EVALUATING THE INSTALLATION AND PERFORMANCE OF MANUALLY DRILLED WELLS IN NORTH-EASTERN MADAGASCAR

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Preface

This report completes the work I began seven years ago as a Peace Corps Volunteer in Madagascar. As a student, I was equipped to approach development with the eye of an engineer. Over the years I gained experiences at the grass roots level during my Peace Corps service (2006-2009), and later with BushProof (2009-current), a social enterprise working in rural development and the water sector. My experience managing a water supply project in northeastern Madagascar was impetus for writing this paper.

This report is submitted to complete my master's degree in environmental engineering from the Peace Corps Master's International Program in Civil and Environmental Engineering at Michigan Technological University.

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Acknowledgments

I wish to thank the following people for encouraging me to complete my degree work when I was tempted to leave it unfinished: Jonathan Annis, a friend and former Master's International student provided constant encouragement not only for this report but throughout my experience working and living in Madagascar. Jim Mihelcic, my previous advisor was steadfast in encouraging me to explore my talents as an engineer in development. Dave Watkins and Blair Orr were generous with their flexibility in allowing me to complete this work after a long hiatus. Finally, my parents Pam and David Barrett have supported me without hesitation and unconditionally throughout my schooling and I am forever indebted to them. I wish to dedicate this paper to my father, who left this world for another in 2011.

Abstract

Manual drilling is a popular solution for programs seeking to increase drinking water supply in rural Madagascar. Lightweight, affordable and locally produced drilling equipment allows rapid implementation where access is problematic and funds are limited. This report will look at the practical implications of using manual drilling as a one-step solution to potable water in rural development. The main benefits of using these techniques are time and cost savings. The author uses his experience managing a drilling campaign in northeastern Madagascar to explore the benefits and limitations of one particular drilling methodology – BushProof's Madrill technique. Just under 200 wells were drilled using this method in the course of one fiscal year (September 2011-September 2012). The paper explores what compromises must be considered in the quest for cost-effective boreholes and whether everybody - from the implementers to project managers to clients and lawmakers - are in agreement about the consequences of such compromises. The paper also discusses water quality issues encountered when drilling in shallow aquifers.

Introduction

The last decade has seen a mix of real progress and unfortunate setbacks for the water sector in Madagascar. Substantial reforms have been made and steps taken to introduce strategy and a legal and regulatory framework to the sector. A long list of initiatives culminated in the Madagascar Action Plan (MAP) in 2006 and the creation of a new Ministry of Water in 2008. While the framework was set for positive action in the sector, results have failed to meet ambitious targets. Water coverage rates in rural areas are reported to have risen from 15% in 1990 to 34% in 2010 but remain low (UNICEF, 2012). These statistics fall short of goals set in the MAP of 65% coverage by 2012 (Government of Madagascar, 2008). In addition, little is known about the effect of the 2009 political crisis on progress. Today, many donors have either suspended, cut or pulled out of investments altogether due to the prolonged instability of the country caused by the crisis (Ranaivojaona, 2013).

Given the current environment, there is a real need for affordable technologies that can be rapidly implemented to help meet earlier goals for water supply coverage in rural areas. One technology that has promise is manual drilling to tap into shallow, localized aquifers (UNICEF, 2009a). Manual drilling was used by BushProof to drill over 200 wells in northeast Madagascar in 2012 as part of a large water and sanitation project.

Objectives

The report takes a closer look at manual drilling and water quality in general through a literature review and the use a case study within the local context of one large donor-funded water project. The report will first look at why manual drilling is considered a viable technique for improving access to potable water and what types are currently in use inside and outside of Madagascar. The history of the cost-effective borehole will be introduced (Chapter 3).

In Chapter 4, the context of the case study will be given. The project that hosted the work will be described, as well as a ‘bio-sketch’ of the implementing organization, BushProof, and the development of their Madrill technique. Local and international standards for implementing water supply will be presented in regards to water quality. Finally, a brief description of the environmental context of the drilling areas will be presented.

Chapter 5 will give the methodology followed for the work itself. Details will be given about how wells were sited in coordination with project partners. BushProof's Madrill procedure will be explained with detail into the drilling, development and pumping procedures. The methodology for collecting, testing and analysing the boreholes water will also be given. Finally, the project's approach to management will be explained.

The results of the case study will be given in Chapter 6, followed by a discussion of practical implications encountered while implementing the boreholes. Finally, Chapter 7 will offer a conclusion and recommendations for those who wish to implement future manual drilling campaigns, and for those involved in water supply in general and in Madagascar.

The author hopes that this paper will add to the discussion begun by the *Manuel de Procedures* (Organization TARATRA, 2005) in regards to the practical implications of manual drilling technologies as well as water quality monitoring.

Literature review

Developments in the manual drilling sector have grown out of the idea that reductions in the cost of boreholes could dramatically increase the number of new water points being implemented each year, and thus go a long way towards meeting the Millennium Development Goals (MDGs) target for water supply.

While manual drilling is certainly not a new concept, only recently has a concentrated effort been placed on building capacity in the sector. The origin of this development can be traced to the work of Wurzel (2001) and Ball (2004) to address the problem of overpriced boreholes in Africa. Wurzel (2001) realized that there was a disparity between handpump and borehole costs in Africa. Whereas significant improvements had been made to handpump design and techniques to reduce costs, the same focus was lacking for borehole drilling techniques. To address this disparity, Wurzel (2001) argued that drilling costs could be reduced by designing boreholes specifically for handpump yields (~1 m^3/hr) and not overdrilling. He argued that groundwater in rural Africa would continue to be a primary source of potable water in the years to come and that hand pumps would be the preferred technique for lifting water to the user. Savings could be made by tailoring the borehole characteristics, including diameter and depth, to the need. Most importantly, these savings could be obtained without compromising the quality of the borehole (Wurzel 2001).

In a field note for the Rural Water and Sanitation Network (RWSN), Ball (2004) concludes that large increases in the number of boreholes constructed could be made possible by relaxing borehole standards to include smaller diameter wells and by promoting new and appropriate technologies for drilling. While both authors were focused on reducing costs for machine drilling, the same principles could presumably be applied to manual drilling.

These ideas were reinforced by Danert et al. (2008) in the paper "Cost-effective Boreholes," a document written for the Cost-Effective Boreholes (CEB) initiative of the RWSN. The document suggests that borehole costs and quality are influenced by six core factors and thirteen elements (Table 1). While the core factors cannot be easily controlled from within the sector, the paper argues, significant opportunity for improvement exists if one pays attention to each of the thirteen elements. Manual drilling techniques are said to be a viable alternative to machine drilling in the right environments and boreholes can be drilled for a fraction of the cost of conventional drilling (Danert et al., 2008).

Table 1. Core factors and elements for CEB proposed by RWSN (adapted from Danert et al., 2008)

Core factors	Elements
Physical environment	Operation and maintenance procedures
Sector players	Preference for local private sector drilling
Finance	Borehole standards and designs
Communications	Smaller and less costly rigs
Materials	Procurement
Fuel	Contract packaging
	Program and contract management
	Siting
	Supervision
	Pumping test
	Groundwater resources monitoring and evaluation
	Hydrogeological data
	Regulation, support and professionalization of the private sector

A case study conducted by Practica Foundation in Chad looked at the potential for manual drilling to increase the rate of delivery of new water points (UNICEF, 2009b). According to the paper, technical capacity has grown in the private sector over time despite a lack of government trust in the techniques. Early problems in the sector were due to water quality issues caused by the use of low-quality materials and the lack of adequate skill in siting wells, borehole design and supervision. Improvements had been noticed, however, as small private-sector businesses continued to drill and became competent in their techniques. This increased well installation capacity, the paper argues, coupled with favorable hydrogeological conditions and existing market potential, could help Chad reach the MDG target for access to drinking water. Donors and implementing organizations are encouraged to consider manual drilling as an appropriate and sustainable technology with the private-sector playing a key role.

Current manual drilling techniques

In general, any type of drilling must accomplish the following: 1) penetration of the formation, 2) removal of the cuttings or excavated materials and, if necessary 3) protection of the hole from collapsing (Carter, 2005). This report will focus in particular on those types that are known to be applicable in unconsolidated geological conditions such as sand, silt and clay formations. Table 2 summarizes several known methods and how they achieve the steps listed above:

Table 2. Comparison of methods (adapted from Carter, 2005)

Method	1) Penetration	2) Removal	3) Support of hole
Percussion	Lifting and dropping of tools	Periodic removal of cuttings manually or by entrainment in drill fluid	Temporary casing if needed or hydrostatic pressure of drill fluid
Augered	Rotary action of auger and drill pipes	Periodic removal of tools and cuttings	Temporary casing if needed
Driven	A drill pipe with a pointed end is driven into the formation from the surface	Material is not removed but rather the wellpoint is forced through it	Not necessary
Jetting	High velocity stream of water from the end of a drill pipe washes material ahead of it as it is lowered.	Water used for drilling returns to the surface by way of the annular space around the jetting pipe carrying the material removed with it.	Temporary casing if needed or hydrostatic pressure of drill fluid
Sludging	Reciprocating action of drill pipe by use of lever.	Pumping action of water down annulus and up drill pipe	Hydrostatic pressure of water.

Most manual drilling techniques consist of one or a combination of two of the methods listed above. This report will focus briefly on sludging and jetting techniques, which were analyzed by BushProof during the development of their Madrill technique.

Sludging

Developments in the sludging method can be traced back to traditional sludging techniques used in Asia (Carter, 2005). Steel pipes were reciprocated vertically in a pit of water to initiate the borehole. A driller moved the pipes up and down using the lever while another used his hand as a valve at the top of the pipes. The pipe was sealed on the upstroke, causing suction in the pipes, and open on the downstroke. Water drained down the annulus from the pit and returned up the drill pipes with cuttings in a sludge or slurry, hence the name “sludging”.

Improvements to this technique were made by Practica Foundation resulting in the Rota Sludge technique. As the name suggests, a rotary action was added by installing a handle on the drill pipes so that the drill bit could be used for cutting and scraping. Weighted bars were added to the drill pipes to enhance the percussion effect when lowering the pipes, and new drill bits were explored for better scraping and cutting. A stone hammer bit and equipment were also added for penetration though more compact layers. The Rota Sludge and stone hammer are promoted by Practica as a package technique (Van Herwijnen, 2005). Practica has since trained over 200 local technicians in Madagascar in the use of the Rota Sludge method. From 2007 to 2010, the Swiss NGO Medair used Rota Sludge to drill 434 boreholes in the Analanjirofo Region. During the same time, Catholic Relief Services drilled 95 boreholes in the south of Madagascar (Practica Foundation, 2012).

Baptist drilling was developed by the NGO Water for All in Bolivia. It is similar to sludging in that drilling pipes are reciprocated vertically in the borehole, and a valve is used to pump cuttings up through the pipes to the surface. The technique differs in that the valve is incorporated in the drill bit at the bottom of the drill pipes, and the pumping is therefore caused by displacement rather than suction (RWSN website, 2013).

Jetting

Richard Cansdale and SWS recorded developments in well jetting in Nigeria in the 1980s (SWS website, 1997). The technique is sometimes referred to as “washboring” and involves the use of mechanical power in the form of a pump to send water down through the drill pipes to aid in the cutting and removal process. The water and cuttings then travel up outside the drill pipes to the surface, where it is recycled back into the system (Carter, 2005). Several types of jetting are in use today. Rapid well jetting involves installing well casings during the jetting process. This is done either by using a self-jetting well-screen (where the casing and screen act as the jetting pipe) or by attaching jetting pipes to well screens and casings. This is perhaps the quickest method for installing wells. After the powerful cyclone Gafilo struck northeast Madagascar in 2004, the NGO Medair installed over 200 jetted wells in a rapid timeframe (Erpf and Gomme, 2005). In 2005, BushProof (see Chapter 2) jetted 150 wells in the course of 3 months (Robinson, 2006). Other techniques have adapted well jetting to go through harder formations in order to drill to deeper depths.

The EMAS technique, a variation of jetting, was developed by Wolfgang Buschner in Bolivia. The technique combines jetting, percussion and rotary methods. A lever aids in the vertical reciprocation of the drill pipes, a handle is used for rotating the drill pipes, and a bit enhances the cutting and removal of soil. Water is pumped down through the pipes by a manual hand pump (Cloesen, 2007).

The Madrill technique, developed by BushProof in Madagascar, is similar to EMAS in that it combines jetting, percussion and rotary actions, but differs in that it uses larger drill pipes and can produce larger diameter boreholes (Table 3).

Table 3. Technical specifications for BushProof's Madrill technique

Madrill (MAnual DRILLing)	
Type of borehole:	Manual
Max depth:	30 meters
Appropriate soil types:	All excluding hard rock
Diameter of borehole:	140 mm
Type of filter pack:	Natural or artificial
Type of casing:	PVC 63 mm
Type of screen:	PVC 63 mm

Advantages and disadvantages

All of the techniques share similar advantages. The materials required to drill the wells using each of these techniques are lightweight and inexpensive in comparison to larger drill rig equipment (Table 4). Local fabrication is possible provided one has access to basic metal and welding shops and technicians, cutting out importation costs for more complicated machine rigs. All techniques (with the exception of rapid well jetting) allow for penetration of up to 30m into the formation. If conditions are favorable, wells can be drilled and casing installed in the course of one workday.

Table 4. Comparison of approximate costs between Madrill and PAT 201[1] equipment.

	BushProof Madrill kit	PAT 201 rig[2]
Cost (USD)	2000	30,000
Weight (kg)	250	730

1. PAT 201 - Promotion of Appropriate Development Co. Ltd. Semi-manual rotary drilling machine.
2. PAT costs include importation fees.
Values were taken from multiple versions of BushProof and PAT equipment quotations and are therefore to be used as approximations only.

Disadvantages are also similar for each method. Access to a large amount of water on site is necessary for all jetting and sludging techniques. In cases where porous materials are encountered above the water table, temporary casings or the addition of drilling mud are required to prevent excessive loss of water into the soil. Each of these methods depends on hydrostatic pressure to keep the borehole from collapsing in loose sediments.

Water quality

Water quality is also known to be an issue when tapping into shallow groundwater aquifers. Regardless of what techniques are used, water derived from hand pumps and boreholes is untreated and a product of the local environment – *what you have is what you get,* so to say. Wurzel (2001) remarks that "water stored in aquifers is almost always of excellent microbiological and chemical quality". While he goes on to warn about the risk of bacteriological pollution in shallow water tables, his remarks do highlight a common perception in the water sector that drilled wells will be likely to produce acceptable water quality. In the document "*Tableau de Bord Social: Secteur Eau et Assainissement*" (Ministry of Energy and Mines, 2002), written about monitoring the activities of the water and sanitation sector, the author recognizes that while water is potable when it conforms to official physical/chemical and bacteriological norms, it is not always possible to test for such. Acknowledging this, the author concludes that one can generally consider water as potable when it originates from infrastructure that is protected against pollution. Water coming from a protected borehole and hand pump, for example, could therefore be considered potable. This perception (or misperception) can lead to problems in implementing shallow boreholes. This report will discuss water quality issues caused by problematic borehole installation as well as those caused by the natural and human environment surrounding the borehole.

Context and Methodology

Context

The following chapter seeks to place the work within the context of several important activities taking place in Madagascar. The implementation takes place within a large United States Agency for International Development (USAID) - funded project titled Ranon'Ala. As an employee of the private sector company BushProof, the author reported first to BushProof and then to the Ranon'Ala project management. Several documents outline standards and procedures for compliance to Malagasy law in regards to implementing water projects, and these are summarized herein. Finally, the overall environmental and hydro-geological context of the project zone is presented.

The Project Ranon'Ala

Ranon'Ala (also called Rural Access to New Opportunities for Health and Water Resource Management) means *water of the forest* in the Malagasy language, hinting at the dual purpose of the project to focus on water and the environment. The project began in 2011 and is currently being implemented by a consortium of partners including Catholic Relief Services (CRS) and their implementing partner Caritas, RTI International (RTI), Conservation International (CI), Human Networks International (HNI), and two private sector partners, BushProof and Sandandrano. The project is financed by USAID. The mandate for this project is "to ensure access to economically viable and safe water and sanitation services for improved health among vulnerable and poor communities in the districts of Mananara, Mandritsara and Soanierana Ivongo" (CRS, 2010). Figure 1 shows the district of Mananara Nord.

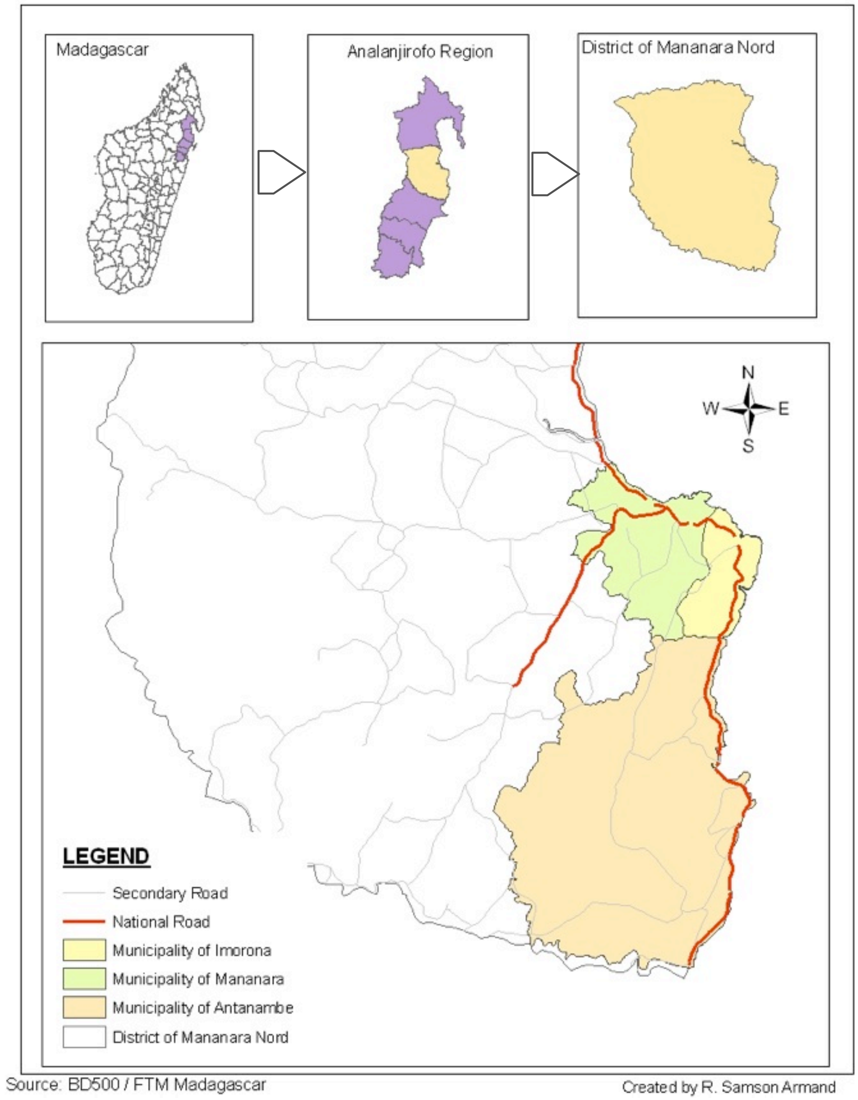

Figure 1. Map of the Ranon'Ala project zone for the district of Mananara Nord. A map of Soanierana Ivongo can be found in Appendix 4 at the end of the report (BushProof, 2013. Used by permission)

The goal of the project is to increase access to potable water to 57% of the population or 125,720 people. The project also intends to improve sanitation and hygiene among 80% of the population. The sites were chosen by USAID based on the low levels of access to clean water in the areas coupled with several other factors – opportunity for synergies with other USAID funded programs, a lack of water and sanitation investments by other NGOs and donors in the area, and the sites' physical location as buffer zones around protected national forests.

The Ranon'Ala project has ambitious goals that focus on capacity building within the sector by improving community governance structures, exploring sustainable financing methods and, perhaps most importantly, encouraging partnership with the private sector. The project seeks to "foster durable public-private partnerships at national and local levels" and has the following three strategic objectives (CRS, 2010):

- *Access to water infrastructure at the commune level is improved;*
- *Appropriate and diverse use of sustainable, safe water supply and sanitation services are increased;*
- *Water resources are protected and managed in a sustainable fashion.*

To this end, BushProof and Sandandrano where incorporated into the project team as decision makers, giving the private sector a voice in the development of the project.

BushProof

BushProof is a social enterprise that specializes in implementing water supply in remote areas in Madagascar. The company was founded in 2005 by two emergency and development professionals. They founded BushProof partly out of frustration with the pace of progress in the water sector but also to see if development by way of local private sector business could achieve more sustainable results. The company began exploring business models for various water supply products and services, with the idea that development could be more sustainable when products that were designed to improve health and wellbeing were made commercially viable and available to low-income households. The business model was two-fold: BushProof would leverage its understanding of the development sector to offer NGOs high impact results for less cost by using techniques like manual drilling. In addition, BushProof would target low-income families themselves with affordable products and services (BushProof website, 2013). A workshop for constructing the Canzee handpump (Table 5) was founded and production began in 2005.

Table 5. Technical specifications for BushProof's Canzee hand pump

The Canzee hand pump, named after it's inventor Richard Cansdale, is fabricated by BushProof in Antananarivo. The pump is approved and recommended by the government of Madagascar for communities of 100 to 200 people. The pump is resistant to ultraviolet rays and corrosive waters (it is mostly PVC with some stainless steel elements). Canzee pumps are ideal for remote areas because they do not contain pistons or seals that are difficult to replace. Valves, which are the main parts that wear out, are easily replaced with an inner tube of a bicycle or motorbike. A schematic of the pump can be seen in Appendix 5.

Max lift:	20 meters
Mechanism:	Direct action pump
Material:	UV- stabel ABS and PVC plastic
Max flow:	Between 20-35 liters per minute
Weight:	Pump head assembley 3 kg. Complete pump kit for 6 meters: 9 kg
Operating principle:	Vertically operated inner pipe within a fixed outer pipe, both fitted with a rubber disk non-return valve

BushProof received a grant from the World Bank to implement a jetting project in the southeast of Madagascar and successfully jetted 150 wells. The Madrill technique was developed by combining several types of existing manual drilling techniques. Since its founding, the company claims to have reached over 100,000 people with the benefits of safe drinking water. A total of 1000 wells have been drilled using the Madrill technique (Ranaivojaona, 2013). While the company has evolved over the years in its approach, incorporating machine drilling as well as construction of larger distribution systems (gravity / pumping), manual drilling with Madrill is still a primary activity. BushProof employs 44 full-time staff members at the time of this writing (Table 6).

Table 6. Current BushProof employees (Ranaivojaona, 2013)

	National	Expatriate
Administration	5	1
Technical Dept. *	28	2
Logistics	4	0
Workshop	4	0
Total	41	3
*Project managers, technical assistants, Madrill *chef d'equipe*, masons and drill assistants		

Standards, regulations and guidelines

Several documents regulate the environmental policies and procedures for the water and sanitation sector in Madagascar. The National Water Policy (*Code de L'Eau*) was introduced in 1999 (Ministry of Energy and Mines, 1999) and revised by decree in 2003 (Ministry of Energy and Mines, 2003). This document outlines the fundamental principles for protecting water resources in Madagascar and enhancing their management. Later, in 2005, guidelines were introduced via the *Manuel de Procedures* (Organization TARATRA, 2005) that aimed to bring harmony to the work of all actors working in the sector. Recommendations were given for every aspect of project implementation including site selection, manual drilling, appropriate hand pumps and control of water quantity and quality. In addition to national standards, the Ranon'Ala project was required to comply with USAID's environmental standards. Finally, most of these standards are based on World Health Organization (WHO) guidelines as stated in the document Guidelines for Drinking-water Quality (WHO, 2011). Table 7 summarizes and compares water quality standards from the relevant sources.

Table 7. Comparison of water quality standards

Parameter	Code[1]	Manuel[2]		USAID[3]	WHO[4]	Reason for guidelines
		Ideal	Max			
pH	6.5-9	6.5-8.5	4.5-10	-	-	Corrosion
Conductivity (µS/cm)	3000	2000	3400	-	-	Taste
Turbidity (NTU)	<5	5	20	-	5	Appearance, disinfection
Nitrates (mg/l NO3)	50	50	100	50	50	Health-based
Nitrite (mg/l NO2)	0.1	0.1	3	0.2	3	Health-based
Iron (mg/l Fe)	0.5	0.3	5	-	0.3	Staining
Arsenic (mg/l As)	0.05	0.01	0.05	0.05	0.01	Health-based
Thermotolerant coliform (E.coli) (TTC/100ml)	0	0	10	0	0	Health-based

1. Ministry of Energy and Mines. (1999). *Code de L'eau.* Ministry of Energy and Mines, Antananarivo, Madagascar.
2. Organization TARATRA. 2005. Manuel de Procedures Pour la Mis en Place des Projets Eau et Assainissement. Ministry of Energy and Mines, Antananarivo, Madagascar.
3. USAID/Madagascar Health Program: Drinking Water Quality Assurance Plan
4. WHO Drinking Water Guidelines, 4th ed.

Project area demographics and environment

The case study and drilling campaign took place in four rural municipalities within two of the three main districts - Soanierana Ivongo and Mananara. These municipalities are Manompana (farthest south), Antanambe, Imorona and Mananara Nord (farthest north). The total population of the zone is approximately 65,500 inhabitants. A *fokontany* is the lowest administrative structure in the Malagasy government. *Fokontany* and village are used interchangeably throughout this report. A total of 37 *fokontany* were initially selected by BushProof as feasible for manual drilling.

The project area starts about 560 km north-east of Antananarivo and is accessible by one main road, Route Nationale 5 (RN5), that travels north to Maroantsetra. The road crosses many rivers, and ferrys are used to transport vehicles. While most of the fokontany are located on the main road, some are farther inland and require transport by foot or canoe of distances up to 5 km. Villages are located along beaches or riverbanks or on hilltops farther inland. They are densely populated pastoral and fishing communities surrounded by rice fields and hillsides cultivated with fruit and spice trees and manioc.

The climate in the project zone is typical of the humid tropical weather characteristics along Madagascar's east coast. On average, the area experiences up to 3600 mm of rainfall annually, with cyclones passing the region regularly during the rainy season (BushProof, 2011).

Project Hydrogeological context

A brief description of the hydrogeological context is important so that one understands the variation encountered across the project zone. In general, three primary types of environments are encountered in the project zone – alluvial sands and dunes along the coastal stretches, Cretaceous clays and sandstone near river deltas, and weathered overburden in the mountain areas. Herivelo Rakotondrainibe classifies the areas as follows (Rakotondrainibe, 2006; translated by author):

Coastal areas:
Alluvial - lithology: clayey sands; type of porosity: porous; type of aquifer: captive or artesian according to the geological structure; static level: 2-3 m; borehole depth: up to 20 m; thickness of aquifer: up to 10m; water quality: fresh water, risk of saltwater intrusion; yield: 2-5 l/sec/m.

Beach sands/dunes: lithology: fine sands; type of porosity: porous; type of aquifer: free; static level: 2-3 m; borehole depth: 1-5 m; thickness of aquifer: 5 to 10 m; water quality: fresh to brackish; sometimes salty; yield: 0.4 to 2.6 l/sec/m.

River deltas:
Cretaceous aquifers: lithology: clayey sandstone; type of porosity: porous; type of aquifer: captive; static level: 2-3 m; borehole depth: up to 40 m; thickness of aquifer: 10-20 m; water quality: risk of iron; yield 0.18 l/sec/m.

Mountain valleys:
Nappes d'arènes: lithology: clayey sands; type of porosity: porous; type of aquifer: free; static level: 2-3 m; borehole depth: 4-15 m; thickness of aquifer: around 5 m; water quality: fresh water, low mineralization; yield: 0.2 – 0.5 l/sec/m.

Methodology

The work was undertaken in two phases. Phase I occurred from September 2011 – March 2012. Phase II followed directly after, from March -December 2012. After a review of progress in early 2012, improvements were made to the strategy. Teams where brought back to headquarters briefly and then sent back into the field.

Siting the wells

BushProof, in coordination with Catholic Relief Services and the implementing partner Caritas, performed feasibility studies at all municipalities in the project zone. Apart from an initial baseline study and water inventory, the feasibility study was the first point of contact for BushProof with the communities. The study included a desk study and a visit to each of the fokontany in the municipality.

The desk study included an examination of existing data: demographics, topographical maps, satellite imagery, and accessible hydro-geological and meteorological information .

A team of two technicians conducted the field visits. One technician from BushProof and one from the other private sector technical partner, Sandandrano (the technician from Sandandrano was a specialist in gravity-fed systems). It is important to note that in this initial study, all options were on the table in regards to choice of water supply technology. The primary focus, however, was on gravity systems where appropriate or multiple wells with hand pumps. Each municipality had between 10 – 20 fokontany. The teams where therefore limited to half a day in each of the fokontany. Tasks included the following:

- Meetings w/ community members and stakeholders;
- Presentation of the project and discussion about motivation;
- Rapid assessments of geology, hydrogeology, and existing water points;
- Selection of appropriate technology for the site;
- If drilling was feasible, selection of potential well sites;
- Observations about site accessibility, drilling water supply and housing for the teams and materials.

An estimated number of pumps per village was chosen during the desk study based on available population data. The number of wells was based on a 10-year design life and a 3% population growth rate. A mapping exercise was used to distribute this number of wells appropriately around the village, taking into consideration the distance between and surrounding users homes, possible pollution vectors and technical considerations (Figure 2). According to criteria, each site should be:

- at least 30 m from pollution source (latrine, contaminated hand-dug wells, trash pit, animal pen, river or pond, stagnant water);
- facilitate adequate drainage;
- less than 200 m from user homes to increase ownership and cut walking distance;
- at least 100 – 200 m between each well;
- equally dispersed throughout the village;
- at least 10 m from the road.

After the mapping exercise, the team then walked through the village to discuss the actual location with landholders and users. Once a site was selected, a document was written up with the landholder and GPS coordinates were recorded. BushProof would come later and drill a test well at this location.

Figure 2. Rudimentary mapping exercise to discern layout of village before further investigation and selection of drill sites. Photo by author.

BushProof's Madrill methodology

BushProof employed permanant and temporary drillers. Teams were made up of one *chef d'équipe,* or drill team leader, two assistant drillers and usually one part-time locally hired assistant (Figure 3). Most *chef d'équipe* have been with BushProof for more than two years and have considerable experience drilling throughout Madagascar. Seven drill teams were deployed for this project, as well as two masonry teams (consisting of two masons per team). Madrill teams drilled the wells, installed casings, developed and pumped the wells, and disinfected them. The masons constructed the sanitary slabs and installed fences.

Figure 3. Madrill team with equipment preparing to drill. Photo by author

A complete list of materials used for Madrill can be found in Appendix 2 at the end of the report. Madrill equipment has a weight of roughly 250 kg (~550 lbs) and a cost of about 2000 USD (material costs alone). Figure 4 shows the approximate volume of the materials.

Figure 4. Complete Madrill kit. Photo by author

Table 8 shows the standard cost price for Madrill (about 3000 USD). The price includes drilling, construction of the borehole, and installation of a standard apron with the BushProof-made Canzee hand pump. Transportation costs are not included. The pricing for the Ranon'Ala project was based on these values. As all USAID projects require a percentage of local cost share, BushProof proposed a unit price of 2500 USD for the Ranon'Ala project.

Table 8. Standard BushProof cost price for manual drilling (adapted from BushProof, 2010)

Madrill Pricing	Unit	EURO	USD
Step one: Drilling			
Test borehole (2 attempts)	Borehole	1260	1638
Mobilization	Day	45	59
Transport	-	real costs	
Step two: Completion (if borehole is positive)			
Completion: PVC casing and screen, gravel pack cleaning and development	Drilling	540	702
Handpump 32/40 VLOM with 6m (VAT waived)	Pump	375	488
Total (assuming 4 days work)			2945
Conversion: 1 euro = 1.3 USD			

The procedure followed for implementation of the wells was an adaption of BushProof's manual drilling standards outlined in the document *Standards de travail BushProof lors du travail sur le terrain* (BushProof, 2012a). The following steps were taken for installation of the water points:

1. *Site selection and preparation and installation of the team*

If the actual well sites were not selected in the initial field study, or if sites previously selected were deemed problematic, BushProof worked together with Caritas and local stakeholders to choose new sites. Once selected, teams were installed and the sites were prepared for drilling. A 4 meter by 4 meter area around the borehole location was cordoned off using security tape. Mud pits were dug and lined for recycling drilling fluid and settling of sediments. A starter hole was initiated and the first pipe with drillbit was installed, aided by a small drill table. The mud pit layout is given in Figure 5:

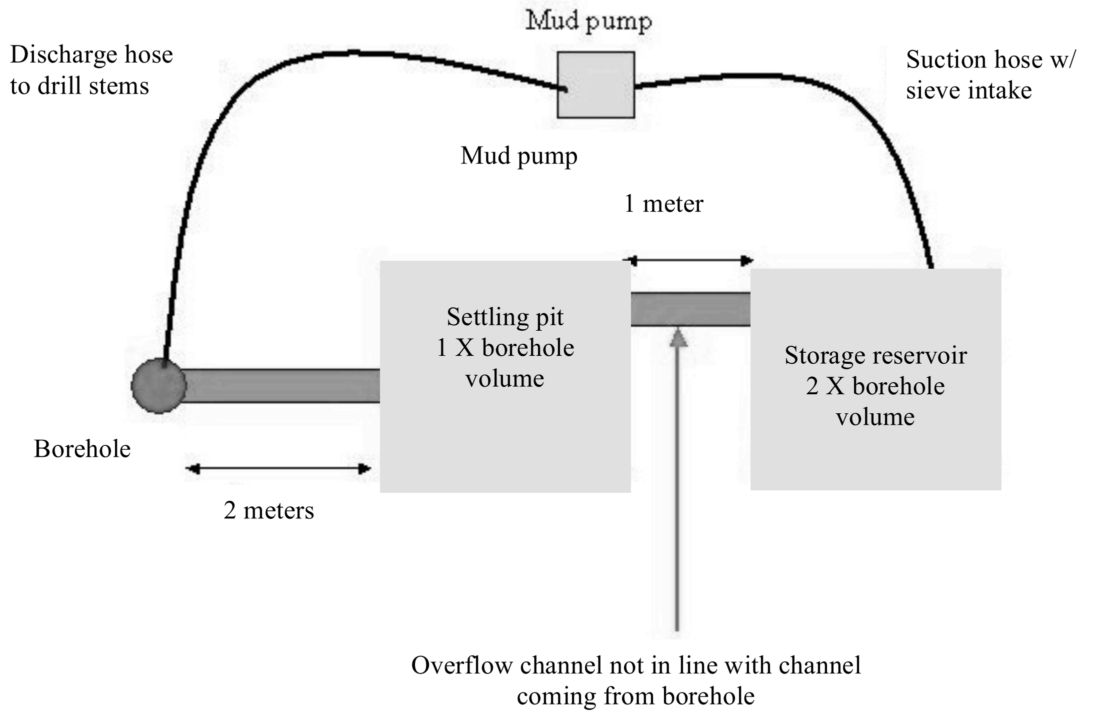

Figure 5. Layout of mud pits (used with permission from BushProof, 2009)

2. *Installation of the borehole*

Drilling utilized a mud pump to transport water from a reservoir (mud pit) to the hollow drill pipes, down to the bottom of the borehole where the drill bit is cutting the hole. The cuttings are transported up the hole between the drill pipe and the borehole (annulus) and evacuated to the settling pit. An overflow channel transports settled water to the reservoir where it is recycled by the pump. Drillers lift and drop the drill pipes and bit using a detachable steel handle secured to the upper-most drill pipe. On impact after the downstroke, drillers rotate the pipes a quarter turn clockwise to aid in cutting. On the upstroke, the pipes rotate back to the initial position. If necessary, clay is added to the drilling water to prevent excessive water loss into the formation and help stabilize the borhole.

A 150 mm hole is drilled in this fashion until a promising aquifer material is observed in the soil samples (usually large grain sand). Samples were taken every meter drilled by observing and collecting the material settled out of the drill slurry. Each sample is stored in a sample box (Figure 6) so that a rough profile of the formation characteristics can be observed.

Figure 6. Madrill sample box used for collecting soil samples from the drill slurry. Photo by author

BushProof standards recommend drilling as deep as possible into the water-bearing layer, with a minimum of 5 m from the static water level acceptable. A 63 mm PVC casing is prepared to include the sump, screen, and subsequent lengths of tubes. The sump is prepared locally by heating and forming the end of a 40 cm long section of 63 mm PVC. The screen is either prepared at BushProof headquarters or locally by using a hacksaw to cut horizontal slots into a section of 1 m 63 mm PVC. Slot sizes are between 1 to 2 mm. For this project, BushProof used screen lengths of 50 cm to 3 m. The boreholes were cased from the bottom to 40 cm above ground surface with 63 mm PVC (outer diameter). A filter pack was prepared using locally sourced, well-sorted sand. This sand is passed through 6 mm and 3 mm sieves. The sand is poured into the annulus between the casing and the borehole wall to cover the length of the screen and an additional meter above it. Regular sand is then placed up to the static water level unless there are water quality issues. If appropriate, a clay ring is installed above this by pouring clay pellets around the pipes and compacting. The hole is then backfilled to 50 cm below the surface, where a concrete seal is later constructed. Figure 7 shows a schematic of the standard installation.

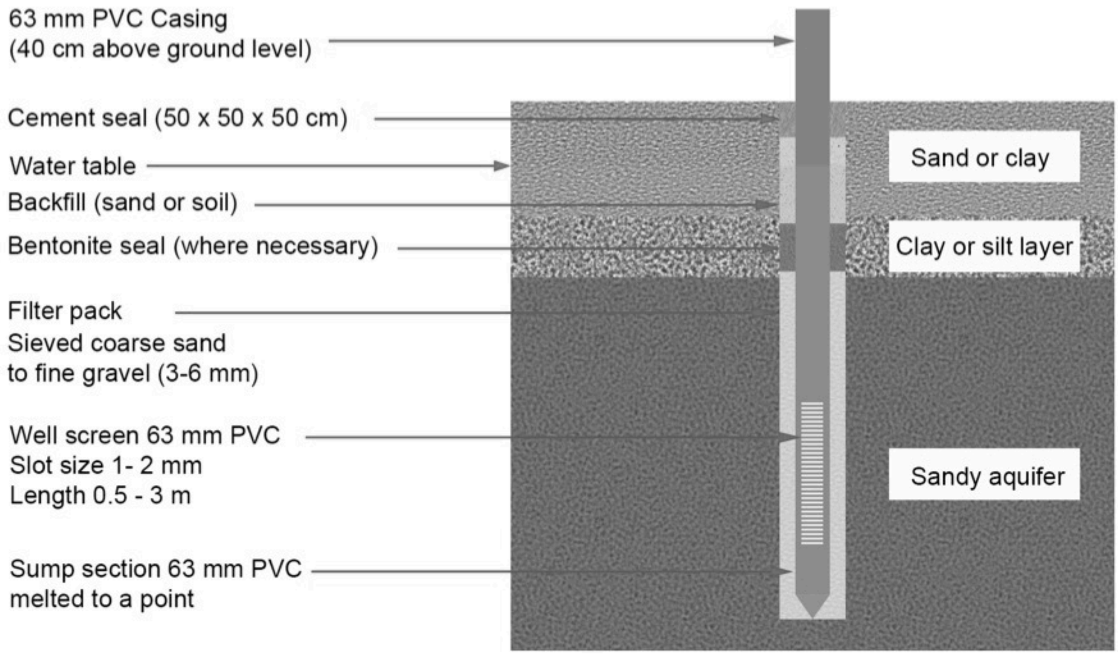

Figure 7. Standard BushProof manually drilled borehole

3. *Development/pump test*

After installation of the casing, the screen and gravel pack is developed by a combination of over pumping, rawhiding (see Driscoll, 1986) and mechanical surging using a modified Canzee pump designated for this purpose. The pipe is 40 mm with a valve on the bottom (acting as a surge block) and partially closed nozzle at the top. Water enters the valve on the down stroke and is lifted on the upstroke. Muddy water is expelled from the top. Periodically, the length of the pump is adjusted so that the valve sits at several depths along the length of the screen. This action continues until the water begins to clear. A preliminary observation of water quantity takes place during this time as water is pumped from the well. If the water clears rapidly, the inner plunger pipes of the Canzee can be installed and regular pumping is performed. The pump test constitutes continuous pumping until the following criteria is met:

- the flow is greater than 1000 l/hr;
- the water level does not drop below the pump valve at any time during pumping.

To meet this criterea, drilling teams are instructed to pump continuously until a minimum of 70 15-liter buckets of water have been removed from the well.

4. Disinfection by sodium hypochlorite

After development, sodium hypochlorite was used to disinfect the well. The procedure is outlined in the document *Standards pour la désinfection de forage* (BushProof, 2012b). First, water is tested for pH and turbidity. If the water is clear and normal in regards to pH, disinfection can proceed. *Sur'eau*, a local form of sodium hypochlorite (1.64%) is added to a bucket of water and poured into the well casing. The dosage is pre-calculated so that the *chefs d'équipe* can select the number of bottles to use based on the water column size. A Canzee pump is then installed and water is pumped to the surface until chlorine can be smelled. The pump is then left for 6 hours. If the smell of chlorine is present after this time, the well is pumped until no chlorine smell remains. If there is initially no smell, the pump is re-dosed and allowed to sit for another 6 hours. After all the chlorine has been pumped from the well, DPD1 (reagent used together with a basic pool testing kit to measure chlorine residual) is used to check for residual concentration. Only when no chlorine is present can samples be taken for testing.

5. Water quality sampling and testing

Sample collection was performed by the author, who travelled to and from drilling sites using a motorcycle. Samples were collected using the Canzee pump and plastic 500ml sample bottles. The procedure calls for wells to be pumped continuously for several minutes before sampling. During this time, sample bottles are washed three times and then filled, labeled and stored. Several parameters are tested at the well: turbidity, pH, conductivity, TDS, and temperature. Organoleptic parameters are also observed: smell, color and taste. These parameters are recorded in a BushProof testing log, *Resultats d'analyse eau pour Ranon'ala* (BushProof, 2012c). Samples are transported to an appropriate field testing location where further testing is conducted. Bacteriological tests must be performed within a 6-hour window. BushProof follows the Delagua procedure for membrane filtration testing of thermotolerant coliform (Figure 8). Physio-chemical tests were conducted within a two-day window with field kits supplied by Palintest. The following summarizes parameters tested for:

- Bacteriological: number of thermotolerant coliform (TTC) ;
- Organoleptic: smell, taste, color ;
- Physical: pH, turbidity, temperature, total dissolved solids (TDS), conductivity ;
- Chemical: Chlorine residual, Arsenic, Nitrate, Nitrite and Iron.

The following methods were used:

- TTC - membrane filtration (Delagua);
- Turbidity - turbidity tube (Delagua);
- Conductivity, pH and TDS - digital meter (Hanna Instruments);
- Arsenic - VisuPAsS system (Palintest);
- Nitrate and Nitrite – color comparator (Palintest);
- Iron and Manganese–color comparator (Palinest);
- Chlorine residual – Pool tester and DPD1 reagent (Delagua).

Figure 8. Bacteriological testing using membrane filtration. Photo by author

Equipment costs are summarized in Table 9. While most of these field kits use simple, relatively low-cost methods, it is interesting to point out that testing equipment, when all shipping and importation costs are incurred, is more than twice as expensive as one complete Madrill kit.

Table 9. Approximate costs for field kits*

Description	Cost (USD)
Complete Delaguawith consumables for 200 tests	2000
Arsenic kitwith consumables for 400 tests	300
Nitrites disk with reagent for 250 tests	100
Nitrates disk with reagent for 250 tests	150
Iron disk with reagent for 250 tests	140
Comparator disk holder and kit	125
pH/Conductivity/TDS digital meter	170
Total	2985

*Costs do not include all consumables, such as testing bottles or paper towels. Shipping and importation fees to Madagascar are also not included. Values were assembled from several quotations, old and new, and are therefore only meant to serve as approximations.

6. *Completion of the well*

If water quality and quantity were deemed acceptable, the sanitary slab was installed. Figure 9 shows the slab, which includes a 1.5 meter diameter apron, drainage canal of 2 meters, pump support and foot pedestal. At the end of the drainage canal, a simple soak pit was installed by filling a 50 x 50 x 50 cm hole with large gravel. A new Canzee pump is then installed and a circular fence is constructed around the sanitary slab.

Figure 9. Completed well with Canzee, apron and drainage (note: the chain seen in the photo was not used on project pumps). Photo by author

7. Trainings

Basic training on use of the pump and maintenance was given to the users surrounding the pump at the time of installation. This was not a complete training, however, as the mechanism for pump management was not in place at the time the pumps were completed.

8. Reporting

BushProof *chefs d'équipe* are responsible for keeping drill logs that document characteristics of the aquifer, borehole and pump, as well as the use of consumables such as fuel for the motorpump, PVC glue and masking tape. An example drill log can be seen in Appendix 3 at the end of the report. The information garnered from these documents was synthesised and reported to the project management periodically.

Results

Summary

Drilling activities took place in 37 villages in total. After the initial studies, 213 wells were expected to be drilled and completed over the course of phases I and II. Nineteen wells were abandoned before drilling due to a reevaluation of the feasibility of the site. In total, 259 wells were drilled and cased. This number includes wells that were abandoned and re-drilled due to technical problems or poor water quality or quantity. Some wells were re-drilled in completely different locations, while others where re-drilled very close to the original site (within meters) in order to explore different depths. Forty-five wells were drilled during the first six months in Phase I (October 2011-March 2012) and 214 wells during seven months in Phase II (April – October 2012). The increase in efficiency is explained in the discussion section. Table 10 shows a summary of the results by *fokontany*.

Of the 259 wells drilled, 170 were deemed appropriate in regards to water quantity and quality and were taken to completion by installation of the sanitary apron, pedestal, pump support and a Canzee pump. Due to logistical and financial reasons, only 52 fences were installed around completed pumps. One well was converted to a hand dug well to increase yield.

Table 10. Summary of results by *Fokontany*

District	Municipality	Fokontany	No. of expected boreholes	No. of boreholes drilled and cased*	No. of wells completed
Sonierana Ivongo	Manompana	Ambodimanga	3	3	0
		Antanambao Ambodimanga	7	10	7
		Ambohitsara	0	9	0
		Fandrarazana	6	6	5
		Sahabevava	7	8	6
		Ambohimarina	10	21	0
		Vatobe	6	8	6
		Ankobalava	3	3	3
		Anove Sud	11	11	7
		Moronivo	3	3	2
		Bevalaina	5	5	3
Mananara Nord	Antanambe	Anove Nord	8	12	9
		Malotrandro	8	10	10
		Ambatoharanana	4	4	4
		Manambato	15	15	15
		Tsaratanana	2	2	2
		Andapavolo	3	3	0
		Antanambao Mandrisy	12	18	11
		Mandrisy	6	6	5
		Vahibe	4	4	4
		Sahasoa	11	18	16
	Imorona	Seranambe	9	13	11
		Hoalampano	5	5	5
		Ambodivondrozana	3	2	0
		Antsirakivolo	5	5	5
	Mananara Nord	Mahambolona	3	3	2
		Analanampotsy	9	9	5
		Antanakoro	3	3	3
		Ambatomilona	3	3	3
		Ambatofitarafana	8	12	6
		Ankorabe	8	14	8
		Ambodiraotra-Centre	1	0	0
		Tanambao-Sata	3	0	0
		Tanambao-Ankady	2	0	0
		Soavinarivo	8	0	0
		Mahafinaritra	2	0	0
		Tampolo-Centre	7	11	7
		Total	213	259	169

*Includes re-drilling at site close by (within a few meters) when different depths where needed or technical issues were being amended.

Water quantity

Water quantity measurements were not tested using conventional pumping techniques. Rather, a simple continuous pumping test was performed using a Canzee handpump according to the given criterea (flow is greater than 1000 l/hr). This criterea is basen on a minimum flow of 600 l/hr as defined in the *Manuel de Procedures* (Organization TARATRA, 2005). Questions of seasonal variation were considered by the chef d'equipe by taking into account the borehole depth, static level and assumed hydrogeological environment surrounding the well. Boreholes were then listed as either positive (meeting the criterea) or negative (not meeting the criterea). Negative boreholes were redrilled where appropriate or abandoned if no alternative site could be found.

In summary, well depths ranged from 5 to 20 meters, with an average depth of 10.3 meters. The static water level ranged from just below ground surface at 0.25 meters to 11 meters deep, with an average of 3.5 meters. Seventy-six percent of wells drilled and cased met the criterea after manual pumping tests.

Water quality

Of the 259 wells drilled, a total of 192 wells were tested for water quality. Some wells that produced poor water quality or quantity were re-drilled before performing the official water quality test. Of the 192 wells tested, only 66 were tested for thermotolerant coliform due to timing and issues encountered during the development of the wells (see discussion below). Of the 66 tested, 54 or 80% tested below the upper limit for thermotolerant coliform (Manuel de Procedures: 10 TTC/100ml). Many of the wells drilled had a high concentration of iron (Figure 10). Out of 167 samples, only 44% were less than 0.5 mg/l Fe. Unfortunately, the equipment used was not able to detect values around the national limit of 0.3 mg/l (*Code de L'Eau*). Ninety-two percent, however, were under the upper limit of 5mg/l (*Manuel de Procedure*). As seen in Figure 11, 72 percent of 186 samples showed a turbidity of less than 20 NTU (Maximum allowed according to *Manuel de Procedures*). Forty-eight percent, however, had a turbidity over 5

NTU, suggesting issues with development and causing problems during disinfection, sampling and testing.

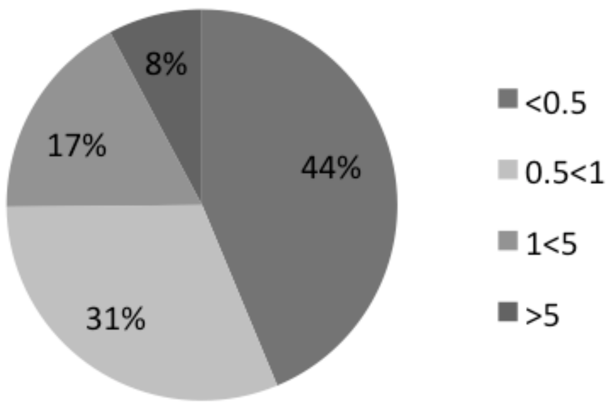

Figure 10. Iron (mg/l Fe)

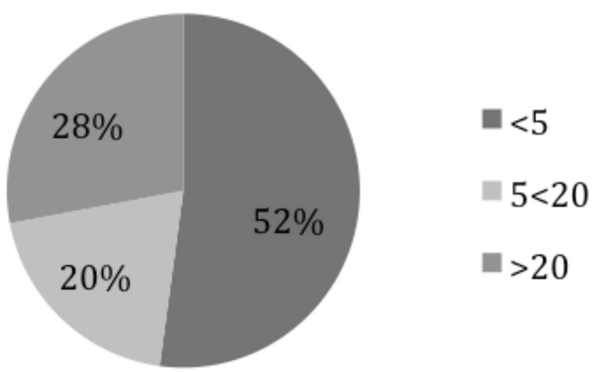

Figure 11. Turbidity (NTU)

Figures 12 and 13 show that none of the wells were above limits in regards to Nitrate and Nitrite (50 mg/l NO_3 and 3 mg/l NO_2, respectively). However, Nitrate levels in 20% of the wells are higher than 15 mg/l NO_3, indicating possible contamination. No wells in the project zone tested positive for arsenic.

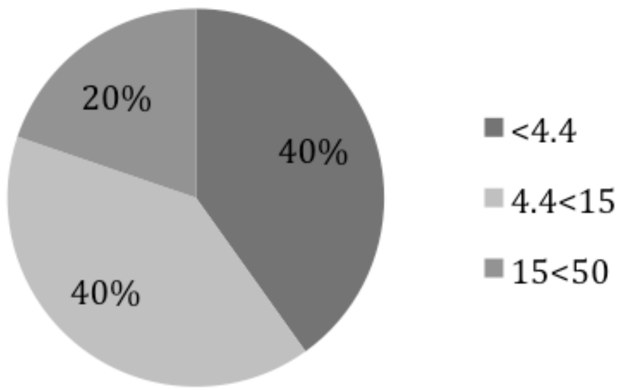

Figure 12. Nitrates (mg/l NO_3)

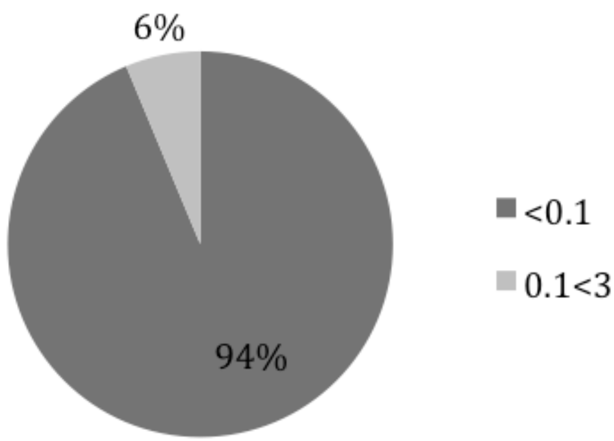

Figure 13. Nitrites (mg/l NO_2)

While many of the sites were located close to the ocean, saltwater intrusion was not a large issue, with only 1 well being above ideal national limits (2000 µS/cm – Manuel de Procedures) and 1 abandoned due to very high conductivity (>3000 µS/cm). Conductivity ranged from 16 – 2435 µS/cm, with an average of 236 µS/cm. It is important to note, however, that efforts were made during drilling to avoid salty water.

With strict adherence to the *Code de l'Eau* and the *Décrit* alone, only 3 of the completed wells can be considered potable. If one allows the upper and lower limits introduced in the *Manuel de Procedure*, however, the number increases to 39, or 23%. While these seem like dismal results, the numbers are low primarily due to the inability to complete bacteriological testing on all the wells, as well as issues encountered during construction, development and sampling of the boreholes.

Discussion

Following the recommendations of Danert et al. (2008), the thirteen elements will be used as a benchmark in discussing the project results. The following elements will be given priority in this report:

- Siting and supervision
- Borehole standards and design
- Groundwater resources monitoring and evaluation
- Hydrogeological data

Siting and supervision

Approach

Initially, sites were chosen based on the feasibility study alone. If a site was deemed feasible, a team would be sent to implement the wells until all the selected water points were drilled, regardless of problems encountered along the way. For example, in Ambohimarina (Table 21, Appendix 1), teams encountered difficult drilling conditions and poor water quality early in their work. Despite this, they drilled 12 boreholes throughout the village, to poor end results. Later, the wells were abandoned due to overly high iron concentrations, causing extreme disappointment to the villagers who had high expectations for the project. This problem exposed the weaknesses of the initial feasibility study. At sites where no existing wells are observed, drilling conditions were often based on the experience of the technician performing the study and a certain amount of guesswork, but certainly not a serious investigation of hydrogeology, which time and costs did not permit. This problem led to a change of strategy in Phase II. The initial boreholes would be considered as test boreholes or, in a sense, a continuation of the feasibility study. Villagers were informed well ahead of time that if results were poor in regards to water quality, the test wells would be removed and implementation would not continue past the study.

Siting wells

Siting wells was often an arduous task. Many factors had to be considered during the placement of each borehole. Significant emphasis was placed on locating the borehole close to the users' homes. To do this, someone had to agree to donate a plot of land to the government, as the pump would become public infrastructure. Often, villagers agreed initially to donate land only to change their minds afterwards. This caused considerable trouble when BushProof drillers arrived to start work only to find that the site was no longer appropriate. Also, the highest village official, or *president de fokontany,* often took advantage of his influence to locate well sites on his property. In general, community mobilization was problematic during implementation due to misunderstandings between Caritas, the 'soft' activity (community mobilization, sensitization) implementer, and BushProof, the implementer of 'hard' activities (infrastructure). BushProof felt that soft activities were often inadequate and unable to match the pace of hardware implementation, especially during Phase II.

Boreholes were also sited according to distances from user homes and pollution sources. This was very difficult in villages where pit latrines were common, as the goal was to site boreholes close to homes but greater than 30 meters from latrines. Coastal villages were particularly difficult because the villages run lengthwise north to south on both sides of the main road, as seen in the example of Sahasoa (Figure 14). In this village latrines were mainly on the beaches to the west, but also within the cluster of houses in the middle and at higher elevations to the east, where the terrain slopes up towards the mountains towards the north of the village. Unfortunately, again due to poor planning between project partners, little was being done to coordinate water supply activities with sanitation activities. Villagers were being encouraged to use and increase the number of latrines at the same time new boreholes were being implemented. Problems were also encountered with animal pens (pig and cow) and distances from irrigated rice fields. While deeper borehole depths would be ideal in these circumstances to reduce risk of bacteriological pollution, the risk of saltwater intrusion was also an issue. Finding the right balance was a formidable task.

Figure 14. The village of Sahasoa. The village runs parallel to the coast for a distance of about 1.2 kilometers. At the widest point, it is only about 200m. The road is about 50m from the beach and runs through the length of the village. Photo by author

In addition to the struggle with distances, the number of wells was also challenging. Initially designed for 10 yrs, the number of wells was based on 10-year growth in the population. A village with a current population of 1000, for example, would have a number of pumps designed to serve a future population of ($P_{10} = e^{(0.03X10)} = 1349$) users. While each well was designed to serve and "increase access" to 150 users, the actual number of users per well was much less due in part to the gowth factor. In addition, population figures often included small hamlets that were not served by the project due to their distance from the central village. For these reasons, the method of calculating number of wells per village (Pop ÷ 150) was perhaps overly simplistic. This is not necessarily an issue in the performance of the borehole itself, but it will be problematic later when private-sector management schemes are being developed. Fewer users will translate to lower revenues per water point, complicating possible business plans.

Supervision

Another weakness of the initial study was the decision to focus on more than one area at a time, with teams dispersed along the main road with distances of greater than 60 km between them. This was an early strategy mistake but highlights the importance of supervision and logistics in maximizing the benefits of manual drilling. Sixty kilometers seems like a small distance, but the road that leads from Ambodimanga (southernmost village in the project zone) to Mananara (northernmost town) is one of the worst in Madagascar and was in various stages of disrepair throughout the implementation window (Figure 15). The results for Phase I (45 wells in six months compared to 214 in Phase II) show clearly the effects of not consolidating the teams. Supervision of the teams was sporadic, and distribution of drilling materials and consumables was a great hindrance to drilling efficiency.

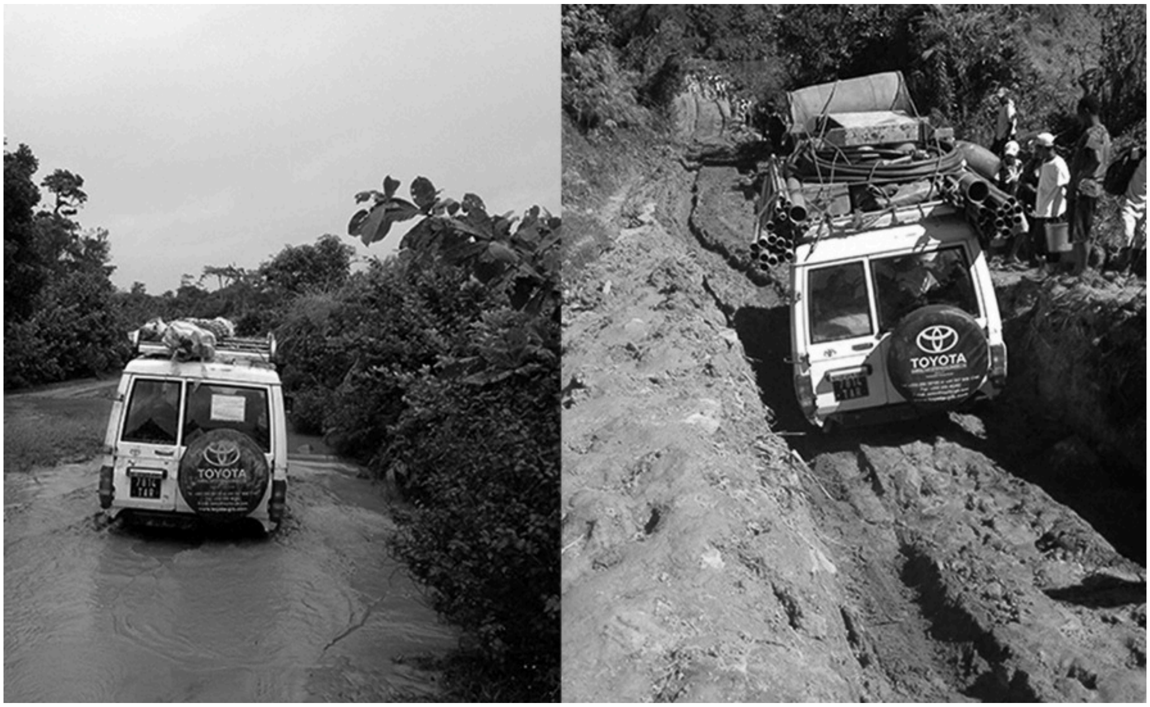

Figure 15. Road conditions caused constant logistical challenges. The BushProof vehicle was often inundated by floodwaters or stuck in mud for hours. Photo by author

In the past BushProof sent out drilling teams with assigned supervisors to ensure quality control. As the drillers are primarily uneducated technicians, this was to ensure that an experienced engineer or hydrologist could monitor the fieldwork. Later on, this was discontinued in an effort to cut costs during a time of financial crisis. *Chefs d'équipe* were assigned higher responsibility and expected to supervise their teams. In Phase I of the project, therefore, the drill teams were only under periodic supervision (once a month) from headquarters. Even when supervision arrived on site, it was brief, as time was lost traveling from the north to the south to visit all the teams. For this reason, problems encountered were not dealt with swiftly, and drilling rates were slow.

The teams were also without a permanent means for transport in Phase I. Materials needed for drilling such as PVC casings and screens, water, clay and consumables were constantly being used up before new shipments would arrive, causing delays. This continued into Phase II and was mostly unavoidable due to road conditions. The amount of materials needed to construct all of the wells and the logistical effort in distributing them to all the sites was underestimated at the beginning of the project. While the equipment used to drill the boreholes is indeed ‘light-weight’ and highly portable, one must think carefully about other construction materials such as water (for drilling) and sand and gravel (for concrete) and how they will arrive on site. Table 11 gives an estimation of weights of some of the materials needed for completing 170 wells. The decision to consolidate the teams and add permanent supervision in Phase II showed immediate improvements in results. This shows that while savings are possible in certain areas, shortcuts are not advisable in supervision and logistics.

Table 11. Weights of materials required for installing 170 borehole and wellhead

Materials	Weight (kg)
Drilling water	510000
Gravel pack (m3)	14025
Drill casings (kg)	2000
Pumps 6 m (kg)	1360
Cement (kg)	34000
Sand (kg)	89760
Gravel (kg)	84150
Fuel (kg)	962
Total	736257

Borehole standards and design

Borehole diameter

The Madrill technique uses drill bits of approximately 140 mm. This translates to a borehole diameter of roughly 150 mm. According to Wurzel (2001), this size is common in Africa where 100 mm well screens are used. Wurzel mentions that should a gravel pack be used, however, it is advisable to ream the borehole to 200 mm. This is due to the thickness of the annulus required for effectively installing a gravel pack (50 mm in this case). The rule of thumb for this dimension (thickness) is not clearly defined in the literature for low-cost wells. Driscol (1986) says that the thickness should be at least 76 mm. Ball (2004) says that conventional standards call for a 75-100 mm thickness but that shallow wells lined with PVC casing could have smaller thicknesses (he does not give a value). Godfrey and Ball (2003) suggest that moving away from convention is sometimes warranted and that gravel pack thicknesses can be reduced if PVC casing is used and the borehole is clean and shallow. Wurzel (2001) mentions that in Mozambique success has been had with thicknesses of as little as 25 mm.

The notion that there is room for flexibility in gravel pack thickness was checked by looking at turbidity levels and how they relate to borehole depth in 185 water samples. With a 63 mm casing and screen and a 150mm borehole, the Madrill technique has a 43.5 mm thickness. Interestingly, a correlation was observed where turbidity was an issue in more wells with deeper depths (Figure 16).

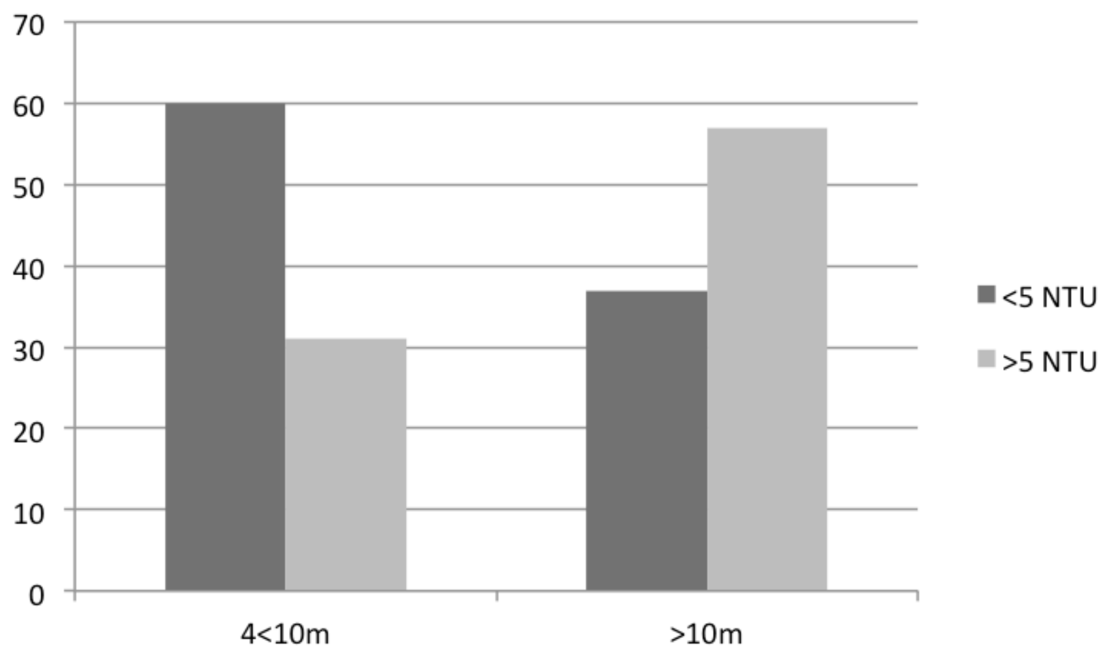

Figure 16. Correlation between borehole depth and Turbidity (number of boreholes)

This would suggest that the gravel pack might not be completely surrounding the filter, causing fines and silt to pass through. While it might not be the only reason or explanation, the small thickness could be hindering proper placement of the gravel pack. While reaming the borehole to a larger diameter is not impossible, it would require a significant increase in drilling water and a larger mud pump for adequate recycling of drill fluid.

Sixty-three millimeter casing, therefore, would seem to be the largest size appropriate for a manual drilled 150 mm hole. While this size accommodates nicely BushProof's direct action Canzee hand pump (with 32/40 mm PVC riser pipes), there is not much room for flexibility in other hand pumps or submergible pumps. While this works out well for BushProof and Canzee production, it might be an issue for those who want to install other pump types.

Development and Pumping tests

Development and pumping techniques may also play a part in whether a well is turbid or not and also have implications on water quantity. Wurzel (2001) argues that savings can be made when drilling low-yield boreholes by using less sophisticated development techniques. He recommends a combination of pumping, overpumping and surging, whereby a bailer pumps and surges at the same time. A variation of this technique is used by BushProof. BushProof standards require the use of a special Canzee outer riser pipe (40 mm) with foot valve and a handle for raising and lowering the pipe into the screen. The valve (Figure 17) acts like a piston in the screen 1) surging on the downstroke while muddy water is taken into the pump and displaced to the surface where it is expelled and 2) pulling water into the screen via displacement during the upstroke. In a sense, the valve acts like a surge block, with built-in pressure relief where the water enters the pipe. *Chefs d'équipe* are encouraged to develop the entire screen in this way by adding and taking out small sections (50 cm) of 40 mm pipe to lower and raise the valve. While surging is recommended for gravel pack development, both Driscol (1986) and MacDonald et al. (2005) mention that this technique is not suitable for aquifers where clay layers are present because the action can cause blocking or clogging of the formation. Driscol warns against over development where mica is observed in the aquifer.

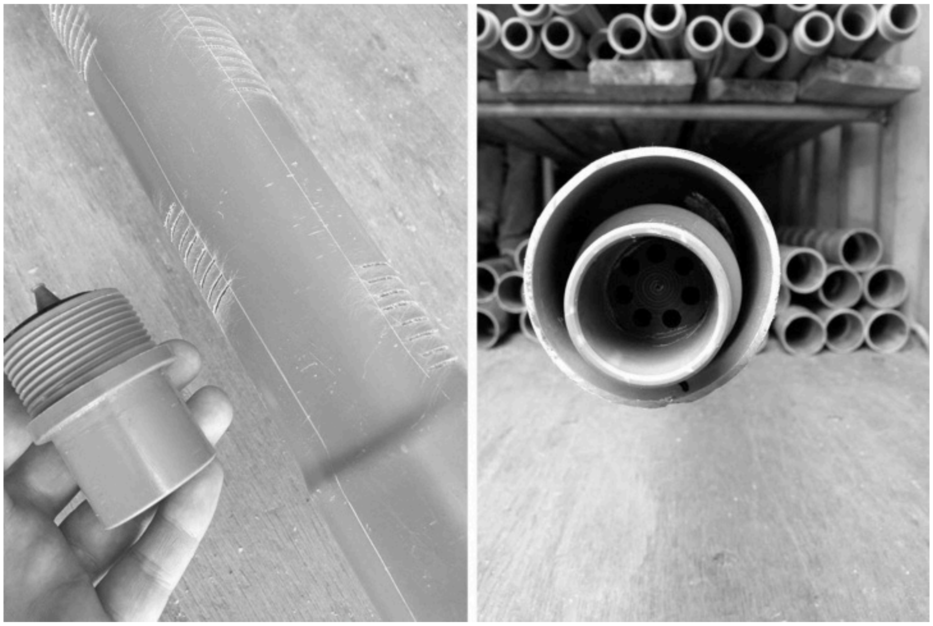

Figure 17. Canzee foot valve inside 63mm screen. Photo by author

The author observed that some *chefs d'équipe* were using various development techniques outside of those recommended in the BushProof standards. Some were using the Canzee with the inner 32 mm plunger during development (normal pumping). In this setup, the foot valve does not surge, but water is only pumped through the plunger. Others were simply over pumping by using the mud pump to constantly 'suck' water from the borehole. Others still were using the surging technique, as suggested, but in aquifers that showed a presence of clay and/or mica. While the use of multiple techniques is certainly appropriate given the variety of aquifer encountered across the project zone, it may be wishful thinking to suppose that the right technique was always applied at the right time. In addition, the author observed that care was not always made to ensure correct gravel sizes, and gluing of casing and screen components was often hurried. Also, many of the teams were using regular Canzee foot valves for developing the wells. These valves are not designed specifically for this purpose and may contribute to screen damage and turbidity in the well due to the possibility of sharp edges catching on the screen slots. All of these observations reveal that while Madrill teams are certainly effective in drilling boreholes, attention to detail is still important and improvements can be made. BushProof would do well to strengthen standards on development and pumping so that *chefs d'équipe* are knowledgeable about when and how to use diverse methods and tools.

In-depth analysis of borehole water quantity and aquifer characterisitcs is perhaps a weakness of the cost-effective borehole. Conventional testing is made almost impossible by the inability to use submergeable pumps (generally around 4 inches in diameter) in small diameter casings, as well as the difficulty in measuring drawdown in the confined space. While a continuous, multistage pump test could add a safety margin to account for seasonal variations, it is arguably not so vital for village boreholes where pumping is mostly intermittant. Unconventional pump tests are assumed to be suitable for assessing water quantity in low-yield boreholes fitted with hand pumps but are limiting in that no real water quantity data is obtained.

Groundwater resources monitoring and evaluation

Water quality

The water quality results at first seem dismal. Out of the 170 boreholes completed, only three wells could be classified as potable according to *Décret N° 2003* (Ministry of Energy and Mines, 2003) and 39 according to the *Manuel de Procedures* (Organization TARATRA, 2005). These numbers demand explanation.

A major cause of the low numbers is that BushProof was unable to test all the wells for bacteriological contamination, and wells that have not been tested cannot, of course, be assumed to be potable. At the start of the project, physico-chemical and bacteriological testing was performed on each completed well. A completed well is one that was cased, developed, pumped and installed with a Canzee hand pump. Several problems arose while collecting samples and testing for bacteria.

First, many of the wells had a high turbidity (48% were greater than 5 NTU). This is not uncommon with newly installed boreholes as they sometimes require continuous pumping to stay clear (see the discussion on borehole standards and design). New wells were not immediately opened to the public, so they would sometimes sit unused after the pumping tests and before sampling. Due to the number of boreholes and the distance between work sites, the sampling regime did not allow excessive time at each borehole to "pump the well clean" again. For this reason, turbidity levels were often observed and recorded as high after sampling. In addition to this, borehole testing occurred before installation of the concrete collar, sanitary apron and drainage. This was necessary to determine preliminary potability (in regards to iron, for example) before construction of components that would be hard to remove if water quality was poor. Initial bacteriological testing showed a presence of bacteria that was higher than expected even after disinfection by shock chlorination. An assumption was made that contamination was probably a result of 1) inefficiency during disinfection due to high turbidity and 2) contamination from the surface where pumped water was draining directly into the ground and around the casing. Many sites, especially in larger towns, were lacking basic sanitation services so areas around boreholes were exposed to litter (Figure 18). It was decided that bacteriological testing, therefore, should only be done after the installation of the sanitary slab and adequate drainage so that erroneous test results could be avoided. The well would be re-shocked, pumped clean and tested after completion of all wells in the area. In the meantime, physio-chemical results (especially nitrates, nitrites and iron) would provide initial indications of potability for the wells. Unfortunately, due to a number of factors outside BushProof's control, this testing activity (bacteriological) was postponed and is therefore beyond the context of this report.

Figure 18. Borehole casing with Canzee pump ready
for preliminary testing. Photo by author

Bacteria (thermo-tolerant coliform)

Out of the 66 samples that were tested for bacteria, 53% showed coliform values greater than 0 TTC/100ml. Thirty-three percent, however, showed values between 1 and 10 TTC/100ml (Figure 19).

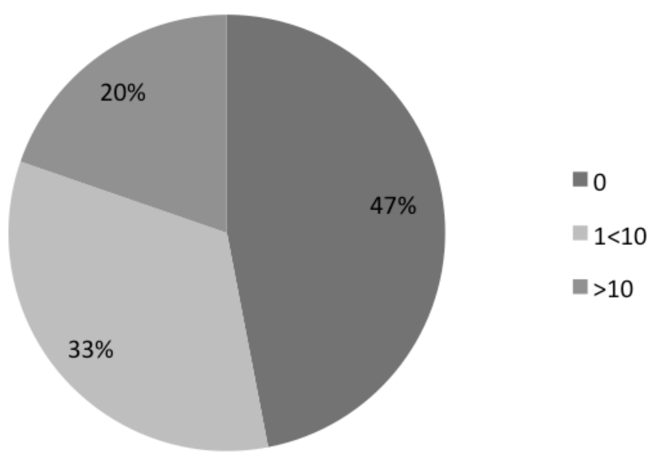

Figure 19. Thermotolerant coliform (TTC/100ml)

Due to the time constraints associated with testing boreholes, only one test per sample was performed. While this is certainly appropriate for giving an indication as to whether TTC are present, it is less useful when used to declare a water point potable or non-potable. One test alone gives no flexibility in regards to user error or changing conditions in the borehole. Ideally, several tests should be performed per sample so that a more reliable result is obtained. The flexibility allowed in the *Manuel de Procedures* (10 TTC/100ml) is therefore sensible when field-testing.

Iron

More than half of the wells tested showed iron concentrations greater than 0.5 mg/l Fe. This was by far the most frustrating parameter to deal with during the campaign. At concentrations of greater than 0.3 mg/l, color begins to be discernable in the water when ferrous iron reacts with air (oxygen) and changes to its ferric state (McDonald et al, 2005). Water is less aesthetically pleasing due to its color and ability to stain clothing, utensils and food (particularly rice in this context). In many of the drilling sites, iron was found in some wells but not others. For example, in Manambato (Figure 20) 60% had concentrations greater than 0.5 mg/l. If one adheres to *Décret N° 2003* (0.3 mg/l), more than half of the wells would be non-potable. Given that these guidelines are based on aesthetic considerations and are not health-based, it would seem that there is flexibility for compromise in cases such as Manambato. Indeed the *Manual de Procedures* allows for concentrations of up to 5 mg/l. Unfortunately, however, there was a great deal of disagreement between BushProof and project management at CRS on which document superseded the other (dates apparently are not ruling), and which standards should therefore be followed. Understanding that providing water supply to one half of a village would undoubtedly cause strife, BushProof made a unilateral decision later on to set the limit at 1 mg/l so that this problem would largely be avoided. In addition, attempts were made to isolate layers of water with lower iron concentrations by shortening screen lengths and exploring different borehole depths.

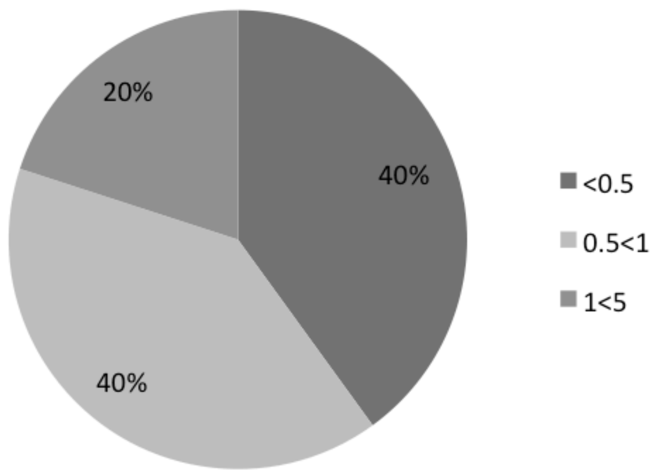

Figure 20. Concentrations of iron in Manambato (mg/l Fe)

Nitrates / Nitrites

In the absence of immediate bacteriological results caused by logistical difficulties, nitrate and nitrite testing was performed as an indicator of fecal contamination due to its ability to detect sewage and pit latrines. Concentrations higher than 15 mg/l NO_3 can indicate pollution from humans (McDonald et al, 2005). Twenty percent of tested wells showed concentrations higher than 15 mg/l. This is not surprising given the number and distribution of pit latrines and other pollution sources in the villages. Even though no tests showed concentrations higher than the limit of 50 mg/l NO_3, results do seem to suggest that pollution is occurring and care should be taken not to exacerbate the situation by poor siting of new latrines or wells. In the village of Seranambe, 5 out of 11 wells showed concentrations of nitrite higher than 0.1 but less than 3 mg/l NO_2 (Table 48, Appendix 1). Interestingly, all of the wells were shallow (5m) because of salinity issues at greater depths. The World Health Organization (WHO) recommends in the third edition of their "Guidelines for Drinking-water Quality" not exceeding 0.1mg/l for long-term exposure but allows up to 3 mg/l for short-term exposure (WHO, 2006). Most standards, however, are based on the lower limit of 0.1 mg/l alone, including those for USAID and the *Code de L'Eau*. Interestingly, in the 4th edition of the Guidelines (WHO, 2011), WHO eliminates the 0.1 mg/l limit as it was only "provisional" and now suggests the 3 mg/l limit. If one uses the lower limit to calculate combined nitrate and nitrite in Seranambe, the 5 wells with nitrite concentration would all be above standards and therefore non-potable (Table 12). If one uses the 3 mg/l limit, however, the combined result would be less than 1 and completion of the well would be allowed.

Table 12. Combined nitrate and nitrite results in Seranambe

			Combined*	
Well number	Nitrite (mg/l NO2)	Nitrate (mg/l NO3)	if Nitrite GV is 0.1 mg/l NO_2	if Nitrite GV is 3 mg/l NO_2
3	0.165	22	2.09	0.50
4	0.26	8.8	2.78	0.26
6	0.66	26.4	7.13	0.75
8	0.1	8.8	1.18	0.21
10	1	13.2	10.3	0.60
*$C_{nitrate}/GV_{nitrate} + C_{nitrite}/GV_{nitrite}$ less than or equal to 1, where C is concentration and GV is guideline value				

For the case of Seranambe, results from nitrate and nitrite proved useful to discern possible contamination from latrines. Where levels are in excess of guideline values, WHO recommends extra vigilance in bacteriological testing, as the presence of nitrate could exacerbate metahemoglobinemia in bottle-fed infants (WHO, 2011). As a side note, using nitrate and nitrite as an indicator for fecal coliform was a decision made by the author to get around the issue of erroneous bacteriological testing during implementation. Others have since warned that this is not a good idea, especially if it replaces bacteriological testing completely, because high nitrate levels can be due to fertilizers and organic influences such as decomposing roots, and not enough is known about whether E. coli produces nitrates. Its reliability as an indicator, therefore, is questionable (Fewster, 2012).

Testing equipment and personnel

While the testing equipment used was convenient for discerning approximate concentrations of various parameters, they were not without weaknesses. The color comparators used were often hard to read, and color differences between values were open to differing interpretations. The range of values for iron concentrations did not allow enough resolution around the important limit of 0.3 mg/l. Bacteriological testing was challenging in the field due to the importance of keeping a sterile environment. In addition, coordinating incubation periods around sampling and supervising tasks was difficult to manage. Several tests were time consuming. Arsenic, for example, requires about 30 minutes per test. A quick calculation reveals that if one were to test all 170 samples, as was expected and done during this project, it would require about eleven 8-hour working days to complete. Similarly, for bacteriological tests, sterilization of the filter apparatus requires a 15-minute wait between tests. For 170 samples, this equates to roughly six 8-hour days just to sterilize the apparatus. BushProof quickly learned that for this type of testing regime, multiple testing devices were fundamental to timely testing.

Even though field-based equipment and testing procedures are relatively simple techniques, attention to detail and strict adherence to procedures require well trained, knowledgeable technicians with the appropriate experience. There is currently a debate about who should conduct testing in projects; the implementer or an independent third party. While the law states clearly that one should test, practical solutions for the 'how' of testing in remote areas are not well developed. Experience shows that different project managers bring different interpretations of the law and standards, and conflicts can occur that impede good decision making and timely delivery of water points. Results indicate that good data can be garnered from the use of affordable testing equipment. More thought needs to go into determining who should be doing the testing and how.

Manual drilling campaigns can provide useful information about groundwater resources in an area if attention is paid to detail and the right personnel and equipment are used. Even if boreholes are abandoned due to poor water quality, the information is useful for future projects and area studies. Planning and proposals should take advantage of affordable techniques, but adequate resources should be allocated to allow for realistic testing regimes and trained personnel.

Hydrogeological data

Similar to water quality, manual drilling can produce valuable information about hydrogeological conditions in project areas, regardless of the potability of drilled wells. A quick perusal of the drill logs produced from this project reveals a great amount of useful data but a lack of attention to detail in regards to order and standardization of the sample profile. This is not surprising given the different levels of competence in BushProofs *chefs d'équipe* (some have been with BushProof longer than others). While some *chefs d'équipe* pay attention to different shades of soil and sand and particle sizes in their logs, others give less detail. There is also no standard for reporting color or size of the sample, so this is open to differences of interpretation by each *chef d'équipe* (see comparison of drill logs in Figure 21). Adequate information is obtained from the sampling method but emphasis is placed on immediate interpretation and subsequent placing of the screen and casings, rather than precise record keeping. With a little more standardization and supervision, accurate information could be garnered from drill logs and used to strengthen national databases. BushProof currently reports annually to the Malagasy Ministry of Water (MOW) about new water points, giving GPS coordinates, depth and other valid information. While this is encouraged by the MOW, there does not currently seem to be a coordinated effort amongst other implementors to comply (Monteleone, 2013). Simple techniques on groundwater resource assessment are available, however, and dissemination is encouraged in order to record valuable data for future analysis (Danert et al. 2008). BushProof would be prudent to look into this and incorporate such tools into future editions of their drilling standards.

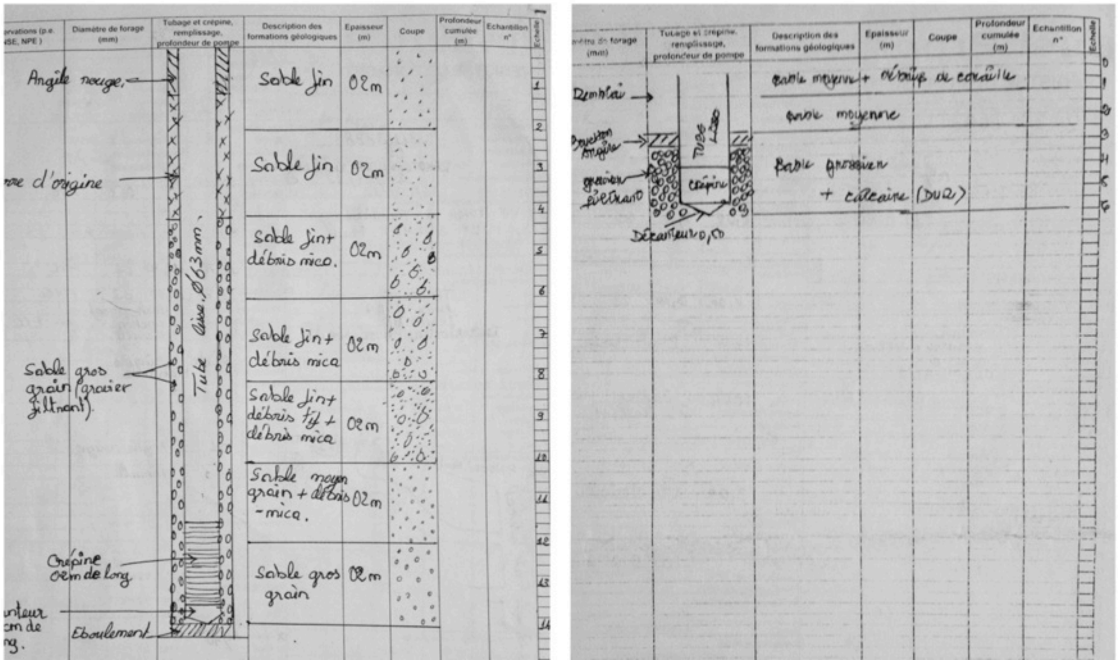

Figure 21. Comparison of drill logs from *chef d'équipe* X (left) and Y (right). X provides more detail and a better description of the sample profile than Y

Conclusion

Despite initial problems in phase I of the project, manual drilling proved to be a useful and effective tool for implementing water points rapidly in northeastern Madagascar. Improvements in supervision and logistics were vital to increase the rate of drilling success from around 8 boreholes per month in phase I to 30 in phase II. Consolidation of teams and a concentrated effort within a smaller region allowed closer monitoring of drilling activities and better coordination of transportation, drilling materials and consumables. Problems encountered throughout the campaign where addressed more quickly and more effectively by full-time supervision in the field and thus better coordination between headquarters and the field teams.

BushProof has made admirable improvements to its drilling technique and standards over the years, showing a desire to professionalize their approach to manual drilling. Steps have been made to standardize all procedures and put in place monitoring and quality control initiatives, such as water quality testing in the field. Testing goals are two-fold in that they serve to 1) demonstrate compliance with national and international norms to ensure safe and potable drinking water and 2) check quality for internal monitoring of BushProof standards.

The problem of turbidity in some wells, for example, indicates that there is still room for improvement in borehole design and development techniques. Particular attention should be paid to correctly installing gravel packs in deeper wells. This may involve double-checking the borehole before installation of casing to ensure smooth and clean borehole walls. Standards should be updated to account for various development techniques being used by the drill teams, with emphasis placed on matching techniques to the appropriate aquifer characteristics. Where mica and clay layers are observed, for example, extra care should be taken to avoid clogging of the gravel pack. Finally, each team should have and use specially designated development tools so that screens are not damaged and Canzee foot valves can be reserved for their intended purpose, to be installed new with the Canzee hand pumps.

Water quality testing and analysis during the project showed that tapping into shallow groundwater resources for potable water in the area is complicated by a variety of factors, some natural and others caused by human influence. The frequent yet sporadic occurrence of iron throughout the project zone presents a challenge to further development of groundwater resources in the area. Results show a high percentage of boreholes with concentrations higher than national and international standards for iron. As there are also plenty of wells with acceptable levels interspersed between these, flexibility should be allowed in regards to the limits. More credence should be given, for example, to health-based results in this situation. Boreholes that are clean in regards to other health-based parameters could still then contribute to increased access to improved drinking water despite unfortunate iron levels. Guidelines introduced in the Manual de

Procedures should be further validated by the Ministry of Water so that there is no confusion on this topic.

While perhaps not the best indicator for fecal pollution, nitrate and nitrite are still valuable when testing new boreholes for pollution, especially when latrines are scattered around the drill area. In towns where nitrate and nitrite levels were unusually high (Seranambe for example), extra care should be taken when installing new latrines and thought should be given to moving existing ones. Bacteriological testing should be conducted as soon as possible to ensure adequate safety of the wells.

Testing equipment and methods used during the project were adequate for discerning the presence of various contaminants but lacked in the precision and range necessary for a thorough analysis, especially in the case of iron and nitrites. Upgrading from simple color wheel tests to the use of a photometer would go a long way to correcting this. BushProof should also continue its dialogue with government actors to gain clarity about whether its testing services can be validated by some sort of certification. This would give weight to BushProof's service and encourage developments and further improvements.

This report focused only on a few of the elements proposed by RWSN for analysing and discussing cost-effective boreholes. BushProof and CRS would be wise to use the other elements as guidelines for a continued debate about the effectiveness of their partnership throughout the project. A more thorough review and synthesis of the many documents on this subject made available by RWSN would also be very helpful for both the private sector implementer and NGO partner.

Finally, BushProof's drilling methodology would benefit from further study into what causes fluctuating turbidity levels in some wells immediately after installation. At sites where wells can be jetted very quickly (within a day) it could be feasible to install several wells in close proximity within a similar aquifer for the purpose of analysis using different development techniques and tools. The borehole would have to be shallow (around 10 meters) to facilitate the removal of casing after analysis. In addition to testing various development techniques, one could also experiment with altering screen length and slot size, gravel pack installation and sanitary seal design. As there are an abundance of sites where iron is an issue, one could also observe how placement of seals at different depths might affect iron concentrations.

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Appendix 1: Results by Locality

Manompana

Ambodimanga

Table 13. Borehole characteristics – Ambodimanga

#	GPS cordinates	Depth (m)	Static level (m)
1	16°48'35.4"S/49°43'23.2"E	6	1
2	16°48'40.3"S/49°43'25.8"E	8.5	0.9
3	16°48'43.9"S/49°43'26.9"E	6.5	1

Table 14. Water quality results - Ambodimanga

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3)	Nitrite (mg/l NO_2)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	Y	Y	Y	>20	5.2	30	15	<4.4[1]	<0.07[2]	<10[3]	0	27	0.5<1
2	Y	Y	Y	10<20	5.3	91	45	<4.4	<0.07	<10	0	26	1
3	Y	Y	Y	5<10	5.4	72	36	<4.4	<0.07	<10	1	26	1

Antanambao Ambodimanga

Table 15. Borehole characteristics - Antanambao Ambodimanga

#	GPS cordinates	Depth (m)	Static level (m)
1	16°45'55.8"S/ 49°42'24.8"E	5.7	0.65
2	16°45'58.1"S/ 49°42'24.3"E	5.47	0.52
3	16°46'01.1"S/ 49°42'21.5"E	7.22	0.25
4	16°46'04.2"S/ 49°42'21.1"E	11.12	0.84
5	16°46'05.5"S/ 49°42'19.3"E	10.93	0.95
6	16°46'06.5"S/ 49°42'15.7"E	10.02	1.11
7	TBD	7.25	0.9

[1] Palintest comparator reads 1.0 mg/l N. This is the lowest value given on the color wheel. The figure is multiplied by 4.4 to convert to NO_3.

[2] Palintest comparator reads 0.02 mg/l N. This is the lowest value given on the color wheel. The figure is multiplied by 3.3 to convert to NO_2.

[3] Palintest VisuPAsS lowest value on color chart.

Table 16. Water quality results - Antanambao Ambodimanga

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	Y	5<10	5.6	32	14	<4.4	<0.07	<10	0	27	0.5<1
2	N	N	Y	<5	5.5	25	12	<4.4	<0.07	<10	0	27	0.5<1
3	N	N	Y	<5	5.3	27	13	<4.4	<0.07	<10	0	27	0.5<1
4	N	Y	Y	<5	5.5	24	12	<4.4	<0.07	<10	1	25	0.5<1
5	N	Y	Y	<5	5.5	20	9	<4.4	<0.07	<10	1	25	0.5<1
6	N	Y	Y	<5	5.3	16	9	<4.4	<0.07	<10	1	26	0.5<1
7	N	N	Y	5	5.8	34	14	<4.4	<0.07	<10	1	26	0.5<1

Fandrarazana

Table 17. Borehole characteristics - Fandrarazana

#	GPS cordinates	Depth (m)	Static level (m)
1	16°45'0.27"S/ 49°43'28.21"E	6	3
2	16°44'58.07"S/ 49°43'27.43"E	6	2.5
3	16°44'56.20"S/ 49°43'27.90"E	6	2.5
4	16°44'54.50"S/ 49°43'29.30"E	6	2.5
5	16°44'52.70"S/ 49°43'30.45"E	6	2.5
6	16°44'50.53"S/ 49°43'31.16"E	6	2.5

Table 18. Water quality results - Fandrarazana

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	Y	N	N	<5	5.6	165	82	26.4	<0.07	<10	9	29	<0.5
2	N	N	N	<5	5.8	115	57	6.6	<0.07	<10	>10	29	<0.5
3	N	N	N	<5	5.5	162	81	22	<0.07	<10	>10	27	<0.5
4	Y	N	N	<5	5.9	86	43	<4.4	<0.07	<10	9	28	0.5<1

5	N	N	N	<5	5.4	42	21	<4.4	<0.07	<10	0	27	<0.5
6	Y	N	N	<5	5.6	97	48	8.8	<0.07	<10	5	27	0.5

Sahabevava

Table 19. Borehole characteristics - Sahabevava

#	GPS cordinates	Depth (m)	Static level (m)
1	16°42'40.5"S/ 49°43'17.1"E	6	1
2	16°42'46.3"S/ 49°43'13.7"E	11	1.5
3	16°42'48.8"S/ 49°43'13.2"E	8	1
4	16°42'51.4"S/ 49°43'12.9"E	15	1.5
5	16°42'55.4"S/ 49°43'13.6"E	8	2
6	16°43'00.8"S/ 49°43'14.0"E	5	1
7	16°43'12.4"S/ 49°43'15.8"E	7	1.5
8	16°43'16.2"S/ 49°43'15.2"E	6	1

Table 20. Water quality results - Sahabevava

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1						>3000							
2	Y	N	N	5	7.3	790	393	<4.4	<0.07	<10	0	29	0.5<1
3	Y	N	N	<5	7.4	288	144	<4.4	<0.07	<10	>10	29	0.5<1
4	Y	N	N	<5	7.4	218	107	<4.4	<0.07	<10	>10	27	0.5<1
5	Y	N	N	<5	7.3	393	197	<4.4	<0.07	<10	0	28	1
6	N	N	N	<5	7.4	390	195	<4.4	<0.07	<10	>10	27	0.5<1
7	N	Y	N	5<10	7	415	204	<4.4	<0.07	<10	10	27	1.5<2
	N	N	N	5<10	7.3	340	170	<4.4	<0.07	<10	1	25	0.5<1

Ambohimarina

Table 21. Borehole characteristics - Ambohimarina

#	GPS cordinates	Depth (m)	Static level (m)
1	TBD	12	8
2	16°42'10.5"S/ 49°43'10.8"E	20	8
3	16°42'9.2"S/ 49°43'07.5"E	14	2
4	16°42'04.8"S/ 49°43'05.9"E	24	8.8
5	16°42'00.3"S/ 49°43'04.8"E	20	7.4
6	16°41'53.7"S/ 49°43'02.9"E	16	8
7	16°41'46.6"S/ 49°43'03.7"E	15.5	9
8	16°42'07.9"S/ 49°43'05.1"E	13	2.2
9	16°42'07.1"S/ 49°43'00.4"E	14	3
10	16°42'13.7"S/ 49°43'06.5"E	17	9
11	16°42'16.8"S/ 49°43'05.9"E	18	11

Table 22. Water quality results - Ambohimarina

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	Y	Y	-	>20	6.1	116	59		<0.07	<10	0	26	2
2	Y	Y	-	5<10	6.3	168	84	<4.4	<0.07	<10	0	26	10
3	Y	N	-	>20	6	64	32		<0.07	<10	0	27	7.5
4	Y	Y	-	>20	6.7	103	57		<0.07	<10	0	26	4
5	Y	N	-	>20	6.8	187	93		<0.07	<10	0	25	10
6	Y	Y	-	20	6	115	58		<0.07	<10	0	26	10
7	Y	N	-	>20	6.6	150	75			<10	0	26	>10
8	Y	Y	-	>20	5.6	61	30			<10	-	26	10
9	N	N	-	20	6.4	136	66	<4.4		<10	0	26	0.5<1
10	Y	N	-	>20	6	59	29			<10	-	26	7.5
11	Y	N	-	>20	6.7	141	70			<10	-	26	>10

Vatobe

Table 23. Borehole characteristics - Vatobe

#	GPS cordinates	Depth (m)	Static level (m)
1	16°38'39.8"S/ 49°47'18.9"E	5	4

2	16°38'41.9"S/ 49°47'18.5"E	5	2.5
3	16°38'42.4"S/ 49°47'16.6"E	4	5
4	16°38'47.4"S/ 49°47'17.0"E	4.5	2.5
5	16°38'54.6"S/ 49°47'13.5"E	5.5	3
6	16°38'58.7"S/ 49°47'12.8"E	5.5	3
7	16°39'02.5"S/ 49°47'12.8"E	7.5	2

Table 24. Water quality results - Vatobe

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	5	5.8	63	31	4.4	<0.07	<10	>10	27	0.5<1
2	N	N	N	<5	6.5	65	33	<4.4	<0.07	<10	0	28	<0.5
3	N	N	N	<5	5.8	55	27	<4.4	<0.07	<10		27	-
4	N	N	N										
5	N	N	N	<5	6.2	977	488	4.4	<0.07	<10	>10	27	<0.5
6	N	N	N	<5	5.5	45	22	<4.4	<0.07	<10	>10	26	0.5
7	N	N	N	<5	6.4	43	21	<4.4	<0.07	<10	6	27	0.5<1

Anove Sud

Table 25. Borehole characteristics - Anove Sud

#	GPS cordinates	Depth (m)	Static level (m)
1	16°37'12.8"S/049°47'42.8"E	12	2
2	16°37'16.73"S/ 49°47'48.99"E	10	2
3	16°37'23.9"S/049°47'49.1"E	10	1
4	16°37'25.30"S/ 49°47'48.60"E	10	4.5
5	16°37'25.20"S/ 49°47'45.00"E	10	2
6	16°37'27.90"S/ 49°47'47.90"E	9.5	3
7	16°37'30.40"S/ 49°47'47.60"E	10	1.8
8	16°37'35.27"S/ 49°47'45.64"E	6.5	2
9	16°37'41.21"S/ 49°47'43.06"E	9.5	1.9
10	16°37'43.30"S/ 49°47'42.12"E	12	1.8
11	16°37'26.85"S/ 49°47'48.51"E	10	-

Table 26. Water quality results - Anove Sud

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	Y	N	<10	6	2435	1218	<4.4	<0.07	<10	0	27	2
2	N	Y	N	20	6.1	84	42	<4.4	<0.07	<10	2	27	7.5
3	N	N	N	<5	5.8	170	86	26.4	<0.07	<10	0	27	
4	N	N	N	<5	5.7	130	65	22	<0.07	<10	0	27	
5	N	N	N	10	6.2	229	114	4.4	<0.07	<10	4	26	2
6	N	N	N	<5	6.2	229	113	30.8	<0.07	<10	0	27	
7	Y	N	N	>20	6.1	108	54	<4.4	<0.07	<10	0	26	
8	N	N	N	<5	7	280	140	8.8	<0.07	<10	3	27	
9	N	N	N	10	7	260	130	6.6	<0.07	<10	9	27	
10	Y	Y	N	>20	6.5	266	128	<4.4	<0.07	<10	>10	26	5
11											-		

Ambohitsara

Table 27. Borehole characteristics - Ambohitsara

#	GPS cordinates	Depth (m)	Static level (m)
1	16°46'09.9"S/ 49°39'50.2"E	21	-
2	16°46'11.8"S/ 49°39'46.4"E	22	-
3	16°46'09.5"S/ 49°39'45.7"E	11	-
4	16°46'04.4"S/ 49°3946.4"E	8	-

Table 28. Water quality results - Ambohitsara

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	-	-	-	-	-	-	-	-	-	-	-	-	>2

2	-	-	-	-	-	-	-	-	-	-	-	-	>2
3	-	-	-	-	-	-	-	-	-	-	-	-	>2
4	-	-	-	-	-	-	-	-	-	-	-	-	>2

Antanambe

Anove Nord

Table 29. Borehole characteristics - Anove Nord

#	GPS cordinates	Depth (m)	Static level (m)
1	16°36'56.5"S/ 49°48'02.8"E	8.45	4.15
2	16°36'46.0"S/ 49°48'02.8"E	7.1	4.2
3	16°36'39.1"S/ 49°48'03.2"E	10.5	4.25
4	16°36'41.4"S/ 49°48'01.9"E	9.83	4.07
5	16°36'42.5"S/ 49°47'59.1"E	10	2.17
6	16°36'36.6"S/ 49°47'52.1"E	12.7	2.13
7	16°36'34.1"S/ 49°47'48.1"E	9.4	3.67
8	16°36'28.8"S/ 49°47'49.2"E	13.1	4.8
9	16°36'38.5"S/ 49°47'45.4"E	14	5.27
10			
11			

Table 30. Water quality results - Anove Nord

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	<5	5.9	65	32	8.8	<0.07	<10		28	<0.5
2	N	N	N	20	5.3	113	56	4.4<8.8	<0.07	<10		27	0.5<1
3	N	N	N	<5	5.2	66	33	4.4<8.8	<0.07	<10		27	<0.5
4	Y	N	N	10<20	5.8	75	37	4.4	<0.07	<10		27	0.5<1
5	Y	N	N	5<10	4.7	109	54	11	<0.07	<10			<0.5
6	N	Y	N	>20	5.8	61	30	4.4<8.8	<0.07	<10		26	1
7	Y	N	N	>20				4.4	<0.07	<10			0.5<1
8	N	Y	N	<5	6.2	118	58	4.4<8.8	<0.07	<10		26	2
9	N	Y	N	>20				4.4	<0.07	<10			2
10													
11													

Malotrandro

Table 31. Borehole characteristics - Malotrandro

#	GPS cordinates	Depth (m)	Static level (m)
1	16°35'26.4"S/ 49°48'51.1"E	8.5	0.8
2	16°35'37.0"S/ 49°48'39.6"E	5.5	0.8
3	16°35'38.0"S/ 49°48'37.5"E	6.5	0.4
4	16°35'41.5"S/ 49°48'38.8"E	7	1
5	16°35'45.5"S/ 49°48'30.7"E	5.5	1
6	16°35'47.1"S/ 49°48'28.2"E	6	1
7	16°35'47.7"S/ 49°48'29.3"E	4.5	0.8
8	16°35'48.4"S/ 49°48'28.1"E	5	1
9	16°35'52.0"S/ 49°48'23.5"E	8	2
10	16°35'06.3"S/ 49°49'14.5"E	7	0.5

Table 32. Water quality results - Malotrandro

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	10	7.2	274	137	22	<0.07	<10	-	-	<0.5
2	N	N	N	<5	7.6	199	100	13.2	<0.07	<10	-	-	<0.5
3	N	N	N	<5	7.1	412	206	26.4	<0.07	<10	-	-	<0.5
4	N	N	N	<5	7.2	298	149	4.4	<0.07	<10	-	-	<0.5
5	N	N	N	<5	7.1	230	115	4.4	<0.07	<10	-	-	<0.5
6	N	N	N	5	6.9	417	208	4.4	<0.07	<10	-	-	<0.5
7	N	N	N	<5	7.2	305	152	13.2	<0.07	<10	-	-	<0.5
8	N	N	N	<5	7.3	413	207	4.4	<0.07	<10	-	-	<0.5
9	N	N	N	<5	7	564	282	22	<0.07	<10	-	-	<0.5
10	N	N	N	<5	7.8	442	220	4.4	<0.07	<10	-	-	0.5

Manambato

Table 33. Borehole characteristics - Manambato

#	GPS cordinates	Depth (m)	Static level (m)
1	16°32'8,4"S/ 49°50'18,6"E	13	7

2	16°32'12,4"S/ 49°50'15.4"E	10	5
3	16°32'11,9"S/ 49°50'19,3"E	9.5	5
4	16°32'14,8"S/ 49°50'18,6"E	10	4
5	16°32'15,2"S/ 49°50'19,6"E	10	5
6	16°32'03,7"S/ 49°50'16,7"E	12	7
7	16°31'59,1"S/ 49°50'11,3"E	11	5
8	16°32'10,2"S/ 49°50'9,6"E	9	4
9	16°32'05,5"S/ 49°50'11,8"E	9.5	5
10	16°32'16,3"S/ 49°49'56,8"E	15	5
11	16°32'15,6"S/ 49°50'15.60"E	10	6
12	16°32'13,0"S/ 49°50'17,3"E	10	5
13	16°32'06,3"S/ 49°50'15,5"E	8.5	2.5
14	16°32'7,2"S/ 49°50'11,0"E	12.5	4
15	16°32'3,6"S/ 49°50'14,4"E	10	3.8

Table 34. Water quality results - Manambato

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	<5	5.7	106	55	4.4<8.8	<0.07	<10	-	26	<0.5
2	Y	N	N	10<20	5.5	88	44	<4.4	<0.07	<10	-	26	0.5<1
3	N	N	N	<5	5.8	103	51	4.4<8.8	<0.07	<10	-	27	<0.5
4	N	N	N	<5	8.4	227	114	13.2	<0.07	<10	-	28	<0.5
5	Y	N	N	<5	6.6	305	152	17.6	0.07<0.17	<10	-	27	<0.5
6	Y	Y	N	10	5.6	58	29	<4.4	<0.07	<10	-	27	1
7	Y	N	N	20	5.7	46	24	<4.4	<0.07	<10	-	26	1
8	Y	N	N	>20	4.6	98	49	<4.4	<0.07	<10	-	26	0.5<1
9	Y	N	N	5<20	5	100	50	8.8<13.2	<0.07	<10	-	27	0.5
10	Y	N	N	>20	4.2	82	41	4.4<8.8	<0.07	<10	-	26	1
11	N	N	N	<5	4.7	108	54	13.2<17.6	<0.07	<10	-	27	<0.5
12	Y	N	N	>20	5.9	88	44	-	-	-	-	26	0.5<1
13	Y	N	N	10	5.7	71	35	-	-	-	-	27	0.5
14	Y	N	N	>20	5.4	49	24	-	-	-	-	25	0.5<1
15	N	N	N	10	6.8	109	54	-	-	-	-	27	<0.5

Antanambao Mandrisy

Table 35. Borehole characteristics - Antanambao Mandrisy

#	GPS cordinates	Depth (m)	Static level (m)
1	16°30'31.6"S/ 49°50'22.5"E	14	2
2	16°30'35.1"S/ 49°50'22.0"E	10	1.85
3	16°30'51.0"S/ 49°50'23.5"E	5	1.5
4	16°30'47.8"S/ 49°50'22.5"E	8	1
5	16°30'53.5"S/ 49°50'24.6"E	12	3
6	16°30'57.0"S/ 49°50'27.0"E	7.8	1.34
7	16°31'06.8"S/ 49°50'31.4"E	10.58	2.24
8	16°31'12.9"S/ 49°50'33.3"E	4.35	2.34
9	16°30'32.9"S/ 49°50'13.2"E	11.29	4.4
10	16°30'39.9"S/ 49°50'13.5"E	10.89	3.47
11	16°30'50.4"S/ 49°50'20.4"E	0	0
12	16°31'12.2"S/ 49°50'30.1"E	11.13	2.18
13	16°31'09.2"S/ 49°50'28.8"E	10.83	1.43
14	16°30'53.5"S/ 49°50'20.5"E	12	3
15	16°30'51.0"S/ 49°50'23.5"E	7	1.5
16	16°30'37.1"S/ 49°50'16.1"E	12	1

Table 36. Water quality results - Antanambao Mandrisy

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	Y	N	N	>20	7	432	216	<4.4	<0.07	<10		26	1.5<2
2	Y	N	N	>20	6.8	188	94	<4.4	<0.07	<10		26	0.5<1
3	Y	N	-	<5	7.6	281	140	<4.4	<0.07	<10		27	0.5<1
4	Y	Y	-	10	6.3	143	71	<4.4	<0.07	<10		26	2<3
5	Y	N	N	<5	7.2	328	163	<4.4	<0.07	<10		26	0.5<1
6	N	Y	N	<5	7.8	335	167	<4.4	<0.07	<10		27	<0.5
7	Y	N	-	>20	8.1	570	286	<4.4	<0.07			27	<0.5
8	N	N	N	<5	7.2	688	344	<4.4	0.07<0.17			27	0.5<1
9	Y	N	N	>20	5.8	75	37	4.4<8.8	<0.07			26	0.5<1
10	Y	N	N	>20	7.3	481	241	22<26	0.17			26	0.5<1
11	Y	N	-	>20	6.6	365	182	4.4<8.8	<0.07			26	3<4
12	Y	N	-	20	8	309	156	4.4<8.8	<0.07			26	0.5<1
13													
14													

15													
16													

Mandrisy

Table 37. Borehole characteristics - Mandrisy

#	GPS cordinates	Depth (m)	Static level (m)
1	16°28'30.6"S/ 49°50'56.6"E	11	6
2	16°28'37.9"S/ 49°50'54.1"E	10.5	6
3	16°28'44.4"S/ 49°50'49.3"E	9.5	6
4	16°28'47.4"S/ 49°50'47.6"E	12	6.5
5	16°28'49.1"S/ 49°50'46.3"E	11.5	6
6	16°28'35.3"S/ 49°50'56.5"E	14	6

Table 38. Water quality results - Mandrisy

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	Y	N	N	5<10	5.7	124	62	4.4<8.8	<0.07	-	-	-	<1
2	Y	N	N	-	-	-	-	-	-	-	-	-	<1
3	Y	N	N	10<20	5.4	90	45	4.4<8.8	<0.07	<10	-	-	<1
4	Y	N	N	>20	6.2	160	80	8.8<13.2	<0.07	-	-	-	<1
5	Y	N	N	-	-	-	-	-		-	-	-	<1
6	Y	N	N	5	5.9	71	34	8.8	<0.07	<10	-	-	<1

Tsaratanana

Table 39. Borehole characteristics - Tsaratanana

#	GPS cordinates	Depth (m)	Static level (m)
1	16°28'41.5"S/ 49°49'35.3"E	8.3	3.45
2	16°28'40.0"S/ 49°49'40.8"E	11.35	3.19

Table 40. Water quality results - Tsaratanana

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	<5	6.4	86	43	4.4	<0.07	<10	-	26	<0.5
2	N	N	N	<5	6.4	107	50	4.4	<0.07	<10	-	26	0.5<1

Andapavolo

Table 41. Borehole characteristics - Andapavolo

#	GPS cordinates	Depth (m)	Static level (m)
1	16°27'45.9"S/ 49°51'16.8"E, Alt.:	5.8	2.8
2	16°27'41.3"S/ 49°51'16.3"E, Alt.:	14	-
3	-	12	-

Table 42. Water quality results - Andapavolo

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	Y	N	Y	5	5.9	80	40	-	-	-	-	-	0.5<1
2	Y	N	Y	>20	6.6	107	52	-	-	-	-	-	3
3		-						-	-	-	-	-	

Vahibe

Table 43. Borehole characteristics - Vahibe

#	GPS cordinates	Depth (m)	Static level (m)
1	16°25'06.7"S/ 49°49'38.1"E, Alt.:	8	4
2	16°25'06.9"S/ 49°49'40.3"E, Alt.:	7	3
3	16°25'07.7"S/ 49°49'38.1"E, Alt.:	7	3

4	16°25'07.3"S/ 49°49'32.0"E, Alt.:	15	7

Table 44. Water quality results - Vahibe

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	30	7.2	353	176	8.8	-	<10	-	26	<0.5
2	N	N	N	20	6.6	105	52	8.8	<0.07	<10	-	25	<0.5
3	N	N	N	<5	6.6	211	106	13.2	<0.07	<10	-	25	<0.5
4	N	N	N	<5	7	182	91	4.4	<0.07	<10	-	27	<0.5

Sahasoa

Table 45. Borehole characteristics - Sahasoa

#	GPS cordinates	Depth (m)	Static level (m)
1	16°20'42.9"S/ 49°48'42.9"E	11	4
2	16°20'43.7"S/ 49°48'44.9"E	7	3
3	16°20'45.2"S/ 49°48'44.7"E	6.5	3
4	16°20'47.6"S/ 49°48'43.8"E	6	3
5	16°20'49.2"S/ 49°48'40.6"E	14	8.5
6	16°20'50.9"S/ 49°48'42.0"E	10	4.5
7	16°20'49.5"S/ 49°48'43.9"E	6	2.8
8	16°20'51.9"S/ 49°48'43.3"E	6	3.2
9	16°20'56.4"S/ 49°48'42.3"E	7.5	3.5
10	16°21'01.4"S/ 49°48'42.6"E	6	2.5
11	16°21'04.0"S/ 49°48'42.6"E	6.5	2.5
12	16°20'58.5"S/ 49°48'42.2"E	8.5	3
13	16°20'54.6"S/ 49°48'42.5"E	6.5	3.9
14	16°20'47.0"S/ 49°48'41.3"E	13	8
15	16°20'41.1"S/ 49°48'42.8"E	6	4
16	16°20'46.8"S/ 49°48'38.6"E	10.5	6

Table 46. Water quality results - Sahasoa

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	<5	5.9	100	49	4.4	<0.07	<10	-	25	<0.5
2	N	N	N	<5	6.4	145	70	8.8	<0.07	<10	-	25	<0.5
3	N	N	N	<5	7.8	417	208	22	<0.07	<10	-	27	<0.5
4	N	N	N	<5	7.6	524	263	26.4	<0.07	<10	-	26	<0.5
5	N	N	N	<5	6.3	259	129	8.8	0.07	<10	-	27	<0.5
6	N	N	N	<5	6.9	730	364	22	<0.07	<10	-	27	<0.5
7	N	N	N	<5	7.5	520	260	22	<0.07	<10	-	26	<0.5
8	N	N	N	<5	7.6	417	208	22	<0.07	<10	-	27	<0.5
9	N	N	N	<5	7.8	309	154	13.2	0.165	<10	-	27	<0.5
10	Y	N	N	<5	7.4	470	234	4.4	<0.07	<10	-	26	1.5
11	N	N	N	<5	7.7	330	164	26.4	<0.07	<10	-	26	<0.5
12	Y	N	N	<5	7.5	376	188	4.4	<0.07	<10	-	26	1.5
13	N	N	N	<5	7.4	500	249	17.6	<0.07	<10	-	26	<0.5
14	N	N	N	<5	5.6	140	70	13.2	<0.07	<10	-	26	<0.5
15	N	N	N	<5	6.5	144	72	13.2	<0.07	<10	-	25	<0.5
16	N	N	N	<5	5.1	144	72	17.6	<0.07	<10	-	26	<0.5

Imorona

Seranambe

Table 47. Borehole characteristics - Seranambe

#	GPS cordinates	Depth (m)	Static level (m)
1	16°14'52.0"S/49°50'22.8"E	10	3.5
2	16°14'48.6"S/49°50'21.6"E	7	2.5
3	16°14'38.7"S/49°50'21.5"E	5	2.5
4	16°14'37.5"S/49°50'22.3"E	5	2.5
5	16°14'34.5"S/49°50'20.1"E	10	2.5
6	16°14'36.0"S/49°50'25.6"E	6	2.5
7	16°14'37.5"S/49°50'25.2"E	5	1.5
8	16°14'36.6"S/49°50'26.9"E	5	2.5
9	16°14'34.4"S/49°50'25.7"E	5	2

10	16°14'36.1"S/49°50'23.2"E	5	2.5
11	16°14'31.8"S/49°50'22.3"E	10	2.5

Table 48. Water quality results - Seranambe

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	>20	5.8	85	42	<4.4	<0.07	<10	-	27	0.5<1
2	N	N	N	15	6.3	175	87	<4.4	<0.07	<10	-	25	0.5<1
3	N	N	N	<5	7.7	500	250	22	0.165	<10	-	26	<0.5
4	N	N	N	<5	7.5	518	260	8.8	0.26	<10	-	26	<0.5
5	N	N	N	5	6.4	167	83	<4.4	<0.07	<10	-	27	0.5
6	N	N	N	5	7.6	837	418	26.4	0.66	<10	-	26	<0.5
7	N	N	N	<5	7.3	765	381	26.4	<0.07	<10	-	26	<0.5
8	N	N	N	<5	7.5	745	372	8.8	0.1	<10	-	26	<0.5
9	N	N	N	5	7.1	598	298	<4.4	0.07	<10	-	26	0.5<1
10	N	N	N	<5	7.7	540	270	13.2	1	<10	-	26	<0.5
11	N	N	N	<5	6.4	145	72	4.4	<0.07	<10	-	27	<0.5

Hoalampano

Table 49. Borehole characteristics - Hoalampano

#	GPS cordinates	Depth (m)	Static level (m)
1	16°16'04.7"S/49°50'18.3"E	6	3.1
2	16°16'06.5"S/49°50'19.4"E	6.1	2.8
3	16°16'08.0"S/49°50'19.3"E	5.85	2.1
4	16°16'04.3"S/49°50'19.4"E	6	
5	16°16'01.3"S/49°50'20.0"E	5.75	2.35

Table 50. Water quality results - Hoalampano

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	<5	7.5	480	240	8.8	<0.07	<10	-	27	<0.5
2	N	N	N	<5	7.6	455	230	<4.4	<0.07		-	26	0.5
3	N	N	N	<5	7.4	675	337	4.4	<0.07	<10	-	26	<0.5
4	N	N	N	<5	7.6	500	250	13.2	<0.07	<10	-	27	<0.5
5	N	N	N	<5	7.5	560	280	26.4	<0.07	<10	-	26	<0.5

Antsirakivolo

Table 51. Borehole characteristics - Antsirakivolo

#	GPS cordinates	Depth (m)	Static level (m)
1	16°10'54.60"S/ 49°48'42.50"E	10.22	3.68
2	16°11'10.32"S/ 49°49'13.43"E	13	7.6
3	16°11'14.50"S/ 49°49'10.03"E	5	1.40
4	16°11'08.74"S/ 49°49'07.40"E	12	2.4
5	16°11'05.91"S/ 49°49'36.50"E	11	4

Table 52. Water quality results - Antsirakivolo

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	<5	8.14	448	224	<4.4	<0.07	<10	0	-	1
2	N	N	N	<5	6.8	264	132	8.8	<0.07	<10	-	-	<0.5
3	N	N	N	<5	5.4	176	88	26.4	<0.07	<10	0	-	<0.5
4	N	N	N	<5	6.1	182	90	22	<0.07	<10	1	-	<0.5
5	N	N	N	<5	5.8	75	37	4.4	<0.07	<10	5	-	<0.5

Mananara

Manambolona

Table 53. Borehole characteristics - Manambolona

#	GPS cordinates	Depth (m)	Static level (m)
1	16°11'08.0"S/ 49°47'02.9"E	13	3.6
2	16°10'59.8"S/ 49°46'48.0"E	15.5	3.5
3	16°11'01.9"S/ 49°46'52.8"E	17	1.8

Table 54. Water quality results - Manambolona

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)
1	N	N	N	<5	5.6	52	26	<4.4	<0.07	<10	0	-
2	N	N	N	>20	4.9	117	58	22	<0.07	<10	2	1
3	N	N	N	>20	5.7	36	18	<4.4	<0.07	<10	0	-

Analanampotsy

Table 55. Borehole characteristics - Analanampotsy

#	GPS cordinates	Depth (m)	Static level (m)
1	16°10'21.50"S/ 49°45'29.10"E	13.9	3.5
2	16°10'20.3"S/ 49°45'20.2"E	9.2	4.7
3	16°10'16.3"S/ 49°45'17.7"E	13.7	5.5
4	16°10'23"S/ 49°45'20"E	8.3	5.6
5	16°10'22.7"S/ 49°45'15.5"E	13.9	5.4
6	16°10'29.6"S/ 49°45'14.2"E	8.6	6.1
7	16°10'34.3"S/ 49°45'13.9"E	18	4.8
8	16°10'23.1"S/ 49°45'6.3"E	10.7	6.9
9	TBD	12	6

Table 56. Water quality results - Analanampotsy

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	>20	6.3	104	52	<4.4	<0.07	<10	2	-	3
2	N	N	N	<5	6.6	121	60	26.4	<0.07	<10	6	-	0.5
3	N	N	N	>20	6.3	172	86	6.6	<0.07	<10	>10	-	-
4	N	N	N	5	6	89	45	17.6	<0.07	<10	0	-	-
5	N	N	N	5	5.7	87	43	13.4	<0.07	<10	1	-	0.5
6	N	N	N	<5	4.8	195	98	30.8	<0.07	<10	0	-	-
7	N	N	N	<5	5.5	242	121	22	<0.07	<10	0	-	0.5
8	N	N	N	>20	6	113	56	8.8	<0.07	<10	>10	-	1.75
9	-	-	-	-	-	-	-	-	-	-	-	-	-

Mahanoro

Table 57. Borehole characteristics - Mahanoro

#	GPS cordinates	Depth (m)	Static level (m)
1	16°9'51.1"S/ 49°45'25.7"E	8.8	3.54
2	16°9'44.4"S/ 49°45'32.2"E	9.1	4.42
3	16°9'49.3"S/ 49°45'25.7"E	7.6	3.12

Table 58. Water quality results - Mahanoro

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	Y	N	<5	6.7	1147	574	6.6	<0.07	<10	6	-	-
2	N	N	N	<5	6.8	120	60	<4.4	<0.07	<10	0	-	-
3	N	N	N	>20	6.6	278	139	6.6	<0.07	<10	>10	-	-

Ankorabe

Table 59. Borehole characteristics - Ankorabe

#	GPS cordinates	Depth (m)	Static level (m)
1	16°12'39.6 "S/ 49° 47'16.0"E	7.87	2.02
2	16°12'33.7 "S/ 49° 47'12.3"E	6.63	1.27
3	16°12'28.4 "S/ 49° 47'09.7"E	13.53	2.97
4	16°12'15.2 "S/ 49° 47'6.5"E	13.04	5.17
5	16°11'59.6 "S/ 49° 49'55.2"E	14.55	6.3
6	16°11'59.60"S, 49°46'55.10"E	9.43	2.53
7	16°11'50.19"S, 49°46'53.58"E	10.15	4.76
8	16°11'33.92"S, 49°46'47.66"E	11.55	3.05

Table 60. Water quality results - Ankorabe

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	>20	5.2	173	86	44	<0.07	<10		25	0.5
2	N	N	N	>20	5.3	106	53	8.8	<0.07			25	1
3	N	N	N	10	6.3	110	55	13.2	<0.07			26	0.5
4													
5	N	N	N	<5	4.8	165	83	17.6	<0.07			26	0.5
6													
7	N	N	N	5<10	5.7	52	26	<4.4	<0.07	<10		26	<0.5
8	N	N	N	10	6.2	100	50	<4.4	<0.07	<10		25	<0.5

Ambatofitarafana

Table 61. Borehole characteristics - Ambatofitarafana

#	GPS cordinates	Depth (m)	Static level (m)
1	16°12'51.30"S, 49°47'37.40"E	18	3
2	16°12'56.40"S, 49°47'38.90"E	19	5.3

3	16°13'7.62"S, 49°47'50.29"E	17	1.5
4	16°13'11.96"S, 49°47'46.53"E	20	4.2
5	16°13'6.48"S, 49°48'4.07"E	17.5	1.1
6	16°13'10.80"S, 49°48'3.50"E	14	4.8
7	16°13'1.3"S, 49°47'36.8"E	19	-
8	16°13'2.3"S, 49°47'42.6"E	-	-

Table 62. Water quality results - Ambatofitarafana

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	<5	6.4	153	76	8.8	0.17	<10	-	26	0.5
2	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-

Ambatomilona-Centre

Table 63. Borehole characteristics – Ambatomilona-Centre

#	GPS cordinates	Depth (m)	Static level (m)
1	16°13'20.5 "S/ 49° 48'36.8"E	13	3.5
2	16°13'18 "S/ 49° 48'34.3"E	14.8	4.5
3	-	13.5	3.5

Table 64. Water quality results - Ambatomilona-Centre

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)

1	N	N	N	<5	5.7	230	115	44	<0.07	<10	-	26	<0.5
2	N	N	N	<5	5.4	310	155	35.2	<0.07	-	-	26	<0.5
3	-	-	-	-	-	-	-	-	-	-	-	-	-

Tampolo-Centre

Table 65. Borehole characteristics - Tampolo-Centre

#	GPS cordinates	Depth (m)	Static level (m)
1	16°09'00.2 “S/ 49° 43'32.2"E	12.5	6.7
2	16°08'57.1 “S/ 49° 43'28.3"E	13	6.1
3	16°08'52.6 “S/ 49° 43'23.1"E	17	8
4	16°08'47.6 “S/ 49° 43'18.9"E	10.5	6.5
5	16°08'43.6 “S/ 49° 43'15.6"E	11.5	6.5
6	16° 8'36.61"S, 49°43'12.19"E	11.05	6.44
7	16° 9'4.86"S, 49°43'39.05"E	9.71	3.07

Table 66. Water quality results - Tampolo-Centre

#	Color (Y/N)	Smell (Y/N)	Taste (Y/N)	Turbidity (NTU)	pH	Conductivity (µS/cm)	TDS (ppm	Nitrate (mg/l NO_3^-)	Nitrite (mg/l NO_2^-)	Arsenic (µg/l)	Thermotolerant Coliform (TTC/100ml	Temperature (°C)	Iron (mg/l Fe)
1	N	N	N	<5	6.7	100	50	<4.4	<0.07	<10	-	26	0.5
2	N	N	N	<5	6.2	85	42	<4.4	<0.07	-	-	26	0.5
3	N	N	N	>20	6.4	100	50	<4.4	<0.07	-	-	26	1
4	N	N	N	<5	6	65	32	4.4<8.8	<0.07	<10	-	26	0.5
5	N	N	N	<5	6.5	131	65	22	0.33	-	-	26	0.5
6	-	-	-		-	-	-	-	-	-	-	-	-
7	-	-	-		-	-	-	-	-	-	-	-	-

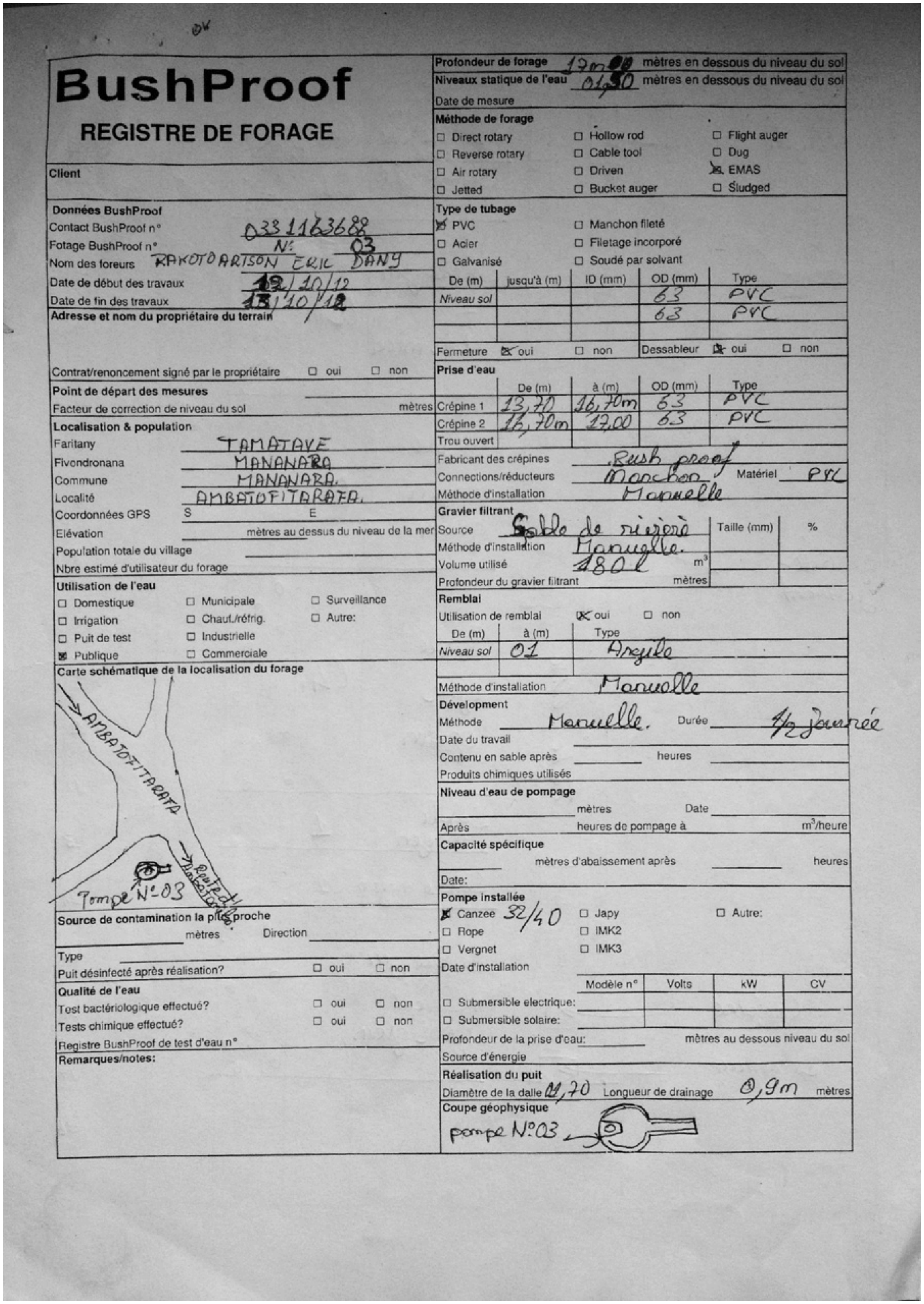
Appendix 2. Madrill equipment and weights

Description	Unit	Qte.	Weight (kg)
I –Mechanical connection			8
Steel tube Ø 100*180	U	01	
Steel tube Ø 60*350	U	01	
Galvanized elbow joint 40/49 45°	U	01	
Wheel bearing 6009	U	02	
Plastic bearing guard 45-62-8	U	02	
Plastic bearing guard 45-75-10	U	02	
Circlips Ø 45 ext.	U	01	
Circlips Ø 75 int.	U	02	
II –Drill pipes			75
Galvanized pipe 40/49	2m	15	
Galvanized connection (male/male) 40/49	U	17	
Connection 40/49	U	02	
Galvanized connection (female/female) 40/49	U	32	
III –Drill handle			14
Galvanized connection (female/female) 40/49	U	01	
Steel bolt M14*100 (Filet à fond)	U	02	
Steel plate 50*50*5	mètre	02	
Steel tube Ø 35*4mm	cm	90	
Welding rod CHE 40 2,5	U	10	
IV –Drill table			17
Sheet metal 12mm	19*20cm	01	
Sheet metal 6mm	21*40cm	01	
Welded hinge 120mm	U	02	
Steel rod Ø 10mm	U	02	
Square tube 50*50*5	80cm	02	
Galvanized connection (female/female) 40/49	U	01	
Steel tube Ø 21*4mm	11cm	01	
Steel rod Ø 16mm	40cm	01	
Steel plate 50*50*5	10cm	01	
Welding rod CHE 40 2,5	U	40	
Oil paint	kg	01	
V –Drillbit			5
Galvanized connection (male/male) 40/49	U	01	
Galvanized connection (female/female) 40/49	U	01	
Iron bar de 20	mètre	01	
Square tube 50*50*5	cm	25	
Bar 50*10	cm	15	
Welding rod CHE 40 2,5	U	60	
VI - Other			50

Flexible hose Ø 50	mètre	15	
Screen for flexible hose	U	01	
Flexible hose connection - motorpump	U	02	
Metal collars Ø 63	U	04	
Motorpump	U	01	
VI –Tool box			30
Wrenches:			
Mixed 22	U	01	
Mixed 17	U	02	
Mixed 14	U	01	
Mixed 13	U	01	
Mixed 12	U	01	
Mixed 10	U	01	
Polygon 20/22	U	01	
Flat 10/12	U	01	
Flat 10/11	U	01	
Flat 14/17	U	01	
Flat 20/22	U	01	
Spark plug N°21	U	01	
Adjustable wrench 24"	U	02	
Screwdrivers:			
Flat	U	01	
Philips	U	01	
Pliers:	U		
Regular	U	01	
Cutting	U	01	
Others:			
Scissors	U	01	
Burin	U	01	
Aiguille	U	01	
Tape measure 5m	U	01	
Measuring-line w/ weight	U	01	
Metalic brush	U	01	
Hacksaw	U	01	
Level 60cm	U	01	
Griffe ferailleur 6/8	U	01	
Hammer	U	01	
Massette	U	01	
File	U	01	
Spark plug for pump	U	01	
VII -Masonry			48
Shovel		01	
Spade		01	
Tape measure 3m		01	

Level		01	
Regular pliers		01	
Cutting pliers		01	
Metal mould for apron		01	
Metal bucket 15l		01	
Plastic bucket for mould 15l		01	
Trowel GM/PM		02	
Morter float GM/PM		02	
Hacksaw blade		03	
Hacksaw		01	
Sponges		02	
		Total weight	247

Appendix 3. Example drill log



BushProof

REGISTRE DE FORAGE

Profondeur de forage	17m00 mètres en dessous du niveau du sol
Niveaux statique de l'eau	01,30 mètres en dessous du niveau du sol
Date de mesure	

Client

Méthode de forage

- ☐ Direct rotary ☐ Hollow rod ☐ Flight auger
- ☐ Reverse rotary ☐ Cable tool ☐ Dug
- ☐ Air rotary ☐ Driven ☒ EMAS
- ☐ Jetted ☐ Bucket auger ☐ Sludged

Données BushProof

Contact BushProof n°	033 11 636 88
Fotage BushProof n°	N° 03
Nom des foreurs	RAKOTOARISON ERIC DANY
Date de début des travaux	12/10/12
Date de fin des travaux	13/10/12

Adresse et nom du propriétaire du terrain

Contrat/renoncement signé par le propriétaire ☐ oui ☐ non

Type de tubage

- ☒ PVC ☐ Manchon fileté
- ☐ Acier ☐ Filetage incorporé
- ☐ Galvanisé ☐ Soudé par solvant

De (m)	jusqu'à (m)	ID (mm)	OD (mm)	Type
Niveau sol			63	PVC
			63	PVC

Fermeture ☒ oui ☐ non Dessableur ☒ oui ☐ non

Point de départ des mesures

Facteur de correction de niveau du sol mètres

Prise d'eau

	De (m)	à (m)	OD (mm)	Type
Crépine 1	13,70	16,70m	63	PVC
Crépine 2	16,70m	17,00	63	PVC
Trou ouvert				

Localisation & population

Faritany	TAMATAVE
Fivondronana	MANANARA
Commune	MANANARA
Localité	AMBATOFITARAFA
Coordonnées GPS	S E
Elévation	mètres au dessus du niveau de la mer
Population totale du village	
Nbre estimé d'utilisateur du forage	

Fabricant des crépines: Bush proof

Connections/réducteurs: Manchon Matériel: PVC

Méthode d'installation: Manuelle

Gravier filtrant

		Taille (mm)	%
Source	Sable de rivière		
Méthode d'installation	Manuelle.		
Volume utilisé	180 l m³		
Profondeur du gravier filtrant	mètres		

Utilisation de l'eau

- ☐ Domestique ☐ Municipale ☐ Surveillance
- ☐ Irrigation ☐ Chauf./réfrig. ☐ Autre:
- ☐ Puit de test ☐ Industrielle
- ☒ Publique ☐ Commerciale

Remblai

Utilisation de remblai ☒ oui ☐ non

De (m)	à (m)	Type
Niveau sol	01	Argile

Méthode d'installation: Manuelle

Carte schématique de la localisation du forage

AMBATOFITARAFA

Pompe N°03

Route d'Antalaha

Dévelopment

Méthode: Manuelle. Durée: 1/2 Journée

Date du travail

Contenu en sable après heures

Produits chimiques utilisés

Niveau d'eau de pompage

mètres Date

Après heures de pompage à m³/heure

Capacité spécifique

mètres d'abaissement après heures

Date:

Source de contamination la plus proche

mètres Direction

Type

Puit désinfecté après réalisation? ☐ oui ☐ non

Pompe installée

- ☒ Canzee 32/40 ☐ Japy ☐ Autre:
- ☐ Rope ☐ IMK2
- ☐ Vergnet ☐ IMK3

Date d'installation

Qualité de l'eau

Test bactériologique effectué? ☐ oui ☐ non

Tests chimique effectué? ☐ oui ☐ non

Registre BushProof de test d'eau n°

	Modèle n°	Volts	kW	CV
☐ Submersible electrique:				
☐ Submersible solaire:				

Profondeur de la prise d'eau: mètres au dessous niveau du sol

Source d'énergie

Remarques/notes:

Réalisation du puit

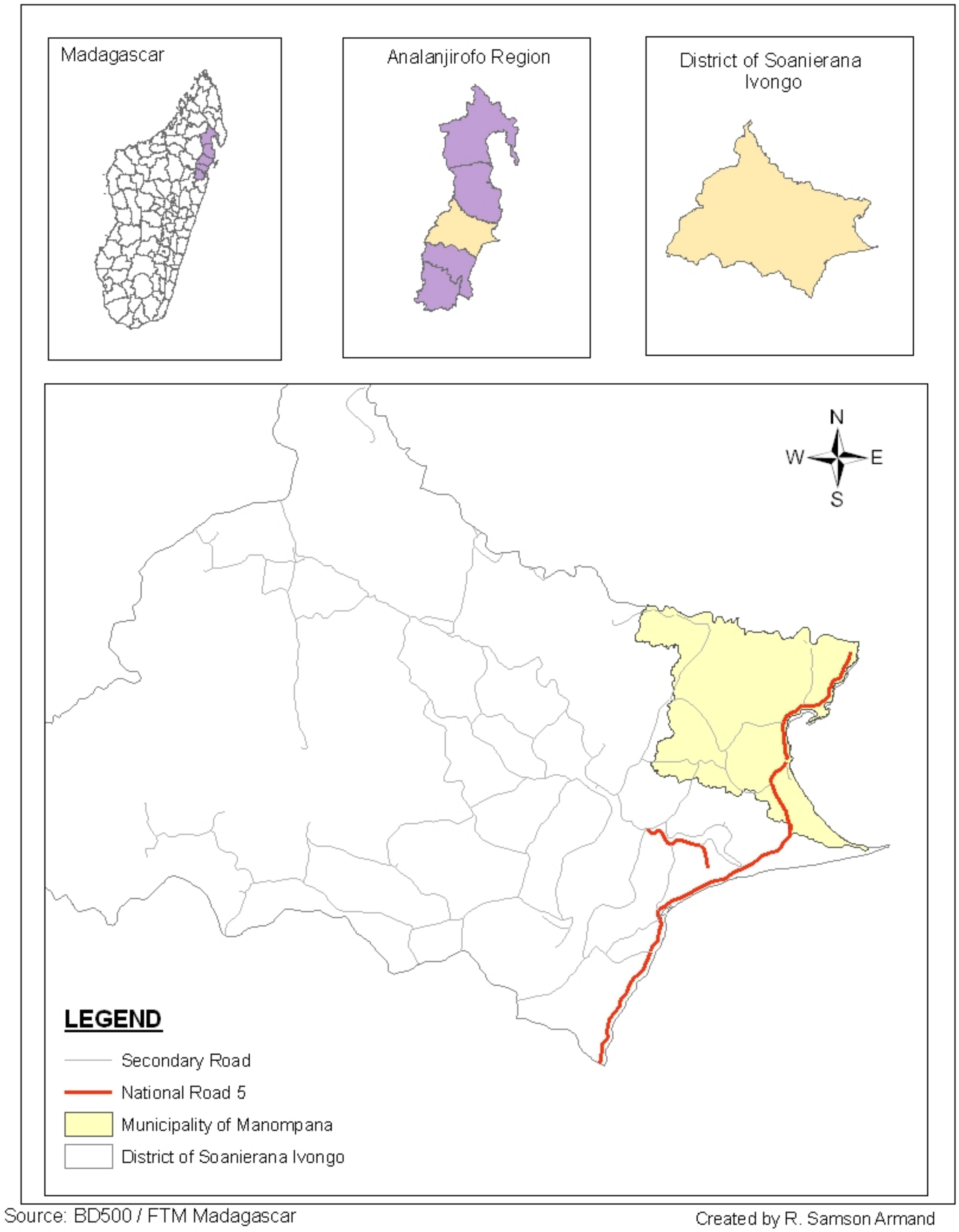
Diamètre de la dalle 01,70 Longueur de drainage 0,9m mètres

Coupe géophysique

pompe N°03

Observations (p.e. NSE, NPE)	Diamètre de forage (mm)	Tubage et crépine, remplissage, profondeur de pompe	Description des formations géologiques	Epaisseur (m)	Coupe	Profondeur cumulée (m)	Echantillon n°	Echelle
Argile			Sable fin + ~~Argile~~ terre Noire	01m				1
			Sable fin	01m				2
			Sable fin + débris mica	03m				3 4 5
graviller filtrant			Sable moyen grain	03m				6 7 8
		Tube lisse	Sable gros grain	04m				9 10 11 12
			Sable moyen	01				13
			Sable moyen	01				14
Crépine			Sable fin + Sable gros grain.					15 16
Décanteur								17
								18

Appendix 4. Map of the Ranon'Ala project zone for the district of Soanierana Ivongo. (BushProof, April 2013. Used by permission)



Appendix 5. Canzee pump schematic (Used by permission)