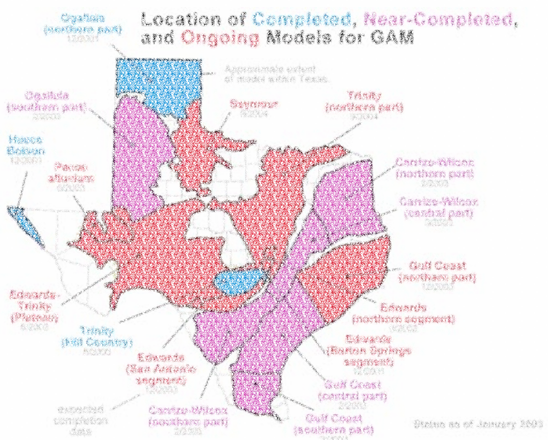
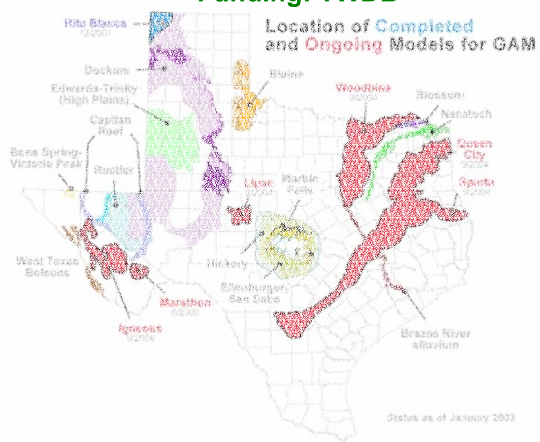
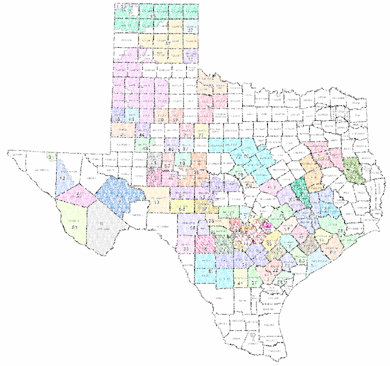
Northern Trinity-Woodbine Aquifer
Groundwater Availability Model (GAM)
3rd Stakeholder Advisory Forum (SAF)
December 3, 2003

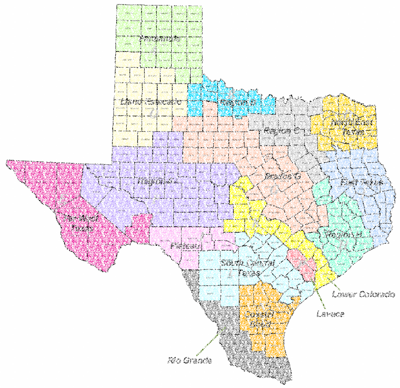
Contractor: Harden and Associates, Inc.
LBG-Guyton and Associates
Freese and Nichols Inc.
HDR Engineering
USGS and Dr. Joe Yelderman
Funding: TWDB



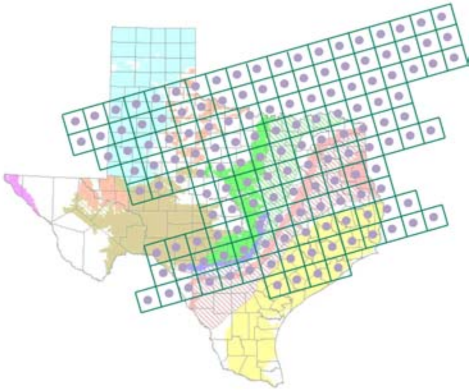




Contract Manager
Ali Chowdhury, Ph.D., P.G.



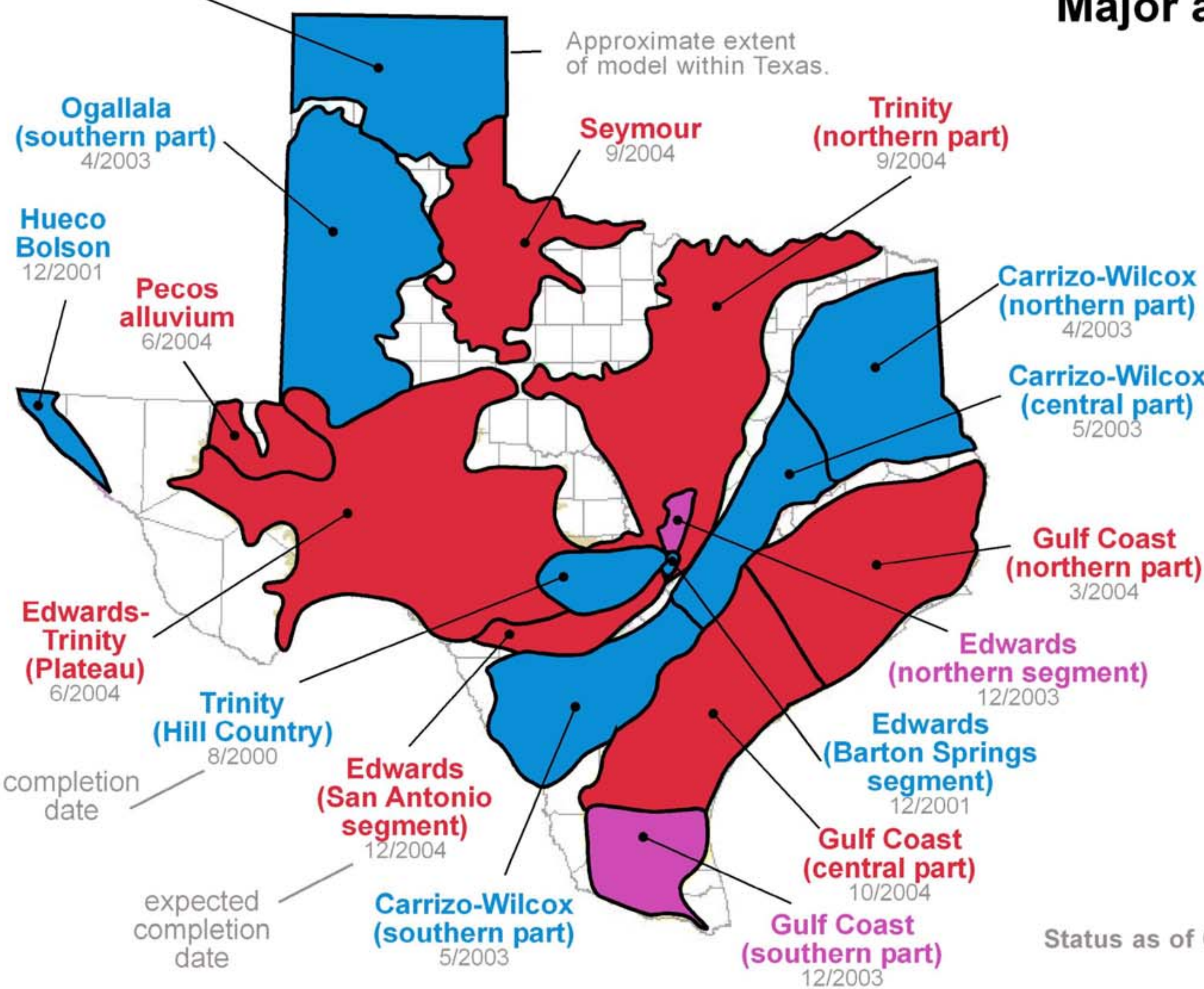
Texas Water Development Board



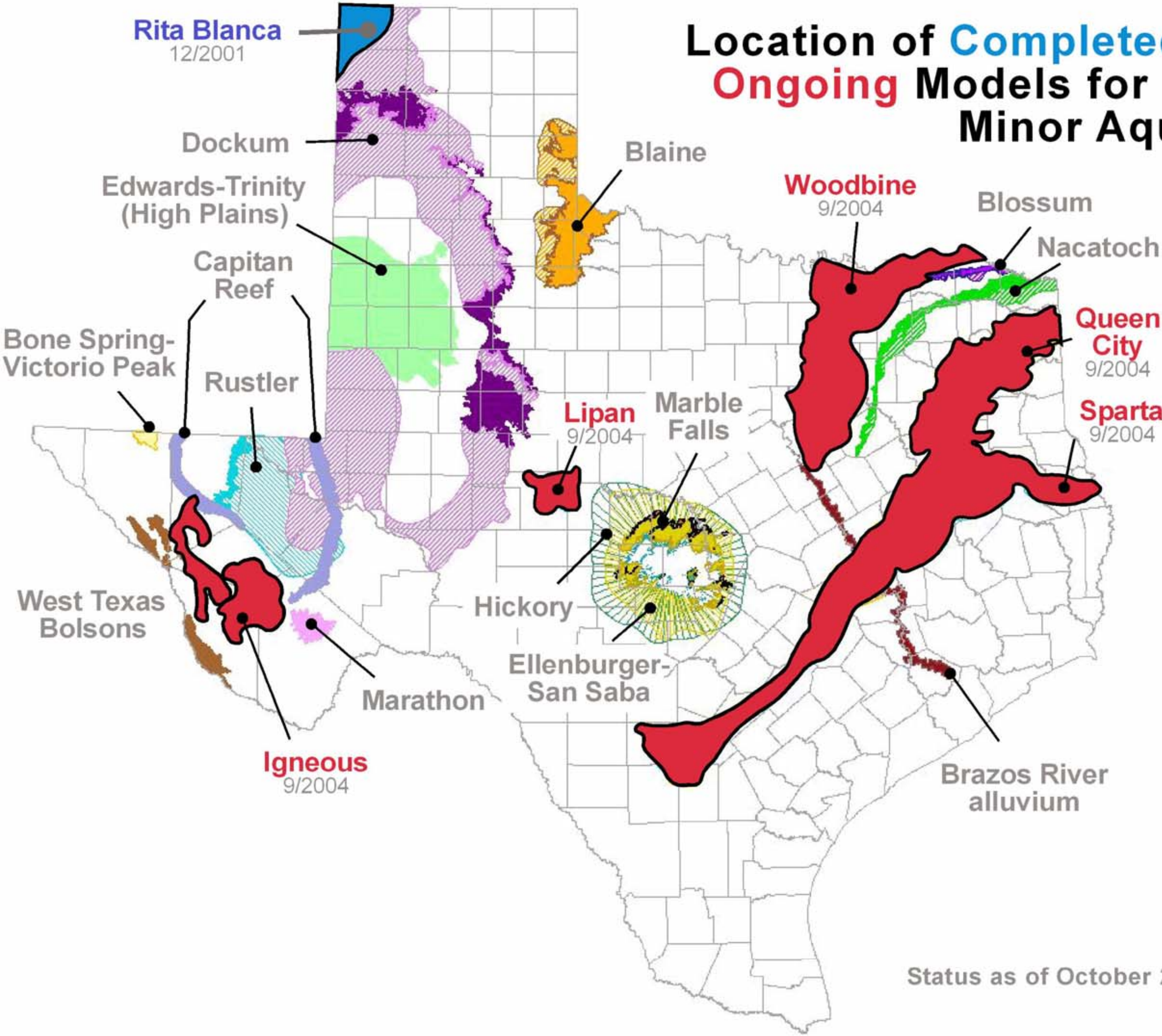
GAM

- 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.

Location of Completed, Nearly-Completed, and Ongoing Models for GAM: Major aquifers



Location of Completed and Ongoing Models for GAM: Minor Aquifers

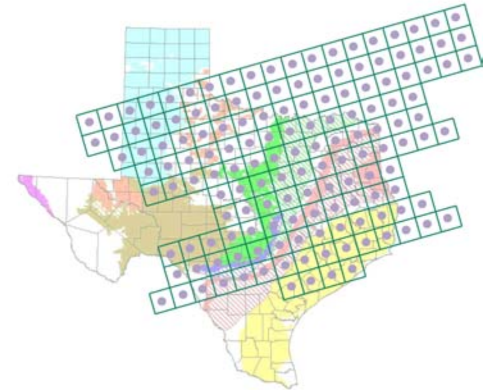


Status as of October 2003

What is a Groundwater Model?

- An aquifer in a computer, a **tool** to estimate field conditions
- Effective use of **available data** and account for complexities
- Expands our ability to better **understand** and **manage** the water resources
- Increases **prediction accuracy** of future events to a level far beyond "best judgement" decisions

Modeling Protocol



Purpose

↓

Conceptual model

↓

Numerical formulation

↓

Model design

↓

Calibration → Steady-State Model ← We are here!

↓

Verification → Transient Model (1980-2000)

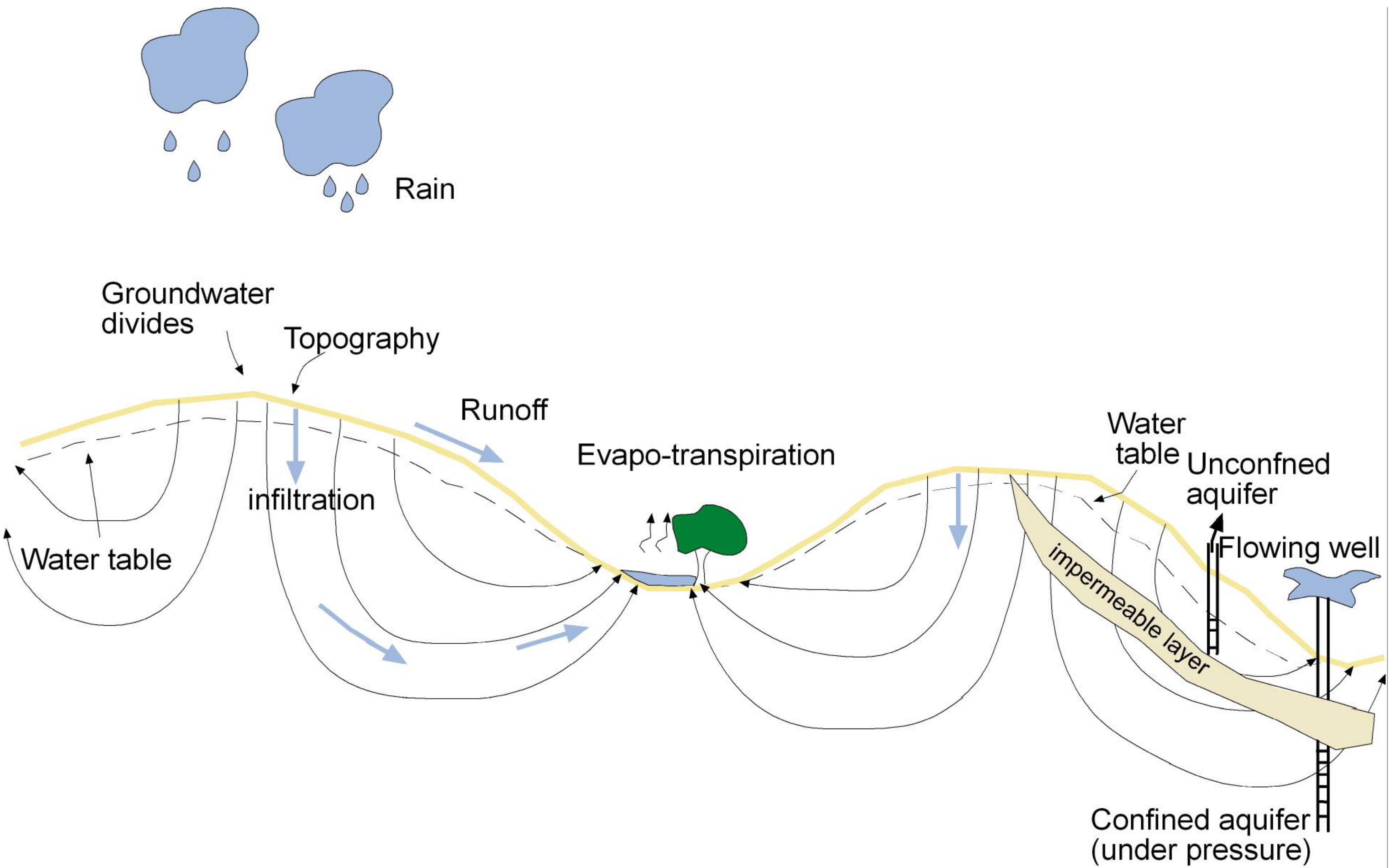
Comparison with field data → Calibration, Verification

↓

Prediction → Prediction Runs (2001-2050)

↓

Field data → Postaudit

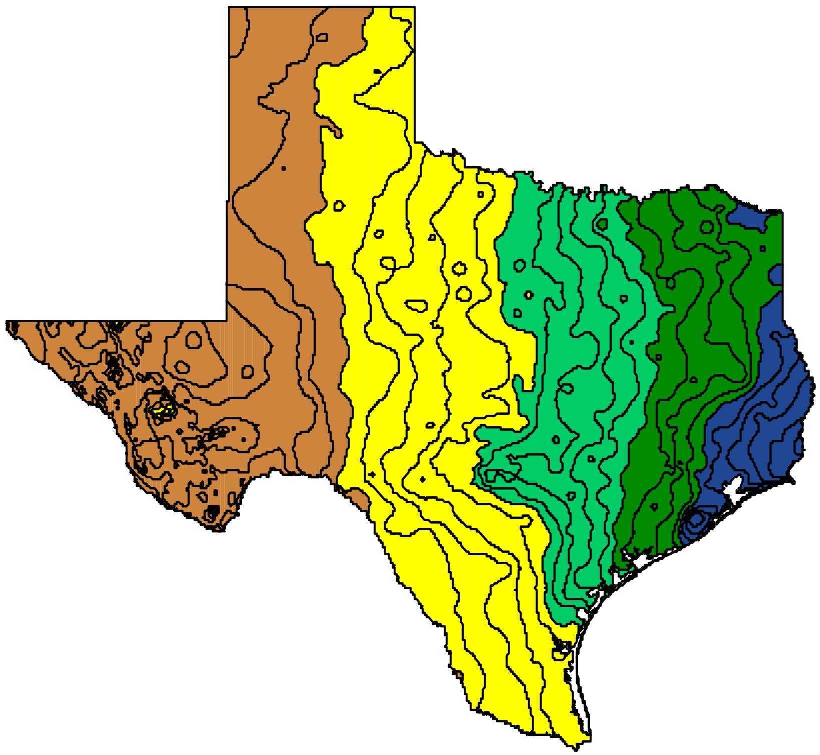


Hydrologic Cycle

Recharge

- ***diffuse (direct) - precipitation or irrigation***
- ***focused or localized - surface depressions, e.g. lakes or playas***
- ***indirect recharge - beneath rivers, lakes***
- ***recharge rate depends on rainfall, vegetation, soil type, topography***

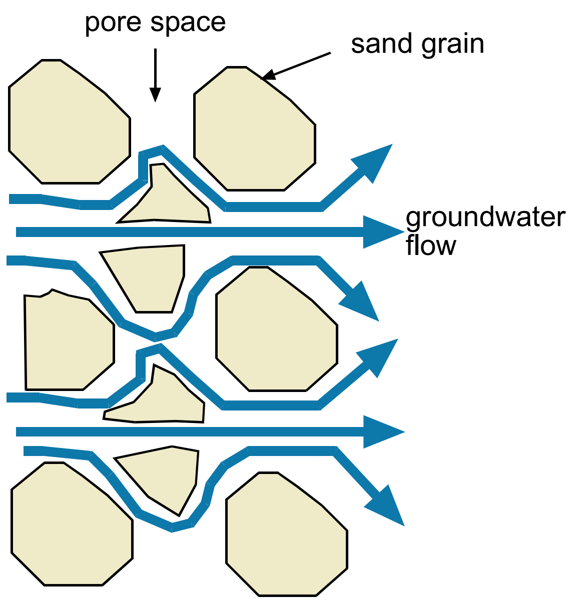
Average annual rainfall map
60 inches in the east to about 8 inches in the west



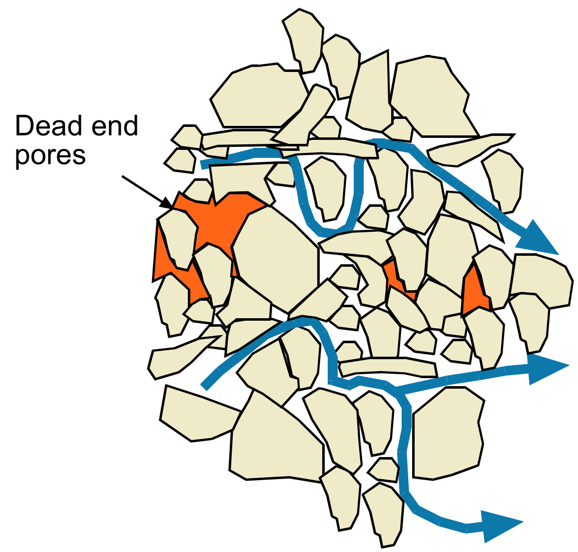
Porosity, Storage, and Hydraulic Conductivity

Porosity: pore space/total voids in a rock
Storage: measure of storativity
Hydraulic conductivity: ability to transmit water

Sand

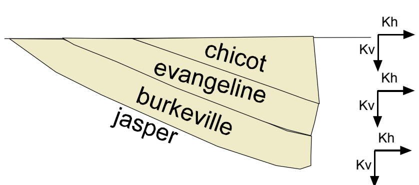


Clay

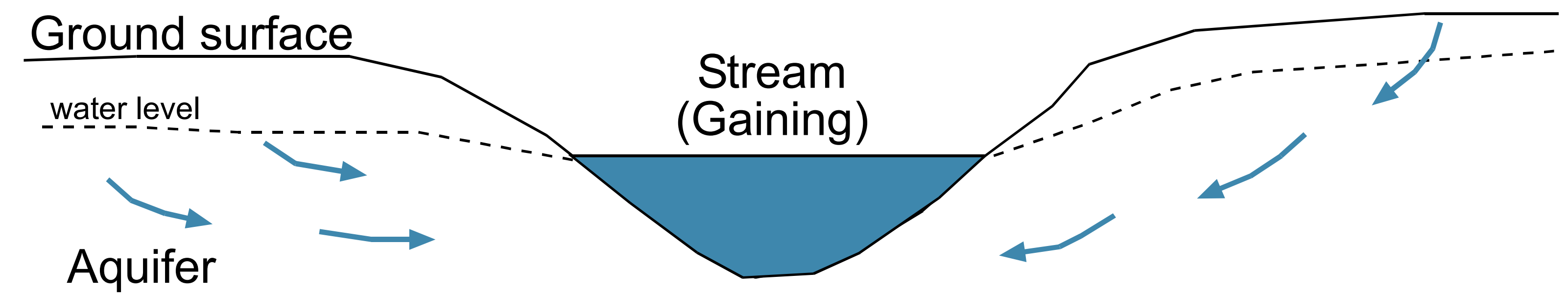


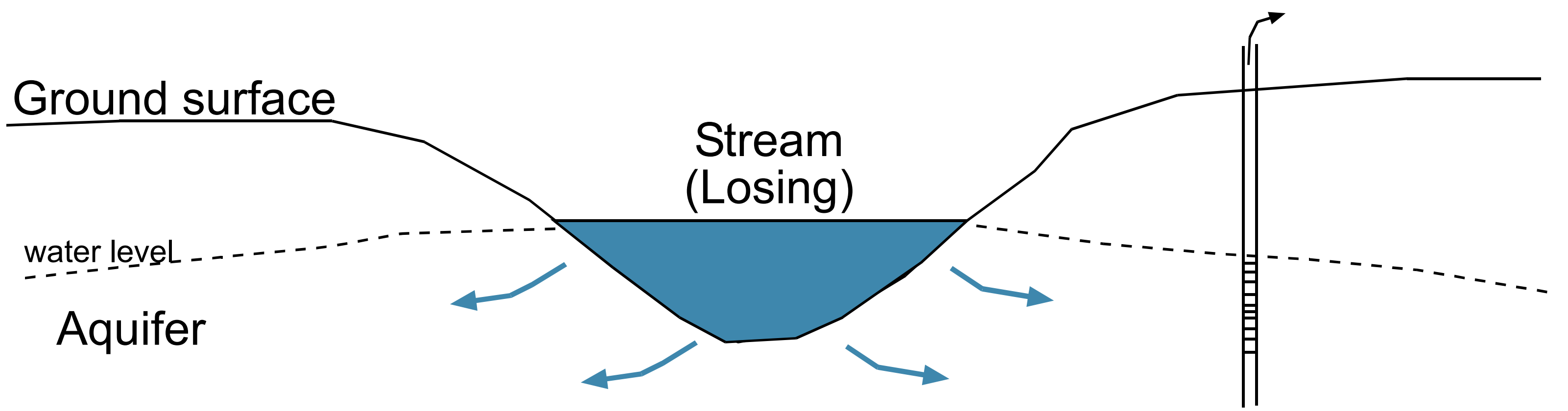
- High effective porosity/High K
- Storage
  - drainable (unconfined)
  - compressible (confined)
- High flow velocity
- Better water quality

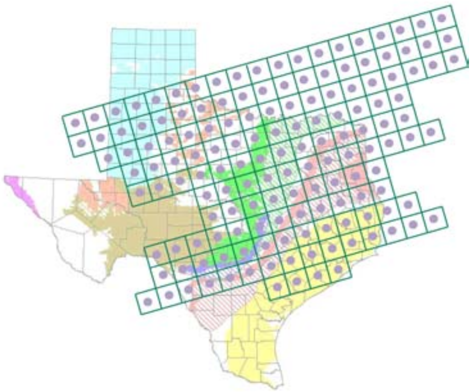
- Low effective porosity/low storage
- Low K
- Low flow velocity
- Poor water quality



Gaining vs. losing stream







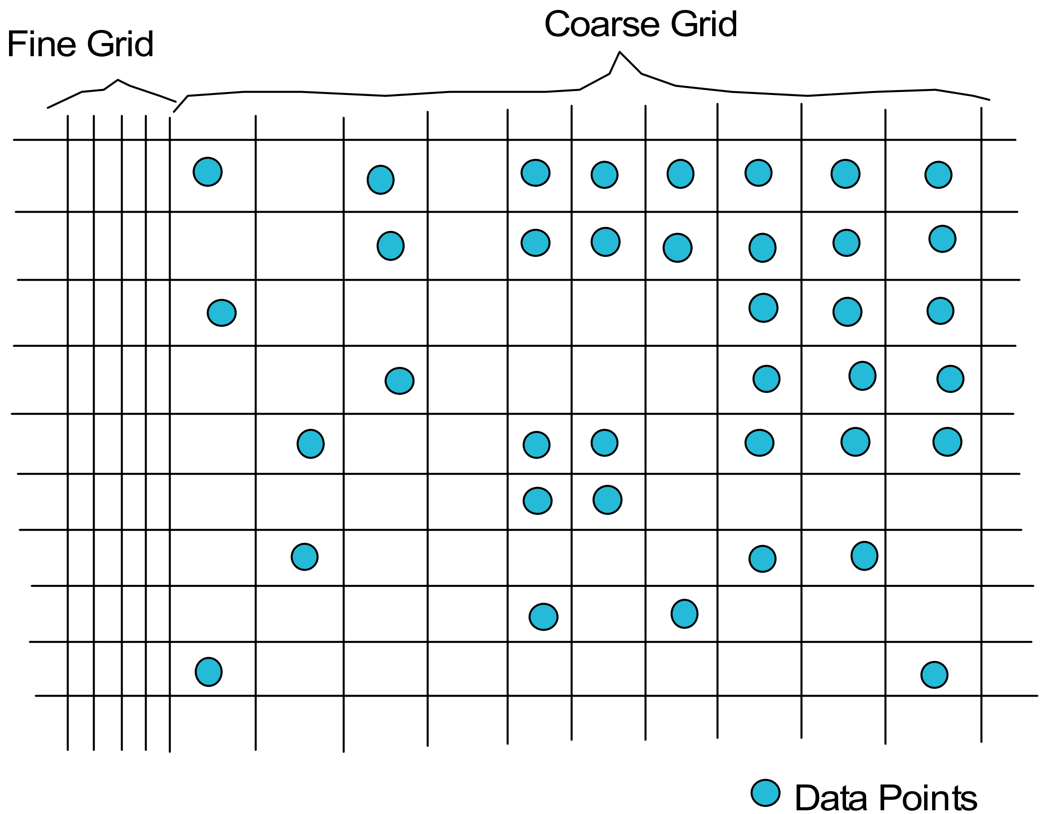
Pumping

- *Historical (pre-development and 1980-2000)*
- *Predictive (2000-2050)*

Categories

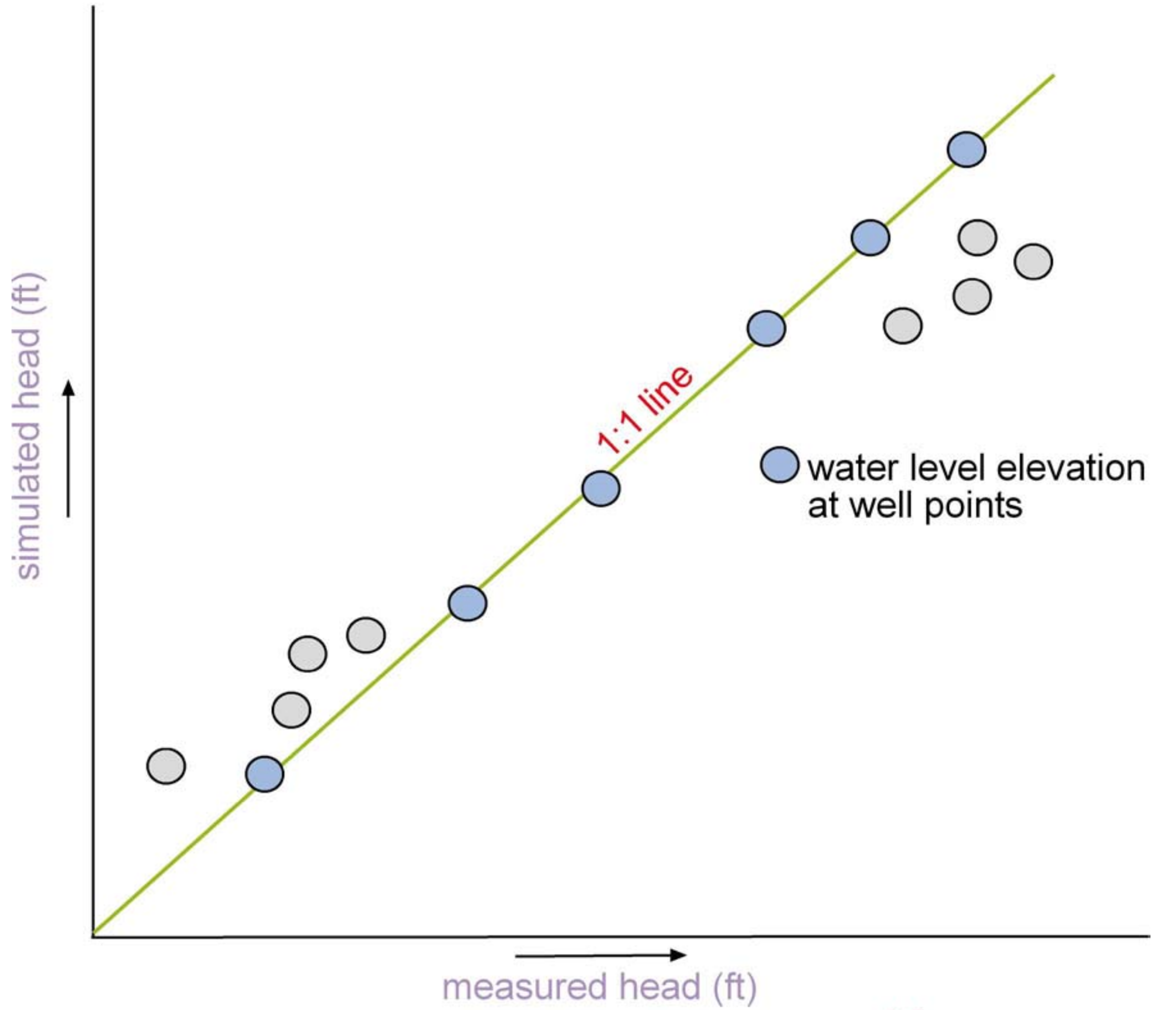
- *municipal*
- *manufacturing*
- *domestic*
- *irrigation*
- *livestock*

Model Grid



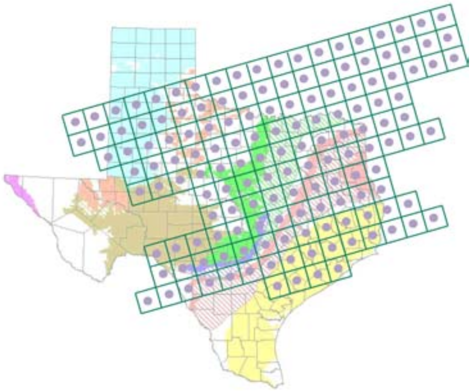
- model area discretized into cells
- cells are populated with field data which are sparse but each model cell needs a value
- data is interpolated (Kriging) between measured points where data is missing
- higher correlation between points at small sepration distance. kriging prserves the field value at the measurement point

Evaluating Calibration



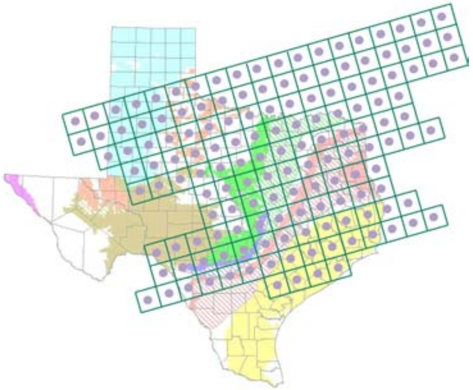
$$RMS = \left[1/n \sum_{i=1}^{n} (h_m - h_s)_i^2 \right]^{0.5}$$

- Error less than 10% of head drop across the model area, No spatial bias
- Fluxes at river gages are also compared



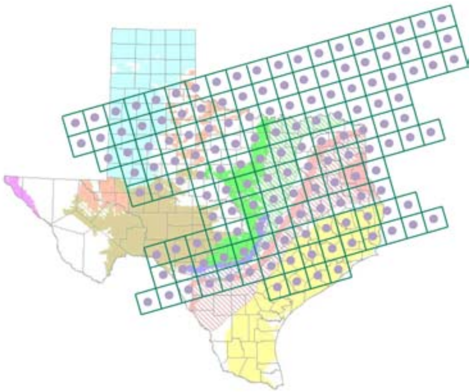
What is groundwater availability?

- …the amount of groundwater available for use.
  - safe yield
  - average recharge
  - recharge and change in storage
  - systematic depletion
- The State does not decide how much groundwater is available for use: GCDs and RWPGs decide.
- A GAM is a <u>tool</u> that can be used to assess groundwater availability once GCDs and RWPGs decide how to define groundwater availability.



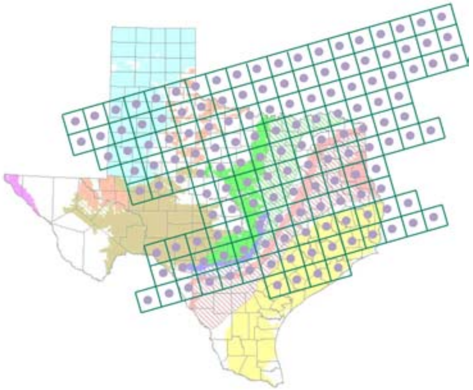
Do we have to use GAM?

- Water Code & TWDB rules require that GCDs
- TWDB rules require that RWPGs use GAM



How do we use GAM?

- The model
  - predict water levels and flows in response to
  - 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.

Comments:

Contract Manager

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(512)936-0834

www.twdb.state.tx.us/gam

Northern Trinity / Woodbine Groundwater Availability Model

Stakeholder Advisory Forum (SAF)

December 3, 2003

R. W. Harden & Associates, Inc.
Hydrologists – Geologists - Engineers

LBG

HDR

FREESE • NICHOLS

USGS
science for a changing world

GAM
Groundwater Availability Modeling

texas water development board

Meeting Outline

- General Information
- Project Work Steps
- Groundwater Flow Model Basics
- Northern Trinity/Woodbine Model Design
- Steady State Simulations – 1890
- Transitional Simulations – 1890 to 1980
- Supply Issues for Aquifer
- Project Schedule

Goals of the GAM Program

- Include substantial stakeholder input
- Provide reliable groundwater supply information
- Predict groundwater conditions over a 50-year planning period
- Produce publicly available groundwater models and supporting data

GAM Project Team

- R.W. Harden & Associates, Inc.
  - Project lead, geology, hydrology, modeling, and reporting
- LBG-Guyton Associates
  - Aquifer characteristics and water levels
- HDR, Inc.
  - Groundwater – surface water interaction
- Freese & Nichols, Inc.
  - Climatic data and stakeholder/RWPG interfacing

Project Team – (continued)

- United States Geological Survey
  - Aquifer data and modeling expertise
- Dr. Joe Yelderman, Jr.
  - Conceptualization of aquifer
- TWDB Staff
  - Technical oversight and assistance
- Stakeholders
  - Real world experience and Project needs/interests

Why is a Model Needed?

- Numerical model allows for more complex analysis than is possible with analytical methods
- Can be used to assess and interpret certain types of groundwater availability issues and/or concepts
- Allows for comparative analysis and testing and understanding of ‘what-if’ scenarios
- Capable of performing predictive analysis

Stakeholder Advisory Forum

- Stakeholder participation is important
- SAF Meetings
  - Held about once every four months
- Contact with Project Team encouraged
- SAF presentation materials and GAM information to be posted on TWDB website: http://www.twdb.state.tx.us/gam/trnt_n/trnt_n.htm

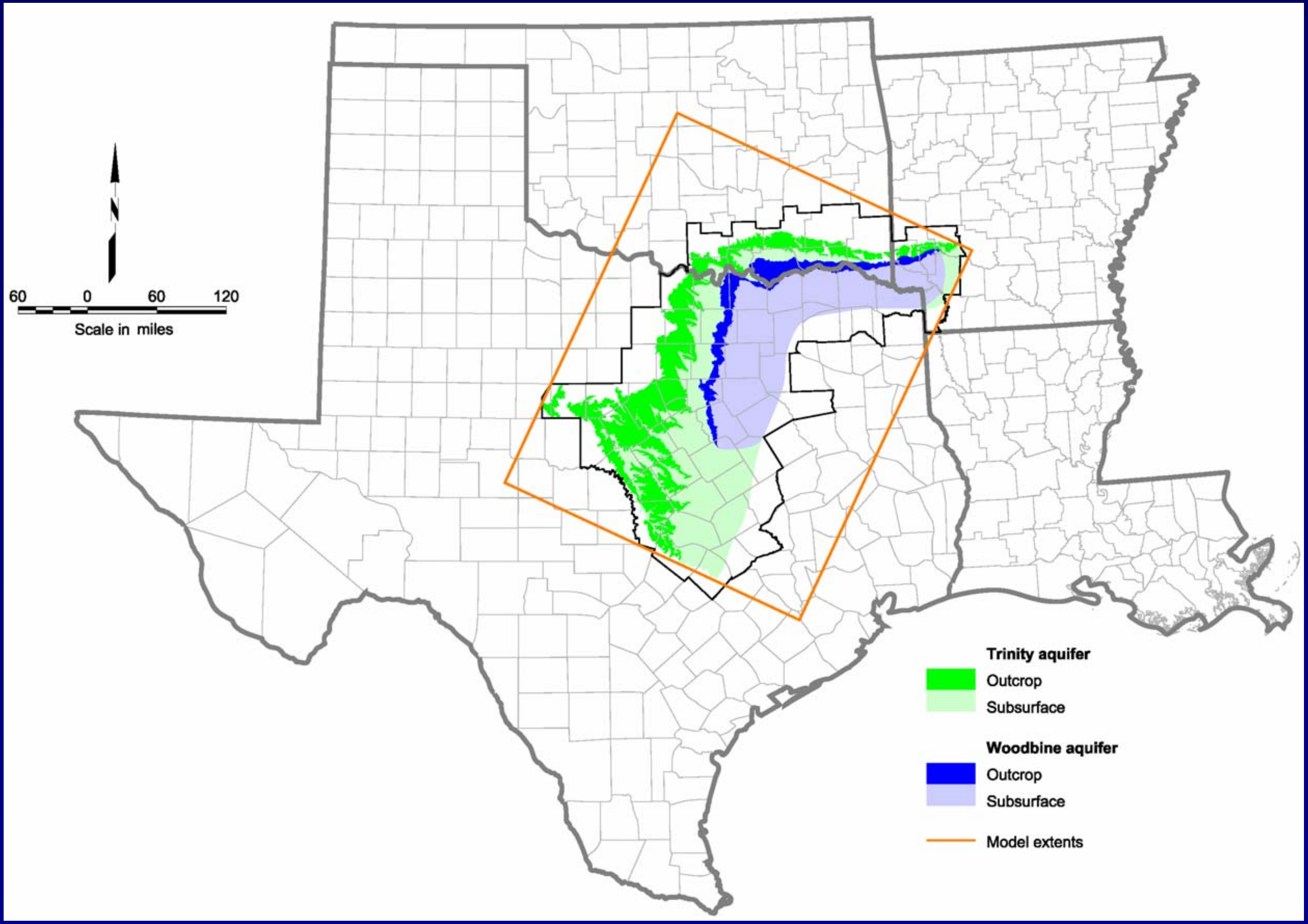
SAF Input

- Your Experiences
  - Historical use
  - Pumping tests
  - Water levels
- Your Interests
  - Identify needs of the model
  - Recognize uses of the model

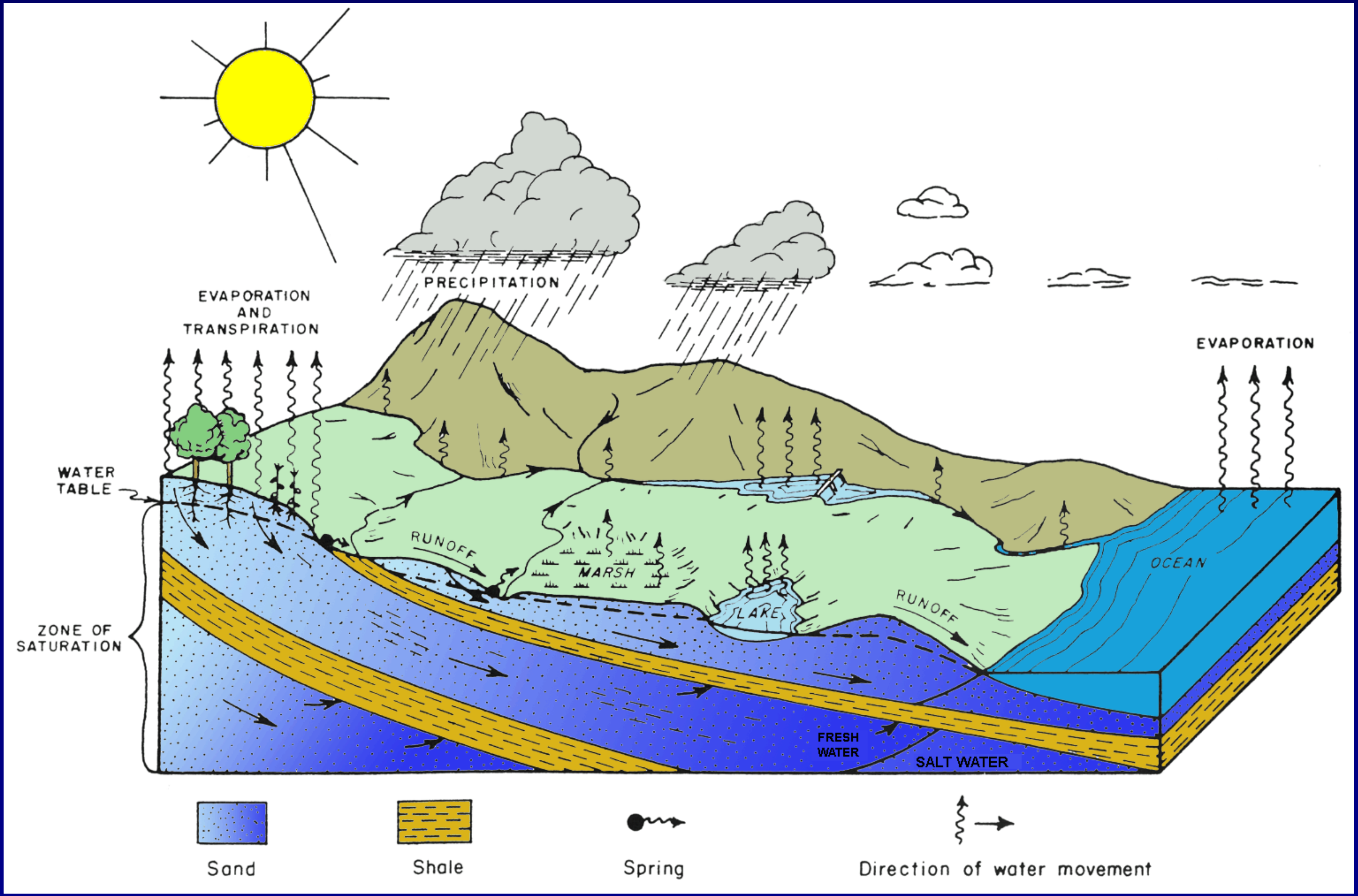
Project Work Steps

- Aquifer characterization
  - Data components of hydrologic cycle (Done)
  - Aquifer stratigraphy (Done)
  - Hydraulic characteristics (Done)
  - Water levels (Done)
  - Historical pumpage (Near completion)
- Computer model
  - Design and initial assignments (Done)
  - Predevelopment simulations (Current work)
  - Calibration, verification and prediction (Future work)
- Final Report and data presentation (Future work)

Study Area


60 0 60 120
Scale in miles
N
Trinity aquifer
Outcrop
Subsurface
Woodbine aquifer
Outcrop
Subsurface
Model extents

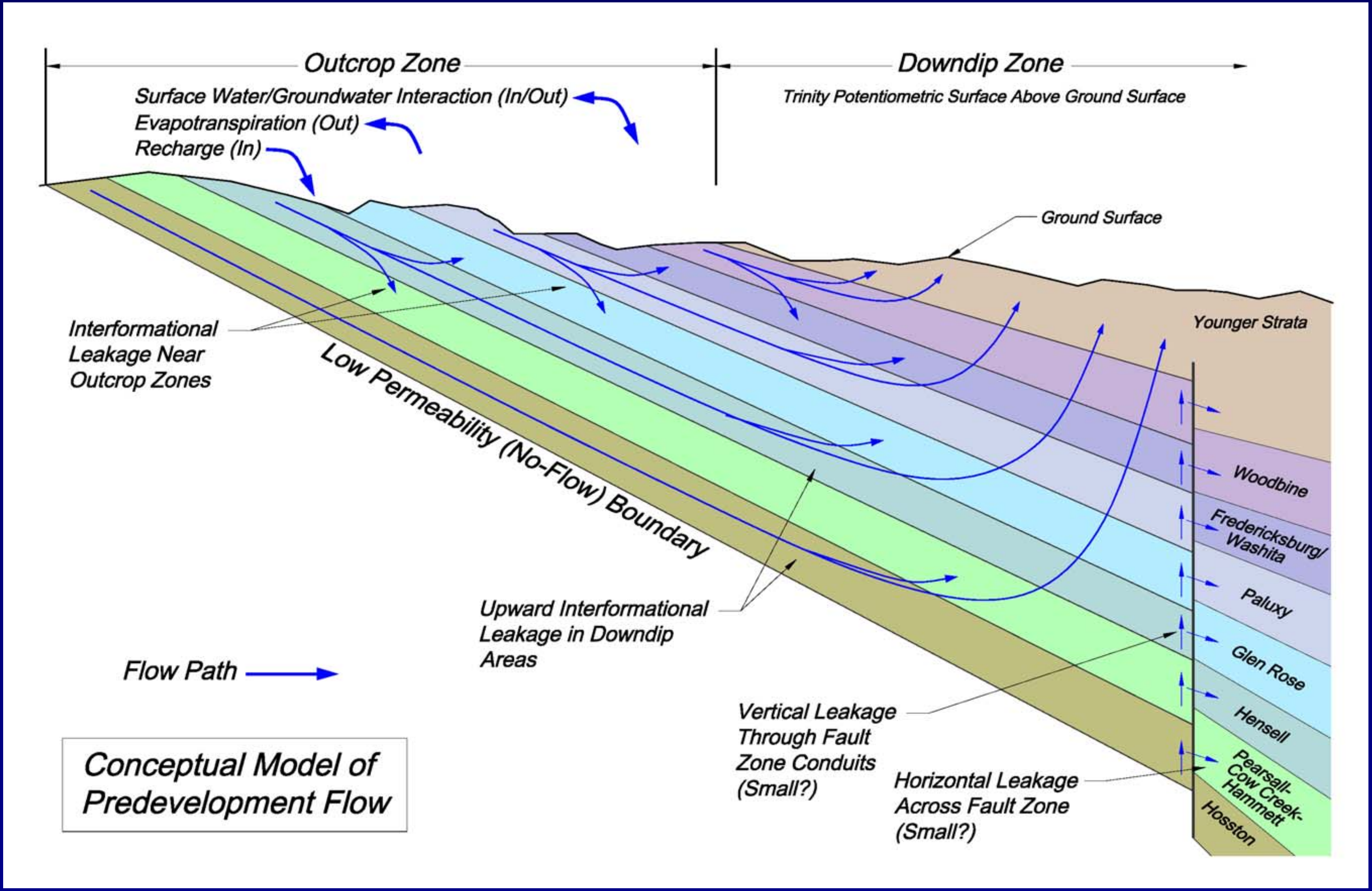
Hydrologic Cycle



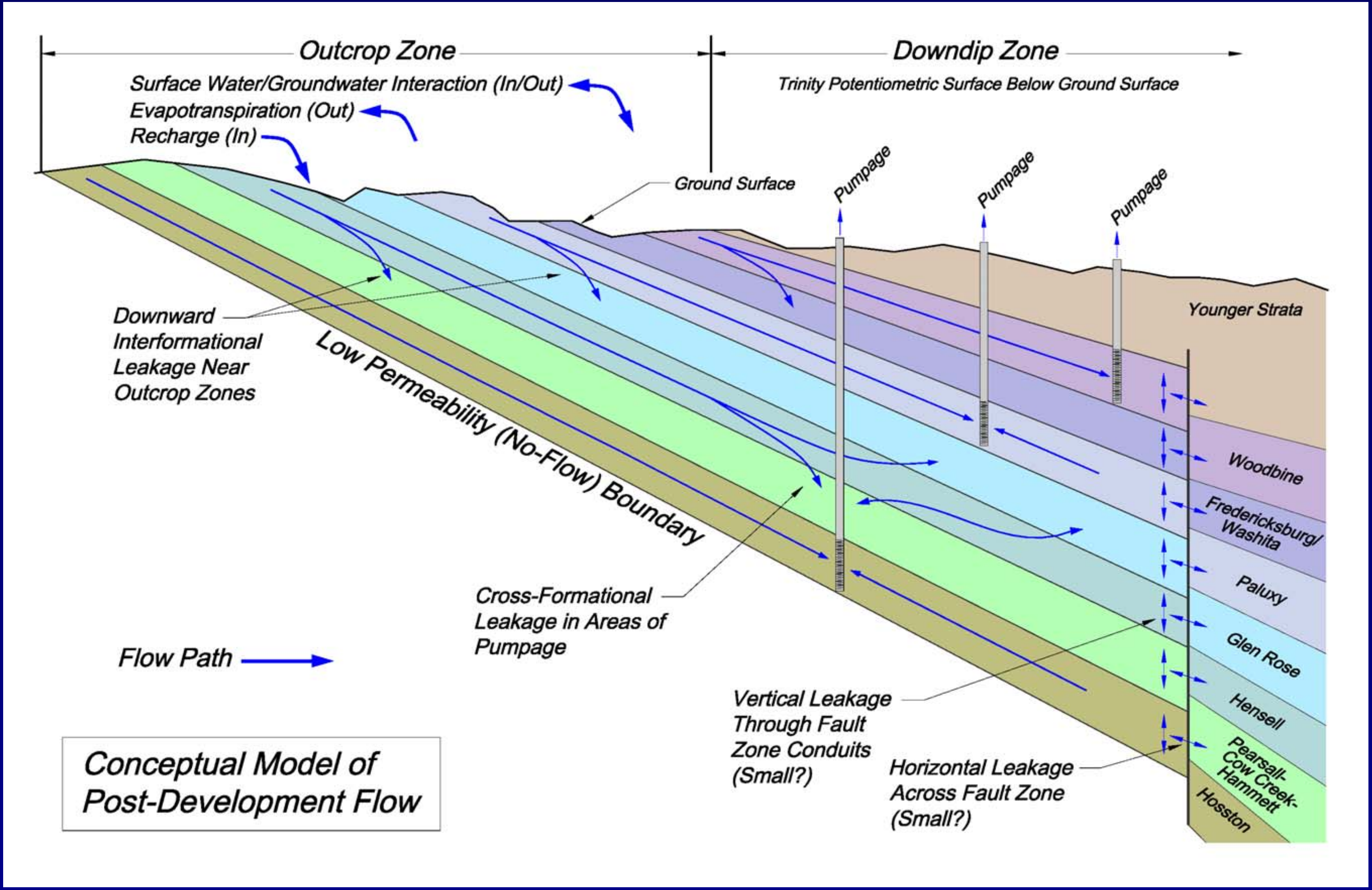
Geology / Hydrostratigraphy

<table>
<tr><th>System</th><th>Series</th><th>Groups</th><th colspan="5">Formation</th><th colspan="2">Approximate Maximum Thickness</th><th>Model Layers</th></tr>
<tr><td colspan="3"></td><th colspan="2">North</th><th colspan="3">South</th><th>North</th><th>South</th><td rowspan="2"></td></tr>
<tr><td>Tertiary</td><td colspan="9">Undifferentiated</td></tr>
<tr><td rowspan="19">Cretaceous</td><td rowspan="5">Gulfian</td><td>Navarro</td><td colspan="2" rowspan="5">Undifferentiated</td><td colspan="3" rowspan="5">Undifferentiated</td><td>800</td><td>550</td><td rowspan="4">GHB</td></tr>
<tr><td>Taylor</td><td>1500</td><td>1,100</td></tr>
<tr><td>Austin</td><td>700</td><td>600</td></tr>
<tr><td>Eagle Ford</td><td>650</td><td>300</td></tr>
<tr><td>Woodbine</td><td>700</td><td>200</td><td>1</td></tr>
<tr><td rowspan="14">Comachian</td><td rowspan="4">Washita</td><td colspan="2">Grayson Marl</td><td colspan="3">Buda, Del Rio</td><td rowspan="4">1,000</td><td>150</td><td rowspan="7">2</td></tr>
<tr><td colspan="2">Mainstreet, Pawpaw, Weno, Denton</td><td colspan="3" rowspan="2">Georgetown</td><td rowspan="2">150</td></tr>
<tr><td colspan="2">Fort Worth, Duck Creek</td></tr>
<tr><td colspan="2">Kiamichi</td><td colspan="3">Kiamichi</td><td>50</td></tr>
<tr><td rowspan="3">Fredricksburg</td><td colspan="2" rowspan="2">Goodland</td><td colspan="3">Edwards</td><td rowspan="3">250</td><td>175</td></tr>
<tr><td colspan="3">Comanche Peak</td><td>150</td></tr>
<tr><td colspan="2">Walnut Clay</td><td colspan="3">Walnut Clay</td><td>200</td></tr>
<tr><td rowspan="7">Trinity</td><td rowspan="7">Antlers</td><td>Paluxy</td><td colspan="3">Paluxy</td><td>400</td><td>200</td><td>3</td></tr>
<tr><td>Glen Rose</td><td colspan="3">Glen Rose</td><td>1,500</td><td>1,500</td><td>4</td></tr>
<tr><td rowspan="5">Twin Mountains</td><td rowspan="5">Travis Peak</td><td>Hensell</td><td>Hensell</td><td rowspan="5">1,000</td><td rowspan="5">1,800</td><td>5</td></tr>
<tr><td rowspan="3">Pearsall</td><td>Cow Creek</td><td rowspan="3">6</td></tr>
<tr><td>Hammett</td></tr>
<tr><td>Sligo</td></tr>
<tr><td>Hosston</td><td>Hosston</td><td>7</td></tr>
<tr><td>Paleozoic</td><td colspan="9">Undifferentiated</td><td></td></tr>
</table>

Conceptual Flow - Predevelopment



Conceptual Flow – Post-Development



Modeling Phases

- Data Acquisition and Development of Conceptual Model of Flow – Completed
- Steady-State Predevelopment Model – Current Work
- Development of Transient Calibration & Verification Model – Future Work
- Predictive Simulations – Future Work

Model Construction

- Structure defined from geophysical logs and National Elevation Dataset (NED)
- Outcrop areas digitized from Bureau of Economic Geology (BEG) Geologic Atlas of Texas maps
- Hydraulic parameters collated from pump test analysis, net sand thickness, and estimated values
- Upper (General Head) boundaries applied to simulate vertical flow flow though the wedge of sediments overlying the confined portion of the Woodbine

Model Construction Cont.

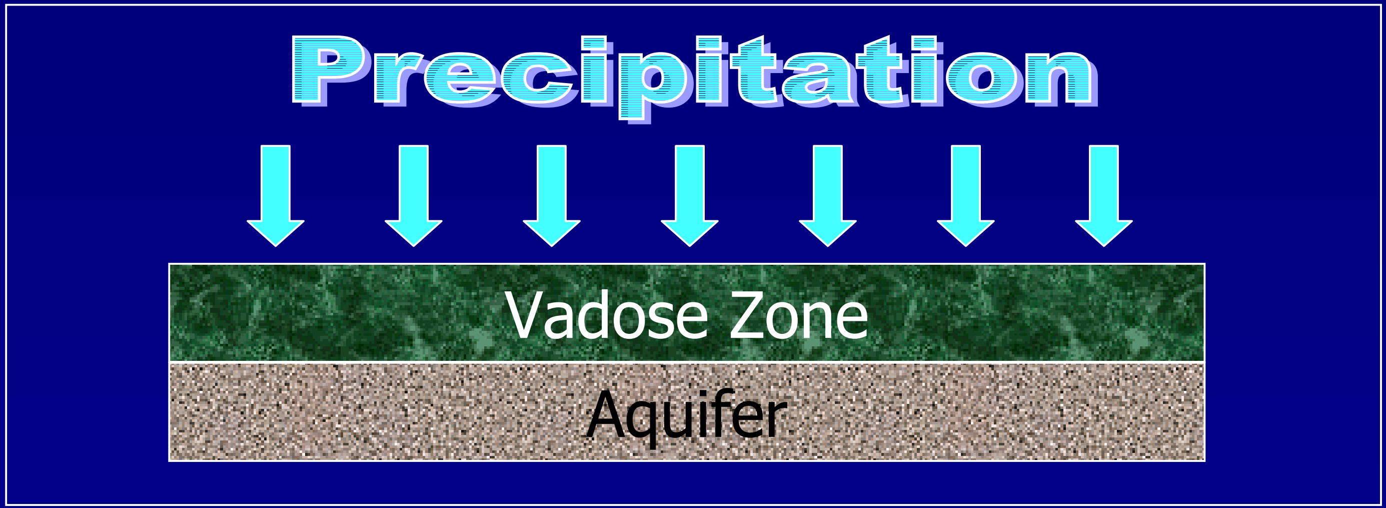
- Stream package employed to simulate surface/groundwater interaction between hydrologic units and major rivers and streams
- Recharge and evapotranspiration were distributed throughout outcrop zones
- Fault locations digitized from BEG Geologic Atlas and Tectonic Map sheets
- Downdip boundary set at the Luling-Mexia-Talco Fault Zone

Hydraulic Properties

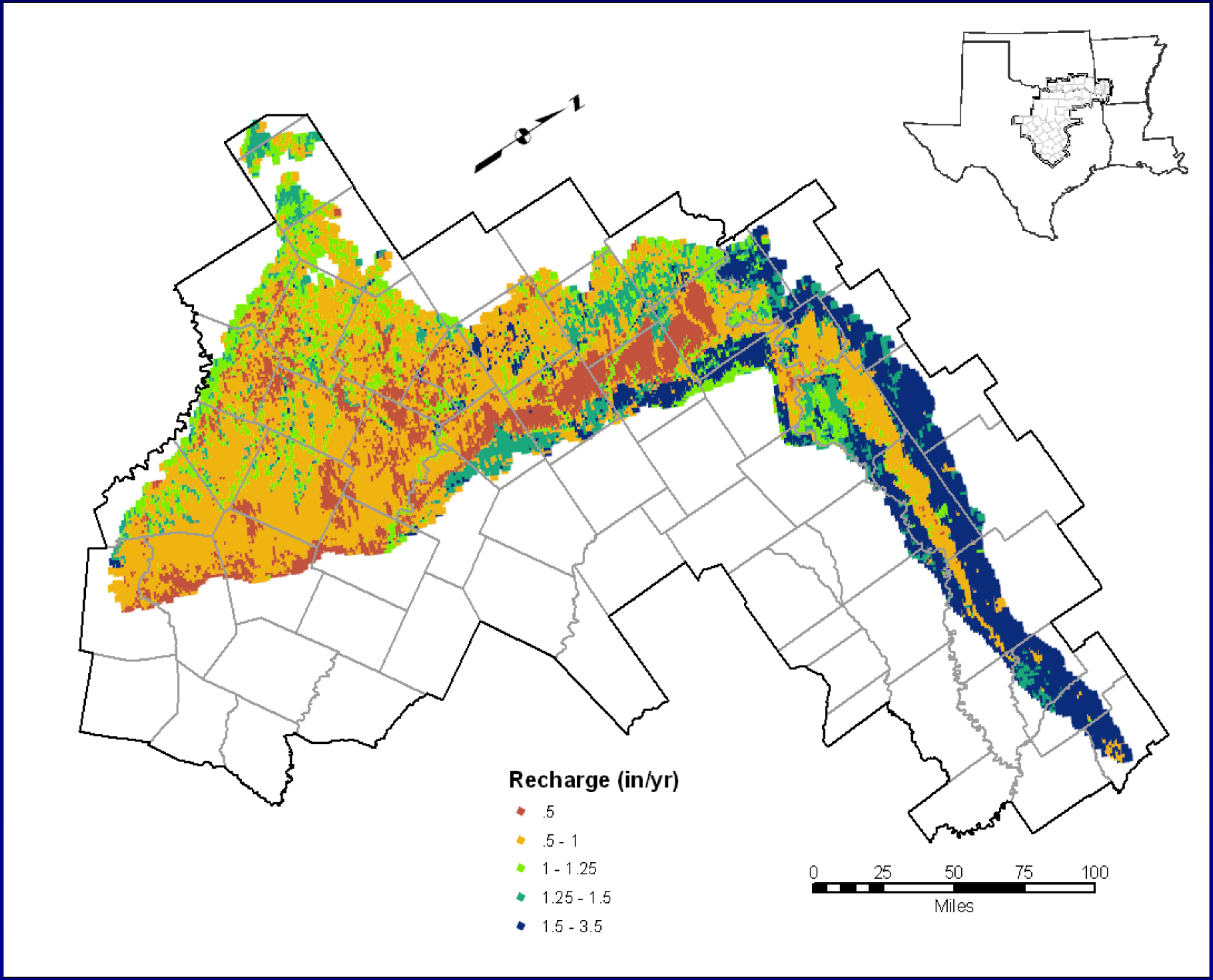
- Data collected from numerous sources published during the last century
- Much of this data was compiled by R. Mace in 1994
- Raw pump test data was used where available and extrapolated to other areas using net sand thickness maps generated during the conceptual model phase

Recharge

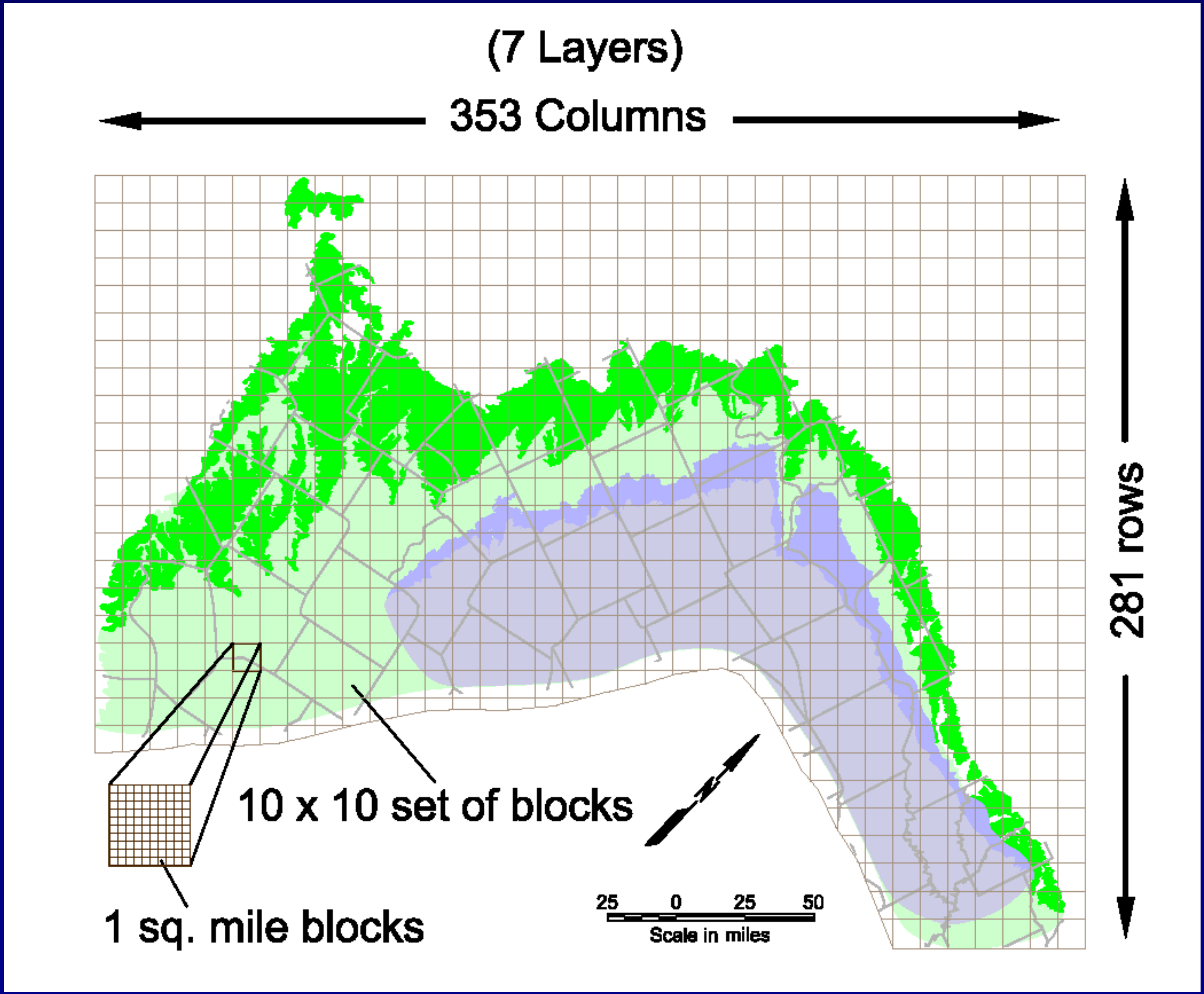
- Recharge Source - Precipitation
- Intermediate Soil (Vadose Zone) Properties - Soil Permeability, Land Use
- Subsurface Hydraulic Properties – Aquifer vs. Confining Units



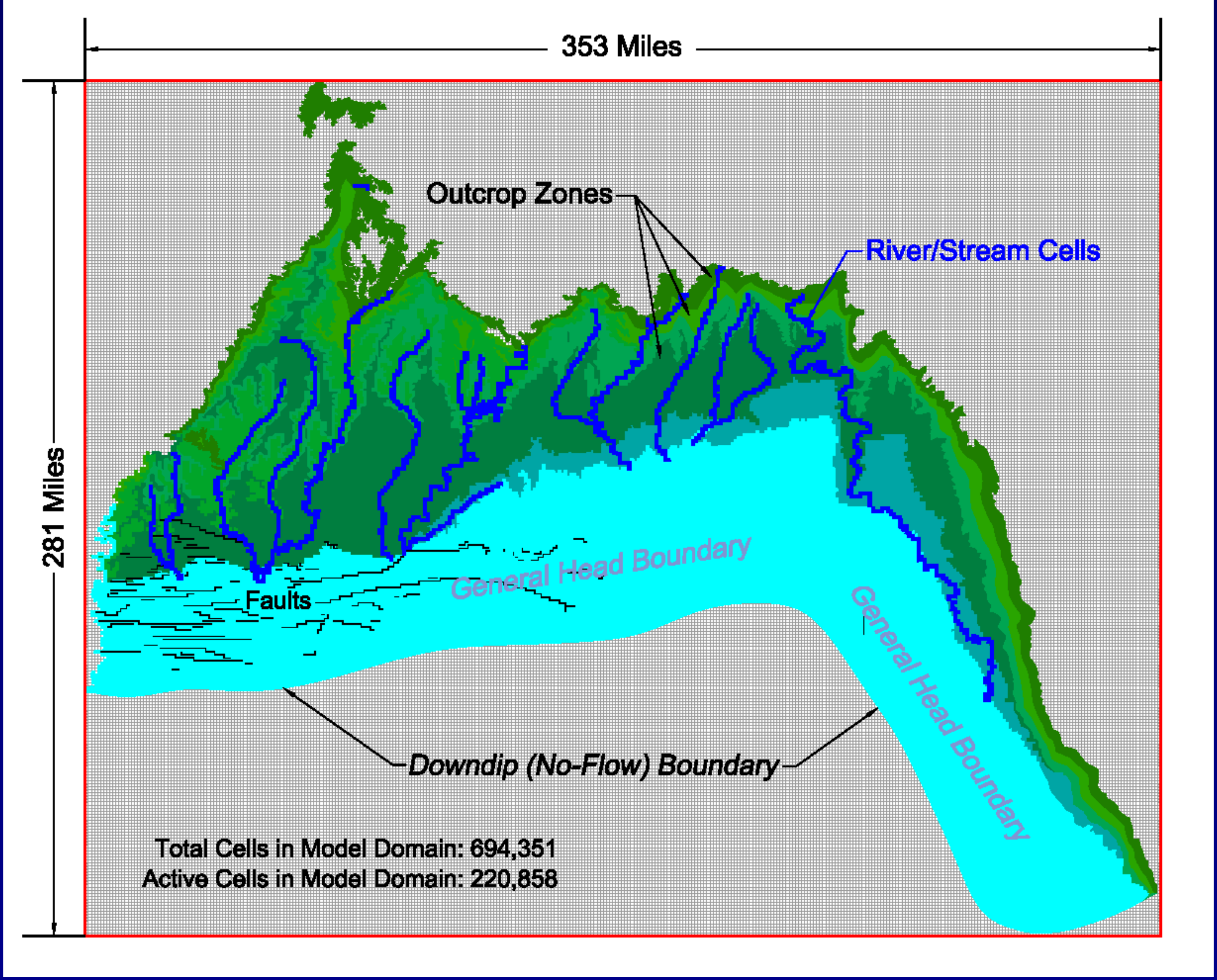
Recharge Distribution



Model Diagram



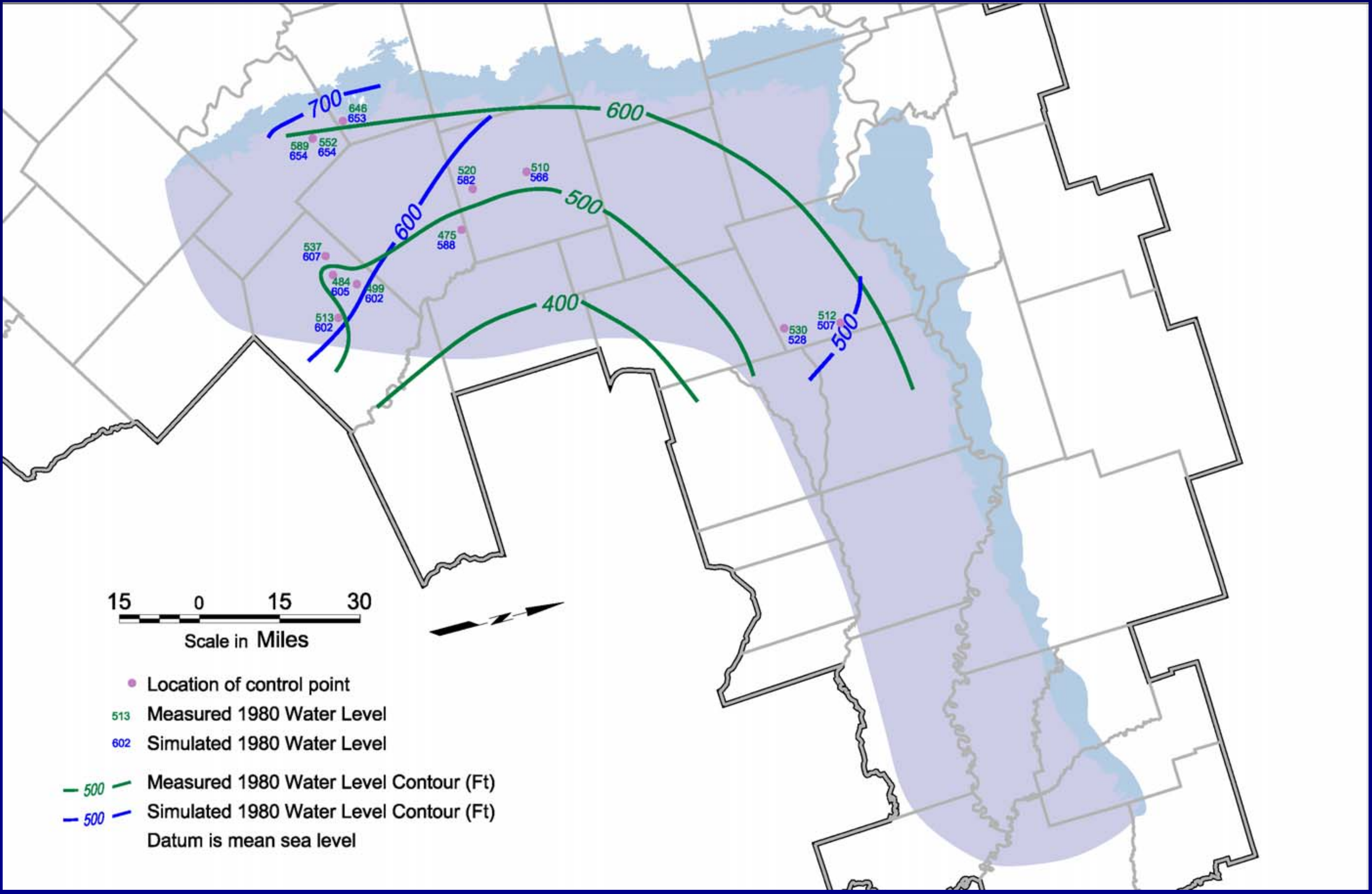
Model Boundaries



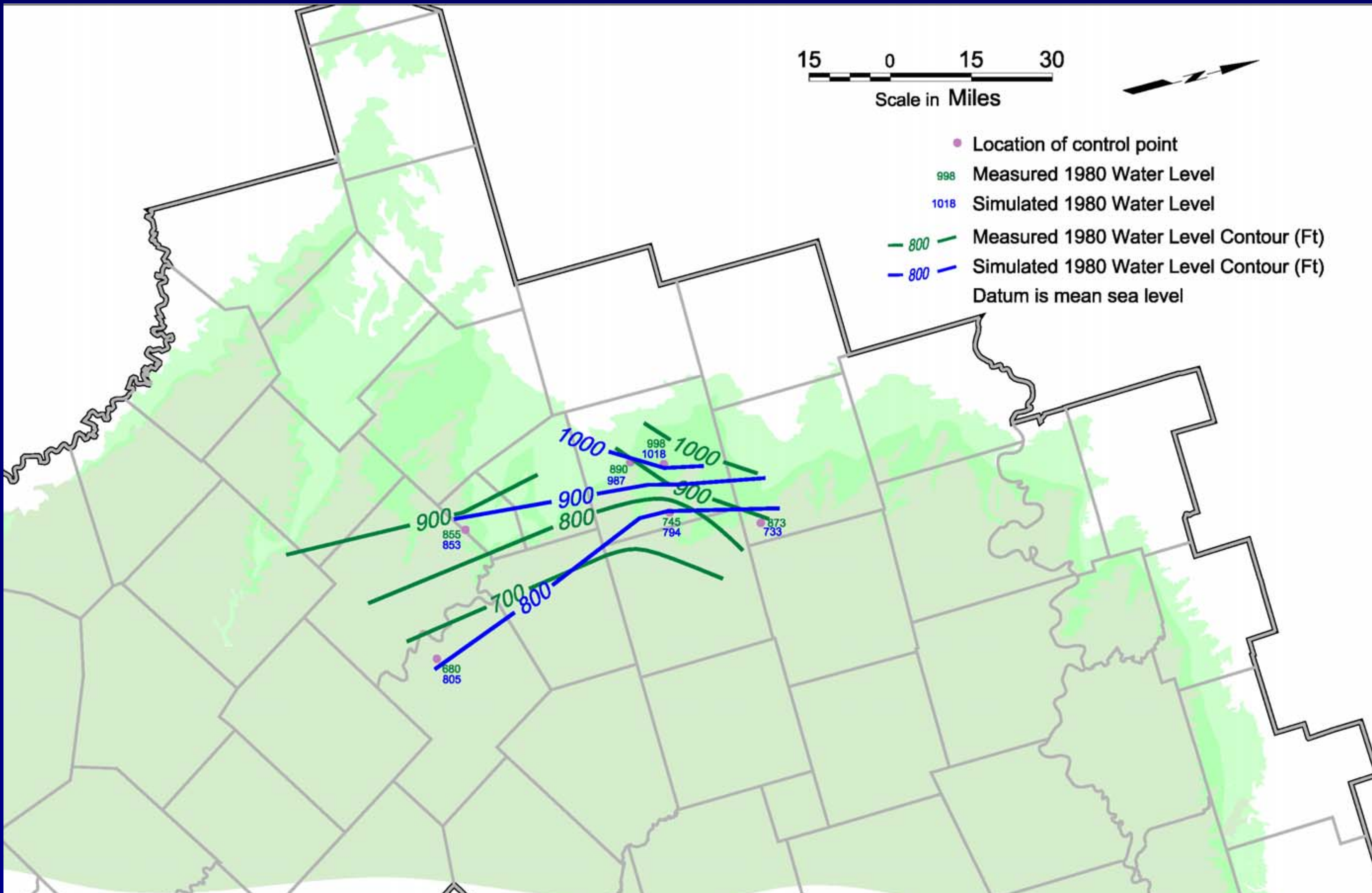
Predevelopment Model

AND THE INITIAL RESULTS ARE…

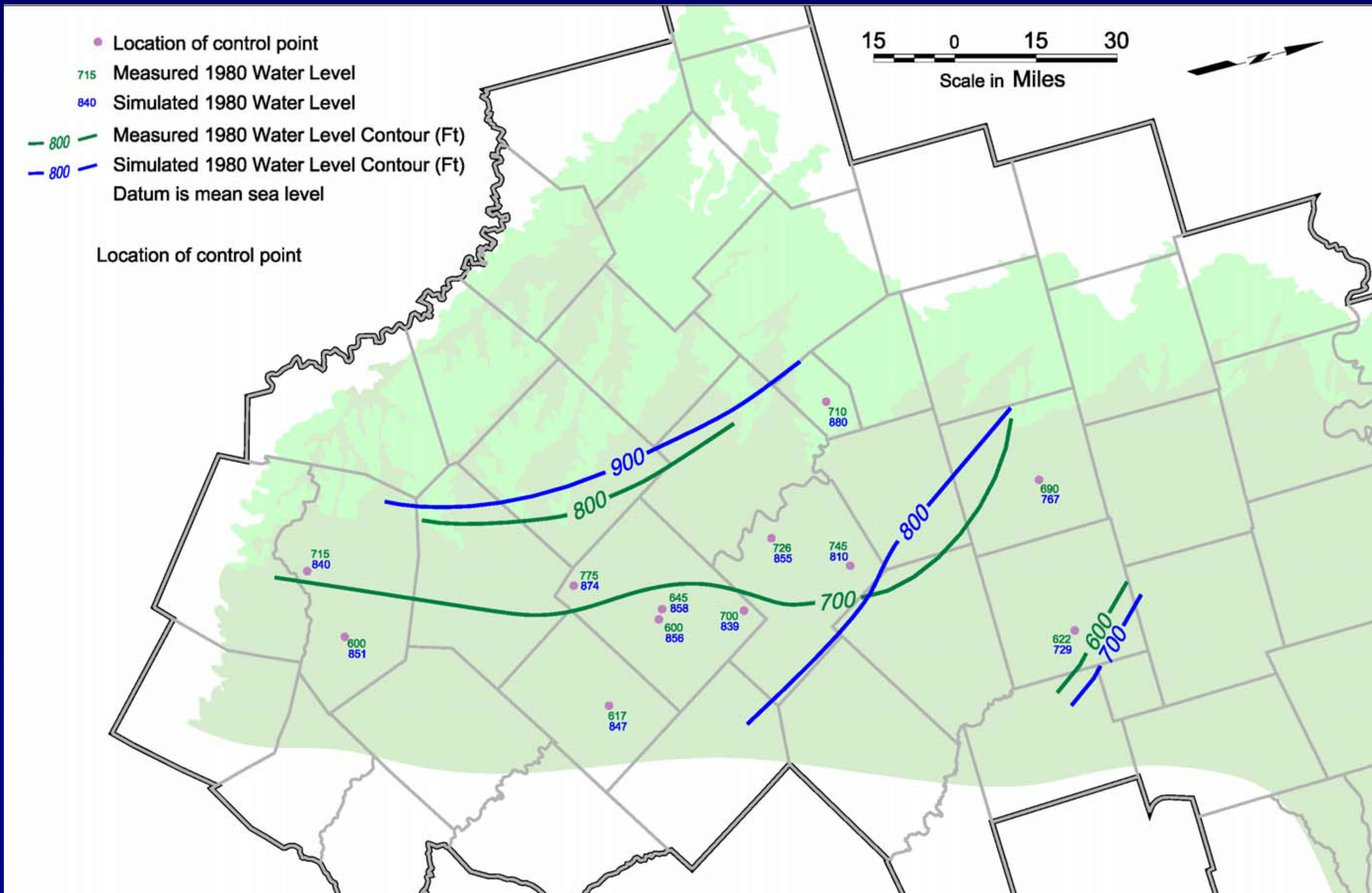
Woodbine Water Level - Predevelopment



Paluxy Water Level - Predevelopment



Hosston Water Level - Predevelopment



Predevelopment (Steady- State) Calibration

Conclusions

- Steady-state model not able to adequately simulate to earliest recorded water levels using reasonable aquifer hydraulic parameter values

Predevelopment (Steady- State) Calibration

Why?

- Very few early water level data recorded for Trinity/Woodbine
- Early water levels most likely reflective of pumpage effects from significant number of wells producing from the aquifers before water levels were measured

Pre-1900 Woodbine Wells

County	Number of Wells
Dallas	43
Denton	8
Ellis	33+
Grayson	25
Hill	12
Johnson	7
McLennan	1
Tarrant	23

Data from Hill, 1901

Pre-1900 Paluxy Wells

County	Number of Wells
Bell	10
Cooke	37
Dallas	1
Denton	45
Hill	3
Johnson	16
McLennan	5
Tarrant	46

Data from Hill, 1901

Pre-1900 Trinity Wells

County	Number of Wells
Bell	36
Bosque	67
Burnet	1
Comanche	numerous
Cooke	6
Coryell	41
Denton	2
Eastland	1
Erath	27+
Grayson	1
Hamilton	24

Data from Hill, 1901

Pre-1900 Trinity Wells (cont.)

County	Number of Wells
Hill	4
Hood	25
Johnson	8
McLennan	27
Mills	3
Parker	21+
Somervell	283
Tarrant	7
Travis	10
Williamson	20
Wise	13

Data from Hill, 1901

Waco Wells Reported by R. T. Hill (1901)

540 BLACK AND GRAND PRAIRIES, TEXAS.

Company. The three remaining flowing wells belong one each, respectively, to the estate of W. R. Kellum, deceased, William L. Prather, and Tom Padgett.

The altitude of the public square of Waco is 421 feet above sea level. The altitude, diameter, depth, estimated flow, temperature, and initial pressure per square foot of the several wells were as follows:

Name of well.	Altitude.	Diameter.	Depth.	Flow per diem.	Temperature.	Initial pressure.
	Feet.	*Inches.*	*Feet.*	*Gallons.*	° *F.*	*Pounds.*
The Moore well	493	6	1,840	600,000	103	*a* 60
The Bell well *b*	500	6	1,820	500,000	102½	*a* 60
Jumbo well No. 1 *b*	500	8	1,848	1,200,000	103	*c* 60
Jumbo well No. 2 *b*	500	8	1,860	1,000,000	103	60
The Glenwood	495	8	1,860	1,000,000	103	*a* 65
The Dickey well	532	8	1,840	1,000,000	103	*a* 60
The Bagby well	475	8	1,845	1,000,000	103	*a* 60
The Waco Light and Water Power Co. well	532	6	1,812	300,000	100	40
The Prather well	655	6	1,607	500,000	97	*c* 40
The Kellum well	420	6	1,776	1,000,000	103	*c* 76
The Padgett well (Fishing Club)	485	6	1,860	1,000,000	90	*c* 72
The W. V. Fort well	425	....	1,825	1,300,000	....	....

a Estimated. *b* These three, the Bell, Jumbo No. 1 and No. 2, are 50 feet equidistant. *c* Tested.

The foregoing statements of flow per diem (twenty-four hours) are estimates. An attempt was made to measure the flow of Jumbo No. 1, but it was unsuccessful. An expert, a member of the United States Artesian Survey Corps, who made the attempt and failed, estimated the flow at 1,000 gallons per minute. If this statement is correct the output per diem would be 1,440,000 gallons.

I have assumed the output of this well to be 1,200,000; with this as a basis the output of the other wells has been estimated. The pressure of the Jumbo, Prather, and Padgett wells has been tested. The temperature of all has been ascertained by the thermometer.

A correspondent from Waco writes: "So far as the history of our wells is concerned, except in the case of the well bored by Mr. Fishback and one recently drilled for Mr. Fort, of which no record was kept, all the wells around Waco have been bored by a man who has kept no record of his borings, supposedly for the reason that such records would be of value to his professional rivals."

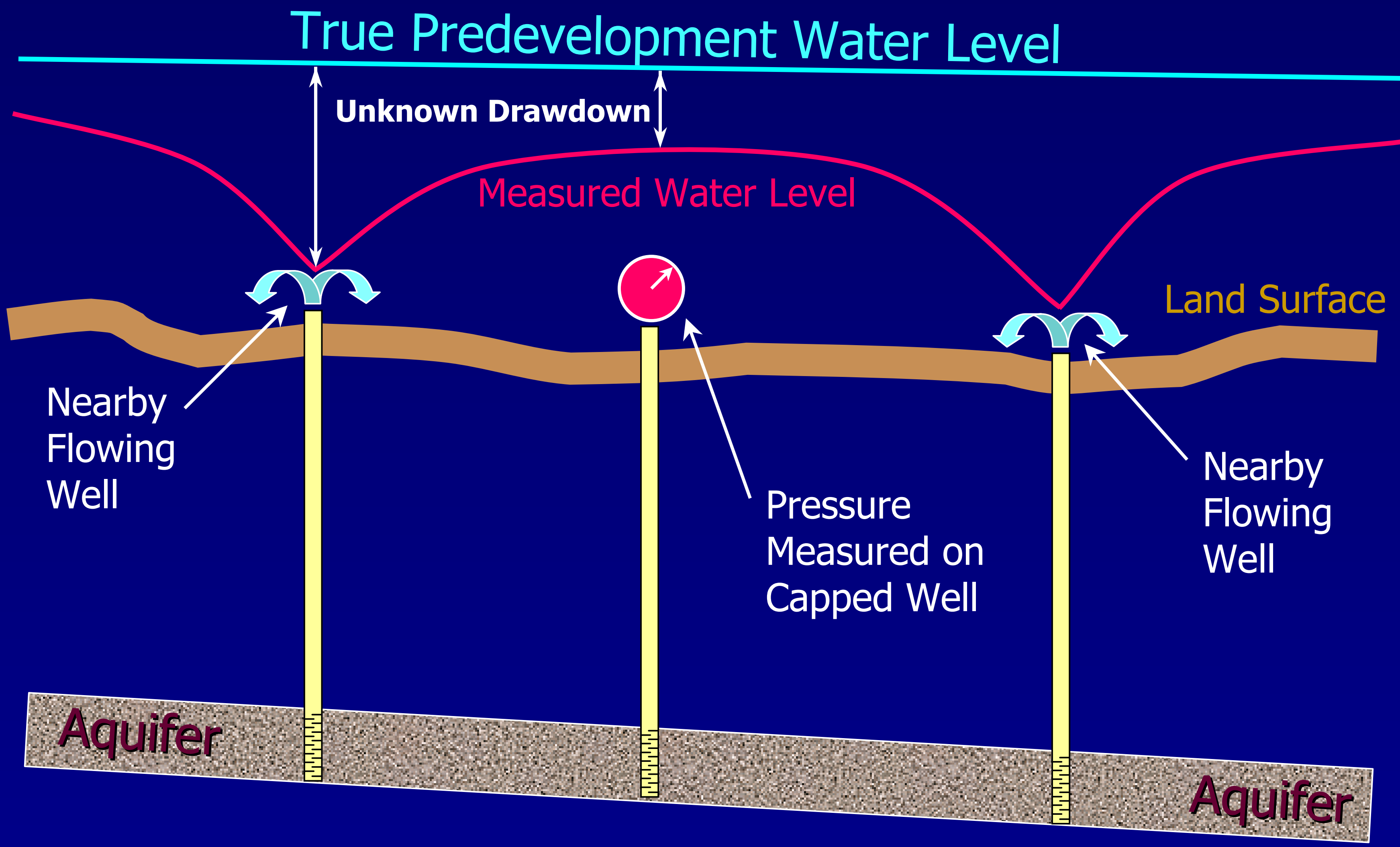
The log of the Padgett well in the city of Waco was furnished the writer through the kindness of Messrs. Fishback and Pope.[1] (See

[1] The original log of this well, as published in the report entitled "Artesian Waters of Texas" by the Department of Agriculture, Washington, D. C., page 109, was badly mutilated and the original manuscript was lost. For this the writer was not responsible. The log as given on p. 541 was based upon the corrections of the log as originally published. Recently, through the kindness of Mr. John K. Prather, of Waco, Texas, another copy of Mr. Fishback's original log was furnished and the log as here published has been verified by it.

- 12 Wells : Total of 7,200 GPM (Average of 600 GPM)
- "(except in two cases) ...all the wells around Waco have been bored by a man who has kept no records of his borings…"

Hill, R.T., Geography and Geology of the Black and Grand Prairies, Texas, 1901.

“Predevelopment” Measurements



Pre-measurement Drawdown Near Waco

Given the available data…

The average drawdown after one month of pumpage from the Waco wells was likely:

- about 50 feet within a 10-mile radius of Waco
- over 200 feet near the well field center

Alternative Solution

- Assume predevelopment water level measurements are in error
- Utilize the water level declines and aquifer use recorded during the 20th century to benefit the modeling process
- Calibrate to more reliable and evenly distributed water level data (i.e. 1980)

Pre-Calibration/Verification Model Development Strategy

- Develop steady-state model
- Create a simplified pumpage data set through reverse extrapolation of 1980 pumpage
- Apply the extrapolated pumpage and run model through a 100-year simulation period (1880 to 1980)
- Compare results to measured 1980 water levels

Predevelopment Solution Cont.

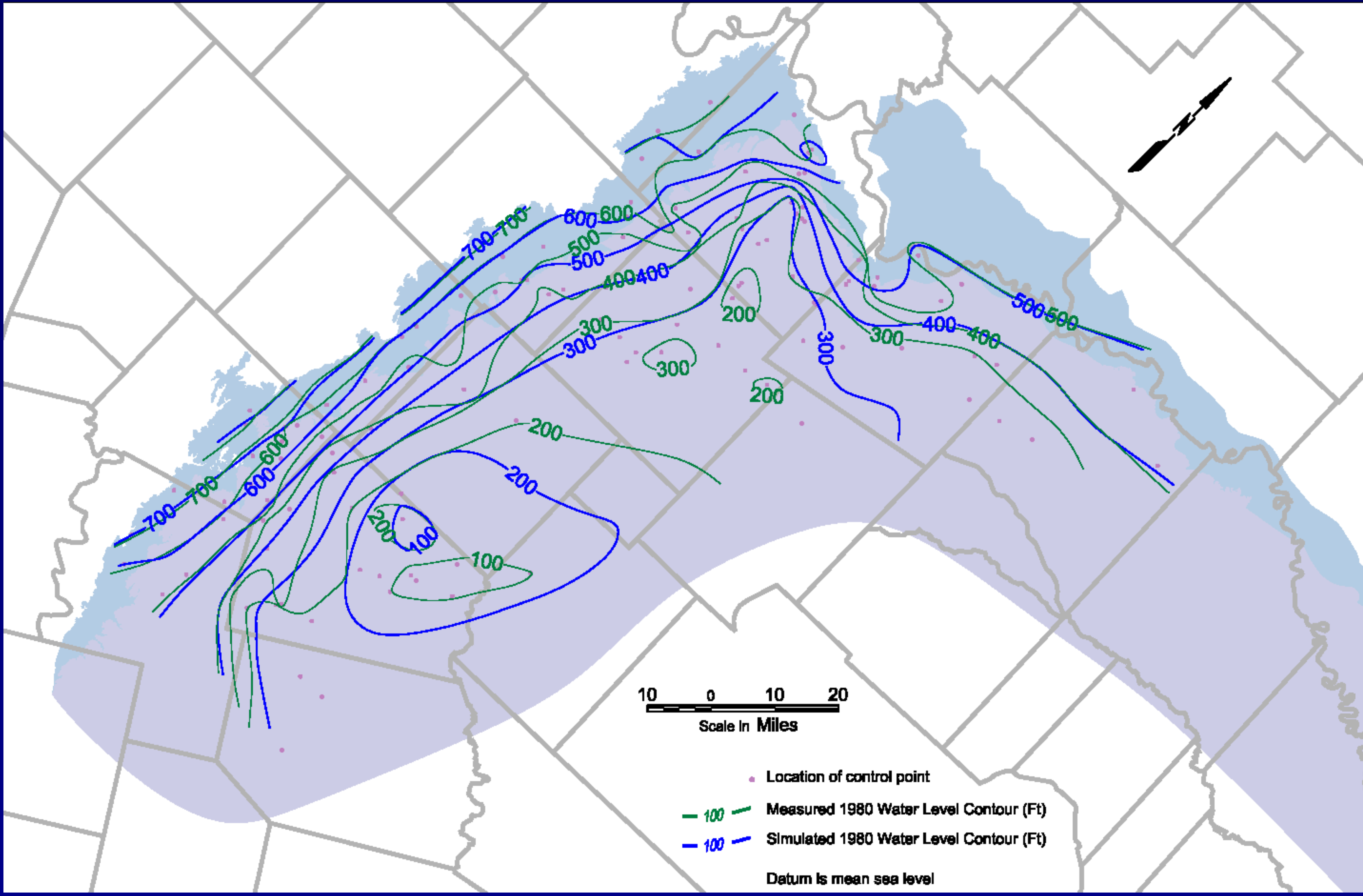
- Advantages to transitional model:
  - Insures the smoothest possible transition between steady-state and calibration/verification models
  - Develop an understanding of what drives the aquifer system and what doesn’t
  - Define model problem areas while utilizing simplified (static) input parameters
  - Develop rejected/captured recharge function and stabilize water levels in outcrop

Transitional Period Model (1880-1980)

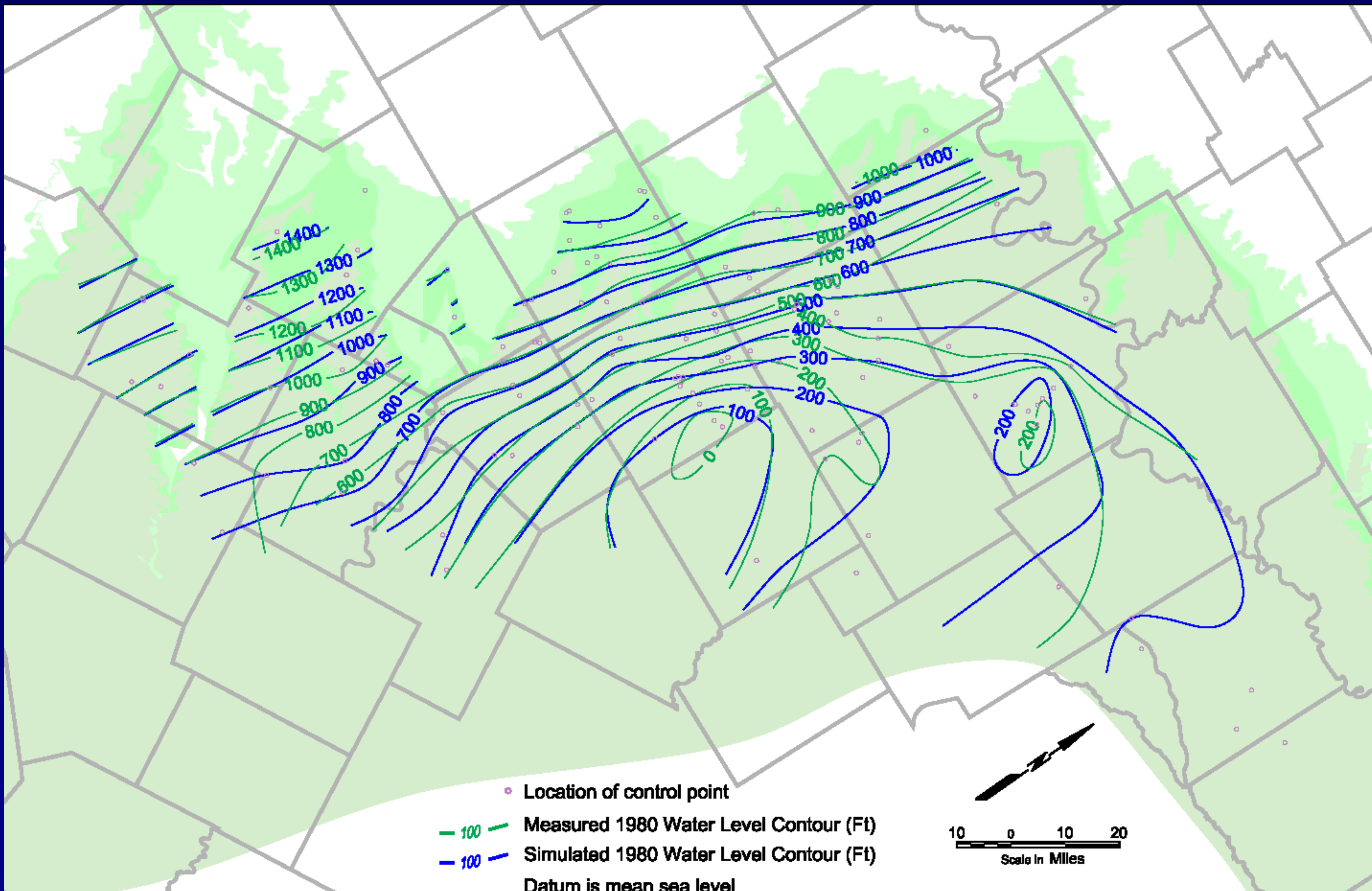
AND THE NEW RESULTS ARE…

Woodbine Water Level - 1980

(Preliminary)

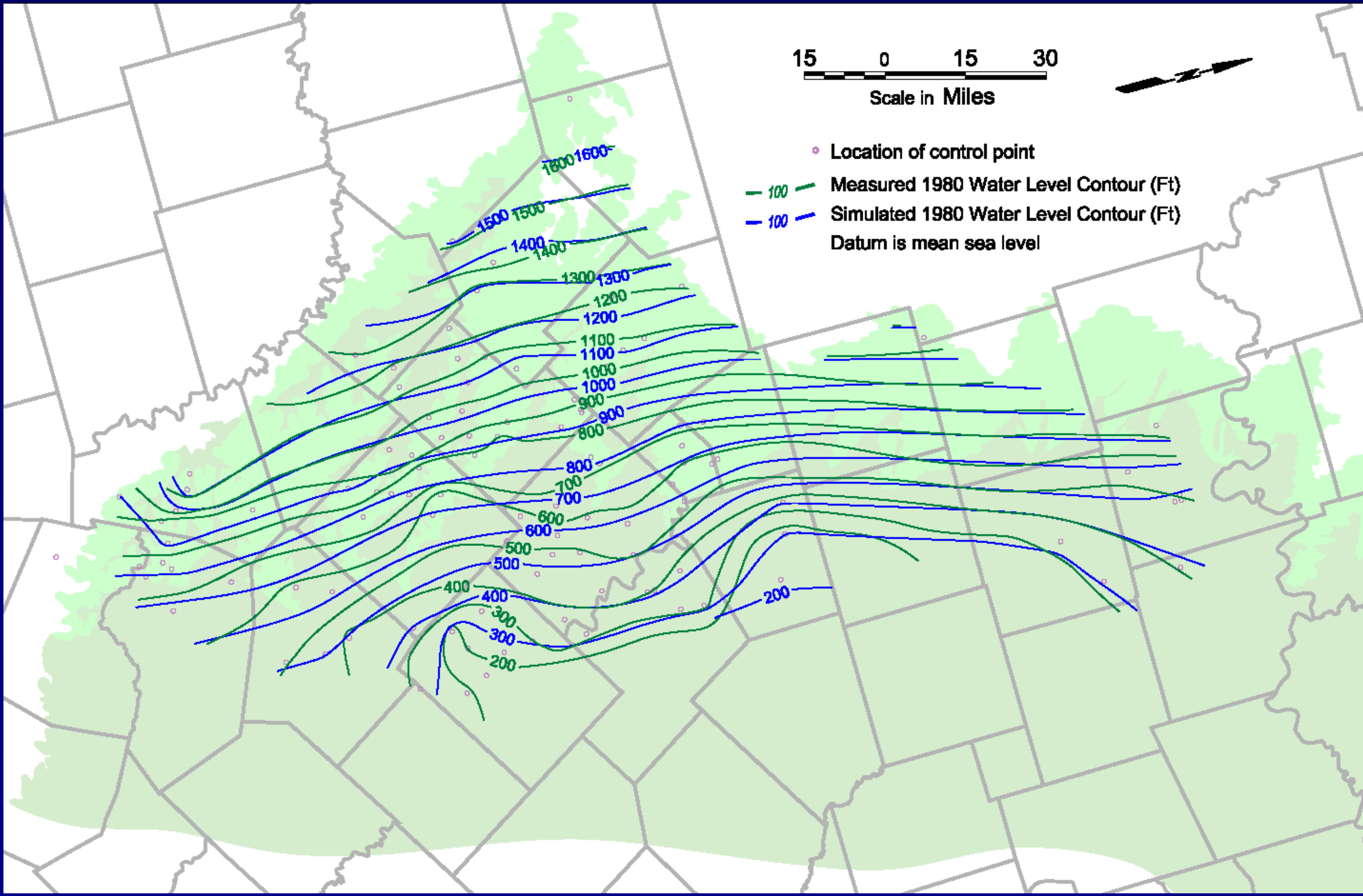


Paluxy Water Level – 1980
(Preliminary)



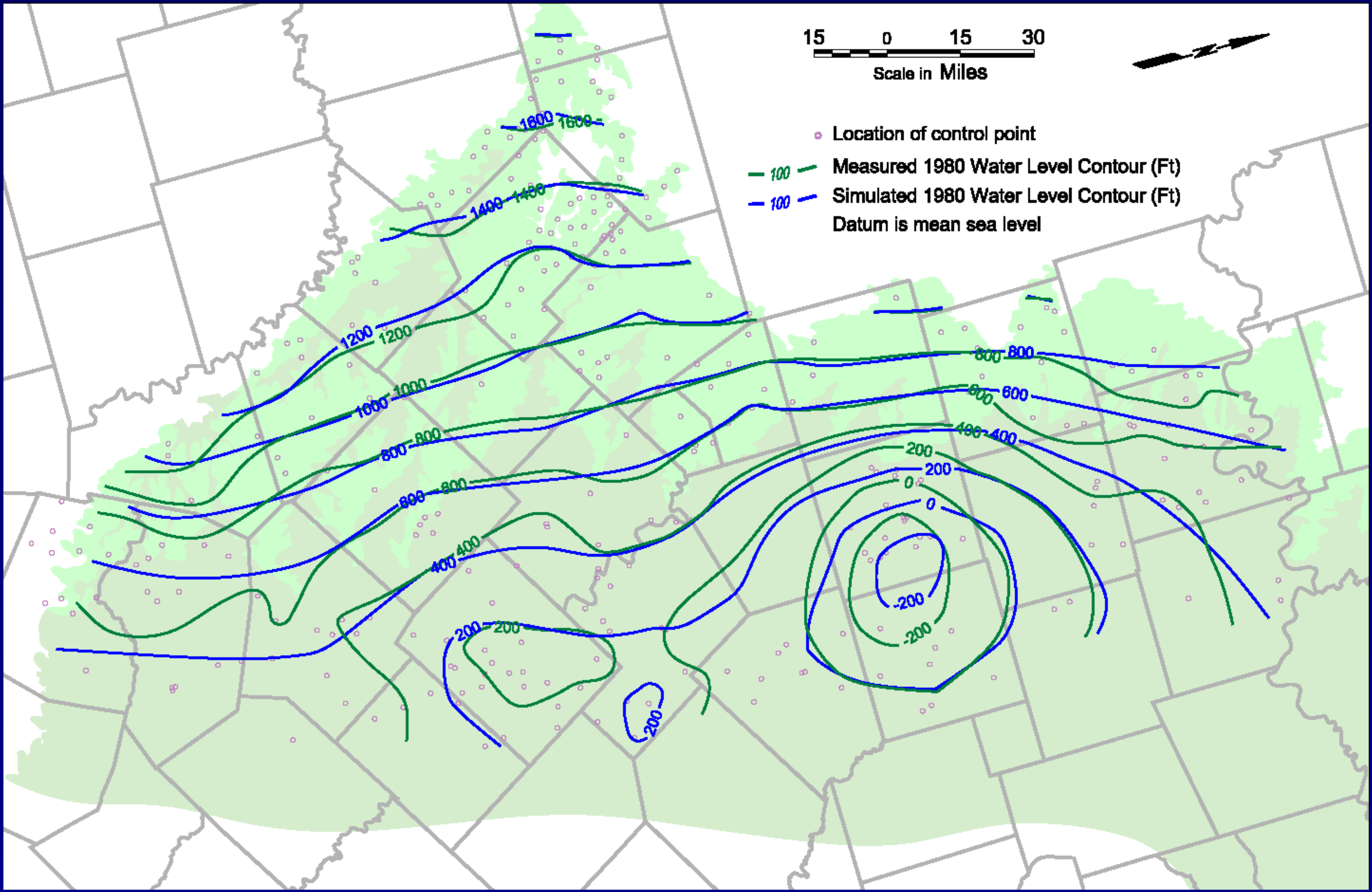
Hensell Water Level - 1980

(Preliminary)



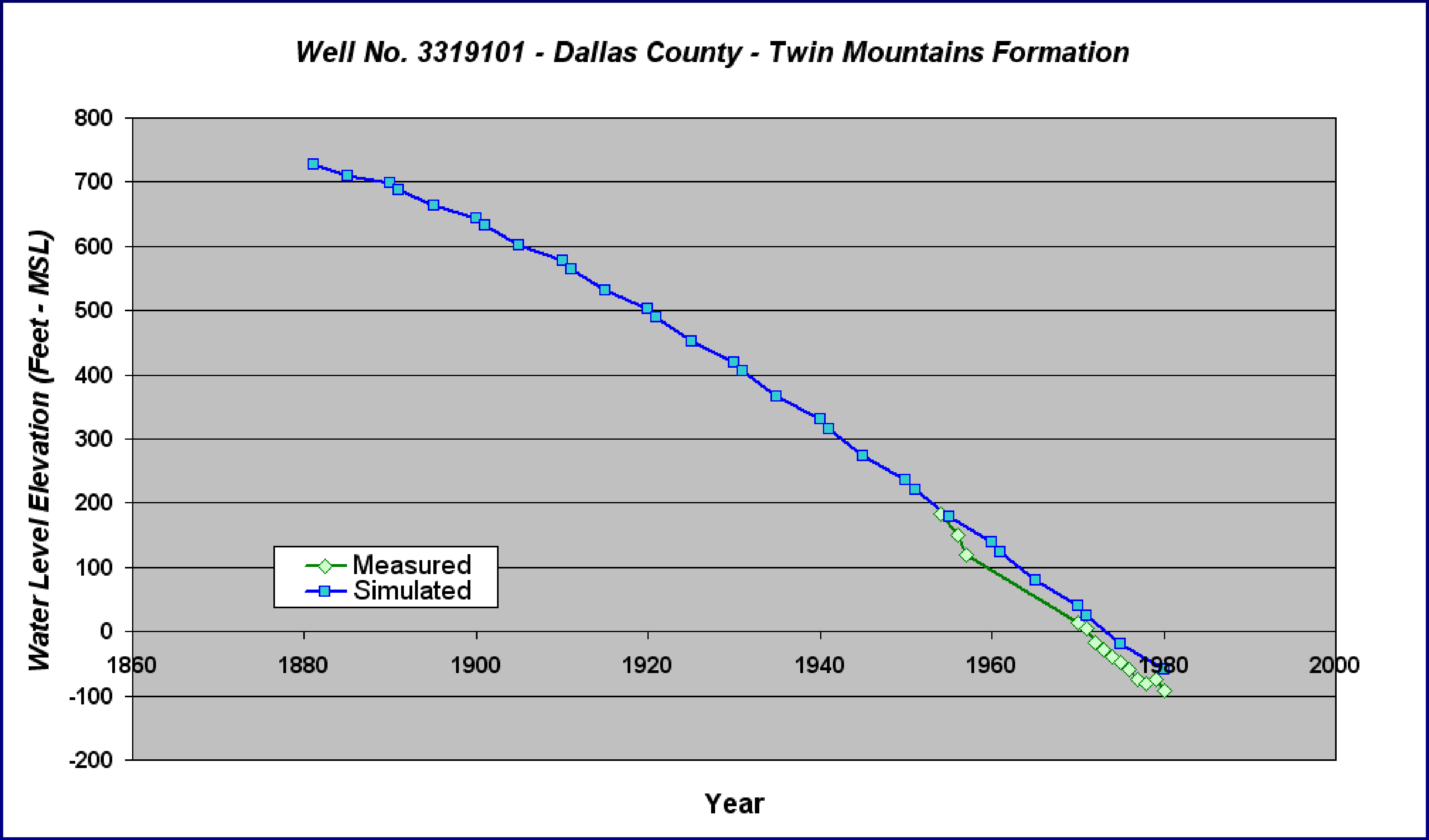
Hosston Water Level – 1980

(Preliminary)

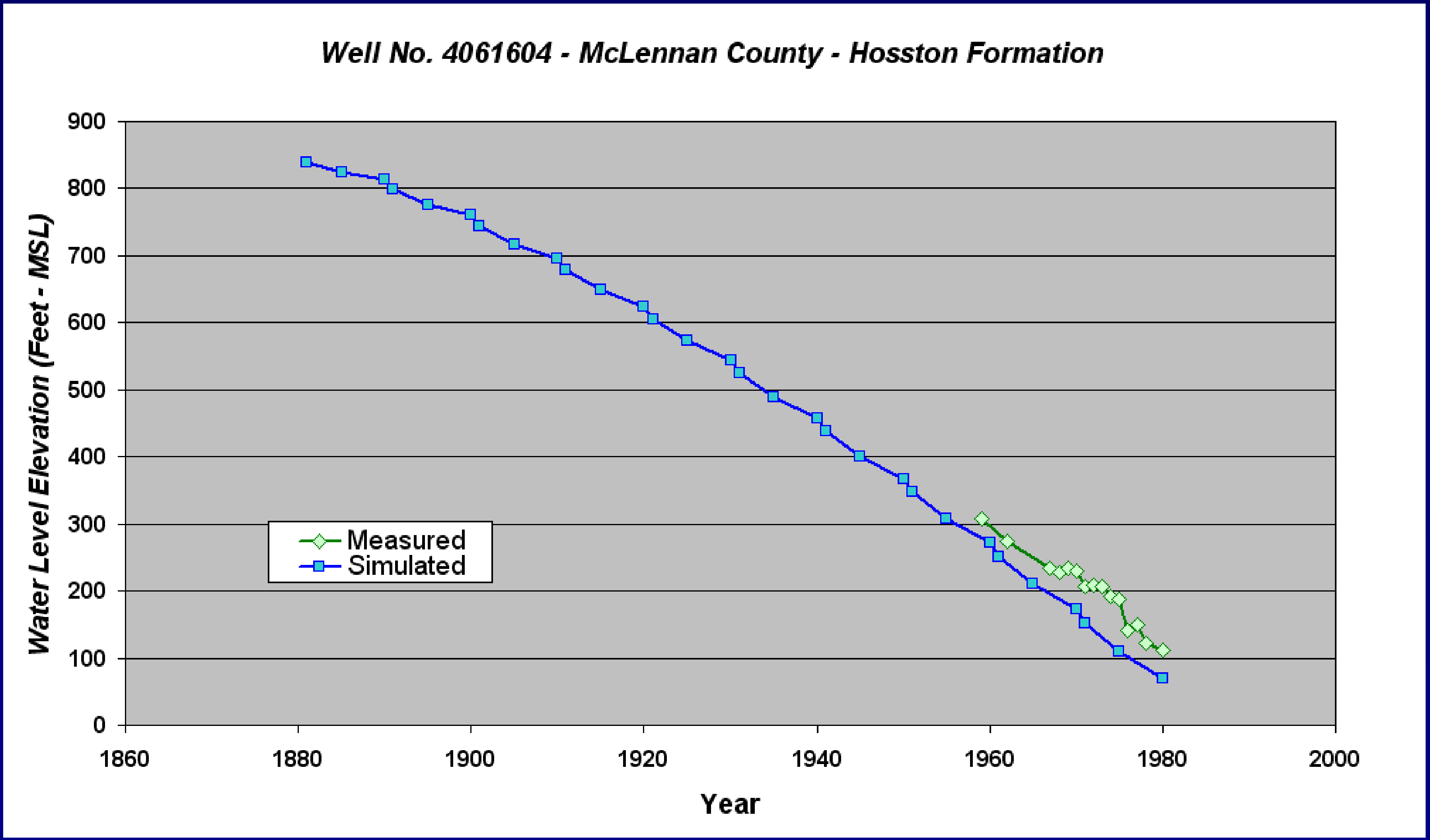


Simulated vs. Measured Water Levels

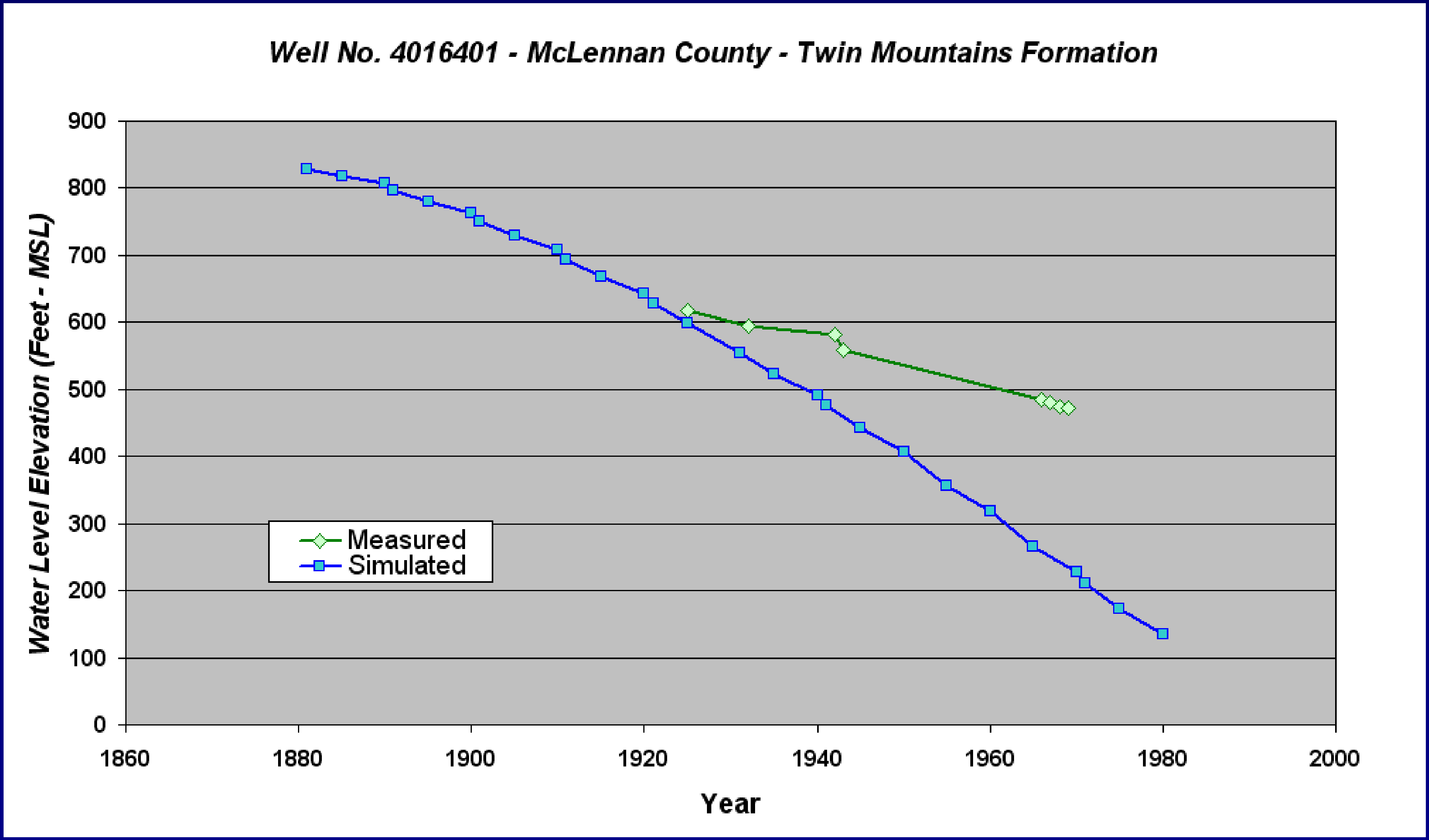
(Preliminary)



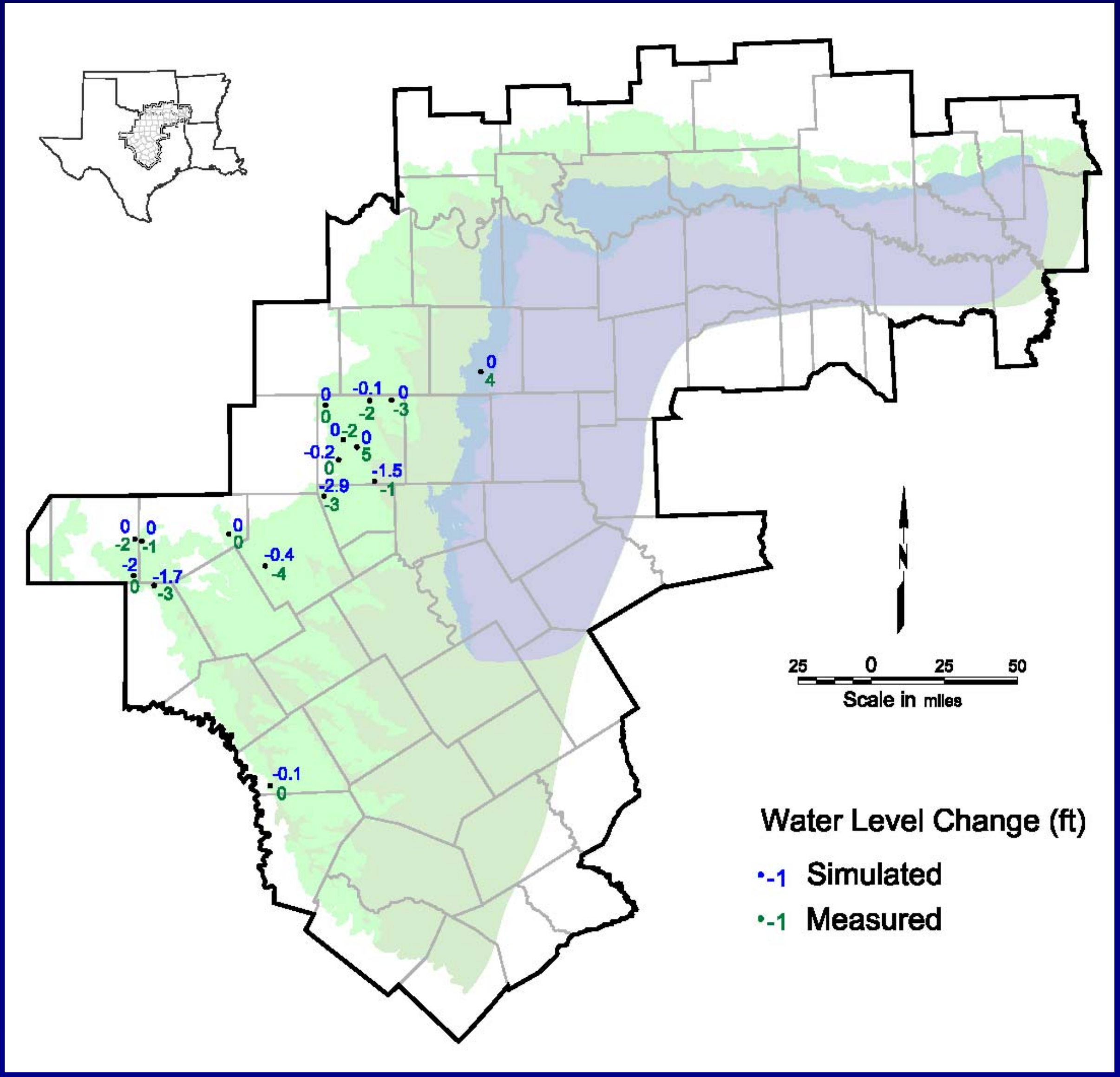
Simulated vs. Measured Water Levels
(Preliminary)



Simulated vs. Measured Water Levels
(Preliminary)



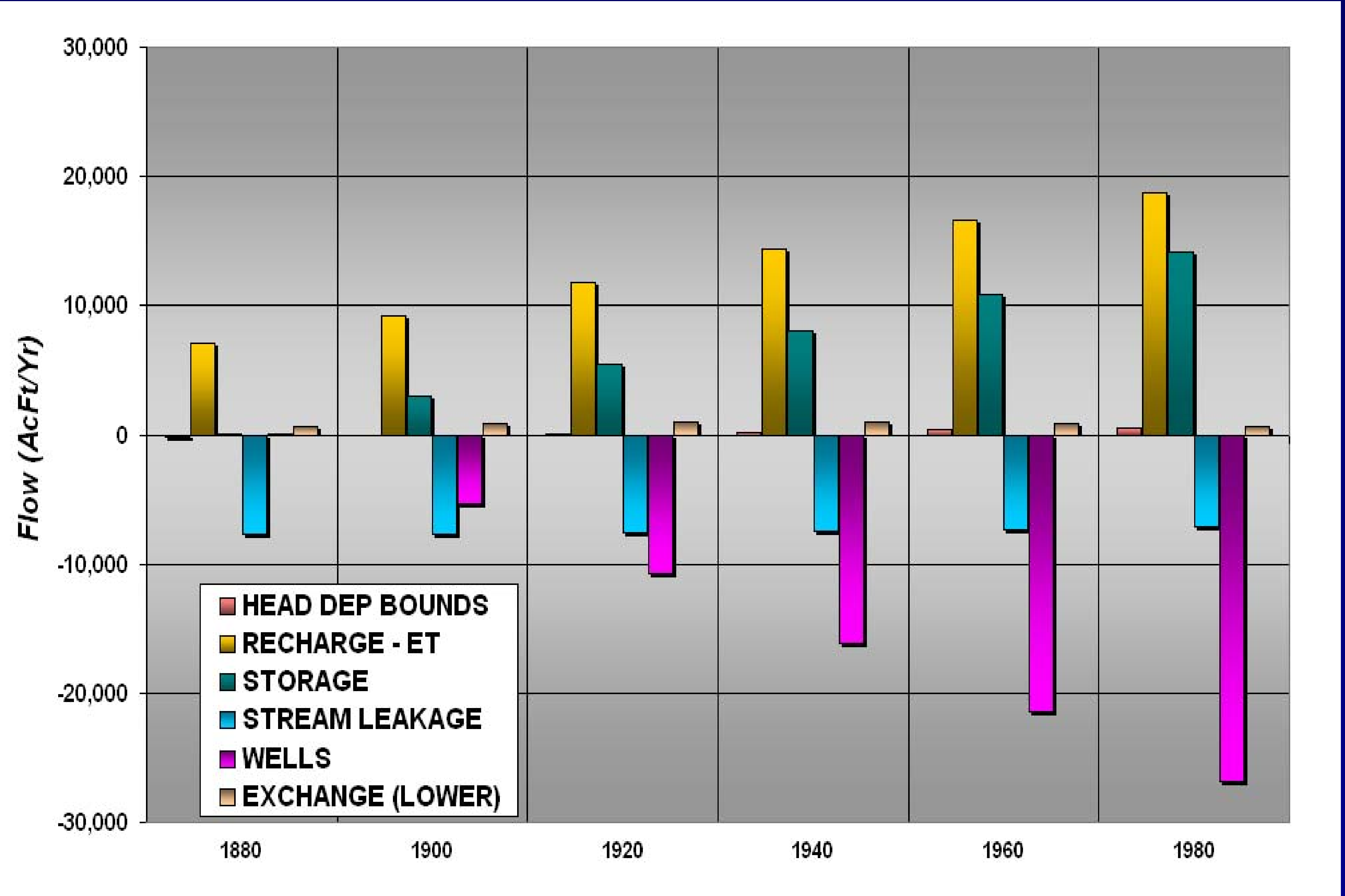
Water Table Change 1950-1980
(Preliminary)



Preliminary Steady-State/Transitional Model Calibration Results

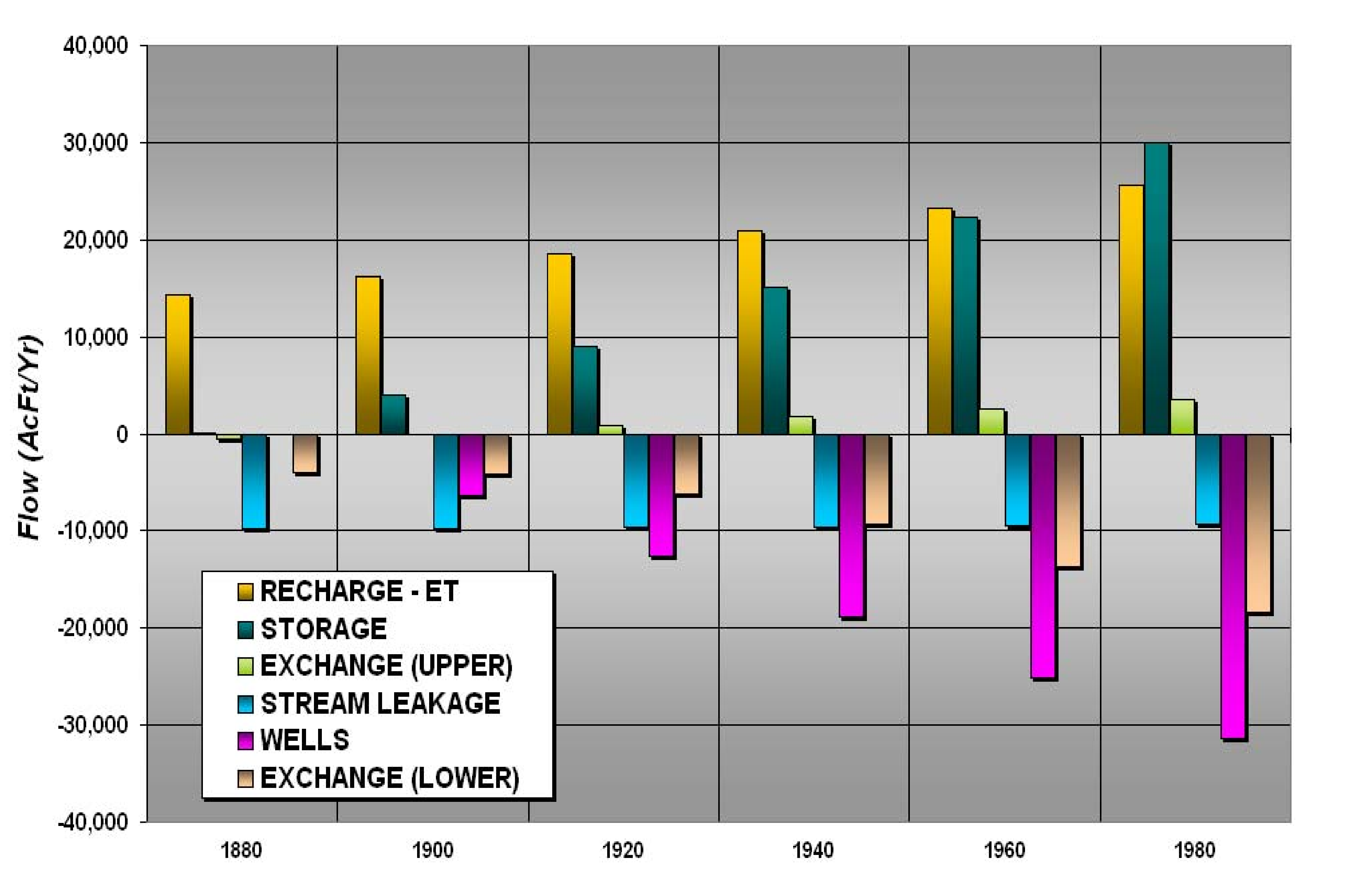
Aquifer	*Mean Residual (ft)*	*Mean ABS Residual (ft)*	*RMS Residual (ft)*	*Total Measured Head Drop (ft)*	*RMS Percent of Measured Drop*
Woodbine	33.5	62.7	80.1	856	9.4%
Paluxy	20.9	47.7	70.4	1,699	4.1%
Hensell	40.9	55.4	67.8	1,794	3.8%
Hosston	-18.1	62.2	92.1	2,639	3.5%

Woodbine Water Budget
(Preliminary)

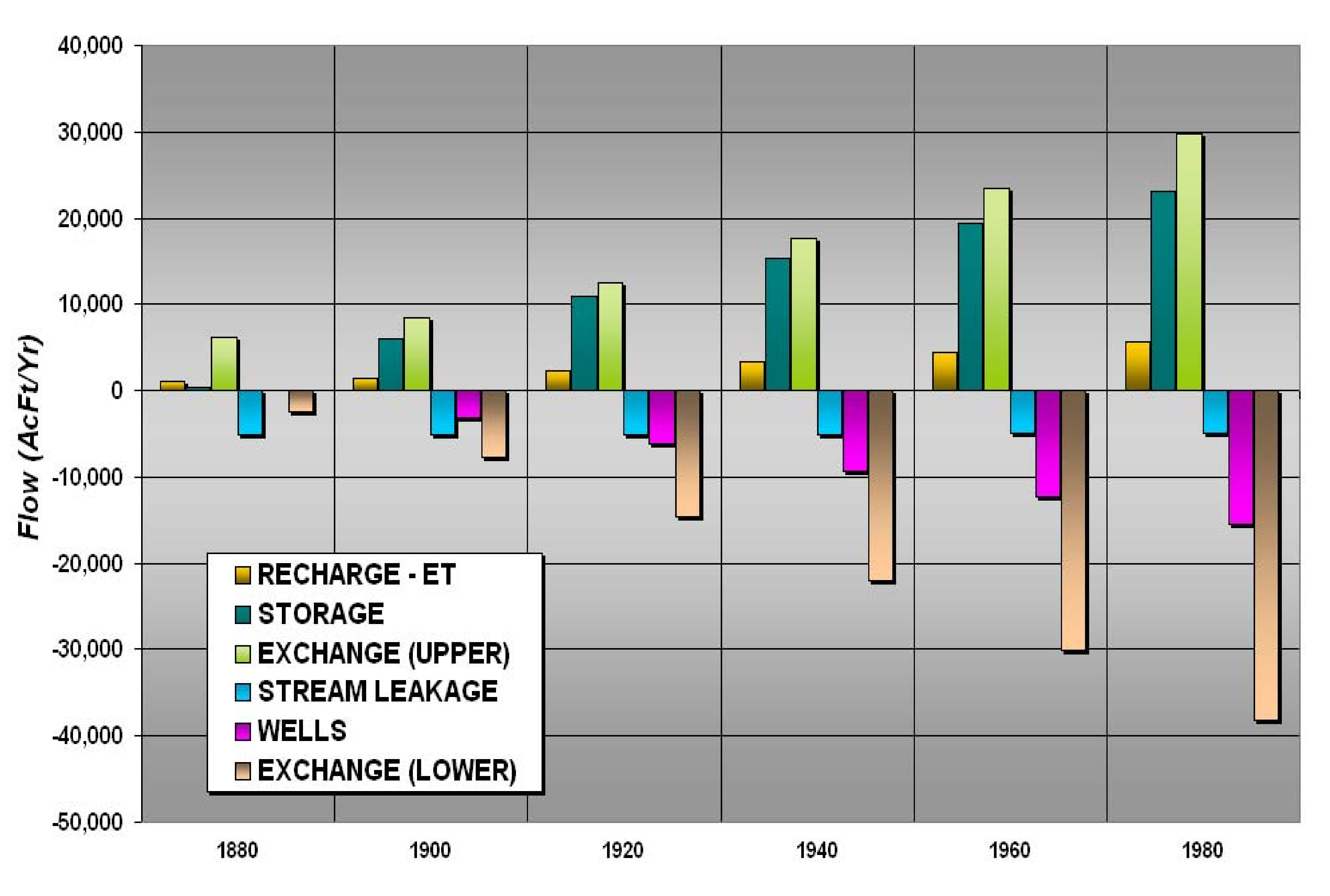


Paluxy Water Budget

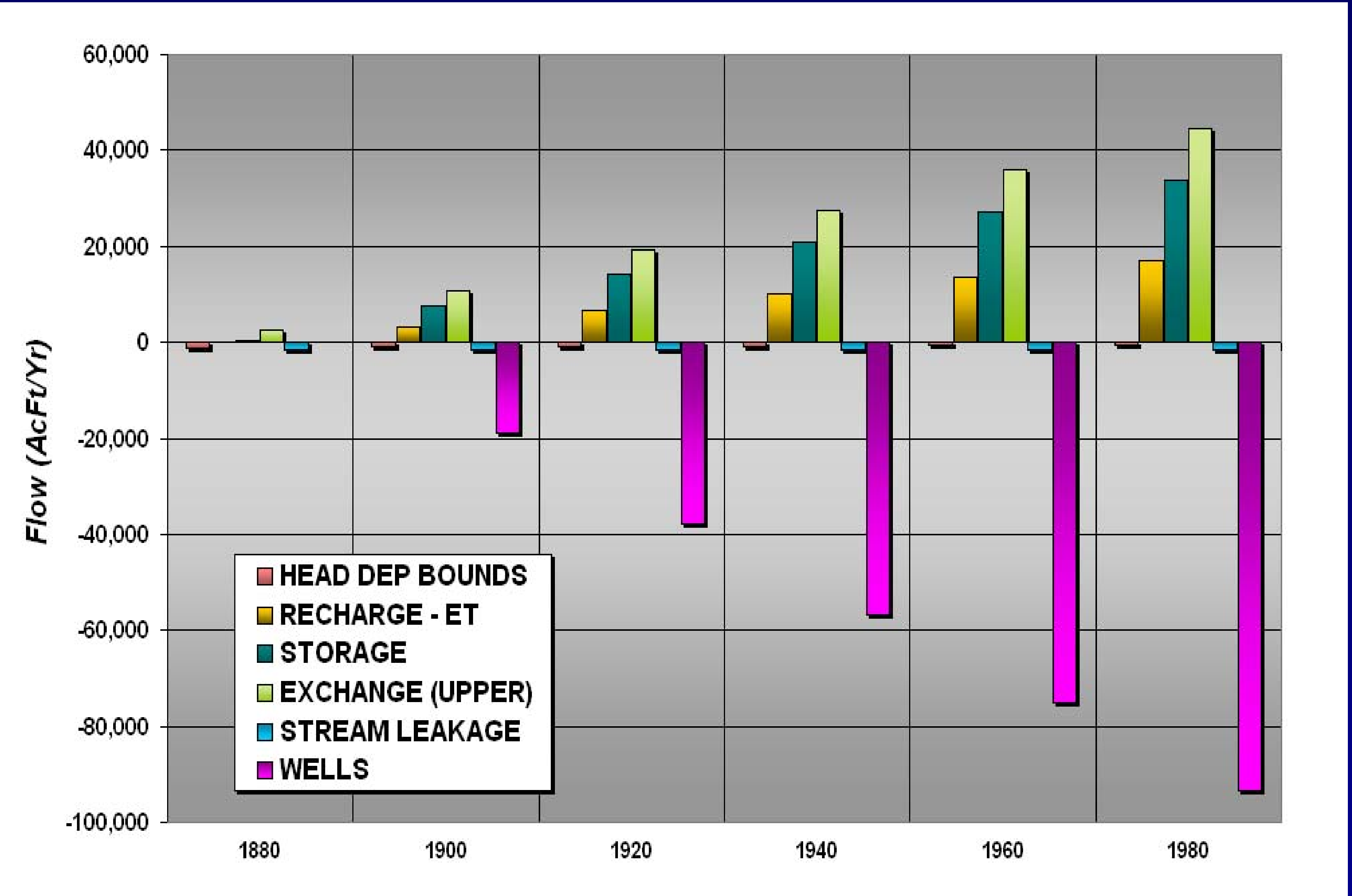
(Preliminary)



Hensell Water Budget
(Preliminary)

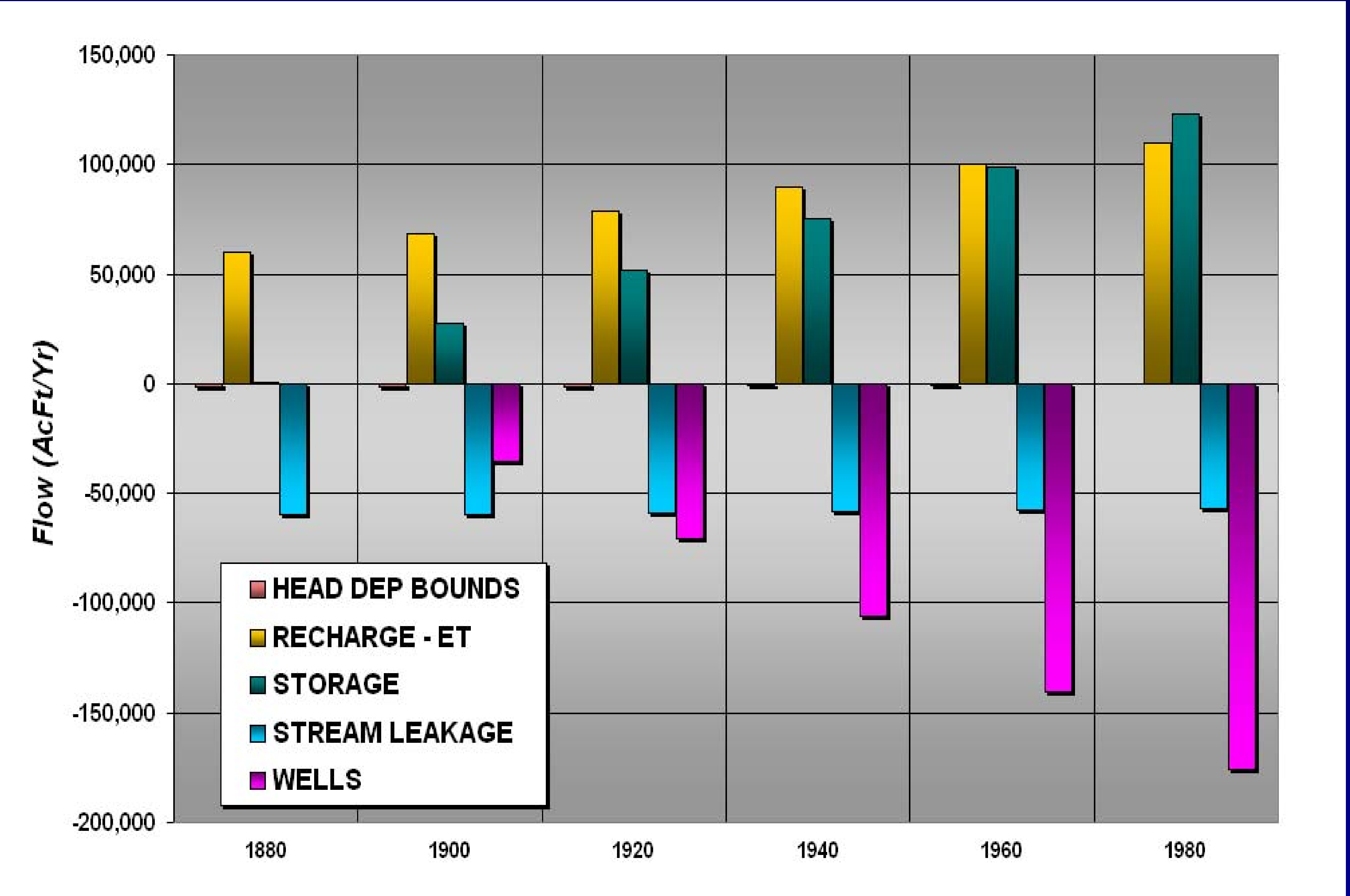


Hosston Water Budget
(Preliminary)

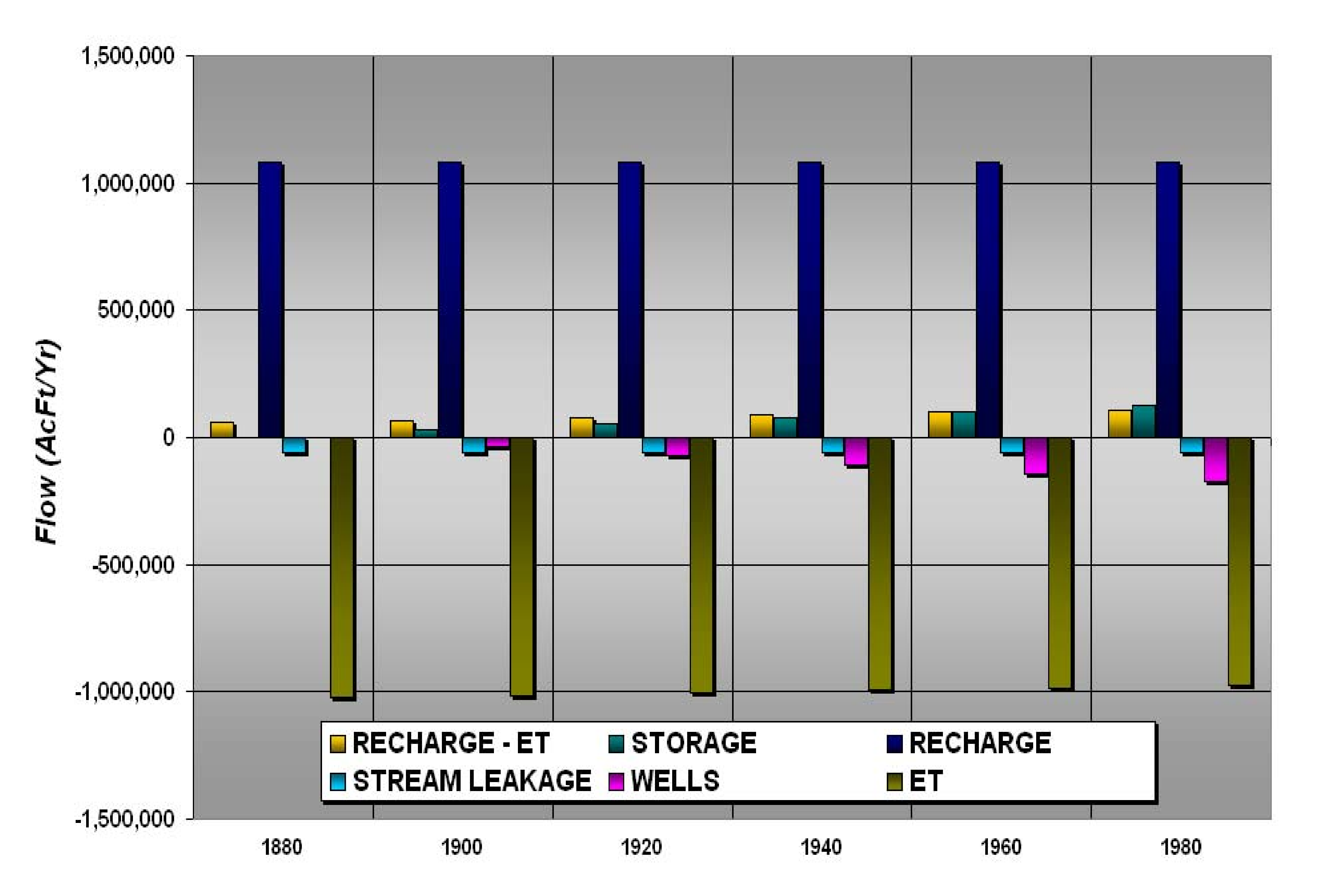


Whole Model Water Budget

(Preliminary)



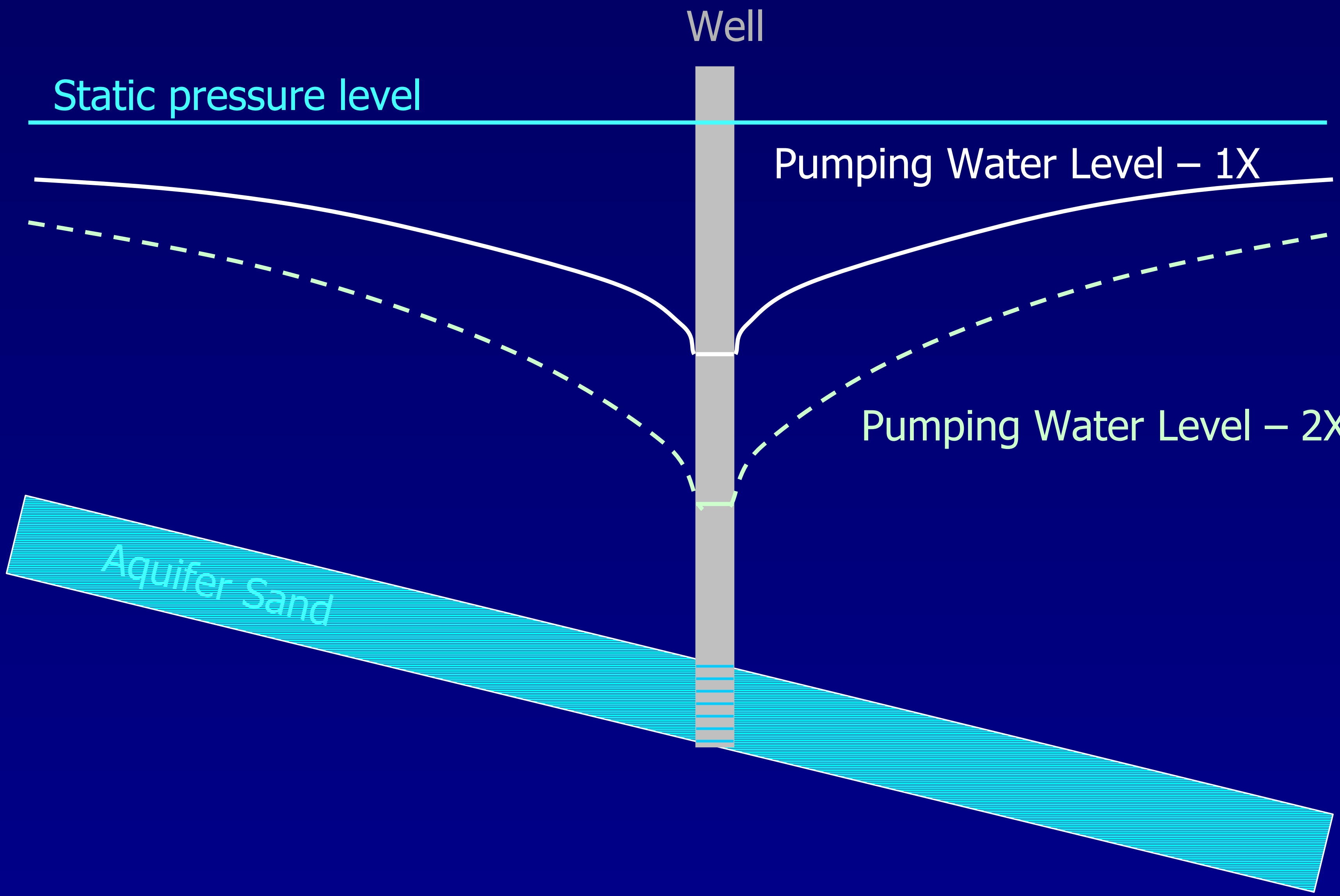
Whole Model Water Budget Cont.
(Preliminary)



Supply Issues for Aquifer

- Artesian drawdown directly proportional to pumpage

Well Pumping Characteristics



Supply Issues for Aquifer

- Distinguish between:
  - Annual average pumping rate
    - Controls long-term water level trend of aquifer
  - Peak pumping rate
    - Typically summer use
    - Higher rate than annual average use

Project Schedule Milestones

- Project Initiation - January 2003
- Draft Conceptual Model Complete – August 2003
- Model Development Begins – Sept. 2003
- Study Completion Date – March 2004
- Final Report - August 2004

Northern Trinity / Woodbine Groundwater Availability Model

SAF Open Discussion

Stakeholder Advisory Forum Meeting
Northern Trinity-Woodbine Aquifer GAM
3-Dec-03

Name	**Representing**
Bob Harden	R.W. Harden & Associates, Inc.
James Bene	R.W. Harden & Associates, Inc.
Tracy Relinski	R.W. Harden & Associates, Inc.
Stephanie Griffin	Freese & Nichols, Inc.
James Beach	LBG-Guyton Associates
Andy Donnelly	LBG-Guyt
Ali Chowdhury	T.W.D.B.
David Wachal	City of Denton
Gary W. Fisher	Dannenbaum
Mary Daly	City of Alvarado
Jacqueline Culton	City of Dallas/Water
Sharon Hayes	City of Weatherford
Paul Phillips	City of Weatherford
Jerry Chapman	GTUA
George Shannon	TRWD
Natalie Houston	USGS
Phillip Price	Brazos River Authority
David Wheelock	Brazos River Authority
Virgil Helm	City of DeSoto
Louis Fleischhauer	Kleinfelder

Summary of Questions/Answers
SAF No. 3
Brazos River Authority
Waco, Texas
December 3rd ,2003

1. Q: Have you used the ET Package to simulate evapotranspiration in the model?

A: Yes, we have used MODFLOW's ET Package to simulate evapotranspiration in the model. The maximum ET rate was initially set such that when water levels in the model are at the top of the cell in outcrop zones water is extracted at measured lake evaporation rates. The ET extinction depth was set to correspond to average plant rooting depths in the cell area.

2. Q: Do you have enough data available from the USGS on stream leakage?

A: We are currently in the process of compiling the rates at which streams in the model area either gain or lose water to the aquifer. These estimates will be more applicable to recent timeframes rather than the predevelopment period.

3. Q: Can you determine the rate at which water moved through the aquifer?

A: We can but have not calculated the rate this time. We can do this relatively easily and will provide this at the next SAF meeting.

4. Q: If the lowest strata remains the same all of the time, why doesn't the upper draw off the lower?

A: Following production in the aquifer, the water levels in the lowest Trinity/Woodbine strata (Hosston Formation) were, in general, lower than the water levels in the overlying strata. Because groundwater flows from regions (or layers) of high water level or high pressure to regions (or layers) of lower water level or lower pressure, the leakage is primarily in the downward direction within the model area.

5: Q: Are there instances of inter-basin transfer between aquifers?

A: There are no instances of transfer of water between the Trinity/Woodbine and other major aquifers. The Trinity/Woodbine are separate from the Ogallala or the Carrizo-Wilcox aquifers.

6: Q: How did you simulate flow in the Hosston and the Hensell in areas where those aquifers are not present or not clearly defined stratigraphically?

A: In areas where these units are not present, or not clearly defined, the structure of those units was interpolated from the nearest elevation data. The hydraulic conductivity of the units in these areas was adjusted (through the application of net sand thickness maps) to simulate flow through less permeable sediments.

7: Q: Have you examined the recharge ratio to rainfall compared with streamflow?

A: We have not examined that ratio at this time but will be looked at closely as model development continues. Additional, adjustments of recharge, evapotranspiration, and stream leakage are likely in the next phases of work. Such work will mainly result in a change in the water budget and only small changes to simulated water levels.

8: Q. The recharge values in the water budget appear uniform. Doesn't recharge vary from time to time.

A. We have used an annual average for the estimated recharge input into the model. Over, the long-term the average recharge is what is important not annual fluctuations. Therefore, it is suitable to use the average recharge for this transitional model. During the calibration/verification phases, recharge will vary annually as a direct response to precipitation rates.