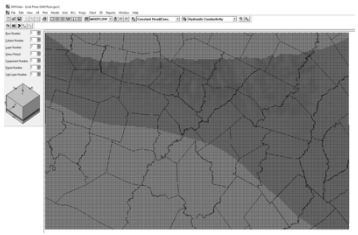
Modeling and Planning

The Joint Groundwater Planning Process and Groundwater Models



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Daniel B. Stephens and Associates

Groundwater Management in Texas

- Water is critical to Texas
- Groundwater in Texas is subject to the "Rule of Capture", established in 1904 *(Houston & Texas Central Railroad Co. v. East))*
- Groundwater Conservation Districts (GCDs) are the State of Texas preferred method of managing groundwater

Joint Groundwater Planning

- Regional Water Planning has been going on for over 20 years
- Groundwater accounts for over half of the water used within Texas
- For such an important natural resource, joint planning from a groundwater perspective was viewed as necessary

Joint Groundwater Planning

- House Bill 1763 regionalizes decisions made regarding groundwater
- Groundwater Conservation Districts are charged with joint groundwater planning
- Decisions on availability of groundwater must be used in Regional Water Planning process

Joint Groundwater Planning Lingo

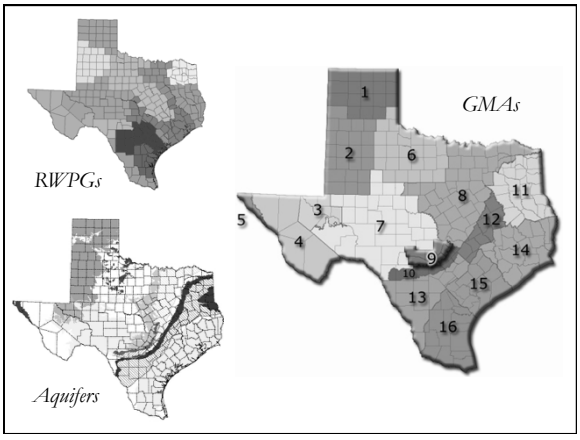
"A GMA, which is made up of GCDs, will adopt DFCs. The TWDB will use the DFCs to determine a MAG using the GAM."

Acronyms, Acronyms, Acronyms...

- GMA- Groundwater Management Area
- GAM- Groundwater Availability Model
- MAG- Modeled Available Groundwater
- DFC- Desired Future Condition
- TERS- Total Estimated Recoverable Storage
- TWDB- Texas Water Development Board
- GCD- Groundwater Conservation District

GMA

- Groundwater Management Area
- Texas has been divided into 16 GMAs
- GMA boundaries are generally aligned with the major aquifers of Texas
- GMAs are composed of Groundwater Conservation Districts
- Makes the regional decisions regarding groundwater management goals
- As with RWP, operate on 5-year cycles



GMA 12

- Lost Pines GCD
- Fayette County GCD
- Post Oak-Savannah GCD
- Brazos Valley GCD
- Mid-East Texas GCD

DFCs (aka Desired Future Conditions)

- Desired future conditions--The desired, quantified condition of groundwater resources (such as water levels, water quality, spring flows, or volumes) for a specified aquifer within a management area at a specified time or times in the future, through at least the period that includes the current planning period for the development of regional water plans pursuant to §16.053, Texas Water Code, or in perpetuity, as defined by participating groundwater conservation districts within a groundwater management area as part of the joint planning process. Desired future conditions have to be physically possible, individually and collectively, if different desired future conditions are stated for different geographic areas overlying an aquifer or subdivision of an aquifer.

DFCs

- Desired Future Condition of an aquifer
- Basically it is what you want your aquifer(s) to "look like" at some point in the future
- "Look like" refers to a physical condition of the aquifer (water levels, spring discharge, etc.)
- They have to be physically possible, individually and collectively

DFCs

- Can relate to water levels, discharge to springs/rivers, water in storage, or any other aquifer condition
- Must be quantifiable. They need to exactly define (numerically) a specific condition about the aquifer
- Typically related to a specific condition 50 years in the future to match RWP planning period

Example DFCs

- "The average drawdown in the Carrizo Aquifer in the Lost Pines GCD should be 62 feet by 2070."
- "Must maintain at least 100 acre-feet per month of stream/spring flow in Salado Creek during a repeat of the drought of record."
- "At least 80 percent of volume in storage in Hemphill County will remain in 50 years."

MAG

- MAG= **M**odeled **A**vailable **G**roundwater
- Is the amount of groundwater that can be produced that will result in the DFCs being met.
- Essentially the "availability" of water from an aquifer
- It is **NOT** the *physical* availability, but rather is an amount based on policy + science
- Policy side are the DFCs that are decided by the GMA and adopted by the GCDs
- Calculations will be made or verified by TWDB staff using the GAM

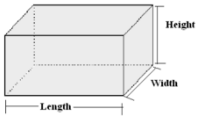
DFCs and MAGs

GMAs establish "Desired Future Conditions" (DFCs)

TWDB calculates or verifies "Modeled Available Groundwater" (MAGs)

TERS

- TERS- **T**otal **E**stimated **R**ecoverable **S**torage
- The estimated volume of water present in each aquifer based on aquifer extent, thickness, storage parameters
- Not based on water quality, ability of the aquifer to produce water, impacts of significant groundwater production



GAM

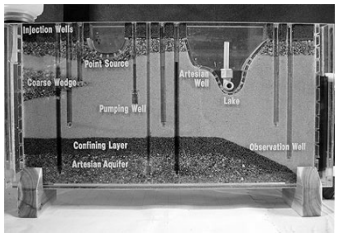
- **G**roundwater **A**vailability **M**odel
- Initiative by the TWDB started in 1999
- Develop regional groundwater flow models of all major and minor aquifers.

What is a Model?

- mod●el (mod*l*), *n*. 10. a simplified representation of a system or phenomenon….. *Webster's Dictionary*
- "A model is any device that represents an approximation of a field situation" *Anderson and Woessner (1992)*
- "a representation of reality that attempts to explain some aspect of it and is always less complex than the system it represents" *Domenico (1972)*

Types of Groundwater Models

- Models can be a physical model such as sand tanks to simulate groundwater flow.



Types of Groundwater Models

- Or a model can be a mathematical model that simulates groundwater flow.

What is a Groundwater Model?

- "representation of reality" = numerical representation of a groundwater flow system
- simplified numerical representation of a more complex groundwater flow system
- "All models are wrong, some are useful." *George Box*

Numerical Groundwater Models

- Numerical models involve a **code** or computer program. The basic code is generic, and doesn't change from application to application.
- The most commonly used code is **MODFLOW**.

What is MODFLOW?

- MODFLOW is a **modular** three-dimensional, finite-difference groundwater **flow** model.
- Developed by the USGS in the 1980s
- Fortran
- "Modular" = individual model packages are easily included or excluded
- Most commonly used groundwater flow model—the industry standard
- Rapidly evolving- more and more capabilities are being added every year

Numerical Groundwater Models

- Your "model" is the set of aquifer-specific parameters used by the code to represent the aquifer.
- These go into the code as **inputs**.
- Inputs may include pumpage, recharge, aquifer properties, surface water parameters, etc.

```
         0         50    999.000          0      0.200          2          0          0          0
 1
         0      1.000(10E12.4)                  0      ANISOTROPY
         0   2640.000(10E12.4)                  0      DELTA-X or C
         0   2640.000(10E12.4)                  0      DELTA-Y or R
        11      1.000(10e15.6)                 -1      PRIMARY STORAGE Layer   1
   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03
   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03
   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03
   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03
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   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03   5.000000e-03
   5.000000e-03
```

So Why Make a Groundwater Model?

- **Research**- To help us understand our aquifers……to help us understand what parameters may be important to flow within an aquifer.
- **Planning**- To help develop strategies to manage our aquifers.
- **Predictions**- People are interested in predicting the future……what are the possible consequences of our actions? Models allow us to quantify predictions.

Constructing a Groundwater Model

- Identify the purpose of the model
- Data collection
- Conceptual model
- Design of groundwater model
- Calibration of groundwater model
- Using the groundwater model

Identifying the Purpose

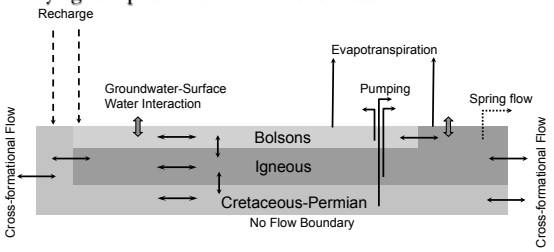
- Define your **objectives**!!!!
- Why build a better gadget if you don't know what you're going to do with the gadget?
- The purpose should be defined before the project even begins.

Data Collection

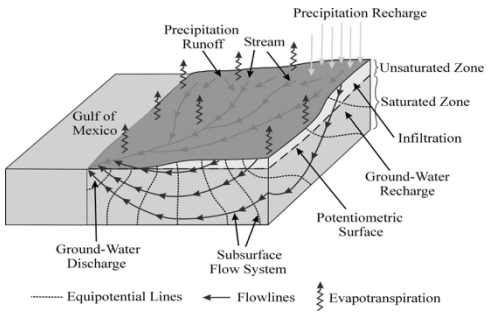
- Very important part of the initial effort in constructing a groundwater model.
- Data is typically found in many locations, can be hard to track down.
- Will typically require a substantial amount of effort, even without development of new data (i.e. field work).
- Data collected will be the basis for any future modeling work (enhancements, etc.)

Conceptual Model

- A conceptual model is typically considered to be a pictoral representation of the groundwater flow system you are trying to represent with a numeric model



Conceptual Model



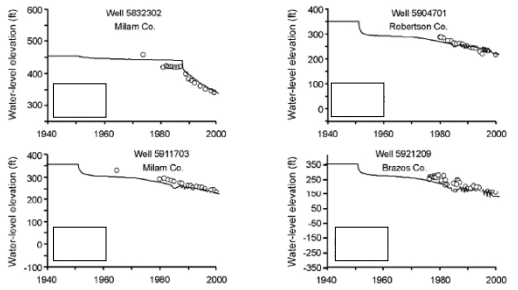
Groundwater Model Design

- Based on the conceptual model, the defined purpose of the model, and the available data, you can begin to design the groundwater model.
- Design elements include:
  - Determining grid size, "time step" length
  - Layers to model
  - What components impacting groundwater flow should be included
  - Inputting initial parameter estimates

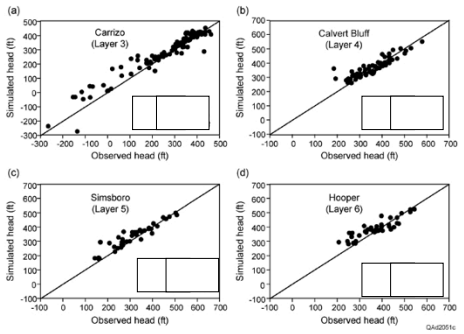
Calibration

- Calibration is the process of adjusting model properties so that your model results match your calibration "targets".
- Calibration Target- Historic measurements, most commonly water levels. Sometimes also includes spring discharge, river/stream flows.

Target Matching



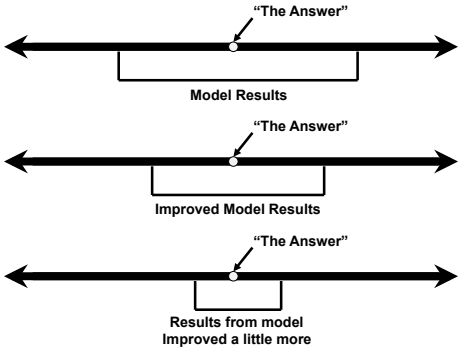
Target Matching



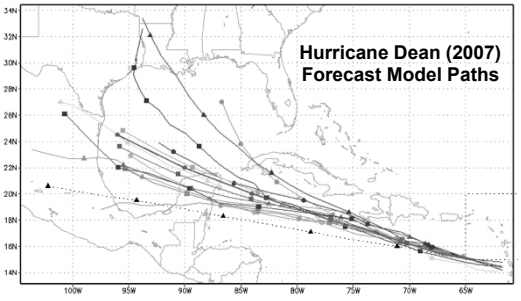
Calibration

- Calibration is **"non-unique"**
- Models (not just groundwater models) don't give you **THE** answer, they give **AN** answer.
- A groundwater model is a **TOOL**

Model Results



Hurricane Models



Using Your Groundwater Model

- Once calibrated a model can be used in predictive simulations
- A well-calibrated model **does not** guarantee accurate predictions
- "It's tough to make predictions, especially about the future." *Yogi Berra*

What Goes Into a Groundwater Model?

- Pumpage
- Recharge
- Aquifer properties
- Surface water features
- Other parameters

Pumpage

- Should be the one parameter for which we have a good estimate.
- In Texas, this typically isn't true, especially for historic pumpage.
- Often has to be estimated.

Recharge

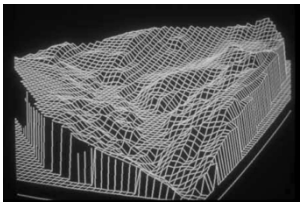
- Very important parameter
- Poorly quantified parameter
- Estimates vary widely
- Many methods to estimate.

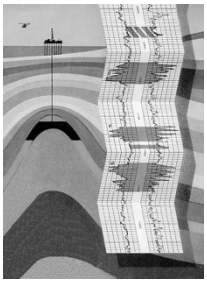
Aquifer Properties

- Hydraulic conductivity/transmissivity
- Storage coefficients

Aquifer Properties

- Aquifer geometry- top and bottom elevations





Aquifer Properties

- These are all often characterized by a lack of data
- Additionally, the data that we do have can vary significantly over short distances for reasons including:
  - Where and how wells are screened or constructed
  - Natural variations in aquifer properties

Surface Water

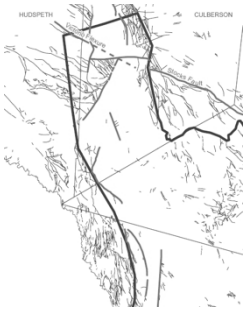
- Surface water data (with respect to surface water/ groundwater interaction) is often characterized by a lack of data.

Surface Water

- Great care must be used when evaluating the results of surface water packages in a groundwater model.
- They are mostly used as just a tool to add/ remove water from the groundwater budget/ system, and not as a calibration target.
- Must evaluate the calibration process before determining if surface water results can be used quantitatively.

Other Components

- Evapotranspiration
- Faults
- Subsidence
- Anything that significantly impacts the groundwater flow system



What Doesn't Go Into a Groundwater Model?

- Water levels (except initial water levels)- Water levels are calculated by the model and are outputs.
- Specific data from individual wells (especially in a regional model like a GAM)
- Pumpage from an individual well may be lumped in with other pumpage

What Doesn't Go Into a Groundwater Model?

- Population
- Water Demand
- Water Use
- Water Strategies
- Precipitation or other weather factors

Limitations

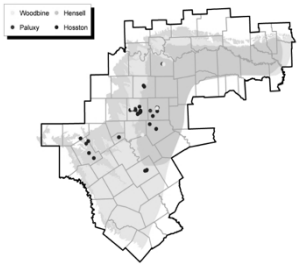
- Due to the nature of models (they are simplified representations of a complex system), they have limitations.
- Need to understand the limitations of the model to properly interpret results.
- Remember: Models don't give **THE** answer, they give **AN** answer.
- Any good report on a groundwater model should discuss limitations.

Limitations

- Data the model is based on
- Conceptual model
- How the model was constructed
- How the model is used

Data Limitations

- Limited data available for many parameters
- **Assumptions** must be made because the model requires inputs for parameters even if there is no data



The Nature of Hydrogeology

- Often sparse data availability
- We rarely can "see" an aquifer
- Collecting even basic data can be expensive and time-consuming
- Assumptions are inevitable
- "All exact science is dominated by the idea of approximation." **Bertrand Russell**

Errors with Assumptions

- "The world always makes the assumption that the exposure of an error is identical with the discovery of truth--that the error and truth are simply opposite. They are nothing of the sort. What the world turns to, when it is cured of one error, is usually simply another error, and maybe one worse than the first one."

H. L. Mencken

The Issue of Scale

- The ability of a model to simulate certain types of scenarios depends on the scale of the model.
- Scale refers to both space and time
- Just because you have created a model of an aquifer doesn't mean it can necessarily model what you want it to model. The scale of the model has to match the application.

Regional vs. Local Scale Models

- The purpose of your model will define how you design your model
- Regional-scale models examine regional-scale issues
- Local-scale model examine local-scale issues
- "Time steps" in the model impact what types of temporal issues can be evaluated

Groundwater Model Summary

- Models are simplified representations of much more complex systems
- All models have limitations. Understand them.
- Groundwater models are **TOOLS**
- A groundwater model won't give you **THE** answer, it gives you **AN** answer.
- A well calibrated model will not necessarily give you accurate predictions.
- Understand how the model was put together in order to properly use it.
- A **GAM** is a regional-scale groundwater model.

Lost Pines GCD/GMA 12 GAM

- Central Queen City-Sparta GAM (2004)
- Includes the Carrizo-Wilcox Aquifer; the GAM is based on the C-W GAM developed in 2002.
- Includes the Sparta, Queen City, Carrizo, and three Wilcox Aquifers (*Calvert Bluff, Simsboro, Hooper*).
- Covers all of GMA 12
- Currently being updated

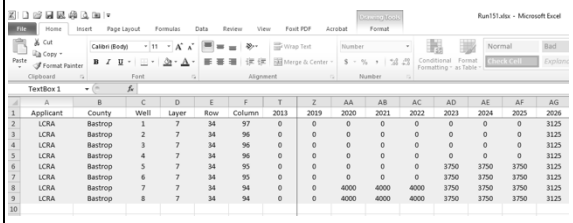
Lost Pines GCD/GMA 12 GAM

- Can be obtained from the TWDB GAM Section
- Can obtain MODFLOW input data files
- Available to anyone free of charge
- Need to be able to use these files to run MODFLOW and analyze the results

Lost Pines GCD/GMA 12 GAM

- Different modelers have different methods to create input files, run MODFLOW, and evaluate results
- My method:
  - Excel is used to create text files *(Input)*
  - Custom-written Fortran programs *(Input)*
  - MFWin32 executable program *(Running the model)*
  - Groundwater Vistas *(Output)*
  - GIS *(Output)*

Input



	A	B	C	D	E	F	T	Z	AA	AB	AC	AD	AE	AF	AG
1	Applicant	County	Well	Layer	Row	Column	2013	2019	2020	2021	2022	2023	2024	2025	2026
2	LCRA	Bastrop	1	7	34	97	0	0	0	0	0	0	0	0	3125
3	LCRA	Bastrop	2	7	34	96	0	0	0	0	0	0	0	0	3125
4	LCRA	Bastrop	3	7	34	96	0	0	0	0	0	0	0	0	3125
5	LCRA	Bastrop	4	7	34	96	0	0	0	0	0	0	0	0	3125
6	LCRA	Bastrop	5	7	34	95	0	0	0	0	0	3750	3750	3750	3125
7	LCRA	Bastrop	6	7	34	95	0	0	0	0	0	3750	3750	3750	3125
8	LCRA	Bastrop	7	7	34	94	0	0	4000	4000	4000	3750	3750	3750	3125
9	LCRA	Bastrop	8	7	34	94	0	0	4000	4000	4000	3750	3750	3750	3125
10															

Input

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 52696      50
 48333    SP =  1     YEAR = 1975
     1      30      1     -24.
     1      30      2     -48.
     1      31      1     -33.
     1      31      2     -76.
     1      31      3    -132.
     1      31      4    -314.
     1      31      5    -239.
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     1      32      4    -360.
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     1      32      6     -89.
     1      33      1    -167.
     1      33      2   -2459.
     1      33      3   -4470.
     1      33      4   -1541.
     1      33      5    -237.
     1      33      6    -141.
     1      33      7     -66.
     1      34      1    -137.
     1      34      7     -56.
     1      34      8    -108.
     1      34      9    -134.
     1      34     10    -150.
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     1      35      9    -111.
     1      35     10    -149.
     1      35     11     -83.
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     1      36      9    -103.
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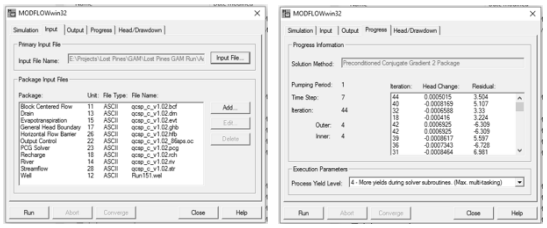
Running the GAM



Output File

```
   8 LAYERS       177 ROWS       273 COLUMNS
  86 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS DAYS
0I/O UNITS:
 ELEMENT OF IUNIT:  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
       I/O UNIT: 11 12 13 14 15  0 17 18  0  0  0 22  0 28 23 26  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0BAS1 -- BASIC MODEL PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT  1
 ARRAYS RHS AND BUFF WILL SHARE MEMORY.
 START HEAD WILL BE SAVED
    3817941 ELEMENTS IN X ARRAY ARE USED BY BAS
    3817841 ELEMENTS OF X ARRAY USED OUT OF   8330757
0BCF5 -- BLOCK-CENTERED FLOW PACKAGE, VERSION 5, 7/9/92 INPUT READ FROM UNIT 11
 TRANSIENT SIMULATION
 CELL-BY-CELL FLOWS WILL BE RECORDED ON UNIT 50
 HEAD AT CELLS THAT CONVERT TO DRY=  0.10000E+31
 WETTING CAPABILITY IS NOT ACTIVE
      LAYER  AQUIFER TYPE    INTERBLOCK T
      ------------------------------------
         1         3         0-HARMONIC
         2         3         0-HARMONIC
         3         3         0-HARMONIC
         4         3         0-HARMONIC
         5         3         0-HARMONIC
         6         3         0-HARMONIC
         7         3         0-HARMONIC
         8         3         0-HARMONIC
    2319408 ELEMENTS IN X ARRAY ARE USED BY BCF
    6137249 ELEMENTS OF X ARRAY USED OUT OF   8330757
0WEL1 -- WELL PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM 12
 MAXIMUM OF     52696 WELLS
 CELL-BY-CELL FLOWS WILL BE RECORDED ON UNIT 50
 DISCHARGE MULTIPLIER IS     1.0000
    210784 ELEMENTS IN X ARRAY ARE USED FOR WELLS
   6348033 ELEMENTS OF X ARRAY USED OUT OF   8330757
```

Output *(Heads File)*

```
023ce130h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce140h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce150h: 80 4F C3 47 CF EE E4 43 26 DB E3 43 08 30 E4 43 ; €OÃGÏîäC&ÛãC.0äC
023ce160h: D1 42 E3 43 91 CF DD 43 D3 41 D9 43 39 6B D5 43 ; ÑBãC'ÏÝCÓAÙC9kÕC
023ce170h: F6 C3 D2 43 9B E7 CF 43 D0 C3 CD 43 A7 BC CB 43 ; öÃÒC›çCÏCÐÃÍC§¼ËC
023ce180h: 4C CF C8 43 05 40 C6 43 87 51 C4 43 C0 E0 B8 43 ; LÏÈC.@ÆC‡QÄCÀà¸C
023ce190h: 69 C4 B6 43 CC 25 B6 43 BE 0F B6 43 BF 9E B5 43 ; iÄ¶CÌ%¶C¾.¶C¿µC
023ce1a0h: 1A AE B3 43 30 76 B1 43 BF 6C B0 43 74 39 B0 43 ; .®³C0v±C¿l°Ct9°C
023ce1b0h: A4 69 B0 43 00 6D B2 43 84 11 B5 43 04 35 B6 43 ; ¤i°C.m²C„.µC.5¶C
023ce1c0h: 2F D4 B5 43 7F 3A B1 43 F3 6A A3 43 E8 79 B6 43 ; /ÔµC.:±Cój£Cèy¶C
023ce1d0h: 35 73 B9 43 DE 82 B9 43 CA 95 B9 43 97 BD BB 43 ; 5s¹CÞ‚¹CÊ•¹C-»»C
023ce1e0h: 48 21 CE 43 C2 5D C7 43 92 D8 BD 43 21 A2 C4 43 ; H!ÎC Â]ÇC'Ø½C!¢ÄC
023ce1f0h: AA 35 C9 43 1F DA CD 43 19 1D CE 43 6D 5F C1 43 ; ª5ÉC.ÚÍC..ÎCm_ÁC
023ce200h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce210h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
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023ce230h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce240h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce250h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce260h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce270h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
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023ce2a0h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce2b0h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce2c0h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce2d0h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce2e0h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce2f0h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
023ce300h: 80 4F C3 47 80 4F C3 47 80 4F C3 47 80 4F C3 47 ; €OÃG€OÃG€OÃG€OÃG
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```
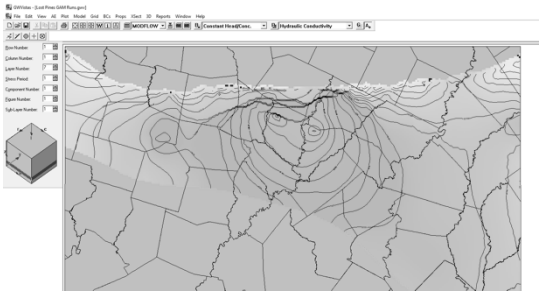
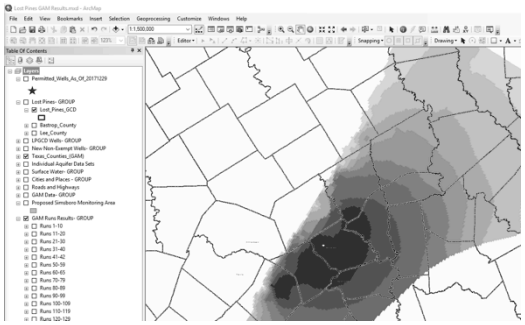

Groundwater Vistas



GIS



Running The GAM

- Running a GAM can be difficult
- Although MODFLOW is free, many of the programs that make it practical (possible) to use are not
- The revised GAM that will be available in 2018 will be significantly more difficult to use

Questions?????