PROTOTYPING A WELL-DRIVER PUP (PURDUE UTILITY PROJECT) TO INSTALL LOW-COST DRIVEN WATER WELLS

by

Zackariah Horn

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THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Dr. Robert Stwalley III, Chair

Department of Agricultural & Biological Engineering

Dr. John Lumkes

Department of Agricultural & Biological Engineering

Dr. Vincent Bralts

Department of Agricultural & Biological Engineering

Approved by:

Dr. Nathan Mosier

Head of the Graduate Program

Dedicated to my family and friends

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Dr. Bernard Engel

Dr. Jane Frankenburger

Dr. John Lumkes

Dr. Robert Stwalley III

Dr. Vincent Bralts

Mr. David Horn

Mr. Eric Kong

Mr. Robert Stwalley Jr.

Mr. Scott Brand

Mr. Stephen Kines

Mrs. Barbara Davies

Mrs. Kimberlee Horn

Mrs. Pam Hancock

Mrs. Rebecca Peer

Ms. Ana Yates, designer, IUPUI Herron School of Art and Design

Ms. Grace Baldwin

Purdue Plumbing Shop Employees and Facility

Water Filters of America Customer Service

Waterra Sales and Customer Service

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ABSTRACT

Author: Horn, Zackariah, J. MSABE
Institution: Purdue University
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Title: Prototyping a Well-Driver PUP (Purdue Utility Project) to Install Low-Cost Driven Water Wells
Committee Chair: Dr. Robert M. Stwalley III

People living in developing countries or undeveloped regions often do not have proper access to quantities of safe, clean water to fulfill their daily needs. Certain members of the families, often women and children, walk miles every day to collect surface waters that are frequently contaminated. To improve water availability and quality, a sustainable mechanical solution to more safely access groundwater has been developed.

A well-driving attachment for a PUP (Purdue Utility Project) vehicle provides a low-cost means for installing driven type wells in areas of high to medium water table heights. PUP vehicles have a niche in developing countries, as they offer impressive value and utility in comparison to other powered machines. The vehicles are built and sourced using locally available materials with basic tooling. A hydraulic post driver has been attached to the rear of a PUP frame to serve as an impact mechanism, driving a well point and a series of inter-connecting pipes to serve as a permanent casing for the well.

Water wells were tested at four different test sites around central Indiana, with the deepest well reaching 23 feet. This suggests that the Well-Driver PUP can install driven water wells in areas of medium to high water tables and may be suitable for a development setting. Water wells can be installed on a communal basis, thus providing an increased level of hygiene and standards of living. Low-cost driven water wells will provide a drinking water supply that is better protected than a hand-dug well and will reduce the likelihood of disease caused by waterborne pathogens. Development of the Well-Driver PUP prototype and its applications will be discussed.

1. INTRODUCTION

1.1 Introduction

Water is a basic necessity to life. It is often said that man can live without food for weeks, but just a few days without water will surely be his demise. It may be hard to understand the true value of water until it is a scarcity. On the July 28th, 2010, the United Nations stated in A/RES/64/292, "[The General Assembly] *Acknowledging* the importance of equitable access to safe and clean drinking water and sanitation as an integral component of the realization of human rights" (United, 2010). Clean, safe water is no longer being treated as a luxury and expendable resource, yet one that all people should have a right to. Developing or under-developed countries often encounter the problem of depending on water access to come from government intervention or donor agencies (Babalola, Ajisegiri, Adisa, Kuye, and Dairo, 2016). Lacking government infrastructure has led many individuals and communities to fend for themselves as they struggle to contend with inadequate water resources.

1.2 Water Quantity & Access Limitations

Access to water in developing or under-developed countries is often limited to the Earth's natural occurring surface waters or hand-dug water wells. Both surface water and well water must be transported, most of the time by women or children. Water is commonly carried atop their head, and they often travel for many miles daily to fetch water for their family's basic needs. The World Health Organization (WHO) stated, "If it takes more than 30 minutes to collect water, the amount they will collect will reduce" (WHO, 2016). Water consumption and return trip travel time are related shown in Figure 1. This may suggest that many families (especially the ones furthest from a water source) will collect only enough water to survive and do basic hygienic tasks as necessary.

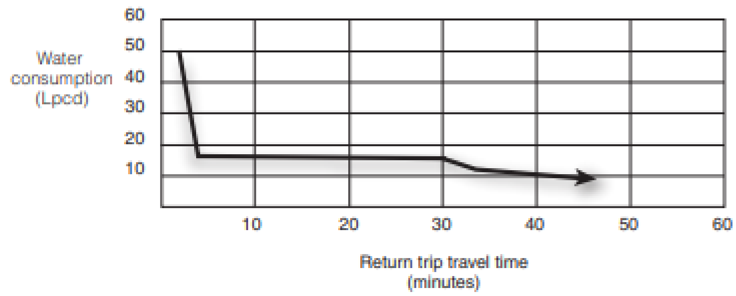


Figure 1 Relationship between Water Collection Journey Time and Domestic Consumption (WHO, 2016)

WHO developed a Hierarchy of Water Requirements pyramid which is shown in Figure 2. It was based off of Maslow's hierarchy of needs: self-actualization, esteem, social, safety, and physiological. Essentially, various quantities of water used per capita per day could be used to estimate the welfare of a person.

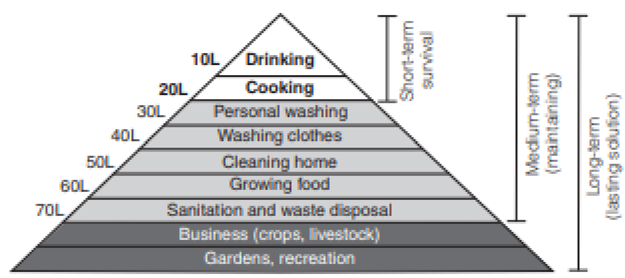


Figure 2 Hierarchy of Water Requirements (WHO, 2016)

1.3 Water Quality

Developing and under-developed countries water supplies are often extremely susceptible to contamination with waterborne pathogens. Contaminants may enter water suppliers in any number of ways, such as leaching through the soil or direct contamination into a well or a surface water source. Pollution may be from chemicals, agricultural chemicals, point sources, and non-point sources can render groundwater unfit for use (Encyclopedia, 2019). Various contaminants could enter a water system, but the most common serious contaminant in developing or underdeveloped countries is human waste. Waste Disposal in Developing Countries and Emergency Situations The Case of Saharawi Refugee Camps stated, "Open uncontrolled dumping is still the most common method of solid waste disposal in Developing Countries and emergency conditions" (Garfi & Allesandra, n.d.). It went on to say, "Degrading waste in such dumps emits greenhouse gases, like methane, toxic leachates pollute subsurface and surface waters and enhance the risk of disease transmission to nearby residents" (Garfi & Allesandra, n.d.).

1.4 Current Methods

Three main types of water wells are in use in areas of development: hand-dug wells, driven wells, and commercially drilled wells. Hand-dug wells are constructed by a laborer or laborers digging by hand below the water table. This type of well can be seen in Figure 3. Often these wells are dug during the dry season (generally lowest water table) as to guarantee water year-round from the well. Hand-dug wells are the lowest costing option for water access (assuming a typically low cost of labor) but are also the riskiest method of accessing water. Risks to laborer while digging a well include wall collapse and reduced air quality to excavators. Naturally, the deeper a well is dug, the higher the risk. Risks are also taken in consumption of water from a hand-dug well. Typically, these wells are at the highest risk for contamination. Contaminants can enter a well either from leaching through the dry laid stone sides of the well or even from the top of the well. Often well openings are uncovered, leaving the well susceptible to direct contaminants such as surface runoff or small animals falling in the well. Hand-dug wells can be advantageous from the variety of pumps which can be used. It can be as simple as a lowered bucket on a pulley or as complex as a submersible pump. The larger diameter of a hand-dug well will allow almost any design of pump.

Figure 3 Hand-dug Water Well (Water, 2018)

Driven water wells are a low to medium cost water access option, with many improvements over a hand-dug well. The wells are constructed with a well point connected to galvanized steel pipe which serves as a well casing. The well point is a sharpened point which is designed to be driven in the soil, accessing groundwater through a fine mesh or perforations on its circumference. Driven wells are typically manually driven into the ground, either by hand with a large weighted tube or through a tripod system in which a weight is dropped onto the assembly (see Figure 4). Manual methods of driving these wells are extremely physically intensive, with laborers repeatedly lifting or pulling heavy loads. This well installation method requires less time than a hand-dug well and can be driven in any season. By design, driven wells are more protected from contaminants than hand-dug wells. The solid well casing is impervious to shallow contaminant leaching and it extends to a height above a floodplain, protecting it from direct contaminants from falling in as well. Although many parts of the driven well are impervious to contaminants, the well may still produce contaminated water. Due to the shallow to moderate depth of water access, the well screen may pull from a groundwater height which has been naturally filtered less than a deep well. Therefore, these types of wells they must be installed in an area devoid of direct surface contamination. Furthermore, due to space constraints of the casing diameter (typically 4" or less inside diameter), only a few types of water pumps may be used. Lever type pumps are the most common, followed by jet pumps and narrow submersible pumps.

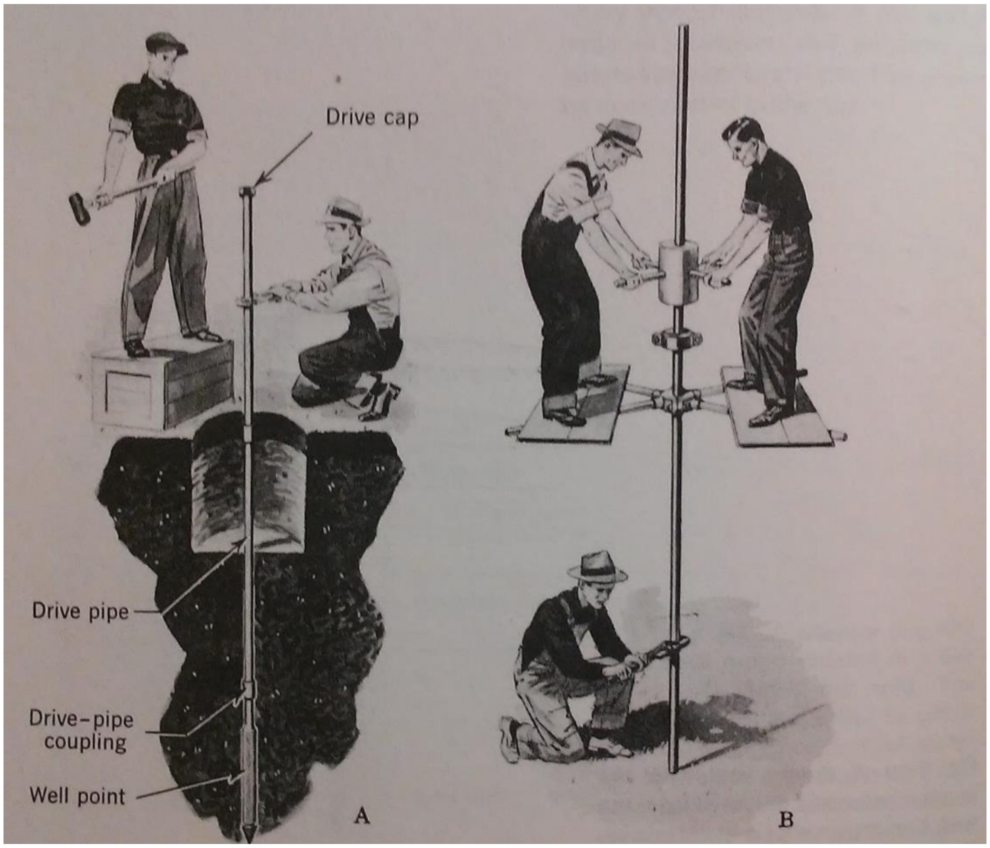


Figure 4 Methods of Installing Driven Water Wells (Wright, 1977)

Commercially drilled wells are by far the highest cost of commonly installed water wells in a development setting. They are drilled using a special well drilling rig, often mounted to a large commercial-sized truck and controlled by an experienced well drilling crew as shown in Figure 5. Due to the size and center of gravity of a commercial drilling rig, it must be on a semi-flat, level surface while still being accessible by a large truck. An earth drilling bit is spun in the ground, while sediments are flushed out, and a well casing is installed. Groundwater is accessed deep underground with minimal risk of water contamination, but at a cost many, even at a community level, may not be able to afford. The high cost associated with drilling a well makes this water access technique only viable for more populated areas, who can communally afford to use a well-driller's services and specialized equipment. Drilled wells are often only pumped by a submersible pump, due to the extensive depth which the aquifer is commonly accessed.

Figure 5 Typical Equipment for a Drilled Water Well (Utopia, n.d.)

1.5 Goals & Research Question

Potential was seen to utilize a mechanized form of driven well installation. The following goals were set for the effort:

- Provide a powered way to install driven water wells
- Provide sustainable impact
- Require minimal training
- Remain low cost

Research Question: *Can a well-driver attachment for a PUP (Purdue Utility Project) provide water at sufficient quantity and quality for communal use in a development setting?*

A hydraulic post driver mated to a PUP is proposed to mechanize the process of installing driven water wells, i.e. the “Well Driver PUP”. PUPs are a three-wheeled utility vehicle developed for developing countries. They are built using commonly available materials and minimal tooling.

PUP's can be seen in Figure 6. PUPs branch into multiple markets, and may serve utility purposes as a truck, taxi, or tractor. Tillage implements, seeders, water pumps, generators, threshers, and corn grinders have all been successfully designed and tested to be powered by a PUP. The Well-Driver PUP would reduce the dependence on manual labor for driven well installations in developing or under-developed countries, while keeping laborers more safe. Furthermore, it would provide a low-cost, sustainable water source for years to come. The Office of the High Commissioner for Human Rights advocates that availability, quality, physical accessibility, economic accessibility, and non-discrimination accessibility are all factors of the freedom and entitlement to water (Office, 2003). Installing low-cost driven wells means to improve the availability, quality, and accessibilities of water sources in regions with inadequate water supplies. In order to be successful, the Well-Driver PUP operation and its components need to remain low-cost and be easy to operate. No formal education in well drilling/ driving or geology should be required to use the equipment in practice.

Figure 6 PUP Vehicles (Purdue, 2019)

2. BACKGROUND AND LITERATURE REVIEW

2.1 Introduction to Groundwater

Forrest B.Wright stated in *Rural Water Supply and Sanitation* groundwater is, "That portion of the total precipitation which soaks into the earth's crust (approximately one-third) percolates downward into the porous spaces in the soil and rock where it remains, or from which it finds its way out to the surface in some way". Groundwater may often be found where surface waters are not. Groundwater supplies are not seriously affected by short droughts and mostly free of pathogenic organisms (Encyclopedia, 2019). Groundwater is an important source of water globally, especially for those in rural areas. It is estimated that 30 percent of Earth's entire freshwater resources are in the ground, while 68 percent is locked up in ice and glaciers (USGS, 2016). Groundwater use varies by country, with the United States supplying 51% of its total population by it. In other countries, the resource remains untapped (Groundwater, n.d.). In West Africa as a whole, "The [groundwater] potential remains almost untapped; only 0.2 percent of recoverable safe yield and 0.02 percent of the groundwater held in reserve is presently used. Main reasons that militate against groundwater exploitation for agricultural production are the [high] cost of drilling wells and lifting water onto the land" (Sonou, 1994).

2.2 Driven Wells & Terminology

Driven water wells are comprised of four main components: a well point, well point couplings, lengths of galvanized steel pipe, and a well point drive cap. The well point is the most critical component of a driven water well. The well point is constructed of a cast steel point, followed by a perforated/meshed section of steel pipe (see Figure 7). The point encourages a plumb drive, while the perforated section allows the flow of groundwater through it. Various mesh and slot sizes exist to best suit the needs of a soil type. Mesh sizes range from 40, 50, 60, 70, or 80 mesh, corresponding to the number of openings per linear inch. Slot sizes range from 18, 12, 10, 8, or 7 slot, which corresponds to the width of a slot opening in thousandths of an inch (Machmeier, n.d.). For example, an eighteen slot well point would have a series of 0.018" inch width slits, and an eighty mesh well point would have eighty openings per linear inch.

Figure 7 Well Point (Personal photograph, 2018)

Well-point drive couplings, as shown in Figure 8, are a specialty pipe connection, differing from standard pipe couplings. Well-point couplings are specifically designed for pipes to butt end to end, ensuring that pipe threading carries minimal load during a vertical impact. In contrast, standard pipe couplings have empty space between the pipe ends. Standard couplings are not designed to have axial impact loading, and they would likely catastrophically fail if used for a driven well. Well-point couplings are a higher grade steel than standard pipe fittings, due to the high impact forces subjected on them.

Figure 8 Well Point Drive Coupling (Home Depot, 2018)

Galvanized steel pipe serves as a casing for the well and forms an impermeable barrier from leaching contaminants. A galvanized, or zinc coated, steel pipe is shown in Figure 9. Lengths of pipe are connected end to end to reach the necessary well depth. Typical pipe sizes are 1-1/4”, 2”, and 4” for a driven well. This suggests that an installed well would be subject to the availability of pipe size and the quantity of water demanded. Availability is likely more limited, if threading equipment for the larger pipe sizes is required. The most common sized pipes in the U.S. for driven wells are 1-1/4” and 2”, as driven well components were numerous in these sizes. Driven well components in the 4” size were not found, but finding access to a pipe threader with 4” pipe capabilities would also be challenging.

Figure 9 Galvanized Steel Pipe (Home Depot, 2019)

Well-point drive caps are another specialty component used in the well-driving process. Drive caps screw onto the top of the driven section, protecting the thread of the driven section and are specifically designed to withstand the repeated impacts required to drive a well. The caps are much thicker and have a larger diameter than standard pipe caps, a testament to their durability. Most drive caps are outfitted with a small hole to reduce the buildup of internal hydraulic pressure during a well drive. A well point drive cap is shown in Figure 10.

Figure 10 Well Point Drive Cap (Home Depot, 2013)

2.3 Water Pumping Options

Water well pumps are often categorized by pump depth as *shallow wells* or as *deep wells*. Shallow wells are approximately 25 feet or less in depth, while deep wells are at any depth greater than that. They are more accurately labeled by whether a pump is able to "suck" standing water from a well or if it has to push it from depth. The maximum distance (typically ~25 feet) in which water may be sucked depends on the effective suction of the water pump and the atmospheric pressure, which is affected by height above sea level. "For any type of pump, the sucking distance decreases about 1 foot for every 1000 feet (305m) of elevation above sea level" (Wright, 1977).

For shallow wells, pumping options include centrifugal pumps, submersible pumps, jet pumps, and hand lever pumps. Centrifugal pumps impart a velocity to the liquid by an impeller, converting this to a head (Hansen, n.d.). Similarly, submersible pumps make a pressure conversion by means of an impeller, but they sit submerged underneath the static water level in a well. Jet pumps use an impeller paired with orifices and Venturi tubes to increase pressure of the liquid to be discharged. Hand pumps operate by suction and are an excellent value for resource-poor regions. Pump choice for shallow wells may be limited by the maximum internal diameter of the well casing, as well as auxiliary power options.

Deep wells require the use of submersible pumps, or special setups, such as a double-drop jet-pump system. Submersible pumps are built to pump water at any depth below the water surface, while a double-drop jet pump reaches maximum depth at around 100-110 feet. A double-drop jet pump is essentially two jet pumps rigged to run in series, one pump's outlet feeds the inlet of the second jet pump. The correct deep well pump will be determined by depth of water withdrawal and financial resources of the well owner(s).

2.4 Driven Well Installation Overview

To install a driven type well, it first must be driven into the ground. Driven wells are typically installed with a sledgehammer or weighted drive tube, but they can be driven by post drivers, jackhammers, and various creative methods to generate repeated vertical impacts to the well casing. The well should be plumb and extend several feet below the start of the water table for a sustainable water supply.

After the well is driven to the desired depth, it should be properly developed by surging, disinfecting, and testing the well. Surging a driven well is necessary to remove fine sands, silts, and clay from the bottom of a water well. Waterra, a groundwater monitoring equipment and supplies dealer, states, "Surging is the process of creating a larger than usual flow through a screened interval usually with the goal of cleaning out smaller particulate matter or biological matter from the filter pack and/or adjacent formation" (Waterra, 2018-a). Well surging allows for the pump to dispense water with fewer particulates, therefore decreasing its turbidity.

Well disinfection is required to kill any bacteria that could cause human harm in a drinking water source, and testing is necessary to confirm the presence of absence of these bacteria. Chlorination is one of the most effective and surefire ways to eradicate bacteria colonies. A Scientific American article states, "Chlorine and chlorine-based compounds are the only disinfectants that can efficiently kill microorganisms during water treatment, and maintain the quality of the water as it flows from the treatment plant to the consumer's tap" (Calomiris, n.d.). Repeated disinfection procedures may be necessary until the water tests absent for bacteria. It may take multiple "shock chlorination" attempts to remove long-established bacteria colonies (American, 2012).

2.5 Well-Driver Attachment (PUP)

A Well-Driver attachment had been previously attached to a PUP to install driven type wells. In the past, two senior capstone teams began working on the Well-Driver PUP vehicle. The first senior Capstone team mounted the post driver to the PUP frame by the three-point hitch. It was designed to pivot at the bottom two link arms and to be raised/ lowered by a hydraulic cylinder on the uppermost point of contact. This allowed the post-driver to have a transport and operation position, improving the vehicle's weight bias during travel for increased safety and practicality. The team recognized the intense striking force of the driver and the need to stabilize the vehicle. Suggestions included adding weights to the rear of the vehicle or to anchor the vehicle to the ground during operation (Zeller & Vaughn, n.d.).

The second senior Capstone team refined the Well-Driver PUP with increased safety features and general operation. The team added a safety shield around the hydraulic pump, fixed hydraulic leaks, and made various vehicle improvements. A support cradle for the post driver was added to stabilize it in the transport position, necessary to eliminate the driver from bouncing around while traveling. A transmission lock-out was added to keep the PUP in neutral while using the driver. This prevented the vehicle from being bumped into gear, while the engine is held at high idle. A SMV (Slow Moving Vehicle) triangle was also rigged to the rear of the driver (Chen, Jarufe, & Yun, 2016). Capstone team II recognized the safety hazards of the Well-Driver PUP, and the addition of various safety components emphasized it. However, supplementary safety features were required, before the vehicle became fully operational. The second capstone team's high standards on safety were upheld as vehicle functionality increased.

3. MATERIALS AND METHODS

3.1 Prototype as Received

The Well-Driver PUP was non-functional as received. The unit's power source, a L100V6 Yanmar diesel engine, spurted fuel from the head gasket onto the muffler, posing a safety hazard. The valves ticked throughout normal operation. The hydraulic system could only build approximately 400 psi, not enough to check the operation or functionality of all hydraulic components. Upon closer inspection, some hydraulic components were not rated for the demanded system pressure, the largest safety concern. Furthermore, the hydraulic system could not be engaged during operation without opening the shield of a belt and hydraulic pump. The rear half of the Well-Driver PUP is seen in Figure 11 with included basic nomenclature of components.

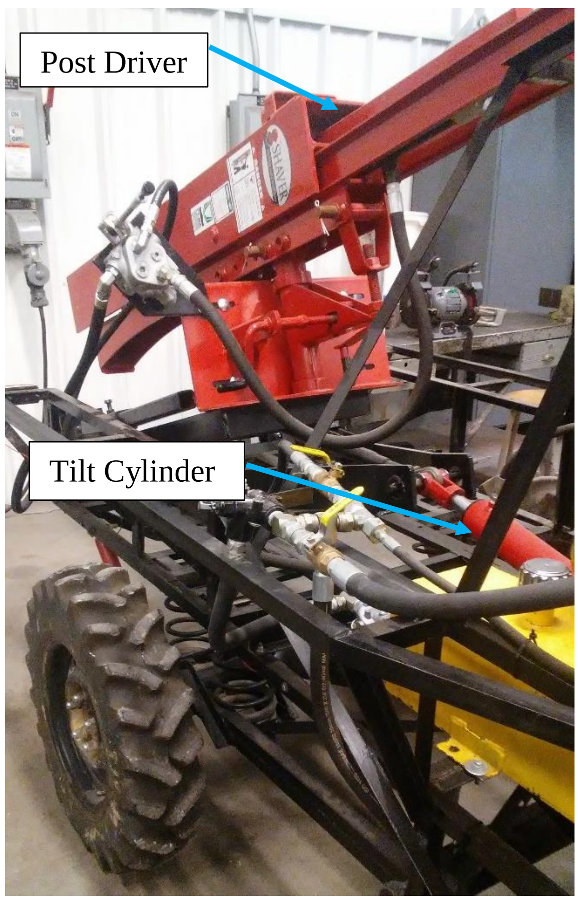


Figure 11 Basic Nomenclature of Well-Driver PUP (Personal photograph, 2018)

3.2 Prototype Repair and Modifications

Prototype repair was essential as the first major step of the project. A list was made of prototype repairs, beginning with the engine, then with the hydraulic system, and finishing with well-driving modifications. The project budget was aimed to spend the least amount on prototype repair and save a greater amount for vehicle modifications or consumable parts.

3.2.1 Engine Health

The power source of the entire vehicle was examined first. A brief external overview revealed a completely disintegrated outer foam air filter. Speculation from the crumbled filter and ticking valves suggested that there may be minor gas blowback between the end of the exhaust and the start of the intake strokes. Past engine overheating was a possibility.

The air filter was replaced to finish the external engine repair. A new OEM head gasket was ordered to fix the leak in the combustion chamber. Upon separating the engine head from the block, the mating face of the block was first checked for flatness to be within tolerance specification of the Yanmar service manual. Due to the possibility of a previous engine overheat, this was necessary to ensure a proper mating surface between the engine block and head. Within tolerance, the head was joined back with the block, and the new gasket in place. Intake and exhaust valve clearances were re-tuned with a feeler gauge set, also as per the Yanmar service manual specifications of 0.006 ± 0.002 in. Valve springs were also checked for integrity, while the engine head was accessible, confirming this was not a factor in any valve problems. The re-assembly of the engine yielded an easy to start, strong running platform to supply the demands of all vehicle functions.

3.2.2 Full Machine Functionality

Gaining full machine functionality was critical for the project. The next step was to build adequate hydraulic pressure. A hydraulic diagram was sketched as a guide to understanding the system operation and fluid flow. The hydraulic diagram can be seen in Figure 12. The hydraulic diagram was modeled using Amesim to show an easy to follow circuit. It should be noted that all solenoid operated valves shown in the diagram are in rather manually operated valves and what is shown in the diagram as a motor is a diesel engine.

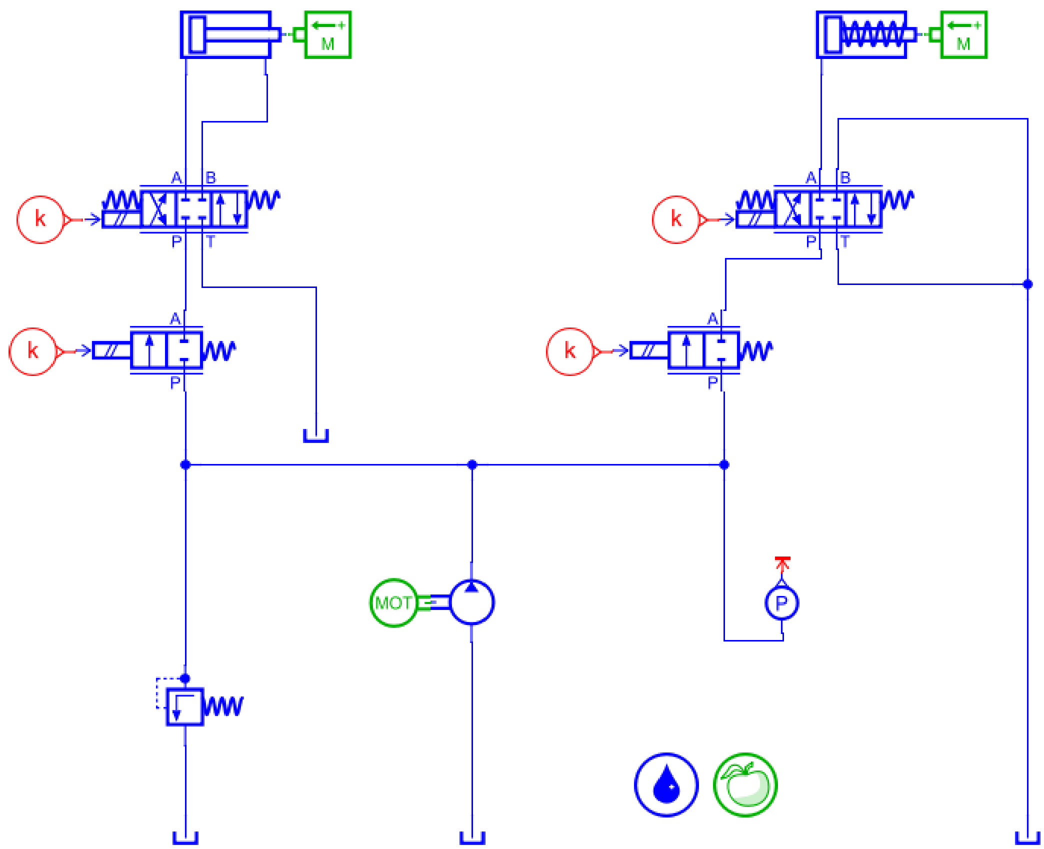


Figure 12 Hydraulic Circuit as Received

Before troubleshooting the setup, hydraulic components that were rated below the maximum system pressure of 2500 psi were first removed and appropriately replaced. The hydraulic pump of the Well-Driver PUP was powered from a sheave on the jackshaft, which ran adjacent to the engine. Upon increasing the operating pressure from the adjustable relief valve, it was evident that the belt or sheaves could not support the demanded torque of the system. Variations of sheave diameters were swapped and tested. Once replaced, a realization developed that the correct ratio could not be obtained while still providing adequate belt tension and sheave wrap angle. The belt was found to be slipping in every configuration: either on the centrifugal clutch, a jackshaft sheave, or the hydraulic pump sheave. To fix this problem, the belt and sheave system was rebuilt in a precision roller chain and sprocket configuration with a larger speed reduction. A 40-pitch chain and sprocket configuration was used to provide a 6:1 speed reduction to the hydraulic motor, increasing the available torque to a functional amount.

The chain and sprocket drive provided more than 2000 psi from the hydraulic pump, surpassing the 1500 psi minimum pressure threshold to power the Shaver post driver. Unlike a belt and sheave arrangement, which has the ability to be disengaged with belt slack, the positive drive chain runs the hydraulic pump at all engine speeds above 1800 rpm (the engagement speed of the centrifugal clutch that spins the jackshaft). This was determined to be acceptable to prove functionality of the Well-Driver PUP attachment.

A few minor adjustments in the plumbing needed to be made for full functionality of all hydraulic components. It was determined that the Shaver Post Driver control valve had been improperly connected. The hydraulic control valve for the Shaver HD-8 was updated several years ago, therefore proper plumbing information was not found in the Operator's Manual. The valve schematic, pressure ports, and tank ports were identified in a pdf of a Salami valves catalog. Corrections to the plumbing of the valve yielded in appropriate movements to the post driver.

A need to remove the vehicle suspension travel while the post driver was in the operational position was recognized. This would allow better energy transfer from the post driver to the driven artifact. This was also suggested by the second senior capstone team. Hydraulic outriggers were fabricated to elevate the vehicle platform, removing any energy dampening from the suspension. Four outriggers were permanently welded to the vehicle chassis, one on each corner of the frame. Outrigger design was based on pre-existing designs for skid-steers, as shown in Figure 13 below. The telescoping-type outrigger was chosen over the arm-type for ease of build and smooth implementation with the vehicle frame. The outriggers were fabricated using 2-1/2" x 0.238" wall square telescopic tubing, 2" x 1/4 " wall square tubing, 4" x 3/8" steel bar stock, and 2" bore x 16" stroke hydraulic cylinders. They are shown in Figure 14. The wet weight of the vehicle (with well-driver attachments) tipped the scales to 2406 lbs. and required a maximum system pressure of 271 psi to raise the PUP to full working height.

Figure 13 Skid Steer Outrigger Design (Everything, 2019)

Figure 14 Fabricated Outriggers (Personal photograph, 2018)

The cylinder with the heaviest loading determined the maximum pressure required to lift the vehicle. This was based on the relationship between area of the cylinder and exerted force as seen in Equation 1.

$$P = \frac{F}{A_{cylinder}} \tag{1}$$

Large steel feet were used on each outrigger to better distribute ground pressure and retain confidence in vehicle stability. The 4” x 8” steel foot pads yielded an average ground pressure of about 19 psi, slightly more than an average 6 foot tall human foot of 16 psi (Terramac, 2013). If extremely soft ground conditions were observed, wide blocks could be placed under the outrigger feet to further reduce contact pressure. Figure 15 shows a spatial arrangement of the outrigger feet to the PUP frame, as well as the loadings and ground pressures under each foot.

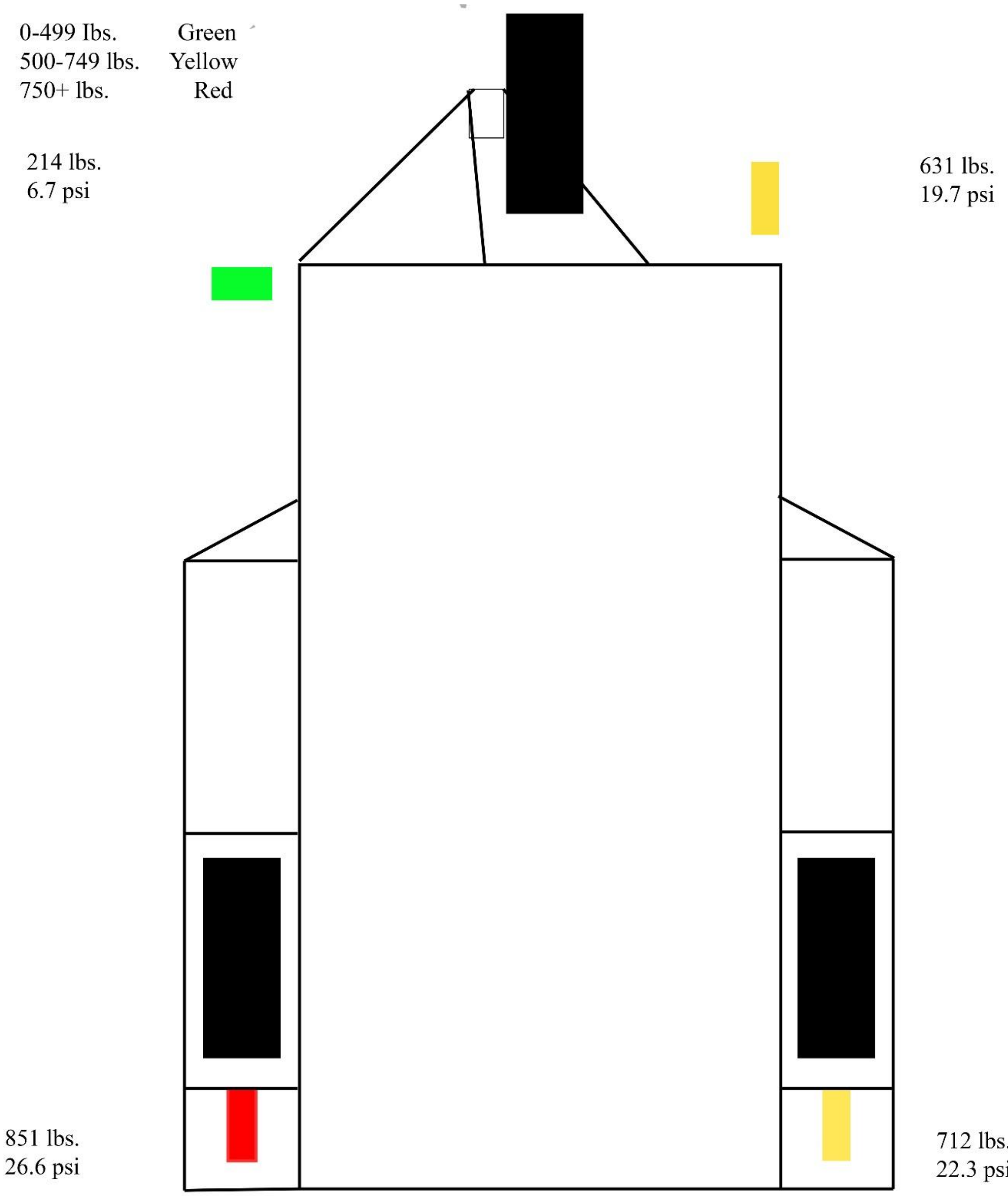


Figure 15 Outrigger Loading and Ground Pressures
(Schematic by Ana Yates)

The assembled and mounted outriggers successfully lifted the PUP completely off the ground and perfectly isolated the frame from the suspension as seen in Figure 16. While lifted, the front tire ground clearance was approximately three to four inches, and the rear tires cleared the ground approximately an inch. The vehicle lift process was smooth, with no noticeable deflections in the frame or the outriggers. A thick layer of grease on the inner telescopic tubes brought the outriggers closer to a uniform lift velocity.

Figure 16 Front/Rear Outriggers Mounted (Personal photograph, 2018)

Outriggers imparted minimal off-road functionality loss to the vehicle. It retained its full ten inches of ground clearance when fully retracted. The outriggers only mildly affected driving performance. The front driver-side outrigger limited the steering pivot by approximately three degrees to the left, forcing a hard-steering stop. The steering stop is shown in Figure 17. The location of the passenger side front outrigger could be a safety concern for extra passengers. Therefore, it would be strongly advised not to carry passengers, that outriggers be fully retracted during travel, and that travel speeds are severely limited on rough terrain. The break-over angle and approach angle of the overall vehicle were unaffected, but departure angle was slightly reduced from 29 degrees to 25 degrees. Relevant off-road vehicle angles can be seen in Figure 18. Figure 19 depicts the slight reduction in departure angle of the Well-Driver PUP. Off-road functionality was also reduced slightly with the added weight of new vehicle components in the form of reduced acceleration and hill climb angle.

Figure 17 Steering Hard Left Stop on PUP (Personal photograph, 2018)

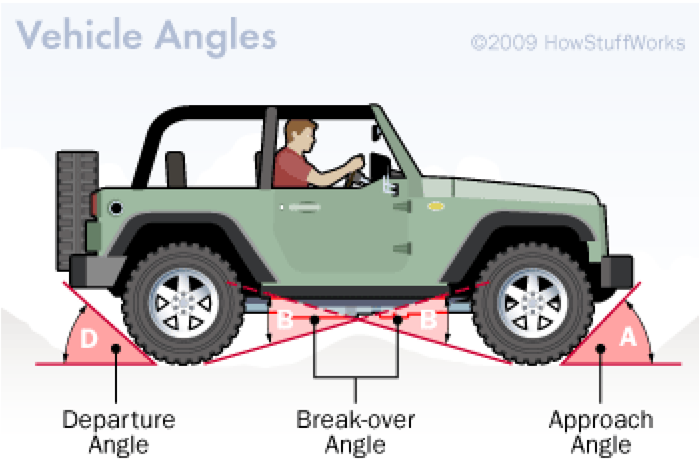


Figure 18 Off-road Vehicle Angles (Uttley, 2009)

Figure 19 Reduction in Departure Angle Shown on PUP (Personal photograph, 2019)

Individual wheel weights are shown in Figure 20 (pre-outrigger) and Figure 21 (post-outrigger) to represent changes in total vehicle weight and the weight distribution. The addition of outriggers and associated components added approximately 411 lbs. to the vehicle. Pre-outrigger wheel weights were obtained by a previous balance study of the Well-Driver PUP (Zhao, 2016). The outriggers had very little effect on the weight distribution of the vehicle. A 19/81 front to rear weight distribution was seen prior to outriggers, and a 20/80 distribution was seen after the addition of outriggers. The addition of the outriggers modified the hydraulic system to have a new circuit. The final hydraulic schematic for the Well-Driver PUP is shown in Figure 22 (it should be noted that any solenoid control valves depicted are actually manual valves and the motor shown is actually a diesel engine).

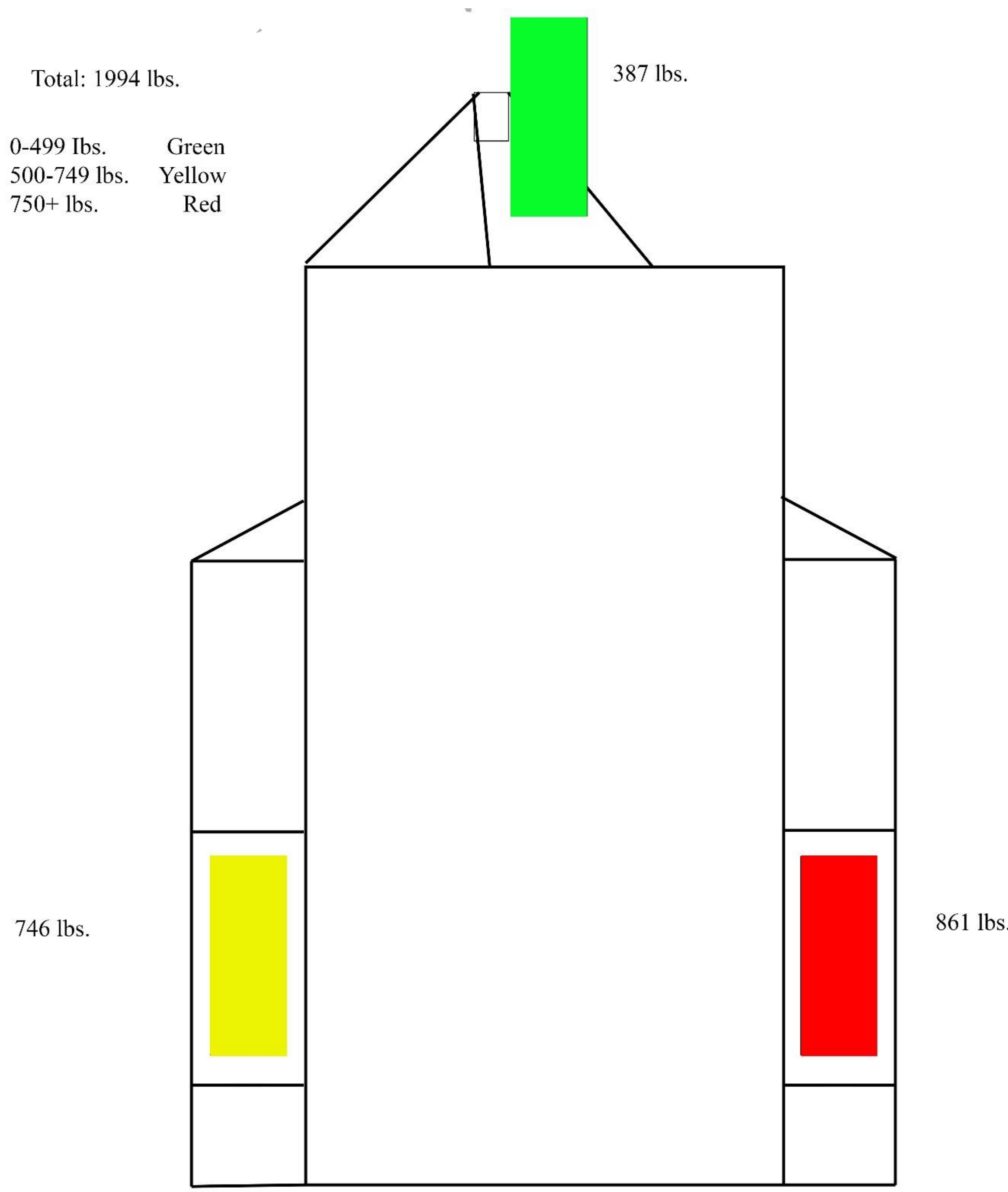


Figure 20 Wheel Weight Distribution Pre-outrigger

(Schematic by Ana Yates)

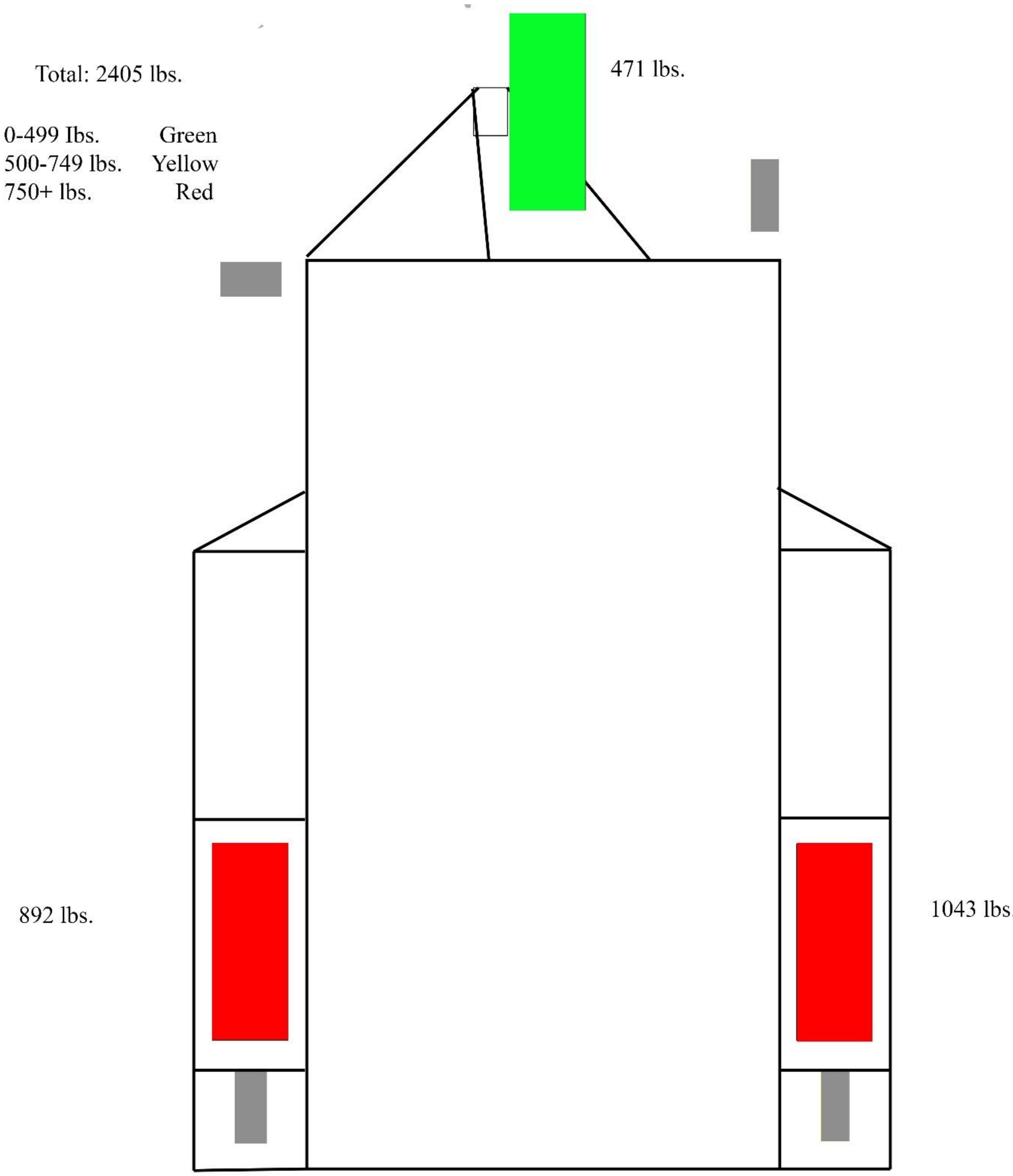


Figure 21 Wheel Weight Distribution Post-outrigger
(Schematic by Ana Yates)

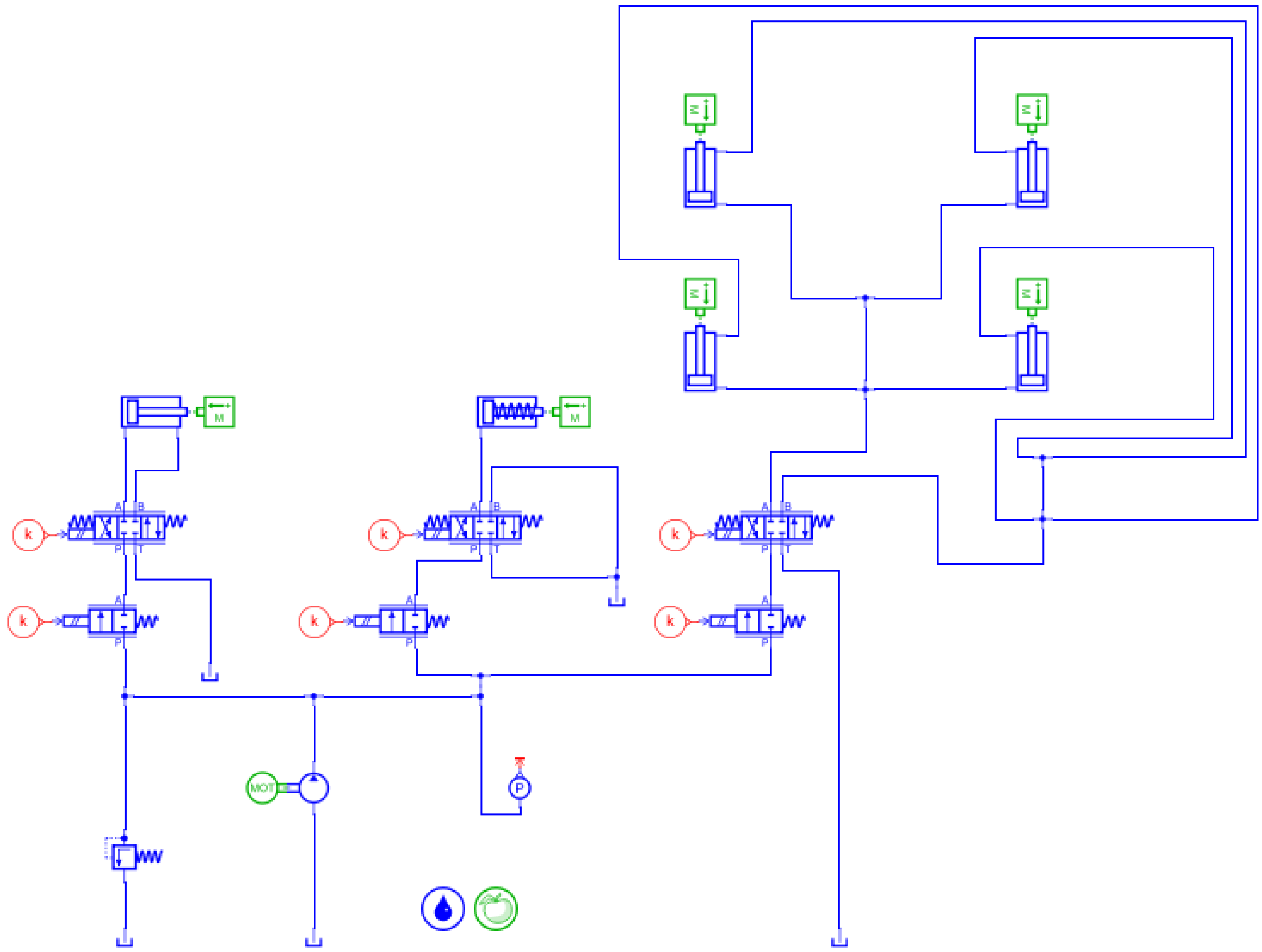


Figure 22 Modified Hydraulic Circuit

To keep the well point and casing in alignment during a drive, a drive sleeve was required. The well point drive sleeve was like one produced by Shaver Manufacturing for driving steel fence posts but was larger in size and material thickness. A comparison of the Shaver HD-8 steel post drive sleeve to the well point drive sleeve is shown in Figure 23. The well point drive sleeve was constructed of 4-1/2” x 3/16” wall drawn over mandrel (DOM) steel tube, ½” steel rod, and ½” A36 steel plate. DOM tubing was specifically chosen as the internal weld bead is ground flush; a raised weld bead would have posed alignment problems and unnecessary damage to a well point drive cap. The fabricated drive sleeve cleared with an approximate ¼” gap around the diameter of a well point drive cap for 2” pipe. The ½” steel rods acted as rub rails for the inner steel channel and spaced the center of the steel tube sleeve in line with the center of the driver strike plate. A ½” steel plate was used to “cap” the top of the drive sleeve, serving as a wear plate and holding the sleeve in the proper position for striking. The final assembled unit is shown in the Shaver post driver channel in Figure 24. The well point drive sleeve is seen in use in Figure 25.

Figure 23 Shaver Drive Sleeve vs. Well Point Drive Sleeve Comparison (Personal photograph, 2019)

Figure 24 Well Point Drive Sleeve in Channel (Personal photograph, 2018)

Figure 25 Fabricated Well Point Drive Sleeve in Use (Personal photograph, n.d.)

For safety of the operator and to maintain proper drive sleeve alignment, retention chains were added to the well driver. The retention chains served to keep the drive sleeve and well casing from popping out of the drive channel during a strike. A 1/4" chain was used as it could be easily welded and was stout enough to survive multiple repeated jolts from the driver. The chain was welded to one side of the driver and hooks welded around the opposite side of the striking beam, remaining neatly out of the way. The retention chains can be quickly hooked and were a pleasant safety feature to use.

3.3 Material Preparations

Not all off-the-shelf components were ready to be used as is. Many required slight modifications to serve their intended function or purpose. Material preparations required minimal tooling and were not difficult. Many of the material preparations were achieved with ordinary hand tools or household items, but some operations might require specialized tooling for satisfactory completion.

3.3.1 Pipe Cutting & Threading

Standard 2”x10’ pipe sections were used as well casings, but they had to be modified before using them for the intended purpose. Ten foot sections were too tall to be used in the well-driver attachment, so they were split into two five foot sections. Both sides of the five foot pipes had to be threaded deeper and longer than standard pipe threads. Pipes were threaded at the Purdue Plumbing Shop, using a Ridgid brand electric pipe threader. The threads were modified to encourage a tight pipe butt joint in the drive couplings and provide proper thread engagement. Pipe threads were tapered, therefore threads were cut or re-cut by adjusting the pipe threading dies to slightly under two inches using an to allow for the proper clearances and fit.

3.3.2 Pipe Cleaning & Preparation

Immediately after being cut or threaded, pipes were not ready to serve as well casings. The pipes were oily from the threading process and contained many burrs from the pipe jaws of the machine. Oil would contaminate water sources easily, so the pipes were cleaned with a degreaser, scrubbed to remove any trace residues of the oil, and sprayed multiple times with water. This process was performed to remove as much oil as possible and flush any remaining degreaser away. Metal burrs were leveled off with a file, and the pipe sections were then touched-up with a Rustoleum Cold Galvanizing Compound. The high zinc compound (93% zinc) was necessary to rebuild the zinc coating and provide corrosion protection (Rustoleum, n.d.).

3.4 General Operations and Well-Driving Process

Minimal training would be required to operate the Well-Driver PUP, but the operator should also be familiar with general machinery and possess a basic understanding of geology or soil formations in relation to groundwater. Machine operation could be learned relatively quickly, as there are only three on/off valves and three working valves, one per operation (outrigger operation, mast tilt, and driver hammer).

3.4.1 Suggested Tools and Personal Protection Equipment

Various common hand tools and personal protection equipment (PPE) are required for a successful and safe well point drive. A non-extensive list of suggested hand tools may include shovels, pipe wrenches to fit pipe and couplings, a post level, an open reel tape measure, flat and round files, and a wrench to fit the throttle lock bolt. Sharp pipe wrench jaws would be necessary to properly grab pipe sections and resist slippage while tightening or loosening sections. Flat and round files would be suggested to knock burrs from the inside or outside of a pipe section to protect users from any injury.

The PPE required during use of the Well-Driver PUP could be best identified by the hazards while using the vehicle. Hazards included noise, compressed fluids, pinch points, sharp edges, falling components, and potential for flying debris. To mitigate the hazards from machine operation, the operator should use ear protection, safety glasses, gloves, a hardhat, and steel toed boots. Using the proper PPE will protect the operator from overhead injuries, cuts or contusions, and any potential sensory damage.

3.4.2 Vehicle Overview

Driving a well with the unit was designed to be straightforward and require minimal training, but a basic knowledge of vehicle operation and driven-well installation would still be necessary. The prototype relies on power from a nine horsepower (6.8 kW) Yanmar diesel engine. The engine shaft drove a centrifugal clutch, which simultaneously engaged power to the drivetrain and hydraulic pump when engine speed reached approximately 1800 rpm. Therefore, a throttle lock and transmission lock out were necessary for certain operations, such powering hydraulics.

3.4.3 Machine Setup

The first step in the well driving process was to adjust the vehicle into operational position. The user had to park the vehicle on a relatively flat surface, within 15 degrees (adjustability level of post driver) of level at a location suitable for a water well (Shaver, 2009). The operator had to be sure the vehicle was idling, and the transmission was in neutral (N) with the transmission lock-out engaged. The vehicle may not be allowed to roll when the operator leaves the driver's seat, so a pair of wheel chocks would be suggested. As a safety precaution, the shifter knob lock-out plate should be set to remove any chance of transmission engagement. As the operator walked to the passenger-side of the vehicle, the operator or secondary operator may increase engine speed with the engine throttle lever and may lock engine rpm at a speed that would engage the centrifugal clutch (>1800 rpm, clutch should be checked visually for engagement). Next, the operator may adjust the hydraulic relief valve to a system working pressure of greater than or equal to 1500 psi. The on/off valve to the hydraulic outriggers may be switched to the "open" position, and the corresponding control valve switched until the outriggers are fully raised. The operator may "shut" the on/off valve to the outriggers. The final step to prepare the driver to operational position would be to extend the tilt cylinder, such that the post driver would be in a vertical configuration. The user would open the on/off valve to the tilt cylinder and may switch the corresponding valve until the tilt cylinder was fully extended. Finally, the operator would close the on/off valve for the tilt cylinder to prevent any unintentional movement.

3.4.4 Site Preparation

Prior to starting the drive process, a hole approximately two feet deep and one foot in diameter had to be dug directly underneath the driving channel of the driver. A plumb bob would be recommended to mark out this position. The user may wish to temporarily tilt the driver back into transport position while the hole is being dug. The hole set the drive point in position and gave the well some support until the well point was firmly set into the ground.

3.4.5 Driving a Well

Upon proper setup of the site and vehicle (outriggers are extended, and driver is vertical), the operator may begin the well driving process. The well point may be connected to a five-foot section of galvanized steel pipe with a well-point coupling, and the upper section of pipe may be topped with a well point drive cap. The operator should ensure that all connections be tightened to a reasonable amount using pipe wrenches. Pipe tape or pipe thread compound should be used to form a water tight seal between pipe sections. The operator may switch the driver cylinder to the “open” position when the engine is at high idle. The corresponding control valve may be switched to raise the cylinder to its full working height. Safety chains may then be unhooked. The leading section of the well assembly may then be lowered into the pre-dug hole, with the drive sleeve assembly slid overtop the well point drive cap. The drive sleeve assembly would nestle in the center of the H-beam driving ram, as both guide rods touched the back of the beam channel. The safety chain of appropriate height may be re-hooked to keep the drive sleeve in position.

The operator may begin driving the well point assembly into the ground. Small taps may wish to be used towards the beginning of the drive process, checking and adjusting the well point/ casing for plumb between drive strokes. As the well was driven into the ground, various height safety chains would require to be hooked and unhooked to provide proper support of the drive sleeve as the pipe is driven progressively deeper in the ground. A safety chain should always be around the drive sleeve prior to every strike from the driver. Every 4-5 strokes, pipe sections should be re-tightened to prevent thread damage. Sections should be tightened forcefully, while preventing the well point from turning while in the soil. At the bottom of the driver stroke, a 2.5 foot section of pipe may be temporarily replaced as the top-most pipe. Again, following the bottom of the driver stroke, the 2.5 foot pipe section may be replaced with a 5 foot permanent section of pipe. The shorter sections of drive pipe were necessary as they accounted for a 53.5” driver stroke (shorter than a 5 foot, or 60” pipe section) and allowed for higher drive energy towards the bottom of the driver cycle. Shorter sections of pipe may be used in tough soils as required.

4. TESTING AND RESULTS

4.1 Preliminary Testing

Preliminary testing of the Well-Driver PUP was done in two tests: one driving standard steel posts and the other driving a 4"x6" wooden fence post. Driving steel fence posts were the first test, as the small cross sections should be easier to drive and would serve as a low-cost visual cue if there could be problems with buckling. A steel fence post is shown being driven in Figure 26. Steel fence posts were driven unsuccessfully at the start, with many being driven only a few inches into the ground before buckling and permanently deforming. This phenomenon proved to be a result of the vehicle suspension bouncing, thus creating strikes that were out of plumb. After "locking out" the vehicle suspension with the addition of hydraulic outriggers, steel posts were driven plumb and true with minimal effort from the driver.

Figure 26 Test Driving a Steel Post (Personal photograph, 2018)

Of the preliminary testing, driving wooden fence posts were tested second. A 4”x6” wood post would approach the capabilities of the driver (7.125” diameter maximum post) and confirm its striking power. The post was over six times the surface area than that of the 2” steel pipe (4”x6” post S.A. 19.25 in^2, 2” round S.A. 3.14 in^2), but it was noted that it would be only driven just a few feet in the soft topsoil. The wooden post was bevel cut at 45 degrees to the bottom and driven with the post driver. The post was successfully driven three feet into the ground, as shown in Figure 27, before bottoming out the cylinder stroke of the driver. The post was plumb and driven solidly in the ground, suggesting that the driver was not bouncing or deflecting.

Figure 27 Test Driving a 4”x6” Wood Post (Personal photograph, 2018)

Both preliminary tests from driving steel and wood fence posts were successful. Buckling was not an issue for the light to medium strokes used while driving steel fence posts, and the driver had provided its full power, which was proved by driving the large wooden posts. These tests were conducted at the university's old tractor pulling grounds, and successful completion of these two tests verified the Well-Driver PUP's functionality.

4.2 Test Wells 1a and 1b

The first well test location was located in Darlington, Indiana shown in Figure 28. This site was chosen due to the ease of access and its proximity to Sugar Creek. A tributary for Sugar Creek began on the 4-5-acre site and had areas of standing water, which made it a good location for a first test well. Water test wells 1a and 1b were in a Cohoctah loam, identified by results from the Web Soil Survey (shown in Figure 29). The Cohoctah soil was classified as a very deep, poorly drained or very poorly drained soil, and the particle-size control section suggested that the percent of silt plus the percent of clay averages more than thirty percent of the total volume (USDA, 2012). The saturated hydraulic conductivity was high for this soil type.

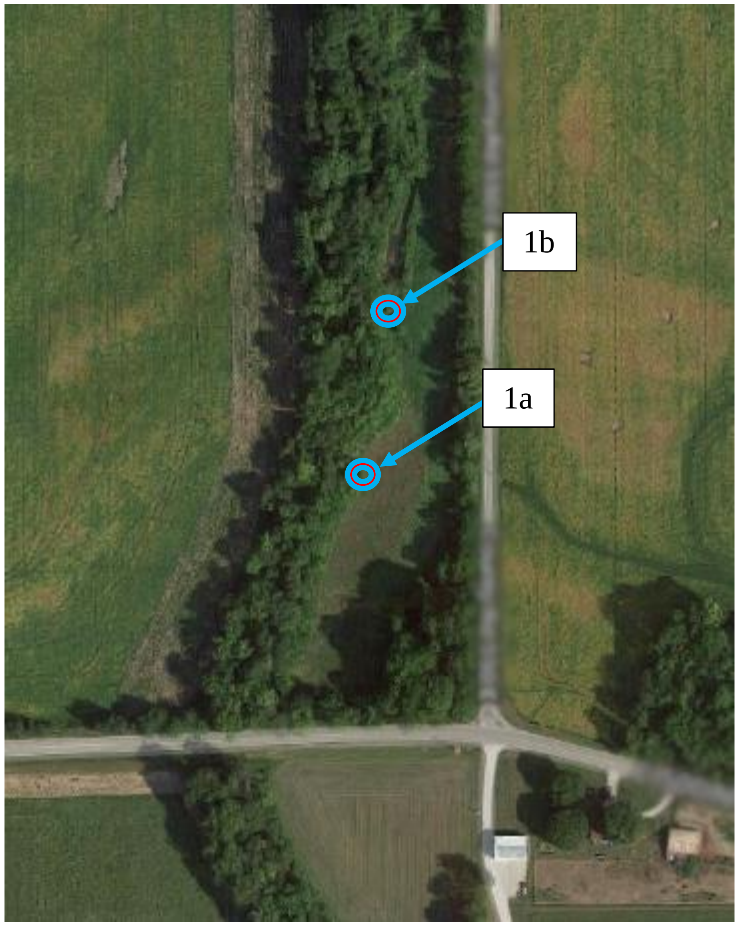


Figure 28 Darlington, IN Test Well Locations 1a and 1b (USDA, n.d.)

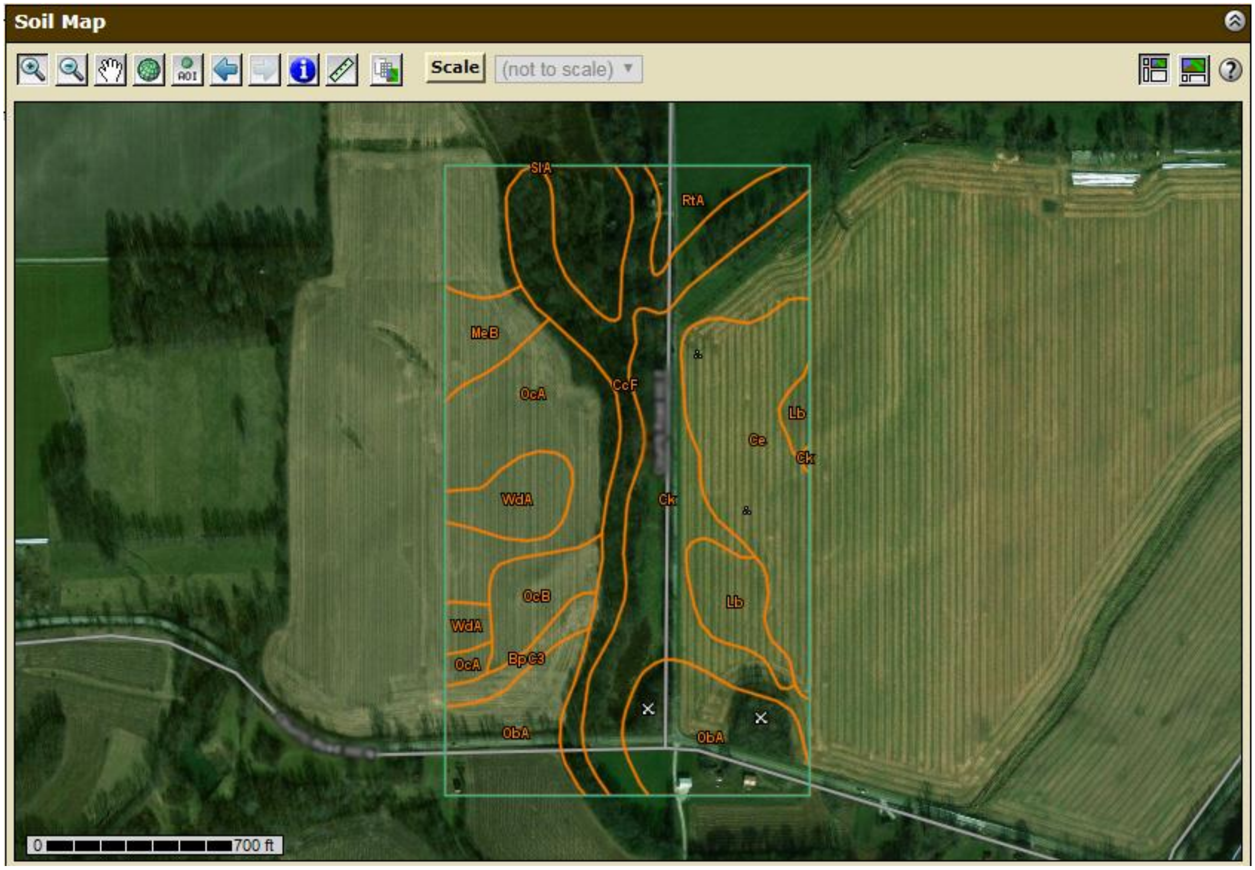


Figure 29 Soil Profile Map of Test Wells 1a and 1b (USDA, n.d.)

At a depth of thirteen feet, water was struck at test well 1a. During the well drive, the galvanized pipe was seen moving out of plumb, perhaps as if it was glancing off an obstacle. As the driving strokes became difficult, the well was checked for water. Depth of the water table was measured with an open reel tape measure, with a heavy nut bound to its end. Lowering the tape into the driven pipe sections resulted in an audible splashing sound, which gave an easy indication that water was hit. The submersible pump was lowered but could not reach the water level. It was speculated that the well point either broke off at the bottom-most coupling or was bent beyond an acceptable amount. This could be a result of hitting a large root or boulder. It was likely that the well point deflected from glancing off an object or buckling after hitting a solid object. The submersible pump used has an outer diameter of 1.82” and a length of 22”, making even a slight bend a major problem while lowering down the unit in a 2” internal diameter pipe. A picture of the well installation can be seen in Figure 30.

Figure 30 Well Installation

A second water well was started at a distance approximately 200 ft. from the first well, in the hope that groundwater could be pumped from the site. Ten feet of pipe (including the well point length) were driven, and again a tape was dropped with an audible water splash at test well 1b. Well-driving started quickly through the topsoil, and then became increasingly difficult with greater depth. The pipe remained plumb during the entire drive. Lowering the submersible pump, muddy water was pumped for approximately six seconds before the well had to re-charge. This suggested that either the groundwater recovery flow or the allowable flow through the well screen was not high enough to keep up with the well pump. Waterra's WSP-12V-3B Super Twister pump moved approximately 3.5 gallons per minute (gpm) at a depth of ten feet, therefore the pump would quickly discharge the few inches of water in the bottom of the well (Waterra, 2018-b).

Perhaps the most important thing that was learned from the first test was how difficult it was to micro-position the vehicle. Small natural valleys or channels in the earth made the vehicle difficult to maneuver, and the centrifugal clutch played a massive role in this problem. Engaging at ~1800 rpm, it was nearly impossible to get a smooth transition of power to the drive wheels. It mimicked having a power transfer of either “all on” or “all off”. The additional weight of additional components seemed to reduce the urge of the vehicle to lurch, but it was still very difficult to maneuver effectively. Based on these circumstances, the well installer should dig the well point starting hole after the vehicle is fixed into final position.

4.3 Test Well 2

The site for test well 2 was chose largely due to the sandy soil profile near the Coal Creek banks (shown in Figure 31). The site featured a once straightened drainage creek with recently dredged banks. From previous tiling work, the field was known to have a shallow water table depth. This location was a likely spot to find water and provide a meaningful test to the well-driver attachment. The soil at this site was also a Cohoctah loam as identified by the Web Soil Survey (shown in Figure 32). The saturated conductivity was high, despite being a poorly drained or very poorly drained soil (USDA, 2012). The proximity of the creek was thought to ensure a saturated water table for good conductivity, ideal for this type of water well.

Figure 31 New Richmond, IN Test Well Location 2 (USDA, n.d.)

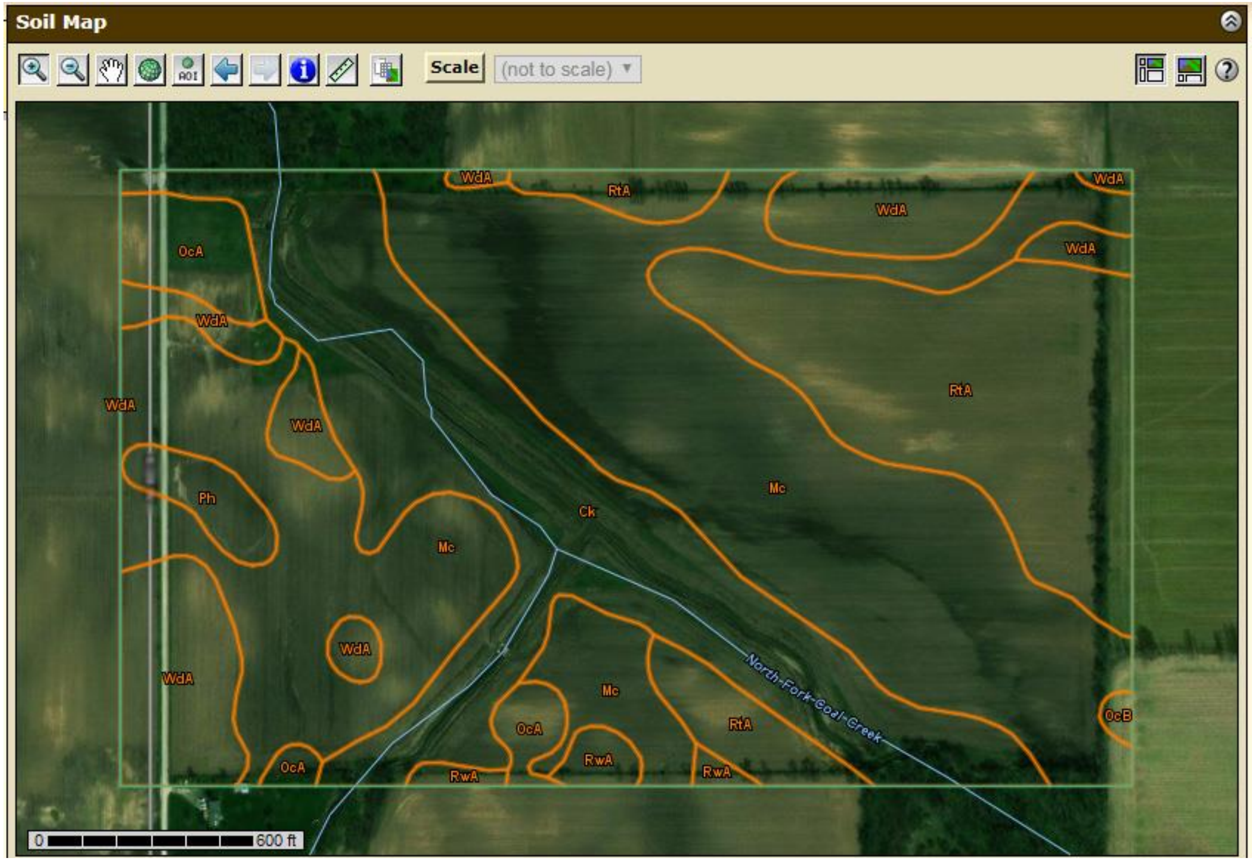


Figure 32 Soil Profile Map of Test Well 2 (USDA, n.d.)

Test well two quickly hit groundwater at 3 feet below the surface. This was likely due to the high water table from the nearby creek. Driving the point was very rapid, with well-landing hits and seemingly softer soil. The well-point was driven to a 23 foot depth, only stopping for fear of driving beyond a confining layer of fairly impermeable soil. The submersible pump was lowered and powered to provide a continuous flow of water as seen in Figure 33. At this depth, the Waterra Super Twister submersible pump supplied between 2.9 and 3.0 gpm. The pump's output is shown in Figure 34.

Figure 33 Pumping Clear Water (Personal photograph, n.d.)

Super Twister Pump Chart

Depth to water (in feet)	Gallons per minute 12V
3	4.0
10	3.5
20	3.0
30	2.9
40	2.75
50	2.4
60	2.0
70	1.5
80	1.0
85	0.6
90	N/A

Figure 34 Waterra WSP-12V-3B Depth Performance (Waterra, 2018-b)

It was apparent that site location would be critical for success with the well-driving apparatus. It was immediately evident at depths greater than 10 feet that the soil at the site was more conducive to this type of groundwater tap. The entire well-driving process (digging a hole, machine setup, well-driving, checking water table depth, etc.) took only four hours, with most hammering blows moving the well casing down several inches per stroke. The driver appeared to be providing continuously ample power, even with the well at a depth of over 20 feet.

4.4 Test Well 3

Great success at the New Richmond location prompted another test site with a similar soil profile. This test site was just outside of the town of Linden, and featured a nearby creek, also similar to the location of the test well 2 site. The aerial view of test well site 3 is shown below in Figure 35. The soil at test well three was a drummer silty clay loam (Du), identified by the Web Soil Survey (shown in Figure 36). It was classified as a very deep, poorly drained soil with saturated hydraulic conductivity that was moderately high to high. The average fine and coarser sand content of the particle-size control section was less than 15 percent (USDA, 2015).

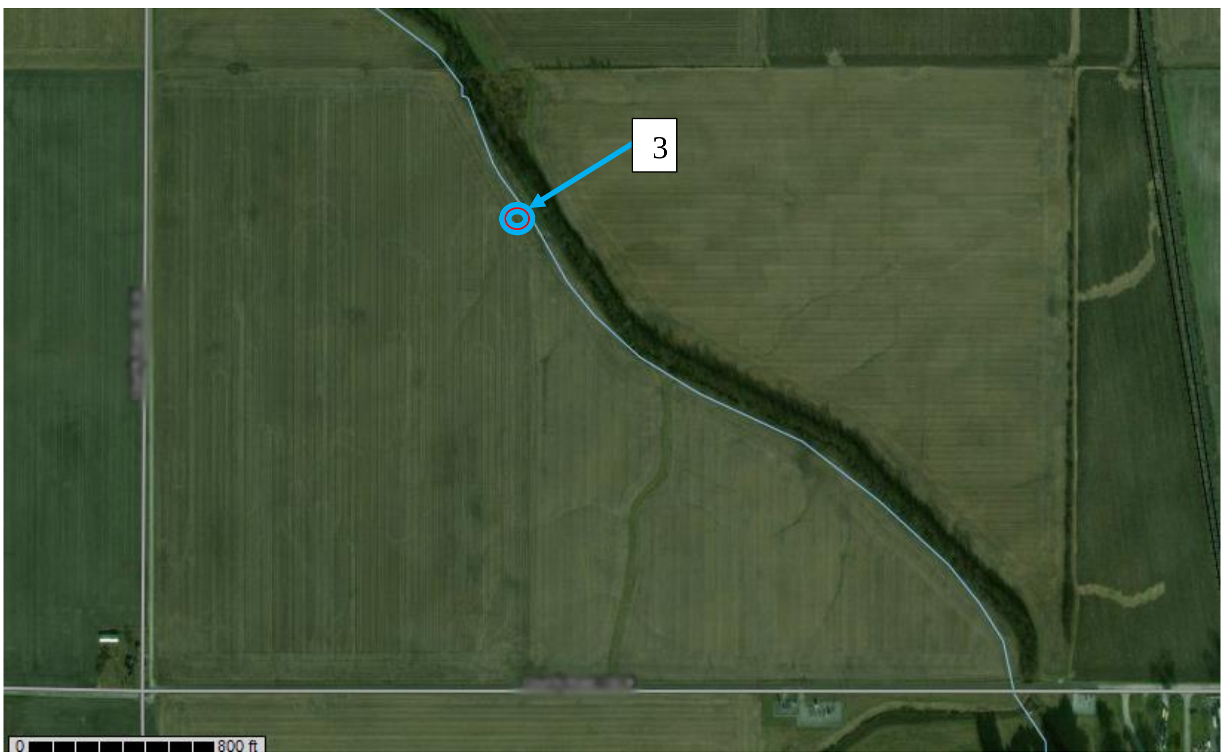


Figure 35 Linden, IN Test Well Location 3 (USDA, n.d.)

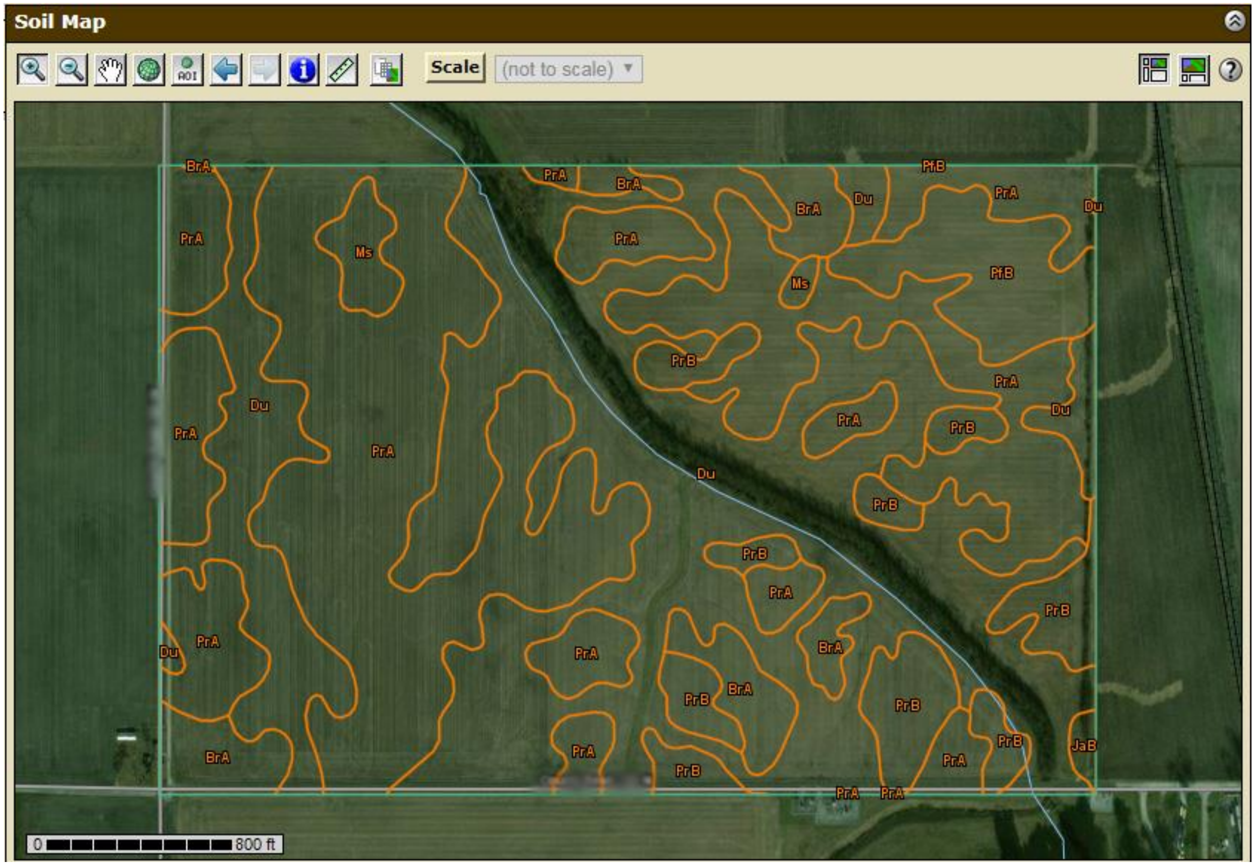


Figure 36 Soil Profile Map of Test Well 3 (USDA, n.d.)

Water was struck first at about eight feet below the surface initially with a rapid drive of the well. The decision to keep driving the well was made in an effort to ensure a well of adequate depth and of the proper filtration could be obtained. At approximately nine feet, it was evident that a confining layer (likely heavy clay) was hit. The driver slowly progressed hammering through the confining layer into smoother driving soil. At approximately 15 feet, another confining layer was hit with the driver providing minimal effect to the depth of the well point. Consultation with the landowner suggested multiple hard clay confining layers similar to the depths that were encountered.

A takeaway from test well 3 was an increased respect for the complex geology of the earth. As Forrest Wright stated in *Rural Water Supply and Sanitation*, “There is no infallible method of locating a successful well previous to drilling. All methods fail at times to produce satisfactory results" (Wright, 1977).

4.5 Test Well 4

The site chosen for test well 4 was due to its location being far from any creek (unlike the previous test wells). This represented a unique test and a more realistic scenario for a driven well installation. Test well site 4 is shown in Figure 37 below. The soil at test well site four was a Fincastle-Miami silt loam identified by the Web Soil Survey (shown in Figure 38). It was classified as a very deep, somewhat poorly drained soil, with five to ten percent of the particle content being fine sand or coarser (USDA, 2014).

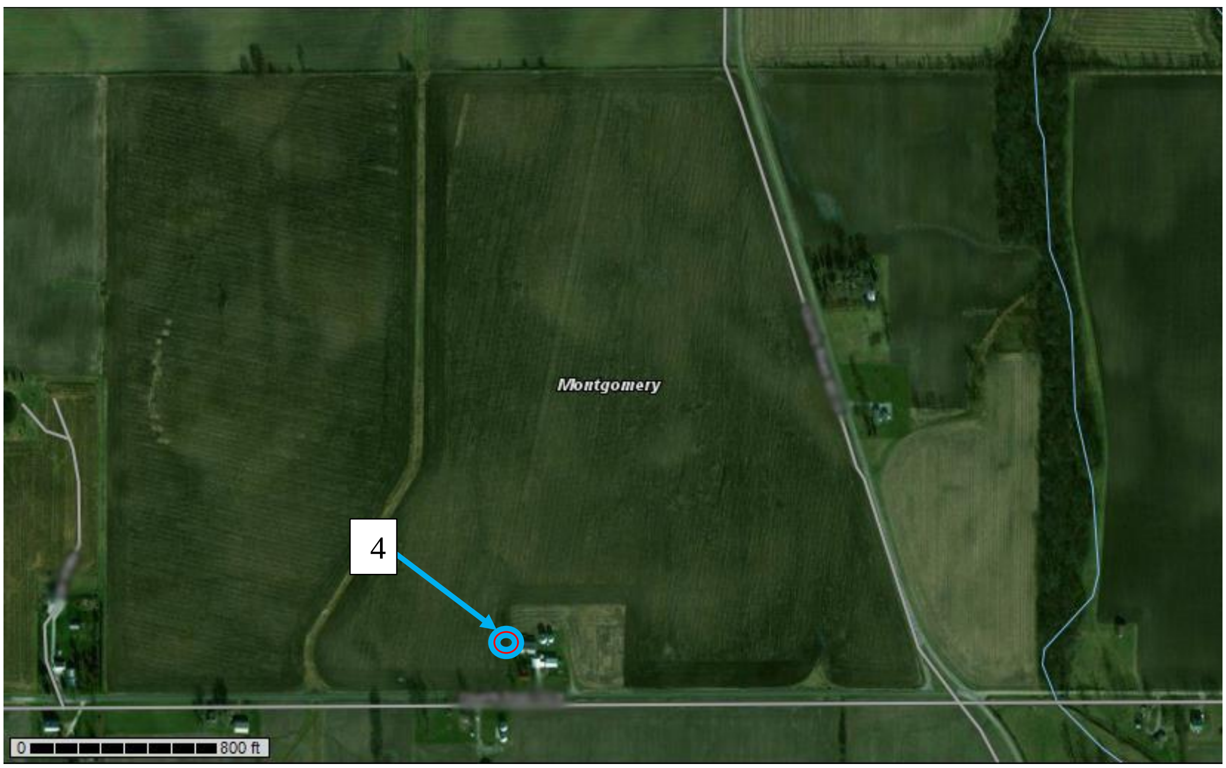


Figure 37 New Richmond, IN Test Well Location 4 (USDA, n.d.)

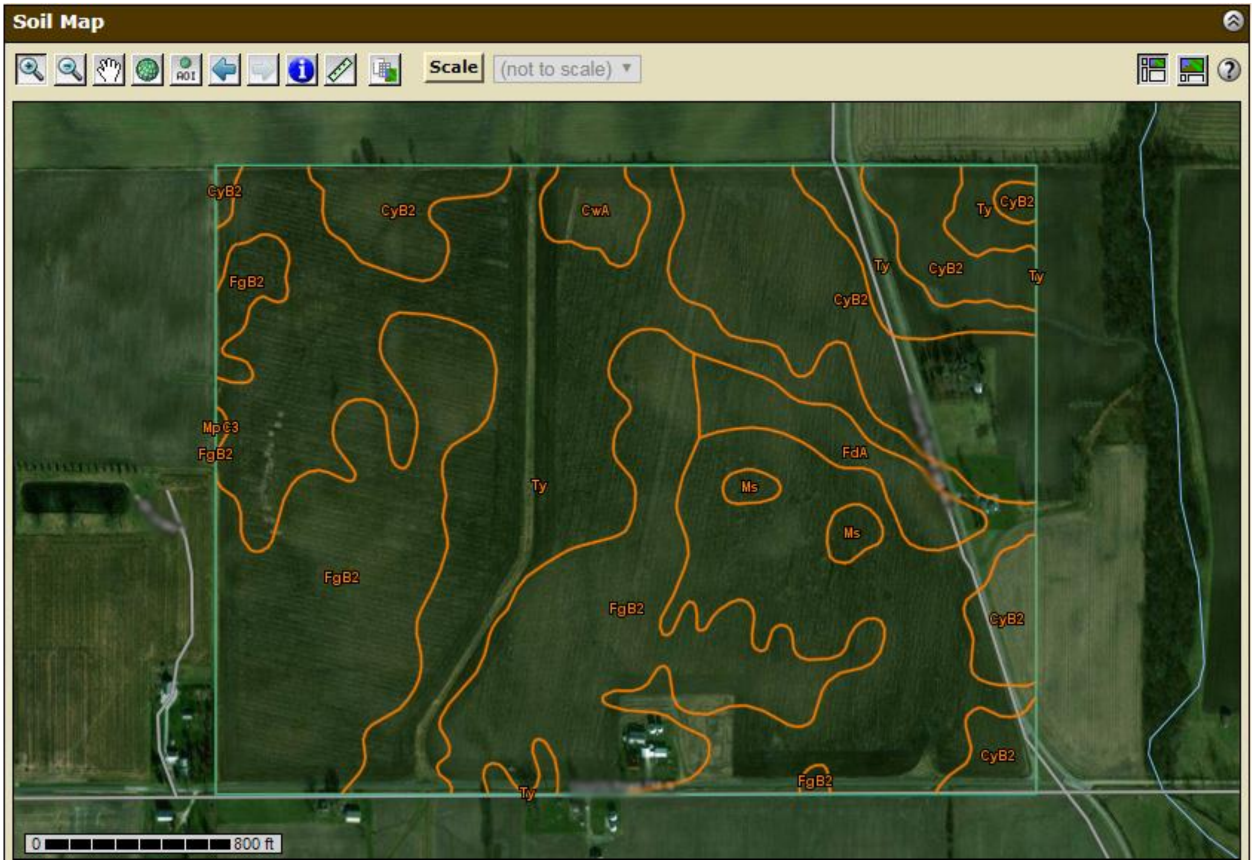


Figure 38 Soil Profile Map of Test Well 4 (USDA, n.d.)

Water was struck at initially at 10 feet below the surface. At a driving depth of 17 feet, still just a few inches of water remained in the bottom of the well casing. To increase the amount of available water for pumping, it was decided to continue driving the well. Driving slowed to a halt at a depth of 23 feet with the same amount of water remaining in the well casing. Likely water was struck before it was checked the first time. The amount of water in the casing may have remained the same as the well point was driven through a confining soil layer and completely driven past any more water bearing soil formations.

Test well 4 was by far the most perplexing well drive of the 5 total wells driven. Retrospectively, driven wells should be checked for water frequently, and the operator must mentally keep track of the depth of drive. It should be noted at which points in the drive hard or dense strata are encountered. A detailed well installation log may prove particularly useful in determining the optimum drive depth of a driven well. The operator should pay particularly close attention to any indications of possible confining layers in the soil. Keeping track of this information, it may be possible to install a second water well, if the first trial is “dry”. Essentially the first well could serve as a probe.

4.6 Well Driving Summary

All test wells hit water at some point in the well drive, with these known depths recorded in Table 1. Water was recoverable from some wells in various extents, either providing a continuous flow, intermittent flow, or not providing a flow of water from the submersible pump. Based on the results of all well driving tests, wells 1a, 1b, 3, and 4 were deemed either as “dry” or “intermittent” wells. Well 2 would be developed into a quality water well for testing purposes.

Table 1 Well-Driving Summary

Well #	Well Depth (feet)	Static Water Column in Well (feet)	Confining Layers (feet)	Water Supply
1a	13	3	N/A	N/A
1b	10	1	N/A	intermittent
2	23	20	N/A	continuous
3	17	N/A	9-11, 15-17	N/A
4	23	N/A	N/A	N/A

4.7 Completing a Well

A concrete pad was poured as quickly as possible after installing a permanent water well at the New Richmond Location (well 2). The 30”x30”x5.5” form was centered around the vertical well casing and inset several inches in the ground. The form used a total of eight 60 pound bags of concrete. The Quikrete Concrete Calculator suggested seven bags for a 30”x30”x6” slab, but eight were used to account for the uneven surface at the bottom of the excavated land area (Quikrete, n.d.). The concrete pad poured for test well 2 is shown in Figure 39.

Figure 39 Concrete Pad at Test Well 2 (Personal photograph, 2019)

Well surging was carried out after concrete was cured to properly develop the well for long-lasting water access. Surging removed fine particles from the bottom of the well tube near the pump inlet and avoided transferring them to drinking water. Surging may also help pack layers of fine particles around the well water inlet screen, which could serve as a “pre-filter” to larger particles. Surging was carried out with Waterra’s inertial pump (part D-25) and 2” surge block. The well surging process can be seen in Figure 40.

Figure 40 Surging Test Well 2 with an Inertial Pump (Personal photograph, 2019)

The permanent water well was disinfected after properly surging the well in accordance with the American Ground Water Trust procedure. The proper amount of chlorine in bleach was dispensed into the well, and a pump recirculated the solution in the well casing. At a rate of one quart bleach to 50 gallons of water, the twenty foot column of water in the two inch well casing called for 0.0652 quarts of bleach, which was slightly more than a quarter cup. As the disinfection process stated, more bleach is not more effective, so a quarter cup of bleach was combined into the well casing. The pump was allowed to recirculate the chlorinated solution for 30 minutes. The “shock chlorination” is seen in Figure 41.

Figure 41 Disinfection of Test Well 2 (Personal photograph, 2019)

4.8 Water Quality Testing

A $20.00 private well water test was conducted by the Montgomery County Health Department for test well 2 in New Richmond, IN. The sample was checked for Coliform and E.coli bacteria, which tested for water safety. Pathogen presence may be tested in the form of Coliform, which served as an indicator organism. According to the New York State Department of Health, "Testing for bacteria is the only reliable way to know if your water is safe" (New York, 2017). They go on to say, "If coliform bacteria are present in your drinking water, your risk of contracting a water-borne illness is increased". Furthermore, "As a result, testing for coliform bacteria can be a reasonable indication of whether other pathogenic bacteria are present". Easy to culture coliform would provide a rapid test of water quality, with results reported often within 24 hours of the sampling date.

The tests came back a day later, a little more than 24 hours after the sample was submitted to the lab. The sample tested positive for total coliform at a concentration at 2.0 ppm (parts per million) and it tested absent for E.coli at less than one part per million. E.coli or fecal coliform testing had to be done if total coliform concentrations are detected. A most probable number (MPN) test was done to estimate the number of coliform or E.coli per volume of water. According to the

Montgomery County Health Department, the water sample was satisfactory and “this water was bacteriologically safe based on USEPA standards”. A copy of the water test is seen in Appendix A. Directions for describing, collecting, and delivering the sample can be seen in Appendix A. Compared to the EPA (Environmental Protection Agency) standards, the sample was adequate for a private drinking water supply.

A second $20.00 water quality test was conducted by the Montgomery County Health Department towards the end of March. A second test was necessary to show a sustained well disinfection. The bacteriological test came back the following day it was submitted to the lab. A present/ absent (P/A) test was performed on the water sample. The sample tested present for total coliform and it tested absent for E.coli. Results from the second water test are shown in Appendix A. According to the Montgomery County Health Department, the water sample was unsatisfactory and “at examination time, this water was bacteriologically unsafe”. It was speculated that the reintroduction of the pump into the well casing resulted in a contamination of the water sample.

A third and final test was performed after another shock chlorination to disinfect the well was made. The water quality test was again conducted by the Montgomery County Health Department after flushing the well of chlorine traces and left to sit a minimum of five days. The bacteriological test came back the following day it was submitted to the lab. A present/ absent (P/A) test was performed on the water sample. The sample tested absent for total coliform and it tested absent for E.coli. Results from the second water test are shown in Appendix A. According to the Montgomery County Health Department, the water sample was satisfactory and “at examination time, this water was bacteriologically safe based on USEPA standards”.

4.9 Decommissioning Unsuccessful Wells

As per Indiana Well Driller’s regulations, the dry or intermittent water wells were completely sealed. Neat cement, or Portland cement, was used to completely fill the well casing. Neat cement, a rapid hardening concrete, was ideal for sealing water wells. Bentonite clay may also be used as an effective abandoned well sealer. The ideal plugging material would be an impermeable and minimal-swelling mixture. It was recommended that abandoned wells be sealed as quickly as possible to reduce the flow of materials or solutes through a well casing. Abandoned or improperly abandoned wells may pose contamination problems to deep water aquifers, because they may mix different qualities of water, some having contaminants. Abandoned wells would ultimately be the responsibility of the landowner to plug, but these wells were plugged as part of the agreement for vehicle testing. Insuring proper closure of abandoned wells would remain a courtesy to all of those who tap groundwater in proximity to the wells.

4.10 Certifications

Dr. Stwalley, the Principal Investigator, possessed a 2019 Well Driller's licensure to be in accordance with local and state laws regarding well installation and plugging. Well Drilling licensure may be obtained with a state administered test and the signature of three other licensed well drillers. Test well 2 (the permanent well in New Richmond, IN) was reported to the Department of Natural Resources (DNR) with its exact location and purpose as a test well. The well documentation is shown in Appendix B.

4.11 Practicality of the Well-Driver PUP

After repairing, modifying, and testing the Well-Driver PUP, several conclusions could be drawn: it may hold a niche place in the market and may remain one of the fastest ways to install low-cost water wells. The well-driver attachment could install a driven well in a manner of hours, while well development and concrete curing would take a matter of days. In about 7-10 days, a functional and usable well could be available. The target market for the well-driver attachment would be those people in developing or under-developed countries whose government infrastructure isn't providing them with proper water access. A driven well installation could be looked at as an investment and something that will pay for itself over time. A driven well may be more expensive than a "free" hand-dug well, but it could pay for itself in nearby, clean, safe, and sustainable water.

4.12 Well-Driver PUP Cost

The total cost of the Well-Driver PUP as received, was approximately \$5,800 from the summation of the Capstone team budget with the largest costs being the PUP (~\$2,000) and the post driver (~\$2,500). Further modifications to the vehicle added approximately at \$2,100, spent on permanent additions to the well-driving rig such as the hydraulic outriggers. The prototype Well-Driver cost totaled just over $7,900. All prototypes are typically much more expensive than the final product, as they are a one-off production. If many of these units were built, costs should be further reduced from this level.

4.13 Limitations

It is imperative to reflect upon the limitations of driven wells and the well-driving attachment when considering their use in a development setting. Driven wells, along with other types of shallow wells, may be susceptible to temporarily running dry in drought conditions. Extreme rain deficits might result in the groundwater table lowering, potentially dropping below the screen of a driven well. Shallow wells are generally more susceptible to contaminant leaching, but the risk of contaminant entry is reduced at greater depths. Proper placement of the well and efforts to avert the proximity of possible contaminants must be considered before installation. Caution and best judgement should always be used in determining the proper application for a driven well.

Component availability should be considered and researched, as it may vary widely across countries or regions. Sourcing problems are most likely to be encountered with hydraulic components (valves/pumps) or with specialty well-driving accessories (post driver/ drive points/ drive point couplings). Imported components may need a significant lead time, but if the attachment saw continuous use, a supply chain could be developed. Proper and thorough in-country market analysis should be conducted prior to implementation in significant numbers.

5. POTENTIAL IMPACT

5.1 People Served per Well

Determining how many people one well could serve depends on depth of water being pumped, the daily per capita water required, duty cycle of water pump, and ability of the water bearing formation to sustain being pumped. A basic calculation was done to suggest a communal size of a sample water well. The World Health Organization suggested water at $\frac{20\ liters}{capita*day}$ would be required to sustain basic personal hygiene and basic food hygiene (WHO, 2016). At a depth of twenty-five feet, the same depth as the successful water well, the Waterra WSP-12V-3B pump moved approximately 2.95 gpm. Assuming best case scenario, in which the pump was running at its continuous duty cycle for eight hours a day, a total of 5361.6 liters (~1416 gallons) of water could be theoretically pumped. This quantity could serve as many as 268 people assuming that the water bearing groundwater formation could keep up.

Water-table drawdown may affect the rate of how much water may be pumped. As water would be pumped and pulled through a well screen, the water bearing formation would begin to develop a cone of depression (shown in Figure 42). The suction effect of a well pump would force the water formation to move towards the water withdrawal source. As the water would be pumped over time, different size cones of depression would exist, and a steady state drawdown may exist for some wells, depending on hydraulic conductivity of the soil and the groundwater recharge rate.

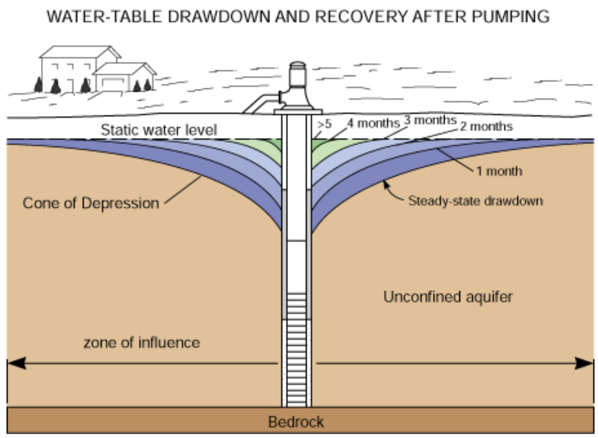


Figure 42 Water Drawdown from a Pumped Well (Buddemeier, 2000)

5.2 Well Cost per Depth & Value Proposition

To further access the impact and the population capacity of each driven well, a cost analysis per well depth from 3 to 50 feet was calculated in Microsoft Excel, using current U.S. market prices of driven well components. Material cost is shown in Table 2 and well cost per depth table is shown in Table 3. Three feet was chosen as the minimum well depth as it was the length of a well point. A maximum well depth of 75 feet was chosen as suggested by the book *Groundwater and Wells* which reads, “Well points driven by hammers weighing 250 to 1,000 lb (113 to 454 kg) reach depths of 50 ft. (15.2 m) and even more in favorable situations” (Driscoll, 1986). According to the Shaver HD-8 Operator’s Manual, the effective weight of the spring powered driving ram was 360 lb (163.3 kg), which suggested that a 75 foot deep well would be an acceptable cutoff range for the driver. The table could be easily modified in Excel to provide depths of greater than 75 feet and to include pump costs, if the user desired. It was assumed that the well casing extended three feet beyond the ground surface and that any section of pipe in use that was less than five feet to be the full cost of a five foot pipe. It should be noted that prices are approximate and might vary by geographical location or taxation rates.

Table 2 Well Material Costs

Materials for Well	Price (USD)	Per	Source	Length (feet)
2"x10' Galvanized Steel Pipe	37.12	each	HD	10
2"x36" Well Point	60.66	each	HD	3
2" Well Point Coupling	12.86	each	HD	0
2" Well Point Drive Cap	17.29	each	HD	N/A
2"x5' Galvanized Steel Pipe Section (plus cut/threading cost)	20	each	HD (approximation)	5

Table 3 Well Cost per Depth

Well Depth (ft.)	Actual Length (ft.)	Cost excluding pump/concrete/labor (USD)
5	8	123.67
10	13	156.53
15	18	189.39
20	23	222.25
25	28	255.11
30	33	287.97
35	38	320.83
40	43	353.69
45	48	386.55
50	53	419.41
55	58	452.27
60	63	485.13
65	68	517.99
70	73	550.85
75	78	583.71

In comparison to a drilled water well, the well-driver attachment could still provide an excellent value. According to Home Advisor, a drilled well in the United States may cost between $15-30 per foot, or up to $50 per foot in tough soil conditions (Home Advisor, n.d.). This price is purely the cost of drilling without a well casing. Averaging the cost per depth table above, a driven well within the capabilities of the driver will average about $10.60 per foot in material costs, not including the cost of labor. Labor costs for a driven well would be less, given the minimal training required in operation. A driven well could provide alternative cost-effective water access options than a drilled well.

5.3 Sustainability

Charles G. Groat, Director of the U.S. Geological Survey (Alley, Reilly & Franke, 1999) stated, "The sustainability of ground-water resources is a function of many factors, including depletion of ground-water storage, reductions in streamflow, potential loss of wetland and riparian ecosystems, land subsidence, saltwater intrusion, and changes in ground-water quality". To put it simply, the sustainability of groundwater supply always would remain a complex system which must be used efficiently to minimize the effects on the environment. To retain maximum long-term impact and future sustainability of a water well, the static water level should be monitored frequently. Due to the multitude of factors, routinely monitoring newly installed water wells would serve as the best indication of the sustainability of the well and would provide information regarding the steady state drawdown level if there is one.

5.4 Improvements to Daily Life

The impact of communal water wells could be huge in developing or under-developed countries. The properly disinfected and fair water producing communal wells would be beneficial to health, education, the labor force, and overall economy of a region. An immediate benefit would be to local community health. Waterborne pathogens and disease transmission should drop significantly, likely reducing infant mortality rates and increasing the average lifespan. Women and children would be at a reduced risk for skeletal deformation or accelerated joint damage caused from carrying heavy water loads for hours every day (WHO, n.d.-b). The education benefit for young girls would be strongest, by reducing lost opportunities. WHO states, "Girls often miss out on an education because they have to help with household chores and, when money is scarce, it's usually the boys who get chosen to go to school". Removing the need to retrieve water from great distances would leave more time for girls to remain in school and gain formal education. The World Health Organization also stated that the economic benefits of water services would be immediate and long term, by averting health-related costs, producing time savings, and allowing an overall higher work productivity (WHO, n.d.-a).

5.5 Potential Small Business

A well-driver attachment may be able to serve as a source of income for a small business or group of entrepreneurs. A business model could be easily developed factoring in the cost of a PUP, the well-driver attachment, maintenance, consumables, and a region specific well cost per depth chart. There would be a huge need for this type of small business, especially on a communal scale. A farm co-op or local national outreaches may be able to purchase and lease PUP vehicles as well as their attachments. ACREST (African Centre for Renewable Energy & Sustainable Technology) may be an excellent first partner as they have worked with the PUP team in years past. They stated on their website, “Let’s use locally available resource for an affordable, reliable and sustainable development” (ACREST, n.d.)! Partnerships and entrepreneurs could likely serve an immediate need, while implementing a small business venture.

6. FUTURE WORK & SUGGESTIONS

6.1 Reduce/ Eliminate Hydraulic Components for Cost Cutting

The biggest limitation to this attachment was its dependency on hydraulics. Although well-supplied hardware and industrial stores in the United States carry many of the fittings required on hand, in a developing country these would be more difficult to source. Hydraulic components may have to be imported, which may drive up build or repair costs, depending on location. A non-hydraulic powered Well-Driver PUP may wish to be developed in the future, until under-developed or developing countries would have a larger range of hydraulic components that could be locally sourced.

Many operations of the driver may be replicated or replaced with mechanic components to reduce costs and improve field serviceability. First, the hydraulic outriggers may be replaced by trailer jacks mounted at each corner of the vehicle. Either a drop-leg jack or a swing-away jack may be used. It would not be necessary to fully lift the vehicle, merely eliminate suspension play. With adequate force exerted on each jack, the vehicle would be fully rigid during operation. As an added benefit, having individual jacks would allow for precise leveling of the vehicle and for it to be used on more adverse topography. Furthermore, the driver-side front jack could be set as a “parking brake” without leaving the driver seat. An estimated 250 lbs could be cut from the total vehicle weight. Secondly, the hydraulic tilt cylinder could be replaced with a winch system. A skillfully placed pulley would allow the driver to be raised and lowered with a hand (or electric) winch. Making this replacement would further reduce cost, while fully maintaining its reliability. Having a winch on the vehicle may also serve other utilitarian purposes, further benefitting the user.

A well-driver with minimal hydraulic components would limit potential for groundwater contamination. One drop of oil spilled could result in as much as one million drops of water contaminated (British, n.d.). On a scale of liters or gallons this figure could be immense. Aging fittings and hydraulic lines would be susceptible to leaks over their life and identifying the precise location of oil leaks may be very challenging, even for experienced technicians.

While far less expensive than a specialized well drilling truck, the Well-Driver PUP was an expensive rig to install wells, mainly due to the hydraulic components. Removing hydraulics would directly lower the cost of the well driving attachment, its long-term maintenance costs, and ultimately the cost of well installation. From an impact perspective, it would be important for the well-driver project to remain low-cost to remain affordable and provide benefits that are greater than the investment in a driven well.

6.2 Hydraulic Considerations

If future work were to retain hydraulic components, it would be suggested to use food-grade hydraulic oil and install independently adjustable outriggers. The oil currently used in a hydraulic system would be expected to remain in the closed circuit, but that doesn’t always happen. It should be noted that hydraulic systems will leak sooner or later. Due to the nature and objectives of the system, it could be advantageous to run a food-grade hydraulic oil as the working fluid. A food-grade oil would be rated for incidental food contact, which should be safer for operators and consumers in case of a minor/ major spill or leak. Although higher cost, the food-grade oil would provide an extended level of safety to the attachment that could not be held with petroleum based oils.

Although the fabricated outriggers served their purpose well, they would need revision in a future design. All outriggers had the same hydraulic stroke, which could not be altered. In uneven terrain, it could be possible for only three of the outriggers to support vehicle weight. Therefore, the operator may need to adjust outrigger legs independently to ensure a level machine lift. This could be achieved with a mono-block hydraulic valve, which could still provide a powered option for independent lifting, or each outrigger could be replaced with a screw-type trailer jack. Independent outriggers may also increase the steepness of grades of which a well could be installed.

6.3 Quick Detach Ability

The current prototype’s components were either semi-permanently or permanently mounted to the vehicle, detracting from the utility of a PUP. A quick attach/ detach method would be an added benefit to retain the capability of the various duties demanded from a PUP. This suggestion was first mentioned in the first senior capstone paper about the Well-Driver PUP (Zeller et al., n.d.). A "skid-type" well-driver attachment should be considered. In this configuration, most components of the well-driver would slide out of the PUP bed and hydraulic quick connects could be used as well. Some hydraulic components may wish to remain permanent on the vehicle to expand its capabilities and utility purposes.

6.4 Install Automotive Style Clutch

Testing the vehicle with a centrifugal clutch was difficult to say the least. Micro-positioning the PUP was nearly impossible, even with a skilled operator. Smooth power transitions were difficult for high starting torque applications to the drivetrain (especially off-road/up-hill climbs). The use of an automotive style clutch would ensure that minimal power would be lost in the drivetrain and provide a smooth engagement of power.

6.5 Install a Parking Brake

A parking brake would add a level of safety and practicality to the well-driver attachment. Being able to lock the vehicle securely on any terrain would prevent the main operator from leaving the driver's seat, effectively making the Well-Driver PUP into a single man operation. The parking brake would allow the vehicle to remain stationary as the outriggers lift the PUP.

6.6 Install a Throttle Lock

An auxiliary throttle lock would be advantageous to the Well-Driver PUP for operation of the hydraulics. An auxiliary throttle lock would hold engine rpms steady as the operator would control hydraulics from the side or rear of the vehicle. The throttle lock should be positioned to be either accessible from the driver's seat or at the side of the PUP, close to the hydraulic controls.

6.7 Waterra PA-10800 Low Flow Sampling Controller

The low-flow sampling controller from Waterra would be suggested to better control the submersible pump. Apart from purging and developing a water well, there would be no benefit to run a water pump dry. The pump controller could be used to limit water flow to a sustainable capacity and provide a more continuous, long term liquid transfer for lower yielding water wells.

6.8 Geological Surveys/ Probe

Methods for a cost-effective geological survey of a well site should be considered, which was also mentioned in Development of a Trailed Tractor PTO Driven Drilling Rig for Rural Water Supply by Babalola et al. (2016). A geophysical investigation with a similar device, such as a resistivity meter, would assist in groundwater prospecting (Guideline, 2016). This would prevent operators from blindly guessing where groundwater could be and boost the chances of a fruitful water well. A geophysical investigation (or a device to conduct one) would be a small investment for a customer, but it would likely save costs by sparing a well point, couplings, and drive pipe.

Serving a similar role to a geological survey, a probe may also wish to be developed. Having a simple, low-cost probe would allow the well-driver operator to choose optimal locations for placing well points and developing the highest productive well possible. Considerations when using a probe would include potential for groundwater contamination, ability to remove the probe when driven into the ground, and proper analysis of a core soil sample. Methods for controlling and analyzing a probe would be extremely beneficial to the scope of this project.

6.9 Test Alternative Pipe Sizes

The use of alternative pipe sizes would be beneficial in exploring the capabilities of the Well-Driver PUP and would provide more options to the users. The Well-Driver mechanism should be tested with 1-1/4" and 4" diameter pipes to contrast the driving process of 2" pipe. Hypothetically, the smaller diameter pipes could be driven much further into the earth and tap into deeper groundwater tables. Larger pipe could be used if higher flow rates were desired. These larger-sized wells could be used for a higher populated community or may be preferred if irrigation is under consideration. Larger sized and higher yielding submersible pumps may be used with increasing sizes of internal pipe diameters.

6.10 Test Various Pumping & Water Storage Methods

Several different types of pumping methods should be tested with the Well-Driver PUP. Tandem wells points could be driven and arranged in a setup similar to Figure 43. Tandem wells would offer the benefit of a greater flow of water than a single well, which would be beneficial in high volume needs such as irrigation or a low hydraulic conductivity found in some soils. It would be beneficial to implement a way to store water as well. A pumping system might be able to run at night and the water could be stored, depending on communal need. Pairing a pump with low-cost impermeable storage tank would ensure a steady reserve of water and put a less intensive flow demand on a well point.

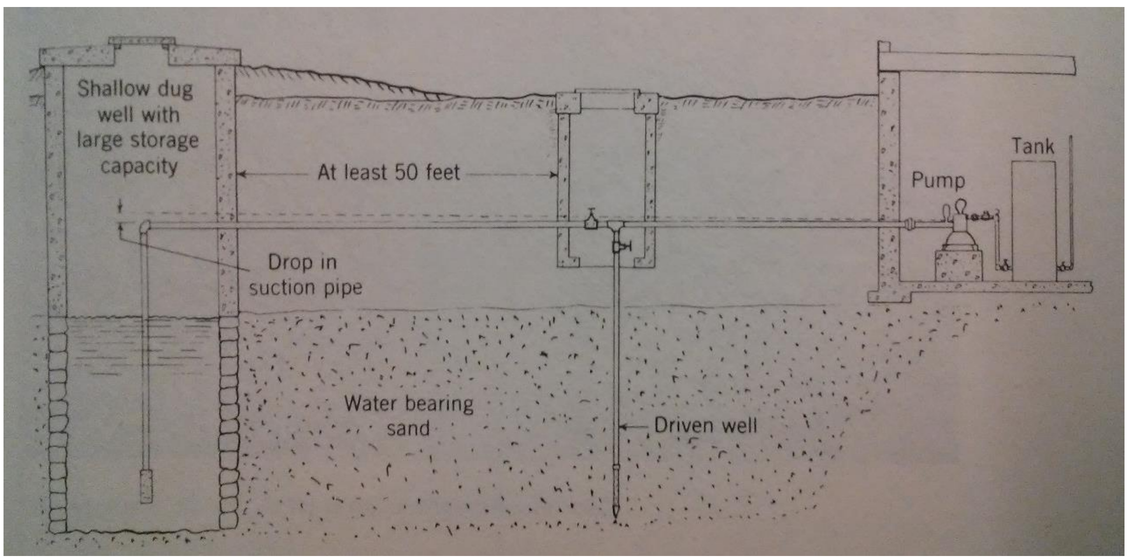


Figure 43 Tandem Well Arrangement (Wright, 1977)

6.11 Test Maximum Depth Capability

Testing the maximum depth capability of the Well-Driver PUP would be beneficial in the implementation of the attachment. Definitively knowing the vehicle's limitations and performance could increase the likelihood that this attachment will be taken seriously and would be used. The capabilities of the machine should be fully examined, perhaps at the test well 2 site as the maximum drive depth was achieved at this location. Driving past the 25 foot depth mark could classify the system as a "deep well" driver, which may add to the overall plausibility of the attachment in a variety of soils and regions.

6.12 Implement the Well-Driver PUP with a Waste Management Plan

The Well-Driver PUP project relied on the fact that a user could find an uncontaminated groundwater source. A highly sustainable, highly impactful water access solution would include best waste management practices with this system. Creating an impermeable barrier of human waste to the soil would prevent leaching by contaminants and bacteria, which are commonly known to infiltrate groundwater. Together, a proper waste management plan and a low-cost, sustainable water access solution would greatly help developing or underdeveloped countries the most.

7. CONCLUSION

A well-driving attachment to the PUP vehicle had been demonstrated to be a potentially viable water access solution in developing or under-developed countries, especially those with high to medium high water tables. The attachment could serve an important role particularly to those communities apart from government infrastructure. Well points were driven up to 23 feet, almost reaching into a "deep well" classification. Driven wells were quick to install. A new water well could be potentially installed in as little as a few hours. The components and installation remained relatively low-cost, which serve as an intermediate cost option between hand-dug wells and professionally drilled wells. Driven wells would have a modest level of protection from leaching contaminants, making them an excellent alternative to current low-cost water well types. The driver and well installation process remained straightforward, so minimal training would be necessary for operation. Anyone with a basic mechanical knowledge and a fundamental knowledge of geology should be able to operate the machine.

The impact of low-cost driven well installation could be huge in any developing or under-developed country. Nearby access to clean, safe water could provide immediate health benefits in the way of reduced transmission of waterborne pathogens, chronic skeletal or joint damages, as well as reduced infant mortality and longer average lifespans. It could provide immediate and long-term economic benefits in a form of reduced worker absence, improved worker performance, and higher education levels as more children may attend school. Furthermore, the well-driver attachment may also serve as a small business venture for local companies or entrepreneurs. Clean, safe water would provide an increased level of dignity to the people who benefit from it and a better standard of living.

APPENDIX A. WATER TEST FORMS

Public Health
Prevent. Promote. Protect.
Montgomery County
Health Department

PRIVATE WATER SUPPLY REPORT
Montgomery County Health Dept.
110 W. South Blvd.
Crawfordsville, IN 47933
Certified Lab ID#: 54-01
765-364-6440

Sample Number 137
Date Received [redacted]

SAMPLES SUBMITTED WITHOUT COMPLETED FORM WILL NOT BE ANALYZED. **USE BLACK INK**

[redacted]
(NAME)
[redacted]
(STREET)
[redacted]
(CITY, STATE, ZIP)

SAMPLE DESCRIPTION

Sample Source:
☐ Drilled Well ☐ Dug Wel ☑ Driven Well
☐ Spring ☐ Cistern ☐ Beach/Ditch

County ____________
Owner ____________
Date Collected [redacted] Time Collected 9:50A
Collected by ____________ Depth ____________
Phone [redacted]
Water use by ____________
Location of water supply ____________
Reason for examination test well
Age of well ________ Date of last repair ________
Location with respect to: privy ___ft. cesspool ____ft.
Septic tank ________ft. Sewers or drains ________ft.
Pump spout-open/closed_____ Require priming? ___
Well diameter ______ Is cover watertight?________

SAMPLE MUST BE TAKEN IN BOTTLE PROVIDED BY HEALTH DEPARTMENT
SAMPLES IN ANY OTHER CONTAINERS WILL BE TURNED AWAY

Fax Number: ____________
Email: [redacted]

TEST: TOTAL COLIFORM
METHOD:
☐ MF ☒ MPN ☐ LST P/A ☐ MM P/A ☐ MM QT

RESULTS:
☒ PRESENT
2.0
☐ ABSENT
ANALYST PP

TEST: ☐ **FECAL COLIFORM** ☒ **E. COLI**
METHOD:
☐ MF ☒ MPN ☐ EC P/A ☐ MM P/A ☐ MM QT

RESULTS:
☐ PRESENT
<1
☒ ABSENT
ANALYST PP

If P/A is checked the result is presence (P) or absence (A)
If MPN or MM QT is checked the result is the most probable number per 100 ml.

WATER LAB HOURS: MON-THUR 8AM-3:30PM
$20 PER SAMPLE

REPORT OF SAMPLES

☒ **SATISFACTORY:** At examination time, this water was bacteriologically safe based on USEPA standards.

☐ **UNSATISFACTORY:** At examination time, this water was bacteriologically unsafe.

☐ **PLEASE SUBMIT ANOTHER SAMPLE. TEST NOT VALID BECAUSE:**

☐ Too long in transit (more than 30 hours)
☐ Invalid/no collection date.
☐ Sample type not designated.
☐ Other ____________

Remarks:

Public Health
Prevent. Promote. Protect.
Montgomery County Health Department

PRIVATE WATER SUPPLY REPORT
Montgomery County Health Dept.
110 W. South Blvd.
Crawfordsville, IN 47933
Certified Lab ID#: 54-01
765-364-6440

EMAILED
MAR 20 2019
Initial: PP

Sample Number 2103

Date Received [redacted]

SAMPLES SUBMITTED WITHOUT COMPLETED FORM WILL NOT BE ANALYZED. **USE BLACK INK**

[redacted]
(NAME)
[redacted]
(STREET)
[redacted]
(CITY, STATE, ZIP)

TEST: TOTAL COLIFORM
METHOD:
☐ MF ☐ MPN ☐ LST P/A ☒ MM P/A ☐ MM QT

RESULTS:
☒ PRESENT

☐ ABSENT

ANALYST PP

TEST: ☐ FECAL COLIFORM ☒ E. COLI
METHOD:
☐ MF ☐ MPN ☐ EC P/A ☒ MM P/A ☐ MM QT

RESULTS:
☐ PRESENT

☒ ABSENT

ANALYST PP

If P/A is checked the result is presence (P) or absence (A)
If MPN or MM QT is checked the result is the most probable number per 100 ml.

SAMPLE DESCRIPTION

Sample Source:
☐ Drilled Well ☐ Dug Wel ☐ Driven Well
☐ Spring ☐ Cistern ☐ Beach/Ditch

County ____________________
Owner ____________________
Date Collected [redacted] Time Collected 9:24 AM

Collected by ____________ Depth ____________
Phone [redacted]
Water use by ____________________
Location of water supply ____________________
Reason for examination test well
Age of well ________ Date of last repair __________
Location with respect to: privy ___ft. cesspool ____ft.
Septic tank _________ft. Sewers or drains _______ft.
Pump spout-open/closed_____ Require priming? ___
Well diameter ______ Is cover watertight?_________

WATER LAB HOURS: MON-THUR 8AM-3:30PM
$20 PER SAMPLE

REPORT OF SAMPLES

☐ **SATISFACTORY:** At examination time, this water was bacteriologically safe based on USEPA standards.

☒ **UNSATISFACTORY:** At examination time, this water was bacteriologically unsafe.

☐ **PLEASE SUBMIT ANOTHER SAMPLE. TEST NOT VALID BECAUSE:**

☐ Too long in transit (more than 30 hours)

☐ Invalid/no collection date.

☐ Sample type not designated.

☐ Other ____________________

Remarks:

SAMPLE MUST BE TAKEN IN BOTTLE PROVIDED BY HEALTH DEPARTMENT
SAMPLES IN ANY OTHER CONTAINERS WILL BE TURNED AWAY

Fax Number: ____________________

Email: [redacted]

Public Health
Prevent. Promote. Protect.
Montgomery County
Health Department

PRIVATE WATER SUPPLY REPORT
Montgomery County Health Dept.
110 W. South Blvd.
Crawfordsville, IN 47933
Certified Lab ID#: 54-01
765-364-6440

Sample Number 295

Date Received [redacted]

SAMPLES SUBMITTED WITHOUT COMPLETED FORM WILL NOT BE ANALYZED. **USE BLACK INK**

[redacted]
(NAME)

[redacted]
(STREET)

[redacted]
(CITY, STATE, ZIP)

SAMPLE DESCRIPTION

Sample Source:
- ☐ Drilled Well
- ☐ Dug Wel
- ☑ Driven Well
- ☐ Spring
- ☐ Cistern
- ☐ Beach/Ditch

County ______
Owner ______
Date Collected [redacted] Time Collected 8:30A
Collected by ______ Depth ______
Phone [redacted]
Water use by ______
Location of water supply ______
Reason for examination ______
Age of well ______ Date of last repair ______
Location with respect to: privy ___ft. cesspool ___ft.
Septic tank ______ft. Sewers or drains ______ft.
Pump spout-open/closed____ Require priming? ___
Well diameter ______ Is cover watertight? ______

SAMPLE MUST BE TAKEN IN BOTTLE PROVIDED BY HEALTH DEPARTMENT
SAMPLES IN ANY OTHER CONTAINERS WILL BE TURNED AWAY

Fax Number: ______

Email: [redacted]

TEST: TOTAL COLIFORM
METHOD:
☐ MF ☐ MPN ☐ LST P/A ☒ MM P/A ☐ MM QT

RESULTS:
☐ PRESENT
☒ ABSENT

ANALYST PP

TEST: ☐ **FECAL COLIFORM** ☒ **E. COLI**
METHOD:
☐ MF ☐ MPN ☐ EC P/A ☒ MM P/A ☐ MM QT

RESULTS:
☐ PRESENT
☒ ABSENT

ANALYST PP

If P/A is checked the result is presence (P) or absence (A)
If MPN or MM QT is checked the result is the most probable number per 100 ml.

WATER LAB HOURS: MON-THUR 8AM-3:30PM
$20 PER SAMPLE

REPORT OF SAMPLES

☒ **SATISFACTORY:** At examination time, this water was bacteriologically safe based on USEPA standards.

☐ **UNSATISFACTORY:** At examination time, this water was bacteriologically unsafe.

☐ **PLEASE SUBMIT ANOTHER SAMPLE.**
TEST NOT VALID BECAUSE:

- ☐ Too long in transit (more than 30 hours)
- ☐ Invalid/no collection date.
- ☐ Sample type not designated.
- ☐ Other ______

Remarks:
______
______

Directions For Describing, Collecting and Delivering The Sample

- **Describing The Sample**

  1. The regulations of the Indiana State Department of Health provide that samples of water shall not be examined unless they are collected in containers furnished for the purpose and the description blanks are filled out completely.

- **Collecting The Sample**
  1. A dechlorinating agent has been added to the bottle. It may appear as a white crystal, a drop of water, or a spot of powder two or three millimeters in diameter. It is sodium thiosulfate. DO NOT wash or rinse it out. The purpose of the bottles containing thiosulfate is to destroy the chlorine present at the moment the sample is collected. Sodium thiosulfate prevents the killing action of the chlorine on the bacteria while the sample is being transported to the laboratory. Water samples which contain chlorine residuals when they reach the laboratory will not be examined.
  2. A sample shall be taken from a tap, such as a faucet, petcock, or small valve. No sample shall be taken from a fire or yard hydrant or a drinking fountain. Kitchen sinks, threaded hose bibs, softened or treated water lines, and spigots with screens or aerators are poor sampling points and should be used only if better sampling points are not available.
  3. When the sample is to be collected from a tap, allow the water to run freely for at least five minutes to flush out pipes and fixtures. Time by a watch; do not guess.
  4. Remove the screw cap being careful not to touch or otherwise contaminate the inside part of the cap or the neck of the bottle itself.
  5. Reduce flow of water in tap to a steady stream about the size of a pencil. Fill the bottle exactly to the 100ml line on the bottle. At this level, there will be 100ml of water and about 25ml of air space.
  6. Replace the screw cap using the same care as before.
- **Delivering The Sample**
  1. Samples are accepted Monday-Thursday, 8am-3:30pm.
  2. Cost per sample is $20, due when sample is brought in.
  3. Present/Absent test results for Ecoli and Coliform Bacteria will be ready 24 hours after sample is brought in.

APPENDIX B. DNR FORMS

RECORD OF WATER WELL
State Form 35680 (R5 / 9-04)

Fill in completely

Driller–Mail complete record in 30 days to:
INDIANA DEPT. OF NATURAL RESOURCES
Division of Water
402 W. Washington St., Rm. W264
Indianapolis, IN 46204-2641
(877) 928-3755 toll-free or (317) 232-4160

County Permit Number: N/A
DNR Variance Number:
Include if applicable

WELL LOCATION

County where drilled	Civil township name	Township number (N-S)	Range number (E-W)	Section
Montgomery	Coal Creek	20 N	5 W	016

Driving directions to the well location *(include trip origin, street & road names, intersecting roads, and compass directions)*. Show well address below and subdivision in box at lower right. There is space for a map on the reverse side.

Driving west out of New Richmond on 1050 N, turn south onto 500 W and follow for approximately one mile (just beyond small bridge). Well is on agricultural property to east, south of the treeline, near stream.

UTM Northing: 709471.68
UTM Easting: 5629686.15
Datum: ☐ NAD 27 X NAD 83
GPS used
Subdivision name & lot number (if applicable)

Well address: 9418 N 500 W; New Richmond, IN 47967

If drilled for water supply, this well is: X First well on property ☐ Replacement well ☐ Additional well on property ☐ Dry hole

OWNER - CONTRACTOR

Well owner–name: [illegible] Horn
Telephone number: [illegible]
Address *(number and street, city, state, ZIP code)*: [illegible]

Building contractor–name:
Address *(number and street, city, state, ZIP code)*:
Telephone number:

Drilling contractor–name:
Address *(number and street, city, state, ZIP code)*:
Telephone number:

Equipment operator–name: Robert Stwalley
License number of operator:
Date of well completion:

CONSTRUCTION DETAILS

Use of well: ☐ Home ☐ Public supply ☐ Industrial / commercial ☐ Livestock ☐ Irrigation X Monitoring / environ. ☐ Test hole Other:

Drilling method: ☐ Rotary ☐ Reverse rotary ☐ Cable tool ☐ Jet ☐ Bucket / bore ☐ Auger (including HSA) ☐ Direct push X Other: Driven

Type of pump: X Submersible ☐ Shallow-well jet ☐ Deep-well jet ☐ No pump installed Other:

Pump depth setting (feet): 23'

Total depth of well (feet)	23	**Borehole diameter** (in.)		**Gravel pack inserted**	☐ Yes X No
Casing length (feet)	20	**Casing diameter** (in.)	2	**Casing material** Other:	☐ PVC X Steel
Screen length (feet)	3	**Screen diameter** (in.)	2	**Screen material** Other:	☐ PVC X Steel
Screen slot size	#80 mesh	**Water quality** (clear, odor, etc.)	clear		

WELL CAPACITY TEST

Test method	Static level below surface	Gallons per min.	Hours tested	Drawdown (change in level)
☐ Air ☐ Bailing X Pumping	3 feet	3	1	1 feet

GROUTING

Grout material	Grout depth	Installation method	No. of bags used
Cement	from 0 to 2	Concurrent w/ Pad	8

WELL ABANDONMENT

Sealing material	Depth filled	Installation method	No. of bags used
	from to		

WELL LOG

FORMATIONS: Type of material	From (feet)	To (feet)
Sandy Loam	0	9
Silt Loam	9	23

Additional space for well log and comments on reverse side

I hereby swear or affirm, under the penalties for perjury, that the information submitted herewith is, to the best of my knowledge and belief, true, accurate, and complete.

Signature of drilling contractor or authorized representative MUST BE SIGNED OR STAMPED: Robert M. Stwalley III

Date:

SITE CONFIRMATION—FOR ADMINISTRATIVE USE ONLY*

—Well driller does not fill out this section—

County	Township	Range	1/4 of 1/4 of 1/4	Section
USGS topo map	Ft W of EL	Ground elevation	Reserve or grant name	Reserve No.
Field location By Date	Ft N of SL	Depth to bedrock	Subdivision name	Lot number
IRREGULAR LAND SURVEY other than 2nd Principal Meridian ❑ **GT** Greenville Treaty area (1st Prin. Merid.) ❑ **MD** Vincennes donations and grants ❑ **CMG** Clark Military Grant (sections 1-298) ❑ **MRL** Michigan Road Land (sections 1-45) ❑ **Reserve** granted by treaty (name above)	Ft E of WL Ft S of NL	Bedrock elevation Aquifer elevation	UTM coordinates on NAD 27 accepted, verified, or determined by Division of Water	UTM Northing UTM Easting

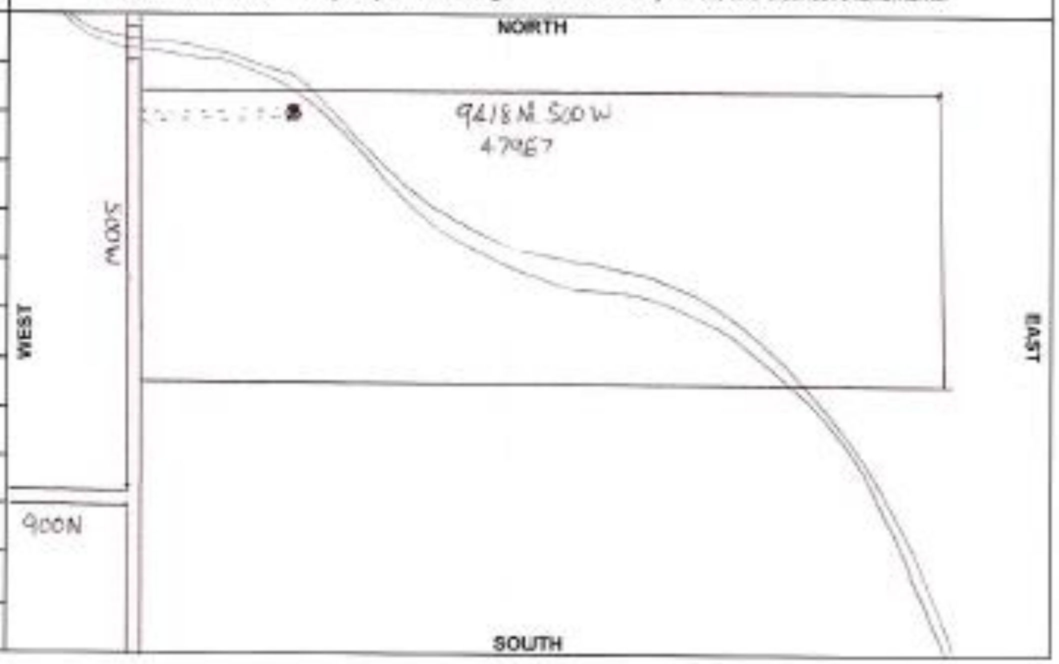
WELL LOG (continued from front)

FORMATIONS: Type of material	From (feet)	To (feet)

COMMENTS

MAP INSERT OR SKETCH SHOWING LOCATION

Locate with reference to highways, intersecting streets and county roads, and distinctive landmarks.



80

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