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**

\[ s = \frac{114.6 \cdot Q \cdot W(u)}{T} \]

\[ W(u) = \text{Well Function = Exponential Integral} \]

\[ u = \frac{1.87^3 \cdot S}{T \cdot t} \]

\[ s = \text{Drawdown (feet)} \quad r = \text{Distance From Well (feet)} \]

\[ T = \text{Transmissivity (gpd/ft)} \quad S = \text{Storage Coefficient} \]

\[ t = \text{Time (days)} \quad Q = \text{Pumping Rate (gpm)} \]
**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)

<table>
<thead>
<tr>
<th>Projected 100-Year Drawdown (Feet)</th>
<th>MODFLOW Grid-Spacing *</th>
<th>MODFLOW Grid-Spacing *</th>
<th>MODFLOW Grid-Spacing *</th>
<th>MODFLOW Grid-Spacing *</th>
<th>MODFLOW Grid-Spacing *</th>
<th>Theis Equation</th>
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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 ft²/d = 112,200 gpd/ft
Sys = 1
Q = 2,500,000 ft³/d = 12,986 gpm = 20,948 AFA

Table 1  Simulation 1: Comparison of Analytical and Numerical Model Results:  

<p>| T = 15,000 ft²/d | Q = 20,948 AFA |</p>
<table>
<thead>
<tr>
<th>Projected 100-Year Drawdown (Feet)</th>
<th>MODFLOW Grid-Spacing *</th>
<th>MODFLOW Grid-Spacing *</th>
<th>MODFLOW Grid-Spacing *</th>
<th>MODFLOW Grid-Spacing *</th>
<th>MODFLOW Grid-Spacing *</th>
<th>Theis Equation</th>
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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

\[ T = 15,000 \text{ ft}^2 \text{/day} \]

\[ T = 112,200 \text{ gpd/ft} \]

\[ Q = 250,000 \text{ ft}^3 \text{/day} = 1299 \text{ gpm} = 2095 \text{ AFA} \]

Table 2 Simulation 2: Comparison of Analytical and Numerical Model Results:  \( T = 15,000 \text{ ft}^2 / \text{Day} \)  \( Q = 2,095 \text{ AFA} \)
Radial Distance From Well At Which Listed Drawdown Occurs (Feet)

<table>
<thead>
<tr>
<th>Projected 100-Year Drawdown (Feet)</th>
<th>MODFLOW Grid-Spacing *</th>
<th>MODFLOW Grid-Spacing *</th>
<th>MODFLOW Grid-Spacing *</th>
<th>MODFLOW Grid-Spacing *</th>
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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 ft²/d = 56,100 gpd/ft
Sy=1
Q=250,000 ft³/d = 1,299 gpm = 2,095 AFA

**Table 3** Simulation 3: Comparison of Analytical and Numerical Model Results:  \( T = 7,500 \text{ ft}^2/\text{d} \)  \( Q = 2,095 \text{ AFA} \)
Radial Distance From Well At Which Listed Drawdown Occurs (Feet)

<table>
<thead>
<tr>
<th>Projected 100-Year Drawdown (Feet)</th>
<th>MODFLOW Grid-Spacing *</th>
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<th>MODFLOW Grid-Spacing *</th>
<th>MODFLOW Grid-Spacing *</th>
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</tbody>
</table>

NC = Not Calculated

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

Unconfined Aquifer, 1000' initial saturated thickness

T = 2,500 ft²/d = 18,700 gpd/ft
Sy = 1

Q = 95,474 ft²/d = 496 gpm = 800 AFA

**Table 4** Simulation 4: Comparison of Analytical and Numerical Model Results: \(T = 2,500 \text{ ft}^2/\text{d}\) \(Q = 800\) AFA
Volume of groundwater removed from storage from within the blue cylindrical volume (radius = 1,320 feet) predicted by MODFLOW = 1,928 acre-feet

Drawdown in model cell that contains well predicted by MODFLOW = 153 feet

Drawdown at well predicted by Theis Equation = 308 feet

Volume of groundwater removed from storage from within the cone of depression of well (hatched volume with maximum radius = 1,320 feet) predicted by Theis Equation = 1,642 acre-feet

Not drawn to scale

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

Details of Model Simulation

- \( T = 15,000 \text{ ft}^3/\text{d} \)
- \( S_Y = 0.10 \)
- Unconfined Aquifer
- \( Q = 2,500,000 \text{ ft}^3/\text{d} \)
- \( t = 36,500 \text{ days} \)
- MODFLOW grid spacing was 2,640 x 2,640 feet
- No corrections applied to Theis results for aquifer dewatering
<table>
<thead>
<tr>
<th>Simulation Number</th>
<th>Volume of GW Removed From Storage Within a Radius of 1,320 Feet of Well (MODFLOW)</th>
<th>Volume of GW Removed From Storage Within a Radius of 1,320 Feet of Well (Theis)</th>
<th>Ratio of GW Removed From Storage (MODFLOW/Theis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,928 acre-feet</td>
<td>1,642 acre-feet</td>
<td>1.17</td>
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<tr>
<td>2</td>
<td>177 acre-feet</td>
<td>164 acre-feet</td>
<td>1.08</td>
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<tr>
<td>3</td>
<td>341 acre-feet</td>
<td>305 acre-feet</td>
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</tr>
<tr>
<td>4</td>
<td>341 acre-feet</td>
<td>308 acre-feet</td>
<td>1.11</td>
</tr>
</tbody>
</table>

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.
SRV Data and Conceptualization

Pumping

Layers 1, 2, 3 Pumping

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AWS BASELINE SCENARIO ASSUMPTIONS

• 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

• Agricultural recharge

  - 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.

• CAGRD Replenishment Recharge

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

• Artificial recharge

  - 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.
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 = 5,752,751 af (2009 - 2109)

Phoenix AMA AWS Application Base
2109 - 100 years Projection + PAD

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

DRAFT
Sept 29th, 2010
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 = 5,752,781 af (2009 - 2109)

Phoenix AMA AWS Application Base
2109 - 100 years Projection + PAD

DRAFT
Sept 29th, 2010
AWS 2008 - Run 1e
Description:
re-Designation Scenario 4 Run 3a.
Non-Recovered USF Recharge removed
Updated 2008 - pumping, recharge, and LTSCs

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Phoenix AMA AWS Application Base
2109 - 100 years Projection + PAD

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

DRAFT
Sept 29th, 2010
What is Local Grid Refinement?

A typical finite-difference grid

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

Top of model

Bottom of model

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

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

1:1 refinement ratio can be used. Refinement extends to the bottom of the model if refining in the 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, IUCBHHSV, 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 may 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
Principal Figures/Illustrations /Maps

• 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

SCAMA Model

Project 3

26,000

15,000

13,000