Cranfield UNIVERSITY
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HUMAN-POWERED DRILLING TECHNOLOGIES

an overview of human-powered drilling technologies
for shallow small diameter well construction, for
domestic and agricultural water supply

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1 Introduction

Technologies for accessing groundwater fall into four broad categories. These are:

- hand-digging
- human-powered methods
- small ‘conventional’ drilling rigs
- large ‘conventional’ drilling rigs

The first two categories include both ‘traditional’ methods (ie long-established, practised by skilled practitioners, but without the benefits of modern materials and ideas) and ‘improved’ technologies. ‘Conventional’ drilling means the standard ‘modern’ techniques of cable-tool percussion, mud-rotary and down-the-hole hammer, as used on small and large mechanical drill rigs.

Table 1 shows the broad characteristics of the four identified groups of technologies.

This paper briefly describes a range of primarily human-powered technologies for well construction which lie between (in cost, complexity of technology, and capability) hand-digging and ‘conventional’ small or large, truck- or trailer-mounted drilling rigs. These human-powered technologies are designed to construct small diameter wells[2], at costs closer to hand-digging than to conventional drilling.

2 Drilling Principles

Any well construction method (hand-digging, human-powered drilling, or ‘conventional’ drilling) requires three processes to be achieved:

➢ drilling tools must **break, cut or otherwise penetrate** the solid formation to be drilled. In the case of unconsolidated materials such as sand and silt, this does not require much energy; in the case of stiffer materials such as clays, or consolidated materials such as laterite, sandstone, limestone,

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[2] In this paper, the word “well” refers to a small diameter (from 50 to about 250mm) groundwater source. The words “borehole” and “tubewell” are often used with the same meaning. No distinction is made between these terms in this paper.

or granite, more (and sometimes a great deal more) energy is required. Well construction methods use one or more of the following methods to break or penetrate the formation:

- **percussion** (striking the formation with pick, chisel, end of pipe, or drill-bit);
- **rotary action** (grinding/tearing at the surface of the formation);
- **high energy percussion with rotation** (as in down-the hole hammer drilling);
- **loosening** by a water jet directed at the bottom of the hole.

➢ The broken/loose material must be removed from the hole. This may be done by one of two methods:

- **alternating with breaking** (ie break some, clean some, break again, ...). Hand-digging proceeds this way, as does percussion drilling in hard ground;
- **continuously** as drilling proceeds, by the use of a flushing medium (water, “mud”, compressed air). This is the principle of mud-rotary drilling (using mud[3]), well jetting or washboring (using water), and down-the-hole hammer drilling (using compressed air).

➢ If necessary, the hole must be **supported** to prevent collapse during or immediately after drilling. This may be done in one of the following ways:

- by **lining** the hole as excavation progresses (with temporary casing, or permanent lining);
- by **maintaining a sufficient hydraulic head** of fluid (water or mud) in the hole at all times.

Table 2 shows how these three features are addressed with each of the well construction methods.

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[3] Drill mud is water thickened with a natural or man-made powder or liquid, to increase its viscosity (and hence its ability to carry cut rock fragments up the hole).

Table 1 Features of Hand-digging, Human-powered drilling, and ‘conventional’ drilling

Feature	Hand-digging	Human-powered drilling	Conventional – small rigs	Conventional – large rigs
Construction technology	Headframe (tripod), windlass, rope, buckets, picks, shovels, hoes, chisels, hammers, dewatering pump, human labour. Sometimes: air supply, temporary support for excavation, explosives.	Frame, scaffold, or tripod (usually), drill pipes/rods, simple drill bits, rope, human labour, (for jetting or wasboring: small pump)	Light trailer-mounted or portable, site-assembled machines; pickup or alternative form of transport; drill pipes, mud pump, drill bits, compressor, hammer.	Truck- or trailer- mounted machine, trucks, pickups, drill pipes, mud-pump, compressor, hammer, temporary casing, drill bits.
Well lining options	Brick or stone masonry, in-situ or pre-cast concrete.	Traditional (eg bamboo) casing and screen, or plastic casing and screen.	Usually plastic casing and screen.	Steel, plastics – manufactured wellscreen and plain casing.
Well diameter	Minimum 1m, usual maximum 10m (parts of Asia).	Minimum 50mm, usual maximum 150mm (exceptionally up to 250mm)	50mm to 200mm, most commonly 100-150mm.	50mm to 1.2m Handpump wells commonly 150mm with 100mm linings.
Well depth	Commonly up to 30m, in extreme 120m.	Typically up to 30m	Typical maximum 50-100m	To 1000m+ Most water supply wells less than 100m.
Water abstraction options	Bucket-lift, handpump, suction lift by motor-pump.	Handpump, suction lift pump, occasionally submersible pump.	Handpumps, small electric submersibles, suction pumps (in favourable cases).	Handpumps, submersible pumps, suction pumps (in favourable cases).
Notional capital cost of construction technology[4]	“Improved” well construction equipment say US$5000	Traditional systems US$100. Simple “kits” and rigs up to US$5000.	US$20-30,000 for rig and drilling accessories (drill pipe, drill bits, mud pump). Extra for vehicles, compressors.	US$100-250,000.
Notional capital cost of well	20m “improved” well say US$1000	Traditional systems as little as US$10, with engineered rigs US$1000	Around US$1000.	20-30m borehole say US$5000. Not unusual to find cases 2-3 times this figure, especially in Africa.
Construction safety	Down-hole hazards: asphyxiation, gas, falling objects, hole collapse, falling on ascent/descent.	Hazards to hands, heads, backs, from human labour	Hazards associated with rotating machinery, compressor hose failure, falling objects.	Hazards associated with rotating machinery, reciprocating machinery, handling heavy loads, compressor hose failure, falling objects.
Construction speed	A few weeks to many months.	A few days to two weeks.	One to a few days.	Commonly one day.

[4] Cost estimates are “ball-park” figures, only for comparison within this table, and not to be used for budgeting. Real costs are very site and location-specific

Table 2 Breaking, Hole Cleaning, and Hole Support during Well Construction

Construction method	Ground breaking	Hole cleaning	Hole support
Hand-digging	Hand-tools and/or explosives.	Bucket, shovel, rope-lift.	In-situ permanent lining, or telescoped caissons; temporary support sometimes by timber or steel.
Human-powered methods			
Hand-augering	Hand-rotated cutting tool (auger) on end of solid steel rod or steel pipe.	Periodic removal of auger with drill rods/pipes.	Sometimes temporary plastic or steel casing is used.
Hand percussion	Human-powered lifting and dropping of tools suspended at end of rope.	Periodic removal of cutting tools, sometimes with use of bailer to gather spoil as slurry.	Temporary steel casing if needed
Sludging	Reciprocating action of steel pipe, by lever.	Pumping action of water down annulus and up drill pipe	Relies on water providing sufficient hydrostatic pressure for support.
Pounder rig	Reciprocating action of hard steel pipe with hardened steel bit.	Pumping action of water down annulus and up drill pipe .	Relies on water providing sufficient hydrostatic pressure for support.
Jetting (washboring)	Washing action of pumped water jet.	Flushing action of water pumped down drill pipe, flowing up annulus.	Hydrostatic pressure of water is usually sufficient. In running sand permanent or temporary casing can be installed during drilling.
Conventional methods (small and large rigs)			
Cable percussion	Engine-powered lifting and dropping of tools suspended at end of left-hand lay steel cable.	Periodic removal of cutting tools, sometimes with use of different tool to gather spoil as slurry.	Temporary steel casing if needed; water or mud can sometimes be used in place of temporary casing.
Mud rotary	Slow rotary action of drill bit together with washing action of pumped mud.	Flushing action of mud pumped down drill pipe, flowing up annulus.	Hydrostatic pressure of mud, if necessary with blocking/thickening agents is sufficient.
Down-the-hole hammer	Slow rotary action of rapidly percussing air-powered hammer.	Flushing action of high volume/high pressure air pumped down drill pipe, flowing up annulus.	In collapsing ground simultaneous (temporary) casing can be drawn in behind hammer.

3 Hand Augering

This is usually carried out with a heavy tripod fitted with a hand winch, using 100-150mm (exceptionally up to 250mm) diameter augers and 25-50mm drill rod (threaded or quick-coupling). Drilling is achieved by rotating the auger into the ground, and adding additional drill pipe as necessary from the top.

Capability: hand augering is suitable for a limited range of unconsolidated formations – non-collapsing sands and silts. Stiff clays, hard materials and gravels are difficult or impossible to remove unless augering is combined with some form of percussion. In collapsing formations, it is possible to use temporary casing with some equipment. Depth is restricted by the time taken to raise and dismantle drill rods to remove from an ever-increasing depth. In practice about 20m is the limit.

“Off-the shelf” equipment exists, so it is not usually necessary to explore local manufacture, unless foreign exchange is a real problem.

Note especially the Vonder Rig, a fully hand operated auger system manufactured in Zimbabwe, and used in many countries throughout Africa (V&W Engineering, for address see below). Equipment is also available from Eijkelkamp and Van Reekum (for addresses see below).

For further information see Blankwaardt (1984), DHV (1979), and Koegel (1985).

The Vonder Rig in action in Zimbabwe. Photo by R. C. Carter.

4 Hand Percussion

Percussion consists of the alternating breaking of formation and cleaning of hole, often with separate down-hole tools (eg chisel alternating with bailer), but sometimes with the same tool (for instance clay-cutting tools). Usually weight is supplied over the cutting tool. The tool string (weights, drilling tools) is suspended from rope or steel cable, which is reciprocated through a stroke of 1-3m. Often small amounts of water are added to the hole to loosen the formation. It is frequently necessary to line the hole with temporary steel casing to prevent collapse.

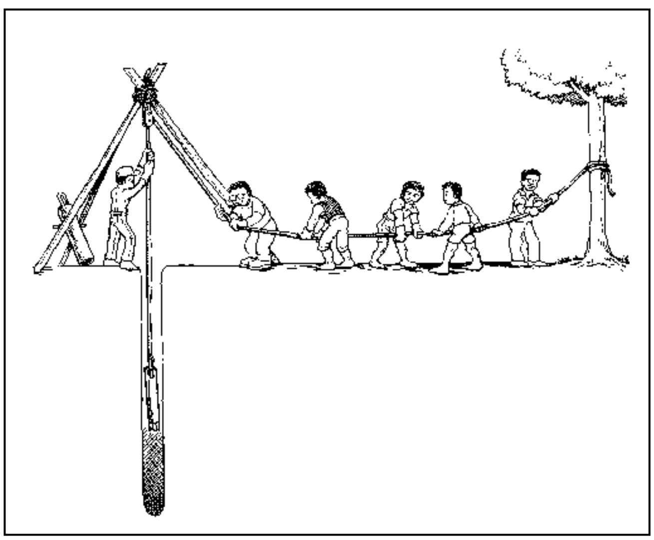
Percussion drilling can in principle deal with most ground conditions. However it is slow or very slow in hard rock, and hand percussion, with limited energy inputs, is even more restricted than conventional percussion. When temporary casing has to be used, the time taken driving and removing it can significantly increase drilling time.

It is difficult to find recent or current examples of "pure" percussion drilling (in other words percussion without rotary action or continuous hole flushing) using only human power. Most other human-powered techniques resort to an element of percussion when consolidated or cemented layers are encountered.

No off the shelf equipment for hand percussion is available.

The "Stonehammer" technique has been used in Nicaragua and north India in combination with, or as an alternative to, sludging or hand augering (see Van Herwijnen and Roy, 2002).

For further information on hand percussion see Koegel (1985) and Wellspring's website (http://www.wellspringafrica.org/) run by Cliff Missen.



Sketch from Wellspring Africa's website.

5 Asian Sludging

This is a traditional technique used in parts of Nepal, India, and Bangladesh, in which a steel pipe (25-40mm) is reciprocated vertically in a shallow pit which is kept full of water. The reciprocating action is achieved by use of a lever attached to a bamboo frame. One operator uses his hand over the top end of the pipe to act as a valve, while the other operates the lever. On the up-stroke the hand seals the top of the drill pipe, and on the down-stroke the operator releases his hand, allowing the cuttings to flow out of the pipe. Water from the pit moves down the annulus, and returns up the drilling pipe, carrying the spoil as a sludge. In effect this is a simple reverse circulation drilling technique. Thickeners or stabilisers can be added to the water in the pit in order to prevent hole collapse and reduce loss of circulation. Cow dung is commonly used, and sawdust is an alternative.

Sludging works best in silts and sands. Hard bands reduce speed or cause penetration to cease altogether. Clays can block the sludging pipe. Coarse gravels and other highly permeable materials cause loss of circulation, and hence failure to clean the hole.

Off the shelf sludging equipment is not available, and the traditional technique is a highly skilled operation.

For an illustrated account of traditional sludging in North West Bengal, India, see Ball and Danert (1999). See also Knight (1995).

Sludging in north India. Photo by P. Ball.

6 The Pounder Rig

This is a derivative of traditional sludging, adapted for African conditions (weathered overburden or 'regolith' over Basement rocks). The Pounder is a human-powered rig which can drill clay, silt, sand, gravel, laterite, and limited amounts of hard rock.

The drilling principle is exactly the same as that of traditional sludging, but the following are the main changes which have been made:

- the bamboo frame has been replaced with a steel frame which ensures verticality as well as assisting in the separation of cuttings from water, and the recirculation of the drilling water;
- the lever has been replaced with an overhead "see-saw" mechanism;
- one end of the "see-saw" supports the drill pipe, while the other can be fitted with a simple counterbalance;
- the hand-valve at the top of the drill pipe has been replaced with a steel and leather flap to perform the same function;
- the usual galvanised steel drill pipe has been replaced with carbon steel "wireline" drill pipe which is several times stronger than GI in order to resist the stresses imposed by impact on hard layers;
- hardened steel drill bits are used in hard rock;

The reports by Ball and Carter (2000) and Carter (2001) describe the Pounder rig and the wider Pounder project concept.

The Pounder rig in Uganda. Photo by K. Danert.

7 Well Jetting or Washboring

Out of all the human-powered drilling techniques described in this paper, jetting or washboring is the only one using mechanical power, in the form of a pump. Water is delivered (by handpump or centrifugal motor-pump) through an open ended pipe (usually up to 50mm), held vertically, and part-rotated and/or reciprocated. The washing action of the water creates a hole larger in diameter than the pipe (100-150mm), and return flow to the surface, up the annulus, carries the spoil out of the hole.

Suitable ground conditions are weakly cohesive sands and silts. Anything too hard will render the method ineffective, clay will be penetrated only very slowly, and gravels or other highly permeable deposits will result in lost circulation.

Equipment consists of: a centrifugal pump, suction hose, flexible delivery hose, elbow and swivel, jetting pipes, and (temporary casing).

Jetting is very fast in the right ground conditions, and it is possible to reach depths of 20m and more. The depth limitation relates to the ability of the operators to handle/lift the jetting pipe string.

Off-the-shelf equipment for well jetting is not available, but the assembly of a simple kit locally is not difficult. A key pioneer of well jetting technology in sub-Saharan Africa is Richard Cansdale (see http://www.swsfilt.co.uk/tech/tech3.htm)

For additional information see Carter (1985), Jose (1988), and Osola (1992).

Well jetting or washboring in northern Nigeria. Photo by R C Carter.

8 Generic issues

There are several issues affecting human-powered drilling, which are common to, or similar among, all the drilling techniques.

Siting: the choice of location for the well must take account, as appropriate, of user/community preference, hydrogeology, accessibility, local and national Government regulations, and the priorities of the donor agency. Although hydrogeology may have the final say, it is important that no single viewpoint dominates to the extent that other important aspects are ignored.

Energy: all the techniques described utilise human energy. Jetting or washboring is the only one described here which employs the assistance of an engine (driving the water pump). Breaking and removing earth material, especially consolidated/cemented materials, requires significant amounts of energy, and so there are limits to what human-powered drilling can achieve.

Diameter: this is related to the previous point. Since the amount of material to be cut and removed from the hole is proportional to the square of the hole diameter, human-powered drilling should aim to drill at the smallest possible diameter. To illustrate this, if a 63mm drilled hole is taken as the likely absolute minimum, and this is compared to larger diameters, then the volumes of spoil to be removed increase as follows:

63mm	1.0 unit
100mm	2.5 units
150mm	5.7 units
200mm	10.0 units

Handpump well design: extending the argument about energy and diameter, the logic is that conventional well designs (in which the drilled hole is lined with casing and screen, and the pump hangs freely within the casing) may be undesirable. “Direct installation” of handpumps, in which a well screen (attached to the bottom end of the pump cylinder), pump cylinder, and casing (which doubles as rising main) are permanently installed in the well, and only footvalve, plunger and pumprods are extractable, is a logical solution. However, as smaller diameter handpumps become increasingly available, ‘conventional’ well designs may be preferable once again.

Community/end user: human-powered drilling allows for, and in some cases requires, the participation of the community during construction. This is in contrast to “conventional” drilling, in which the machine arrives, the drilling time is very short, the operation is highly technical, and the community can hardly be involved. Community mobilisation and participation cannot be taken for granted, and it is often an area to which lip-service is paid.

Transport: all the equipment described needs to be moved from site to site, and this requires bicycle, ox- or donkey-cart, pickup, or truck, depending on the size and weight of the equipment. At one extreme – traditional sludging – bicycles suffice; at the other – some heavy tripods and hand auger equipment – a small truck is needed. Jetting equipment and the Pounder rig require a pickup for mobility.

Consumables: all techniques require the mobilisation to site of consumable materials which may include well screens and casing, pumps, gravel pack/formation stabiliser, sanitary seal material (eg bentonite, local clay, or cement), sand, aggregate, and cement for the handpump pump apron.

Water for drilling: some of the techniques described need significant amounts of water for drilling – especially sludging, Pounding, and jetting. Percussion and hand-augering also often benefit from the use of smaller quantities of water. This needs to be conveyed to the site.

Rig operator: careful consideration should be given as to who will operate any of the techniques described. The common options are local Government (direct labour teams), NGOs, and small private contractors.

Costing: the estimation of per well costs is a complex matter. It is common that elements of the real total cost are neglected. The true costs include siting, the mobilisation of equipment and consumables to and from site, time spent on site, wear-and-tear on equipment and vehicles, personnel costs, costs of materials supplied in kind by the community, overheads of the implementing organisation, and overheads of the donor (if applicable). Installed pumps and headworks are part of the cost of the well, and should be explicitly included. No two wells cost exactly the same, since they vary widely in location, depth, geology, and other aspects. It is important therefore to only use “average” well costs for budgeting purposes, but individual well costs for reimbursement of private contractors.

9 Annotated Bibliography

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19. Equipment and Contacts

Eijkelkamp (hand-auger kits)

Physical address:
Nijverheidsstraat 30
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Jon Naugle	Developed hand auger drilling in Niger in the 1990s. Now Senior Program Officer for Africa with Enterprise Works.	nauglej@enterpriseworks.org

[5] RWSN is the Rural Water Supply Network of the World Bank's Water and Sanitation Programme (WSP). See http://depuran.mhs.ch/ for more information.