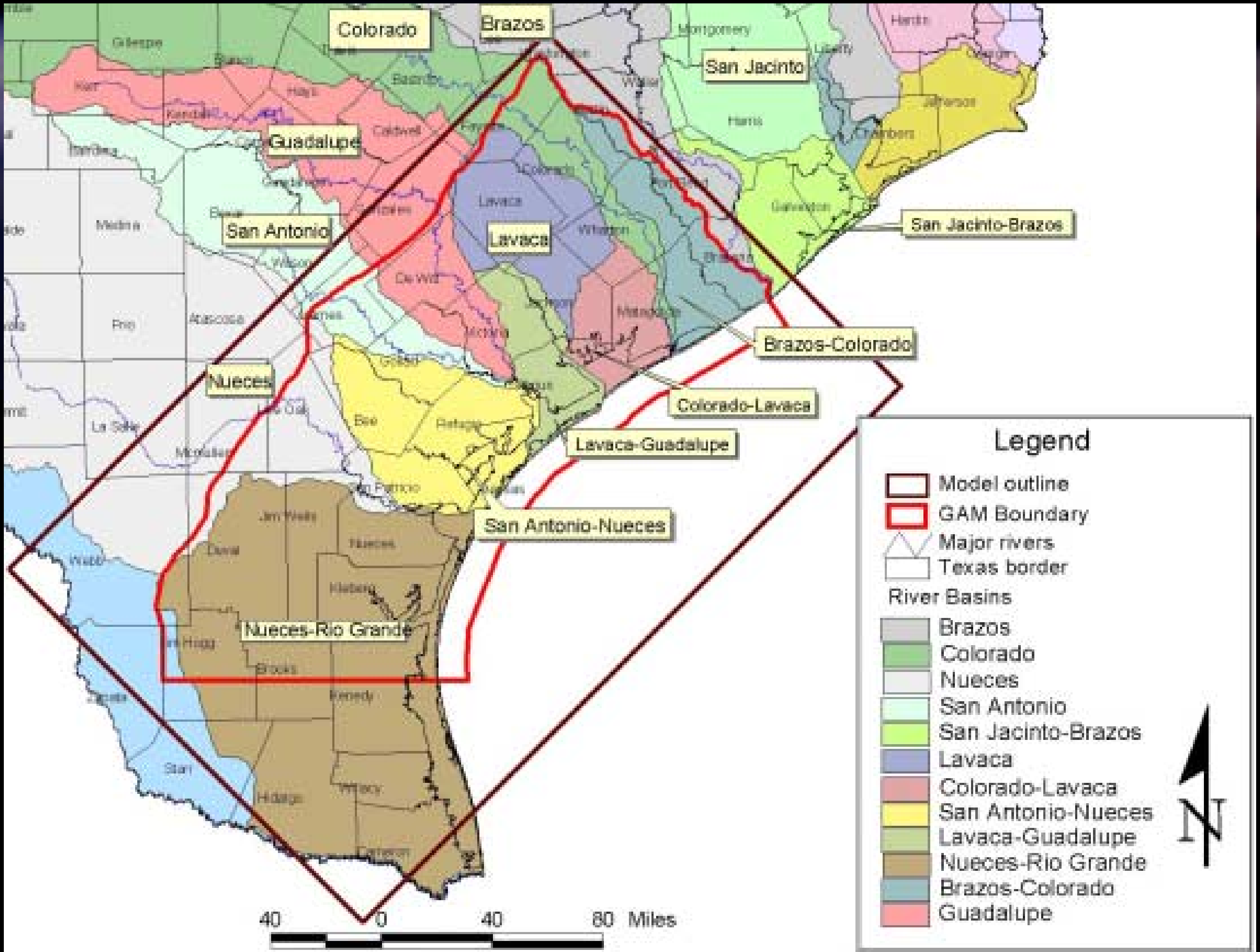
The Central Gulf Coast Groundwater Availability Model: Steady State and Transient Simulations

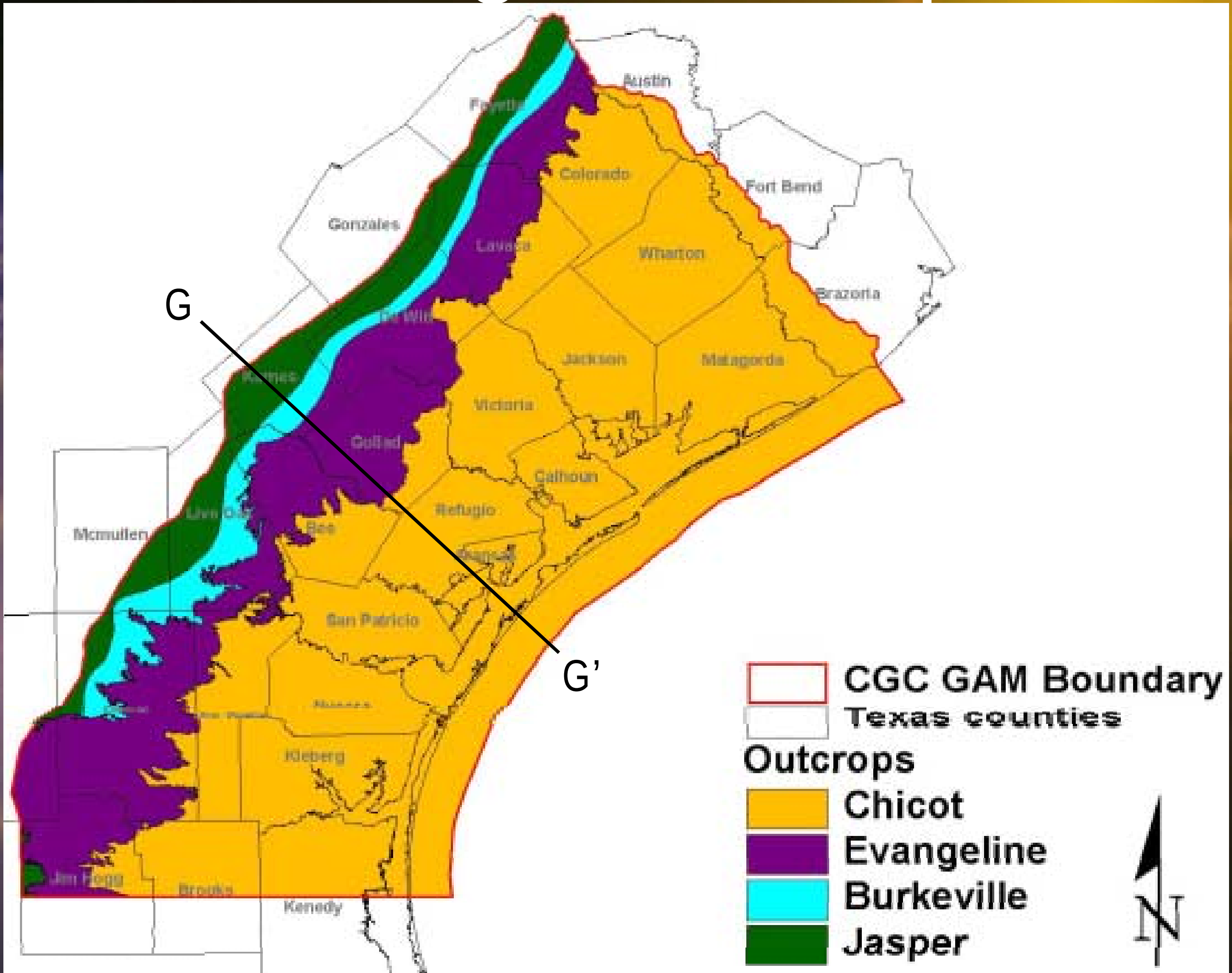
Sixth Stakeholder's Advisory Forum
Bay City Civic Center
Bay City, Texas
August 15th, 2002

Waterstone
Environmental Hydrology and Engineering, Inc.

Model Grid, GAM Region, and River Basins



Hydrostratigraphic Unit (HSU) Geologic Outcrops



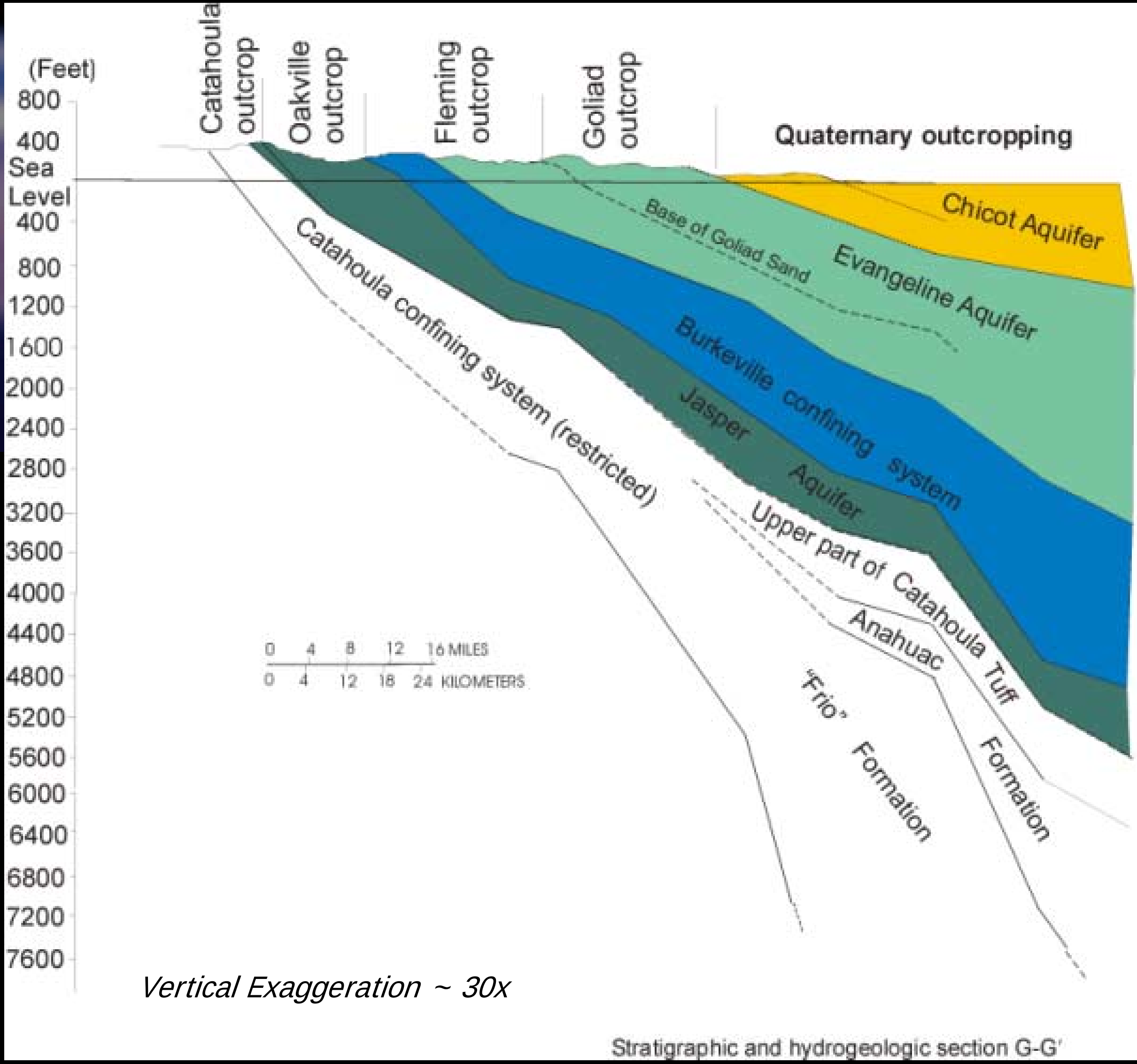
Vertical Cross Section Showing The Major Aquifer Composition

Jasper:
- Oakville sandstone
- Catahoula sandstone and tuff

Burkeville:
- typically lower Fleming

Evangeline:
- Goliad sand
- upper Fleming

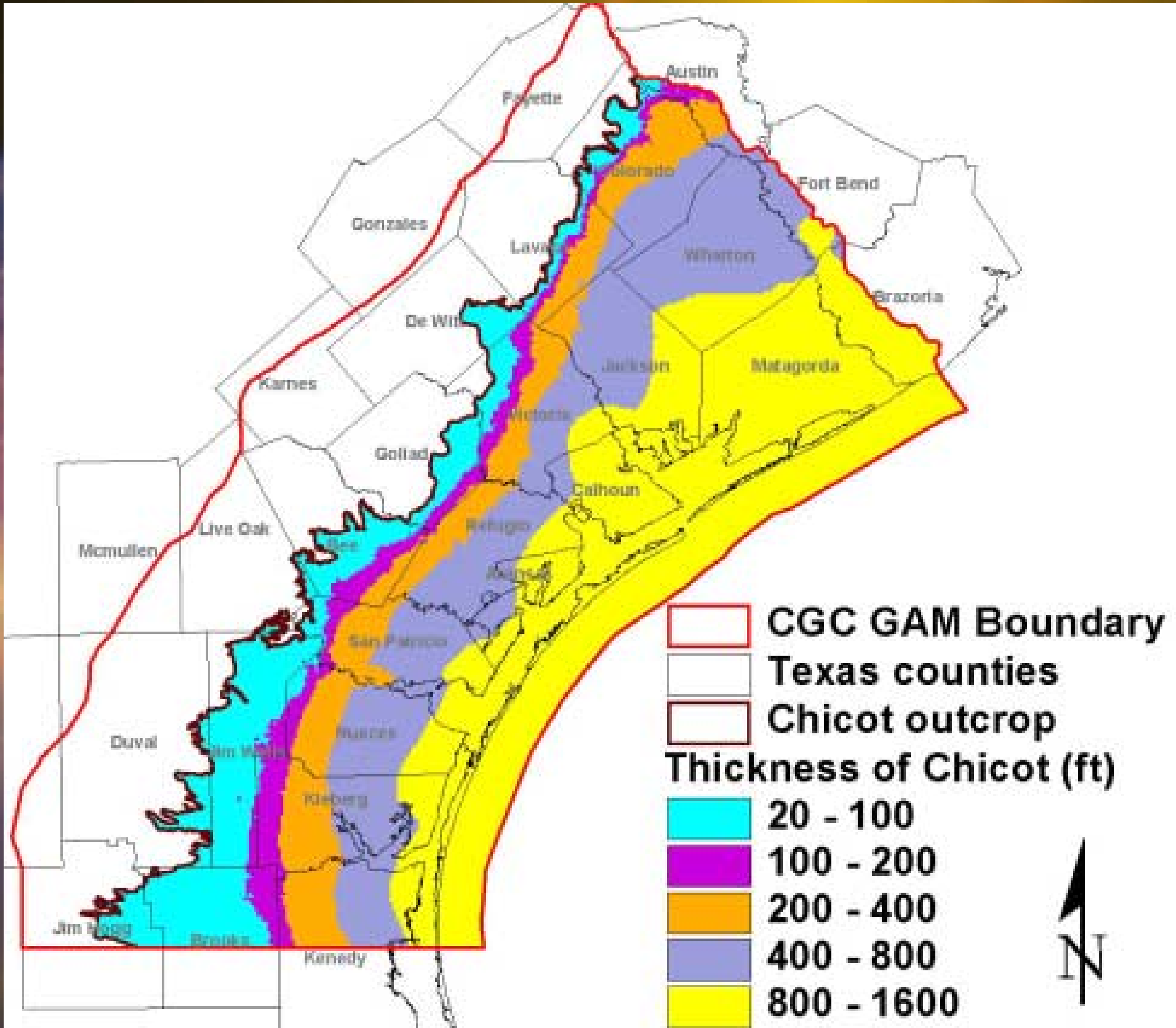
Chicot
- surface alluvium
- shallow units overlying Evangeline



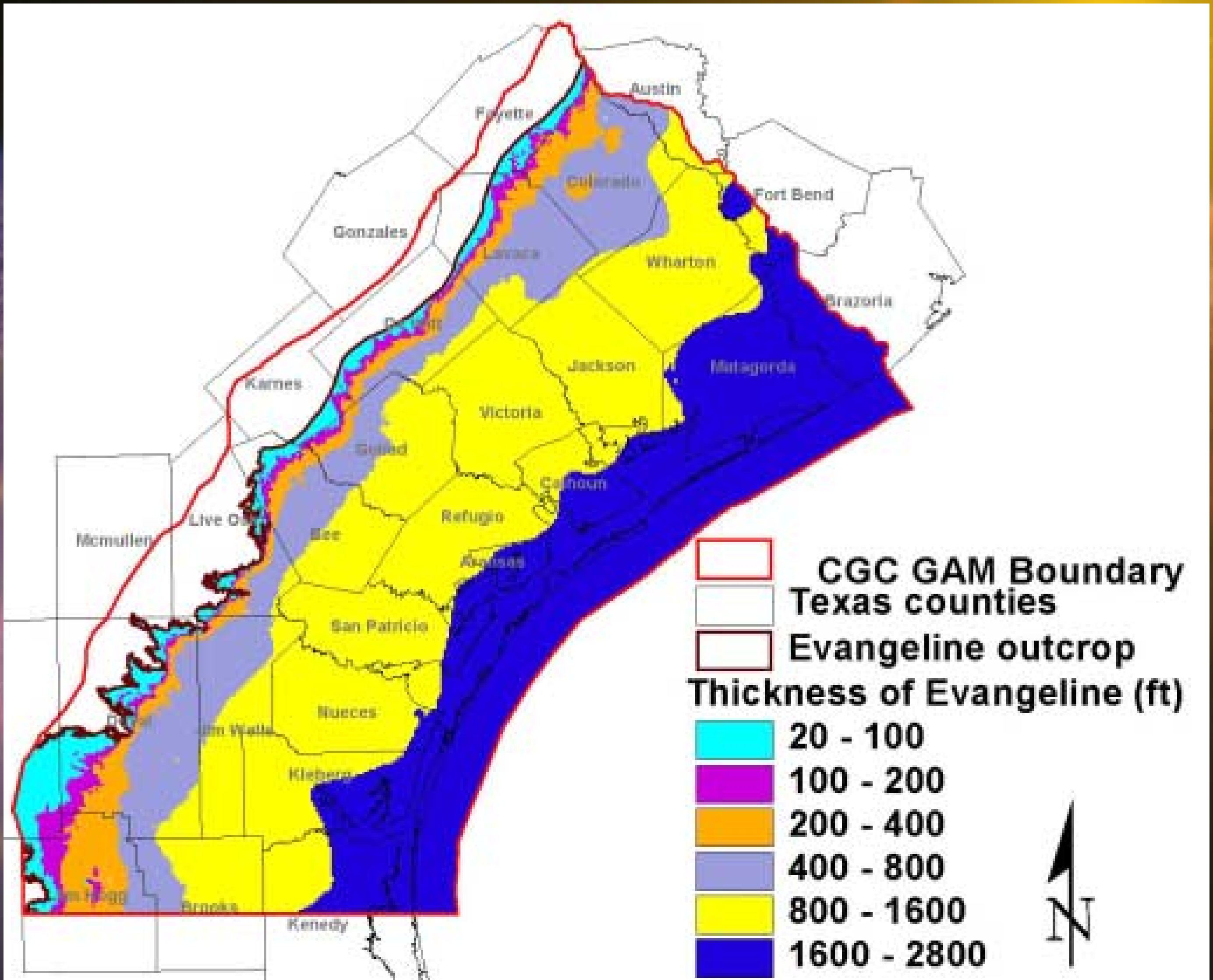
Chicot Aquifer Thickness

Structure based on:

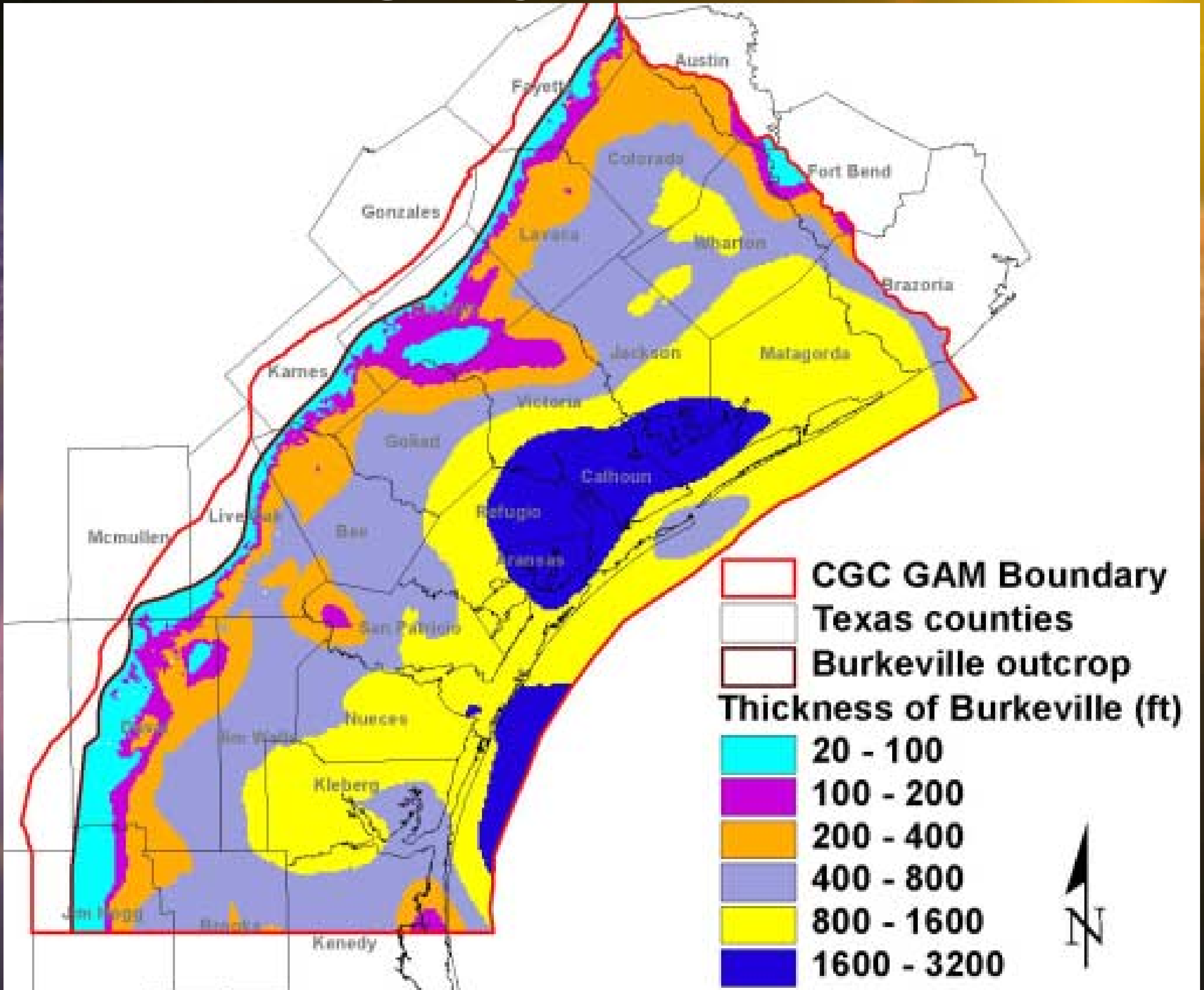
- Baker (1979),
- Carr (1985),
- Kasmarek and Strom (1996).



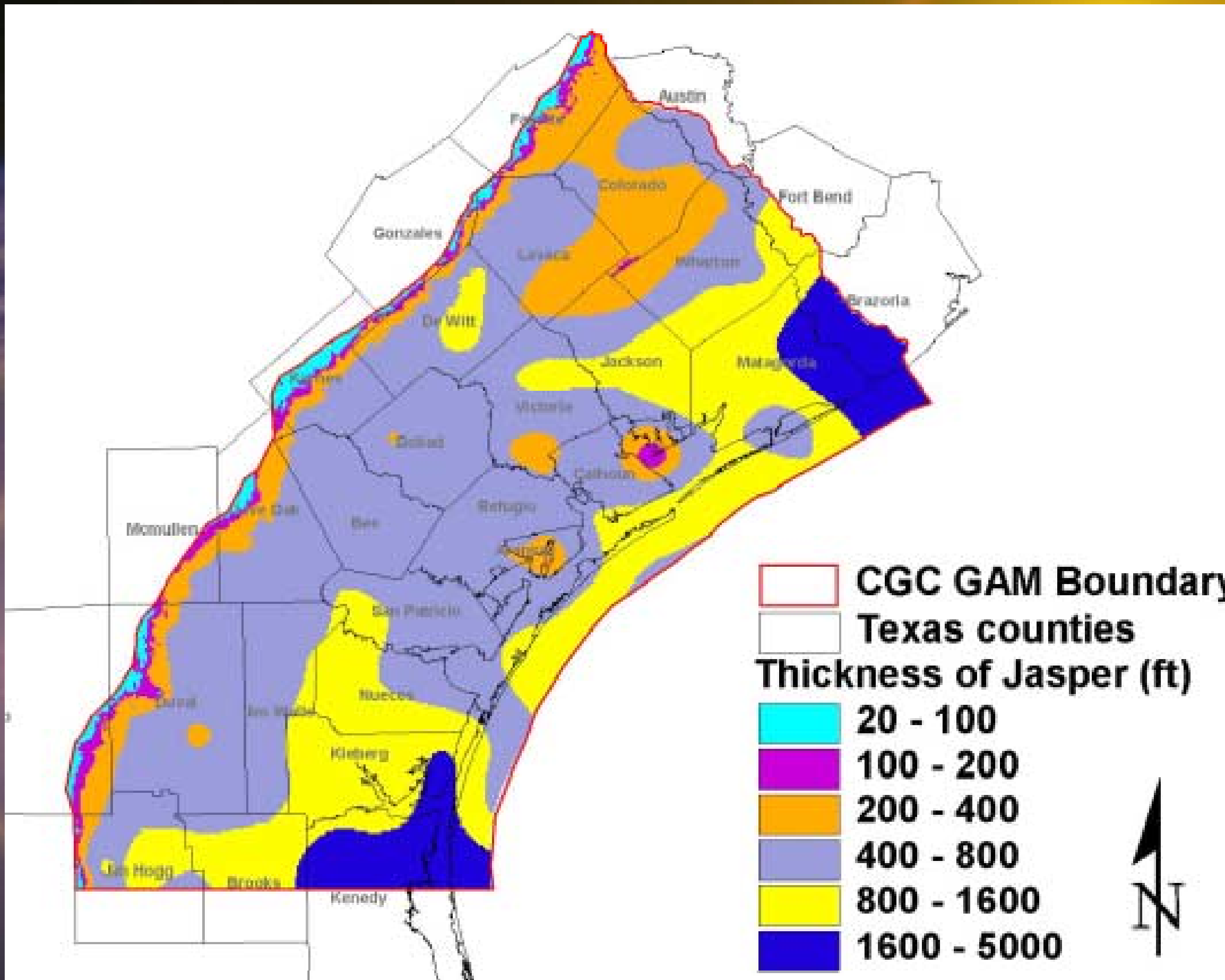
Evangeline Aquifer Thickness



Burkeville Confining-System Thickness

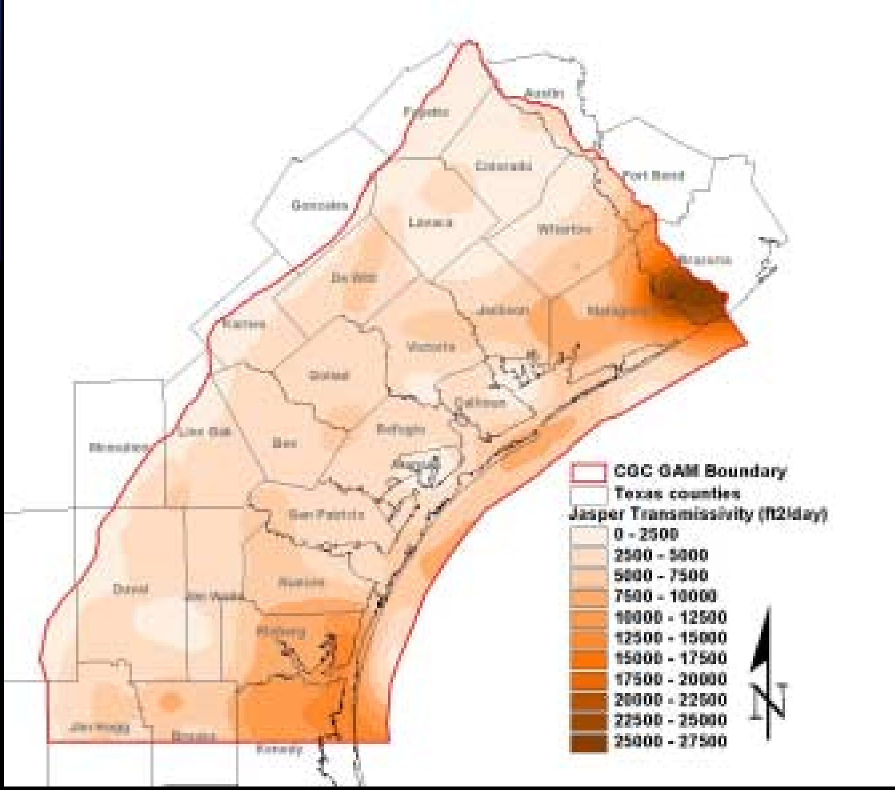


Jasper
Aquifer Thickness



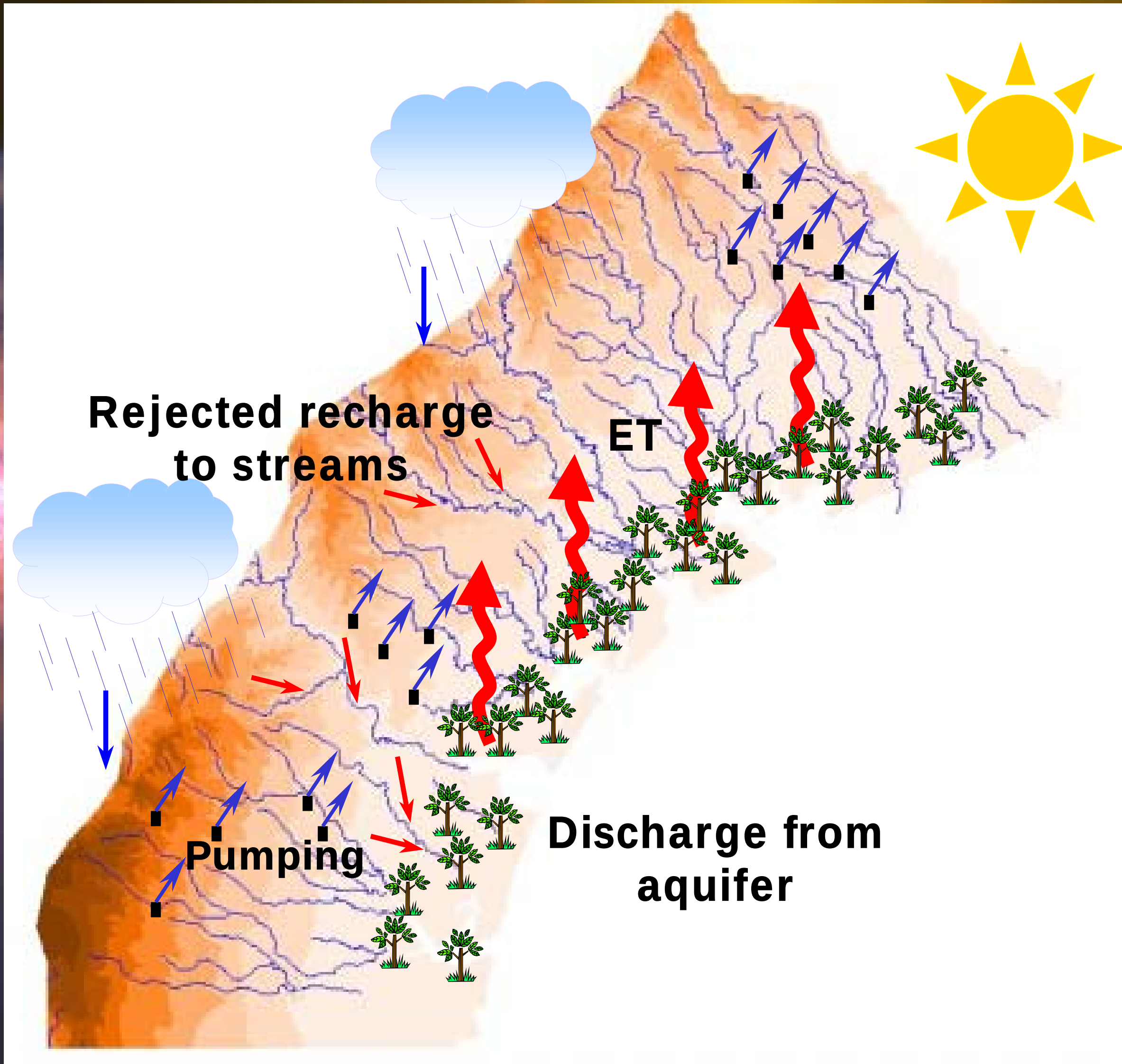
Transmissivity

- Water comes primarily from the sand lenses
- Quantify flow potential by characterizing sand hydraulic conductivity and distribution
- Transmissivity calculations
  - pump-test transmissivity
  - screened interval ⇨ hydraulic conductivity of sands
  - hydraulic conductivity geometric mean
  - sand percentage and aquifer thickness ⇨ sand thickness
  - aquifer transmissivity values



Characterizing Recharge, ET, Streams and Pumping and Temporal Variations

- Long-term water balance from the steady-state model
- Characterize time varying deviations from steady-state conditions
  - Recharge
  - Evapotranspiration
  - Discharge/recharge to streams
  - Pumping

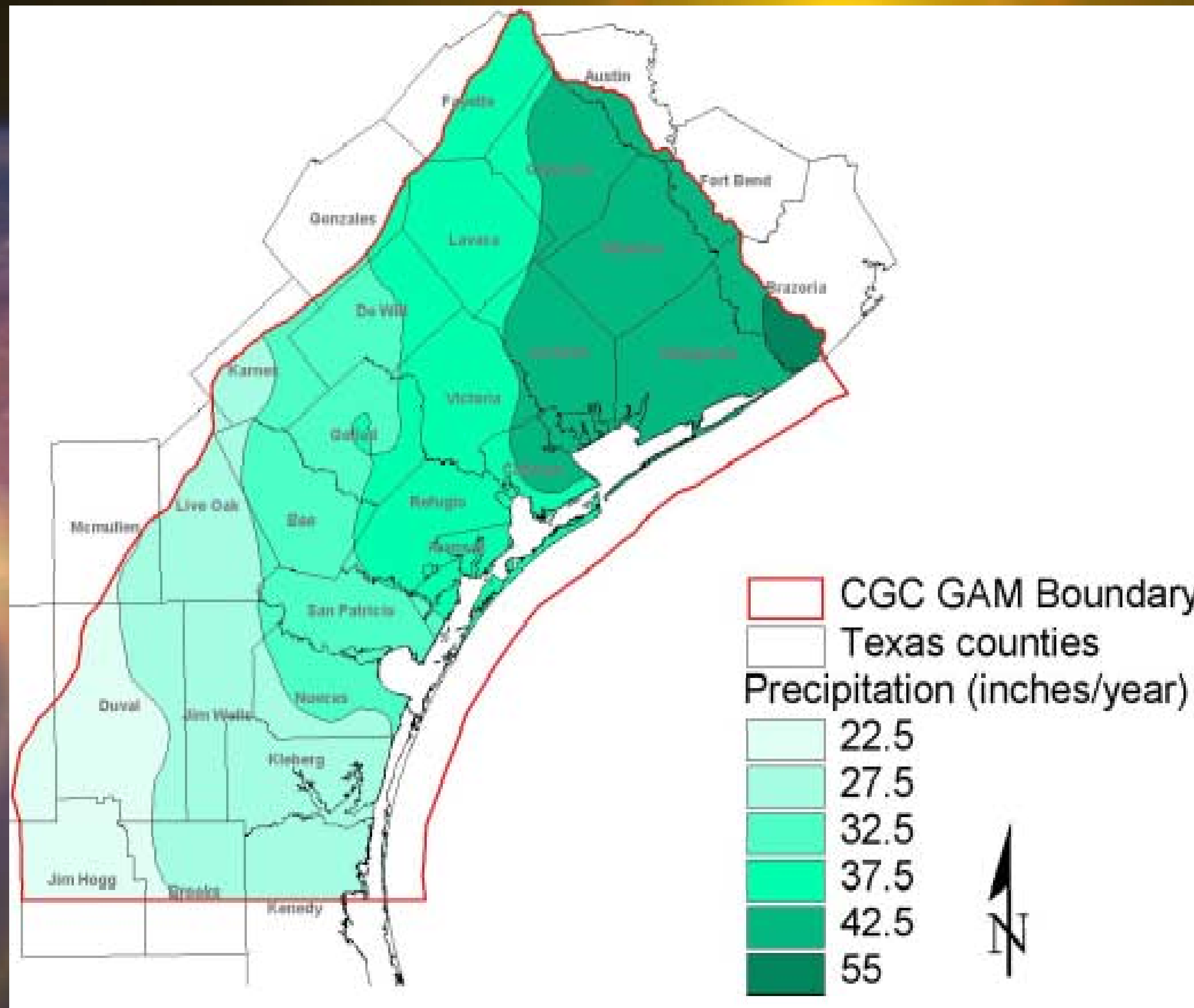


Precipitation: Potential Recharge

Precipitation is a primary source of water to the aquifer

Data are mean annual averages from 1961-1990

- PRISM (Parameter-elevation Regressions on Independent Slopes Model)



Recharge

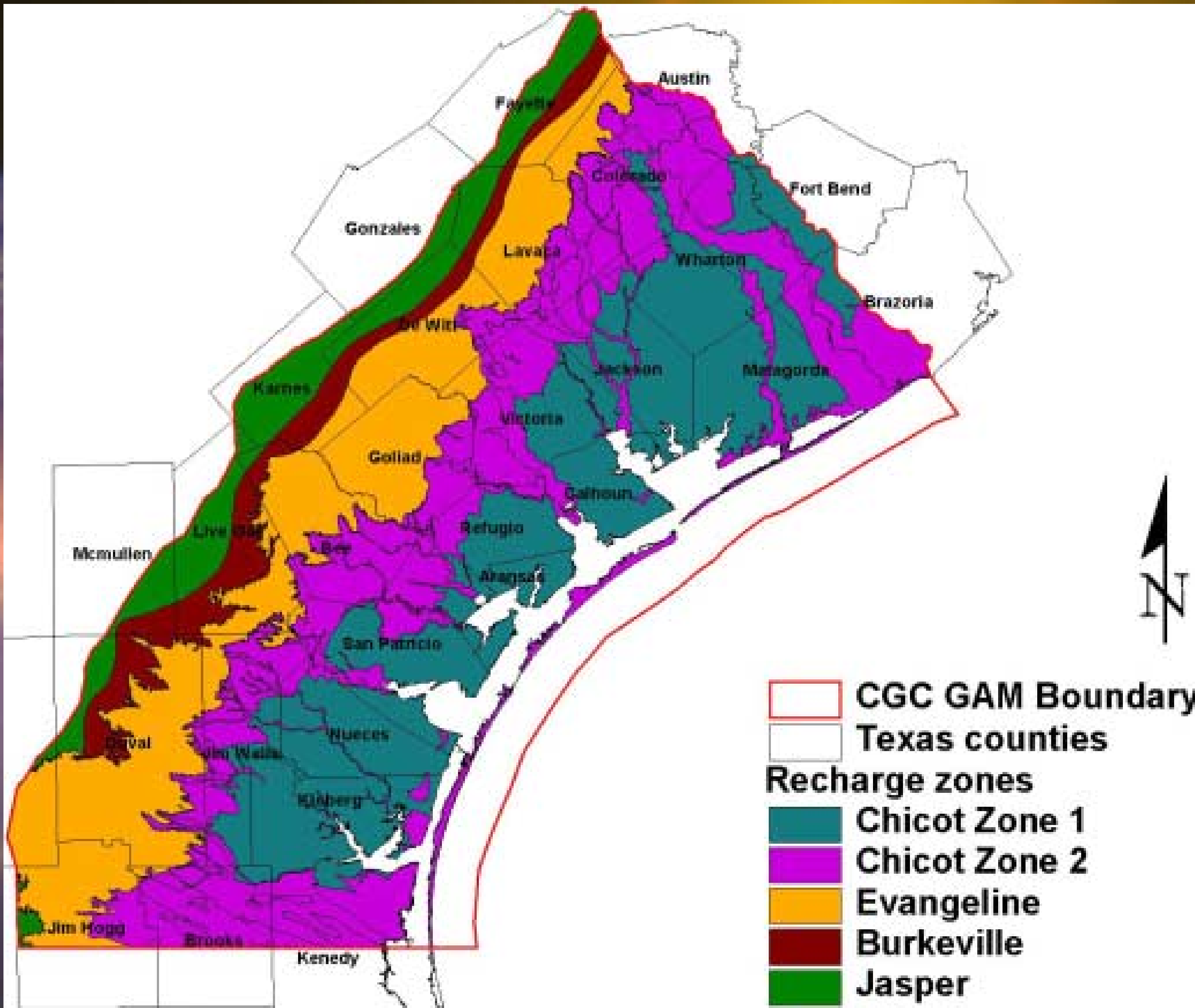
Surface material affects potential for recharge.

- Land-type map (Bureau of Economic Geology)

Recharge zones based on

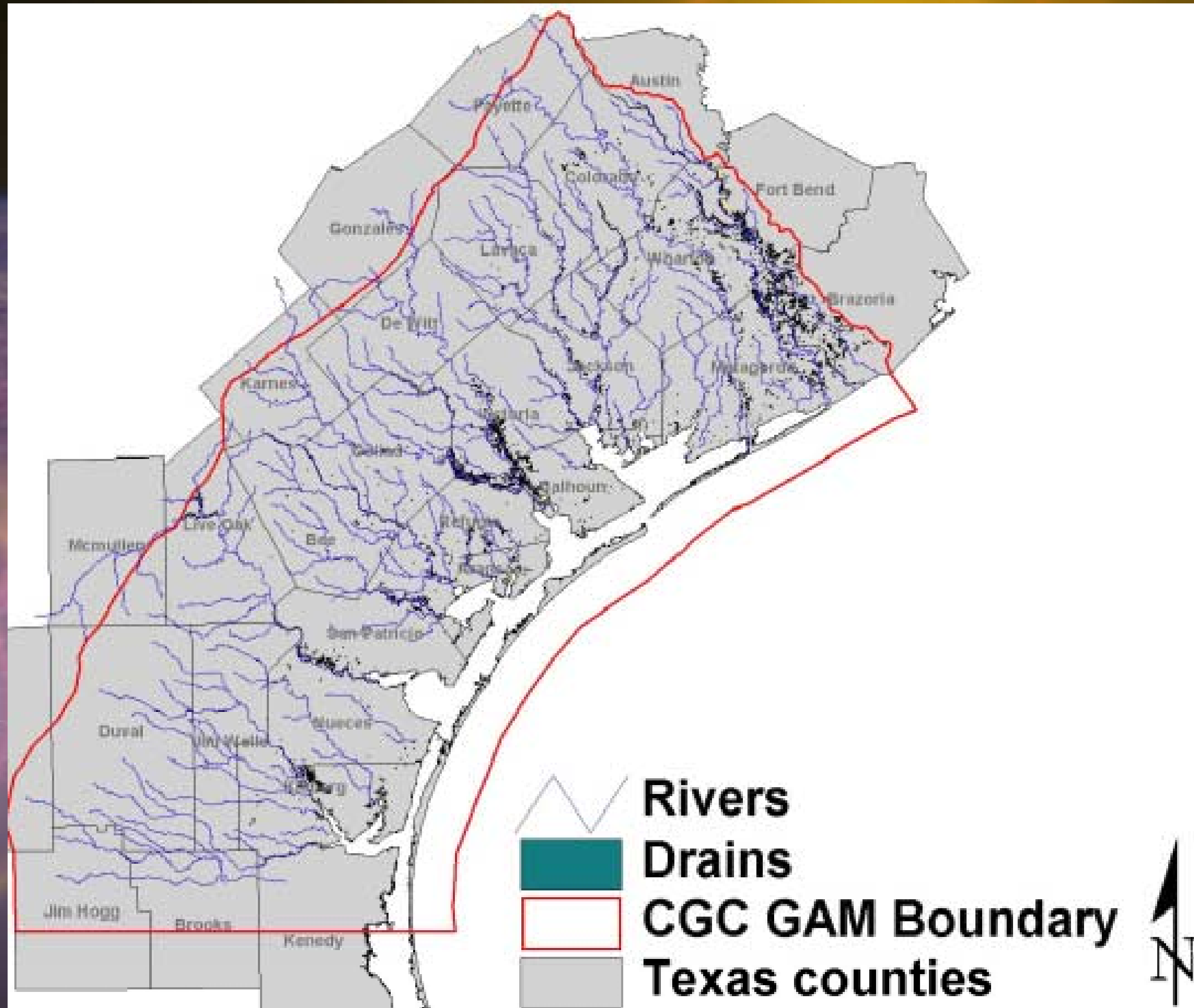
- land type
- HSU outcrops

Estimate the deviations from steady-state and apply to model



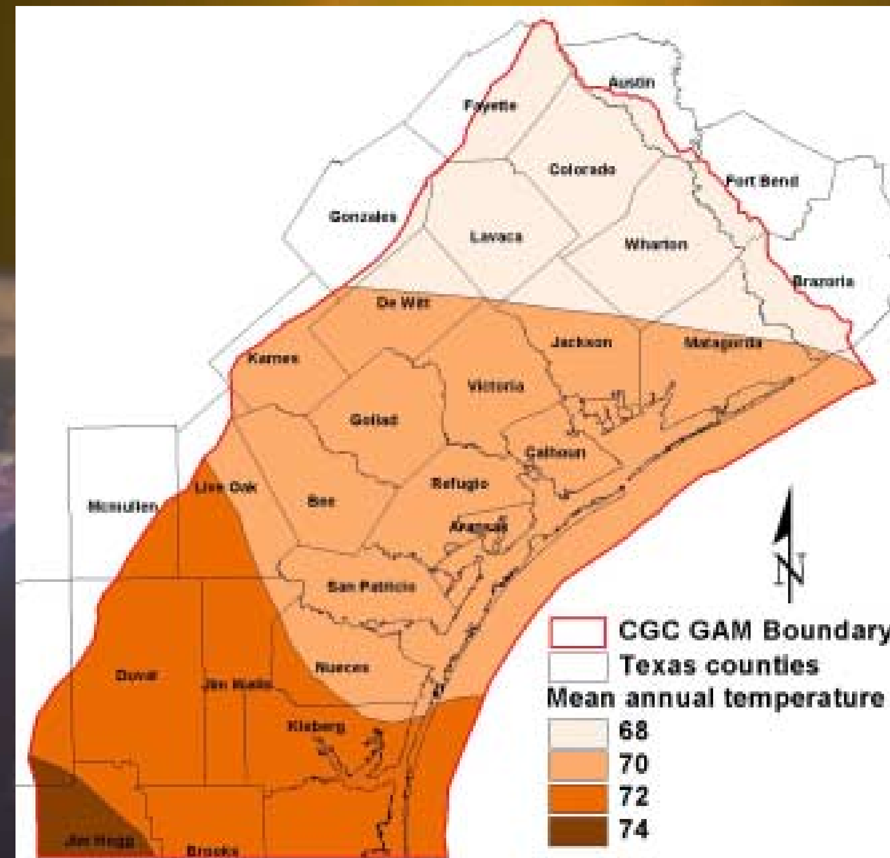
Seepage from the Aquifer

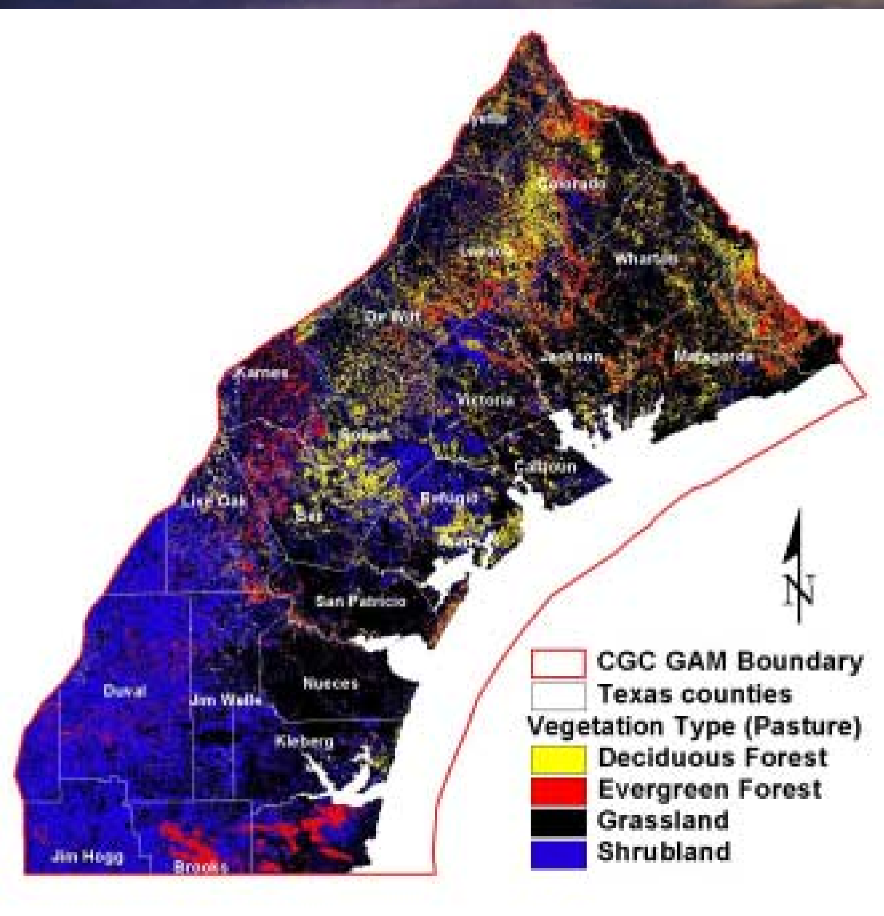
- Water leaves the aquifer through springs, seeps and wetlands represented as **drains**
- Wetlands indicate high potential for discharge from the aquifer



Evapotranspiration (ET)

- Hargraeves method based on temperature and vegetation



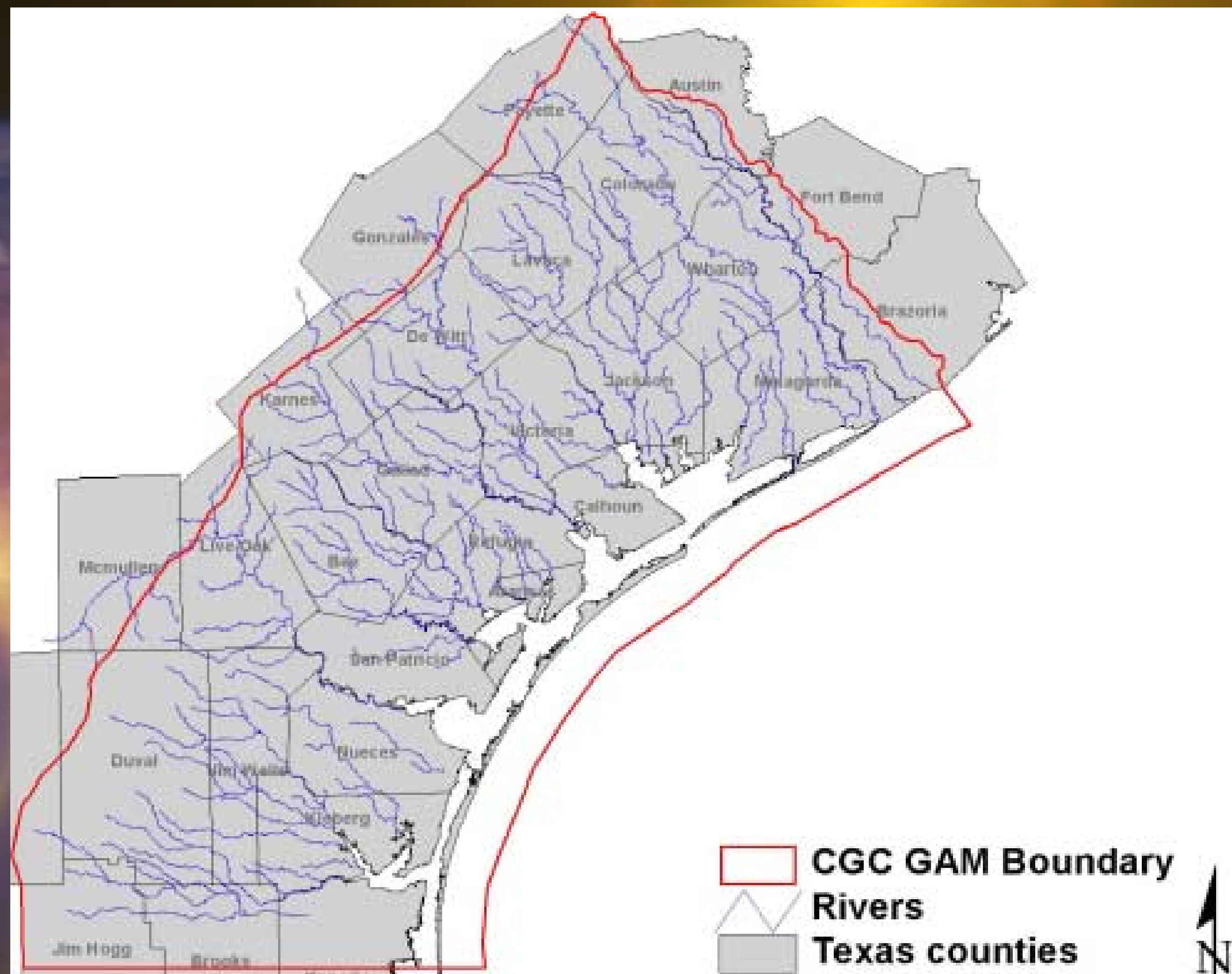


- Simulation of ET in MODFLOW also uses root depth (vegetation type)

Streamflow

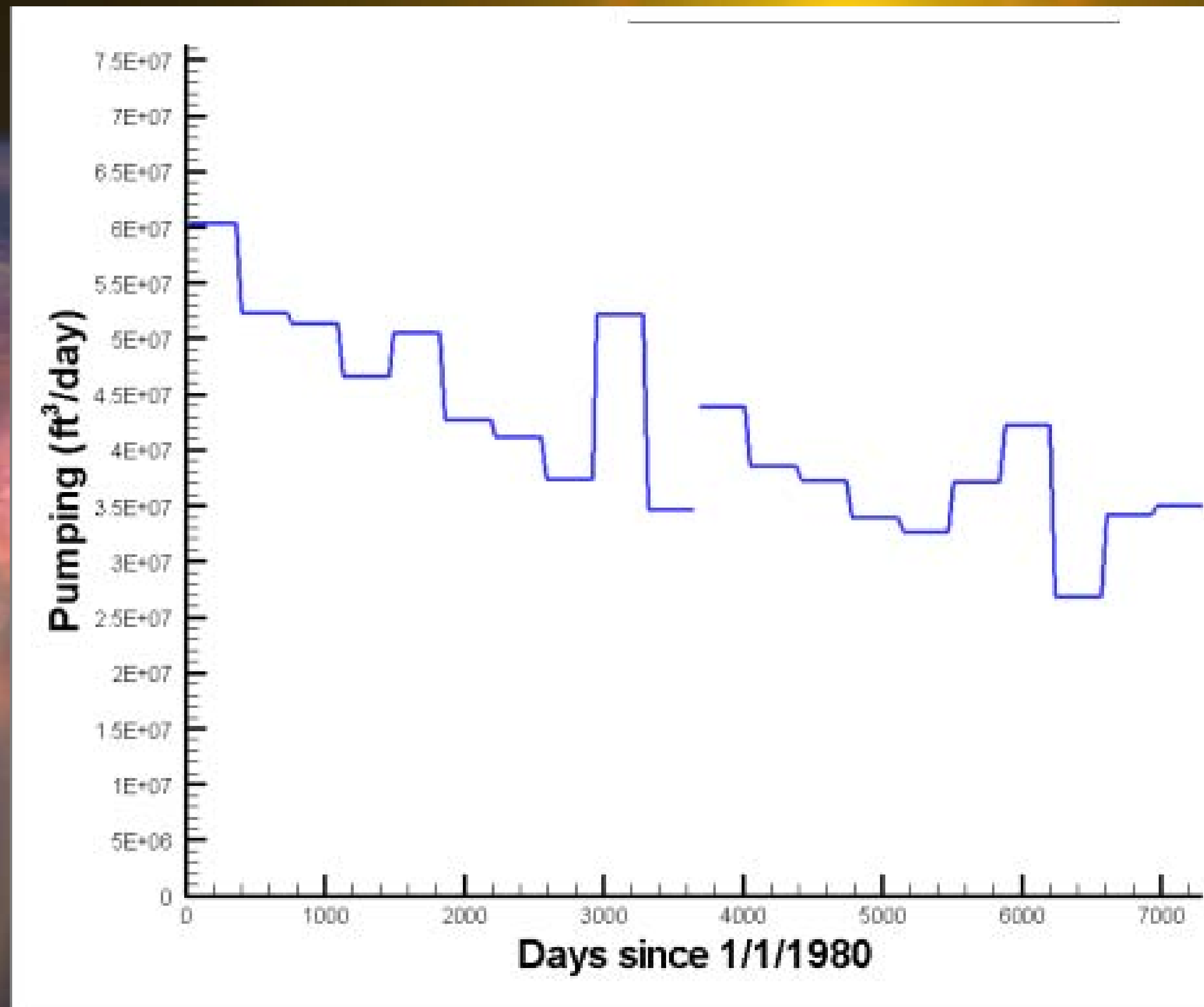
Characterize the temporal variations in flows

- associate each segment with stream gage
- mean flow for each segment: $RF1_s$
- segment with a gage: $RF1_g$
- segment multiplier: $RF1_s / RF1_g$
- gage average by stress period: g_i
- Time varying flow: $g_i * RF1_s / RF1_g$



Pumping

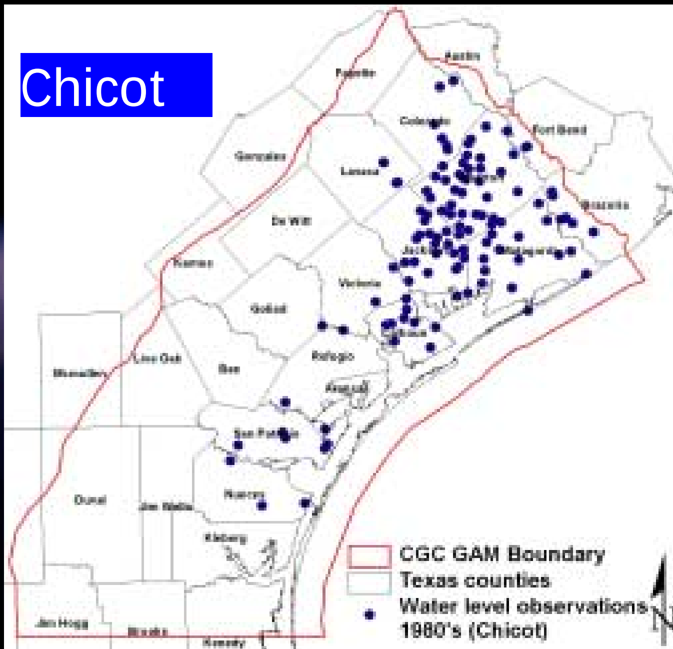
- Parsons SOP for pumping
- Different uses
- Vertical discretization
- 30,000 model cells have pumping

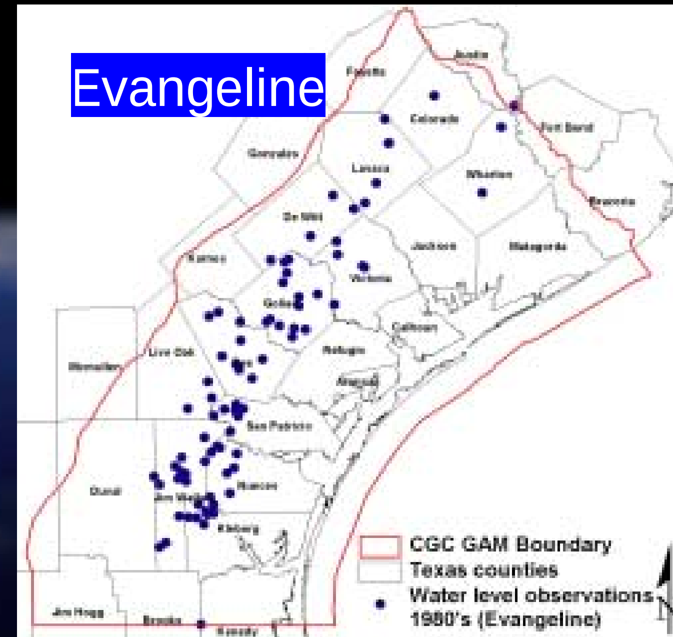


Observations

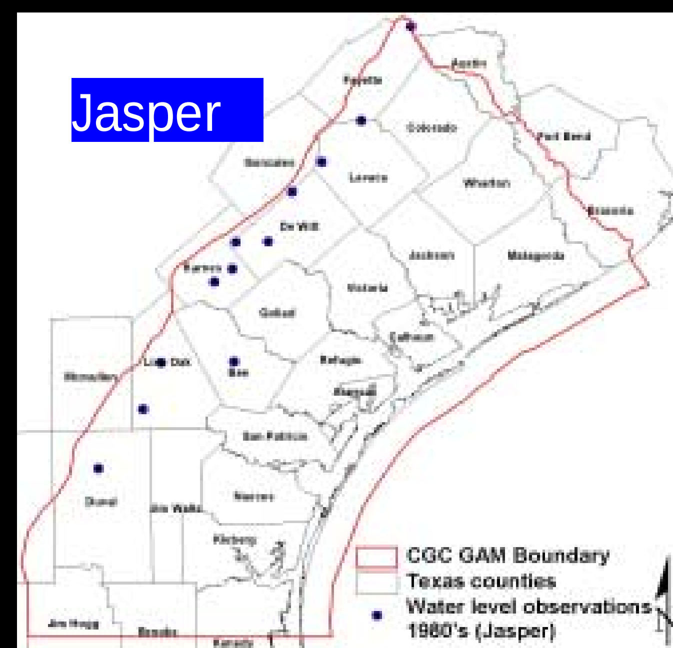
Water levels in wells

Water-Level Observation Locations





- Locations where we can get explicit residuals

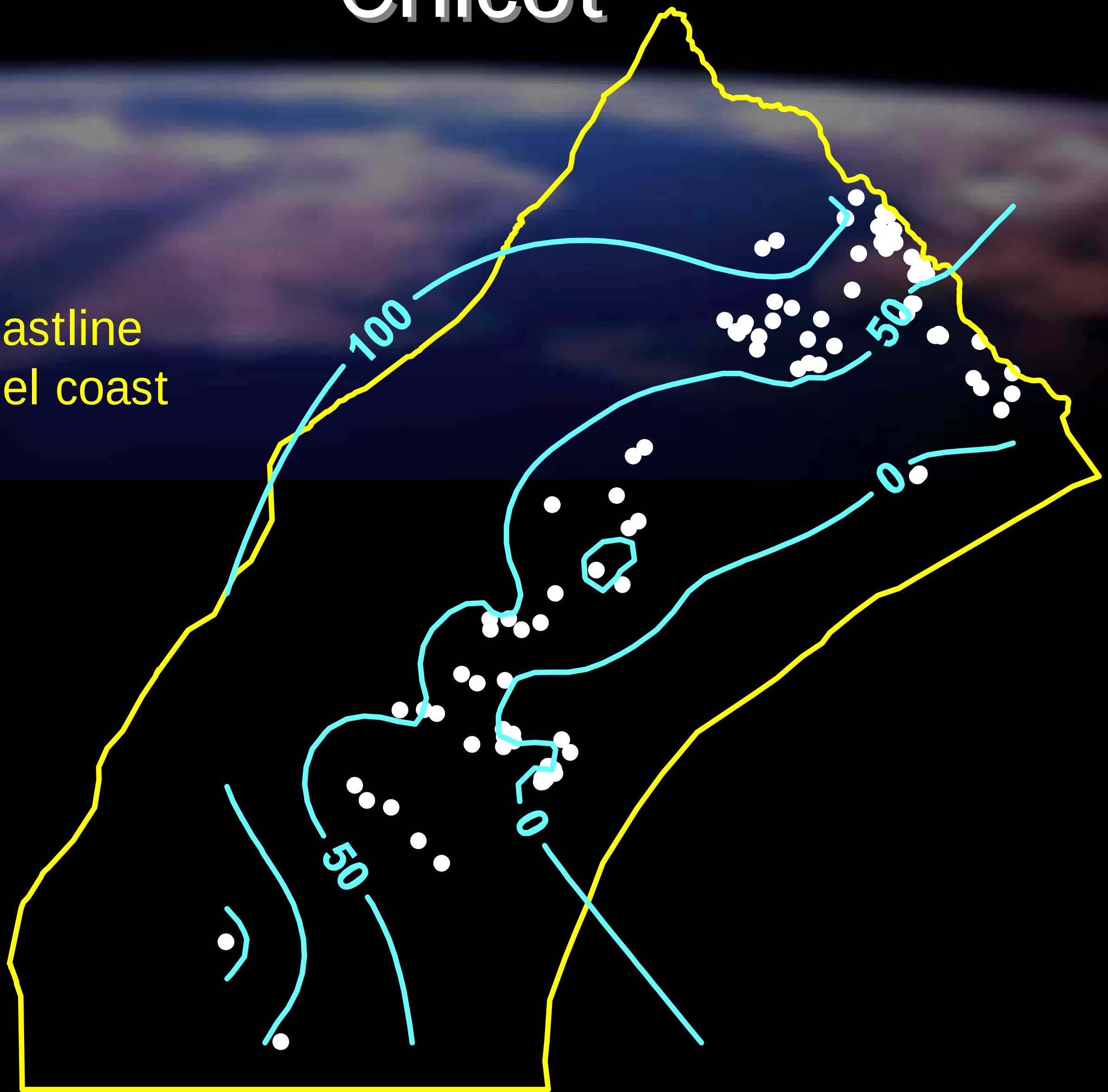


Results

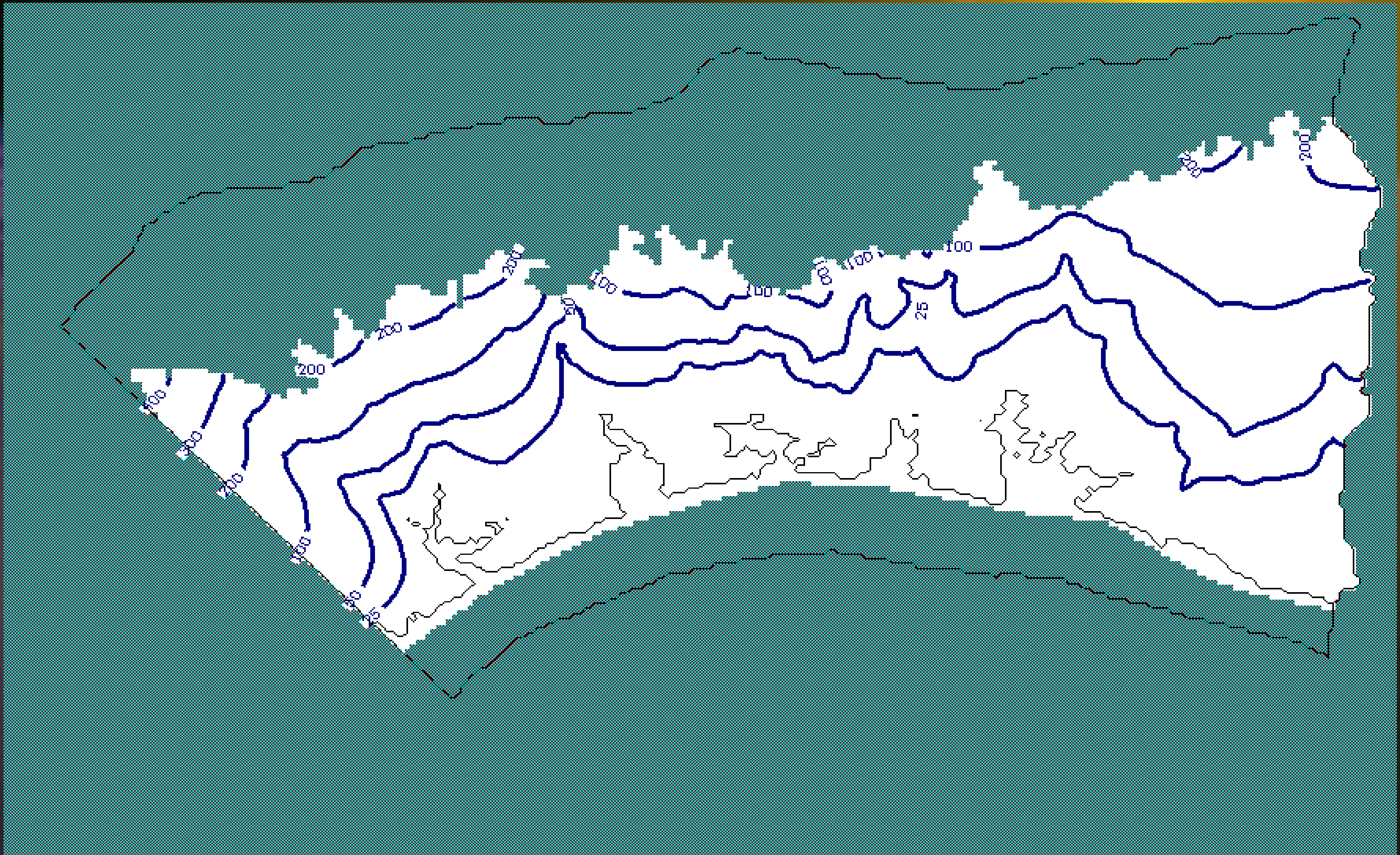
Steady-State Model

Observed Water-Level Contours Chicot

- Zero follows coastline
- Contours parallel coast

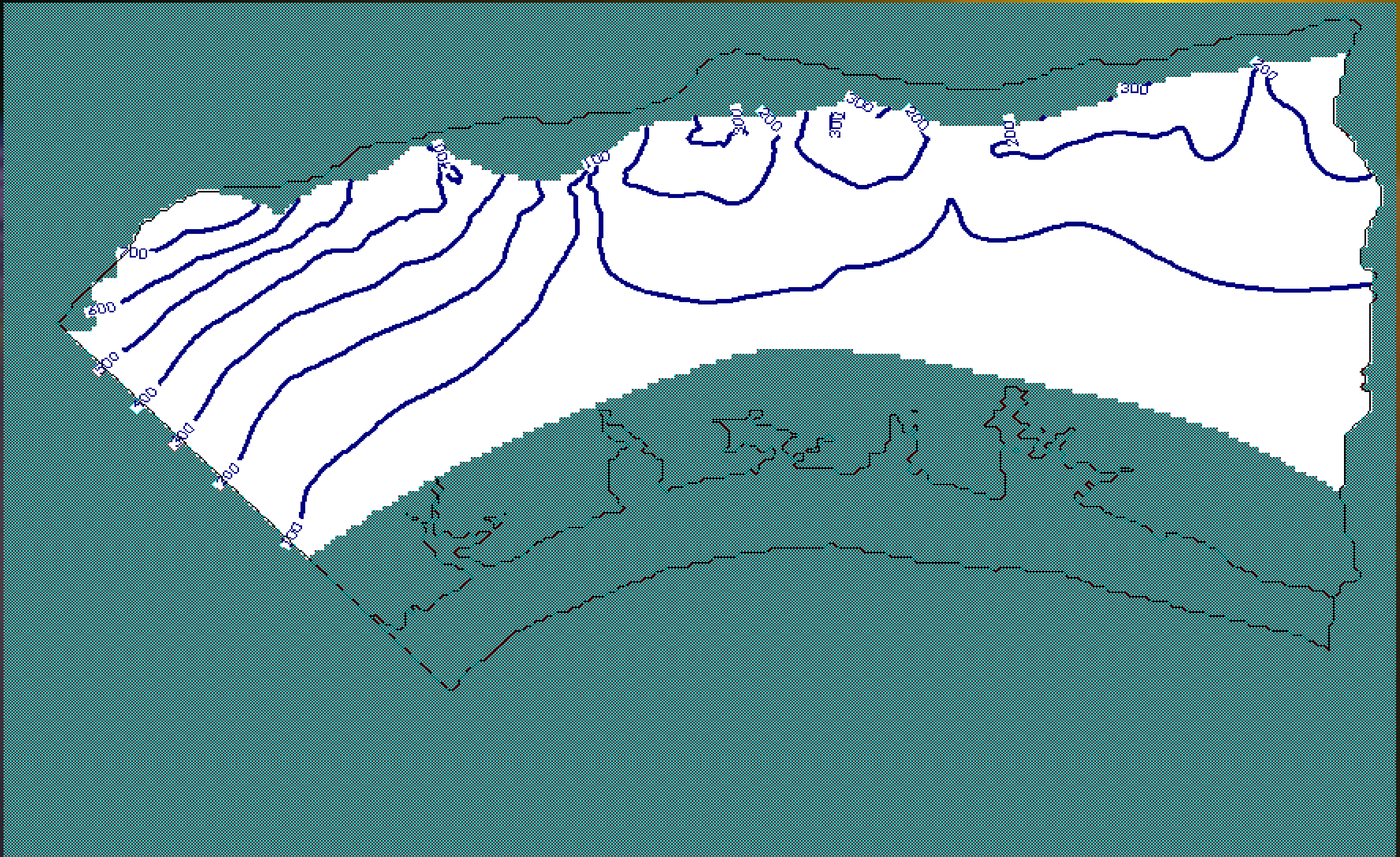


Simulated Water-Level Contours Chicot

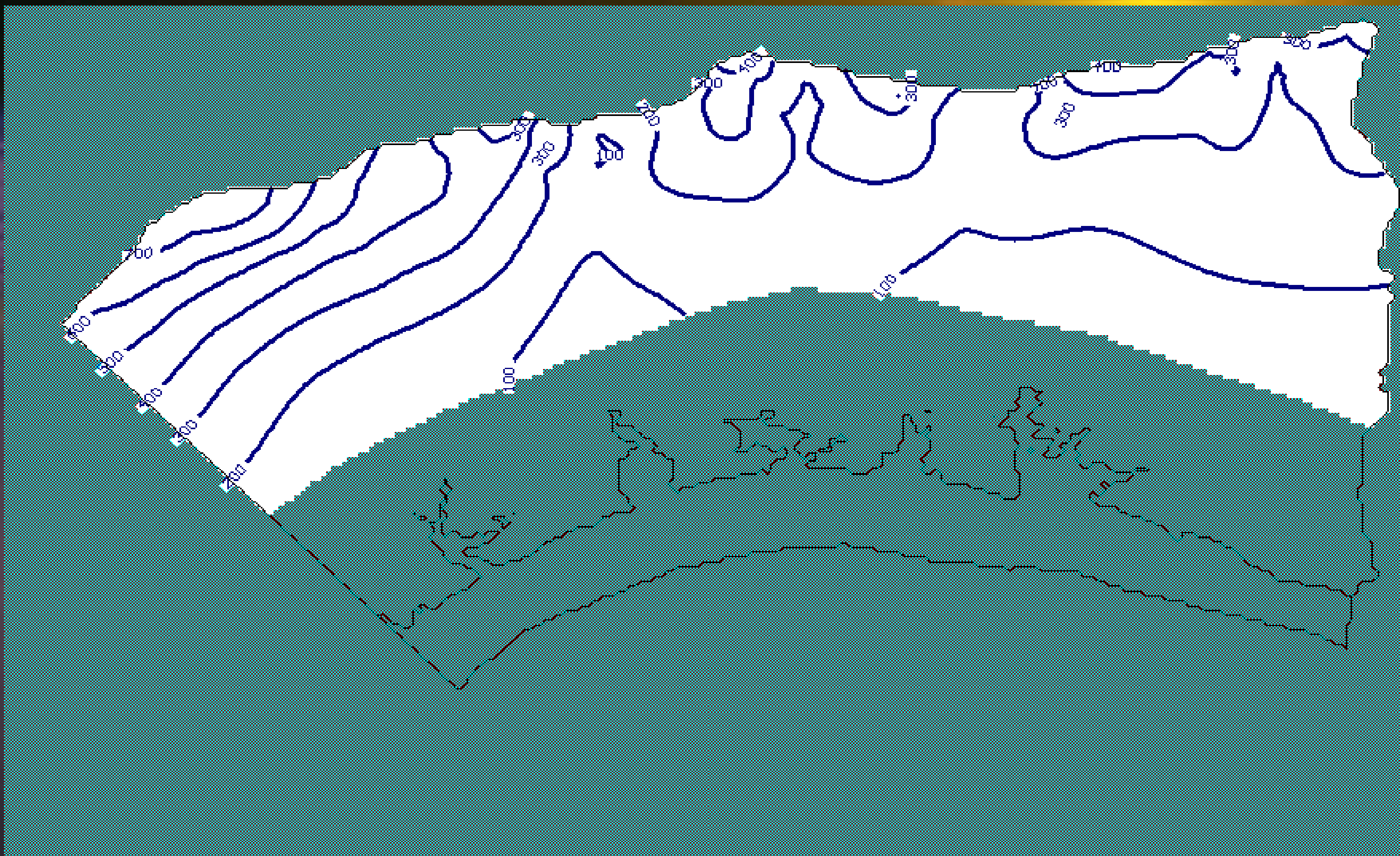


Simulated Water-Level Contours Evangeline

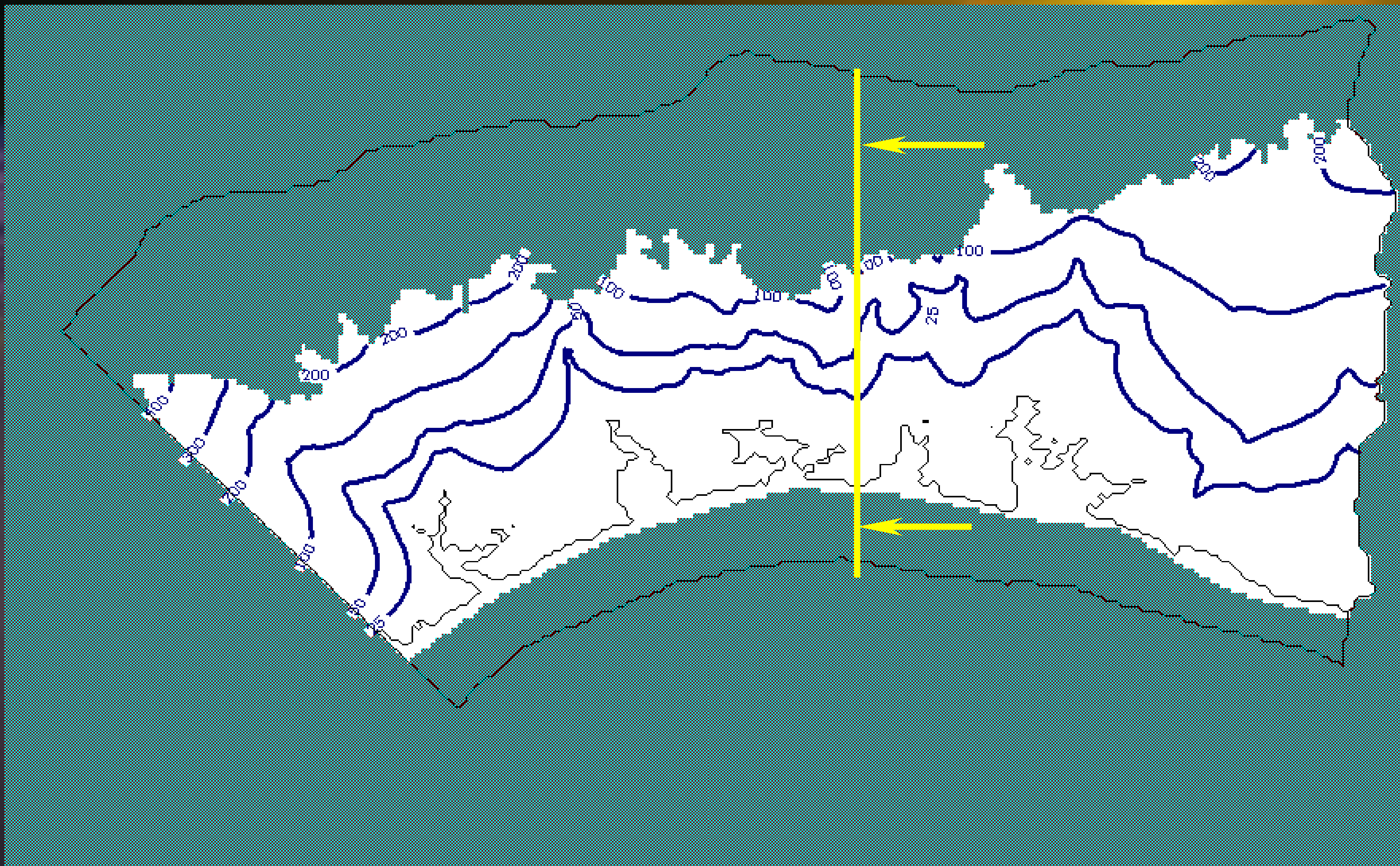
Simulated Water-Level Contours Burkeville



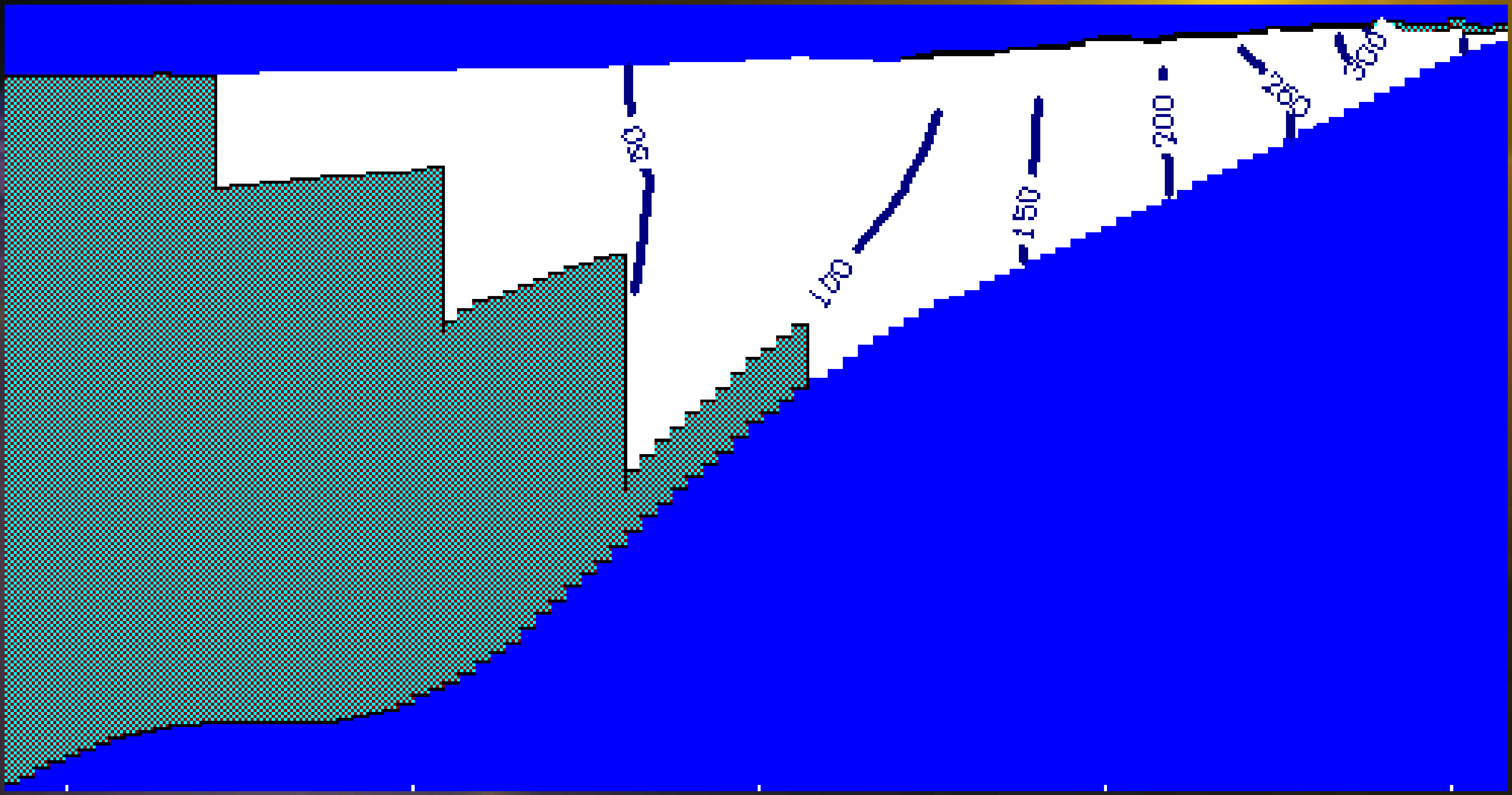
Simulated Water-Level Contours Jasper



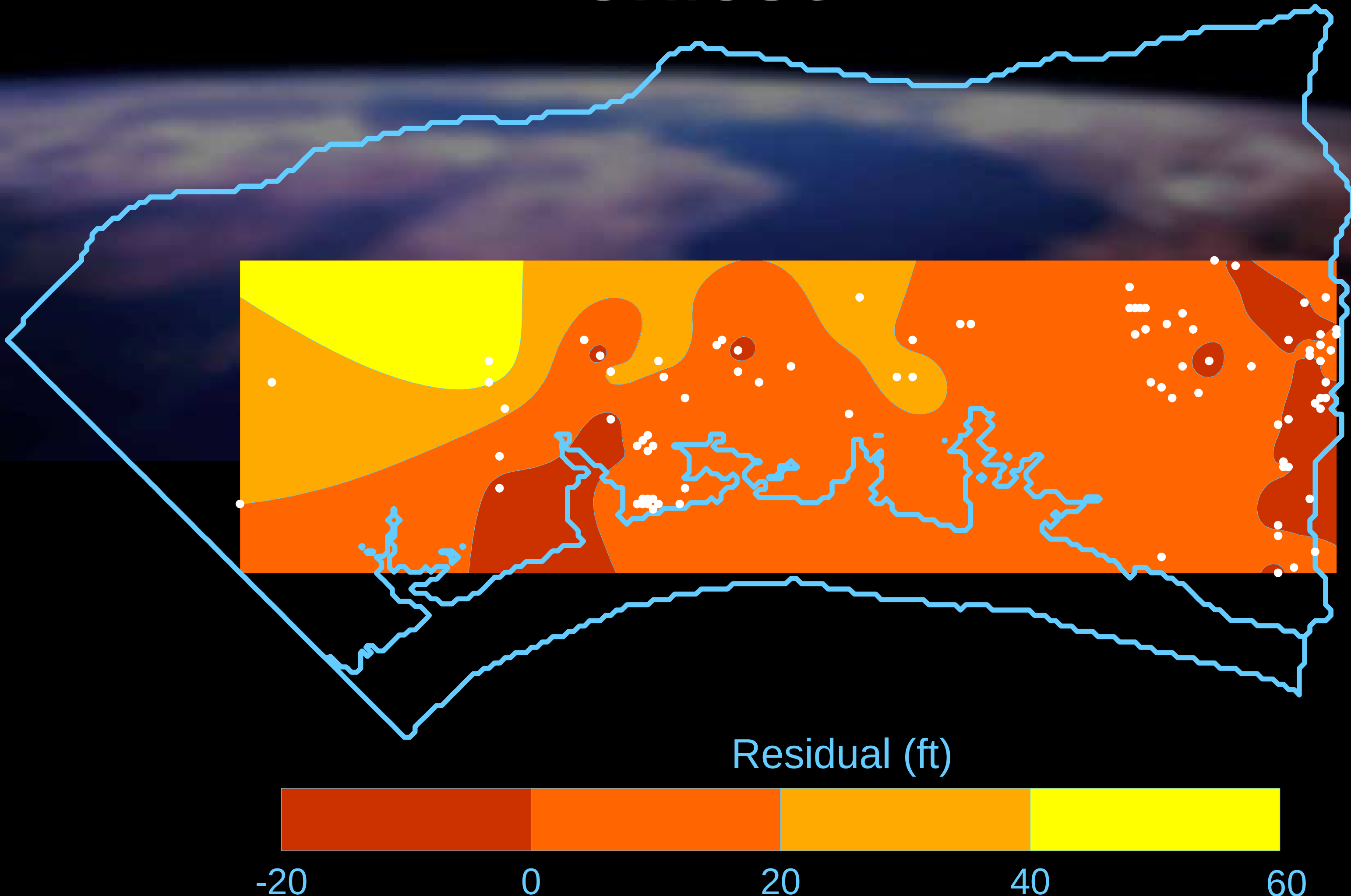
Cross Formational Flow: Cross-Section Location



Simulated Water-Level Contours Cross-Section

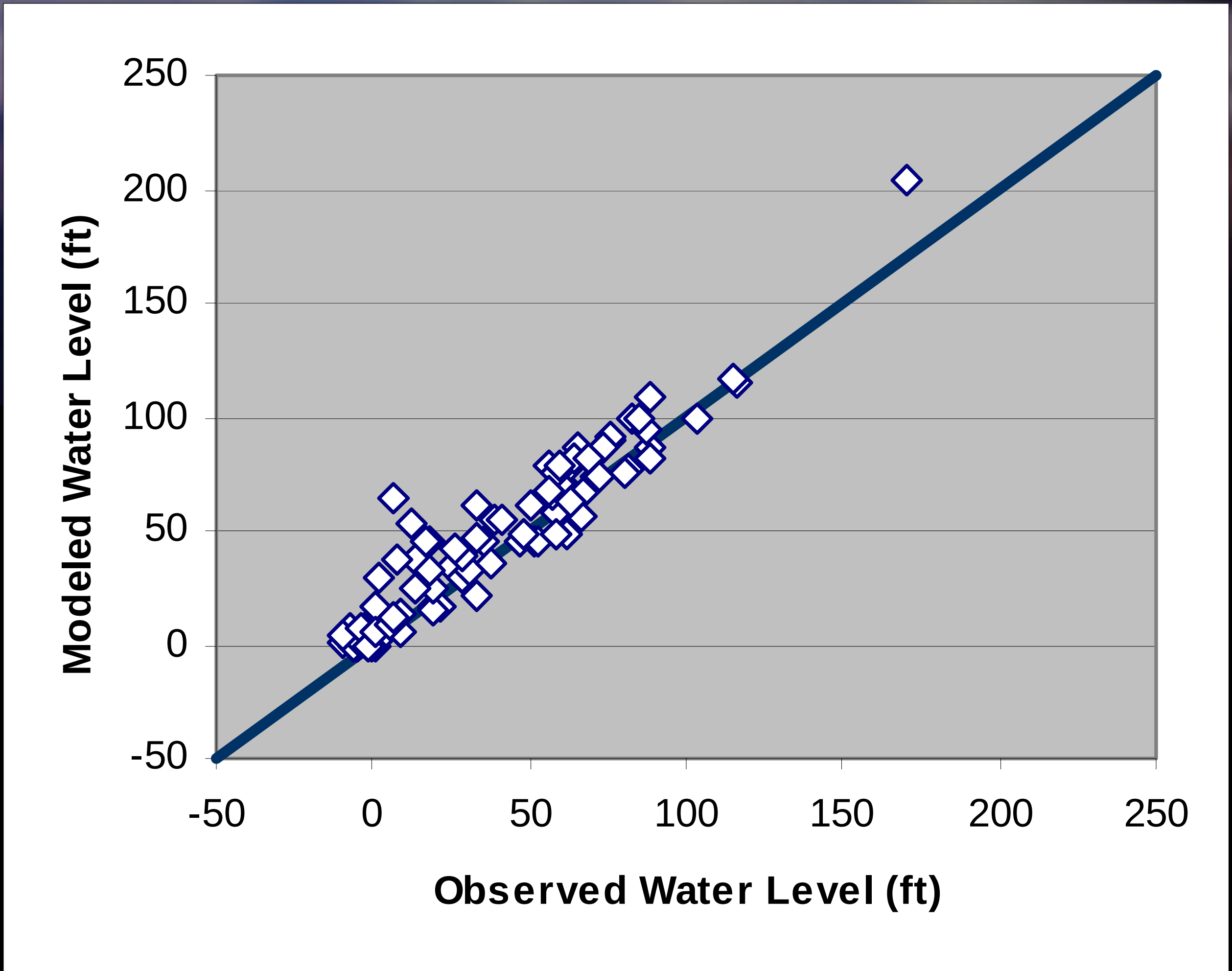


Water-Level Residuals Chicot

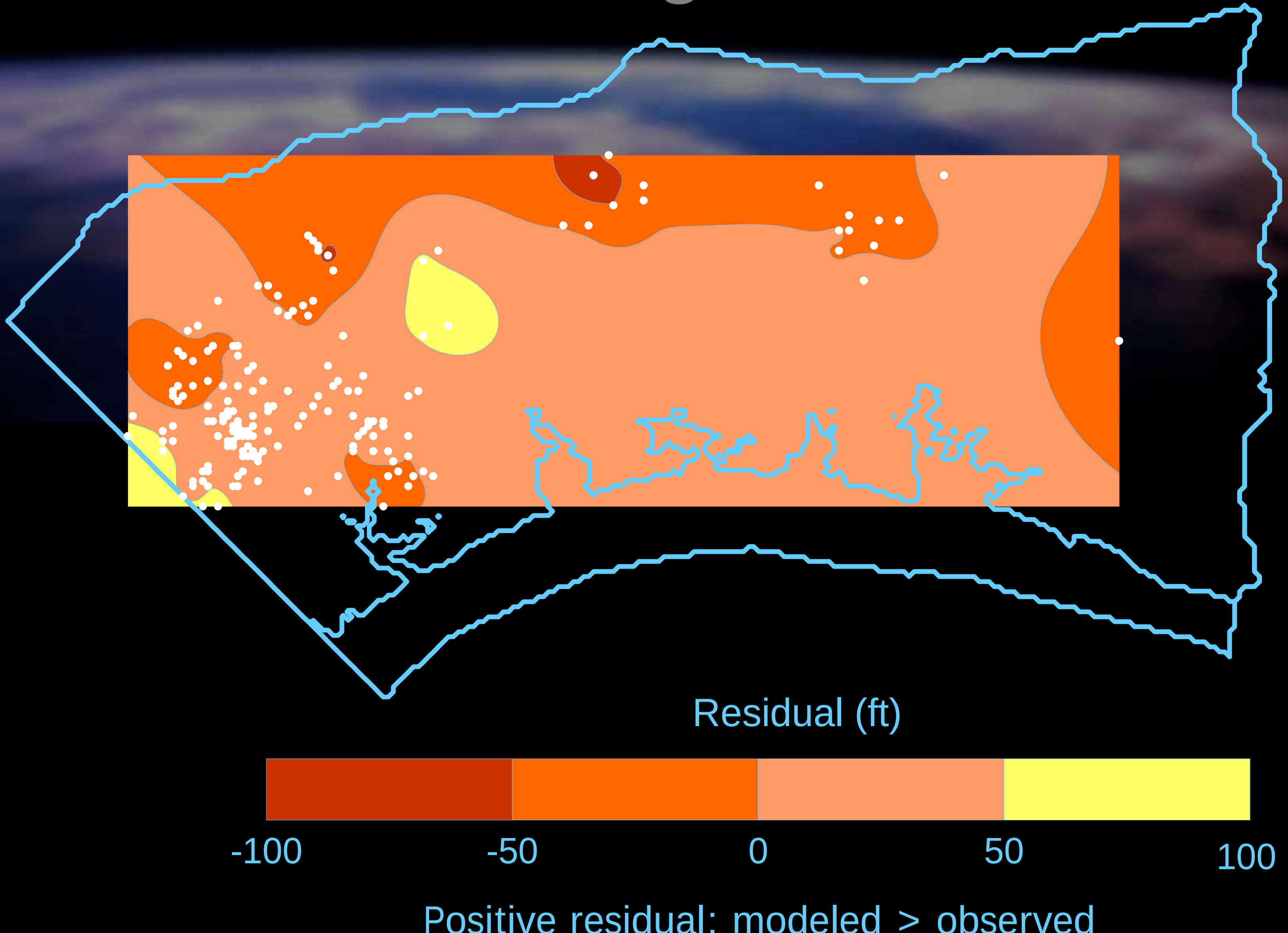


Positive residual: modeled > observed

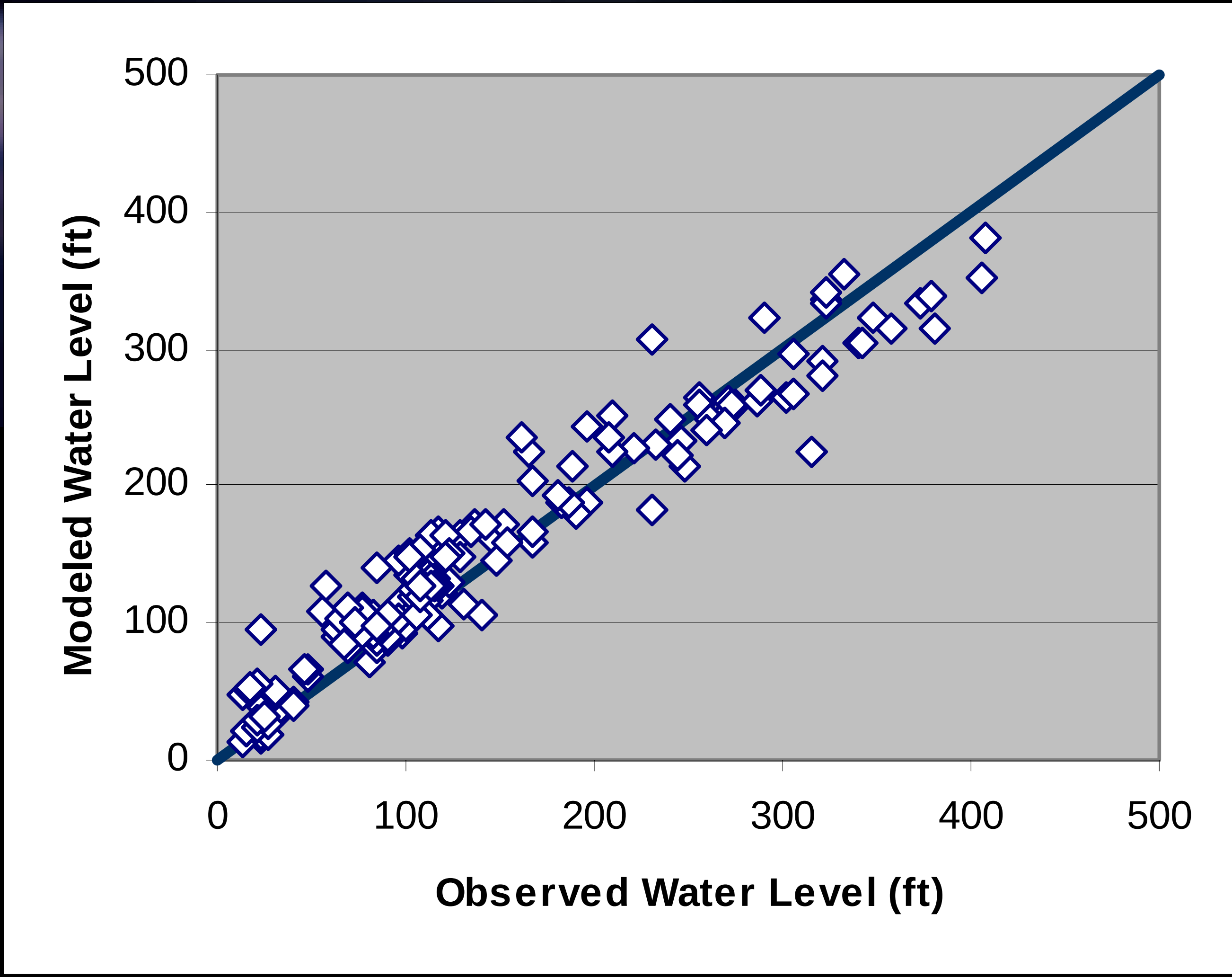
Water-Level Residuals
Chicot



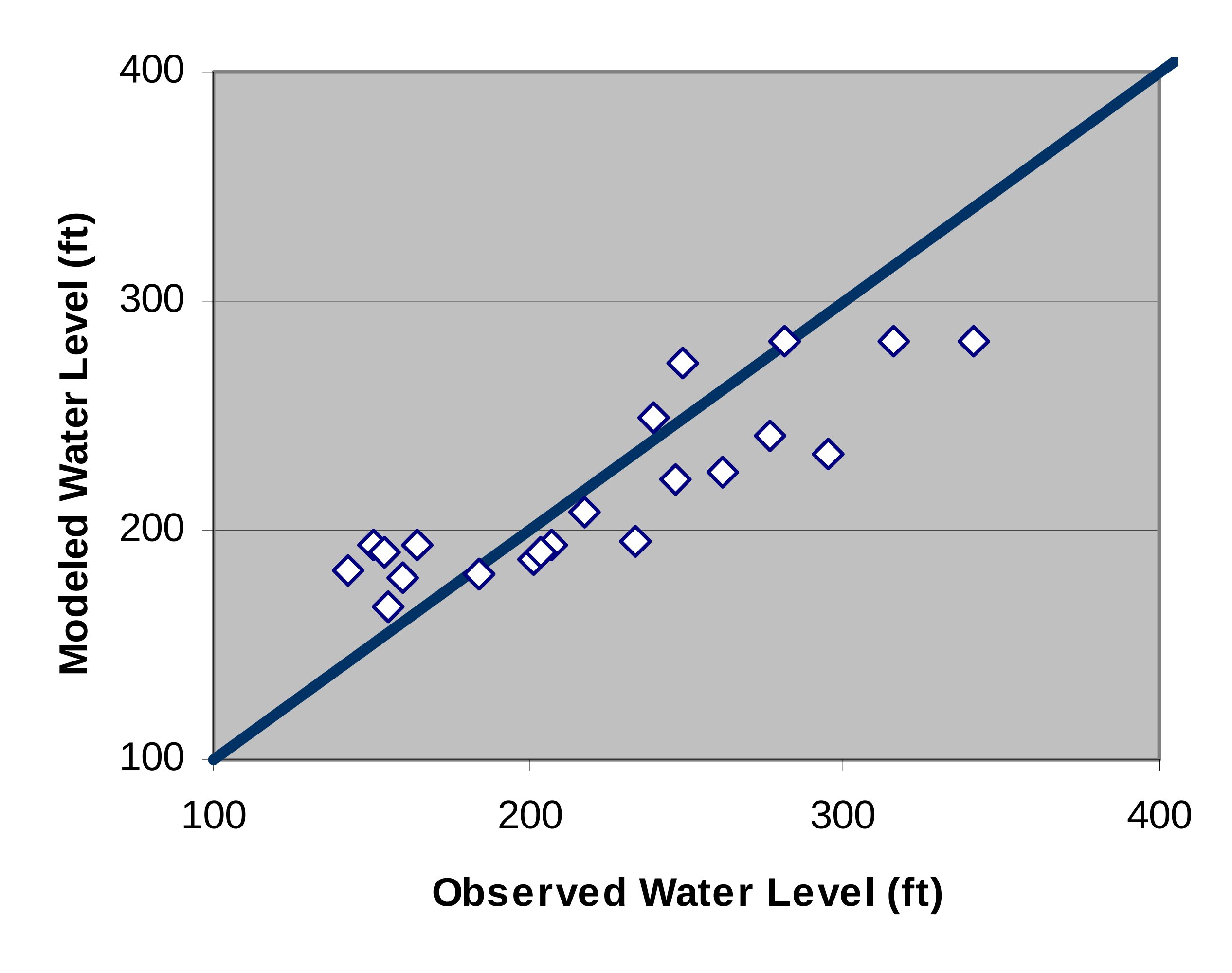
Water-Level Residuals Evangeline



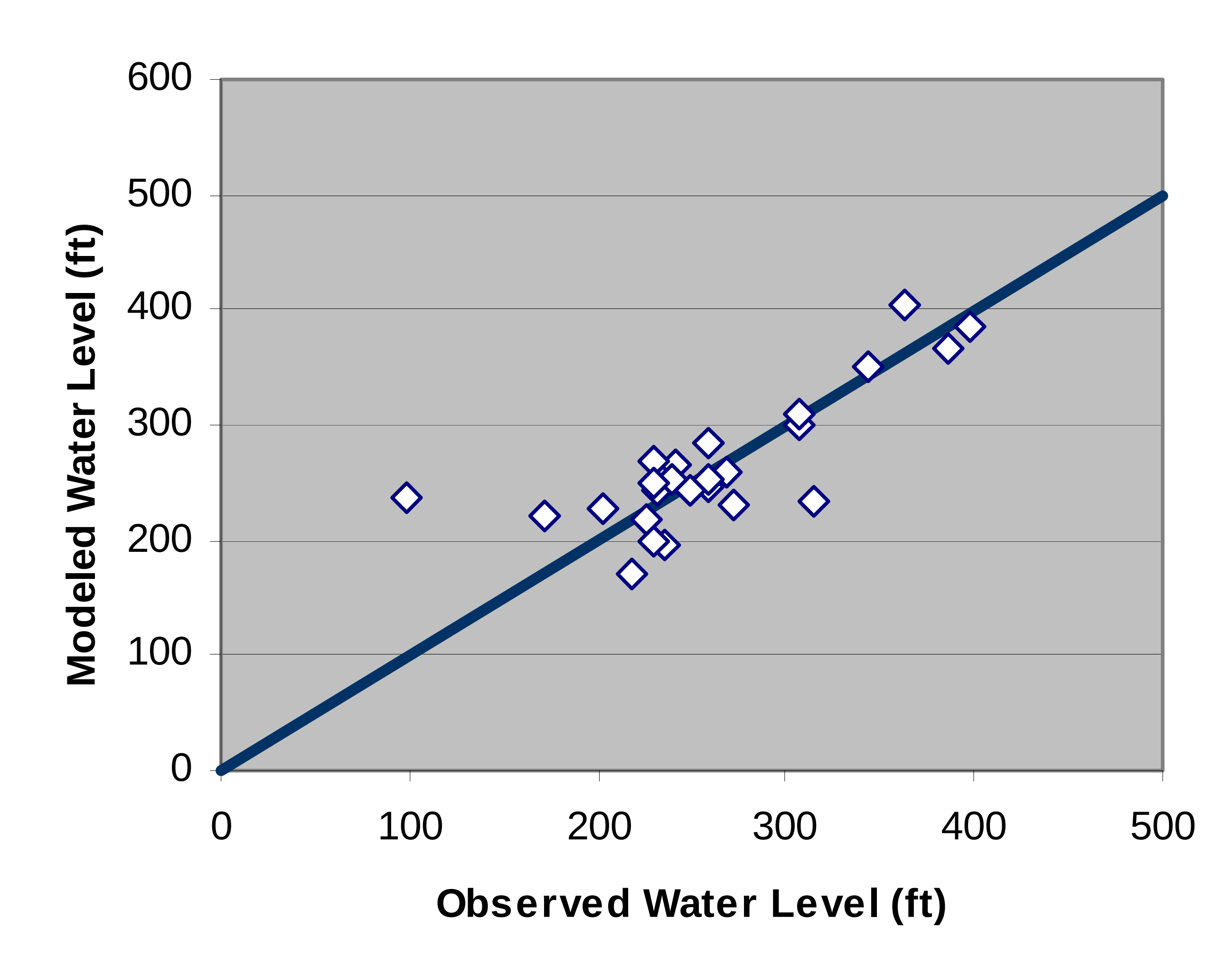
Water-Level Residuals Evangeline



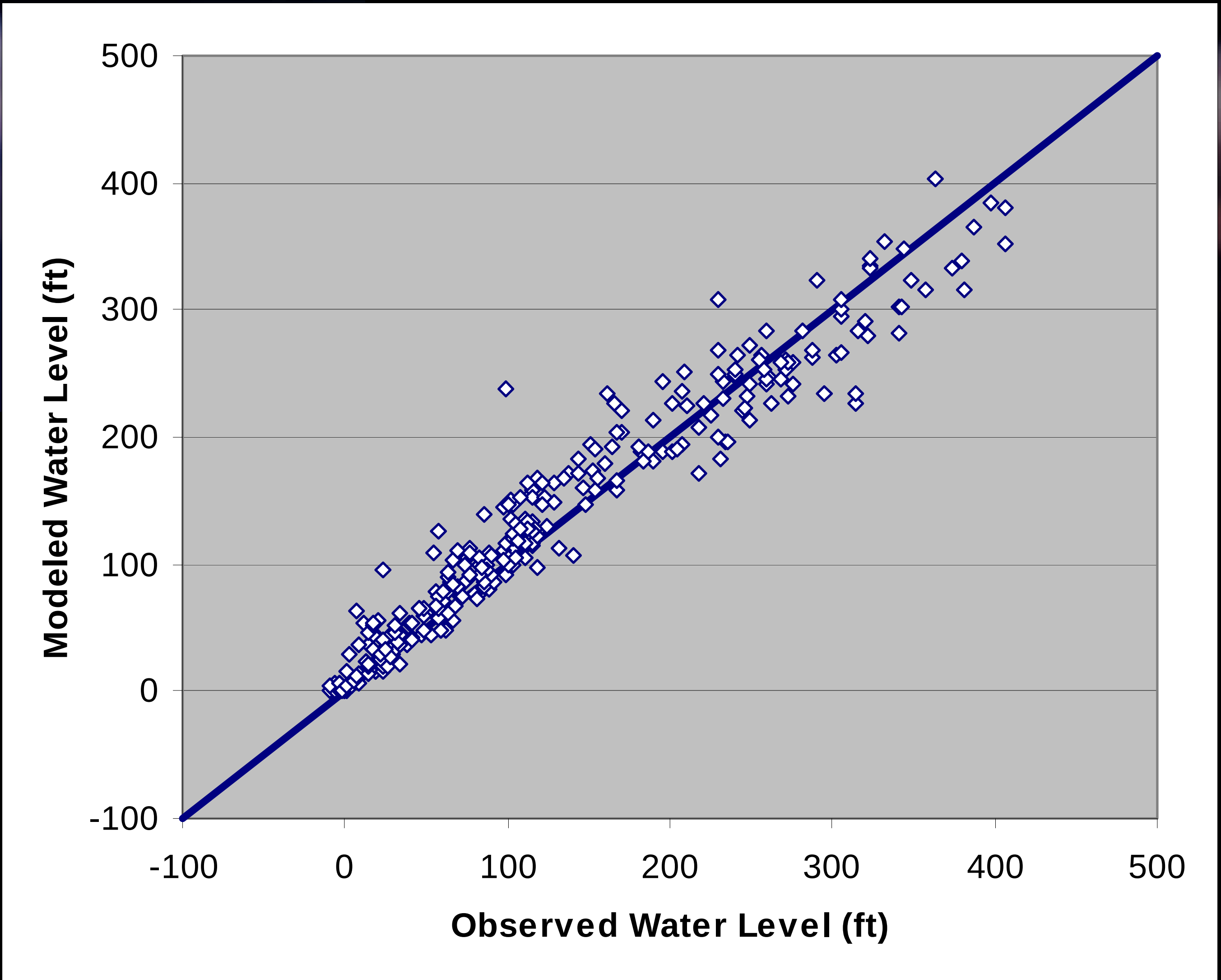
Water-Level Residuals
Burkeville



Water-Level Residuals
Jasper



Water-Level Residuals
All Layers



Calibration Statistics

Layer	No. Targets	AME (ft)	RMSE (ft)
Chicot	89	8	14
Evangeline	165	9	28
Burkeville	21	-6	31
Jasper	25	3	41
All	**300**	**7**	**27**

(Target RMSE = 42 ft)

Calibrated Pre-Development Model Water Budget

WATER BALANCE				
	Flow (ft^3/day)		Percentage	
Package	**In**	**Out**	**In**	**Out**
Recharge	42,831,060	--	44.2%	--
Streams	52,976,220	83,686,320	54.7%	86.4%
GHB	0	12,669,478	0.0%	13.1%
Reservoirs	1,105,552	0	1.1%	0.0%
Drains	--	556,964	--	0.6%
Total:	**96,912,832**	**96,912,762**		

Cross-Formational Flow:

Layer Interface	Net (ft^3/day)	Downward (ft^3/day)	Upward (ft^3/day)
Chicot - Evangeline	-3,825,395	10,828,169	14,653,564
Evangeline - Burkeville	-117,204	461,029	578,233
Burkeville - Jasper	-94,338	530,708	625,046

Note: negative net cross-formational flow is in the upward direction

- Recharge and streams are primary sources
- Discharge is to streams and along coast
- Most cross-formational flow is between Chicot and Evangeline

Parameter Value Summaries

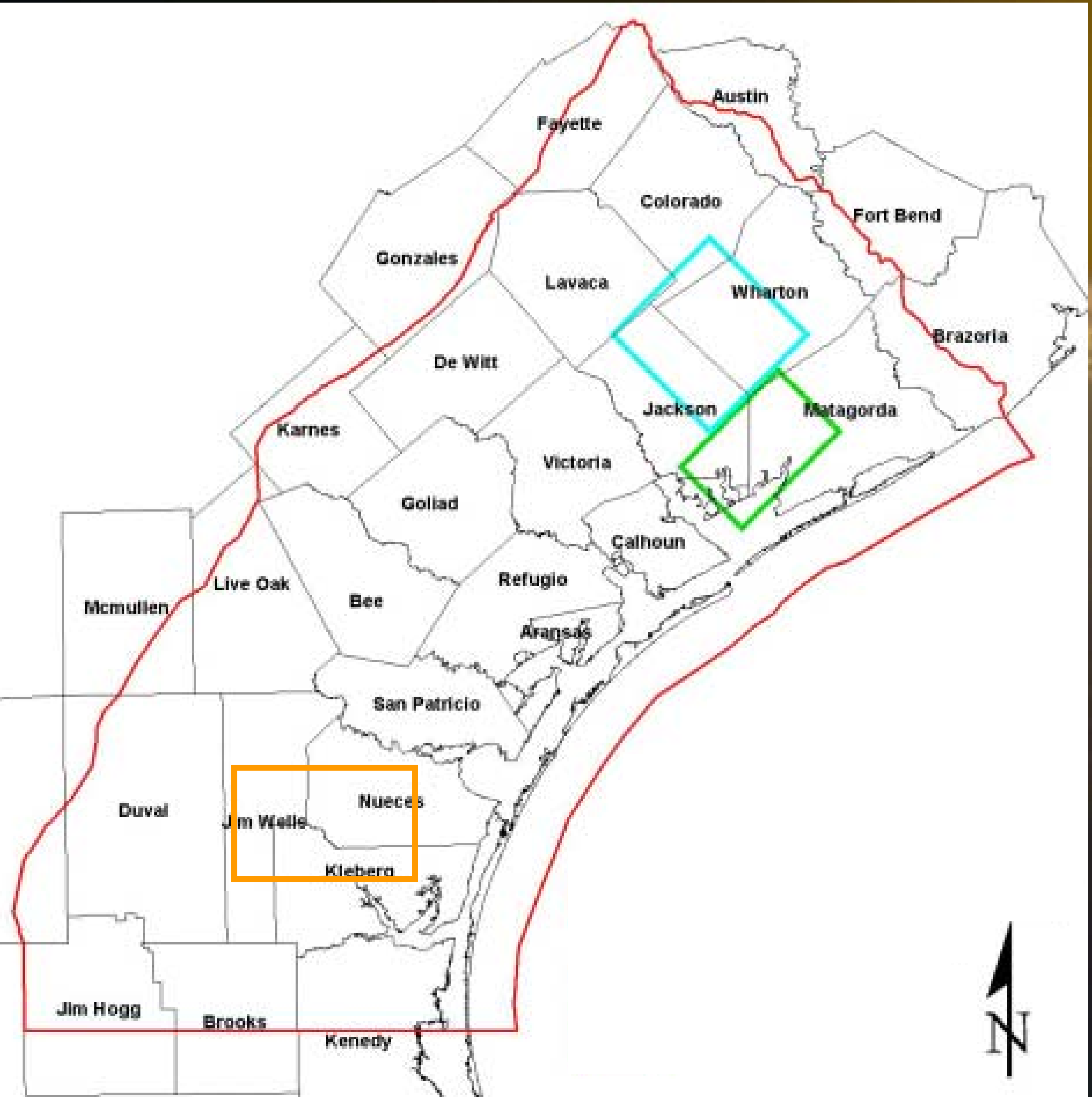
		Initial Parameter	Calibrated Parameter	Calibrated/ Initial
Horizontal K (ft/day)	Chicot	4.80E+01	4.80E+01	1
	Evangeline	1.42E+01	1.42E+01	1
	Burkeville	2.45E+01	2.45E-01	0.01
	Jasper	1.35E+01	6.75E-01	0.05
Vertical K (ft/day)	Chicot	3.00E-03	1.00E-02	3.33
	Evangeline	8.00E-04	1.00E-02	12.5
	Burkeville	1.00E-04	1.00E-04	1
	Jasper	1.00E-04	1.00E-03	10
Streambed K (ft/day)		3.00E-01	1.00E+00	3.33
GHB Conductance (ft^2/day)		1.00E+00	1.00E+04	10000
Drain and Reservoir K (ft/day)		3.00E-03	1.00E-03	0.33
Recharge (ft/day)	Chicot (low)	1.20E-05	1.00E-06	0.08
	Chicot (high)	1.20E-04	2.00E-04	1.67
	Evangeline	1.20E-04	5.00E-05	0.42
	Burkeville	1.20E-05	1.00E-07	0.01
	Jasper	1.20E-04	5.00E-06	0.04

- Adjustments between initial and final values are realistic considering the uncertainty associated with each parameter.

Results

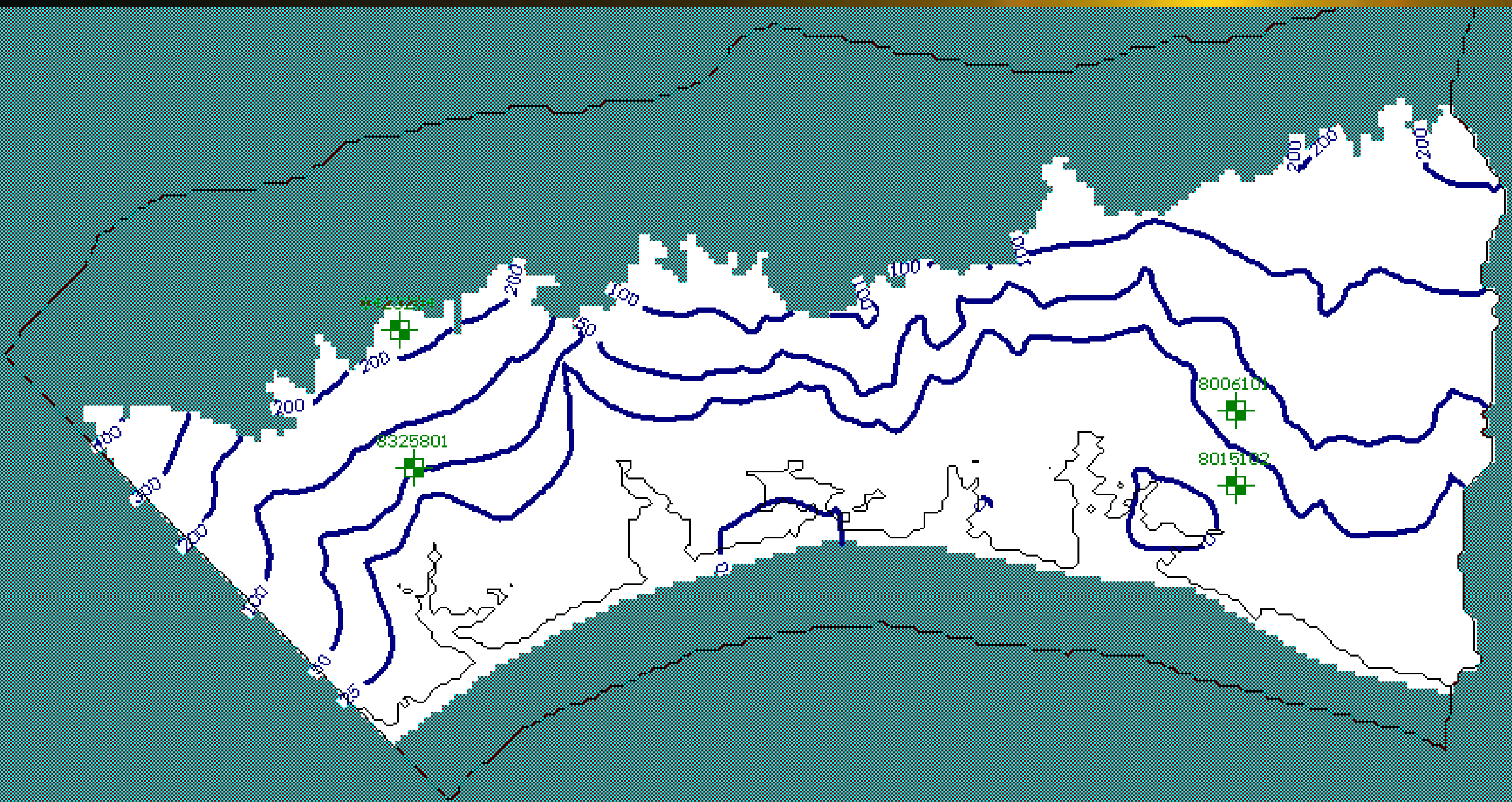
Transient Model

Pumping Adjustments

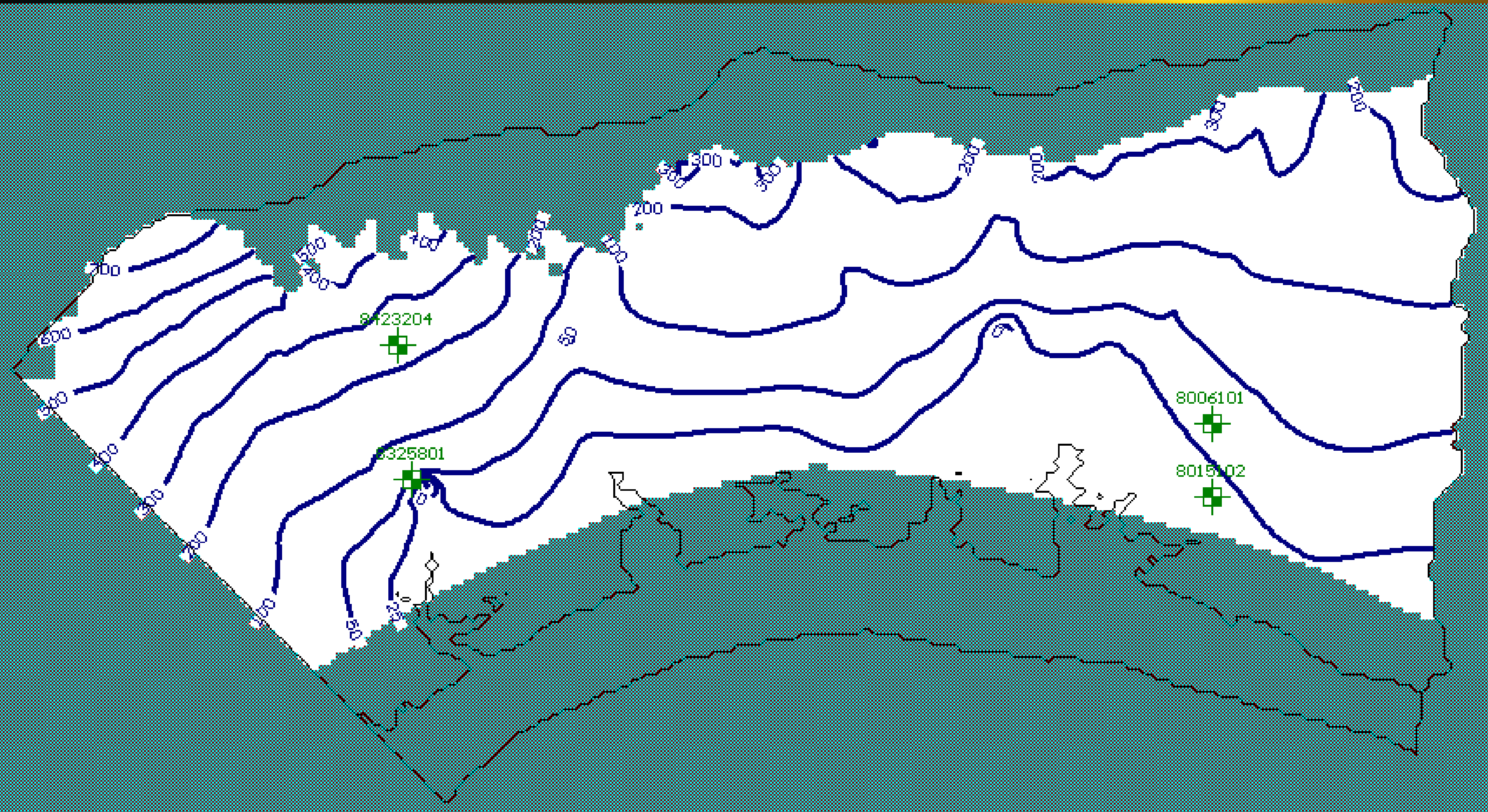


- Observations contrasted strongly with the simulated water levels
- Investigated
  - Observation depth
  - Pumping depth
  - *K* adjustment
- Adjusted pumping
- Local features or pumping dominate the drawdown

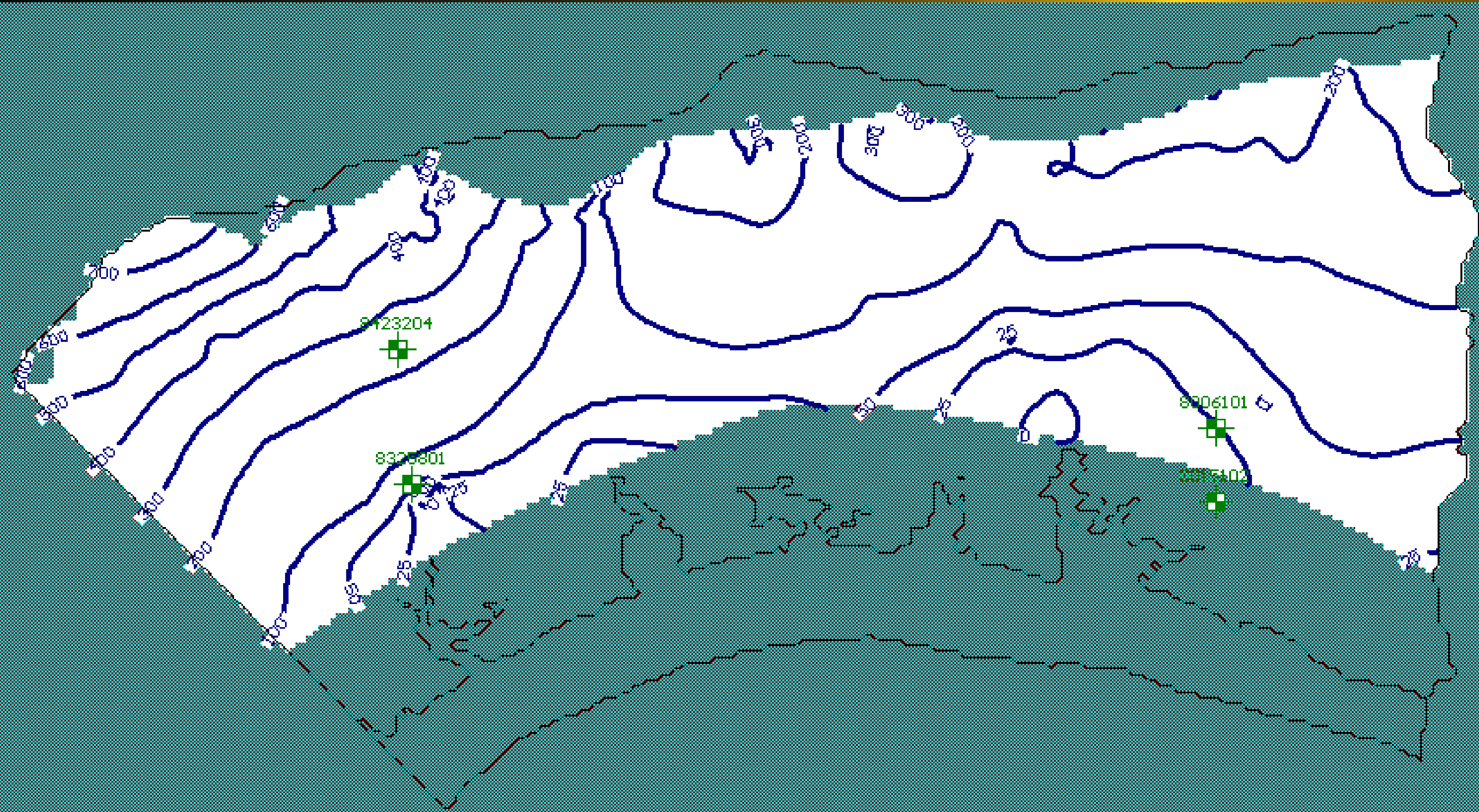
Simulated Water-Level Contours
Chicot (1999)



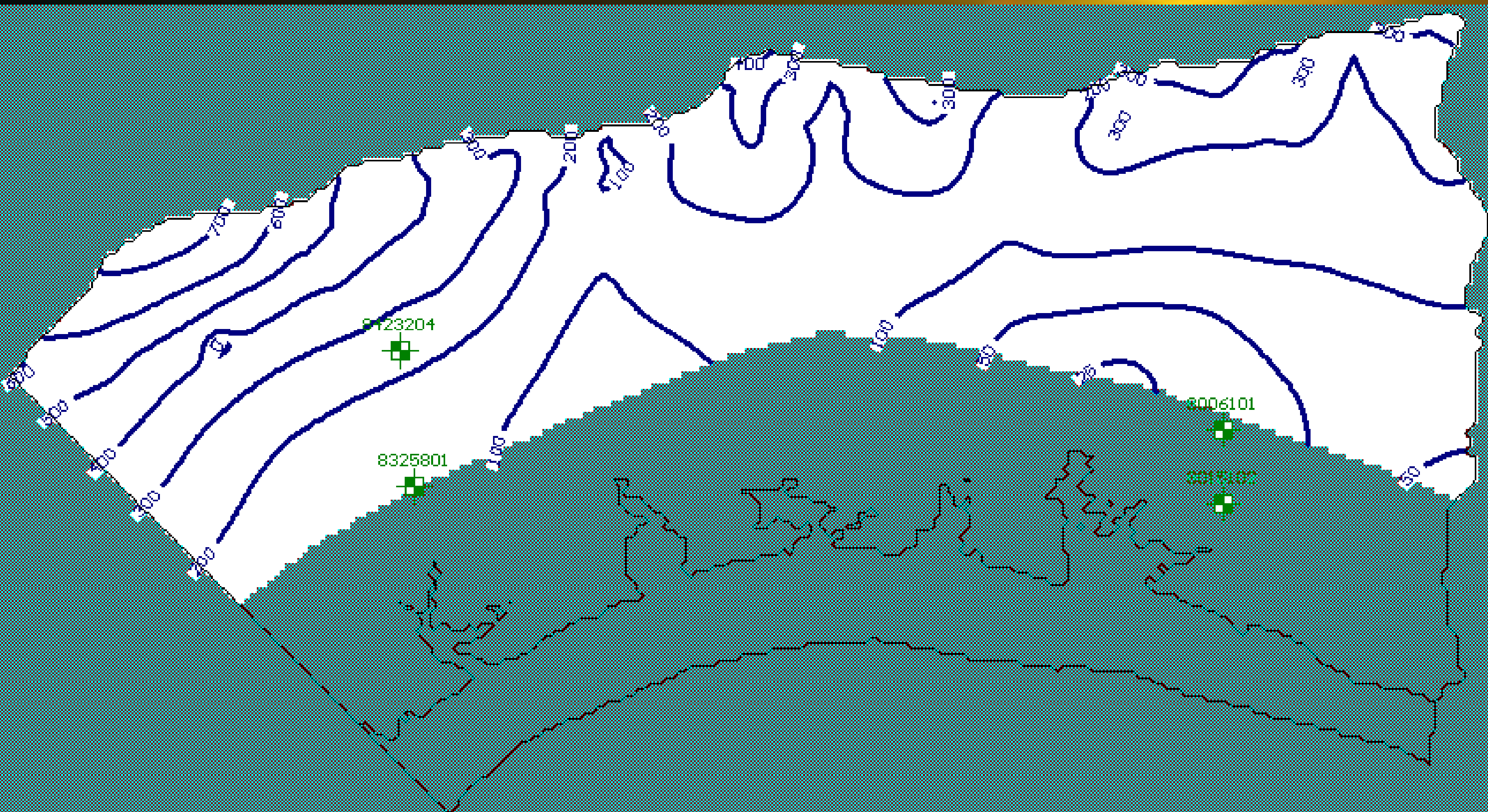
Simulated Water-Level Contours Evangeline (1999)



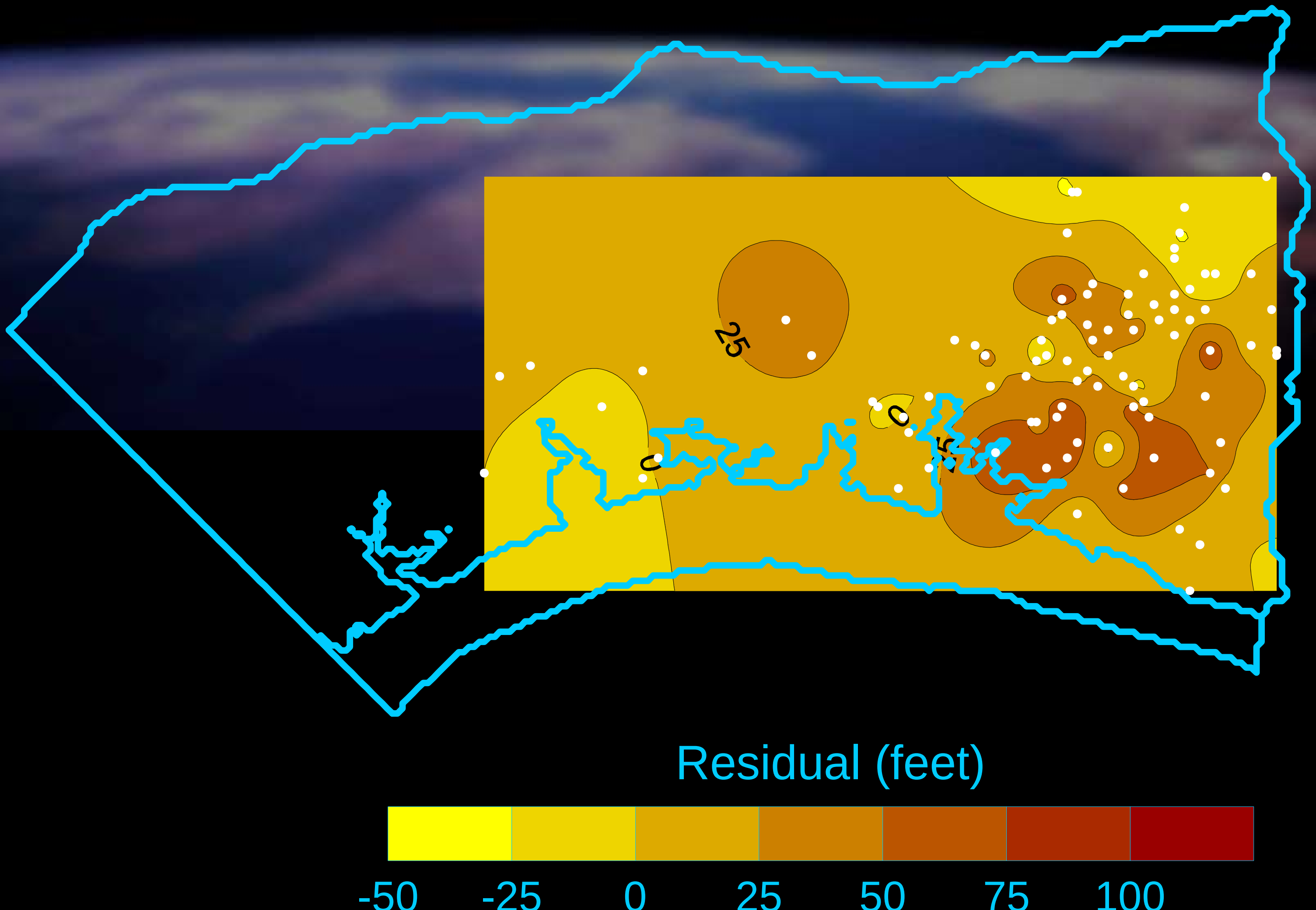
Simulated Water-Level Contours Burkeville (1999)



Simulated Water-Level Contours Jasper (1999)

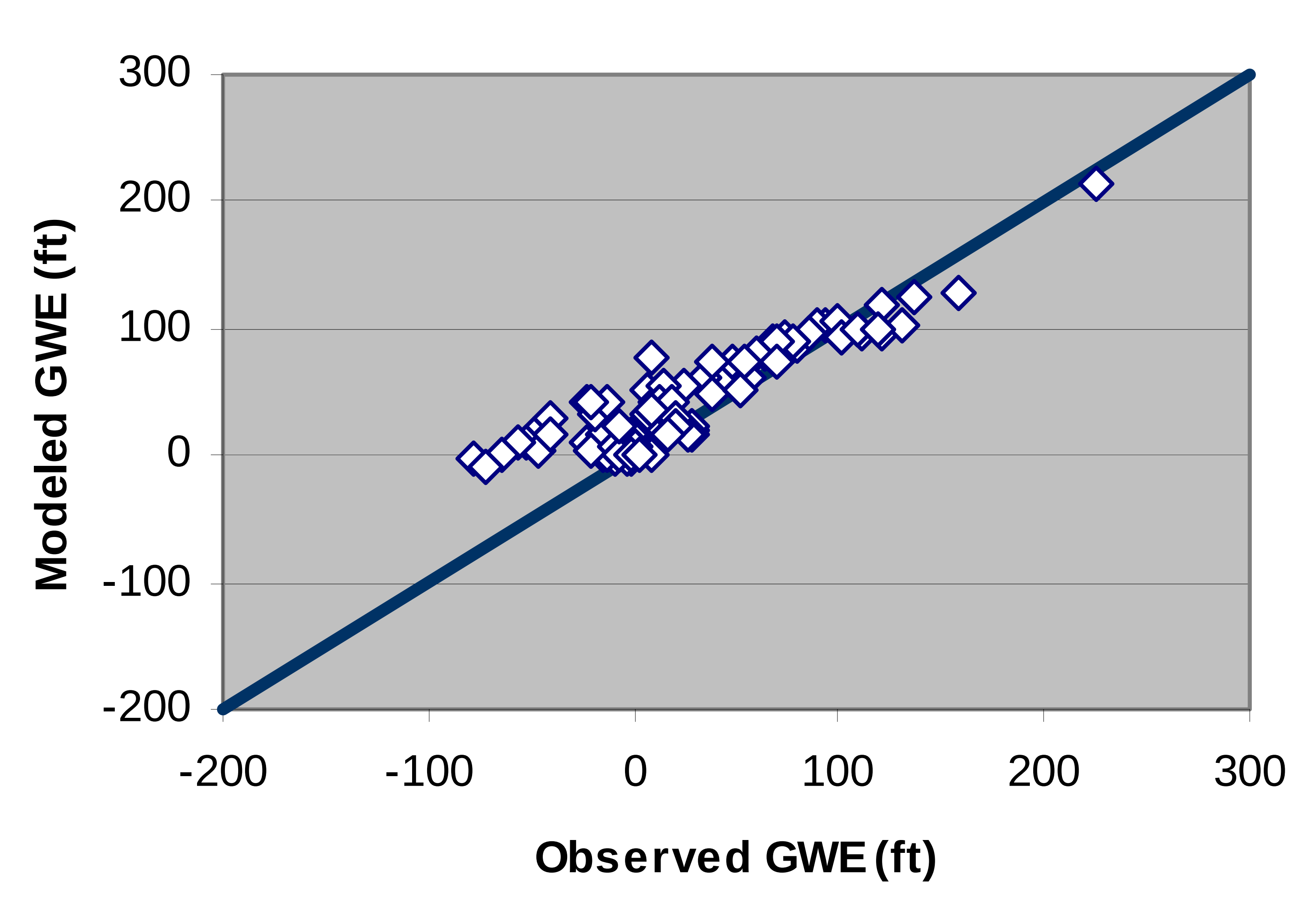


1989 Water-Level Residuals
Chicot

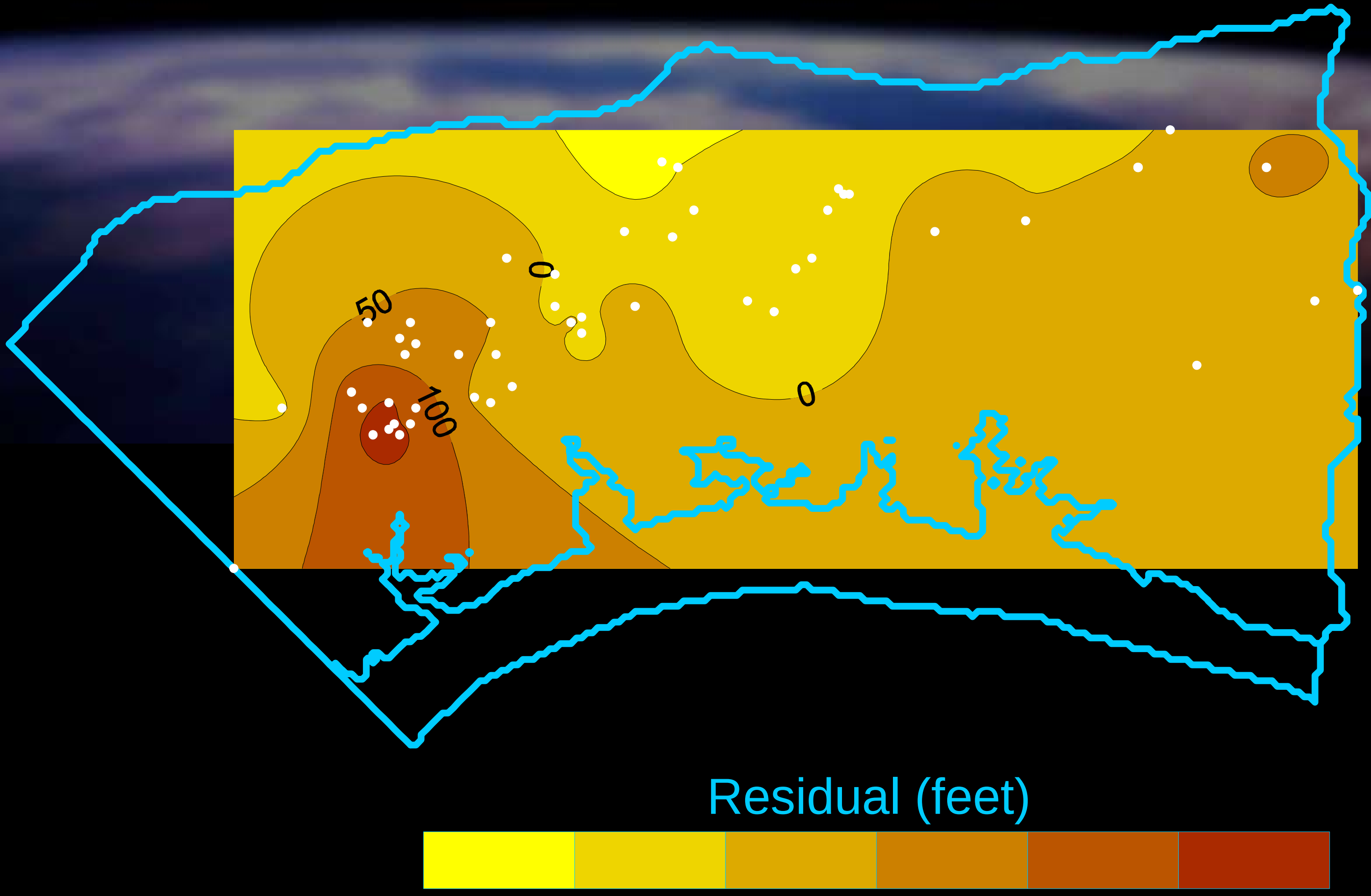


Positive residual: modeled > observed

Water-Level Residuals
Chicot (1989)

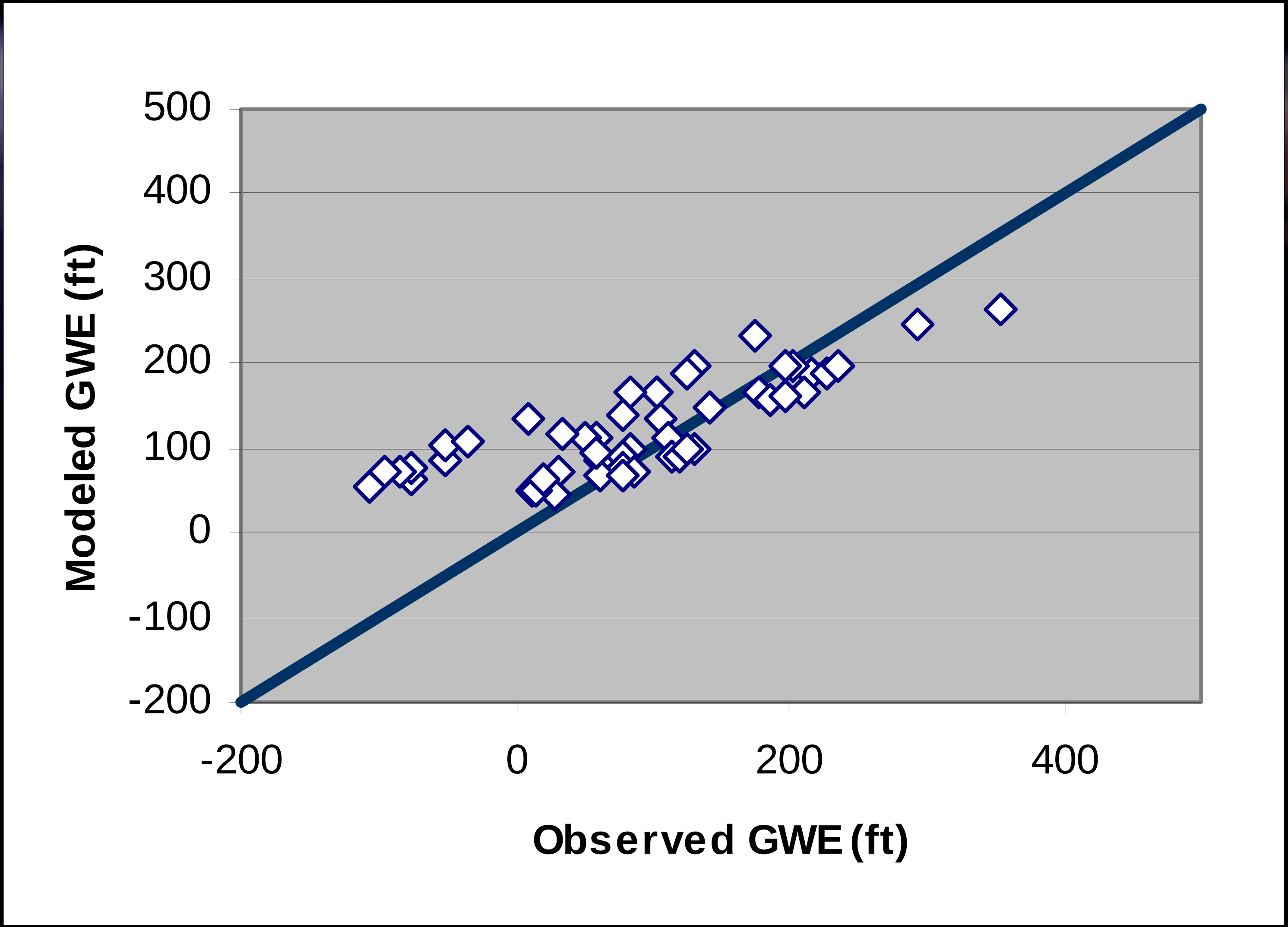


1989 Water-Level Residuals
Evangeline

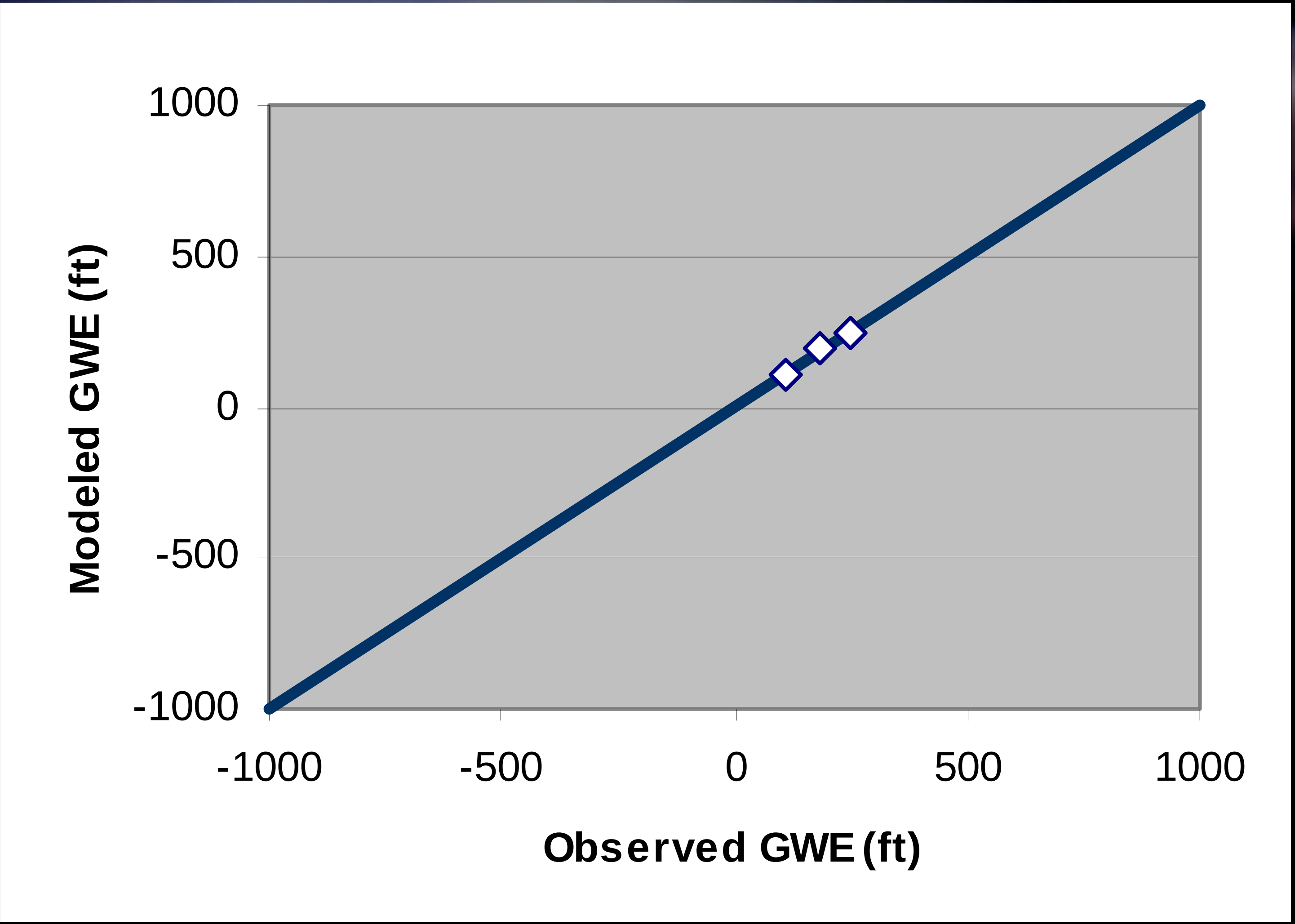


Positive residual: modeled > observed

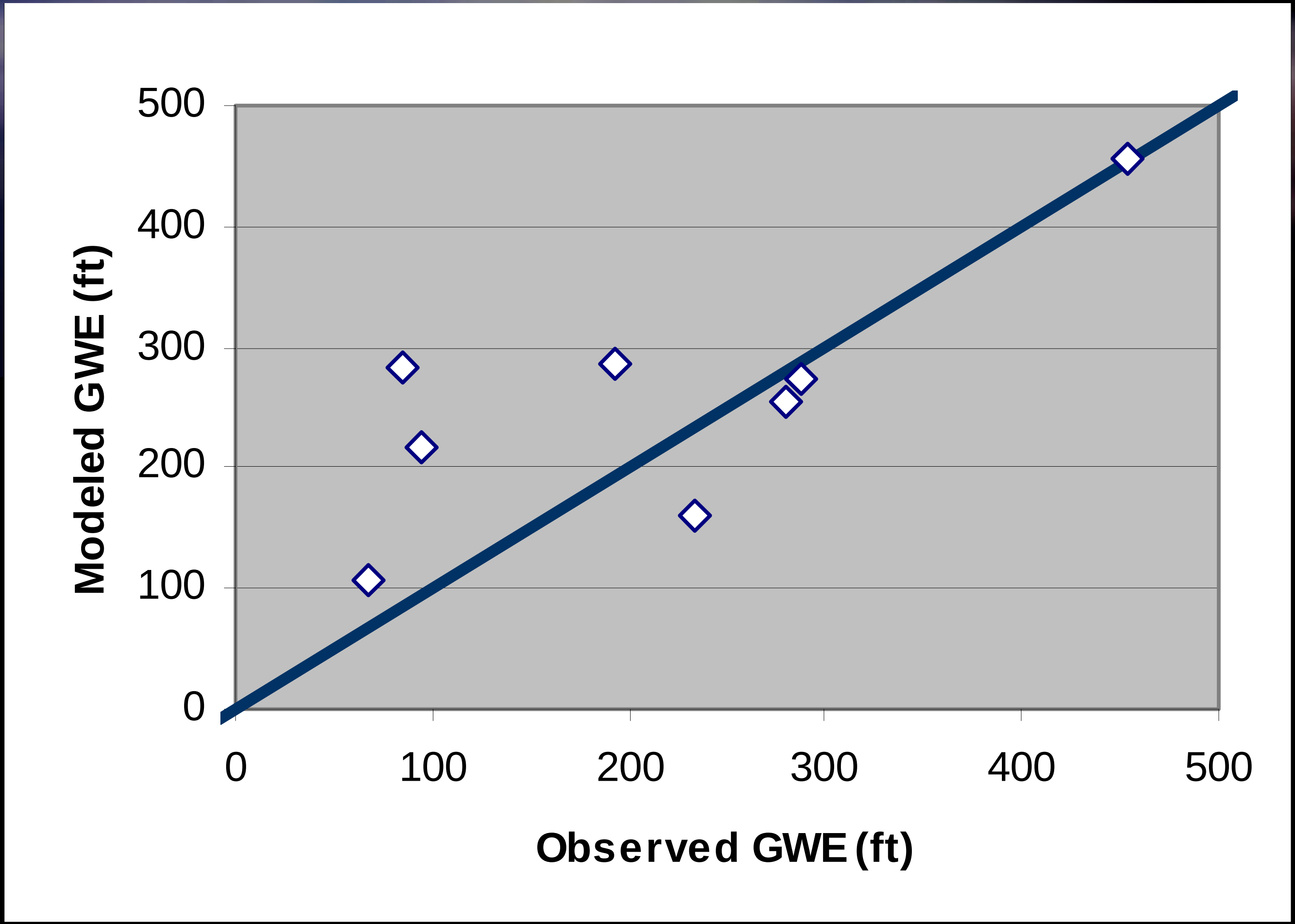
Water-Level Residuals Evangeline (1989)



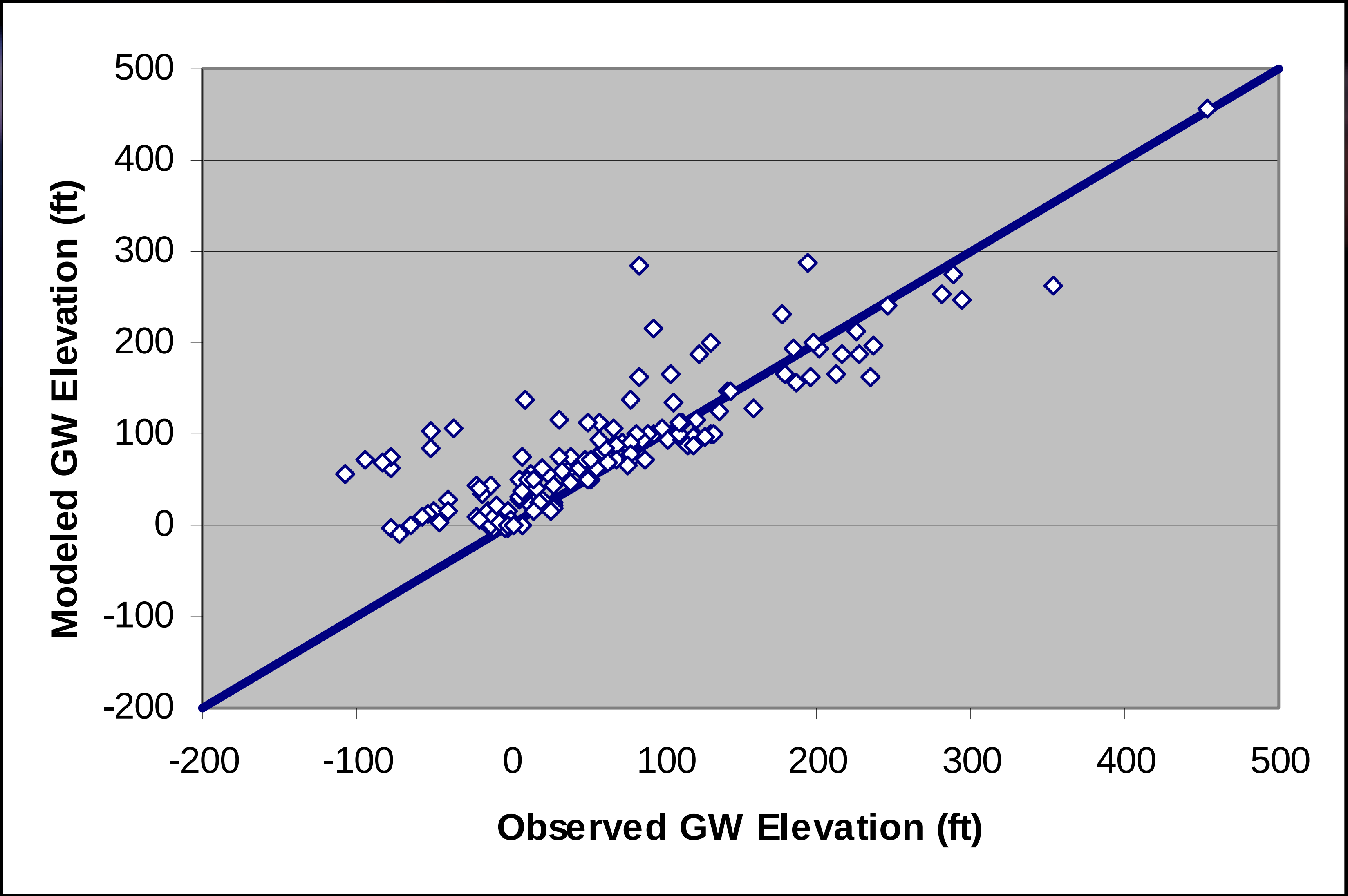
Water-Level Residuals Burkeville (1989)



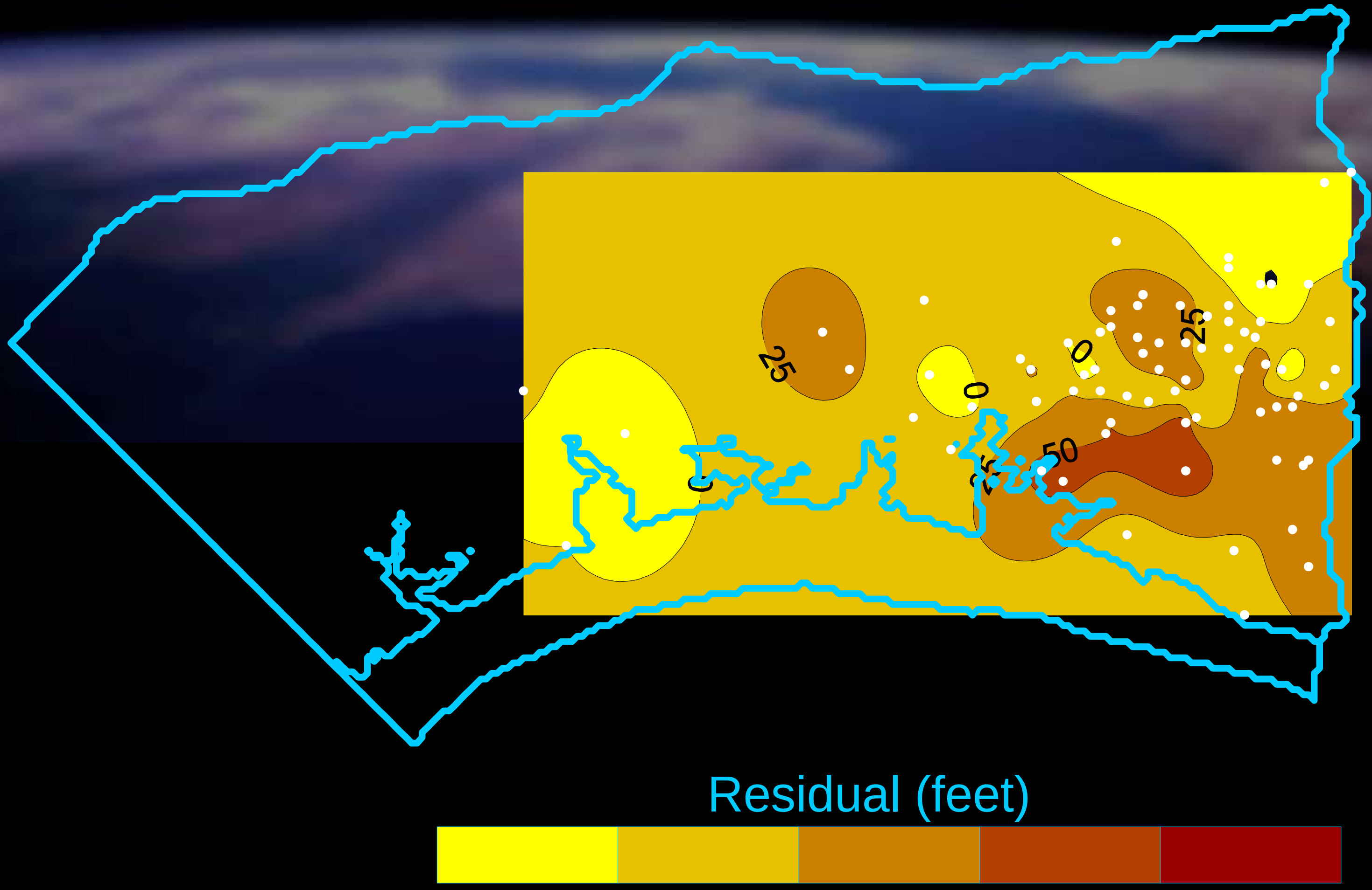
Water-Level Residuals Jasper (1989)



Water-Level Residuals All Layers (1989)

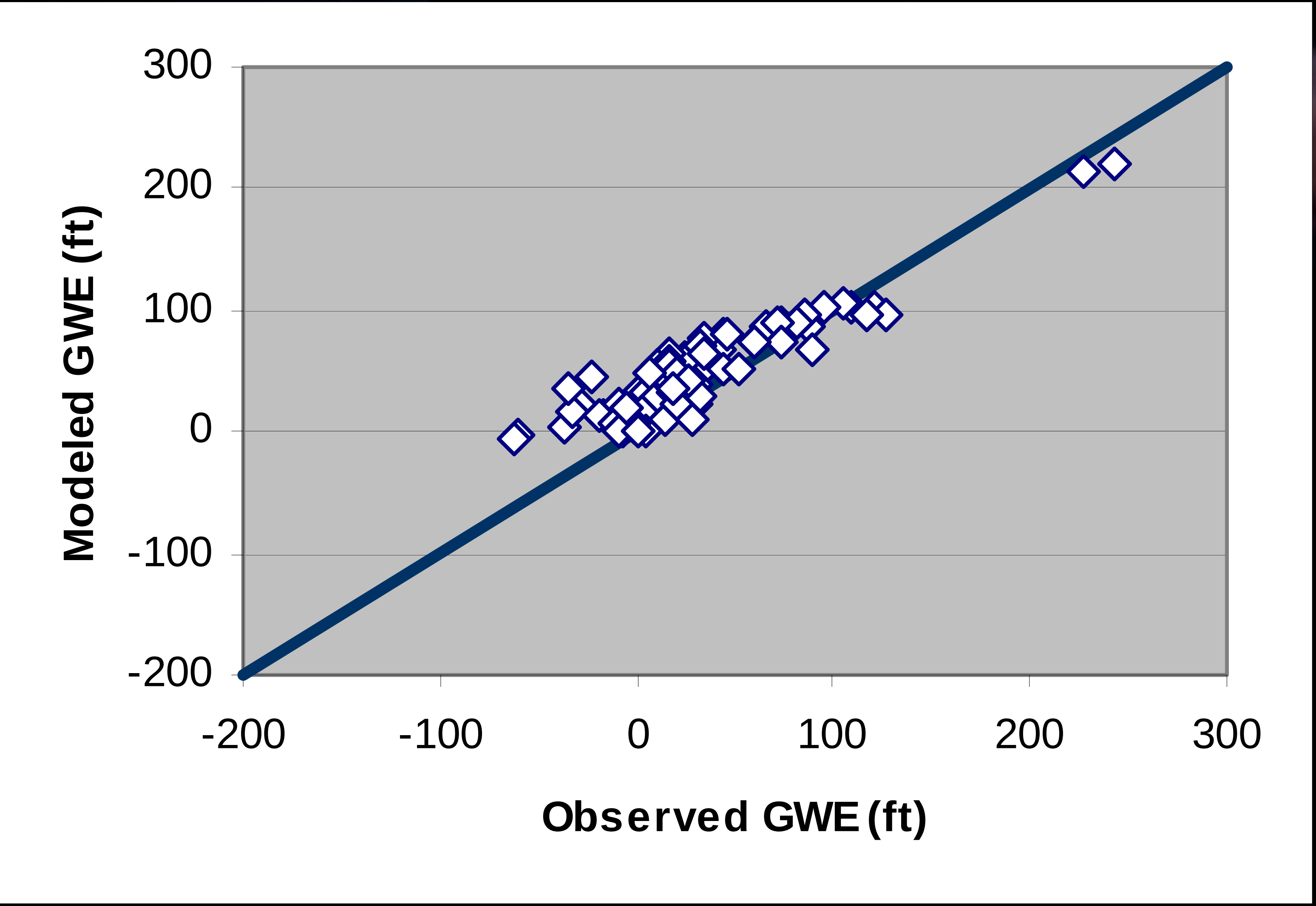


1999 Water-Level Residuals
Chicot

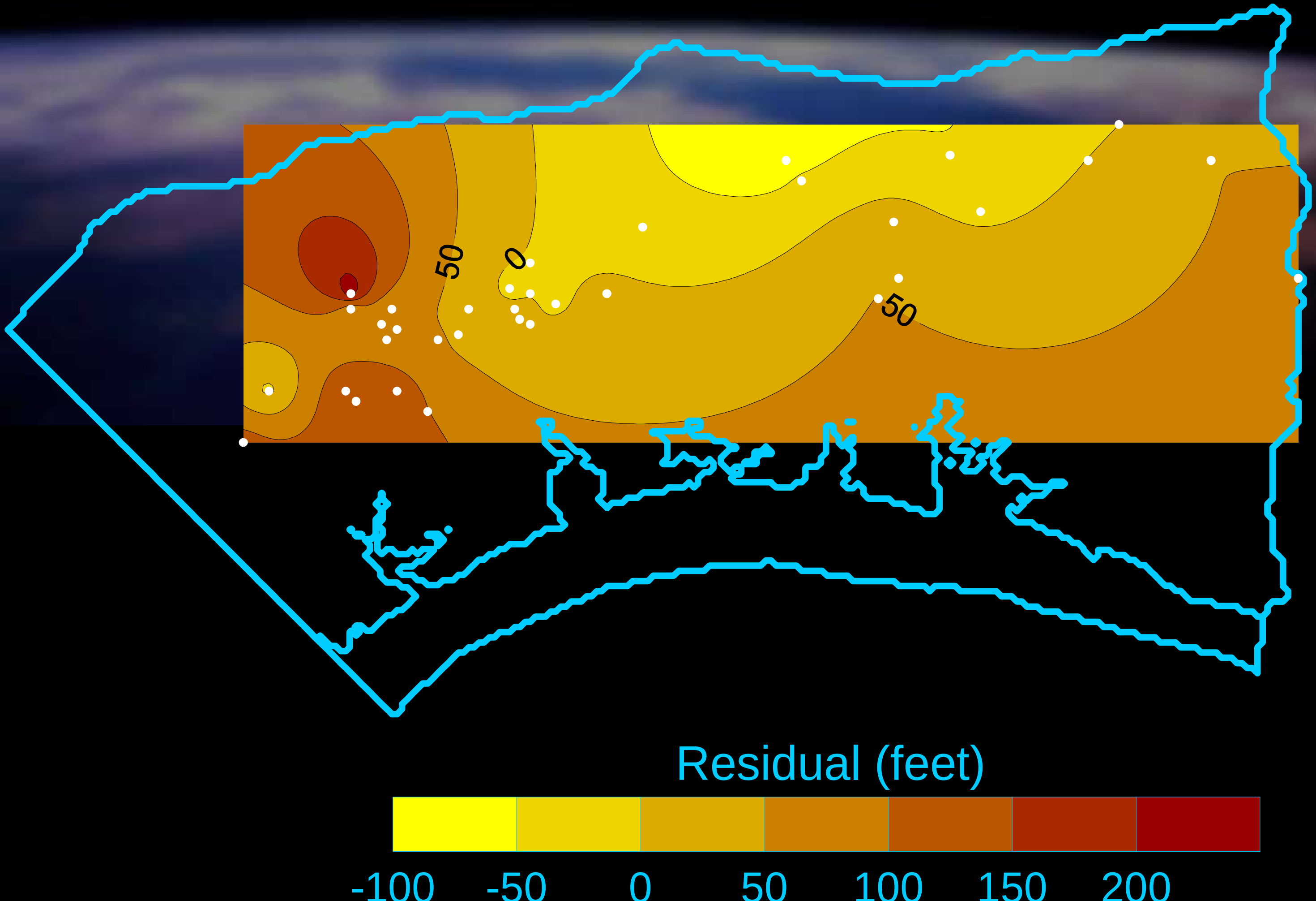


Positive residual: modeled > observed

Water-Level Residuals
Chicot (1999)

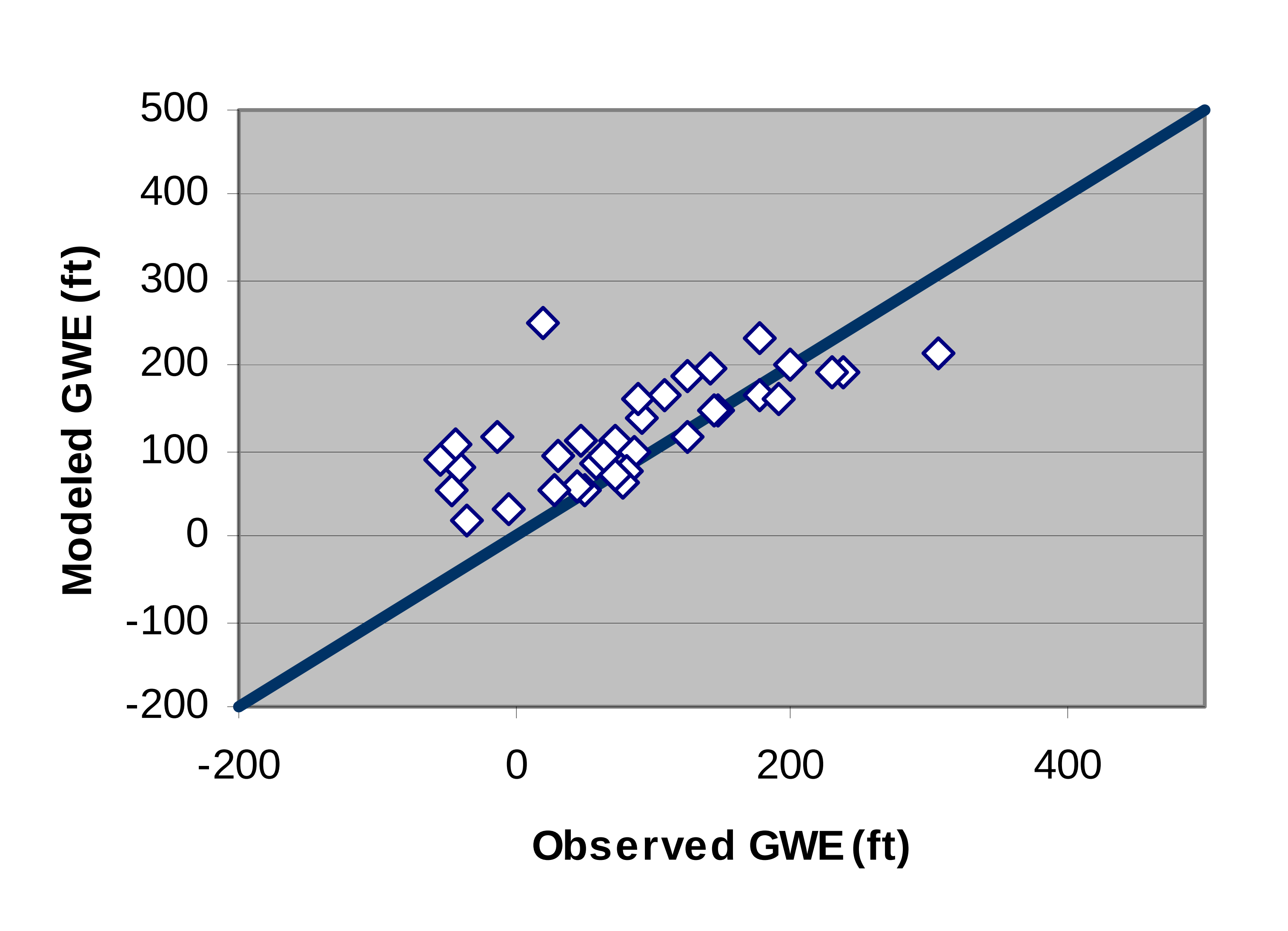


1999 Water-Level Residuals Evangeline

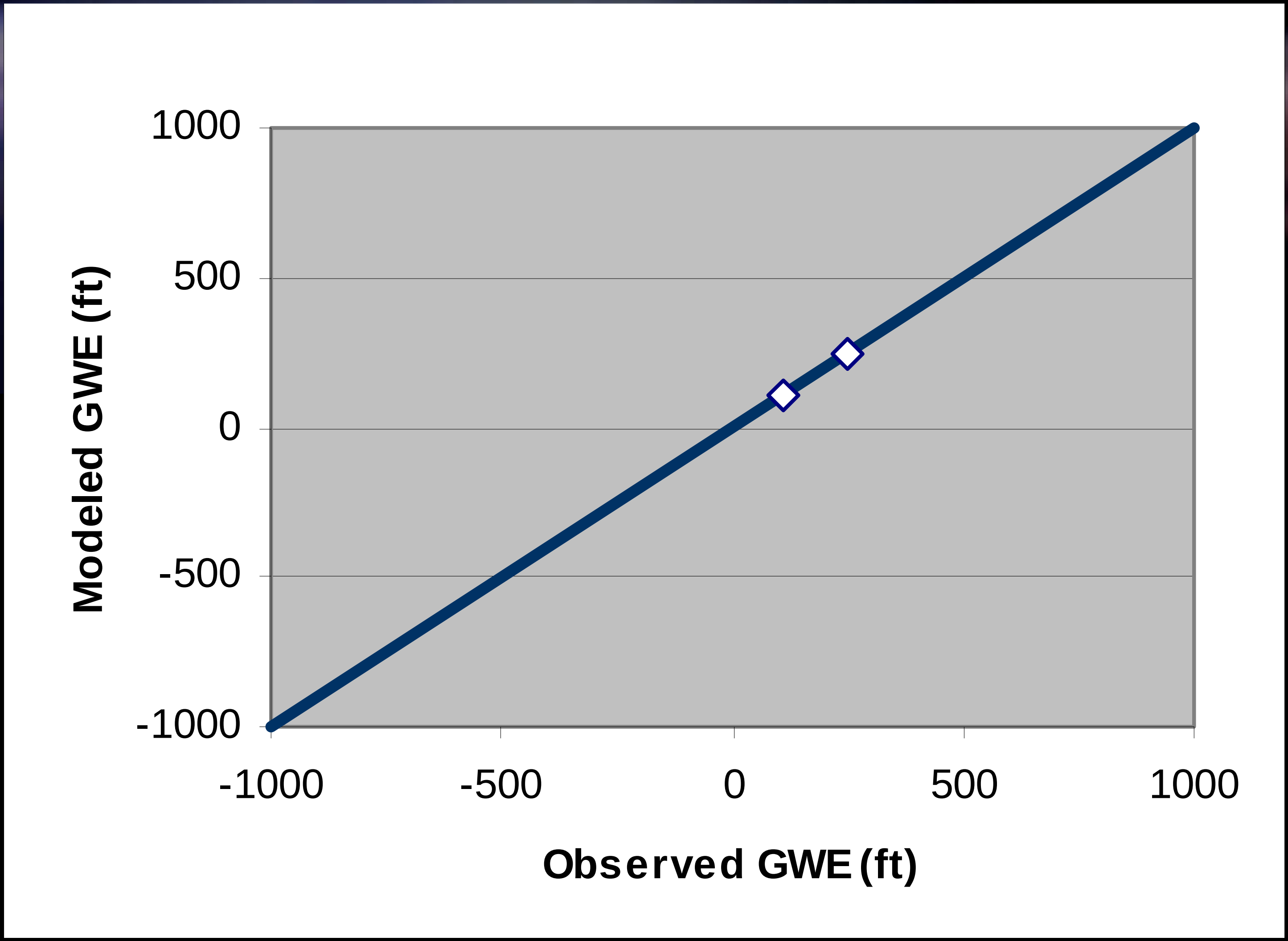


Positive residual: modeled > observed

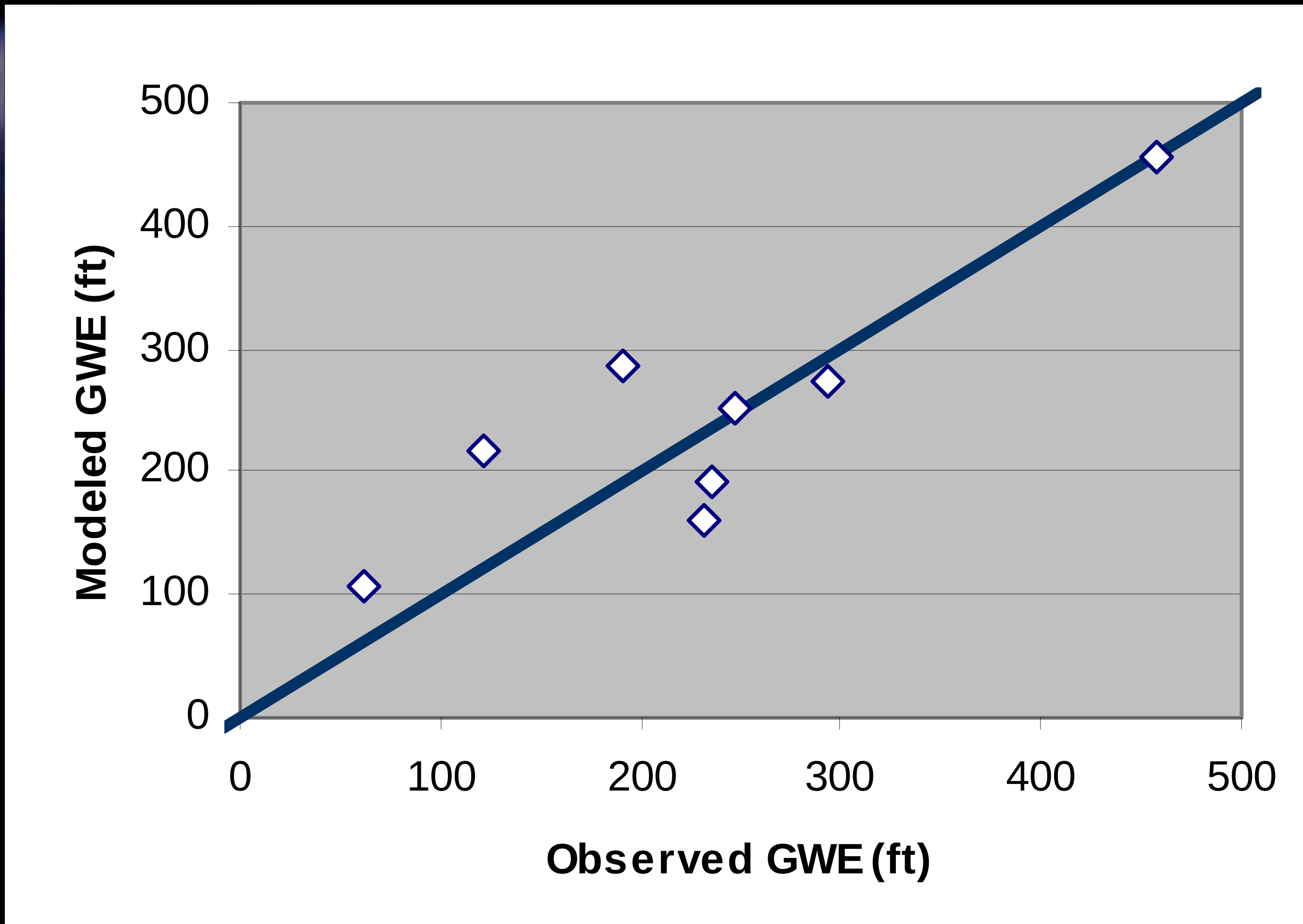
Water-Level Residuals Evangeline (1999)



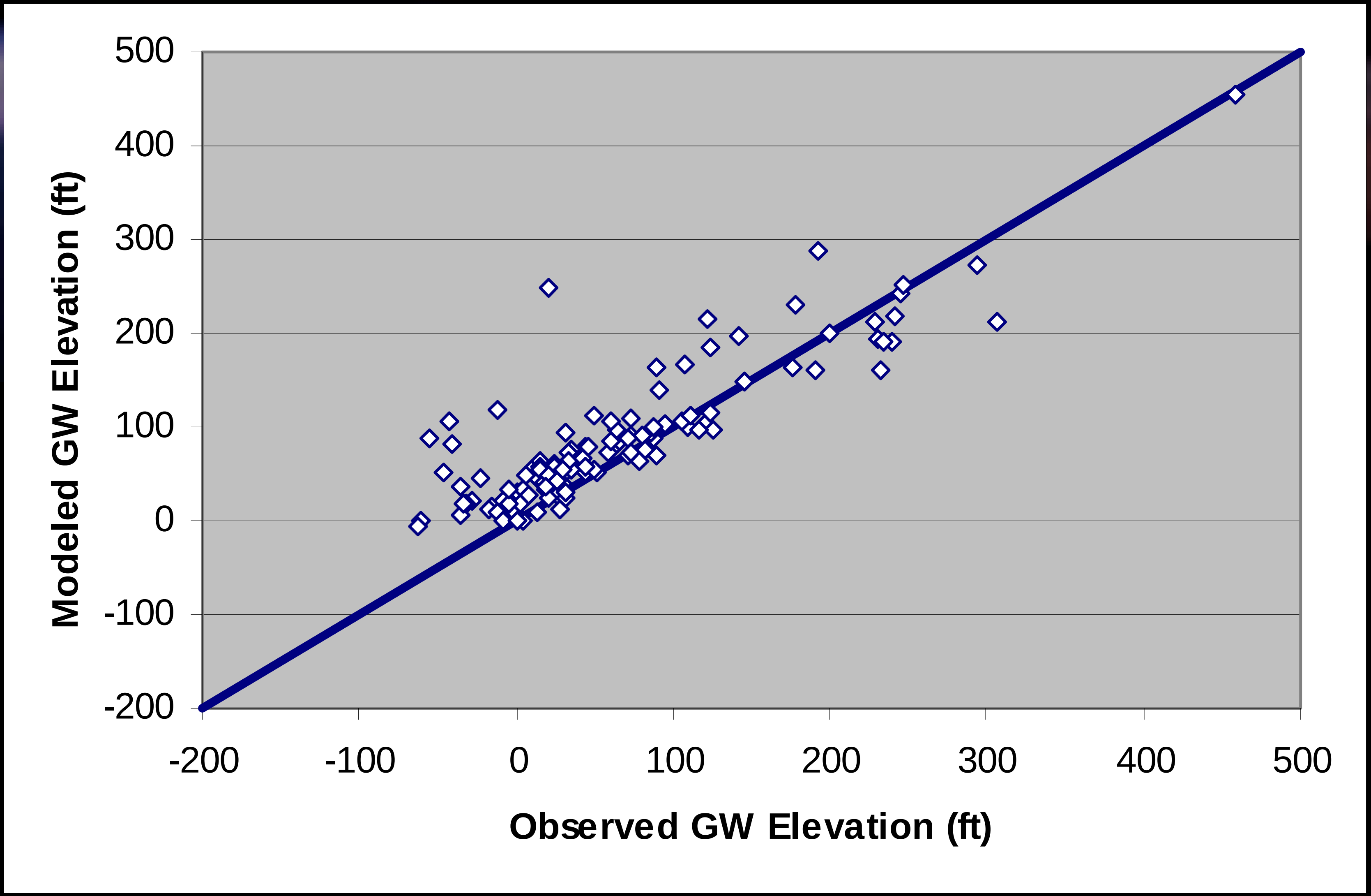
Water-Level Residuals
Burkeville (1999)



Water-Level Residuals
Jasper (1999)



Water-Level Residuals
All Layers (1999)



Calibration Statistics

1989

Layer	No. Targets	AME (ft)	RMSE (ft)
Chicot	90	18	30
Evangeline	51	33	73
Burkeville	3	1	6
Jasper	8	43	94
All	**152**	**24**	**53**

(Target RMSE = 56 ft)

1999

Layer	No. Targets	AME (ft)	RMSE (ft)
Chicot	74	19	28
Evangeline	36	37	72
Burkeville	2	-1	3
Jasper	9	12	55
All	**121**	**23**	**48**

(Target RMSE = 73 ft)

Water Budget

WATER BALANCE				January 1980
	Flow (ft^3/day)		Percentage	
Package	**In**	**Out**	**In**	**Out**
Storage	6764498	7052183	5.4%	5.6%
Wells	--	57877824	--	46.0%
Recharge	38294792	--	30.4%	--
Streams	76234520	52503660	60.6%	41.7%
GHB	3145776	8215497	2.5%	6.5%
Reservoirs	1343411	0	1.1%	0.0%
Drains	--	128949	--	0.1%
Total:	**125,782,998**	**125,778,112**		

Cross-Formational Flow:

Layer Interface	Net (ft^3/day)	Downward (ft^3/day)	Upward (ft^3/day)
Chicot - Evangeline	6,034,000	16,650,000	10,616,000
Evangeline - Burkeville	2,537,000	3,068,000	531,000
Burkeville - Jasper	-67,000	509,000	576,000

Note: negative net cross-formational flow is in the upward direction

- Recharge and streams are primary sources
- Discharge is to streams and along coast
- Most cross-formational flow is between Chicot and Evangeline
- Trend is reversed from steady-state

Water Budget

WATER BALANCE			July 1988	
	Flow (ft^3/day)		Percentage	
Package	In	Out	In	Out
Storage	71501752	18928216	39.4%	10.4%
Wells	--	98875096	--	54.5%
Recharge	40183232	--	22.2%	--
Streams	66732196	55309164	36.8%	30.5%
GHB	1614689	8102311	0.9%	4.5%
Reservoirs	1319381	0	0.7%	0.0%
Drains	--	135454	--	0.1%
Total:	**181,351,250**	**181,350,241**		

Cross-Formational Flow:

Layer Interface	Net (ft^3/day)	Downward (ft^3/day)	Upward (ft^3/day)
Chicot - Evangeline	4,157,000	14,930,000	10,773,000
Evangeline - Burkeville	2,700,000	3,177,000	477,000
Burkeville - Jasper	-25,000	551,000	576,000

Note: negative net cross-formational flow is in the upward direction

- Chicot Evangeline net dropped by more than 30%

Water Budget

WATER BALANCE			December 1989	
	Flow (ft^3/day)		Percentage	
Package	**In**	**Out**	**In**	**Out**
Storage	38017340	32955264	37.1%	32.2%
Wells	--	7254411	--	7.1%
Recharge	32227086	--	31.5%	--
Streams	29243740	54474316	28.6%	53.2%
GHB	1617865	7641426	1.6%	7.5%
Reservoirs	1317072	0	1.3%	0.0%
Drains	--	127168	--	0.1%
Total:	**102,423,103**	**102,452,585**		

Cross-Formational Flow:

Layer Interface	Net (ft^3/day)	Downward (ft^3/day)	Upward (ft^3/day)
Chicot - Evangeline	2,893,000	13,808,000	10,915,000
Evangeline - Burkeville	2,667,000	3,161,000	494,000
Burkeville - Jasper	-2,000	550,000	552,000

Note: negative net cross-formational flow is in the upward direction

- Chicot – Evangeline net ~ 50% of 1980

Water Budget

WATER BALANCE			December 1999	
	Flow (ft^3/day)		**Percentage**	
Package	**In**	**Out**	**In**	**Out**
Storage	33771440	5199495	31.3%	4.8%
Wells	--	35056824	--	32.5%
Recharge	21450290	--	19.9%	--
Streams	50861032	58464500	47.1%	54.1%
GHB	564146	9124500	0.5%	8.4%
Reservoirs	1282791	0	1.2%	0.0%
Drains	--	151474	--	0.1%
Total:	**107,929,699**	**107,996,793**		

Cross-Formational Flow:			
Layer Interface	**Net (ft^3/day)**	**Downward (ft^3/day)**	**Upward (ft^3/day)**
Chicot - Evangeline	2,444,000	13,547,000	11,103,000
Evangeline - Burkeville	182,000	677,000	495,000
Burkeville - Jasper	78,000	602,000	524,000
Note: negative net cross-formational flow is in the upward direction			

- Chicot Evangeline stayed about 50% of 1980 rate
- Evangeline Burkeville decline about 1 order of magnitude

Parameter Value Summaries

		Initial Parameter	Calibrated Parameter	Calibrated/ Initial
Horizontal K (ft/day)	Chicot	4.80E+01	4.80E+01	1
	Evangeline	1.42E+01	1.42E+01	1
	Burkeville	2.45E+01	2.45E-01	0.01
	Jasper	1.35E+01	6.75E-01	0.05
Vertical K (ft/day)	Chicot	3.00E-03	1.00E-02	3.33
	Evangeline	8.00E-04	1.00E-02	12.5
	Burkeville	1.00E-04	1.00E-04	1
	Jasper	1.00E-04	1.00E-03	10
Streambed K (ft/day)		3.00E-01	1.00E+00	3.33
GHB Conductance (ft^2/day)		1.00E+00	1.00E+04	10000
Drain and Reservoir K (ft/day)		3.00E-03	1.00E-03	0.33
Recharge (ft/day)	Chicot (low)	1.20E-07	1.00E-06	8.3
	Chicot (high)	1.20E-06	2.00E-04	167
	Evangeline	1.20E-06	5.00E-05	42
	Burkeville	1.20E-07	1.00E-07	0.83
	Jasper	1.20E-06	5.00E-06	4.2

- Transient calibration did not require any changes in parameter values

Final Stages

- Transient model finishing touches
- Sensitivity analysis
- Create predictive stress input files
  - pumping
  - recharge and ET
- Predictive runs
- Draft Report

Sixth Stakeholder Forum Central Gulf Coast GAM
August 15th, 2002, Bay City, TX
List of attendees that signed the attendance list.

Name	Affiliation
Gilbert Barth	Waterstone
W.R. (Bob) Pickens	Region K
Travis Wegenhoft	Private
Bill Neiser	Private
Jim Naismith	San Patricio MWD
Larry Mayberry	Post Oak GCD
Ronnie Hernandez	San Antonio River Authority
Haskell Simon	Colorado River Valley Federation
Cindy Ridgeway	TWDB
Rick Hay	CWSS-TAMU-CC
L.G. Raun	Region P Member (Wharton Co. GCD)
Billy Mann	Matagorda Co. Groundwater District
William Wood	Bay City Tribune
James Dodson	J.F. Welder Heirs
Karen Dodson	Private
Cliff Lowe	EVWCD
David Meesey	TWDB

Summary of Questions/Responses/Discussion from
Sixth Stakeholder Advisory Forum
Central Gulf Coast GAM
Held
August 15th, 2001
Bay City Civic Center, Bay City, Texas

As with postings for previous SAF meetings, this document summarizes the technical questions, answers and discussions.

1. What is the relationship between the Groundwater Conservation District Plans and the GAM?

Response: There are five questions in the TWDB Groundwater Conservation District Plan administrative completeness checklist concerned with data quality that must reference GAM or another documented source. Data from other than the GAM will be reviewed by the TWDB to assess the source and whether the information represents the best available data.

2. Were geostatistics used to determine parameter input values for the model?

Response: No, the scarcity and clustering of data that was available made it unreasonable to apply a geostatistical approach.

3. Are the groundwater conservation districts required to use the data collected in the GAMs for the groundwater management plan?

Response: The legislation states, the GAMs shall be used unless better information is available and has been approved by the executive administrator.

4. How is the variability of the aquifer material properties represented in the model?

Response: Within each of the four aquifers the ability of the aquifer to convey water varies as a function of both the aquifer thickness and the percentage of sand. The sand is considered the primary water-bearing portion of the aquifers, so we characterize the sand's ability to convey water and then use the spatially varying sand thickness within each aquifer to determine the aquifer's ability to convey water.

5. There are a lot of accounts of stream-aquifer interaction from 40 or more years ago. That interaction that has decreased in the last 40 years. Does your model represent any of the stream aquifer interaction?

Response: Yes. Results during this presentation will demonstrate the historic interaction and how that has changed more recently.

6. How can we determine well spacing using the GAM?

Response: The GAM should not be used to determine well spacing. There are analytical methods available that will allow you to determine reasonable estimates for well spacing according to calculated drawdown. If you are interested in evaluating a quantity of pumping for scales larger than one mile, the GAM will show you the changes that occur for different quantities of pumping, but it should not be used for evaluating well spacing.

7. Will it be obvious when using the model how much data was used to determine the property values for a particular model cell or group of cells?

Response: All of the information used to create the model will be turned in with the model when it is completed. It will take some investigative work to determine exactly where there was a lot of data and where it may have been sparse, but all the information will be included. In the model you will usually only see the water level observation locations, but all of the data used to make the model will be delivered to the TWDB.

8. Do the historic water level contours pretty much follow the land-surface elevation contours?

Response: Yes. For the most part they do follow the land-surface elevation closely.

9. Why are there some dramatic bends in the simulated water-level contours?

Response: That is the effect of the interaction between the aquifer and the streams. If we overlay a map of the rivers, those bends or kinks in the contours would line up with the rivers. The rivers can contribute or take water from the aquifer so that depending on the particular circumstances the river may cause a contour to shift higher or lower.

10. Were the county-wide estimates of pumping just distributed evenly across each county?

Response: For major cities, mining, manufacturing and power pumping was distributed according to actual well locations. For livestock and irrigation the county-wide use was distributed according to land-use maps.

11. During the 1970s, in parts of Wharton and Jackson counties, the water table was lowered by about 90 feet. Could you use data from that period to evaluate how well the model represents the system under extreme stress?

Response: The GAM calibration period starts in 1980. Unfortuantely there was not much data collected during the 1970s. Given the limited data it would not be worth trying to simulate conditions during that period.

12. What did you do with water level values from wells that were screened in multiple aquifers?

Response: We did not use the water level observations from that well.

13. How did you use screen interval information to select or eliminate wells?

Response: Evaluating screen intervals was only one of several criteria. If the water-level observation passed the other criteria, if the well record included information on the screen intervals, and if the intervals were all within a single aquifer, then we would use the water-level observations from that well.

14. In Wharton County there are a lot of individual wells that pump from multiple aquifers. How does using only water-level observations from wells screened within a single aquifer affect the pumping?

Response: The pumping is still distributed to all of the layers in which the pumping well is screened. It is only the observations that must come from a well screened in a single aquifer. Observations from wells screened in more than one aquifer do not reflect the actual water level in any of the aquifers.

15. What is a “residual”?

Response: A residual is the difference between the modeled water level elevation and the observed water level elevation.

16. Are you going to use these results, the residuals that we see, to further calibrate the model?

Response: There is one relatively small area where we are still making adjustments, but that is the exception. The majority of the model and results are in their final form at this point.

17. Why do you not further refine the model?

Response: The costs of additional improvements far outweigh the benefits and we are close to the limit of what the data can support. There is not sufficient data to support additional refinement.

18. Which parameters do you adjust in order to calibrate the model?

Response: It depends on the circumstances, on which aspect of the model is not reproducing observed behavior. For most situations it is quite possible that we will end up looking at adjusting a variety of parameters including transmissivity, recharge, and pumping. The two primary things to evaluate after adjusting parameters are whether the simulated results now do a better job of matching the observed, and if the new parameter value is reasonable.

19. If you had a situation where you only had one observation for a county, and that observation had a high residual, then you would not have a lot of confidence in the simulated values at the location. Does that mean that you would not have much confidence in the entire county?

Response: No. For most locations where we are seeing high residuals it is a fairly localized issued. There is no reason to assume low confidence within an entire county just because a single location in the county has a high residual.

20. The values you are reporting in the water budget are in cubic feet per day?

Response: Yes, those are the units that the model works with. Feet cubed per day divided by about 100, 119.3 to be precise, would give you a rough estimate of acre-feet per year.

21. Would the model function differently for a wet year versus a dry year?

Response: Yes, the stresses would be different and it is quite possible that you would see a change in water level that would also impact the amount of stream-aquifer interaction. However, there is a fair amount of inertia in the system. A relatively short-term change in the stresses may not have a significant impact on the aquifer water levels, in either the physical or simulated system.

22. Can you talk about the storage for this system at the end of 1999?

Response: The storage IN/OUT values indicate that there is water being taken from storage into the flow system. The model indicates that if you maintained the stresses that existed in 1999 for a long period of time you would continue to pull water from storage and end up with a net decrease in water levels.

23. How do you determine where the water is going in any of the individual components?

Response: The model simulates water movement between the components of the water budget based on the stresses in the system: water will always move from where there is more water to where there is less. The rate at which the water moves will depend on the material it is seeping through and just how much difference there is between the areas with more water and less water.

24. Can you generate information about the variations in time of the water budget?

Response: The model generates a water table budget at the end of every stress period. The data from each stress period could be put into a time series to produce a graph of the temporal variations in water budget.

25. Have you considered flow from clay?

Response: No. For the Central Gulf Coast GAM, based on the literature and limited amount of subsidence that has occurred, we considered sands to be the primary water bearing material, and considered the contribution of clays to be relatively insignificant.

26. When is the draft report due?

Response: It is due on September 30th.

27. Is review of the draft report internal only? Will the draft be available to the public, and what is the general timeline for reviewing the report and getting the final product?

Response: The review is both internal and external. The TWDB has two weeks to post the report and model information on the Web. The final stakeholder meeting will be in the beginning part of October and cover the final results, presentation of the report, explanation of each chapter in the report and solicitation of any questions. The TWDB will review the report until the end of November, providing feedback to Waterstone. Public input will be evaluated by the TWDB and sorted into policy and technical questions. Policy questions will be addressed by the TWDB project managers and technical questions will be passed on to Waterstone. During December and January, Waterstone will address questions and concerns and produce a final report at the end of January along with all supporting data and documentation. At the end of January, Waterstone will also providing training on using the Central Gulf Coast GAM for the TWDB and stakeholders.

28. Do we have to have a working knowledge of PMWIN for the training session?

Response: It certainly would help. The objective of the training session is to familiarize you with the Central Gulf Coast GAM specifics, not as an introduction to PMWIN or using a model.

29. Can you post the presentation to the Web in a different format? The PDF file requires a lot of ink to print out. If we had a PowerPoint version we could turn off the background. Could we get a CD with the PowerPoint presentation on it?

Response: The PowerPoint files cannot be posted to the Web, the files are too large. If you send the TWDB project manager a blank, recordable CD they can copy the file and send it to you.

30. Will there be the opportunity in the future to add data to this model? Maybe another observation?

Response: Yes. However, the TWDB is the keeper of the model and needs to review and assess any new information before incorporating. Depending on demand there may be some delay in getting it into the official version. The model files will be available, it will be possible to run and modify the model on your own, to evaluate different scenarios or the impact of additional data in a more timely manner.