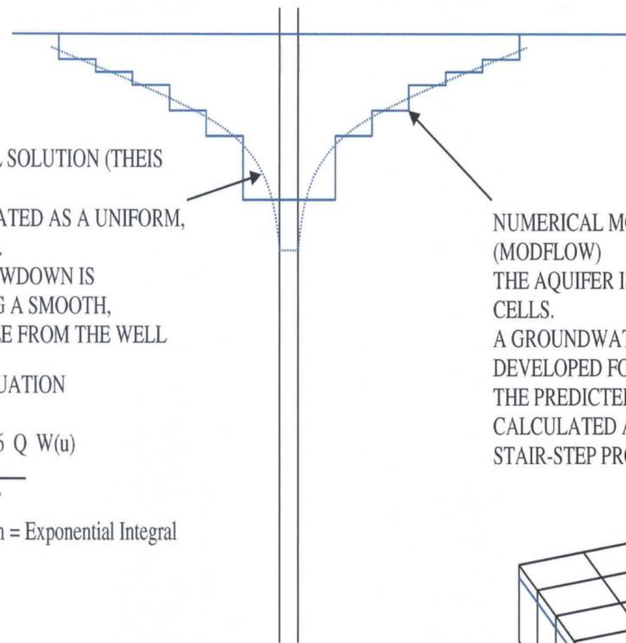
USE OF REGIONAL MODELS FOR AAWS APPLICATIONS

Challenges of Reviews

- Numerical vs Analytical Drawdown Simulation
- New software that can be use in AAWS simulations
- Numerical simulation combined with analytical simulation

Figure 1 COMPARISON OF THE DRAWDOWN PREDICTIONS FROM ANALYTICAL AND NUMERICAL GROUNDWATER MODELS



ANALYTICAL MODEL SOLUTION (THEIS EQUATION)
THE AQUIFER IS TREATED AS A UNIFORM, CONTINUOUS MEDIA.
THE PREDICTED DRAWDOWN IS CALCULATED ALONG A SMOOTH, CONTINUOUS PROFILE FROM THE WELL

THEIS EQUATION

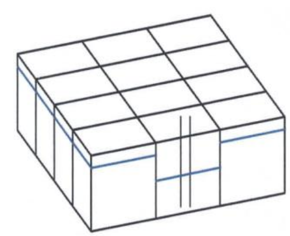
$$s = \frac{114.6\ Q\ W(u)}{T}$$

W(u) = Well Function = Exponential Integral

$$u = \frac{1.87\ r^2\ S}{T\ t}$$

s = Drawdown (feet)
T = Transmissivity (gpd/ft)
t = Time (days)
r = Distance From Well (feet)
S = Storage Coefficient
Q = Pumping Rate (gpm)

NUMERICAL MODEL SOLUTION (MODFLOW)
THE AQUIFER IS DIVIDED INTO MODEL CELLS.
A GROUNDWATER FLOW EQUATION IS DEVELOPED FOR EACH CELL
THE PREDICTED DRAWDOWN IS CALCULATED AND AVERAGED AS A STAIR-STEP PROFILE FROM THE WELL



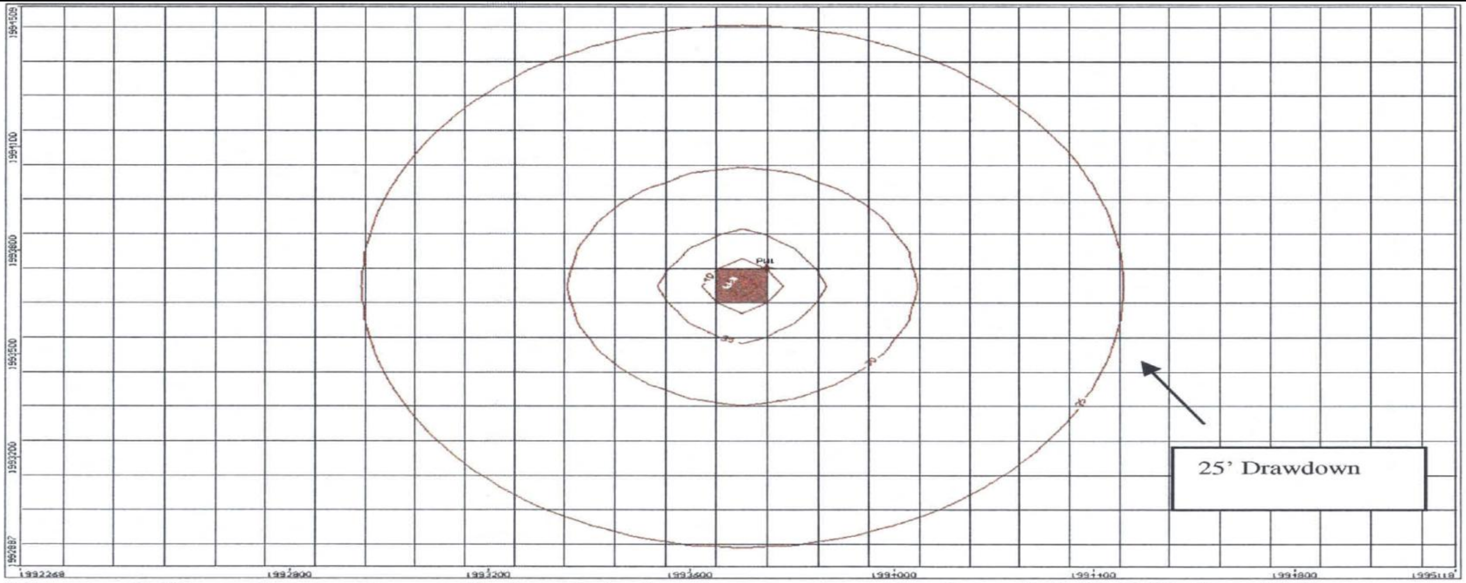


Figure 2 Drawdown at a well simulated using a numerical model (2,640-ft cells)

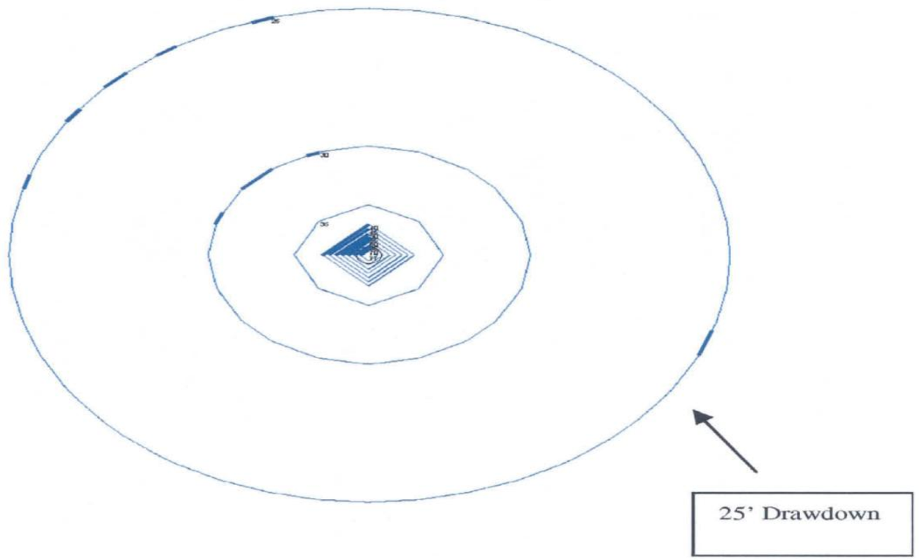


Figure 3 Drawdown at a well simulated using an analytical model (100-ft grid)

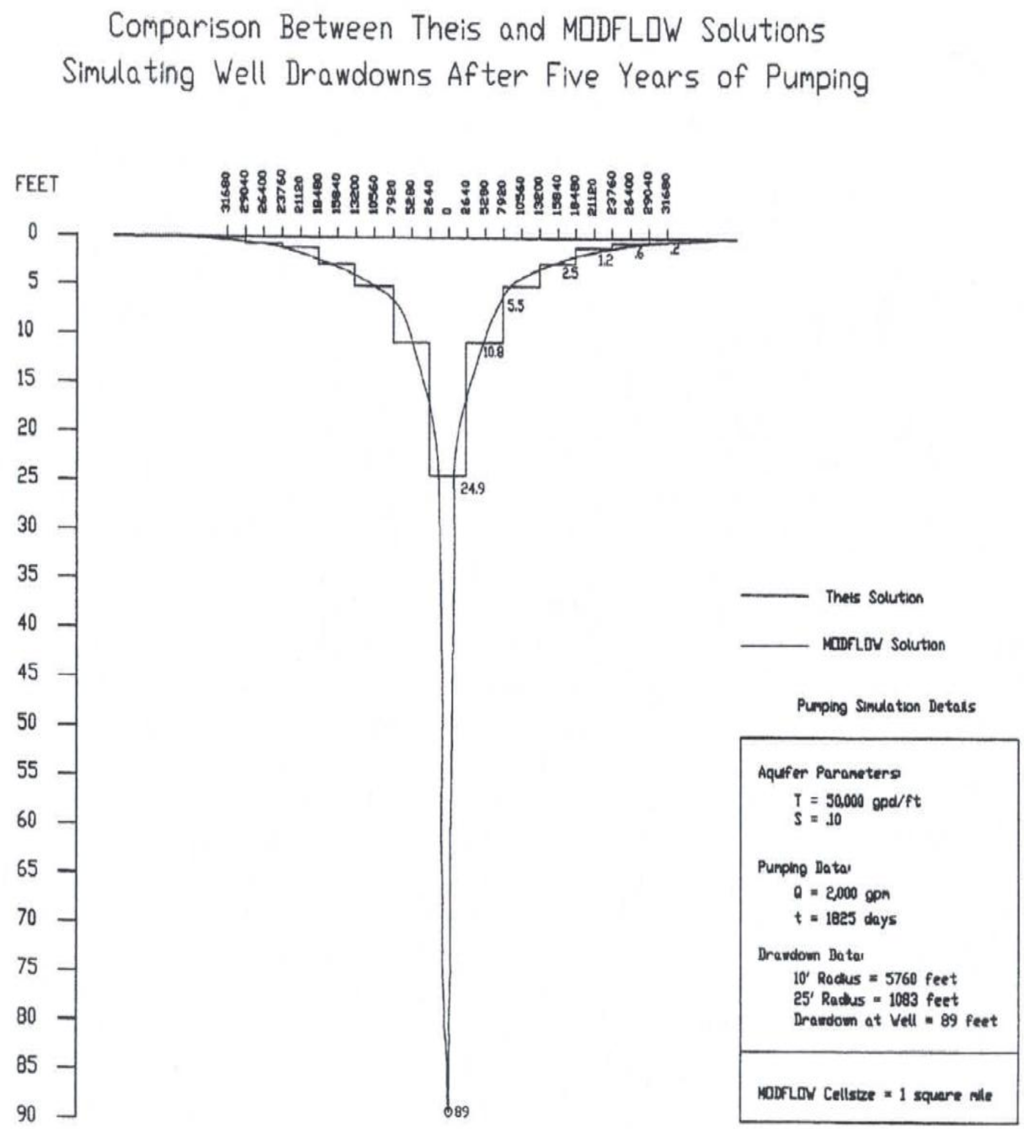


Figure 4. Comparison of Analytical and Numerical Model Solutions

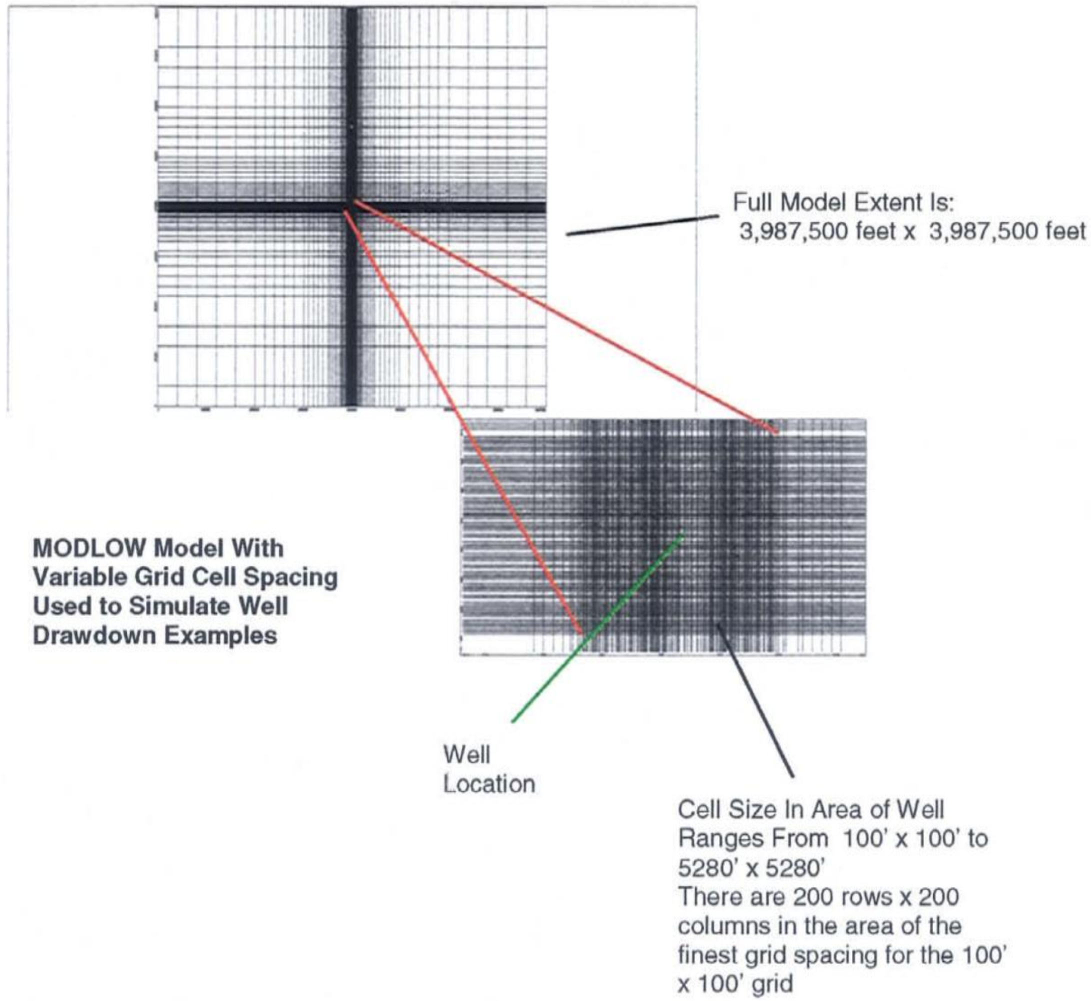


Figure 5 General layout of telescoping model grid used for drawdown simulations

Radial Distance From Well At Which Listed Drawdown Occurs (Feet)

Projected 100-Year Drawdown (Feet)	MODFLOW Grid-Spacing * 5280	MODFLOW Grid-Spacing * 2640	MODFLOW Grid-Spacing * 1320	MODFLOW Grid-Spacing * 660	MODFLOW Grid-Spacing * 100	Theis Equation
1	198572	198270	198255	198293	199826	192950
25	44636	44479	44454	44483	44482	45129
50	17557	17340	17199	17200	17200	16873
100	3537	3268	3108	3018	2989	2563
131	At Well	NC	NC	NC	NC	NC
150		NC	660	623	576	389
153		At Well	NC	NC	NC	NC
175			At Well	NC	NC	NC
197				At Well	NC	NC
200					134	59
250					23	9
262					At Well	NC
308						At Well

NC = Not Calculated

* Actual MODFLOW Model Had A Variable Grid Size. Model Cells in Vicinity of Well Had Listed Dimensions

MODFLOW Model Was A Square Model Area 3,987,500 feet x 3,987,500 feet = 755.2 mi x 755.2 mi.

Drawdown At Well = Drawdown in model cell containing well for MODFLOW models

Drawdown at Well = Drawdown at a radial distance of one foot for Theis model

Unconfined Aquifer, 1000' initial saturated thickness

T=15,000 ft^2/d = 112,200 gpd/ft

Sy=.1

Q=2,500,000 ft^3/d = 12,986 gpm = 20,948 AFA

Table 1 Simulation 1: Comparison of Analytical and Numerical Model Results: T = 15,000 ft^2 / d Q = 20,948 AFA

	Radial Distance From Well At Which Listed Drawdown Occurs (Feet)					
Projected 100-Year Drawdown (Feet)	MODFLOW Grid-Spacing * 5280	MODFLOW Grid-Spacing * 2640	MODFLOW Grid-Spacing * 1320	MODFLOW Grid-Spacing * 660	MODFLOW Grid-Spacing * 100	Theis Equation
1	88841	88678	88074	88767	88620	90016
5	16849	16642	16630	16602	16556	17194
10	2968	2661	2629	2567	2523	2605
12	At Well	NC	NC	NC	NC	NC
14		At Well	NC	NC	NC	NC
15			340	472	396	383
16			At Well	NC	NC	NC
18				At Well	NC	NC
20					72	57
23					At Well	NC
31						At Well

NC = Not Calculated

* Actual MODFLOW Model Had A Variable Grid Size. Model Cells in Vicinity of Well Had Listed Dimensions

MODFLOW Model Was A Square Model Area 3,987,500 feet x 3,987,500 feet = 755.2 mi x 755.2 mi.

Drawdown At Well = Drawdown in model cell containing well for MODFLOW models

Drawdown at Well = Drawdown at a radial distance of one foot for Theis model

Unconfined Aquifer, 1000' initial saturated thickness

T=15,000 ft^2/d = 112,200 gpd/ft

Sy=.1

Q=250,000 ft^3/d = 1299 gpm = 2095 AFA

Table 2 Simulation 2: Comparison of Analytical and Numerical Model Results: T = 15,000 ft^2 / Day Q = 2,095 AFA

Radial Distance From Well At Which Listed Drawdown Occurs (Feet)

Projected 100-Year Drawdown (Feet)	MODFLOW Grid-Spacing * 5280	MODFLOW Grid-Spacing * 2640	MODFLOW Grid-Spacing * 1320	MODFLOW Grid-Spacing * 660	MODFLOW Grid-Spacing * 100	Theis Equation
1	87104	86865	86817	86723	86703	86922
5	31588	31360	31385	31317	31295	31912
10	12242	11955	11814	11797	11774	11931
20	1873	2090	2020	1877	1839	1812
23	At Well	NC	NC	NC	NC	NC
25		539	855	792	731	661
27		At Well	NC	NC	NC	NC
30			82	330	295	274
31			At Well	NC	NC	NC
34				At Well	NC	NC
35					128	109
40					55	42
45					At Well	NC
60						At Well

NC = Not Calculated

* Actual MODFLOW Model Had A Variable Grid Size. Model Cells in Vicinity of Well Had Listed Dimensions

MODFLOW Model Was A Square Model Area 3,987,500 feet x 3,987,500 feet = 755.2 mi x 755.2 mi.

Drawdown At Well = Drawdown in model cell containing well for MODFLOW models

Drawdown at Well = Drawdown at a radial distance of one foot for Theis model

Unconfined Aquifer, 1000' initial saturated thickness

T=7,500 ft^2/d = 56,100 gpd/ft

Sy=.1

Q=250,000 ft^3/d = 1,299 gpm = 2,095 AFA

Table 3 Simulation 3: Comparison of Analytical and Numerical Model Results: T = 7,500 ft^2/d Q= 2,095 AFA

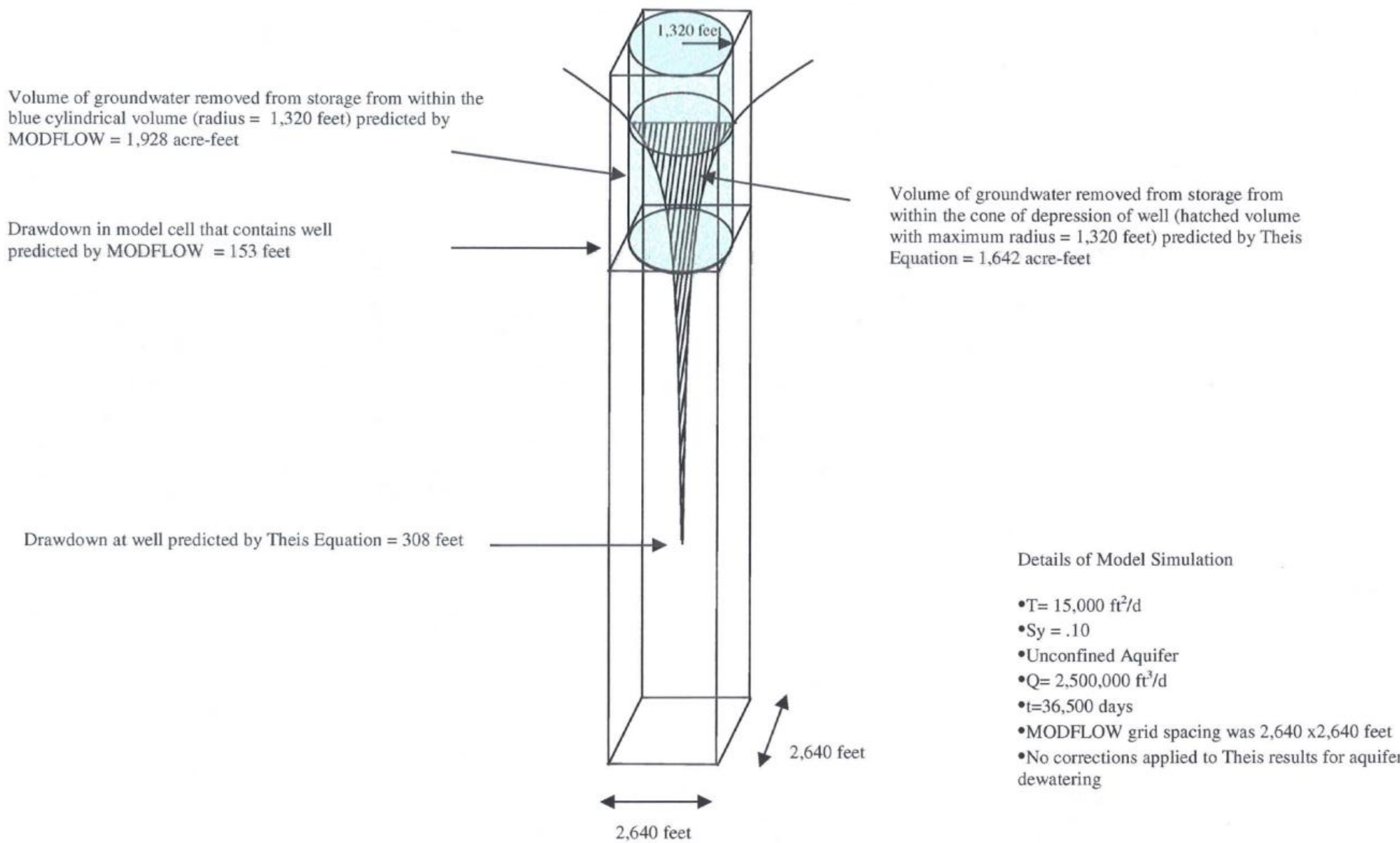
Radial Distance From Well At Which Listed Drawdown Occurs (Feet)

Projected 100-Year Drawdown (Feet)	MODFLOW Grid-Spacing * 5280	MODFLOW Grid-Spacing * 2640	MODFLOW Grid-Spacing * 1320	MODFLOW Grid-Spacing * 660	MODFLOW Grid-Spacing * 100	Theis Equation
1	53035	53104	53034	52999	52960	53014
5	20758	20778	20699	20659	20610	20928
10	9268	8826	8717	8678	8651	8755
20	1625	1971	1869	1756	1696	1687
23	At Well	NC	NC	NC	NC	NC
25		612	887	832	761	740
27		At Well	NC	NC	NC	NC
30			210	404	348	325
32			At Well	NC	NC	NC
35				65	170	143
36				At Well	NC	NC
40					81	63
45					29	28
48					At Well	NC
65						At Well

NC = Not Calculated
* Actual MODFLOW Model Had A Variable Grid Size. Model Cells in Vicinity of Well Had Listed Dimensions
MODFLOW Model Was A Square Model Area 3,987,500 feet x 3,987,500 feet = 755.2 mi x 755.2 mi.
Drawdown At Well = Drawdown in model cell containing well for MODFLOW models
Drawdown at Well = Drawdown at a radial distance of one foot for Theis model

Unconfined Aquifer, 1000' initial saturated thickness
T=2,500 ft^2/d = 18,700 gpd/ft
Sy=.1
Q=95,474 ft^3/d = 496 gpm = 800 AFA

Table 4 Simulation 4: Comparison of Analytical and Numerical Model Results: T = 2,500 ft^2/d Q = 800 AFA



Not drawn to scale

Figure 6 Comparison of Predicted Volumes of Dewatering In Vicinity of Well For Comparable MODFLOW and Theis Simulations

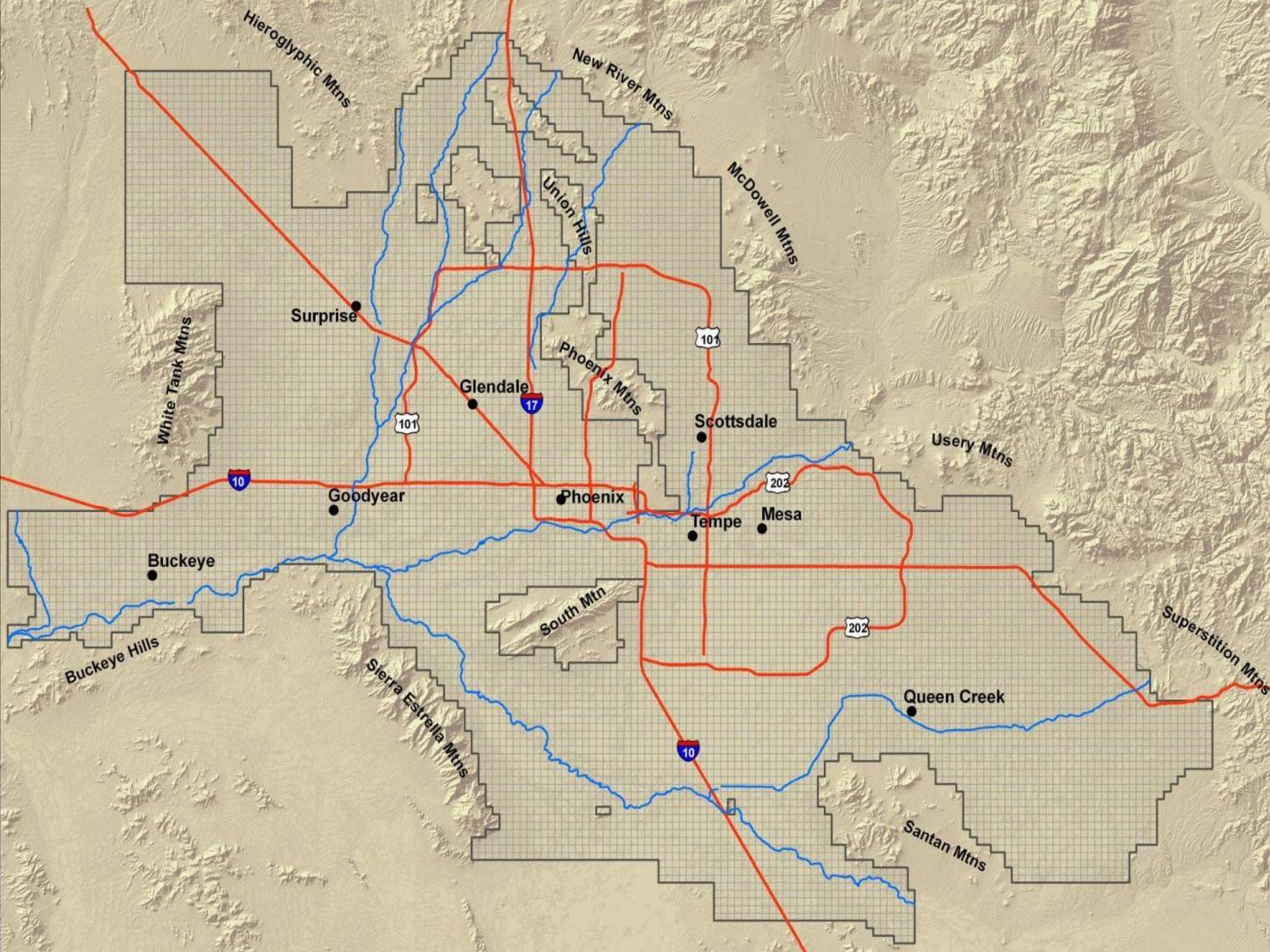
Simulation Number	Volume of GW Removed From Storage Within a Radius of 1,320 Feet of Well (MODFLOW)	Volume of GW Removed From Storage Within a Radius of 1,320 Feet of Well (Theis)	Ratio of GW Removed From Storage (MODFLOW/Theis)
1	1,928 acre-feet	1,642 acre-feet	1.17
2	177 acre-feet	164 acre-feet	1.08
3	341 acre-feet	305 acre-feet	1.12
4	341 acre-feet	308 acre-feet	1.11

Table 5 Comparison of volumes of predicted dewatering in vicinity of well from comparable MODFLOW and Theis simulations

- The 2,640 x 2,640 model grid spacing is an appropriate grid size for most AAWS physical availability demonstrations (particularly in recognition of the fact that the demonstration of physical availability applies to the area of withdrawals, rather than at the precise location of the well).

- If there is a situation where a numerical model predicts that the drawdown of an AAWS well would be greater than 50 percent of the original remaining saturated thickness of the aquifer in the cell containing the well then an analytical model simulation may be necessary to determine whether the well would actually run dry.

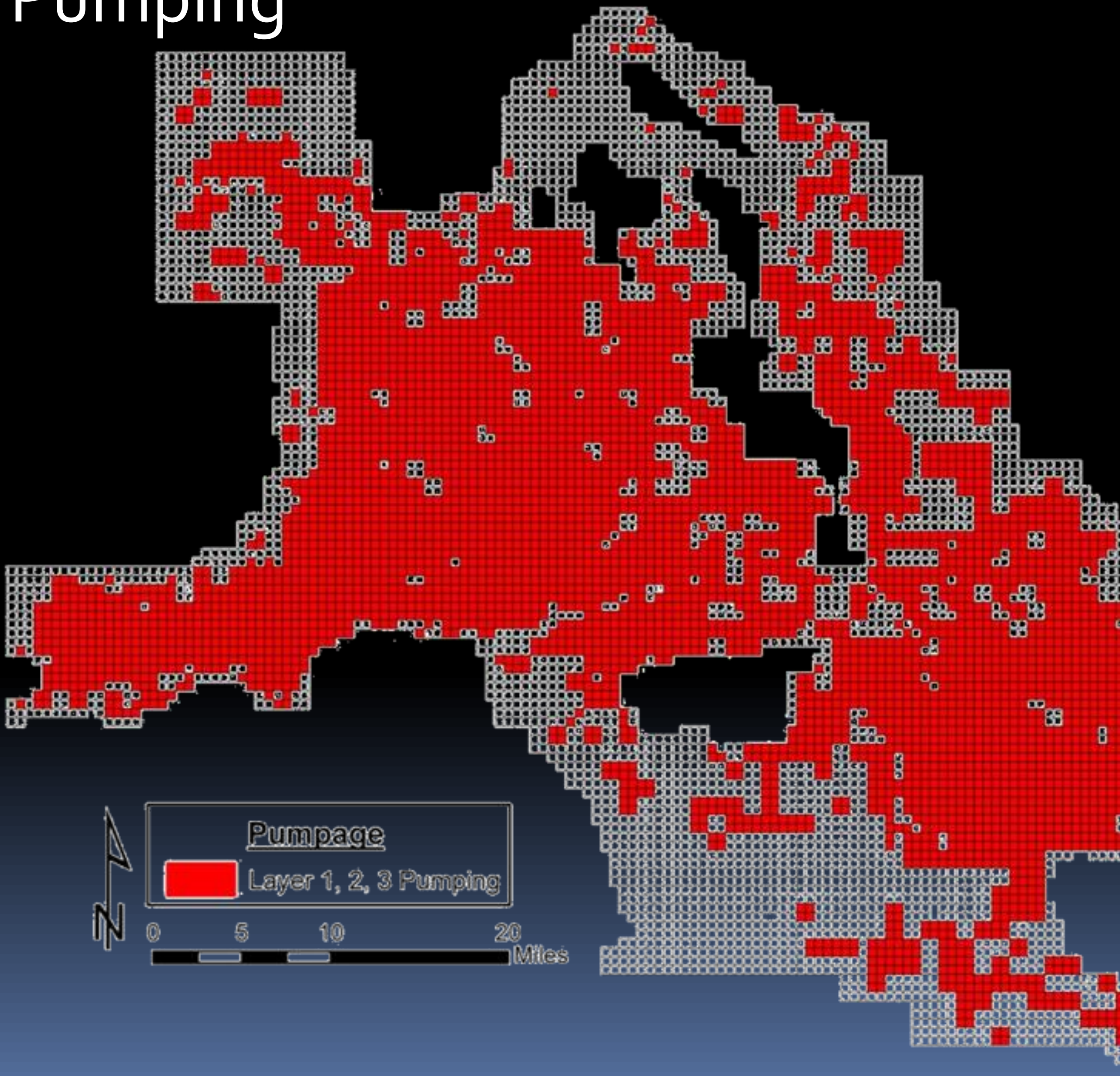
- It seems clear that for most situations the 2,640 x 2,640 foot model cell size should be appropriate to determine the area of hydrologic impact, which is defined by the Department to be the maximum extent of the area that would experience a minimum water level rise of 1 foot, due to the recharge of the proposed project.

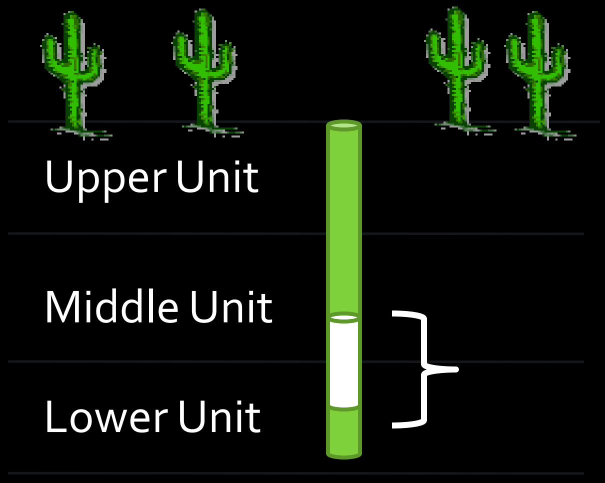


Hieroglyphic Mtns
New River Mtns
McDowell Mtns
Union Hills
White Tank Mtns
Surprise
101
Phoenix Mtns
Glendale
17
101
Scottsdale
Usery Mtns
10
202
Goodyear
Phoenix
Mesa
Tempe
Buckeye
South Mtn
202
Superstition Mtns
Buckeye Hills
Sierra Estrella Mtns
Queen Creek
10
Santan Mtns

SRV Data and Conceptualization

Pumping





AWS BASELINE SCENARIO ASSUPTIONS

- **PROJECTING PUMPING**

•Current Non - AWS Demands

-Industrial Pumping – held constant at 2008 volumes and locations.

-Type I and Type II Pumping – held constant at 2008 volumes and locations.

-Irrigation District Pumping – 2008 volumes and locations used as a starting base

a. Pumping volumes removed from the simulation when the location of the wells urbanizes.

b. Urbanization based on population projection.

c. SRP and RID were not urbanized.

-

-Agricultural Pumping – 2008 volumes and locations used as starting base

a. Pumping volumes removed from simulation when the location of the well urbanizes.
b. Pumping at GSF's was increased to reflect the agricultural demand that is currently being met through surface water sources earning LTSCs.
c. The water associated with CAGRD replenishment was not included in the increased pumping.

-Indian Pumping – Held constant at 2006 volumes and locations used in ADWR's SRV8306

- Issued AWS Demands

    a. Issued AWS demands include the Re-designation committed demands .
    b. Re-designation committed demands include groundwater pumping and recovery.
    c. Projected committed demands are considered to be all groundwater pumping.

- Removal of LTSCs

    LTSCs earned through 2008 that were also removed.

•PROJECTED RECHARGE

•<u>Agricultural recharge</u>

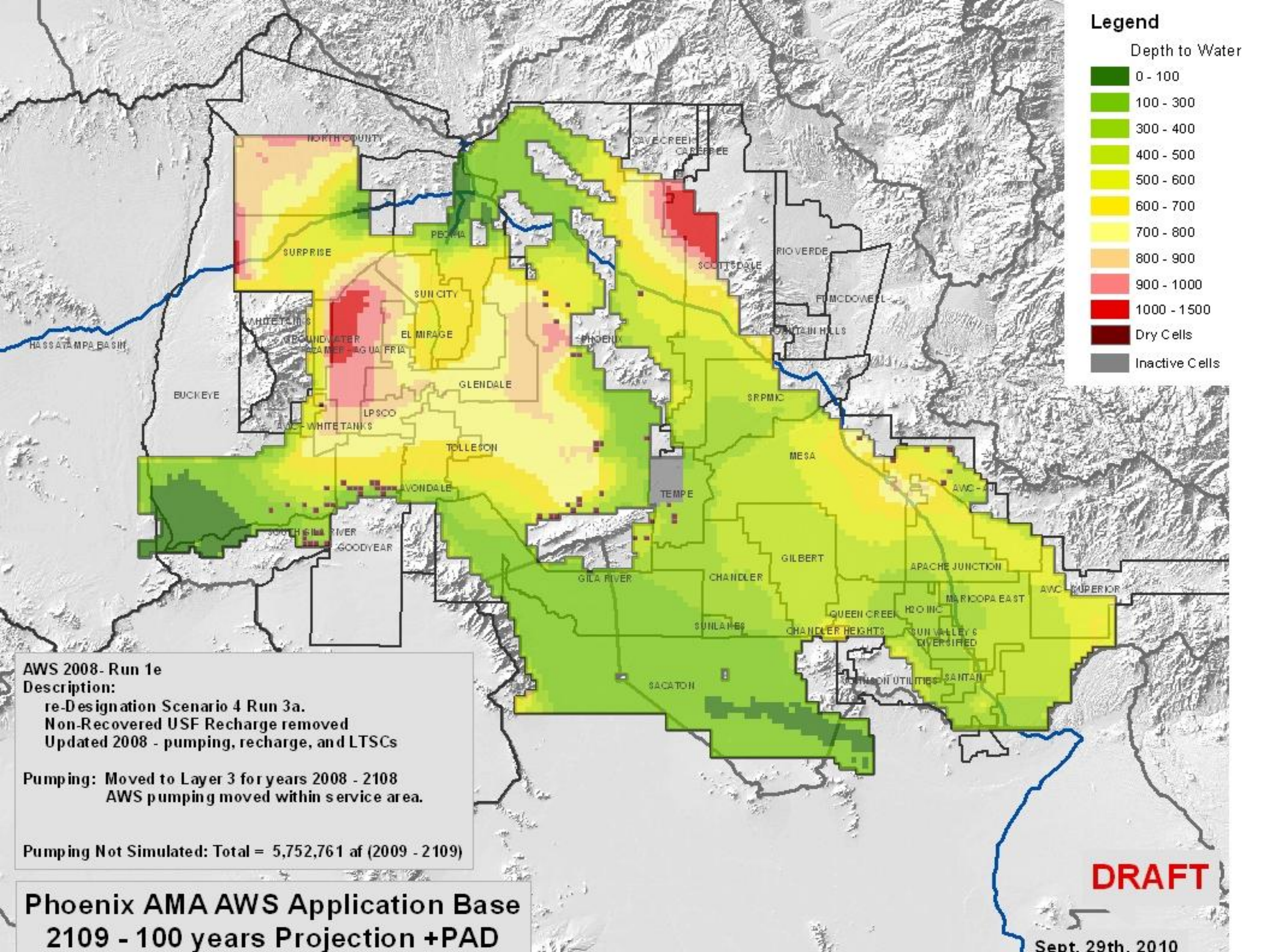
-2006 volumes and locations used in ADWR’s SRV8306 model are used as starting base.
- Ag recharge volumes are removed when the recharge occurs in urbanized cells.

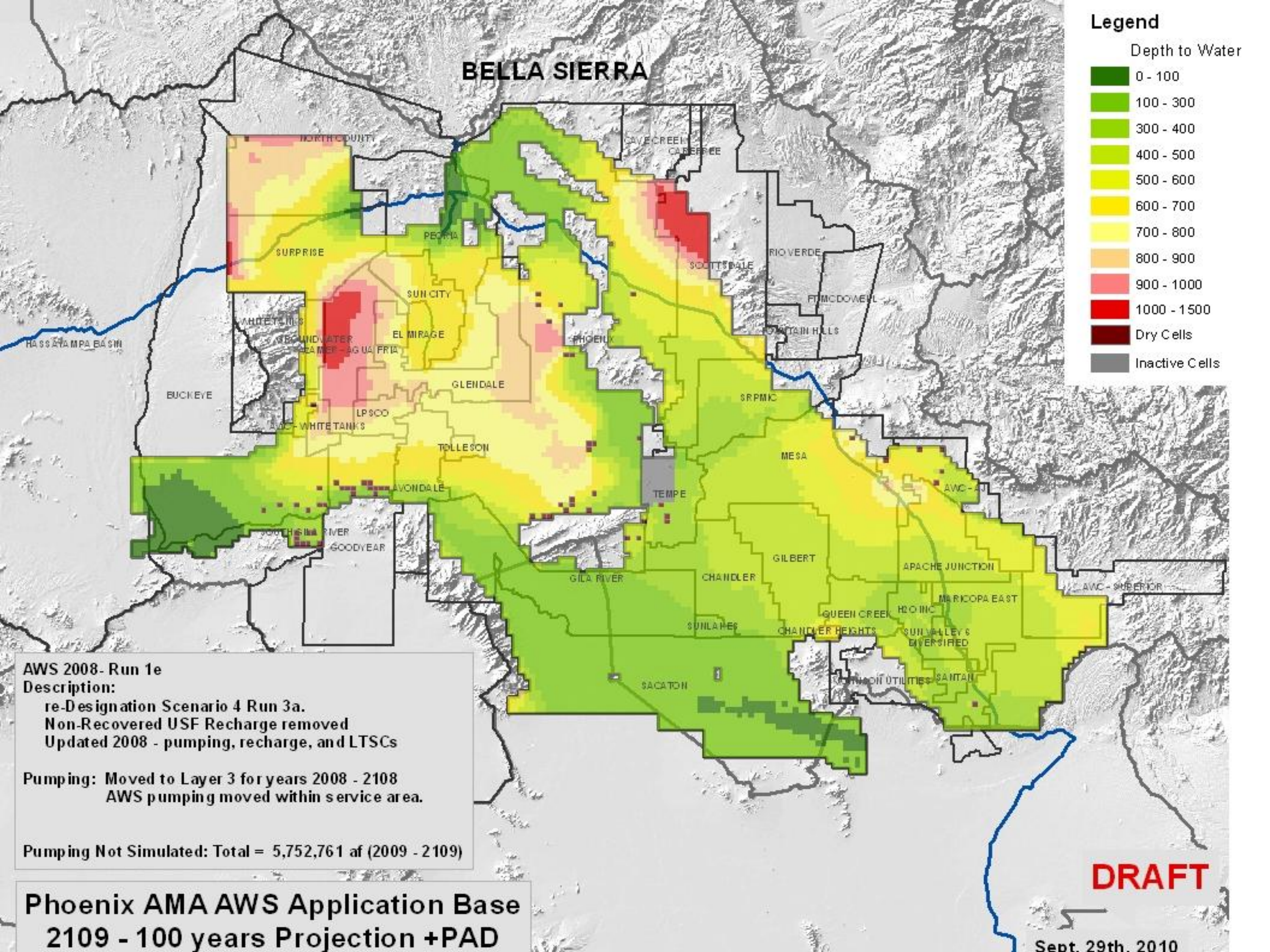
•<u>CAGRD Replenishment Recharge</u>

-Projected CAGRD replenishment is based on a five year average of which USFs and GSFs were used for replenishment.

•<u>Artificial recharge</u>

-Except for CAGRD replenishment all other recharge volumes at USFs and GSFs above what was projected to recover were not used for the 100 year projection.


Legend
Depth to Water
0 - 100
100 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
800 - 900
900 - 1000
1000 - 1500
Dry Cells
Inactive Cells
NORTH COUNTY
CAVE CREEK
CAREFREE
PEORIA
SURPRISE
RIO VERDE
SCOTTSDALE
SUN CITY
FT MCDOWELL
EL MIRAGE
PHOENIX
FOUNTAIN HILLS
HASSAYAMPA BASIN
BUCKEYE
GLENDALE
SRPMIC
LPSCO
AWC - WHITE TANKS
TOLLESON
MESA
AVONDALE
TEMPE
GOODYEAR
GILBERT
APACHE JUNCTION
GILA RIVER
CHANDLER
AWC - SUPERIOR
MARICOPA EAST
H2O INC
QUEEN CREEK
SUNLAKES
CHANDLER HEIGHTS
SUN VALLEY & DIVERSIFIED
SANTAN
SACATON
AWS 2008- Run 1e
Description:
re-Designation Scenario 4 Run 3a.
Non-Recovered USF Recharge removed
Updated 2008 - pumping, recharge, and LTSCs
Pumping: Moved to Layer 3 for years 2008 - 2108
AWS pumping moved within service area.
Pumping Not Simulated: Total = 5,752,761 af (2009 - 2109)
DRAFT
Phoenix AMA AWS Application Base
2109 - 100 years Projection +PAD
Sept. 29th, 2010



BELLA SIERRA
Legend
Depth to Water
0 - 100
100 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
800 - 900
900 - 1000
1000 - 1500
Dry Cells
Inactive Cells
NORTH COUNTY
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BUCKEYE
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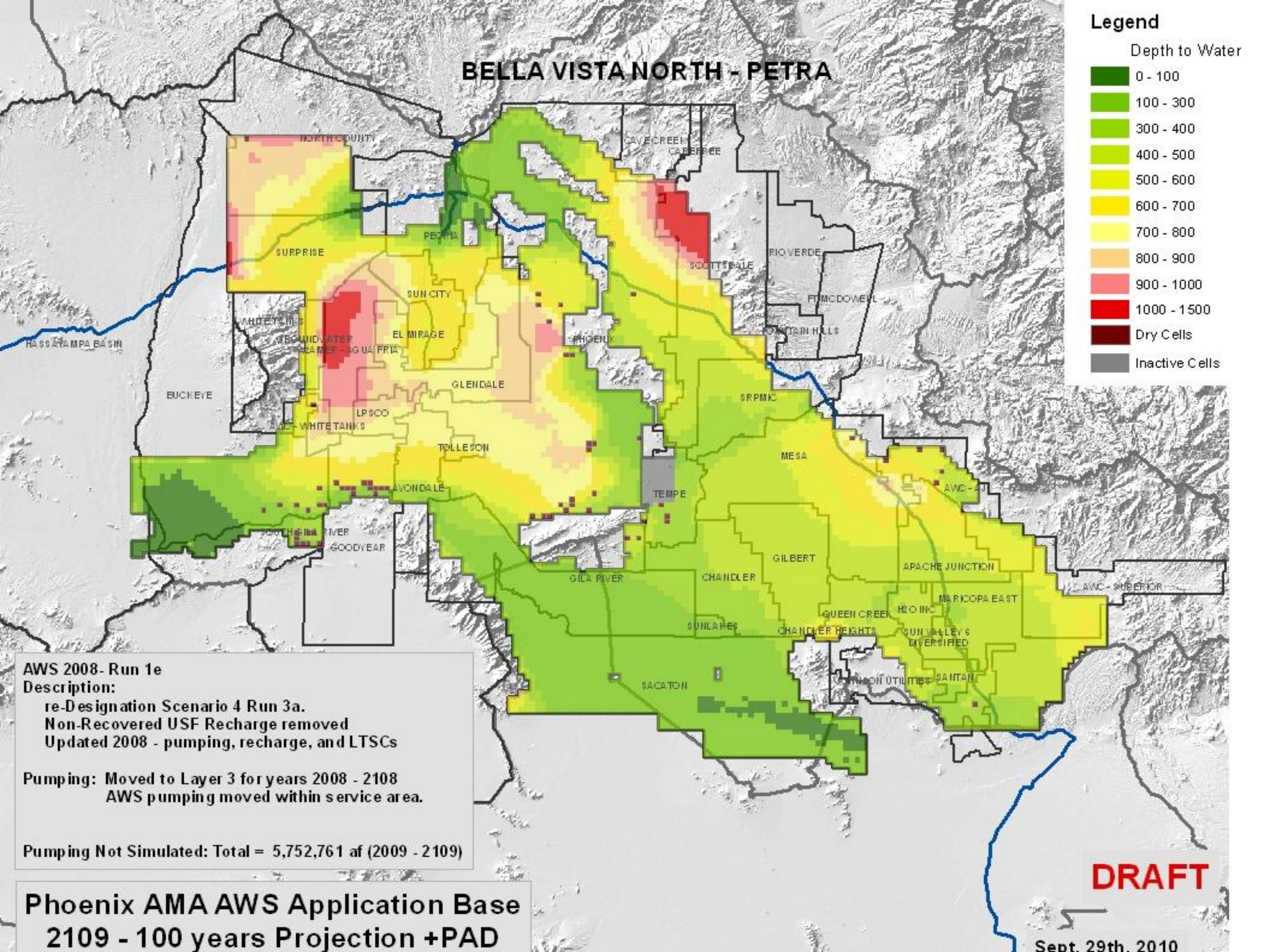
BELLA VISTA NORTH - PETRA
Legend
Depth to Water
0 - 100
100 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
800 - 900
900 - 1000
1000 - 1500
Dry Cells
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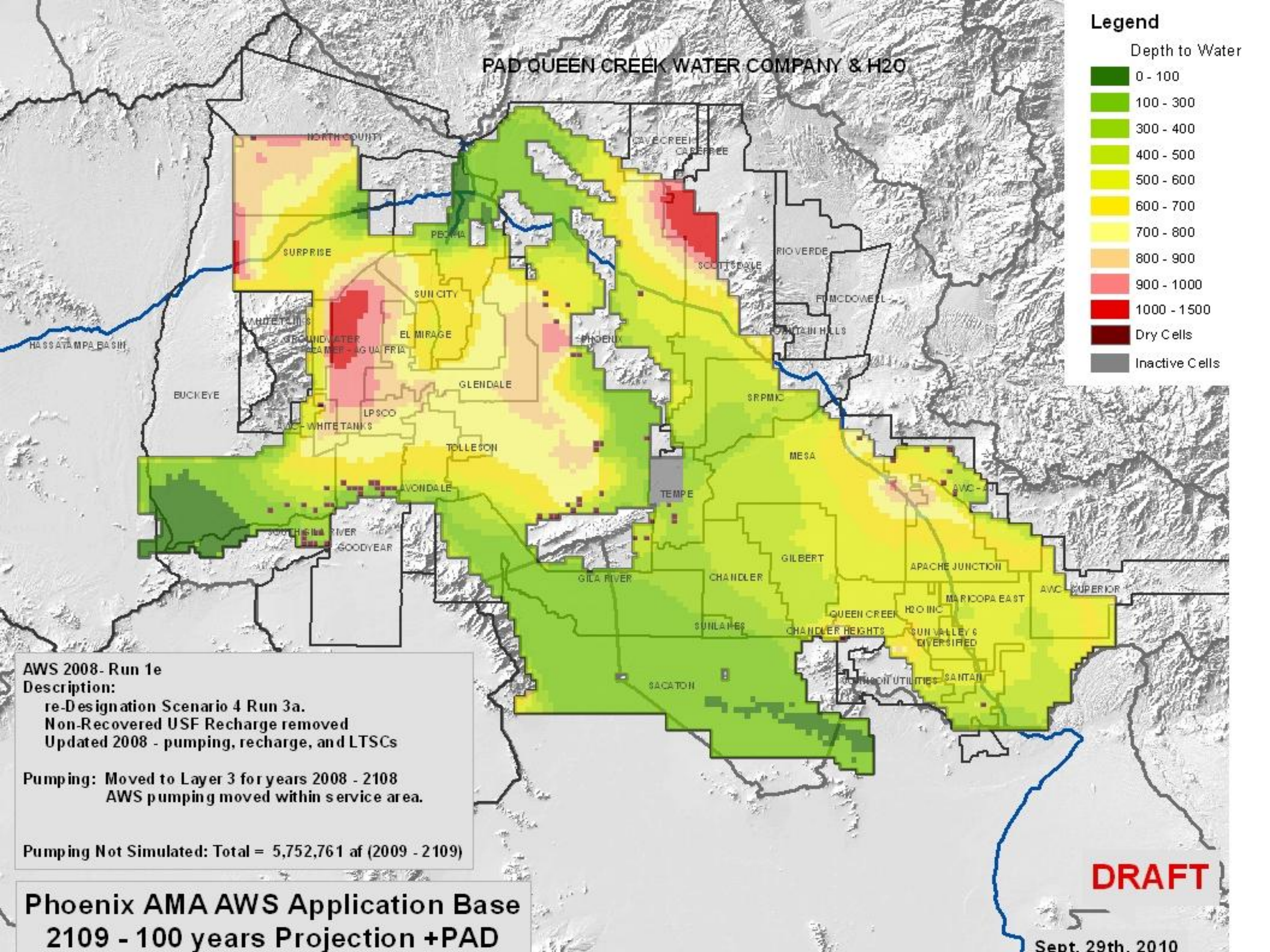
2109 - 100 years Projection +PAD
Sept. 29th, 2010



PAD QUEEN CREEK WATER COMPANY & H2O
Legend
Depth to Water
0 - 100
100 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
800 - 900
900 - 1000
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Dry Cells
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PHOENIX
HASSATAMPA BASIN
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AVONDALE
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GILA RIVER
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MARICOPA EAST
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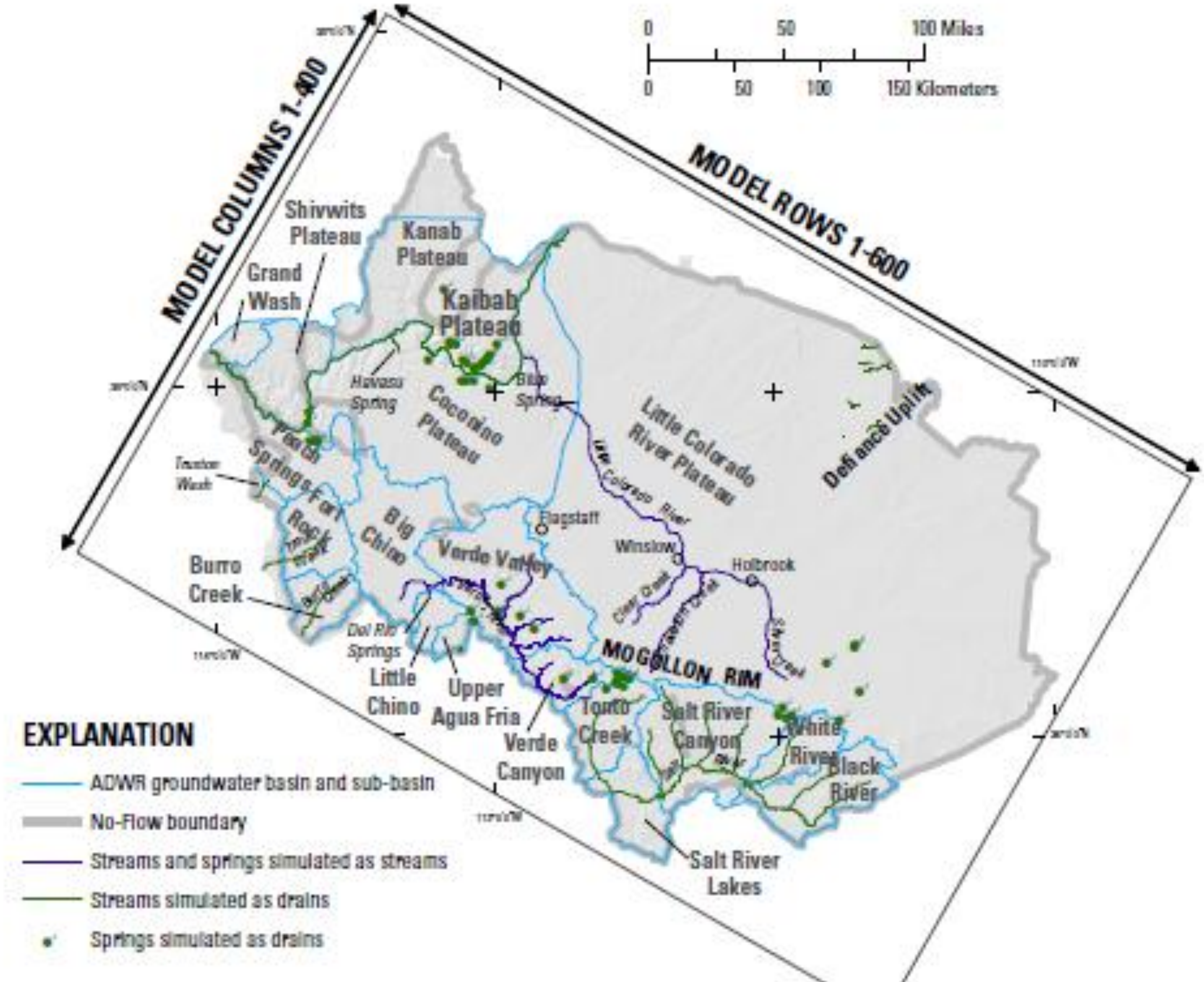
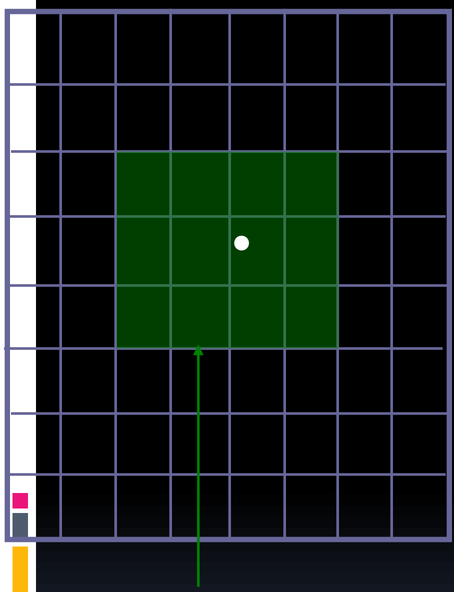
Sept. 29th, 2010


MODEL COLUMNS 1-400
MODEL ROWS 1-600
0 50 100 Miles
0 50 100 150 Kilometers
Shivwits Plateau
Kanab Plateau
Grand Wash
Kaibab Plateau
Havasu Spring
Blue Spring
Coconino Plateau
Little Colorado River Plateau
Defiance Uplift
Peach Springs
Fort Rock
Truxton Wash
Big Chino
Verde Valley
Flagstaff
Winslow
Holbrook
Little Colorado River
Clear Creek
Burro Creek
Del Rio Springs
Little Chino
Upper Agua Fria
Verde Canyon
MOGOLLON RIM
Tonto Creek
Salt River Canyon
White River
Black River
Salt River Lakes
EXPLANATION
ADWR groundwater basin and sub-basin
No-Flow boundary
Streams and springs simulated as streams
Streams simulated as drains
Springs simulated as drains

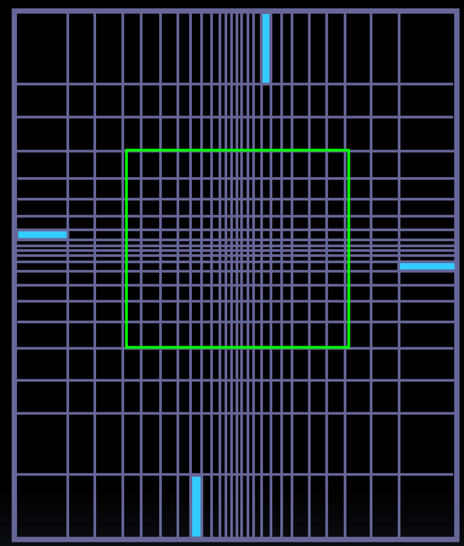
What is Local Grid Refinement?

A typical finite-difference grid



Area of interest

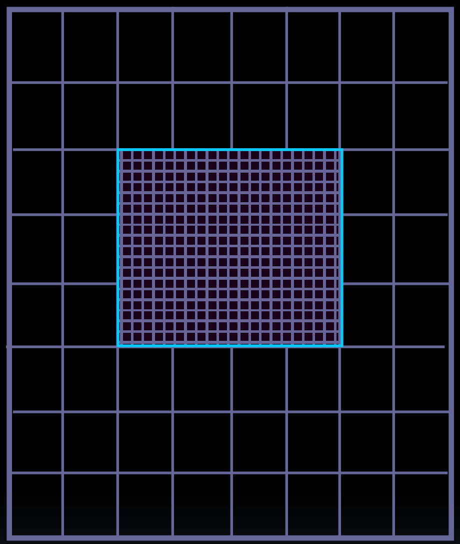
A finite-difference grid with variable grid spacing



Disadvantages
- Extra nodes
- Large aspect ratio

Advantages
- Regular structure

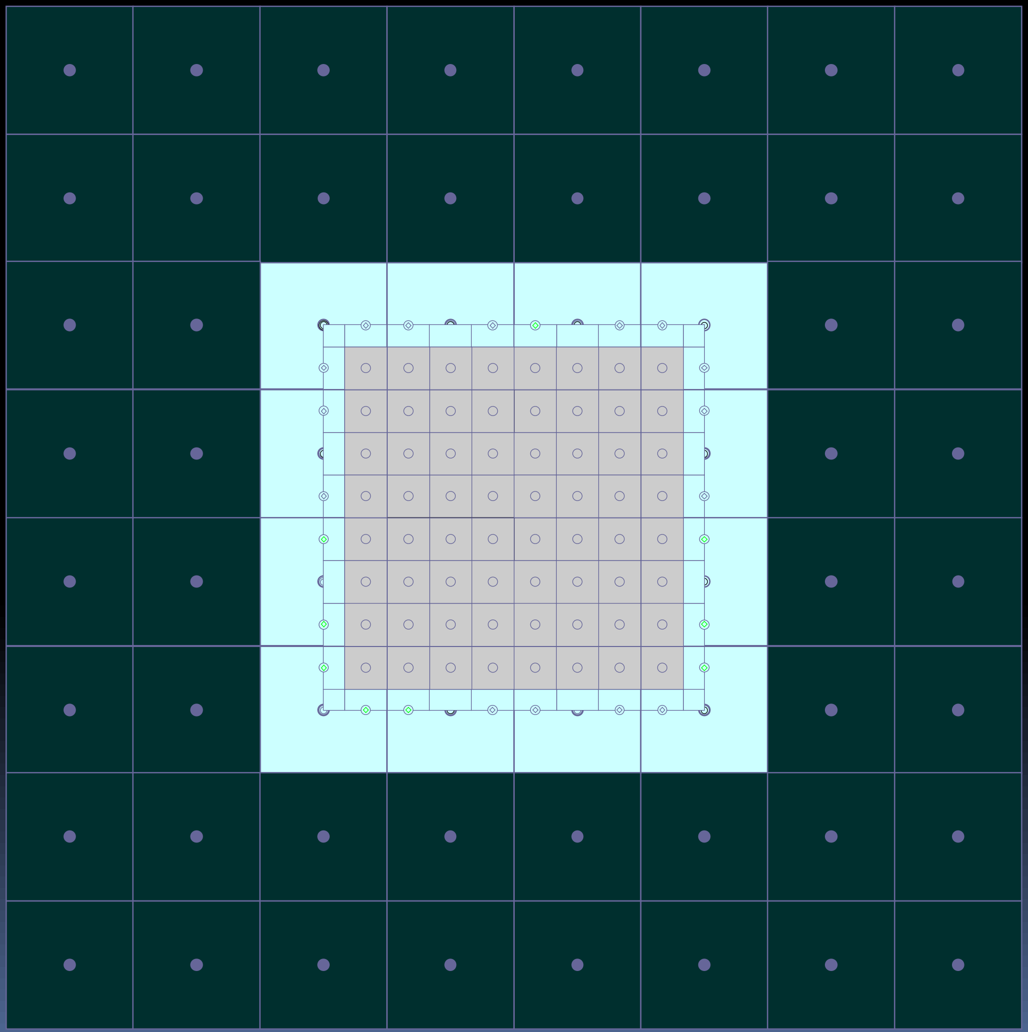
A finite-difference grid with local refinement



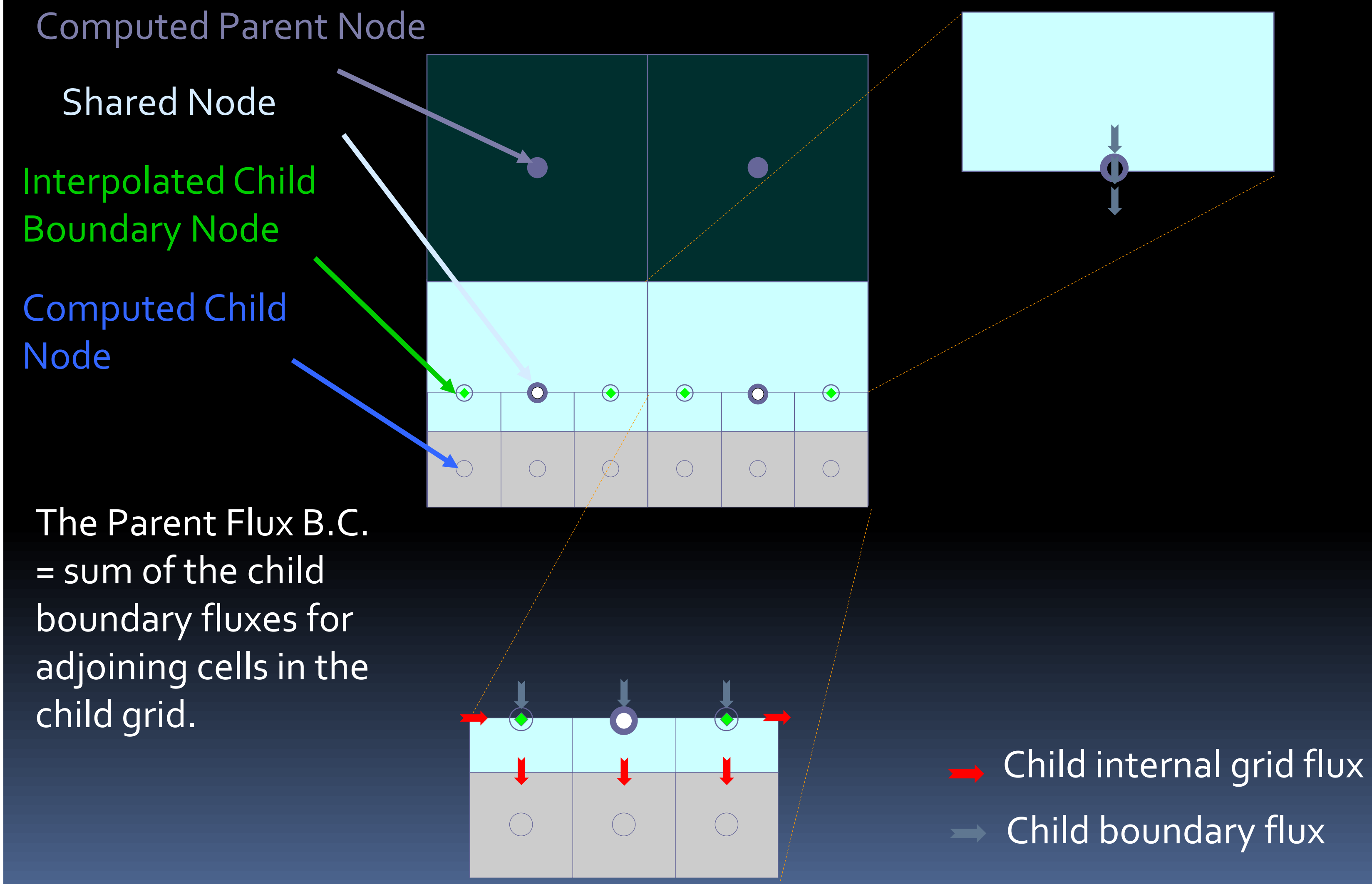
Disadvantages
- Irregular structure at grid interface

Advantages
- Refinement is truly "local"

The Grid Structure of LGR

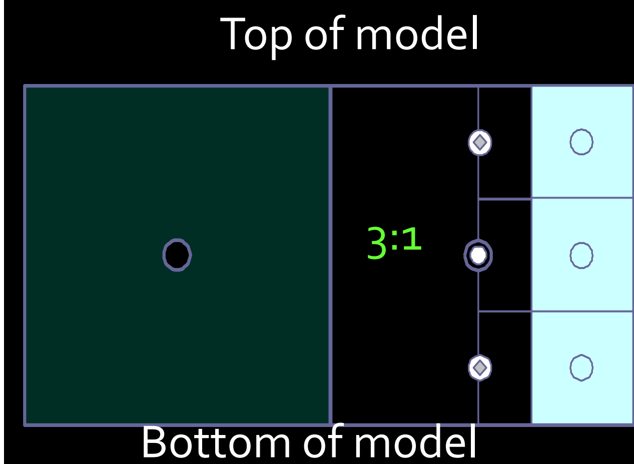


Parent Grid Boundaries: Flux Calculation of flux?

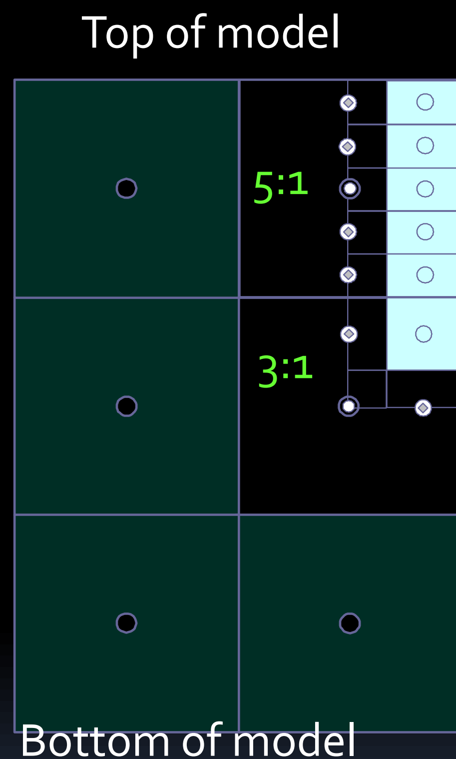


The Parent Flux B.C. = sum of the child boundary fluxes for adjoining cells in the child grid.

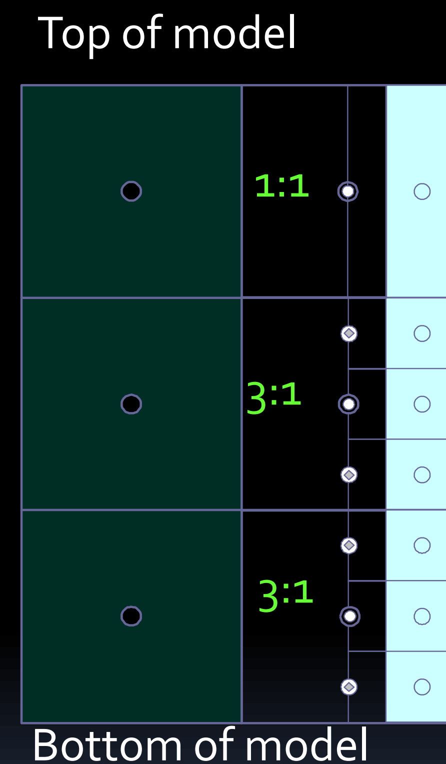
Options for Vertical Refinement



Single layer models can be split into an odd number of child layers

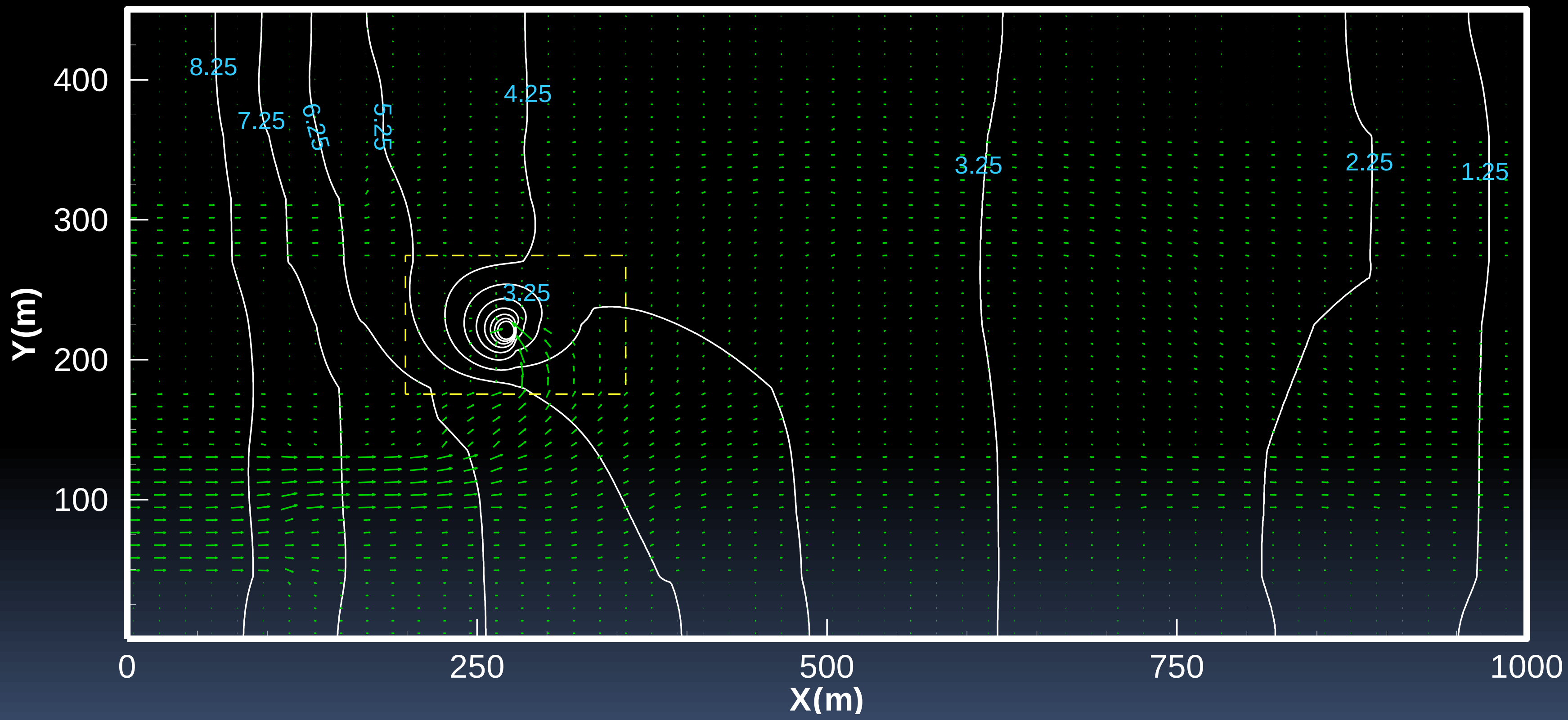


Refinement must begin in first layer. Refinement ratio can vary. Refinement terminates at shared node



1:1 refinement ratio can be used. Refinement extends to bottom of model if refining in last layer.

Head Contours and Flow Field



Input Instructions (LGR\examples\2D_SS)

LGR File: modflow.lgr

```
LGR              ;Indicates this is an LGR input file
2                ;NGRIDS: # of grids
PARENT.nam       ;Name file of the parent model
PARENTONLY       ;GRIDSTATUS: (Parent must be listed first)
00 00            ;IUPBHSV, IUPBFSV:  Unit #'s for saving BFH info
CHILD.nam        ;Name file of the child model
CHILDONLY        ;GRIDSTATUS
1 -59 00 00      ;ISHFLG, IBFLG, IUCBHSV, IUCBFSV: starting heads, IBOUND flag, unit #'s for BFH info
15  -1           ;MXLGRITER, IOUTLGR: max. # of LGR iterations, print flag
0.500  0.500     ;RELAXH, RELAXF: relaxation for heads and fluxes
1.0E-5  1.0E-5   ;HCLOSELGR, FCLOSELGR: closure criteria for head and fluxes
1 20 22          ;NPLBEG,NPRBEG,NPCBEG: beginning layer, row and column
1 31 39          ;NPLEND,NPREND,NPCEND: ending layer, row and column
9                ;NCPP: # of child cells per width of parent
1                ;NCPPL (NPLBEG to NPLEND): # of child cells per parent layer
```

Limitations of many Analytic Models

- **Theis Assumptions:**
- Single layer
- Single value for transmissivity or hydraulic conductivity
- Single value for storage property
- Single value for saturated thickness
- # wells that my be included (including image wells)
- No recharge allowed by ADWR

Key Analytic Input Parameters

- Aquifer Condition (confined, unconfined)
- Transmissivity &/or Hydraulic Conductivity values
- Storage coefficient/ Specific Yield
- Initial Saturated Thickness
- Hydrologic Boundary simulation (image well theory)
- Number of wells & location
- Discharge rate per well

Future Concerns

•Analytic Model Selection & Availability

•License & Cost

•Ease of use & reproduction of results

•Unilateral use by everyone

<u>Principal Figures/Illustrations /Maps</u>

•Geologic Map

•Geologic Cross-sections

•Depth to Bedrock

•Aquifer Test Plots (drawdown & recovery data)

•Maps with Boundary Conditions

•Well Location(s)

•Hydrographs (Historic groundwater decline rates)

•Hydrological Properties (k, sy) Distribution

•Principal Figures/Illustrations /Maps (continuation)

•The Measured vs. Simulated Water Level.

•Interpretation of the Results, Including a comparison between conceptual model budget and simulated model budget.

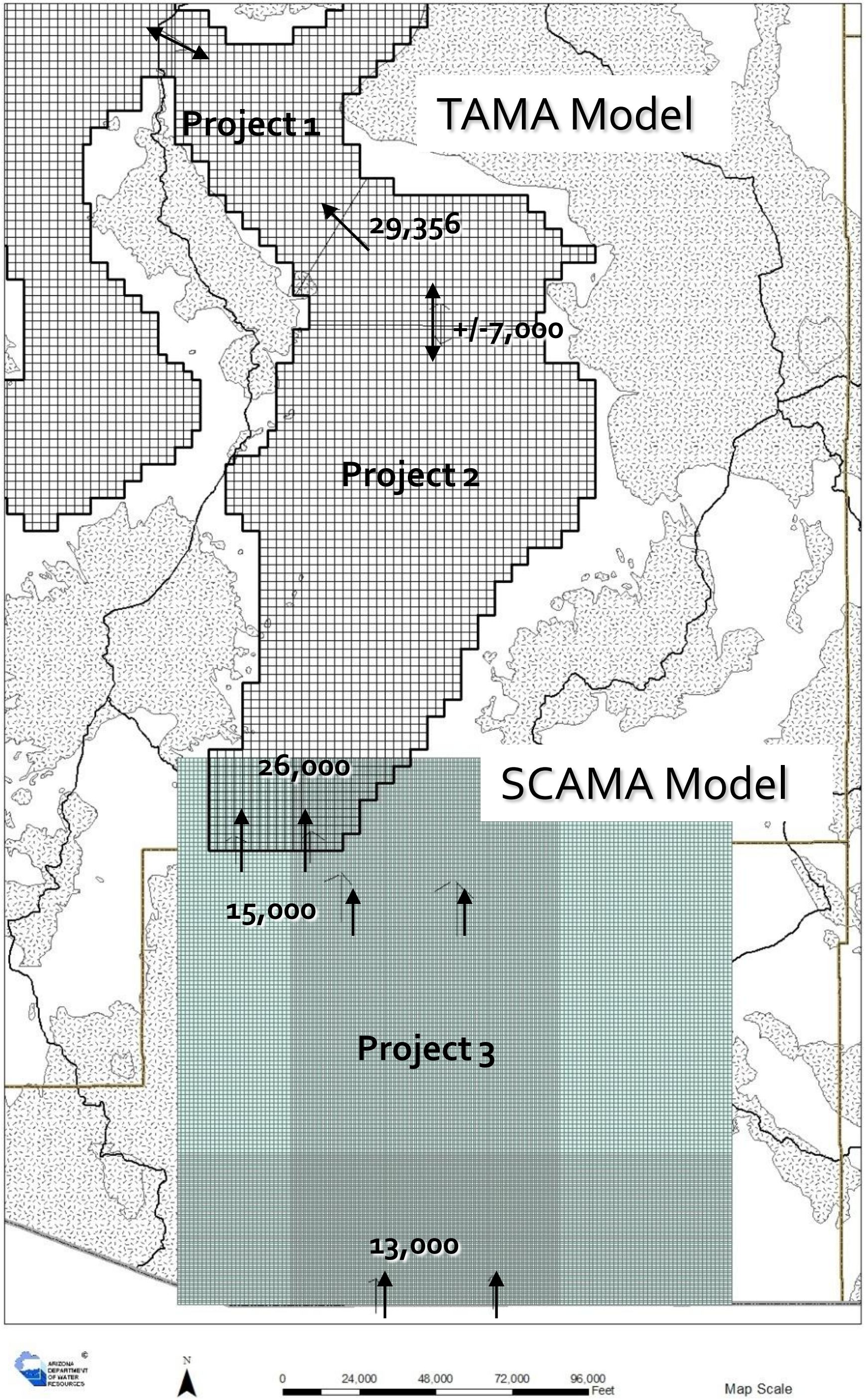
•Statistical Interpretation of the Results of Calibration.

•Sensitivity Analysis.

•Maps of Projected: 100 Year Impact (drawdown)

•Map of Projected: 100 Year Depth-To-Water.

•Table Showing the Components of the Budget.


TAMA Model
Project 1
29,356
+/-7,000
Project 2
26,000
SCAMA Model
15,000
Project 3
13,000
N
0
24,000
48,000
72,000
96,000
Feet
Map Scale