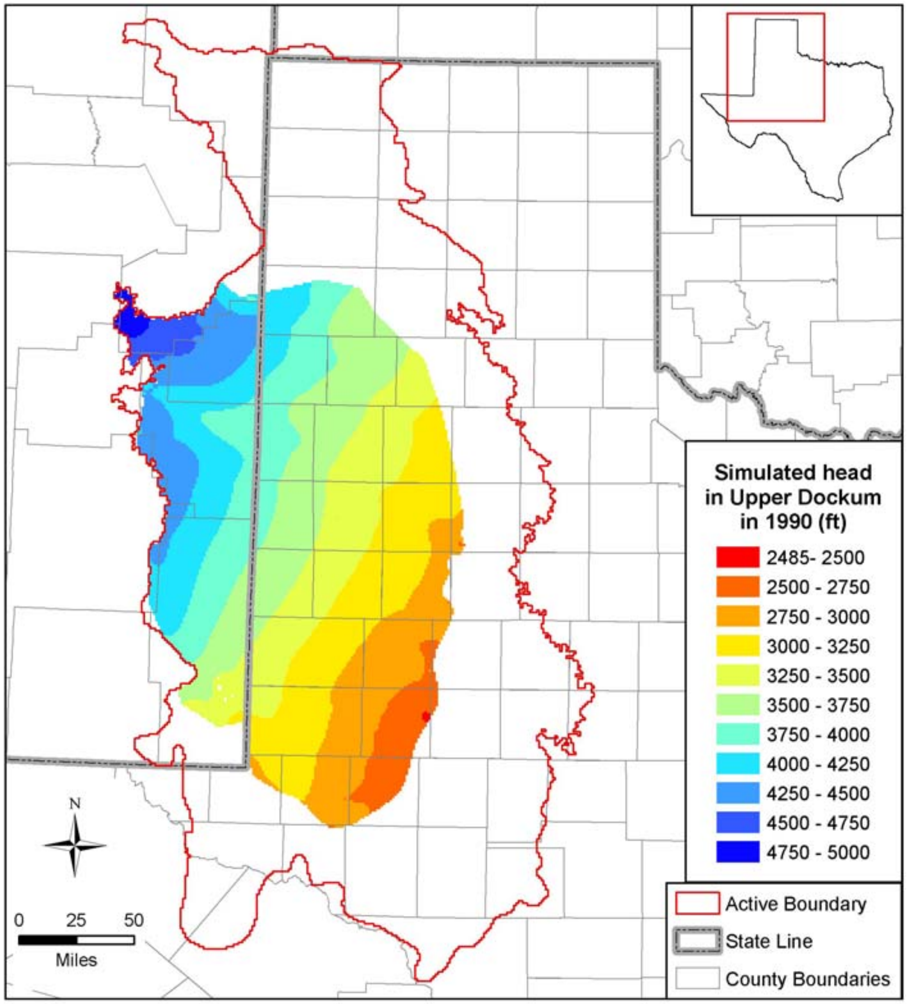


1980

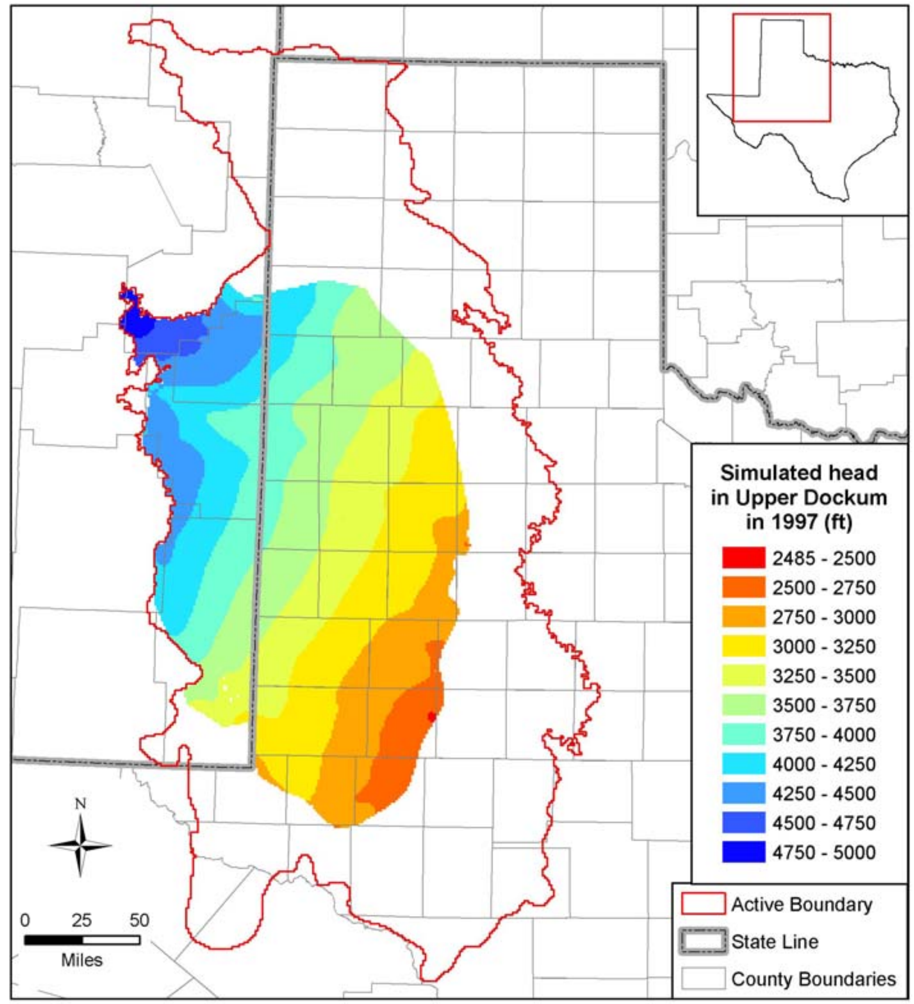


Simulated Head in Upper Dockum

1990

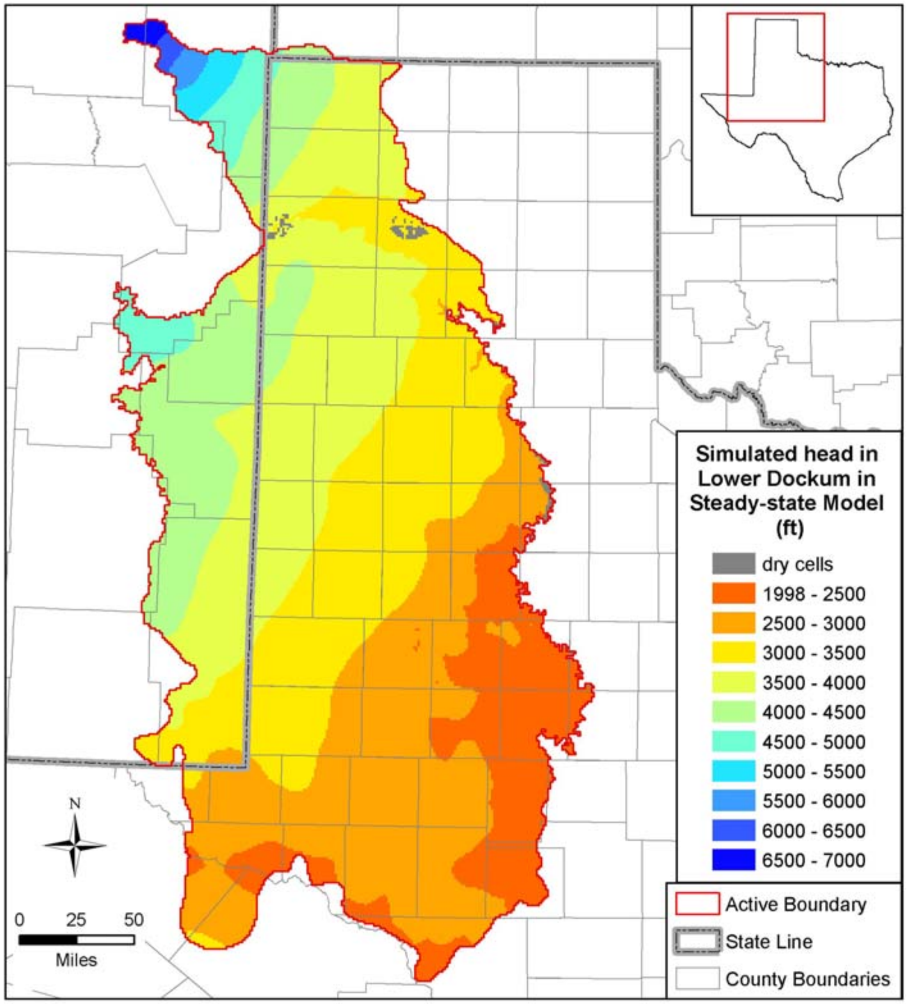


1997

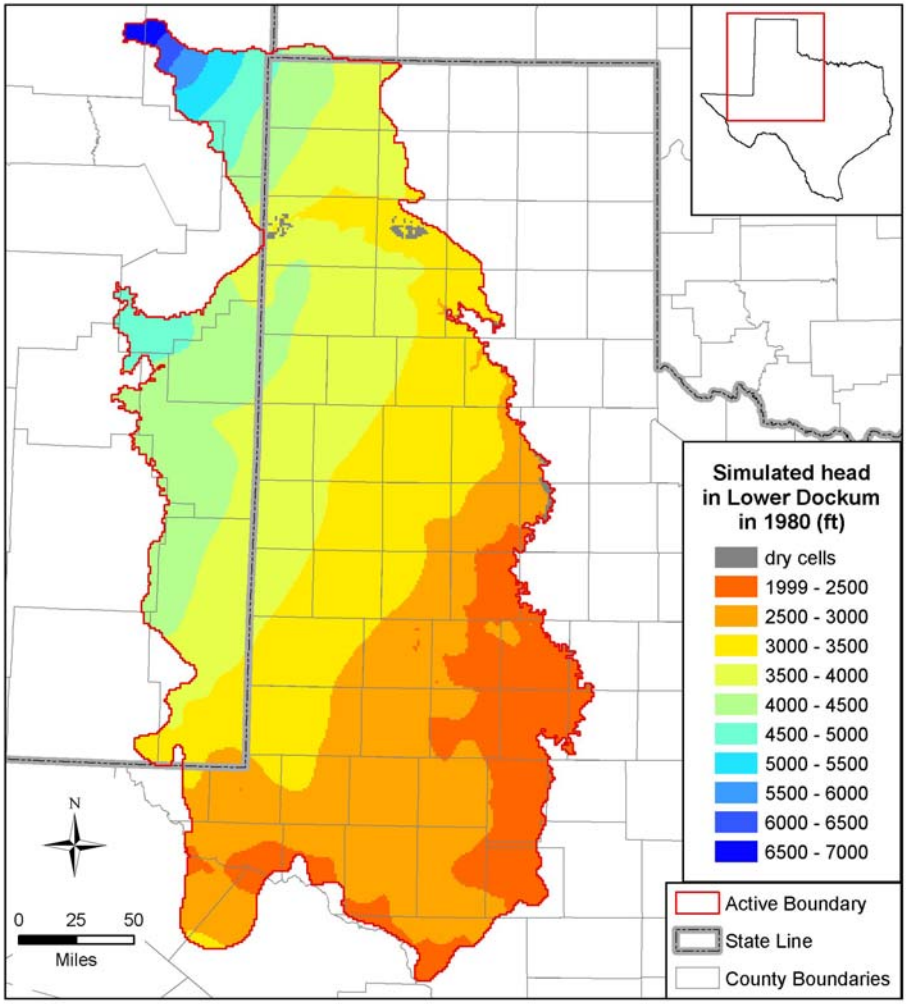


Simulated Head in Lower Dockum

Predevelopment

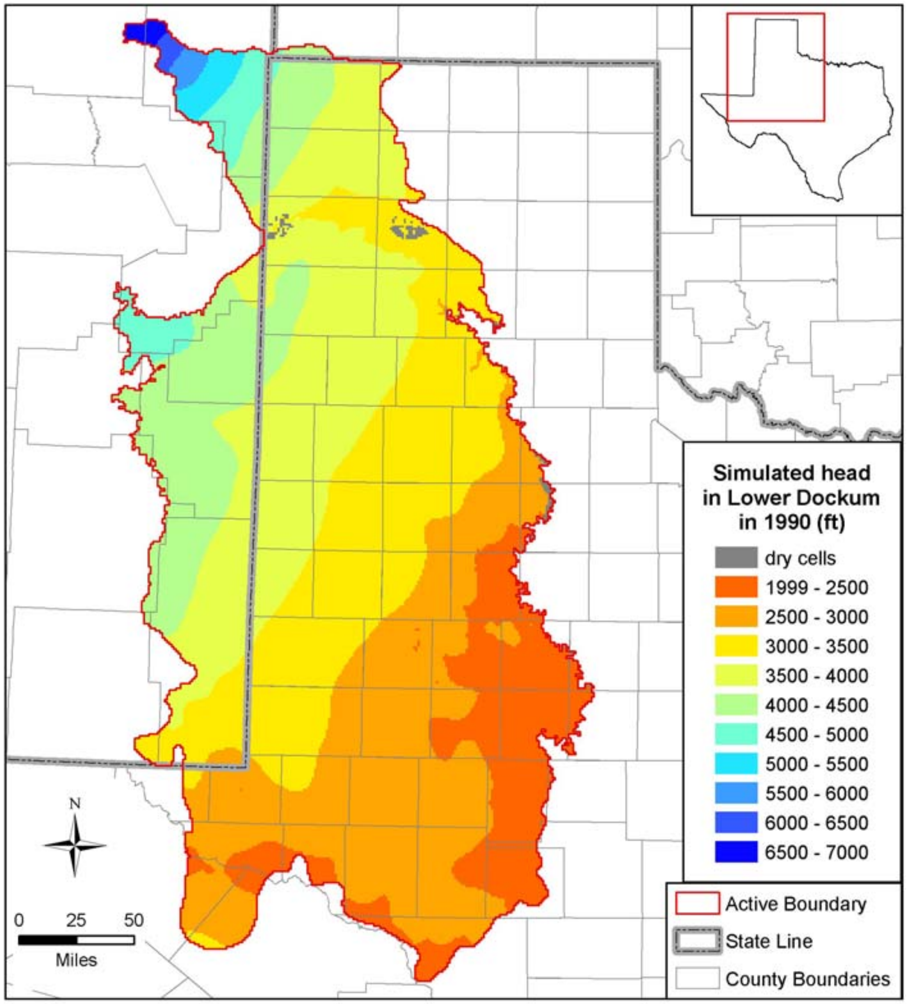


1980

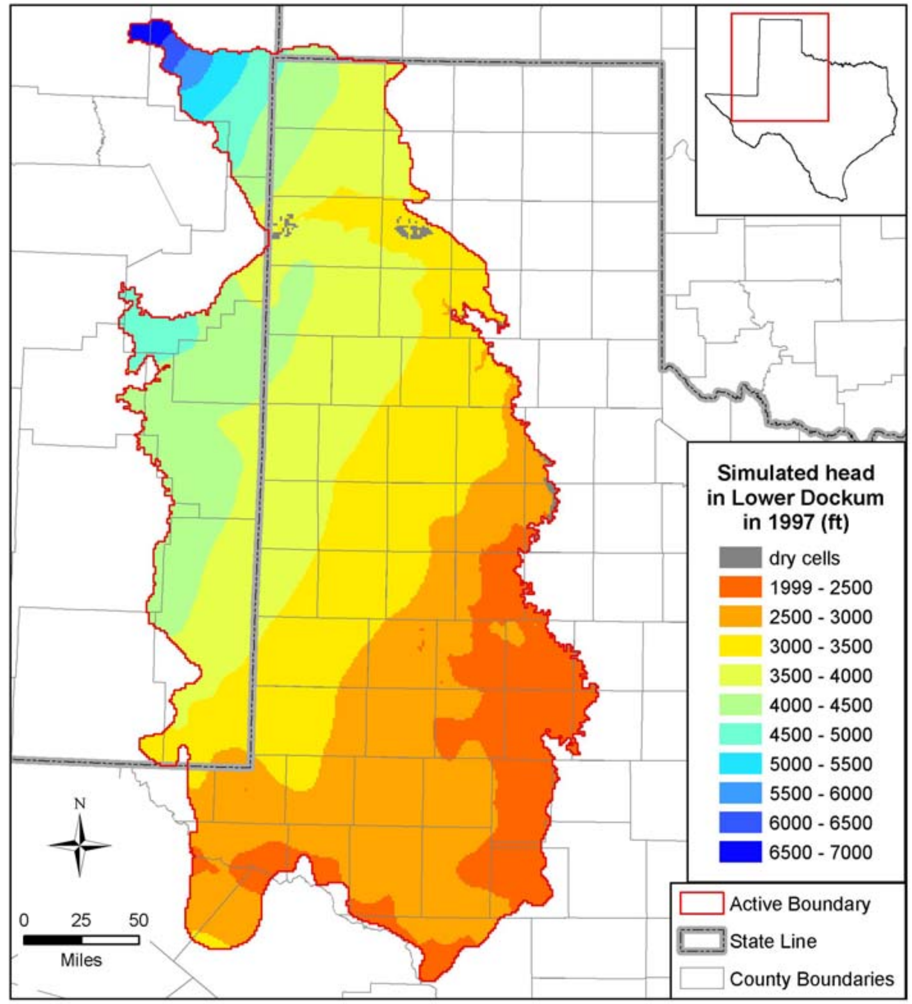


Simulated Head in Lower Dockum

1990

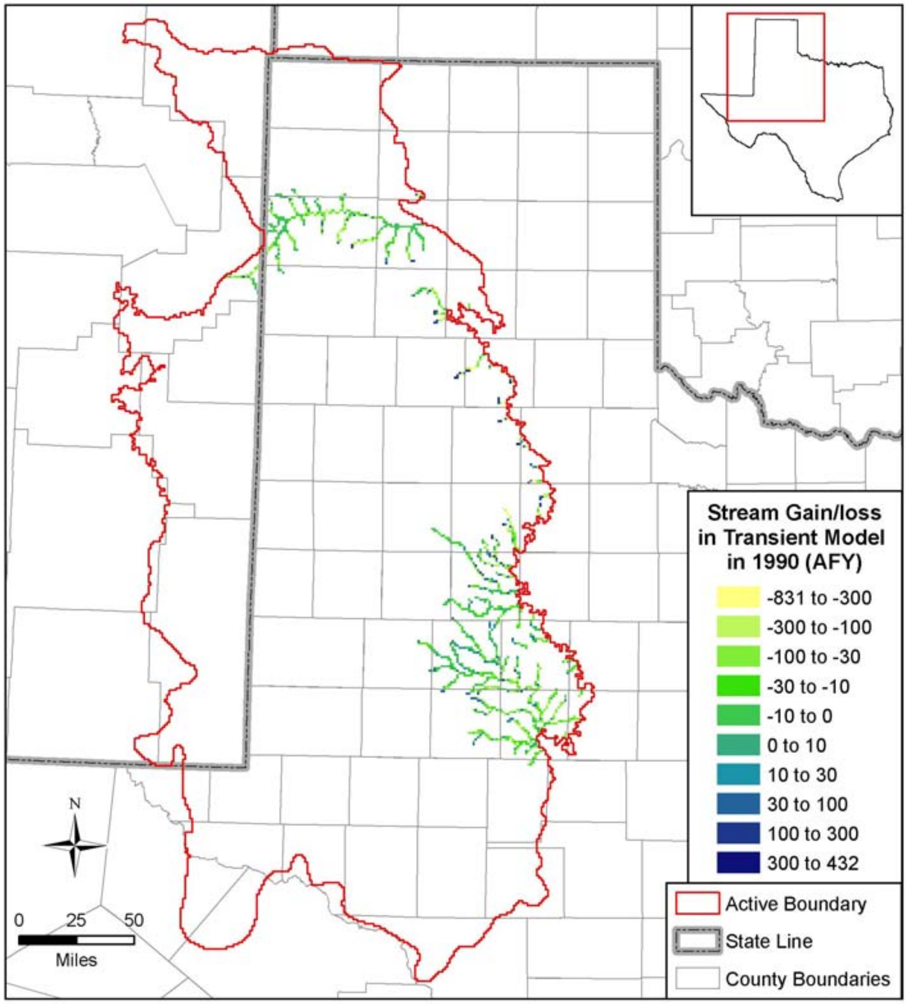


1997

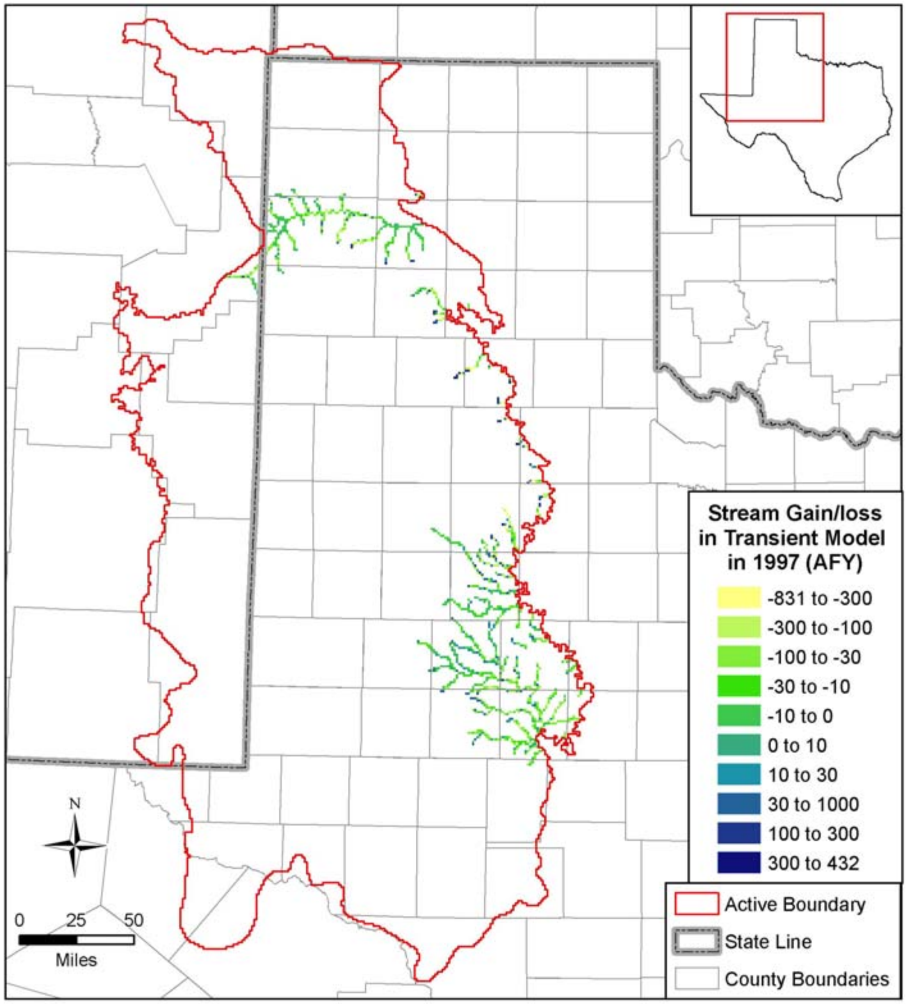


Stream Gain/loss

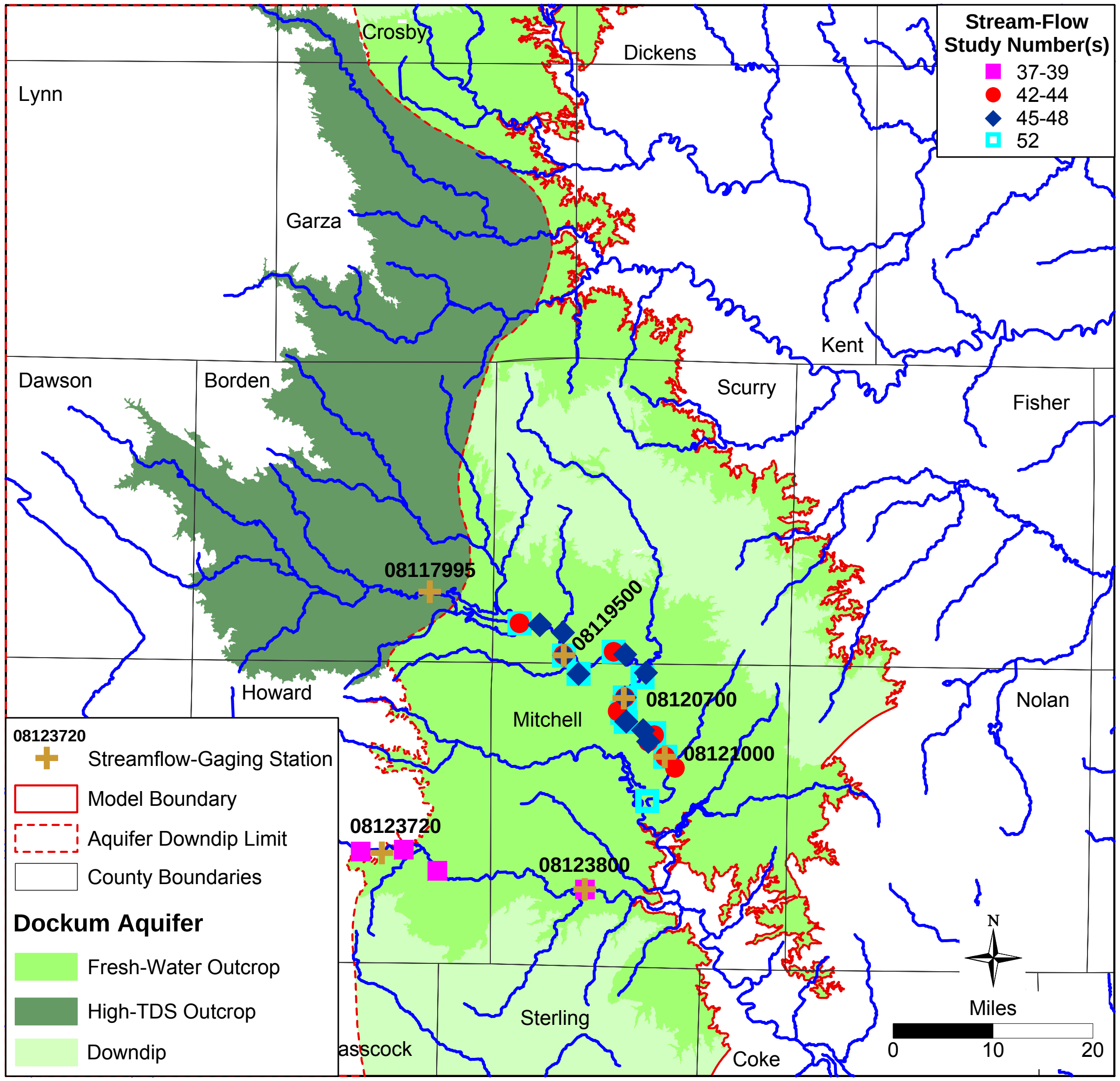
1990



1997

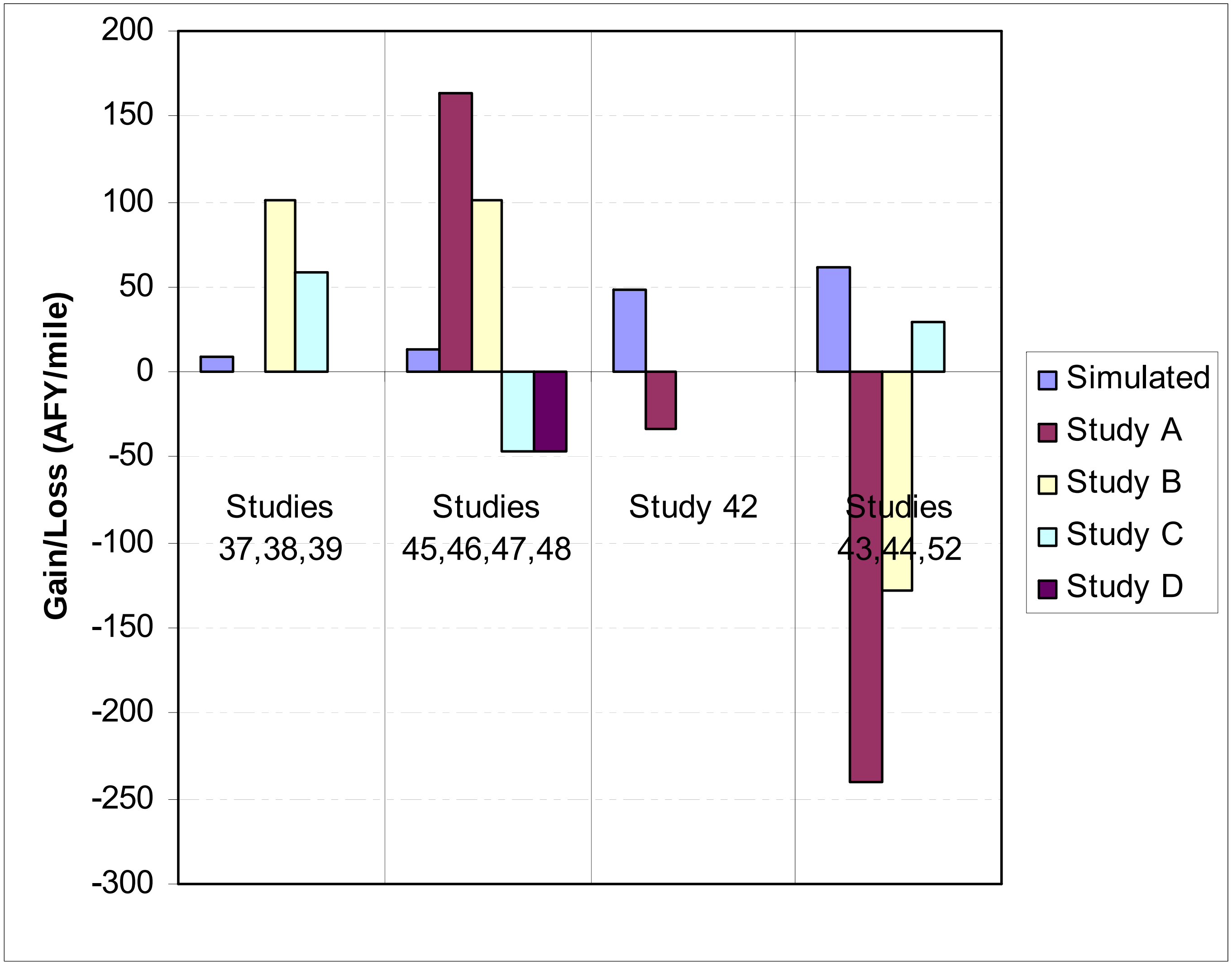


Streams and Rivers – Gain/Loss Studies



Slade et al., (2002)

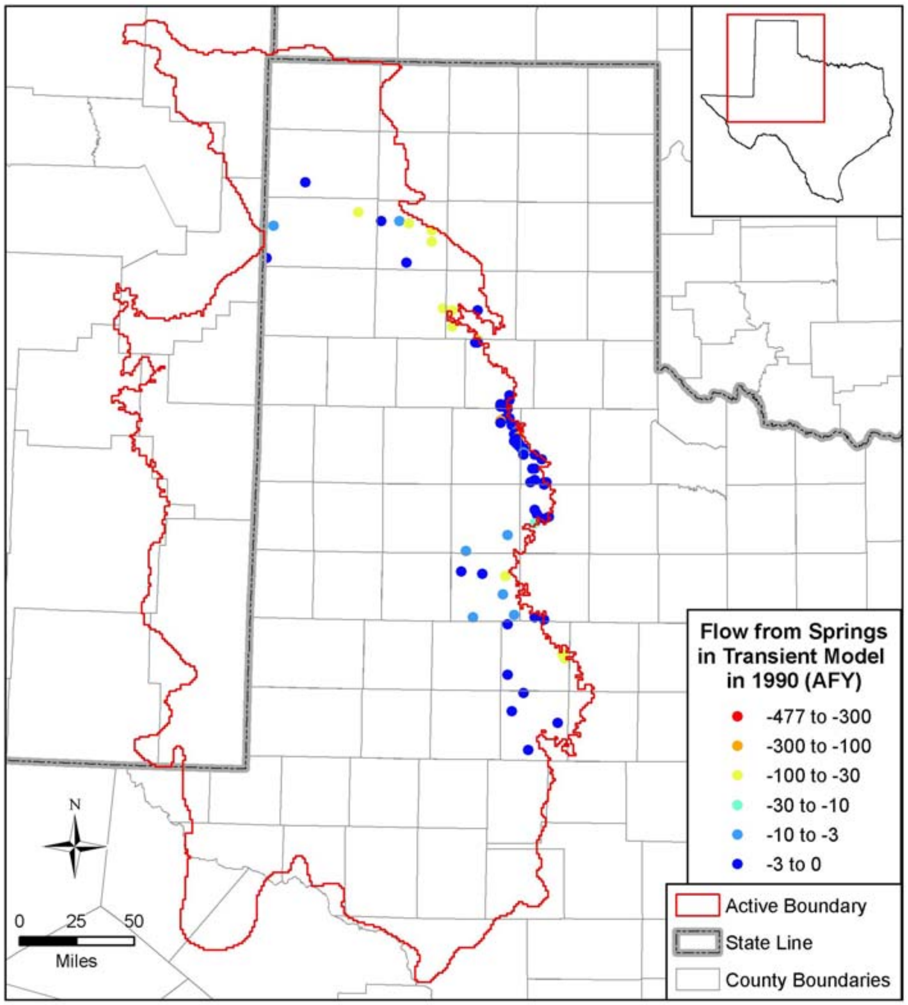
Simulated vs. Observed Stream Gain/Loss



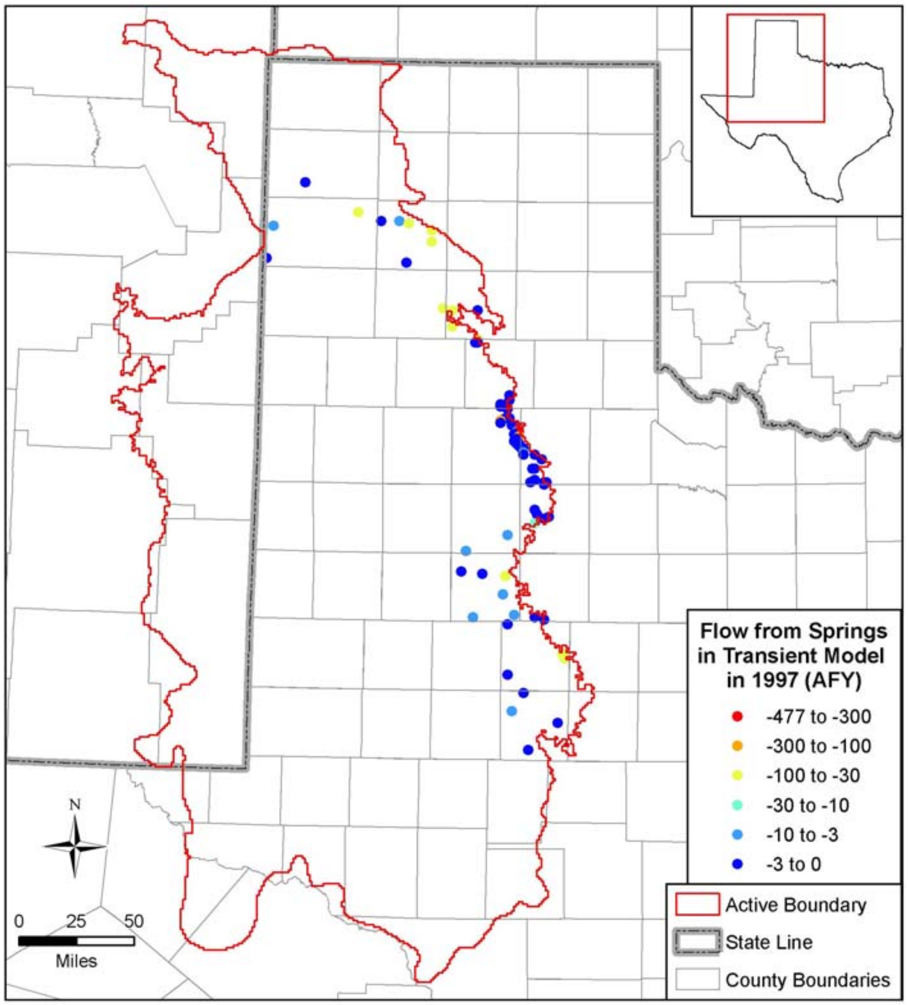
Note: positive denotes gain and negative denotes loss

Spring Flow

1990



1997

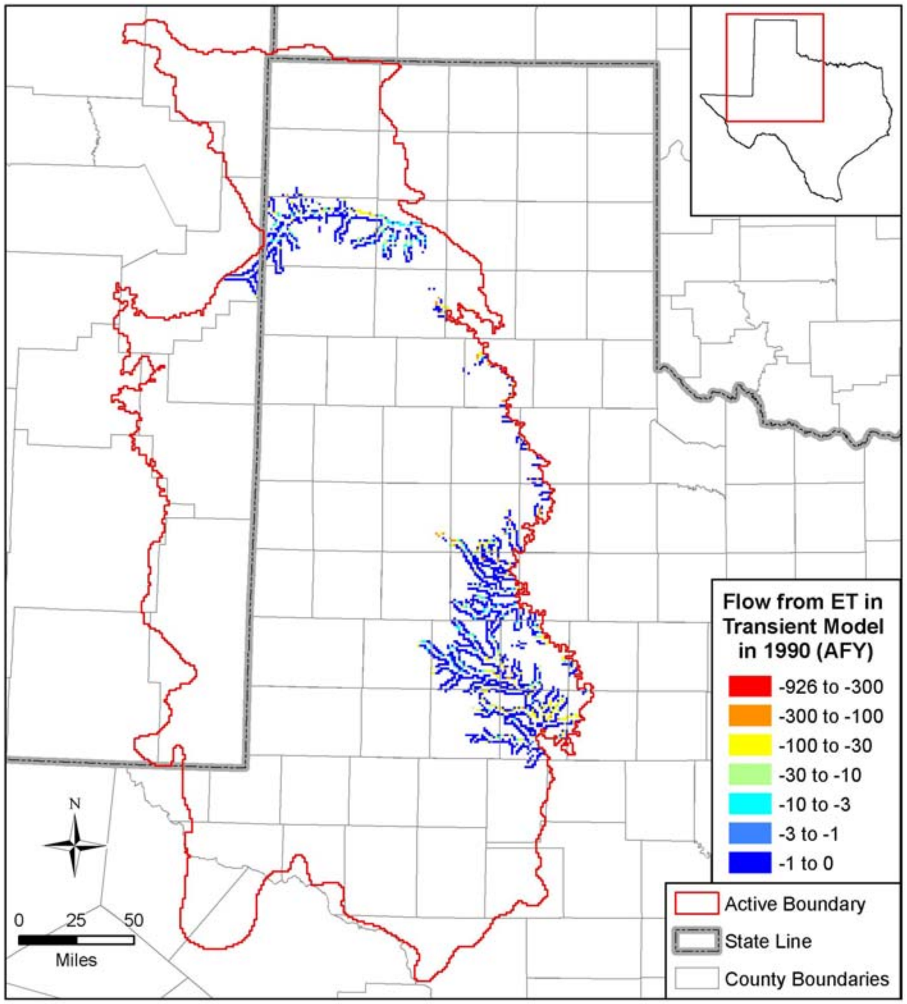


Spring Issues

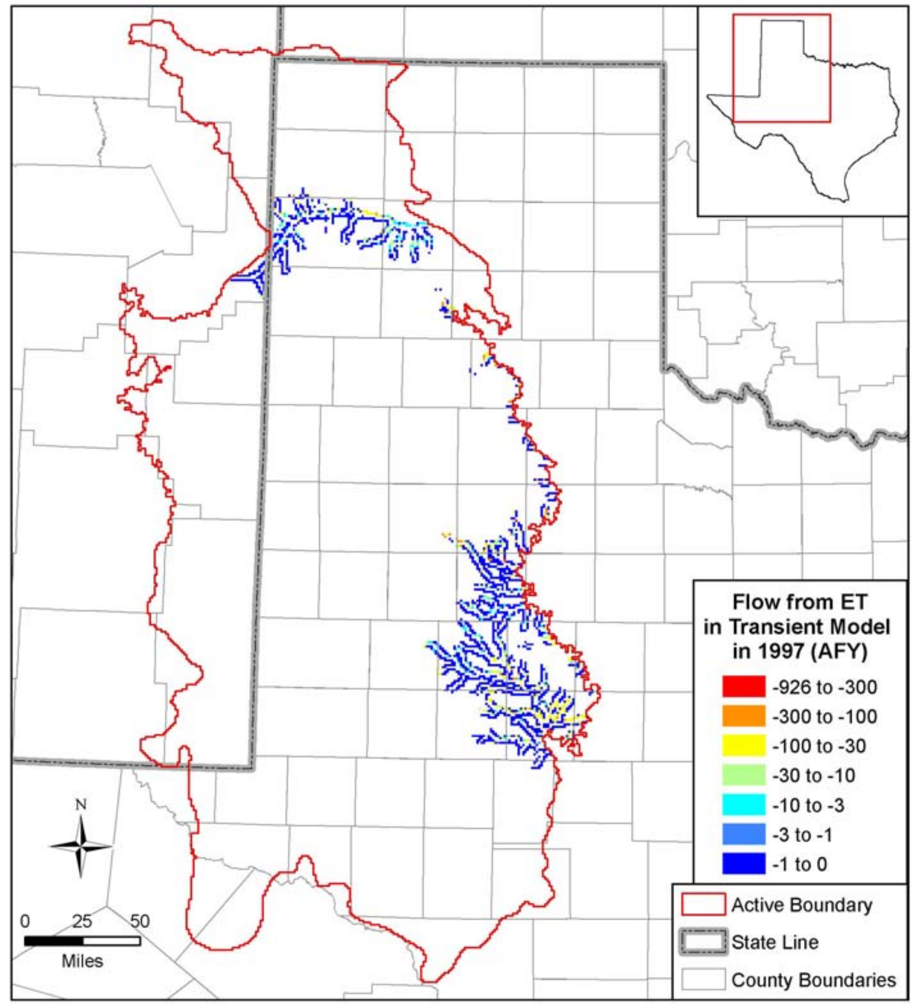
- Many springs exhibit flow, however, some larger flows cannot be matched
- Lowering spring elevation or increasing conductance does not alleviate problem for larger springs
- Water is not being thieved by ET or streams
- Model inflows from recharge and from overlying younger units are consistent with the conceptual model
- Springs may be fed by high K seams/channels that are sub model-scale and cannot be simulated

ET Flow

1990



1997

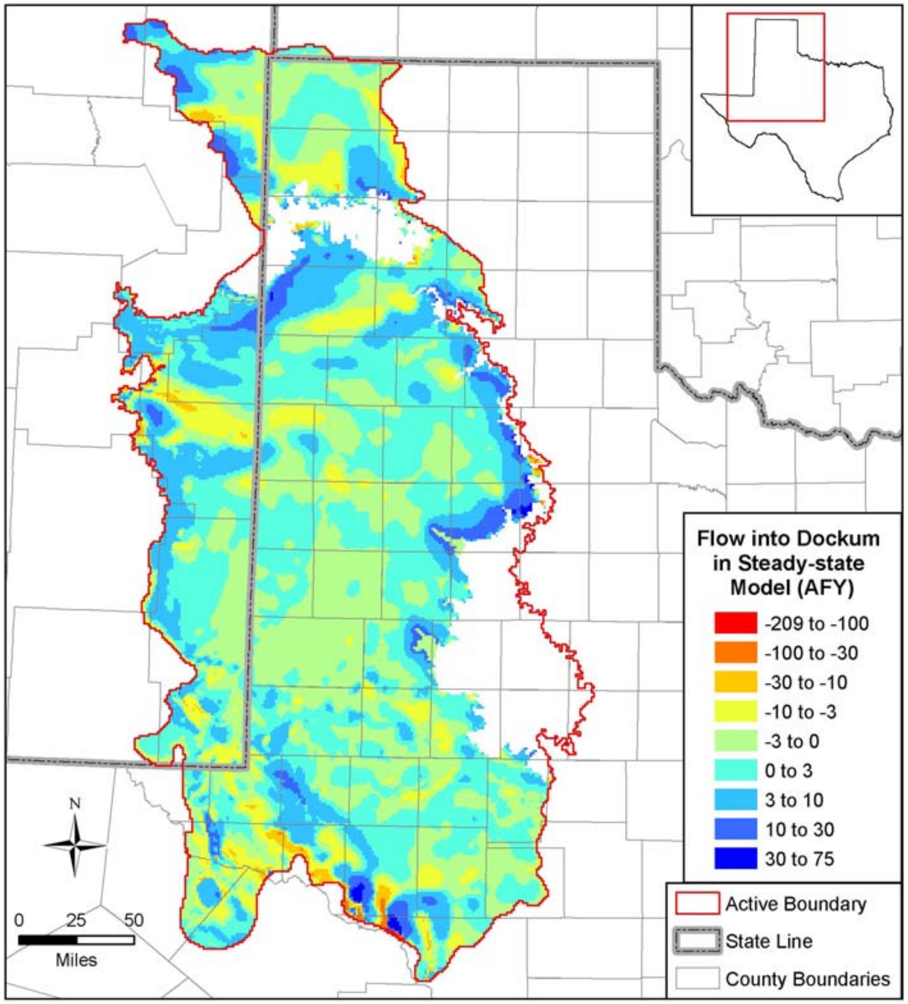


ET Issues

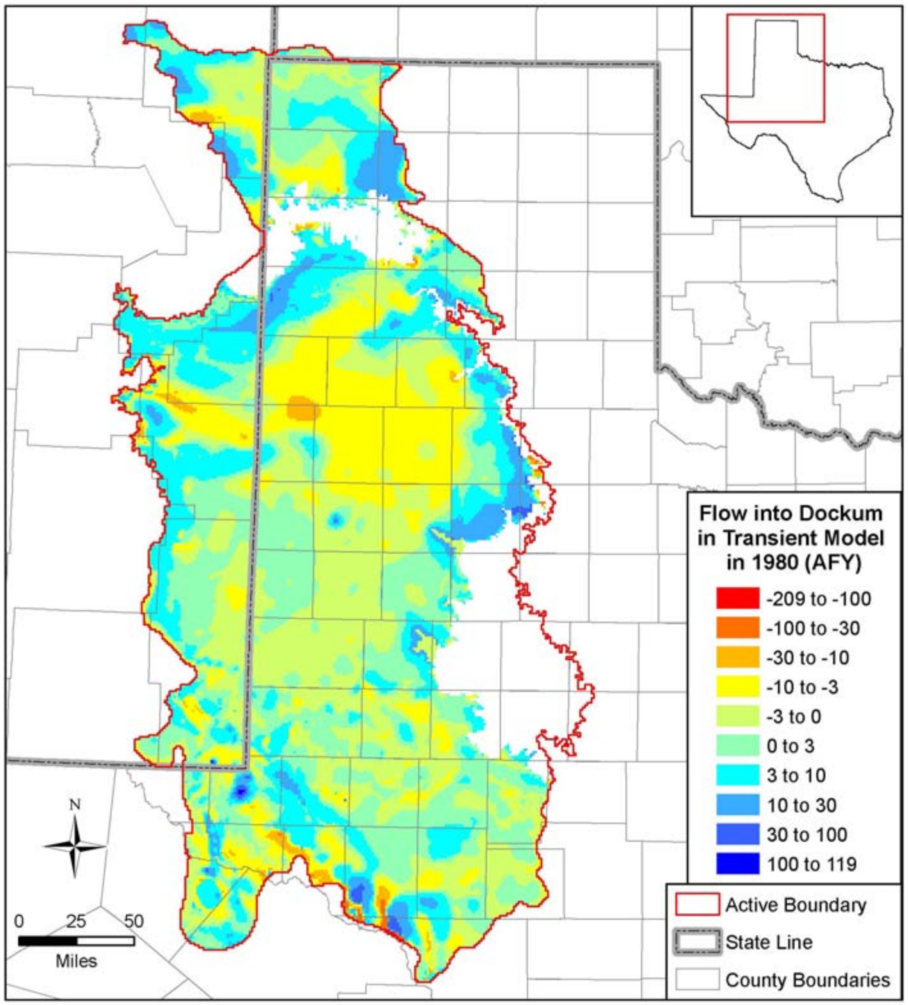
- Calculated ET_{max} ranged from 32 to 52 in/yr
- With very large ET drain conductances, a maximum of 18 in/yr was simulated and generally much less
- ET flow is insensitive to drain conductance
- The Dockum formation is the limiter to ET flows
- The solver cannot handle relatively large rates being drawn from ET cells
  - Cells dry out
  - Rewet option is invoked resulting in convergence issues

Flow into Top of Dockum

Predevelopment

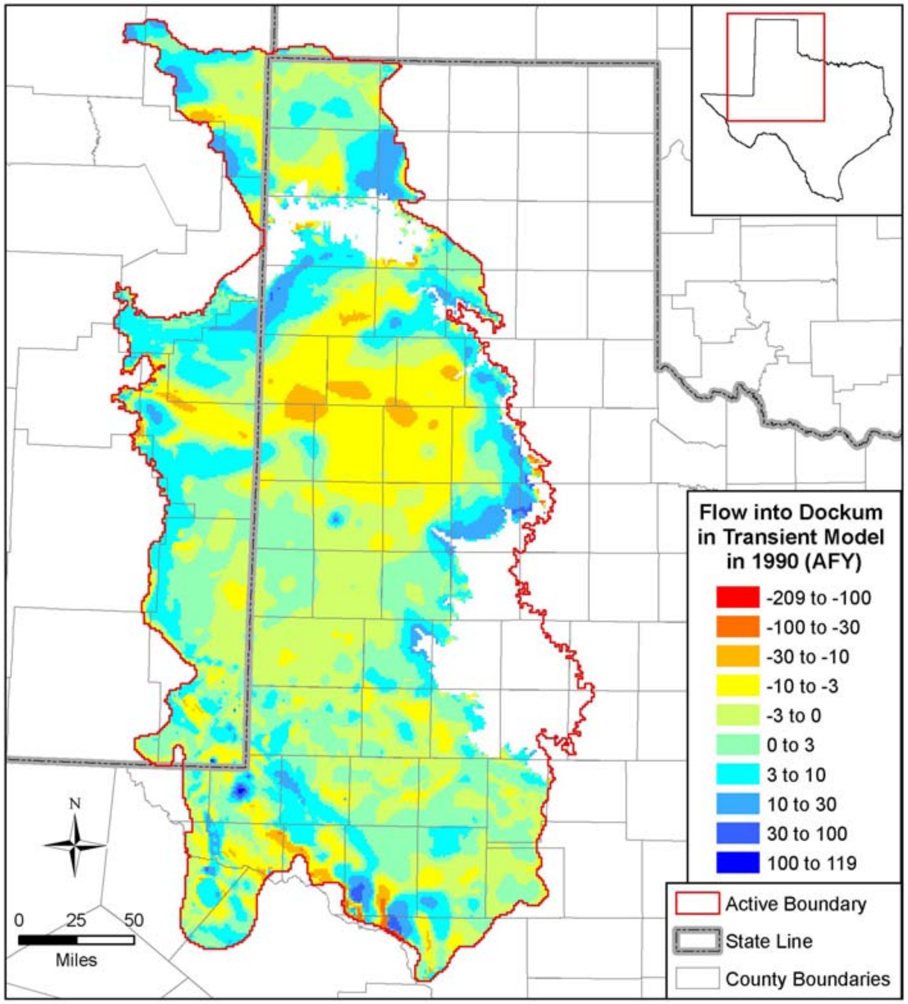


1980

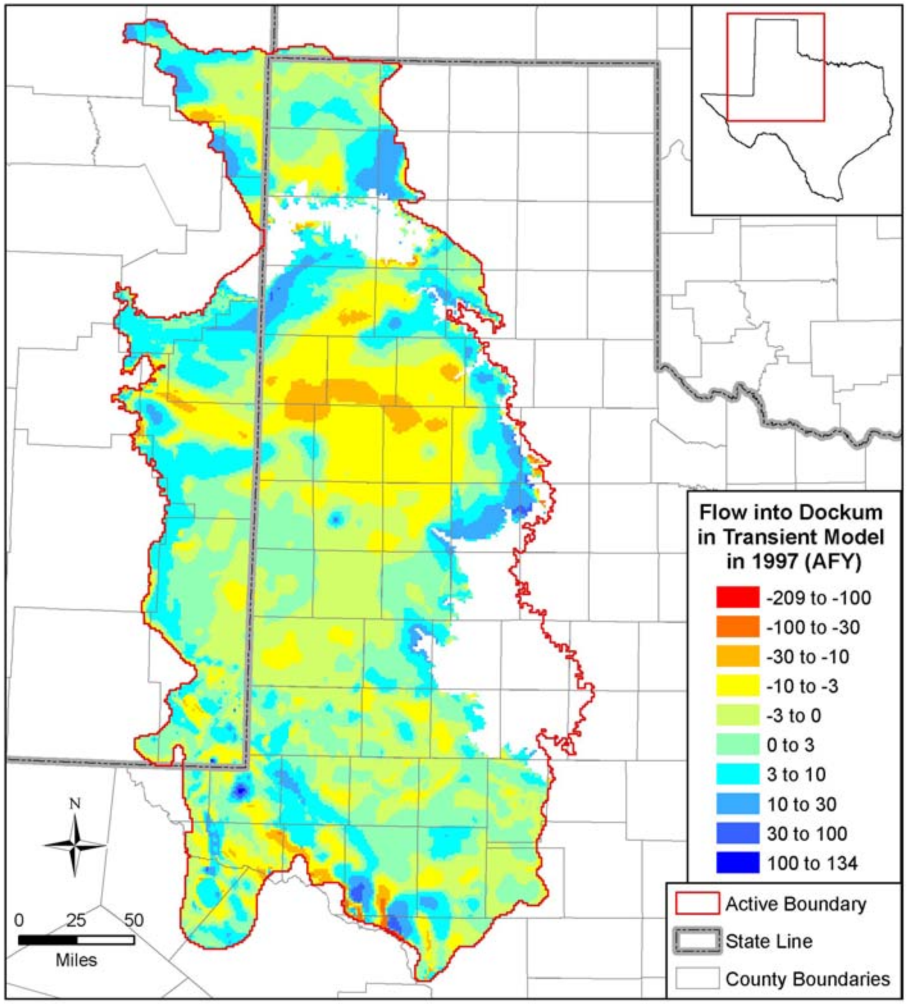


Flow into Top of Dockum

1990

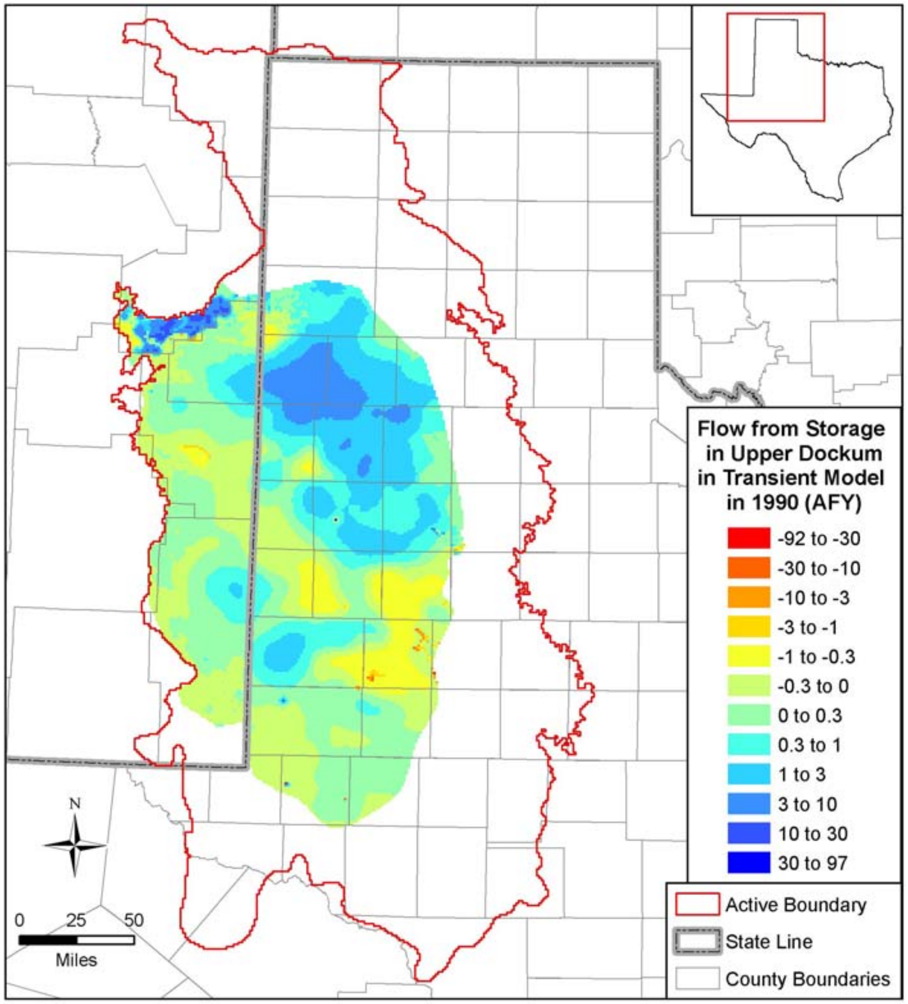


1997

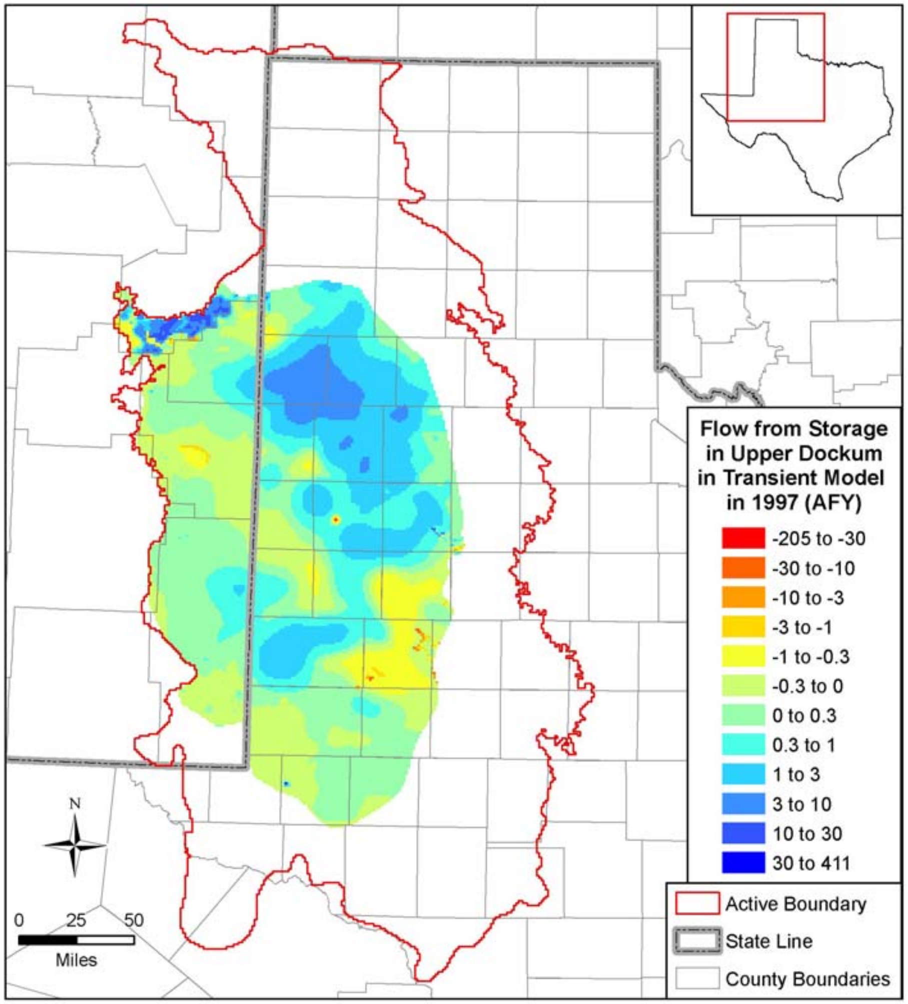


Flow from Storage in Upper Dockum

1990

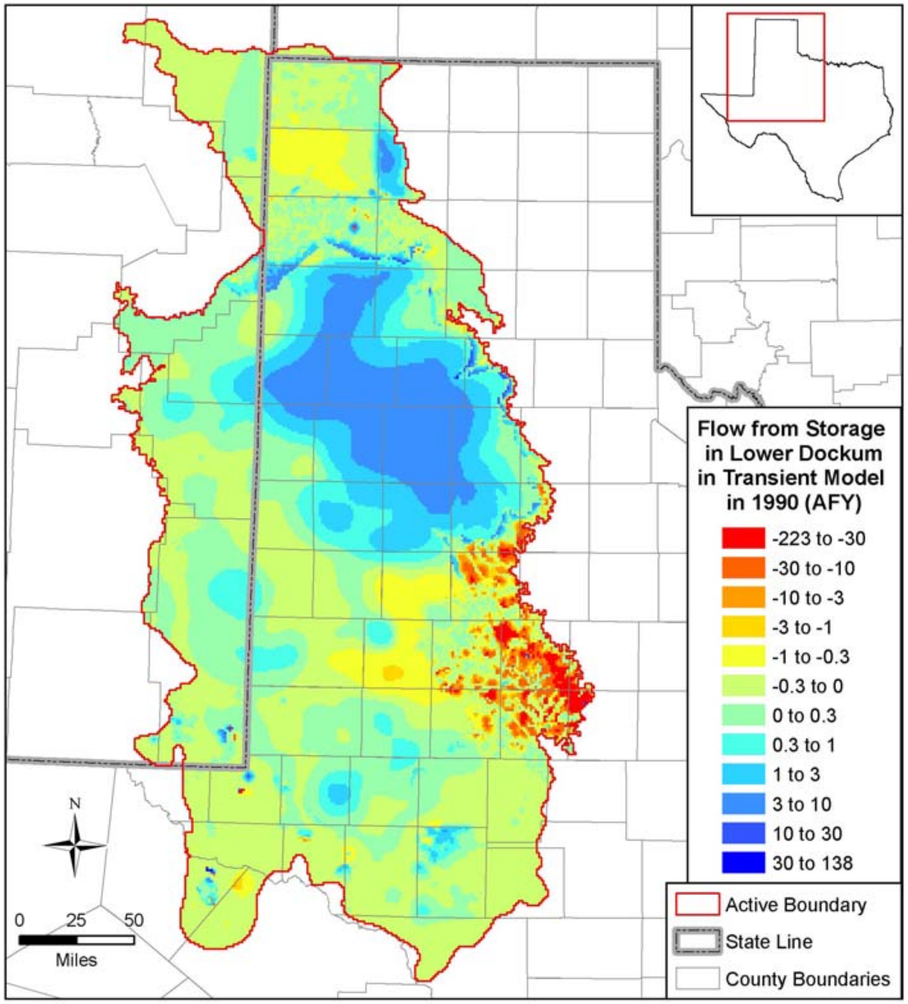


1997

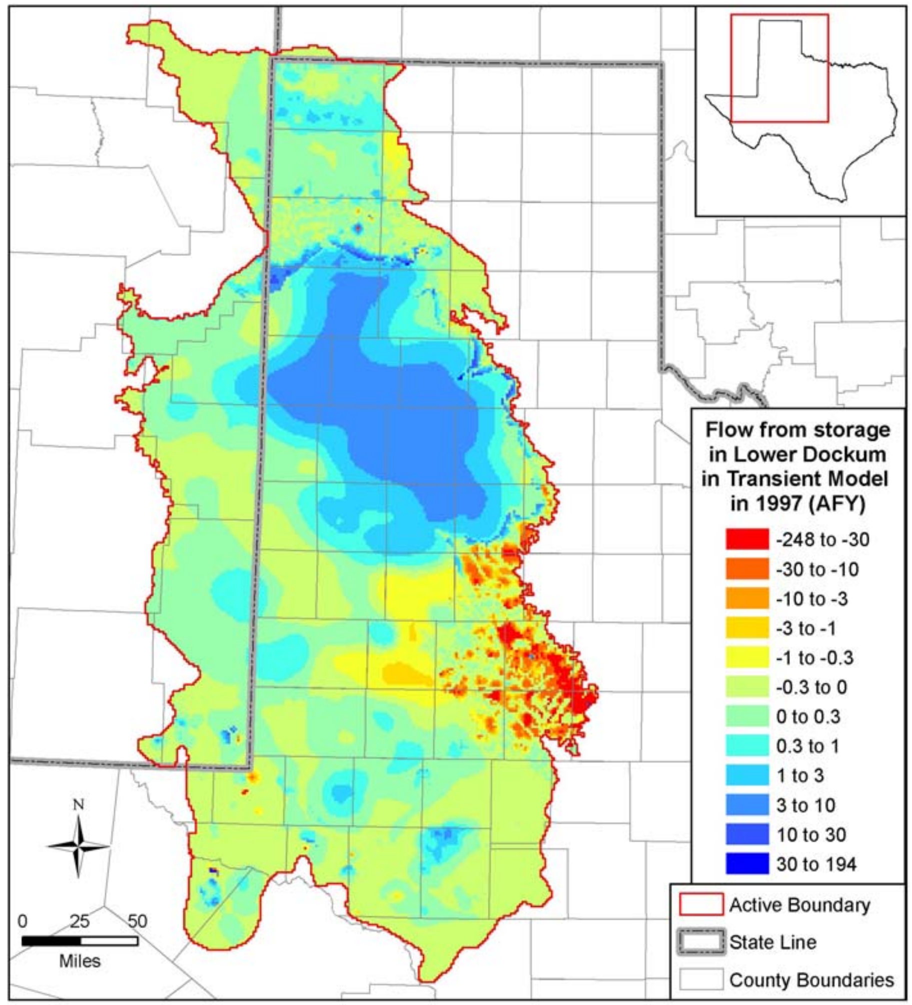


Flow from Storage in Lower Dockum

1990



1997



Dockum Mass Balance – pre-D & 1980

pre-development		Inflow (AFY)	Outflow (AFY)	Net (AFY)	
Recharge		24,837	0	24,837	← 0.17 in/yr
X-Formational	Upper	38,617	18,596	20,020	← 0.015 in/yr
X-Formational	Lower	57,601	33,921	23,680	← 0.020 in/yr
Streams		10,633	39,690	-29,056	
Springs		0	1,446	-1,446	
Evapotranspiration		0	38,044	-38,044	
Wells	Upper	0	0	0	
Wells	Lower	0	0	0	
Storage	Upper	0	0	0	
Storage	Lower	0	0	0	
Total		131,688	131,697	-9	
Discrepancy				-0.01%	

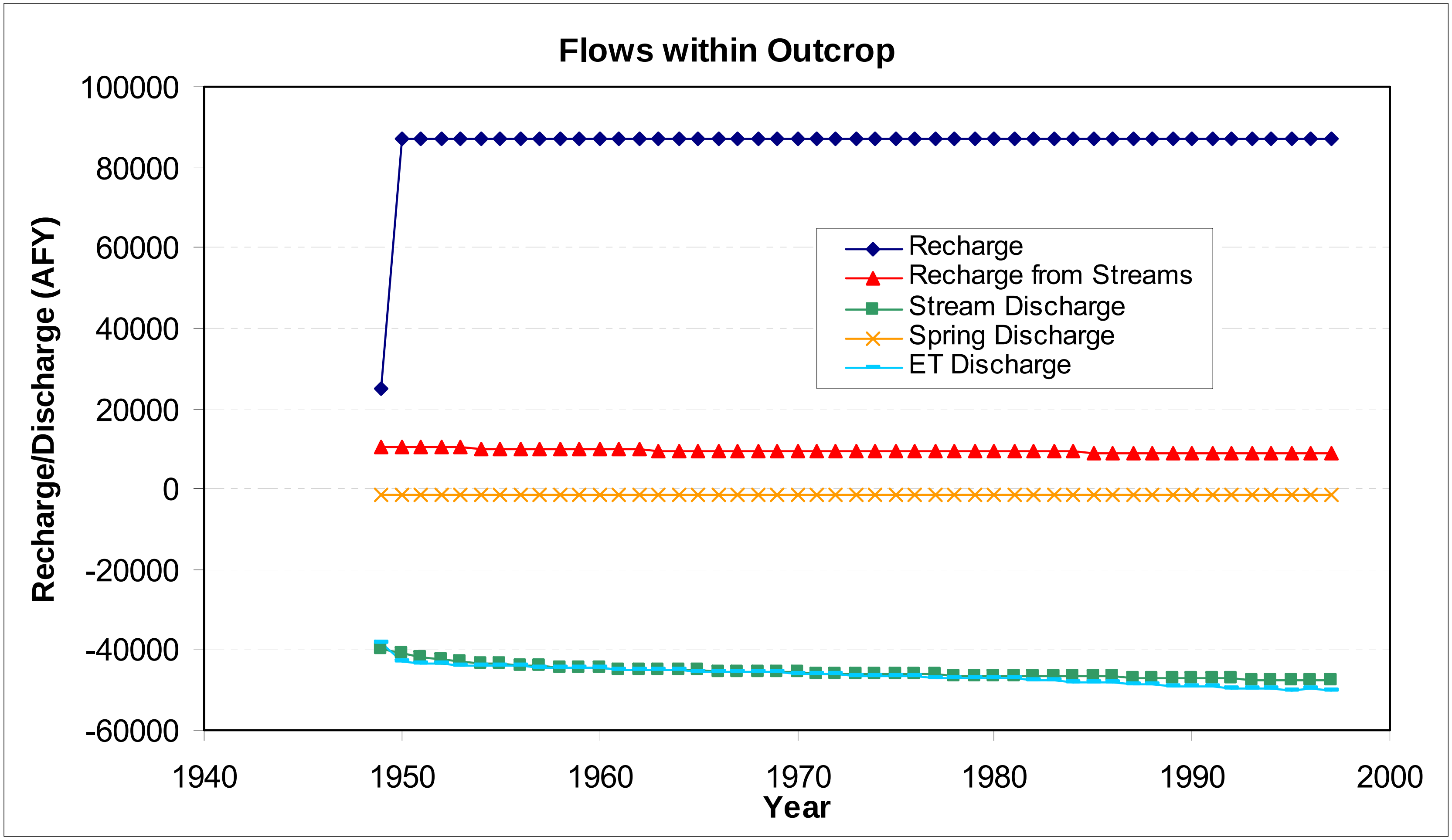
1980		Inflow (AFY)	Outflow (AFY)	Net (AFY)	
Recharge		87,167	0	87,167	← 0.58 in/yr
X-Formational	Upper	38,384	41,476	-3,092	← -0.002 in/yr
X-Formational	Lower	74,737	31,573	43,164	← 0.036 in/yr
Streams		9,235	46,368	-37,133	
Springs		0	1,475	-1,475	
Evapotranspiration		0	46,996	-46,996	
Wells	Upper	0	9,713	-9,713	
Wells	Lower	0	39,083	-39,083	
Storage	Upper	17,516	2,316	15,200	
Storage	Lower	29,666	37,551	-7,885	
Total		256,705	256,551	155	
Discrepancy				0.06%	

Dockum Mass Balance – 1990 & 1997

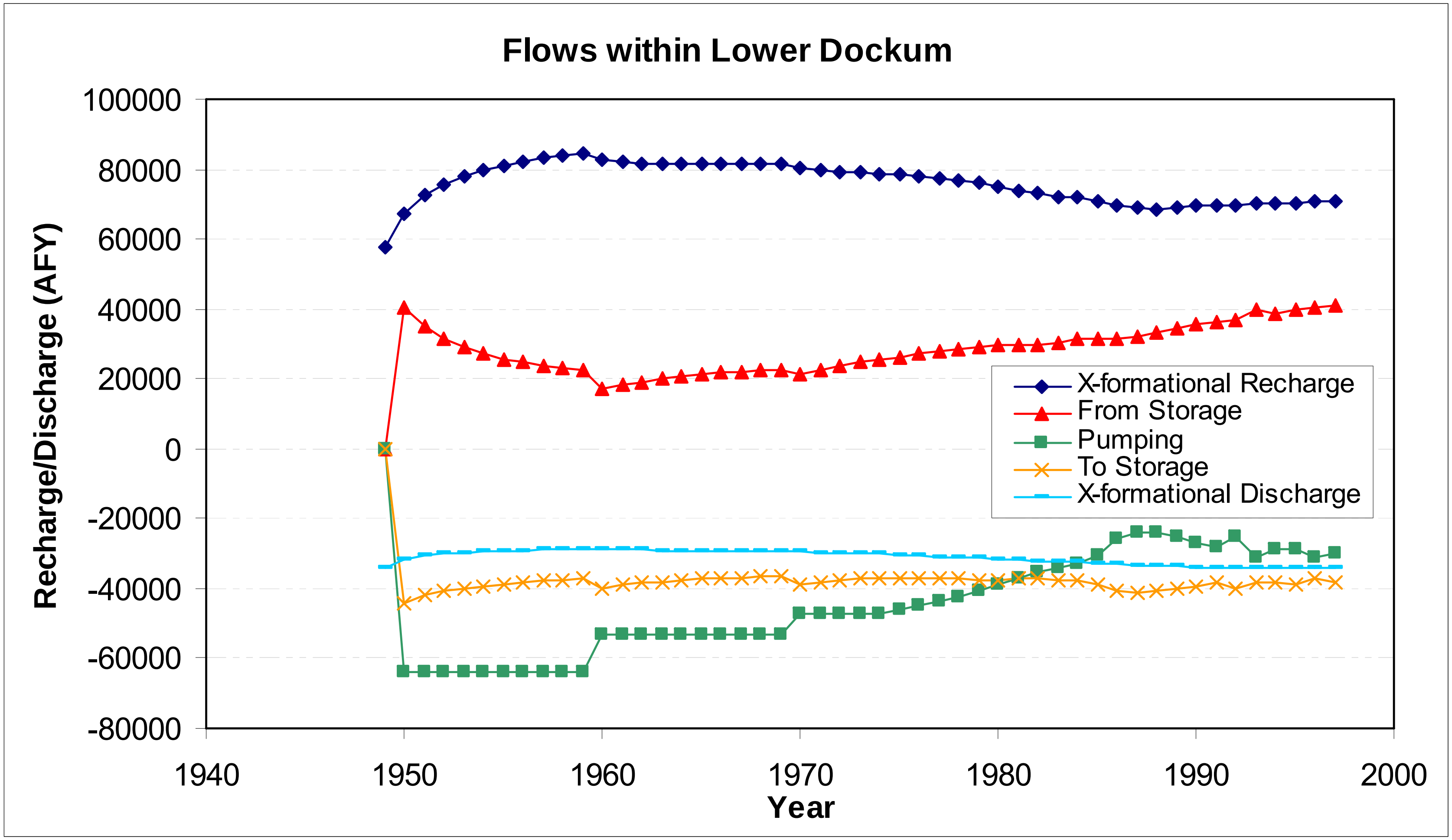
1990		Inflow (AFY)	Outflow (AFY)	Net (AFY)	
Recharge		87,167	0	87,167	← 0.58 in/yr
X-Formational	Upper	38,077	49,254	-11,178	← -0.008 in/yr
X-Formational	Lower	69,664	33,847	35,818	← 0.030 in/yr
Streams		9,046	47,153	-38,106	
Springs		0	1,478	-1,478	
Evapotranspiration		0	49,220	-49,220	
Wells	Upper	0	8,729	-8,729	
Wells	Lower	0	26,878	-26,878	
Storage	Upper	17,918	1,634	16,284	
Storage	Lower	35,835	39,481	-3,645	
Total		257,707	257,673	34	
Discrepancy				0.01%	

1997		Inflow (AFY)	Outflow (AFY)	Net (AFY)	
Recharge		87,167	0	87,167	← 0.58 in/yr
X-Formational	Upper	38,312	52,737	-14,426	← -0.011 in/yr
X-Formational	Lower	70,810	33,989	36,820	← 0.031 in/yr
Streams		8,932	47,547	-38,615	
Springs		0	1,478	-1,478	
Evapotranspiration		0	50,087	-50,087	
Wells	Upper	0	9,197	-9,197	
Wells	Lower	0	29,955	-29,955	
Storage	Upper	18,735	1,624	17,111	
Storage	Lower	40,898	38,217	2,681	
Total		264,854	264,833	21	
Discrepancy				0.01%	

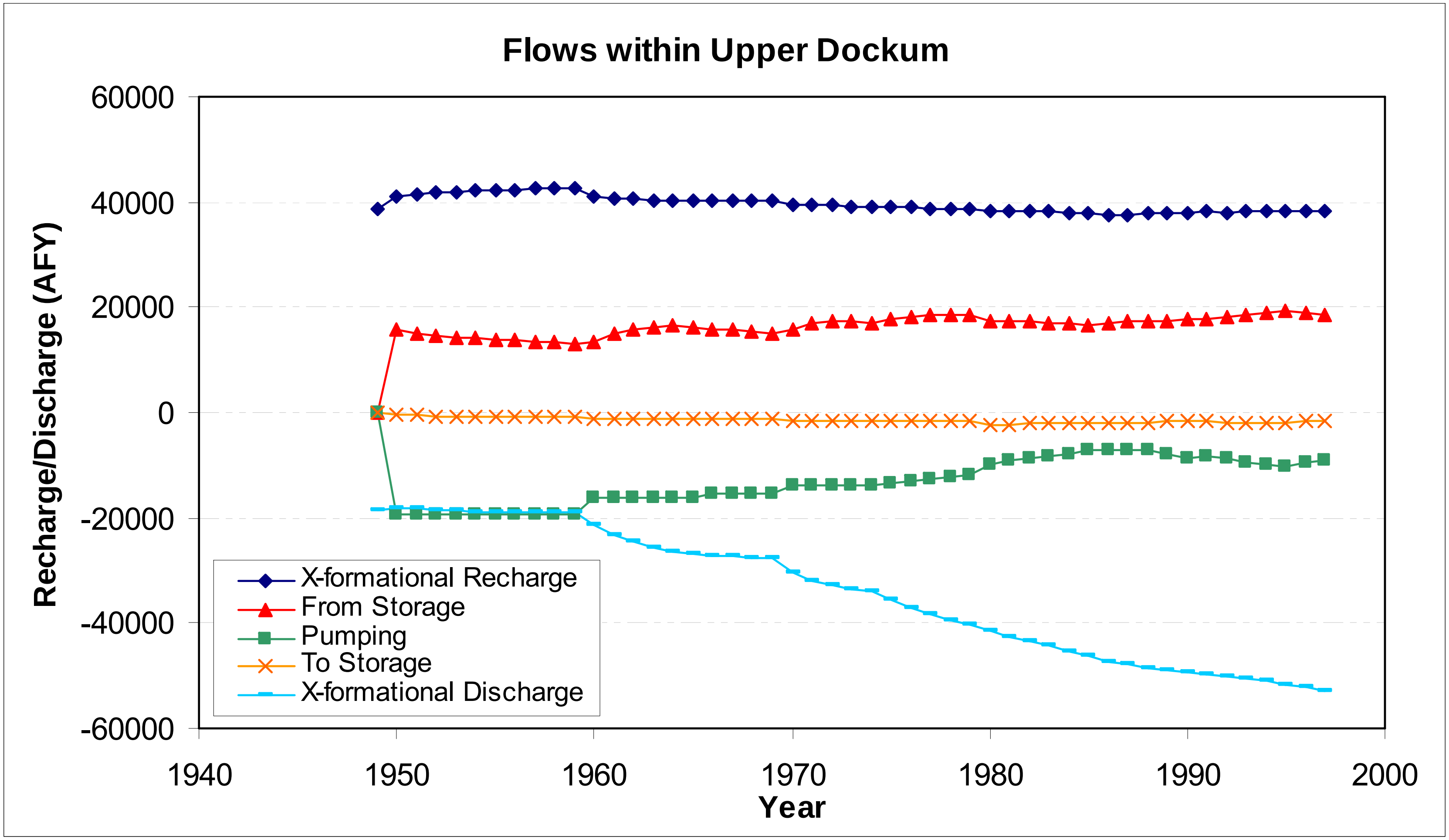
Transient Water Balance – Outcrop



Transient Water Balance – Subcrop



Transient Water Balance – Subcrop



Model Conclusions

- Recharge within the outcrop and cross-formational flow from younger formations are the largest sources of inflow to Dockum followed by stream losses
- Pumping, evapotranspiration, and stream gains are the significant discharge mechanisms
- Model is sensitive to K_H of Lower Dockum and GHB head
- Upper Dockum heads are sensitive to K_V of Upper Dockum
- Surface water discharge is sensitive to K_H of Lower Dockum, recharge and specific BC elevations

Model Limitations

- Dockum is a “minor” aquifer underlying “major” aquifers
- Regional model with groundwater availability prediction applicable at approximately county scale
- Temporal stress periods of one year preclude prediction of short-term head/flow variability
- The model does not provide a rigorous solution to surface water modeling
- Large portions of the Upper Dockum unconstrained by observed water-level data

GAM Schedule

- Project start – May 24, 2006
- Draft concept. Model mtg. – April 26, 2007
- Draft conceptual model report – May 16, 2007
- Steady-state model calibration mtg. – March 28, 2008
- Transient calibration & verification mtg. – May 20, 2008
- SAF3 Model calibration – June 4, 2008
- Draft Model Report to TWDB – June 30, 2008
- TWDB feedback on Draft Report – August 31, 2008
- Post draft final report review mtg. – September 2008
- Model Training Seminars – September 2008
- Final Model Report to TWDB – October 31, 2008

Dockum GAM
3rd Stakeholder Advisory Forum
June 4, 2008

Lubbock, TX

Name	Affiliation
Melanie Barnes	LWV
Ray Brady	RMBJ Geo Inc.
H.P. “Bo” Brown	Region D
Jason Coleman	South Plains UWCD
Steve and Nan Coneway	City of Hereford
Jim Conkwright	HPWD
Amy Crowell	PGCD
Harvey Everheart	Mesa UWCD
John Ewing	INTERA
Michelle Guelker	Lone Wolf GCD
Kevin Hopson	DBS&A
Ian Jones	TWDB
Mike McGregor	Llano Estacado UWCD
Bret Mills	Security State Bank
John Pickens	INTERA
Don M. Reynolds	HPWD
Julie Weathers	TTUHSC
Ben Weinheimer	TCFA
Chris Wingert	CRMWD

Dockum Aquifer GAM
3rd Stakeholder Advisory Forum
Comments and Responses
June 4, 2008
Lubbock, Texas

Questions and Answers:

Q. Flow data control points – where available to define the Dockum structure contours?

A. We have the data control points in the figure used in the Conceptual Model Report and this level of detail will be provided in the Final Report.

Q. Moore County – are they combined, Ogallala and Dockum wells?

A. Yes, likely. We attempted to remove dual completion wells from model calibration.

Q. Have Santa Rosa wells drilled in Deaf Smith County in past 5 to 7 years been included in the model?

A. Yes, if the well property data has been submitted to the TWDB for posting on their website prior to our downloading of TWDB database for development of conceptual model report.

Note that the model calibration period is from 1980 to 1997, so water level data from last 5 to 7 years would not be included, but prior data would be included.

Details on the database and conceptual model were presented at SAF2 and a CM report was prepared and posted. All data will be included in the Final Report.

Q. What is the source of pumping data in NM?

A. Numbers for pumping by county were taken from either the New Mexico Office of the State Engineer (NM OSE) (for 1975, 1980, 1990, 1995, and 2000) or the USGS (for 1985). Irrigation and Livestock pumping was distributed by land use type from the National Land Cover Data (NLCD) map. Rural Domestic pumping was distributed by population density. Municipal, Industrial, and Manufacturing well locations were taken from the NM OSE. For Dockum/Ogallala and Dockum/Pecos wells, 25% of the pumping was applied to the Dockum.

Q. Question on the reliability of the 5,000 mg/l aquifer limit definition.

A. There is sufficient data to reasonably define the 5,000 mg/L TDS boundary. The location is uncertain and based on limited data in some areas, however. It is a gradual decline in concentration from 5,000 mg/L and, because the high TDS area is being included in the active model domain, it is really only a qualitative threshold for reference rather than anything included in the MODFLOW model.

Q. For Deaf Smith County model area, should pumping be in Lower Dockum rather than Upper Dockum?

A. Yes. After reviewing the methodology for pumping layer assignments, it became clear that all the pumping applied to the Upper Dockum throughout the entirety of the model domain should be applied instead to the Lower Dockum. Because of the relatively small amount of this pumping, the change had minimal impact on the model results.

Q. What does "Water is not thieved by ET or streams" mean?

A. This was just one of the tests to identify the mechanisms limiting spring flow in the model. It turns out that the Dockum aquifer properties (not the spring properties or nearby stream and ET properties) limit the spring discharge rate in the model. We are aware that ET occurs in reality and have included it in the model for this reason.

Q. Deaf Smith County pumping issue?

A. See prior answer regarding reassignment of pumping to Lower Dockum.

Q. Should there be a separation of Upper and Lower Dockum?

A. While there may be uncertainty in the interface between the Upper and Lower Dockum, the two units have significant differences in hydraulic properties and stresses. By separating the two units into model layers, a more accurate representation of the conceptual model is possible.

Q. If asked to look at decline of 1 ft, 2 ft, etc. per year in Deaf Smith County, how usable is model?

A. It is applicable to apply the model at the county scale. However, limited water level data in Deaf Smith county during the calibration period means that the model is not well constrained by data in that area.

Q. Good to include high TDS region in model because of future desalinization potential. Should there be caution in using data points 80 miles apart?

A. This area of the model is certainly poorly constrained data. However, the model imposes physical constraints based on the reasonable estimates of hydraulic properties and structure and the equations governing groundwater flow so it may be a useful estimation tool. It should be noted, though, that MODFLOW does not account for density dependant flow as a function of salinity.

Q. We would like to see where data is limited (e.g., dashed lines).

A. In the Final Report attention will be given to clearly delineate areas where data is insufficient for contouring.

Q. Can we use more color consistency between figures showing similar information?

A. In the Final Report we will attempt to provide consistent color scales between all comparable figures so that they may be more efficiently compared visually.