CE EN 547 – BRIGHAM YOUNG UNIVERSITY

MODFLOW Solvers

Lecture Objectives

- Understand how an iterative solver works
- Know the basic solver parameters and understand how they impact the solver
- Understand how and why solvers don't converge
- Know how to troubleshoot solver convergence problems

Iterative Solvers

- Starting head values are iteratively “tweaked” until head differences satisfy governing equation
- Each solver uses a different algorithm to modify heads
- Sometimes we need to switch solvers or tweak solver parameters to get a model to converge

369.45...	369.41...	369.30...	369.13...	368.90...	368.61...	367.85...
369.44...	369.39...	369.28...	369.11...	368.87...	368.58...	367.83...
369.41...	369.35...	369.24...	369.06...	368.83...	368.54...	367.78...
369.35...	369.29...	369.17...	369.00...	368.76...	368.47...	367.71...
369.27...	369.21...	369.09...	368.91...	368.68...	368.38...	367.61...
369.16...	369.10...	368.98...	368.80...	368.56...	368.27...	367.49...
369.04...	368.98...	368.86...	368.67...	368.43...	368.13...	367.35...
368.90...	368.83...	368.71...	368.52...	368.28...	367.97...	367.17...
368.73...	368.67...	368.54...	368.35...	368.10...	367.78...	366.98...
368.55...	368.49...	368.36...	368.16...	367.90...	367.58...	366.75...
368.36...	368.29...	368.16...	367.95...	367.68...	367.35...	366.49...
368.15...	368.08...	367.94...	367.73...	367.45...	367.10...	366.21...
367.93...	367.86...	367.71...	367.49...	367.20...	366.84...	365.90...
367.70...	367.62...	367.47...	367.24...	366.94...	366.56...	365.57...
367.46...	367.38...	367.23...	366.99...	366.67...	366.27...	365.23...
367.22...	367.14...	366.98...	366.73...	366.40...	365.98...	364.88...
366.98...	366.90...	366.73...	366.47...	366.13...	365.69...	364.54...
366.75...	366.66...	366.48...	366.22...	365.86...	365.41...	364.21...

Solver Packages

Code	Name	Notes
SIP	Strongly Implicit Procedure	One of the original solvers. Simple but can have speed and stability issues.
SSOR	Slice-Successive Over-Relaxation	One of the original solvers. Can result in incorrect solutions. Not recommended.
PCG2	Pre-Conditioned Conjugate Gradient	Good all-around solver. Default solver in GMS.
PCGN	PCG with Improved Non-Linear Control	Newer version of PCG2 package. More stable under some conditions.
NWT	Newton Solver	Used with MODFLOW-NWT. Best for wetting/drying problems.
GMG	Geometric Multi-Grid	Multi-grid solver requires more memory but results in faster solution. USGS version.
DE4	Direct Solver	Direct matrix solution (non-iterative).
LMG/ SAMG	Algebraic Multi-Grid	Commercial multi-grid solvers. Outstanding performance but extra cost.

Basic Solver Options

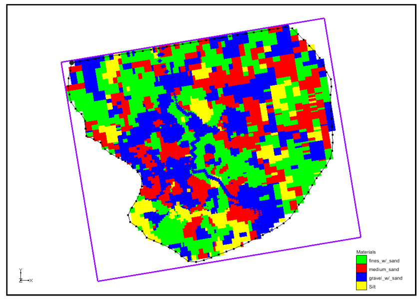
- Max number of iterations
  - Iteration stops at this point regardless of convergence
- Convergence tolerance
  - Iteration stops if max head change is less than this amount
- Acceleration parameter
  - Controls the amount of adjustment made to heads at each iteration
  - Options
    - =1.0 Default value. Head changes standard amount determined by solver
    - <1.0 Head change is reduced. Improves convergence but results in slower solution
    - >1.0 Converges faster but may be unstable

Solver Comparison

- Using MODFLOW 2000
- Run on Intel Core2 Quad CPU 2.4 GHz
- Initial condition the same for all solvers
  - Starting heads = constant value OR
  - Starting heads = top of grid
- HCLOSE = .001
- RCLOSE = .001 (all solvers except SIP)

Solver Comparison Case #1

- Woburn model
- HUF package
- 8 layers
- 152,880 cells



SIP	PCG2	SAMG	GMG
980 sec*	64 sec	39 sec	87 sec

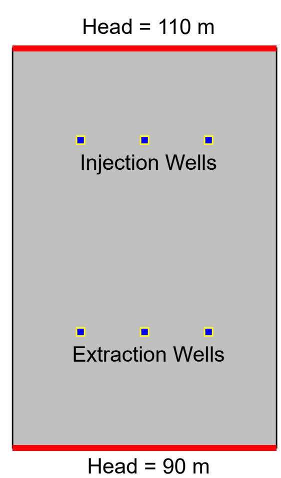
*had to reduce acc. param to 0.25 in order to converge

Solver Comparison Case #2

- One layer model
- Unconfined
- 96,000 cells

SIP	PCG2	SAMG	GMG
5 sec*	6 sec	2.5 sec	6 sec

*had to reduce acc. param to 0.1 in order to converge, large flow budget error

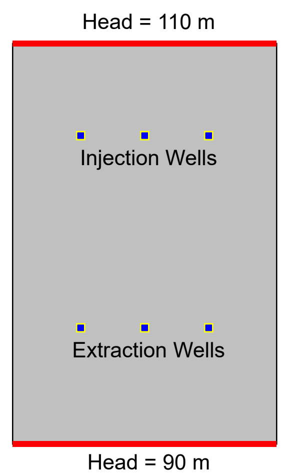


Solver Comparison Case #3

- Same as previous
- Increased num cells to 216,000

SIP	PCG2	SAMG	GMG
16 sec*	15 sec	6 sec	13 sec

*had to reduce acc. param to 0.05 in order to converge, large flow budget error

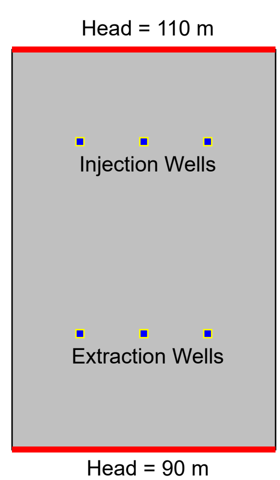


Solver Comparison Case #4

- Same as previous
- Changed to transient
- 4 stress periods, 10 time steps

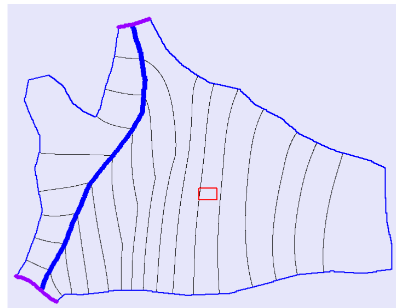
SIP	PCG2	SAMG	GMG
50 sec*	120 sec	55 sec	110 sec

*had to reduce acc. param to 0.05 in order to converge, large flow budget error



Solver Comparison Case #5

- Two layer model
- Unconfined
- Steady state
- 600,000 cells



SIP	PCG2	SAMG	GMG
587 sec*	56 sec	29 sec	40 sec

*had to reduce acc. param to 0.05 in order to converge

Solver Comparison Summary

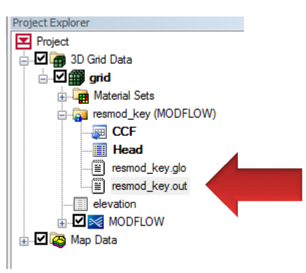
Num. Cells	# Layers	Trans.	SIP*	PCG2	SAMG	GMG
152,880	8	No	980	64	**39**	87
96,000	1	No	5	6	**2.5**	6
216,000	1	No	16	15	**6**	13
216,000	1	Yes	**50***	120	55	110
600,000	2	No	587	56	**29**	40

*had to reduce acc. param in order to converge, some of the models had large flow budget error

- Improper aquifer properties
- Unbalanced flow budget
- Improper initial conditions
- Improper boundary conditions
- Wetting and drying issues
- Highly sensitive model
- Etc.

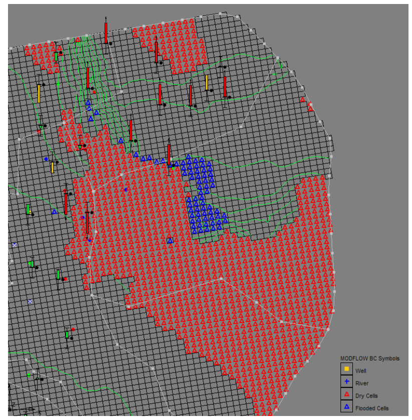
Troubleshooting Steps

1) Review command line output from MODFLOW (Run MODFLOW Window)
2) Run Model Checker
3) Look in MODFLOW output file (*.OUT)

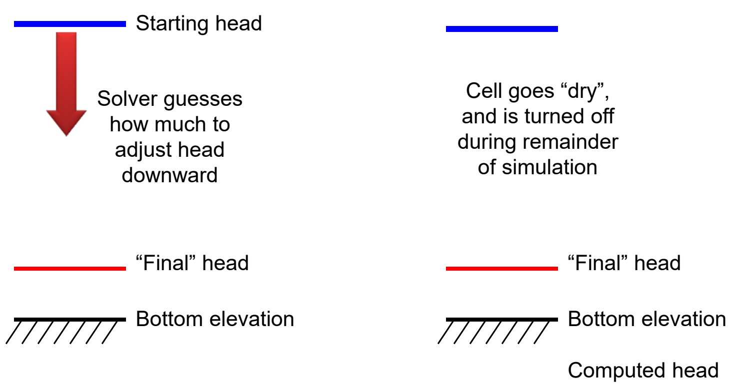


Wetting and Drying

- With most solvers, if head drops below bottom of cell, the cell becomes dry and is “turned off”
- Can occur during any portion (iteration) of solution process, not just at end of time step
- Causes
  - Head overshoot
  - Model parameters
  - Transient conditions



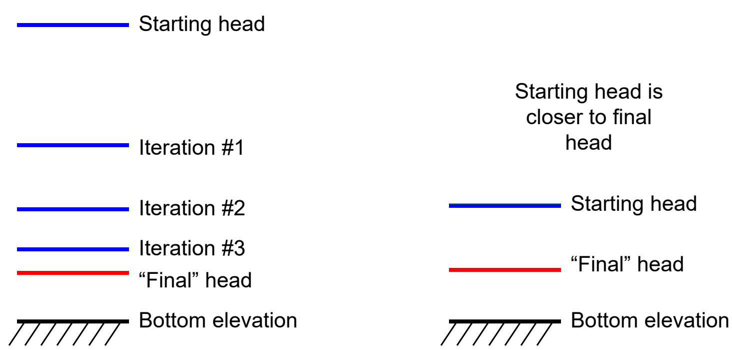
Head overshoot



Initial Condition

After One Iteration

Eliminating Head Overshoot



Reduce Acceleration Parameter

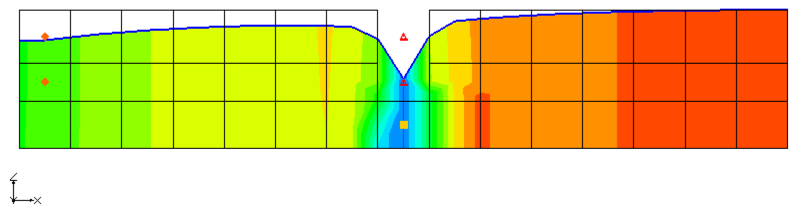
Improve Starting Head Estimates

Model Parameters

- In many cases, cells are going dry due to:
  - Recharge too low
  - K too high
  - Etc.
- Solution
  - Adjust parameters to better calibrate model

Transient Water Table

- Transient conditions will cause heads to fluctuate and cells to go dry
- Particularly an issue for multi-layer models



Rewetting Option

- Option available in all flow packages (BCF, LPF, HUF)
- Off by default
- Rewetting increases solution time
- May case solution to be less stable

MODFLOW-NWT

- New version of MODFLOW released in 2011
- Designed to solve nonlinear problems due to unconfined conditions or nonlinear boundary conditions
- **Best solution for wetting and drying**