Problem Set 1

Steady-State Flow with Constant Head Boundaries

Introduction

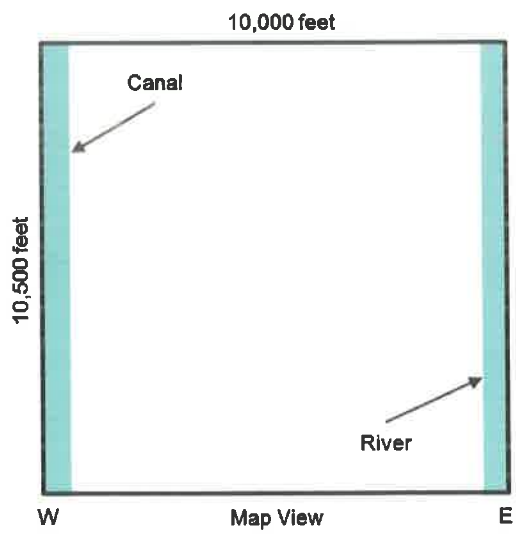
The flow system is in a valley which is 10,000 ft wide and 10,500 feet long. There is an unconfined upper sand aquifer and a lower sand aquifer which are separated by a fine-grained silt that acts as a confining layer for the lower aquifer. The flow system is bounded on all sides and its bottom by impermeable bedrock. At the eastern boundary there is a river, with a stage or 320 ft, which flows south. On the western boundary there is a canal, with a stage of 330 ft.

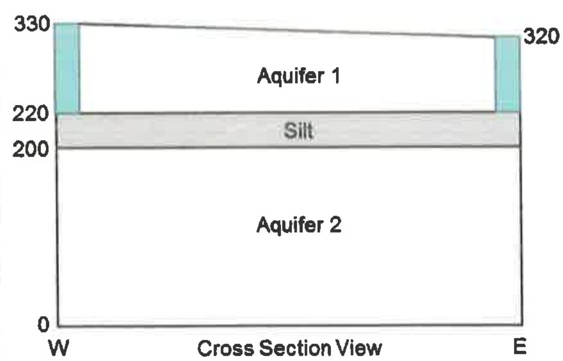
In the upper aquifer, the horizontal conductivity in both the x and y directions is 50 ft/d, the vertical conductivity is 10 ft/d. The bottom of the upper aquifer is at an elevation of 220 ft. The top is at land surface, which can be specified as 400 ft.

In the silt unit, the horizontal and vertical conductivity is 0.01 ft/d. The bottom of the silt layer is at 200 ft.

In the lower aquifer the horizontal conductivity in both the x and y directions is 200 ft/d, the vertical conductivity is 20 ft/d. The bottom of the lower layer is at 0 ft.

Simulate groundwater flow as a steady-state flow system. Use 3 layers, 21 rows and 20 columns with a uniform horizontal grid spacing of 500 feet in each direction. The upper aquifer is represented by layer 1, the silt is represented by layer 2, and the lower aquifer is represented by layer 3. The northern and southern boundaries and the bottom of aquifer 2 are no flow boundaries. The eastern and western boundaries will be constant head boundaries representing the river and the canal. The head in the river is 320 ft the head in the canal is 330 ft.





Base Run – PS1A

Create the data files for the base run of this problem set in the directory PS1A that has been created for you. The following data files are needed for this problem:

- mfsim.nam – MODFLOW simulation name file
- ps1.nam – Groundwater flow process (GWF) name file
- ps1.dis – Spatial discretization package (DIS) file
- ps1.tdis – Time discretization (TDIS) package file
- ps1.ims – Iterative model solver (IMS) package file
- ps1.ic – Initial conditions (IC) package file
- ps1.chd – Constant head (CHD) package file
- ps1.npf – Node property flow (NPF) package file

We will work as a group to create this first dataset. When your dataset is complete, run MODFLOW and examine the output in the MODFLOW listing files, ps1.lst and mfsim.lst.

Before we go any further, we need to make some changes to the MODFLOW data to allow us to use a post-processing graphics display program, HeadViewer, to look at plots of the head output. We also will increase the precision of the head output in the MODFLOW listing files so that we can make some hand calculations of key flow terms in the model. Those changes require the addition of another data file, the output control file. We will discuss how to create the output control file as a group.

When you have created the output control file with the necessary input to save head and increase the head printout precision, run MODFLOW again use your output to answer the questions listed below. But, before we go on the exercises, we will use the output from your new run to look at how to use the HeadViewer post-processor to help examine the MODFLOW output.

<u>Exercise 1:</u>

Using the water budget summary in the MODFLOW listing file, what is the total volumetric rate of flow leaving the canal and the total volumetric rate of flow entering the river?

For comparison, use Darcy's Law and the head output in the listing file to compute the total flow rate out of the canal and into the river. Calculate the flow from one canal cell and multiply by 21 rows to get the total flow. To simplify your calculations, use the average saturated thickness between columns 1 and 2 for the horizontal flow calculation. For the vertical flow calculation, assume that all of the head difference between the canal and the node in layer 2 occurs within the confining layer between the bottom of layer 1 and the node in layer 2. How do these flow rates compare with those determined from the MODFLOW water budget summary?

Exercise 2:

Between which two columns does the flow between layer 1 and layer 2 change from downward to upward?

Exercise 3:

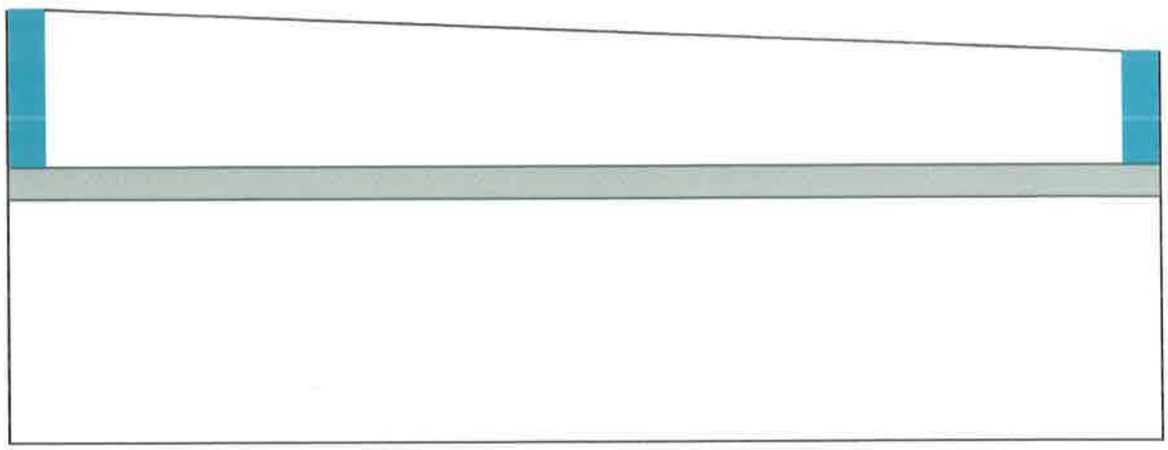
What are the total volumetric rates of flow from column 10 to column 11 in each of the three model layers. Use Darcy's Law and the head output from the MODFLOW listing file to make these calculations.

	h_{10}	h_{11}	Δh ($h_{11} - h_{10}$)	b layer thickness	Q (all 21 rows)
Layer 1					
Layer 2					
Layer 3					

Exercise 4:

What is the total volumetric rate of flow downward across the top of layer 3 for columns 1 through 10? What is the total volumetric rate for flow upward across the top of layer 3 for columns 11 through 20?

HINT: Use a simple water balance equation and the information from your answers to the previous exercises. Show your results on the schematic cross section below.



Explain how you could use Darcy's law as an alternative approach for calculating the total downward and upward flow rates described above. You do not actually need to actually make the calculations, just describe how you would do it.

Additional Runs – PS1B, PS1C, PS1D, and PS1E

Each of these runs is a modification of the base case dataset, PS1A. In each case, use the data files from problem set PS1A as the starting point by copying the files from directory PS1A into the sub-problem directories that have been created for you (PS1B, PS1C, PS1D, and PS1E).

PS1B

Copy all of the files from directory PS1A into directory PS1B and work in directory PS1B. Double all of the hydraulic conductivity values (vertical and horizontal) in both aquifers and the confining layer, and run the simulation again. How much water is leaving the canal? What is the effect on head distribution?

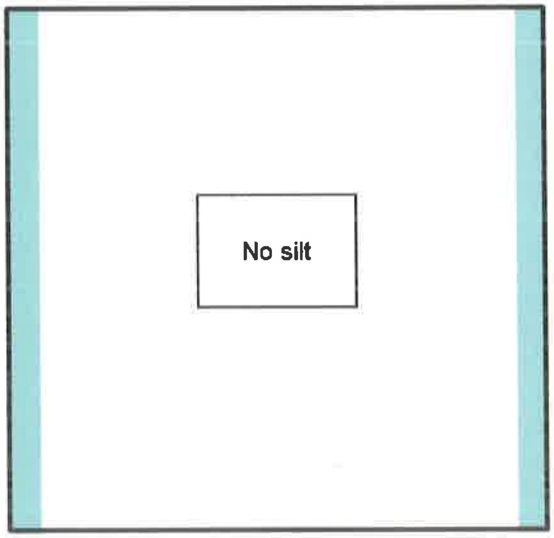
PS1C

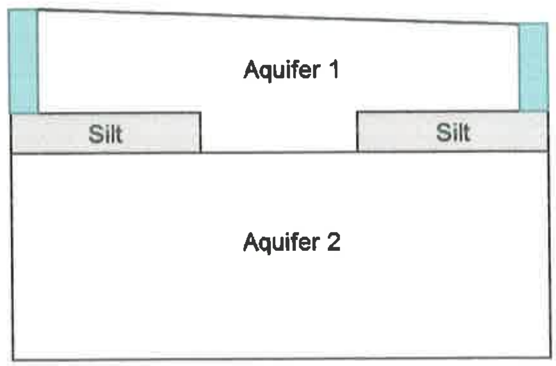
Copy all of the files from directory PS1A into directory PS1C and work in directory PS1C. Reduce the vertical and horizontal hydraulic conductivity of the silt to 0.0001 ft/d. Run MODFLOW and observe the effect on the heads and flow rates in each layer? Calculate the rate of flow between column 10 and column 11 for layer 1 and layer 3.

PS1D

Copy all of the files from directory PS1A into directory PS1C and work in directory PS1D. Simulate a hole in the silt (layer 2) by setting the horizontal and vertical hydraulic conductivity for a rectangular block of cells in layer 2 extending from (row 9, column 5) to (row 13, column 15) equal to the hydraulic conductivity values used for layer 1. Summarize the effect of the discontinuous silt on the groundwater flow pattern.

HINT: You will need to read arrays of horizontal and vertical hydraulic conductivity values for layer 2 instead of simple constant values.





PS1E

Copy all of the files from directory PS1A into directory PS1E and work in directory PS1E. Simulate the hole in the silt a different way by using an IDOMAIN array for layer 2 to indicate that layer 2 is missing in the region of the hole. To do that, set IDOMAIN for layer 2 equal to -1 in the cells that correspond to the hole and equal to 1 elsewhere. Also change the bottom elevation for layer 1 so that the elevation is equal to 200 feet in the region of the hole, which corresponds to the top elevation of layer 3. Run the simulation and compare the results with those of problem PS1D.

Problem Set 2
Introduction to Stress Packages

This problem set introduces the use of stress package features. The groundwater flow system is similar to the base case in problem set 1 (PS1A), except the canal on the left side has been removed and areal recharge has been added to layer 1 as the new source of water for the system. The recharge rate is 0.005 foot/day.

The problem set consists of 5 major parts (A, B, C, D, and E). Part A introduces the use of the recharge package. Parts B, C, and D demonstrate the river, drain, general-head boundary, and well packages. Part E introduces transient flow simulation using multiple stress periods. This problem consists of a total of 7 MODFLOW runs. As with problem 1, each MODFLOW run requires a separate folder. The empty folder have been provided for you. Each run builds on a previous run.

Part A – The Recharge Package

1. Run PS2A builds off of run PS1A from problem 1. To be sure everyone starts with the same dataset, a completed copy of dataset PS1A is provided for you in the folder named "Initial". Note that the dataset file names have been renamed with the "PS2" root name. To begin work on problem PS2A, copy all of the files in the "Initial" folder into the "PS2A" folder.
2. Be sure you are working on the files in the PS2A folder, then make whatever changes are required to remove the canal and add recharge.
3. Run MODFLOW by double-clicking the batch file named "runmf6.bat". Examine the MODFLOW listing file, ps2.lst, to check the status of the run. Once you have a successful run, complete the exercises below.

Exercise 1:

Multiply the recharge rate you used by the model area. Does the recharge in the budget match the recharge that you thought that you had applied?

Exercise 2:

How much water is going into the river?

Exercise 3:

How is the head distribution in this simulation different from that in problem set 1? What causes the difference?

Exercise 4:

Between which two columns does the flow switch from downward across the bottom of layer 1 to upward across the bottom of layer 1?

Exercise 5:

For each of the three model layers, calculate the total volumetric rates of flow between the two columns you identified above in exercise 4. To simplify the computation for layer 1, use the arithmetic average of the heads in the left and right cells to compute the thickness (b) at the cell face. Round the computed values of Q to the nearest whole number.

	h_{left}	h_{right}	Δh $h_{right} - h_{left}$	b thickness	Q (all 21 rows)
Layer 1					
Layer 2					
Layer 3					

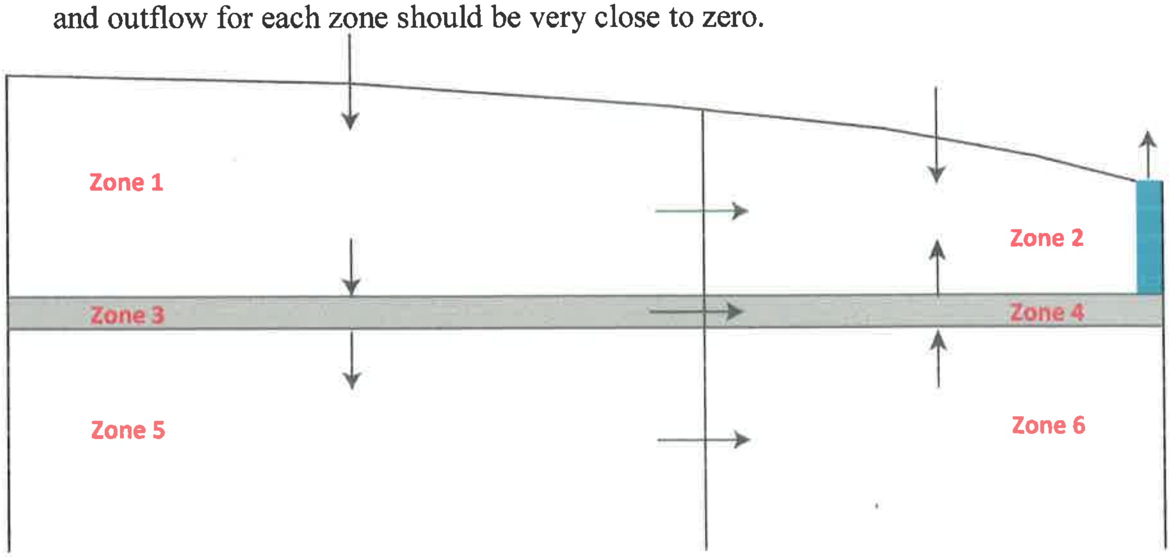
Exercise 6:

Copy all of the files from folder PS2A into folder PS2A1. Double all the vertical and horizontal hydraulic conductivity terms in all layers and then run MODFLOW. Describe the changes in the flow system.

Exercise 7:

Using the results from PS2A (the original run with the recharge package), do water budget calculations, for the 4 sub-regions in the idealized cross section shown below.

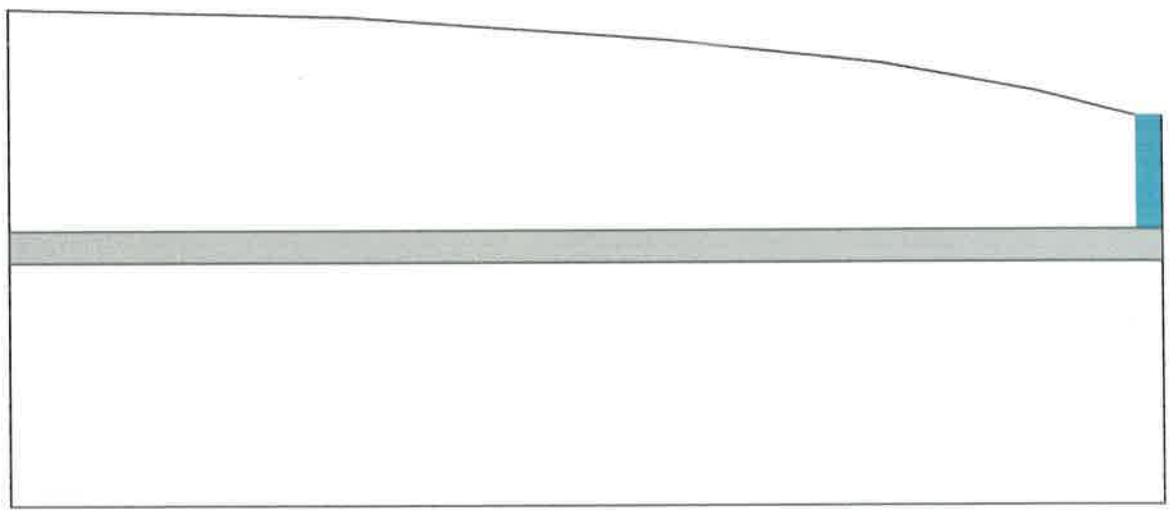
HINT: The horizontal boundaries between the zones are at the location where flow between layer 1 and layer 2 switches from downward to upward. So, the horizontal flows at those locations are the flows you calculated in exercise 5. You also know the recharge flows to zones 1 and 2 and the outflow to the river from the problem input. You could calculate the four vertical flows between model layers by summing up the Darcy's law calculations for the individual cells corresponding to the zone boundaries. But, there is an easier way to estimate the vertical flows between layers by recognizing that the volumetric budget of each zone must balance. Start with zone 5 and estimate the flow down into zone 5 from zone 3. Then work your way through the other zones to estimate the remaining three vertical flows. When you are done, check the water balance for each of the 6 zones. The difference between the inflow and outflow for each zone should be very close to zero.



Exercise 8:

All of the water that enters the system comes from areal recharge. On the schematic cross section shown below, delineate the area at the water table in layer 1 that represents the source area for water that enters model layer 3.

Hint: Flow in the system is from left to right. The source area for layer 3 extends to the left edge of the system. You have enough water budget information to determine the width of the source area required to capture enough recharge to supply layer 3.



Part B – The River Package

This problem is the same as the problem PS2A except that the constant-head river on the east side of the grid is represented using the river package. The hydraulic conductivity of the river bed is 20 ft/d, and the width is 10 ft. The elevation of the river bed bottom is 317 ft. The riverbed is 1 ft thick. Follow these steps to make a simulation:

1. Use the original hydraulic properties from dataset PS2A. Copy all of the files in folder PS2A into folder PS2B.
2. Make whatever changes are required to simulate the river using the River Package.
3. Run MODFLOW.

Compare run PS2B with run PS2A and explain any differences.

Exercise 9:

Identify all of the inflow and outflow terms for cell 1, 1, 20 (layer, row, column). Compute the volumetric flow rate (Q) for each term and use them to calculate the water balance for the cell.

Part C – The Drain and General-Head Boundary Packages

This is the same as problem PS2B except that a buried drain tile, simulated with the DRAIN package, is installed in row 15 in columns 10-20. The conductance between the aquifer and the drain is 100,000 ft2/d, the elevation of the drain is 322.5 ft. Follow these steps:

1.Start with problem PS2B and copy all of the files in folder PS2B into folder PS2C.

2.Make whatever changes are required to add the drain.

3.Run MODFLOW.

4.Examine the listing file to notice the impact that the drain has on water levels.

When you have a successful run, complete the following exercises:

Exercise 10:

Examine the drain discharge rates in the MODFLOW listing file (ps2.lst). Explain the difference in the drain discharge rate in cells (1, 15, 18) and (1, 15, 19)

Exercise 11:

Copy the files from PS2C into folder PS2C1. Make a new MODFLOW run in which you replace the drain with a general head boundary using the same head and conductance. Compare the drain and general head boundary discharge rates from the listing files for runs PS2C1 and PS2C. Explain any difference you observe.

Part D – The Well Package

This is the same as problem PS2C but with the addition of a well located in layer 1 at row 11, column 10. The discharge rate of the well is 75,000 ft^3/d. Follow these steps:

1. Copy all of files from folder PS2C (which uses the drain package) into folder PS2D.
2. Make whatever changes are required to add the well.
3. Run the simulation
4. Examine the listing file to notice the impact that the well has on water levels.

When you have a successful run, complete the following exercise:

Exercise 12:

What is the change in the total volumetric rate of flow to the river in run PS2D compared with that of run PS2C? What is the change in the total volumetric rate of flow to the drain in run PS2D compared with that in run PS2C? Add the change in river discharge to the change in drain discharge and compare the sum to the well discharge rate. Record your results in the table below. Round the values to the nearest whole number.

Flow Rate Out	PS2D	PS2C	PS2D – PS2C
River			
Drain			
Well	75,000	0	75,000
			Sum =

Part E – Transient Flow

Start with dataset PS2D, to create a new dataset named PS2E. We will convert the new dataset containing 3 stress periods. The first stress period is steady-state flow and is identical to the steady-state run for dataset PS2D. Stress period 2 is a transient stress period 36,500 days long. Stress period 2 contains an additional second pumping well in layer 3, row 13, column 5 that has a withdrawal rate of 100,000 ft^3/d. Stress period 3 is another steady-state stress period that includes both wells pumping at the same rate as in stress period 2. Recharge rate and river stages stay the same throughout the entire simulation. Copy all of the files in folder PS2D to folder PS2E and make the following changes:

- Edit the time discretization package data file (TDIS) so that it has 3 stress periods with the following properties:

  Period 1: length =300,000 days; 1 time step; multiplier = 1.0
  Period 2: length = 36,500 days; 10 time steps; multiplier = 1.5
  Period 3: length = 300,000 days; 1 time step, multiplier = 1.0

- Add the Storage package data file to the dataset. Storage properties were not needed for our previous steady-state simulation. Set specific yield = 0.1 and specific storage = 0.0001 for all cells. Set the ICONVERT property equal to 1 for all cells. Finally, set the steady-state/transient stress period style flags for each of the 3 stress periods.

- Edit the Well package data file to add the second pumping well to stress periods 2 and 3. Make any other changes that may be required for the Recharge and rRver package data files.

Exercise 13:

Examine the water budget print out in file PS2E.LST for each of the time steps in stress period 2. Describe how the (1) outflow to the river, (2) outflow to the drain, and (3) inflow from storage change from the first time step to the last time step in stress period 2. How are the changes in those three components over time related to one another?

Exercise 14:

How does the value of stress period length specified for steady-state stress periods 1 and 3 affect the results of the simulation?

McDonald Valley Calibration Exercise

INTRODUCTION

In this problem, we have designed a hypothetical field problem. You will get to go through a simulation analysis much as you would in simulating a real field problem. The exercise is intended to give you experience in calibrating a flow model when you have limited information and are forced to make decisions about how to use limited resources to obtain useful new information.

We will approach this problem in four stages:

STAGE 1 –

Review the existing information and the project objectives to design an effective approach to simulating the system. It is at this stage where you want to consider the pros and cons of various boundary conditions discretization schemes, etc.

STAGE 2 –

Make a first attempt at developing a calibrated model for the predevelopment condition based on existing data that we will give you.

STAGE 3 --

Obtain new field information to help you improve your description of the flow system. Use the new information to refine your calibrated predevelopment model. You should use your simulations in stage 2 to guide your data collection activities in stage 3. In real life, you always have limited resources and are forced to make choices about what kind of information is worth obtaining and what is not. We try to create that same type of situation in this problem by setting up a simulated "project" with an initial amount of money that you can use to buy information, such as drilling wells, conducting slug tests, running seismic sections, etc. The budget is tight, so you will be forced to think carefully about what information to buy.

STAGE 4 --

Simulate the effects of the proposed stresses using the calibrated parameters from stage 3.

Background Information

McDonald Valley is an undeveloped, closed alluvial valley surrounded by low permeability crystalline bedrock (figures 1 and 2). The valley is dominated by scenic Lake Harbaugh located in the northwest corner of the valley (lots are available). Lake Harbaugh sits in a gentle depression that is bounded by Sand Ridge, which extends from the western edge of the valley to the northeastern corner. The south face of Sand Ridge is relatively steep. South of Sand Ridge, the valley slopes gently toward the southern boundary. The Straight River, which has its headwaters at the base of sand ridge just south of Lake Harbaugh, flows south and eventually leaves the valley along the southern boundary.

You have been given the task of examining the possible effects of groundwater development that has been proposed for McDonald Valley. The following development has been proposed:

1. A 268,000 ft3/d well in the southern part of the valley at either site 1 or site 2 as shown in figure 2. The well would provide a water supply for Virginia City located to the south of McDonald Valley.

2. A 67,000 ft3/d well is located in the northern part of the valley (site 3 in figure 2). This well would provide natural spring water for Reilly's Premium Beverages, Inc.

The county is concerned about the effect of this development. Specifically,the county is concerned that:

1. Development will cause excessive water table declines in the northern half of the valley where a number of summer homes have very shallow water table wells that are used for domestic supply. The county has established the requirement that any development not cause more than a 2 foot decline in the water table anywhere in the northern half of the valley. Consultants for the Reilly Brewing Company contend that pumping from the Reilly well will have a negligible effect on the water table because the well will be placed below a clay layer that occurs across much of the northern part of the valley.

2. McDonald Valley is the site of the Pollock's Ford National Historic Site and Recreation Area located 1000 feet south of the headwaters of the Straight River. Pollock's Ford is the site of an heroic fording of the Straight River during the battle for Sand Ridge during the American Revolution. Even though easier routes around the north side of the headwaters were discovered within minutes of Pollock's heroic crossing, the event nevertheless remains one of extreme historic importance. The county maintains a stream gage at Pollock's Ford and has decided that any potential development by Virginia City or Reilly's Brewery must not reduce the stream flow at that site by more than 20
percent. In addition, the county is requiring that development not lead to any induced infiltration from the Straight River anywhere along its course.

3. Water quality issues:

A. An increase in the number of vacation cabins in the northern part of the valley has lead to concern about the impact of septic systems on Lake Harbaugh. The county is interested in determining the source area for ground water that discharges to Lake Harbaugh so that it can develop effective and rational regulations for septic system permits.

B. Reilly's was required to do a capture zone analysis to determine the source area for its deep well. The company's consultants did a model of the Reilly site and concluded that the source area is contained entirely within the Reilly property. The county suspects that that analysis is not correct because the boundaries of the model extended only to the property lines of the Reilly facility. A flow model of the entire valley would provide a better basis for evaluating the source area for the well.

C. The county is requiring capture zone analyses for the proposed Virginia City wells.

Hydrogeology and Hydrology of McDonald Valley

Hydrogeology

The valley contains unconsolidated valley fill alluvium. No hydraulic tests have been performed in the valley, but the sediments are similar to those in other valleys in the area which generally have horizontal hydraulic conductivities ranging between 10 feet/day and 500 feet/day. The sediments are predominantly medium to coarse grained sands and some gravels, however a low permeability lake clay has been observed in some bore holes in the valley. The valley contains 17 existing observations wells. Well logs for those 17 wells are presented in Table 1. The crystalline bedrock surrounding the valley has a very low hydraulic conductivity.

Hydrology

The hydrologic system in McDonald Valley is in steady state with no significant seasonal or short term fluctuations in conditions.

McDonald Valley has a mean annual precipitation of 36 inches per year based on measurements made at Lake Harbaugh. Other stations in the area also report annual precipitation of 36 inches per year.

There is no surface water inflow into the valley. The Straight River originates in McDonald Valley. The headwaters of the river is located 9000 feet upstream from the southern boundary of the valley. The river stage at the southern boundary of the valley is defined to be 0, the datum to which all other head measurements in the valley are referenced. The stream gradient is 0.0002, which corresponds to a stage of 1.8 feet at the headwaters. The river is approximately 100 feet wide over its entire length and has a depth of 1 foot or less in most locations. Stream gages are located at the river's southern discharge point and at Pollock's Ford.

Measured Stream Flow (ft3/d)	Location
884,494	Southern Boundary (gage 1)
96,402	Pollock's Ford (gage 2)

Lake Harbaugh is a dominant hydrologic feature in the valley. A previous study of Lake Harbaugh yielded the following information:

Stage = 11 feet
Area of the lake = 1.625 x 10**7 square feet
Lake Evaporation = 27 inches per year (2.25 ft/y)
Precipitation = 36 inches per year (3 ft/y)

Lake Harbaugh is a closed lake with no surface water inflow or outflow. The morphology of the lake basin consists of a relatively steep sloping shore that levels out to a very uniform depth of 16 feet within 50 feet of the lake shore. The lake bottom is sandy and free of fine grained sediments over most of its bottom, especially near the shore. Very minor amounts of fine grained sediments occur in the very center of the lake basin.

Table 1

Data for Existing Wells

Well 1

(Row 3 Column 18)
Top of screen = -195.74 feet; Bottom of screen = -200.74 feet
Water Table = 12.05 feet; Head in screened interval = 11.85

Drillers Log :
12.05 to -50.65 >very coarse sand with occasional thin gravel layers
-50.65 to -51.87 >tight clay
-51.87 to -200.74 >very coarse sand with occasional thin gravel layers
-200.74 to ? >Bedrock

Well 2

(Row 4 Column 11)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 11.63 feet; Head in screened interval = 11.35

Drillers Log :
11.63 to -50.35 >coarse sand with occasional stringers of fine sand
-50.35 to -51.47 >tight clay
-51.47 to -100.00 >coarse sand with occasional stringers of fine sand

Well 3

(Row 7 Column 21)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 12.15 feet; Head in screened interval = 11.83

Drillers Log :
12.15 to -50.86 >medium sand with some interbedded fine sand
-50.86 to -51.95 >tight clay
-51.95 to -100.00 >medium sand with some interbedded fine sand

Well 4

(Row 13 Column 23)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 11.44 feet; Head in screened interval = 11.43

Drillers Log :
11.44 to -100.00 >coarse sand with occasional stringers of fine sand

Well 5

(Row 15 Column 12)
Top of screen = -219.62 feet; Bottom of screen = -224.62 feet
Water Table = 10.86 feet; Head in screened interval = 10.50

Drillers Log :
10.86 to -50.59 >medium sand with some interbedded fine sand
-50.59 to -51.93 >tight clay
-51.93 to -224.62 >medium sand with some interbedded fine sand

-224.62 to ? >Bedrock

Well 6

(Row 17 Column 19)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 10.80 feet; Head in screened interval = 10.79

Drillers Log :
10.80 to -100.00 >medium sand with some interbedded fine sand

Well 7

(Row 18 Column 2)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 9.16 feet; Head in screened interval = 9.13

Drillers Log :
9.16 to -100.00 >medium sand with some interbedded fine sand

Well 8

(Row 19 Column 7)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 8.82 feet; Head in screened interval = 8.79

Drillers Log :
8.82 to -100.00 >medium sand with some interbedded fine sand

Well 9

(Row 20 Column 12)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 8.86 feet; Head in screened interval = 8.83

Drillers Log :
8.86 to -100.00 >medium sand with some interbedded fine sand

Well 10

(Row 19 Column 23)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 10.65 feet; Head in screened interval = 10.64

Drillers Log :
10.65 to -100.00 >coarse sand with occasional stringers of fine sand

Well 11

(Row 27 Column 6)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 4.26 feet; Head in screened interval = 4.25

Drillers Log :
4.26 to -100.00 >medium sand with some interbedded fine sand

Well 12

(Row 28 Column 12)

Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 4.19 feet; Head in screened interval = 4.18

Drillers Log :
4.19 to -100.00 >medium sand with some interbedded fine sand

Well 13

(Row 29 Column 24)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 7.57 feet; Head in screened interval = 7.56

Drillers Log :
7.57 to -100.00 >medium sand with some interbedded fine sand

Well 14

(Row 31 Column 7)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 2.70 feet; Head in screened interval = 2.69

Drillers Log :
2.70 to -100.00 >medium sand with some interbedded fine sand

Well 15

(Row 34 Column 15)
Top of screen = -228.22 feet; Bottom of screen = -233.22 feet
Water Table = 4.59 feet; Head in screened interval = 4.57

Drillers Log :
4.59 to -233.22 >medium sand with some interbedded fine sand
-233.22 to ? >Bedrock

Well 16

(Row 37 Column 2)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 2.76 feet; Head in screened interval = 2.73

Drillers Log :
2.76 to -100.00 >medium sand with some interbedded fine sand

Well 17

(Row 38 Column 23)
Top of screen = -95.00 feet; Bottom of screen = -100.00 feet
Water Table = 6.23 feet; Head in screened interval = 6.22

Drillers Log :
6.23 to -100.00 >medium sand with some interbedded fine sand

Figure 1 – Regional Map

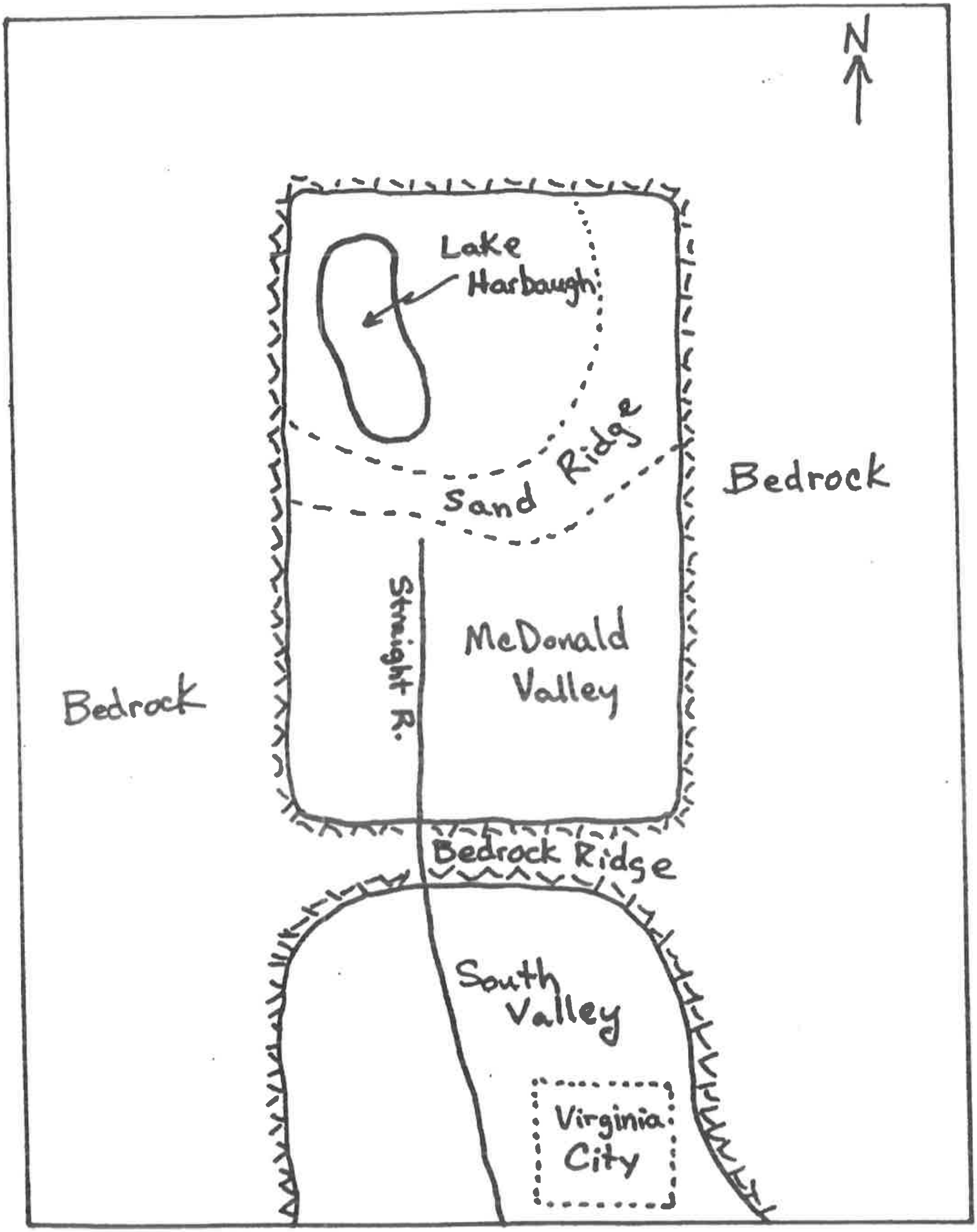
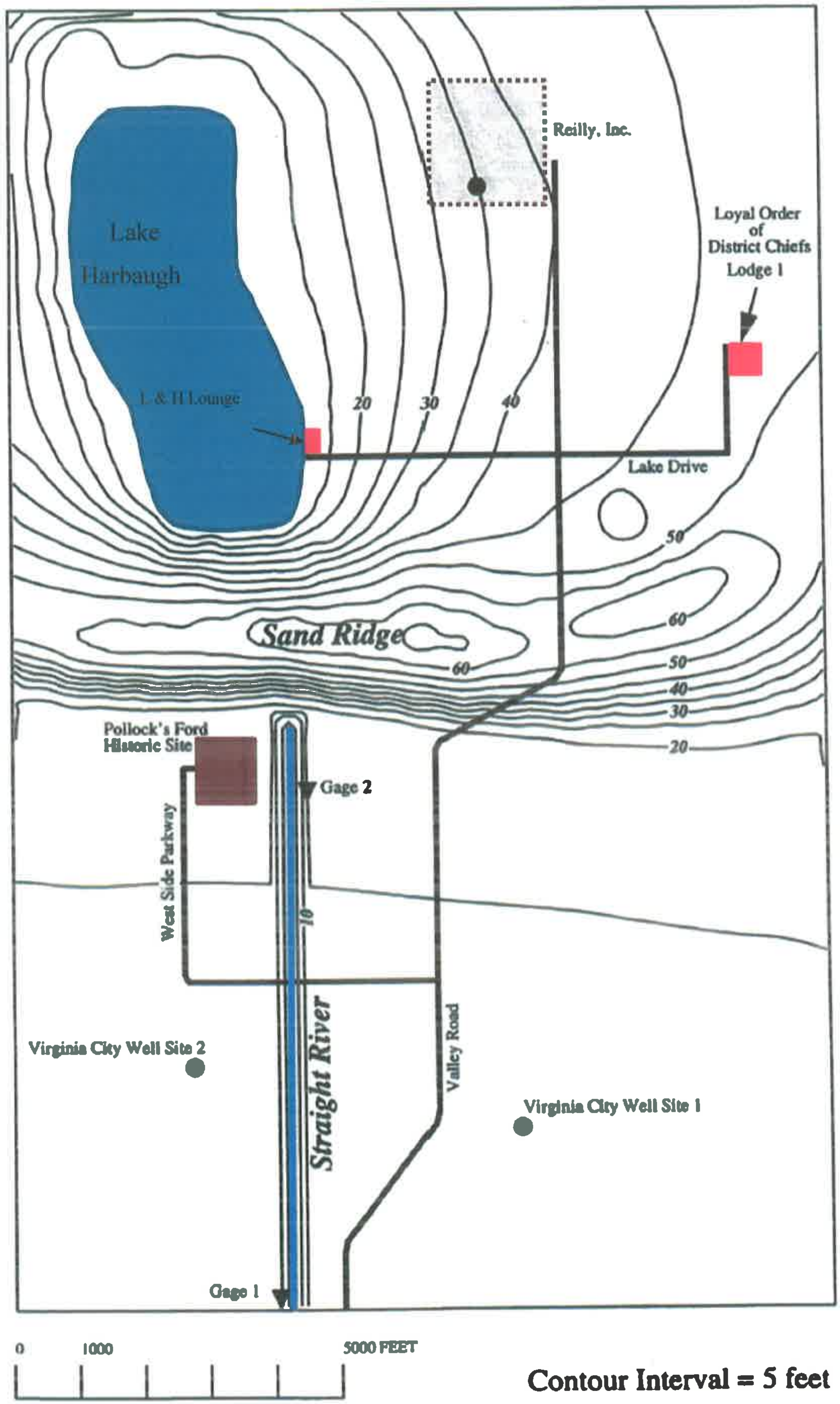


Figure 2 – Topographic Map of McDonald Valley



Contour Interval = 5 feet

McDonald Valley Calibration Exercise
Stage 1

PROBLEM FORMULATION AND ANALYSIS OF EXISTING DATA

Stage 1 is the planning phase of the study. Based on the information you have been given, develop a conceptual model of the flow system. What things are important with respect to the objectives of your study? After you have a conceptual model formulated, you need to translate that into discretized form so that you can use MODFLOW to simulate the system. We have included some questions that you should consider as you plan your strategy.

To simplify things for the purposes of this class problem, we will all use the same areal grid which has 40 rows and 25 columns. The grid cells are constant 500 foot by 500 foot squares over the entire area. Copies of the grid are attached to this hand out. You have some freedom to discretize the problem in the vertical direction. However, you should try to use no more than 4 layers to simulate this problem. Remember, the more layers you have, the more data you will have to manage when you run your simulations.

Study Questions

1. Sketch a contour map of the water table on the worksheet we have provided.

2. Describe the elements of the hydrogeology of this system that you believe will be most important in your analysis.

3. Describe how you would treat the boundary conditions and stresses.

4. On the grid worksheet, label the cells that would be used to simulate the lake and river. How will you incorporate the effects of the lake and river into those cells.

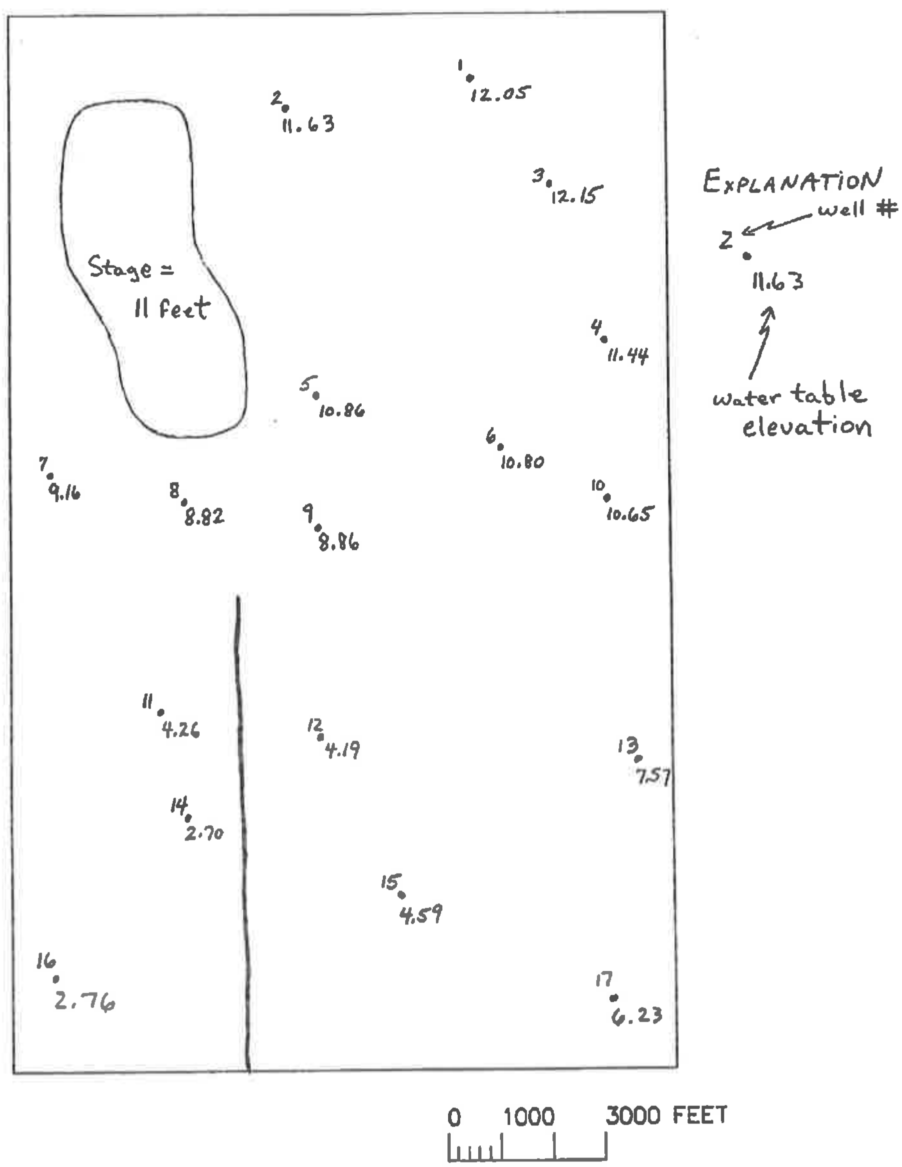
5. Describe how you would discretize the system in the vertical dimension.

6. On one of your maps, mark the portion of the lake shore where groundwater discharges to the lake. Do the same for the portion of the lake shore where flow is from the lake to the ground water system.

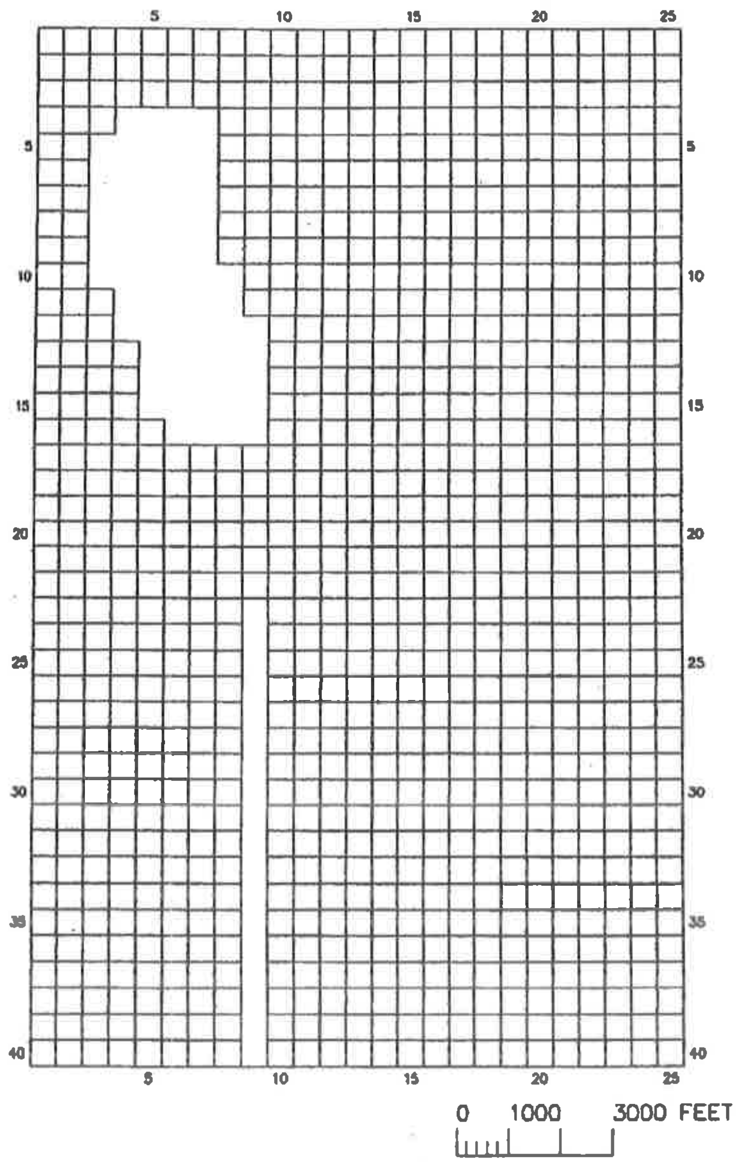
7. Write a water budget equation for the lake. Is the lake a net source or sink of water for the ground water system? Can you make a quantitative estimate of the net rate of ground water recharge or discharge due to the lake?

8. What is the total recharge to McDonald Valley and how is it distributed

Worksheet

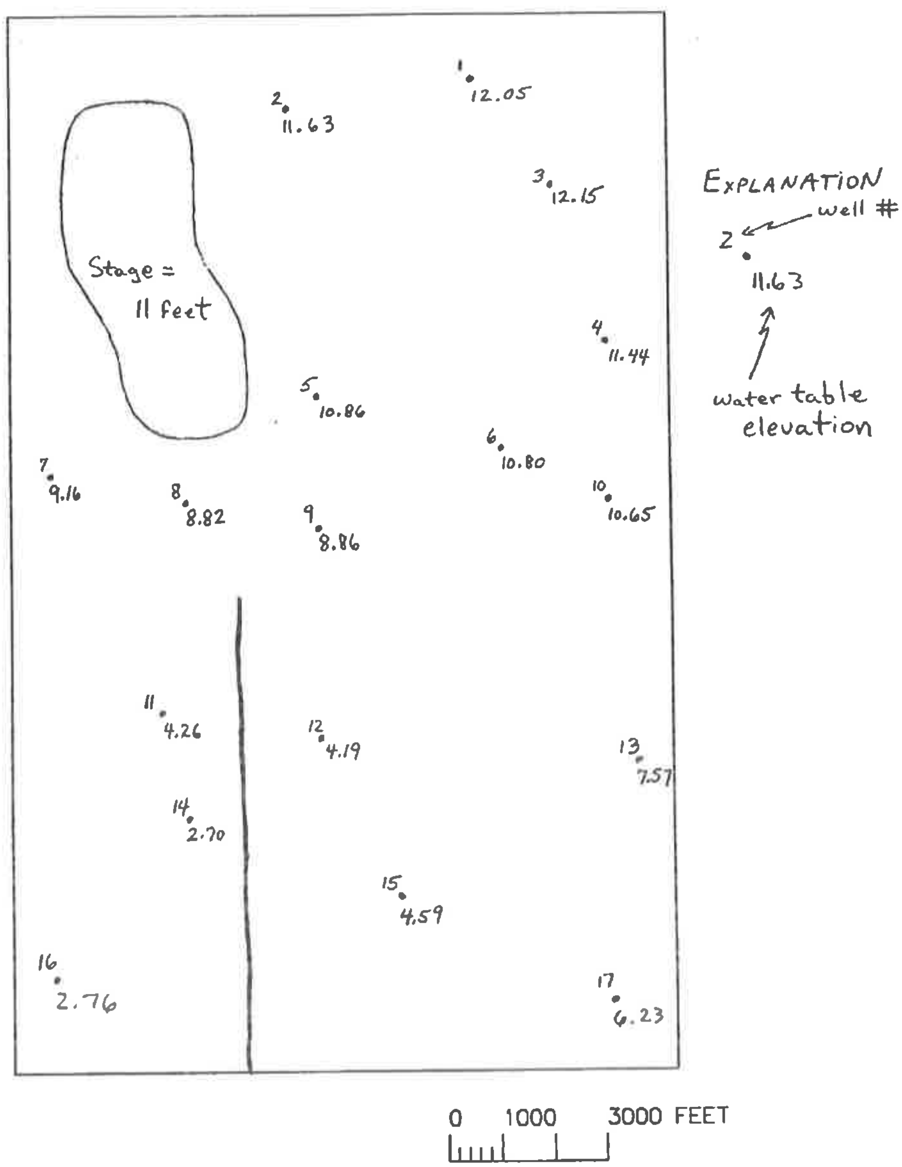


McDonald Valley



Grid: 40 rows, 25 columns, 500 feet x 500 feet

Worksheet



McDonald Valley

McDonald Valley Calibration Exerciss
Stage 2

CALIBRATION FOR PREDEVELOPMENT CONDITIONS USING PRE-EXISTING INFORMATION

During this stage of the exercise you will calibrate your flow model for predevelopment conditions using the existing information that we have provided. Calibration involves selectively adjusting aspects of your model,such as hydraulic parameters and boundary conditions, so that the simulated results reproduce the observations as closely as possible. Remember not to fall into the trap of treating calibration solely as a curve fitting procedure. You should always try to adjust parameters within ranges that you can justify based on what you know about the system and to avoid adjusting parameters in ways that cannot be supported. That almost always means your "calibrated" model will be less than perfect when you are finished. However, the calibration process can provide you with a great deal of insight into what hydrologic features are really important in controlling the function of the ground water system. You can use this insight to plan your field work so that you will be able to obtain new data to fill in gaps in areas that are of critical importance.

As you construct your calibrated model, keep the following things in mind:

1. What are the critical elements of the hydrology of the McDonald Valley ground water system that the model must reproduce?

2. To what parameters is the model most sensitive?

3. What are the critical gaps in information and what kind of data should be collected to fill those gaps.

Attached are some worksheets to help you summarize the results of your calibration analysis.

Calibration Exercise -- Stage 2

Worksheet

1. The head at the water table (layer 1) for cells:

well number	row	column	head	(Simulated - Observed)
3	7	21		
6	17	19		
8	19	7		
11	27	6		
14	31	7		
16	37	2		
17	38	23		

2. The hydraulic conductivity in layer 1 for cells:

row	column	hydraulic conductivity
19	7	
38	23	
7	21	

3. The river conductance (or a range if it was not a constant).

4. On one of the attached map worksheets, sketch the hydraulic conductivity distribution in model layer 1.

5. On one of the attached map worksheets, sketch the distribution of the clay layer.

6. The vertical conductivity value for the clay (or a range if it was not a constant).

McDonald Valley Calibration Exercise -- Stage 3

MODIFIED CALIBRATION USING ADDITIONAL DATA

Now that you have made a first attempt at calibrating a flow model to existing data, you have the opportunity to collect additional data in the field to help fill in the gaps in information and, we hope, improve your model of the groundwater system. After subtracting essential overhead expenses, you have a field work budget of $20,000 for the total duration of the study. You will have three "field seasons" in which you can collect new data. You should use the three field seasons to iterate back and forth between data collection and analysis, analyzing the impact of one season's data to plan the next round of data collection.

You have the option to collect the following types of data:

1. drill wells

shallow wells -- down to a maximum elevation of -100 feet. Shallow wells provide water levels for the screened interval as well as the location of the water table. You specify the bottom elevation of the well. All wells are are assumed to be screened in the lower 5 feet. Each well comes with a driller's log that includes information on major lithology changes with depth.

deep wells -- deep wells are guaranteed to reach bedrock. Water level information, screened intervals, and well log information are the same as described for shallow wells.

2. hydraulic tests

slug tests -- these tests give local values of horizontal hydraulic conductivity. You can conduct up to 7 slug tests on any of the 17 pre-existing wells and any number of slug tests on the wells that you choose to drill.

aquifer test -- this is a large-scale hydraulic test that must beconducted on a deep well. Since deep wells are always screened in the lower 5 feet, this test will give you horizontal conductivity and aquifer thickness. It will also provide a leakance coefficient if the well penetrates a confining clay layer. You cannot conduct an aquifer test on any of the original 17 wells, nor can you drill new wells in cells that already contain a well.

3. seismic analysis

Seismic sections can be run along any row or column. Each run must be the full length of a column or a row. Seismic analyses only provide information on the bedrock elevation. (Please, no arguments from surface geophysicists!)

4. Stream flow measurements

Discharge measurements are provided at several points along the Straight River.

In order to keep track of your expenditures, an accounting form has been provided. The back page is a table of costs for each data item.

Field Data Options
Table of Costs

Well drilled by district auger rig.................... (bottom elevation -100 feet)	$ 1,000
Well drilled by contract driller..................... (guaranteed to reach bedrock)	$ 3,000
Slug test .... (limit of 7 slug tests on initial 17 wells)	$ 250
Aquifer test .... (test must be on a new well drilled to bedrock) (cost includes drilling of new well to bedrock)	$ 4,000
Seismic Sections (N-S or W-E) .... (seismic section provide bedrock elevation only)	$ 2,000
Stream Flow Measurements (seepage run)	$ 500

McDonald Valley Calibration Exercise -- Stage 3

CALIBRATION EXERCISE DATA SUMMARY FORM

Group Number ______

Initial project budget =	200,000
Overhead charges =	180,000
Initial working field budget =	20,000
Funds used for request 1 =	
Funds remaining after request number 1 =	
Funds used for request 2 =	
Funds remaining after request number 2 =	
Funds used for request 3 =	
Funds remaining after request number 3 =	

Wells

Well Number	Location: row	Location: column	Location: bottom	Costs: Drilling	Costs: Slug Test	Costs: Aquifer Test	R#
1	3	18	-200.74(D)				
2	4	11	-100.00				
3	7	21	-100.00				
4	13	23	-100.00				
5	15	12	-224.62(D)				
6	17	19	-100.00				
7	18	2	-100.00				
8	19	7	-100.00				
9	20	12	-100.00				
10	19	23	-100.00				
11	27	6	-100.00				
12	28	12	-100.00				
13	29	24	-100.00				
14	31	7	-100.00				
15	34	15	-233.22(D)				
16	37	2	-100.00				
17	38	23	-100.00				
18							
19							
20							
21							
22							
23							
24							
25							

Wells

Well Number	Location			Costs			R#
	row	column	bottom	Drilling	Slug Test	Aquifer Test	
26							
27							
28							
29							
30							
31							
32							
33							
34							
35							

Total Costs for Request 1			
Total Costs for Request 2			
Total Costs for Request 3			

Group Number ____

Seismic Sections

row	column	cost	R #

Total Cost for Request 1	
Total Cost for Request 2	
Total Cost for Request 3	

Stream Flow Measurements

request #	cost

McDonald Valley Calibration Exercise -- Stage 4

DEVELOPMENT SCENARIOS

Use your calibrated model to simulate the impact of the following two development options:

Case A. 2 wells; Reilly Well and Virginia City Well in Location 1

owner	row	column	Q (ft3/d)
Reilly	6	15	-67000
Virginia City(1)	35	16	-268000

Case B. 2 wells; Reilly Well and Virginia City Well in Location 2

owner	row	column	Q (ft3/d)
Reilly	6	15	-67000
Virginia City(2)	33	6	-268000

Fill in the information on the attached worksheet.

Calibration Exercise -- Stage 4

worksheet

Record the following information for your simulated development scenarios in cases A and B:

Case A.

----

1. Head in the lake = ________________

2. Total river discharge at southern boundary = ____________________

3. River discharge at Pollock's Ford (gage 2) = ____________________

4. Percent change in discharge at gage 2 = ________________________
(base the percent change on the difference between your stressed and unstressed simulations)

5. Is there any induced infiltration from the river to the aquifer.
If so, where does it occur and what is the rate?

6. Maximum drawdown in the northern part of the valley = __________
(model rows 1 - 16)

Case B.

----

1. Head in the lake = ________________

2. Total river discharge at southern boundary = ____________________

3. River discharge at Pollock's Ford (gage 2) = ____________________

4. Percent change in discharge at gage 2 = ________________________
(base the percent change on the difference between your stressed and unstressed simulations)

5. Is there any induced infiltration from the river to the aquifer.
If so, where does it occur and what is the rate?

6. Maximum drawdown in the northern part of the valley = __________
(model rows 1 - 16)

Extra Run

The cooperator has asked you to evaluate one additional development option:

- The Reilly well pumps at -67,000 just as in the other cases.
- The Virginia City wells are removed.
- A dewatering operation is initiated at row 23, column 20. The head in row 23, column 20 must be lowered to 2 feet above datum.

Questions:

1. How much water must be pumped from row 23, column 20, layer 1 to keep the head in that cell equal to 2?

2. What will the lake stage be for this situation?

HINT: Use a drain with a high drain conductance in row 23, column 20, layer 1.