Doing and Understanding: Installing Monitoring Wells to Understand Groundwater Hydraulics

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Abstract

"I hear and I forget. I see and I remember. I do and I understand." Engineering Technology educators have always focused on the last phrase of this famous Confucian saying. This paper presents a unique "doing" approach for deeper understanding of groundwater hydraulics. Each year, students in *Introduction to Hydrology Laboratory* at Rochester Institute of Technology install a groundwater monitoring network into a confined silty sand aquifer. Students working in small groups install wells to approximately 15 feet depth using hand augers and standard materials (well points, slotted screen, riser, lockable cap, sand pack, bentonite seal, cement grout, and concrete surface completion). Design elements include well placement, well depth, well construction material, and well screen slot size. After preparing well logs and geologic cross sections the students determine hydraulic conductivity, groundwater flow direction, gradient, discharge and velocity, comparing the results obtained through classical techniques and popular software. Each group prepares a "consultants report" and presents their findings to a "client", the professor. Students enjoy this innovative five week project, and report that it makes a relatively difficult topic understandable. This paper presents technical issues, field techniques and learning outcomes. Examples of student work are included, along with a discussion of how this activity could be replicated at other institutions.

Introduction

Rochester Institute of Technology enjoys a 1,300 acre campus south of Rochester New York . It lies within the Ontario Lowlands physiographic province, an area of 10,000 year old glacial deposits. The state was covered by up to a mile of ice during the Wisconsin glacial maxima, which left the site covered by a 30 foot thick layer of glacial outwash and lake deposits over Cambrian age limestone bedrock. The surficial deposits form a fining upwards sequence, grading from a sandy gravel at 12' to a clay at the surface. This sequence contains a confined aquifer extending from the bass of the gravel to 2 feet below the surface. The surficial clay is the confining unit.

Each year, students in *Introduction to Hydrology* laboratory install a groundwater monitoring network to investigate the flow characteristics of this aquifer. This class is part of the Environmental Management curriculum within the Civil Engineering Technology, Environmental Management Technology & Safety department. This curriculum leads to a BS in Environmental Management, with most graduates finding employment in major industry or consulting. The students take a full complement of science, management, and environmental technology courses including the geology, hydrology, monitoring & measurement, remedial investigation/corrective action sequence.

In that more than half of the US population relies on groundwater for drinking water, and that groundwater is the primary vector for movement of chemicals from contaminated sites, (Fetter[3]) it is important for our students to be able to design, install and operate a groundwater monitoring system. To achieve this, our third year students are tasked with determining the groundwater depth, flow direction, gradient, and velocity of a confined aquifer below a portion of the RIT campus.

Problem Statement

We all have direct experience with surface water, and therefore have an innate understanding of some aspects of its flow. Most of us have no direct observations of groundwater, and have either no understanding of its existence and flow, or a distorted impression based on folklore such as the "underground river" myth.

To overcome this deficit students investigate the groundwater flow regime of a portion of the RIT campus. The investigation includes: well and monitoring network design, material and cost estimates, well installation, surveying, slug testing for hydraulic conductivity, determination of the gradient of piezometric surface by triangulation, mapping, calculation of groundwater velocity, and presentation of results.

Summary of Technical Issues

Well Placement Determination

The students know that three points define a plane, so three wells are needed to determine the slope of the water table, groundwater flow direction and gradient, and that the wells should be arrayed in a triangular pattern. They must determine the minimum spacing between wells to ensure that the differences in groundwater elevation are sufficient to accurately define the plain of the water table or piezometric surface. Groundwater elevation can be measured to the nearest 0.01 foot, so wells must be placed far enough away from each other so that they encompass at least a 0.20 foot difference in groundwater elevation in order to achieve an error of 5% or less. Students use the groundwater slope determined by the previous year's class to help them determine proper well spacing.

Stratigraphic Investigation

The prime objective of a hydrologic investigation is, ”a description of the principle stratigraphic units underlying the site, including their thickness, lateral continuity, and water bearing properties.” (Bedient , Rafai, Newell[1]).

Working in groups of three or four, students complete soil borings and soil descriptions. Boreholes are completed using soil hand augers and extension rods to auger refusal, usually about 12 feet. A continuous core is assembled. Students complete visual/manual soil descriptions in the field, and note depths of changes in stratigraphy. Representative samples of each strata are jarred and labeled for future comparison among the boreholes. Students make a field map using a surveyors tape and brunton compass as well as a GPS unit. The visual/manual soil descriptions and depths of strata change are recorded and used to produce a soil borehole log (see Fig. 1).

Well Installation

Wells are installed next. This is one of the most enjoyable portions of the process, because the students create something tangible that they know that they and future students will be using for years to come. Students select 5-foot lengths of standard 2’PVC slotted and threaded well screen in 8, 10, or 12-slot (slots of 0.08, 0.10, or 0.12 inch), depending on the sediment size distribution found during borehole installation. The screen gets a well point cap and sufficient standard 2’PVC threaded well riser and is lowered into the borehole. Students then carefully add clean silica sand as a filter pack to 1/5 foot above the top of the installed screen. At this point the students see first hand the difficulty of reconciling

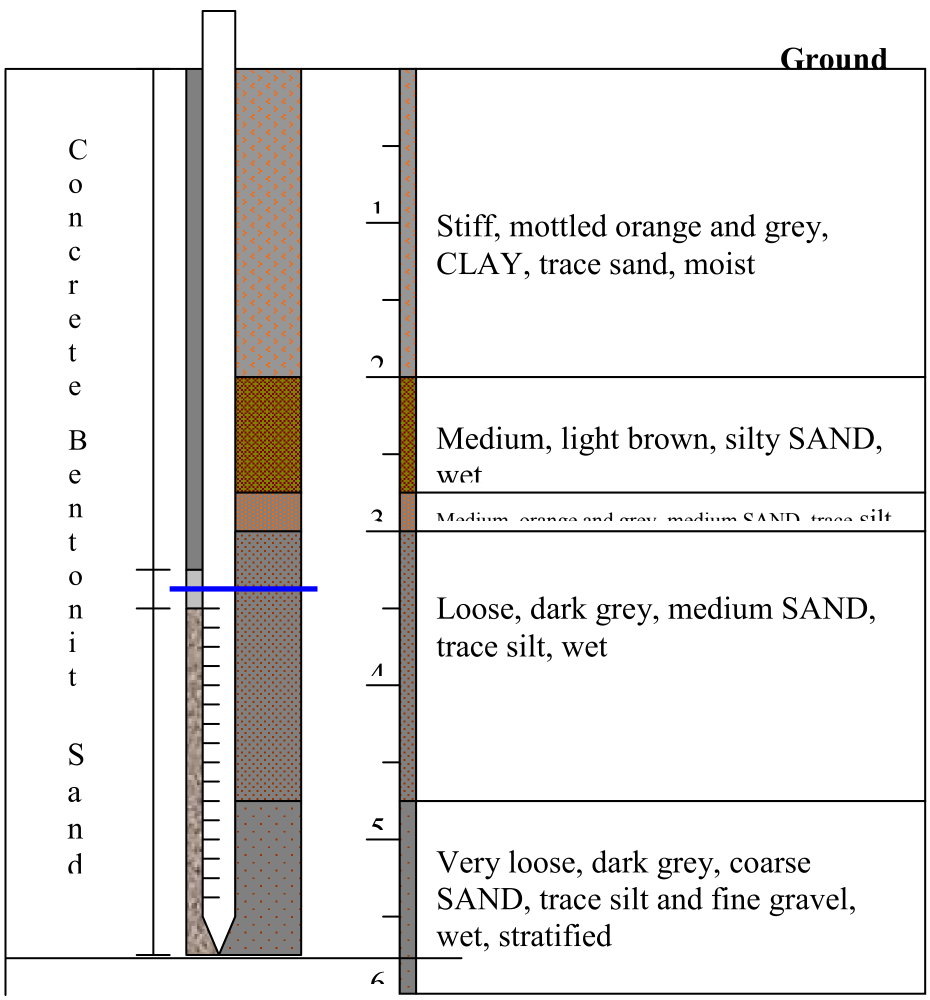

Figure 1, Borehole log/well completion report (Rickles[6]) nominal screen length, actual screen length, riser length, and depth to top of sand as measured from the ground surface! They also begin to perceive the difficulty of measuring depths within the mud filled annulus between the borehole wall and the riser!

The sand is followed by a ½ foot bentonite chip annular seal, and cement grout. The well is finished off on subsequent days with a formed-in-place concrete surface completion and a locking cap. In short, the only difference between these wells and a professionally installed monitoring well is that our boreholes are dug by hand. A complete soil borehole log/well completion report for one of the completed wells is included as Figure 1.

Testing

After developing the wells students plan and perform hydrologic tests to allow calculation of groundwater flow characteristics. Students used Darcy's law in the

$$Q=KAdh/dl$$

form for groundwater discharge in ft^3/day, and in the

$$q=(Kdh/dl)/n$$

form for groundwater velocity in ft/day, where

Q=discharge
A=cross-sectional area perpendicular to flow
dh/dl=gradient of piezometric surface
q=velocity
n=porosity

The remainder of the project involves field testing, geometrical analysis and calculations to determine the value of variables for the Darcy equations.

Hydraulic conductivity (K, in ft/day) is determined using rising head tests conducted on the new wells, with data analysis via the Hvorslev equation (Butler[2]). An example of rising head test data, plot, and Hvorslev analysis is presented in Figure 2.

The gradient and groundwater flow direction is found by a triangulation of the water table elevations on a map of the site. This phase of the project is very worthwhile for the students because they have a chance to use new tools and apply skills learned earlier in the curriculum to a new technical challenge. Students realize that to determine the slope of the piezometric surface they must first find the elevation of top of groundwater in each well. To accomplish this students first survey the well locations and the elevation of the top of each well (MP or measuring point) using an auto level, surveyors tape and rod, or a total station, depending on the skill level of the group. They then collect a round of depth-to-water from the MP of each well. The elevation of the piezometric surface for each well is the MP elevation minus the depth to water. The well

Well Log: Well MW-603S

Well Number:	MW603S	**Date:** October 1, 2003
Well Location:	Rugby Field NW	**Time:** 14:58
Well Data	Casing Diameter - 0.167'	**Depth of Well:** 4.54'
	Screen Diameter - 0.167'	**Depth to Water:** 3.27'
Measuring Point:	Top of Casing	**Type of Test:** Rising Head
Water Level Measuring Device:	Depth to Water / Water level during test: Electric Water Level Probe	
Slug Injection / Withdrawal Method:	Bailer	

Slug Test: Well MW-603S

Time (sec)	Elapsed Time	Depth (ft)	h/h0	Time (sec)	Elapsed Time	Depth (ft)	h/h0
12	0:00:12	4.05	1	600	0:10:00	3.66	0.5
36	0:00:36	4.04	0.99	660	0:11:00	3.64	0.47
55	0:00:55	4.02	0.96	720	0:12:00	3.62	0.45
81	0:01:21	4	0.94	780	0:13:00	3.59	0.41
107	0:01:47	3.97	0.9	840	0:14:00	3.56	0.37
150	0:02:30	3.93	0.85	900	0:15:00	3.54	0.35
180	0:03:00	3.9	0.81	960	0:16:00	3.52	0.32
240	0:04:00	3.86	0.76	1020	0:17:00	3.5	0.29
300	0:05:00	3.83	0.72	1080	0:18:00	3.48	0.27
360	0:06:00	3.8	0.68	1140	0:19:00	3.45	0.23
420	0:07:00	3.76	0.63	1200	0:20:00	3.45	0.23
480	0:08:00	3.73	0.59	1500	0:25:00	3.37	0.13
540	0:09:00	3.69	0.54	1576	0:26:16	3.35	0.1

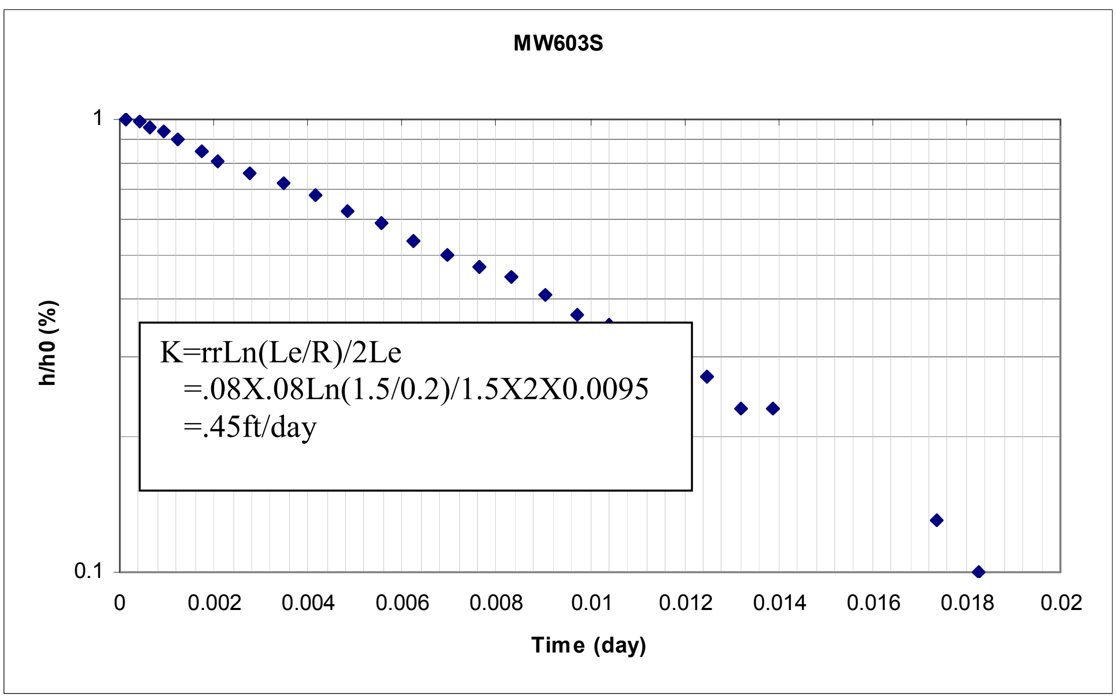

Figure 2, Data, h/h_o ,Vs. time graph and Hvorslev calculation for K, (Hoffner[5]) locations, along with the piezometric surface elevation for each well is plotted on base map. The.groundwater flow direction and gradient is then solved via triangulation as shown in Figure 3. Some students plot their basemap and triangulation results as a GIS overlay on a digitized aerial photo

Having finished that task students can determine all the basic parameters of a hydrologic study: groundwater flow direction from Figure 3, groundwater velocity and travel time using dh/dl from Figure 3 and hydraulic conductivity from Figure 2, and groundwater discharge below the site by applying the above mentioned results to knowledge of the subsurface shown as Figure 1.

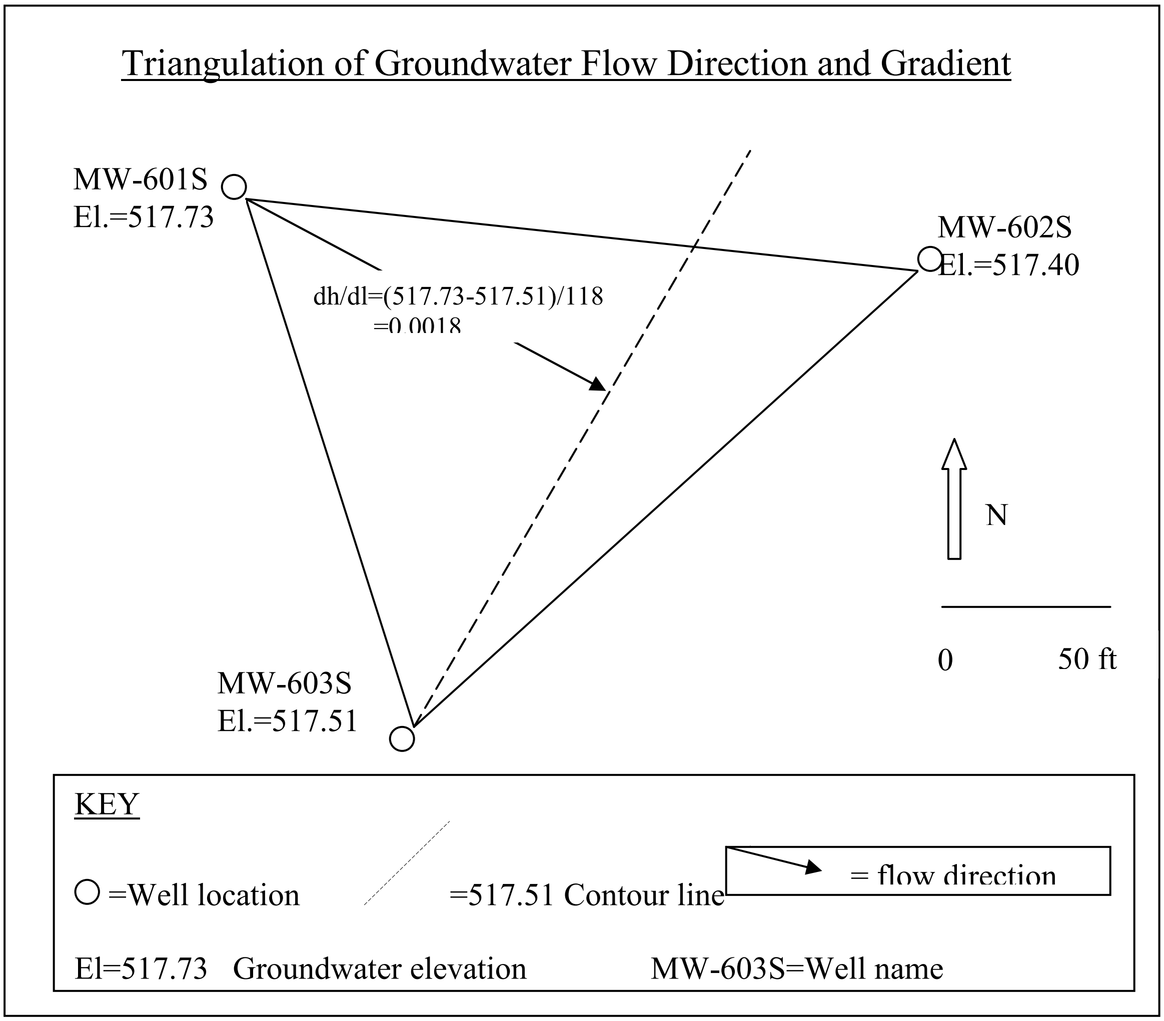

Figure 3. Triangulation of groundwater flow direction and gradient (Adapted from Hoffner[5])

Replication at Other Institutions.

This series of labs exercises can be replicated at any institution in an area of relatively shallow groundwater. It is reasonable to expect that a well borehole can be dug to 15 feet using hand operated soil augers, but that maximum depth will vary depending on soil compaction and texture. Total costs for this project are small. Capital equipment includes only augering equipment (a cross handle, three 5-foot extensions and a bucket auger: total cost roughly $350) and an electric water level probe (cost roughly $300) (Forestry Suppliers[4]). Consumable supplies for three wells includes soil sample jars, PVC well screen and riser pipe, sand, bentonite, cement, concrete, well bottom points, well caps and locks with a total cost of approximately $150. This project can be adopted by any curriculum that includes either a geology class, a soils class or a hydraulics class.

Conclusion

Small groups of students design and install a groundwater monitoring network. They subsequently perform hydrologic tests and use the results to determine groundwater flow direction, velocity and discharge. The students then present this information in the form of a consultant's hydrogeologic report.

This lab activity provides a link between the prerequisite geology class, the corequisite hydrology class, and the subsequent remediation methods class. Students gain the knowledge, confidence and understanding to lead a hydrogeologic investigation of a simple system The author has not collected data documenting improvements in student understanding of this difficult subject, but anecdotal evidence indicates that the lab leads to good understanding of groundwater flow. Alumni of the Environmental Management & Technology program, and students returning from coop often site this activity as among the most useful in terms of preparing them for the workplace.

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