# Stakeholder Advisor Forum for the High Plains Aquifer GAM

## Numerical Model Construction and Calibration

**Presented at HPWD**
**Lubbock, TX**

**Presented By:**

INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS

Texas Water Development Board

**August 11, 2015**

# Presentation Outline

- Introduction to the Groundwater Availability Program by Cindy Ridgeway (TWDB)
- High Plains Aquifer System Background and Conceptual Model Review
- Model construction
    - Structure
    - Head boundaries
    - Properties
    - Flux boundaries
- Model Calibration
- Schedule

# Introduction of Texas Water Development Board (TWDB) Groundwater Availability Modeling (GAM) Program

Cindy Ridgeway, P.G.

Manager of Groundwater Availability Modeling

Texas Water Development Board

Texas Water Development Board

# Disclaimer

The following presentation is based upon professional research and analysis within the scope of the Texas Water Development Board's statutory responsibilities and priorities but, unless specifically noted, does not necessarily reflect official Board positions or decisions.

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# Groundwater Availability Modeling Program

- **Aim**: Develop groundwater flow models for the major and minor aquifers of Texas.
- **Purpose**: Tools that can be used to aid in groundwater resources management by stakeholders.
- **Public process**: Stakeholder involvement during model development process.
- **Models**: Freely available, standardized, thoroughly documented. Reports available over the internet.
- **Living tools**: Periodically updated.

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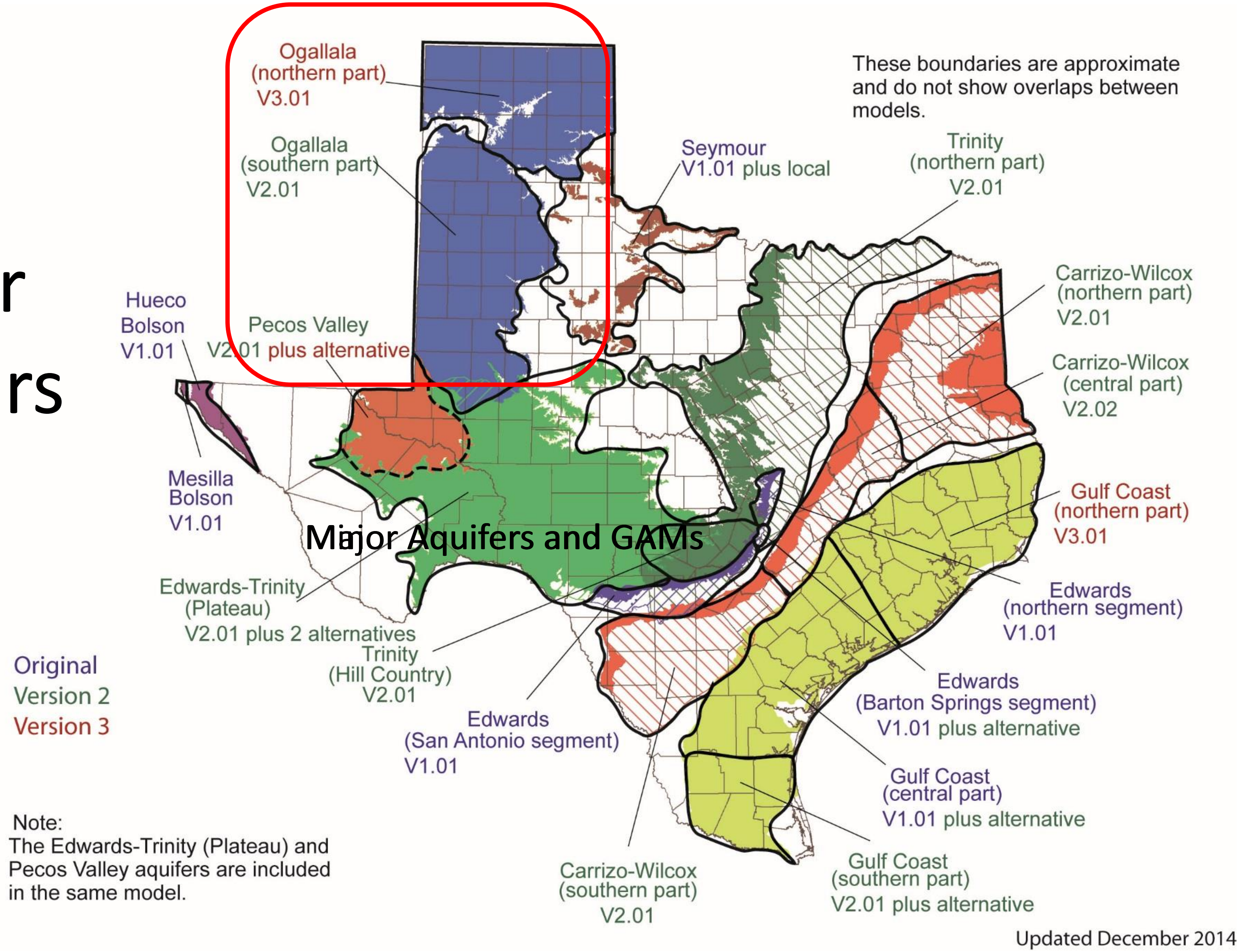
# Major Aquifers




Miajor Aquifers and GAMs

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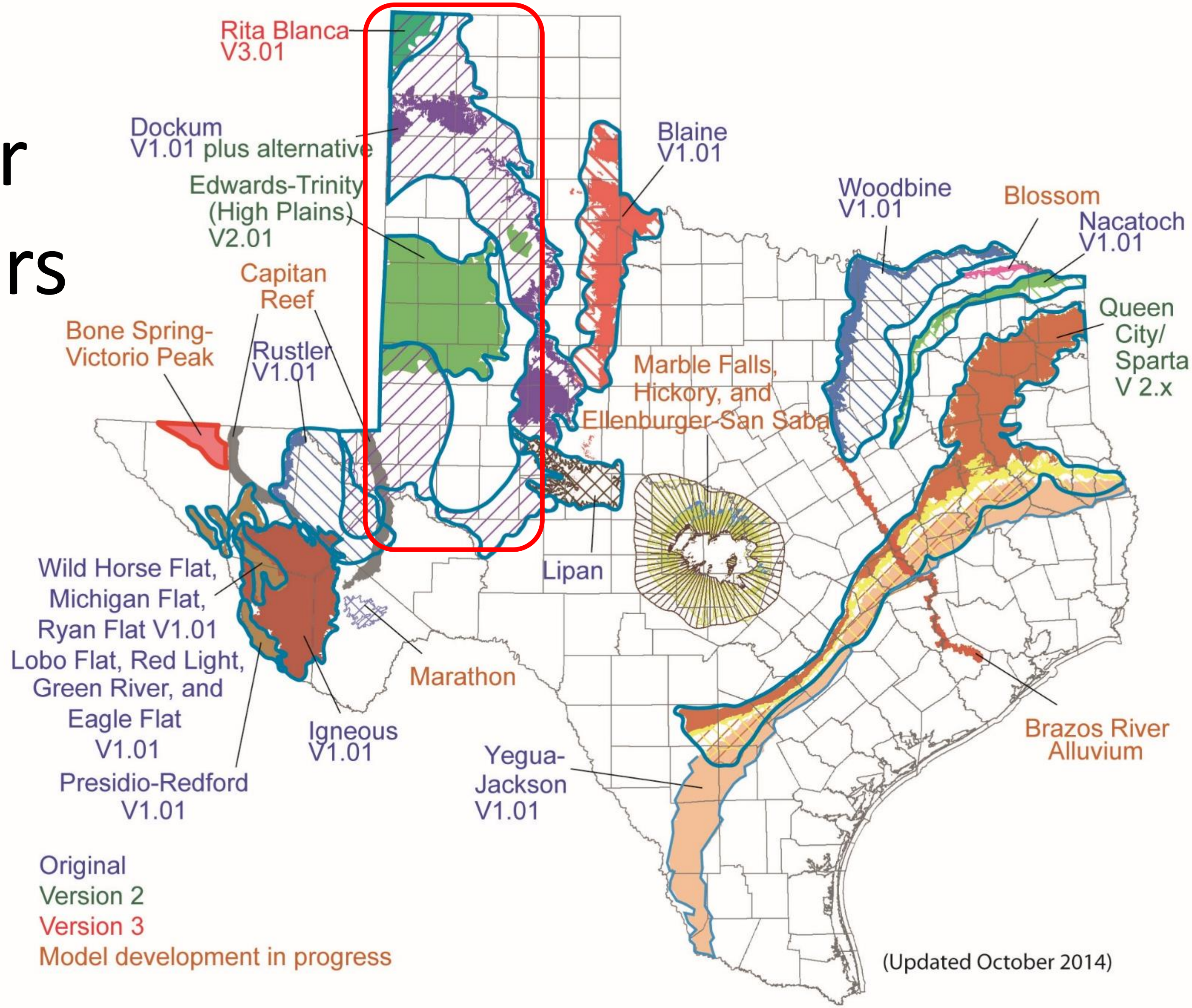
# Minor Aquifers

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# How we use Groundwater Models?

Per Statute:

- TWDB provides groundwater conservation districts with water budget data for their management plans.
- Groundwater management areas can use to assist in determining desired future conditions.
- TWDB uses when calculating  estimated Modeled Available Groundwater.
- TWDB uses when calculating Total Estimated Recoverable Storage.

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# Why Stakeholder Advisory Forums?

- Keep stakeholders updated about progress of the model
- Inform how the groundwater model can, should, and should not be used
- Provide stakeholders with the opportunity to provide input and data to assist with model development

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# Contact Information

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**Texas Water Development Board**
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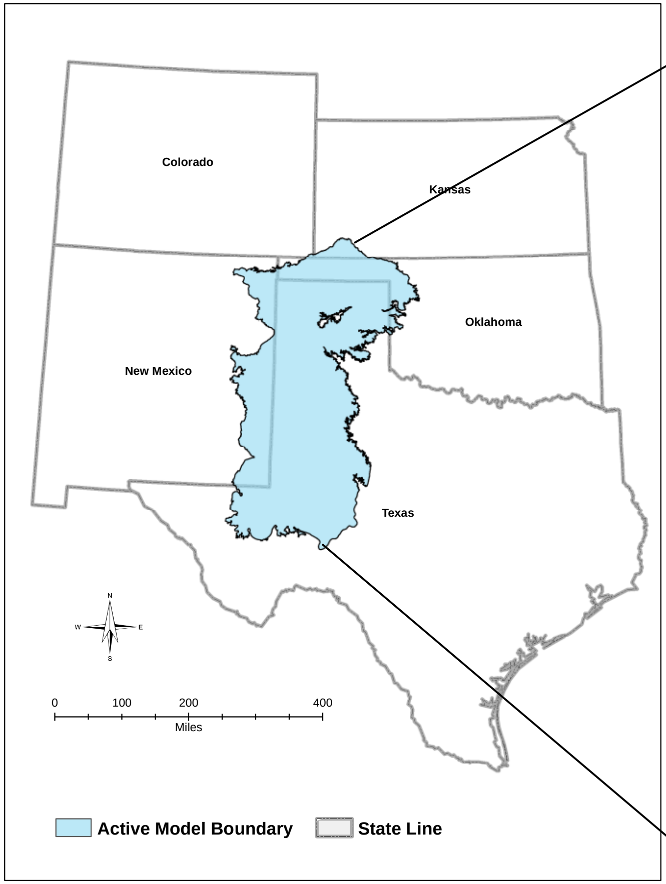
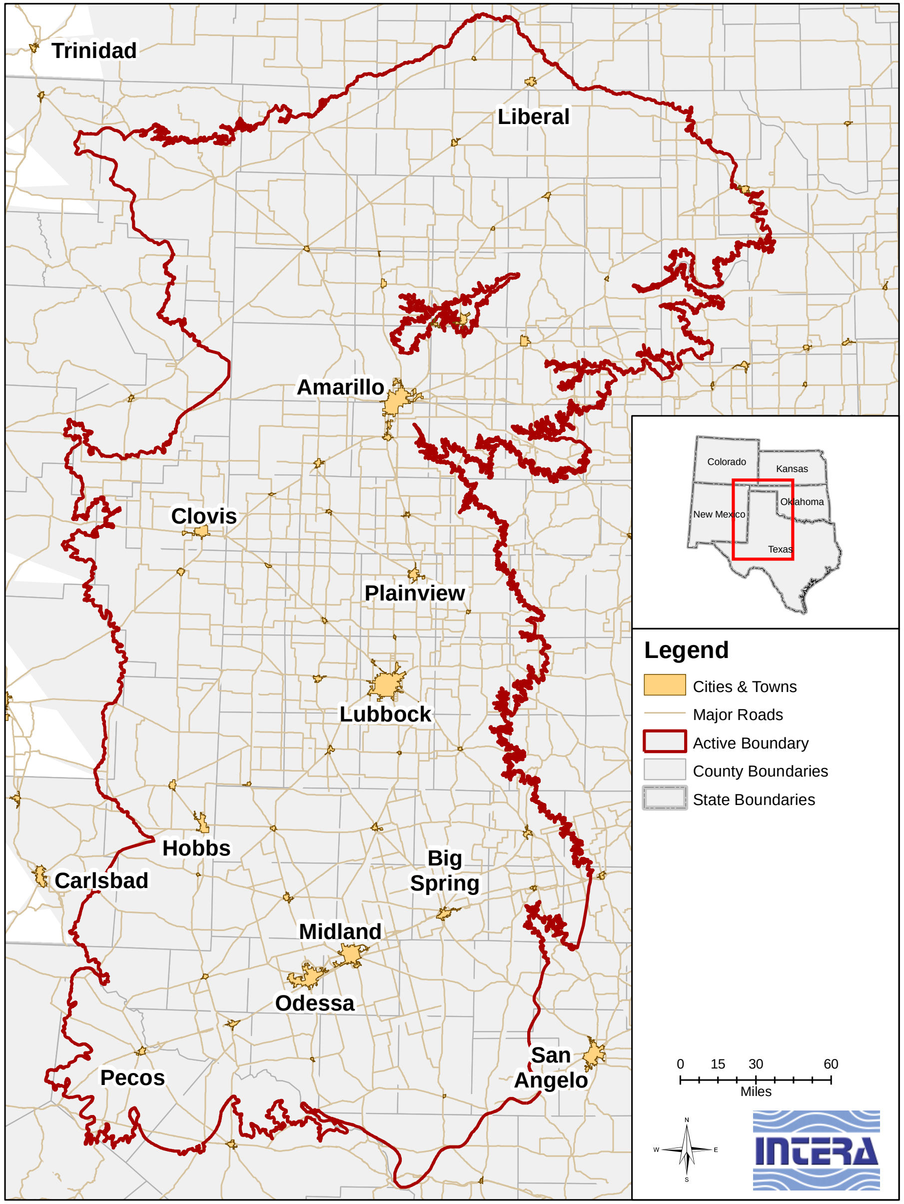
**Austin, Texas 78711-3231**

**Web information:**
**http://www.twdb.texas.gov/groundwater/models/gam/hpas/hpas.asp**

# Study Area


Colorado
Kansas
Oklahoma
New Mexico
Texas
N
W
E
S
0
100
200
400
Miles
Active Model Boundary
State Line


Trinidad
Liberal
Amarillo
Clovis
Plainview
Lubbock
Hobbs
Carlsbad
Big Spring
Midland
Odessa
Pecos
San Angelo
Colorado
Kansas
New Mexico
Oklahoma
Texas
Legend
Cities & Towns
Major Roads
Active Boundary
County Boundaries
State Boundaries
0
15
30
60
Miles
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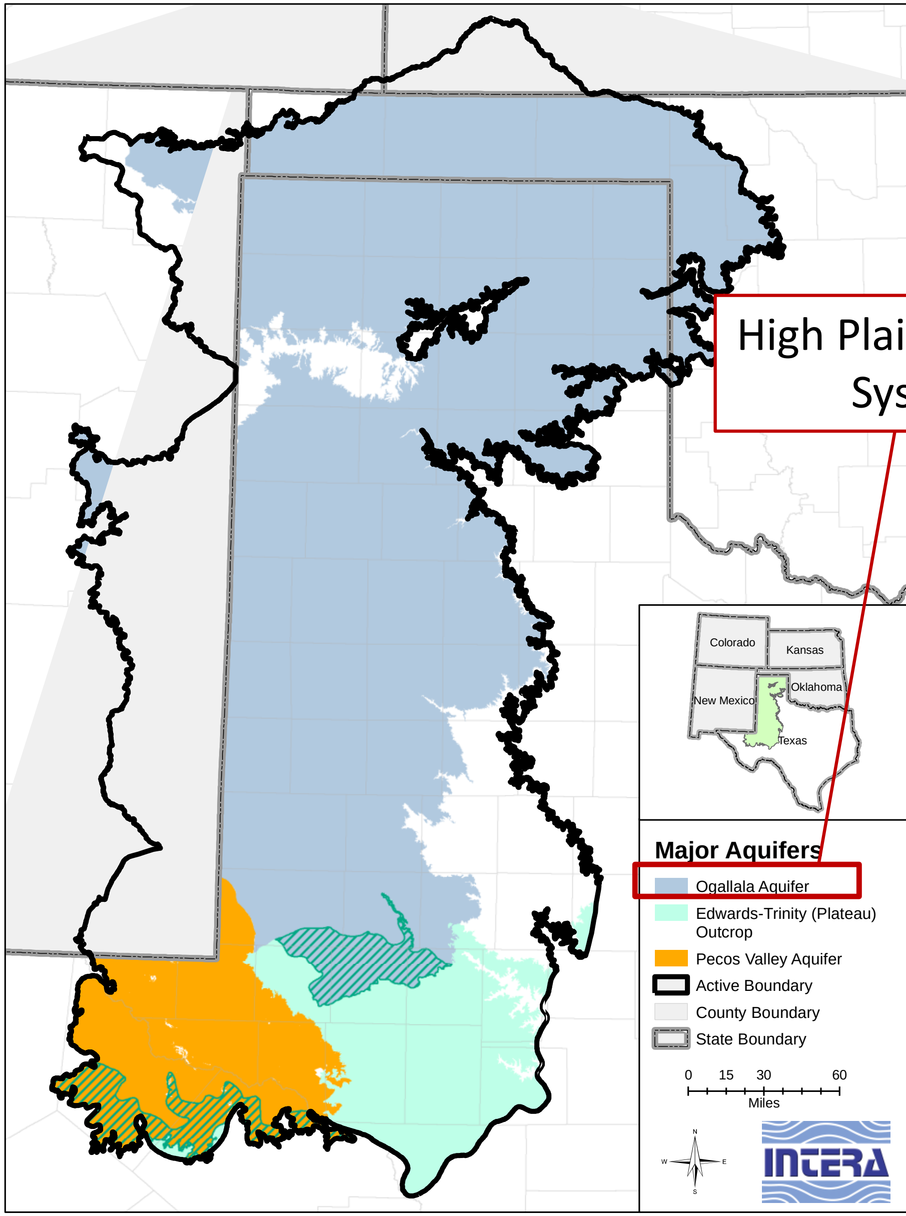
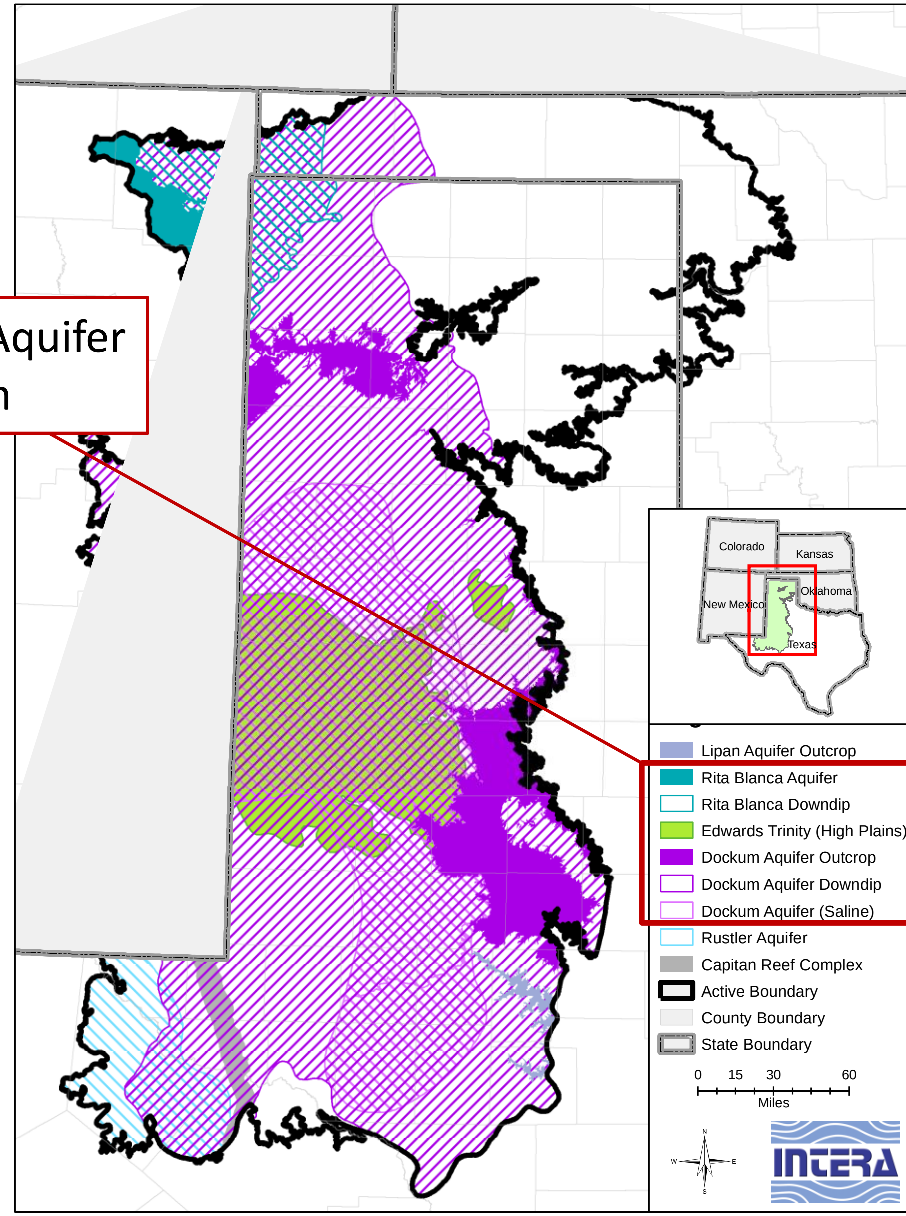
# Aquifers in the Study Area



# Model Layer Representation

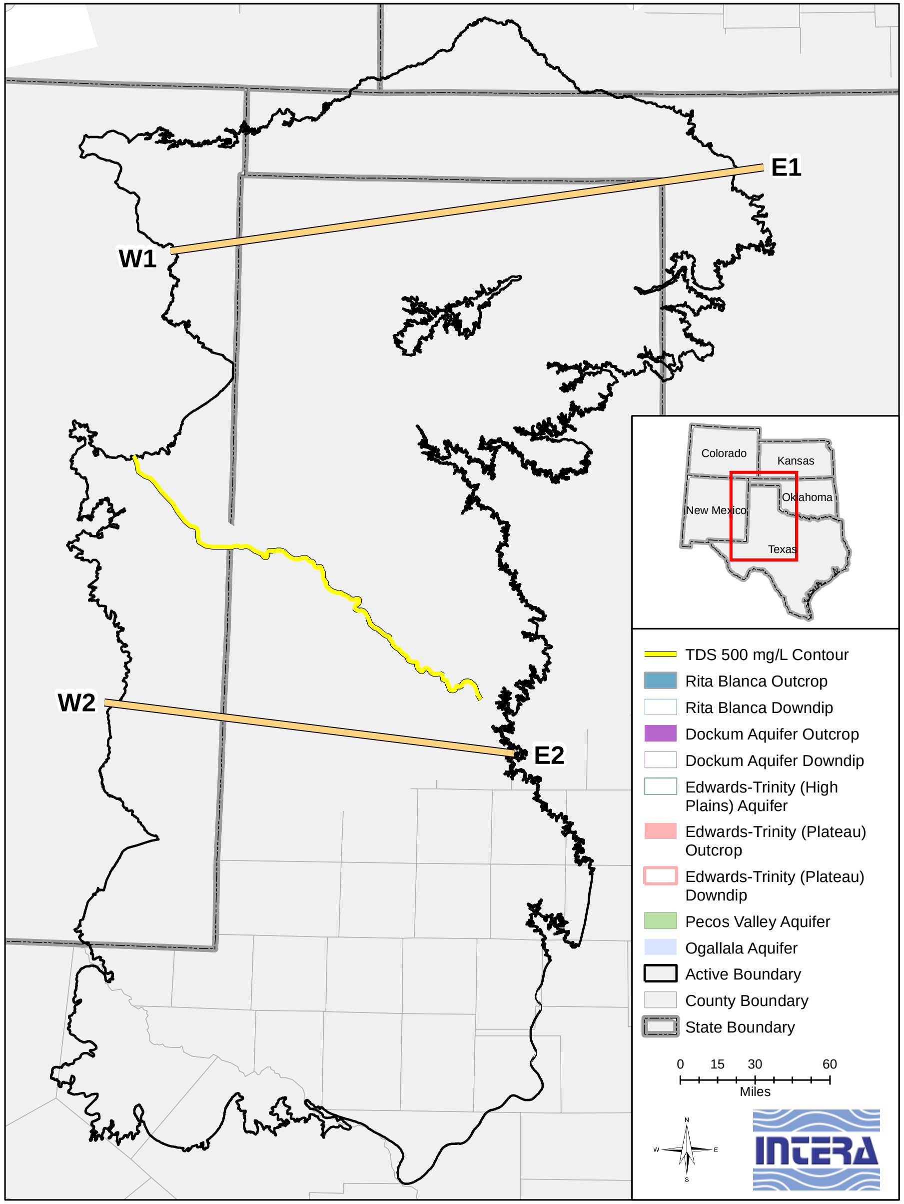
<table>
<tr><th rowspan="2">System</th><th rowspan="2" colspan="2">Formation</th><th rowspan="2">Aquifer</th><th colspan="3">Model Layer</th></tr>
<tr><th>North</th><th>Central</th><th>South</th></tr>
<tr><td>Quaternary</td><td colspan="2">Pecos Valley Alluvium</td><td>Pecos Valley</td><td></td><td></td><td>1</td></tr>
<tr><td>Tertiary</td><td colspan="2">Ogallala</td><td>Ogallala</td><td>1</td><td>1</td><td></td></tr>
<tr><td rowspan="6">Cretaceous</td><td>Duck Creek [II]</td><td>Boracho*</td><td rowspan="6">Edwards – Trinity</td><td rowspan="6"></td><td rowspan="6">2[II]</td><td rowspan="6">2*</td></tr>
<tr><td>Kiamichi [II]</td><td rowspan="4">Finlay*</td></tr>
<tr><td>Edwards [II]</td></tr>
<tr><td>Comanche Peak [II]</td></tr>
<tr><td>Walnut [II]</td></tr>
<tr><td colspan="2">Antlers</td></tr>
<tr><td rowspan="2">Jurassic</td><td colspan="2">Morrison</td><td rowspan="2">Rita Blanca</td><td rowspan="2">2</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="2">Exeter</td></tr>
<tr><td rowspan="4">Triassic</td><td colspan="2">Cooper Canyon</td><td rowspan="2">Upper Dockum</td><td rowspan="2">3</td><td rowspan="2">3</td><td rowspan="2">3</td></tr>
<tr><td colspan="2">Trujillo</td></tr>
<tr><td colspan="2">Tecovas</td><td rowspan="2">Lower Dockum</td><td rowspan="2">4</td><td rowspan="2">4</td><td rowspan="2">4</td></tr>
<tr><td colspan="2">Santa Rosa</td></tr>
<tr><td rowspan="2">Permian</td><td colspan="2">Dewey Lake</td><td></td><td rowspan="2" colspan="3">No Flow</td></tr>
<tr><td colspan="2">Rustler</td><td>Rustler</td></tr>
</table>

[II] Edwards-Trinity (High Plains) Aquifer represented by layer 2 in the central portion of the domain.
* Edwards-Trinity (Plateau) Aquifer represented by layer 2 in the southern portion of the domain.

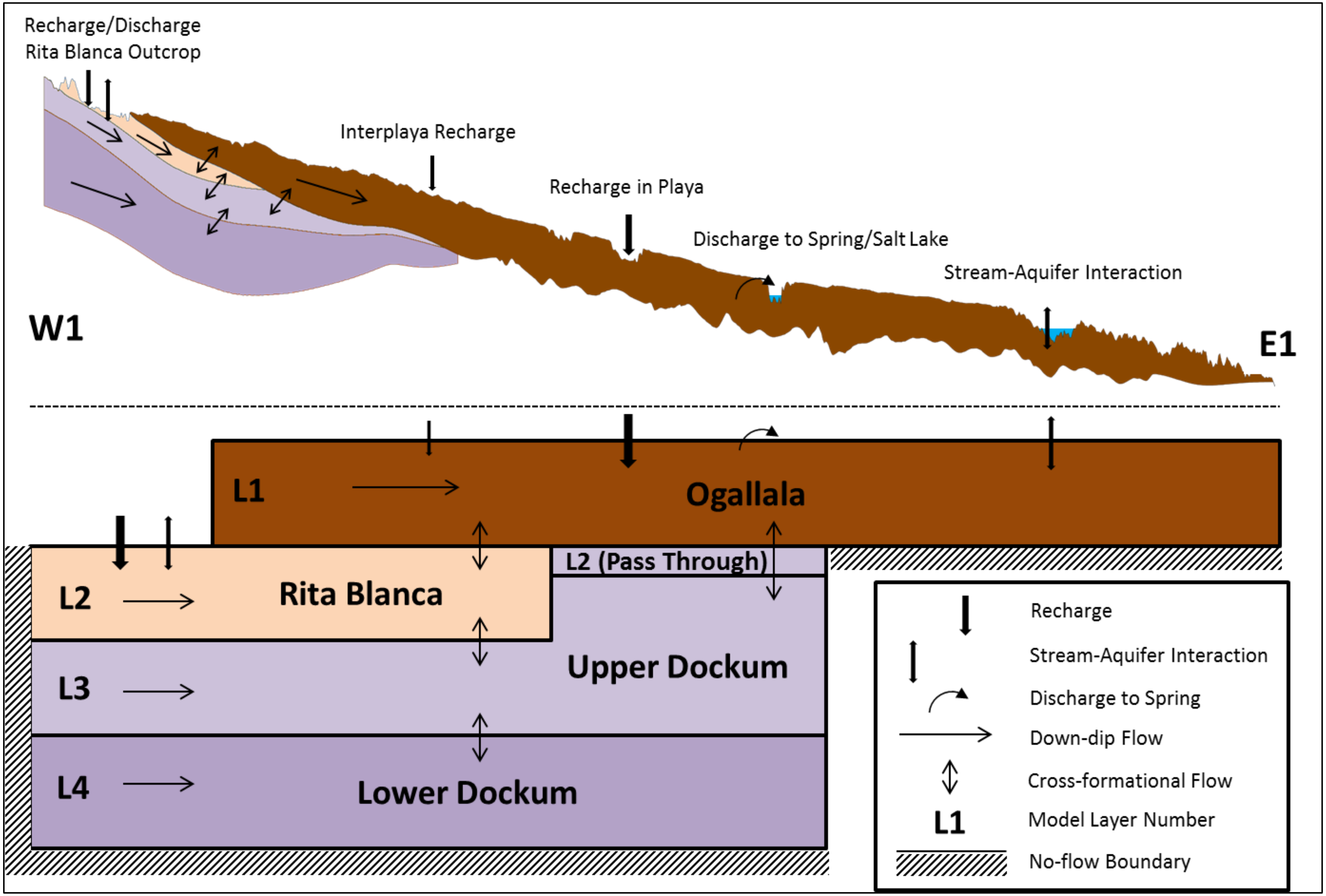
Head Boundaries

# Conceptual Model

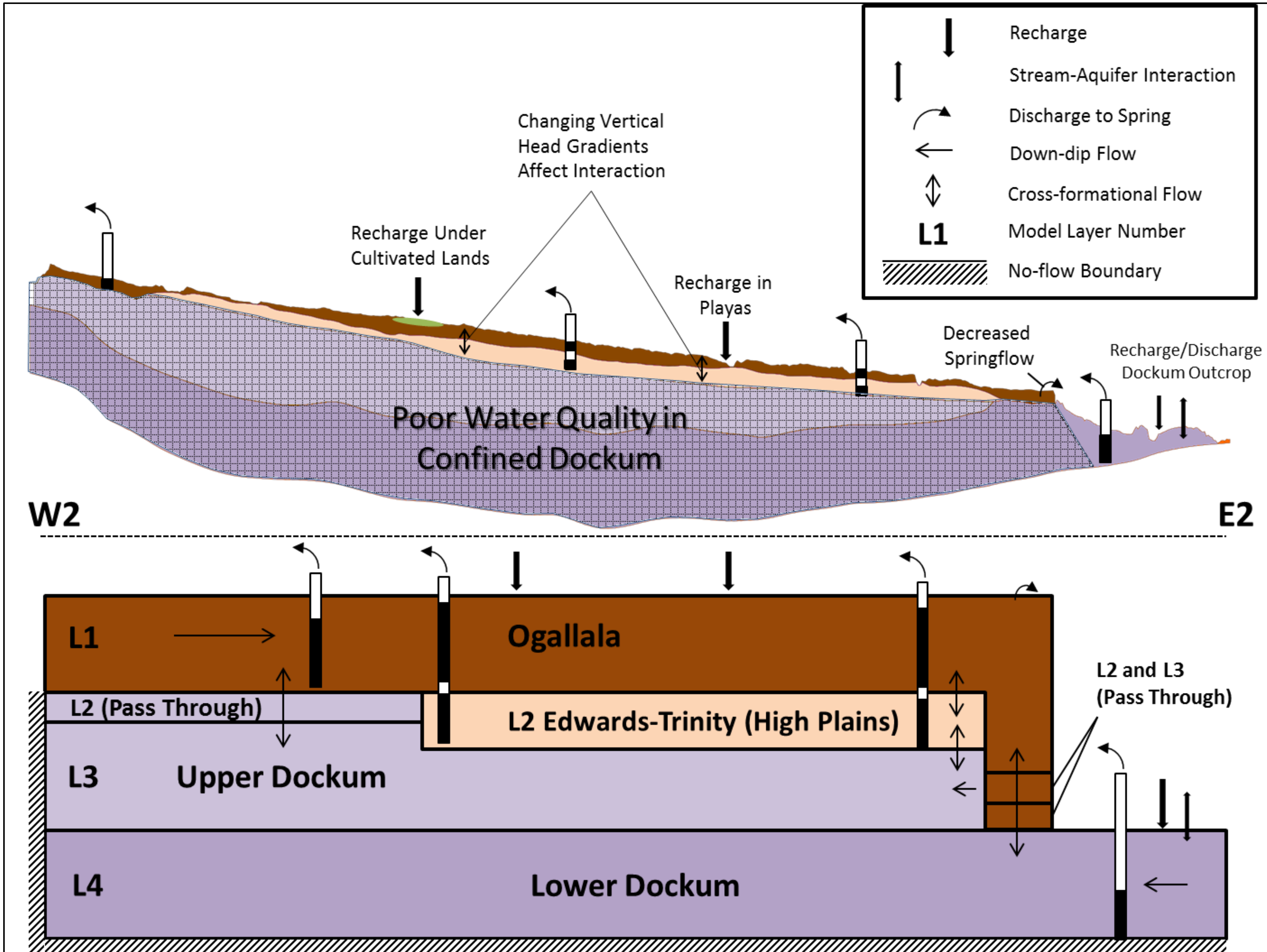
- During Pre-development: recharge balances discharge, no net change in groundwater storage
- During Post-development: Increased discharge from pumping, locally increased recharge from irrigation, overall reduction in natural discharge and GW storage
- Northern and Southern sections have different hydrostratigraphy and recharge patterns.



# Conceptual Model: Predevelopment

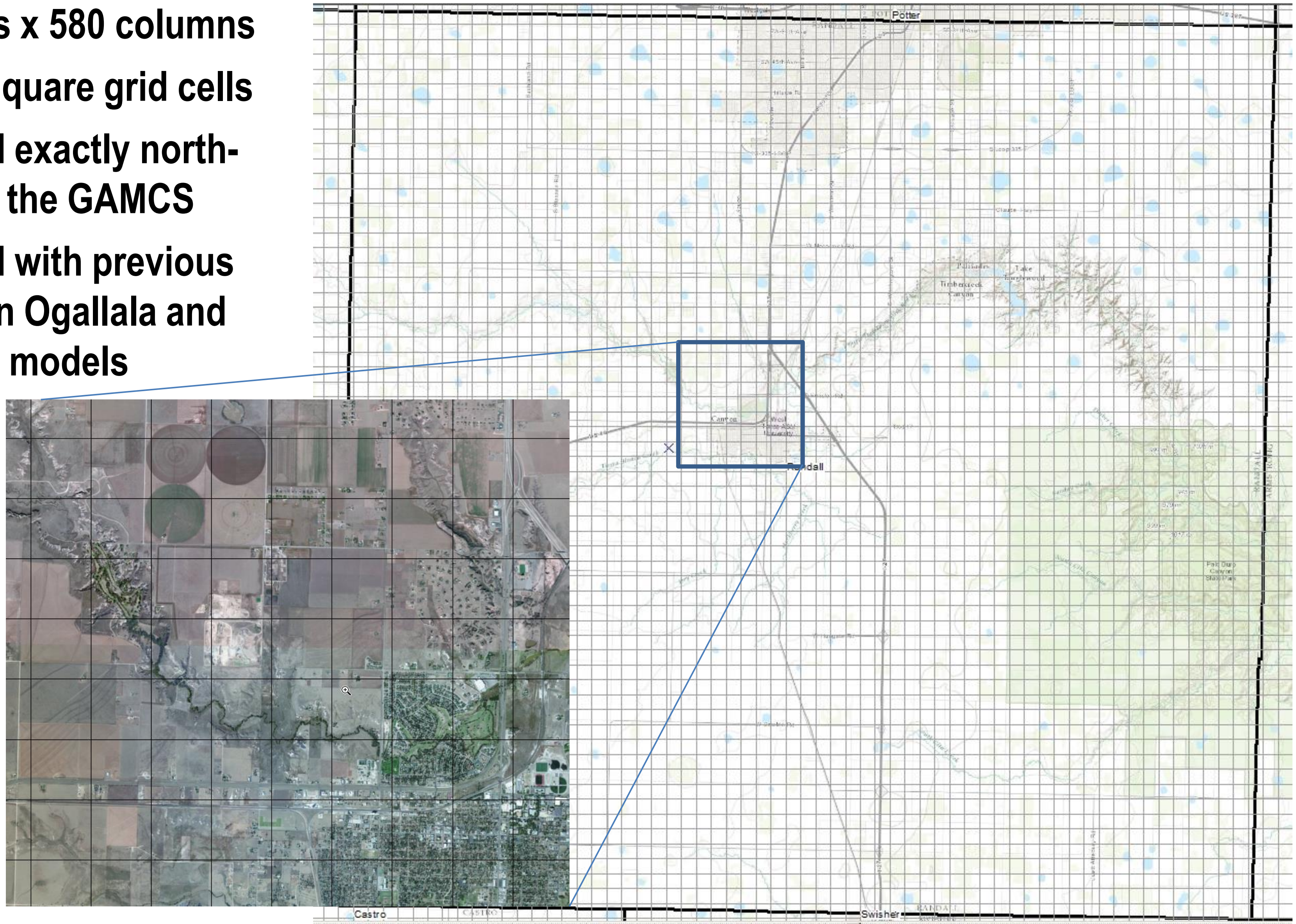


# Conceptual Model: Post Development



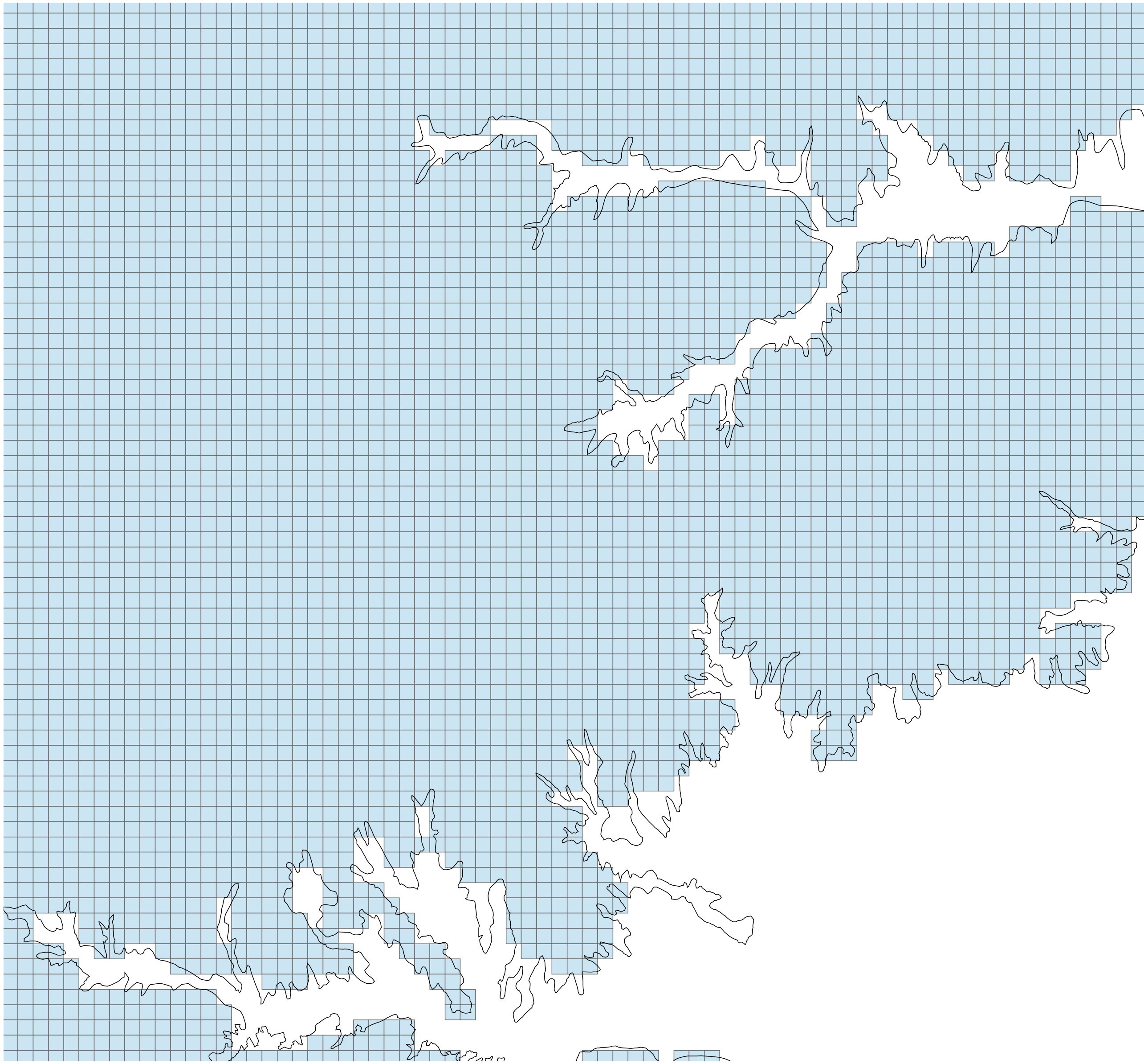
# Model Grid

- 932 rows x 580 columns
- 2640 ft square grid cells
- Oriented exactly north-south in the GAMCS
- Oriented with previous Southern Ogallala and Dockum models



# Model Grid

- Base active areas based on grid centroids
- Smoothing to remove corner connections, small islands and peninsulas
- Without smoothing, steady-state model does not converge



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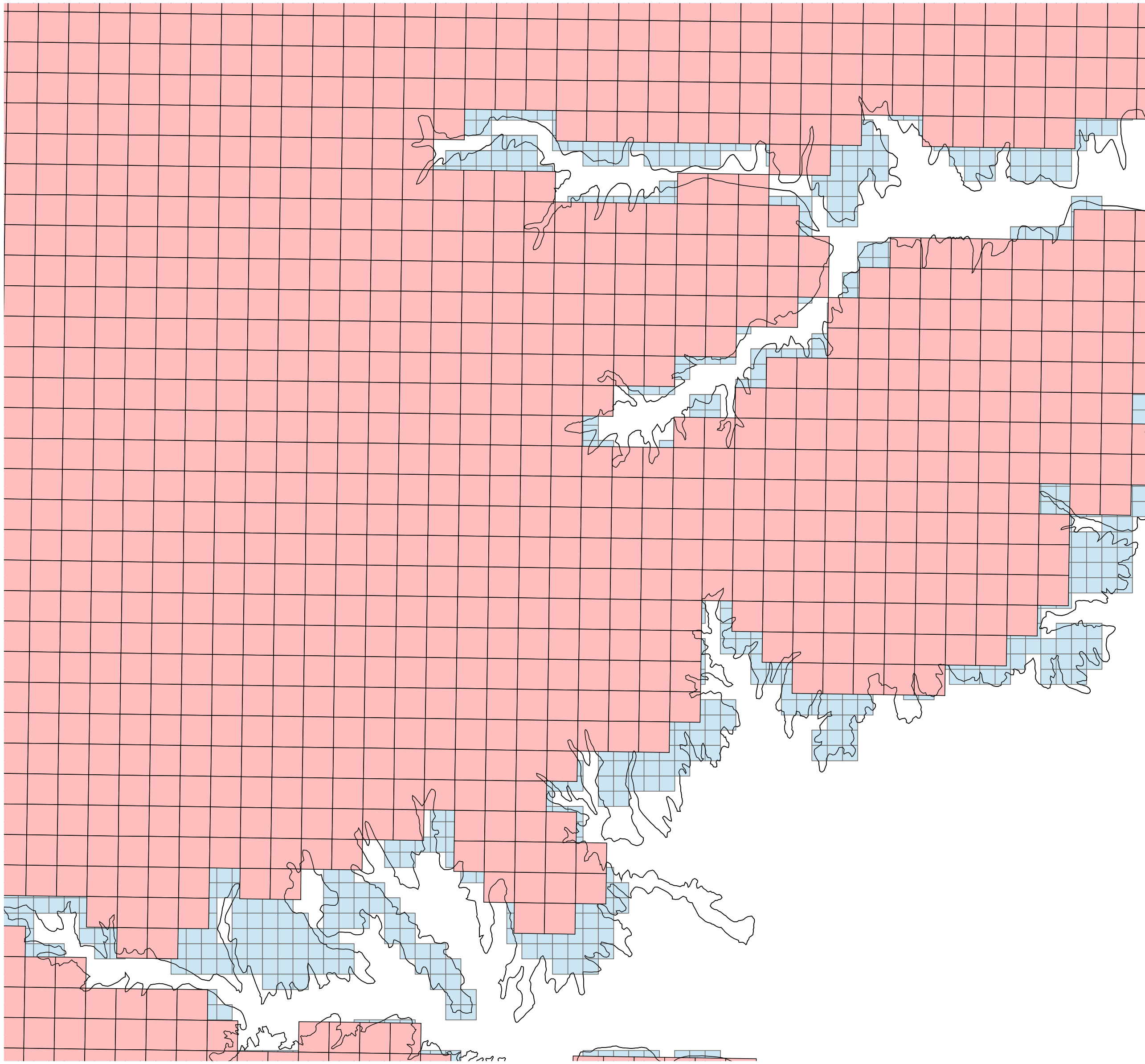
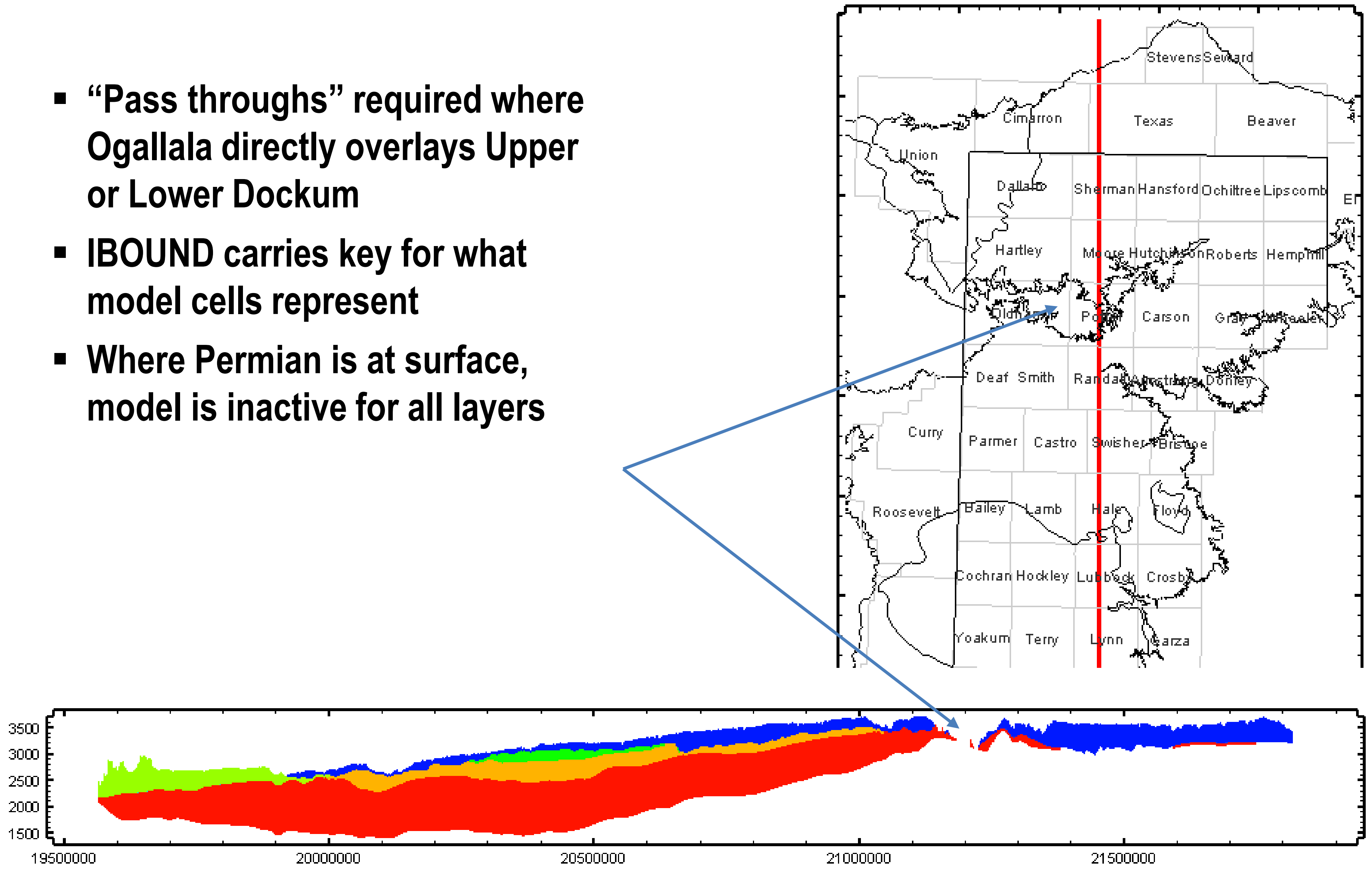


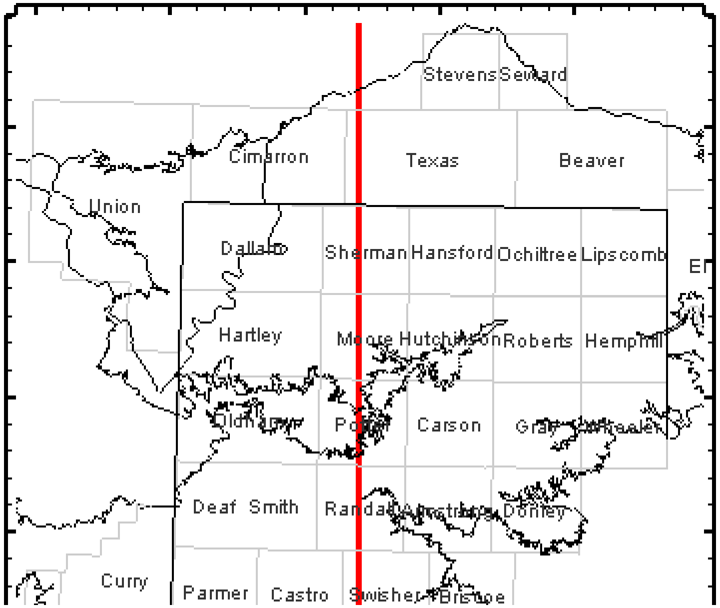
# Structure on Grid

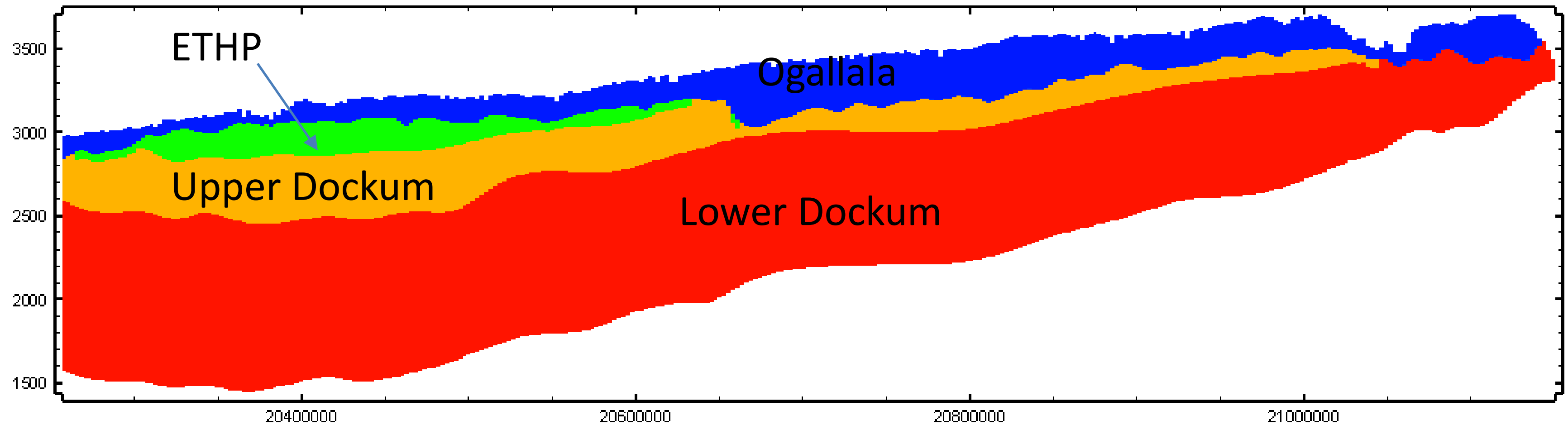
- "Pass throughs" required where Ogallala directly overlays Upper or Lower Dockum
- IBOUND carries key for what model cells represent
- Where Permian is at surface, model is inactive for all layers



# Structure on Grid

- "Pass throughs" required where Ogallala directly overlays Upper or Lower Dockum, and a few other places where aquifers have pinched out
- IBOUND carries key for what model cells represent
- Where Permian is at surface, model is inactive for all layers



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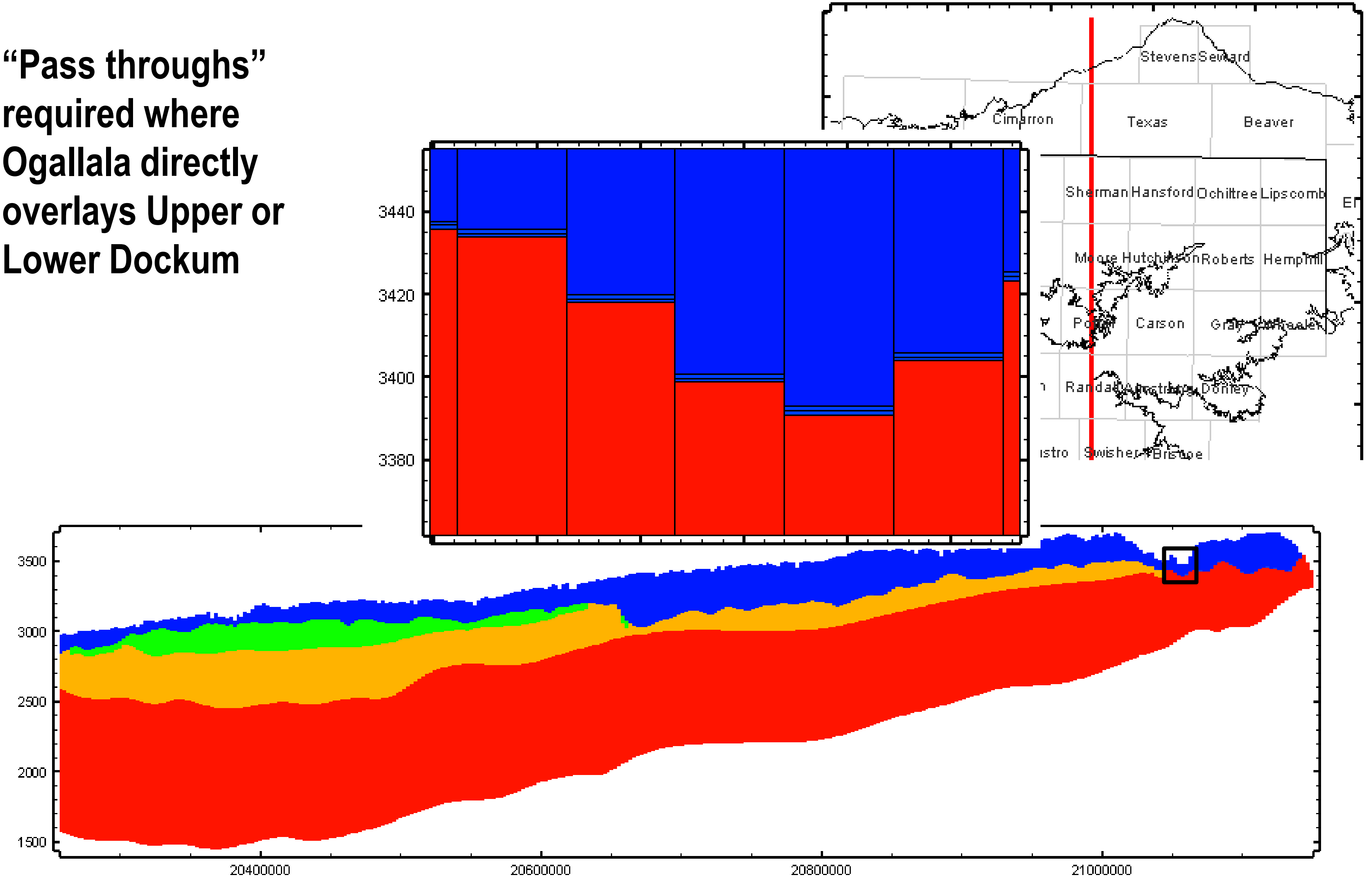
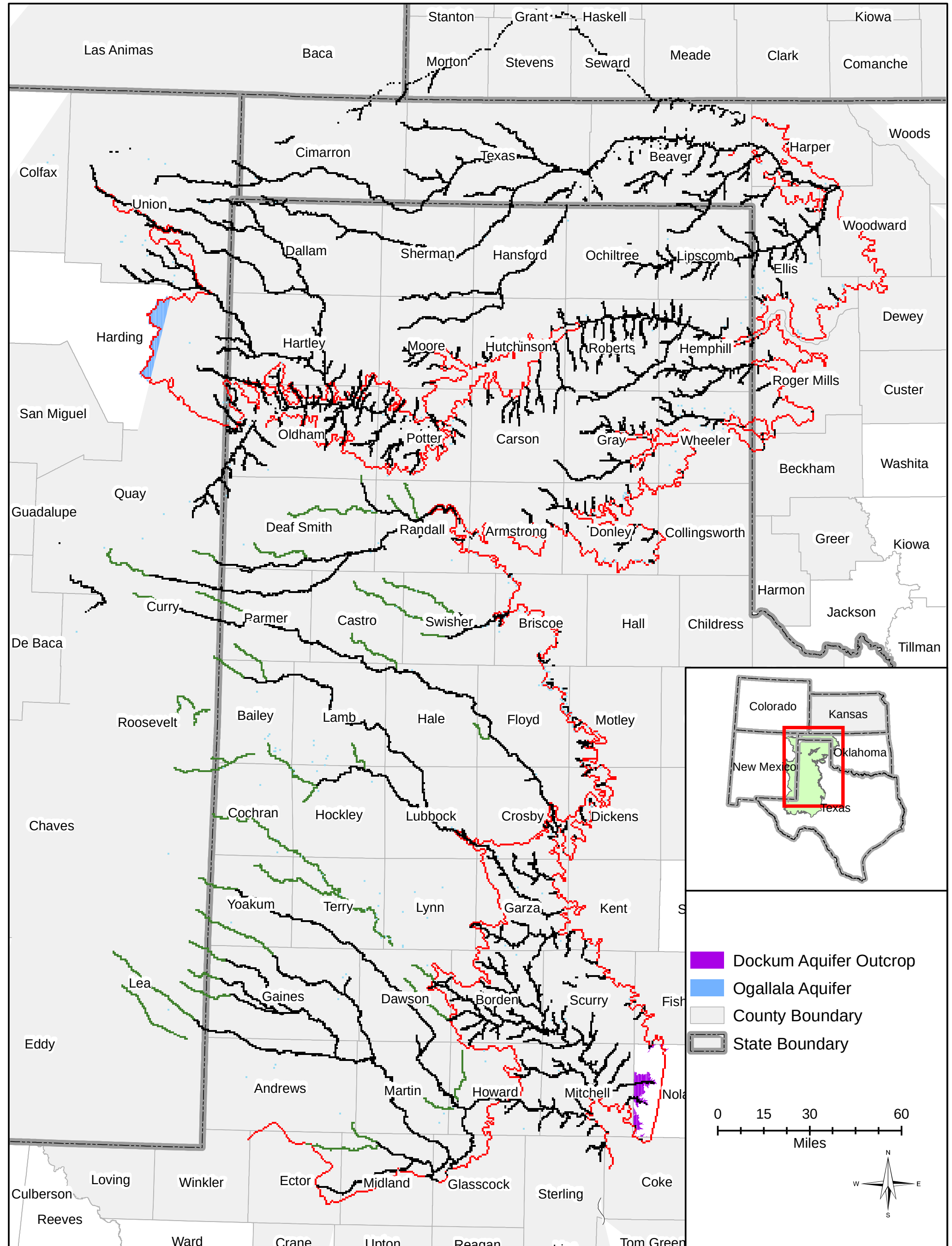


# Head boundaries: DRN and RIV

- Drains represent springs, draws, and seeps along escarpment
- RIV cells represent rivers, streams, and reservoirs



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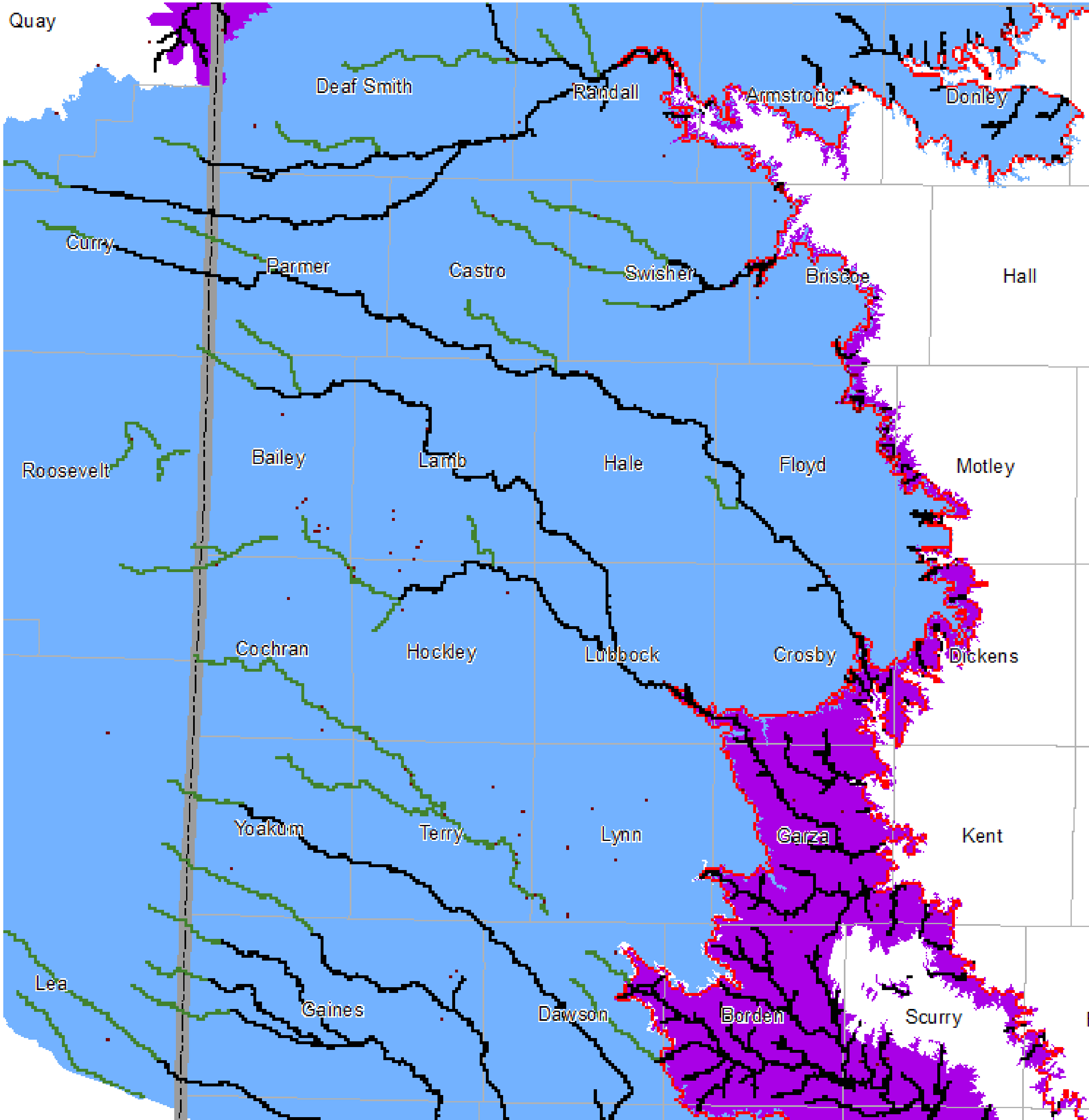
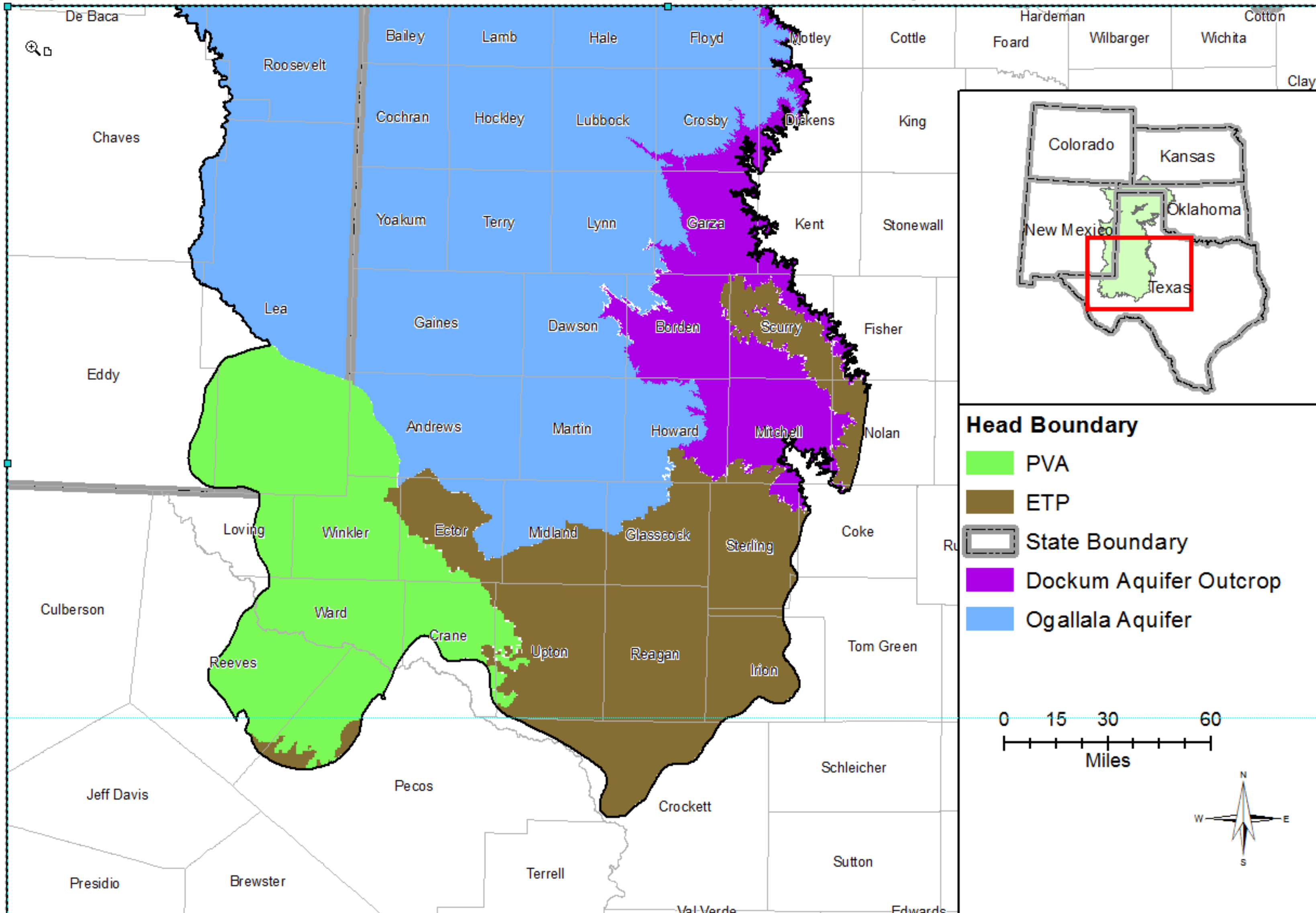


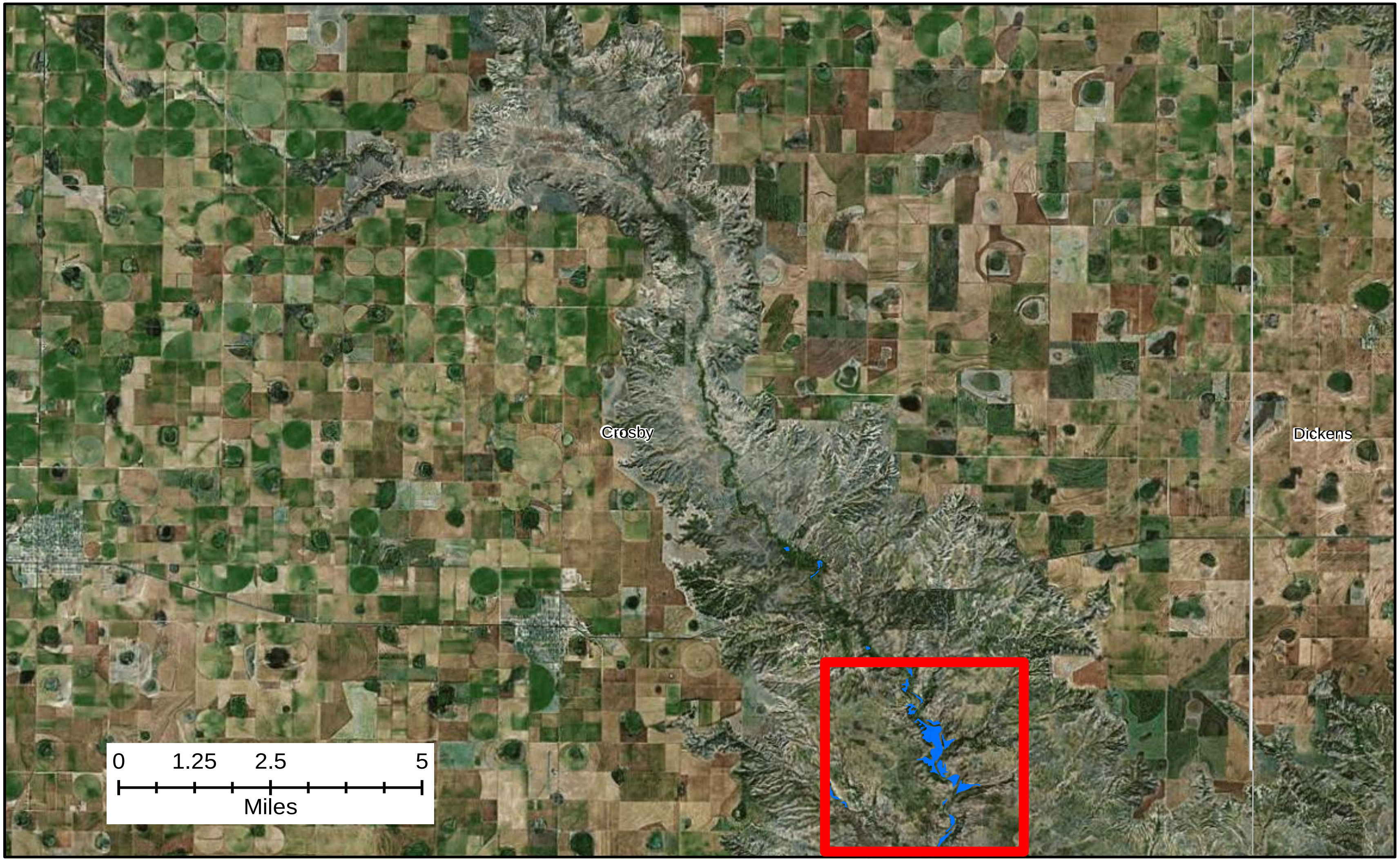
# Head boundaries: RIV as "GHB"

- Used to set heads in PVA and ETP through time
- RIV package allows for fixed contribution under large vertical gradients

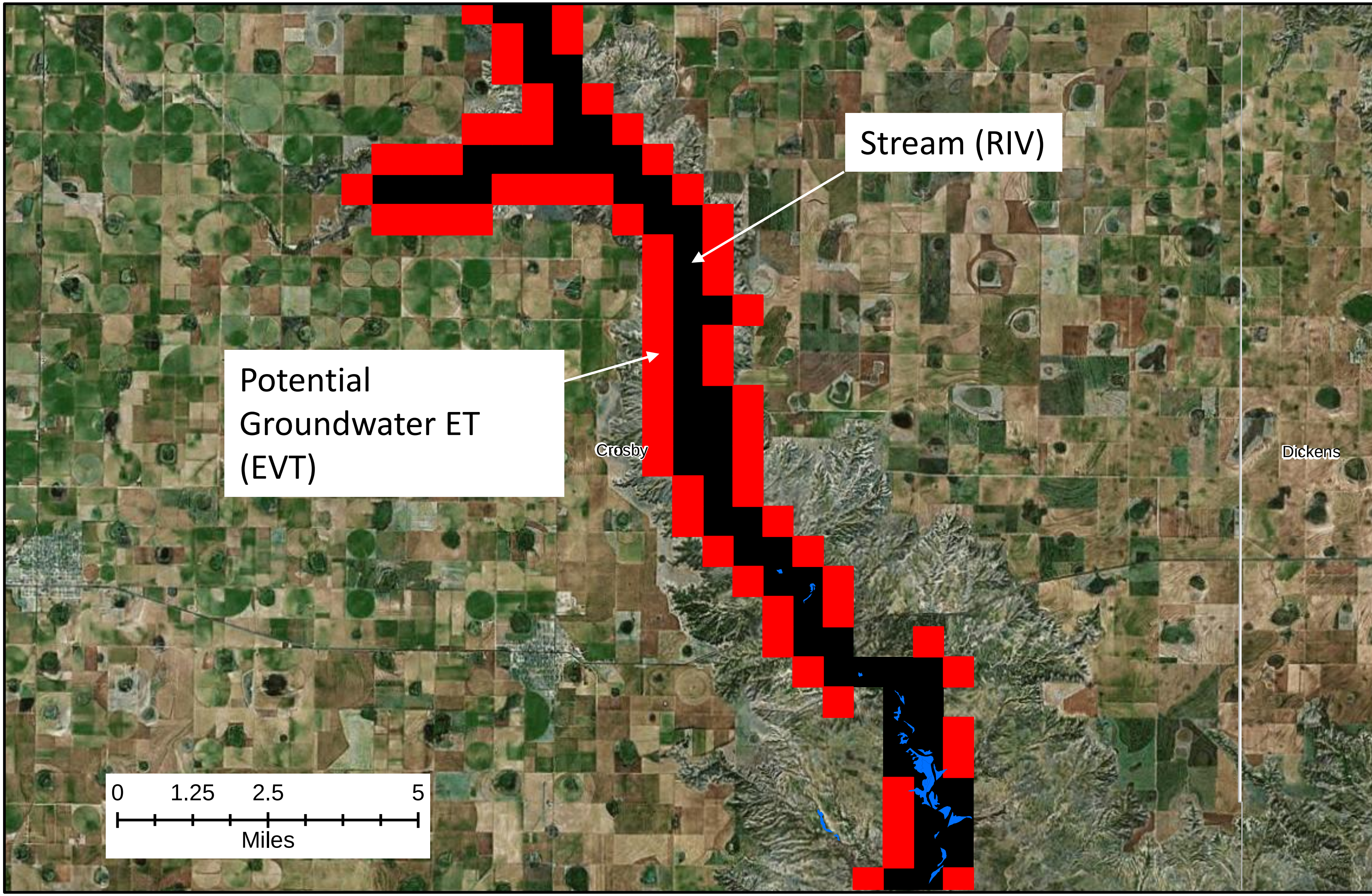


# Head boundaries: EVT

- ET was placed along streams
- Used US Fish and Wildlife NWI riparian zones as a starting point, coverage was not sufficient

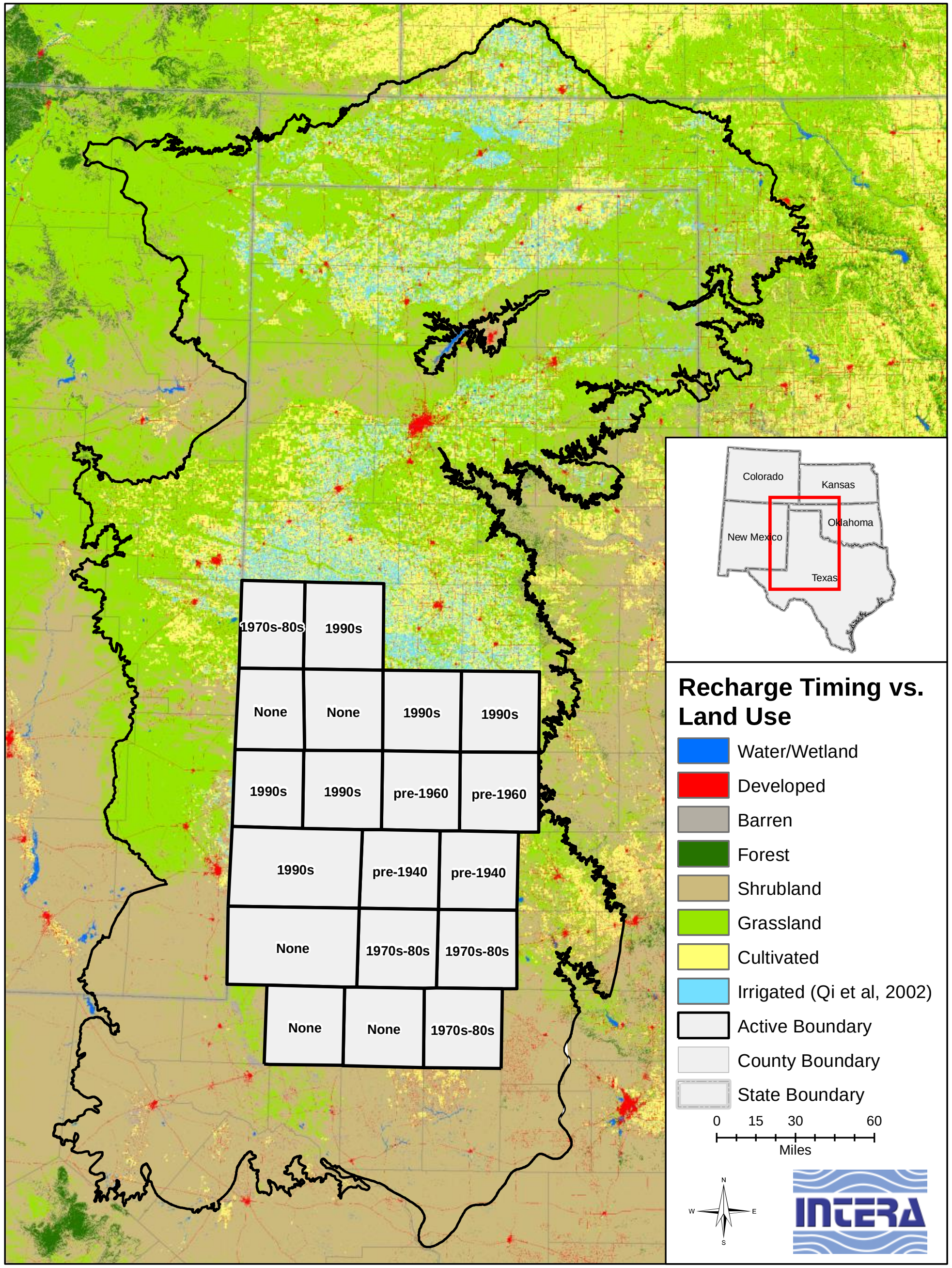


# Head dependent flux: EVT



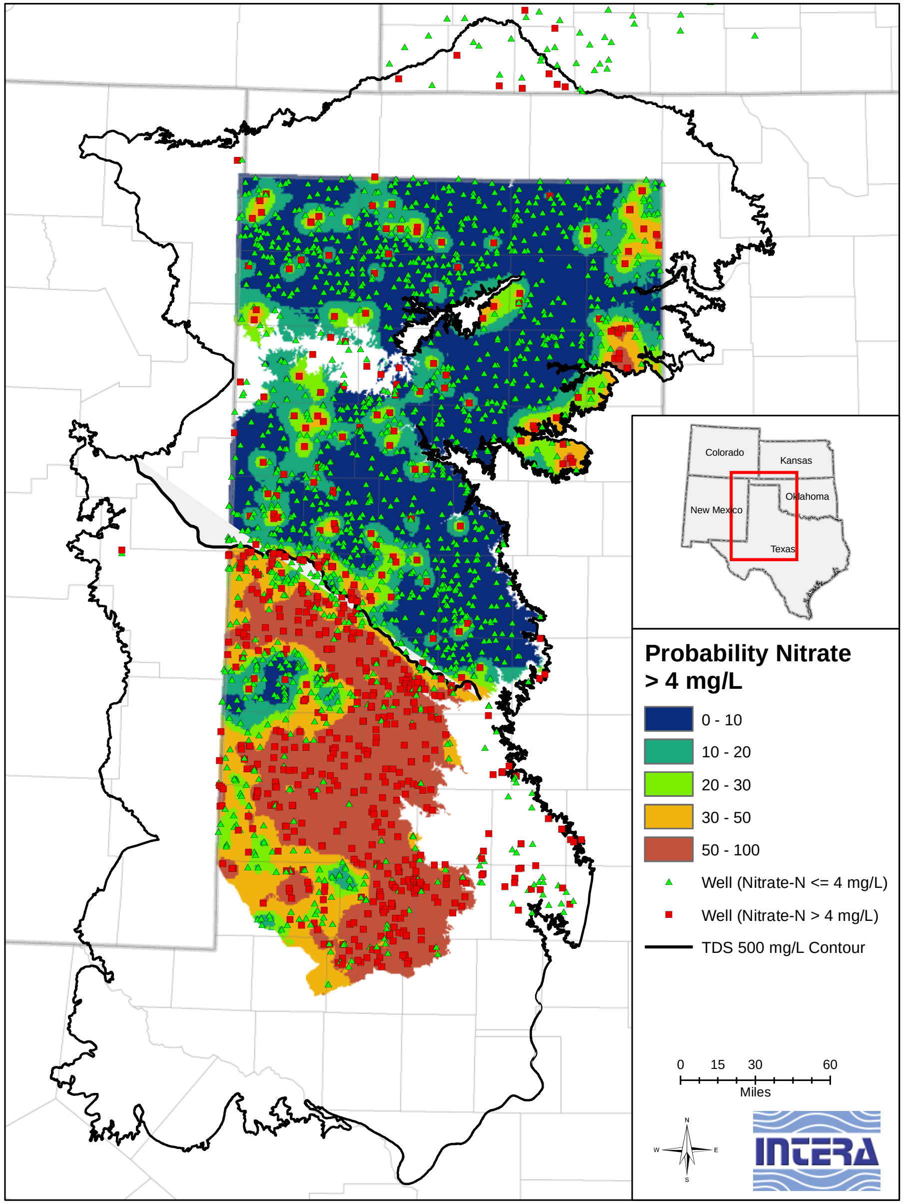
# Flux Boundary: RCH

- Initialized steady-state with Reedy/Scanlon estimates
- Transitioned to post-agriculture estimates based on breakthrough map



# Flux Boundary: RCH

- Areas with no evidence of agriculturally-enhanced recharge were kept at steady-state values



# Flux Boundary: Pumping

- Created combined database of all known wells from all sources
  - TWDB GWDB
  - Driller databases
  - TCEQ PWS
  - GCD Databases
- Used actual wells for pumping assignment when possible
- Located wells vertically based on screen location or well depth, and transmissivity weighted allocation to the wells
- Had meter data for only a few wells (primarily CRMWA)
- “Fuzzy” matched owner name and survey type (MIN, MUN, etc) when possible for survey data pumping (i.e. >= year 1980)

# Flux Boundary: Pumping

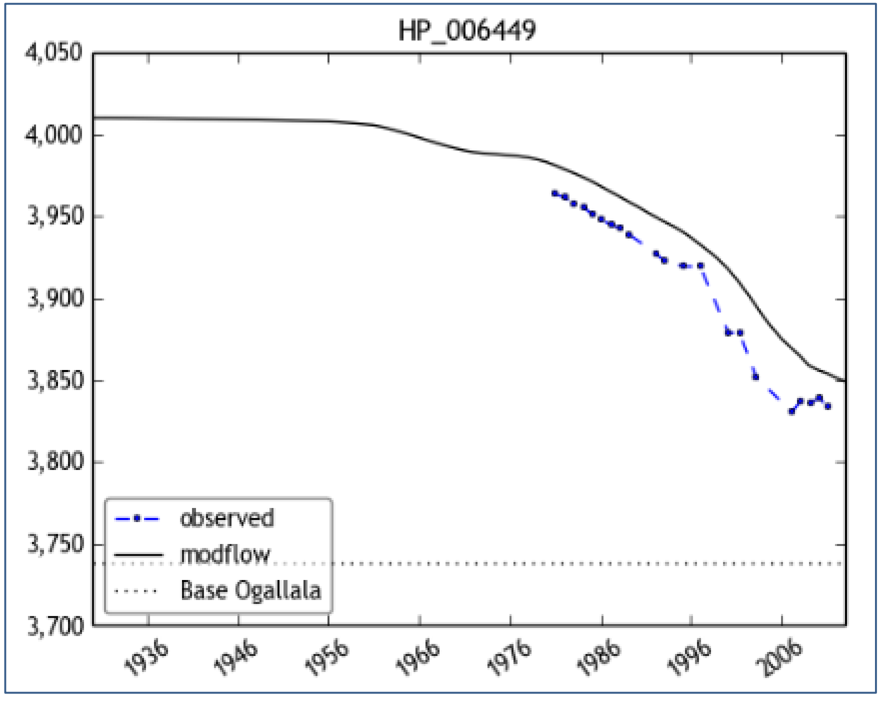
- For irrigation pumping (the bulk of the pumping), used irrigation well locations
- Estimated maximum pumping rates based on saturated thickness
- Added “ghost” wells in places where pumping exceeded the number of wells available in the database
- Added wells in locations where pivot circles were recorded, but no wells were in place

# Flux Boundary: Pumping

- Added wells in locations where pivot circles were recorded, but no wells were in place
- Attempted to honor estimated pumping post-1980 by county
- Pumping prior to 1980 was reduced in some cases (more later)

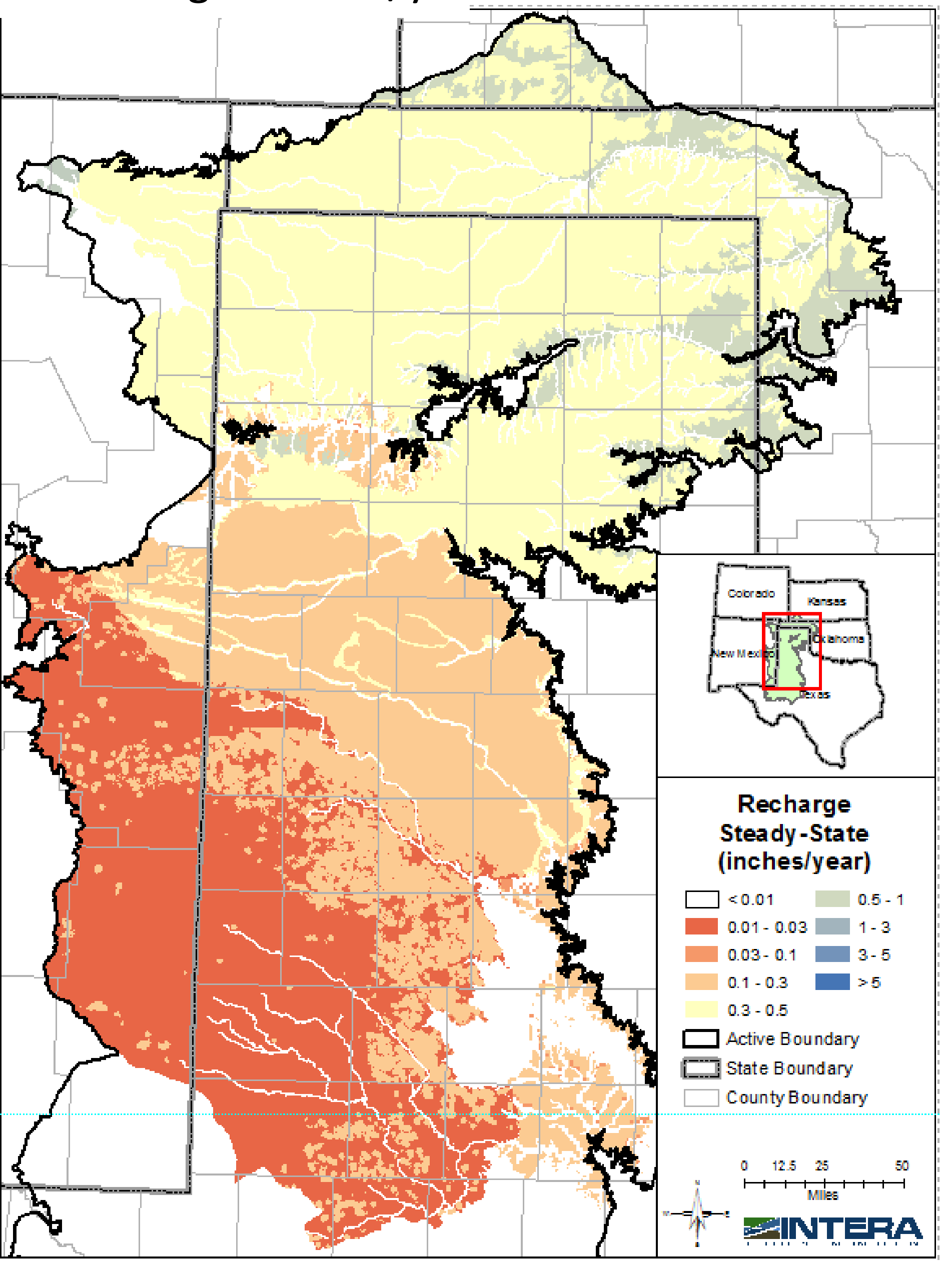
# Model Calibration

- Model calibration is the adjustment of parameter values within well-defined bounds to improve the fit between simulated and measured or estimated results
- Model is calibrated to both steady-state (prior to development) and transient conditions
- Calibrating to both conditions helps constrain parameters, creating a more realistic model
- The steady-state condition represents the starting point for the model
- Primary calibration target is water level measurements

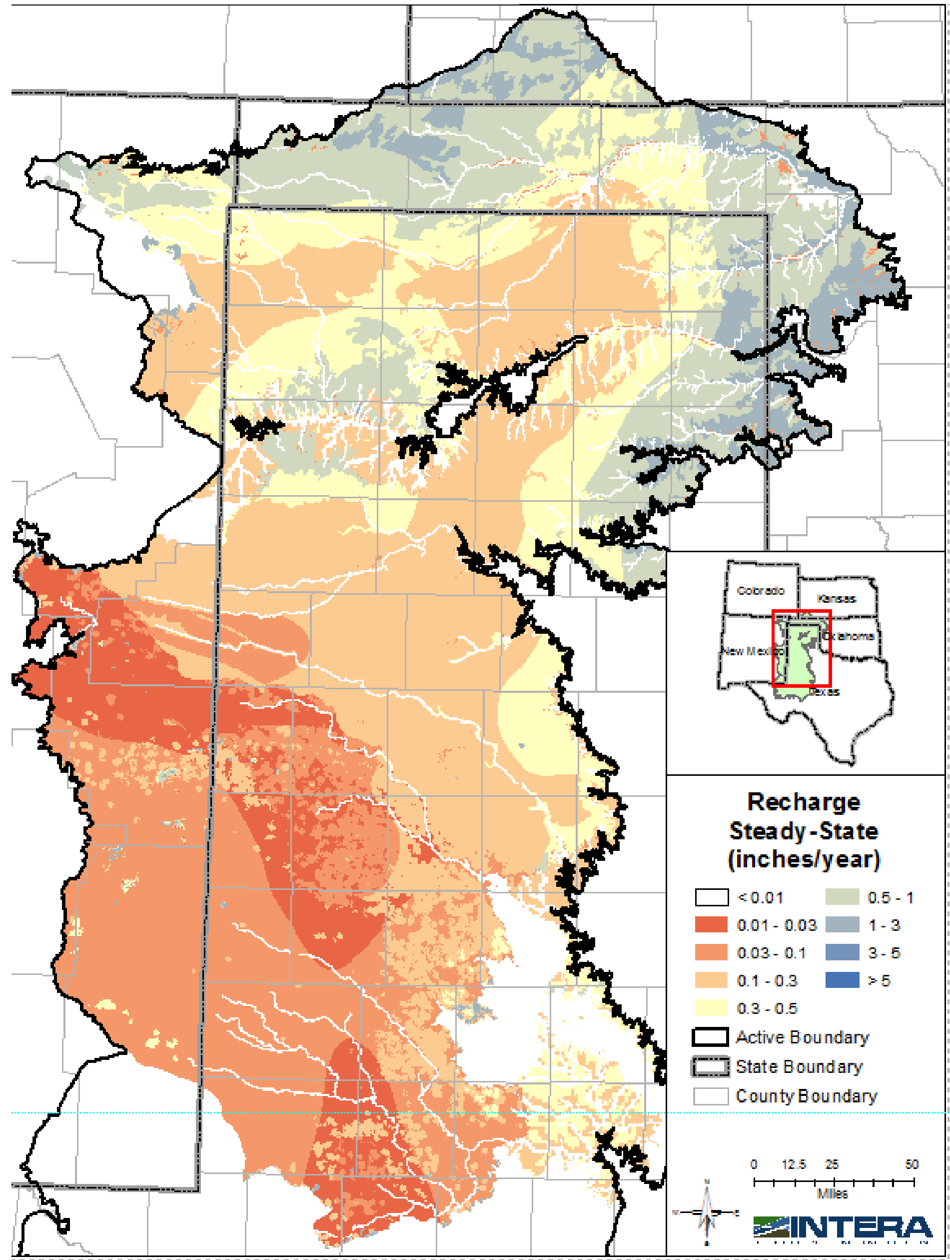


# Steady-State Calibration

Initial Avg = 0.23 in/y

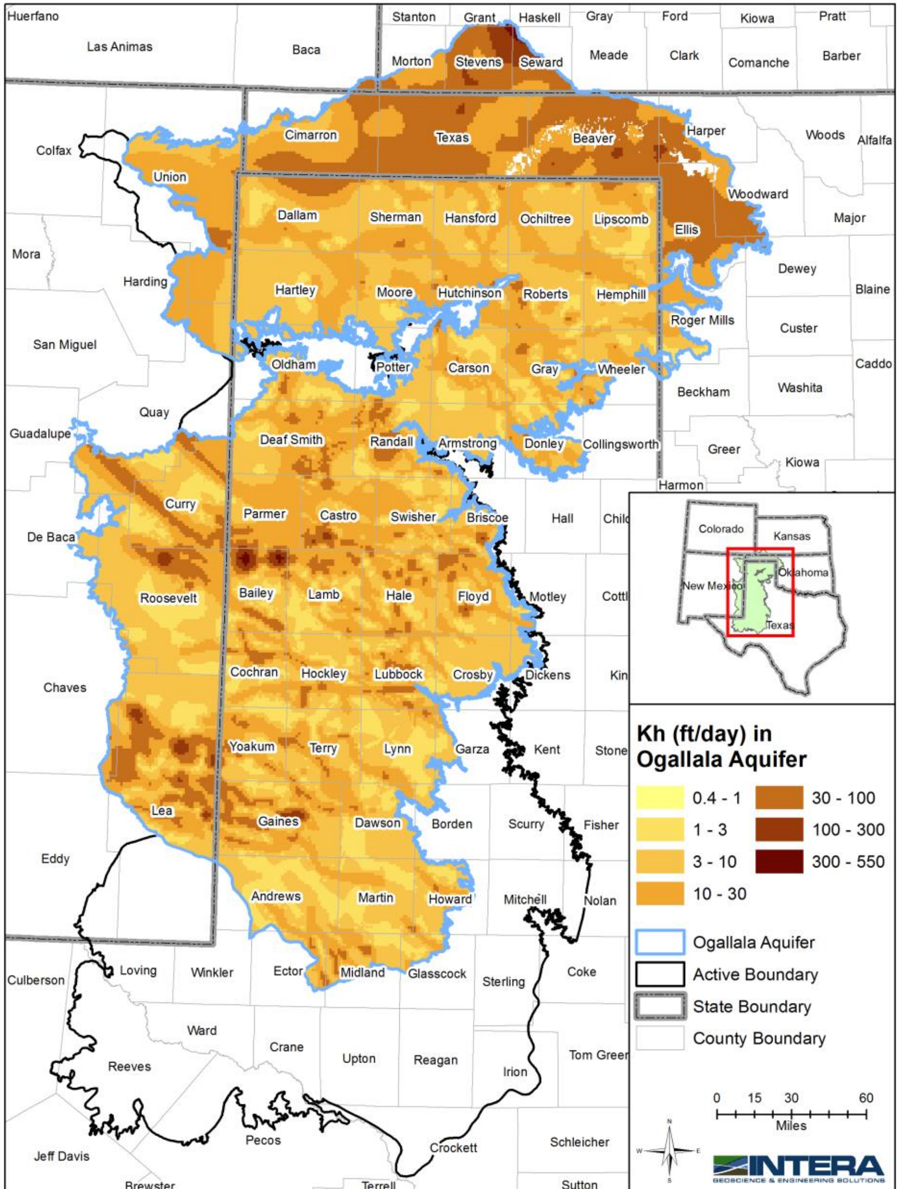



Calibrated Avg = 0.28 in/y

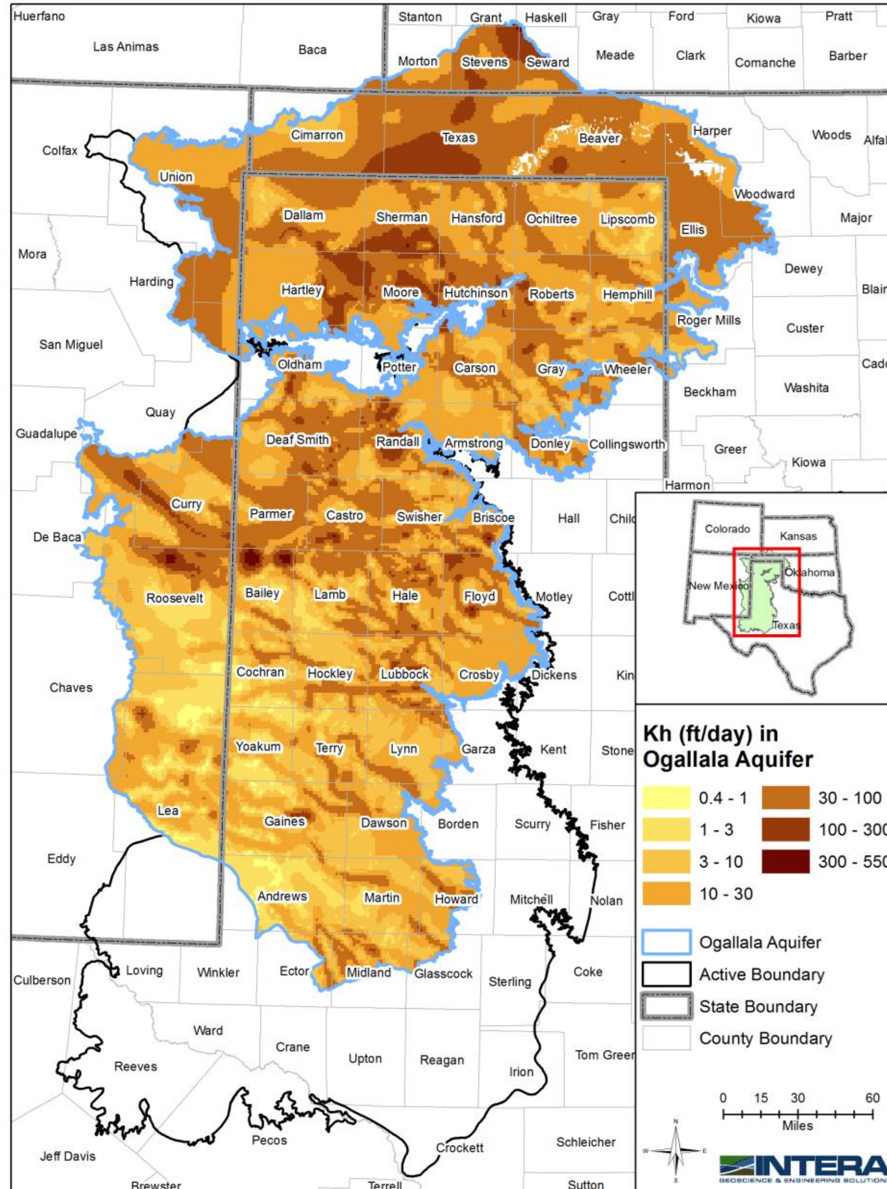


# SS Calibration

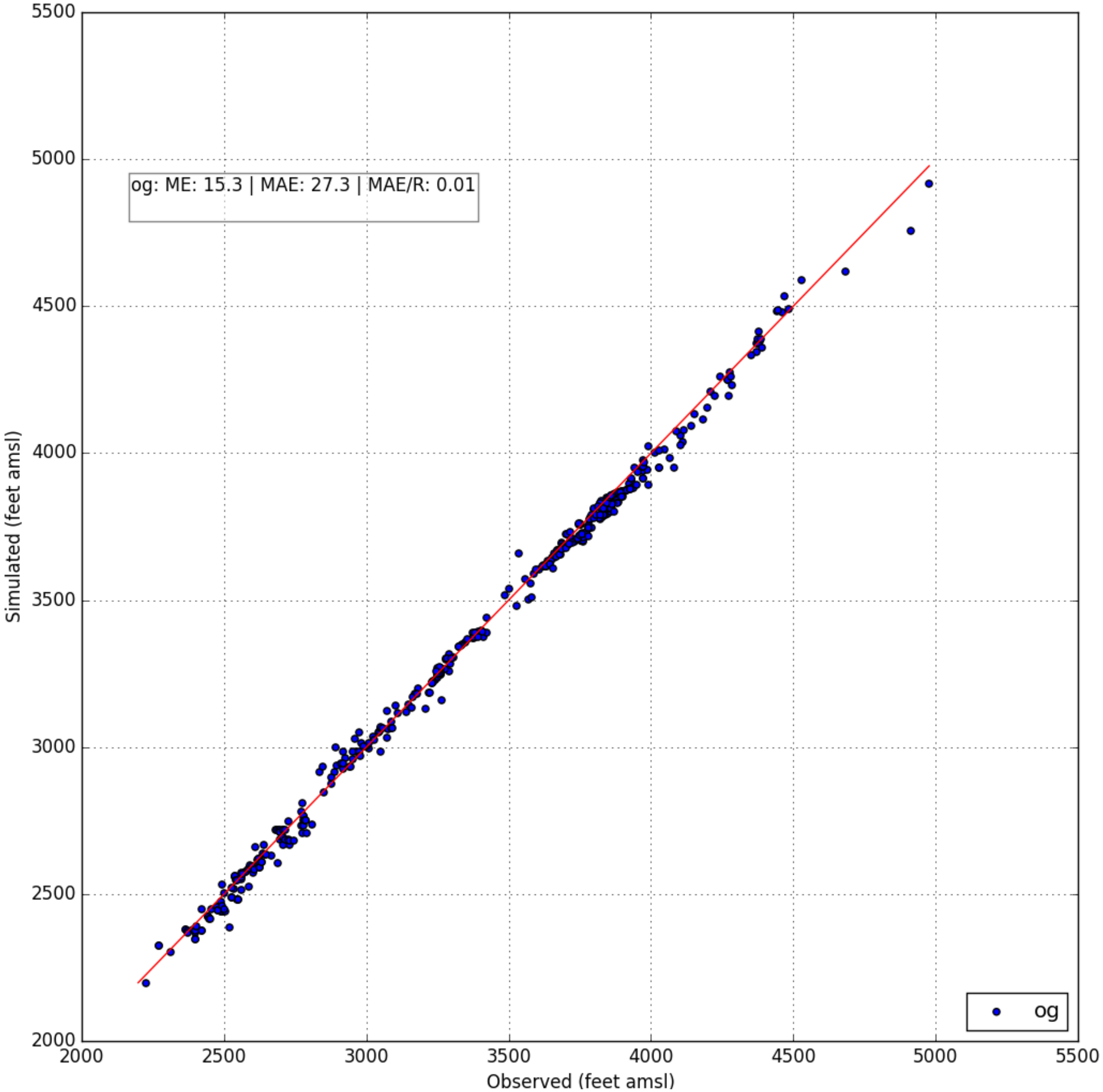
Initial Avg = 18 ft/d




Calibrated Avg = 33 ft/d

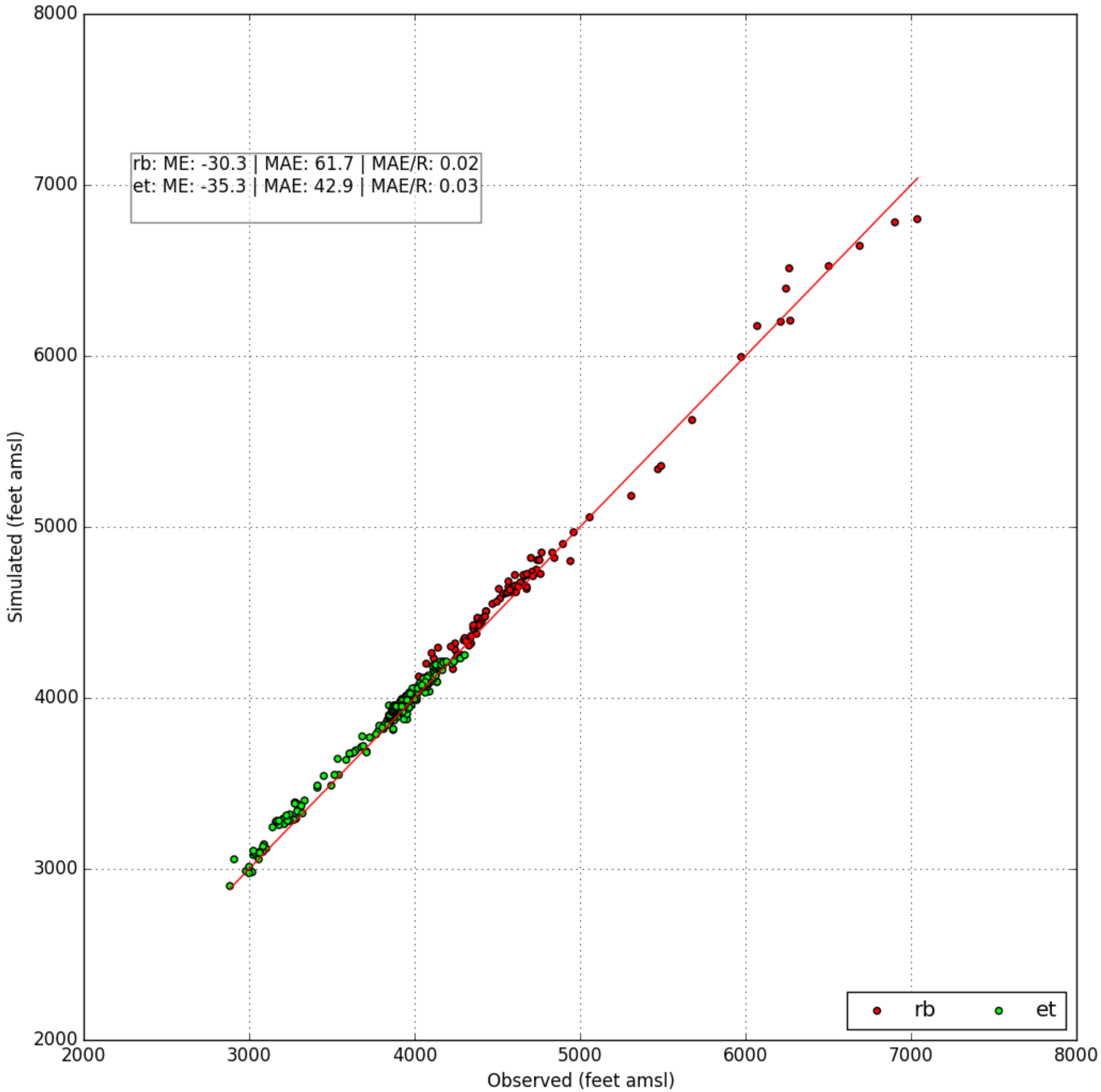


# Draft Steady-State Calibration



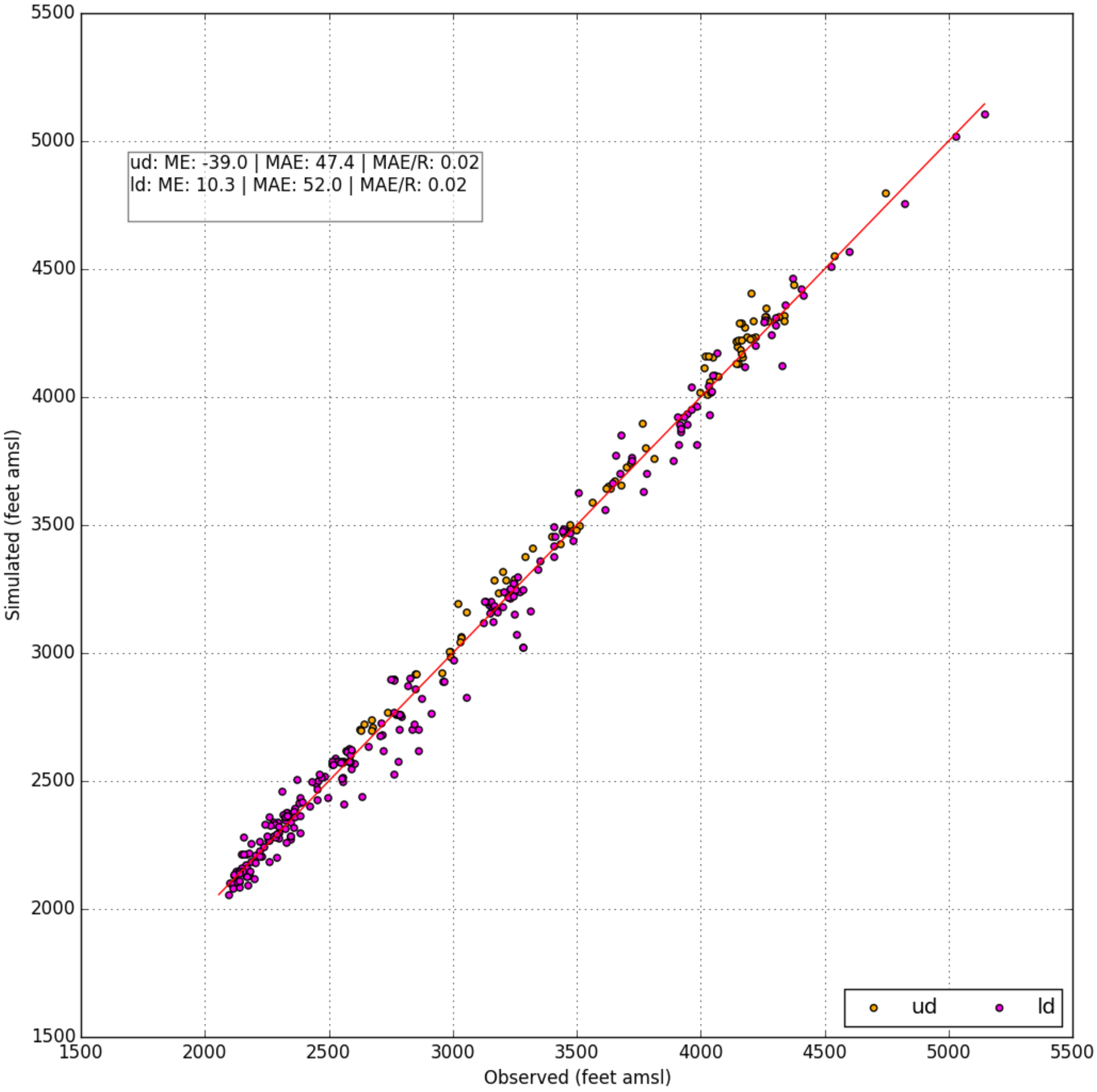

- Biggest challenge was keeping Ogallala “wet” in the west at high topography
- Wet/dry was sensitive to parameterization of underlying units
- Using parameters from current GAMs “as-is” does not work well

# Draft Steady-State Calibration



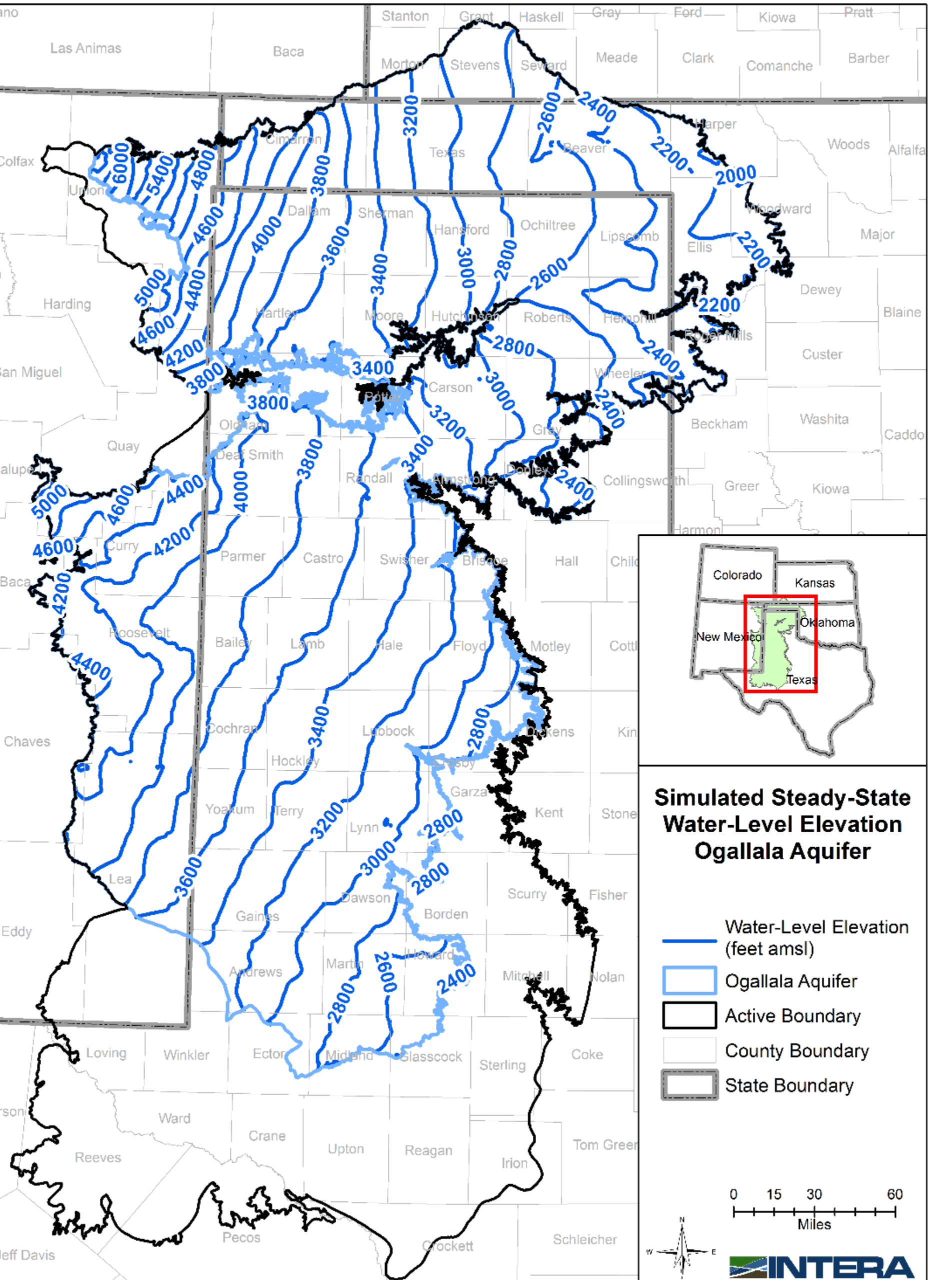

- Some bias in ETHP a compromise with:
  - Keeping Ogallala wet in the west
  - Getting sufficient drawdown in ETHP in transient
- Being on the simulated high-side in steady-state most consistent with water levels affected by development

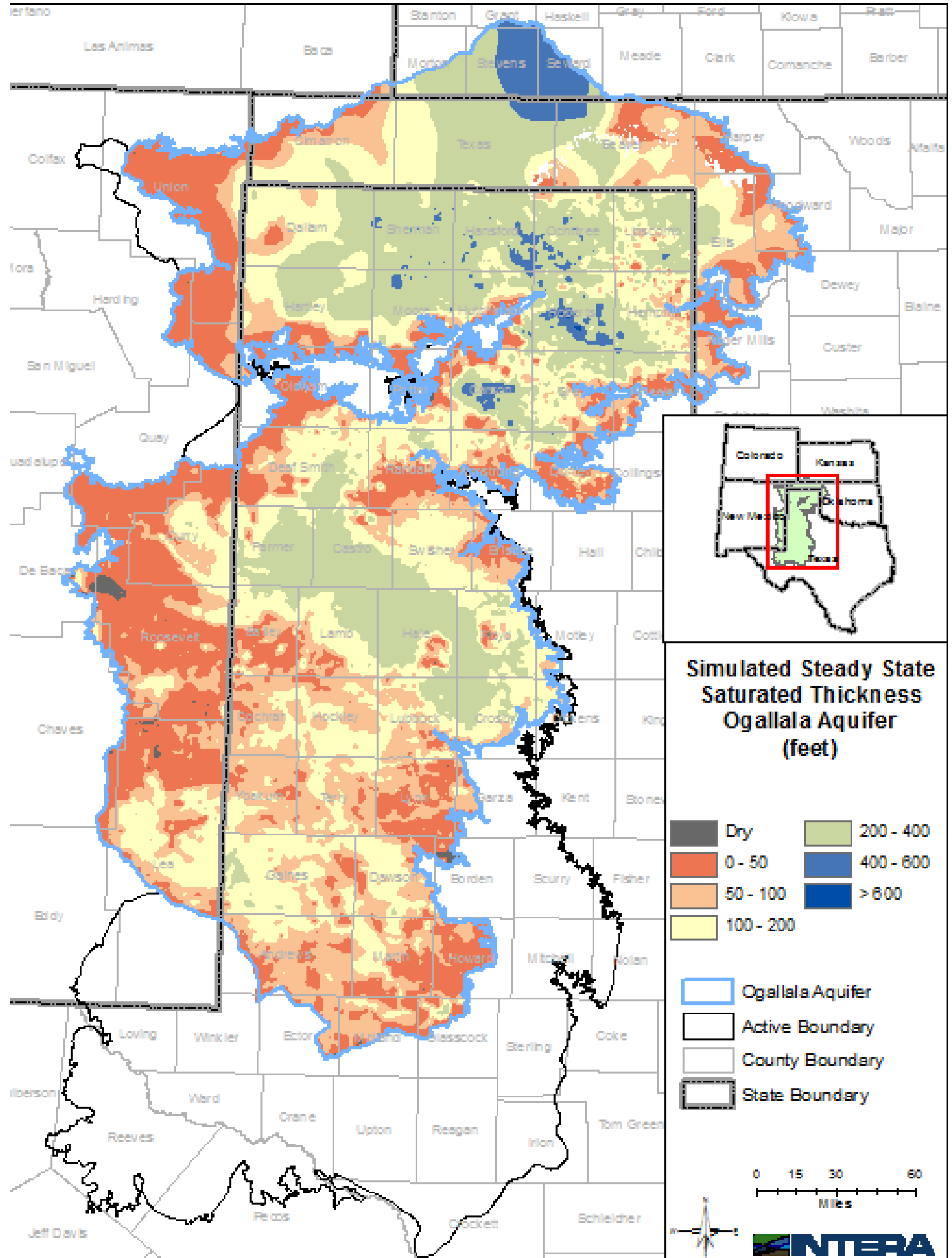
# Draft Steady-State Calibration




- Dockum shows the most "scatter"
- Few targets in Upper Dockum, probably not worth calibrating it separately

# Steady-State Calibration



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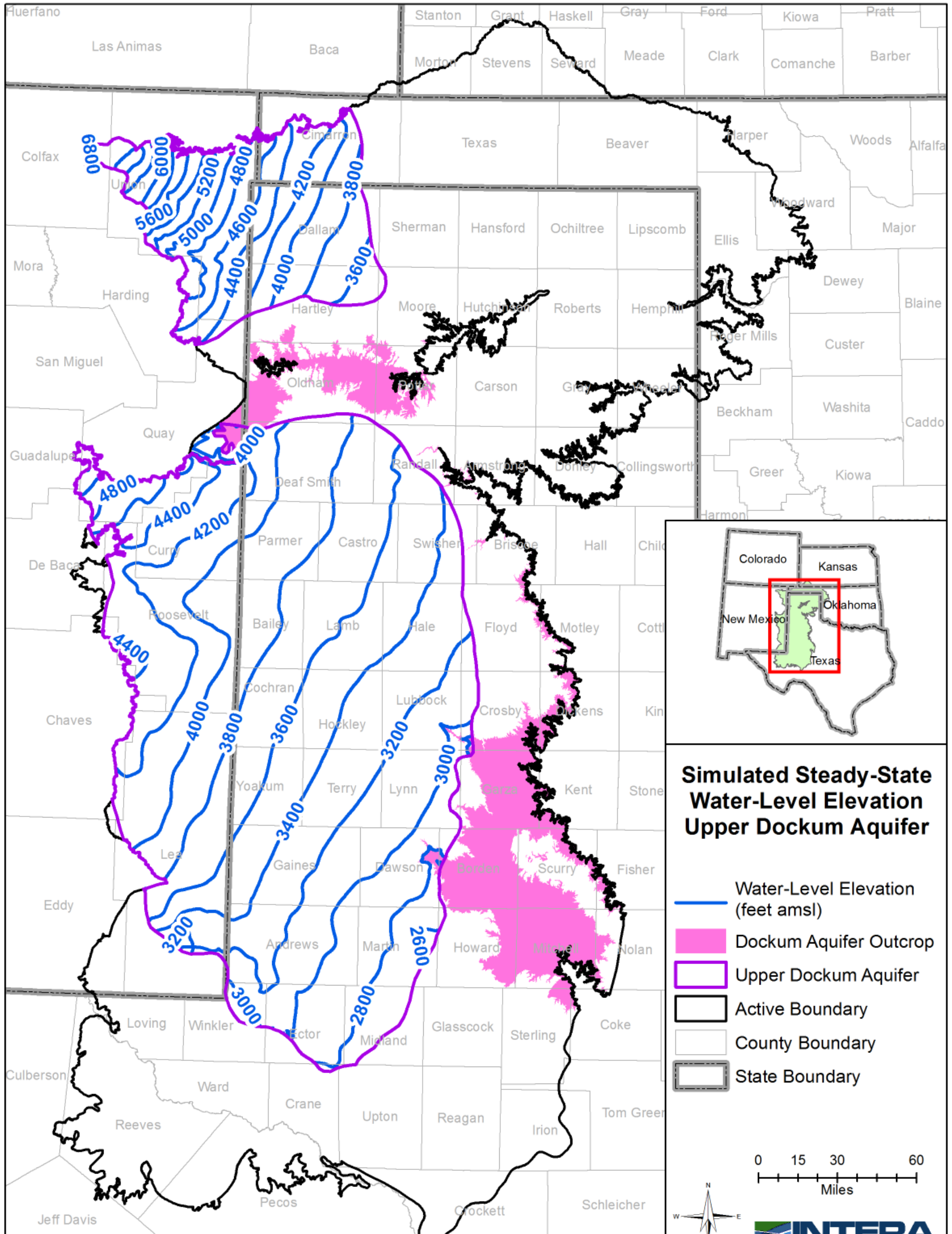


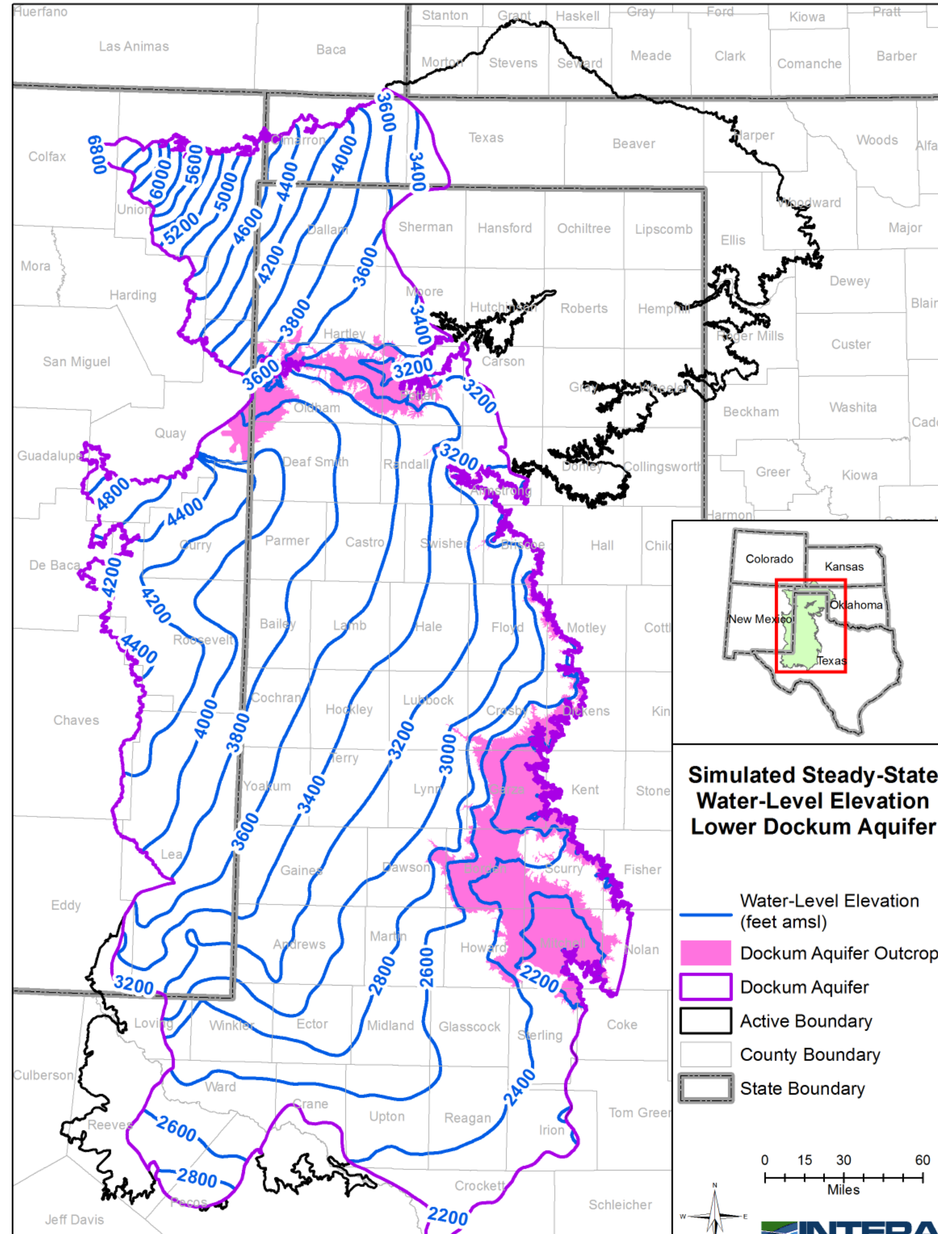

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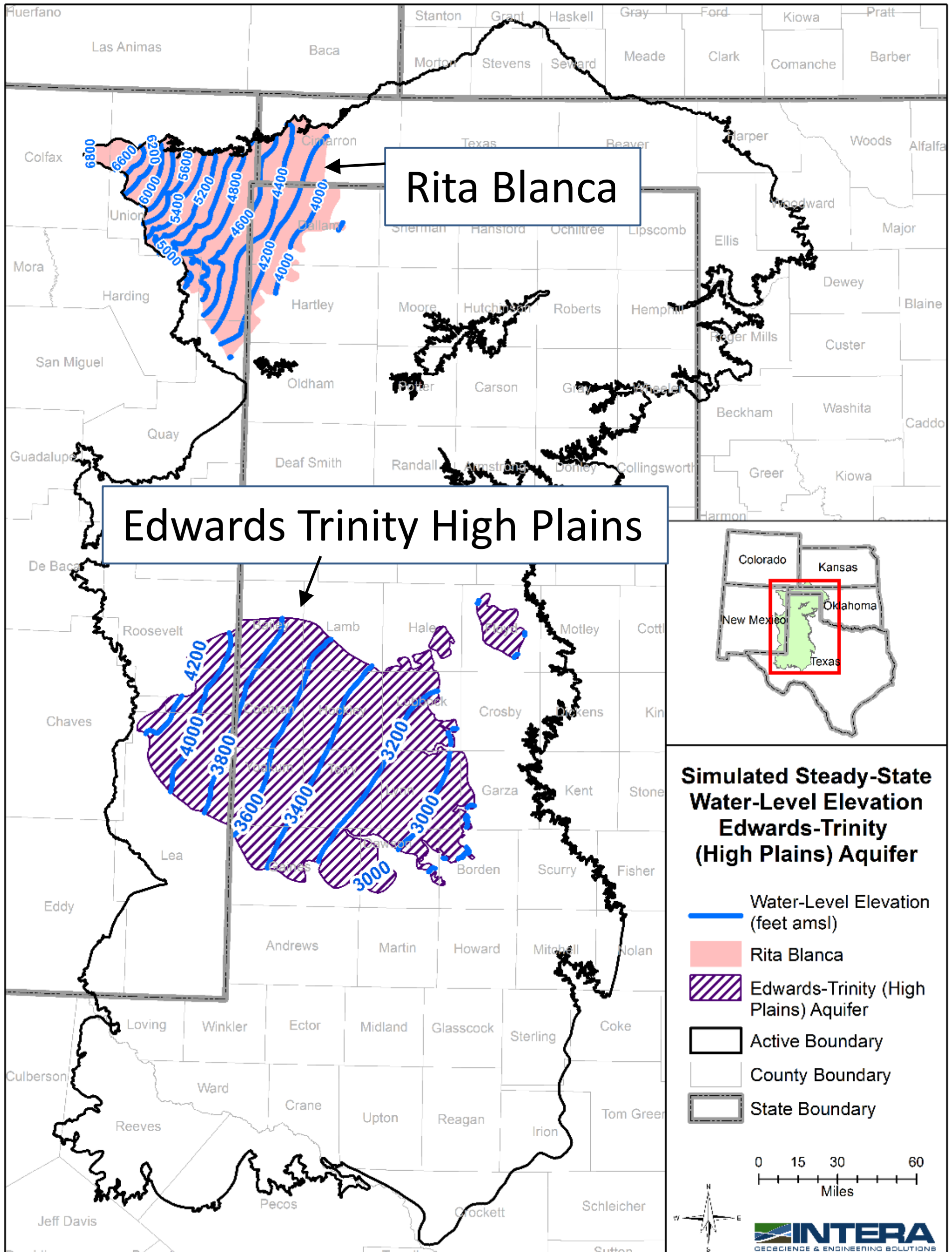
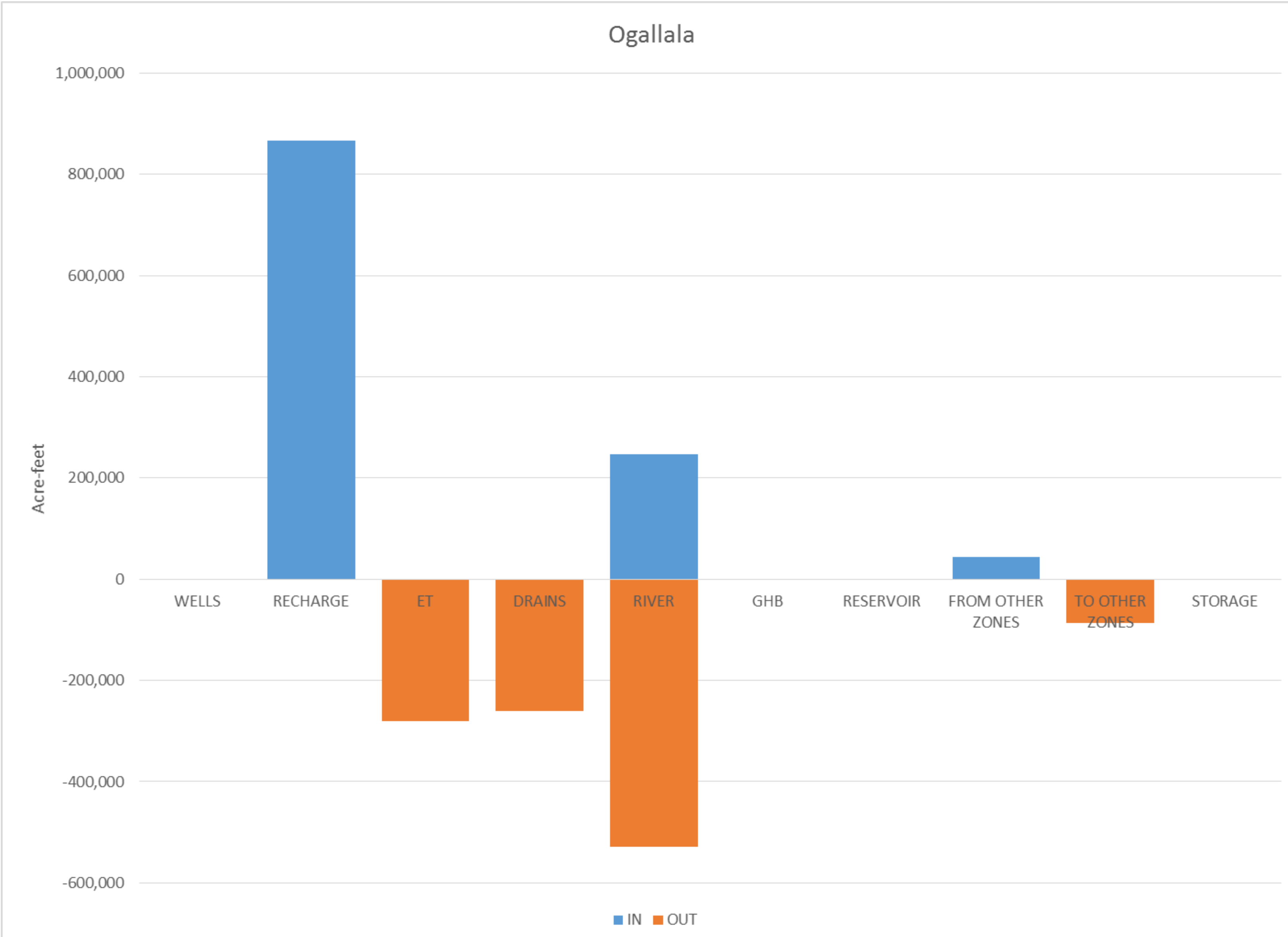


# Steady-State Water Balance



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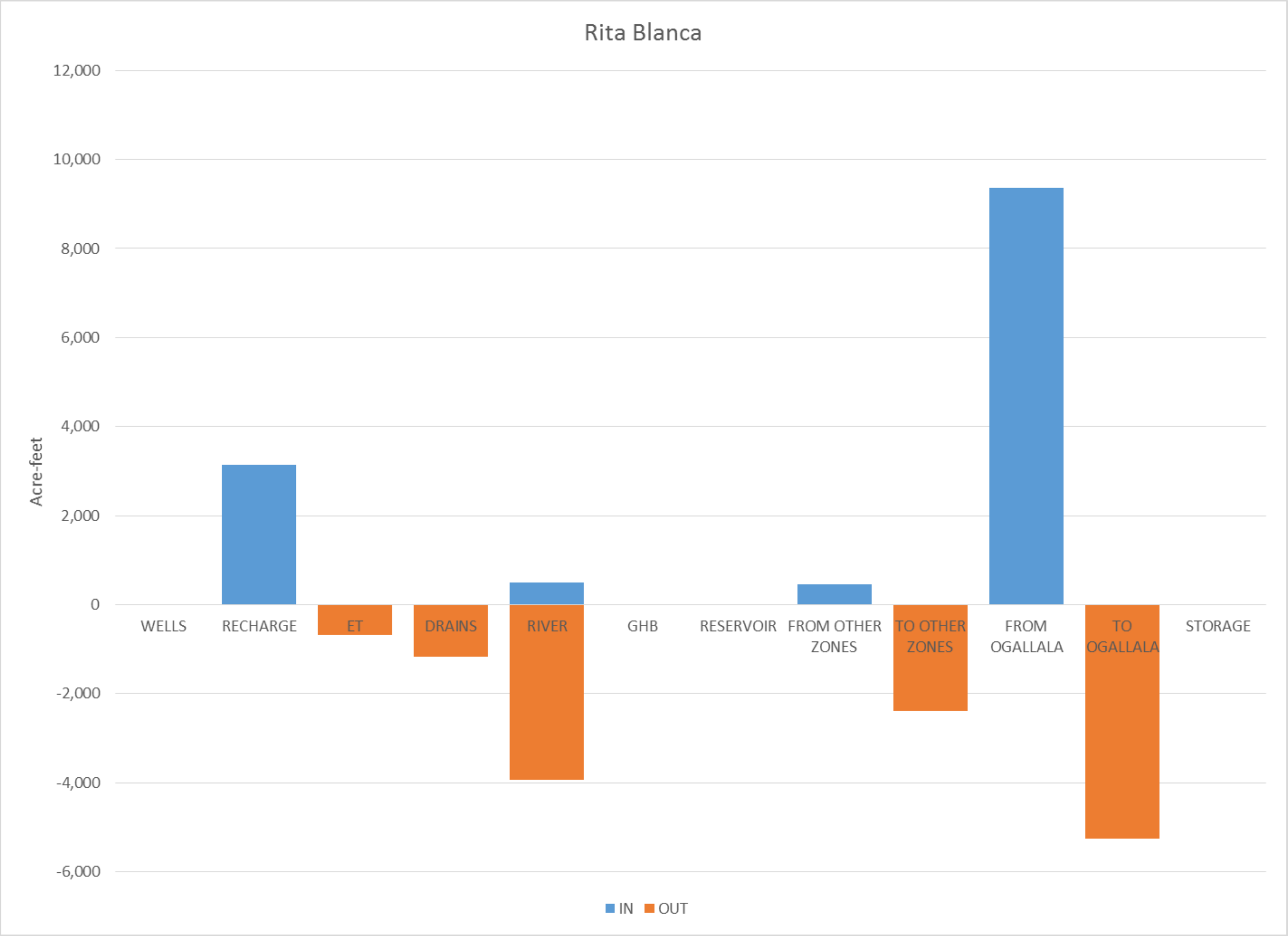

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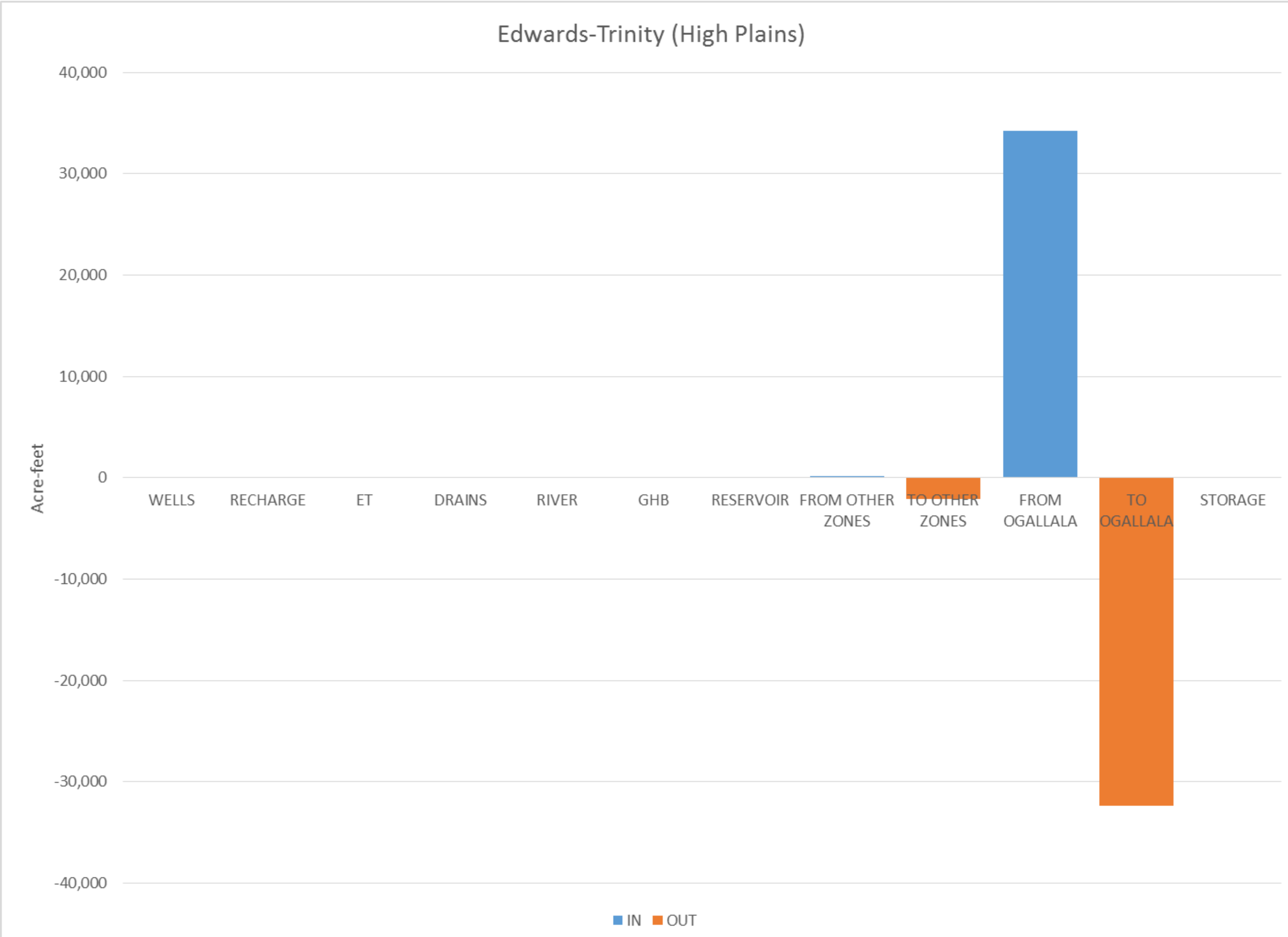

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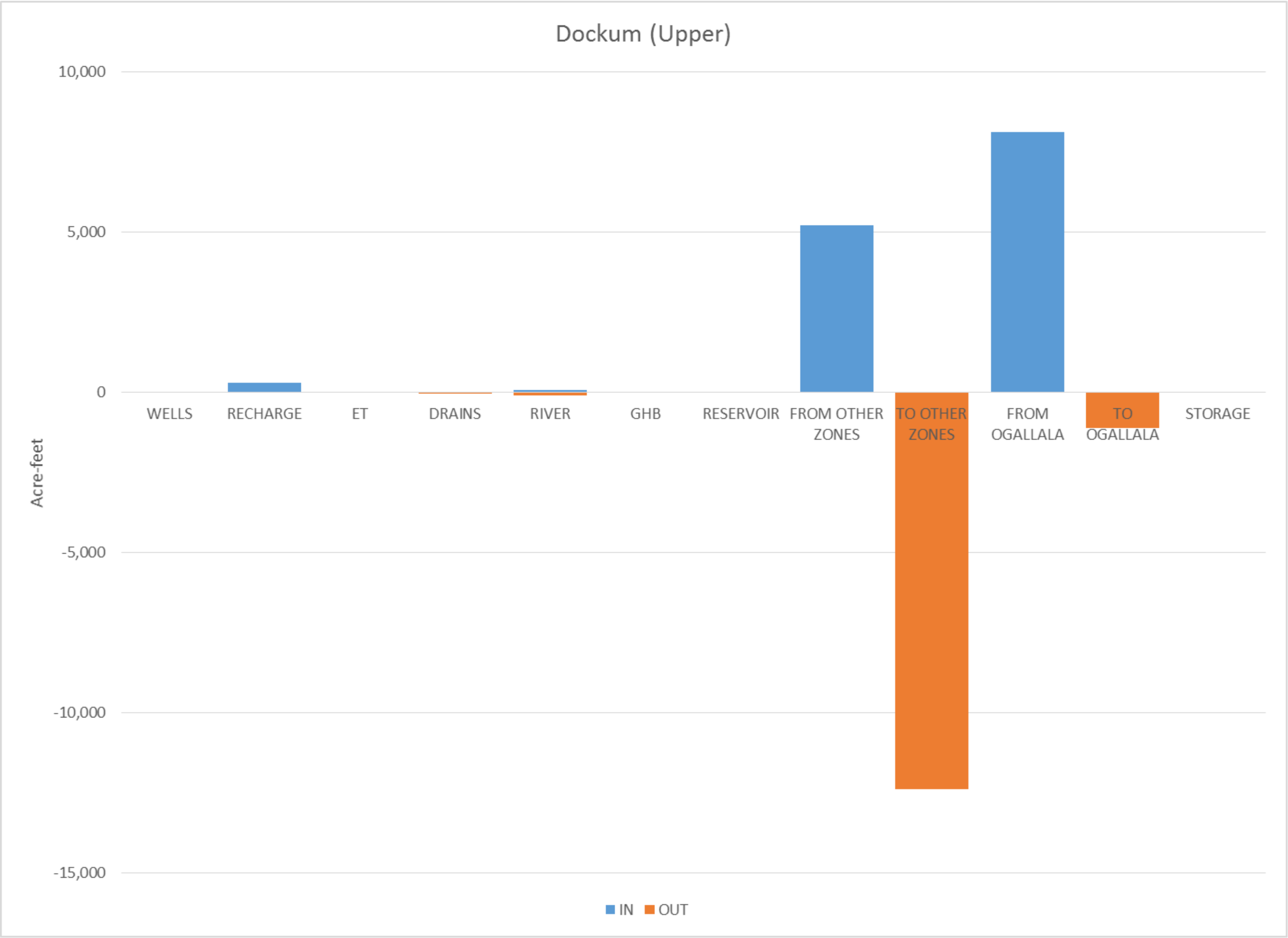

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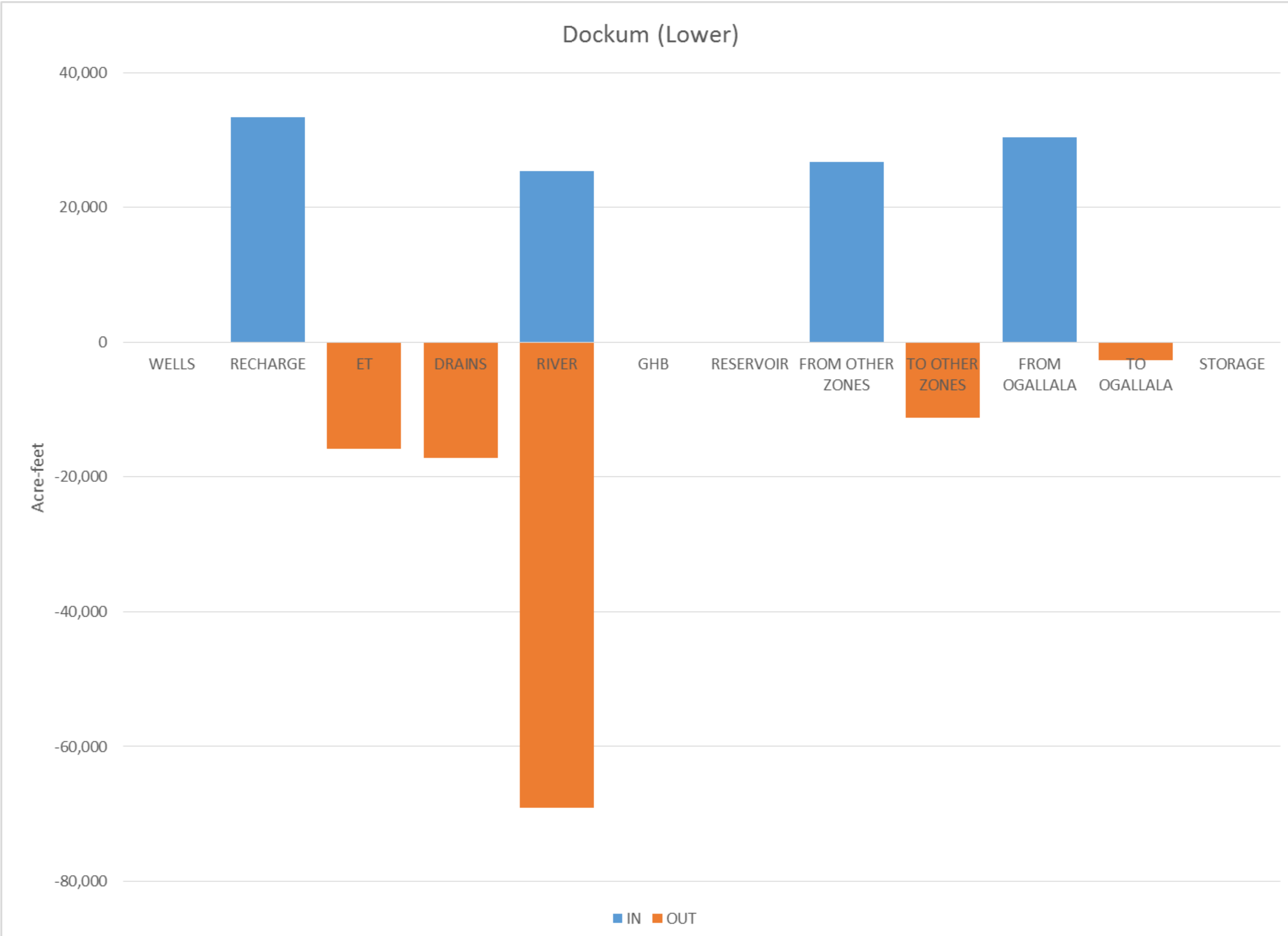
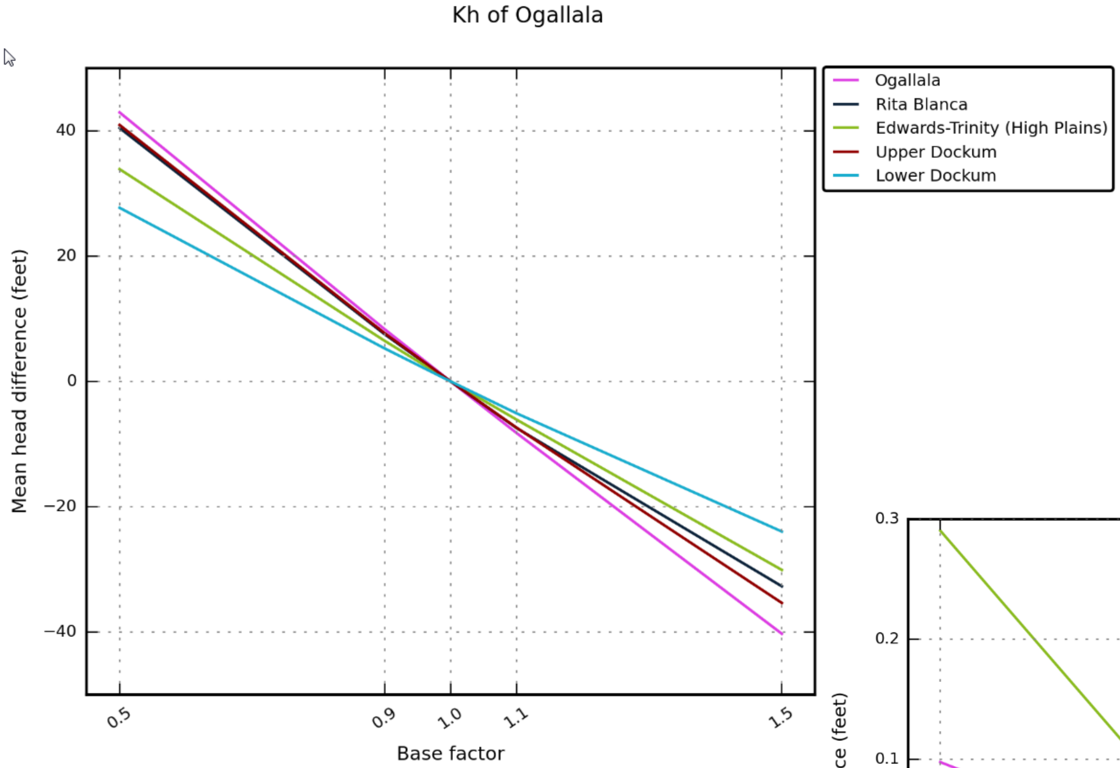
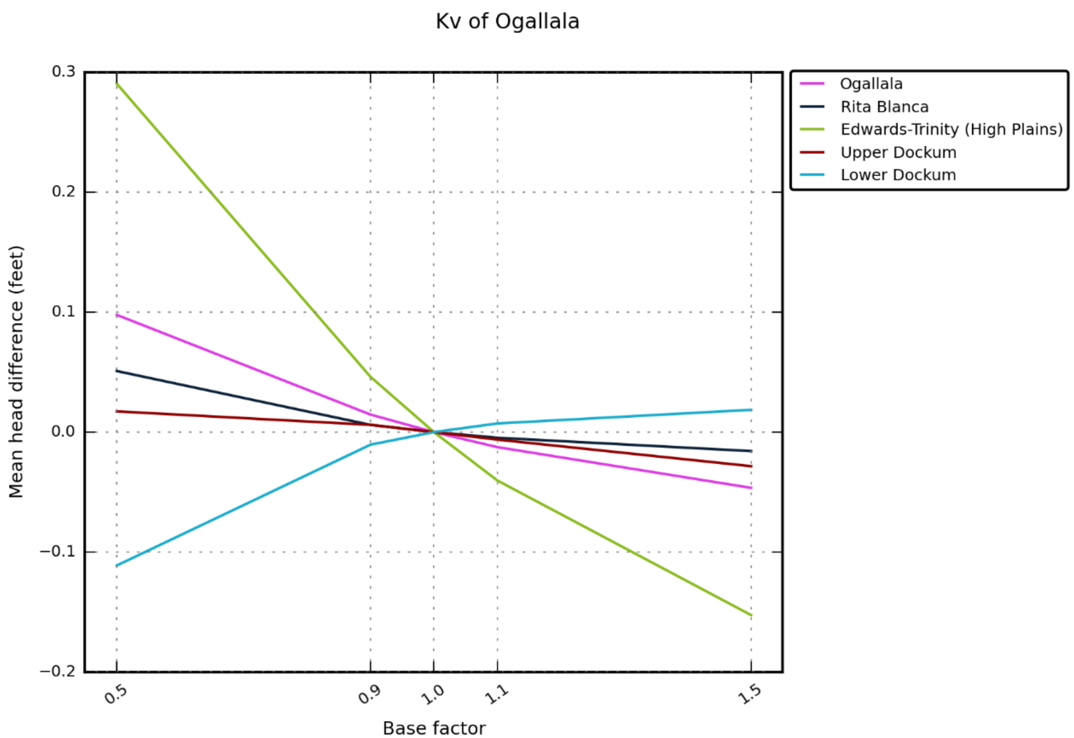


# Steady-State Sensitivities

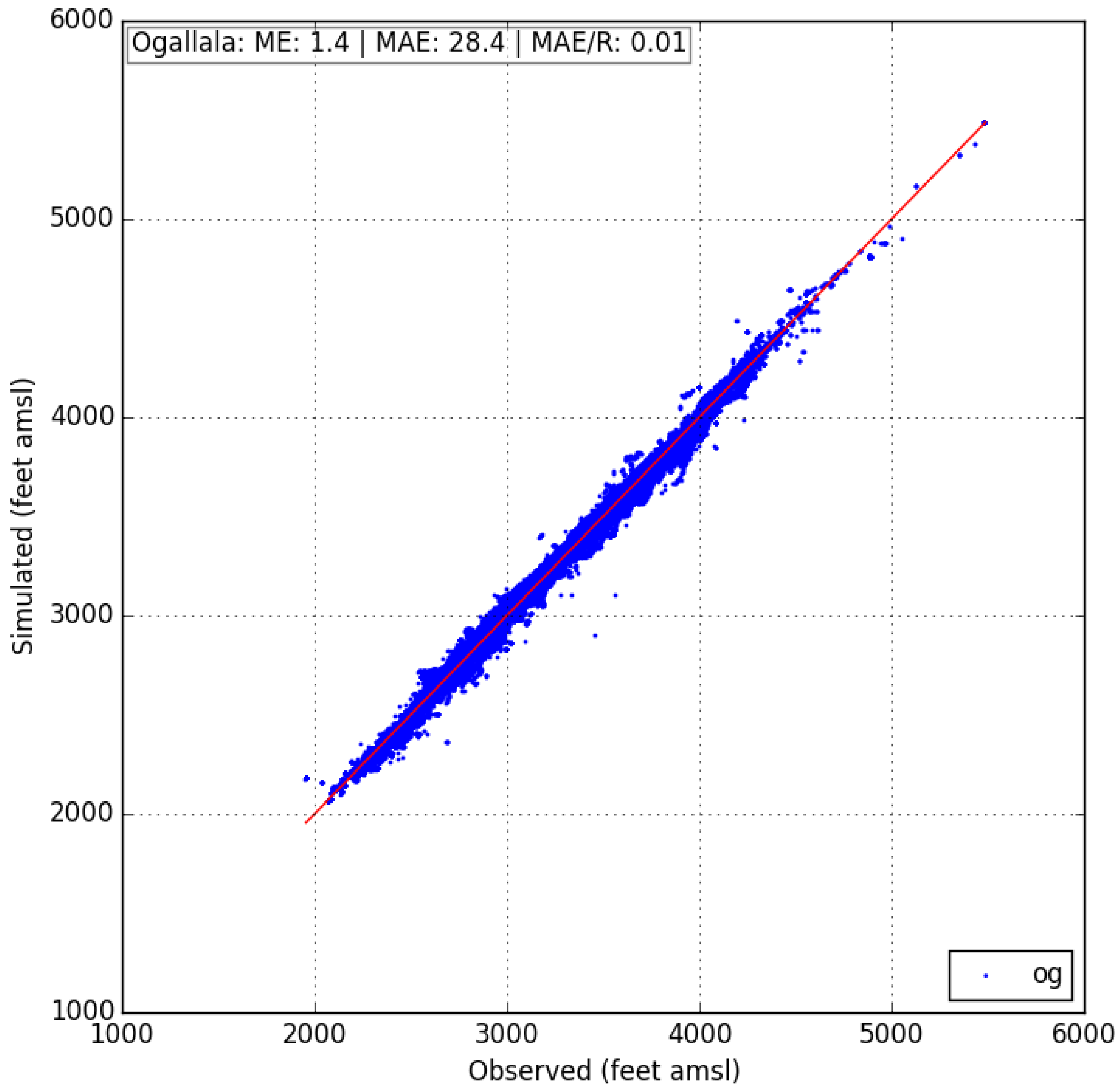



Ogallala lies on lower Kv sediments

# Transient Calibration

- Model goes from 1929 (SS) to 2012, with 84 annual SPs
- Kh/Kv were modified somewhat from steady-state (fields were shown previously)
- Specific storage not changed
- Sy modified in a small area
- Pumping is the big driver in the Ogallala



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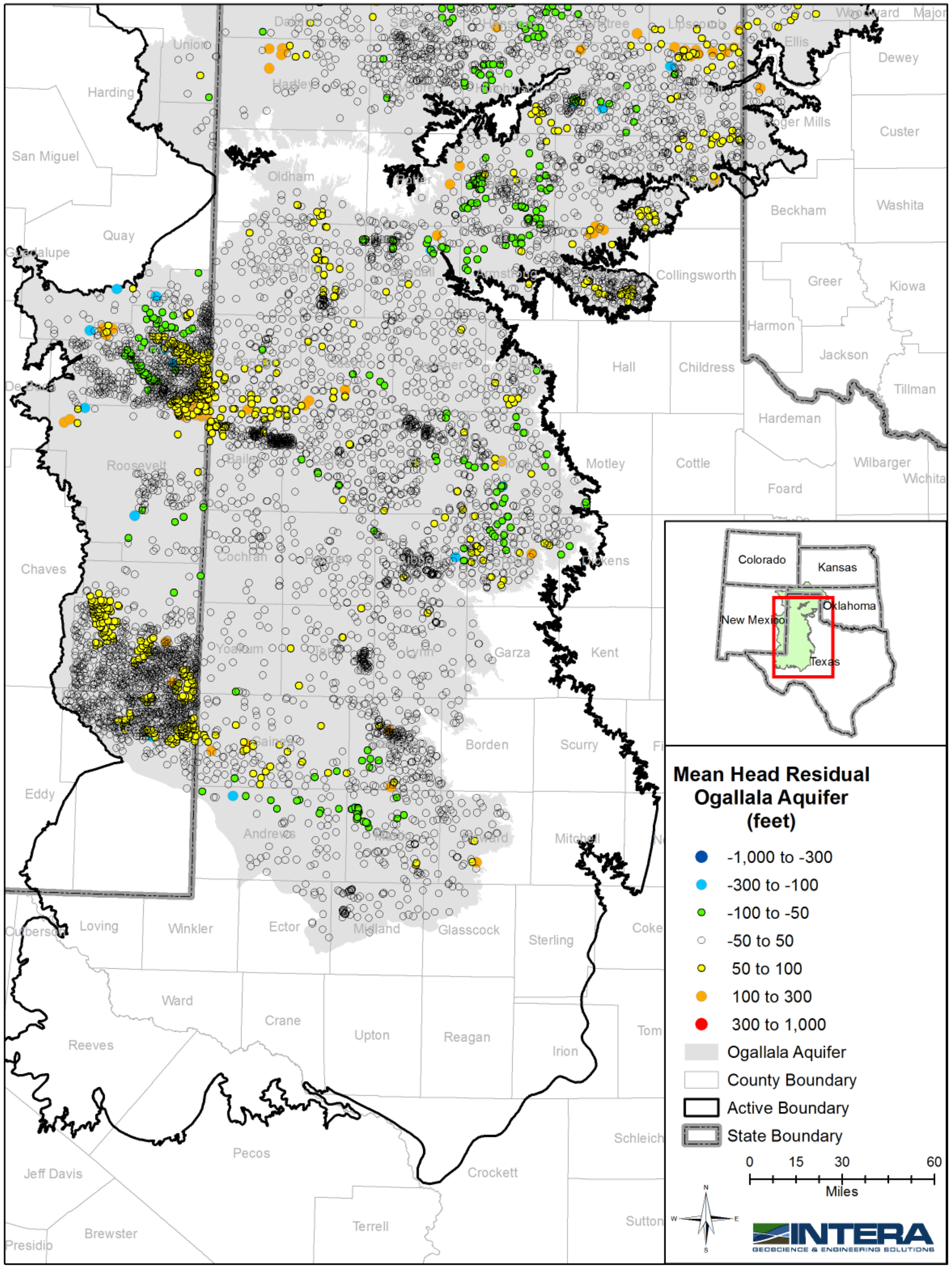

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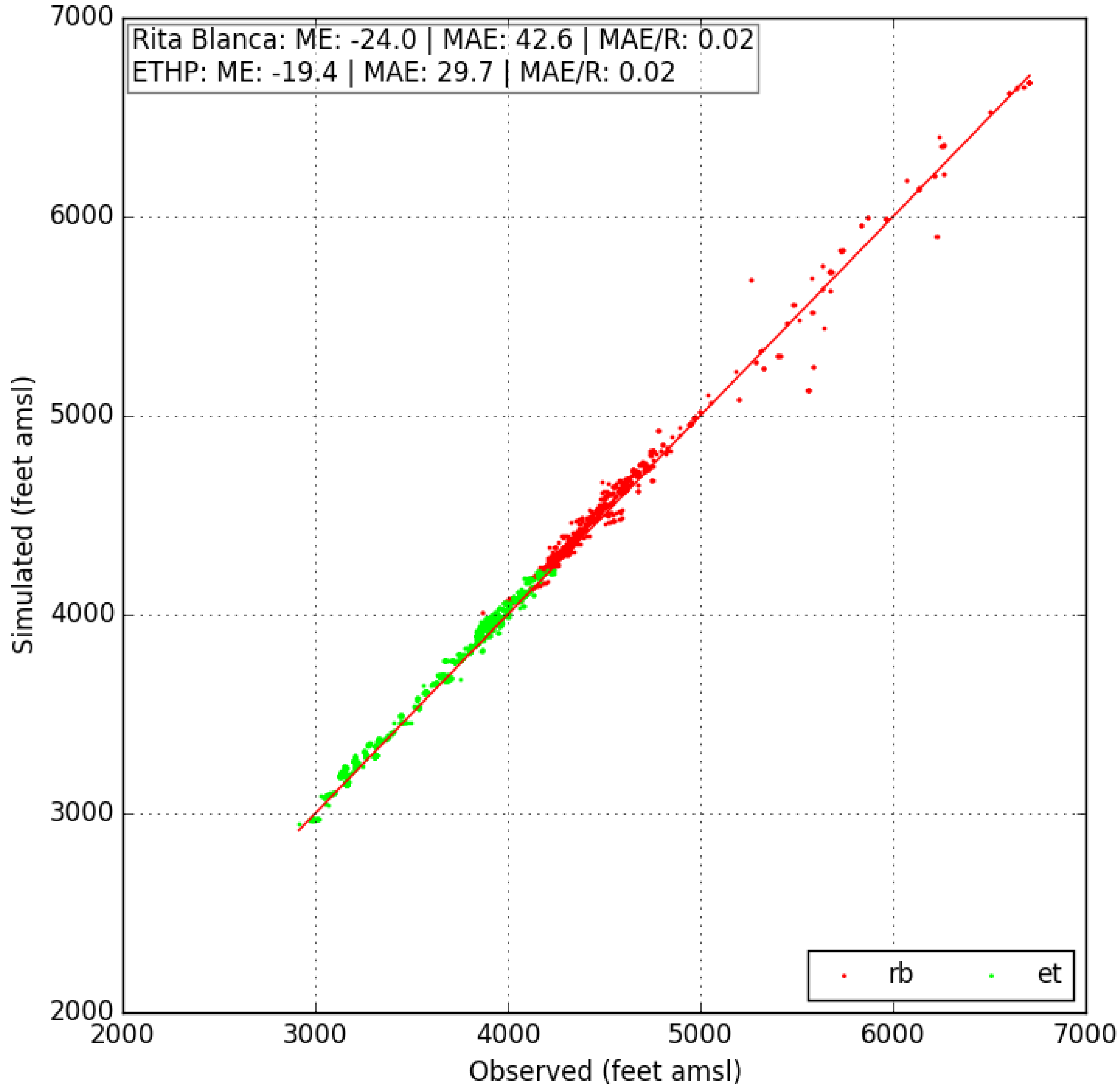

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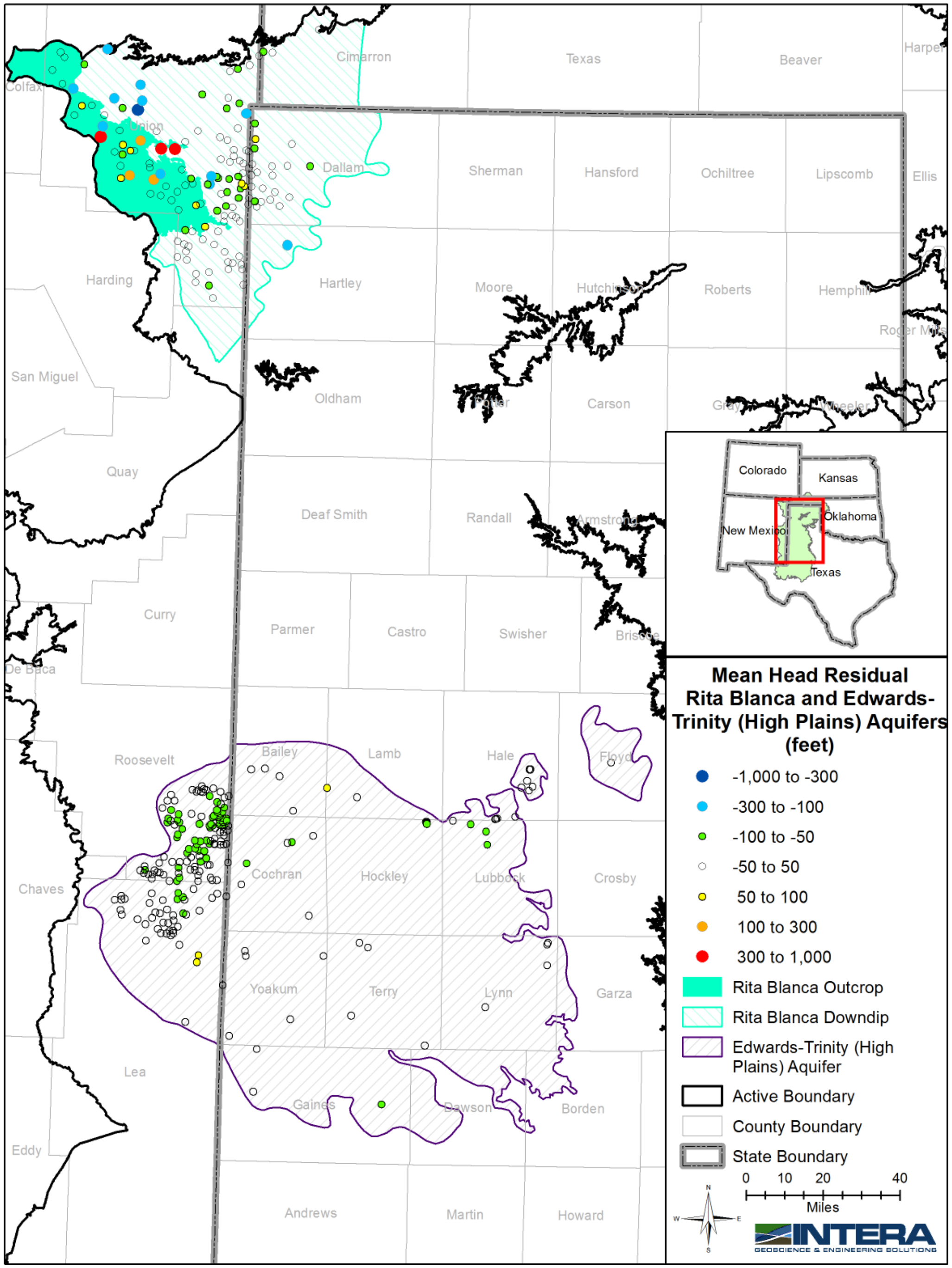

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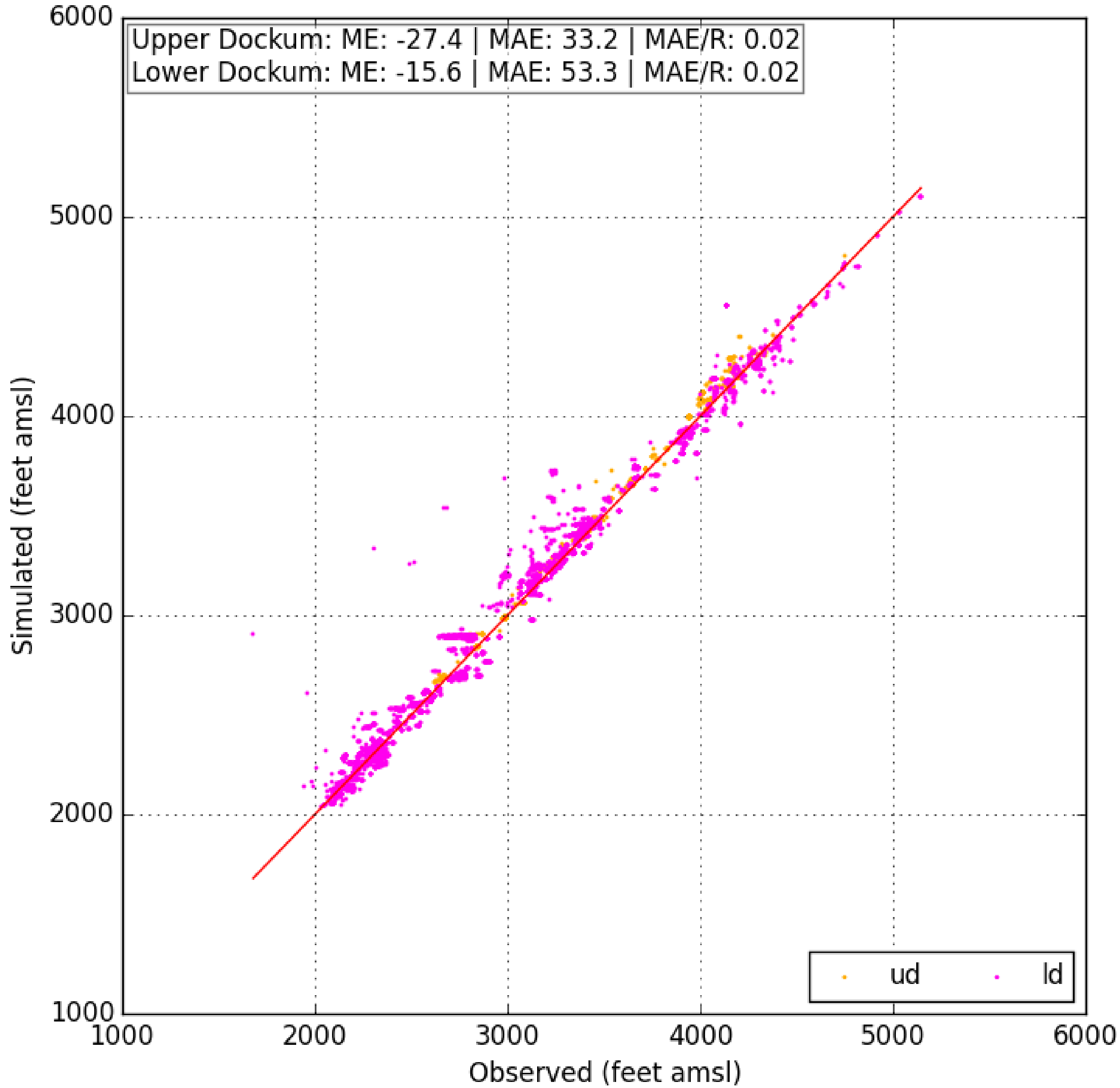
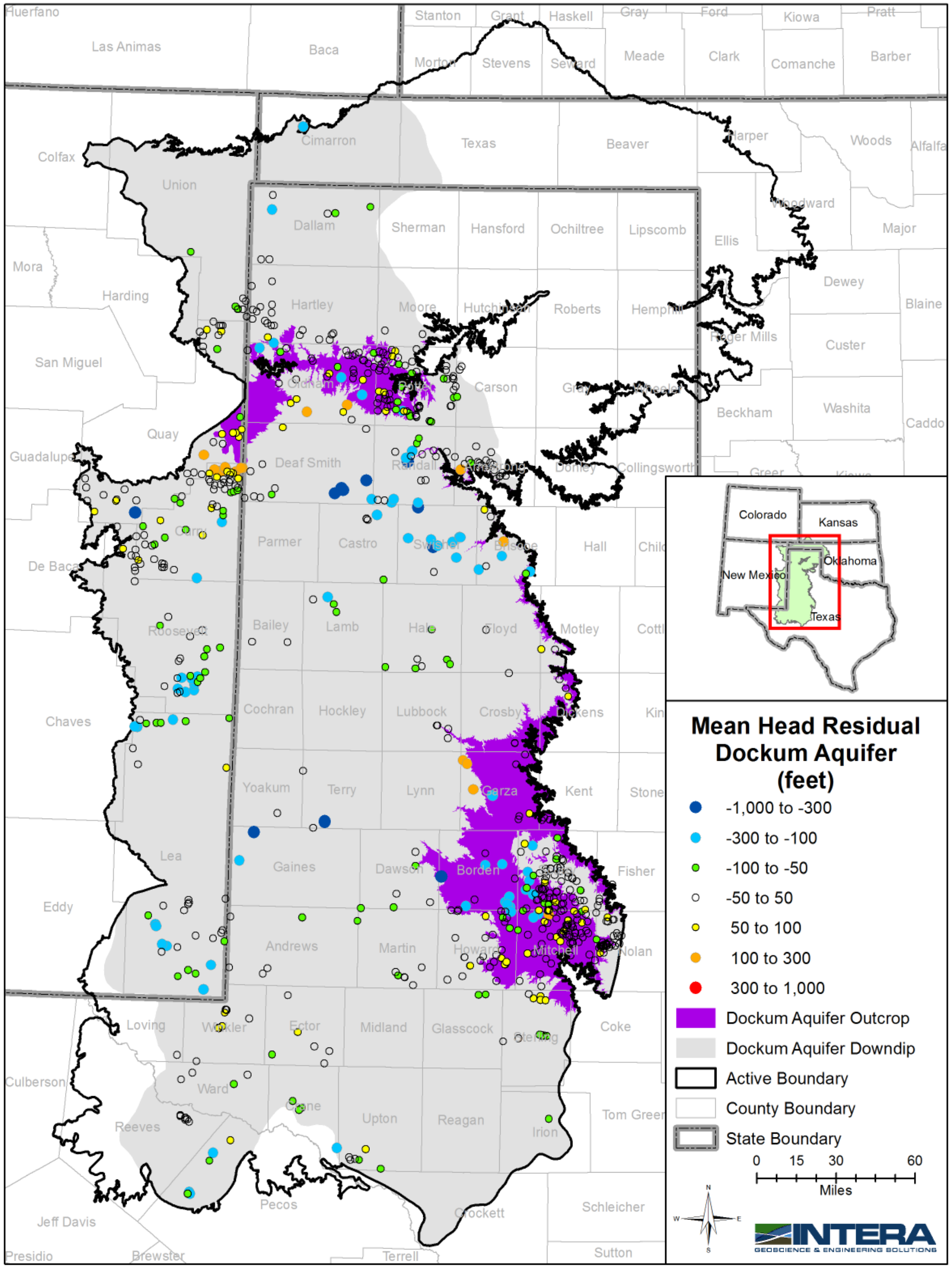
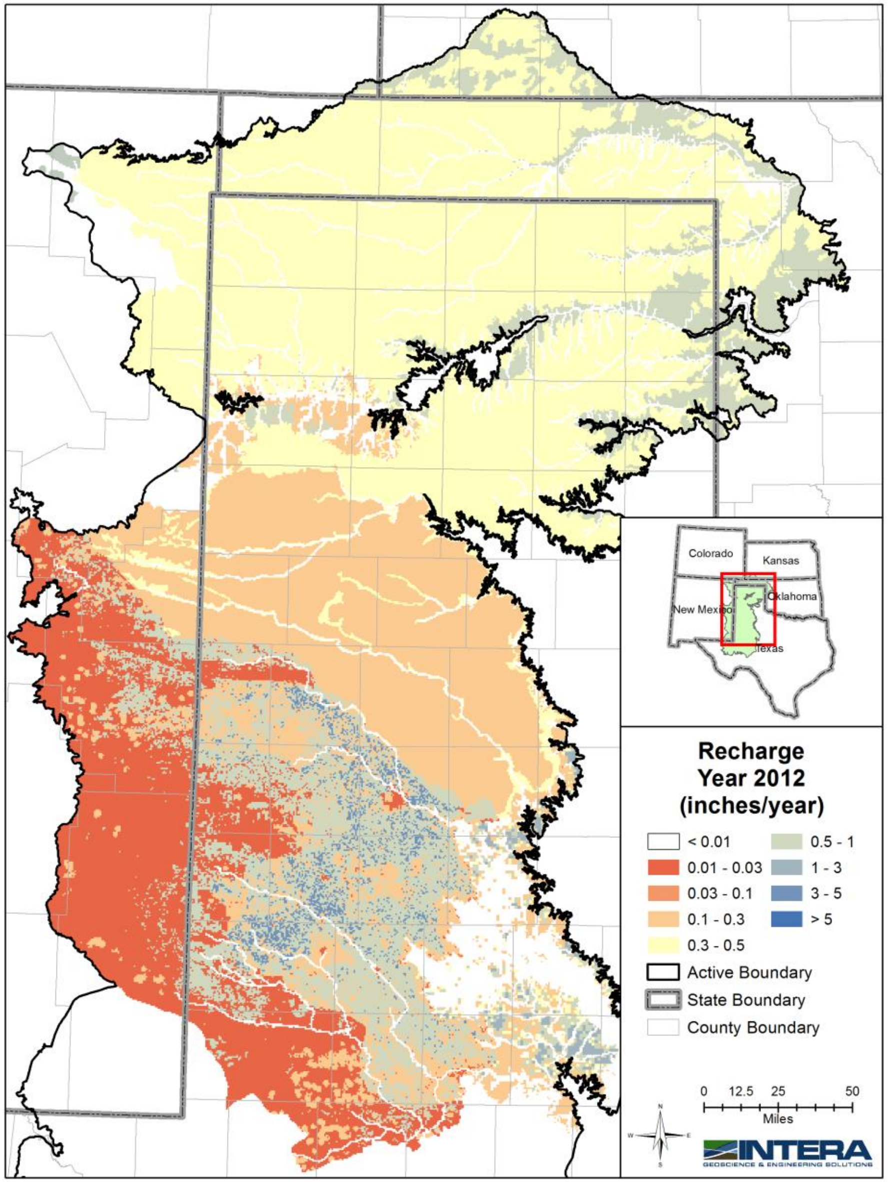


# Transient Dockum Calibration

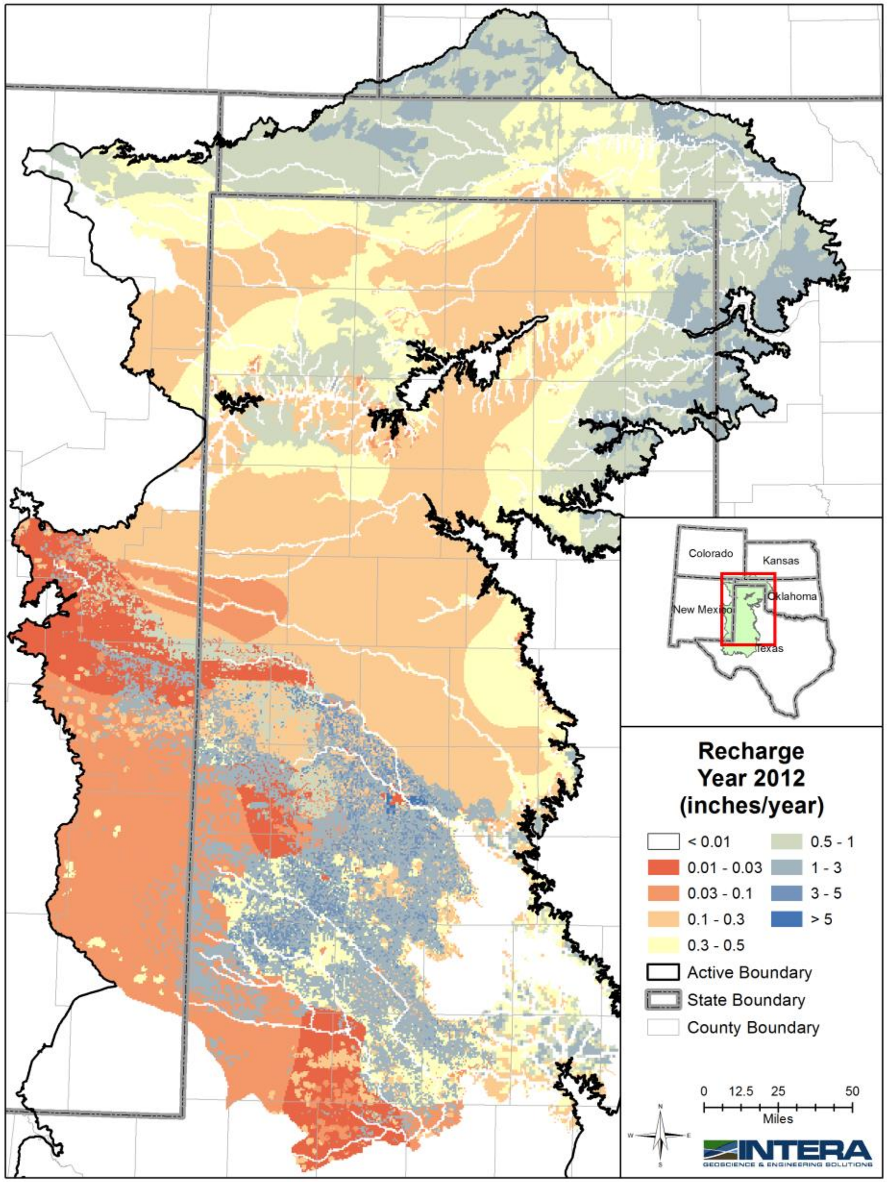


# Transient Recharge Calibration

Initial

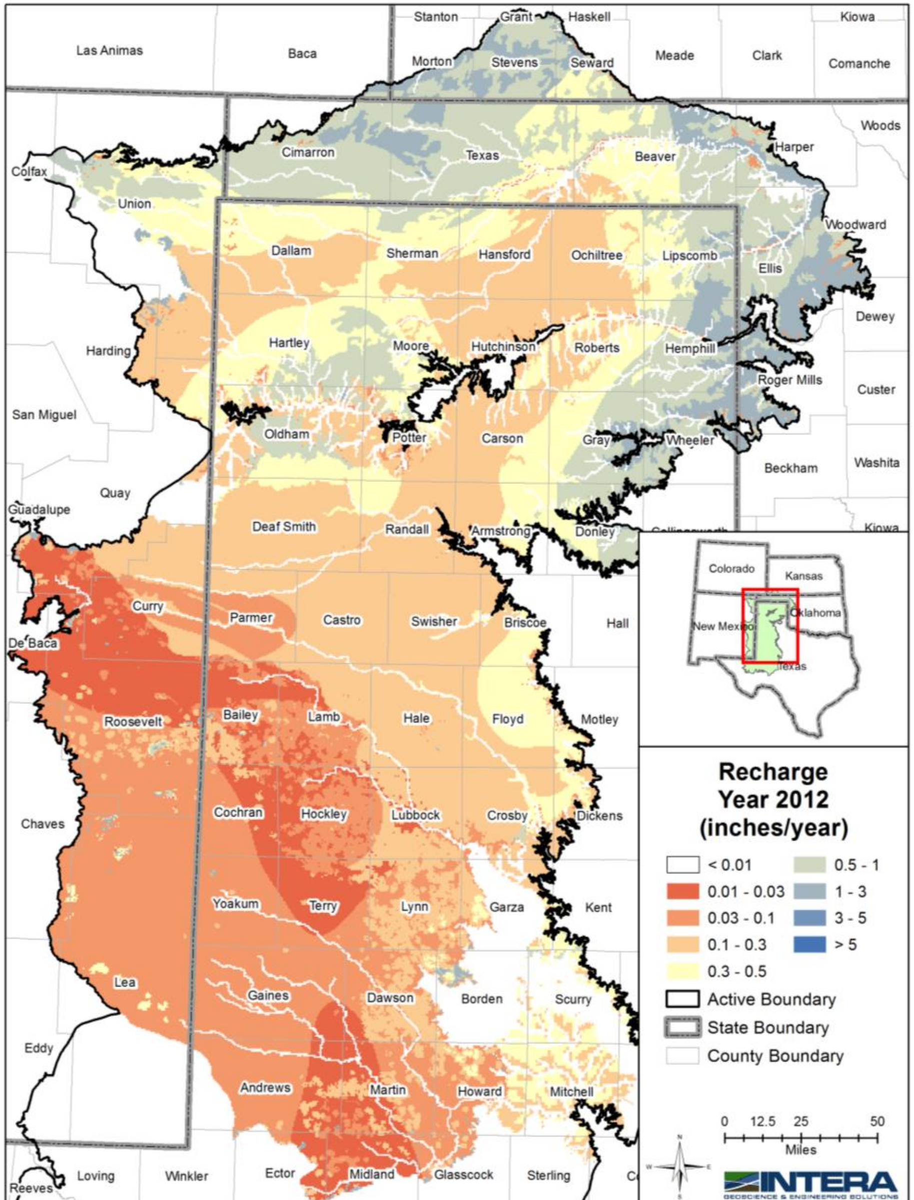



Calibrated

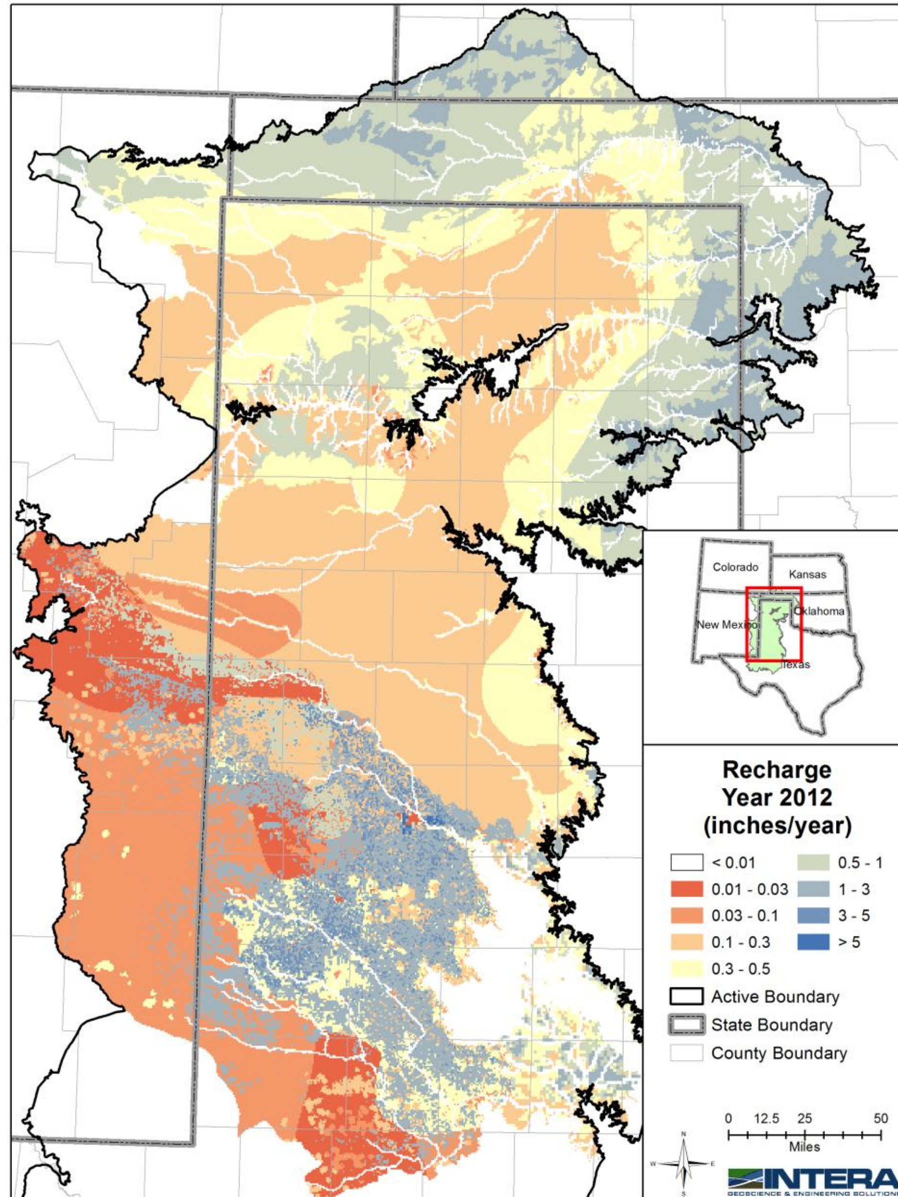


# Recharge

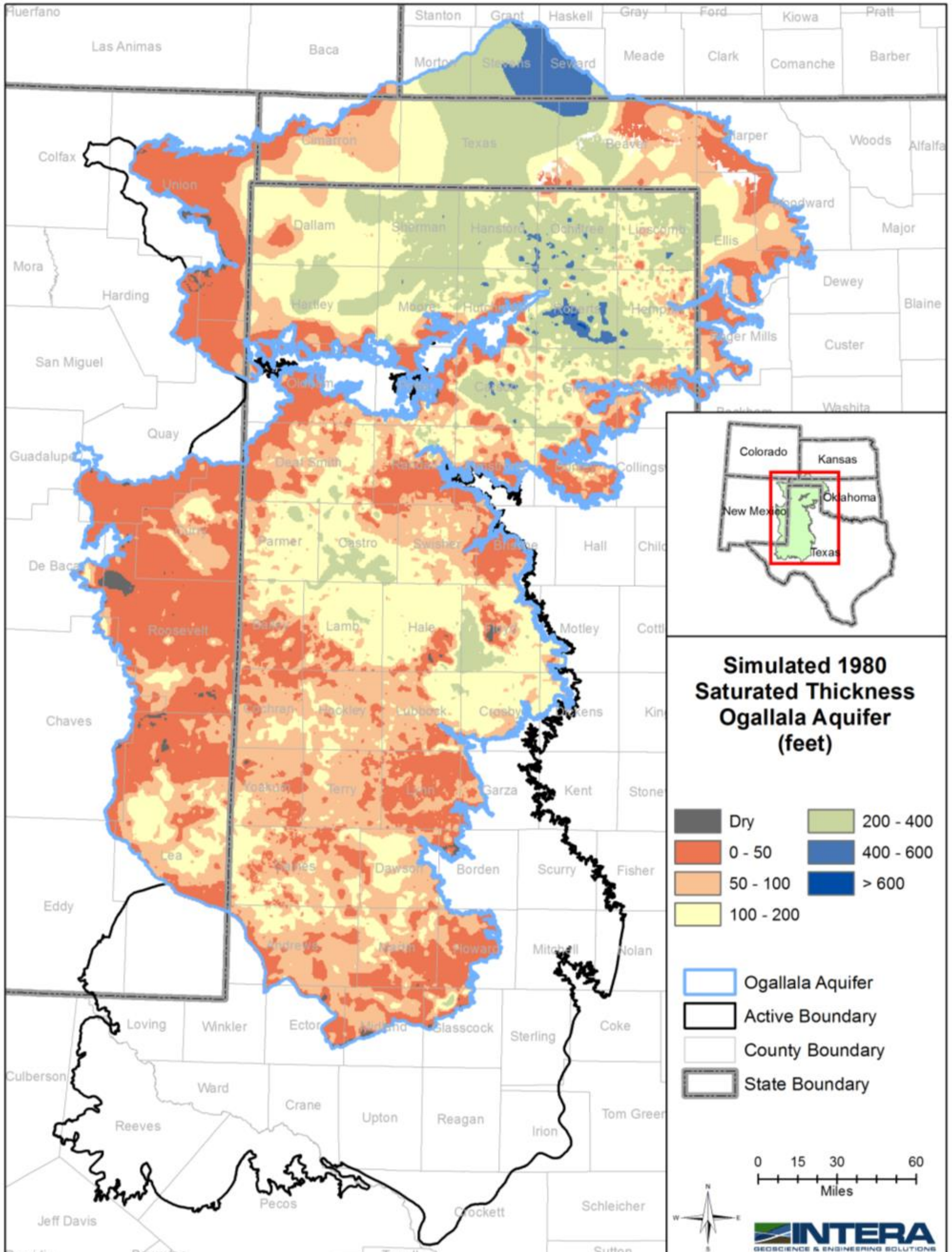
Predevelopment

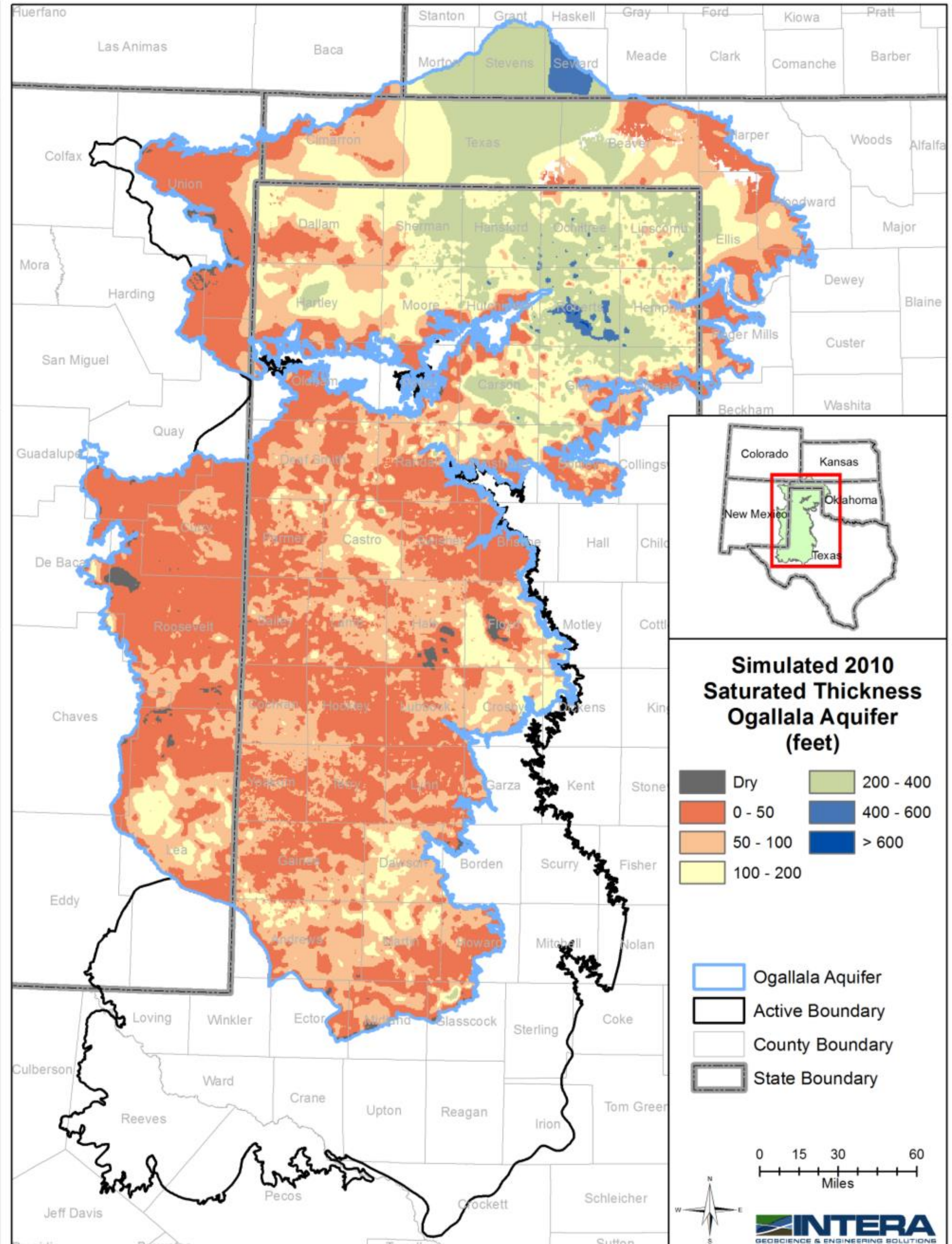



Post-development

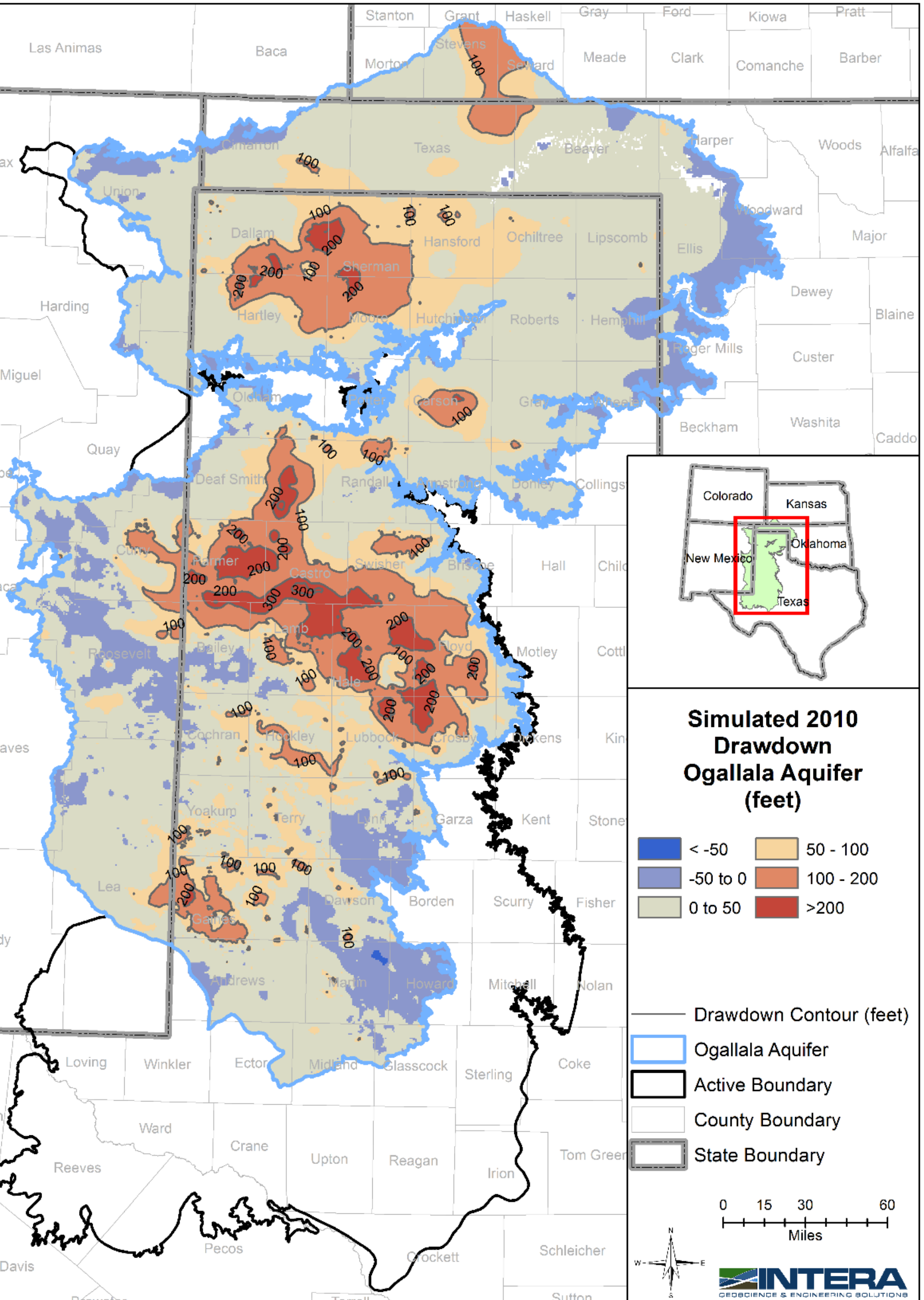


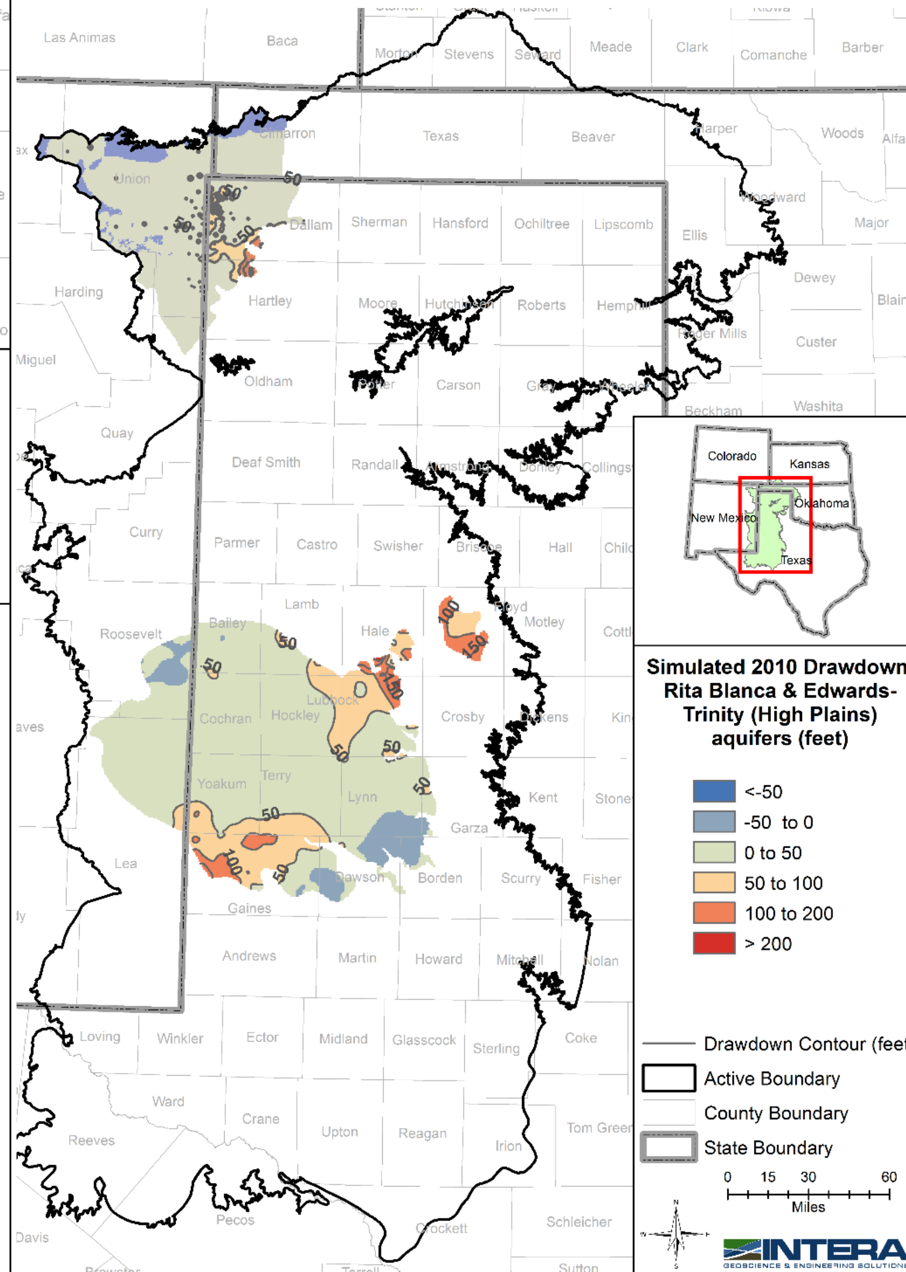
# Ogallala Saturated Thickness



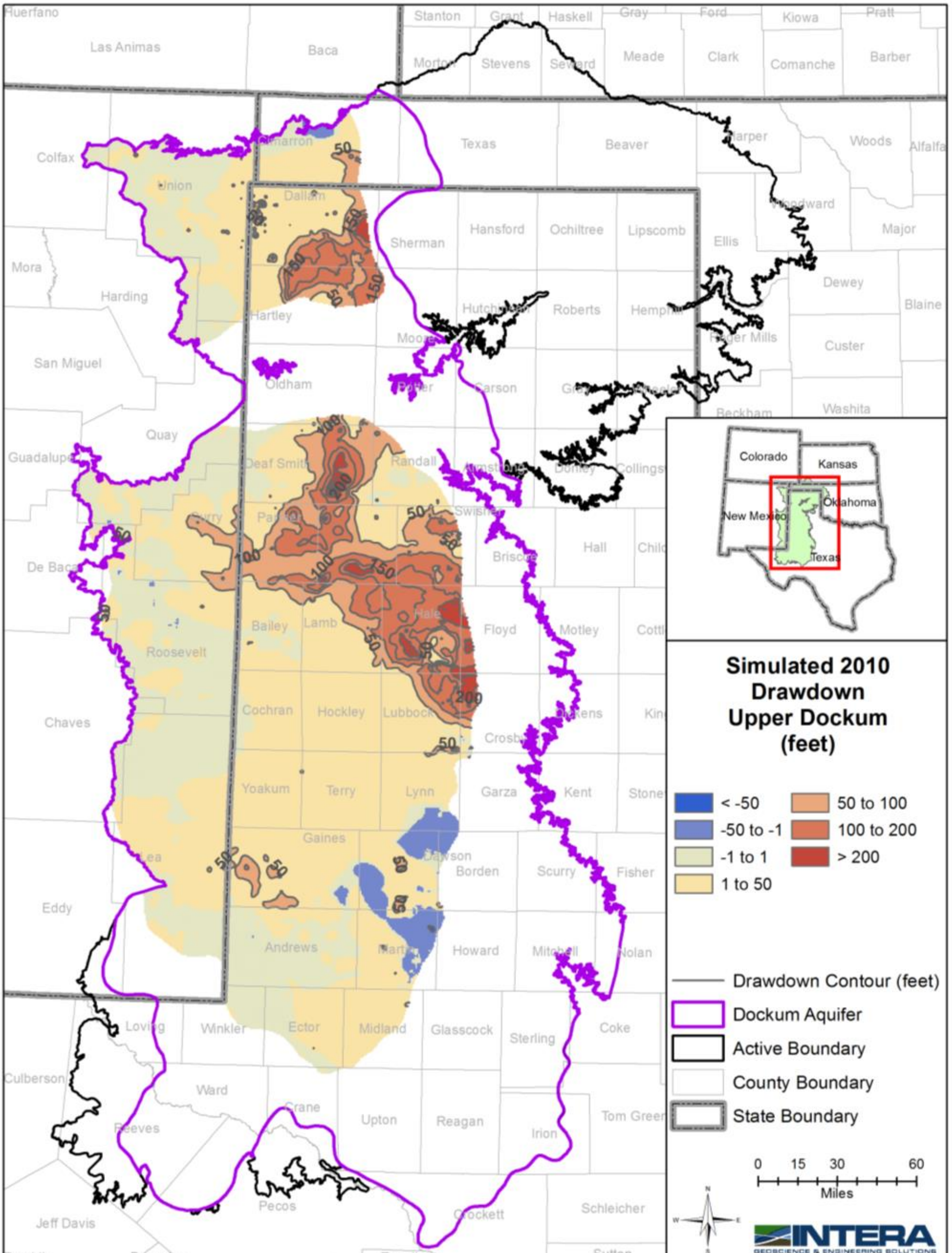



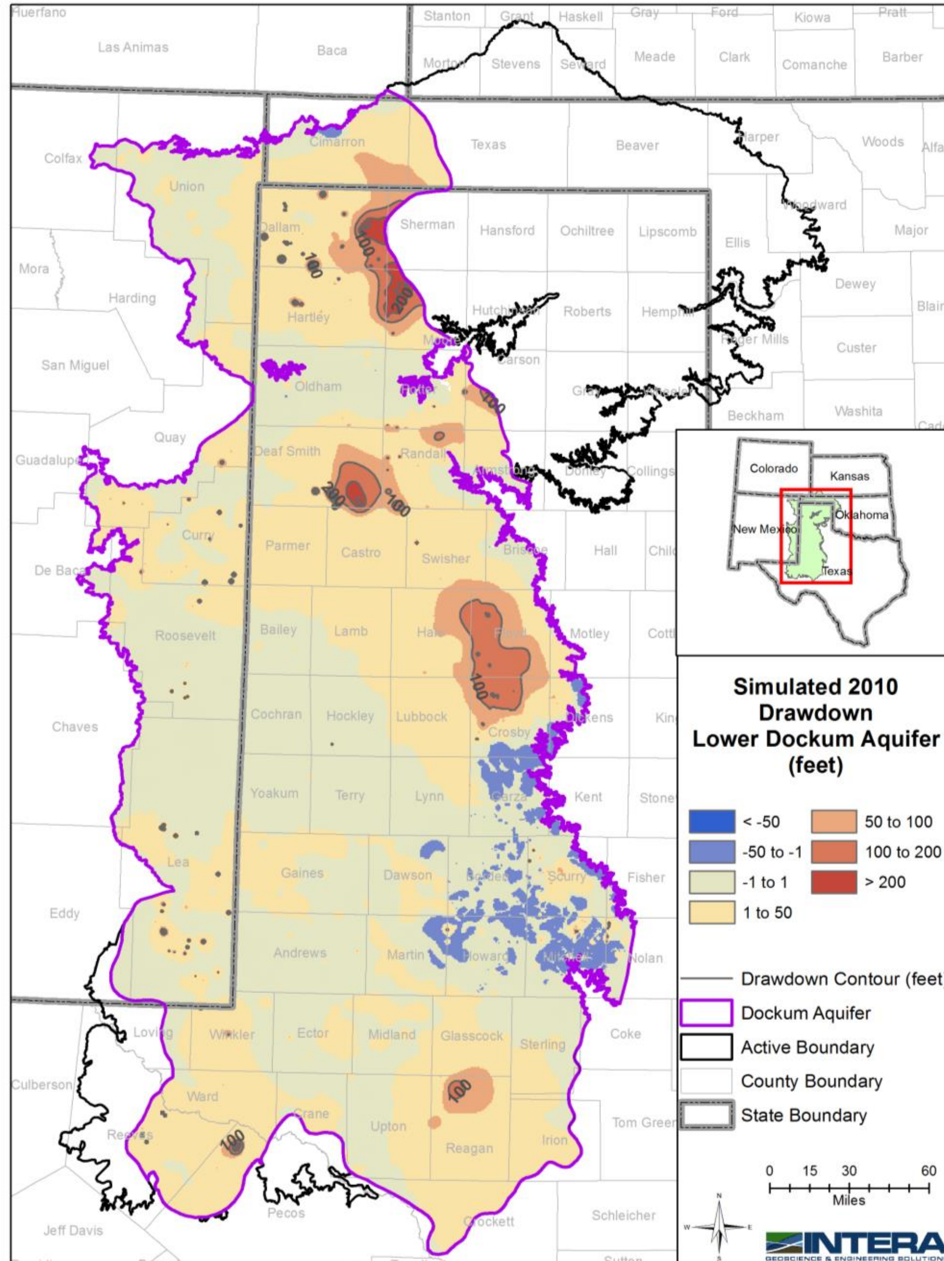
# Drawdown from Predevelopment



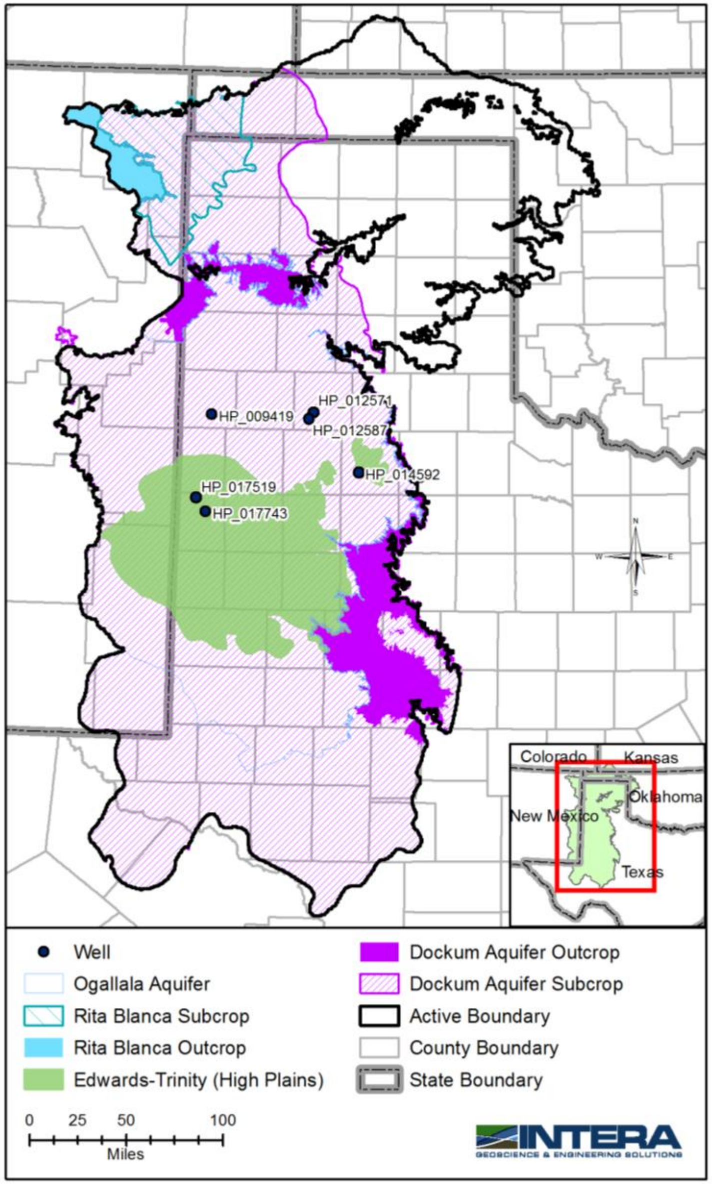



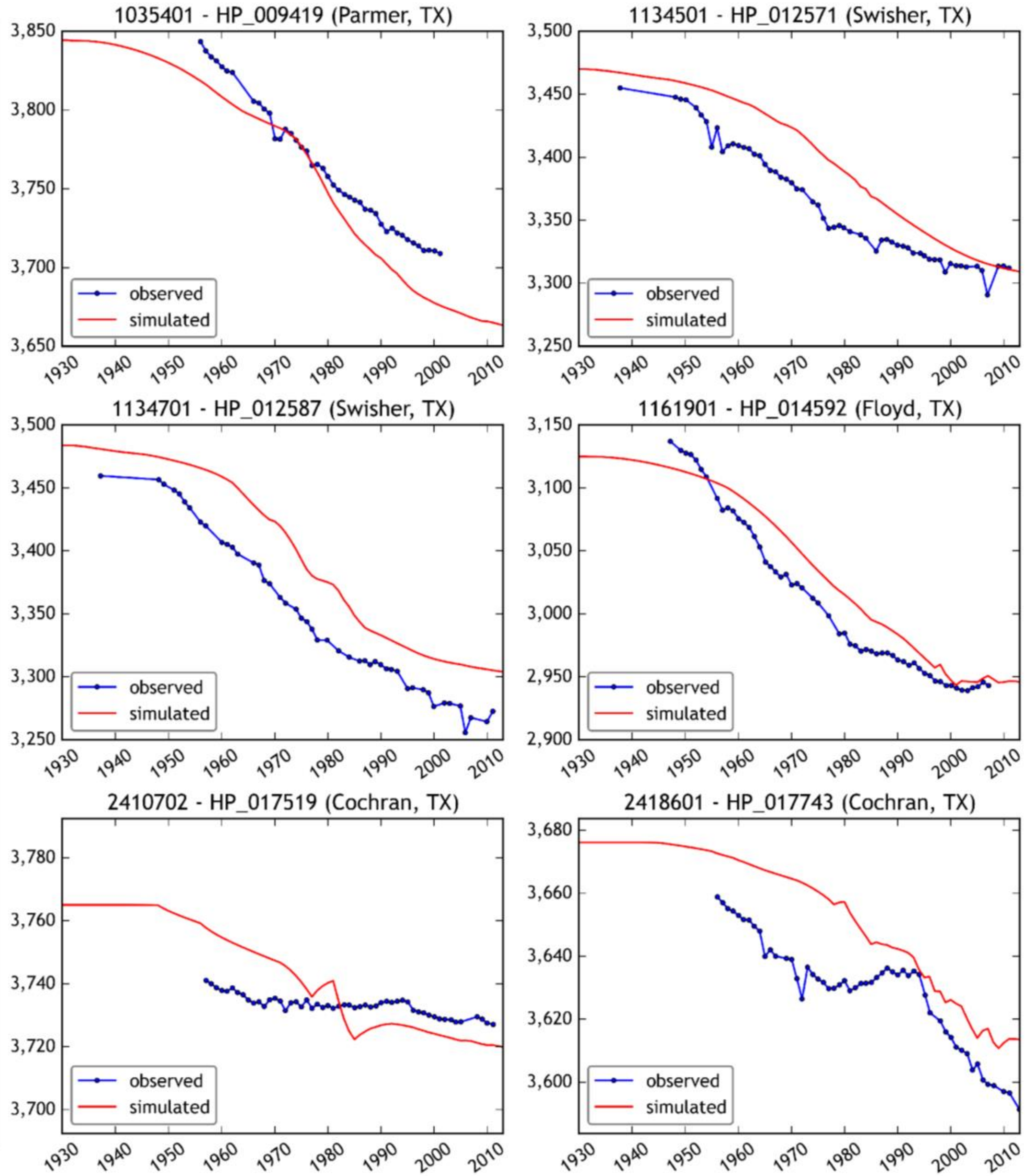
# Transient Calibration: Drawdown in Dockum



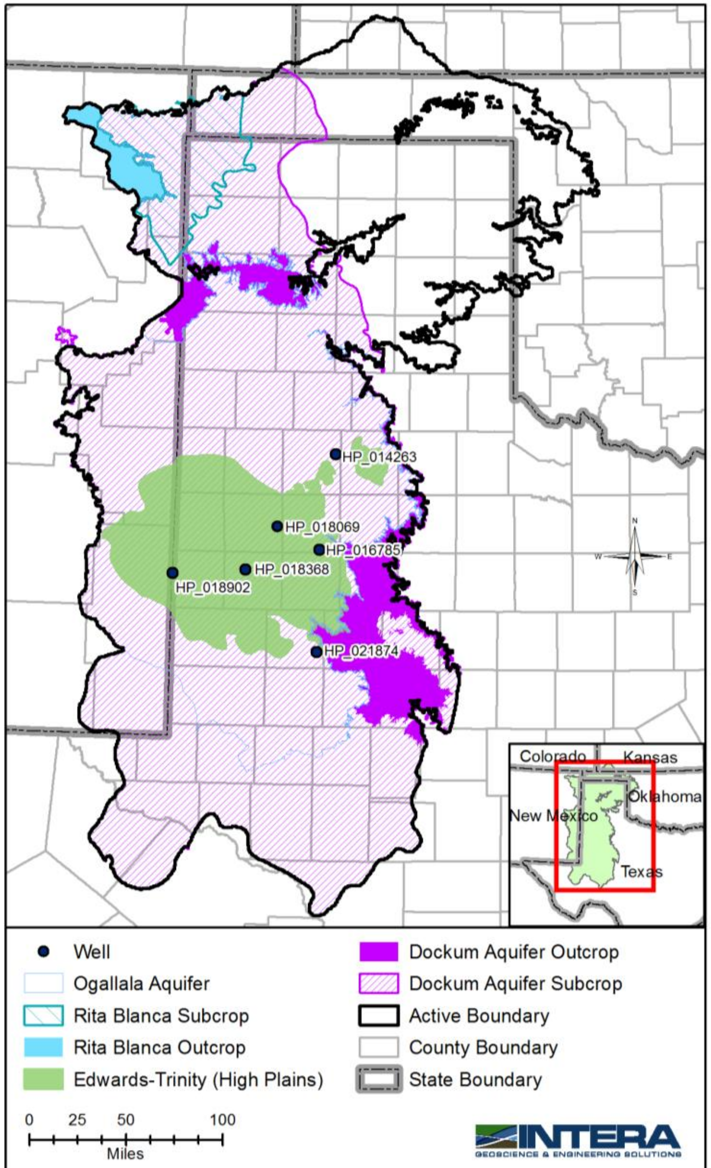



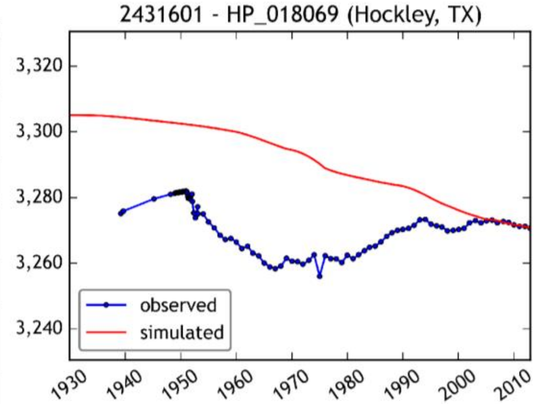
# Ogallala Aquifer

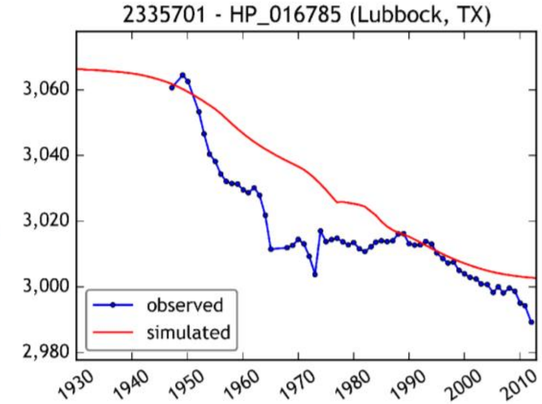


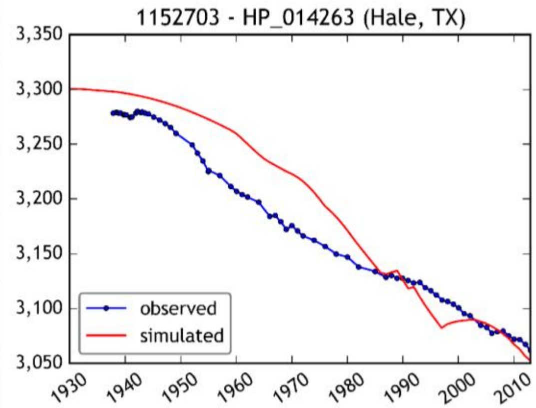



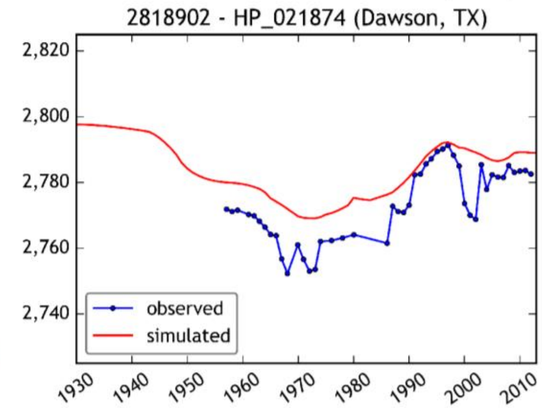
# Ogallala Aquifer

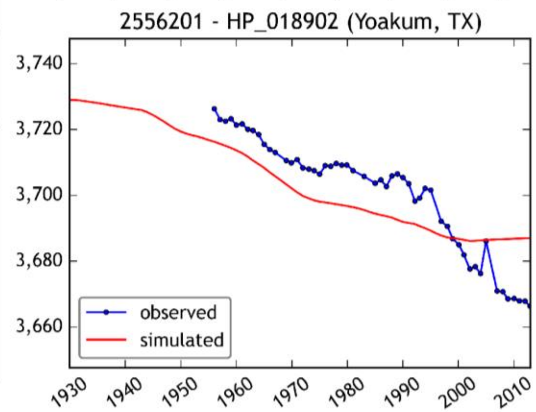


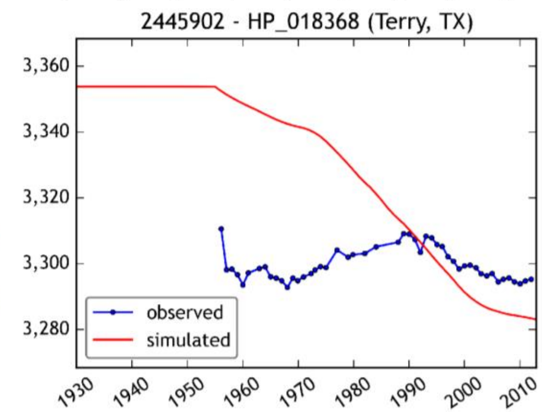



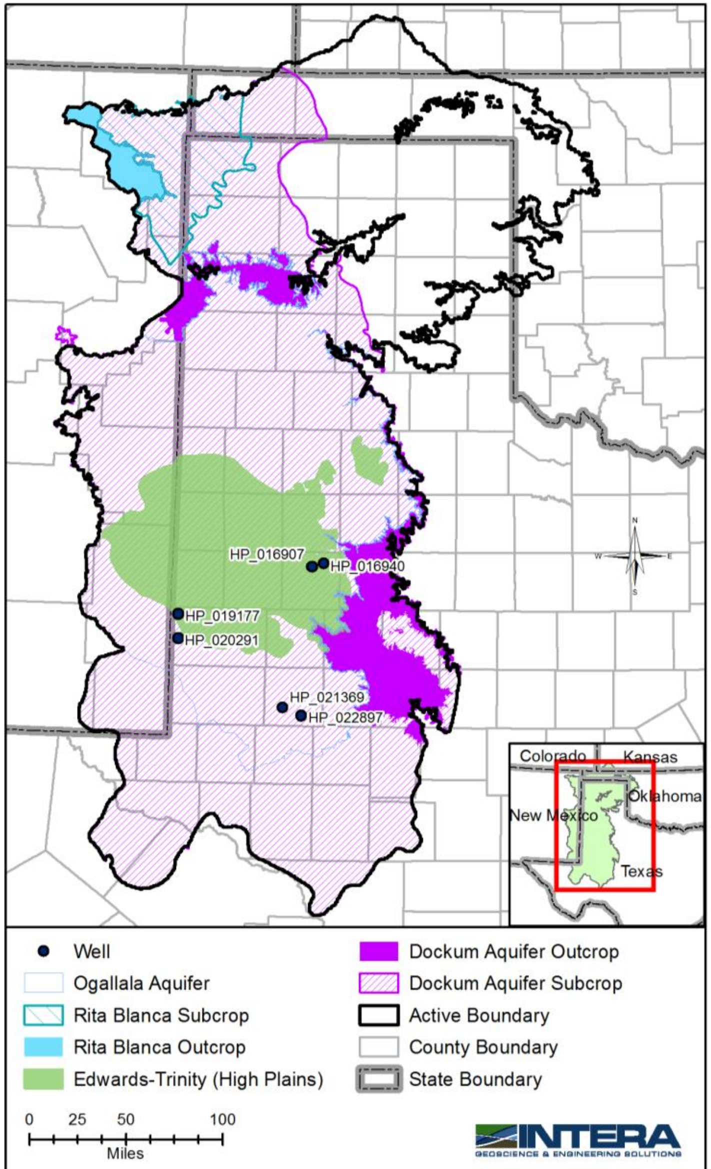



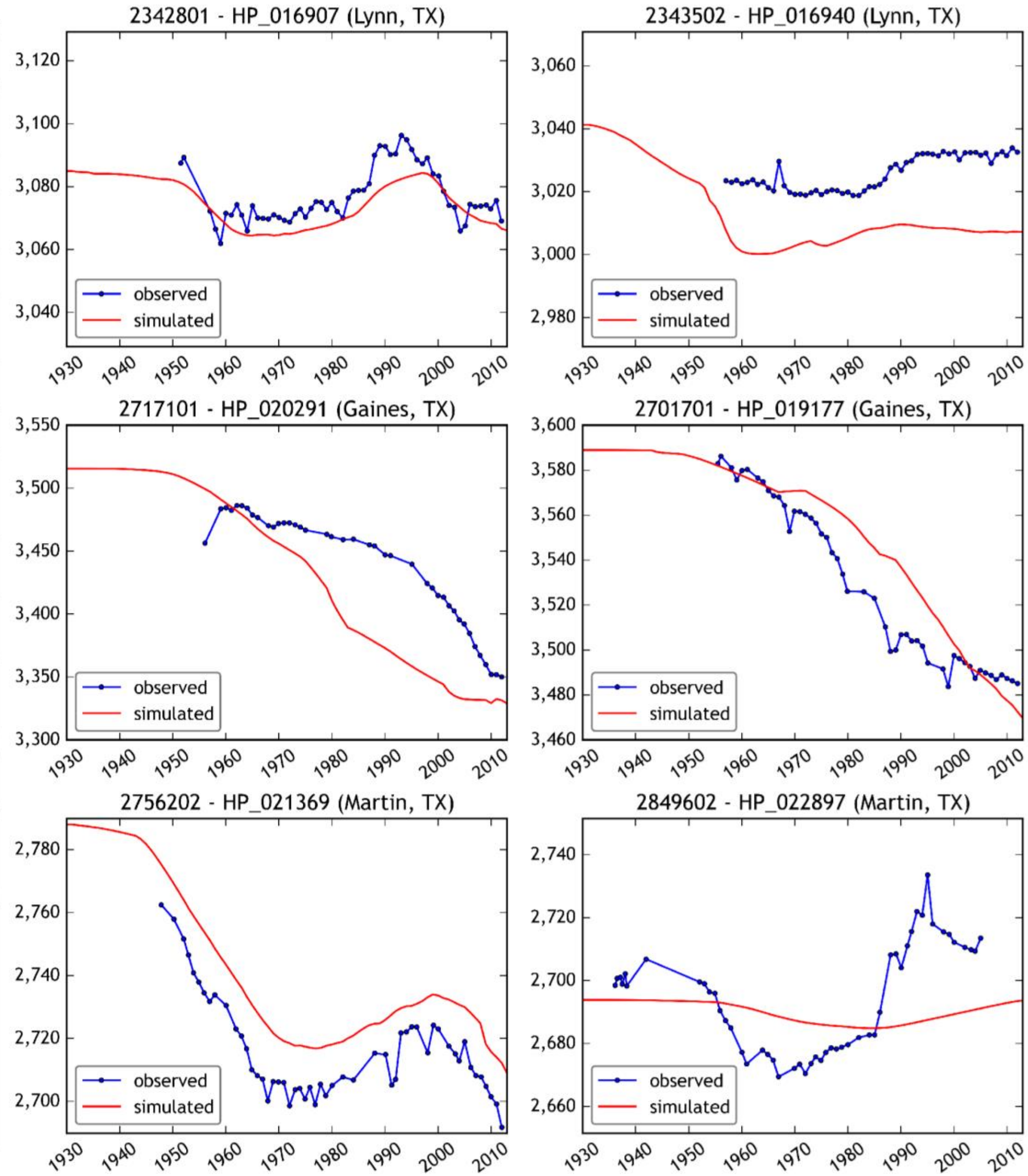



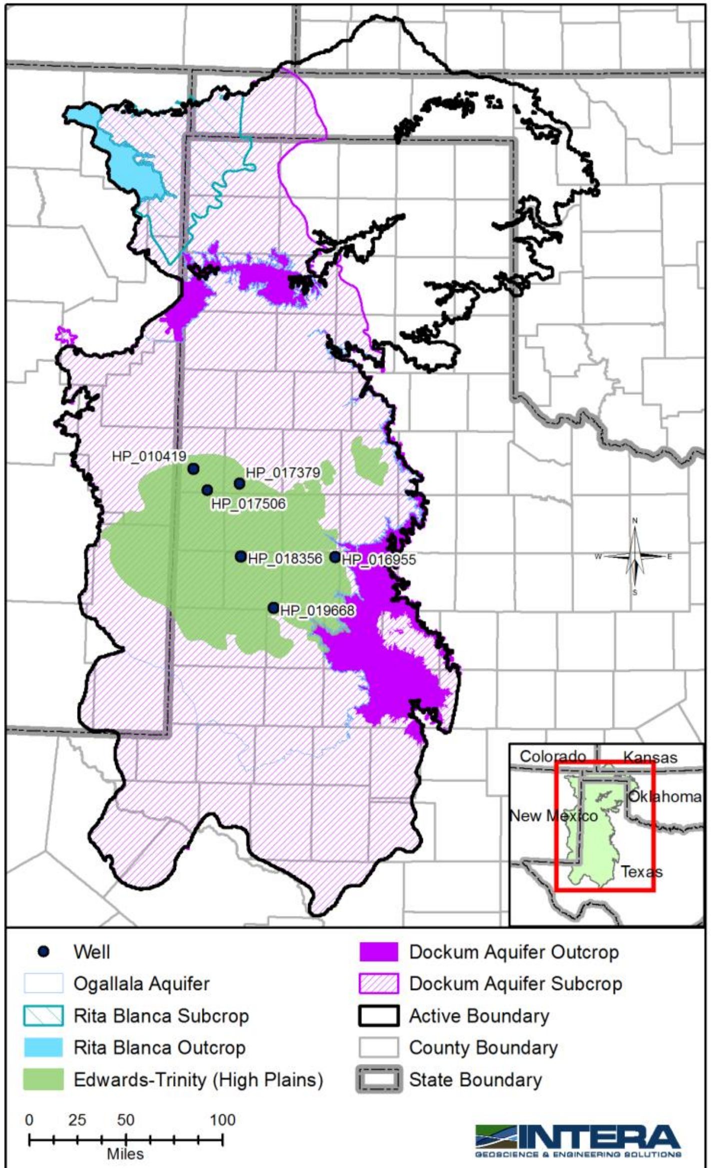



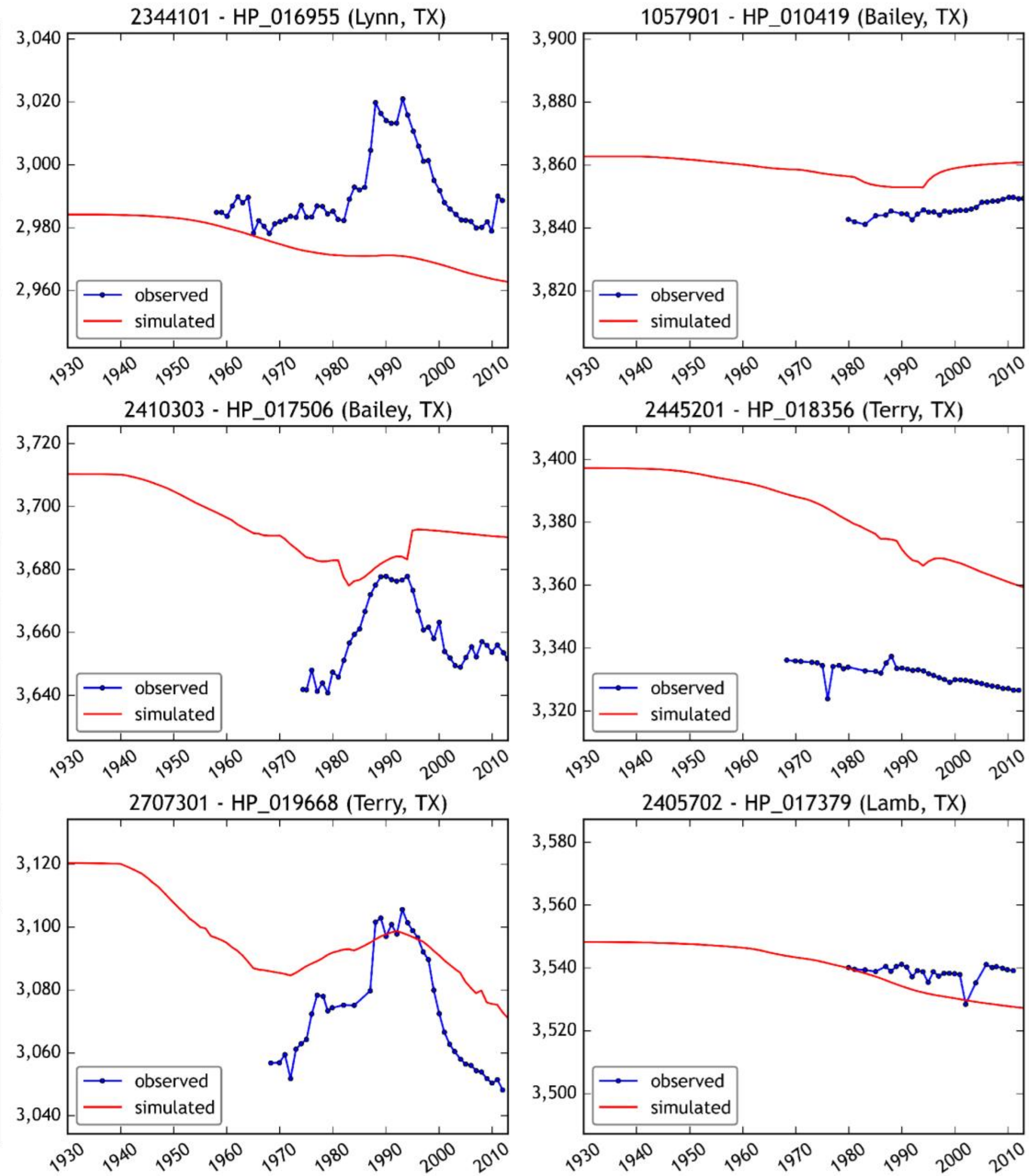
# Ogallala Aquifer



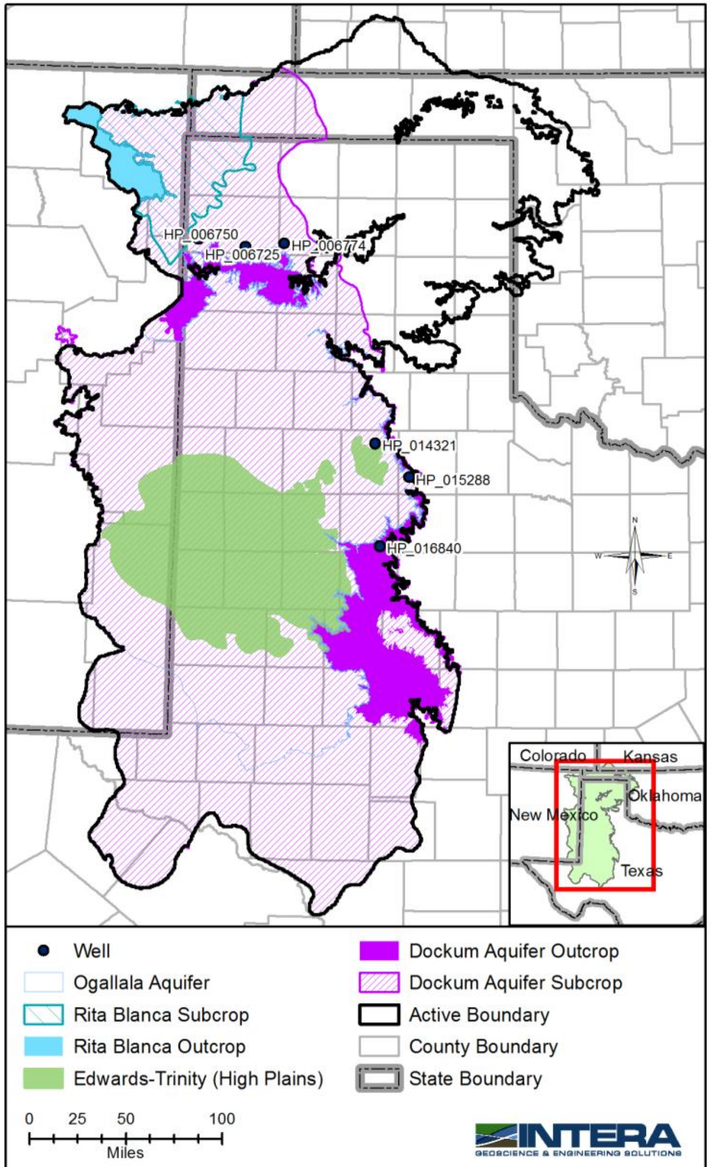



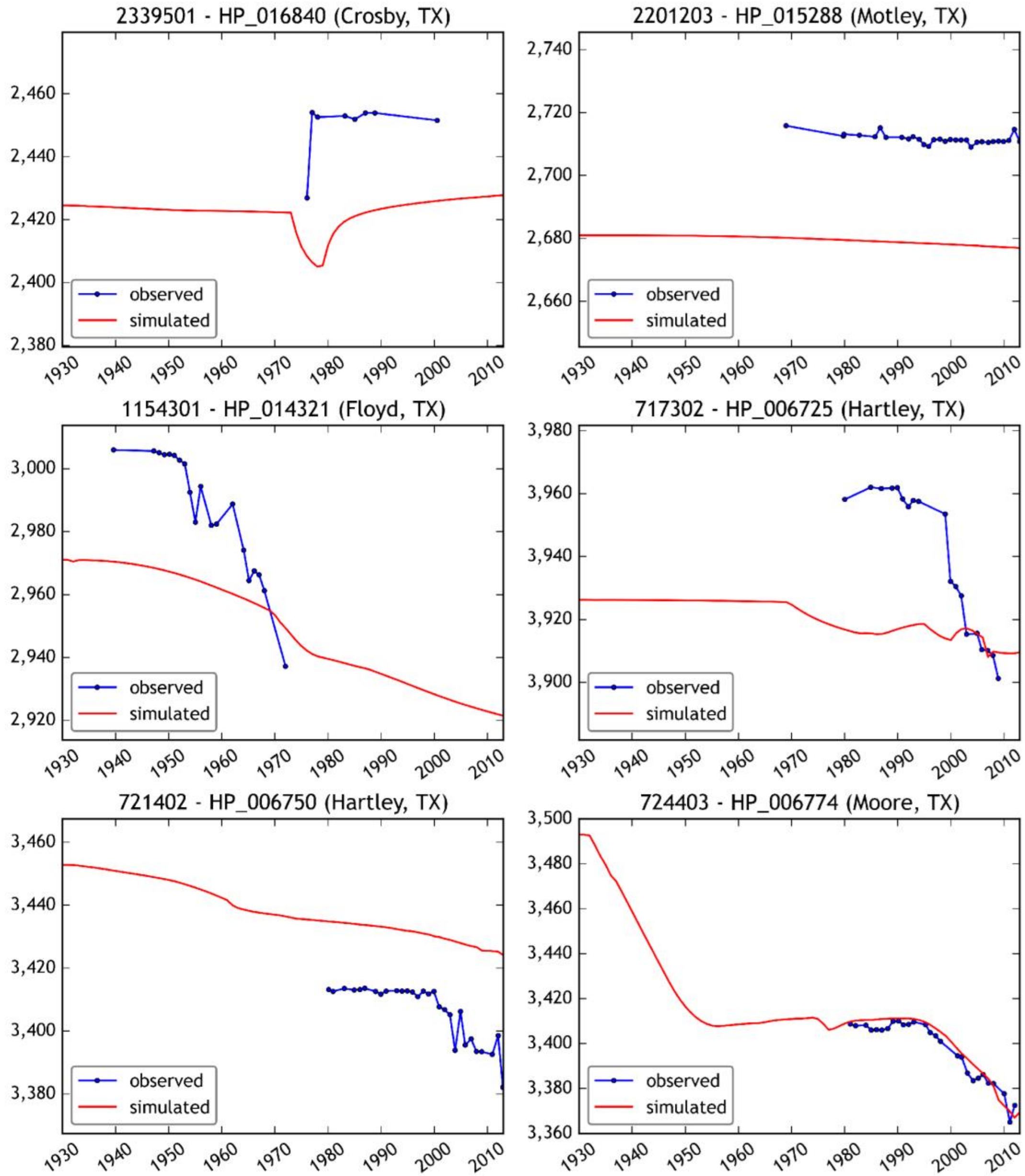
# Edwards Trinity (High Plains)



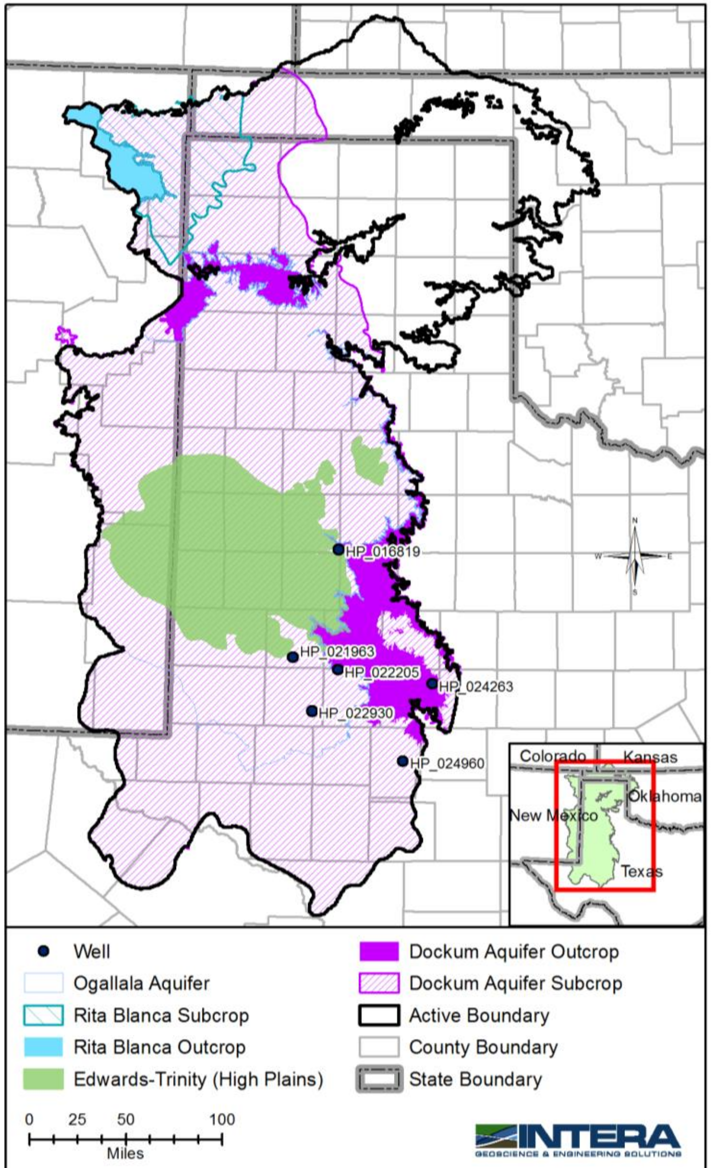



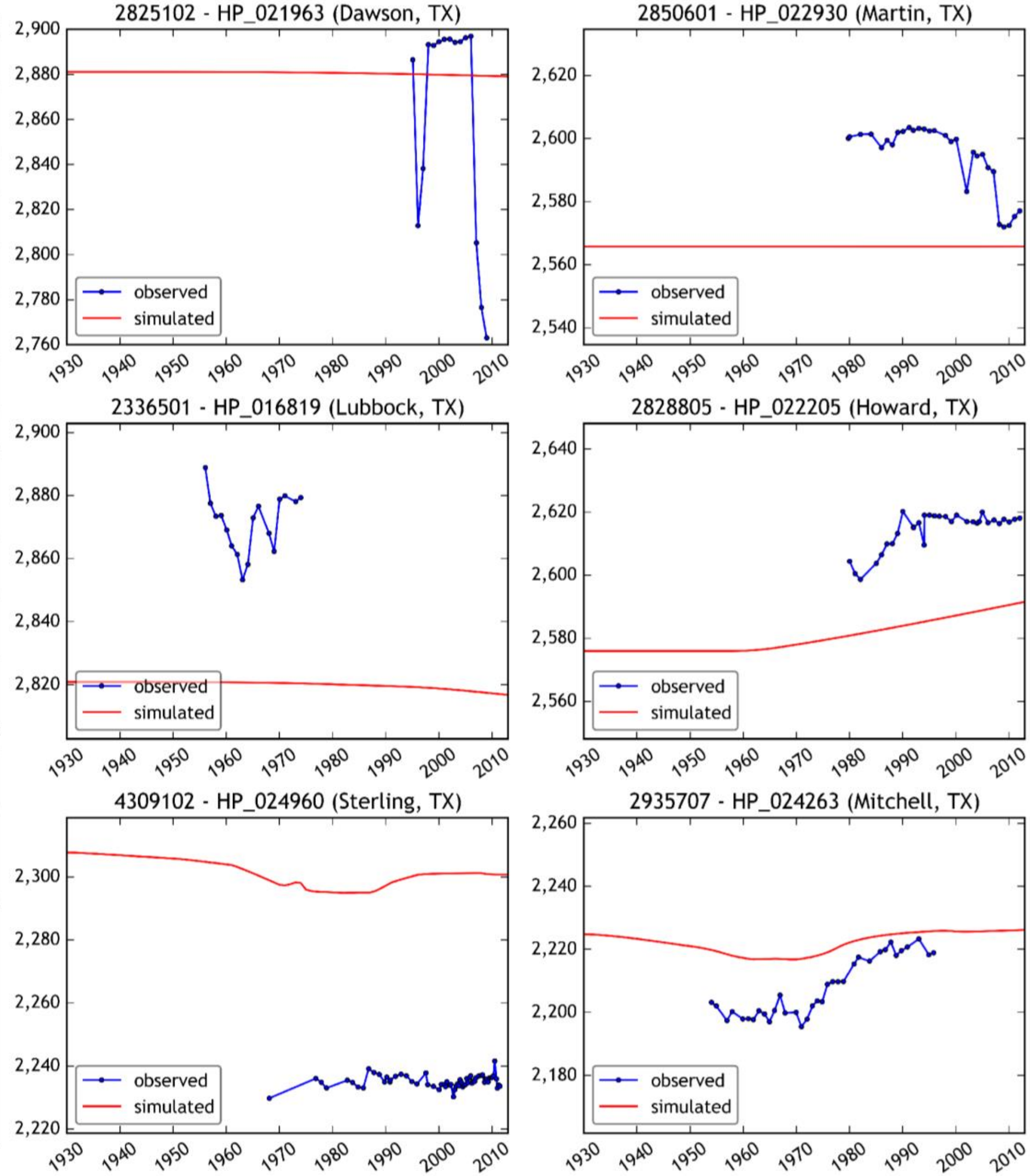
# Lower Dockum



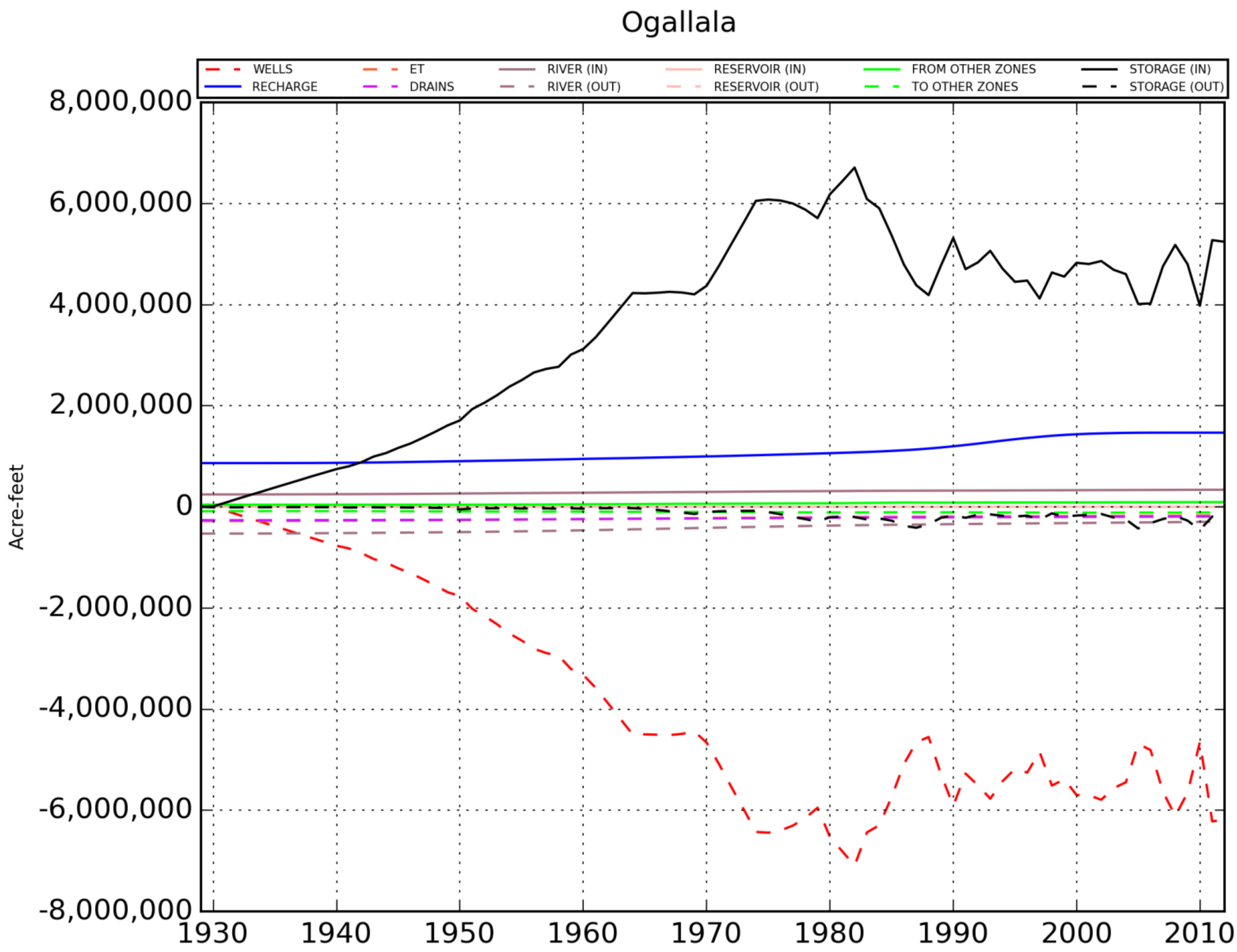



# Lower Dockum

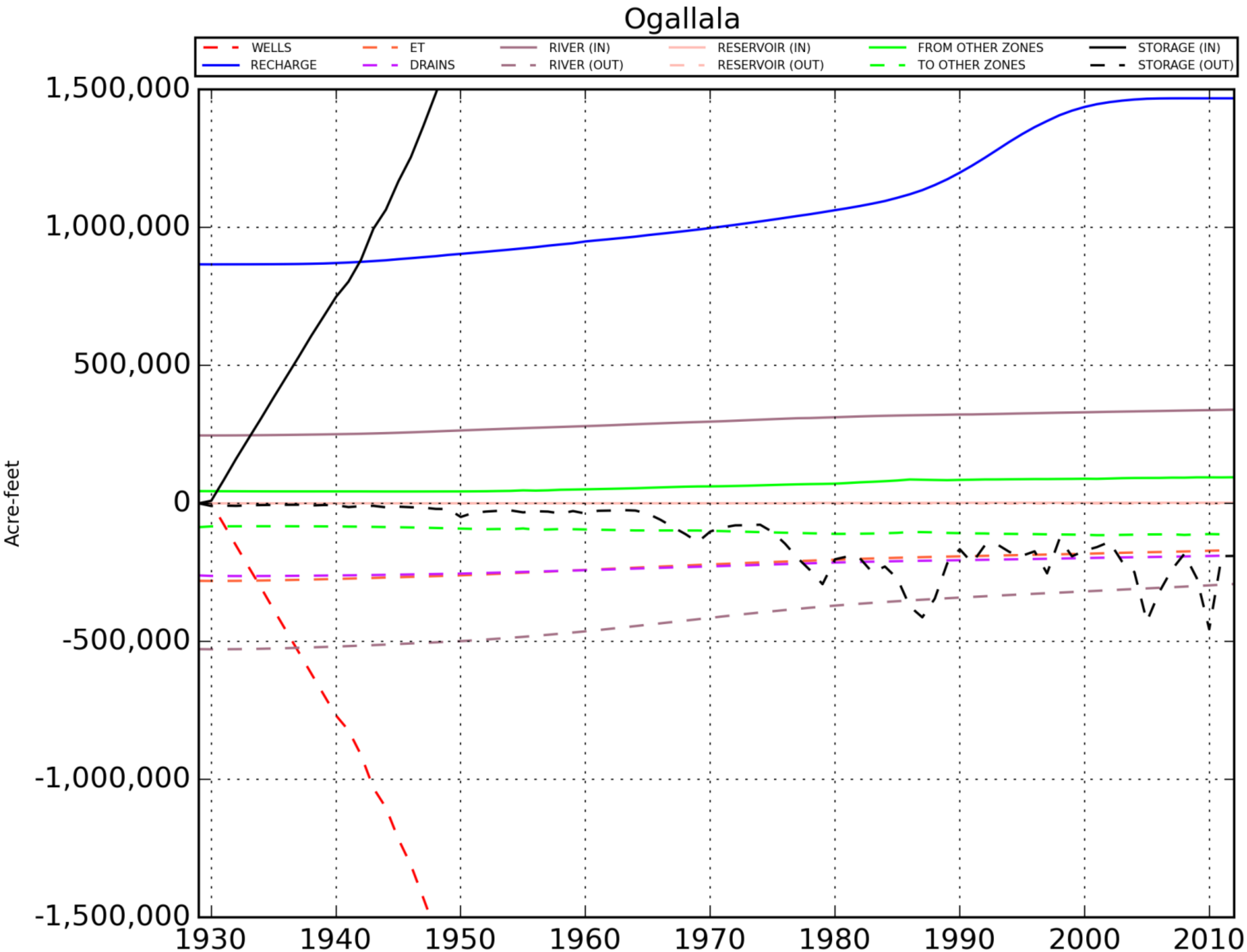


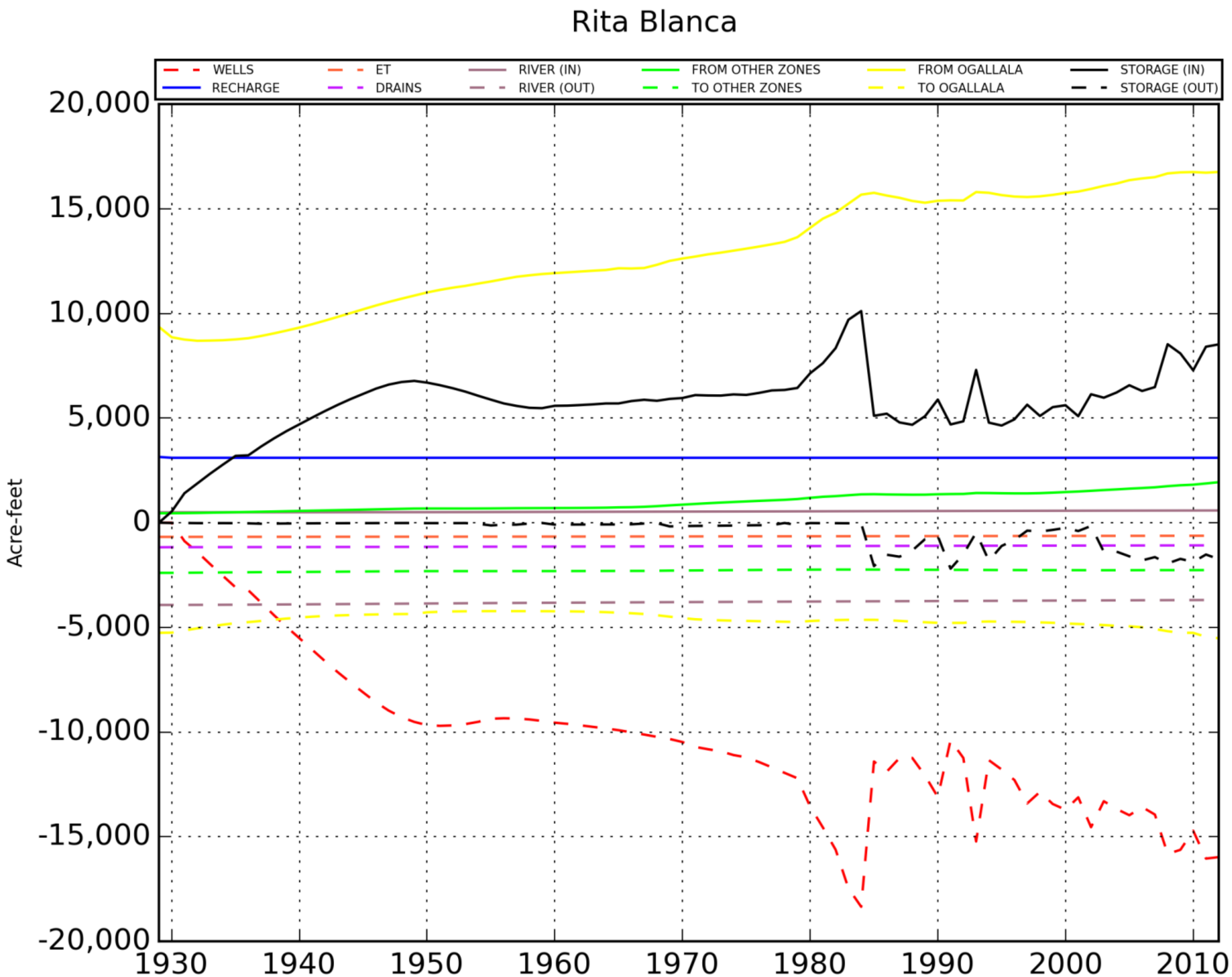
# Water Budget



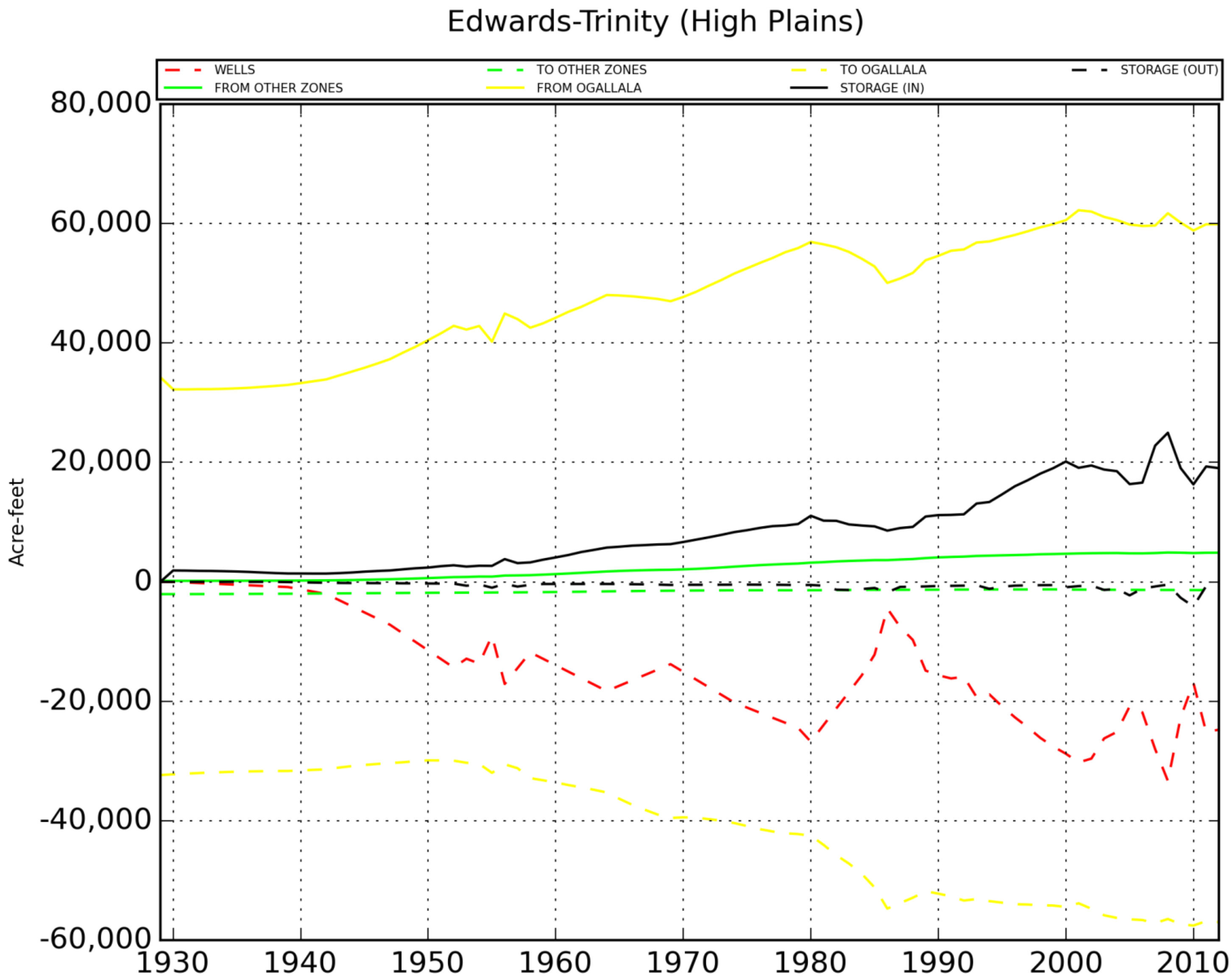
# Water Budget



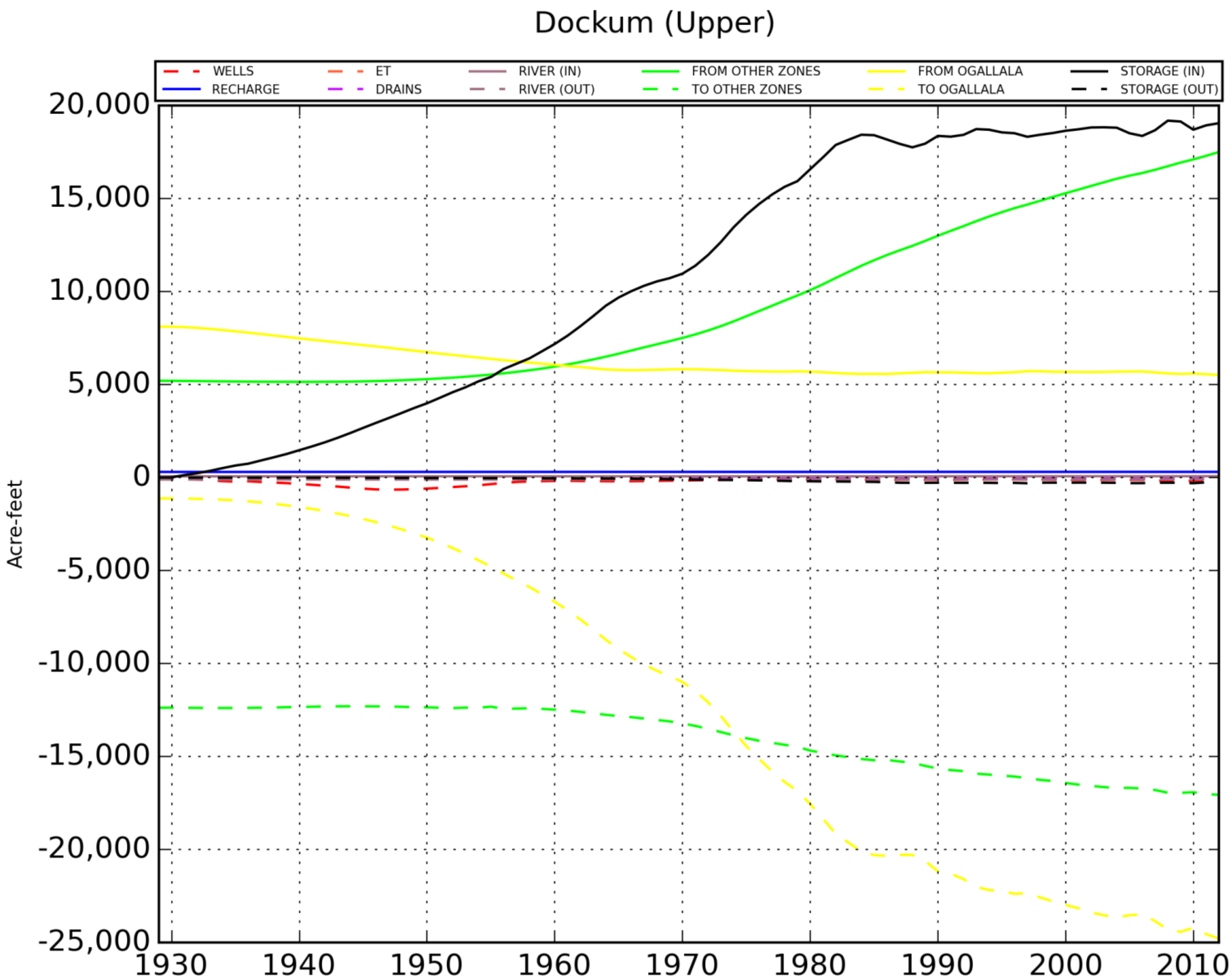
# Water Budget



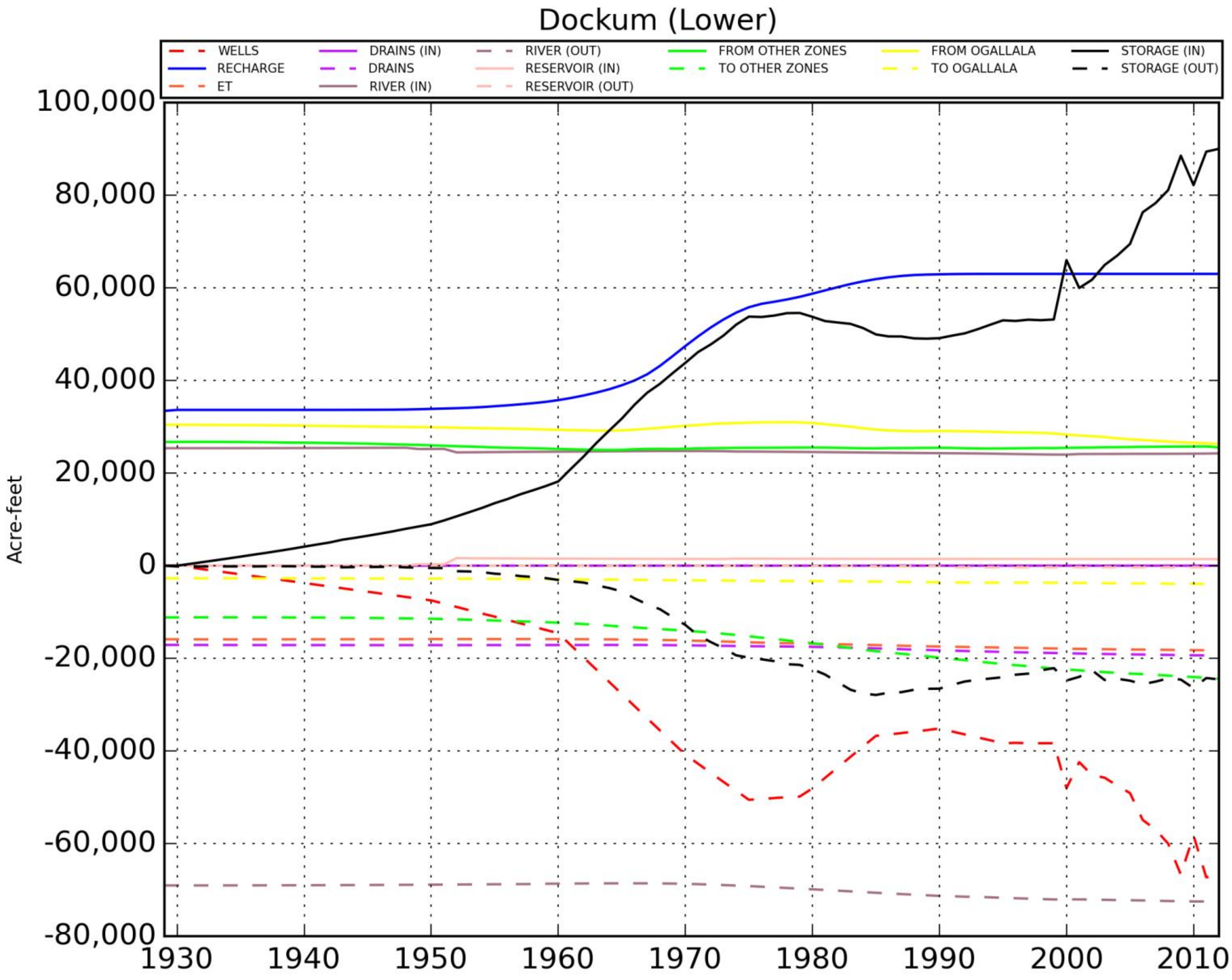
# Water Budget



# Water Budget



# Water Budget



# Transient Calibration: Pumping Prior to 1980

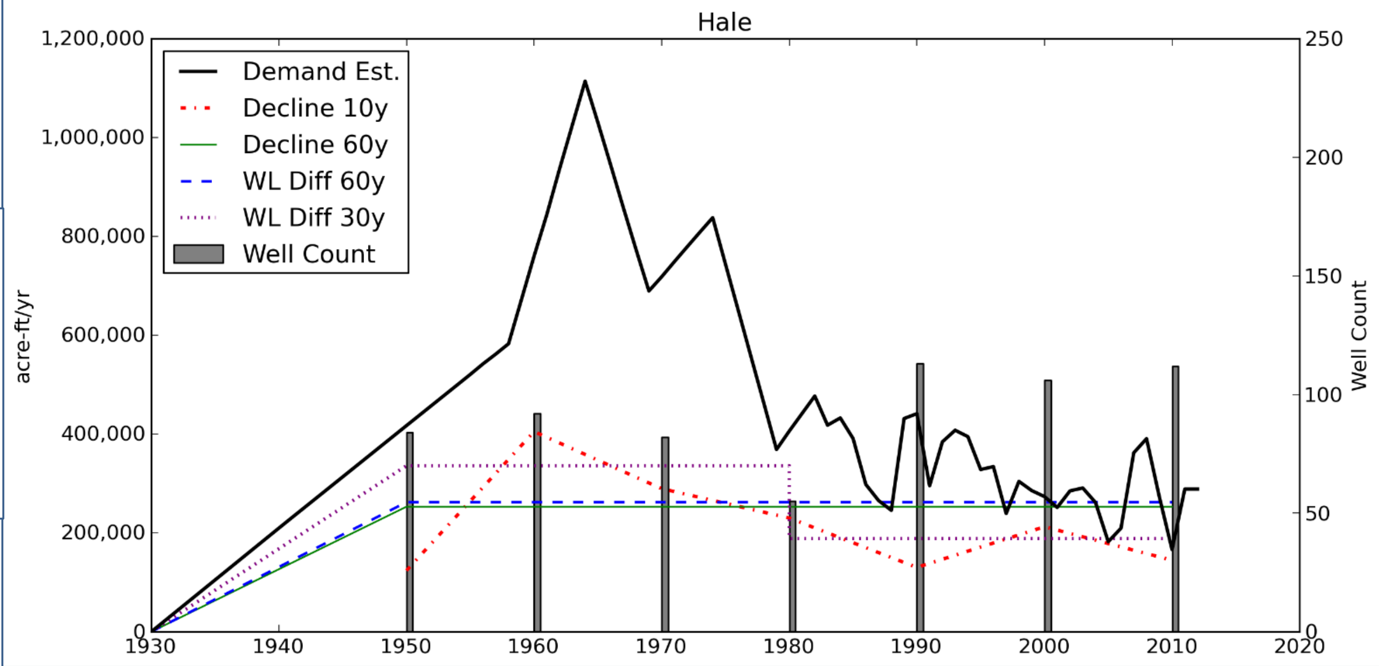
Blandford and others (2004) reduced pumping by factors ranging from 0.45 to 0.9

**Table 1: Return Flow Estimates for Texas and New Mexico**

| Period | Return Flow[a] (%) Texas | New Mexico |
|---|---|---|
| 1940-1960 | 55 | 55 |
| 1961-1965 | 50 | 50 |
| 1966-1970 | 45 | 50 |
| 1971-1975 | 40 | 50 |
| 1976-1980 | 35 | 40 |
| 1981-1985 | 25 | 40 |
| 1986-1990 | 20 | 35 |
| 1991-1995 | 15 | 25 |
| 1996-2000 | 10 | 20 |

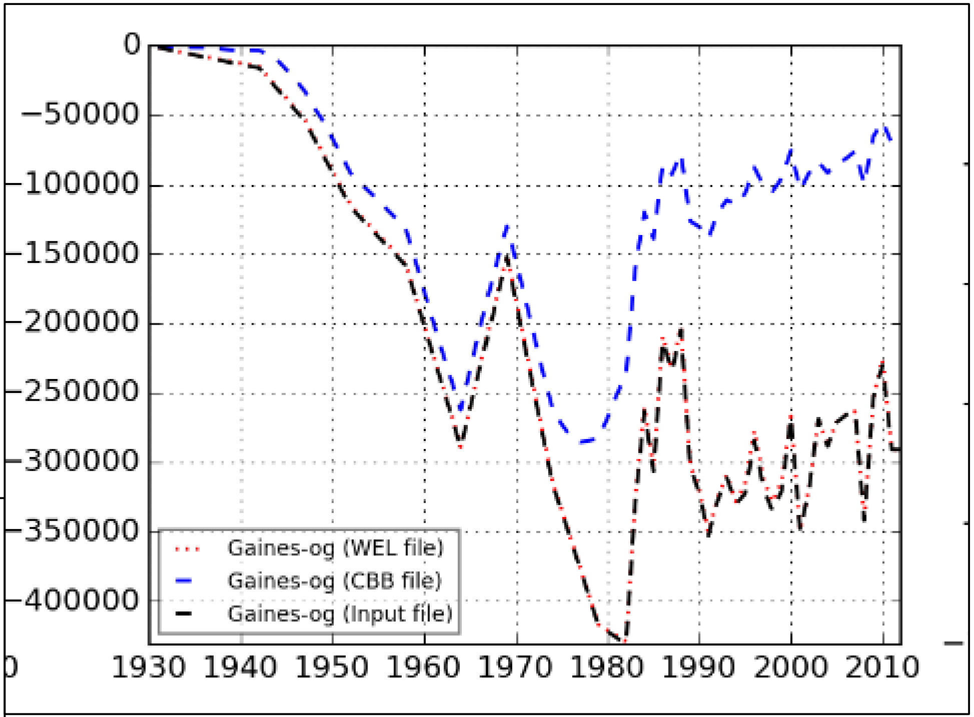
[a] Assumed to occur in same year as pumping.

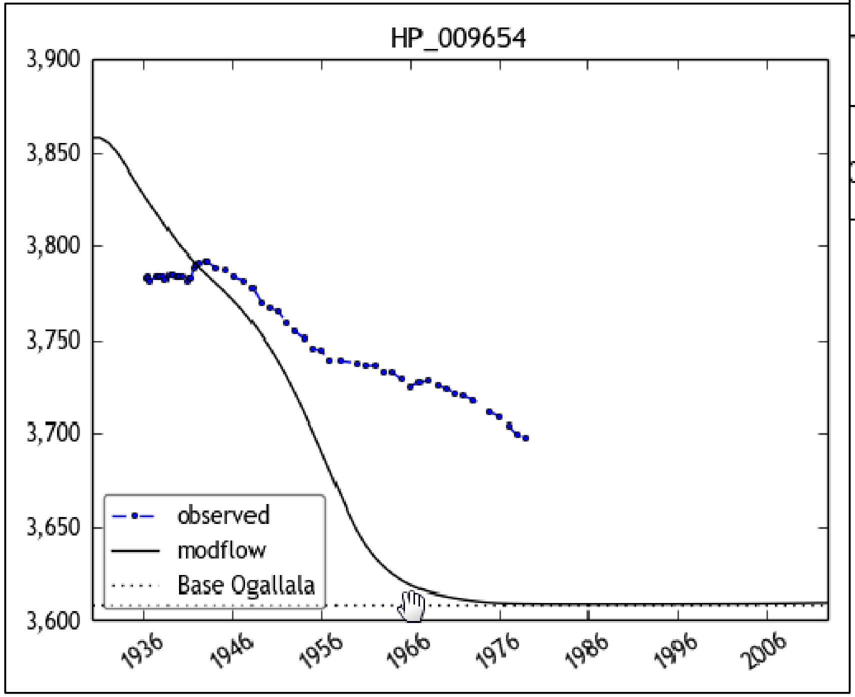
Current study found significant overestimates of pumping based on water level decline



# Transient Calibration: Pumping Prior to 1980

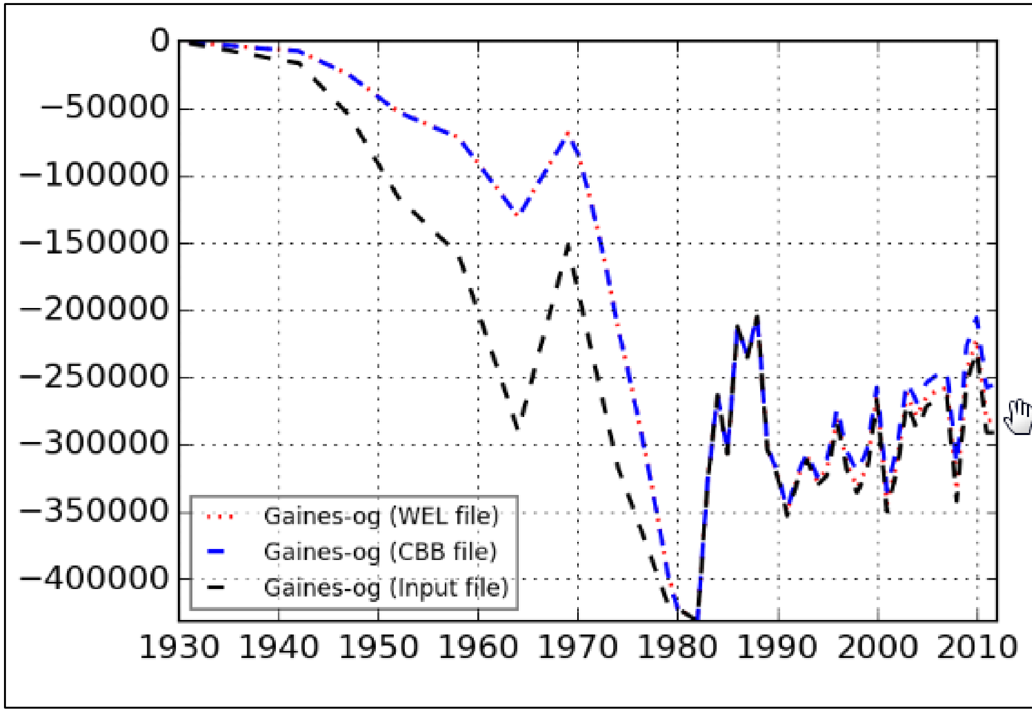
During calibration we found that using unmodified pre-1980 estimates results in dramatically reduced pumping post-1980

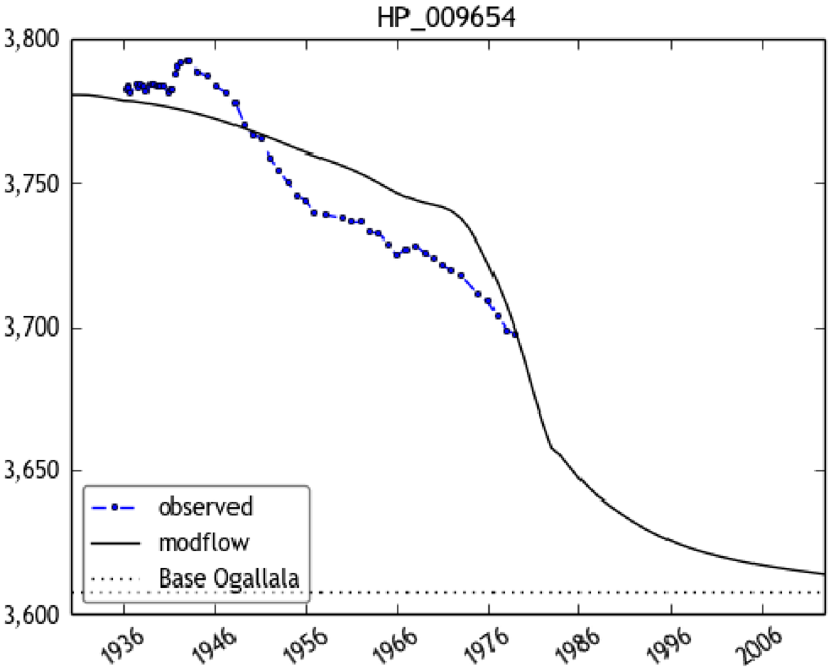


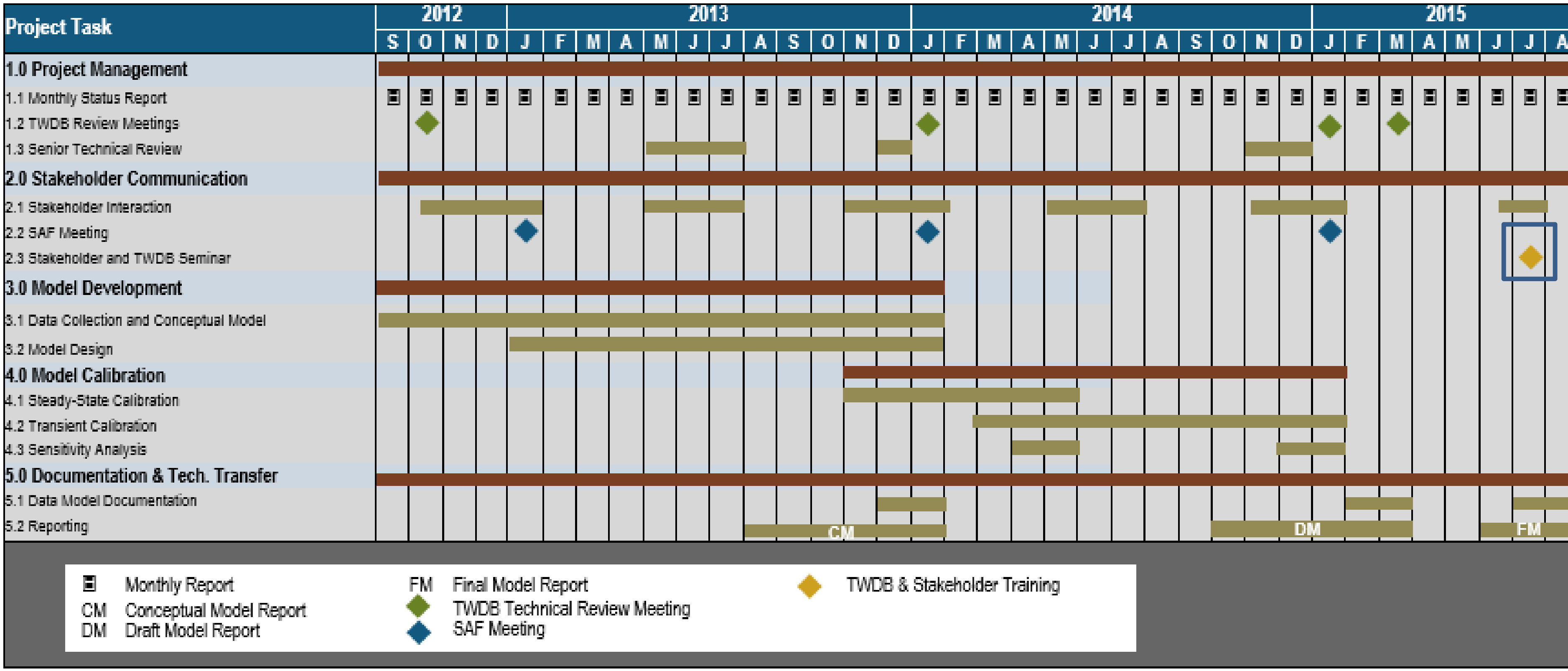
# Transient Calibration: Pumping Prior to 1980

Decreasing pumping prior to 1980 allows post-1980 pumping to be nearly matched




This occurs only in the southern Ogallala counties, similar to the current GAM


Project Task
2012
2013
2014
2015
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A
1.0 Project Management
1.1 Monthly Status Report
1.2 TWDB Review Meetings
1.3 Senior Technical Review
2.0 Stakeholder Communication
2.1 Stakeholder Interaction
2.2 SAF Meeting
2.3 Stakeholder and TWDB Seminar
3.0 Model Development
3.1 Data Collection and Conceptual Model
3.2 Model Design
4.0 Model Calibration
4.1 Steady-State Calibration
4.2 Transient Calibration
4.3 Sensitivity Analysis
5.0 Documentation & Tech. Transfer
5.1 Data Model Documentation
5.2 Reporting
CM
DM
FM
Monthly Report
CM Conceptual Model Report
DM Draft Model Report
FM Final Model Report
TWDB Technical Review Meeting
SAF Meeting
TWDB & Stakeholder Training

**High Plains Aquifer System Groundwater Availability Model**

Stakeholder Advisory Forum

High Plains Water District

August 11, 2015

1. Questions and Answers

<u>Summary of Questions and Answers</u>

1. Q. (refers to Slide 35) The average horizontal conductivity in the Ogallala Aquifer was increased from 18 to 33 ft/d during calibration. Did this affect the number of dry cells in the model?
   A. Overall, Ogallala dry cells were more sensitive to the properties of the underlying units, as we will see later in the presentation.
2. Q. (refers to Slide 44) Where there measurements for the amount of vertical flow between the Edwards Trinity (High Plains) and the Ogallala Aquifer
   A. That flow is basically not measureable on a regional basis, but we can estimate it based on vertical gradients
3. Q. (refers to Slide 51) How are rivers treated in the model? Are they gaining or losing? How was the Pecos River treated?
   A. Rivers could be simulated as either gaining or losing, depending on the simulated water level and the elevation of the river stage. We did not specifically calculate what the net gain/loss was in the Pecos River. [Editor's note: the Pecos River is not actually simulated in the model because it occurs over the Pecos Valley Alluvium, the cells of which are treated as a head boundary conditions.]
4. Q. (refers to Slide 53) Comment: the low measured heads in the Dockum are consistent with wells that are completed not in the Santa Rosa, but in a less permeable "rock".
   A. It could be that the recorded well screen location is wrong in some cases.
5. Q. (refers to Slide 55) What is the average recharge in the post-development period, such as in 2012?
   A. Do not know the exact number off the top of my head, but would estimate it to be around 0.4. It can range as high as 1-3 inches/year in the enhanced recharge areas.
6. Q. How do you explain a well in Floyd County getting rising water levels during the drought?
   A. I cannot explain it with recharge, unless a neighbor has stopped pumping a nearby well, causing groundwater levels to recover. We do not see regional recovery occurring in Floyd County in the Ogallala Aquifer.
7. Q. (refers to Slide 60, in particular the lower right hydrograph that does not have a very good trend match to measured water levels. The presenter had referred to the modeler "not getting the pumping right at that location.") What do you mean you didn't get the pumping right? Did you put pumping in a monitoring well?
   A. No, I mean that we did not have individual well records of pumping. We had a general technique for allocating pumping to wells, but the technique cannot be expected to reproduce reality on a per-well basis. The simulated pumping at that particular well does not create a good match to the measured water level.
8. Q. (refers to Slide 66) Is that recharge for the Ogallala Aquifer in Texas?

A. That is the total recharge in the Ogallala model-wide, which includes portions of NM, OK, KS as well.

9. Q. And that average recharge is less than an inch per year?
   A. Correct.
10. A general explanation of the water budget slide was requested. The major components, including about 6,000,000 AFY pumping, balanced by about 4,500,000 AFY decrease in storage, and 1,500,000 AFY recharge was described.
11. Q. (referring to Slide 68, which showed the water budget for the Edwards Trinity (High Plains)) What was the calibrated vertical conductivity of the Edwards Trinity (High Plains)?
    A. It varied with shale fraction, but it ended up in the range of $1x10^{-5}$ to $1x10^{-4}$ feet per day.
12. Q. (referring to 71-73 which show how calibration was not possible with the original estimates of pumping in the 1950s) A general discussion occurred, where the following points were made:
    a. The flood irrigation that occurred prior to the advent of pivot irrigation was very inefficient, and pivots have become more efficient through time. Farmers used a lot more water early on.
    b. A 36% efficiency could approximately explain the difference between estimated and calibrated pumping if the irrigation water that moved past the root zone returned to the water table

    A. Our decrease in pumping estimates was based on an analysis of the change in the water table elevation, i.e. a storage calculation. The storage calculation indicates that groundwater use estimates were too high prior to the 1980s. That argument could be offset by b), however, the assumption that flood irrigation water that passed the root zone could travel all the way through over 100 feet of vadose zone and return to the water table immediately was not considered plausible, based on previous vadose zone modeling. The TDS and nitrate breakthrough analysis performed by the BEG indicated that in many counties, the enhanced recharge from agricultural activity took decades or longer to show up in the groundwater. Our assumption is that the early historical estimates were just biased high, due to the estimation techniques used.
13. Q. Hale County was shown as an example where the storage change estimates did not match estimates of groundwater pumping. Did this occur in other counties?
    A. Yes, pumping estimates prior to 1980 were adjusted downward in several counties, as documented in the numerical model report.
14. Q. Comment: pivot irrigation in Texas has helped to reduce water use. This is not the case in Kansas because of the rolling hills, where furrow irrigation tended to shed water more quickly. Agricultural water use is less now than in the past.
15. Q. Comment: if the model duplicates water levels for recent years, then that is the most important thing for planning, i.e making predictions with the model
    A. True, unless mismatch in the past indicates a fundamental flaw in the parameterization of the model. We do not feel that this is the case.
16. Q. Comment: A comment was made about property rights, and their importance.
17. Q. In the February GMA-1 meeting, did you say that 30 or 40 feet was the minimum achievable saturated thickness?
    A. The Groundwater Conservation Districts were discussing at what point saturated thickness was too thin to allow economical agricultural production. As the modeler, I was not in on that decision, but was taking input from the stakeholders. I have heard a number 30 or 40 feet being considered

the limit for economical production of row crops. (At this point, there was a general discussion about the large variation in productivity of wells, even at small saturated thickness. The consensus was that the well productivity was dependent on the existence of gravels at the bottom of the well).

18. Q. You said that the Ogallala was always higher than the Edwards Trinity (High Plains). There are places in the southern region where this obviously isn't the case.
    A. What I said, or meant to say, was that the Ogallala was the youngest unit. There may be places where the Ogallala has eroded away to the point where Edwards Trinity (High Plains) is exposed at surface (although those areas were not represented in the model), and in those areas, Ogallala Aquifer to the east would be of lower elevation.
19. Q. Where springs represented in the model, and did you try to match their flow measurements?
    A. Yes, hundreds of springs are represented in the model (especially along the escarpment), and many are simulated as still flowing although flow has reduced as water levels have declined. There were no springs with solid measurements of flow through time, but we did use reported flows to determine where water levels were likely high enough to produce or sustain springflow.
20. Q. There was discussion about schedule, the final product will be delivered to TWDB on August 31.
21. Q. Still confused on why you reduced peak pumping in the 1950s or 1960s, what was that based on?
    A. Storage change calculations.
22. Q. Do you think that the nitrate analysis showed some bias? I appreciate that you mentioned that the source of the nitrate was not known to be agricultural (speaker noted that it could have been flushing of concentrates that had built up over years of grassland land type).
    A. If I understand the question correctly, I don't think there is any bias in the analysis of nitrate breakthrough performed by the BEG.

2. Attendance List

| Name | Organization |
|---|---|
| Neil Deeds | INTERA Inc. |
| Cindy Ridgeway | Texas Water Development Board |
| Amber Blount | Sandy Land UWCD |
| Lori Barnes | Llano Estacado UWCD |
| Lindy Harris | South Plains UWCD |
| Ron Lacewell | Texas A&M Agrilife |
| Bill Hutchison | Consultant |
| Kevin Krueger | Colorado River Municipal Water District |
| Venki Uddameri | Texas Tech University |
| Ronnie Hopper | High Plains Water District |
| Sue Young | Lone Wolf GCD |
| Latrice Adams | Permian Basin UWCD |
| Donna Springer | Permian Basin UWCD |
| JC Adams | Land Owner |
| Alyson McDonald | Texas A&M Agrilife |
| Kyle Ingham | Panhandle Regional Planning Commission |
| Charles Hillyer | Texas A&M Agrilife |