INTRODUCTION

General Instructions:
The completion of this Lab does NOT require a formal Lab report or write up. Instead you will present your data by completing a Lab Template. This template is available as a separate document. Only the completed **LAB5: UNCONFINED AQUIFER PUMPING RESULTS** needs to be turned in for credit!!!

Reading Assignments:
In preparation for this Lab and the other pumping lab, READ the following in your FREE Open Access Textbook(s):
- Kresic, 2024, Hydrogeology 101: Lecture 3.1; 4; 6.2; 9.1; 14.6.4; 15.3.3
- Freeze & Cherry, 1979, Groundwater: Chapter 2, Chapter 8

(Optional) and if you have it, READ the following in your *optional* Textbook:
- Hölting & Coldewey, 2019, Hydrogeology: Section 4; 16.3.1

GENERAL INSTRUCTIONS ON COMPLETING THE LAB and GRADING:

For ALL assignments use a citation's database:

ZOTERO citations database	ZOTERO is a citations database that incorporates itself into Word and your Browser.	Free open source software available at https://www.zotero.org/

Note: You may use a different citations database, if desired. But you MUST use a citations database!

NOTE: After downloading and installing ZOTERO, take an hour or two to become familiar with the operation of the software. One of your first tasks will be to set the citation style to the United States Geologics Survey (USGS) format in ZOTERO. The USGS citation system will be required for this course and your final product.

Loading the USGS citation format into ZOTERO: Once Zotero Standalone is installed, click on "Preferences" under the Edit tab. Once there click on "Cite" and go to the "Styles" tab. Click on the "Get additional styles..." below the Styles Manger Box. When the Zotero Styles Repository Window opens, click on the "geology" button within the "Fields" section. A list of geology journals should now appear. Scroll down to the U.S.Geological Survey and click on it. The U.S.G.S style will now be part of your Zotero system and you can set your citations to be formatted accordingly in Zotero.

General Writing Instruction Summary:
- Use professional language, which means AVOID first person expressions such as “I”, “we”, “our”. Use normal prose, active voice and third party language. Do NOT use informal wording, contractions, jargon, slang terms, or superlatives. Exclude similes/metaphors (and humor!)
- Use present tense to report well accepted facts, e.g. 'Pyrite is a sulfide mineral'. Use past tense to describe specific results, e.g. 'When acid was applied, the specimen effervesced'
- Be quantitative wherever relevant (stats, numbers etc.).

Subscript & Superscript	Use appropriate subscript and superscript, especially when it comes to chemical formulas and mathematical units.. Acceptable examples: 2.9 g/cm^3, H_2O, PO_4^{3-}, a_g=9.8m/s^2 Unacceptable examples: 2.9 g/cm3, H2O, PO4 3-, ag=9.8m/s^2

- Use precise concrete language, no ambiguity e.g, ‘correlated’ ≠ ‘related’. Use simple language – no unnecessary “frills” (distractions). Pay attention to sentence structure and grammar

COMPILING TABLES, FIGURES and EQUATIONS
GRAPHICS are the heart of any report. Nothing is more true than in science that a picture is worth a thousand words. Always compile graphics first and then write your text focusing on your graphic. In order to create good graphics and photographs, follow the instructions below.

Cameras and Photos:
Cell phones with a 7.2MP camera are usually ok. When taking pictures, lighting and background is key. This means dark objects should be photographed with light or white backgrounds (sheet of paper) and visa versa for light objects. Having adequate lighting will also help to get sharp, crisp, in focus pictures. Blurry and out of focus pictures are not acceptable.

Graphics:
You should be able to modify, enhance, annotate or overlay graphics. Minimum resolution is 300dpi. Make sure graphics are crisp, clear and any label is easily readable. All graphics should have a caption stating the author and/or citation. Preferably use lossless graphic formats, such as .tif or .bmp. Unfortunately .jpg is NOT lossless and will degrade a little every time you open and save it again in order to manipulate picture contents.

Graphics Editor Software: You will need a graphics editor and learn how to use it. Windows comes with its default Windows Paint editor. It is found in the Windows Accessories Folder. For a more advanced option with many more professional features you may try GIMP: https://www.gimp.org/ This is a FREE, open source image editor working across all computing platforms (Windows, Apple, Linux, etc.). The software comes with ample documentation and examples on how to manipulate any picture or graphic.

Screen Capture Software: A screen capture or snipping software is advantageous in order to only grab the part of a graphic from the screen that is important or necessary. Windows 10 comes with a default snipping tools, such as "Snip & Sketch" found in its own folder or "Snipping Tool" found in the Windows Accessaries Folder. Note: When snapping a picture, make sure it is large enough on the screen to capture enough pixels to have adequate resolution for the final product.

NOTE: Compiling acceptable and good looking graphics and photographs is very involved and can not be rushed. These are often the heart of any report and should be compiled BEFORE writing. Last minute thrown together graphics will without doubt lower your grade.

COMPOSITION, LAYOUT, WRITING & GRAMMAR SUMMARY

Language

The following list is an example of common faults in language usage and attribution.

Errors / Mistakes / Faults	Examples with margin *Fault Counts & Codes*	
Spelling:	| |	The mineral florite has a mohs hardness of four.
incl. capitalization errors & spacing	|	Nicolas Steno_was trained in the classical texts on science.
Grammar:		
incl. punctuation, superfluous	|	Isometric crystals are also isotropic Here light propagates at the same speed.
words, transpositions	| |	Rocks are composed of many ~~many~~ minerals mixed.
Style:		
incl. paragraph,	|*Para.*	... in the geologic sciences.¶Near the end of the 19th a new theory ...
repetitive expressions / words	|||*rep*	... is a light colored mineral. These light colored minerals are often light...
erroneous expression / words,	|	Stalactites hang from the sealing? of a limestone cave.
sub- or superscription,	|*sup*	The density of quartz is 2.65 g/cm3.
unprofessional style,	| |	I was investigating the outcrop with my group.
word insertion	|	Sodium sulfate forms a chalky, ~~incoherent~~ precipitate. *amorphous?*
Sentence:		
incl. grammar,	|	The density of gold is greater then? the density of silver.
run-on,	|	Pyrite has a symmetrical crystal structure, it is cubic.
strings of nouns	| |	Skarn mineral zonation? is apparent in the sample.

Content

Errors in content are spelled out. Severe infractions may count for multiple errors.

Errors / Mistakes / Faults	Examples with margin *Fault Counter & Codes*	
Unclear / erroneous statements	|*unclear, units?*	Mohs hardness of the mineral in question is 16.5.
False / nonsense	||*Nonsense*	~~Glaciation cause severe metamorphism of the region~~

TABLES, FIGURES & EQUATIONS SUMMARY

Tables

Each table must be sufficiently complete that it could stand on its own, separate from text.

Only HORIZONTAL lines are allowed in tables. Do NOT use any VERTICAL lines.

DO consecutively number and caption tables and refer to them accordingly within your text. Captions go ABOVE the table.
DO provide a short description of your table within the caption.
DO place your tables appropriately, closest to their mention in the text.
DO make sure tables are legible and reproduce well. Print can be smaller than text, with an 8pt size minimum.
DO appropriately label columns. Do NOT forget units for numeric values.

AVOID splitting tables across pages.

Figures

Each figure must be sufficiently complete that it could stand on its own, separate from text.

DO number and caption figures consecutively and refer to them accordingly within your text. Captions go BELOW the figure.
DO provide a short description of your figure within the caption.
DO place your figures appropriately, closest to their mention in the text.
DO use appropriate citations for figures that are NOT your own. If you use a figure that has been modified by you, the phrase "modified after...." is most appropriate. Photos should show the name of the photographer.
DO make sure figures are legible and reproduce well. Print can be smaller than text, with an 8pt size minimum. Use a minimum resolution of 300dpi. This is a common publication standard.

AVOID cluttering of figures with too much detail. Simplify if necessary.
AVOID moire patterns in photos, a nuisance in copied or scanned pictures. Most scanners come with a moire pattern removal tool.

GRAPHS
Understand graphs: Bar graphs and/or line graphs are used when plotting nominal vs. ratio or interval data. Scatter plot graphs are used when plotting numeric vs. numeric data.
DO make sure that the graph axis are appropriately labeled and scaled. Axis should have titles as well as scalar units.
DO use electronic means to generated graphs. Hand drawn graphs are no longer acceptable.

Equations & Computations

- ☐ Equations should contain explanation of symbols used.
- ☐ A reader should be able to follow where your values or numbers come from. Indicate accordingly.
- ☐ WRITE DOWN UNITS!!!!
- ☐ Show equations used before indicating any computation

Acceptable Example: $F = m \times a = 0.034kg \times 9.8\, {}^{m}/{}_{s^2} = 0.33\, {}^{kgm}/{}_{s^2}$

where *m* is mass of the object in kg as determined with a triple beam balance and *a* is the gravitational acceleration. *F* indicates force expressed in kgm/s^2 or *N* (Newtons).

Unacceptable example: The answer is 0.33. This is obtained by multiplying gravity by 0.034.

Introduction: Confined Aquifer Pumping

General Instructions:

During this LAB you will analyze pumping data from a well drilled into a confined aquifer. Your task is to plot the indicated graphs and calculate the following from the data:

1. Transmissivity
2. Hydraulic Conductivity
3. Storativity
4. Approx. Diameter of the draw down funnel

In order to solve for these parameters you will need the following:

- ☐ (2) Log-Log Graph Paper **IMPORTANT: Physical size of graph paper MUST BE THE SAME, including same scalar and number of log cycles!**
- ☐ Calculator or better yet, Excel spreadsheet
- ☐ 1/u vs. W(u) constant curve drawn to scale of your graph paper used ... or use the included curve and graph paper!
- ☐ Ruler, Pencil(s)

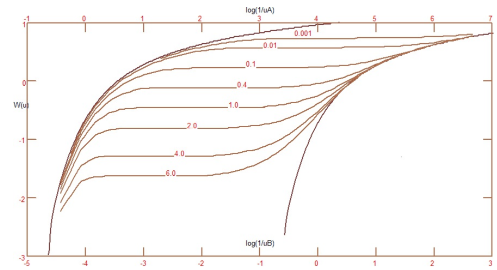
UNCONFINED AQUIFER PUMPING ANALYSIS using the Neuman Method

Intro: How to use the Neuman Method overview.

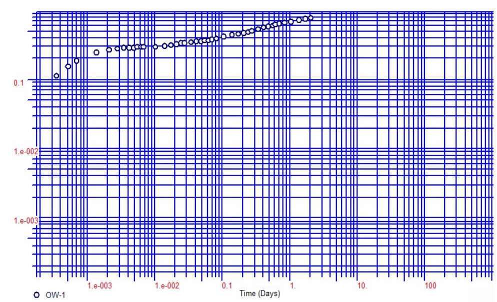
▶ *You may also watch a lecture excerpt video explaining the method at :*
https://youtu.be/0F6aMV7WvXo

1. Use two sheets of Log-Log Graph paper of same size/dimensions. With the Neuman method you will most likely have to glue two adjacent lag-log graph sheets together or have an extended log-log sheet with at least 7 log cycles in the x direction. *Note: Log-Log Paper has a direction, there is a up, down, left and right. Make sure your two graph papers are oriented the same with the smallest numbers in the lower left hand corner and the highest numbers in the upper right-hand corner.*

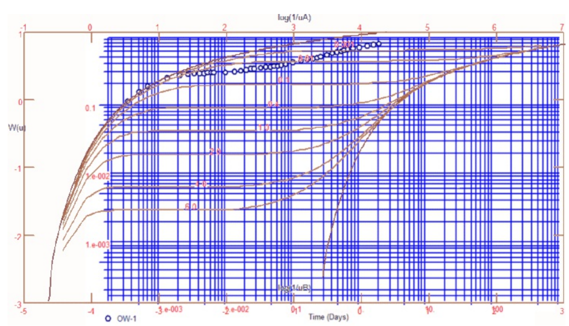
   a. Plot the $W(u_A, u_B, \beta)$ and $1/u_A + 1/u_B$ (Inverse of u!) on one graph with W(u) on the Y axis and 1/u on the X axis. Note that the scalar is the same, no matter if u_A or u_B If possible, draw on transparent graph paper. You can use the already made graph above or you can generate your own using the given Neuman constant curve as an example.



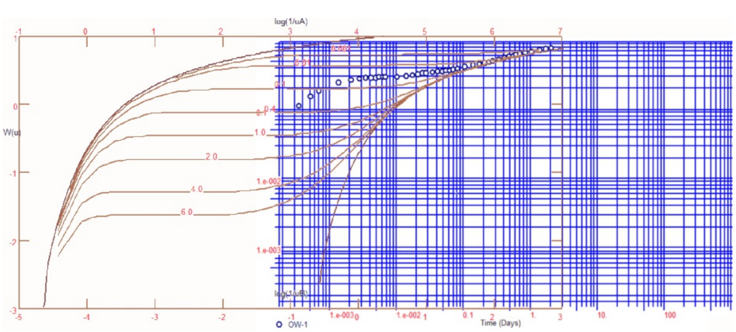
   b. On the blank log-log graph of same size plot your measured data of drawdown in the observation well and time. Drawdown should be on the Y axis and time on the X axis. To simplify you may want to plot time in seconds. See example here:



2. Overlay both graphs and match EARLY drawdown first. Keep graph papers parallel to each other (NO TILTING) when moving the graph to get a match. See example:



3. Once satisfied, while keeping both graphs exactly parallel, slide the constant curve to try to match LATE drawdown. However, do NOT move vertical, only horizontal. See the example picture:



   a. If there is a match, slide back to the early drawdown position and go to step 4.

   b. If there is NOT a good match, adjust graph vertically and slide back to early drawdown to see if things match, remembering to keep everything parallel. Repeat going back and forth between EARLY drawdown and LATE drawdown, adjusting as necessary, until you find the best compromise for both matches. Keep your graphs perfectly parallel. Then slide to the early drawdown position and go to step 4.

4. For EARLY drawdown pick one point, ANY POINT, covered by both graph papers. The points do NOT have to be on the graph itself. Use a pin to poke a hole through both overlain graph papers. Now read off the hole coordinates both on the $W(u_A)$ vs $1/u_A$ graph and the Δh vs t graph.
NOTE: You may want to poke the step 6 hole as well before you separate the graphs, so you do not undo your parallel orientation
5. Record Δh, t, $W(u_A)$, and $1/u_A$. Convert $1/u_A$ to u_A. Plug this data into the Neuman **Early** Drawdown equations. BE CAREFUL WITH YOUR UNITS! Then go to step 6.
6. Now slide your graph to the LATE drawdown (remember to keep your graphs precisely parallel) and again pick one point, ANY POINT, covered by both graph papers. As before, the points do NOT have to be on the graph itself. Use a pin to poke a hole through both overlain graph papers. Now read off the hole coordinates both on the $W(u_B)$ vs $1/u_B$ graph and the Δh vs t graph.
NOTE: As previously mentioned, you may want to poke step 4 and step 6 holes together before you separate the graphs, in order to not undo your parallel orientation.
7. Record Δh, t, $W(u_B)$, and $1/u_B$. Convert $1/u_B$ to u_B. Plug this data into the Neuman **Late** Drawdown equations. BE CAREFUL WITH YOUR UNITS!

The well pumping data and useful equations are given below:
Note 1: Not all data and/or equations given might be useful
Note 2: Do NOT forget to convert into the correct units for your calculations.

Aquifer Equations

$$\Delta h_{cor} = \Delta h - \left(\frac{\Delta h^2}{2b_{sat}^0}\right)$$ Drawdown correction for unconfined aquifers.

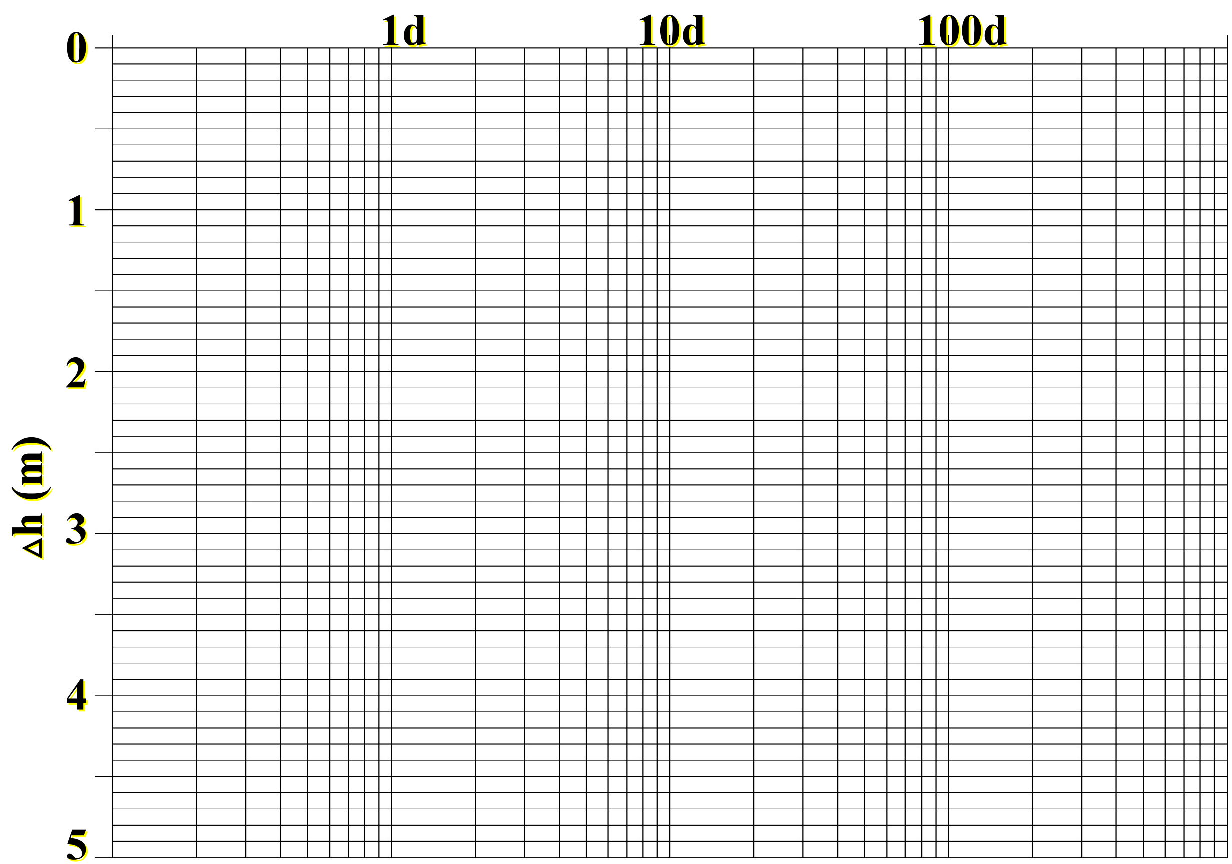
$$\beta = \frac{r^2 k_{fv}}{b_{sat}^2 k_{fh}}$$ Neuman Curve β

Unconfined Early Drawdown $$T = \frac{Q}{4\pi\Delta h} W(u_A, \beta) \qquad S_A = 4T\left(\frac{t}{r^2}\right)u_A$$

Unconfined Late Drawdown $$T = \frac{Q}{4\pi\Delta h} W(u_B, \beta) \qquad S_y = 4T\left(\frac{t}{r^2}\right)u_B$$

UNCONFINED AQUIFER PUMPING ANALYSIS using the straight-line Cooper Method

1. The straight line Cooper method plots drawdown vs time on a semilog paper. Time in days is usually plotted on the x-axis, while drawdown (m) is plotted on the y-axis.



2. IMPORTANT: The Cooper straight line method is usually used for CONFINED aquifer analysis. In order to use it for UNCONFINED analysis, a few assumptions need to be made, and the drawdown has to be CORRECTED!
   - A. This straight line analysis would estimate values for LATE drawdown in the Neuman method. Hence values obtained through this method should approach the LATe drawdown in the Neuman approach.
   - B. Remember:

. following drawdown correction is used:

Plug into Confined Equations or Graph Plots!

$$\Delta h_{cor} = \Delta h - \left(\frac{\Delta h^2}{2b_{sat}^0} \right)$$

Δh_{cor}: Corrected Drawdown!

Δh: Measured Drawdown!

b_{sat}^0: Saturated Aquifer Thickness at beginning of Test

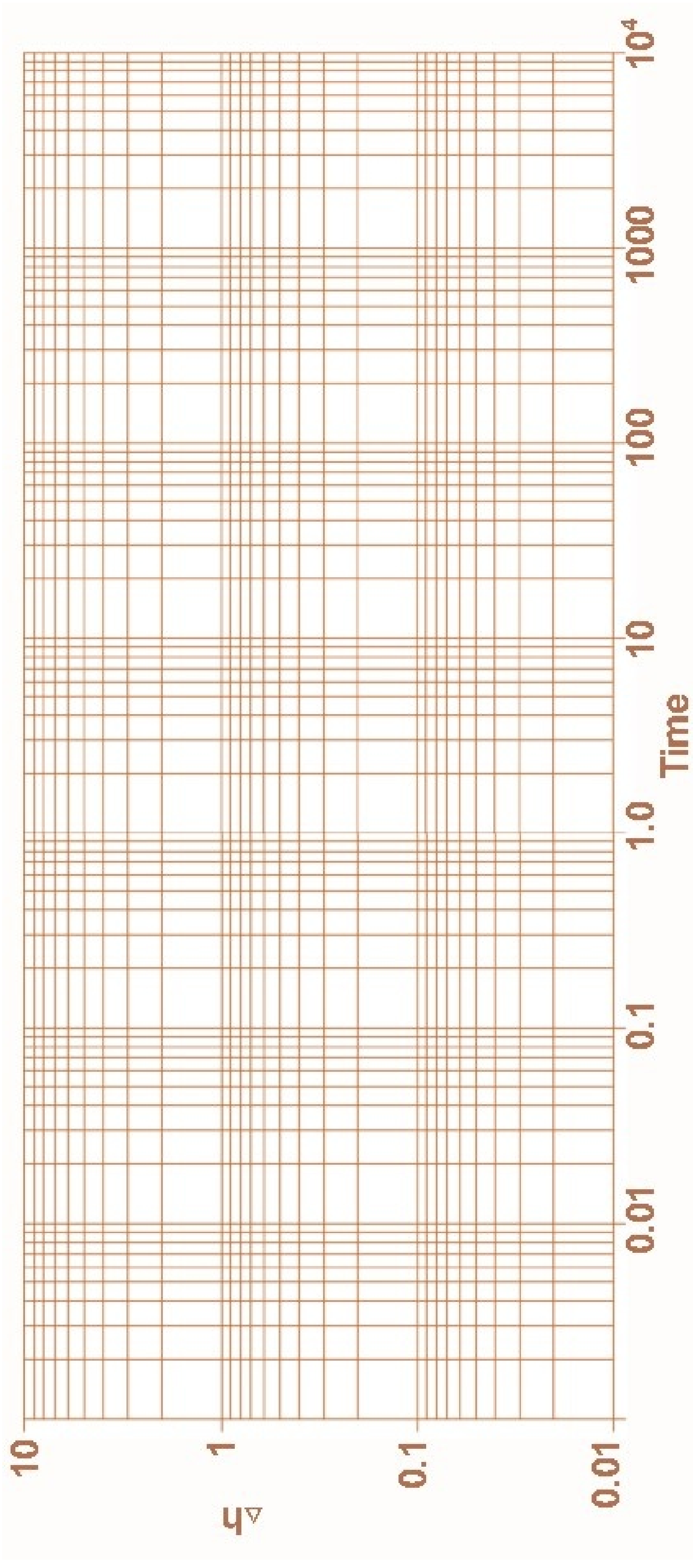
Unconfined Aquifer Pumping Data

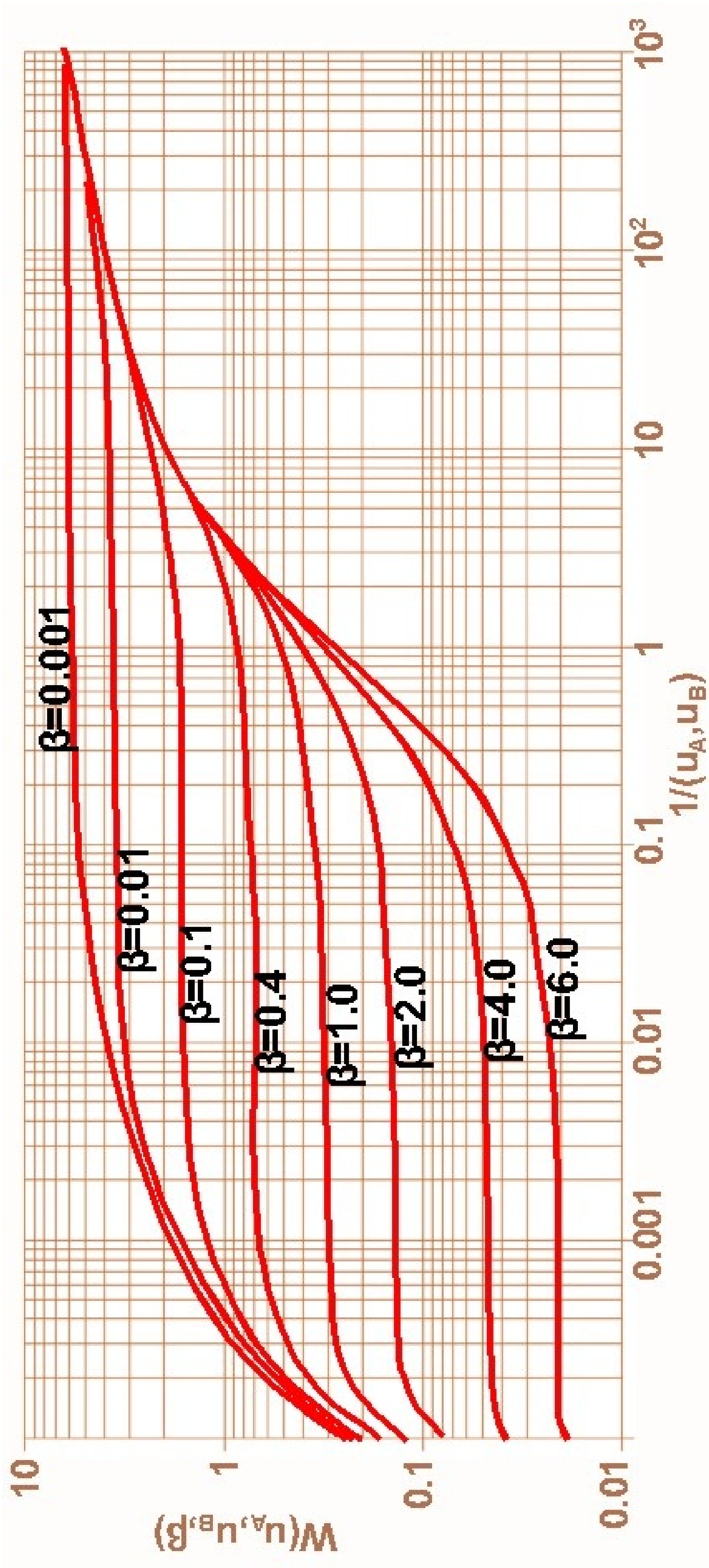
r (Observation Well 1) = 50 m **Q = 30L/s** **b_{sat} = 50 m**

time (hrs)	Δh_{well1} (m)	time (hrs)	Δh_{well1} (m)	time (hrs)	Δh_{well1} (m)
0.17	0.01	6.75	1.05	269.34	1.12
0.29	0.06	11.43	1.06	456.03	1.16
0.49	0.18	19.36	1.06	772.10	1.24
0.82	0.39	32.78	1.06	1,307.26	1.36
1.39	0.64	55.49	1.07	2,213.34	1.55
2.36	0.85	93.96	1.08	2,880.00	1.68
3.99	0.99	159.08	1.09		

Objective

Use whatever steps are necessary to evaluate the aquifer. Calculate Transmissivity, Hydraulic Conductivity, Storativity, and the size of the drawdown funnel.


Time
0.01
0.1
1.0
10
100
1000
10⁴
Δh
10
1
0.1
0.01



NEUMAN METHOD - UNCONFINED AQUIFER PUMPING

You may generate your own Neuman Constant Curve. Make sure the size is equal to the Neuman graph as presented on the previous page.

Only turn in the LAB5: UNCONFINED AQUIFER PUMPING RESULTS page for grading after completion.