Groundwater Hydrology: Using Manual Water-Lifting Devices in Groundwater Pumping Labs

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Abstract

Mercer University's Groundwater Hydrology course has been incorporating low-cost field testing and exploration methods for the past several years, including manual drilling techniques, inexpensive geophysical testing techniques, and manual pumping. This paper focuses on the use of manual water-lifting devices (bailers and pumps) that can be effectively used to test hydraulic conductivity, well drawdown, and well recovery.

Pumping tests are conducted using two methods. An established 'bailer test' is carried out using bailers that can either be purchased on-line or built in a university setting using affordable materials available at local hardware stores. Pumping tests are also carried out using an EMAS Pump, a low-cost direct-lift pump that can be fabricated using basic tools with materials commonly found in local hardware stores.

Potential benefits to students of incorporating the fabrication and use of these two manual devices for groundwater hydraulic testing relate to active learning methods and understanding of fundamental engineering theory/knowledge. Students carrying out these hands-on groundwater hydraulics tests using manual devices may be more likely to remember the procedures of the test, compared to using electric or fuel-powered water-lifting devices which can distance students from fundamental mechanical aspects of the pumping/water-lifting process. In turn, students may be more likely to retain over time the principles of groundwater flow. Student learning of pumping theory/processes is another benefit.

The use of low-cost manual water-lifting devices can be combined effectively with other appropriate technologies, such as manual drilling techniques to install wells, and low-cost geophysical instruments (e.g. resistivity meters and seismophones) to detect soil types and depth-to-water. These affordable groundwater education technologies are very appropriate to teaching in university field labs due to the affordability of the instruments as well as their suitability to teaching fundamental engineering theory and applications.

Keywords

hydrogeology, water resources, wells, bailer, handpump

Introduction

Mercer University's Environmental Engineering and Engineering for Development (E4D) programs have been incorporating low-cost field testing and exploration methods for the past several years, including manual drilling techniques,[1] and inexpensive geophysical testing techniques. Other in-class groundwater-related activities have also included a focus on hands-on learning.[2] Many of the techniques and technologies used are inspired by common applications in developing communities, and are used in Mercer's E4D program.[3] The activity presented herein extends these initiatives to incorporate hands-on, field lab experiences to teach engineering students about well drawdown and well recovery, with field tests being carried out using manual water lifting devices (bailers and an EMAS Pump). With the intent of creating an active learning class atmosphere, these activities are designed to maximize student engagement with the corresponding material components, fabrication, and testing procedures for each of the two devices.

Background

Mercer University's Groundwater Hydrology course presents students with fundamental theories and properties of porous media, groundwater movement, and geological factors. The course emphasizes development of fundamental governing equations and the determination of aquifer formation constants. The design of production and monitoring wells and the development of aquifer testing plans are introduced.

In Mercer University's Groundwater Hydrology course, students actively participate in lab activities that employ low-cost, appropriate technologies related to groundwater development and study of the subsurface: manual drilling techniques, and low-cost geophysical instruments. Some of these devices and instruments allow for simple demonstration of mechanical and theoretical principles of engineering design. For example, demonstration of manual drilling techniques introduces students to the four basic techniques of drilling (augering, percussion, jetting, and sludging). Fundamental understanding of these technologies can help students not only retain the theory and principles, but also prepare them for careers where they use related instruments and devices.

The groundwater pumping field lab activity part of this curriculum involves students using (and in some cases constructing/assembling) bailers and EMAS Pumps. These two devices are manual water lifting devices that can be employed to conduct aquifer tests in water wells and boreholes. Their construction involves basic tools and relatively low-cost materials that can be found at local hardware stores. The fabrication and use for testing by students, as taught during the course, is a hands-on and active learning process by which the students piece the materials together strategically, with guidance from the instructor.

The purpose of the manual 'bailer test' and pump test is to determine whether a borehole is successful and able to sustain pumping from a manual pump. The theory behind the test is the same as that used in pumping tests designed to assess boreholes for higher quantities of water use that employ electric or fuel-powered pumps. For this pump test, recovery of the water level is determined by measuring the maximum drawdown and the 50% and 75% recovery times. The maximum drawdown is measured after pumping for a set amount of time or a set volume of water. The 50% and 75% recovery times are the times it takes for the well water level to rise up ½-way and ¾-way from its maximum drawdown to its initial (static) water level, respectively.

A bailer can be thought of as an adapted bucket – a pipe with a one-way valve at its lower end (Figure 1a) which opens when the bailer (attached to a rope) is dropped into the water well/borehole. As the bailer sinks below the water surface, the pipe fills with water. Once the bailer has filled with water, the device is then lifted out of the well/borehole; this action induces the weight of the water to close the one-way valve. The bailer used for this class activity consists of a 75-mm diameter PVC pipe (secured at the top end with a rope) which has a ball valve at the lower end. In addition to being used for pump testing, water sampling, and well development, bailers (sometimes referred to as 'bucket pumps'[4]) are also used in some developing community settings to collect drinking or irrigation water from boreholes (Figure 1b, 1c).

Figure 1 (a) an engineered diagram of a bailer, with a one-way valve at bottom,[5] *(b) a bailer being lowered into a borehole in northern KwaZulu-Natal, South Africa,*[6] *and (c) water from a bailer being emptied into a jerrycan*[6]

An EMAS Pump is a direct-lift pump commonly used at the household level in many communities in South America (particularly in Bolivia) and elsewhere in the developing world.[7,8] It essentially functions as a bailer within a bailer. Figure *1* (a) shows an EMAS Pump in use for a pumping test. The EMAS Pump consists of an inner PVC pipe, with a one-way valve ('piston valve') at its lower end. The top end of the inner pipe is attached to a galvanized iron pipe which functions as a pump handle and a spout. This inner pipe is inserted into a slightly larger diameter PVC pipe ('outer pipe'), which also has a one-way valve ('foot valve') at its lower end (Figure 2(b)). These two pipes, which make up the EMAS Pump, are then installed into a well/borehole, to a considerable depth below the static water table (i.e., to a depth greater than the expected water level at maximum drawdown during pumping tests). The EMAS Pump functions by alternately lifting and dropping the handle, and thus the inner pipe. On the pump up-stroke, the foot valve (of the outer pipe) opens while the piston valve (of the inside/inner pipe) remains closed, allowing well water to enter the pump's outer pipe (Figure 2 (c)). On the pump down-stroke, the foot valve closes and compression of the water causes the piston valve to open, forcing water to rise up the inside/inner pipe. Continuing these motions causes water to flow up the inside/inner pipe and out the spout.

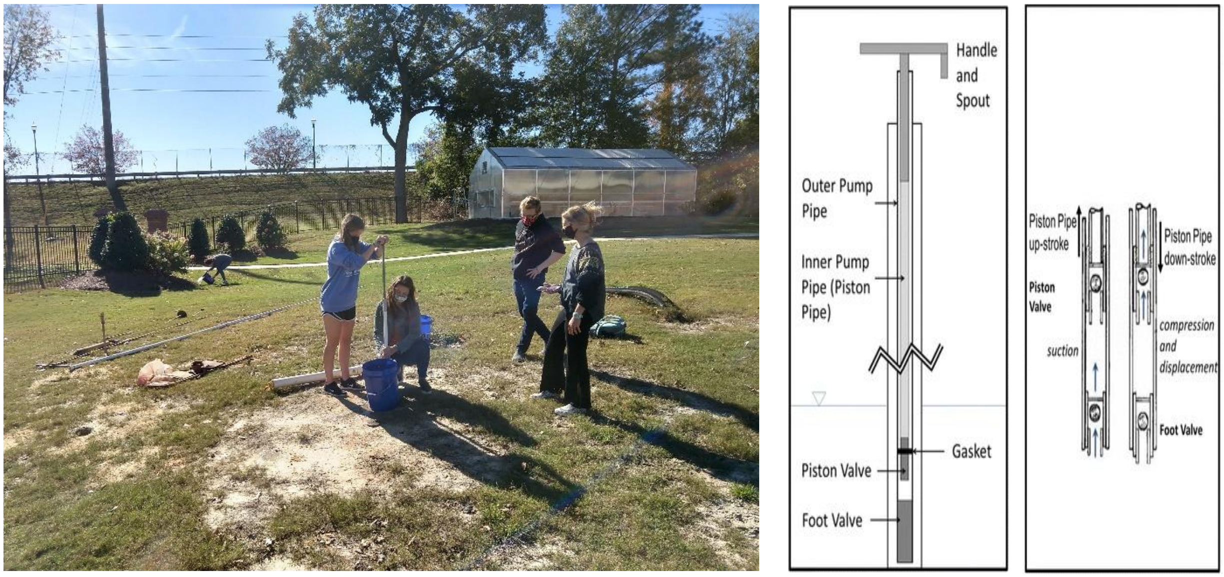

Figure 1. (a) Pump test being carried out by students at the Mercer University Groundwater Teaching & Research site, using an EMAS Pump [left]; (b) Diagram of EMAS Pump, installed on a drilled well [middle][8]; (c) details of functioning of EMAS Pump valves [right][9]

Methods

The EMAS pump was constructed primarily by students from the class in an open-air outdoor laboratory space using materials purchased at a local hardware store (Table 1). First, the full length of the pump was determined, considering previously collected well drawdown data. The offset of the two pipe lengths allowed for the top PVC joint of the inner pipe to move freely within the last joint-free segment of outer pipe and prevented the inner pipe from damaging the foot valve on the down-stroke. Next, the inner piston pipe was assembled by joining the piston valve with several lengths of ½”-diameter PVC pipe via bell/socket and spigot joints, and PVC pipe primer and glue. The ½“ galvanized steel handle, which was threaded, was screwed onto the top-most inner PVC pipe. Complete video instructions, including for construction of the valves, are provided on-line by EMAS. [10] The outer pipe component was assembled using the same methods as for the inner pipe, by joining the foot valve and several lengths of PVC pipe. The EMAS pump was completed by guiding the inner assembly into the outer assembly. The unit is placed into the well and secured at ground surface, to prevent it from falling into a well that is deeper than the EMAS pump length.

Table 1. Materials required to EMAS pump and bailer testing.

size	item	use
EMAS pump		
1/2"	galvanized iron handle	pump handle and spout
1"	PVC pipe	(outer) cylinder pipe
1/2"	PVC pipe	(inner) outlet pipe & valves
3/4"	PVC pipe	valves
	marbles	ball valves
bailer		
77 mm diameter x 1 m length	PVC pipe	"adapted bucket"
-	rubber ball	ball valve
-	rope	securing & leash
testing		
-	string and steel nut	water level recorder
-	stopwatch	time-keeping

The bailer was constructed by students in a prior year, using 77-mm diameter PVC pipe cut into 1-meter length. A ball valve was attached to the bottom. The bailer is secured with rope, tied into holes drilled at the top of the pipe. Diagrams for constructing a bailer can be found on-line.[5] Alternatively, bailers can be purchased on-line.

Time

A. 1.5-2 hours per lab section (i.e., to carry out 2 pumping tests – one with bailers, and one with an EMAS Pump).
B. Bailer test is conducted in 10 minutes, there may be more than 1 bailer test conducted per group.
C. After the bailer test is conducted, an additional 30 minutes is required for measurement of water table levels.

Procedure

A. Measure the initial (i.e., undisturbed) water table level.
B. Lift water from the well, alternating bailers so that one is being emptied while the other is being used to lift water from the well. Continue bailing for 10 minutes. Be sure to count the number of bails used in order to estimate pumping rate.
C. For the next 30 minutes, measure the water level every couple of minutes seconds. *Note*: the standard bailer test calls for measuring the water level up to every 30 seconds, with an

electric water-level measuring device. As in our laboratory we were simply measuring the water level with a steel nut attached to a string (listening for the sound when the steel nut hits the water, which can take several seconds), we chose to measure the water level every two minutes.

D. Determine whether the borehole is successful using Table 1, from *The Bailer Test: A Simple Effective Pumping Test for Assessing Borehole* Success.[11] A successful borehole is indicated by a maximum drawdown and 50% and 75% recovery time less than the values shown in the table for the corresponding borehole diameter and pumping rate.

Table 2. Drawdown and Recovery Times for Borehole 'bailer test' / pump test[11]

Guidelines for success of rural water-supply boreholes using the 10-min bailer test. If the maximum drawdown and time for 50 and 75% recovery are less than that quoted here, then the borehole is likely to be successful

Borehole diameter	Pumping rate → (Number of standard bails)[a]	$10\ m^3\ d^{-1}$ (16)	$15\ m^3\ d^{-1}$ (24)	$20\ m^3\ d^{-1}$ (32)	$25\ m^3\ d^{-1}$ (40)	$30\ m^3\ d^{-1}$ (48)
100 mm	Max drawdown (m)	3.5	5.3	7.1	8.8	10.6
	Time for 50% recovery (mins)	6	6	6	6	6
	Time for 75% recovery (mins)	14	14	14	14	14
125 mm	Max drawdown (m)	2.9	4.3	5.7	7.1	8.5
	Time for 50% recovery (mins)	9	9	9	9	9
	Time for 75% recovery (mins)	21	21	21	21	21
150 mm	Max drawdown (m)	2.3	3.4	4.6	5.7	6.9
	Time for 50% recovery (mins)	12	12	12	12	12
	Time for 75% recovery (mins)	28	28	28	28	28
200 mm	Max drawdown (m)	1.5	2.3	3.1	3.8	4.6
	Time for 50% recovery (mins)	19	19	19	19	19
	Time for 75% recovery (mins)	46	47	47	47	47

[a] Standard bailer is 4.4 L (1-m long 75-mm pipe)

E. Repeat the previous steps with the EMAS Pump.

Benefits

Students carrying out these hands-on groundwater tests using manual devices may be likely to understand and retain the principles of groundwater flow (flow to the well, well drawdown, transmissivity, etc.). They may also be likely to remember the procedures of the test, compared to if the tests were carried out using electric or fuel-powered water-lifting devices. Another benefit is student learning of pumping theory/processes.

The use of low-cost manual water-lifting devices combined with the use of manual drilling techniques to install wells and low-cost geophysical instruments (e.g. resistivity meters and seismophones, to detect soil types and depth to water) form a suite of affordable groundwater education technologies. These technologies are very appropriate to teaching in university field labs, due to the affordability of the instruments as well as their suitability to teaching fundamental engineering theory and applications.

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