

A MULTI-FACETED HYDROLOGY EXPERIMENT FOR ENRICHING OUR UNDERGRADUATE ENVIRONMENTAL ENGINEERING STUDENTS

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I. INTRODUCTION

Fieldwork is an integral part of most engineering disciplines, particularly environmental engineering. Assessing the impact of environmental problems often requires field investigations. Engineering students need to develop the confidence to work in the field. Lectures, problem solving exercises and computer simulations are essential tools in training our students, however, no amount of LabView ® simulations can substitute for “hands-on” experience. In an attempt to assure our students receive some field experience before graduating and undertaking their profession, they participate in several environmental engineering laboratory exercises out in the field.

A laboratory exercise that has been used with great success in Mercer University’s Environmental Engineering program is a unique combination of environmental and civil engineering techniques. This hydrology experiment was created in order to give our students some in-field experience and introduce them to some of the basic tools, both physical and analytical, of the environmental engineer. This experiment includes the construction of groundwater monitoring wells, basic surveying, flow net construction and an introduction into groundwater flow estimations. The purpose of this paper is to describe this field exercise.

II. BACKGROUND

Protection of our water resources is a major concern of environmental engineers. Sources of fresh water are precious and need to be monitored and protected. Whether through ignorance or carelessness, our fresh water supply is continually endangered by many of man’s activities.

A major source of fresh water is groundwater located in subterranean aquifers. This groundwater can be investigated using monitoring wells. A monitoring well is typically a screened PVC pipe (Figure 1). It serves as an observation port between the aquifer and the ground surface. For an unconfined aquifer, watertable elevations can be obtained with monitoring wells. For a confined aquifer, pressure heads are measured. With this information, groundwater flow direction can be determined.

This monitoring well can also be used as an access port for extracting water samples for chemical testing. Environmental engineers, in their effort to monitor and protect these aquifers, find great use for this information on groundwater flow and chemical composition.

III. PROCEDURE

In the laboratory, the class is instructed on the proper construction of a monitoring well (Figure 1). They are then asked to determine the minimum number of wells needed to determine the three-dimensional surface of the groundwater table, assuming it is flat. Once we agree that three wells/points will be sufficient to define a plane, such as this groundwater surface, the class

proceeds to the fenced-in soccer field on campus. This is the most convenient area on our campus for this exercise. An intramural field would also be a good choice. Once on the field, the class needs to be instructed in both surveying elevations with a surveyor's level and in the actual construction of monitoring wells.

Markers are placed at three widely separated locations on the fenced perimeter of the field (Figure 2). These points will be the vertices of what will probably be a scalene acute triangle. The class is divided up into two teams, A and B. Both teams observe and assist the instructor in installing the first monitoring well. A hand auger is used to drill a four-inch diameter hole. (A depth of four feet intersected a surficial aquifer in our field.) This boring and subsequent borings will be logged during augering. This involves attempting to classify the various types of soils encountered and the elevation where transitions occurred. The screened two-inch diameter PVC well pipe is inserted into the augered hole and prepared as illustrated in Figure 1. Team A is then directed to install a second well unassisted while the instructor, with the assistance of Team B, will set up the surveyor's level. Team B will then, under direction, start to survey and record the elevations of points on the field. This information will consist of the angle and distance of each point, along with the elevation, all with respect to the level.

When Team A has completed placing the second well, it will be inspected by the instructor. Team B will then be directed to drill the third well while Team A will take over the surveying task. The instructor will instruct Team A on proper leveling and use of the surveyor's level, all without moving the present settings. (Once all the surveying has been completed, Team A will then have the opportunity to truly level the survey instrument.) When Team B has completed the third well, all students are gathered to shot a reference location. This location should be a permanent structure on the field (e.g. a spigot, well head, etc.) If the elevation of this point above mean sea level (msl) is known, it should be recorded. Otherwise, an approximate value for msl will serve. The students will then shot the top of well for all the wells.

Enough locations should be shot to map the boundaries of the field, locations of the wells, and, depending on time limitations, topography of the field (see section VI Possible Extensions). Lastly, the depth of water in each well is measured using a simple water level indicator (e.g. Fisher Water Level Indicator Model WLT). An alternative to purchasing one of these indicators is to have a freshman design class build one. (See section VI Possible Extensions).

If water has not accumulated in the wells by the end of class, a brief visit to the field the following morning will quickly supply this information. (If no water table has been intersected, artificial levels can be created, so values exist for use with analysis, by pouring in an appropriate six to ten inch level of distilled water by hand.)

IV. TASKS FOR STUDENT

Students are asked to take the data gathered and generate two maps. One will be a plan view of the soccer field (Figure 2). This map should clearly mark the location of the corners of the study area, wells, surveyor's level, and reference point. Elevations should be noted at all points and true North should be labeled on this figure, along with a length scale. If time has permitted the surveying of the surface of the field, then a topographic presentation would be possible (see

section VI Possible Extensions).

The second map would be one depicting the groundwater surface (Figure 3). The students should take the groundwater elevations, convert them to msl (mean sea level) and then create a contour map by interpolating groundwater elevation values between wells. Interpolating is simplified by assuming linear variability between wells. The contour lines will be straight and represent lines of equipotential.

The next task for the student is to complete a flow net. Flow lines are drawn perpendicular to the equipotential lines and are spaced such that the equipotential lines and the flow lines form squares (Viessman, 1996). This simple flow net will clearly tell the student the groundwater flow direction by the orientation of the flow lines. In the example in Figure 3 the flow is proceeding toward the NE.

With some more information the student can use the flow net to determine discharge through the aquifer. The information that is needed is the depth or thickness of the aquifer and the hydraulic conductivity of the soil. Our cores were not extensive or probably deep enough to give the aquifer depth value. However, for the exercise the instructor can give the students an arbitrary, but reasonable, aquifer thickness of 10 meters. If a representative hydraulic conductivity is given for local soil, the student can use the following flownet equation to determine flow rate or discharge through the aquifer (Freeze and Cheery, 1979, Lee and Fetter, 1994):

$$Q = \frac{n_s}{n_d} K w H$$

where Q is flow rate,

n_s is the number of flow tubes in the net,

n_d is the number of potential drops across the net,

K is hydraulic conductivity,

w is the thickness of the aquifer, and

H is the total head loss across the flow field.

This equation needs to be carefully applied for this application. Flow nets using this equation typically are oriented in a vertical plane to determine flow under a structure, such as a dam. The soccer field application will orient the flow net in a horizontal plane. The w in this equation represents a length in a third dimension. That will be in the z direction here and represent the thickness of the aquifer. It must also be recognized that this aquifer has no boundaries in the horizontal plane. Therefore, the flow rate computed from this flow net needs to be adjusted to represent flow for a unit length in a direction perpendicular to flow direction. The following example will help clarify these points.

V. EXAMPLE RESULTS

From Figure 3, a convenient portion of the flow net is selected. This section is marked in thick lines. This section has $n_s = 5$, $n_d = 6$, K has been given as 10^{-5} m/s (typical value for silty sand, Freeze and Cherry, 1979), w has been given as 10 meters and H is 316.2 feet – 315.0 feet =

1.2 feet (0.37 meters). Therefore, Q for these five flow tubes is calculated to be $3.1 \times 10^{-5} \text{ m}^3/\text{s}$ or $0.11 \text{ m}^3/\text{hr}$.

What remains is to normalize this value. Since each tube is seen from Figure 3 to be approximately five meters wide, the flow through a unit width would be calculated as $.11 \text{ m}^3/\text{hr} / (5 \text{ tubes} \times 5 \text{ meters}) = 4.4 \times 10^{-3} \text{ m}^3/\text{hr}$ (per meter of section perpendicular to flow).

VI. POSSIBLE EXTENSIONS

This lab exercise has great potential for lead in and follow-up projects or labs. Several suggestions follow:

- We have asked our freshman design class to come up with a device to determine the depth of water in a monitoring well. Simple, inexpensive devices can be designed and constructed by our freshman to be used with this lab. It would eliminate the \$ 250 or more cost of a device, such as the Fisher Water Level Indicator.
- This lab can be extended to use the surveyor's level to complete the mapping of the field surface. This would yield a topographic map of the field. This exercise would afford a greater opportunity for our students to work with contouring. It gives the engineering student an important ingredient, surface slope, needed to determine surface runoff. It also gives the soccer team a home field detail they may be able to capitalize on.
- The wells become sites for groundwater sampling which can be used in future labs. Water samples can be extracted using a bailer and these then can be used as samples for water chemistry testing.
- These sites also become convenient sampling stations on campus. Not only can our environmental engineering laboratory class use them but they also could be used to demonstrate to our freshmen sampling techniques used by environmental engineers. This is very useful for our Introduction to Engineering class. In this class we have modules for each engineering discipline, attempting to inform and interest our students in these disciplines.

VI. CONCLUSIONS

In this paper, an in-field exercise is described that broadens the experience of the environmental engineering student. The stated problem for the student is to determine the groundwater flow under a field. Students are first asked to determine the best number and location for a set of groundwater monitoring wells to be constructed on the perimeter of the field. Once on the field, students are instructed in the proper construction of a monitoring well. Using a hand auger and screened well pipe, they then proceed to construct the wells. The locations of the wells are determined and recorded using a simple surveyor's level and tape measure. The depth of the groundwater within the wells is measured using a pipe water level indicator. With this information, the students can create a flow net from which groundwater flow direction can be determined and flow rate quantity estimated.

After this exercise, the monitoring wells become convenient sites for groundwater sampling for water chemical testing. The surveying could (and has been done at Mercer) be expanded to

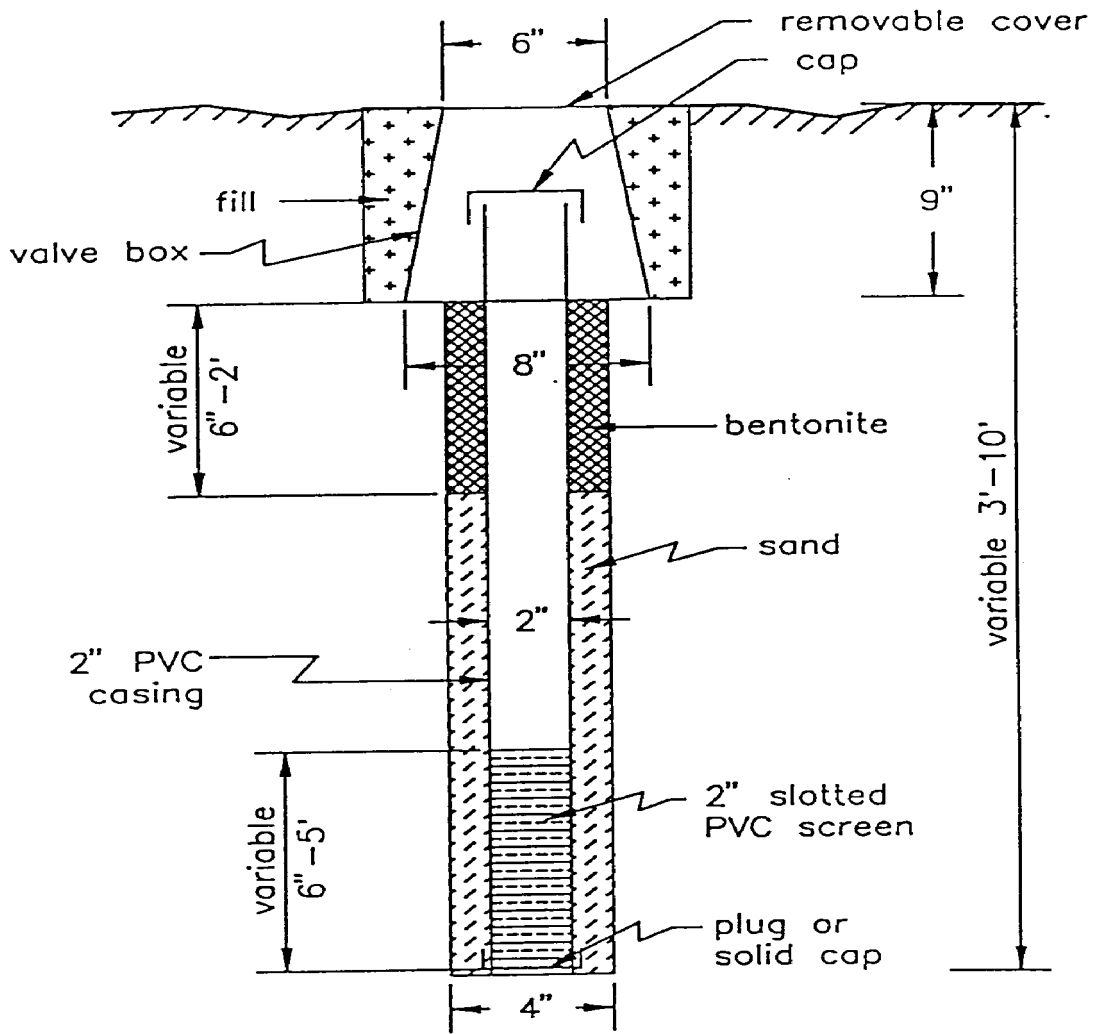
map the topography of the ground surface. It also can be used for several freshman projects. This then is a lab that is inexpensive, gives the students hands-on experience while exposing them to several basic hydrologic techniques and establishes the foundation and opportunities for build-on labs. Upon completion of this lab the student has a physical appreciation of what an aquifer literally feels and looks like from our borings and has a familiarization of some simple techniques into determining groundwater flow direction and quantity. At the same time, this laboratory exercise supports the student's course work in several courses, such as, Engineering Hydrology, Groundwater Contamination, Water Resources Engineering and Water/Wastewater Treatment.

REFERENCES

Freeze, R.A. and Cherry, J.A. (1979). Groundwater, Prentice-Hall, Englewood Cliffs, NJ, 604 p.

Lee, K. and Fetter, C.W. (1994). Hydrogeology Laboratory Manual, Macmillan Publishing Company, New York, 135 p

Viessman, W. and Lewis, G.L. (1996). Introduction to Hydrology, Harper Collins College Publishers, New York, 760 p.



TYPICAL SHALLOW WELL DETAIL

Figure 1. Typical Shallow Well Detail

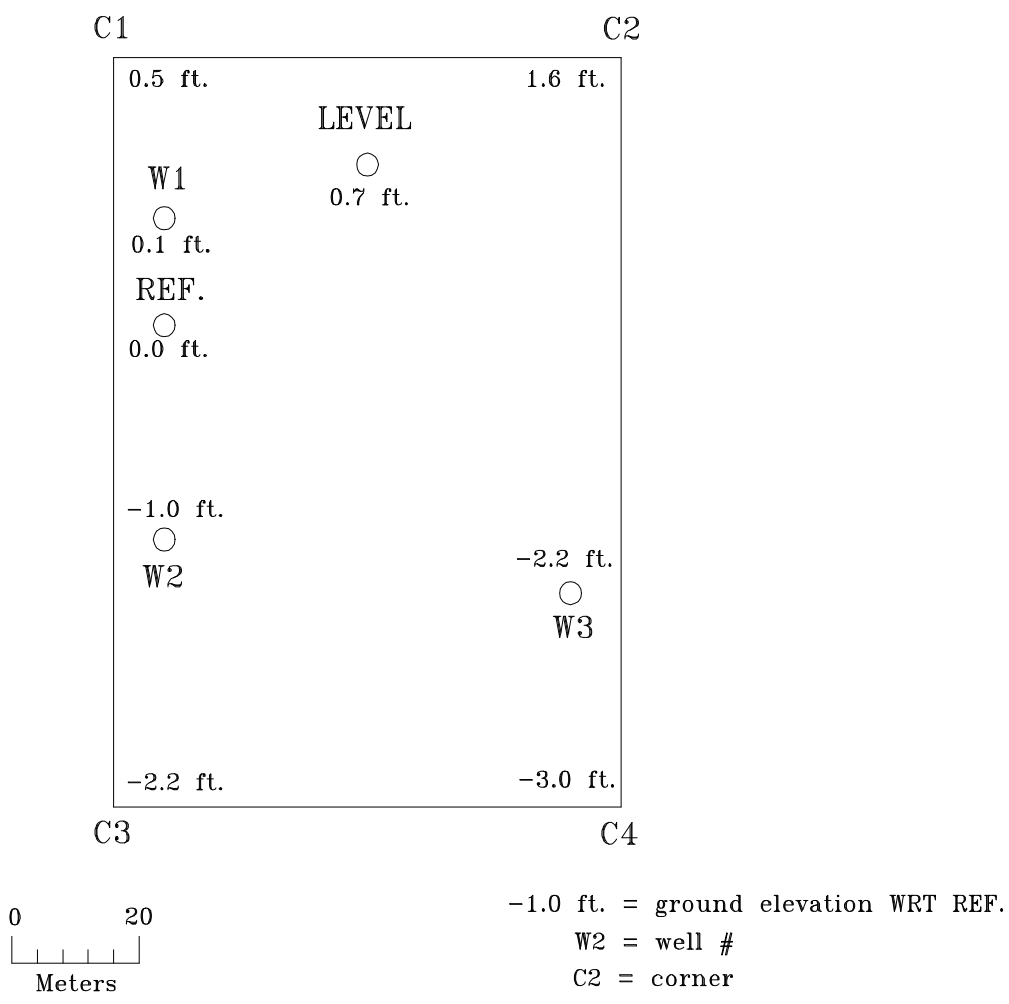


Figure 2.
Mercer Soccer Field With Ground Elevations

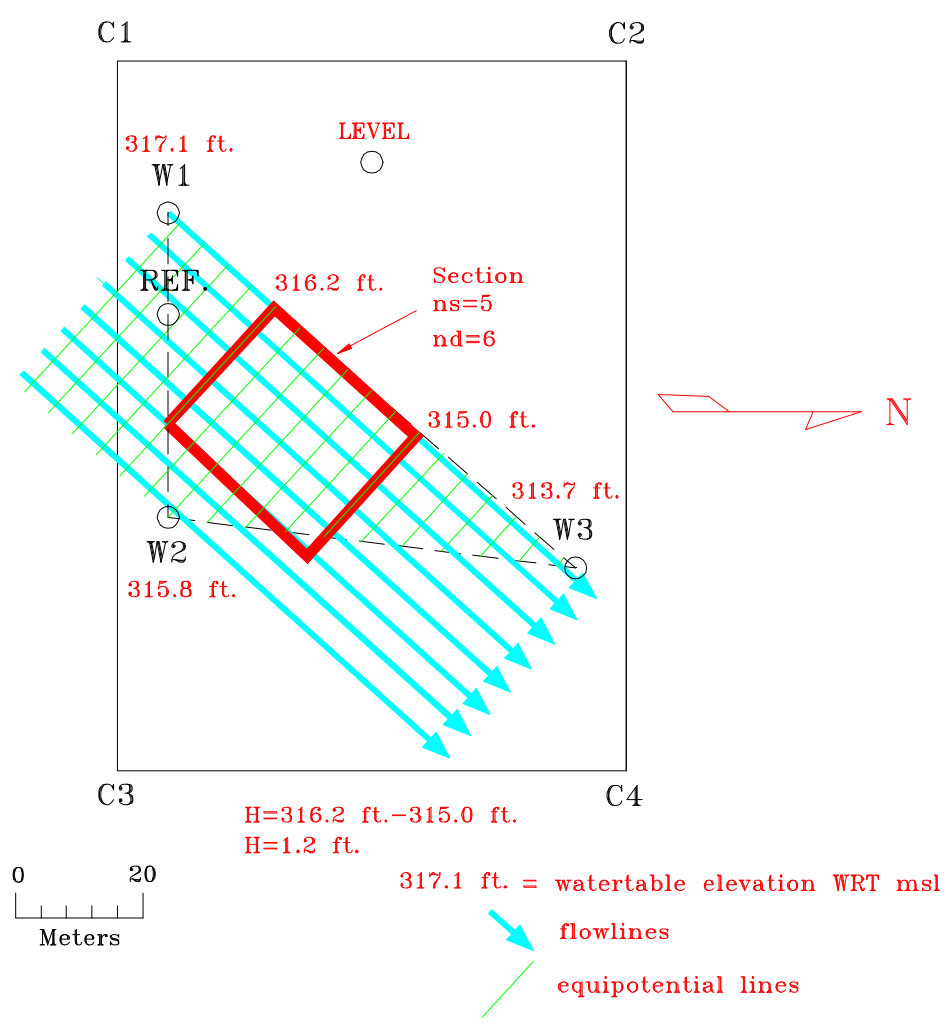


Figure 3.
Mercer Soccer Field With Flowlines and Equipotential Lines