Low-Cost Groundwater Development: Manual Drilling in Academic Research and Training

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Abstract
Manual drilling techniques can be of value in academic research and training environments, and are increasingly being promoted as a cost-effective way of providing water for drinking and irrigation purposes in developing communities throughout the world. The relatively low cost of manually drilled wells, compared to machine-drilled or hand-dug wells, as well as the relative portability of their equipment, make them an attractive water supply option when hydrogeological conditions are favorable. Those same qualities also make manually drilled wells useful in many academic research and training situations. The research consists of an assessment of percussion-jetting-rotation manual drilling, a low-cost hybrid method developed in Bolivia. The equipment set-up is assessed for relevance in academic field research, where collection of hydrogeological data is often limited by the expense of conventional machine drilling. The study also considers how manual drilling can be used to teach essential aspects of drilling concepts and groundwater science from a field perspective. Nine monitoring wells were installed at the University of South Florida Geological Park (USF GeoPark) using the manual percussion-jetting-rotation drilling method, up to a maximum depth of nine meters, through sands, clays, and thin layers of limestone. Drilling, well installation, and well development experiences were recorded. Geology was observed and logged during drilling. For training purposes, groundwater flow was determined between three wells. Hydraulic head was measured in each well, and hydraulic conductivity was measured in one well.

Keywords
EMAS, well, water supply, appropriate technology

I. Introduction
The presented work is part of research conducted by the low-cost groundwater development applied research group at the University of South Florida and Mercer University. This project includes properly developing nine wells drilled in the USF Geological Park (USF GeoPark), an open area on the University of South Florida campus in Tampa, Florida, from 2013-2015. Additionally, installed wells were monitored bimonthly to establish groundwater flow data. A goal for this project was to determine if the drilling fluid could be adequately removed during the well development process so as to not interfere with the monitoring of the wells. Following this work, a second phase of the project will be implemented (in 2017) where a low-cost multi-level monitoring system will be installed in a manually drilled well at the USF GeoPark.

EMAS Manual Well Drilling Method
The EMAS (Escuela Movil Aguas y Saneamiento Basico) manual well drilling method was developed by Wolfgang Buchner, with an aim of helping to provide potable water at affordable costs for families in developing countries[1]. This method incorporates percussion, jetting, and rotation techniques. The materials required for installing wells using EMAS drilling are low-cost

and generally widely available in developing countries. This is advantageous because it allows for the cost per meter of installed well to be sufficiently affordable to sustain a family's, or several families', water needs. This drilling method could be used in varied locales and soil strata, depending on the type of drill bit used during drilling[2]. 'EMAS standard', as it is called, is capable of drilling up to 100-meter deep wells[3]. The limiting factor to the depth of drilling is often human power; the deeper the borehole gets, the more pipe is needed, and the heavier the drilling assembly becomes. Presence of consolidated bedrock may also cease drilling.

Figure 1 shows the details of the EMAS standard drilling method, which consists of three techniques. The percussion technique is performed by raising and dropping the drilling assembly (comprised of the drill pipes, couplings, and drill bit) using a rope and pulley system. Rotation refers to turning the drilling assembly via the drill handle a quarter to half turn in each direction, upon drill bit impact at the bottom of the hole. Jetting makes use of a trench-pit system, mud pump, mud hose, and the drilling assembly. Drilling fluid (composed of water and bentonite mixed in the mud pit) is pumped via the mud pump, through the hose, and down the drill pipes. The drilling fluid exits through open spaces in the drill bit and scours the soil. As pumping continues, the drilling fluid carries drilled cuttings out of the borehole and into the settling pit. There the cuttings settle out, and the drilling fluid enters the mud pit to be recirculated.

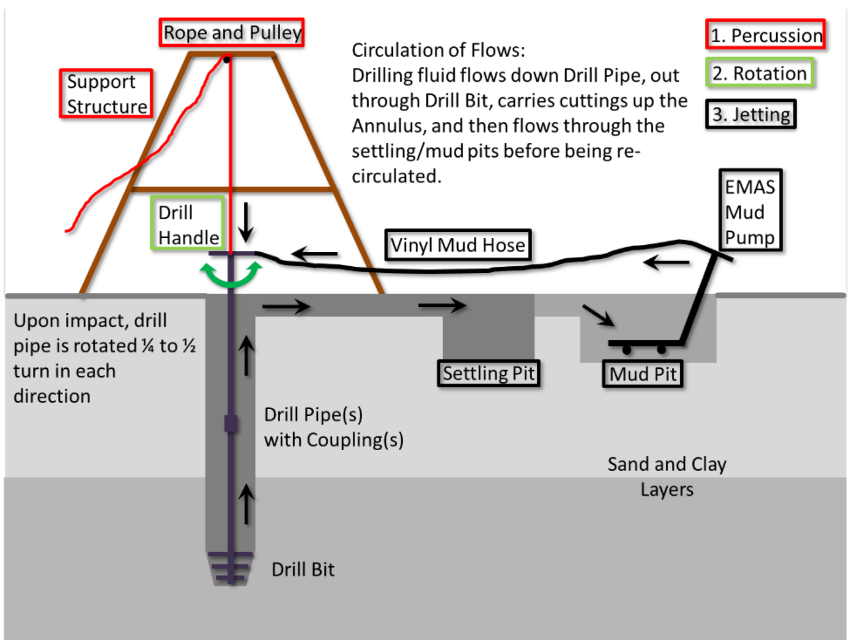

Figure 1. Diagram of the EMAS standard drilling method[1].

Manual Drilling and Well Installation

During the summer of 2013, five wells were installed at the USF GeoPark, by a team of undergraduate students, during the Research Experience for Undergraduates Tampa Interdisciplinary Environmental Research (REU-TIER) program. The purpose of the research conducted during the REU-TIER program was to introduce EMAS standard drilling and to assess its academic applicability. Achievements during this ten-week program included:

- Learning about and understanding the EMAS standard drilling method
- Adapting the drilling techniques to better suit them for research applications
- Repairing and improving EMAS standard drilling equipment (previously built by USF graduate students and engineering technicians)
- Learning proper site assessment for deciding well locations

These wells were installed as cluster wells. This practice is helpful when the goal is to monitor various soil layers for groundwater flow or contaminant concentrations. This is achieved by installing a main well in the deepest possible groundwater unit, and then installing satellite wells in water saturated lithological layers shallower than the main well[4].

An installed well is comprised of the well pipe (usually PVC) with a well screen at the end. This screen is either manufactured to a certain size, or can be cut manually with a hand saw, and allows for the flow of water into the well. In monitoring wells, carefully choosing the well screen length allows for isolation of one soil layer for study purposes. The well screen is usually covered by a gravel pack, comprised of sand and poured into the borehole. This keeps fine sediment out of the well water, which may impact water quality testing results and impair water for consumption.

Four additional wells were installed during the year following the Summer 2013 REU-TIER.

Well Development & Well Monitoring

Well development is the removal of the drilling fluid, which can clog the gravel pack and well screen, in order to make the well as productive as possible and not interfere with the groundwater flow. Ineffective removal of the bentonite-containing fluid can decrease the productivity of the well and cloud the collected water. It can also interrupt the groundwater flow and make well monitoring difficult. This investigation involved determining if the bentonite could be sufficiently removed from the well screen and gravel pack.

The second goal for this research was to monitor all of the installed wells. The purpose of this component was to successfully carry out well monitoring techniques, gather data regarding the productivity of the aquifer at each well, and determine the general groundwater flow direction at the USF GeoPark. This component was important and demonstrated that these specific well-monitoring tests could be done on EMAS standard drilled wells. The monitoring program also supported the summer REU-TIER conclusion that an EMAS drilled well can assist academic researchers to conduct their research without major financial investment (e.g. in buying or renting costly drilling rigs).

II. Background

Well Development

Well development is thought as most important in regions where groundwater is scarce because it significantly improves well productivity by guaranteeing that the flow into the well is unobstructed by sand and drilling fluid, thereby maximizing well capacity.

Methods for developing wells can vary and are dependent on in-situ lithological conditions. These methods are utilized to achieve several objectives. One objective of well development is to repair the damage to the aquifer and soil surfaces within the borehole due to the drilling process. Drilling fluid damages soil surfaces by leaving ‘mud cake’ on the walls of the borehole and bedrock which must be dislodged and flushed out. The obstruction caused by these foreign particles causes the groundwater flowing toward the well to become crowded. Well development also improves flow through and stability of the adjacent aquifer[5]. This is especially necessary for production wells, where well capacity must be maximized, and important for monitoring wells. Wells become more productive when sediment is removed because there is more porous space for water to flow through. Additionally, flushing out fines from the area adjacent to the pipe will prevent future contamination of the well water.

Bentonite drilling fluid is problematic because it is pervasive and forms a thick “mud cake” on the borehole wall. Alternatively, one may opt for a polymer-based drilling fluid. These can degrade over time and also create a much thinner “mud cake”.

Well development requires planning and consideration of available equipment, time constraints, and financial resources. Development methods and drilling fluid options may differ with respect to well purpose, desired well capacity, aquifer characteristics, and installed well screen.

Well development methods include:
• Chemical: involves gently or violently acting solvents that dissolve clogging material and open up pore spaces for water to pass more efficiently. These could pose human health hazard, so it is imperative to assure that they are safe to use and approved by the local governing authority.

• Washing and Backwashing: washing (overpumping) involves removing water from the well which causes sediment to flow from the well and leave the soil adjacent to the well sediment-free. This method is not effective on its own because the water is only flowing in the direction of the removal. The backwashing technique involves injection of water into the well. This method must also be used in combination with others because it is not very effective if used alone.

• Mechanical Surging: involves using a plunger tool to repeatedly and quickly suck and push the water through the well screen to dislodge particles and open porous space. This method could potentially damage the aquifer. It is best to utilize a plunger with a one way valve to remove the sediment rich water from the well.

Slug Tests and Hydraulic Conductivity
The most reliable test for determining hydraulic conductivity is the aquifer test. This test cannot be performed accurately for aquifers where “sustained flow rates” cannot be maintained, and cannot be performed at all for pumping out groundwater that is possibly contaminated[6]. The flow-meter and tracer tests are used to compare the results from other hydraulic conductivity tests and can determine the velocity and flow path of groundwater in a site. These tests are unfortunately both time consuming and expensive.

Slug tests involve measuring the rise or fall of the water level when water is instantaneously removed or introduced, respectively. A disadvantage is that this test cannot be conducted for aquifers characterized by a transmissivity greater than 7000 cubic feet per day or for slow aquifers. Wells drilled and installed in a clay-rich condition can have low permeability and the slug test would not be able to test these conditions. A well must be developed properly before using slug tests to estimate hydraulic conductivity.

III. Results and Discussion

A review of literature on the study area gave an understanding of the different geological profiles present at the USF GeoPark. In order to test the capabilities of the drilling method, five sites with expected different strata were chosen (Figure 2).

Figure 2. Shows the extent of the study area and locations of each site.

Three wells were drilled at each of three sites (Site #1, Site #2, and Site #4). At each of these sites, the main well was drilled and installed at maximum depth and data were gathered on the soil profile for the site. Utilizing that soil profile, the other two wells were installed at different, shallower geological layers below the water table.

Three drill bits were tested and are shown in Figure 3. The universal drill bit performed best in the overburden at the GeoPark. It did not get clogged through clay, unlike the sand bit, and was tough through unconsolidated limestone. Utilizing the universal drill bit minimized interruptions to the drilling process.

Figure 3. Drill bits utilized in this research (from top to bottom): Christmas tree, sand, and universal.

Short-circuiting of the drilling fluid containing cuttings through the trench-pit system (shown in Figure 4) was observed. To prevent this, two modifications were made to the system. First, the trench entering the settling pit (labeled ‘A’) and the trench leaving the settling pit were dug perpendicular to each other. Secondly, the entrance mouth to the settling pit was dug deeper than the exiting mouth. This allowed for the drilled cuttings to be more effectively settled out, and the drilling fluid to be skimmed off the top of the settling pit before passing into the trench to the mud pit (at ‘B’).

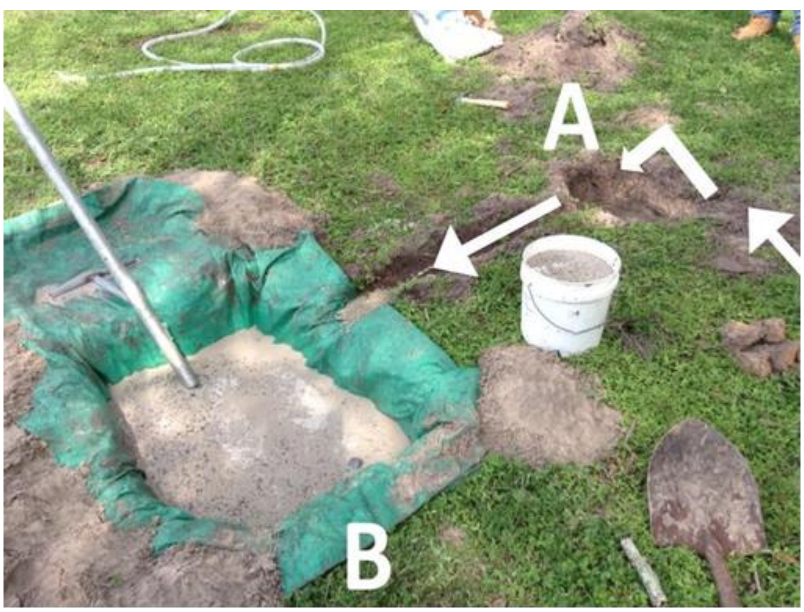

Figure 4. Trench pit system, consisting of (A) the settling pit, (B) the mud pit, and connecting trenches dug perpendicular to each other.

Asynchronous pumping of the mud pump and lifting of the drill assembly was causing pressure to build up within the drill assembly and mud hose (due to the drill bit being submerged in sediment) and forcing the hose off of the drilling handle. To prevent this, synchronicity was established between the jetting and percussion techniques: the drilling fluid was pumped during the upstroke of the drilling assembly**.**

Data gathered from this research included soil removed at each site, observed from the drilled cuttings exiting the annulus and from the 'feel' of the drilling. This data was compiled to create a soil profile at each site, and was crucial in determining the depth of the installed satellite wells. Figure 5 shows the soil profile for each well at Site #2.

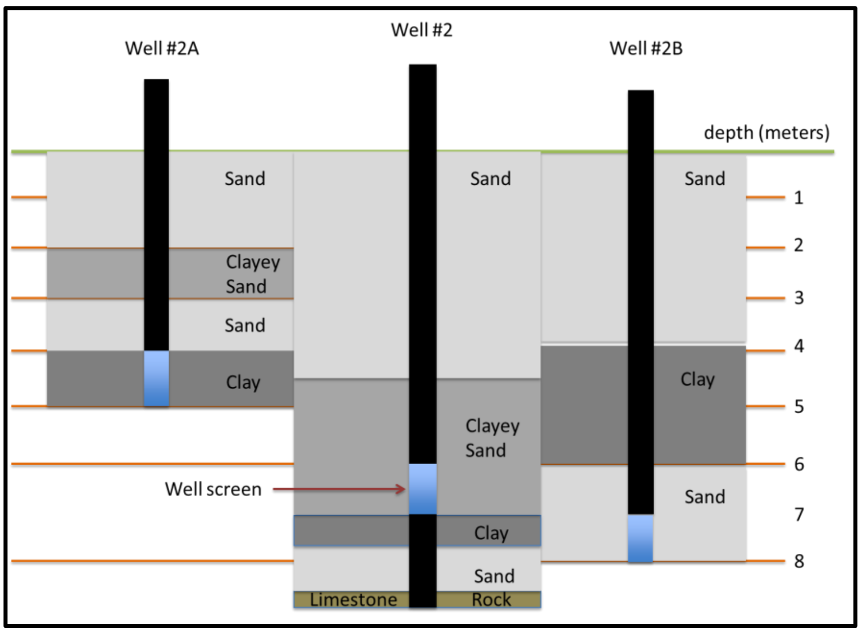

Figure 5. The soil profile for the three wells at Site #2.

Conducting this research with minimal interruptions required more than three persons. A minimum of three people are required during drilling: at least one person lifting the drilling ensemble, one person rotating the handle (drill bit), and one person pumping the drilling fluid. An additional person is advantageous for managing the viscosity of the drilling fluid, unclogging the mud pump intake, and assisting with adding sections to the drilling assembly.

Preliminary trials for developing the wells to sufficiently remove the bentonite drilling fluid have proven minimally successful. The time lapse between well installation and development (1.5 years) was not ideal. The chosen well development method (washing and backwashing) appeared to clear the wells of sediment temporarily, but the water would again become murky after a period of time. Well development also shed light on interactions between wells, evident by the fact that continuously pumping one well would significantly decrease the hydraulic head within an adjacent well. For development of future wells, it is planned to combine manual washing and backwashing with manual surging.

To demonstrate the possibility of using such monitoring wells for testing, slug tests were conducted on one well. EPA Standard Operating Procedure #2046 was utilized and values for hydraulic conductivity were calculated (for three trials). The values shown in Table 1 correlate well with values given by Freeze and Cherry[7] for silty and clean sand.

Table 1. Hydraulic conductivity (K) values calculated from three rising head tests on well #1.a.

Well #1a: K value (meter/day)
4.63
5.10
4.58

In analyzing the REU-TIER program achievements and costs, it was concluded that university researchers can gain valuable experience in learning the process of well installation using the EMAS standard method. During drilling, students can gain experience in soil classification to understand the soil profile and lithology of the study site. These drilled wells can become monitoring wells to test for groundwater flow and hydraulic conductivity, groundwater contaminants, and water quality. The EMAS standard method was deemed successful in providing a low-cost way of drilling cluster wells for monitoring. This method can be used in university teaching labs to give student researchers valuable hands-on experience that can be applied in engineering design, construction, and monitoring work in domestic and international settings.

IV. Next Steps

Well monitoring techniques have improved greatly in the past three decades; it is no longer necessary to install well clusters to monitor groundwater. Multilevel monitoring systems have been designed to monitor different layers of groundwater flow through different ports in the same well. This is an advantage since well material is only needed for one well installation, and this method can be advantageous in areas with limited space. In 2017, a low-cost multi-level monitoring system will be installed on a new manually drilled well at the USF GeoPark. A cost analysis for this method of well monitoring will be performed, and compared to the well cluster approach to establish which is better suited for academic research.

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