Water-Management Modeling in a Karst Environment

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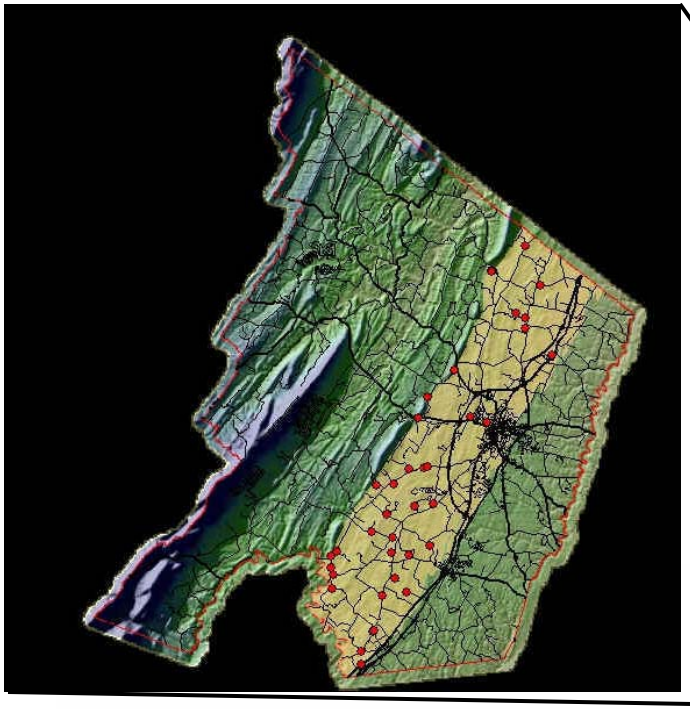
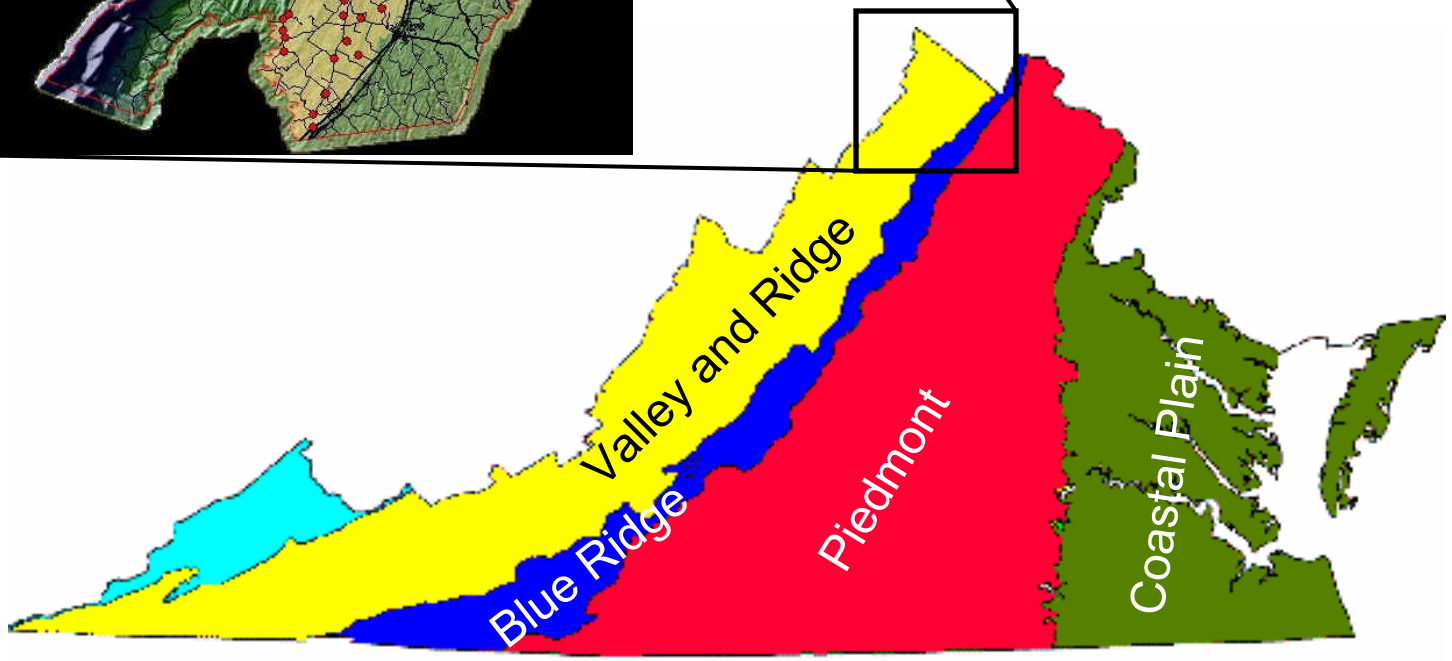
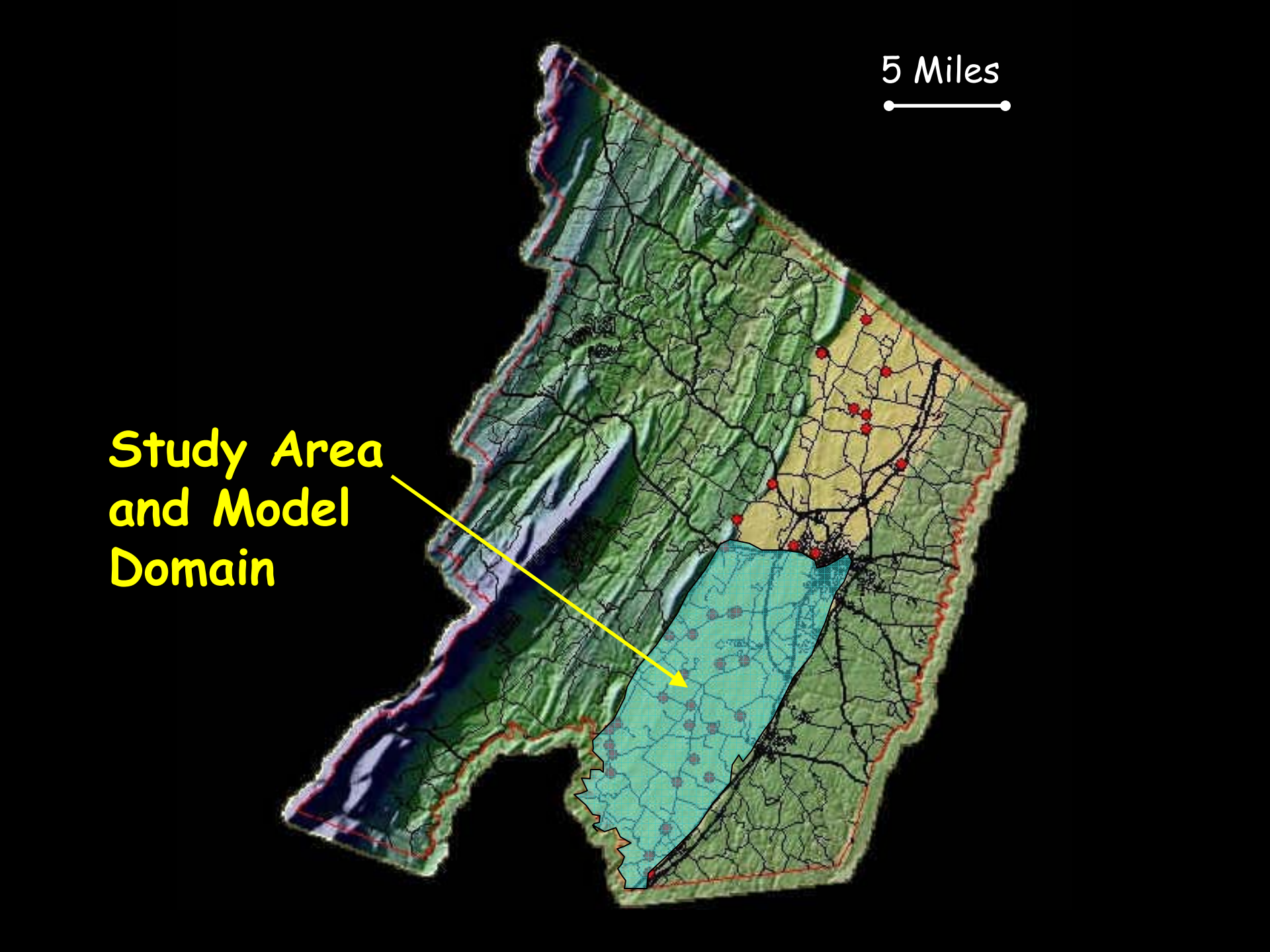
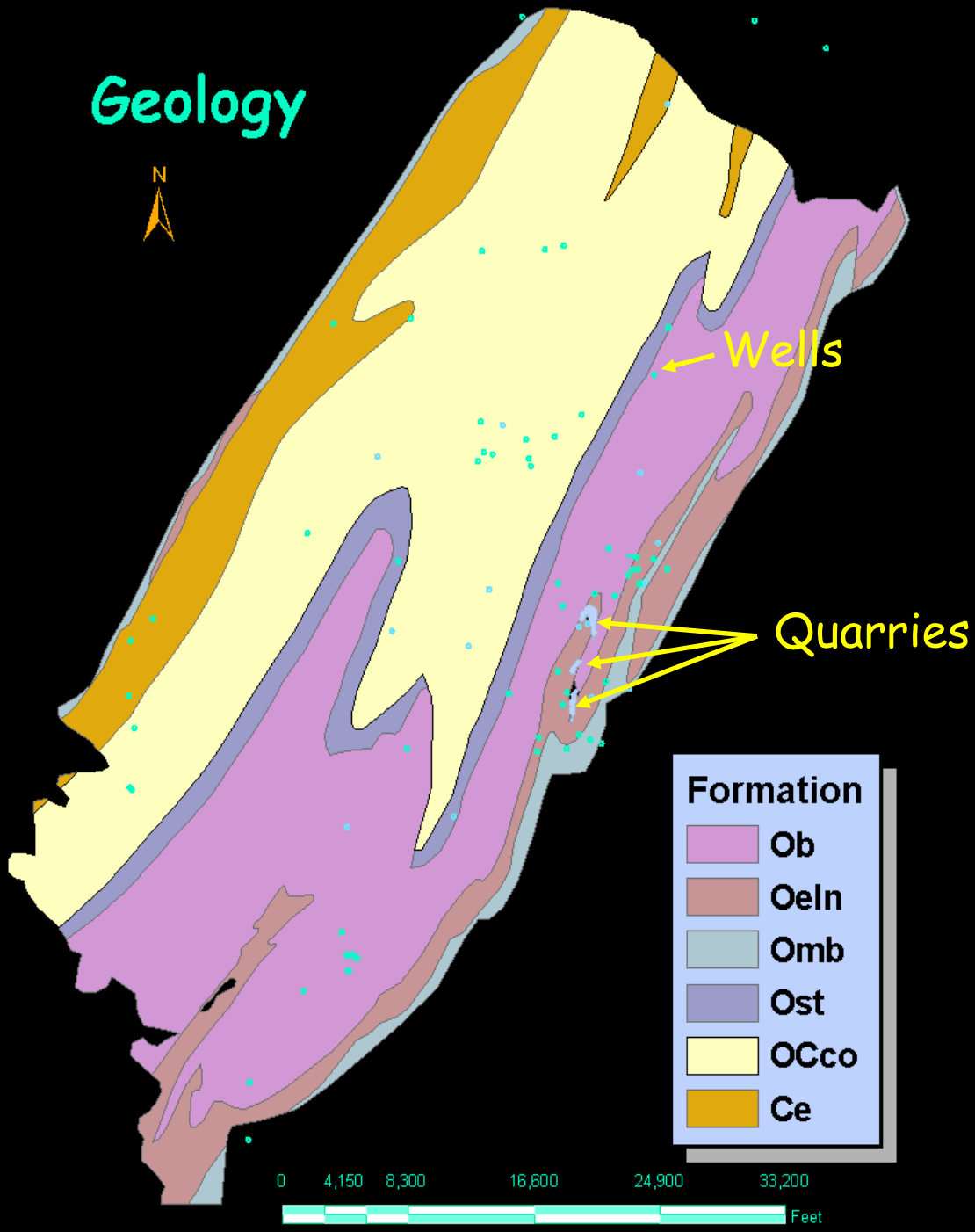
Study Area: Frederick County, Virginia






5 Miles
Study Area and Model Domain


Geology
N
Wells
Quarries
Formation
Ob
Oeln
Omb
Ost
OCco
Ce
0
4,150
8,300
16,600
24,900
33,200
Feet

Motivation for Investigation

- Concern of local farmers and residences that pumping will impact their wells
- FCSA wanted to know how much they could pump without drastically impacting water levels in the quarries during periods of drought
- Potential for sinkhole development

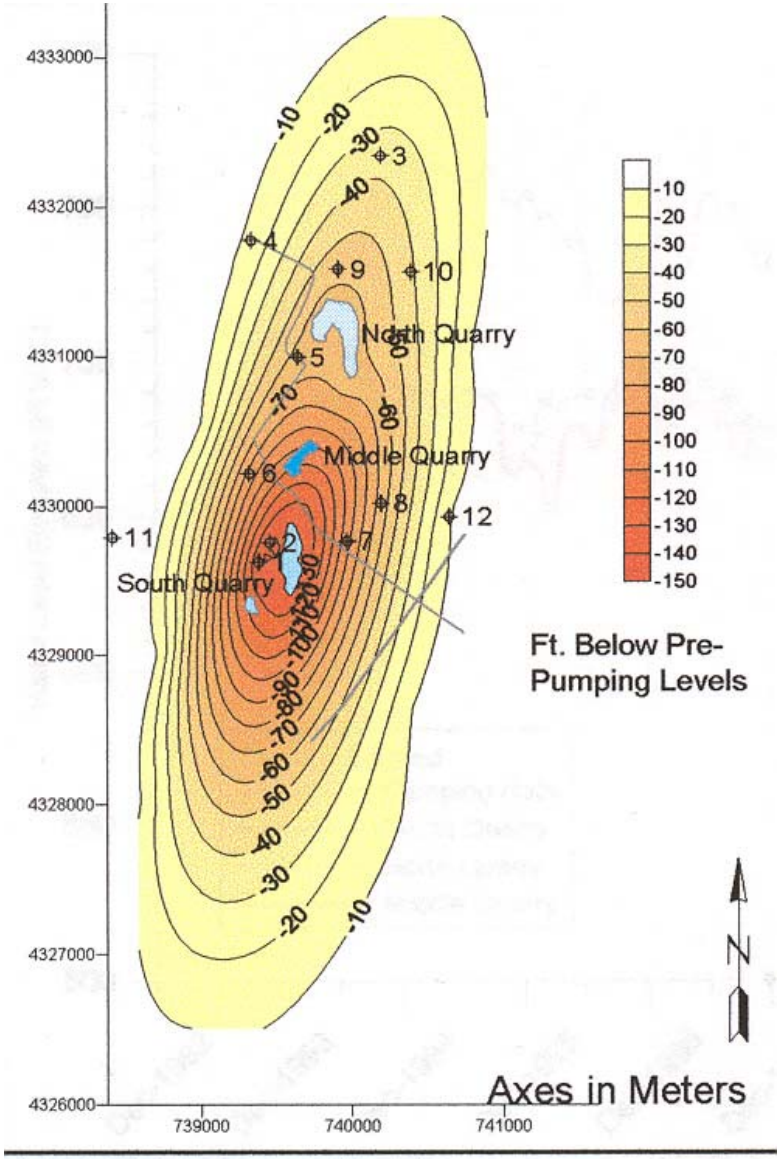


Illustration courtesy of ATS Int. Inc.

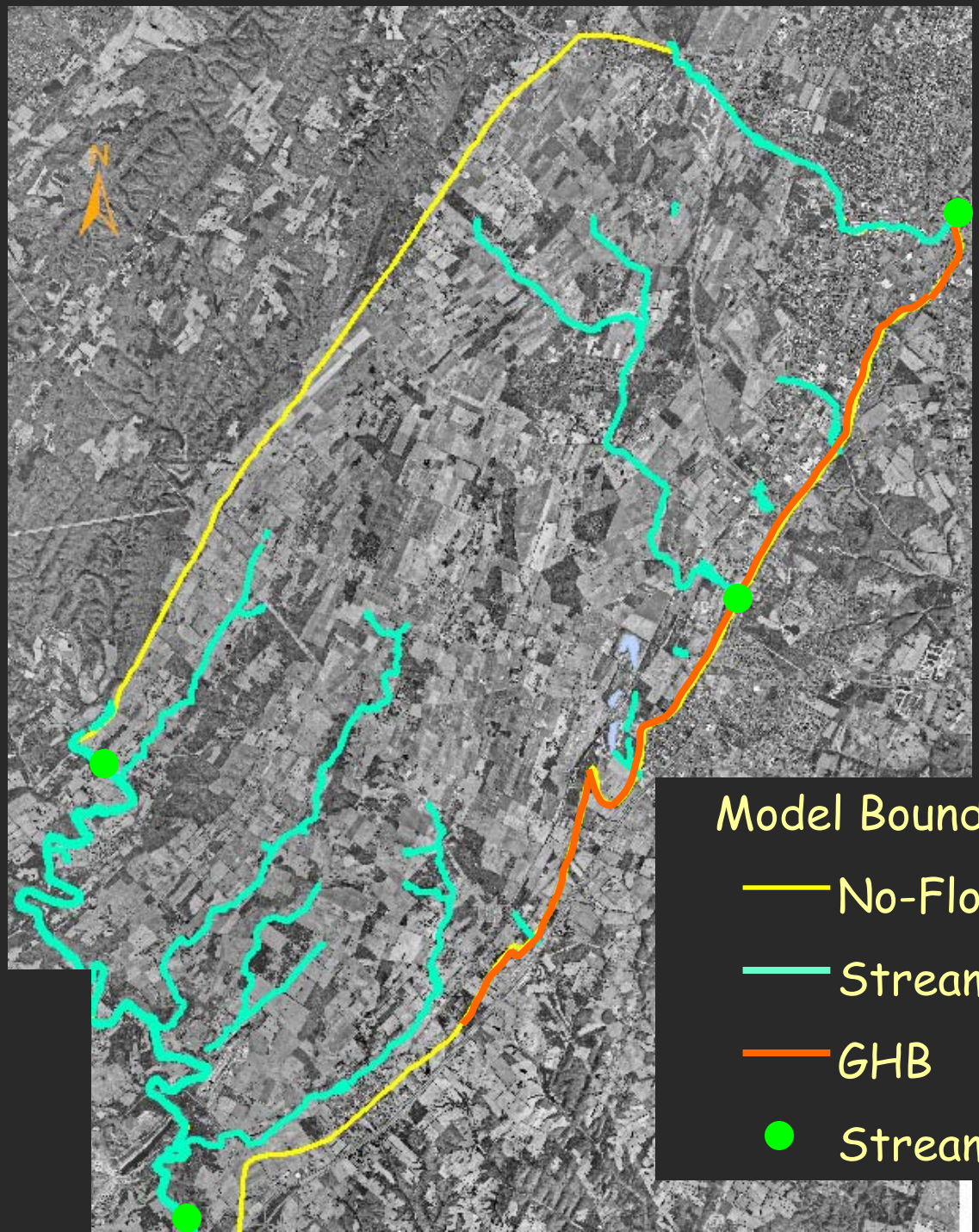
- Municipal pumping of nearly 2 million gpd from South quarry created an elongated cone of depression.
- Maximum drawdown occurred near end of 2001 and coincided with 5-year drought from 1997-2001.

Modeling Objectives

- Evaluate effects of municipal pumping from quarries based on current recharge estimates and local inflows
- Estimate a monthly recharge flux
- Provide a water-management model for predicting water levels based on pumping trends and climatic cycles.

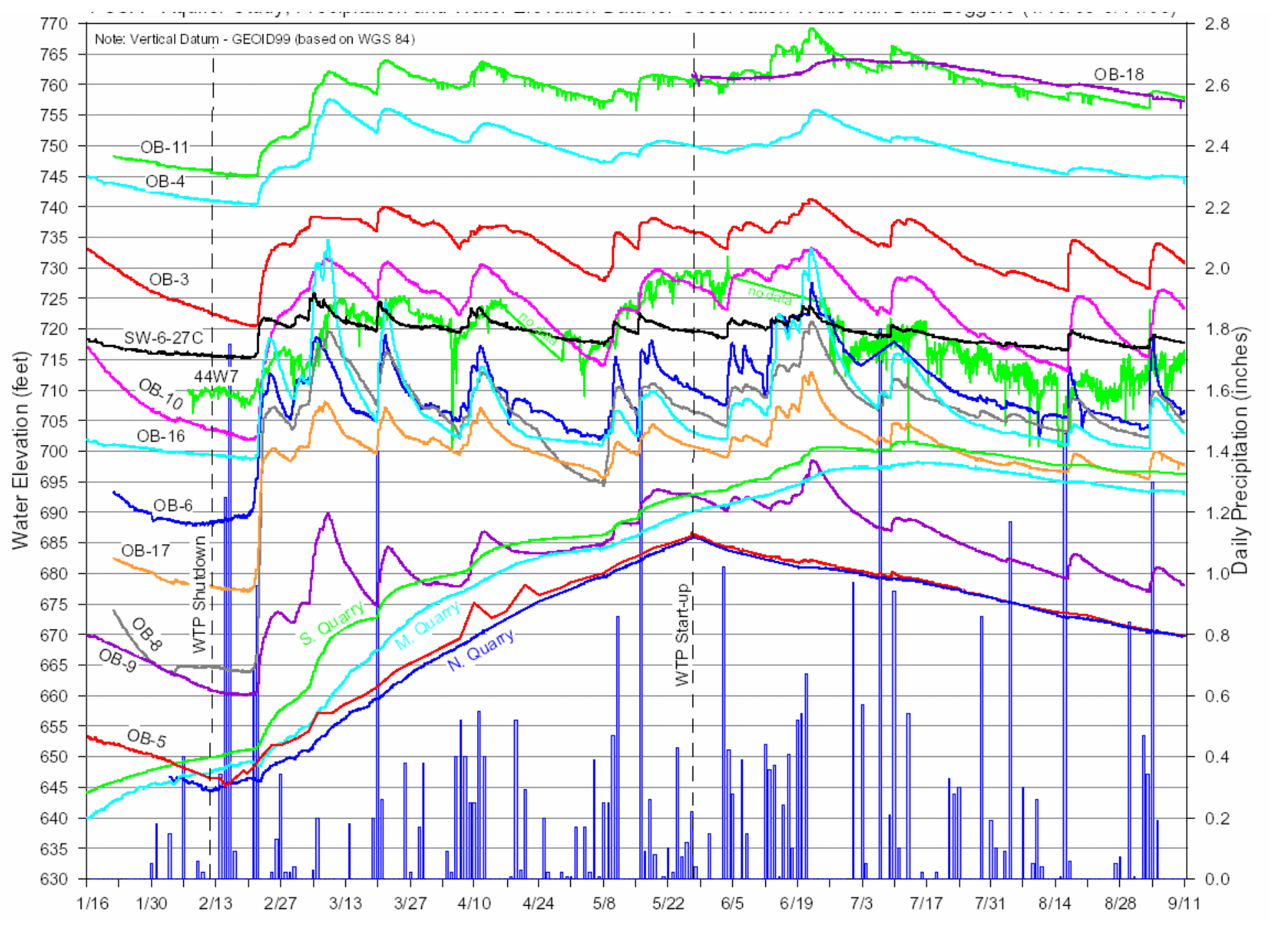
Regional Conceptual Model

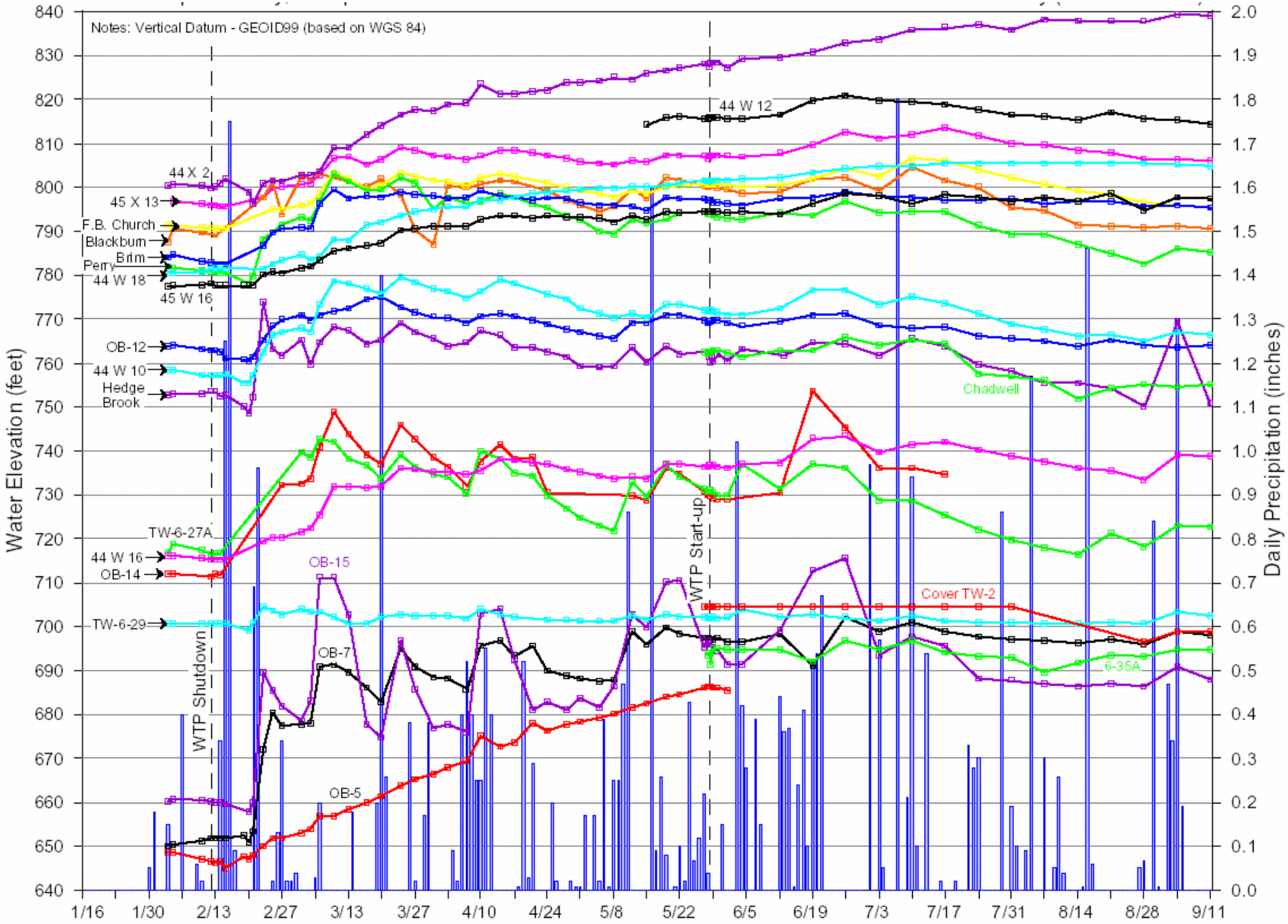
- One layer (ave. thickness 400 ft)
- Cell size 150 ft
- K, S_y, Aniso Zones based on Geology
- Monthly stress periods to reflect changes in recharge and pumping

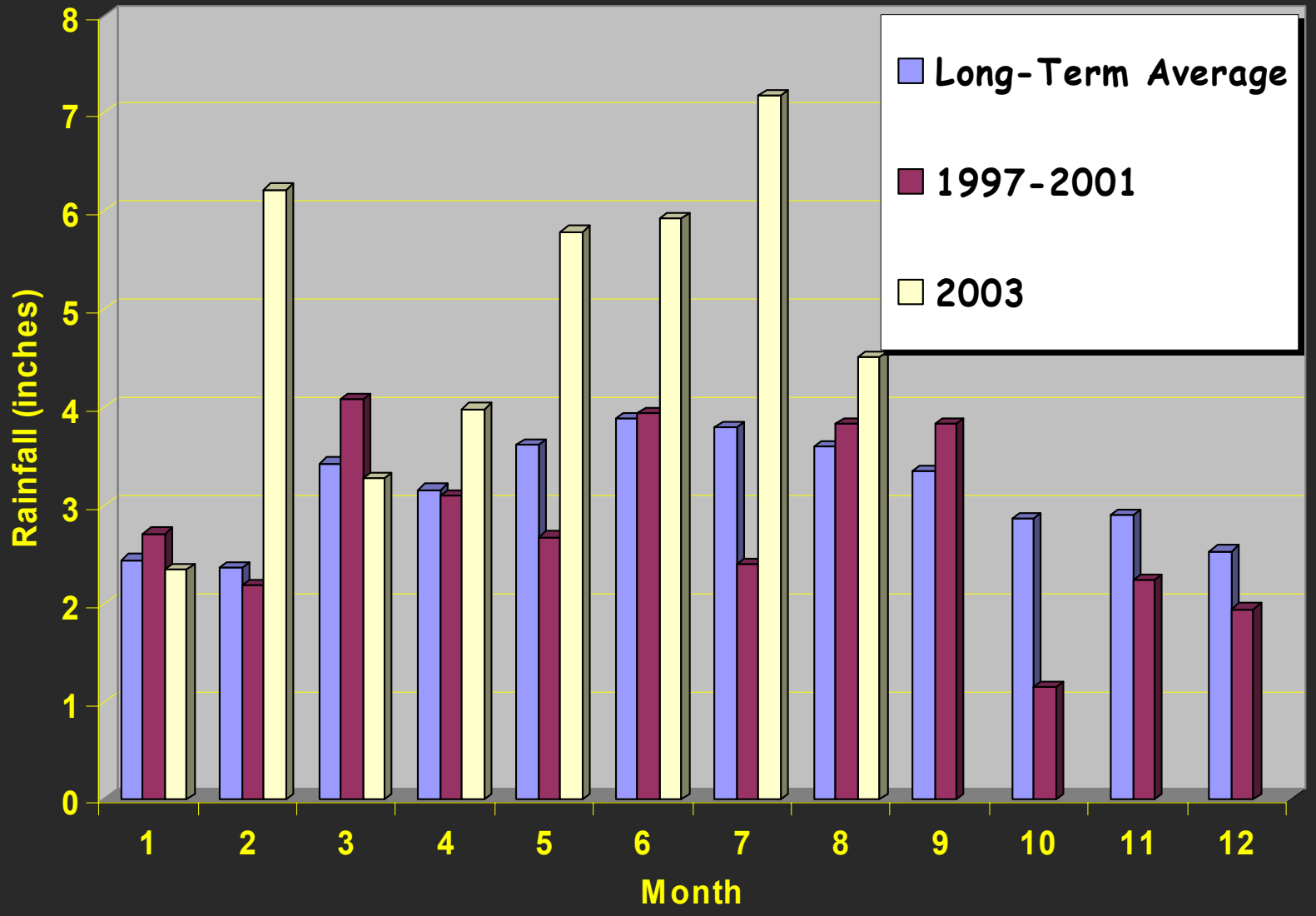


Modeling Approach

- Calibrate model using
  - Monthly head measurements as weighted observations from Jan-Aug, 2003
  - Streamflow measurements and estimation of monthly baseflow as observations
  - Hydraulic conductivity, anisotropy, streambed leakance, GHB conductance, monthly recharge, and specific yield as parameters to be estimated using PE
  - Planned aquifer test from North Quarry involved pumping 3 million gpd for 90 days beginning June 1, 2003


Note: Vertical Datum - GEOID99 (based on WGS 84)
Water Elevation (feet)
Daily Precipitation (inches)
OB-18
OB-11
OB-4
OB-3
SW-6-27C
44W7
OB-10
OB-16
OB-6
OB-17
OB-8
OB-9
OB-5
no data
no data
S. Quarry
M. Quarry
N. Quarry
WTP Shutdown
WTP Start-up
770
765
760
755
750
745
740
735
730
725
720
715
710
705
700
695
690
685
680
675
670
665
660
655
650
645
640
635
630
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1/16
1/30
2/13
2/27
3/13
3/27
4/10
4/24
5/8
5/22
6/5
6/19
7/3
7/17
7/31
8/14
8/28
9/11


Notes: Vertical Datum - GEOID99 (based on WGS 84)
Water Elevation (feet)
Daily Precipitation (inches)
840
830
820
810
800
790
780
770
760
750
740
730
720
710
700
690
680
670
660
650
640
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1/16
1/30
2/13
2/27
3/13
3/27
4/10
4/24
5/8
5/22
6/5
6/19
7/3
7/17
7/31
8/14
8/28
9/11
WTP Shutdown
WTP Start-up
44 X 2
45 X 13
F.B. Church
Blackburn
Brim
Perry
44 W 18
45 W 16
44 W 12
OB-12
44 W 10
Hedge Brook
Chadwell
TW-6-27A
44 W 16
OB-14
OB-15
TW-6-29
OB-7
OB-5
Cover TW-2
6-35A

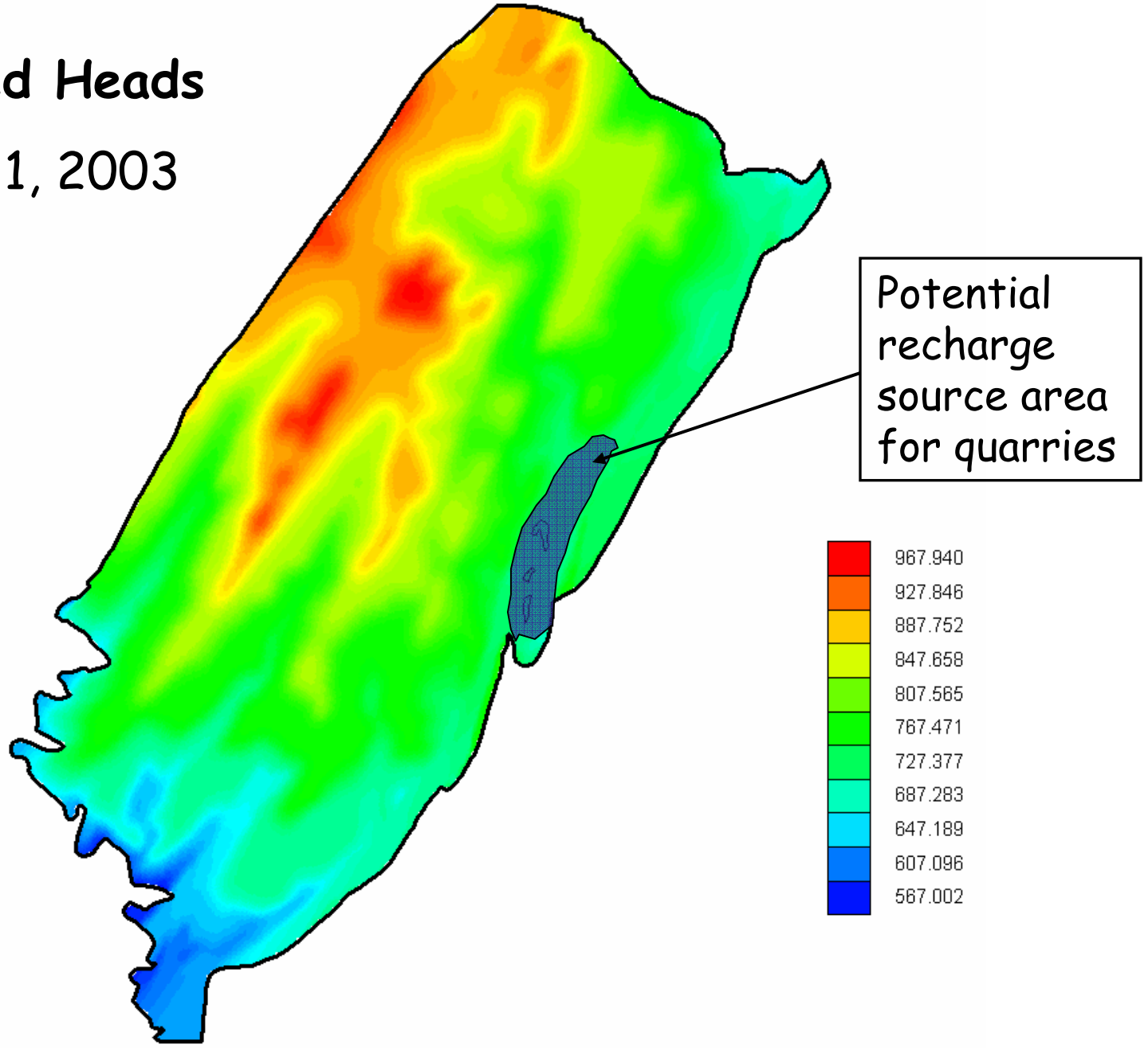

Rainfall (inches)
0
1
2
3
4
5
6
7
8
Month
1
2
3
4
5
6
7
8
9
10
11
12
Long-Term Average
1997-2001
2003

Regional Model Findings

- Regional fluctuations in head largely due to variations in precipitation
- Sensitivity of hydraulic conductivity and storage values generally low due to lack of sufficient stress on system and need for more detail
- Concluded that historic model needed
  - Drought period from 1996-2001
  - Large observed drawdown in quarries
  - Summary statistics and sensitivities indicate that more information was needed in vicinity of quarries
    - Need more geologic detail
    - Need finer grid spacing

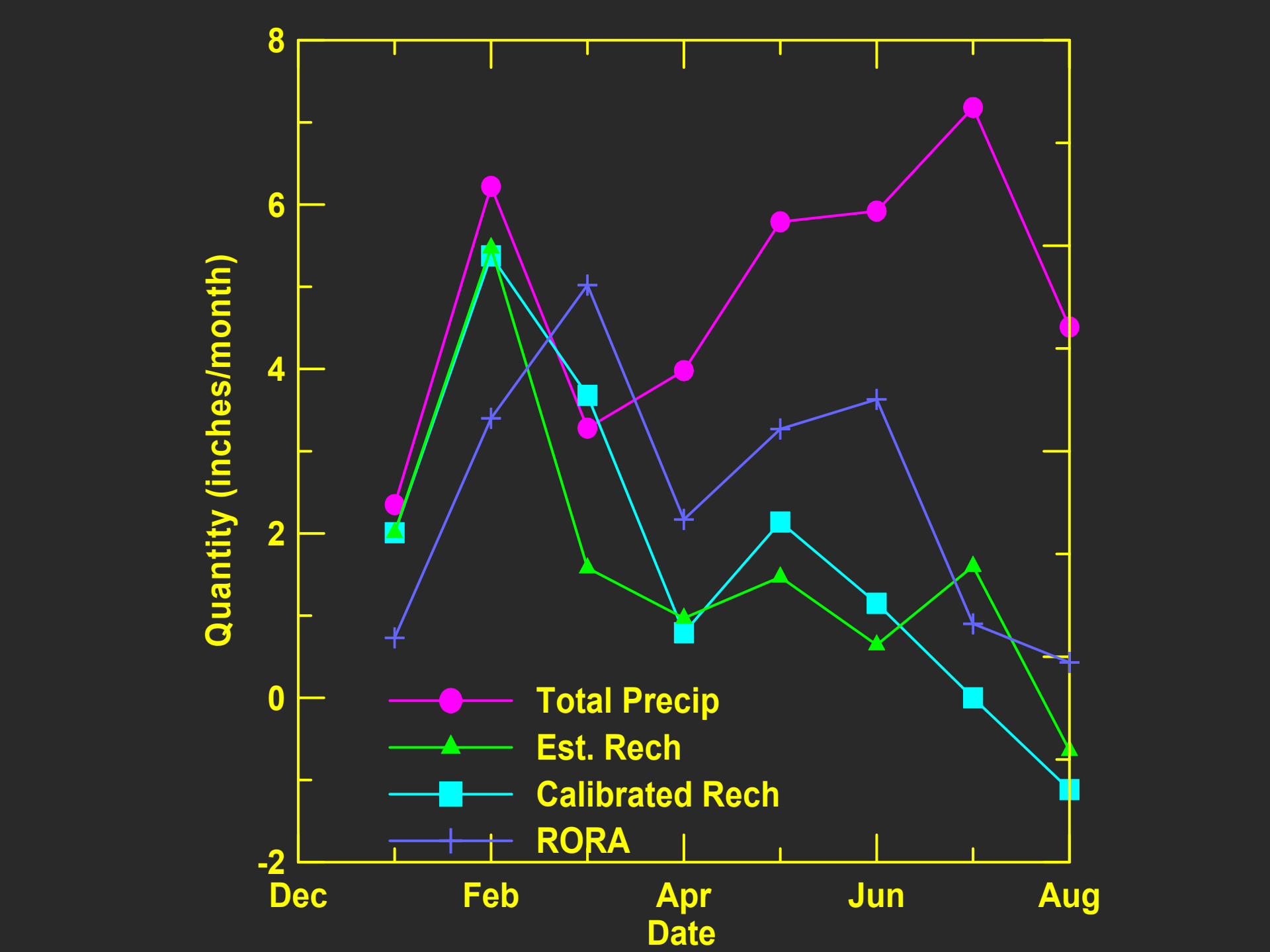
Simulated Heads

August 31, 2003



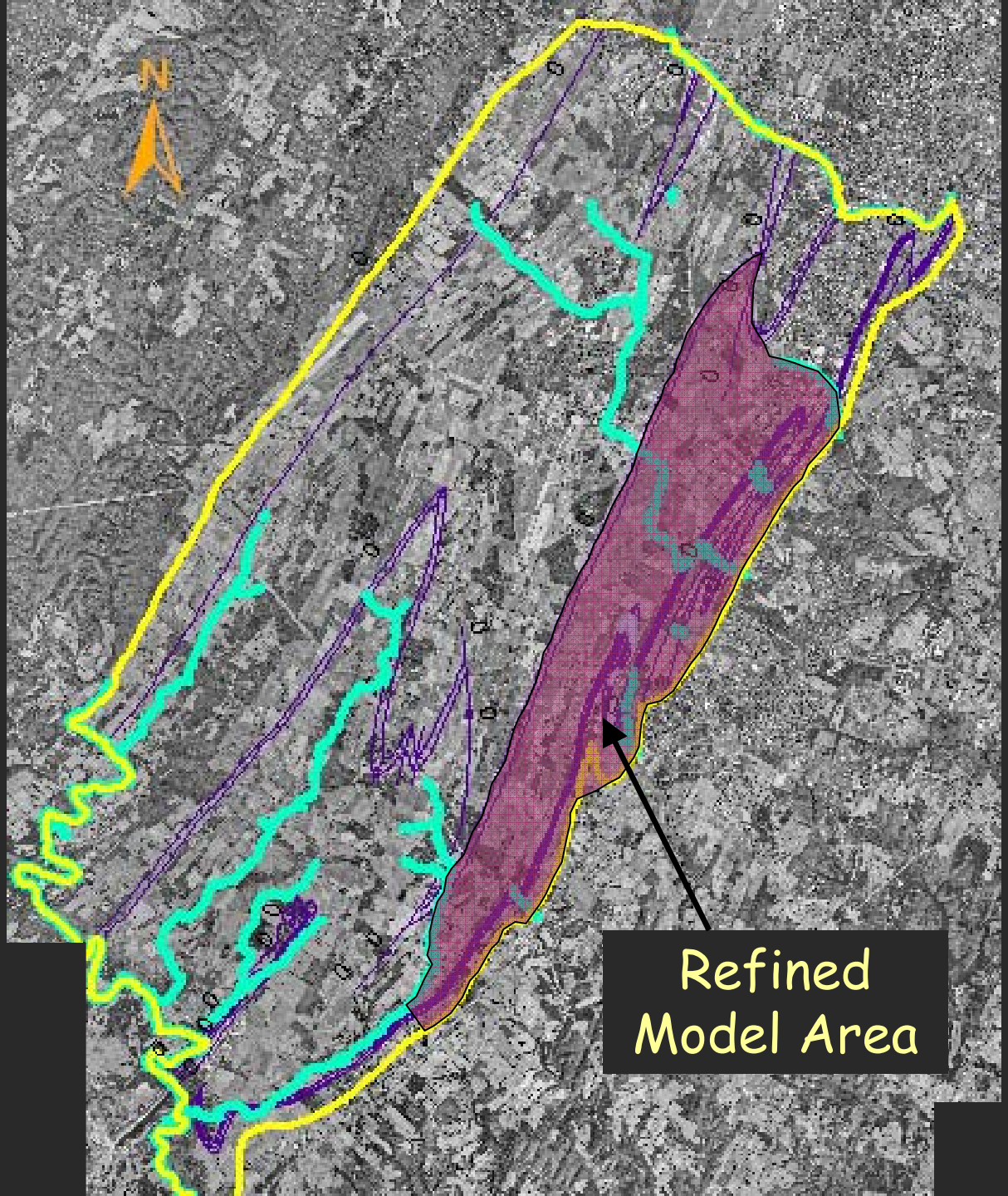
Evaluation of Recharge

- Estimated from Fourier Series of Evaporation and Transpiration Functions on basis of monthly changes in factors affecting these parameters
- Inverse parameter estimation
- Rorabaugh method using streamflow discharge


8
6
4
2
0
-2
Quantity (inches/month)
Dec
Feb
Apr
Jun
Aug
Date
Total Precip
Est. Rech
Calibrated Rech
RORA

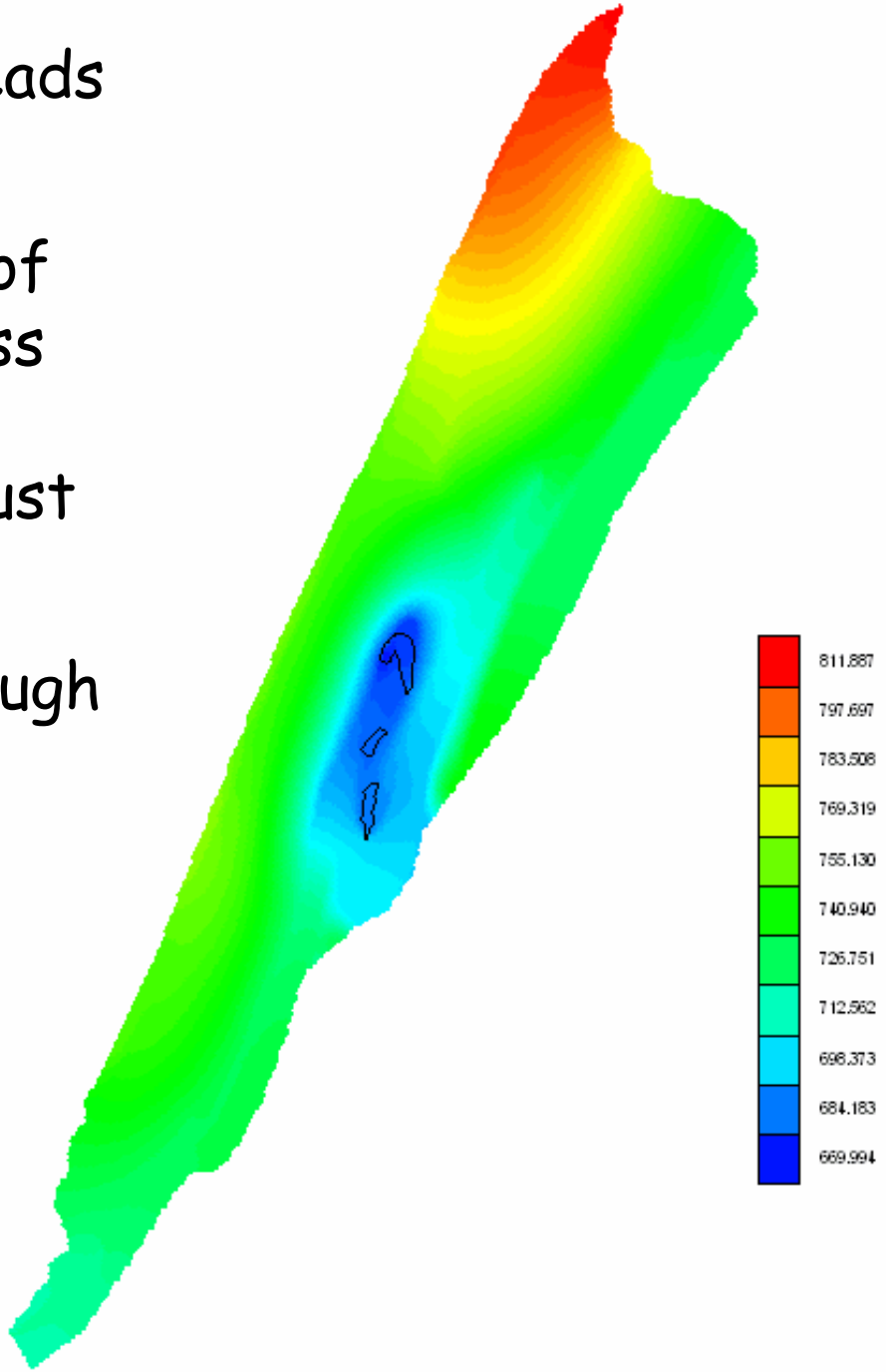
Why a New Model Grid?

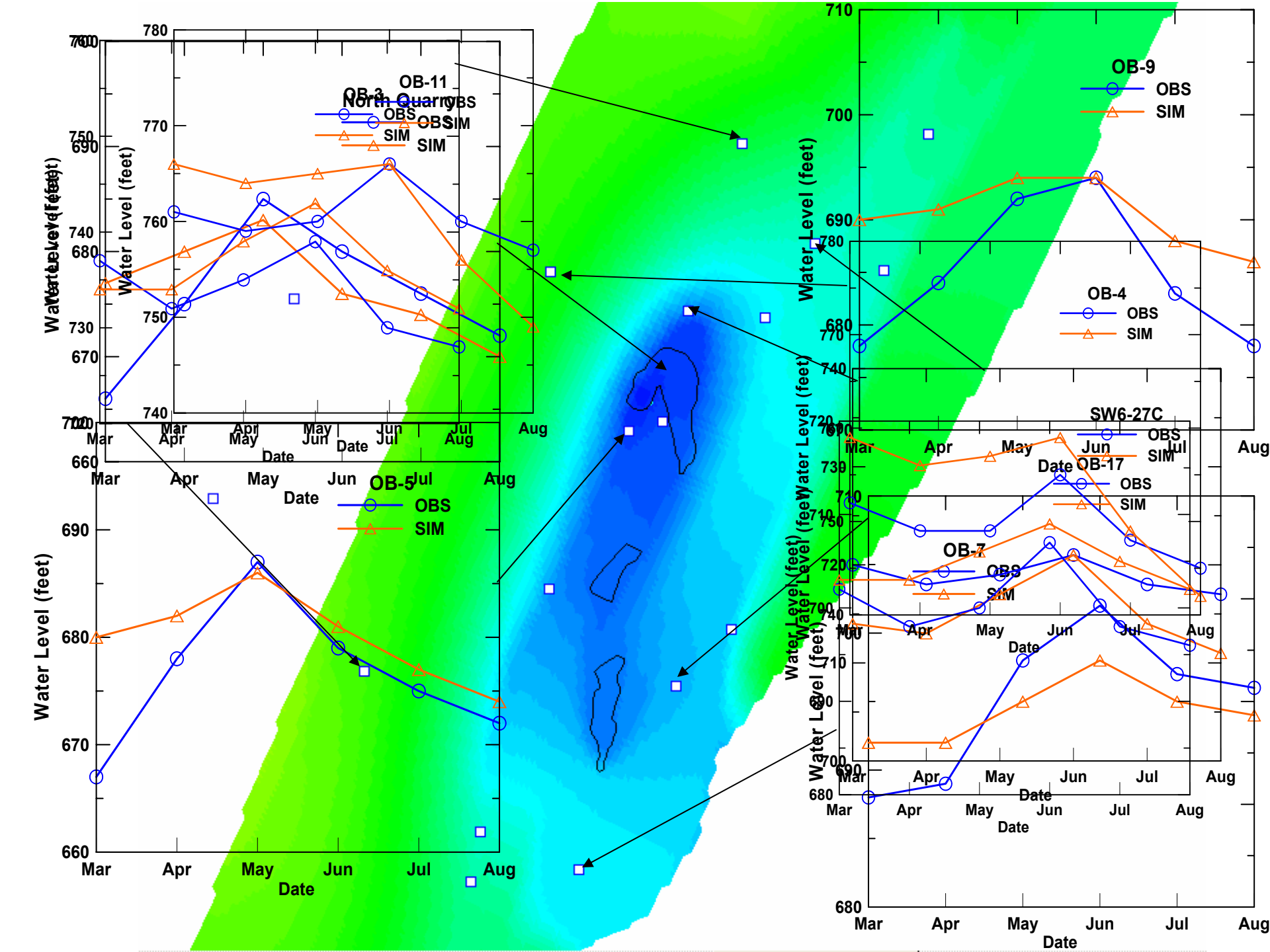
- Statistics and sensitivities suggest that more geologic detail is needed
- Grid size reduced to 100 ft, 2 layers
- Initial model indicates area west of Stonehenge Fm. Is of very low conductivity and does not contribute to area of interest
- Model helped to determine where more data are needed

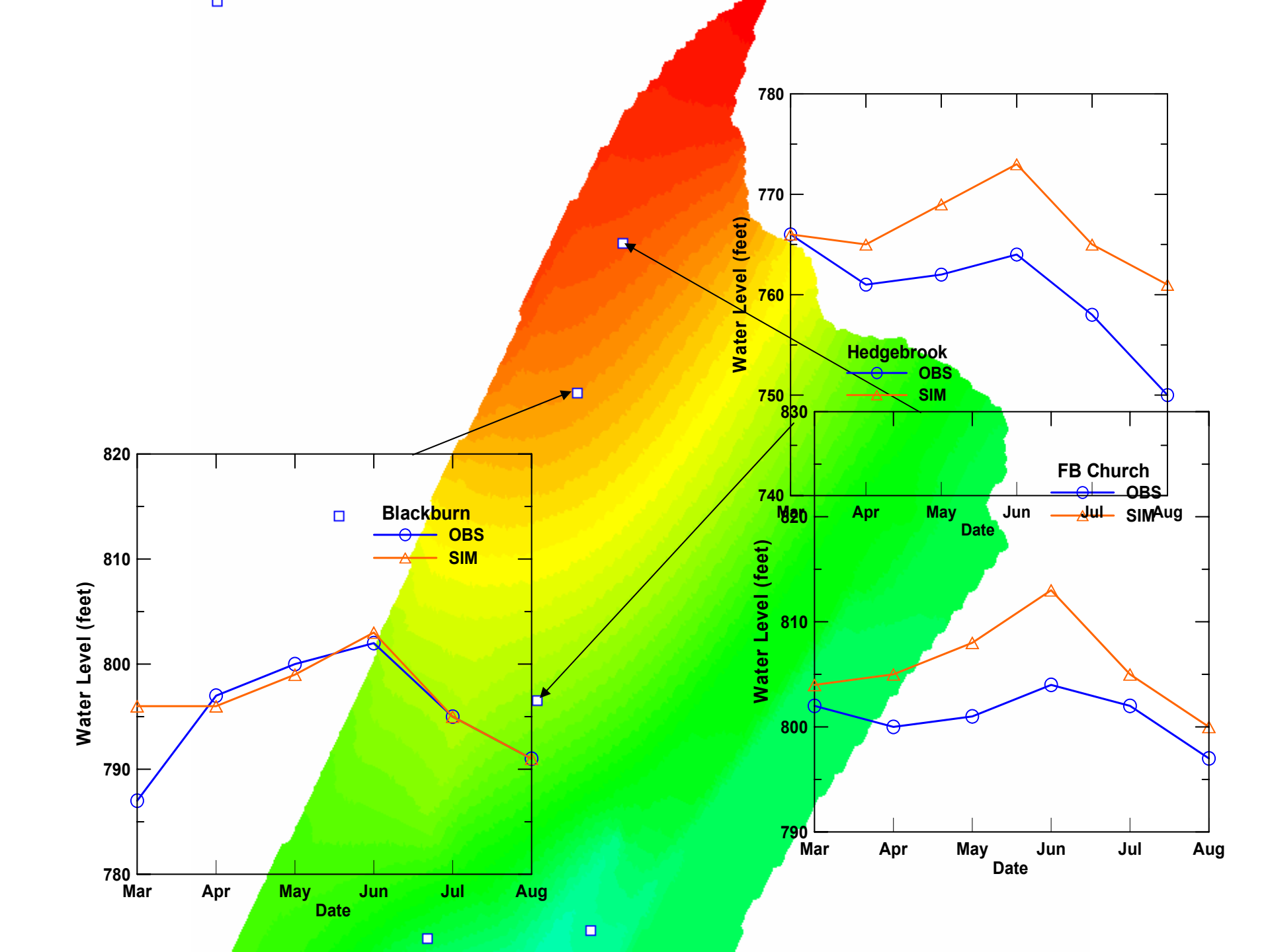


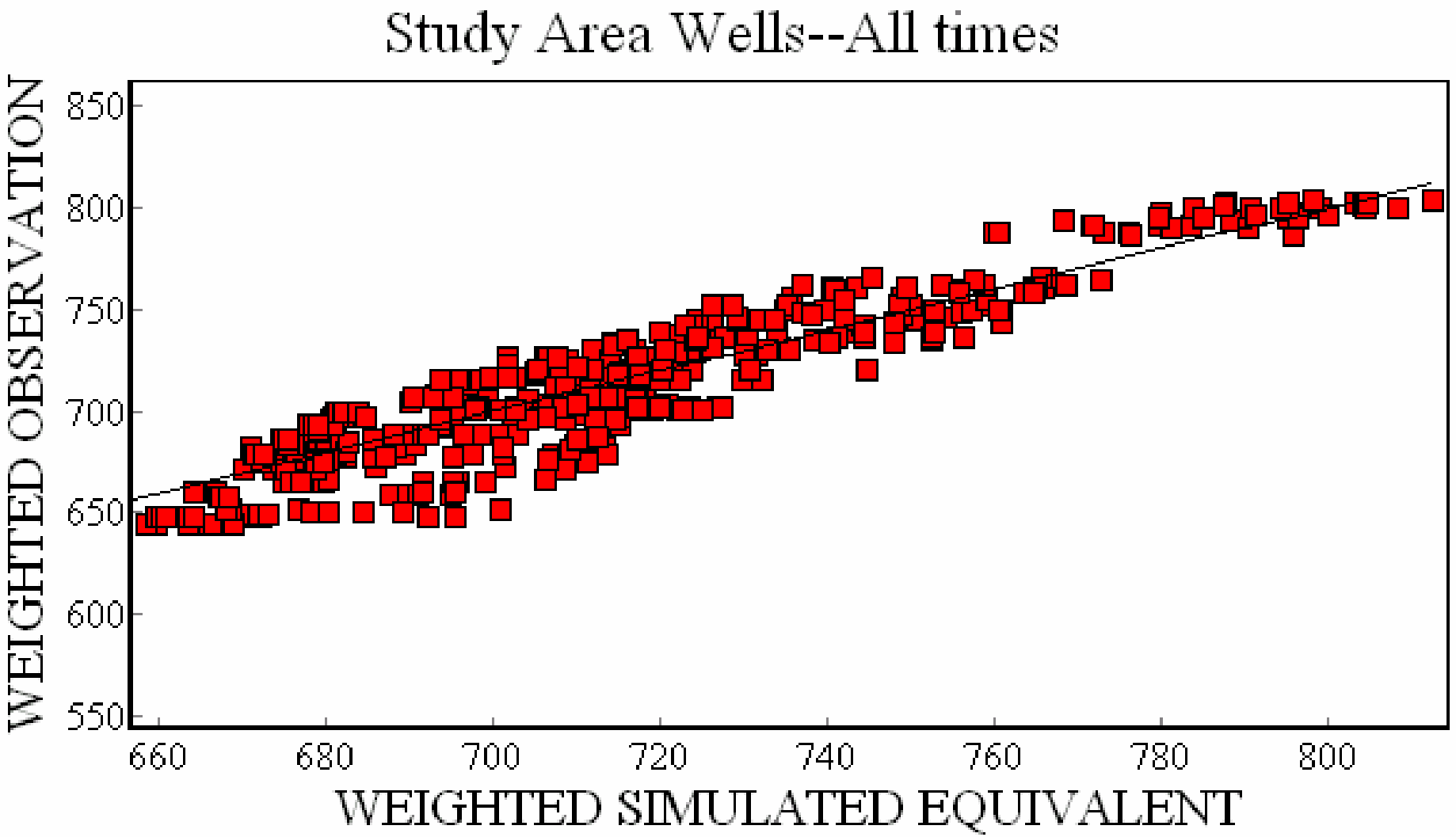
Simulated Heads August 2003

- Culmination of monthly stress periods from January-August
- Recovery of quarries through May
- Pumping of north quarry from June-August




OB-3
OBS
SIM
Water Level (feet)
Date
Mar
Apr
May
Jun
Jul
Aug
OB-11
OBS
SIM
OB-5
OBS
SIM
OB-9
OBS
SIM
OB-4
OBS
SIM
SW6-27C
OBS
SIM
OB-17
OBS
SIM
OB-7
OBS
SIM


Blackburn
OBS
SIM
Water Level (feet)
820
810
800
790
780
Mar
Apr
May
Jun
Jul
Aug
Date
Hedgebrook
OBS
SIM
Water Level (feet)
780
770
760
750
740
Mar
Apr
May
Jun
Jul
Aug
Date
FB Church
OBS
SIM
Water Level (feet)
830
820
810
800
790
Mar
Apr
May
Jun
Jul
Aug
Date


Study Area Wells--All times
WEIGHTED OBSERVATION
850
800
750
700
650
600
550
660
680
700
720
740
760
780
800
WEIGHTED SIMULATED EQUIVALENT

Local Model

- Covers period from January-August, 2003
- More data available for "fine-tuning" parameters
- Difficult to obtain an initial-head condition for model because of the dynamic nature of heads and dependency on karstic system

Conclusions

- Pumping from quarries creates drawdowns that are localized and extending primarily southward with recharge occurring locally and from the north.
  - Little or no drawdown occurs west of the quarries and limited drawdown occurs to the north
- Fluctuations in water levels in study area largely due to weather conditions and quantity of natural recharge
  - ET is large and can exceed natural recharge during summer months
- Karst conditions make it difficult to simulate "measured" values using a PMM