Groundwater Availability Modeling (GAM) for the Lipan Aquifer

LBG-GUYTON
Associates

Presented to

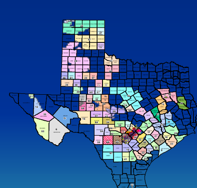
Stakeholder Advisory Forum

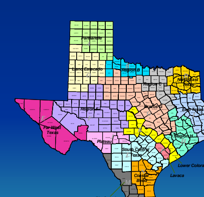
San Angelo, Texas

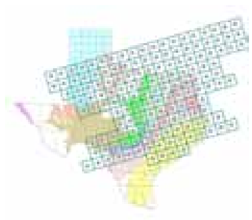
July 31, 2003

Groundwater Availability Modeling

Contract Manager
Texas Water Development Board

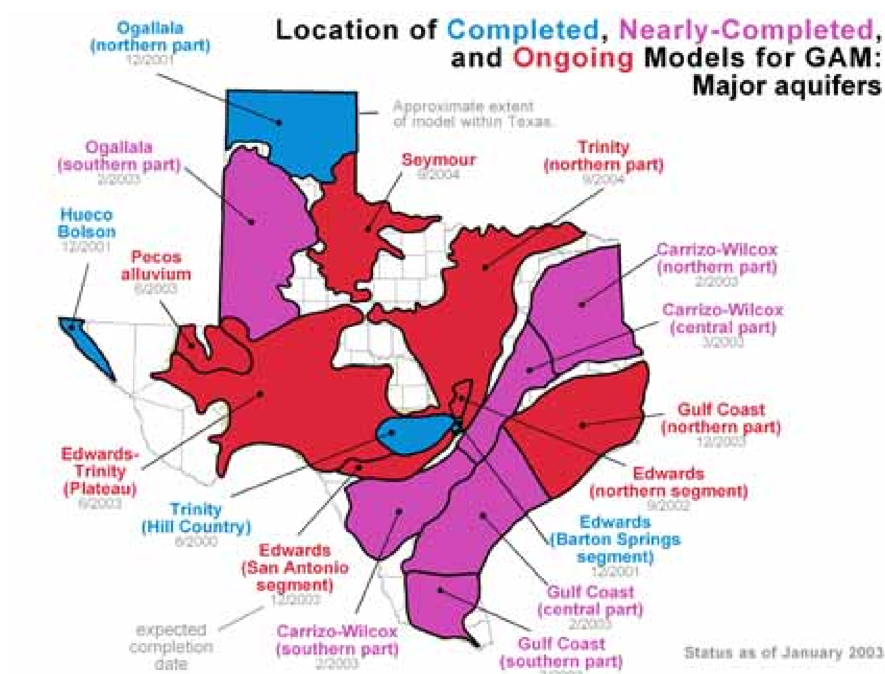


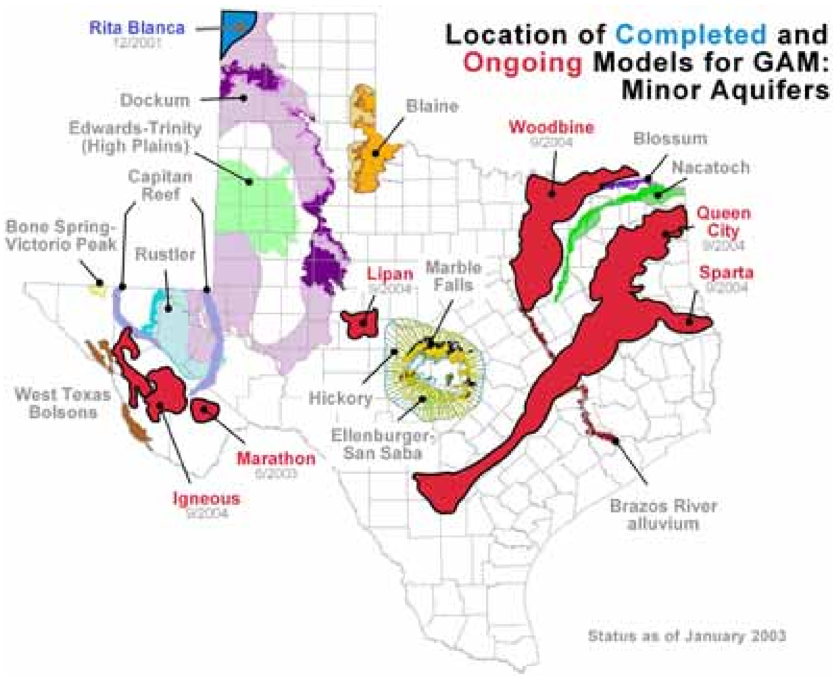




GAM

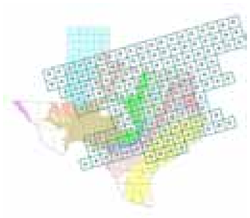
- Purpose: to develop the best possible groundwater availability model with the available time and money.
- Public process: you get to see how the model is put together.
- Freely available: standardized, thoroughly documented, and available over the internet.
- Living tools: periodically updated.





What is groundwater availability?

- …the amount of groundwater available for use.
- The State does not decide how much groundwater is available for use: GCDs and RWPGs decide.
- A GAM is a tool that can be used to assess groundwater availability once GCDs and RWPGs decide how to define groundwater availability.

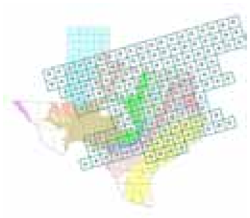


Do we have to use GAM?

- Water Code & TWDB rules require that GCDs use GAM information. Other information can be used in conjunction with GAM information.
- TWDB rules require that RWPGs use GAM information unless there is better site specific information available

How do we use GAM?

- The model
  – predict water levels and flows in response to pumping and drought
  – effects of well fields
- Data in the model
  – water in storage
  – recharge estimates
  – hydraulic properties
- GCDs and RWPGs can request runs



Living tools

- GCDs, RWPGs, TWDB, and others collect new information on aquifer.
- This information can enhance the current GAMs.
- TWDB plans to update GAMs every five years with new information.
- Please share information and ideas with TWDB on aquifers and GAMs.

Participating in the GAM process

- SAF meetings
  - hear about progress on the model
  - comment on model assumptions
  - offer information (timing is important!)
- Report review
  - at end of project
- Contact TWDB
  - Robert Mace
  - Richard Smith

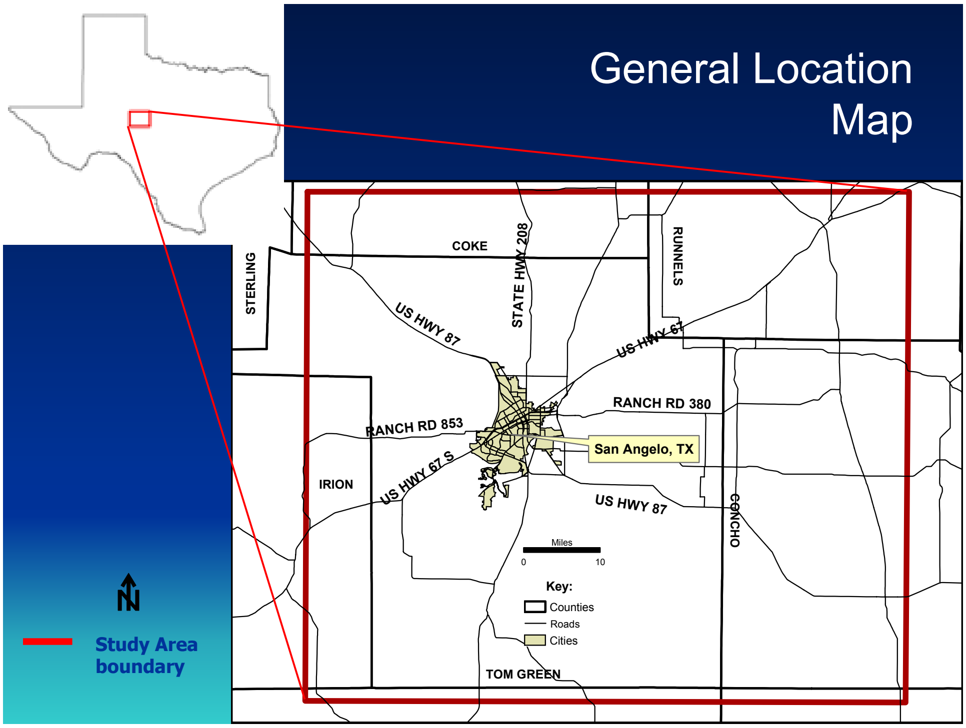
Comments:

Richard Smith
richard.smith@twdb.state.tx.us
(512)936-0877
www.twdb.state.tx.us/gam

Conceptual Model for Lipan Aquifer GAM

Physiography and Climate

General Location Map



Physiographic Provinces

http://www.lib.utexas.edu/geo/physography.html

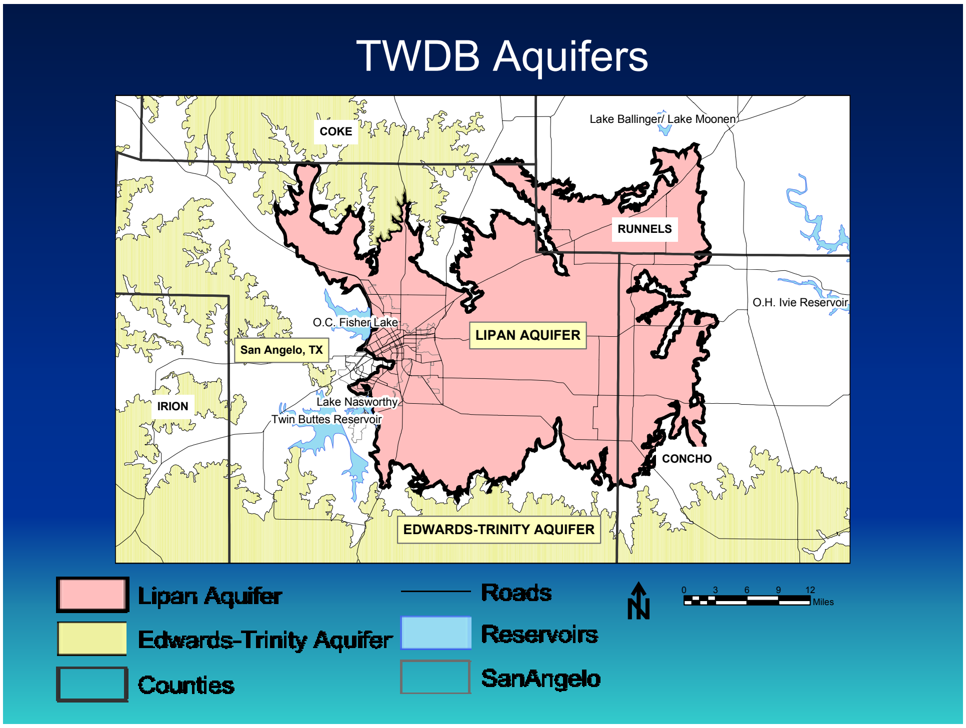
- **Central Texas (North-Central Plains)**
  - ❖ Shale Bedrock characterized by meandering rivers through local prairie
  - ❖ Harder Bedrock forms hills and rolling plains dissected by rivers.
  - ❖ Live oak ashe juniper parks grade westward into mesquite lotebush brush.
- **Edwards Plateau**
  - ❖ The Edwards Plateau is capped by hard Cretaceous limestones. Local streams entrench the plateau as much as 1,800 feet in 15 miles.
  - ❖ The upper drainages of streams are waterless draws that open into box canyons where springs provide permanently flowing water.
  - ❖ Sinkholes commonly dot the limestone terrain and connect with a network of caverns.
  - ❖ The vegetation grades from mesquite juniper brush westward into creosote bush tarbush shrubs.

General Climate

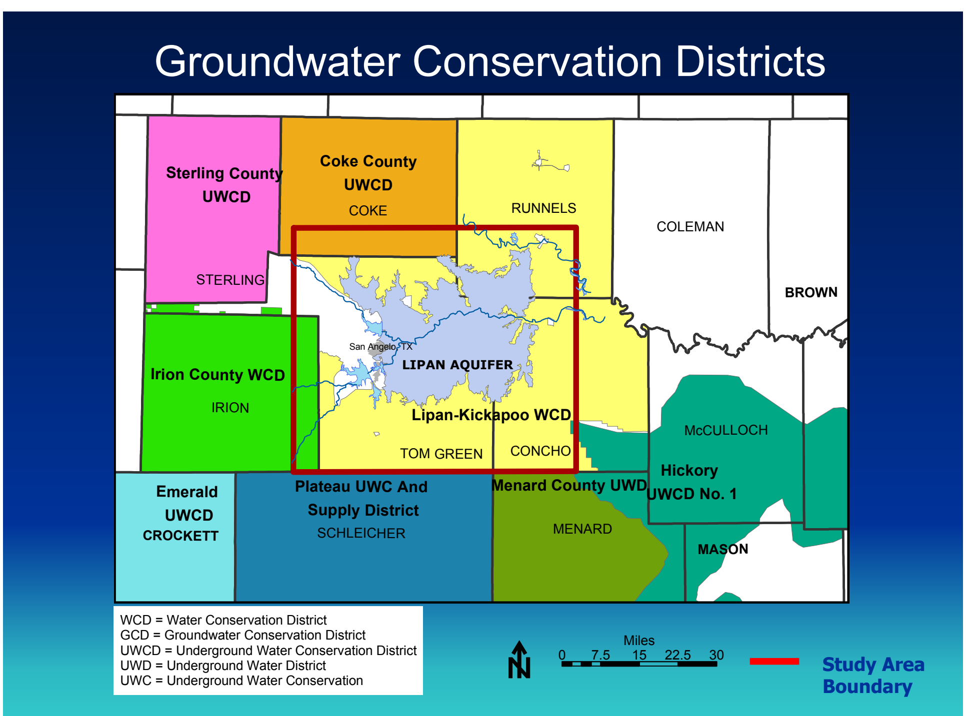
(San Angelo, TX www.sanangelo.org)

- San Angelo, TX Elevation is 1900 ft – Model Area Elevation Range is 1500 ft to 2500 ft
- Located Near the Northern Boundary of the Chihuahuan Desert
- Average Morning Humidity of 79%, That Drops to an Average of 44% in the Afternoons
- average annual temperature is 64.9 degrees, with average highs of 78.1, and lows of 51.6.
- San Angelo receives 251 days of sunshine each year, and the average rainfall is 20.45 inches.

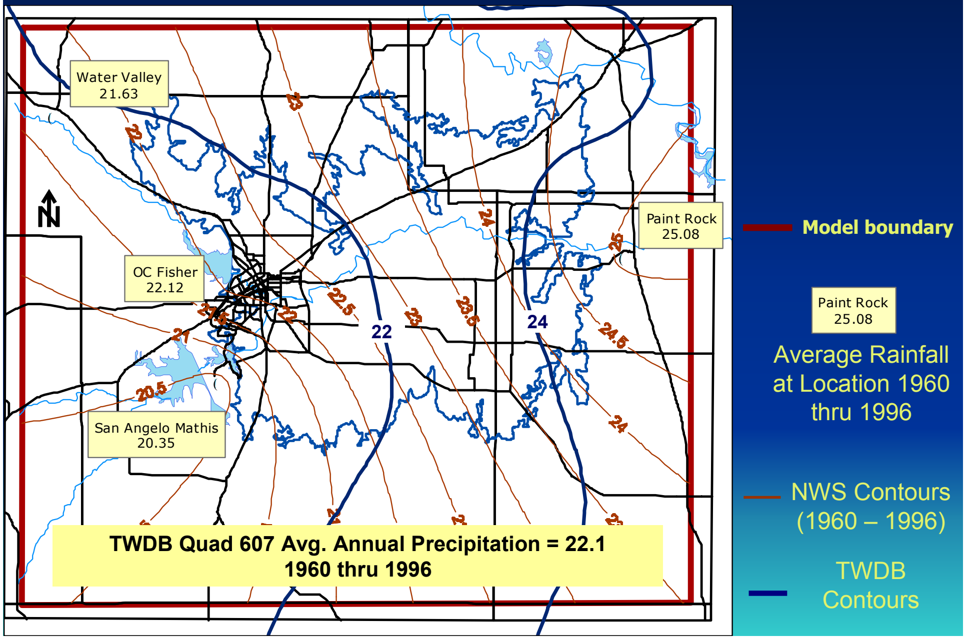
TWDB Aquifers



Groundwater Conservation Districts

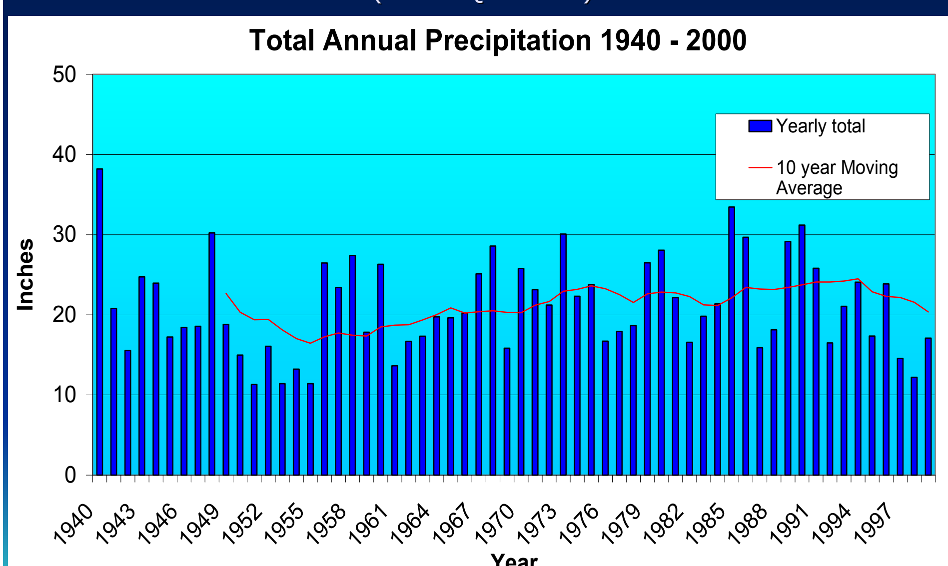


Mean Annual Rainfall 1960 thru 1996

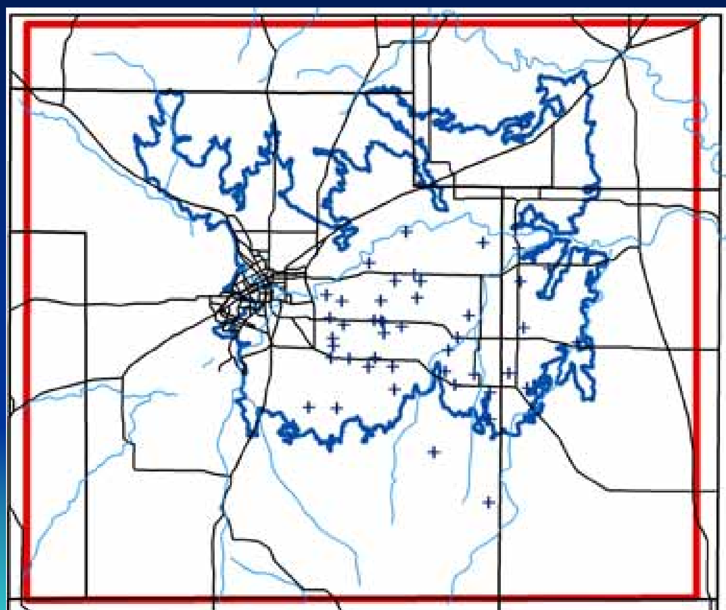


Annual Precipitation

(TWDB Quad 607)



Lipan-Kickapoo WCD Rain Gages

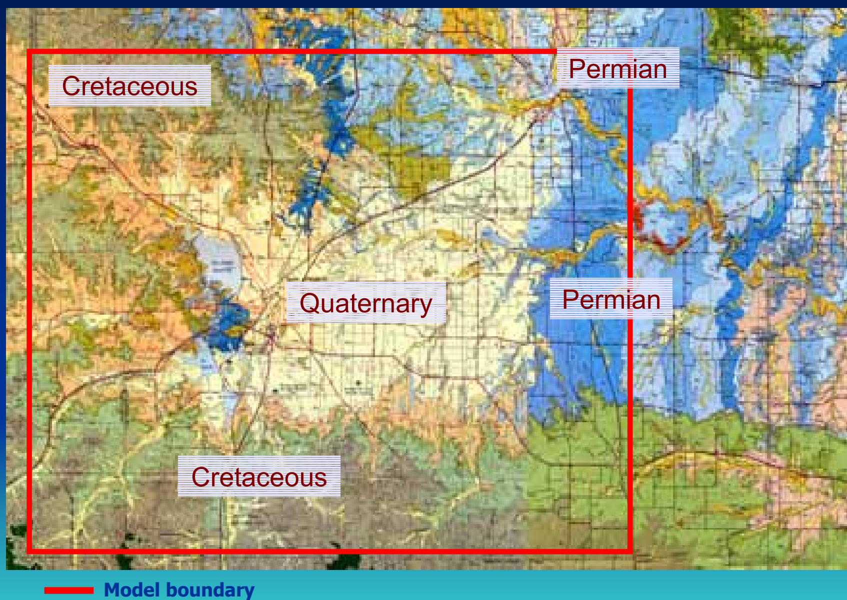


Data Only Available from 2000 to Present

+ Rain Gage Locations

Geology

Surface Geology



Geologic Formations in the Model Area

- Leona Formation – Quaternary Alluvial Deposits Consisting Mainly of Gravels and Conglomerates Cemented with Sandy Lime
- Permian Formations – Primarily Limestone Units in the Model Area Including the Choza, Bullwagon, Vale, Standpipe, and Arroyo Formations
- Cretaceous Formations – Edwards – Trinity Formations Located to the South and West

Geologic History in Model Area

- Permian Deposits Overlain by Quaternary Alluvium
- Rising and Falling Water Levels Created Karst Features
- Quaternary Alluvium Subsequently Filled These with Gravels and Conglomerates
- No Mapped Faults However there is Evidence of Recent Active Faulting in Kickapoo Creek

Stratigraphic and Hydrostratigraphic Section

Stratigraphic and Hydrostratigraphic Section of the Lipan Aquifer

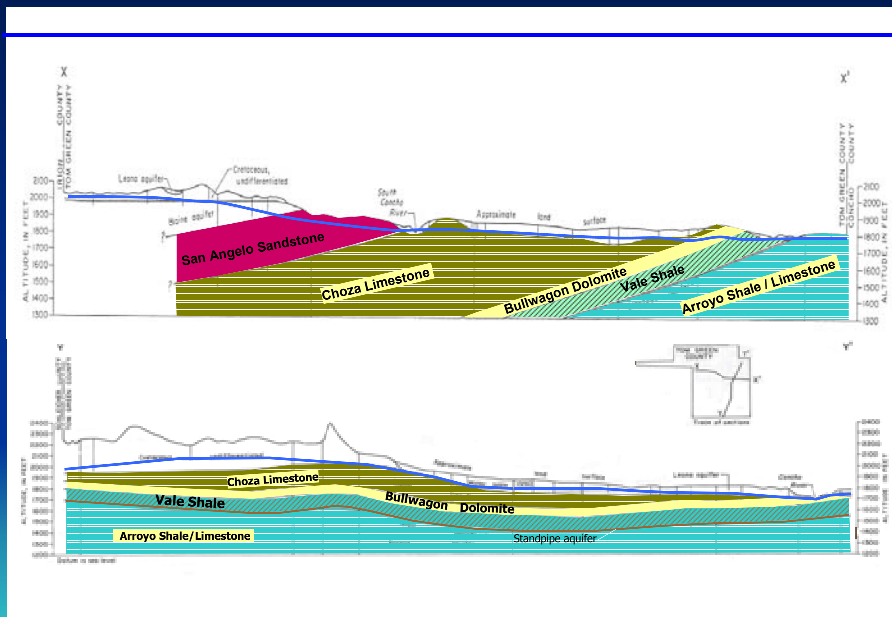
Age	Formation	Thickness	Hydrologic Unit	Description and Water-Bearing Characteristics
Quaternary	Leona Formation and Alluvium	0 - 125 feet	Leona Aquifer	Gravel and Stream Channel Deposits with conglomerate of Limestone cemented with sandy lime. Some layers of caliches and clay. Yields sufficient water for irrigation where thickness is suitable
Permian	San Angelo Sandstone	250 feet	San Angelo Aquifer	Bright red sandstone with some clay and gypsum. Conglomerate at base. Yields small quantities of water.
	Choza Formation	625 feet	Choza Aquifer	Gray dolomitic limestone with clay and some silty clay layers. Yields small quantities of water.
	Bullwagon Dolomite	75 feet	Bullwagon Aquifer	Massive yellow to gray dolomitic limestone and green and red shale layers. Yields sufficient water for irrigation.
	Vale Formation	140 feet	Vale Aquifer	Shale at top. Rest is red sandy shale with thin streaks of green shale. Yields small quantities of water.
	Standpipe Limestone	15 feet	Standpipe Aquifer	Yellowish to light gray marly limestone. Yields small quantities of water.
	Arroyo Formation	60+ feet	Arroyo Aquifer	Alternating layers of shale and limestone. Yields small quantities of water from the limestone horizons.

Figure 10. Stratigraphic and Hydrostratigraphic Section of the Lipan Aquifer

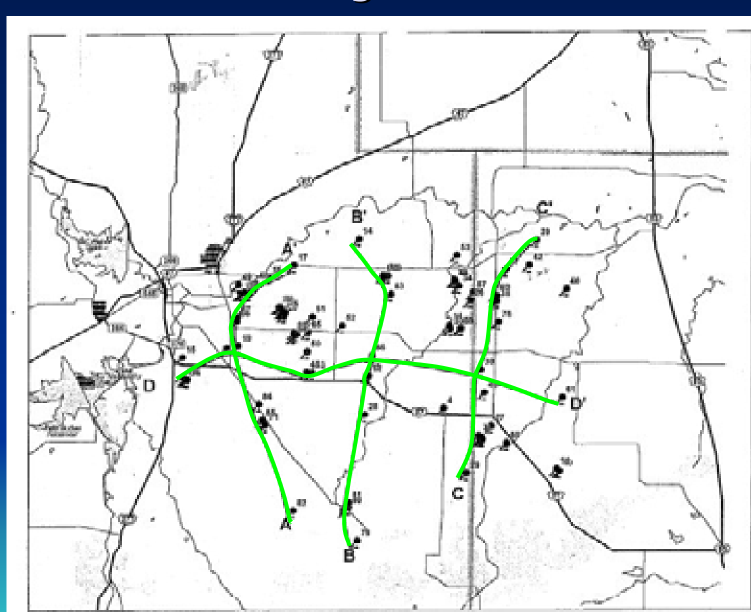
Data: After Lee (1986) "Shallow Ground-Water Conditions, Tom Green County, Texas

Location: S:\Projects\GAM\GAM\Lipan\LEON\cordata\geol\Strat_section.xls

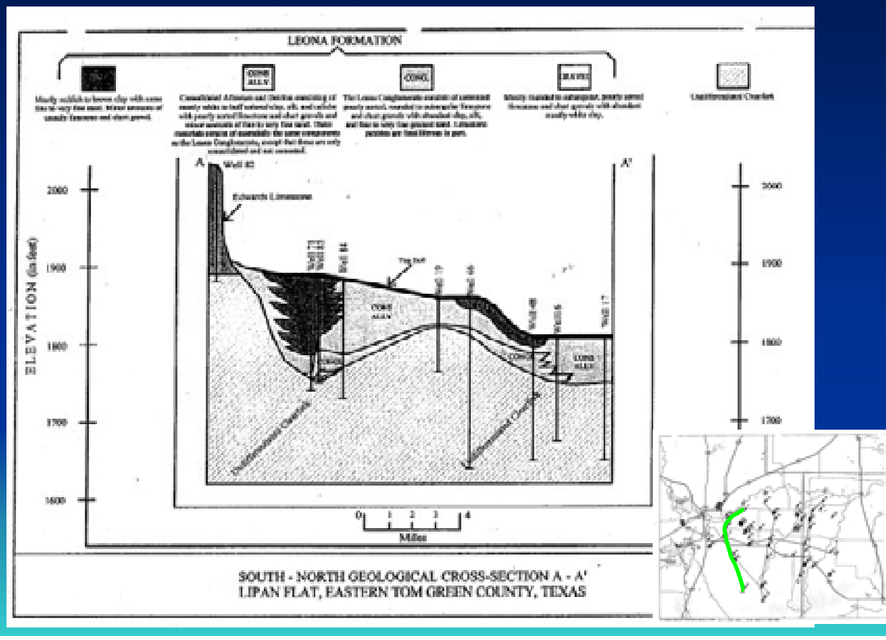
Geologic Cross-Sections (after Lee, 1986)



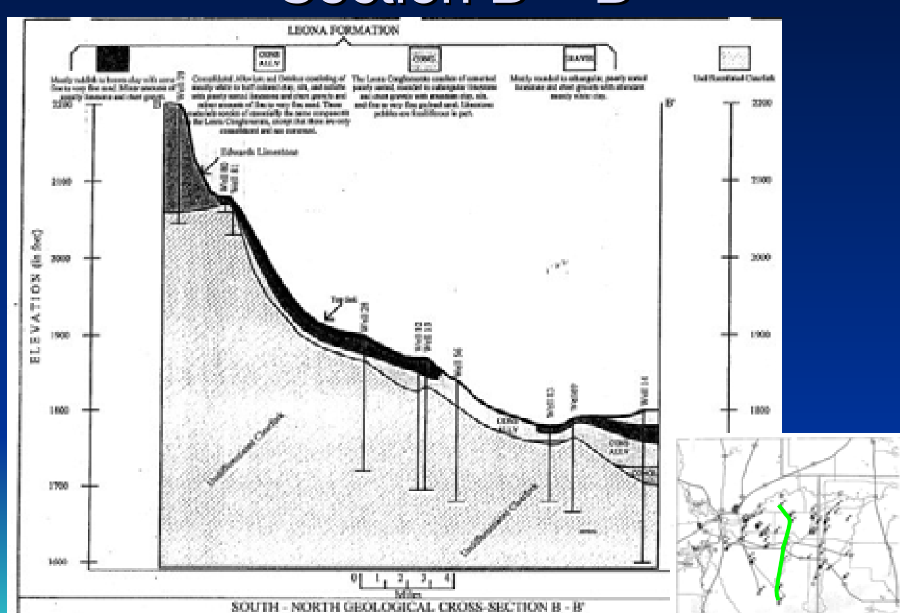
Driller's Logs Cross-Sections



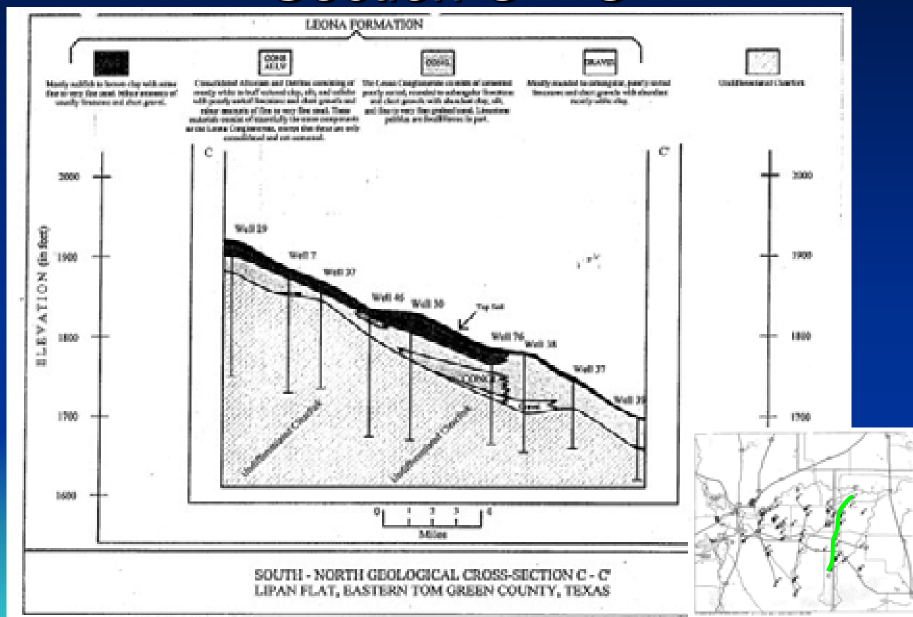
Section A - A’



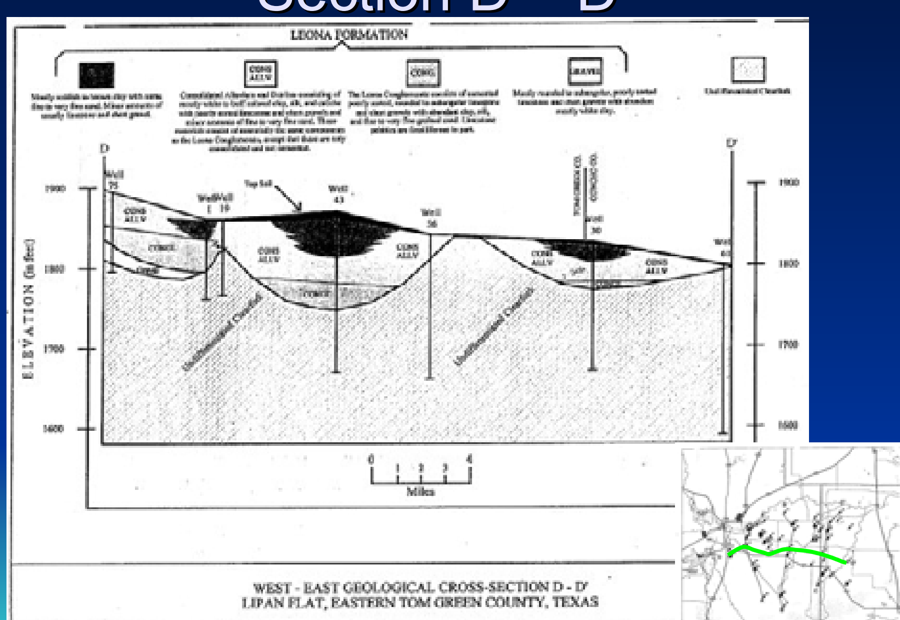
Section B – B’



Section C – C’



Section D – D’



Hydrostratigraphy

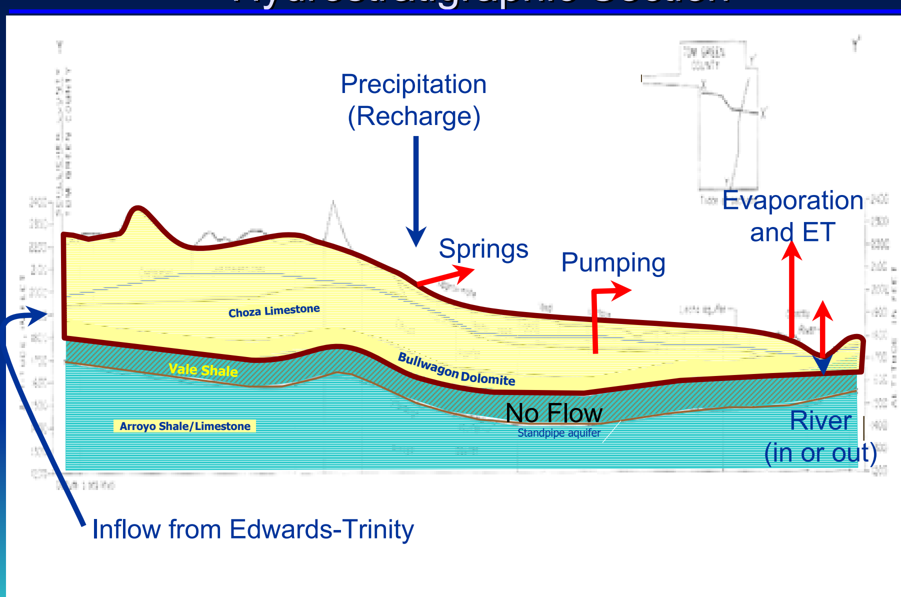
Hydrostratigraphic Properties

- Leona, Cretaceous and Permian Units are Hydraulically Connected.
- In General they Behave as one Hydrostratigraphic Unit with no Observable Hydraulic Head Differences Related to Hydrostratigraphy
- Water Quality and Transmissivity Deteriorate with Depth
- Aquifer Productivity is Partially Influenced by Presence of Paleo-features with Higher Transmissivity

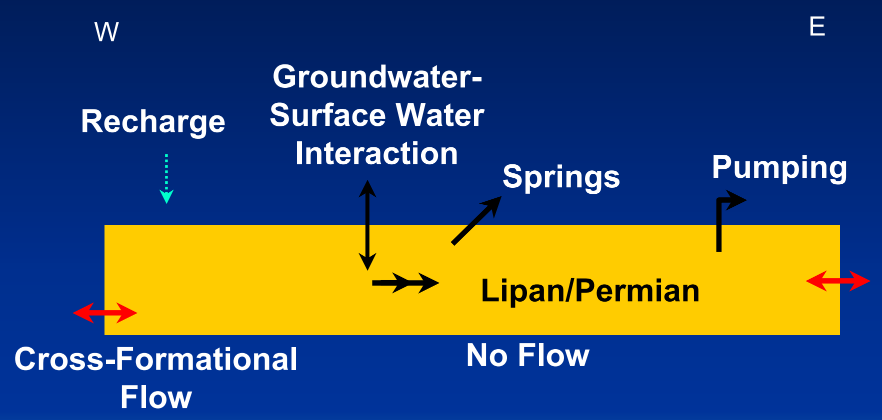
Why a One Layer Model?

- Most of the Leona Formation is Dry
- Generally, Leona Gravels and Underlying Permian Units are Hydraulically Indistinguishable
- There is no Data to Substantiate Vertical Gradients
- Most of the Larger Production Wells are in the Permian which Initially was not Designated as Part of the Lipan Aquifer

Hydrostratigraphic Section

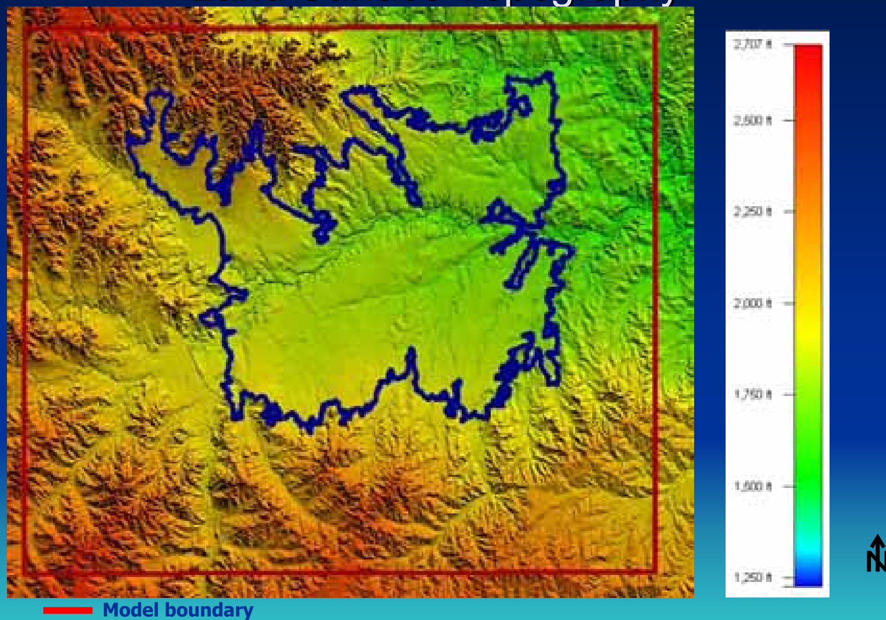


Numerical Model Block Diagram

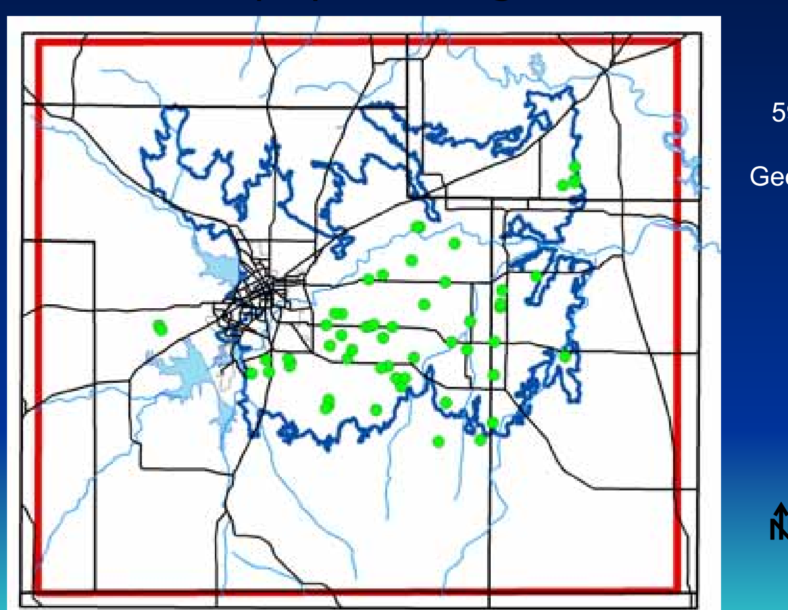


Structure

Land Surface Topography

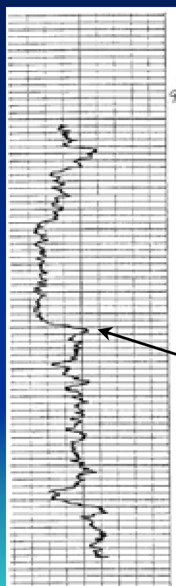


Geophysical Log Locations



59 Wells With Geophysical Logs

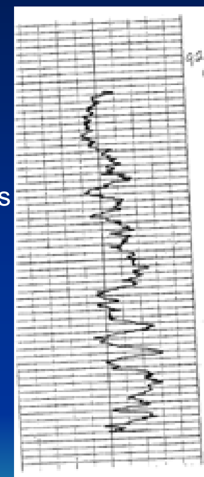
Geophysical Log Interpretation



Used Geophysical Logs to Attempt to Locate the Base of the Leona Formation

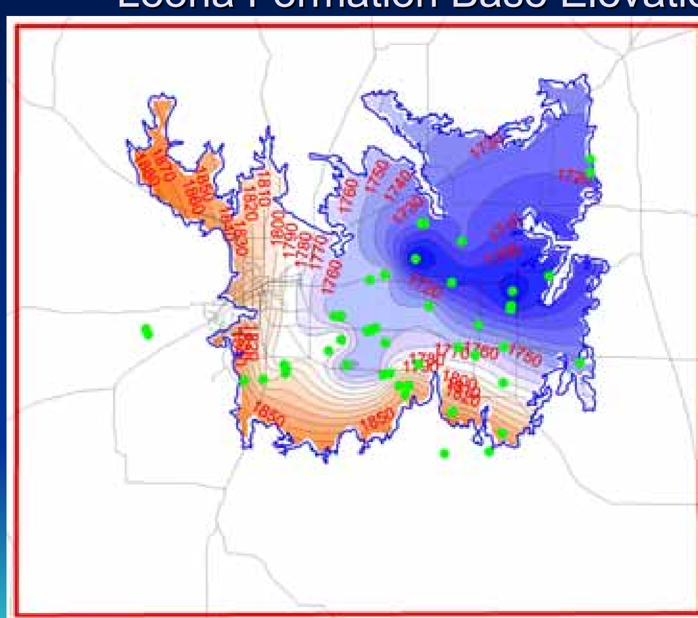
- On Some Logs, A Possible Lithologic Contact is Evident
- On Others, It is Difficult, if not impossible to Discern the Contact

Assumed Leona / Permian Contact



Picks were made on 48 of the 59 Logs

Leona Formation Base Elevation

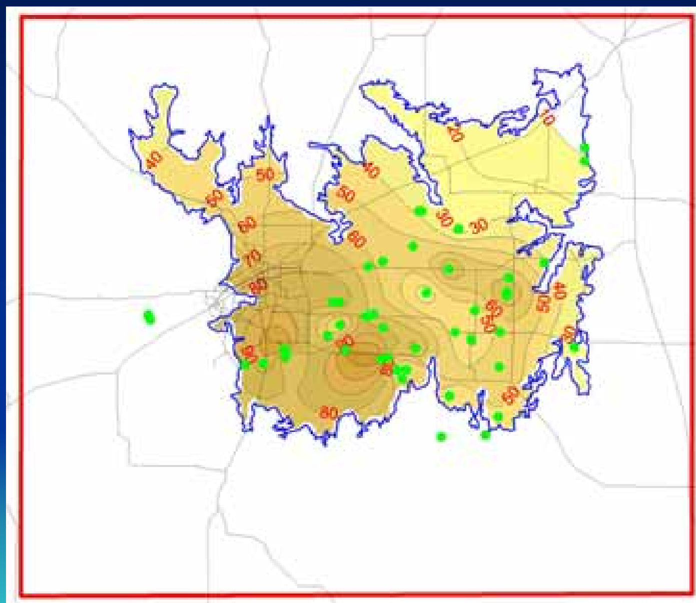


Based on Geophysical Logs

Log Location

Model boundary

Total Thickness of the Leona Formation

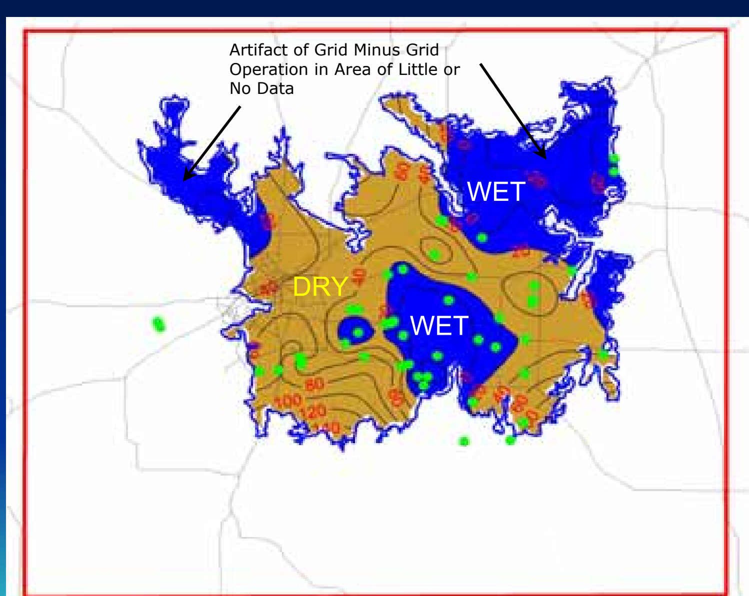


Based on Geophysical Logs

Log Location

Model boundary

Saturated Thickness of Leona Formation 1980



Based on Geophysical Logs

Log Location

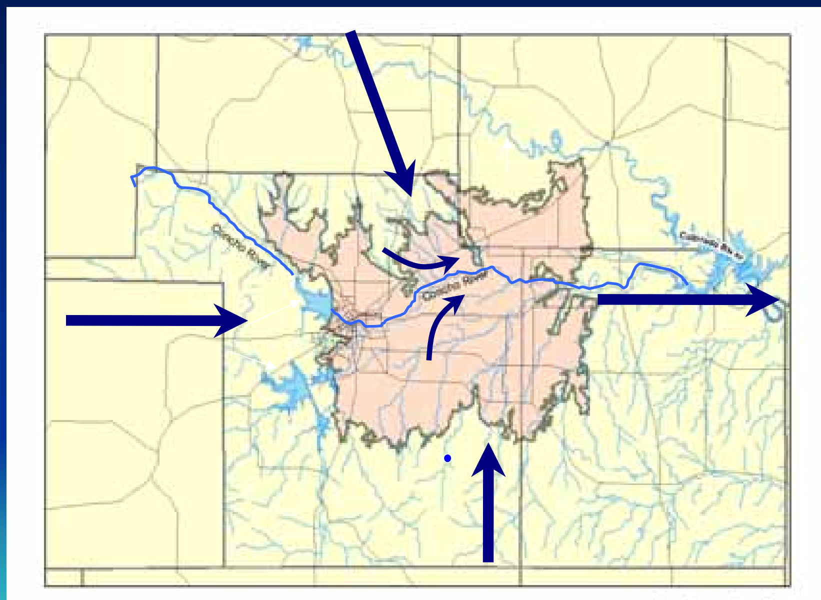
Model boundary

Permian Geology

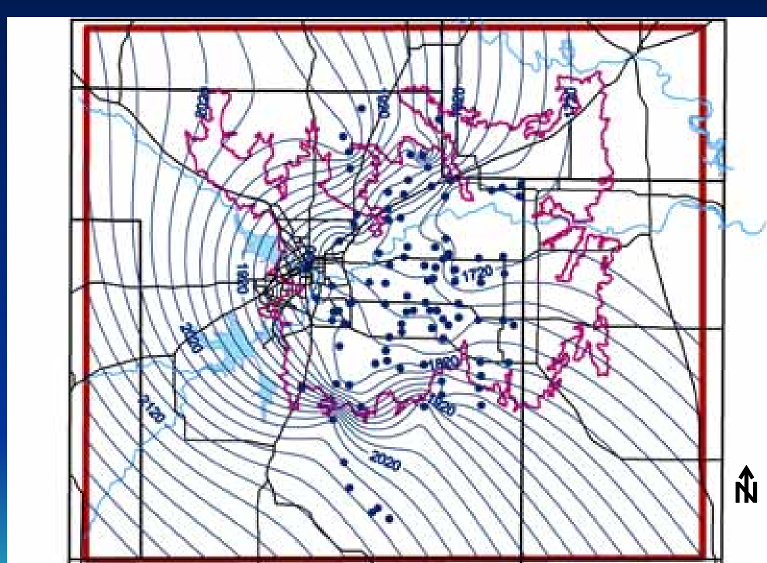
- Permian units predominantly act as a single hydrostratigraphic unit beneath the Lipan aquifer and are in direct communication with the Lipan aquifer
- Different Permian units are not distinguishable based on drilling logs or water levels
- Base of the aquifer will be 400 feet below ground surface

Water Levels and Regional Groundwater Flow

Regional Groundwater Flow Paths

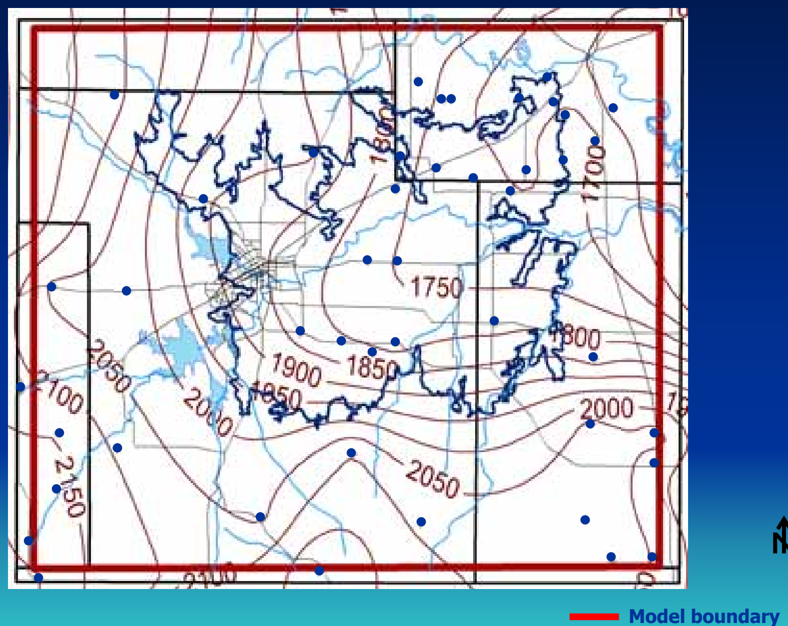


Predevelopment Groundwater Elevations from TWDB Database
First Quarter (Jan - Mar) 1950 Filtered Data

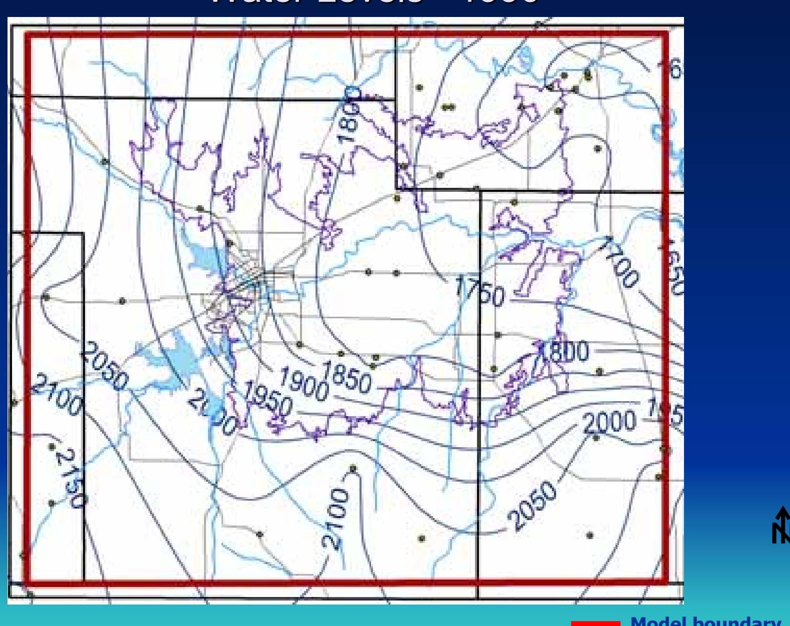


Model boundary

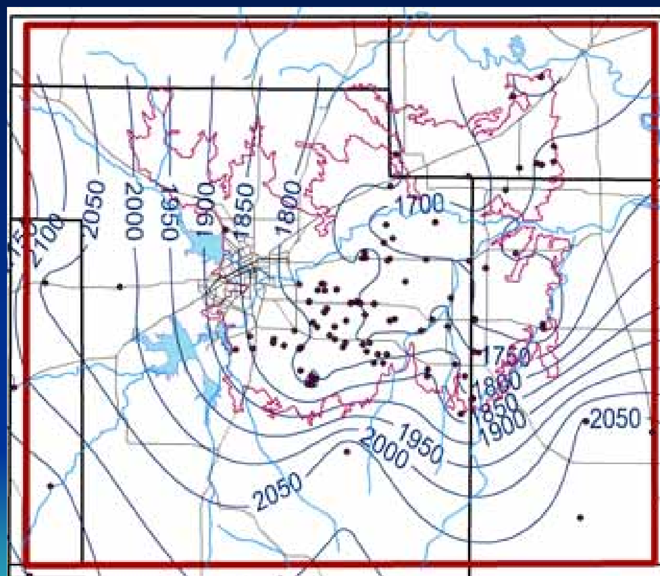
Water Levels - 1981



Water Levels - 1990



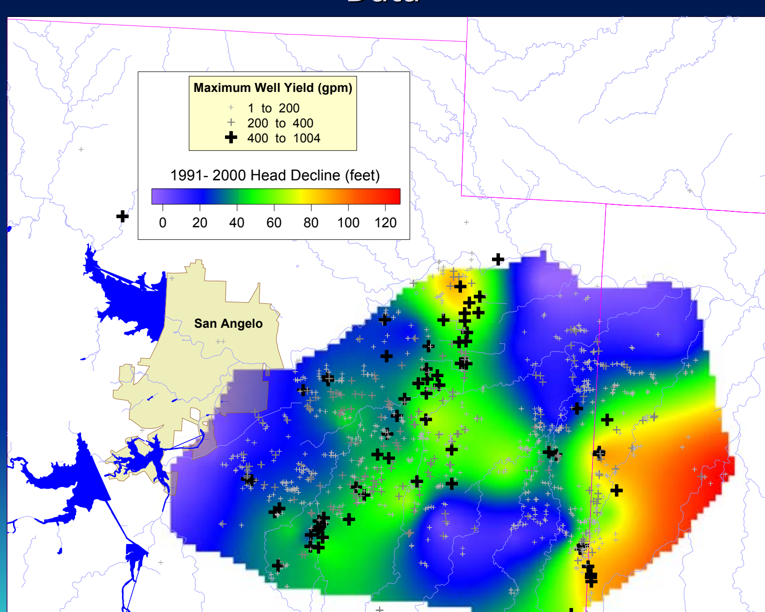
Water Levels - 2000



Added LKWCD Data to TWDB Data

Model boundary

Water Level Decline 1991 –2000 Based on LKWCD Data



Recharge and Evapotranspiration

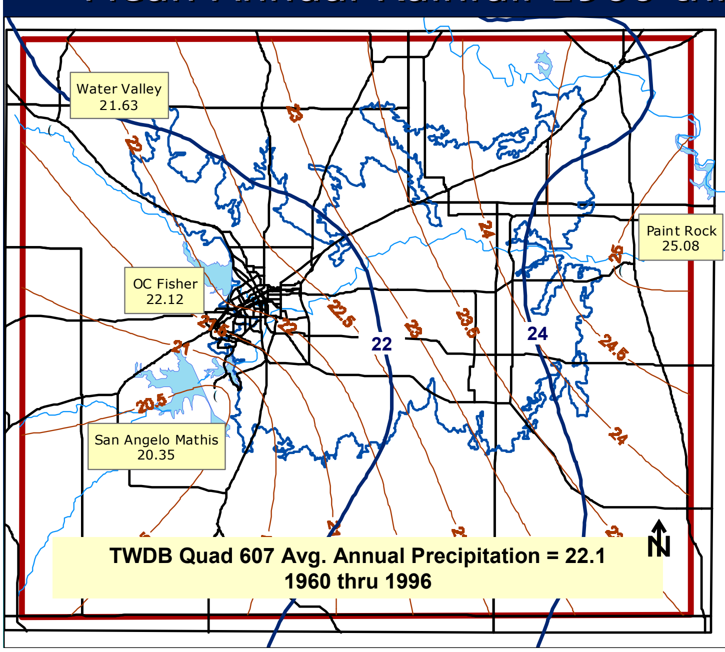
Sources of Recharge

- Precipitation
- Irrigation Return Flow
- Stream and River Leakage
- Lake and Pond Leakage
- Injection Wells

Factor Influencing and Controlling Recharge

- Precipitation and Evapotranspiration
- Soil Characteristics including Permeability and Thickness
- Geologic Controls – Structure, Rock Type and Sat/Unsat Hydraulic Conductivity
- Land Use / Land Cover
  - Vegetation Density
  - Agricultural Areas
  - Urban Area
  - Crops and Irrigation
- Stream and River Flow characteristics
- Topographic Slope

Mean Annual Rainfall 1960 thru 1996



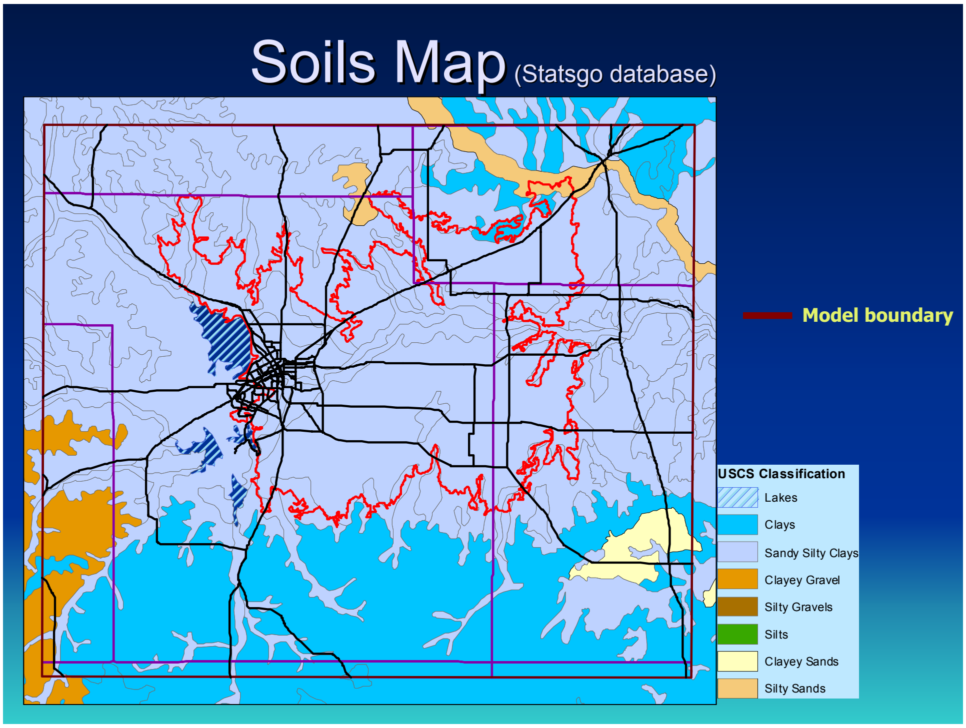
Model boundary

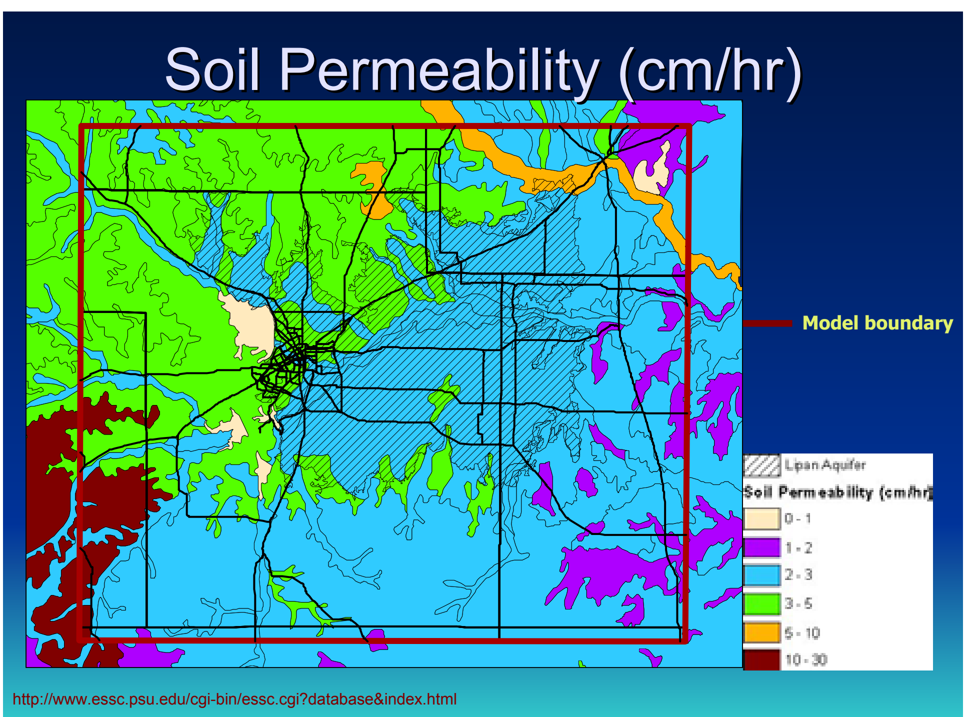
Paint Rock
25.08

Average Rainfall at Location 1960 thru 1996

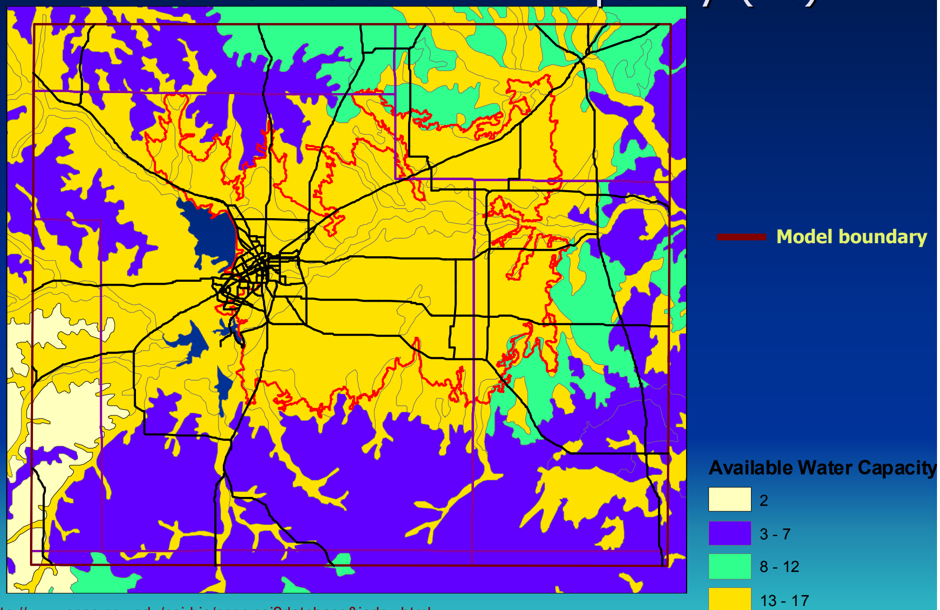
NWS Contours (1960 – 1996)

TWDB Contours


Soils Map (Statsgo database)
Model boundary
USCS Classification
Lakes
Clays
Sandy Silty Clays
Clayey Gravel
Silty Gravels
Silts
Clayey Sands
Silty Sands

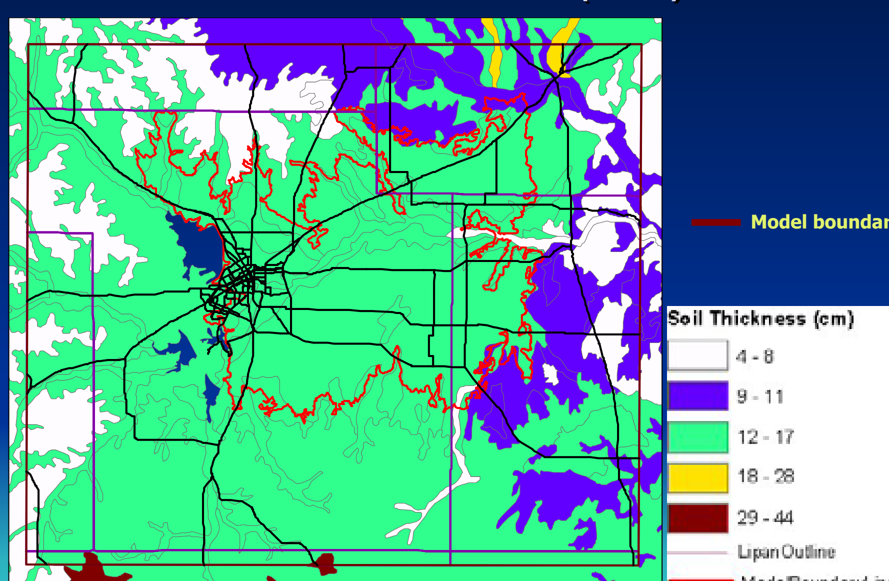

Soil Permeability (cm/hr)
Model boundary
Lipan Aquifer
Soil Permeability (cm/hr)
0 - 1
1 - 2
2 - 3
3 - 5
5 - 10
10 - 30
http://www.essc.psu.edu/cgi-bin/essc.cgi?database&index.html

Soil Available Water Capacity (%)



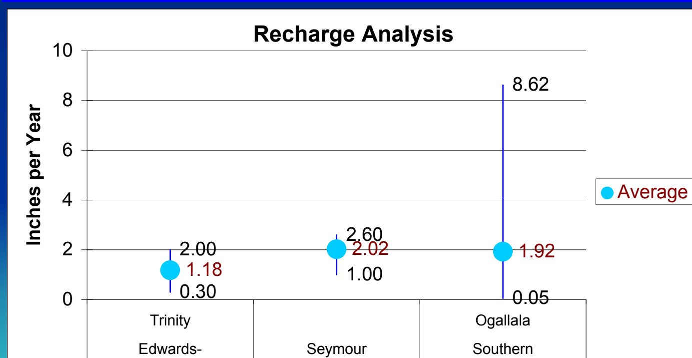
http://www.essc.psu.edu/cgi-bin/essc.cgi?database&index.html

Soil Thickness (cm)



Nearby Recharge Estimates

	Aquifer		
Recharge Rate (in/yr)	Edwards-Trinity	Seymour	Southern Ogallala
Min	0.30	1.00	0.05
Max	2.00	2.60	8.62
Average	1.18	2.02	1.92
Count	4	5	17

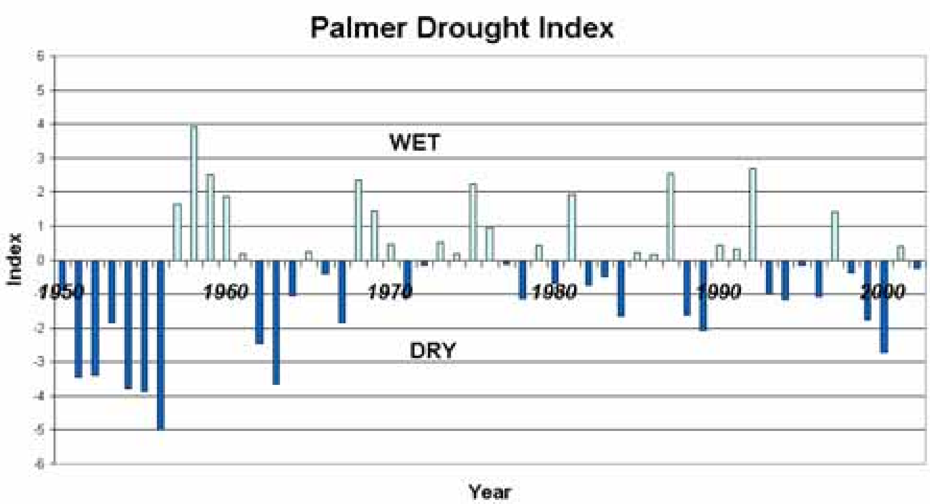


Recharge in the Model

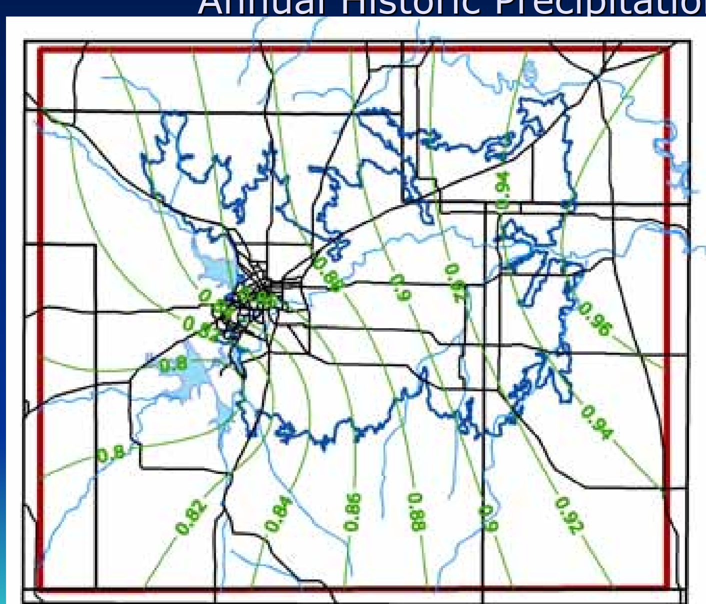
- For yearly stress periods, initial recharge estimates will be spatially-varied distributed based on a percentage of mean annual precipitation
- For monthly stress periods, recharge will initially be distributed, both spatially and temporally, based on percentage of mean monthly precipitation.
- During calibration, recharge will be adjusted as necessary, within reasonable constraints, both temporally and aerially.

Palmer Drought Index

http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/main.html



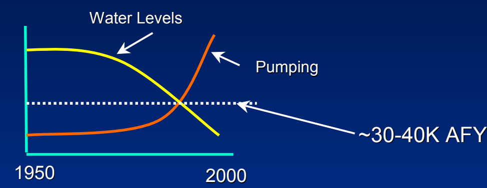
Initial Estimate of Recharge as 4% of Mean Annual Historic Precipitation



Model boundary

Is This Recharge Rate Reasonable?

1. Analysis of Long-Term pumping and water-levels indicate that Annual Recharge is on the order of 40,000 AFY
2. Assuming Half of the recharge to the system is due to Precipitation
3. Area of Lipan Aquifer from TWDB Outline ~ 400,000 Acres
4. It is assumed that Lateral and Vertical Recharge are in the range of 10,000 to 30,000 AFY Each



$R_t = R_v + R_l$ %Precip = R_v

Vertical Recharge

Assume 4% Precipitation as Recharge

1.75 ft/yr (Precip) x 0.04 x 400,000 Acres = 28,000 AFY

Lateral Recharge is Q=-KiA

Assume K =10 ft/Day, i = 0.003 and A = 4.5 X 10^6 ft (Perimeter of Upgradient edges of Aquifer X 100' thick)

Q = 10 X 0.003 X 4.5 X 10^6 = 11,340 AFY

Evapotranspiration (ET)

- Refers to the Loss of Groundwater and Soil-moisture Due to Free-water Evaporation, Plant Transpiration or Soil-moisture Evaporation.
- Potential Evapotranspiration; "The Water Loss That Will Occur If at No Time There Is a Deficiency of Water in the Soil for Use by Vegetation" Thornthwaite,1955
- Actual Evapotranspiration, the Amount of ET That Occurs Under Field Conditions, Is Controlled by the Soil Moisture Content, Precipitation, Vegetation Density and Root Zone Depth

Applying ET in the Model Area

- Crops will be main source of ET in the irrigated areas
- Recharge and ET the irrigated areas will be coupled resulting in an effective recharge rate in those areas
- ET in riparian areas may be substantial
- There is no readily available data for vegetation in the riparian areas of the model
- ET in the rest of the model area will be driven by mesquite because it has a very high ET rate, a deep root zone depth and is prevalent outside the Lipan Flats

Evapotranspiration in Model Area

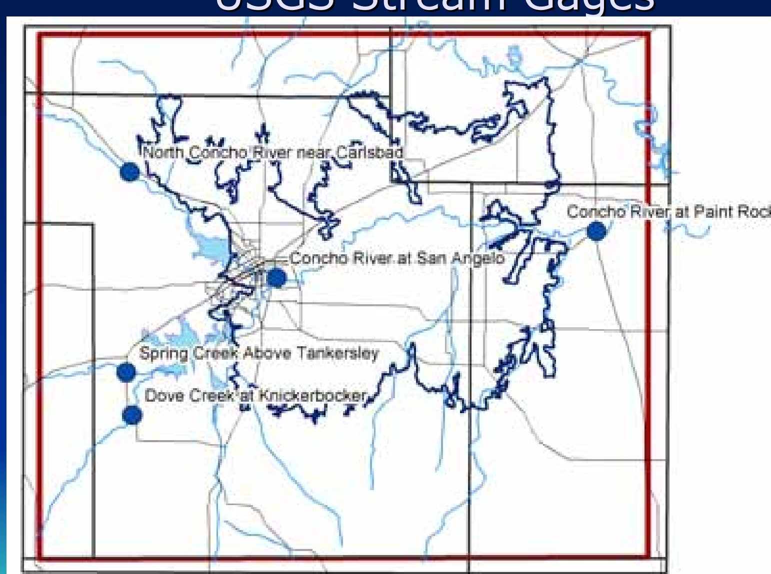
Evapotranspiration Rates and Maximum Root Zone Depths for Vegetation Found in the Model Area

Plant	Estimated Rate Min (in/yr)	Max (in/yr)	Mean Maximum Root Depth (Feet)	Source
Crops	30.8		6.9	From Data for Edwards Plateau (Borelli, et. al., 1998)
Live Oak	30.2		13 - 41	Doleman, 1990
Juniper	23.3	25	12.8	Dugas, et. al., 1998
Mesquite	8.8	25.4	39 - 46.9	Duell, 1990; Tromble, 1977; Ansley et al, 1998

Data From Shirley Wade's Preliminary Approach for Estimating Evapotranspiration

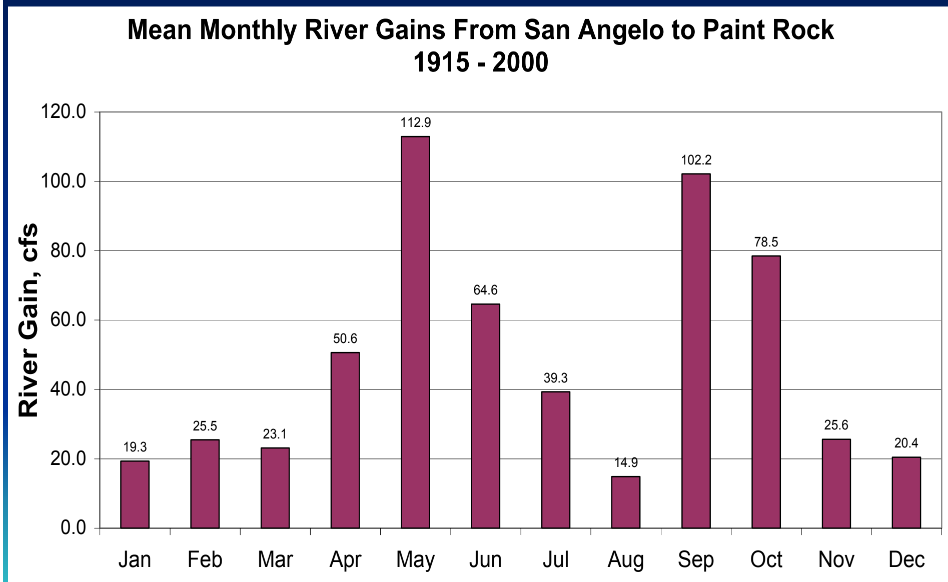
Rivers, Streams, Springs and Lakes

USGS Stream Gages

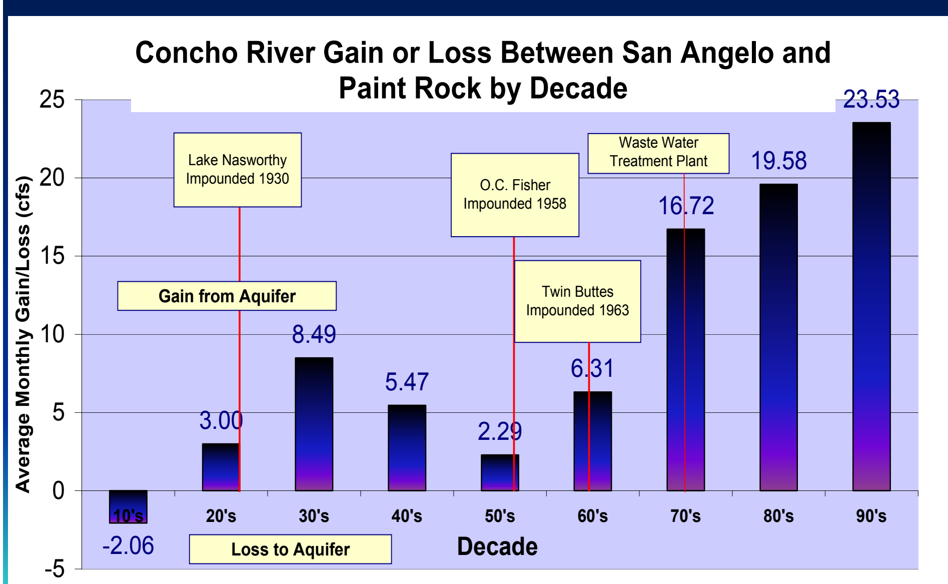


Model boundary

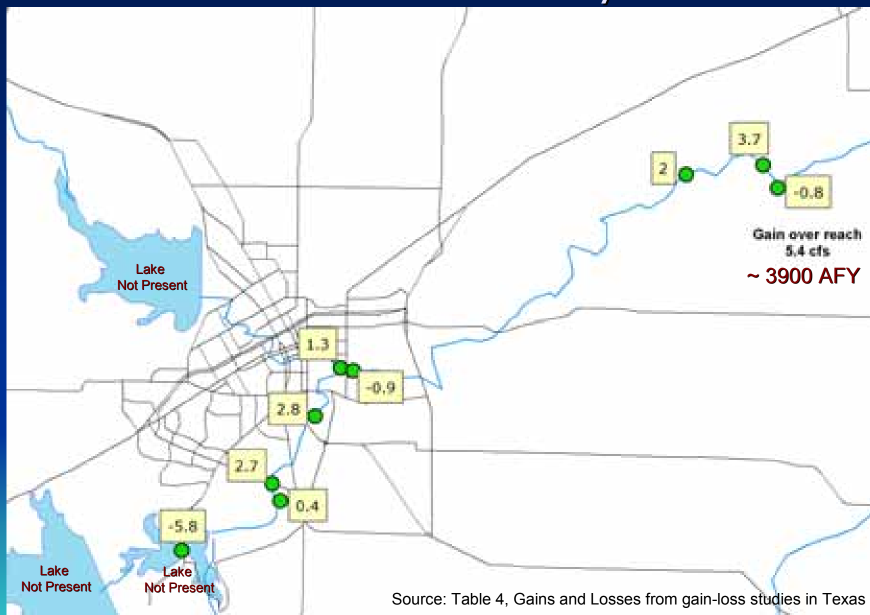
Surface Water / Ground Water Interaction



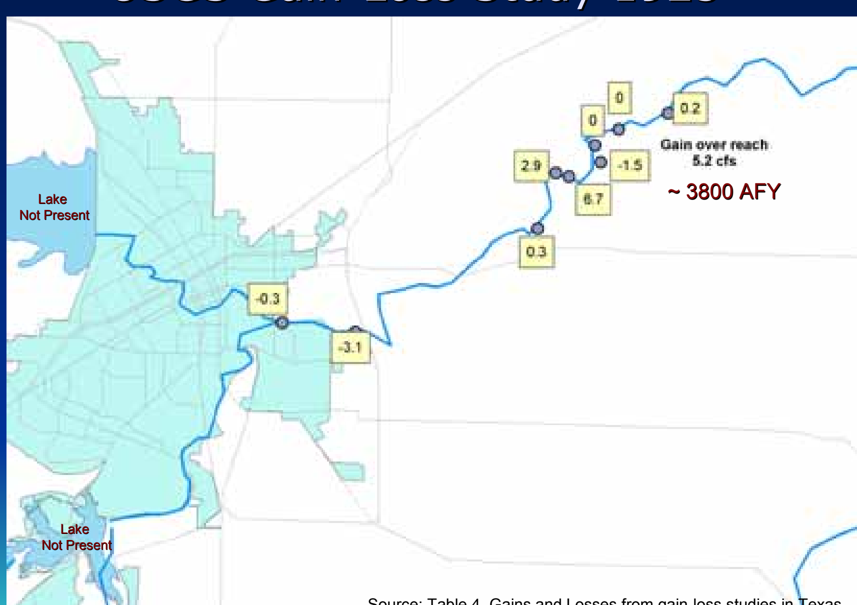
Concho River Gains and Losses



USGS Gain-Loss Study 1918



USGS Gain-Loss Study 1925



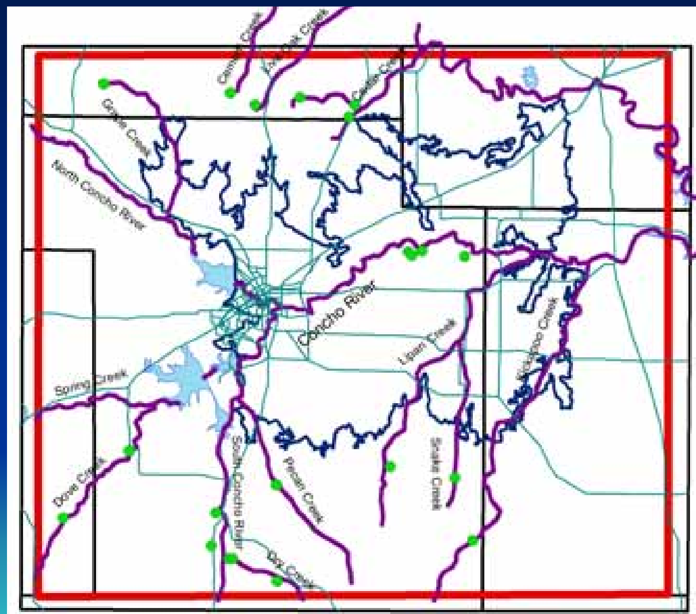
Modeling the Streams

- Use MODFLOW stream routing package (STR)
- This package routes the streamflow based on stream geometry, roughness coefficient, and groundwater gains or losses
- Streams are divided into segments which, in this model, represent each creek or river
- Each cell of the model with the stream package in it is assigned a reach number.
- Streamflow in a segment is routed from the upstream reach to the next downstream reach
- Groundwater gains and losses are calculated based on the stage in each river reach

Assigning Stream Properties

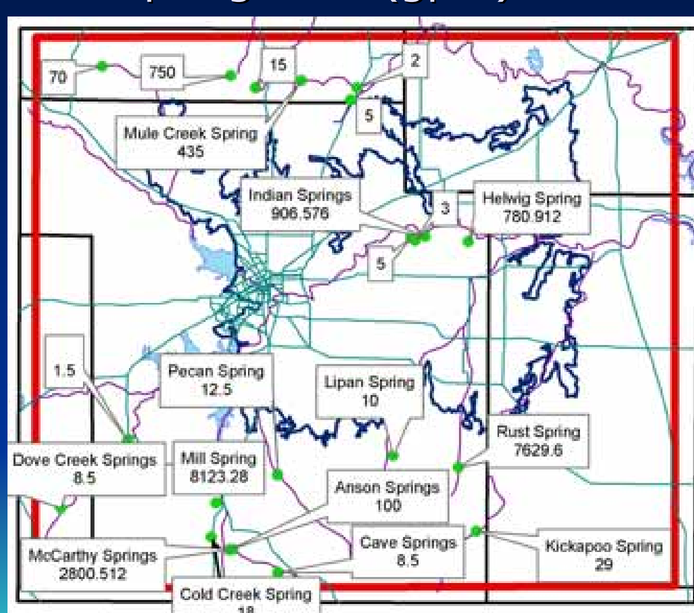
- Stream properties are assigned using river reach files from the US EPA
- River reach GIS coverages are overlain on the model grid
- Measured versus calculated streamflow will be used as a calibration target at stream gage locations

Springs in Model Area



Franklin T. Heitmuller and Brian D. Reece, 2003. U.S. Geological Survey (USGS) Open-File Report 03-xxxx, "Springs of Texas and springflow measurements".

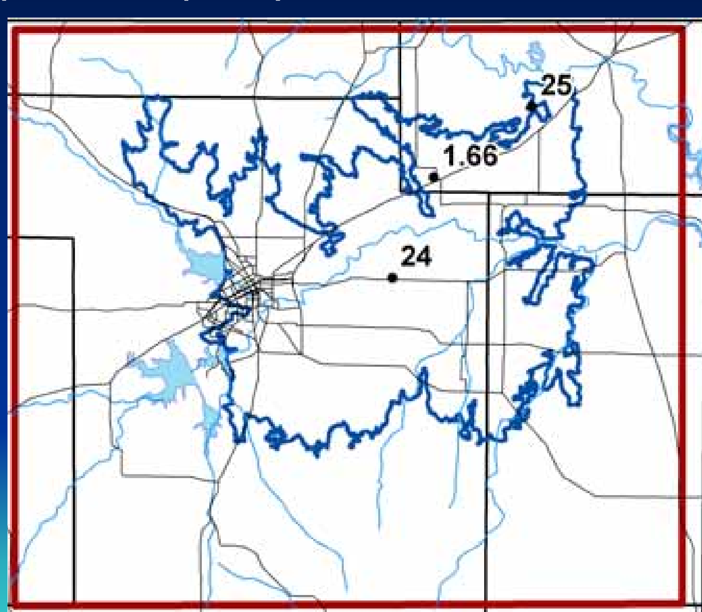
Historical Spring Flow (gpm) in Model Area



Franklin T. Heitmuller and Brian D. Reece, 2003. U.S. Geological Survey (USGS) Open-File Report 03-xxxx, "Springs of Texas and springflow measurements".

Hydraulic Properties

Specific-Capacity Data in TWDB Database



Model boundary

Estimating Specific-Capacity and Transmissivity using Production Capacity

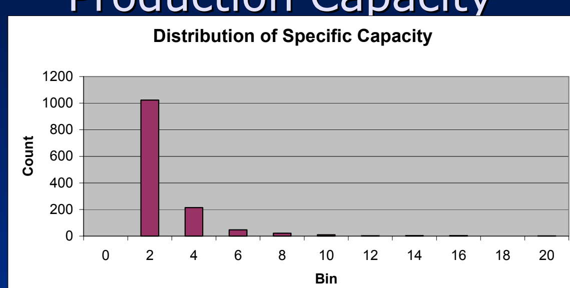
Specific-Capacity from Production Capacity

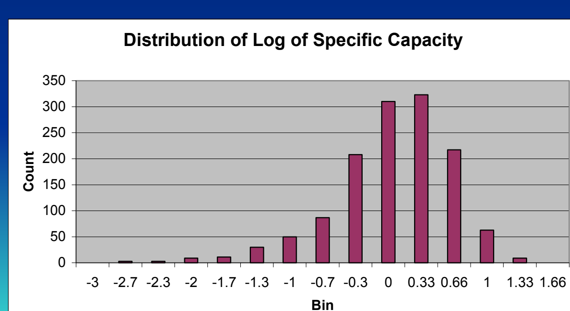
- Use Production Capacity (Q) and Saturated thickness in Well (b)
- Assume Specific-Capacity (Sc) = Q/b
- Assume Q is in gallons per minute
- Sc is in Gallons per minute per foot

Transmissivity from Specific-Capacity

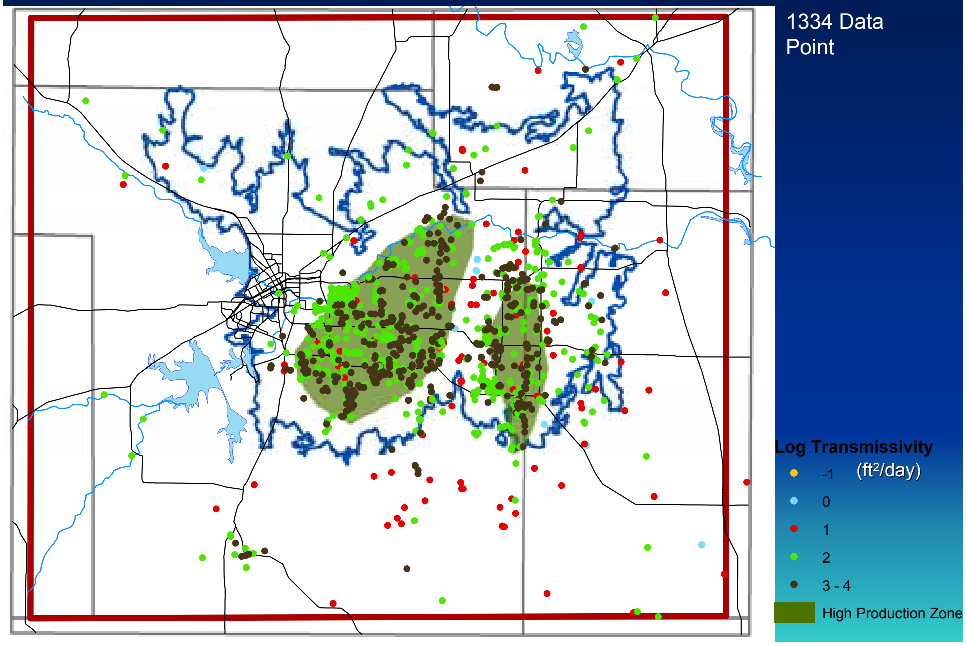
- Used "Estimating Transmissivity Using Specific-Capacity Data" (Mace, 2000) Appendix A
- Assumptions: 10 minute Pumping time, 8" Well Diameter, Storativity (S) of 0.0001
- Estimated Transmissivity Values range from 0.3 to 4000 ft^2/day

Estimated Specific-Capacity Based on Production Capacity



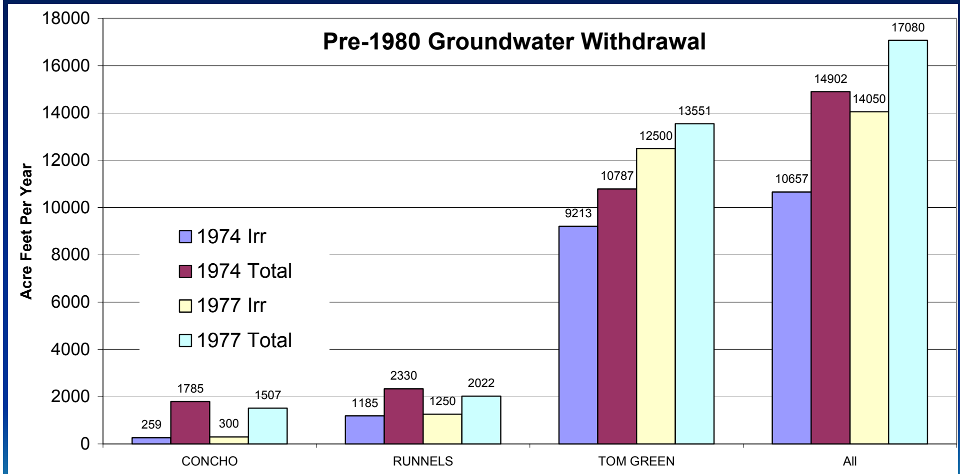


Calculated Transmissivity Based on Production Data



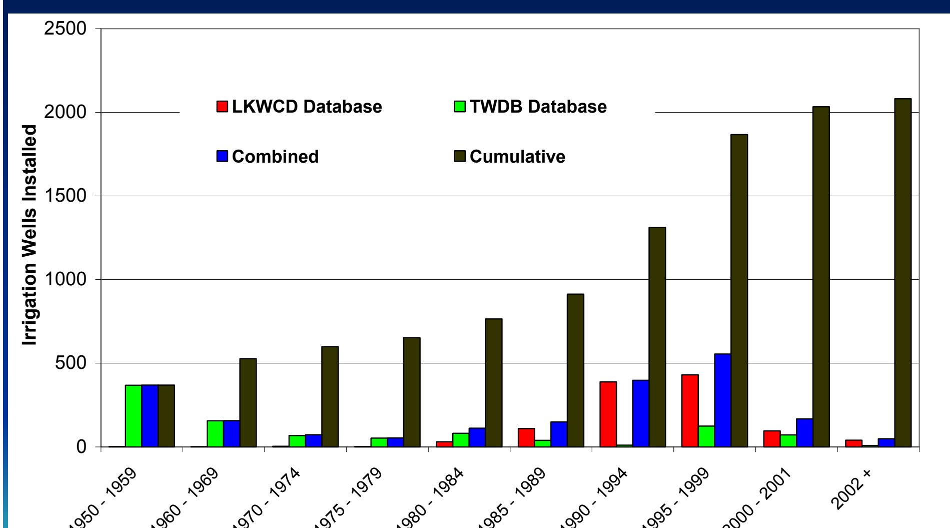
Discharge

Groundwater Discharge 1974 & 1977



Data Source: TWDB HistoricalSummary_1974and1977.xls
data Location: [sburton] D:\Active_Projects\Lipan\LEON\srcdata\subhyd\irrigation\HistoricalSummary_1974and1977.xls
File Location: [sburton] D:\Active_Projects\Lipan\LEON\srcdata\subhyd\irrigation\HistoricalSummary_1974and1977.xls

Irrigation Wells Installed Since 1950



Population Changes in Model Area

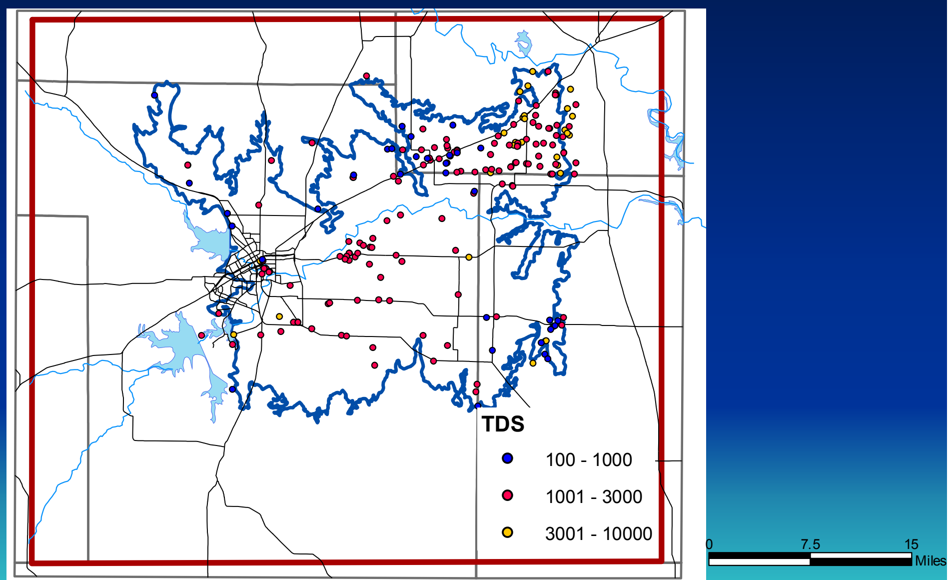
County	1980	1990	2000
	Population		
Concho	2,915	3,044	3,966
Runnels	11,872	11,294	11,495
Tom Green	84,784	98,458	104,010

	Numerical Change	
	1980-1990	1990-2000
Concho	129	922
Runnels	-578	201
Tom Green	13,674	5,552

	Percent Change	
	1980-1990	1990-2000
Concho	4.43	30.29
Runnels	-4.87	1.78
Tom Green	16.13	5.64

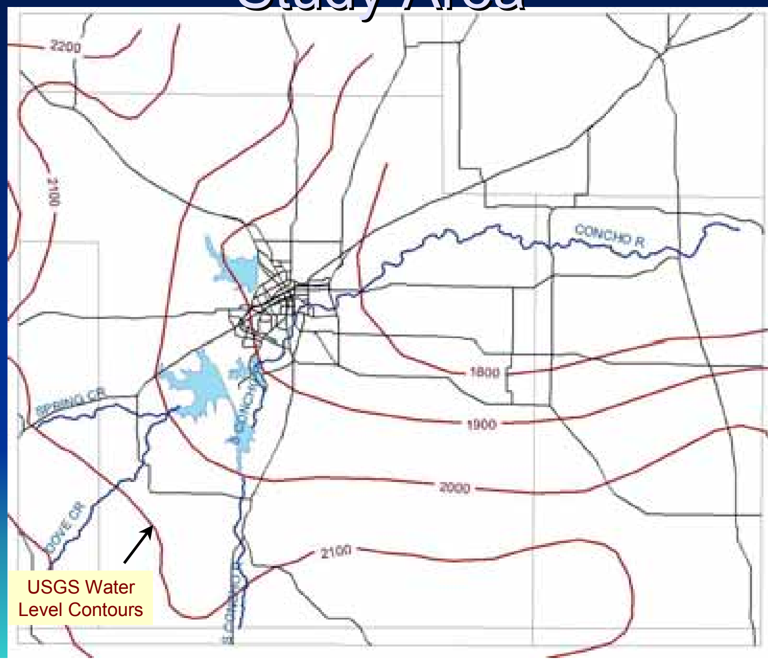
Water Quality

Lipan Water Quality

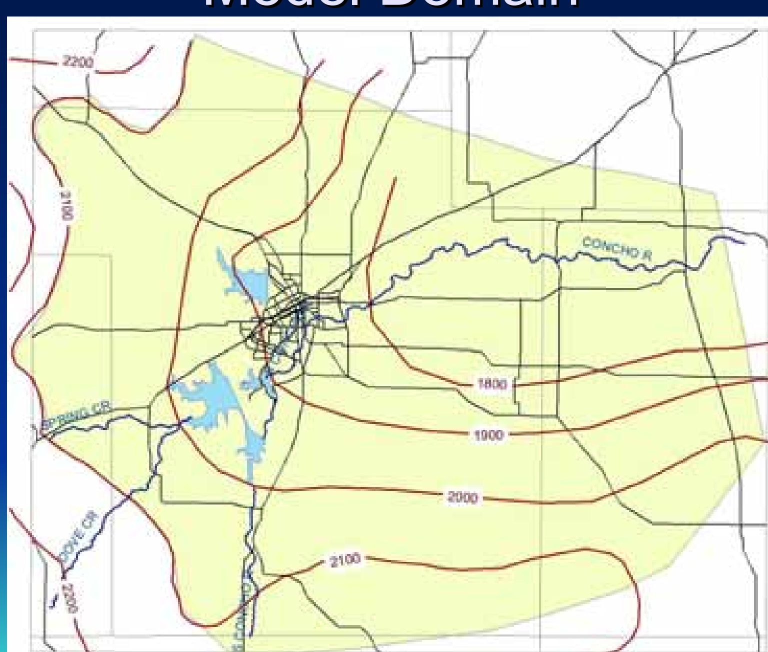


Steady-State Calibration Model Architecture

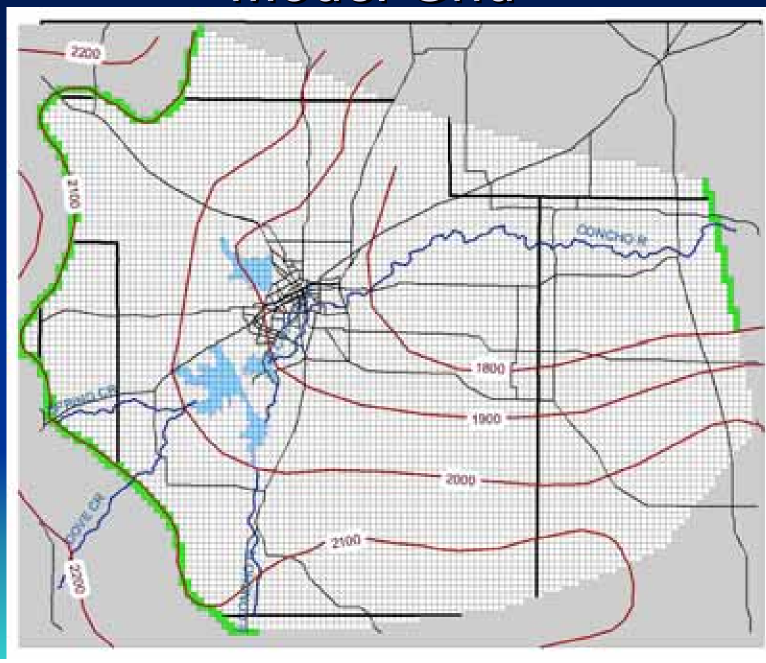
Study Area



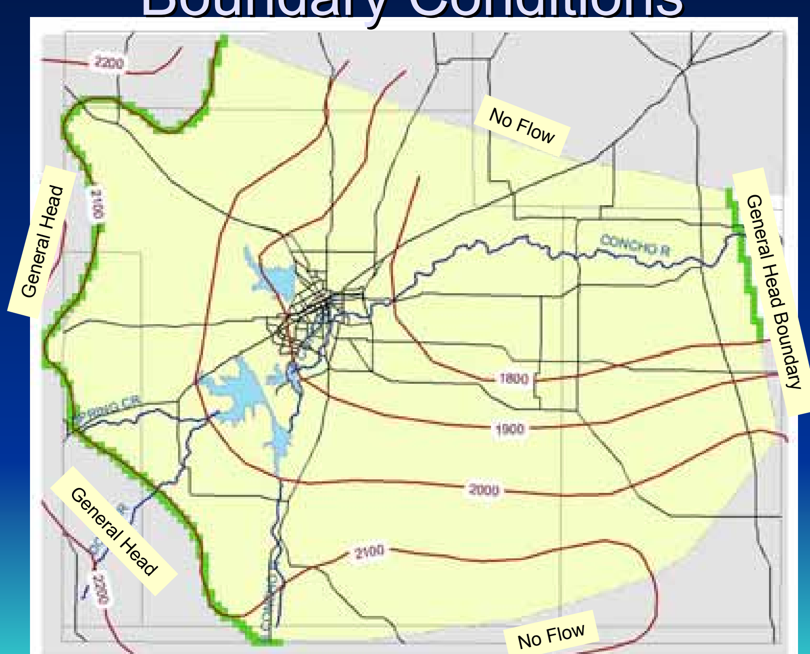
Model Domain



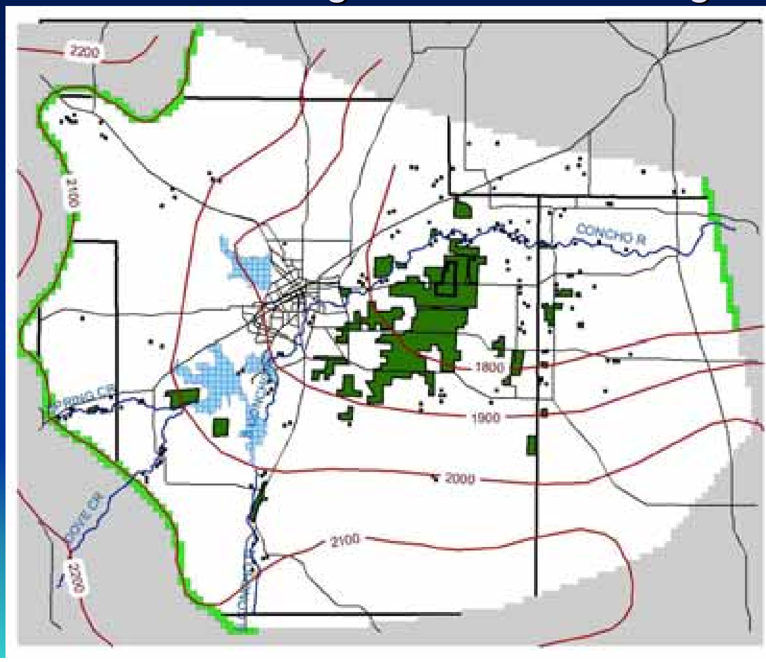
Model Grid



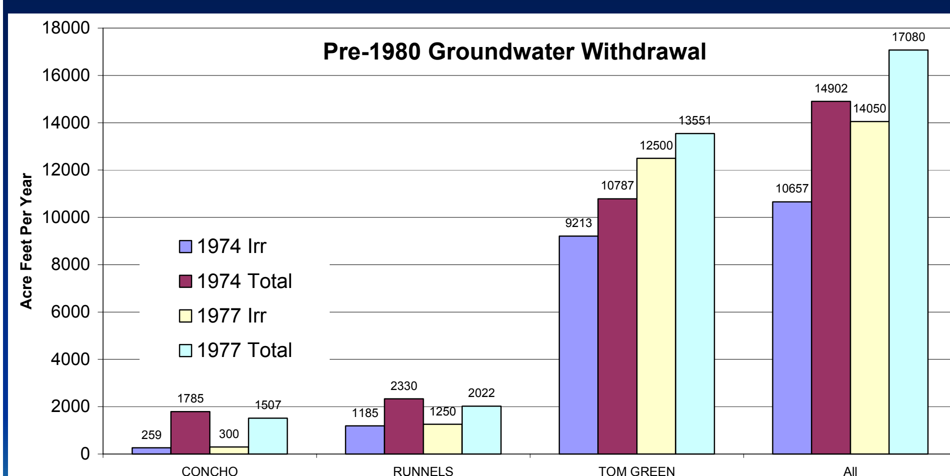
Boundary Conditions



1989 TWDB Irrigated Land Coverage



Groundwater Discharge 1974 & 1977



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data Location: [sburton] D:\Active_Projects\Lipan\LEON\srcdata\subhyd\irrigation\HistoricalSummary_1974and1977.xls
File Location: [sburton] D:\Active_Projects\Lipan\LEON\srcdata\subhyd\irrigation\HistoricalSummary_1974and1977.xls

Methodology

Irrigated Land Coverage

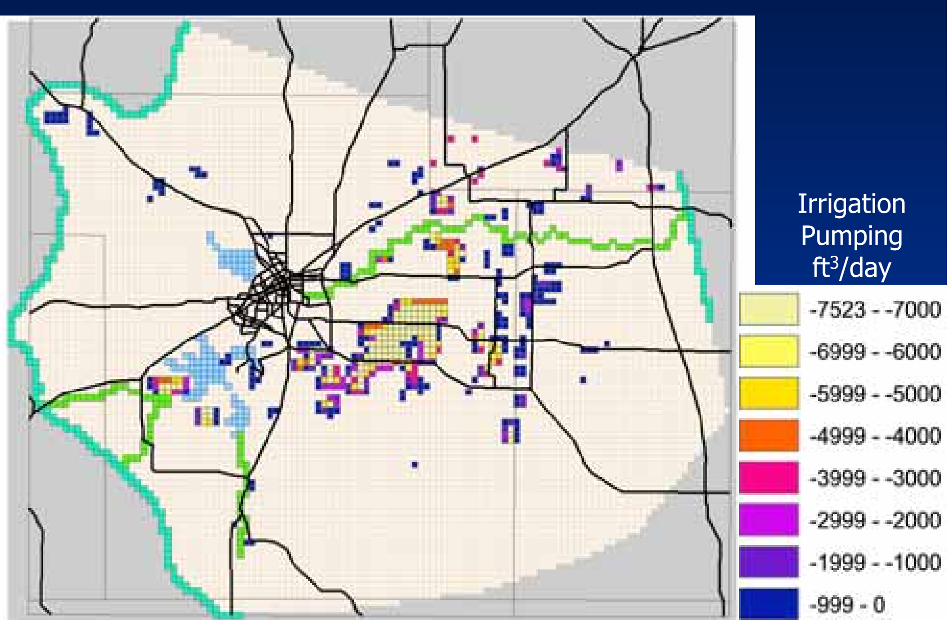
Model Grid

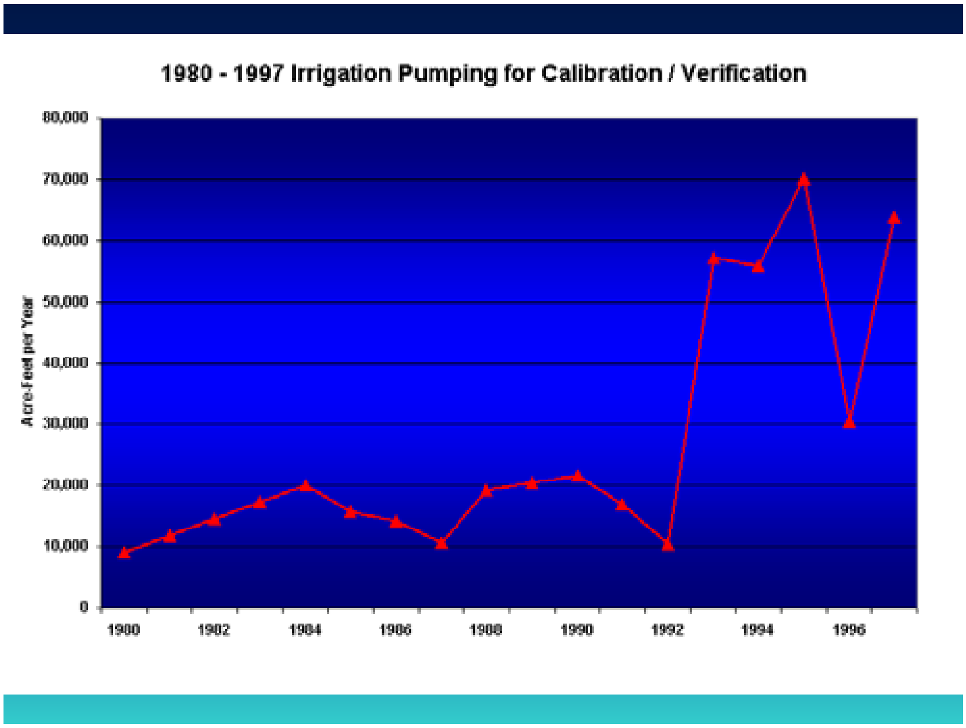
Overlay these Coverages

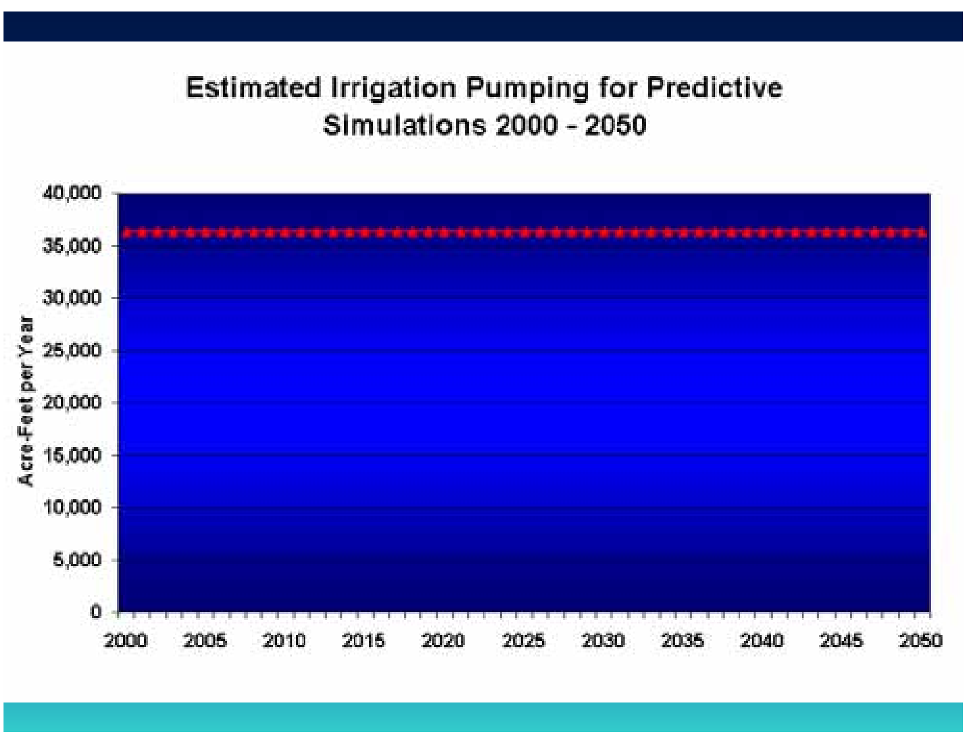
Distribute County Wide Pumping Evenly Over Grid Cells with Irrigated Lands

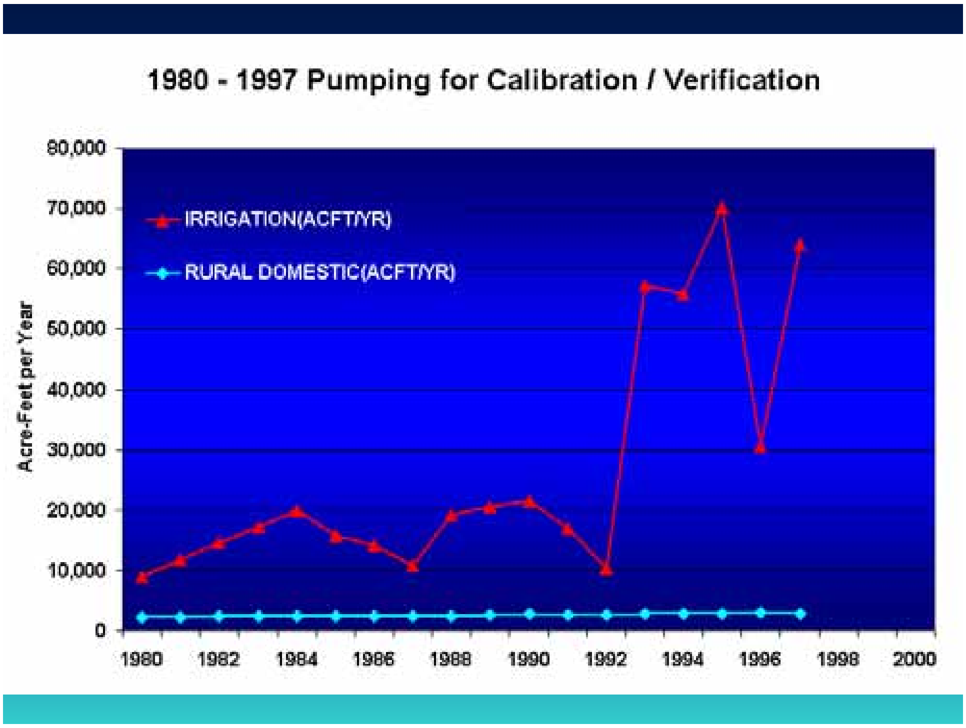
Result: Grid Coverage with Pumping Assigned to Cells Based on Volume of Cell Covered by Irrigated Lands Coverage

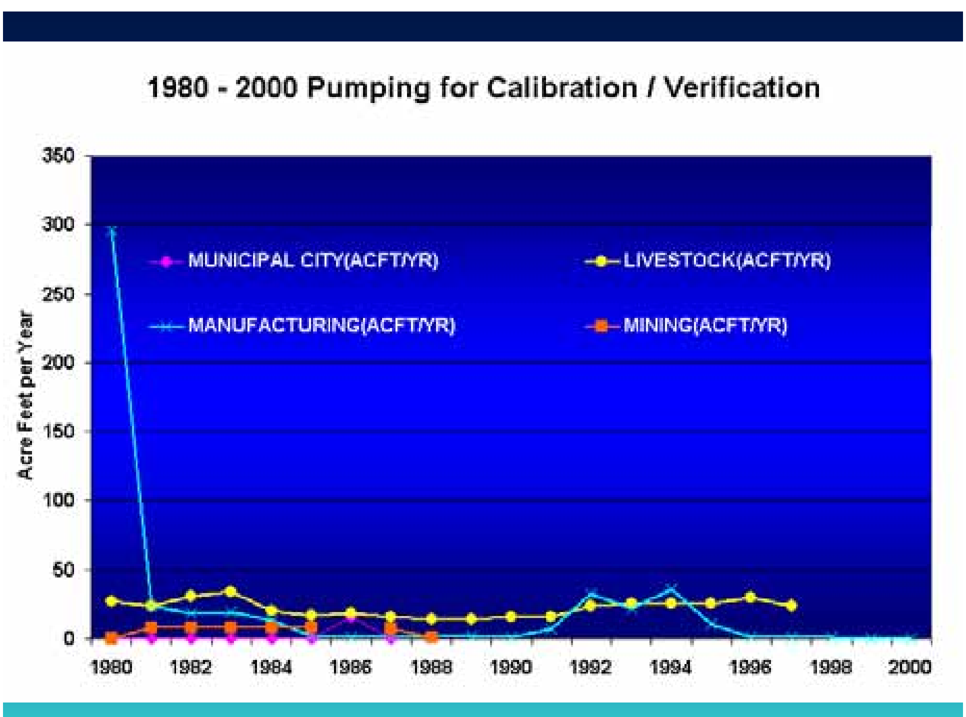
Distribution of 1977 Irrigation Pumping Based on 1989 Irrigated Land Coverage

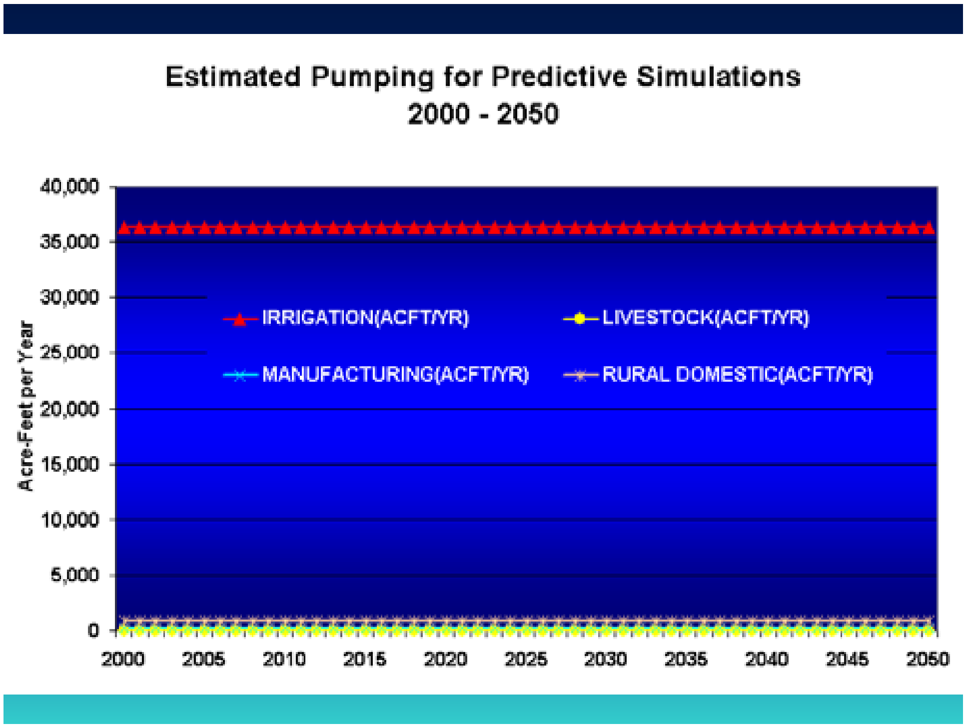


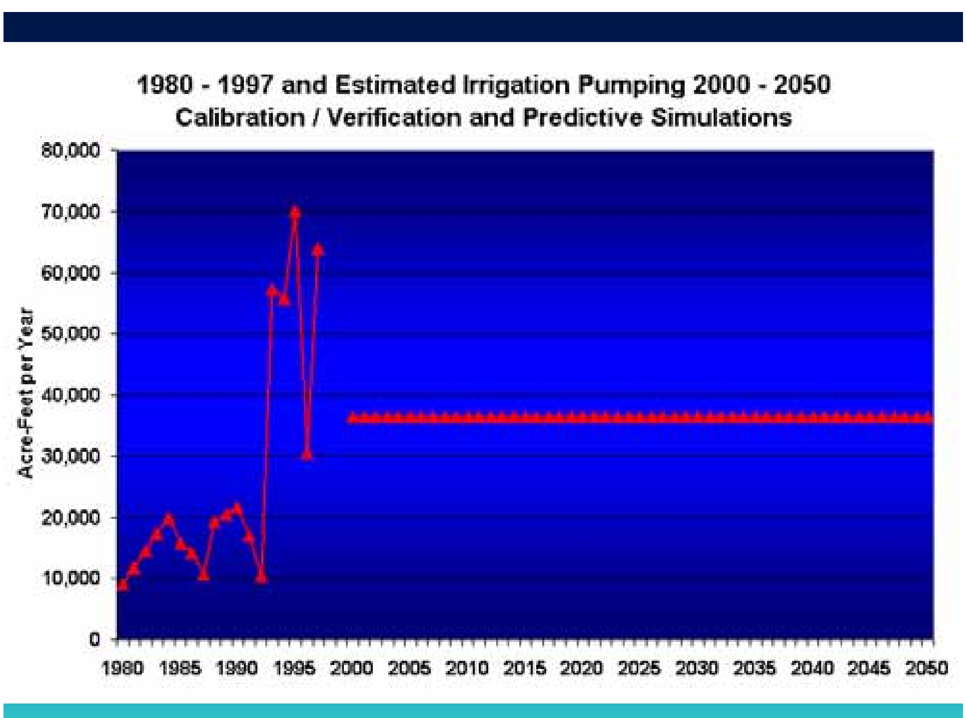

1980 - 1997 Irrigation Pumping for Calibration / Verification
Acre-Feet per Year
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1980
1982
1984
1986
1988
1990
1992
1994
1996


Estimated Irrigation Pumping for Predictive Simulations 2000 - 2050
Acre-Feet per Year
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050

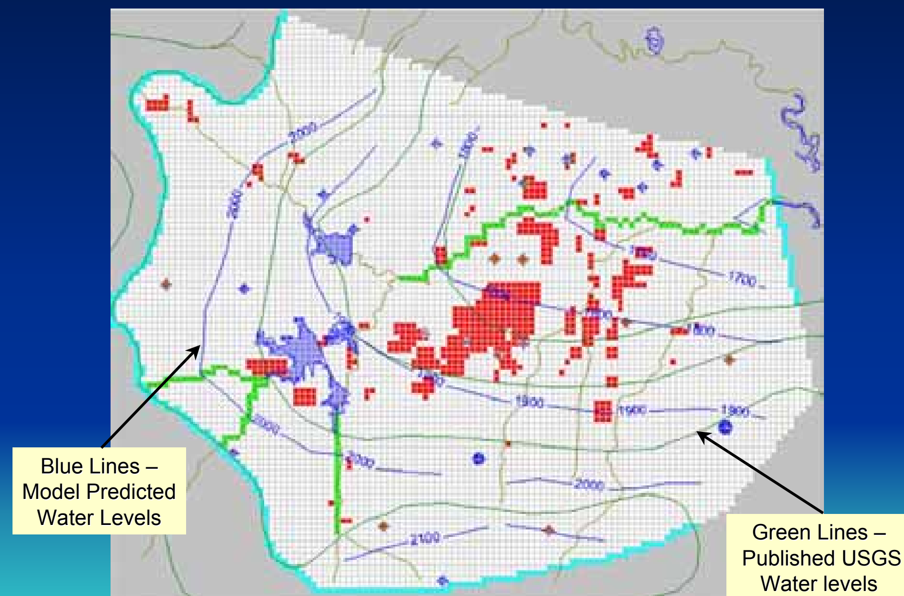

1980 - 1997 Pumping for Calibration / Verification
IRRIGATION(ACFT/YR)
RURAL DOMESTIC(ACFT/YR)
Acre-Feet per Year
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000


1980 - 2000 Pumping for Calibration / Verification
MUNICIPAL CITY(ACFT/YR)
LIVESTOCK(ACFT/YR)
MANUFACTURING(ACFT/YR)
MINING(ACFT/YR)
Acre Feet per Year
350
300
250
200
150
100
50
0
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000


Estimated Pumping for Predictive Simulations
2000 - 2050
Acre-Feet per Year
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
IRRIGATION(ACFT/YR)
LIVESTOCK(ACFT/YR)
MANUFACTURING(ACFT/YR)
RURAL DOMESTIC(ACFT/YR)
2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050


1980 - 1997 and Estimated Irrigation Pumping 2000 - 2050
Calibration / Verification and Predictive Simulations
Acre-Feet per Year
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050

Preliminary Steady-State Model Simulation



Project Schedule

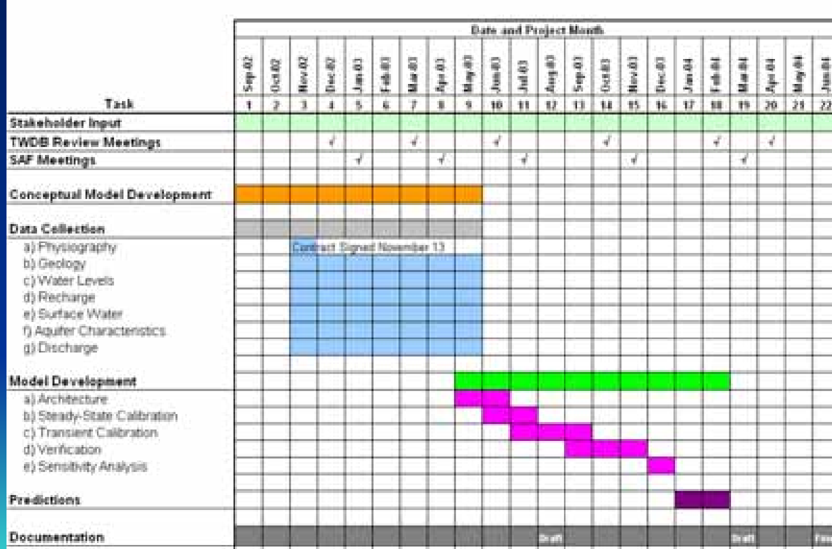


Figure 2. Schedule for Lipan GAM Project (June 4, 2003)

Attendees of the 3rd Stakeholder Advisory Forum for the Lipan GAM July 31, 2003

Name	Affiliation
James Beach	LBG-Guyton Associates
Richard Smith	TWDB
Scott McWilliams	UCRA
Bill Lange	Lange Drilling Co.
Allan Lange	Lipan-Kickapoo WCD
Will Wilde	City of San Angelo
Mr. and Mrs. E.R. Talley	Talley Farms

Lipan Aquifer Groundwater Availability Model (GAM)
3rd Stakeholder Advisory Forum (SAF) Meeting
July 31, 2003
San Angelo, Texas

Meeting Summary

The third Stakeholder Advisory Forum (SAF) meeting for the Lipan Aquifer Groundwater Availability Model (GAM) was held on July 31st from 7:00 to 8:30 PM at the Texas A&M Research Center in San Angelo, Texas. TWDB project manager Richard Smith gave an introduction to the GAM program and introduced LBG-Guyton Associates.

James Beach of LBG-Guyton made a presentation to an audience consisting of five attendees. The presentation, along with a list of participants who signed up at the meeting, is available at the TWDB GAM website (www.twdb.state.tx.us/gam). The presentation was structured to cover all the components of the conceptual model and the data assimilated for the project.

The questions and answers from the SAF are presented below.

Questions and Answers

Q: *Why does the model simulate flow with one layer when we know that there are unique zones in the limestone that are usually one to two feet thick that produce most of the water in the wells?*

A: MODFLOW uses a continuous porous media conceptualization to simulate groundwater flow. This basically means that the aquifer material in each model layer is the same throughout the thickness of that model layer. To appropriately implement a model with many layers, we would need to know where each of the high permeability zones is located in each well, as well as how contiguous that zone is in the surrounding area. That level of information does not exist; therefore the aquifer has been conceptualized to contain one layer and that layer is assumed to represent the overall transmissivity of the aquifer. The transmissivity value in each model grid block represents the overall "productivity" of the aquifer in that area. This conceptualization is consistent with the overall GAM model objectives and the level of data that is available at this time. This approach has been used successfully to simulate overall ground-water availability in aquifers that have similar vertical variation in hydraulic properties.

Q: *Some of the spring data is not consistent with current observations. When was the data collected?*

A: The USGS compiled these data. The database does not indicate the date of observation or the hydrologic conditions at the time.

Q: *Groundwater pumpage for irrigation has occurred in the areas designated as areas where surface water is used. How will the model account for this?*

A: We will discuss this issue with the TWDB and evaluate existing data regarding irrigation wells in these areas during the calibration and verification periods of the model (1980-2000) as well as predictive periods.

Q: *Will the conceptual model report be released before the next SAF meeting?*

A: The draft report is for internal TWDB use and is intended as a means of insuring that the model development remains on schedule. The report is generally not for public release; however, we will ask the TWDB to consider releasing the conceptual model report for review by stakeholders.