GEGN 583 Spring 2011
Mathematical Modeling of Ground Water Systems
CLASSROOM: BH201

Instructor: Dr Eileen Poeter
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Office: Room 121B Berthoud Hall
OFFICE HOURS: http://www.mines.edu/~epoeter/OfficeHours.htm
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class web page: http://inside.mines.edu/~epoeter/583CSM

Goal: After students complete this course, they will be able to pick up any viable groundwater modeling software manual and set up a simulation of a groundwater system, calibrate the model and make predictions using the model. The individual will feel a bit uncertain about details of the process, but will know how to identify concerns and find information that will help them resolve their concerns.

Course format: Information specific to this class is on http://inside.mines.edu/~epoeter/583CSM. Each student should connect to the site each week for class information and materials. An old ground water modeling course is presented, in stand-alone web format, as sequential units on a web page for which a link is provided on the http://inside.mines.edu/~epoeter/583CSM page. Students may find these additional pages useful, but they are only supplemental and do not constitute the GEGN583 course.

Each student will choose a specific modeling project to work on throughout the semester. There is a tendency for students to want modeling knowledge presented to them via lectures. Generally it is not effective and does not prepare one for modeling in a professional environment where teaching yourself is critical. Active learning is effective in developing modeling ability. Consequently, class sessions will start with a lecture then students will work on projects interspersed with impromptu lectures based on student questions about their projects. Students are encouraged to discuss issues, work together and help one another.

Assignments are designed to lead you through the modeling process phase by phase, thus 10 submissions rather than 1 or 2. On average, plan approximately 6 hours per week outside of class studying related material and conducting your modeling project. If you can do the work in less time, that is good, you are grasping quickly the essence of what is required. Requiring more time than this generally is due to thinking the task is more difficult than it is. That is a good reason to contact me. **Start each study session by reviewing this document and visiting the class web page to recall: 1) what topic to study; 2) what is due next week; and 3) submission directions for each assignment. Meet all submission deadlines with the best product you can provide. I will grade and provide feedback, returning the graded work no later than the next class session. You will be allowed to resubmit at the end of the following class session to improve your grade based on my comments. If you want the grade reconsidered, you must submit the paper that I graded with my annotations on it and your revised paper (associated computer files should be submitted as a zip file and clearly labeled) by the very next class period.**

Optional Recommended Text: Anderson, M.P., and W.W. Woessner, 1992, Applied Groundwater Modeling, Academic Press, 381 p. Although this text is dated there is much valuable information that does not change with time. It is still the most referenced modeling book for consulting work. Note references to pertinent sections as [A&W Chp X] on the schedule.

Tentative Schedule (subject to change to adjust to our pace, changes will be announced in class and updates posted to the class web page):

JAN 12 Introduction and Boundary Conditions (Old on-line course Units 1 & 2) [A&W Chp 1, 3, 4, 5] Analytical Modeling (Units 3, 4 & 5)

19 Finite Difference Theory & Grid Design **ASSGN#1** (Old on-line course Units 6 & 7) [A&W Chp 2 & 3]

26 Finite Difference by spreadsheet & Intro to MODFLOW (Unit 8) **ASSGN#2 and 3** [A&W Chp 8 & 9]

FEB 2 MODFLOW (Unit 8) continued **ASSGN#4**

9 MODFLOW (Unit 8) continued / Trouble Shooting (Unit 12)
Submit MODFLOW files covered on 2/2 but for your project to get credit for Assgn#5

16 MODFLOW continued as needed
Submit MODFLOW files covered on 2/9 but for your project to get credit for Assgn#5

23 Calibration Overview (Unit 9) [A&W Chp 8] **ASSGN#5**

MAR 2 Calibration with UCODE
Submit MODFLOW observation files that work with the files you submitted for Assgn#5

9 Calibration, Linearity, Prediction, Uncertainty
Submit calibration files covered on 3/2 but for your project to get credit for Assgn#6

16 Spring Break

23 Calibration, Linearity, Prediction, Uncertainty continued as needed
Submit calibration files covered on 3/9 but for your project to get credit for Assgn#6

30 GUI's (Unit 10)/Transient Flow Modeling (Unit 11) [A&W Chp 7] **ASSGN#6**

APR 6 MODFLOW GUI's / Transient Flow Modeling **Submit transient MODFLOW files covered on 3/30 but for your project to get credit for Assgn#7**

13 Transient continued if needed and Intro to Transport Modeling & MT3D (Units 13 & 14) [A&W Chp 12] **Submit transient MODFLOW files covered on 4/6 but for your project to get credit for Assgn#7**

20 MT3D continued if needed (Unit 14) **ASSGN#7** **Submit MT3D files covered on 4/13 but for your project to get credit for Assgn#9**

27 Projects & Issue resolution for projects **ASSGN#8** **Submit MT3D files covered on 4/20 but for your project to get credit for Assgn#9**

MAY 4 As needed for catching up **ASSGN#9 (I will return these by noon May 6.**

Finals Week ASSGN#10 Presentation during Exam **submit lessons May 6 & ppt 1 hrs before exam block starts**

All submissions should be typed except presentation of hand calculations, which should be very neat and easy to follow because of comments connecting each equation or calculation explaining what is being done (e.g. the equation, what it represents in the physical world, the values of parameters and boundary conditions and where they were obtained).

All submissions should be organized and written for a person familiar with ground-water hydrology, but not familiar with your project or the assignment.

All assignments should be submitted as specified below. If you submit electronically by email put all files in a zip file named ASSGN#_LASTNAME.ZIP, and accompany with a hard copy of the report. You do not need to make hard copies of computer input and output, which can be voluminous, but these need to be provided by email. If your **diagrams** are hand-drawn, scan them and insert them in your report**. Number figures in the order that you mention them in the text, referring to them by number from your text discussion.**

Assignment #1 Conceptual Model: Select a **SINGLE-PHASE, CONSTANT DENSITY, SATURATED, FLOW** modeling project with both a steady and transient aspect, and write a summary describing it to me. If you do not have a place to model, I can help you identify one. Your description should use illustrations and include:

- **Title**
- **Objective**
- **Problem Description**
- **Geohydrologic Setting**
  - **FIGURES (at least one plan and one cross section) ARE REQUIRED TO ILLUSTRATE THE FOLLOWING ITEMS**
    - **location (show on map)**
    - **geometry (draw outline of modeled area on the maps and cross sections)**
    - **boundary conditions (head and flux boundaries and head dependent flux boundaries)**
    - **property value ranges (i.e. hydraulic conductivity, storage parameters, thicknesses)**
    - **stresses that will be applied for which you will predict the resulting conditions**
    - **special considerations (if any)**
  - **AT LEAST ONE FIGURE needs to show the outline of the area you will model with arrows indicating where water enters and leaves the system and a rough sketch of the pattern of flow through the area, hatched lines where there are no-flow boundaries and a few sketched lines indicating the pattern of flow in the area.**
- **Calibration Data that are available (head and groundwater discharge to surface water features). Indicate location of stream flow gages and wells along with the frequency and period of record of flows and water levels)**
- **A description of what you envision your final result will be**
- **References**

submit a description and the drawings as hard copy OR as ASSGN1_LASTNAME.ZIP

ALL FILES IN ZIP FILE MUST EITHER INCLUDE YOUR LAST NAME OR BE IN A FOLDER THAT INCLUDES YOUR LAST NAME

Assignment #2 a) Finite Difference Calculation & b) Grid:

a) Calculation: For the problem using 5 finite difference grid blocks numbered 1 to 5 left to right and with the following parameters:

confined flow ; y = 3 ft ; b = 3 ft ; K = 0.02 ft/day ; T= 0.06 ft^2/day ; s = 0.00033 ft^{-1} ; S = 0.001

initially, $h_1 = h_2 = h_3 = h_4 = h_5 = 8.2$ ft ; constant head left $h_1 = 8.2$ ft ; for t>0 constant head right $h_5 = 3.6$ ft as posed on:

http://inside.mines.edu/~epoeter/583/06/exercise/finite_diff_exer.htm

using the explicit approach on

http://inside.mines.edu/~epoeter/583/06/exercise/explicit_exer.htm

and the implicit approach on

http://inside.mines.edu/~epoeter/583/06/exercise/implicit_exer.htm

For both approaches:

1. Calculate h_4 @ 0.07 day increments to 0.7 days using the implicit approach
2. Repeat #1 @ 0.14 day increments to 0.7 days using the implicit approach

3. Compare the mass balance at each step for the 0.07 and the 0.14 day time steps.
4. Graph your results as head vs. time
5. Compare your result to those from the explicit method

Submit the spread sheet electronically. Submit a hard copy of the graphs of head at each cell and flows (in, out and change in storage) versus time as well as the tables of head, inflow, outflow, change in storage and mass balance for each method and each time step size, so there will be 4 sets of graphs and tables.

Assignment #2 CONTINUED

b) Grid: Layout the finite difference grid over a map of the model area for your problem and in a vertical cross-section. Discuss why you chose to grid the problem as shown. Keep your grid small (e.g. less than 20rows x 20col would be best, but absolutely no larger than 40x40) in order to make the project manageable such that you optimize your learning about modeling. The goal is for you to learn about modeling, not to produce a detailed model of your system. Use at least 2 layers so you can become familiar with issues related to multiple layers. Even if you are only simulating one geologic unit you can break it into an upper and lower portion which will give you a bit of information about vertical gradients in the system. Label the diagrams to describe the initial properties and boundary conditions you will use. These will be adjusted later in the calibration process. Your submission should include:

*** In the following grid drawings number the columns from left to right and the rows from top to bottom in plan view, and indicate the size of each row and column. If they are uniform squares state that and give the size.**
*** Drawing of plan view of each layer with properties & boundary conditions labeled**
*** Drawing of cross section view of grid with properties & boundary conditions labeled**
***In addition to the constant head and no-flow boundaries, remember to include flux boundaries such as recharge and wells, head dependent fluxes such as rivers and ET, explain if the top boundary is confined or a water table.**
* Submit a description and the drawings as hard copy OR as ASSGN2_LASTNAME.ZIP

Assignment #3 Analytical Model: Choose an analytical model to represent some aspect of your modeling project and implement it with your model conditions. Describe the problem set-up and solution in a concise and clear manner. If you use a spreadsheet, mathcad, or other code for calculation, provide at least one hand calculation to confirm that your results are correct. Your submission should use illustrations to describe the conceptual model and how it fits your problem. It should include the following items:

Title
Objective
Problem Description
Analytical Model Description
Simplification of System in order to use the analytical model
Parameter values used
Calculations
Results
References

submit the write-up as hard copy and if you have electronic files include it in your zip file
submit a zip file labeled: ASSGN3_LASTNAME.ZIP

Assignment #4 Finite Differencing by spreadsheet: Create a simplified 2D steady finite difference spreadsheet model of your problem, explain what it does. Your submission should include:

- **Title**
- **Objective**
- **Problem Description**
- **Spreadsheet setup Description**
- **Simplification of System in order to use the spreadsheet model**
- **Be sure to include at least one head-dependent flux boundary**
- **Explanation of spreadsheet calculations**
- **Explanation of Results (if appropriate comparison to analytical solution)**

submit the write-up as hard copy and include it in your zip file with the spreadsheet
submit a zip file labeled: ASSGN4_LASTNAME.ZIP

Assignment # 5 Steady State Numerical Models: Create two steady state MODFLOW simulations of groundwater flow in your system. One of the simulations should represent the flow system without the stress and the other should simulate the steady state condition with the stress. Build on your work from assignments 1 through 3. Using the MODFLOW manuals and class examples, create a name file, then build each of the input files. When you have them all, execute the model, look at the output or error messages and revise the file until you have models that "run". Be sure to save your files because you will want to use them later in the semester. **Compare your results to the result of your spreadsheet and analytical modeling.** Be sure to save your files because you will want to use them later in the semester.

Suggested Steady State Modeling Report Outline

- **Title**
- **Introduction**
  - **objective**
  - **problem description**
- **Geohydrologic Setting**
- **Results of analytical and spreadsheet modeling**
- **Numerical Model setup**
  - **geometry**
  - **boundary conditions**
  - **initial conditions**
  - **parameter value ranges**
  - **stresses**
  - **special considerations**
- **Uncalibrated model results**
  - **predictions**
  - **problems encountered, if any**
- **Comparison with Analytical/Spreadsheet results**
- **Assessment of future work needed, if appropriate**
- **Summary/Conclusions**
- **References**

submit the paper as hard copy and include it in your zip file of model input and output
submit the model files (input and output for both simulations) in a zip file labeled:
ASSGN5_LASTNAME.ZIP

Assignment # 6 Steady State Model Calibration: Calibrate your model. If you want to conduct a transient calibration, talk with me first. Perform **calibration using UCODE.** **Be sure your report addresses global, graphical, and spatial measures of error as well as common sense.** Consider more than one conceptual model and compare the results**. Remember to make a prediction with your calibrated models and evaluate confidence in your prediction.** Be sure to save your files because you will want to use them later in the semester.

Suggested Calibration Report Outline

- **Title**

Introduction
- **describe the system to be calibrated (use portions of your previous report as appropriate)**

Observations to be matched in calibration
- **type of observations**
- **locations of observations**
- **observed values**
- **uncertainty associated with observations**
- **explain specifically what the observation will be matched to in the model**

Calibration Procedure

Evaluation of calibration
- **residuals**
- **parameter values**
- **quality of calibrated model**

Calibrated model results
- **predictions**
- **uncertainty associated with predictions**
- **problems encountered, if any**

Comparison with uncalibrated model results

Assessment of future work needed, if appropriate

Summary/Conclusions

References

submit the paper as hard copy and include it in your zip file of model input and output
submit the model files (input and output for both simulations) in a zip file labeled:
ASSGN6_LASTNAME.ZIP

Assignment # 7 Transient Modeling: Using starting heads from the calibrated steady state simulation without stress that you developed under model assignment #6, develop a transient model of the stressed scenario that you simulated in steady state under model assignment #5. Then, choose a complexity associated with changing boundary conditions in time (for example the variable recharge and pumping offset in time) and add it to the model. Whatever complexity you choose, **be sure that it requires you to use more than one stress period. Finally, carry out the same complex transient exercise with a different underlying geology** (for example, add some heterogeneity to the system). Remember that when you add the heterogeneity you will need to rerun the steady state case without pumping to obtain the proper starting heads. Be sure to save your files because you will want to use them later in the semester.

Suggested Transient Modeling Report Outline

Title

Introduction
- **objective**
- **problem description (be sure to describe the transient stresses including the complexity added since your work on assignment #4 and the change in geology)**

Geohydrologic Setting

Numerical Model setup
- **geometry**
- **boundary conditions**
- **initial conditions**
- **parameter value ranges**
- **stresses**
- **special considerations**

Results
- **discuss the transient responses and the time required for them to occur (this includes changes in heads, flows and water flowing into or out of storage)**
- **discuss how the transients differ when the underlying geology changed**
- **discuss problems encountered if they occurred**

Assessment of future work needed, if appropriate

Summary/Conclusions

References

submit the paper as hard copy or include it in your zip file of model input and output
submit the model files (input and output for all simulations) in a zip file labeled
ASSGN7_LASTNAME.ZIP

Assignment # 8 Analytical Transport Modeling: Simplify the system that you setup for assignment #5 and use a simple analytical transport model to represent the addition of a source of contamination and simulate migration of the plume. Do not make this more difficult than it is. Refer to http://inside.mines.edu/~epoeter/583/05/discussion/transport_anal_main_page.htm OR http://inside.mines.edu/~epoeter/_GW/22ContamTrans/ContaminantTransport.htm if you are not familiar with transport solutions. Adapt one of the basic equations to your situation, define the appropriate parameter values and calculate a concentration at a point and time in your system. Describe the problem set up and solution in a very concise but completely clear manner. Your submission should use illustrations and include:

- **Title**
- **Objective**
- **Problem Description**
- **Analytical Model Description**
- **Simplification of System in order to use the analytical model**
- **Parameter values used**
- **Calculations**
- **Results (concentrations as a function of space and time)**
- **References**

submit the write-up as hard copy and if you have electronic files include it in your zip file
submit a zip file labeled: ASSGN8_LASTNAME.ZIP

Assignment # 9 Numerical Transport Modeling: For the steady state system and MODFLOW model that you setup in assignment #5 use MT3D to represent the addition of a source of contamination and simulate migration of the plume. Compare your results to the result of your analytical modeling in assignment #8. <u>If there is very little "action", change the stress, the contamination scenario or the system parameters so that you see a major change</u>. Write this up in your report for Assignment #9.

Suggested Transport Modeling Report Outline

- **Title**
- **Introduction**
  - **objective**
  - **problem description**
- **Geohydrologic Setting**
- **Numerical Model setup**
  - **geometry**
  - **boundary conditions**
  - **initial conditions**
  - **parameter value ranges**
  - **stresses**
  - **special considerations, if any**
- **Predicted concentrations as a function of space and time**
- **Problems encountered, if any**
- **Comparison with Analytical model results**
- **Assessment of future work needed, if appropriate**
- **Summary/Conclusions**
- **References**

submit the paper as hard copy or include it in your zip file of model input and output
submit the model files (input and output for all simulations) in a zip file labeled
ASSGN9_LASTNAME.ZIP

IF YOU ARE SIGNED UP FOR GEGN483, ASSIGNMENT 10 is not included

Assignment # 10 Final Presentation, due Exam Week during the scheduled exam block for the class (there is no exam). NOTE preliminary submission indicated below. <u>You need not provide a comprehensive review of your work for the semester. Rather the objective of this presentation is to focus on some portion of the work that you feel can be used to teach the class something that you learned from your modeling project.</u> Assume that you are talking to a group of people who do not know your project or the assignments. Your grade will be based on my judgment of your success in achieving this objective.

> **NOTE 1: Prior to developing you presentation but no later than Friday May 6 submit lesson(s) you will teach as one sentence summaries per lesson. I will provide feedback as soon as possible for early submissions, but no later than Midnight Saturday May 7 for those submitted by 11:50AM.**
>
> **NOTE 2: The power point file for your presentation must be submitted at least 1 hour prior to start of the exam block. These can be emailed to me or you can bring them in on disk.**

Grading GEGN583: **Points of 100**

Assignments are due by the end of class 11:50AM on the due date

Parts of assignments are due on non bold dates, full assignment is due on final bold date

Assignment #1 Conceptual Model, due January 19		5
Assignment #2 a) Finite Difference Calculation & b) Grid, due January 26		10
Assignment #3 Analytical Model, due January 26		5
Assignment #4 Finite Difference Spreadsheet, due February 2		10
Assignment # 5 Steady State Numerical Models		15
	parts due February 9, 16 and **23**	
Assignment # 6 Model Calibration		20
	parts due March 2, 9, 23, and **30**	
Assignment # 7 Transient Modeling		10
	parts due April 6, 13, **20**	
Assignment # 8 Analytical Transport Modeling		10
	due April 20	
Assignment # 9 MT3D Transport Modeling		10
	parts due April 20, **27**	
(returned by Fri April 29 to allow for resubmission [if desired] by Wed May 4)		
Assignment # 10 Final Presentation		5
Submit lesson(s) you will teach as one sentence summaries per lesson before you prepare your presentation but no later than Friday May 6		
Power point file must be submitted at least 1 hour prior to start of exam block		
Presentation will be given Finals week during exam block		
Total		**100**

View assignments 1-10 as a progressive process of learning about modeling using one project. These submissions do not need to be major documents. Rather they should be clear and concise illustrating your work. The most important aspect of the submission is that it reveals your understanding. Late submission results in a zero score. Plan to have each submission ready well before it is due, then any unforeseen problem will not get in the way of submission. If at the last minute you cannot attend class, email the assignment to me by the deadline 11:50 AM on the due date. If you wish you may email the assignment early to cover any unforeseen problems.

Grading GEGN483: **Points of 100**

Assignment #1 Conceptual Model, due January 19		5
Assignment #2 a) Finite Difference Calculation & b) Grid, due January 26		12
Assignment #3 Analytical Model, due January 26		5
Assignment #4 Finite Difference Spreadsheet, due February 2		12
Assignment # 5 Steady State Numerical Models		15
	parts due February 9, 16 and **23**	
Assignment # 6 Model Calibration		20
	parts due March 2, 9, 23, and **30**	
Assignment # 7 Transient Modeling		11
	parts due April 6, 13, **20**	
Assignment # 8 Analytical Transport Modeling		10
	due April 20	
Assignment # 9 MT3D Transport Modeling		10
	parts due April 20, **27**	
(returned by Fri April 29 to allow for resubmission [if desired] by Wed May 4)		
Total		**100**