# Evaluation of Hand Augered Well Technologies' Capacity to Improve Access to Water in Coastal Ngöbe Communities in Panama

by

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# Abstract

Amid the global efforts surrounding United Nations' Millennium Development Goal Target 7c to improve access to safe and sustainable drinking water among populations who lack this resource, it has become essential to monitor and evaluate progress. Development initiatives working to achieve improved drinking water access often introduce appropriate technologies designed to be sustainably owned and operated by populations in rural areas suffering from water related hardships. It is valuable to thoroughly examine the degree to which these technologies satisfy intended objectives and affect user experienced water access. The accurate reflection of impact and progress can be complex, as the evaluation of water supplies can be made based on a variety of indicators that range from "improved' or "unimproved" water source definitions to measurements of the capacity of a source to satisfy desirable conditions related to water quality, quantity, reliability, or user's preference. The goals of this research are to conduct a comprehensive analysis of the effects of two appropriate technologies on local water access using an assortment of methods including: water quality analysis, visual and manual inspection, user interviews, and an overall sustainability analysis.

In Panama, the indigenous Ngöbe people in the ÑöKribo coastal area are a group disproportionately affected by a lack of improved access to drinking water and challenges to the feasibility of piped gravity fed water systems that typically serve the rest of the country. An NGO aiming to ameliorate this situation introduced two improved groundwater supply technologies to the region: bailers and EMAS hand pumps. This study assesses the comparative performance of these systems and evaluates the respective performances of existing water sources, using the wide variety of quantitative and qualitative data obtained.

The data collected in this investigation suggested that bailers and EMAS pumps yielded a mixed level of performance based on physical, chemical, and bacteriological water quality measurements in the shallow wells of the study environment. The technologies generally satisfied international guidelines and expected ranges based on chemical and physical parameters such as conductivity, TDS, and turbidity (with 57% of samples under 5 NTU). EMAS hand pumps demonstrated excellent bacteriological water quality with all samples indicating undetectable levels of *E.coli*, while bailers had a fair performance with 83% of samples falling into a range signifying intermediate to no associated health risk.

When comparing the overall water quality performance between the two hand augered well systems and with existing sources, the results indicated that bailers and EMAS pumps performed similarly in all aspects except for bacteriological quality. Overall, analysis based on groupings of “improved” and “unimproved” sources yielded very little distinction between the two categories when considering chemical, physical, and bacteriological parameters. This highlights the added value of using alternative indicators such as WHO guidelines to assess water sources, despite the challenges associated with field water quality sampling.

Interview data demonstrated that hand augered wells significantly improved household water access in the study area based on user considerations by providing a reliable water drinking water alternative with adequate quantities of water perceived to be clean. Accordingly, the improved water systems were integrated as a resilient water source into a socio-cultural context noting variable dependence on multiple water sources with categorized, appropriate related water uses set informally by Ngöbe families. The overall sustainability analysis found

EMAS hand pump and bailer technologies to be effective and appropriate; featuring low costs, few materials, and simple designs. Bailer systems were considered to be especially promising for applications in similar remote areas with high groundwater tables. However, the ultimate sustainability of both systems in the local context was found to be largely dependent on factors related to the development strategy adopted while implementing these systems in the ÑöKribo area.

# Chapter 1: Introduction

## 1.1 Improving Access to Safe Drinking Water

Lack of access to adequate water supplies and basic sanitation services results in more than one million preventable deaths throughout the world each year (Montgomery et al., 2009). Correspondingly, the United Nations' set Millennium Development Goal (MDG) Target (Goal 7, Target 7C) for water provision with the purpose of decreasing the global morbidity and mortality rates associated with water-borne diseases and promoting environmental sustainability. This target, set in 1990, aims to halve by 2015 the proportion of the global population without sustainable access to safe drinking water (UN, 2013). The UN and World Health Organization (WHO) have jointly measured progress toward reaching Target 7c using access to an "improved water source" as a representative indicator for target conditions. Table 1 provides a comparison of how the global community defines improved and unimproved drinking water sources.

In the greater efforts to mitigate the associated health burdens of unimproved water access however, there are outcomes and challenges that extend beyond the scope of Target 7c indicators. Attainment of improved water source access has been proven to yield reductions in mortality due to diarrheal diseases and reductions of diarrheal related morbidity (by an estimated 21%) (WHO, 2000). However, there are other lesser referenced, considerably valuable benefits of safe and stable water supplies. Households acquiring access to these supplies often experience positive increases in time for education (as opposed to using that time traveling to distant water sources and or fetching water), income generation, maternal health, child care, and food security (Loevinsohn, 2013).

Alternative globally recognized indicators by which water access can be qualified are provided by WHO. As part of an integrated strategy to improve water supplies that focuses on maximizing health outcomes, WHO proposes widely acknowledged guidelines and standards for water quality, water quantity, and sanitation practices (WEDC, 2011).

**Table 1: Drinking-Water Source Categories: Improved Versus Unimproved (definitions from WHO & UNICEF, 2013)**

| **Improved Source of Drinking Water** | **Unimproved Source of Drinking Water** |
|---|---|
| Piped water into dwelling | Unprotected spring |
| Piped water to yard/plot | Unprotected dug well |
| Public tap or standpipe | Cart with small tank/drum |
| Tubewell or borehole | Tanker-truck |
| Protected dug well | Surface water |
| Protected spring | Bottled water |
| Rainwater | |

Although these guidelines are considerably more expensive and challenging to monitor (than improved source definitions) in the field, they have been found to be incredibly valuable in further qualifying water access. Furthermore, it has been repeatedly established that programs that target improvements in local hygiene practices and or simply increases general water availability can have a considerable and often greater impact than solely improving water access or water quality (Esrey et al., 1990; Fry, 2010). Ultimately, the synergy attained through multifaceted approaches to drinking water improvements has been associated with the greatest reduction in disease and overall health improvements (Esrey et al., 1991).

Local, national, and international governments as well as nongovernmental organizations (NGOs) have been collaborating to achieve MDG Target 7c mainly through supporting the design and implementation of water supply infrastructure projects in areas across the globe where populations lack access to improved drinking water sources. In some cases, investments are made to rehabilitate or alter existing unimproved sources until they comply with “improved” definitions. Yet, development projects in areas lacking access more commonly introduce brand new water supply infrastructure or technologies in approaches integrated with community capacity building and empowerment efforts (Lockwood, 2004). With all the resources being dedicated to such efforts, the need for evaluating project sustainability and the appropriateness of introduced water systems is increasing, as institutions desire to improve effectiveness of their programs, gauge their impact, and overcome the inherent challenges and setbacks associated with development endeavors.

### 1.2 Water Access in Panama

Panama is a small, yet culturally and geographically diverse country located in Central America with a population of approximately 3.6 million (WorldFactbook, 2013).  In 2013, it was estimated that 94% of Panamanians had access to an improved water source while rural populations reported only 86% access (WHO & UNICEF, 2013).  Ethnically, rural areas of Panama are predominately populated by the nation's indigenous groups.  Panamanian indigenous populations experience disadvantages in access not only to potable drinking water and sanitation systems, but other critical resources (such as education, roads, healthcare, and electricity), as 96.3% live below the poverty line (INEC, 2010; World Bank, 2011; Aligandi, 2013).

Of the various minority groups in the nation including Afro-Panamanians, Chinese, Ngöbe-Bugle, Guna Yala, Embera-Wounan, Bri-Bri, and Naso, the indigenous Ngöbe-Bugle people are the largest, with an estimated total population of 250,000 (Minority Rights Group Int., 2008).  The majority of the Ngöbe-Bugle people live in a geographic area similar to a reservation with considerable political and administrative autonomy that was created in 1997.  This region, known as the Comarca Ngöbe-Bugle, is detailed in Figure 1.  A 2010 census reported that only 61.4% of the Ngöbe-Bugle population (the majority of which resides in the Comarca Ngöbe-Bugle) had access to an improved drinking-water source (INEC, 2010).

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**Figure 1: Map of the Comarca Ngöbe-Bugle**

The Comarca Ngöbe Bugle is divided geographically and culturally by the Cordillera mountain range. North of the Cordillera is the area of the Comarca known as ÑöKribo, which consists of 2 large districts: Kankintú and Kusapín. ÑöKribo, meaning “place of much water” in the native dialect, is characterized by abundant rainfall, high water tables, plains and rolling hills, mangrove zones, and relatively indistinguishable dry season (which is typically a pronounced seasonal event in the rest country) (Lovelock, 2005; WorldFactbook, 2013). Due to these factors, gravity fed water supply systems from shallow streams and springs (for description of these systems, see Mihelcic et al., 2009) that are commonly implemented in rural communities in the rest of the country are often not a feasible or dependable means of water access in ÑöKribo. In fact, these coastal Ngöbe communities often rely on alternative sources including shallow streams, unimproved wells, and or rainwater collection to meet their water needs (Green, 2011; Yoakum, 2013). This type of water access is unique to the ÑöKribo region within the Comarca Ngöbe Bugle.

Institutional efforts focusing on improving water access in the nation are primarily overseen by the *Proyecto de Agua y Sanaemiento de Panama* (PASAP) or Water and Sanitation Project of Panama, a division of Panama's Ministry of Health. PASAP's overarching mission targets rural and indigenous areas of Panama, including the Comarca Ngöbe Bugle. They outline three main objectives: (1) rehabilitate, amplify, and construct new water systems as well as personal sanitation solutions; (2) contribute to the sustainability of water systems through community development programs; and (3) contribute to the institutional empowerment of Ministry of Health programs (translated and adapted from Guillén, 2012).

In order to meet these goals, PASAP largely focuses their programs on renovating and implementing piped gravity fed aqueducts systems which comprise 92% of the nation's access to improved water sources (WHO & UNICEF, 2013). Currently, only 2% of the nation's improved drinking water access can be attributed to other improved sources which include tubewell or boreholes, protected hand dug wells, protected springs, and rainwater collection (WHO & UNICEF, 2013).

PASAP, with the contributions of foreign development organizations programs and NGO's, has made significant progress in extending access to improved water sources in the rural Panama since 1990. At that time, the percentage of rural users with access to improved drinking water sources was estimated at only 66% (WHO & UNICEF, 2013). Indeed as a country, Panama is on track to meet Target 7c of the MDGs. However, the indicator for reaching the MDG is based on a population's access to an "improved drinking water source" (UN, 2013). It is valid to emphasize that "safe" and "improved" drinking water are not synonymous. Improved source definitions, as referenced in Table 1, are based almost solely on protection around the source while "safe" drinking water is has been closely linked to human health outcomes and can be defined as having (bacteriological, chemical and physical) characteristics that meet WHO guidelines or national standards on drinking water quality (Yoakum, 2011; WHO & UNICEF, 2013). Numerous recent studies indicate that improved sources do not always supply *safe* water due to microbial or chemical contaminants (Bain et al., 2012; Onda et al., 2012). Thus in Panama, the percent of the population with access to *safe* drinking water (meeting WHO guidelines for water quality) or to water sources that *reliably* provide sufficient quantities of water (especially in the case of protected springs, rainwater collection, and piped water from shallow streams sources in a seasonal climate), may be even lower than reported for the UN MDGs.

### 1.3 Selection of Study Sites and Technologies

The sites studied in this thesis are on located on Peninsula Valiente in the Kusapín district of the ÑöKribo region of the Comarca Ngöbe-Bugle. The five communities of: La Ensenada, Kani Kote, Barriada Trotman, Barriada Record, and Bahia Azul are all located in the area known as Bahia Azul, or Bluefield Bay as seen in the northwest corner of Figure 2.

The location of the study offers the unique context of water challenges within a minority disadvantaged population with the least conventional type of water access within Panama; communities largely dependent on water from shallow wells and rainwater systems to complement piped water from small streams. The Ngöbe people that populate this rural coastal region of the Comarca Ngöbe Bugle typically depend on subsistence farming, fishing, and government social assistance programs for their economic livelihoods. Transportation modes within ÑöKribo are limited to walking, canoeing, and motorboat access. The nearest city with electricity, the port town of Chiriquí Grande, can be reached by a two to four hour motorboat ride, typically with only one departure and arrival per day. The U.S. based NGO presence of

"The Healing Fund" (which can be referred to online at <www.healingfund.org>) introducing hand drilled well technologies as an improved water source alternative provided an opportunity to monitor and evaluate the reception of this technology in an area where no previous studies on groundwater have been documented.

(adapted with permission from L.S. Collins & A.G. Coates (1999))

**Figure 2: Research Area of the Peninsula Valiente with Study Sites Noted in Red**

Furthermore, as a Peace Corps Environmental Health volunteer in the area for two years, the author became familiar with the culture of the Ngöbe people and their associated water and sanitation practices and challenges. She was able to develop a working relationship with local people as well as The Healing Fund, monitor and evaluate their improved well projects, and provide logistical support and constructive feedback. Over the course of the study, the author provided recommendations for improving project sustainability and communicated user feedback about the technologies being implemented to the Healing Fund.

## 1.4 Motivation

The motivation for this study is to increase access to improved drinking water sources which ideally provide safe water and decrease water related illnesses in the ÑöKribo region of the Comarca Ngöbe-Bugle.  This is addressed by assessing the potential for recently introduced hand augered well technologies in the region to provide sustainable, improved, and safe drinking water sources appropriate for the Ngöbe people.  Water quality, sociocultural analysis, and technical performance of improved wells within the study area will be the primary indicators used in this evaluation.  The hand augered well systems being assessed incorporate two different water lifting mechanisms: (1) bailers and (2) EMAS hand pumps.  This research also examines the appropriateness of MDG defined “improved” and “unimproved” drinking water source definitions through investigating the degree to which water sources in these categories provide safe and reliable drinking water.  Ultimately, this evaluation seeks to offer recommendations for improving the long term sustainability of low cost hand augered groundwater technologies being introduced in Panama and to establish a basis for comprehending the role that these technologies could play in improving drinking water access in similar areas in the future.

No peer reviewed articles were identified by the author relevant to low cost hand augered well technologies in coastal or indigenous regions of Central America.  This research aims to fill that gap while adding to limited knowledge on water use behaviors, perceptions, and in rural developing areas and specifically among indigenous peoples.  Also, very limited research exists on the performance of shallow unimproved or improved wells as drinking water sources in clay soil environments.  Bailers, commonly used in the construction, development, and monitoring of groundwater sources across the world, are also a simple, effective, low cost water lifting mechanism that have been largely neglected in the context of sustainable development.  More research is necessary to investigate the use of self supply technologies in general and the application of bailers as a viable alternative to hand pumps for wells in rural developing areas.

### 1.5 Research Objectives and Questions

The proposed research is believed to be the first independent field study to assess and compare the sustainability and performance of groundwater supply options in the context of coastal indigenous communities in rural Panama. This paper examines the relative water quality outcomes, technical performance, and social implications of a variety of improved and unimproved water sources (primarily open hand dug wells, hand augered wells with bailers, and hand augered wells with EMAS hand pumps). The specific research objectives are:

1. Evaluate household groundwater supply technologies (EMAS pumps and bailer systems) recently introduced in the ÑöKribo region of Panama based on water quality outcomes and technical performance and compare these two technologies to existing water supply options.
2. Examine and compare socio-cultural impacts related to water access and level of improvement through assessing local water usage, access, perceptions, and maintenance behaviors for existing sources as well as recently introduced groundwater water supply technologies.
3. Recommend best practices for improving the sustainability and appropriateness of low-cost hand augered well projects implemented in the research context and similar areas.

The specific research questions (and associated research tasks) that this study aims to address are outlined as follows:

1. How will the level of improvement of a water source be reflected in the water quality data? What effect (if any) will the type of water lifting mechanism (EMAS pumps or

bailers) have on water quality measurements of improved hand augered wells?

Research Task 1a: Perform systematic water sampling of categorized water sources, and measure standardized outcomes of various water quality parameters. Research Task 1b: was to assess water quality of the two improved groundwater source technologies available to users in the study area.

2. How has the introduction of improved groundwater supply technologies affected the water usage behaviors of users in the context of the study? What are local perceptions and preferences regarding water access and water use?

   Research Task 2: Conduct surveys with users of all categorized water sources with respect to water access, water usage, water quantity, maintenance behaviors, and perceived water quality.

3. How do recently implemented improved groundwater well technologies rate based on the following sustainability factors: socio-cultural respect, community participation, political cohesion, economic sustainability, and environmental sustainability? How does the NGO organization introducing the systems to the area incorporate considerations related to sustainability into their operational strategies?

   Research Task 3: Evaluate the sustainability and appropriateness of the study’s hand drilled well technologies and make applicable operational recommendations for future work.

# Chapter 2: Literature Review

## 2.1. Evaluating Sustainability and Appropriateness of Water Supplies

In the effort to gauge progress toward reaching MDGs of extending and improving access to drinking water supplies in developing nations, it is necessary to analyze corresponding environmental, socioeconomic, and health effects of structural improvements to water access. The concept of sustainability is commonly integrated into the literature and policies of development and international aid organizations.

**Table 2: Factors of Sustainable Development of Water and Sanitation Projects**

| Sustainability Factor | | Description |
|---|---|---|
| Social Sustainability | Socio-Cultural Respect | A socially acceptable project is built on an understanding of local traditions and core values. |
| | Community Participation | A process which fosters empowerment and ownership in community members through direct participation in development decision-making affecting the community. |
| | Political Cohesion | Involves increasing the alignment of development projects with host country priorities and coordinating aid efforts at all levels (local, national, and international) to increase ownership and efficient delivery of services. |
| Economic Sustainability | | Implies that sufficient local resources and capacity exist to continue the project in the absence of outside resources. |
| Environmental Sustainability | | Implies that non-renewable and other natural resources are not depleted nor destroyed for short-term improvements. |

(McConville & Mihelcic, 2007)

A sustainable development approach is one that addresses not only short term, but long term implications and distinctly integrates environmental, social, and economic considerations

(McConville, 2006). Consequently, in order to adequately assess sustainability, it has been proposed that one must consider projects not at one point in time, but during every stage of a project’s life cycle, as sustainability applies to all actions surrounding a development initiative from initial needs assessment to monitoring and evaluation and beyond (Mihelcic et al., 2006; McConville & Mihelcic, 2007). Five overarching factors recognized to affect the sustainable outcomes of water and sanitation projects in particular (throughout the entire project life cycle) are identified in Table 2.

Engineers approaching sustainable development are often challenged to design and implement appropriate technologies. Appropriate in this context is defined as a solution available to people at an affordable price, using local materials, with a useful and relevant function, that minimizes harm to both human society and the environment (McConville & Mihelcic, 2007). Appropriate technologies are thus effectively adapted for sustainable application within the context of a local environment and socio-cultural setting (McConville, 2006). With the introduction of hand augered well technologies as a new means of obtaining water in the study location, appropriateness will be considered in this context.

## 2.2 Sustainable Water Supplies: Approaches and Technologies

In a shift to promote sustainability and increase the capacities of developing world nations to actively participate in their development, a variety of agencies including governments, donors, NGOs, and multilateral lending institutions agreed to implement community management concepts during the 1980s and 1990s (Lockwood, 2004). Accordingly, funding and programs were designed to support community managed approaches to improving water access. Community managed water systems typically involve securing a water source with high enough flows to provide for a large portion of a community’s population. The source, usually a spring or small stream, is then developed with corresponding water storage tanks and piped distribution systems to provide water access (in the form of a single or shared household spigots) while remaining connected to a system that is communally owned and maintained.  In Panama, the labor associated with managing and operating these community water systems typically falls disproportionately on a few members of a water committee.  Rural water committees, (formally established and overseen by laws governed by PASAP) are comprised of five to seven community members elected to serve without compensation for the common good by managing issues related to the distribution and upkeep of water supplies.

The performance and lasting sustainability of such systems has been under review, as the burdens of maintenance and operation of the systems can provide complex social, technical, and economic challenges for developing communities in rural areas.  Multiple studies of community managed water supply systems in parts of Latin American and the Caribbean show failure rates reaching twenty to forty percent (based on whether a system is nonfunctional or in a state of disrepair) (Reents, 2003; Schweitzer, 2009; Suzuki, 2010). In Africa, similar studies have shown community managed rural water supply systems to have failure rates between thirty and sixty percent (Harvey & Reed, 2007).

An alternative sustainable development strategy for attaining and maintaining improved access to water and sanitation supplies is known as the “self supply” model.  Self supply pertains typically to household level improvements to water access through user investment in supply construction, water treatment, and upgrading (Sutton, 2009). Through promoting water systems that serve household units, many challenges of projects focusing on community systems such as expansive distribution systems, imbalanced water pressures, and organized maintenance efforts are evaded.

Development agencies which adopt a self supply approach require more participatory action of local users interested improving their water access.  Accordingly, personal investments of time, labor, money, and a commitment to learning about the operation and maintenance of introduced technologies is often expected and sometimes required of participants in self supply development initiatives (Sutton, 2009).  The self supply concept and its associated small scale affordable technologies are critical to achieving the MDGs and improving drinking water supply coverage, as they are often feasible in the poorest, most remote communities where expensive community water supply systems are not feasible (Smits & Sutton, 2012).

Low-cost household water supply technologies, which can complement community management supplies, generally focus on groundwater and rainwater supplies which can be harnessed in the vicinity of a given household. Common self supply technologies include: (1) family wells, which can be either hand dug or manually-drilled; (2) water-lifting devices, which can range from a simple rope and to a bucket to a manually operated pump; and (3) rainwater harvesting systems (MacCarthy et al., 2013).  Incorporating concepts of sustainability, these water systems are also designed to be economically and logistically feasible for a user to obtain or construct, use, maintain (often a phased process requiring incremental improvements) (Sutton, 2009).

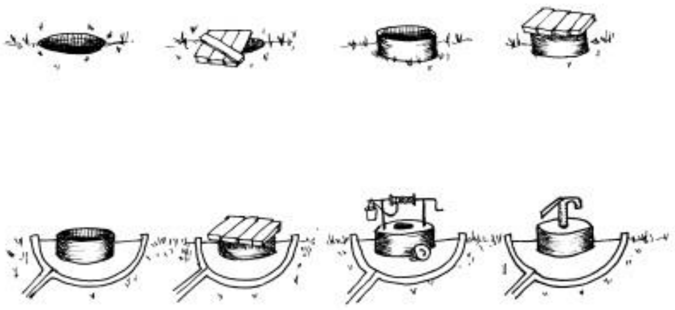
## 2.3 Groundwater Supplies

### 2.3.1 Hand Dug Wells

The original and still the most common self supply approach to obtaining groundwater supplies in rural areas of the developing world is by means of hand dug wells (WaterAid, 2013). They are implemented as both a household and communal means of water supply, with a wide variety of size and depth characteristics, depending largely on the hydrogeology of the area.

Hand dug wells are often implemented using local materials and labor, according to local practices, in areas where knowledge of groundwater exists close to the surface (WaterAid, 2013).

Typically, a hole is dug or carved using tools such as shovels and pickaxes, until groundwater level is reached and then the well is further expanded to create a reservoir below the standing water table. Depths of hand dug wells range from shallow wells (about 5 meters deep) to deep wells (commonly over 20 meters deep) depending on soil type, while diameters are generally near 1.5 meters (WaterAid, 2013). However, because of tool limitations, their existence is restricted to areas with soils containing clays, sands, or gravels, where few rocks or boulders are present. The natural earthen walls of hand dug wells often need to be retained, or "lined" to prevent erosion, depending on the soil type (SMET & WIJK, 2002). A wide range of construction methods and materials including brick, stone, masonry, and concrete cast can then be used to line or reinforce the earthen walls of wells.



(reproduced with permission of Linda A. Phillips from Mihelcic et al., 2009.)

**Figure 3: Well Head Protection Methods Displaying Incremental Improvements from Unprotected Well towards Sealed Well with Apron, a Raised Lining, and a Hand Pump**

Hand dug wells can be improved or unimproved depending on the level of protection of the source. In order to be considered an improved drinking water source, the well head should be protected from potential contamination, particularly through preventing possible re-entry or infiltration of contaminated spilled water or surface water into the borehole (WHO & UNICEF, 2013). This is commonly done through the addition of a well cap, covering, sanitary seal, and or/an apron, or protective platform around the well. A variety of incremental well head protection methods moving from left to right are displayed in Figure 3.

### 2.3.2 Improved Hand Augered Wells

Hand augered (or hand drilled with an auger) wells are wells in which a borehole or tube well is created through the use of a manually operated auger, as depicted in Figure 4. Typically, two people turn the crossbar, or “T” attached to the auger rod, while applying a downward force that causes the drill bit to cut away at the soil beneath. When the bit fills with soil, drillers extract the auger and remove the accumulated soil material known as “cuttings” (Naugle, 1996). As the well reaches deeper below the ground surface, a pin attaching the drill bit to the “T” frame is removed and extension rods are added to the body of the hand auger.

((4a) reproduced with permission of Hydromissions International)

**Figure 4: (a) Hand Auger (b) Hand Auger in Operation, Detaching Bit to Remove Soil**

Below the water table, the auger cannot bring the bored material to the surface because the cuttings become semi-solid and escape. This situation calls for the use of a bailer, which is discussed in more detail in Section 2.3.3. After excavation of a borehole, casing, screening, and packing processes can be pursued to secure the well body, prevent the small diameter hole from caving in, and protect the water source from sediment or contaminant infiltration (Naugle, 1996). It is important to note that like hand digging, hand augering is largely limited to alluvial soils, since the drill bit can be damaged when encountering rock or stone (Labas & Vuik, 2010).

Improved hand augered well technologies are more expensive and technically advanced operations requiring more materials and skilled labor than hand dug wells. However, they offer several advantages over unimproved wells, as they often reach deeper into the groundwater table, provide increased supplies, and reduce risks of contamination in water supplies (Sworobuk et al., 1987; Morgan, 1990). They also offer resiliency from the strains on supplies that seasonal fluctuations can cause on the groundwater table and against the impacts of global climate changes (WHO, 2009). It is a common practice, particularly in Africa where traditional hand dug wells are prevalent to improve water access through rehabilitating unprotected wells and or introducing drilled well technologies (Harvey & Reed, 2004).

### 2.3.3 Bailers

As a result of variances in terminology used in field work and literature, it is noted that in this thesis the term “bailer” will refer to single buckets lifting water through reciprocating action and the term “pump” will be used to refer to devices which employ other mechanisms including direct action, piston action, and rotary action. The definitions established for the purpose of this thesis are summarized in Table 3.

Bailers, used in the process of hand augering, are as a basic, effective means of lifting water from a well. Bailers are arguably the least expensive, least technical way to draw water from a tube well or borehole, making them a viable appropriate technology for rural self supply (Morgan, 1990; Hydromissions, 2011). Characteristically, they are more affordable, require fewer materials, and incur less maintenance than pumps. Although they have the advantage of working when recharge rates are too slow for a pump, they are often slower, less efficient, and provide a more limited yield of water (one bail volume at a time) (Hussey, 2007; Hydromissions, 2011). Bailing system designs can include the following materials: metal or plastic bucket containers, PVC tubing, metal tubing, nuts and bolts, a check valve, rope, chain, a pulley, or a windlass. They can be implemented with a rope or chain that is either free for direct manual operation, or used in conjunction with a pulley or crank handle with windlass system.

**Table 3: Bailer and Pump Terminology Used in This Thesis**

| **Considered in this study as:** | **Water lifting mechanism** | **Referred to in literature as:** |
|---|---|---|
| Bailer | Reciprocating action | Direct lift pump<br>Bailer bucket<br>Blair bucket pump<br>Bucket pump (windlass) |
| Pump | Rotating action | Rope and Washer pump<br>Bucket pump (rotating buckets) |
|  | Piston action | Bucket pump (piston mechanism, hydraulic ram) |
|  | Direct action | EMAS pump<br>Blair pump |

(adapted from (Hussey, 2007))

Common bailers, like the one depicted in Figure 5, function as water is drawn from the tubewell into the lower end of the cylinder through a check valve. When the user lowers the bailer into the borehole, water is forced to rise up through the open valve and fill the body of the bailer. When the user raises the bailer to ground level, the valve closes under the weight of the water and effectively stores water in the bailer body. In other designs, a combination foot valve and piston valve is used as water fills the bailer body through a suction action created by pressure change. In shallow, wells bailers function even with damages causing leaky valves, but for deep wells leaky valves are more problematic (due to the volume of water lost during the time it takes for a user to lift the bailer) (Fraenkel, 1986).

(Reproduced with permission from (Naugle, 1996))

**Figure 5: Bailer with Bottom Disk for Valve Attachment**

Apart from serving as a primary water lifting mechanism for an improved well, bailers are utilized in the process of hand augering and other hand drilling methods to remove volumes of cuttings or “slurry”, a mix of water and excavated soil, from the well (Koegel, 1985). Bailers are also used by well drillers to perform tests upon reaching water bearing soil. In order to determine whether a given well depth will provide sufficient yield for a household or community, bailers are used to carry out procedures that involve taking volumes of water out of a well several times consecutively. While bailing, the well driller observes the recharge behavior of the well and notes the relative time for the borehole or the bailer body to fill with water again, providing a crude estimate of the well recharge (Katz, 1955). This valuation incurs considerable error, especially in deeper wells where the water table level is difficult to see, because it does not account for the well recharge behavior during time spent lifting the bailer (one cannot see inside the borehole when lifting the bailer) (Katz, 1955). Depending on the recharge behaviors observed, drillers can decide whether to increase the well depth. Bailer tests for use specifically in a rural development context have also been designed to indicate the types of yield and associated population that a given borehole can sustain (through removing between twenty and fifty bails from a borehole over a ten minute period and then measuring the recovery and associated transmissivity, or rate of horizontal groundwater flow of the aquifer source) (MacDonald et al., 2008).

It is acknowledged that bailers have been installed across the world as part of development efforts associated with organizations such as Hydromissions International, Lutheran World Relief, Blair Research Laboratory, V & W Engineering, however the true scope of their implementation is unclear due to gaps in monitoring and documentation (Naugle, 1996; Morgan, 2003; Hydromissions, 2011). Bailers specifically using a windlass mechanism as a lifting apparatus have been documented to be implemented as part of development projects that improve rural water access through programs rehabilitating existing hand dug wells and or installing tubewells in South Africa and Zimbabwe (Morgan et al., 1996; Morgan, 2003; MacCarthy, 2004). An example of these bailer systems with windlasses is depicted in Figure 6.

(with permission from MacCarthy, (2004))

**Figure 6: Bailers with Windlasses in South Africa (known as “Blair Bucket Pumps”)**

The Ubombo Family Wells Programme (UFWP), under oversight from the local Ministry of Health, began operations to improve access to safe water supplies in rural South Africa the mid 1990’s (MacCarthy, 2004). Approximately 500 bailer units were implemented by 2002 (Still & Nash, 2002). The technology was also in use in Zimbabwe beginning in the late 1980’s, as bailer systems were installed in tubewells as a technology of choice (under the name of bucket pumps) in local government efforts to increase rural drinking water coverage (Morgan & Chimbunde, 1991; Morgan, 2003). The number of systems that were installed is unknown.

In both cases, the design and implementation of bailer technologies in improved wells was considered to be sustainable and appropriate due to very low costs, high reliability, and ease of user interaction with the technology (Morgan, 1990). However, later issues emerged with desirability of the systems in the Ubombo Family Wells Programme because of low pumping rates and altered preferences by local government officials considering other water lifting alternatives (MacCarthy, 2004). In Zimbabwe, government programs developing rural water sources also shifted away from bucket pumps, but to focus on improving existing traditional hand dug well sources through integrating well head protection measures, use of a windlass, and proper hygiene and maintenance education campaigns (Morgan et. al, 1996; Morgan, 2003).

### 2.3.4 Hand Pumps

Institutional and NGO programs customarily endorse projects improving access to groundwater in rural areas through incorporating a hand pump technology to be used with hand dug or hand drilled well. A wide variety of hand pumps for applications in the developing world have been designed and marketed, with user preferences and prevalence of systems often dependent on geographic location. Positive displacement pumps, which typically incorporate reciprocating pistons or plunger mechanisms are among the most numerous hand pumps in the world because they are often cheap and technically appropriate for household pumps (WaterAid, 2006). It is vital to consider that pumps have different effectiveness and appropriateness based on characteristics such as well depth, soil type, and number of users. Hand pumps, are capable of lifting small quantities of water (from depths of up to 100 meters), require adequate sealing of the tubewell to produce high quality drinking water, and are widely used in places where access to water is scarce (Olley, 2008). However, in rural areas where access to money, materials, and skilled labor required for hand pump technology installation, operation, and maintenance are often limited, there are major challenges to systems' technical performance.

Over the past 20 years, monitoring and evaluation data of hand pump projects has appeared in literature and sparked major concerns as to the suitable selection and long term sustainability of the projects and technologies. In Africa, where dependence on groundwater sources is often prevalent in poor rural areas, the quantity of hand pumps installed was estimated at approximately 250,000 in 2004 (Harvey, 2004). Numerous studies indicate that operational failure rates of drilled boreholes with hand pumps (most common) in Africa typically range between 40 and 50% (Harvey, 2004). The persistence of benefits of improved groundwater technologies introduced has been questioned, as one study in Mali found that almost 90% of all hand pumps on boreholes failed after one year of use (World Bank, 1997).

Assessments of hand pump projects in Africa attribute failures to numerous reasons that generally relate to technical, socioeconomic, environmental, and cultural factors. These include: (1) design issues such as lack of attention to available yield of a borehole or capacity to satisfy user water demand, (2) maintenance issues as users lack knowledge, materials, and/or economic means of sustaining the pumps, and (3) user preferences (Harvey & Reed, 2004; Baumann, 2009; Carter et al., 2010).

Upon identifying and assessing these faults, numerous development organizations have responded by committing explicitly to improving the sustainability of such services, integrating a variety of measures across all phases of their project approach to assure the long-term benefits of installed systems. Several notable groups dedicated to ensuring the sustainability of groundwater supply services include: Rural Water Supply Network, Water for People, International Water and Sanitation Centre (IRC), and WaterAid (Carter et al., 2010).

#### 2.3.4.1 Rope Pump

The most recognizable hand pump in the context of Latin America is the Rope and Washer Pump (i.e., the rope pump), or *bomba de mecate*. Over the past three decades, the rope pump has seen widespread implementation as a selected appropriate technology in local and international development efforts, particularly in Nicaragua (Alberts, 2004; Harvey & Drouin, 2006; Sutton & Gomme, 2009). As seen in Figure 7, this pump functions through the use of a crank handle which moves a rope passing through a wheel base down into the well head. Regularly spaced plastic or metal washers or knots, called pistons, on the rope bear water as they are pulled up in the riser pipe at the bottom of the well through to the pump's spout (SKAT, 2005). The rope pump, which is suitable for both household self supply systems and communal managed wells can be adapted to unimproved hand dug wells or boreholes, is capable of lifting water from depths reaching 30 meters, and is priced in rural developing areas at approximately $US 125 (Brand, 2004; Baumann, 2011).

The rope pump technology has seen widespread implementation in Nicaragua, where an estimated 70,000 rope pumps are in use (the majority of which have been built by a dozen local workshops), and to lesser degrees in countries like Mexico, Honduras, Guatemala, El Salvador and Bolivia (countries with a cumulative sum of 10,000 rope pumps) (Alberts, 2004; AKVO, 2012). An estimated 110,000 are in use worldwide by nearly 5 million people (Holtslag, 2011). The successful application of rope pump technology can be largely attributed to its low cost, available materials, durability, and simple operation in comparison to other hand pump options (Smet et al., 1995; MacCarthy, 2004). However, it is critical to consider that successful programs included adequate training of local community members in rope pump construction, use, and repair.

(Image reproduced from the public domain)

**Figure 7: Rope Pump in Operation**

#### 2.3.4.2 EMAS Hand Pump

EMAS (*Escuela Mobil de Agua y Saneamiento* in English: Mobile Water and Sanitation School) was founded by Wolfgang Buchner in Bolivia in the early 1980s with the goal of making adequate water supply and sanitation infrastructure available to poor households in rural Bolivia. The EMAS hand pump developed by Buchner has been a widely promoted appropriate technology in Bolivia with over 20,000 households owning manually drilled well systems with locally constructed EMAS technologies (Danert, 2009). The technology has also been introduced to a lesser extent in other developing countries, mostly in South and Central America, including: Peru, Ecuador and Nicaragua, and (an estimated 10,000) in Brazil (AKVO, 2012).

As shown in Figure 8, the EMAS pump consists of two major pieces, an inner PVC pipe with a one way piston valve at the bottom which fits inside an outer PVC pipe with a one way foot valve at the bottom. The outer pipe remains static and when the handle (attached to the inner pipe) is lifted, suction force causes the foot valve to open (while the piston valve remains closed), lifting water from the tubewell into the outer pipe. When the handle is alternately lowered, the foot valve on the outer pipe closes and the piston valve on the inner pipe opens, causing water to flow upwards into the inner pipe and finally out of the spout that is an elbow in pump handle (MacCarthy et al., 2013).

**Figure 8: EMAS Hand Pump in Operation**

Similar to rope pumps, EMAS pumps utilize materials commonly found in developing areas: PVC and galvanized iron, marbles for the pump valves, and rubber cut from an old car tire for gasket seal around the pipe containing the piston valve. Due to its pumping capacity from depths of 30 meters and beyond, to elevations above the pump head, the EMAS pump is considered by some to be a versatile technology (Buchner, 2006). It can be used in conjunction with other water systems in order to lift rainwater from underground storage tanks, to pump groundwater to elevated storage tanks, or in irrigation applications (MacCarthy et al., 2013). However, the EMAS pump design is limited to use as a household system (around 6 families, or 30 users maximum) (MacCarthy et al., 2013). Due to the wear that would incur on moving parts in the pump mechanism, is not considered appropriate for communal water systems and is solely considered for implementation in households.

EMAS pumps have been evaluated to be appropriate and sustainable in programs increasing rural groundwater supplies like rope pumps, however with lower costs, of approximately US $30 (Brand, 2004; MacCarthy et al., 2013). Also, as in the case of rope pump studies, it has been identified that user capacity building with respect to pump design, operation, and maintenance is critical to EMAS pump sustainability (Brand, 2004; MacCarthy et al., 2013).

## 2.4 Relevant Studies

### 2.4.1 Sustainability and Appropriateness of Groundwater Supply Technologies

Several studies have investigated the sustainability and appropriateness of groundwater supply technologies in the developing world, as discussed. However, the investigations that are most closely related to this thesis are by MacCarthy (2004) and Morgan (1990, 2014) where the bailer systems discussed are referred to as “bucket pumps”. MacCarthy assessed the potential for rope pumps to be introduced as an alternative sustainable technology to bailers through analysis and comparison of pump technical performance, water quality, and economic feasibility in the context of the Ubombo Family Wells Programme in rural South Africa. It was shown that bailers had comparable water quality to rope pumps in a short term analysis involving five rope pumps and five bucket pumps. Bailers were also noted for being an appropriate technology in the area due to the durability of the systems, and the fact that they were successfully being maintained and repaired by the users themselves.

Morgan (1990, 2014) examined the bailer performance with respect to economic considerations, pumping rates, microbiological water quality, the flushing effect, and associated sanitary improvements incorporated into the bailer design. Bacteriological water quality from bailer systems was compared to that of hand dug wells and a technology called the Blair pump (with a design that is conceptually related to the EMAS pump). It was shown that bailers produced water of markedly better bacteriological quality than hand dug wells, and quality in the range of improved wells with Blair Pumps.

The flushing effect analyzed described the capacity of bailer technologies to provide water of high clarity and bacteriological quality. Mechanisms occurring within the borehole cause a rapid filling of the well body with fresh groundwater as a result of the difference in pressure head experienced when bail volumes are removed from the tubewell forcing the aquifer to compensate and generate new water to maintain the water table level. The flushing effect was demonstrated using *E. coli* per 100 mL as an indicator for water quality. Tubewells were spiked with *E. coli* and concentrations were shown to decrease drastically as bailer volumes were removed. Overall, Morgan concluded that bailer technologies he investigated proved to be sustainable and an appropriate household improved water source alternative, especially in the context of shallow aquifers (Morgan, 1990, 2014).

### 2.4.2 Water Quality

As a part of sustainable development programs increasing water access through tapping into new drinking water sources, it is necessary to check for contaminants threatening water safety to ensure that new systems are in fact mitigating the outbreak of water related diseases.

Quality drinking water necessitates satisfying guidelines and meeting standards for permissible limits of not only bacteriological, but physical and chemical parameters (WHO & UNICEF, 2013). Drinking water contaminated with bacterial, viral, parasitic, and worm organisms, are known to cause numerous stomach and intestinal illness including diarrhea and nausea, and can lead to death, especially in impoverished areas (Esrey, 1985). *E.coli* presence in particular suggests that water may contain traces of fecal matter that may include other harmful disease causing organisms, including bacteria, viruses, or parasites (Gwimbi, 2011). The practice of measuring *E. coli* presence in water samples has been a largely accepted form of indicating health risk as it has been found to be the most specific indicator of fecal contamination in drinking water (Gwimbi, 2011).

In general, groundwater has been shown to contain lower levels of harmful pathogens than surface water, although the quality of water drawn from hand pumps fitted to boreholes is variable with contamination which can be caused by poor sanitary seals or latrine proximity (WHO, 2011). Several studies have included microbiological water quality analysis of various types of water sources including unimproved and or improved groundwater sources (e.g., Morgan, 1990; Parker et al., 2010; Gwimbi, 2011). Generally, these studies demonstrate that bacteriological water quality from tubewells offering sealed protected groundwater sources is superior to that of traditional open hand dug well sources. However, it is important to consider that hygiene practices, water availability, and water quantity are more important factors in generating measureable health improvements than water quality performance alone (Morgan, 2003; Fry, 2010; Gwimbi, 2011; Seib, 2011). Thus, it can be argued that is generally recognized that while incremental increases in water quality should be an important design consideration for improved groundwater technologies, it should be considered alongside other factors when selecting an appropriate water source technology.

### 2.4.3 Socio-cultural Considerations

Numerous studies explore the social and cultural factors that surround water access and water use, which play a definitive role in the sustainability of water technologies newly introduced to a region. In fact, challenges related to the political, social, economic systems that sustainable determine water use and management practices have been acknowledged to be equally if not more challenging factors than technical concerns with water systems (Baird et al., 2013). Particularly relevant to this study are the examination of trends related to water access, use, preferences, and quality perceptions (and relationships between these indicators). The existing trends and related local cultural practices can be important to acknowledge and incorporate into develop strategies seeking to improve water access, as they affect residents attitudes and decisions related to implementing, operating, and maintain water sources (Baird et al., 2013).

Disciplines such as public health, engineering, and anthropology have utilized wide range of methods and indicators when examining relationships the sociocultural factors related to water use. Quantitative data such as measurements of water quantity, water quantity, water supply cost analyses, distance to water sources, and time spent gathering water, as well as qualitative data evaluating factors such as taste, perceived health risks, and familiarity with or comfort using a water source have been assessed (Doria, 2010; Baird et al., Prouty, 2013; Putnam, 2013). Due to the variability in the approaches adopted while assessing the topic, recognized trends cannot be applied or generalized into an overarching paradigm or theory.

Literature specifically investigating user perceptions of source water quality and related consumer behavior has largely emanated from urban or semi-urban settings with advanced public water supply or bottled water systems (Doria, 2010). Prior experience with the source, influence by personal or impersonal information, sensorial cues, cultural background, and world views were all recognized factors affecting perceptions of water quality in a study analyzing public perceptions of drinking water (Doria, 2010). These trends could be quite different however in rural developing communities or in societies with nature based religious beliefs and traditions. Among indigenous people for example, water is traditionally viewed as a precious resource: connected to physical, mental/intellectual, spiritual, and emotional well-being (McGregor, 2009).

**Table 4: Common Categories of Water Use and Examples of Each Type of Use**

| Water Use Category | Examples |
|---|---|
| Consumption | Drinking and cooking |
| Hygiene | Personal and domestic cleanliness (i.e., bathing, laundry, washing floors, dust suppression) |
| Productive | Gardening, brewing, animal watering, construction (e.g., manufacturing concrete) |
| Amenity | Washing a vehicle or motor scooter, lawn watering |

(Mihelcic et al., 2009)

Links between socioeconomic factors, user perceptions, and choices made by users with respect to water use, preferences, and management have been investigated in urban towns in the developing world (Prouty, 2013; Putnam, 2013). Prouty’s (2013) statistical analysis of water quality data as well as household survey data from a variety of water sources revealed that more community members in Uganda preferred to use sources that required less collection time and had lower viable levels of visible turbidity, but were accompanied by high costs (among other factors) (Prouty, 2013). In Peru, ties between household water use behaviors, perceptions and values were evaluated in relation to corresponding household water demand and management practices in municipal piped water systems (Putnam, 2013). Increasing availability of water supplies marked increases in water use, particularly with respect to water quantity.

When evaluated from a development and public health perspective, water can be characterized by socially constructed water use categories (Mihelcic et al., 2009). Table 4 illustrates categories for water use and provides examples of four typical uses for water which have differing associated human health implications (Howard & Bartram, 2003). These water use categories can also be distinguished by variances in desirable characteristics related to water quantity and water quality such as those applicable to WHO guidelines (Howard and Bartram, 2003). It is unknown whether these categories would be similarly defined by users in rural developing areas.

# Chapter 3: Materials and Methods

## 3.1 Field Research Overview

The research methods applied in this study consist of four primary means of data collection: (1) literature review, (2) measurement, (3) interviews, and (4) direct observation. Both qualitative and quantitative data are considered. All data collected for this investigation are primary data directly collected by the author, through experiment, measurement, or observation, unless otherwise noted. Over the course of the study, the author was directly involved in providing technical and training support for the introduction and operation of the hand drilled well technologies in the Peninsula Valiente area, through collaboration with community members, local counterparts, Peace Corps Volunteers, as well as the Healing Fund NGO group, who had overall responsibility and oversight for the project. The author conducted field research through twelve site visits to the study area between December 2012 and December 2013. The first five site visit excursions consisted of familiarizing herself with the context of the study area, developing relationships with local counterparts and community members, visual and manual inspections, and observation. The subsequent seven data collection excursions consisted of visual and manual inspections, observation, conducting interviews, and water quality sampling.

### 3.1.1 Local Hydrogeology

The Peninsula Valiente area of ÑöKribo, and its regional province of Bocas del Toro is noted for its abundance of annual rainfall (an average of 363 mm a month for the months during the period of this study and a maximum average of 563 mm during rainy season) with a indistinguishable, mild dry season relative to the rest of the country (Green, 2011; WWIS, 2011). A prevalence of high water tables accompanies the mangrove swamp terrain that naturally fringes all communities in the study area. Regional data on water table characteristics was unavailable, but were observed from a range of less than 1 foot to 5 feet on non-hilly terrain. Since rainfall is expected to influence measurements of water quality (e.g., Wright, 1986; Howard, 2002), rainfall data were collected by a variety of methods including rainfall gauge and noting the number of days since a rain during water quality sampling.

Due to limited available data on the specific geology of the area, soil classification of research sites was performed by the author using a variety of qualitative ASTM methods without the use of analytical equipment. Soil was classified by the author at every well study location through recommended methods of visual examination and physical soil behavior when handled as determined by Test Method D 2488 of Visual-Manual Test Procedures (ASTM, 2014). Three methods were executed with soil samples from every community included in the study: (1) a soil sample was formed into a ball and dropped from a height of one meter, (2) a dry soil sample in the form of a lump was tested for toughness, and (3) a soil sample was elongated and rolled into a thread.

### 3.1.2 Water Source Characteristics of Study Sites

The twenty-three water sources assessed in this study are summarized in Table 5, and can be classified as: (1) improved hand augered wells with bailers, (2) improved hand augered wells with EMAS pumps, (3) unimproved hand dug wells for washing, (4) unimproved hand dug wells for drinking, (5) piped aqueduct systems, and (6) rainwater catchment systems. All improved wells included in this study were installed between 2012 and 2013 and were initially implemented with bailer buckets as their water lifting mechanism. However, in November 2013 bailer buckets were replaced by EMAS hand pumps in three of the eleven improved wells.

**Table 5: Water Sources Assessed in this Study by: Community, Source Type, and Number**

| Community | Source Type | Number |
|---|---|---|
| La Ensenada | Improved hand augered well with bailer | 5 |
| Kani Kote | Improved hand augered well with bailer | 3 |
| Kani Kote | Improved piped aqueduct system | 1 |
| Barriada Record | Improved hand augered well with bailer | 1 |
| Barriada Trotman | Unimproved hand dug well for drinking | 1 |
| Barriada Trotman | Improved hand augered well with bailer | 1 |
| Bahia Azul | Improved hand augered well with bailer | 1 |
| La Ensenada | Improved hand augered well with EMAS pump | 3 |
| La Ensenada | Improved piped aqueduct system | 1 |
| La Ensenada | Improved rainwater collection | 1 |
| La Ensenada | Unimproved hand dug well for washing | 3 |
| La Ensenada | Unimproved hand dug well for drinking | 1 |
| Kani Kote | Unimproved hand dug well for drinking | 1 |

#### 3.1.2.1 Local Unimproved Hand Dug Wells

All of the studied hand dug wells on Peninsula Valiente are considered unimproved sources (refer back to Table 1 in Section 1) because they lack any form of interior casing, well apron, or covering. Thus, the wells remain vulnerable to pathways of contamination including sediment from the sides caving in and surface water entry during rain events. Furthermore, as the community sanitation systems in the study area include practices of open defecation; there is the potential for fecal contamination to runoff directly into the wells. Additionally, grey water contamination is an issue for washing wells, as soap from bathing and washing clothes mixes with well water. Hand dug well sources included in this study vary widely in dimension with diameters between 1.5 and 8 feet and total excavated depths between less than 1 foot and 4 feet.

**Figure 9: (a) Hand Dug Drinking Well (b) Partitioned Drinking (upper) and Washing (lower) Unimproved Well Sources in La Ensenada**

Existing hand dug wells in La Ensenada, Barriada Trotman, and Kani Kote serve between one and five families per well. Adult males decide on the appropriate location of a well when moving into or constructing a house with no other available water source. The well is then dug out by adult males and male youth of related to the family. Most of these traditional sources provide water year round, though a few may dry up for a short period on rare occasions of time marked by the extended absence (more than 3 weeks) of rain during the year. Water is typically collected by women or children scooping water into a bucket or jug and then carrying it to their houses. In instances where the water level is shallow, there is a designated “scoop”, made from a jug or bowl for example, which people use to distribute water from the well to a storage receptacle.

It is interesting to note that all hand dug wells evaluated in the study have informal appropriate water use designations set by the users. That is, some wells are designated to be used for cooking and drinking only (Figure 9a); while others are designated for washing clothes and bathing only (Figure 9b).  Designations are made typically by the family that initially digs the well, as the size, depth, and location of the well often are recognizable cues in the local context that indicate the intended purpose of its water.  The designations are generally respected, as they are seen as practical and logical. It is often not desirable to drink water from a washing well (due to the soaps and detergents introduced) and it is not desirable to wash in a drinking well (due to an insufficient volume of water and constrictive size of the well not allowing for proper washing methods).  There is no system for monitoring the use of a well beyond visible indicators of water quality and water depth.  Accordingly, there are no repercussions for when wells happen to be used in a manner that contradicts its appropriate use designation as norms are largely expected to be followed.

The wells that are designated specifically as drinking water only sources are typically small diameter (1.5 to 4 feet), very shallow (less than a foot to 3 feet in depth), and have visibly less turbid water than their washing well counterparts.  In some cases drinking water wells are partially covered from the possible entrance of animals and dirt through the construction of an open walled thatched roof covering.  The wells that are used for a mixture of bathing and clothes washing purposes are typically larger (4 to 8 feet diameter), depth (3 to 5 feet), and have visibly more turbid water.

Local efforts to maintain hand dug well sources involve no established schedule, rather they are largely dependent on visible indicators of water quality such as water color (grey hues due to soap or brown hues due to sediment), and water depth.  The frequency of well cleaning events can range from several times yearly, to monthly, weekly, or daily during heavy rainfall periods.  The wells are cleaned by well owners and well users including women, men, youth, and children who often independently decide to initiate clean the well before gathering water or bathing, upon recognizing that the water is visibly dirty or that some time has passed since cleaning. They flush water from the well by discarding a large volume of water using buckets or scoops and then remove any noticeable contaminants such as sticks, rocks, leaves, or trash that may have accumulated in or near the well. More arduous well cleaning events are typically left for males to perform, as the associated labor can be physically exhausting, depending on the size of the well and the amount of water extracted. Local residents then allow the wells to recharge with “clean” fresh water before seeking water to take to their homes for consumption.

#### 3.1.2.2 Local Improved Wells

In March 2010, a U.S. based NGO group called “The Healing Fund” began to introduce hand drilled well technologies to the Bocas del Toro province as part of an international service endeavor. The group is comprised of volunteers from a variety of organizations (including church groups and the Arlington and Stanwood Rotary International clubs) and is led by Mr. Aleph Fackenthall. Between March 2012 and May 2013, approximately 12 hand drilled wells, complete with either bailing devices or EMAS hand pumps, were installed in the Bahia Azul area of Peninsula Valiente and 15 in the Isla San Cristobal area of the Bocas del Toro province. This study only examines improved wells in the Peninsula Valiente region.

Although the initial wells were implemented in the study area under the supervision and training of volunteers from The Healing Fund during their annual service trip to Panama, the majority of wells in the area were installed completely by locally trained Ngöbe men. The Healing Fund entrusted three hand augering apparatuses known as the Hydromissions “Explorer” Hand Drilling Systems to be used by four trained individuals in the Bocas del Toro province who were provided funds for acquiring necessary materials and for their labor of installing wells.

All materials for the bailer bucket and EMAS pump systems were purchased in the port cities of Almirante or Chiriqui Grande, and then transported by boat to the well sites (approximately 2 to 6 hour motor boat ride). Well installation was completely funded by the Healing Fund, including materials, transportation, and paid skilled labor. Table 6 provides a summary of the month of installation of the improved wells included in this study. Recipient families often contributed with food provisions for laborers.

**Table 6: Date of Installation of Improved Wells Assessed in this Study**

| Well | Date of Well Installation |
|---|---|
| MikMIW | April 2012 |
| AbeIW | June 2012 |
| ValIW | February 2012 |
| EnrIW | March 2013 |
| LydIW | April 2013 |
| RamIW | April 2013 |
| KaniIW | April 2012 |
| NinIW | April 2013 |
| MikHIW | August 2013 |
| MelIW | January 2013 |

All wells included in the study were drilled to the same diameter, using well casings of 4-inch PVC pipe to line the entirety of the well. A basic well screen was made by cutting 0.5-inch slots in the pipe with a hack saw for roughly the bottom third of the length of the casing. No additional screening or packing was implemented, due to the clay soil type. All improved wells included a concrete apron, implement as: (1) a rectangular section of concrete slab approximately 3 inches thick and 2 square feet surrounding the PVC well head (as seen in Figure 8 of Section 2.3.4.2**)** or (2) a 5 gallon bucket equivalent volume of concrete encasing the protruding PVC tubing (as seen in Figure 11 of Section 3.1.2.2.2). No additional drainage or water runoff diversions were implemented. All wells were also installed with a PVC end cap to be fitted over the well head. This cap offered additional protection of the well body, and remained attached to the rope used to hoist the bailers through a small hole in the cap.

#### 3.1.2.2.1 Local Bailer Systems

All of the improved wells in this study were introduced with bailers as their water lifting mechanism, as shown in Figure 10. The bailers were constructed in Panama, based off of designs and materials adapted from Hydromissions International (a for-profit company and a non-profit missions agency) (Hydromissions, 2013). The materials for the bailer body include cut 3-foot long sections of 3-inch diameter PVC pipe, and a variety of bolts and washers. Also, a plastic foot valve bought locally was screwed into a 3- inch end cap on the bottom of the bailer body. The rope used for hoisting was knotted around two bolts near the top of the tube. These bailers had a measured storage capacity of approximately 4.5 liters and were utilized by tilting the bucket to empty water out of the open end into a storage container (as opposed to water exiting the bottom of the bailer in some designs).

After initial installation, families were provided instructions and recommendations by the well drillers and other local well owners on how to develop the well and maintain the bailers. They were not provided any materials from the Healing Fund with respect to caring for the wells, rather these recommendations are largely determined by local experiences. Families and children are directed for example to: not touch (or play with) the bottom valve so as to not damage it, not expose the bailer body to surfaces with dirt or mud, and to always keep the PVC cap on the well head to prevent mosquitos from breeding or people from dropping items into the well.

Also, specifically in the first few months after well installation, families were told to be persistent in bailing water from the well *cada rato*, or every moment, as initially the water is initially very turbid and brown. Well owners were advised that continued bailing would allow the wells to recharge with clean, “fresh” water, but that infrequent bailing would keep “old” dirtier water stored in the well body. This concept was generally understood by users, especially those who had access to unimproved hand dug wells. Although well owners were typically discouraged in the first few months upon extracting visibly turbid water from the source, they were often encouraged by recognizing the water clarity of other local improved wells and through sharing experiences with other well owners.

**Figure 10: (a) Bailer Demonstrated in La Ensenada (b) Bailer System Top View**

#### 3.1.2.2.2 Local EMAS Hand Pumps

The Healing Fund organization learned of EMAS pump technologies in 2012 and began to direct their implementation in improved wells in various Ngöbe communities of Bocas del Toro in 2013. The EMAS pumps utilized in the study area were fabricated by volunteer members of the Healing Fund in the U.S. and then transported to the well site during an annual service trip. Due to logistics and time constraints of the Healing Fund volunteers, they were not able to teach or train local people about the function, use, and maintenance of the hand pumps.

Three of the four local well drillers were trained by the author between August and October 2013 on basic EMAS pump function and assembly. Under the supervision of the author, these men learned how to install the prefabricated EMAS pumps in November 2013. Bailer bucket systems were removed from three improved wells in La Ensenada willing to try using the EMAS hand pumps. This process involved gluing PVC as well as galvanized iron pieces and lengthening the assembled EMAS pump bodies to the depth of the well through adding PVC extensions. They did not receive any training on or experience with EMAS pump manufacture or repair.

**Figure 11: EMAS Pump Installed by the Healing Fund**

The design of the EMAS pumps installed (as shown Figure 11) differs slightly from manufacturer recommendations in two ways: (1) pumps with 0.5-inch diameter PVC pistons were implemented, although 0.75-inch diameter PVC pistons are recommended for implementation specifically in shallow wells, and (2) pumps incorporated threaded PVC as bars in the pump handle, only using galvanized iron for the “T” (EMAS, 2008),. It was decided by the Healing Fund that the 0.5-inch diameter design was more appropriate to implement in Panama, because the larger 0.75-inch diameter pump is more difficult for users to pump and more expensive to implement. Also to reduce costs, PVC pipe was substituted for galvanized pipe in in all handle pieces except for the “T”.

### 3.1.3 Other Water Sources Considered

Two piped gravity fed water systems (referred to as aqueducts in Panama) and one rainwater collection system were also assessed in this study. They are representative samples of the existing improved drinking water access most available to users in local communities. The aqueducts (in Kani Kote, La Ensenada, and Bahia Azul – not sampled) originate from a small stream, and are known to experience supply issues in period with little rainfall. The aqueducts are community managed through established water committees that oversee operation and maintenance. In a study conducted on the Peninsula Valiente, it was concluded that “rainwater harvesting is one of the most widely available source improvement technologies that is feasible and appropriate for this particular region and climate” (Green, 2011). Indeed, all communities included in the study had some degree of household rainwater collection, as well as communal rainwater systems for institutions such as schools, churches, and health centers.

## 3.2 Methods Used to Assess Water Quality

Quantitative data were obtained in the form of measured results of water quality methods and tests analyzing three types of water quality parameters: (1) physical and chemical parameters including pH, conductivity, alkalinity, total dissolved solids, salinity, and nitrate (reported as nitrogen), (2) bacteriological parameters including *E. coli* and total coliforms (discussed separately in Section 3.2.3), and turbidity characteristics (discussed separately in Section 3.3.3). Samples were periodically collected and analyzed from all water source types between June and December 2013. The erratic sample size and consistency of sampling across locations was largely affected by equipment, local weather, and transportation options. Due to these reasons, although numerous water sources on the Bahia Azul side of the bay are included in the study, they are only included in 4 out of the 7 data sets obtained. There is substantially more consistent sampling and observation of the La Ensenada area, where the highest number of water sources studied could be found in one single location, as indicated by Table 5 in Section 3.1.2.

### 3.2.1 Data Collection

Samples for testing of all parameters except for turbidity and bacteriological presence (discussed separately) were collected in clean (but not sterilized) PETE 250 mL plastic bottles. All bottles were prepared for collection by rinsing 3 times with sample water (filling, closing, shaking vigorously, and then emptying) from the source before officially sampling. Samples were collected in the manner that is commonly practiced by the users, depending on the water source:

- For unimproved well sources, samples were collected by submerging the sample bottle directly in the well from the same area, without disturbing the underlying sediment, or if it was a very shallow well then the same scoop locally used was utilized to pour water into the sample bottle.
- For bailed water sources, water was collected by pouring water from the bailer directly into the bottle.
- For pumped sources, water was collected directly from the pump head.
- For rainwater sources, samples were collected from the household tap.
- For aqueduct systems, samples were collected from the household tap.

Bailers, pump heads, taps and containers utilized by local users were not cleaned or disinfected in any way; therefore, the sample is thought to be a reflection of the water quality as it is accessed by the user. No measures were implemented to assure or control the state of use of the well.  Water samples were collected from the well in the state that the well was encountered. This varied widely depending on whether the wells were in use at the time of sampling, used earlier in the day, used earlier in the week, used earlier in the month, or (in one case in Bahia Azul rarely used/abandoned wells).

### 3.2.2 Testing Procedures- Physical and Chemical Water Properties

A suite of chemical and microbial water quality parameters were used to measure the various water samples collected. Appendix D provides a list of equipment and corresponding units of measurement for each water quality parameter and additional materials related to water quality testing.  The majority of water quality parameters were tested using equipment at the *Instituto de Acueductos y Alcantarillados Nacionales* (IDAAN- in English: National Institute of Aqueducts and Sewage Systems) water treatment plant facility located in El Silencio in the Bocas del Toro province (approximately 7 hours by public transportation from the study area).

The following parameters were tested in the IDAAN laboratory:  pH, salinity, conductivity, alkalinity, total dissolved solids (TDS), nitrate as nitrogen, total coliforms, and *E.coli*. Alkalinity tests were performed by the author with manual visual titration methods evidenced by the color change of phenolphthalein indicator using 0.035N $H_2SO_4$ as the titration acid.  The remaining water quality parameters were measured on site in the study area: turbidity and the Coliscan EasyGel method for total coliforms and *E.coli*.

### 3.2.3 Testing Procedures- Total Coliform and *E.coli*

The IDEXX (Westbrook, ME) Colilert Quanti-tray 2000® (Colilert), 2000 method was selected to quantify coliform presence in water samples for the first two data sets.  Samples were collected in the field (as described in Section 3.2.1) and stored on ice in a foam cooler within 4 hours of collection.  Based on local transportation logistics, samples were transported to the

IDAAN laboratory within 34 hours of collection. At time, ice arrived in the state of ice water upon arrival in the laboratory. Samples were prepared in accordance with the manufacturer's specifications and incubated in the laboratory at a temperature of 45 $^{o}$C. Unimproved water source samples were diluted by 1:10, with sterile deionized water prior to testing, based on standard procedures and manufacturer recommendations. Most probable number (MPN) estimates of total coliform and *E. coli* concentrations were obtained. Wells with a yellow color were counted as positive for total coliforms. Wells that visibly fluoresced beneath a 366 nm ultraviolet light were counted as positive for *E. coli*. MPN estimates were calculated using tables supplied by the manufacturer.

The remaining five bacteriological data sets were obtained using the Micrology Laboratories, (Goshen, IN) Coliscan EasyGel® (EasyGel) method to quantify total coliforms and *E.coli*. EasyGel media bottles were stored in coolers at the study location but were not frozen, as recommended by the manufacturer. Samples were collected as described in Section 3.2.1, directly into the plastic bottles containing Easy Gel media provided by the manufacturer. Samples were plated using (using 3, 4, or 5 mL volumes of sample mixed with media) within 4 hours of sampling. One sterile syringe was used per sample location to plate the samples. The samples were not kept on ice after collection until plating as recommended by the manufacturer due to transportation logistics and the lack of available ice.

Due to lack of availability of electricity in the study area, plates were incubated at ambient temperature for 46 to 48 hours, in concordance with manufacturer recommendations when controlled incubation methods are not feasible. Ambient temperature during the months of the study can be approximated by World Weather Information Service average monthly temperatures for the Bocas del Toro province which range between 31 and 32 $^{o}$C (WWIS, 2011).

After 46 to 50 hours of incubation, plates were counted as colonies appearing blue were counted as *E.coli* and colonies appearing pink were counted as other coliform, as per manufacturer procedures. By Coliscan EasyGel methods, colony counts were totaled and the corresponding numbers of colony forming units (CFU) per representative 100 mL of sample were derived according to manufacturer procedures. Depending on available equipment and logistics at the site, water samples were measured in a variety of single, duplicates, or triplicate samples from all the sources assessed.

### 3.3 Methods Used to Assess Well Performance

A variety of data were collected with the purpose of assessing the technical performance and appropriateness of the bailer bucket and EMAS pumps technologies in the hand drilled wells recently implemented in the study area.

### 3.3.1 Visual and Physical Inspection

All water sources were visually inspected, and in the case of EMAS pumps and bailer systems, tested to confirm that they were operational (i.e., pumping water or not), as well as level of performance (i.e., pumping or lifting water without significant problems). It was also deemed necessary to assess the respective sanitary seal and well apron of each improved well location. Visible pathways of exposure to contamination (such as latrines, trash, damaged/unprotected casings, or cracks in concrete well aprons permitting surface water entry) in the vicinity of the water source were observed and noted.

### 3.3.2 Depth Measurements

Well depth is a characteristic of wells that designates relative hydrogeological context and aquifer presence at the well site. Well depth for improved wells was a reported estimate provided by well drillers through the water user interviews discussed in Section 3.4. For unimproved wells, depth of water in the well was measured with a tape measure consistently from the same point in the well, from the well bottom to the water surface.

Similarly, depth to water level in the tubewells was considered an indicator that could reflect groundwater activities such as well recharge and groundwater infiltration within the hydrogeological context of the study area. For improved wells with bailing systems, the depth to water level was measured in inches with a tape measure, from the top edge of the well casing to the surface of the water within the well. No measurements were taken for improved wells with EMAS pumps because it became problematic to remove the pump head.

### 3.3.3 Assessing Turbidity and the Flushing Effect

In order to address well recharge dynamics, also known as the "flushing effect" and provide another characteristic by which to compare source water quality, turbidity was chosen as a representative water quality indicator. Turbidity, when in excess of 5 NTU, is an indicator of water quality that is noticeable and distasteful to consumers (WHO, 2011). The flushing effect in this instance refers to the act of removing existing water from the water chamber in a well in order to provoke a rapid recharging with fresh groundwater percolating or infiltrating into the well chamber (Minihane, 2009; Morgan, 2003). The flushing effect was assessed through the following method: turbidity of well water was monitored periodically as bail volumes (approximately 4.5 liters of water per bail volume) were being continuously drawn and flushed from the system. Samples to be tested for turbidity were collected at a variety of arbitrarily selected bail/pump volume intervals of 1, 3, 5, 7, 10, 14, 15, 17, and 20 unit volumes during numerous sampling excursions over the course of the study. Water samples were collected in clean glass vials provided with the turbidity meter. Glass vials were reused, following the same rinsing procedures described for the plastic sampling bottles. All samples were agitated by hand before measurement according to manufacturer procedures and analyzed within eight hours of collection.

### 3.4 Methods Used to Assess Socio-cultural Implications of Water Access

An individual's water management, perceptions, and preferences are often deeply rooted in customs, beliefs, and the socioeconomic as well as environmental context of a specific area (Baird et al., 2013). Consequently, when considering the appropriateness of the groundwater technologies introduced to Peninsula Valiente and categorizing their role in improving access to drinking water, it was considered necessary to establish a basic understanding of the local belief systems and social structures. Due to its complex nature, examining the ties between water usage, perceptions, behavior and their respective water sources often involves a mix of both quantitative and qualitative analyses (Doria, 2010). Qualitative data, such as the data obtained in this study, allows the analysis as of valuable factors such as community dynamics, varied opinions, and cultural perceptions (Dynes, 1971; Doria, 2010, Prouty, 2013).

#### 3.4.1 Interview Structure

The research methods employed were first proposed for review by the Institutional Review Board (IRB) at the University of South Florida and considered exempt (see Appendix A for IRB correspondence). Household surveys developed by the author were the planned primary method of data acquisition as the most effective form of collecting information from the users of water sources in the context area. They were designed in concordance with the purpose of surveys demonstrated in the similar research: to elicit the range and dominance of perceptions about a resource within a community or among communities (McDaniels et al., 1997) and contribute to appropriate water use and management decisions (Baird et al., 2013). Specifically, as part of the assessment of the sustainability of the hand drilled well project, survey questions also incorporated objectives of indicating local political cohesion, community participation, and socio-cultural factors relating to water use behaviors and preferences. Human factors such as: household water usage, water source maintenance, user satisfaction, and user perceptions were addressed in the Well User Interview Guidelines provided in Appendix B.

Depending on the comfort level and familiarity of the user with the researcher, interviews were conducted in either a semi structured or informal manner. The individual respondents' background (age, language, literacy, and education level) largely determined the execution of the interview using the Well User Interview Guide as a baseline format. Considering the comfort and literacy level of users, interviews were verbally conducted by the author; primarily in Spanish with minor Ngaberi native dialect.

The interview format was reevaluated after initial interviews were conducted. Several questions posed in the Well User Interview Guidelines were found in some cases to elicit unintended information, to be unanswerable by the respondent, or to be misunderstood. In these cases, the questions were noted, then reposed by the author on a subsequent data collection event. In some cases, additional questions were added to the survey.

### 3.4.2 Water User Interviews

Both quantitative and qualitative data with respect to the human factors assessed in the study were collected. The author attempted to implement various best practices while designing and conducting the interviews, particularly with respect to the qualitative questions. For instance, the following factors were taken into consideration:

- Leading questions or questions with ambiguous wording
- Respondents' abilities to explain their choice process
- Respondents' abilities to confidently estimate distance, time, and volume of water

- Respondents’ ability to rank or compare systems
- Respondents’ age and gender roles (as women performed more water collection, washing, cooking tasks, while men were more involved with technical aspects of water sources such as well implementation and maintenance)
- General subjectivity of respondents, as preferences can vary widely from person to person

Although qualitative data collection has the potential to contain a wide variety of error, it remains critical for use in research; providing a means of direct community feedback and eliciting a [more] comprehensive, well-rounded study (Prouty, 2013). Accordingly, survey and observation methodology was incorporated, not to offer statistically significant evidence, but to add contextual relevance to the evaluation of research objectives and the wholeness of the study.

### 3.4.3 Supporting Observations

Supplemental information often emerged through informal dialogue between the research and with the users. This, along with other notes, were documented and summarized in the form of User Water Profiles included in Appendix C. Users were asked in the final question of the survey whether there was anything else they wanted to add or comment on regarding the wells or their water access. In some cases, responses to questions changed over time, as improved wells developed for example. In these instances the author reported only the most recent response.

## 3.5 Methods Used to Assess Sustainability

Due to the intricacies associated with the interrelated, interdisciplinary dynamics of sustainability which can be variable when considering geographical context, project scale, and status over time the evaluation of sustainability can be quite complex (Loucks, 2000). Approaches to sustainability metrics which involve the use of computer modeling software and databases to process the variety of related data, were considered outside of the scope of this study. The most relevant methods used to assess the sustainability of a water project in the context of development work involve a practical tool that weighs qualitative measures of the sustainability factors presented in Table 2 of Section 2.1: socio-cultural respect, community participation, political cohesion, economic sustainability, and environmental sustainability as part of a matrix framework (McConville & Mihelcic, 2007)

The tool, which is simple and adaptable for use by engineers and development workers seeking to recognize strengths and weaknesses related to projects, recognizes project life stages and factors of sustainability through a series of checklists associated with best practices in the development context (McConville, 2006). However the approach can be subjective and is limited by a lack of existing standards against which to compare results or defined thresholds which indicate acceptable levels of performance.

The appropriateness of bailers and EMAS pump systems were assessed adapted methods based on McConville's tool. A rank number was assigned to each groundwater supply technology for every sustainability factor, using a scale of 1 to 5 with 1 the lowest and 5. Ranking was performed by the author based on guidelines related to best practice approaches to sustainable development, as suggested by the recommended methods presented with McConville's sustainability assessment tool (McConville, 2006). Although McConville indicates that the tool should be utilized for a qualitative analysis of the sustainability of water and sanitation projects at all phases of a project's life cycle, the tool was applied in the context of this study solely based on the approach of the project since conception by the Healing Fund and throughout the course of the study period. Factors affecting the evaluation of sustainability and appropriateness include differences in sample size of the two water systems and stages of project implementation (as EMAS hand pumps were introduced to the area only for the last two months of the study).

Both types of systems were considered on two levels, with one number assigned to embody a representative overall sustainable performance. First, the hand augered well technologies were assed based on inherent characteristics of the technologies and respective outcomes of all evaluations performed in this study. Second, the improved water sources were assessed based on aspects related to the strategies utilized to implement the technologies through considerations of data gathered through correspondence with the Healing Fund which indicated the organization’s oversight of the hand augered well projects before and during the period of the study.

## 3.6 Data Analysis Methods

### 3.6.1 Water Quality and Well Performance

Descriptive statistics were utilized to characterize the water quality parameters and well performance data such as range, minimum, maximum, mean, and standard errors of the mean were chosen to represent the data. Water quality parameters were assessed based on source types and categories described in Table 1 of Section 1.1.

**Table 7: Water Source Type and Assigned Source Type Number**

| Source Type | Assigned Source Type Number used to Facilitate Analysis of Data |
|---|---|
| Improved hand augered well with bailer | 1 |
| Improved hand augered well with EMAS pump | 2 |

**Table 7: (continued)**

| | |
|---|---|
| Unimproved hand dug well for washing | 3 |
| Unimproved hand dug well for drinking | 4 |
| Improved piped aqueduct system | 5 |
| Improved rainwater collection | 6 |

In order to facilitate analysis, source types were assigned a numeric value, as explained in Table 8. Furthermore, physical and chemical quality was evaluated with respect to seasonal patterns through acquired rainfall data and over time during the study period, figures for which can be found in Appendix E.

### 3.6.2 Total Coliform and *E. coli*

Analysis was based on the MPN's and total CFUs per representative 100 ml water sample for the total coliform and *E. coli* for both the Colilert and the Coliscan EasyGel results. In unchlorinated waters, it is typical for crude water samples to contain large numbers of total coliform bacteria which may or may not be of sanitary significance (WHO, 2011). All water samples were known to be from unchlorinated sources (except for samples obtained from unimproved washing wells). No treatment to remove chlorine in water was applied to water samples.

**Table 8: WHO Risk Categories with Corresponding *E. coli* Concentrations and Assigned Numeric Risk Categories**

| **WHO Risk Category** | ***E.coli* Concentrations** | **Numeric Risk Category** |
|---|---|---|
| Conformity | 0 CFU/ 100 ml | 1 |
| Low Risk | 1 – 10 CFU/ 100 ml | 2 |
| Intermediate Risk | 10 – 100 CFU/ 100 ml | 3 |
| High Risk | 100 – 1000 CFU/ 100 ml | 4 |
| Very High Risk | and >1000 CFU/ 100 ml | 5 |

As recommended by WHO guidelines, *E. coli* was selected as the appropriate indicator for bacteriological activity and associated health risk of water samples (WHO, 2011). Descriptive statistics were used to summarize and compare the microbial quality of water samples from all sources considered, with results of the statistical analyses displayed in graphic and tabular forms. It was decided to categorize results based on WHO recommendations for risk categories associated with fecal coliform bacteria in piped water systems (WHO, 1997). These risk categories were then assigned numerical values for the purpose of statistical analysis, as summarized in Table 9.

Although the WHO risk categories are based on concentrations reported as CFU per 100 mL, it was decided to include the 16 samples collected by QuantiTray methods which reported *E. coli* presence in MPN. For this study, precision water quality was not an attainable objective, rather it was considered most appropriate to evaluate relative bacteriological water quality to allow for general comparisons between the various water source types being evaluated. Thus, *E. coli* values reported in MPN were placed into the most appropriate WHO risk categories using the categories presented for concentrations in CFU as a guideline. This subjective categorization was performed with the knowledge that results between the two tests have been found to correlate, with MPN values paralleling behavior indicated by CFU values (Noble et al., 2004). Furthermore, it was determined to be more important to fulfilling the objectives of this study to consider the relative bacteria related health risk associated with a water sample. Table 9 denotes the risk categorization performed on the 16 samples collected that reported *E. coli* presence in MPN. In this manner, despite the change in methods that occurred over the course of the study, the data from water samples collected using QuantiTray methods could still contribute to the overall analysis of the bacteriological water quality.

**Table 9: Risk Categorization into WHO Related Risk Categories of Water Samples Based on *E. coli* Concentrations Reported in MPN**

| ***E. coli* Concentrations in MPN** | **Assigned WHO Risk Category** | **Numeric Risk Category** |
|---|---|---|
| 1 | Low | 2 |
| 1 | Low | 2 |
| 6.20 | Low | 2 |
| 1 | Low | 2 |
| 1 | Low | 2 |
| 1 | Low | 2 |
| 1 | Low | 2 |
| 1 | Low | 2 |
| 9 | Low | 2 |
| 19.90 | Intermediate | 3 |
| 1203.00 | Very High | 5 |
| 32.30 | Intermediate | 3 |
| 1 | Low | 2 |
| 1203.00 | Very High | 5 |
| 32.30 | Intermediate | 3 |
| 1 | Low | 2 |

# Chapter 4: Results and Discussion

## 4.1 Research Area Background: Hydrogeology

Table 10 summarizes site specific rainfall data collected by Peace Corps volunteers living in the study area (in the communities of La Ensenada and Bahia Azul) using a rainfall gauge during the time frame of the study. The measurements gathered specify a level of rainfall higher than suggested by the World Weather Information Service (WWIS) monthly averages.

**Table 10: Total Monthly (mm) Rainfall Measured in Study Area**

| Month | Total Monthly Rainfall (mm) 2012 Bahia Azul | Total Monthly Rainfall (mm) 2012 La Ensenada | Total Monthly Rainfall (mm) 2013 La Ensenada |
|---|---|---|---|
| January | 445 | 420 | 470 |
| February | 356 | 360 | 270 |
| March | 686 | 636 | 540 |
| April | 241 | 192 | 480 |
| May | 254 | 180 | 660 |
| June | 438 | 444 | 470 |
| July | | 1068 | 690 |
| August | | 444 | 310 |
| September | | 408 | 470 |
| October | | 528 | 301 |
| November | | 924 | 448 |
| December | | 490 | 400 |

(data collected by Erik King, Louis Graham, and Colleen Hickey)

In La Ensenada, for the combined months of June through December when water quality testing was performed, measured rainfall averaged 615 mm in 2012 and 441 mm in 2013. In contrast, the WWIS indicated an average for this period of 363 mm a month for the province of Bocas del Toro. Similarly, the maximum averages during rainy season in La Ensenada were measured to be 1,068 mm in 2012 and 690 in 2013. These values compare with a WWIS maximum average of 563 mm reported during rainy season.

All soil samples in the research area were classified as “CL”; that is, inorganic clays of low to medium plasticity. Pockets of rocky soil were also observed in the study area. The soil characterization of the sites studied is considered unique in the context of hand augered well technologies, which are typically implemented under sandy or gravelly soil conditions. This is because sand and gravel soils offer more permeable soil conditions which facilitate the movement of fluid through the soil media and thus generally produce higher recharge rates and higher yield wells than clay soils (Van der Wal, 2010).

## 4.2 Physical Chemical Water Quality Tests

### 4.2.1 Evaluation of Water Quality by Water Source Type

Average measurements of water quality parameters obtained from six dates between July 2013 and December 2013 are presented in Figure 12. Additional data is presented in Appendix D and E. pH ranged from 5.58 to 7.71 with a mean of 6.40, which generally falls within acceptable drinking water values between 6 and 8 as recommended by the WHO. Alkalinity describes the acid-neutralizing capacity of a water source. Measured values varied from 3.50 mg/L $CaCO_3$ to 115.50 mg/L $CaCO_3$ with a mean of 22.71 mg/L $CaCO_3$, which is consistent with low alkaline fresh water sources as described by the EPA. There are no national (U.S.) or international standards or guidelines for alkalinity as it is not treated as a contaminant related to health risks.

Similarly, conductivity is a water quality parameter that is not classified as a contaminant but rather is used as an indicator of the ability of ions in water sources to conduct charge. Conductivity levels were detected at an acceptable range between 6.21 µs to 226.00 µs with a mean of 50.84 µs for all water sources sampled. Total dissolved solids (TDS), which are calculated based on measurement of dissolved ionized solids and other very small particles in water, varied from 2.99 mg/L to 109.30 mg/L with a mean of 24.66 mg/L. All samples demonstrate TDS values well below the WHO secondary guideline of 600 mg/L, beyond which drinking water is described to become unpalatable. Salinity, which was a parameter measured due to proximity of research sites to to the Carribbean Ocean, varied from 10.89 mg/L to 106.40 mg/L with a mean of 25.99 mg/L. The observed range signifies that waters sampled clearly fall into the categorization of freshwater with concentrations of dissolved salts well below the 1,000 mg/L (which is the upperbound for fresh water sources according to the USGS). Note that salinity is a measure of dissolved ions in water, which is expected to parallel dissolved ion concentrations related to TDS and conductivity measurements. Indeed, similar behavior amongst these three water quality indicators is consistently observed across all water source types.

Finally, nitrate reported as nitrogen ($NO_3$-N) values were assessed in all water sources included in this study to evaluate the potential of anthropogenic contamination (from sources such as human sanitation systems or fertilizers) and health risks (e.g., methaemoglobinaemia in infants). The concentrations detected ranged from 0.5 mg/L $NO_3$-N to 53.00 mg/L $NO_3$-N with a mean of 5.43 mg/L $NO_3$-N. The WHO recommended maximum limit for nitrate concentration in drinking waters is typically reported as 50 mg/L $NO_3$, which is equivalent to 11.3 mg/L as $NO_3$-N (Chilton, 1996). This would classify 92.3% - all but four water samples (one from an unimproved washing well and three from shallow improved wells) below the WHO guideline. All water quality parameters (except four measures of $NO_3$-N described above) fell within expected values for drinking water guidelines when applicable, specifically for concentrations of pH, TDS, and nitrate. Figure 12 demonstrates that most average water measurements did not differ between samples collected from EMAS pump and bailer technologies, or when compared to samples obtained from hand dug drinking and washing wells. Both the improved hand augered well technlogies demonstrated water with notably higher conductivity, alkalinity, TDS, and salinity values in comparison to unimproved hand dug well sources.  This may be from increased dissolved ion presence instrinsic in subsurface materials. As hand augered wells reach depths much greater than those of shallow hand dug wells, they can tap into embedded aquifer sources that reach deeper below the groundwater table in the subsurface environment that may release dissolved ions from contact with groundwater. Thus water samples from improved wells demonstrate higher dissolved ion related water quality parameter concentrations relative to shallower unimproved wells which are also likely to fill with surface water (during rain events, due to their characteristics as open and unprotected) and thus, are not considered representative of pure groundwater.  The trends noted among conductivity, alkalinity, and TDS concentrations are not of concern to associated human health risk.

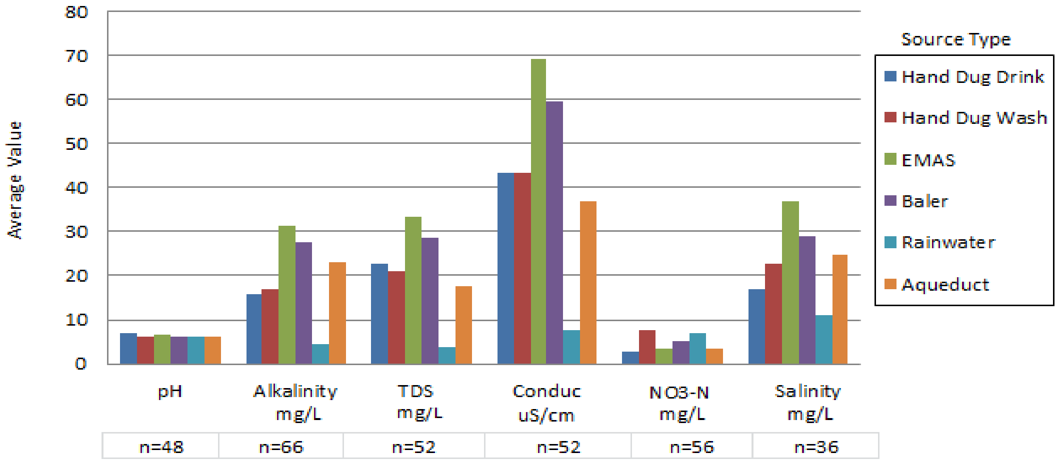


**Figure 12: Water Quality Parameter Averages by Water Source Type Measured from Jun. – Dec. 2013**

In order to better compare the water quality performance of water sources based on level of improvement, the data were re-categorized into improved and unimproved sources by WHO definitions discussed in Section 1.1 (see  Figure 13).  Improved water sources were characterized by having higher salinity and alkalinity (with means of 21.56 mg/L and 4.76 mg/L respectively) when compared to unimproved sources (with means of 16.32 mg/L and 2.83 mg/L respectively). However, it is doubtful that this trend is characteristic of improved sources, rather it represents a by-product of grouping and number of samples per group, because improved sources include a greater variety of sources (improved well, rainwater systems, and aqueducts) while unimproved sources only refer to unimproved wells in this case.  This is exemplified by the fact that water collected from improved sources in the form of rainwater collection demonstrated very low relative salinity and alkalinity concentrations while improved wells showed higher values. In addition, more samples were collected from improved sources than unimproved sources for every water quality test, as indicated by labels in Figure 13.  With respect to the general physical and chemical water quality parameters assessed in this study, there is no great difference observed between grouped improved and unimproved water sources.

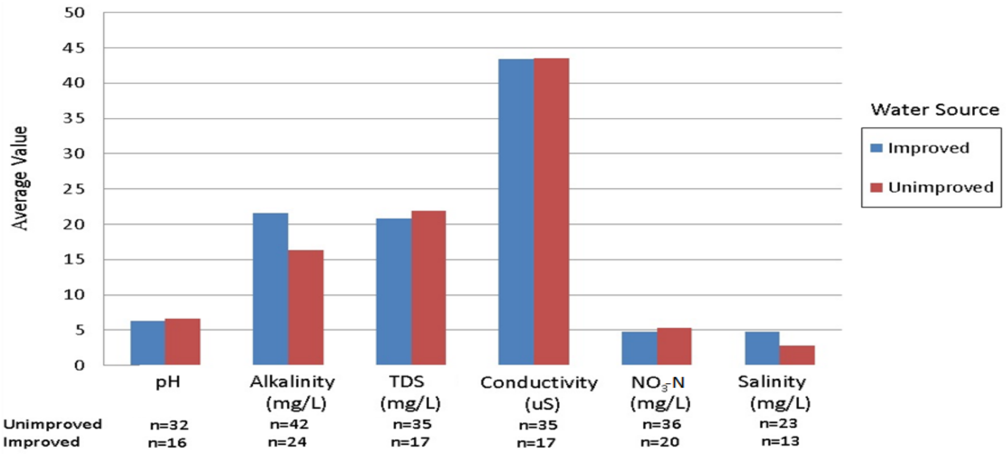


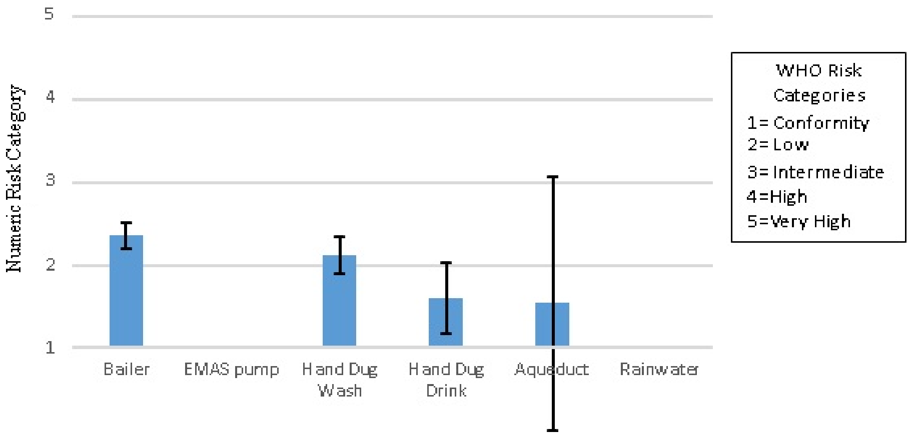
**Figure 13: Measured Water Quality Averages for Improved Versus Unimproved Sources Measured from Jun. – Dec. 2013**

## 4.3 Bacteriological Water Quality Tests

Bacteriological water quality data representing 133 samples were evaluated based on the relative risk of water samples collected from the variety of water sources included in this study through categorization using WHO risk categories for piped water systems, as discussed in Section 3.5.2. The results of the associated risk based on the grouped average mean of the six source types assessed are presented in Figure 14, with the sample size noted for each source type.

Figure 14 shows that rainwater and EMAS pump sources appeared to display conformity with WHO guidelines for risk associated with piped drinking water, with all samples measured as approximately 0 (non-detectable) CFU per 100 mL. This validates expected behavior for the two improved water sources. Water from gravity fed aqueduct systems averaged a numeric risk of 1.54 on a scale of 5, demonstrating average water quality between the ranges of conformity and low risk. Unimproved hand dug wells with local appropriate use designations for drinking produced water of very similar microbial quality, ranked at an average of 1.64 on a scale of 5. This suggests that, although the water source type is unimproved, the provided water generally offers microbial quality with low health risk, contrary to expectations. No chlorine was reported or observed to be introduced into hand dug drinking water wells.

Samples from unimproved washing wells were rated to have an average risk of 2.12 out of 5. These water sources were however known to be affected by the introduction of soap and liquid chlorine in the form of liquid bleach while people washed clothes in well water. The degree to which the presence of chlorine affected bacteriological findings is unknown, as chlorine concentrations were not measured and no quantitative data was obtained regarding chlorine related behaviors in water use interviews. Bailer systems had the highest associated risk of the water sources assessed, with an average of 2.35 out of 5. Thus, water from bailer systems were furthest from conforming with WHO guidelines with respect to *E. coli*, with water that corresponded to low to intermediate health risk categories.



| n | 62 | 9 | 34 | 10 | 14 | 5 |
|---|---|---|---|---|---|---|

**Figure 14: Categorized Bacteriological Risk by Water Source Type: Based on WHO Risk Categories Samples Measured Aug. – Dec. 2013; Total n=133**

Overall, the results show that the bacteriological water quality of all sources was generally good, with the majority of risk averages based on source type indicating conformity or low associated health risks. When comparing results shown in Figure 14 between the two improved well technologies, it is observed that EMAS hand pumps appear to produce water with less risk than the bailer systems (with averages of 1 and 2.35 respectively). However, it is important to note that differences in sample size between these two groups (n= 62 for bailers and n=9 for EMAS systems) could be a major factor impacting the suggested trend. Additional results related to the comparative performance of these two systems will be presented in Section 4.3.1.

In order to compare microbial water quality performance based on level of improvement, the data were categorized by appropriate classification as improved or unimproved sources and group mean risk level was determined, as shown in Figure 15. This comparison strongly suggests that there is little difference between the bacteriological associated health risks of unimproved and improved water sources in this study, with averages of 1.96 out of 5 and 2 out of 5 respectively. Further analysis can be performed (excluding aqueduct, rainwater, and unimproved washing wells) solely comparing the relative performance of improved hand augered well technologies to unimproved drinking water wells. This improved versus unimproved grouping of the data also shows very similar bacteriological quality, with associated health risk averages of 1.675 and 1.6 respectively. These trends illustrate details discussed in Section 1.1 which proclaim that classification of water sources by UN defined improved and unimproved categorization does not necessarily reflect differentiation in these sources with respect to water quality or safety (UN, 2013).

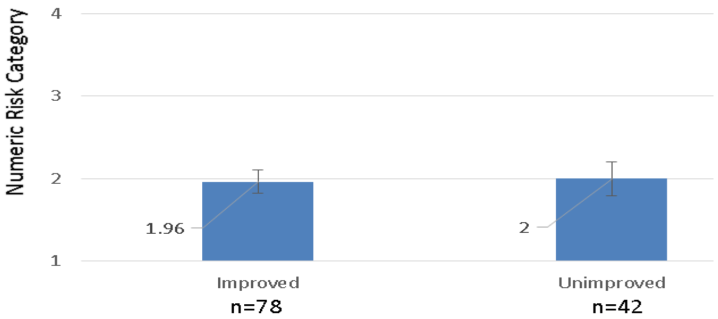


**Figure 15: Categorized Bacteriological Risk of Improved Versus Unimproved Sources: Based on WHO Risk Categories Samples Measured Aug. – Dec. 2013; Total n=133**

### 4.3.1 Comparisons of Improved Water Sources

Further examination of and presence of *E.coli* and associated health risks amongst improved water sources is possible through reviewing the frequency of samples that pertain to the designated risk categories for each water source type. Due to the timing of EMAS pump installation; only nine samples that analyzed for *E.coli* from EMAS pump systems were collected. All nine samples fell into the conformity risk category with no detectable CFU per representative 100 mL of sample. This indicates that, within the sample population, the EMAS pumps appear to provide excellent quality drinking water with respect to bacteriological parameters. Similarly, of the other improved water sources assessed 73% of water samples taken from aqueduct systems were classified in the category of conformity to guidelines, as well as all five samples from rainwater systems.

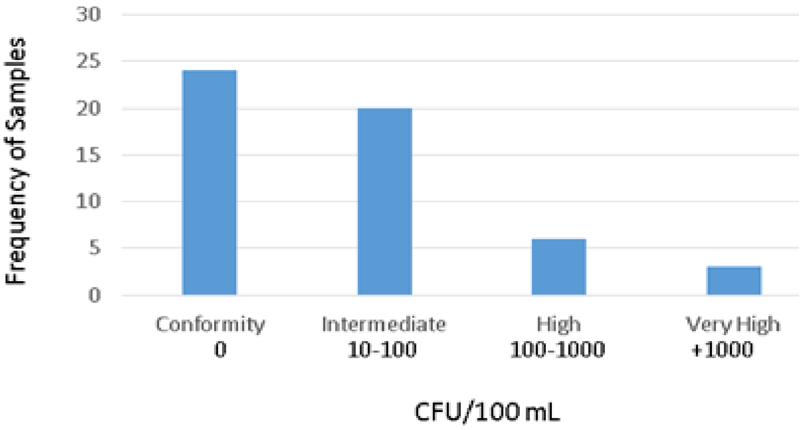


**Figure 16: Categorized Bacteriological Risk Histogram for Bailer Systems Using WHO Risk Categories, Sampled Jun. – Dec. 2013; Total n=53**

Figure 16 shows that 83% of the water samples collected from bailer systems fell into the categories of conformity and intermediate risk according to WHO guidelines. It is possible that the observed variance in bacteriological water quality could be attributed to external factors such as rainfall well age, or frequency of use. It is also possible that bailer systems produced samples with higher measured *E.coli* as contaminants entered the tubewell through handling of the bailer and the rope by the user, or the bailer coming into contact with the ground or other potentially contaminated objects during the transfer of water from the bailer to a water storage receptacle when users collect well water.

### 4.3.2 Comparison of Unimproved Water Sources

Measured water quality of unimproved water sources also indicates a substantial number of samples with water quality that suggests a negligible risk for presence of pathogens. Figure 17 demonstrates that 56% of water samples tested from shallow hand dug wells primarily used for washing clothes and bathing purposes were found to have no detectable *E. coli* (i.e., 0 CFU per 100 mL). Like bailer systems however, the data shows a distinct variation among all samples, with 44% of samples suggesting poor water quality in associated categories of intermediate and high risk.

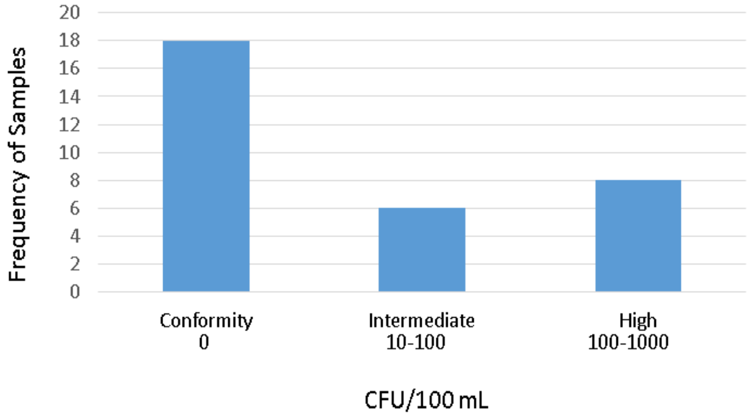


**Figure 17: Categorized Bacteriological Risk Histogram for Hand Dug Washing Wells Based on WHO Risk Categories, Sampled Jun. – Dec. 2013; Total n=32**

In comparison, data from shallow hand dug drinking assessed wells suggest better bacteriological quality than that of hand dug washing water wells, with 80% of samples having no detectable *E. coli* colonies (see Figure 18). This could be attributed to differences associated with the appropriate use designations of the two water sources. People in communities in the study area reported the practice of bathing and washing clothes directly in unimproved washing wells, which likely introduced more contaminants into the system in contrast to unimproved drinking water wells which were only disturbed by users flushing water from the well and scooping water into a storage container while gathering water for consumption. It is important to recognize that the data presented suggests differences in bacteriological water quality between water sources that are categorized primarily by user defined factors such as water use and maintenance behaviors. This highlights the benefit that considering socio-cultural factors has on the assessment performed in the context of Ngöbe communities in ÑöKribo. It is possible that the use of chlorine which is known to be present in hand dug washing wells in the form of liquid bleach for washing clothes may be affecting the representative microbial water quality in these results, but unfortunately it is unknown at what concentrations and at what time in relation to sampling this chlorine was added to the sources.

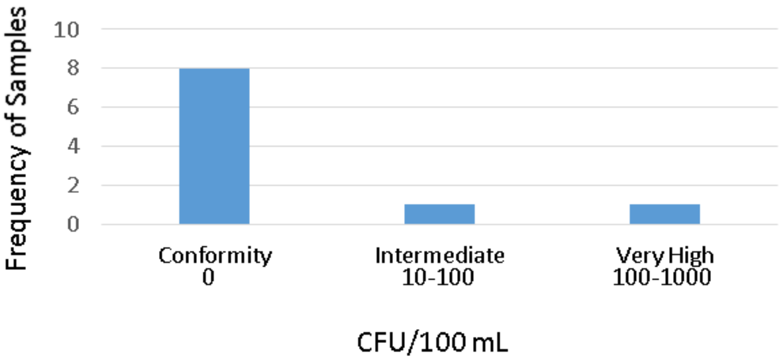


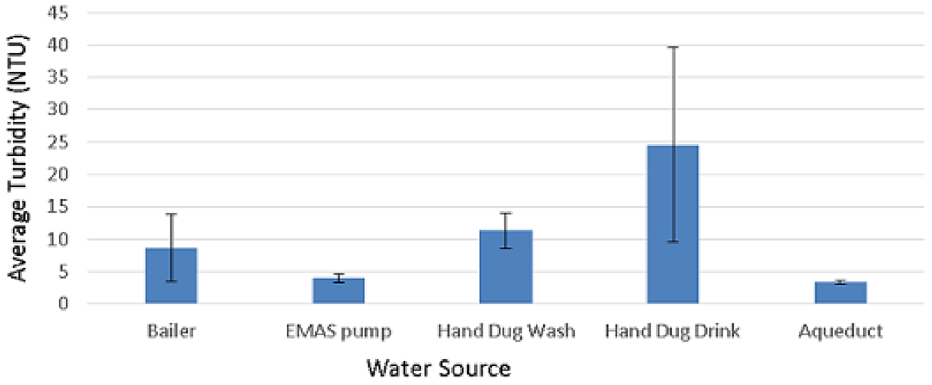
**Figure 18: Categorized Bacteriological Risk Histogram for Hand Dug Drinking Wells Based on WHO Risk Categories, Sampled Jun. – Dec. 2013; Total n=10**

Some potential error associated with the bacteriological measurements could be from factors such as field conditions that resulted in non-sterile sampling methods, equipment/sample storage, transportation time, and plating methods which differ from manufacturer's recommendations and standard procedures as discussed in Sections 3.2.1 and 3.2.3. In most cases, this error would likely cause the overestimation of fecal coliform concentrations: i.e. greater time between sample collection and plating, delays in transferring samples collected to storage on ice before transportation to the IDAAN laboratory, and the deterioration of ice on which samples were stored all contributing to potential extraneous colony growth. However, taking to account that the majority of samples were incubated at ambient temperatures, which could not be kept constant and were likely to be lower than the manufacturer recommended range (between 30-37˚C) at night, it is possible that colony growth was in fact stunted and coliform counts were underreported. Furthermore, error or misinterpretation of risk could be introduced through the author's inclusion of categorization of MPN values into WHO risk categories that were developed for piped water systems, as described in Section 3.5.2. It is unclear if, and to what degree these factors actually affect the data presented.

## 4.4 Turbidity Tests

### 4.4.1 Comparison of Turbidity by Water Source Type

Turbidity is a measurement of the clarity of a substance gauged by to what degree suspended materials obstruct the passage of light through a sample. It is a parameter often detectable by users above 5 NTU, as indicated by WHO guidelines. Although it is a physical parameter of water quality, turbidity levels are also associated with microbial water quality, as microorganisms commonly attach to particles suspended in water (WHO, 2011). Figure 19 shows the averages of measured turbidity of water sources in the study area. Aqueduct systems (from shallow stream sources) appear to have the least turbid water of all sources assessed, with an average 3.32 NTU, followed by EMAS hand pumps with an average of 4.02 NTU. Bailer systems displayed higher turbidity water samples in comparison, with approximately double the average turbidity of EMAS pumps at 8.61 NTU. Water from unimproved hand dug well sources showed more noticeably turbid water; with average value of 11.32 for hand dug washing wells and 24.59 NTU for hand dug drinking water wells.



| | | | | | |
|---|---|---|---|---|---|
| n | 31 | 6 | 17 | 3 | 3 |

**Figure 19: Average Measured Turbidity Values in NTU by Water Source Type, Sampled Jun. – Dec. 2013; Total n=60**

Overall, data in Figure 20 suggest that the recently introduced hand augered well sources have a lower turbidity than unimproved sources and similar turbidity to an existing improved (aqueduct) source in the study area. This behavior corresponds to the expected trend, as the source protection offered by boreholes is expected to produce water with fewer particles in comparison to water from sources exposed to runoff such as hand dug wells. In addition, the EMAS hand pump and aqueduct sources were the only sources in compliance with the WHO turbidity guideline for drinking water of less than 5 NTU. Note however that bailer systems fall within this range when taking standard error of the mean into account.

### 4.4.2 Comparison of Turbidity of Improved Versus Unimproved Sources

Turbidity measurements grouped by improved or unimproved source type categorizations are displayed in Figure 20. The data suggest that improved and unimproved sources displayed similar turbidities in the study area, with average values of 12.81 NTU and 13.31 NTU respectively. This finding is contrary to expectations as water from unimproved hand dug well sources lays more visibly exposed to the entry of particles and material during rain events or user interactions with the well water such as washing, bathing, or scooping water for drinking. However, it is true that the hydrogeology associated with the soil conditions for both unimproved and improved wells should be the same. Overall, it remains unclear why the relative turbidities of improved and unimproved water sources appear to be very similar.

Similar to bacteriological water quality, when assessing the turbidity data it must be considered that there were notable different in sample sizes between water source types (e.g., n=29 for bailers while n=6 for EMAS pumps and n=3 for aqueduct sources). Additional factors that may influence measured turbidity values and overall trends include well age, frequency of well use, the time of last use of a well when the sample was recorded, and seasonality concerns with rainfall events.

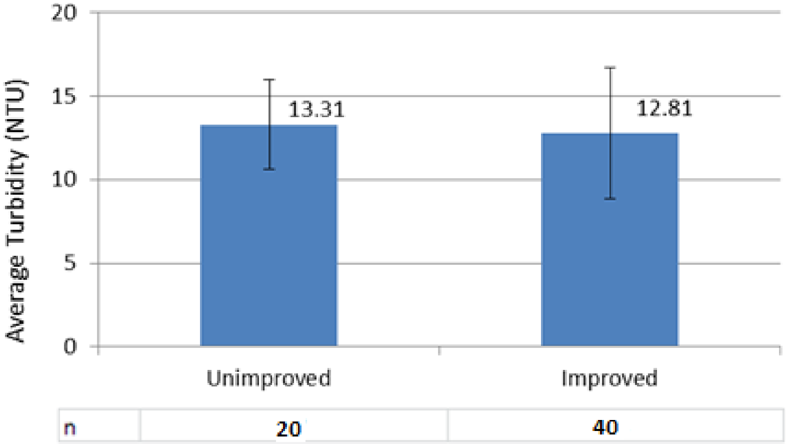


**Figure 20: Average Measured Turbidity Values in NTU Improved Versus Unimproved, Sampled Jun. – Dec. 2013; Total n=60**

Considering that turbidity values can also be indicative of bacteriological quality, it is valuable to contrast the findings in Figures 19 and 20 with those of Figure 14 and 15. Turbidity trends suggest that improved sources should have better bacteriological water quality with lower associated health risks than unimproved sources. However, the converse relationship was observed. This finding supports the suggestion that it is valuable to consider indicators other than solely *E.coli* concentrations when attempting to evaluate water quality and the associated health risk of water sources. Furthermore, the turbidity data presented substantiates the idea that external factors such as the presence of chlorine in unimproved hand dug wells may be affecting documented *E.coli* presence.

### 4.4.3 Evaluation of Well Recharge Effects on Turbidity

Turbidity was noted to undergo numerous peaks and drops but increase in general with bailing or pumping activity in tests performed to generate the flushing effect in improved wells (shown in Figure 21). Average turbidity values ranged from 12.98 NTU on the first flush to 71.03 NTU on the twentieth flushing event. There marked multiple peaks and declines in turbidity throughout the flushing process indicate a complex behavior. All improved wells selected for testing for flushing effect were improved wells in use on a daily basis. Additional factors that could influence the turbidity during well flushing include: the type of water lifting mechanism (EMAS pump or bailer), well age, and rainfall.

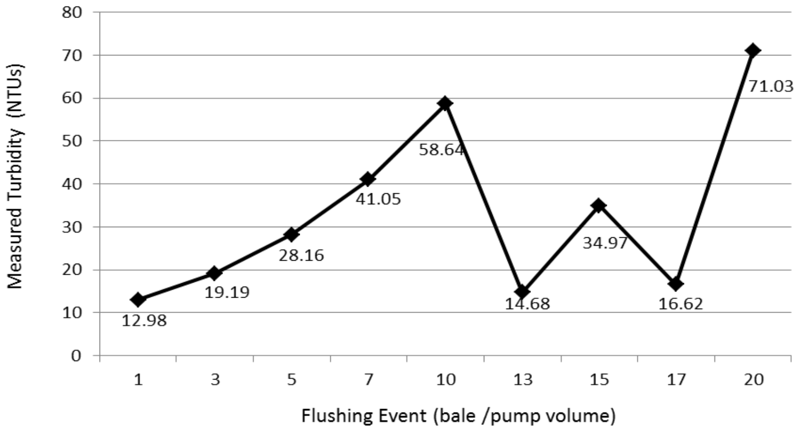


**Figure 21: Frequency of Peak Values of Average Measured Turbidity Versus Number of Bail Volumes Removed During Flushing Test; Sampled Jun. - Dec. 2013; n=31**

A further attempt at examining the effect that well flushing has on turbidity measurements was investigated by plotting the frequency of peak turbidity by bail number as shown in Figure 22. The figure illustrates that there is no distinct peak turbidity of water samples removed from improved wells during the flushing process. Furthermore, it is evident from this figure that measured turbidity is highly variable while flushing water from a borehole. Error could be reflected in this data because of the lack of control of the state of the well at the time of testing. That is, some wells could have been stagnant for hours upon testing, while other wells may have been freshly bailed or pumped only minutes before testing occurred, which would generate a different expected trend for peak in turbidity.

In order to further visualize the variability in measured turbidity, turbidity values on the first bail for all improved wells are displayed in Figure 23. The two red bars indicate samples that were outliers in the data set. This figure shows that the majority of the data falls within two ranges, less than 5 NTU and between 5 and 10 NTU. Indeed, 54.8% of improved well sources had average turbidity values of less than 5 NTU and 67.7% of samples had average turbidity values of less than 10 NTU at the first flush.

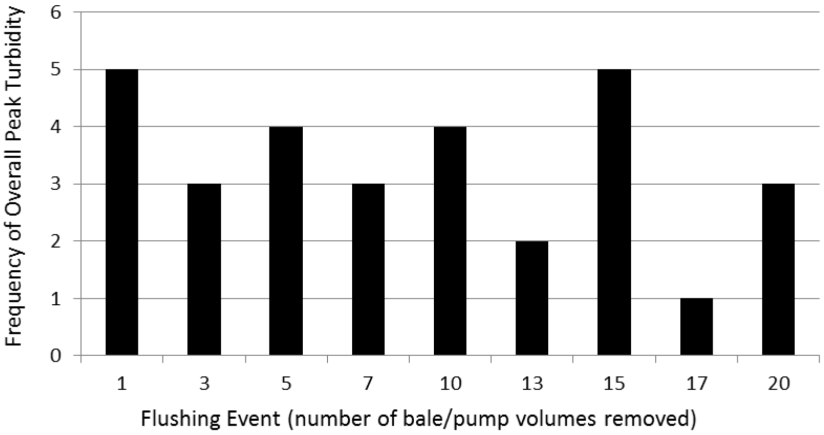


**Figure 22: Frequency of Peaks of Measured Average Turbidity Versus Number of Bail Volumes Removed During Flushing Test; Sampled Jun. - Dec. 2013; n=31**

When taking into account that samples from both EMAS hand pumps and bailer systems are reflected in the data presented in this section, it can be useful to examine variation between the two technologies with respect to measured turbidity during well flushing. Table E.1 in Appendix E shows raw turbidity data that measured performance of EMAS pumps and bailer systems during flushing tests. One EMAS hand pump sample is observed to have exceedingly high turbidity values out of range of the turbidity meter used (1,000 NTU) because this sample was collected from a malfunctioning pump described in Section 4.4.2. Bailer systems were documented to yield water samples with higher turbidity averages than EMAS hand pumps at all stages during the flushing test performed. However, the turbidity values of the two sources are highly variable, showing numerous increases and decreases over time (with bail or pump volume removed) and no detectable pattern.

The analysis of the flushing effect presented in this study is potentially affected by the greater recharge demand by volume that bailers expend on tubewells as approximately 4.5 liters of water are removed with every bail in comparison to EMAS pumps which were measured to remove approximately 325 mL of water by volume with each pump stroke. Since bailers remove larger volumes of water, higher recharge activity is incurred when greater volumes of water are expected to seep or infiltrate from the aquifer into the tubewell casing and further, up into the bailer body. This level of disturbance of the groundwater during this process could cause increased number of particles to enter into the well body. However, one could also expect that any increase in number of particles in the water would be counteracted by the volume of fresh groundwater (with presumably low NTU) entering the tubewell, in essence it should be diluted. Overall, the dynamics of well recharge and the flushing effect with respect to turbidity are not evident in the data and further investigation is required.

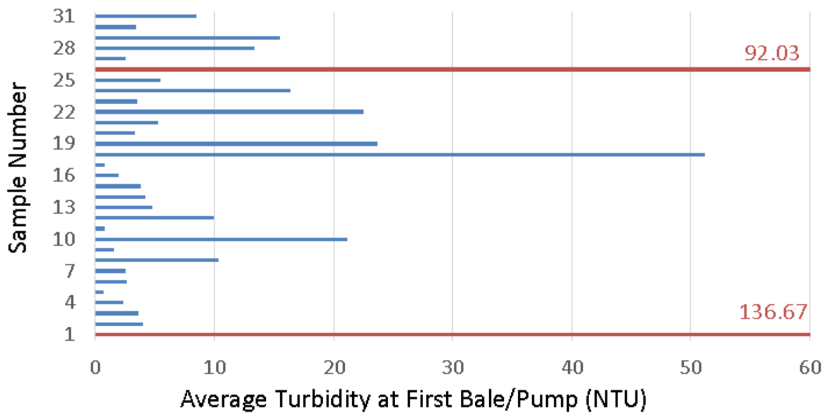


**Figure 23: Average Measured Turbidity at First Flush from Improved Well Sources Sampled Jun. - Dec. 2013; n=31**

## 4.5 Improved Well Performance Tests

### 4.5.1 Qualitative Assessments

Analysis of well performance data indicates that improved wells were mostly in operation under appropriate sanitary conditions. Sanitary inspections indicated that all 11 improved wells included proper sanitary seals throughout the duration of the study. All improved wells were also observed to be covered with PVC fitted 4-inch end caps over the tubewell body when not in use.

Household inspections of bailers showed 11 out of 11 to be operational consistently throughout the data collection period. Of these operational bailers 11 out of 11 were found to be consistently functional at a high level of performance (without significant problems with water withdrawal) over the testing period. Although operational, one bailer was not in use due to its proximity to a local cemetery and availability of other water sources. EMAS pump systems evaluated during household inspections showed only one out of three pumps to be operational consistently throughout the two month data collection period. Related to this observation, one of three EMAS pump systems was found to be consistently functional at a high level (pumping without significant problems) over the two month performance analysis. The two EMAS pumps that failed were implemented in the two deepest augered wells evaluated in the study (at approximately 7.62 and 9.75 meters). The pumps experienced damages for two identifiable reasons: (1) the use of PVC instead of galvanized iron in the pump handle, and (2) the well depth challenging the capacity of the pump built with 0.5-inch diameter pump body (despite design recommendations for 0.75-inch diameter pipes in shallow wells).

In one case, after three weeks of use, the threaded 0.5-inch PVC handle bars glued into the threaded galvanized iron “T” detached and could not be securely re-attached with PVC glue. The family stopped using the well and contacted the local man who installed the well (known to have access to materials and technical experience) to assist in repairing the handle. In the second case, the household of a local skilled well driller began experiencing problems with the EMAS pump after two months as more pumping was required to yield less water, pumping involved considerably more labor, and increasingly turbid water was produced. No one in the family understood what the cause of the failure was. With the assistance of the author, it was determined that the rubber gasket creating a seal between the piston pipe and the pump body failed.  Users and local well drillers attempted to repair these faulty EMAS pumps with the author during the last data collection event in December 2013.  However due to lack of replacement materials (rubber gasket) and time, repairs were not completed.  The local well drillers planned to attempt to repair the two pumps, but noted that if they could not repair them, they would most likely replace the bailers in the improved wells.

### 4.5.2 Well Depths

Total well depth of improved wells was estimated (in feet), in most cases by the well driller (7 out of 11) and in other cases by the well owner, as summarized in Table 11.  Although all wells could be considered relatively shallow by typical well standards, wells were categorized into two depth categories: shallow and intermediate with the purpose of distinguishing two wells which were augered to depths of greater than 5 meters.  Shallow categorization thus signifies depths less than 5 meters and intermediate signifies depths between 5 and 10 meters.

**Table 11: Reported Hand Augered Well Depths and Assigned Depth Categories**

| Well | Estimated Well Depth (m) | Category |
|---|---|---|
| AbeIW | 7.62 | Intermediate |
| MikHIW | 9.75 | Intermediate |
| EnrIW | 2.29 | Shallow |
| MikMIW | 1.83 | Shallow |
| NinIW | 2.44 | Shallow |
| LydIW | 2.44 | Shallow |
| MelidIW | 4.88 | Shallow |
| BAIW | 2.44 | Shallow |
| RamIW | 2.59 | Shallow |
| ValIW | 2.74 | Shallow |
| KaniIW | 3.05 | Shallow |

### 4.5.3 Impact of Rainfall on Measured Depth to Water Level in Improved Wells

Depth to water table was measured in bailer systems and depths of well water measurements were taken in unimproved hand dug wells. The number of calendar days since a rainfall event were also noted at the time of sample measurement. The collected data are summarized in Table 12, using numeric source types as designated in Table 7 of Section 3.5.1. As expected, unimproved wells show gains in well depth with proximity of a rainfall occurrence (fewer days since rain) and hand augered wells show a decrease in the measured depth to water table. This demonstrates the level of infiltration and seepage that is occurring to recharge the aquifers in groundwater sources.

In order to quantify the degree of linear dependence between measured depth to the water surface and the number of days since a rainfall event at the time of sampling, a Pearson's correlation coefficient test yielded a value of - 0.175, indicating a weak negative linear correlation between depth to water level in the improved wells and the number of days since a rainfall event. The overall negative correlation suggests that the water level in the wells decreases as number of days since rain increases, as expected, however the weak correlation valuation suggests that the relationship between the two variables is not adequately described in a linear fashion.

**Table 12: Measured Depth to Water Table in Meters**

| Date | Well | Source Type | Depth of Water or Depth to Water Table (m) | Days Since Rain |
|---|---|---|---|---|
| 07-Nov-2013 | CUIdrink | 4 | 0.25 | 2 |
| 22-Nov-2013 | CUIdrink | 4 | 0.27 | 0 |
| 07-Nov-2013 | CUIwash | 3 | 0.29 | 2 |
| 22-Nov-2013 | CUIwash | 3 | 0.36 | 0 |
| 30-Jun-2013 | EnrIW | 1 | 1.12 | 2 |
| 28-Aug-2013 | EnrIW | 1 | 1.42 | 0 |
| 09-Oct-2013 | EnrIW | 1 | 1.55 | 0 |
| 07-Nov-2013 | EnrIW | 1 | 1.40 | 2 |
| 22-Nov-2013 | EnrIW | 1 | 1.33 | 0 |
| 06-Dec-2013 | EnrIW | 1 | 1.28 | 0 |
| 30-Jun-2013 | MikMIW | 1 | 0.33 | 2 |
| 19-Jun-2013 | MikMIW | 1 | 0.48 | 0 |

**Table 12: (continued)**

| | | | | |
|---|---|---|---|---|
| 28-Aug-2013 | MikMIW | 1 | 0.75 | 0 |
| 29-Aug-2013 | MikMIW | 1 | 0.76 | 1 |
| 09-Oct-2013 | MikMIW | 1 | 0.91 | 0 |
| 07-Nov-2013 | MikMIW | 1 | 0.72 | 2 |
| 09-Oct-2013 | NinIW | 1 | 1.22 | 0 |
| 07-Nov-2013 | NinIW | 1 | 1.10 | 2 |
| 21-Nov-2013 | NinIW | 1 | 1.10 | 3 |
| 22-Nov-2013 | NinIW | 1 | 1.09 | 0 |
| 06-Dec-2013 | NiIW | 1 | 1.07 | 0 |
| 08-Oct-2013 | RamIW | 1 | 0.91 | 6 |
| 29-Aug-2013 | RamIW | 1 | 1.85 | 1 |
| 30-Jun-2013 | AbeUIwash | 3 | 0.28 | 6 |
| 22-Nov-2013 | AbeUIwash | 3 | 1.17 | 0 |
| 30-Jun-2013 | MikUIWash | 3 | 0.20 | 2 |
| 07-Nov-2013 | MikUIWash | 3 | 0.18 | 2 |

### 4.6 Well User Interviews

The interviews conducted with well users elicited responses about the various local water sources, including qualitative and quantitative information about water source access, quantity, use, and perceptions. Although the interviews were primarily conducted in one visit, several questions were revisited over the course of the study, as respondents exchanged quantitative and qualitative information regarding their water source access during repeated dialogues with the author. Data are summarized in tables in the following sections and in the Water User Profile Field Notes from Observation and Survey Data provided in Appendix C.

#### 4.6.1 Assessment of User Source Type and Access

Water access in the context of the study is complex, involving a variety of existing sources that are reported to be used depending on whether the source is functional and whether water is available. Water access for all improved well users interviewed indicated respondents have access to more than one source: 7 out of 11 users reported having access to three water sources, and 4 out of 11 respondents reported using two water sources. One user reported access only to unimproved hand dug wells. Figure 24 provides a profile of local water access.

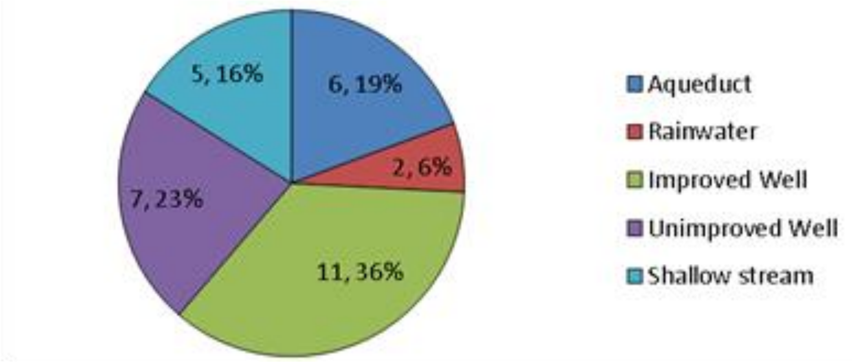


**Figure 24: Water Access by Source Type of 11 Water Users Interviewed**

The percentages indicated are calculated to reflect how the source type reflects a portion of the total number of sources the total number of users reported having access to, and the numbers in every partition indicate the number of users who reported having access to the water source. Of the users interviewed, the most common reported source type access was improved wells, comprising 36% of all water access. This access is not representative of the general population in the communities however; it is a byproduct of the author's selection for participation in the user interviews in this study. Twenty-three percent of all water access indicated by the users involved unimproved (drinking and or washing) sources, followed by piped aqueduct systems from shallow streams representing 19% of water access. Only 2 users interviewed owned household rainwater collection systems, demonstrating an associated 6% of water access. The variable distribution of water access across source types implies that the water use behavior in the context of the Peninsula Valiente region of ÑöKribo is complex and multifaceted.

### 4.6.2 Comparison of Water Use Designation Versus Type of Water Access

Based on data collected from visual inspection, observation, and surveys several trends regarding water use considerations of water users with different types of water access are evident. Table 13 establishes the user defined categorization through a summary of responses to the question: assuming all your available sources are functioning how (for what purposes) would you use the water available? Responses were coded into categories for ease of interpretation.

**Table 13: Current Water Use Designations by Source Type of 11 Users Interviewed With Categories Represented as Follows: 1=Drinking, Cooking, and Washing Dishes, 2=Bathing, 3=Washing Clothes**

| User | Aqueduct | Rainwater | Improved Well | Unimproved Wells | Shallow stream |
|---|---|---|---|---|---|
| AbeIW | | | 1 | 2 and 3 | |
| MikHIW | | 1 | 1 and 2 | 2 and 3 | |
| EnrIW | | | 1 and 2 | 2 and 3 | |
| MikMIW | | | 1 and 2 | 2 and 3 | |
| NinIW | 1 | | 1 | 2 and 3 | |
| LydIW | 1 | | 1 | | 2 and 3 |
| MelidIW | 1 | | 1 | 2 and 3 | |
| RamIW | | | 1 | 1 and 2 | 2 and 3 |
| ValIW | 1 | | 1 | | 2 and 3 |
| KaniIW | 1 | 1 | 1 | | 2 and 3 |
| Chunki | | | | 1, 2, and 3 | |

Table 13 conveys that water from improved sources was utilized for consumption and water from unimproved sources was used for hygiene. This agrees with the expected trend, as it could be a common assumption that water from an improved source provides cleaner water, as it has visible measures in place to protect a water source from potential contamination entering the system. Thus, water tends to be prioritized for consumption purposes in the efforts of a user to minimize the health risks associated with consuming water of poorer quality. Water from the recently acquired improved wells was utilized by all interviewees for the purposes of drinking, cooking, washing dishes in all cases, and in some cases for bathing. For users with access to no other improved sources, water from hand augered wells profoundly altered their water use behaviors, particularly with regards to water utilized for consumption purposes. Also, improved wells offered a new, resilient water source option to help compensate for experienced water scarcity incurred by seasonal vulnerabilities for users with access to aqueducts and rainwater sources.

In the five cases where the well owner reported access to an aqueduct and an improved well all respondents still utilize unimproved sources (shallow stream or unimproved wells) for the task of washing clothes. This use trend can be attributed to cultural preferences, as the traditional manner of washing clothes requires a very large quantity of constantly running water. Women and children, who are largely responsible for washing clothes as part of the assigned gender roles in Ngöbe society, often spend one to three hours daily washing clothes for members of their household. In order to wash clothes in the traditional manner, clothes must be taken to the stream or hand dug well, repeatedly submerged in water, scrubbed with soap, and beat repeatedly against a hard rock or wood surface. This process is energy, water, and time intensive; lasting about five minutes for a single pair of pants for example. Washing clothes in this manner with an aqueduct source would be less efficient: require a tap constantly running and an incredible quantity of wasted run off water. Therefore, despite access to improved water sources, water used in the context of washing clothes remains a designation of unimproved sources, in the context of this study.

It is useful to further frame the results presented in Table 13 with the observation that the categories of water use defined by the user showed marked deviations from the definitions of consumption and hygiene presented previously in Table 4 of Section 2.4.3. For instance, water used to wash dishes was included with water used for consumption purposes. This altered categorization can be explained by local customs. In the context of the study area water used for consumption is brought very near, or stored inside the house. In the case of an aqueduct or rain water catchment, the water is piped to a tap stand near the house or directly into the kitchen, and in the case of improved wells water is transported from the improved well in a bucket to be stored near the cooking area of a home.  Since this water is already in the house, it is immediately utilized (when available) due to its convenience, for cleaning pots and dishes.

Similarly, water for washing clothes could not be grouped with water for bathing in the same category of “hygiene” due to cultural and gender based traditions. It is customary for water users in the Ngöbe communities included in the study to bathe one to three times a day, using a variety of water sources depending on privacy, time of day, social invitation, and availability or functionality of water sources. Typically, women and children are responsible for washing clothes, and bathe primarily in unimproved sources after performing this task (because they are already wet and at a water source).  Men and children reported bathing in unimproved sources, but also noted bathing with water from improved sources such as improved well water or aqueduct water.  The option of bathing at an improved water source is more culturally available to men and children because improved sources such as hand augered wells and aqueduct taps typically offer less privacy.

In order to examine if and how water use categories changed after recently acquiring access to hand augered well technologies, all interviewees were asked the following question: Before having access to an improved well, how did you use the water from each of the sources you have access to, assuming that all water sources were available? The results are displayed by water source type in Table 14, as cells with values indicate sources that were available to a user. In cases where people used multiple sources for the same purpose, the same value was assigned.

**Table 14: Prior Water Use Designations by Source Type of 11 Users Interviewed With Categories Represented as Follows: 1=Drinking, Cooking, and Washing Dishes, 2=Bathing, 3=Washing Clothes**

| User | Aqueduct | Rainwater | Unimproved Wells | Shallow Stream |
|---|---|---|---|---|
| AbeIW | | | 1, 2, and 3 | |
| MikHIW | | 1 | 2 and 3 | |
| EnrIW | | | 1, 2, and 3 | |
| MikMIW | | | 1, 2, and 3 | |
| NinIW | 1 | | 2 and 3 | |
| LydIW | 1 | | | 2 and 3 |
| MelidIW | 1 | | 2 and 3 | |
| RamIW | | | 1 and 2 | 2 and 3 |
| ValIW | 1 | | | 2 and 3 |
| KaniIW | 1 | 1 | | 2 and 3 |
| Chunki | | | 1, 2, and 3 | |

When comparing the results presented in Table 14 to current water use designations in Table 13 it appears that access to a new improved water source in the form of a hand augered well did not alter respondents' water use designations of existing improved sources or shallow streams. The only changes in water use were noted in unimproved well sources. In fact, in 9 out of 10 cases after receiving access to an improved well, water from unimproved wells was no longer used for the purposes of drinking, cooking, and washing dishes. Overall, it can be recognized that gaining improved access to water signified an upgrade in the sense of another water source option that became available, rather than a means of completely replacing or incurring a corresponding downgrading of existing supplies in the context of the study.

### 4.6.3 Qualitative Assessment of User Water Source Preferences

When considering the number of existing water source options and the user defined categorization of water, it can be meaningful to also understand user water source preferences. Users were asked, of water sources that they currently have access to, (assuming that all sources are available and functioning) which water source they prefer to drink from? The results to this question are provided in Figure 25. The majority of users interviewed preferred to drink water from improved well sources. It was reported that water from the improved wells had a good taste, and was often colder than other sources. It is interesting to note that 4 out 5 households with access to aqueduct systems preferred to drink water from the hand augered well source.

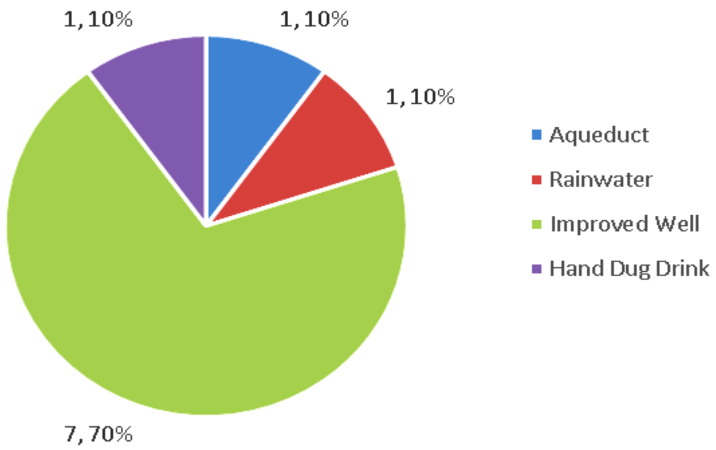


**Figure 25: Preferred Drinking Water Source by Source Type of 10 Water Users Interviewed**

In terms of preferences between the two water lifting mechanisms assessed in this study it can be reported that of the 3 users who switched from bailing systems to EMAS pumps for the last two months of this study, 1 out of 3 preferred using the bailer. The other 2 users could not say which of the two they preferred, because late in the first month of installation they experienced problems with EMAS pumps malfunctioning. In these cases the EMAS pumps installed were placed in intermediate depth wells, and the 0.5-inch diameter pumps installed did not sustain the pumping action in two households (as discussed later). Failures occurred as the pump handle broke and the internal rubber gasket seal failed. The well users were still interested in (and making efforts to) repair and use the EMAS pumps, despite the fact that the apparent fragility of the pumps raised doubts as to whether they should use bailers instead. All three users with EMAS pumps observed that bailers could *aguantar más*, or endure more, and that if their EMAS hand pumps failed, they would still be able to use the bailers in the improved wells.

### 4.6.4 Quantitative Assessment of Water Use

In order to gauge water demand and understand the quantities of well water being utilized, all improved well owners were asked: when you use your improved well, how much water do you use in one day? About how much water do you use for cooking, drinking, washing clothes, and bathing? The results are summarized in Table 15. Users could not report how much water they used for cooking versus drinking purposes or for washing clothes. So, the data were grouped into two categories, consumption and hygiene, where hygiene referred to bathing only (for reasons discussed in Section 4.6.2). All answers were reported in five-gallon bucket equivalents per household and when the user gave a range the average was taken.

**Table 15: Quantitative Analysis of Water Use of Improved Wells in Gallons per Household per Day**

| Owner | Consumption (gal/day/household) | Hygiene (gal/day/household) |
|---|---|---|
| AbeIW | 12.5 | 0 |
| MikHIW | 22.5 | 0 |
| EnrIW | 20 | 25 |
| MikMIW | 20 | 5 |
| NinIW | 10 | 0 |
| LydIW | 25 | 0 |
| MelidIW | 10 | 5 |
| RamIW | 15 | 0 |
| ValIW | 15 | 0 |
| KaniIW | communal | communal |

In an attempt to gauge if and how quantities of water typically used in households changed with recent access to improved wells, interviewees were asked to compare how much water they use now (with access) versus before installation of their well. It was determined that this answer could only be answered in a qualitative form, as respondents typically could not offer details with respect to quantities or volumes of water, but could offer relative answers such in the form of whether they used more, less, or equal quantities of water now compared to before owning an improved well. Almost all (9 out of 10) users indicated that they used more water (for drinking, cooking, and bathing purposes) now than they used before. One respondent reported using about the same quantity of water as before access to the improved well.

### 4.6.5 Qualitative Assessment of Well Use and Maintenance Behaviors

Due to the complex multi-source water access indicated by all users in this study, it is important to understand the frequency of use of the improved well systems. As seen in Table 16, the majority of users extract water from the improved wells on a daily or weekly basis, with only 2 out of 10 reporting use on a monthly basis. The presented data incorporate maintenance behaviors, as sometimes water is bailed occasionally by improved well owners in some households in an effort to help maintain water quality through promoting "fresh" well recharge.

**Table 16: Reported Frequency of Use of Improved Wells from 10 Well Owners**

| Owner | Daily | Weekly | Monthly |
|---|---|---|---|
| AbeIW | 1 | 0 | 0 |
| MikHIW | 0 | 1 | 0 |
| EnrIW | 1 | 1 | 0 |
| MikMIW | 1 | 0 | 0 |
| NinIW | 1 | 0 | 0 |
| LydIW | 0 | 0 | 0 |
| MelidIW | 0 | 0 | 1 |
| RamIW | 0 | 1 | 0 |
| ValIW | 0 | 1 | 0 |
| KaniIW | 0 | 0 | 1 |
| Total | 4 | 4 | 2 |

Considering that the data falls into distinctly different categories when evaluating the frequency of use patterns, this further validates suggestions that the regularity of use improved well sources is a potential factor influencing the reported physical and bacteriological water quality data in this study. It is critical to note also that the role of the hand augered well technologies for owners not using it daily is one of being a notably resilient system among other water sources whose supplies fluctuate and fail to provide (due to seasonality, design limitations, poor maintenance, or technical failures).

### 4.6.6 Assessment of Water Quality Perceptions Versus Type of Water Access

In order to identify user perceptions of the quality of the water provided by the various water sources in the study area, it was considered appropriate to ask the user to make comparisons between the different water sources they had access to. Initially, this question was proposed in a ranking format, but numerous respondents were not comfortable or accustomed to answering this style of question. In these cases the question was adapted and asked in the following way: of the water sources you have access to which has the cleanest water? Then, to qualify the remaining sources, a follow up question was asked: of the remaining sources, which has cleaner water? The answers were then transcribed by the author and sources were ranked with 1 as the cleanest and 4 as the dirtiest, as seen in Table 17. Sources reported to have water of about the same cleanliness were given the same value.

It can be observed that improved sources are believed to have cleaner water than unimproved sources in all but one case. This is largely consistent with the results from Section 4.6.2 which suggested that water use categories for various source types were largely determined by their perceived cleanliness or superior water quality. Furthermore, it is noted that the recently introduced hand augered wells were considered by users to provide cleaner water than existing aqueduct sources. Users often framed this response with the observation that water from aqueduct sources gets visibly turbid (and often stops functioning) during rain events, while well water does not.

**Table 17: Perceived Water Quality of Source Types by Ranking System**

| Owner | Aqueduct | Rainwater | Improved Well | Unimproved Wash | Unimproved Drink | Shallow stream |
|---|---|---|---|---|---|---|
| AbeIW | | | 1 | 3 | 2 | |
| MikHIW | | 1 | 2 | 4 | 3 | |
| EnrIW | | | 1 | 3 | 2 | |
| MikMIW | | | 1 | 3 | 2 | |
| NinIW | 2 | | 1 | | 2 | |
| LydIW | 2 | | 1 | | | 2 |
| MelidIW | 2 | | 1 | | 2 | |
| RamIW | | | 2 | | 1 | 2 |
| ValIW | 2 | | 1 | | | 2 |
| KaniIW | 2 | 1 | 1 | | | 2 |
| Chunki | | | | 2 | 1 | |

## 4.7 Sustainability Assessment

The results of the sustainability assessment performed considering the two water lifting mechanisms implemented in hand augered wells in the study area as well as the development approach adopted by the Healing Fund to introduce the technologies are summarized in Table 18. Notable trends can be analyzed through considering reasoning behind the ranking number selected with respect to each sustainability factor.

**Table 18: Ranked Sustainability Assessment of EMAS Pumps and Bailers**

| Sustainability Factor | EMAS pump | Bailer |
|---|---|---|
| Socio-cultural Respect | 5 | 5 |
| Community Participation | 2 | 3 |
| Political Cohesion | 3 | 3 |
| Economic Sustainability | 2 | 4 |
| Environmental Sustainability | 5 | 5 |
| Total Average Ranking | 3.4 | 4 |

In terms of socio-cultural sustainability, bailers and EMAS pumps both received 5 out of 5, as the technologies and the Healing Fund’s presence in the region is noted to respect local traditions and values. This can be demonstrated as people reported had a positive response to adding a new water source option to their water use profile. Both improved hand augered well technologies engendered desirable increases in water availability and improved overall household hygiene behaviors. The introduction of these technologies largely did not disturb existing customs or rituals involving water, such as bathing or washing clothes in creeks or unimproved well sources, as discussed in Section 4.6.2.

With respect to community participation, EMAS pumps receive a 2 out of 5 while bailer systems receive a 3 out of 5. Both systems were evaluated primarily considering the development strategies implemented by the Healing Fund, which did not allow community members to directly participate in the decision making processes surrounding the implementation of the improved wells. Although local families expressed interest in obtaining a well and attempted to initiate participating in the project by personally approaching local well drillers, there was no established needs assessment of interested households or set requirements for project participation. Community members were not required to put in labor, materials, or monetary contributions into the project, and no measures were made to encourage these contributions. Thus well owners could not claim ownership or responsibility for the project, as they considered it similar to receiving a gift. In the long term, this is seen as a major hindrance to the persistence of operational benefits of the improved water sources, as they ultimately require the direct participation of well owners in the form of investments necessary for well upkeep.

Furthermore, well owners generally did not feel comfortable with the responsibility of performing their own repairs or maintenance (with presented with questions related to potential damages to foot valves for bailers and replacement marbles or rubber gaskets for EMAS pumps, for example). They cited reasons of not knowing where to obtain parts, not knowing how much it would cost, or whether money would be available (for transportation or for purchasing the part). Women often felt particularly ill prepared to perform necessary improvements or maintenance of the improved well technologies due to lack of knowledge or participation in well installation, and the local men trained in well drilling techniques were depended on for help with experienced difficulties or uncertainties related to the wells.

Bailers were given a slightly higher score of 3 out of 5 because more of a participatory approach was involved with these technologies as local well drillers were trained by the Healing Fund and by other local skilled laborers in the fabrication and repair of bailer systems. Also, local people were familiar and comfortable interacting with the technology because they visibly recognized how it worked. Bailer systems, with their incredible durable and simplistic design, require infrequent replacements and have no fragile parts. As particularly resilient systems, they rated slightly higher with respect to community participation, considering the Healing Fund's overall project approach incorporated little education directly to well owners (though indirectly through well drillers) with respect to the frequency or available means (closest hardware store, approximate price, potential substitute parts or materials) through which repairs should be performed on bailer systems.

However, with EMAS hand pumps, local well drillers did not take part in the acquisition or fabrication of the pump parts, only their assembly and installation. There was also confusion among well drillers and well owners with respect to EMAS pump operation and repair, largely because they were not able to see how the double check valves and the suction mechanism by which the EMAS pump works to lift water. No education or training was provided to residents regarding the necessary maintenance efforts surrounding EMAS hand pump technologies, which involve more moving parts that experience wear (rubber gaskets, pump handle, glass marbles) in comparison to bailers. Due to associated lack of understanding, the three well owners who were able to briefly experience using EMAS pumps had less of a sense of ownership or attachment to this system. It is important to consider however, that bailer systems were considerably further along in the process of technology transfer and implementation than the EMAS pump systems. It is possible for the weighed rating of EMAS technologies to change with any follow up efforts of the Healing Fund to teach about hand pump operation, fabrication, and repair for example.

The political cohesion factor of sustainability of the two improved well technologies was weighted with equivalent scores of 3 out of 5. The Healing Fund initiated the hand augered well activities in the Bocas del Toro region through coordinating with several local contacts: primarily through networking with faith based organizations and local Ngöbe churches. Through these networks the Healing Fund was able establish the delivery of services with four local Ngöbe men who were paid and trained in hand augering techniques and well installation. The coordination of efforts and transfer of knowledge surrounding the implementation of hand augered wells in the area was largely limited to these four community counterparts however.

No larger political support was attained for the project as no contact was made with the appropriate regional local government agencies such as PASAP (Water and Sanitation Project of Panama). PASAP is the official designated entity responsible for overseeing coordinated efforts to increase water access and provide potable water services among indigenous populations. Foreign entities contributing to related development efforts are expected to make introductions to local PASAP representatives, who prefer to be informed of relevant water and sanitation activities within the areas they govern. However, this expectation and courtesy could be easily missed by an outsider, as it is not well publicized. Community level political organization in the form of elected community officials were also not engaged by the Healing Fund as a potential group able to contribute to decisions related to project participation or the acquisition of materials for example. Considering the lack of knowledge of existing sociopolitical structures as well as time, communication, and logistics limitations during the annual service trips through which the Healing Fund operates, it was observed by the author to be particularly challenging for the development organization to satisfy best practices related to political support.

Economic sustainability is the second category where the two well technologies rank differently: with a 2 out of 5 for EMAS pumps and a 4 out of 5 for bailers. Due to the extreme remoteness of the communities in the ÑöKribo area, the availability of materials and related transportation concerns are critical to a project's sustainability. As noted previously the Healing Fund's development strategy did not require any type of economic contribution to during well installation of either technology. This is largely contrary to the self supply approach related to the successful application of the two hand augered well systems in rural developing communities. The lack of local well owner financial investment during the initial stages of a project threatens long term success and operation, because it does not engender a participatory role in well ownership which will undoubtedly require monetary investments related to the upkeep of the systems over time.

EMAS pumps, which in this study were fabricated in the United States, require considerably more tools and materials during construction, operation, and maintenance phases than bailers. The organizational decision to fabricate these systems in the U.S. as opposed to locally in Panama is seen as largely economically unsustainable due to the unknown costs (and availability) related to: (1) the materials and tools required to performance necessary pump maintenance and (2) the materials and tools associated with manufacturing the systems locally (under conditions involving no electricity and limited selection of hardware store supplies). As local families experience extreme poverty conditions, the estimated US $10-15 initial investment in an EMAS pump (assuming materials are available in local hardware stores and the design only uses one galvanized iron piece as implemented by the Healing Fund which is not recommended) is considerable in comparison to US $5-6 for a bailer technology in the area.

Finally, both groundwater technologies installed by the Healing Fund ranked 5 out of 5 in the category of environmental sustainability, due to little to no measureable negative impact on the environment. The hand augered well projects do not compromise local natural resources. Also, neither technology is recognized to cause foreseeable contamination or environmental hazards.

### 4.8 Comparison to Relevant Studies

The results presented are considered in comparison to the most relevant studies involving the sustainability of bailer technologies performed by Morgan (1990, 2014). The bacteriological water quality data of various source types was assessed in both studies including unimproved wells, improved wells with bailers, and improved wells with pumps. In both studies, improved wells with pumps were found to have better microbial quality than improved wells with bailer systems. In Morgan's studies, unimproved wells were found to have drastically higher average *E.coli* levels than bailers (reported at 475.39 CFU per 100 mL sample versus 16.69 CFU per 100 mL sample), while in this study the bacteriological water quality between unimproved hand dug wells and bailers were more comparable, (with an average risk level of 1.64 out of 5 for unimproved wells versus 2.34 out of 5 for bailers).

The differences in these findings could be attributed to sample size considerations and chlorine presence in local washing wells causing lower than normal *E.coli* concentrations for a typical unimproved well source. Upon selecting turbidity as the water quality parameter by which to compare water sources (also an indicator of microbial water quality as noted by WHO), the water quality results from this study better mirror Morgan's findings. More specifically, average turbidity measurements showed bailer systems to provide water of better quality than unimproved well sources with average values of 14.9 NTU for unimproved (grouped washing and drinking) wells versus 8.61 NTU for bailers.

When evaluating well performance with respect to the flushing effect, different methods were used in each study. While Morgan spiked bailer tubewells with fecal coliform and measurements demonstrating the rapid removal of this contamination from the system, this research attempted to display the flushing effect of existing water within the tubewell using turbidity as the measurable indicator. Morgan (1990, 2014) demonstrated a distinct trend with the decline of *E. coli* concentrations yet this trend was not mirrored in the flushing tests performed using turbidity as an indicator, which generated multiple peaks and declines in turbidity with a lot of variation throughout the flushing process. In both cases the desire for better understanding of borehole dynamics and corresponding changes in water quality due to flushing activity are recognized.

When assessing technical performance, appropriateness, and the sustainability of bailer technologies in comparison to other improved and unimproved water sources, the two studies show similar findings. Comparable to Morgan's assessments indicating that bailer systems in the form of "bucket pumps" implemented were appropriate technologies for household use as part of the Ubombo Family Wells Program, it was found that bailer technologies were a vaild sustainable household water source option in the Peninsula Valiente area. While Morgan did not perform a sustainability analysis of the technology, observations and data with respect to sustainability factors were offered. His findings can be grouped as follows: social factors which identified ease of maintenance and the concept of ownership of bailer systems within a household context, economic considerations which identified bailer systems as arguably the lowest cost option for extracting water from shallow tube-wells, and environmental factors identified like the simplistic design of the bailer systems requiring few materials. Similarly, from data gathered through interview, observation, and review of technical performance in this study, the bailer systems implemented were demonstrated to be socially acceptable, the most economically affordable groundwater alternative, and consistently operational over the course of the study due to their simplistic design.

# Chapter 5: Conclusions and Recommendations

This investigation was motivated to improve access to improved drinking water sources and decrease water related illness and better the quality of life in the ÑoKribo region of the Comarca Ngöbe-Bugle (Panama). The sustainability and appropriateness of two recently introduced self supply related hand augered well technologies were assessed: (1) bailers and (2) EMAS hand pumps. The research examined the relative water quality parameters, technical performance, and social implications associated with these two improved water lifting mechanisms in the context of existing improved and unimproved water sources in the study area (including open hand dug wells, piped aqueduct systems, and rainwater collection systems).

## 5.1 Evaluation of Objective 1

Research Objective 1 was to evaluate household groundwater supply technologies (EMAS pumps and bailer systems) recently introduced in the ÑöKribo region of Panama based on water quality outcomes and technical performance and compare these two technologies to existing water supply options. Research Task 1a was to perform systematic water sampling of categorized water sources, and measure standardized outcomes of various water quality parameters. Research Task 1b was to assess water quality of the two improved groundwater source technologies available to users in the study area.

It was determined that the systems assessed in this study yielded a mixed level of performance based on measured physical, chemical, and bacteriological water quality indicators. When compared to existing water supply options, bailer and EMAS pump technologies generally offered a quality of water that satisfied international drinking water guidelines and expected ranges of chemical water quality parameters such as pH, alkalinity, nitrate, salinity, TDS, and conductivity. Physical water quality data also followed expected trends, and turbidity measurements from hand augered well sources indicated better water quality (with averages in the range of those of aqueduct and rainwater collection sources) in comparison to unimproved sources with notably more turbid water quality. Finally, the measured bacteriological water quality of bailer and EMAS hand pump systems introduced in the Peninsula Valiente area, characterized as improved water sources, had little to no associated health risks (with calculated risk averages of 1 and 2.35 out of 5 respectively) comparable to the unimproved source of hand dug drinking water wells (with a risk average of 1.64 out of 5).

Although it is unclear to what degree this observation was affected by factors such as frequency of well use or random chlorination of unimproved wells, the finding reinforces the concept that water quality performance does not always parallel categorization of water sources as improved or unimproved by Joint Monitoring Programme definitions (UN, 2013). Thus, with efforts to attain and the evaluate progress towards reaching MDG Target 7c, especially in rural developing areas such as ÑöKribo, it is important to consider the significance of achieving improved access when this access is not based on indicators of a water source's quality (or quantity or reliability for example). While investigation of issues surrounding water access through the use of "improved" and "unimproved" water source indicators is easier to measure, gauging other indicators such as those suggested by WHO drinking water and sanitation guidelines is valuable in identifying (and arguably more representative in conveying) user experienced conditions regarding water sources. Therefore, despite the associated challenges related to the inspection of water sources and water quality testing in the field, it should be considered in the monitoring and evaluation efforts of national and international entities aspiring to implement sustainable and appropriate water systems in areas that lack them.

Overall, because of error associated with the execution of field research and associated water quality analyses, as well as variation in sampling size and sample frequency among water sources, this study demonstrates variability in reported water quality results. For this reason, no strong conclusion could be made with respect to Research Task 1a, as there was a notable lack of consistency and confidence in identified trends across water quality indicators in this investigation.

In efforts to satisfy Research Task 1b, water quality measurements between the two water lifting mechanisms recently implemented with hand augered well technologies were compared. EMAS pumps demonstrated excellent water quality with complete conformity to WHO guidelines for *E. coli* in drinking water, while bailer systems had fair quality, with averages of *E. coli* measurements denoting water of low to intermediate health risk and 45% of samples conforming to WHO guidelines. In terms of technical performance, bailer systems displayed better performance when compared to EMAS systems because they were found to be consistently operational and satisfactory to users when weighing data obtained through visual inspection and user interviews.

However, it is important to qualify this result, taking into account differences in sample size and the methods of implementation of the two different water lifting mechanisms by the NGO directing the transfer of technologies. Indeed, EMAS pumps were evaluated at a different stage in the project life cycle, as three systems were implemented in household wells only for last two months of the study period while bailers were installed more than a year and a half earlier and totaled eleven systems in the research area. Additionally, the introduction of EMAS hand pumps in local improved wells differed based on meaningful indicators of project sustainability that included the level of community participation, materials requirements, economic considerations, and complexity of EMAS system design. For these reasons, (and taking into account the variation in water quality data discussed) comparisons of the performance of two types of water lifting mechanisms based on indicators of water quality assessed in this study remains largely undetermined.

## 5.2 Evaluation of Objective 2

Research Objective 2 examined water access and level of improvement of water sources in regards to socio-cultural factors through assessing local water usage, perceptions, and maintenance behaviors for existing, as well as recently introduced groundwater water supply technologies. Research Task 2 involved conducting surveys with users of water sources in the study area to obtain information on local water access, water usage, water quantity, maintenance practices, and perceived water quality.

Numerous trends which serve to characterize and complement findings based on water quality were identified through assessing the socio-cultural impacts related to water access and level of improvement by observation, water user interviews, and related data analysis. It was concluded that hand augered well technologies, implemented in the context of the study region, were largely incorporated into existing local water usage behaviors, as they offered a (more) reliable water source alternative to people accustomed to having access to and using multiple water sources. These improved well systems were utilized with a frequency that ranged from daily to weekly to monthly, depending largely on the availability of other improved sources such as aqueducts and rainwater. The categorization and prioritization of water from particular sources for designated use(s) was practiced in the local context, as suggested by the literature

(Mihelcic et al., 2009). People noted using more water after acquiring access to the bailer and EMAS pump technologies; however, they reported using this water largely for drinking, cooking, and washing dishes, not bathing or washing clothes. Indeed, due to expressed user preferences rooted in Ngöbe culture and customs, women and children especially were found to use water from unimproved sources further from their homes such as hand dug wells and shallow streams for the purposes of bathing and washing clothes, despite access to improved sources.

Overall, improved hand augered well technologies were well received by users in the context of the Ngöbe society in the ÑöKribo region where they were implemented. These systems (along with other improved water sources in general) were perceived to have cleaner water than other sources and accordingly were preferred for drinking water and used when available for consumption purposes. The qualitative findings with respect to socio-cultural factors surrounding water in this study exemplify the complexity of the interrelatedness of water use choices, preferences, and culture characteristic of rural developing areas, and the appropriateness of qualitative data for revealing these tendencies as proposed by the literature (Dynes, 1971; Doria, 2010, Baird et al., 2013, Prouty, 2013). Using these methods, the data collected on water quantity, water usage, and water source availability served to supplement the overall assessment of bailer and EMAS technologies in research area.

### 5.3 Evaluation of Objective 3

Research Objective 3 of this investigation was to provide useful recommendations for improving the sustainability and appropriateness of low-cost hand augered well technologies and the development approach utilized in the research context. Research Task 3 was to evaluate the appropriateness of hand drilled well technologies through performing a qualitative sustainability analysis in order to make applicable operational recommendations for future work. Bailers and

EMAS hand pumps are recognized to be a technically promising means of accessing water with effective potential for sustainable and appropriate use applications, especially in the context of shallow wells and the rural coastal environment of this study's research area. A literature review and the qualitative sustainability analysis performed in this study made evident specific sustainable features that are characteristic of the two household self supply alternatives. The notable highlights of EMAS and bailer systems include ease of use, low costs, and use of locally available materials that are incorporated into a simplistic design.

With regards to the overall project sustainability and appropriateness of the Healing Fund's project that aimed to improve water source access in coastal Ngöbe communities, general strengths, weaknesses, and opportunities for improvement became evident through qualitative methods of sustainability analysis. In terms of the sustainability factors related to political and social cohesion, it was observed that the involvement of local community members and organization is critical to the success of project in all phases, as sense of ownership and human capacity to properly operate and maintain water source can have a profound influence on effective operation and long term use of a water source.

Accordingly, a variety of measures should be implemented to increase the sustainability of hand augered well technologies in Panama such as potential knowledge transfer and coordination between the Healing Fund nongovernmental organization and an appropriate local government agency such as Proyecto de Agua y Saneamiento en Panama, a division of the Ministry of Health which oversees Water and Sanitation Projects in Panama. Making this contact could facilitate the support and coordination of project logistics (communication, accountability, materials acquisition). Establishing this professional relationship also provides an offer an opportunity for local governments to monitor and evaluate the technologies and conduct independent assessments of the role which these types of systems could play in local strategies for providing improved drinking water access in rural indigenous areas of Panama.

Furthermore, to improve the social cohesion surrounding hand augered well technologies, there should be increased knowledge transfer between the Healing Fund and local skilled well drillers as well well owners and the general community. The development and dissemination of relevant operation and maintenance training materials (such as lectures to be delivered by well drillers upon installing a new well, guidelines with diagrams depicting upkeep activities, or a checklist providing information on the materials utilized in both systems) would be extremely beneficial investments in long term capacities to sustain the water sources. Furthermore, a formal process could be established by the Healing Fund to allow local residents to express interest in attaining an improved well. Needs assessment based approaches could be considered, as local residents that have access to no improved water sources willing to make contributions to the project could be prioritized. Women could be specifically incorporated in well installation and development efforts, so as to facilitate their comfort with using and maintain the systems.

Additionally, in order to facilitate the economic appropriateness of the technologies it is necessary to make changes to the operational approach of the Healing Fund in the study area so as to encourage lasting availability of the technology (beyond complete financing of well drillers' labor and the materials necessary to install wells). Local well drillers should collaborate with the Healing Fund to evaluate the associated labor, installation costs, and user demands associated with the project. In this manner, trained individuals could be guided to offer hand augered well services through approaches that permit community members to make direct investments in attaining the technology, without depending on (and waiting for) full external funding. Essentially, it is considered critical to take measures which promote local capacities to financially contribute to the process of not only attaining access to bailers and EMAS hand pumps, but maintaining these systems.

With traditional concepts of a sustainable self supply development model in mind, and the fact that bailer systems are arguably the least expensive water lifting mechanism in existence for improved wells, it could be useful to incorporate bailers in development approaches as an incremental step in improving water access in rural communities, especially in remote areas with relatively high water tables.  Since these systems are a lower cost, more durable alternative to hand pumps, they could be presented in improved household hand augering well programs for households interested in participating in the process of improving their water access, but find the investments associated with hand pumps to be financially challenging (or out of reach).

Furthermore, in efforts to maximize overall project sustainability and appropriateness of both EMAS pumps and bailer systems specific technical recommendations can also be offered. In particular with respect to design considerations, it should be noted that EMAS pumps implemented in shallow tubewells (less than 10 meters) should be constructed using 0.75-inch diameter PVC pump bodies and with completely galvanized iron pipe in the pump handle. Despite the acknowledgement that these materials substitutions will cause the price of EMAS systems to increase an estimated 50%, it is absolutely vital to the performance capacity and durability of the EMAS systems to follow manufacturer guidelines.  The increased diameter would allow for greater water volume output per pump and less user applied stress to moving parts.  The pure galvanized iron handle would minimize fragility of the pump, especially at junctures between threaded PVC and threaded galvanized iron which become significantly vulnerable areas during pumping action receiving considerable repeated forces applied in alternate directions.

Upon recognizing limitations of their organizational capacity as well as the fact that recommended improvements to the project sustainability of EMAS pumps in the study area are considerably more demanding than those for bailer systems, the Healing Fund may find it to valuable to reassess the decision to implement two different kinds of technologies. EMAS pumps will only become sustainable in the area if they can be affordable, locally manufactured, technically understood, and appropriately maintained. Since true improvements in local water access involve resilient systems which can provide long term benefits, it can be important to for the Healing Fund to consider whether bailer systems are effectively more appropriate than EMAS pumps for them to sustainably implement (considering budget, time commitments, and feasibility to conduct necessary capacity building) and for local users to obtain and maintain, considering all relevant data provided.

### 5.4 Recommendations for Future Research

Future research investigating potential applications and performance of bailer systems and EMAS pumps as low costs methods of self supply would be useful to organizations interested in promoting appropriate technologies in sustainable development efforts focused on improving water access and related health outcomes. Specifically, research exploring the water quality and technical performance, economic feasibility, resilience, and user acceptability of bailer systems in comparison to traditional water sources and other improved systems such as hand pumps would be valuable. Trends and correlations regarding considerations of well recharge, frequency of use, and rainfall events could be expanded in this context. This could lead to future recommendations regarding the implementation of bailer systems as a reliable household self supply alternative in areas with shallow aquifers, especially in remote areas suffering from water related hardships.

Additionally, it would be meaningful to further document the mechanisms involved in the flushing effect that is noted to occur in tubewells in a state of forced rapid recharge.  Analysis of well flushing considering the rate of bail volume removal (using volumes of water per time) from a well could expand on tests performed by others to document the capacity of bailer systems in tubewells to diminish concentrations of bacteria. Additionally, testing of tubewells with respect to turbidity could be performed, improving upon methods employed in this study. Specifically, if the state of the well at the time of the test could be controlled (e.g., by purging the wells based on a standard well volume (a function of the height of the water table within a given well)), tubewells could then be spiked with a substance of known volume and turbidity, and turbidity measurements could be taken as water is flushed from the system (at intervals of time or volume of water).  This data could provide meaningful implications with respect to recommendations for well development of households with bailer systems or during well monitoring.

Finally, statistical analysis and modeling of user choices with respect to water access in rural areas that offer multiple source options, are particularly vulnerable to seasonal changes, or have experienced a lack of reliability of water systems could add to studies like that of Majuru (2012) and WHO (2009).  This research could generate recommendations for the approach that water services should be introduced to areas similar to the location of this study, to ensure complementary adoption of the new technology into the water use patterns of a population.

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# Appendices

# Appendix A: Email Correspondence- IRB Exemption

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From: Hart, Olivia [redacted] Fri, Jun 14, 2013 at 8:55 AM
To: "Hayman, Sarah" [redacted]

Hi Sarah,

Your email was forwarded to me for a response. Based on the information you have provided, I do not think IRB oversight will be necessary for this project. As you indicated, you are evaluating the water system and not researching about the individuals. Feel free to contact me if you need additional assistance.

Olivia Hart, MPA, CIP

IRB Education Coordinator
Research Integrity & Compliance

Phone: [redacted]

FAX: [redacted]

USF IRB website: http://www3.research.usf.edu/dric/hrpp/

# Appendix B: Water User Interview Guidelines (English Translation)

## Table B.1: Water User Interview Guidelines

| |
|---|
| Community: |
| Name: |
| Well depth: |
| Age: |
| Date of well installation: |
| Access Type: a. hand dug well b.hand augered well with bailer c. hand augered well with pump |
| If hand dug well, are there rules set for the permitted uses of the well? |
| Is a. drinking b. bathing c. bathing sick/elderly/babies d. cooking e. washing dishes f. washing clothes g. other permitted? |
| Do people comply with the rules? A. yes B. no |
| Does the well dry up? A. yes B. no |
| If so, for what duration (maximum) _days _weeks _ months |
| How many households use water from this well? |
| How many people total use water from this well? |
| Who collects water from/uses the well? a. children 13< b. youth 13- 18 c. adult women d. adult men e. elderly women f.elderly men |
| How often do you use water from the well? A. _ times Daily? B. _ times weekly C. _ times monthly? D. only in the dry season |
| For all of the following activities what source(s) of water do you use: IW (improved well), UW (unimproved well), Q (creek), A (aqueduct), Ra (Rain), Ri (River) |
| drinking |
| bathing |
| bathing sick/elderly/babies |
| cooking |
| washing dishes |
| washing clothes |
| other |
| For all of the following activities what source(s) of water did you use prior to access: IW (improved well), UW (unimproved well), Q (creek), A (aqueduct), Ra (Rain), Ri (River) |
| drinking |
| bathing |
| bathing sick/elderly/babies |
| cooking |
| washing dishes |
| washing clothes |
| other |
| How do you store/transport water? A. 5 gallon bucket B. barrel C. jug D. larger tank E. Other |
| Is the storage container A. covered or B. uncovered |

## Table B.1: (continued)

| |
|---|
| How often do you clean the storage container? A. weekly B. monthly C. Every few months D. only when visibly dirty |
| How much well water do you use per person per day for:? |
| drinking |
| bathing |
| bathing sick/elderly/babies |
| cooking |
| washing dishes |
| washing clothes |
| other |
| How is the quantity of water that the well provides? A. bad B. ok C. good D. excellent |
| Is the quantity of water you use A. more B. less, or C. the same as it was prior to improved access? |
| If more or less- by how much? (per household) |
| Does the improved well make the distance to the water you access A. closer B. further C. the same? |
| If closer or further- by how much? (distance) |
| Is the process of acquiring water for daily household needs physically A. easier B. the same C. harder than prior to improved access? |
| Is the process of getting water to your house A. faster B. slower C. the same as it was prior to improved access? |
| If faster or slower- by how much? [] 1 to 5 minutes [] 5-10 minutes [] 10 - 30 minutes [] > 30 minutes |
| How often do you use the well? How often do you take steps to maintain the well? |
| A.weekly B.monthly C.every few months D.after every hard rain E. never |
| Have you done any of the following in the past month? a.replaced parts b.cleaned parts c.treated water d.reassembled/tightened parts e.other f.none |
| Did you provide A. labor B. money C. materials D. nothing for the implementation of the well? |
| Do you feel like you know how to or could fix this pump or bailer if it breaks? A. yes B. no C. maybe or with help |
| Do you feel like you have the money available to replace parts of this pump if it breaks? A. yes B. no C. maybe or with help |
| Do you ever bail water/pump water out of the well with the purpose of cleaning the well? |
| If so, how often?(daily, weekly, monthly) How many times do you pump/bail or for how long do you pump bail it to clean it? |
| Do you treat well the water by: A. boiling B. chlorine C. filtering D. none |
| From all of the water sources that you have access to which water do you prefer to drink? |
| How do you feel about the typical cleanliness of water in the well? A. bad B. ok C. good D. excellent |
| Do you think that the cleanliness of water you drink affects your health? A. yes B. no C. maybe |
| Of all the water sources you have access to can you rank them by which you think has the cleanest water to which you think has the dirtiest water? |
| How often does someone in your household experience [] diarrhea/vomito [] skin infections []headaches ( at least once a week, at least once a month, once every few months) |
| What activities do you use soap for? A. bathing B. handwashing C. washing clothes d. washing dishes E. Other |

## Appendix C: Water User Profile Field Notes from Observation and Survey Data

### Table C.1: User Interview Definitions and Descriptions Used

| Definition | Description Used |
|---|---|
| 65+ years old | Elderly |
| 18-65 years old | Adult |
| 12-18 years old | Youth |
| 1-12 years old | Child |
| <1years old | Baby |
| Unimproved wells for washing | Washing clothes and bathing in the well itself. |
| Unimproved wells for drinking | Used indirectly for drinking, cooking, and washing dishes |

Notes from household interviews are provided below and labeled by well owner.

MikMIW: Had access during the study to an improved well with bailer, then EMAS pump. Prior access was unimproved well for washing and unimproved well for drinking located about 5 minutes further away than her current access. When she gained access to an improved well with a bailer she used it as her primary water source for the following activities drinking, cooking, dish washing, and her children have used it for bathing. Neither the improved well nor the unimproved well ever dried up for any amount of time. Household consists of 2 adults, 3 youth, and 2 children. Family does not have improved sanitation access. The improved well was utilized by her one household, daily. The unimproved well marking her prior access was used for washing/bathing, and drinking was utilized by up to 4 households, approximately 30 people. The family stores and transports water in uncovered buckets, covered buckets, and a variety of sizes of jugs. The mother and her children look for water, while her husband does not. She was the only respondent who preferred EMAS pump to bailer. They had the shallowest improved well out of all examined, and the first well installed in the region.

MikHIW: Current access is an improved well with bailer, then upgraded to an EMAS pump in November 2012. Prior access was an improved rainwater collection system for cooking and drinking, as well as unimproved washing and drinking wells located about 10 minutes further away than her current access. The rainwater tank when full provided enough water for cooking, drinking, and washing dishes for about 5 days. Household consists of 2 adults, 1 youth, 1 child, and one baby. Family does not have improved sanitation access. The household was interested in EMAS pump applications to pump water from the improved well to their rainwater tank so that they could store water when a few days pass with no rain. EMAS pump installed here broke at the "T" of the pump handle in late November 2013. Has one of the two intermediate depth wells in the study; live on top of a small hill.

AbeIW: Current access is an improved well with bailer, then upgraded to an EMAS pump in November 2012. Prior access was unimproved hand dug well for washing and unimproved well for drinking located 2 minutes away further from current access. They stopped using unimproved well for drinking. Household consists of 2 adults, 4 youth, and one baby. Family does not have improved sanitation access. Has one of the two intermediate depth wells in the study; live on top of a hill. One of four skilled hand augered well drillers lives here. The rubber gasket seal in his EMAS pump broke while sampling for turbidity though the family had experienced signs of wear over a few days. The matriarch of the family wants to install the bailer again while waiting for the men to fix the EMAS pump (with the help of a local Peace Corps volunteer). The women and children transport water from the improved well to the house in uncovered buckets and jugs, they cover the buckets when they are stored in the house.

NinIW: She got an improved well with a bailer in the mid-August 2013. Improved piped aqueduct access that is unreliable due to issues with water pressure and scarcity when 3 or more days pass without rainfall and there is no water in the aqueduct. Household consists of 2 adults, 2 youth, and 2 children. She was skeptical about the cleanliness of the water from the improved well for the first 3 months and would only use it for washing dishes. She was not following instructions to bail water (develop the well) so that the water would clear up over time. She was encouraged by other improved well owners to be patient and keep bailing water out of the well so that it could get cleaner. She and her children began bailing water more often (until they got tired, 2 to 3 times a week). In the fourth month of access she reported being satisfied with the water quality and the taste. She began using the water for drinking and cooking purposes. The kids would play and bathe in the well water occasionally. Family does not have improved sanitation access.

EnrIW: Had access to an improved well with bailer. Prior access was unimproved hand dug wells for washing and drinking as well as his neighbor's aqueduct source. Initially the family felt skeptical about the well because it was providing turbid water. For this reason in the beginning no one in the family drank from the improved well, but the women washed dishes with the well water. In the first two months after installing the bailer a family member (either the mother or father) would bail out three to five volumes of water so that it would fill up again with fresh water. They noticed that the well water got clearer over time and was not affected by rain events. The male was trained as a hand augered well driller by the Healing Fund and was interested in working to install more wells and learning how to make EMAS hand pumps. The household consists of 7 adults, 1 youth, 3 children, and two babies. Family does not have improved sanitation access. Several family members noted that they liked that the well water was cold and the male adult and youth would bathe with improved well water out of a bucket occasionally.

BAIW: was found to have an improved well with bailer. This well is abandoned due to location downhill from a cemetery. No one claimed to own, ask for, or maintain the well. The majority of households in this community have improved access to drinking water in the form of a piped aqueduct system that is sometimes faulty, especially after hard rains. The third skilled hand augered well driller lives in this community as well as a church organization with which The Healing Fund collaborates. There are some composting latrines in the community.

KaniIW: Improved well with bailer that is located at a church. Prior access to all community members was an improved aqueduct system from a shallow stream source providing taps in most households. open well/stream where people bathe and wash clothes. The aqueduct in this community of Kani Kote does not provide service to the majority of households when more than 3 days pass without rain, because the stream source has low flow. Some households lose water access from the aqueduct after one day. When the aqueduct is not functioning, up to 10 households use water from the bailer; serving a total of approximately 50 people. The respondent believed that the community would help maintain the improved well if there were damages to the bailer, as funds could be collected through the church. The bailer was not in use daily, but was in use weekly. When not in use for several days, community members flush 3 to 5 well volumes before collecting water to take back to their own household. The respondent put 5 to 10 drops of liquid bleach (chlorine) in the well one time while the well was developing. Some access to improved sanitation in the form of a composting latrine but the majority of the community lacks access to improved sanitation and practices open defecation.

ValIW: Improved well with bailer. Prior household water access includes a piped aqueduct system, an open drinking water well, and a stream for washing and bathing, about 10 minutes away. A cow damaged the wooden posts holding up the pulley above the well, and the type of wood selected for the posts rotted, so now they just pull the bailer up directly using the rope. He uses his improved well primarily when the aqueduct is not working, which is usually weekly. He thinks that people should organize to drill more wells in the community because they have the hand auger and they know how. The women believe that water from the well is better than water from the aqueduct because of the taste, the cold temperature coming from within the earth, and the clarity of the water.

LydiaIW: Primary water source is piped aqueduct from a shallow stream. Only uses the improved well with bailer when the aqueduct is not functioning, about one period of time a month, it can last several days up to several weeks, depending on rain and how long it takes for the people to go fix the aqueduct if there was a damage. The household's prior access when the aqueduct was not functioning was bringing water from a stream, which is a 10 minute walk away from the house. This action was done by the women and youth primarily. Currently, when the aqueduct is not functioning, people from 5 houses use water from the bailer, which serves a total of 28 people. Yes they would spend money to fix the well if it broke but they say they do not have knowledge of what to do to maintain it. They do not apply any household treatment to the water. They report that when it rains the aqueduct water gets very turbid while the improved well stays clear. They believe that the water quality is excellent and that the water has a good flavor. Family does not have improved sanitation access.

MelIW: 2 houses utilize water from this improved when water when the aqueduct is not working, summing to a total of 22 people, about once a month. When there is no rain especially, they use this source. The kids also use it sometimes to bathe during the day. Before gaining Access to this improved well they walked 5 minutes to an unimproved well to gather water. They have performed no maintenance on the well. They notice that when it rains the water table rises but the water stays clean. Family does not have improved sanitation access

RamIW: Had an Improved well with bailer. The man is the main one who looks after the well. Prior access was unimproved well for drinking and stream for washing and bathing. When the stream runs high they use a PVC pipe to send water to a bucket near the house. Household consists of 2 adults who are elderly. They feel that the well water in the new unimproved well is not as clean as the improved well which the man dug out have owned for more than five years ago when he moved into the house. They have not bailed water out with the purpose of cleaning the well. They notice that the water level rises very high in the improved well when there is rain. Family does not have improved sanitation access.

# Appendix D: Additional References Related to Water Quality Testing

Figure D.1: Example Household Piped Aqueduct System from Shallow Stream Source

Figure D.2: Unimproved Drinking Water Source and Water Scoop Top View (which demonstrates soil and depth characteristics)

Figure D.3: Kani Kote Shallow Stream Source Used to Wash Clothes and Bathe

Figure D.4: Broken Handle of EMAS Pump at Attachment between Galvanized Iron "T" and PVC Half Inch Pipe La Ensenada

Figure D.5: IDAAN Research Laboratory Setting in El Silencio

Figure D.6: (a) Alkalinity Titration Apparatus (b) OAKTON PCD 650 Probe

Figure D.7: (a) HANNA HI 4211 Bench Meter (Ann Arbor, MI) (b) HACH Spectrophotometer DR 2800

## Table D.1: Water Quality Parameters, Units, Accuracy, Measurement Methods, and Instruments

| **Water Quality Parameter** | **Unit of Measurement and Accuracy** | **Method of Measurement and/or Instrument** |
|---|---|---|
| pH | pH units<br>Range: -2.000 to 20.000<br>Accuracy: +/- 0.001 pH units | HANNA HI 4211 bench meter (Ann Arbor, MI) |
| Salinity | mg/L<br>Range: 90 mg/L<br>Accuracy: +/- 0.2 mg/L | OAKTON PCD 650 probe (Vernon Hills, IL) |
| Conductivity | Microsiemens µS<br>Range: 0 to 500 µS<br>Accuracy:+/- .01 | OAKTON PCD 650 probe (Vernon Hills, IL) |
| Alkalinity | mg/L $CaCO_3$ equivalent<br>Range: 0 to 5,000 mg/L $CaCO_3$ | Manual colorimetric buret titration method using sulfuric acid. HACH Permachem Reagents Bromcresol Green-Methyl Red Indicator Powder Pillows and Phenolphthalein Indicator Powder Pillow |
| Total Dissolved Solids (TDS) | mg/L<br>Range: 0 to 200 ppm<br>Accuracy: +/- 0.05% | OAKTON PCD 650 probe (Vernon Hills, IL) |
| Nitrate as $NO_3$-N | mg/L<br>Range: 0.3 to 30.0 mg/L $NO_3$-N)<br>Accuracy: +/- 0.01 mg/L | HACH Method 8039. NitraVer® 5 Nitrate Reagent Powder Pillows HACH spectrophotometer DR 2800 (Pittsburgh, PA) |
| Turbidity | NTU<br>Range: 0 to 1000 NTU<br>Accuracy: +/- .02 | HACH 2100Q Portable Turbidity Meter (Pittsburgh, PA) |
| *E.coli* | Maximum Probable Number (MPN) per 100 ml<br>Range: non-detectable (0) to 2419 MPN per 100 ml<br>Colony Forming Units (CFU) per 100 ml<br>Range: non-detectable (0) to 300 CFU (with official accuracy, though more can be counted) | Standard Method 9223 B using IDEXX Colilert QuantiTray 2000 (Westbrook, ME)<br>Coliscan Method using Coliscan EasyGel (Micrology Laboratories, Goshen, IN) |
| Total Coliform | MPN per 100 ml<br>Range: non-detectable (0) to 2419 MPN per 100 ml<br>Colony Forming Units (CFU) per 100 ml<br>Range: non-detectable (0) to 300 CFU | Standard Method 9223 B using IDEXX Colilert QuantiTray 2000 (Westbrook, ME)<br>Coliscan Method using Coliscan EasyGel (Micrology Laboratories, Goshen, IN) |

# Appendix E: Collected Data

**Table E.1: Measured Turbidity During Flushing Tests: Bailers Versus EMAS Pumps Jun. - Dec. 2013; n=7 for EMAS, n= 15 for Bailers**

| | **Turbidity in NTU** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Bail/pump volume removed** | 1 | 3 | 5 | 7 | 10 | 13 | 15 | 17 | 20 |
| **Bailer systems** | 15.50 | 18.40 | 41.90 | 41.90 | 48.90 | 34.20 | 42.83 | 34.43 | 28.65 |
| | 8.46 | 8.08 | 6.81 | 9.46 | 6.90 | 9.89 | 3.16 | 4.37 | 8.38 |
| | 13.40 | 41.07 | 51.40 | 78.40 | 71.73 | 34.27 | 83.17 | 44.97 | 55.13 |
| | 21.20 | 79.03 | 158.00 | 232.67 | 233.00 | | 196.00 | | 89.87 |
| | 0.80 | 5.40 | 3.48 | 3.71 | 4.78 | | 4.57 | | 2.14 |
| | 9.92 | 9.92 | 5.98 | 6.36 | 14.77 | | 9.32 | | 9.62 |
| | 4.77 | 6.88 | 6.69 | 11.70 | 6.65 | | 9.49 | | 16.60 |
| | *4.16* | *44.90* | *46.67* | *75.43* | *472.00* | | *1000.00* | | *920.00* |
| | 3.81 | 15.77 | 23.90 | 19.25 | 69.20 | | 71.37 | | 44.47 |
| | 1.98 | 6.74 | 5.29 | 5.59 | 3.61 | | 3.86 | | 1.88 |
| | 0.78 | 6.25 | 11.40 | 6.58 | 6.86 | | 4.33 | | 14.13 |
| | 51.15 | 120.00 | 238.00 | 252.00 | 227.00 | | 166.50 | | 213.00 |
| | 23.70 | 15.65 | 13.95 | 16.00 | 11.35 | | 18.20 | | 16.75 |
| | 3.37 | 6.65 | 5.82 | | 21.60 | | 5.64 | | 6.51 |
| | 5.24 | 7.93 | 13.40 | 22.70 | 22.40 | | 44.15 | | 42.13 |
| **Average** | 11.22 | 26.18 | 42.18 | 55.84 | 81.38 | 26.12 | 110.84 | 27.92 | 97.95 |
| **EMAS hand pumps** | 3.48 | 4.31 | 12.27 | 18.03 | 12.73 | | 12.67 | | 5.54 |
| | 2.14 | 3.20 | 5.48 | 2.75 | 4.15 | | 2.12 | | 2.98 |
| | 2.08 | 1.60 | 1.61 | 0.75 | 1.06 | 0.35 | 1.17 | 0.87 | 0.97 |
| | 5.24 | 26.23 | 14.75 | 31.05 | 31.05 | 8.53 | 31.30 | 20.35 | 60.05 |
| | 4.97 | 7.11 | 6.49 | 8.07 | 2.90 | 5.00 | 3.90 | 3.35 | 2.00 |
| | 6.21 | 12.43 | 12.57 | 11.90 | 8.35 | 11.43 | 11.77 | 13.93 | 10.80 |
| | 3.43 | 7.23 | 11.30 | 7.75 | 9.03 | 13.80 | 8.77 | 10.65 | 11.14 |
| **Average** | 3.94 | 8.87 | 9.21 | 11.47 | 9.90 | 7.82 | 10.24 | 9.83 | 13.35 |

## Table E.2: User Reported Existing Water Access by Water Source Type

| Owner | Aqueduct | Rainwater | Improved Well | Unimproved Wells | Shallow stream | Total Number of Sources |
|---|---|---|---|---|---|---|
| MikHIW |  | 1 | 1 | 1 |  | 3 |
| EnrIW |  |  | 1 | 1 |  | 2 |
| MikMIW |  |  | 1 | 1 |  | 2 |
| AbeIW |  |  | 1 | 1 |  | 2 |
| NinIW | 1 |  | 1 | 1 |  | 3 |
| LydIW | 1 |  | 1 |  | 1 | 3 |
| MeliIW | 1 |  | 1 |  | 1 | 3 |
| BAIW | 1 |  | 1 | 1 |  | 3 |
| RamIW |  |  | 1 |  | 1 | 2 |
| ValIW | 1 |  | 1 |  | 1 | 3 |
| KanIW | 1 | 1 | 1 |  | 1 | 4 |
| Chunki |  |  |  | 1 |  | 1 |
| Total | 6 | 2 | 11 | 7 | 5 | 31 |
| Percent | 19.35 | 6.45 | 35.48 | 22.58 | 16.13 | 100 |

## Table E.3: Water Source Turbidity for all Water Sources Sampled Using Descriptive Statistics

| Owner | Descriptive Statistic | Turbidity (NTU) |
|---|---|---|
| AbeIW | N | 7 |
| | Mean | 5.82 |
| | Grouped Median | 3.98 |
| | Range | 15.62 |
| | Std. Deviation | 5.52 |
| | Std. Error of Mean | 2.09 |
| AbeUIwash | N | 4 |
| | Mean | 10.41 |
| | Grouped Median | 9.14 |
| | Range | 21.33 |
| | Std. Error of Mean | 4.48 |
| | Std. Deviation | . |
| ChunkiUIdrink | N | 4 |
| | Mean | 4.65 |
| | Grouped Median | 4.26 |
| | Range | 3.73 |
| | Std. Error of Mean | 0.88 |
| | Std. Deviation | 1.75 |
| ChunkiUIwash | N | 4 |
| | Mean | 16.85 |
| | Grouped Median | 11.19 |
| | Range | 36.79 |
| | Std. Error of Mean | 8.26 |
| | Std. Deviation | 16.53 |
| EnrIW | N | 7 |
| | Mean | 6.40 |
| | Grouped Median | 3.43 |
| | Range | 22.17 |
| | Std. Error of Mean | 2.94 |
| | Std. Deviation | 7.78 |
| IglesiaIW | N | 2 |
| | Mean | 2.15 |
| | Grouped Median | 2.15 |
| | Range | 0.35 |
| | Std. Error of Mean | 0.17 |
| | Std. Deviation | 0.25 |
| LaEnsAq | N | 3 |
| | Mean | 24.59 |
| | Grouped Median | 20.50 |
| | Range | 51.39 |
| | Std. Error of Mean | 14.98 |
| | Std. Deviation | 25.94 |

## Table E.3: (continued)

| | | |
|---|---|---|
| LydIW | N | 2 |
| | Mean | 3.73 |
| | Grouped Median | 3.73 |
| | Range | 0.17 |
| | Std. Error of Mean | 0.09 |
| | Std. Deviation | 0.12 |
| MikHIW | N | 4 |
| | Mean | 9.12 |
| | Grouped Median | 5.24 |
| | Range | 19.02 |
| | Std. Error of Mean | 4.48 |
| | Std. Deviation | 8.96 |
| MikMIW | N | 7 |
| | Mean | 3.74 |
| | Grouped Median | 3.37 |
| | Range | 9.61 |
| | Std. Error of Mean | 1.26 |
| | Std. Deviation | 3.34 |
| MikUIWash | N | 5 |
| | Mean | 12.97 |
| | Grouped Median | 9.62 |
| | Range | 30.13 |
| | Std. Error of Mean | 5.53 |
| | Std. Deviation | 12.37 |
| NinIW | N | 5 |
| | Mean | 36.11 |
| | Grouped Median | 15.50 |
| | Range | 83.58 |
| | Std. Error of Mean | 15.90 |
| | Std. Deviation | 35.56 |
| Rainwater | N | 3 |
| | Mean | 3.32 |
| | Grouped Median | 3.26 |
| | Range | 0.73 |
| | Std. Error of Mean | 0.21 |
| | Std. Deviation | 0.37 |
| ValIW | N | 2 |
| | Mean | 70.41 |
| | Grouped Median | 70.41 |
| | Range | 132.51 |
| | Std. Error of Mean | 66.25 |
| | Std. Deviation | 93.70 |
| Total | N | 60 |
| | Mean | 12.98 |
| | Grouped Median | 5.07 |
| | Range | 135.98 |

## Table E.3: (continued)

| | | |
|---|---|---|
| Total | Std. Deviation | 22.49 |
| | Std. Error of Mean | 2.90 |

# Table E.4: Water Source Turbidity for all Water Sources Sampled Raw Data

| **Turbidity in NTU's** | | DSR= days since rain | | | Source type 1 baler 2 emas 3 handdugwash 4 handdugdrink 5 aqueduct 6 rain | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Bale number | | | | | | | | | | |
| Improved | Source type | Date | DSR | Name | 1 | 3 | 5 | 7 | 10 | 13 | 15 | 17 | 20 | Trend | Peak |
| yes | 1 | 6/19/2013 | 0 | ValIW | 136.67 | | 124.75 | | | | | | | - | 1 |
| yes | 1 | 6/19/2013 | 0 | AbeIW | 3.98 | | 4.57 | | | | | | | + | 5 |
| yes | 1 | 6/19/2013 | 0 | LydIW | 3.64 | | 3.55 | | | | | | | - | 1 |
| yes | 1 | 6/19/2013 | 0 | Iglesia | 2.33 | | 2.55 | | | | | | | + | 5 |
| yes | 1 | 6/19/2013 | 0 | MikMIW | 0.69 | | 0.65 | | | | | | | - | 1 |
| yes | 1 | 6/19/2013 | 0 | EnrIW | 2.60 | | 6.36 | | | | | | | + | 5 |
| no | 3 | 6/19/2013 | 0 | AbeUI | 1.02 | | | | | | | | | | |
| no | 3 | 6/19/2013 | 0 | MikUI | 9.62 | | | | | | | | | | |
| yes | 4 | 6/19/2013 | 0 | Enraq | 0.94 | | | | | | | | | | |
| yes | 1 | 6/30/2013 | 2 | AbeIW | 2.53 | 1.07 | 1.38 | | | | | | | - | 1 |
| yes | 1 | 6/30/2013 | 2 | MikMIW | 10.30 | na | na | | | | | | | | na |
| yes | 1 | 6/30/2013 | 2 | EnrIW | 1.53 | 4.62 | 3.70 | | | | | | | +- | 3 |
| yes | 1 | 8/27/2013 | 1 | BAIW | 21.20 | 79.03 | 158.00 | 232.67 | 233.00 | | 196.00 | | 89.87 | +- | 10 |
| yes | 1 | 8/28/2013 | 0 | MikMIW | 0.80 | 5.40 | 3.48 | 3.71 | 4.78 | | 4.57 | | 2.14 | +-+- | 3 |
| no | 3 | 8/28/2013 | 0 | MikUIWash | 34.70 | | | | | | | | | | na |
| no | 3 | 8/28/2013 | 0 | ChunkiUIdrink | 5.17 | | | | | | | | | | na |
| no | 3 | 8/28/2013 | 0 | ChunkiUIwash | 13.90 | | | | | | | | | | na |
| yes | 1 | 8/28/2013 | 0 | AbeIW | 9.92 | 9.92 | 5.98 | 6.36 | 14.77 | | 9.32 | | 9.62 | -+- | 10 |
| yes | 1 | 8/28/2013 | 0 | EnrIW | 4.77 | 6.88 | 6.69 | 11.70 | 6.65 | | 9.49 | | 16.60 | +-+-+ | 20 |
| yes | 1 | 8/28/2013 | 0 | ValIW | 4.16 | 44.90 | 46.67 | 75.43 | 472.00 | | overrange | | 920.00 | +- | 15 |
| yes | 1 | 8/28/2013 | 0 | LydiaIW | 3.81 | 15.77 | 23.90 | 19.25 | 69.20 | | 71.37 | | 44.47 | +-+- | 15 |
| yes | 1 | 8/28/2013 | 0 | IglesiaIW | 1.98 | 6.74 | 5.29 | 5.59 | 3.61 | | 3.86 | | 1.88 | +-+-+- | 3 |
| yes | 1 | 10/9/2013 | 6 | AbeIW | 0.78 | 6.25 | 11.40 | 6.58 | 6.86 | | 4.33 | | 14.13 | +-+-+ | 20 |
| yes | 1 | 10/9/2013 | 6 | NinaIW | 51.15 | 120.00 | 238.00 | 252.00 | 227.00 | | 166.50 | | 213.00 | +-+ | 7 |
| yes | 1 | 10/10/2013 | 0 | EnrIW | 23.70 | 15.65 | 13.95 | 16.00 | 11.35 | | 18.20 | | 16.75 | +-+ | 15 |
| yes | 1 | 10/10/2013 | 0 | MikMIW | 3.37 | 6.65 | 5.82 | - | 21.60 | | 5.64 | | 6.51 | +-+ | 10 |
| yes | 1 | 10/10/2013 | 0 | MikHIW | 5.24 | 7.93 | 13.40 | 22.70 | 22.40 | | 44.15 | | 42.13 | +-+- | 15 |
| no | 3 | 10/10/2013 | 0 | AbeUIwash | 11.05 | | | | | | | | | | |
| no | 3 | 10/10/2013 | 0 | ChunkiUIdrink | 6.90 | | | | | | | | | | |
| no | 3 | 10/10/2013 | 0 | ChunkiUIwash | 40.90 | | | | | | | | | | |
| yes | 1 | 10/10/2013 | 0 | MikHIW | 22.50 | | | | | | | | | | |
| yes | 1 | 10/10/2013 | 0 | MikMIW | 3.50 | | | | | | | | | | |
| no | 3 | 10/10/2013 | 0 | MikUIWash | 5.91 | | | | | | | | | | |
| no | 2 | 11/7/2013 | 2 | MikHIW | 3.48 | 4.31 | 12.27 | 18.03 | 12.73 | | 12.67 | | 5.54 | | 7 |
| yes | 1 | 11/7/2013 | 2 | AbeIW | 16.40 | | | | | | | | | | |
| yes | 1 | 11/7/2013 | 2 | MikMIW | 5.43 | | | | | | | | | | |
| no | 3 | 11/7/2013 | 2 | ChunkiUIdrink | 3.17 | | | | | | | | | | |
| yes | 4 | 11/7/2013 | 2 | LaEnsAq | 20.50 | | | | | | | | | | |
| no | 3 | 11/7/2013 | 2 | ChunkiUIwash | 4.12 | | | | | | | | | | |
| yes | 1 | 11/7/2013 | 2 | NinaIW | 92.03 | | | | | | | | | | |
| no | 3 | 11/7/2013 | 2 | AbeUIwash | 7.23 | | | | | | | | | | |
| no | 3 | 11/7/2013 | 2 | MikUIWash | 4.57 | | | | | | | | | | |
| yes | 1 | 11/7/2013 | 2 | EnrIW | 2.59 | | | | | | | | | | |
| yes | 5 | 11/7/2013 | 2 | Rainwater | 3.26 | | | | | | | | | | |
| yes | 2 | 11/21/2013 | 3 | AbeIW | 2.14 | 3.20 | 5.48 | 2.75 | 4.15 | | 2.12 | | 2.98 | | 5 |
| yes | 1 | 11/21/2013 | 3 | NinaIW | 13.40 | 41.07 | 51.40 | 78.40 | 71.73 | 34.27 | 83.17 | 44.97 | 55.13 | | 15 |
| yes | 2 | 11/21/2013 | 3 | MikHIW | 5.24 | 26.23 | 14.75 | 31.05 | 31.05 | 8.53 | 31.30 | 20.35 | 60.05 | | 20 |
| no | 3 | 11/22/2013 | 0 | ChunkiUIdrink | 3.35 | | | | | | | | | | |
| no | 3 | 11/22/2013 | 0 | ChunkiUIwash | 8.48 | | | | | | | | | | |
| yes | 2 | 11/22/2013 | 0 | AbeIW | 4.97 | 7.11 | 6.49 | 8.07 | 2.90 | 5.00 | 3.90 | 3.35 | 2.00 | | 7 |
| no | 3 | 11/22/2013 | 0 | AbeUIwash | 22.35 | | | | | | | | | | |
| yes | 1 | 11/22/2013 | 0 | NinaIW | 15.50 | 18.40 | 41.90 | 41.90 | 48.90 | 34.20 | 42.83 | 34.43 | 28.65 | | 10 |
| yes | 2 | 11/22/2013 | 0 | EnrIW | 6.21 | 12.43 | 12.57 | 11.90 | 8.35 | 11.43 | 11.77 | 13.93 | 10.80 | | 17 |
| yes | 4 | 11/22/2013 | 0 | LaEnsAq | 52.33 | | | | | | | | | | |
| yes | 5 | 11/22/2013 | 0 | Rainwater | 3.71 | | | | | | | | | | |
| no | 3 | 11/22/2013 | 0 | MikUIWash | 10.04 | | | | | | | | | | |
| yes | 2 | 12/6/2013 | 0 | EnrIW | 3.43 | 7.23 | 11.30 | 7.75 | 9.03 | 13.80 | 8.77 | 10.65 | 11.14 | | 13 |
| yes | 1 | 12/6/2013 | 0 | NinaIW | 8.46 | 8.08 | 6.81 | 9.46 | 6.90 | 9.89 | 3.16 | 4.37 | 8.38 | | 13 |
| yes | 2 | 12/6/2013 | 0 | MikMIW | 2.08 | 1.60 | 1.61 | 0.75 | 1.06 | 0.35 | 1.17 | 0.87 | 0.97 | | 1 |
| yes | 5 | 12/6/2013 | 0 | Rainwater | 2.98 | | | | | | | | | | |
| Improved | Source type | Date | DSR | Name | 1 | 3 | 5 | 7 | 10 | 13 | 15 | 17 | 20 | Trend | Peak |

## Table E.5: Descriptive Statistics of Chemical Water Quality Parameters by Source Type

| Source Type | Descriptive Statistic | pH | Alkalinity (mg/L $CaCO_3$ eq) | TDS (mg/L) | Conductivity (µS/cm) | $NO_3$-N (mg/L) | Salinity (mg/L) |
|---|---|---|---|---|---|---|---|
| Bailer | N | 18 | 27 | 21 | 21 | 25 | 10 |
| | Mean | 6 | 27.54 | 28.73 | 59.57 | 5.04 | 29.06 |
| | Std. Error | 0 | 6.71 | 5.81 | 12.05 | 1.07 | 6.6 |
| | Minimum | 6 | 3.50 | 5.75 | 11.98 | 0.00 | 14.60 |
| | Maximum | 7 | 115.50 | 94.73 | 196.50 | 23.90 | 85.51 |
| | Std. Deviation | 1 | 34.86 | 26.62 | 55.23 | 5.34 | 20.88 |
| EMAS | N | 6 | 6 | 6 | 6 | 4 | 6 |
| | Mean | 7 | 31.21 | 33.53 | 69.46 | 3.5 | 36.79 |
| | Std. Error of Mean | 0 | 14.43 | 15.84 | 32.75 | 2.06 | 14.45 |
| | Minimum | 6 | 5.25 | 8.02 | 16.68 | 0.30 | 14.71 |
| | Maximum | 7 | 89.25 | 109.30 | 226.00 | 8.40 | 106.40 |
| | Std. Deviation | 1 | 35.36 | 38.81 | 80.22 | 4.12 | 35.4 |
| Hand dug wash | N | 11 | 17 | 12 | 12 | 14 | 10 |
| | Mean | 6 | 16.93 | 20.94 | 43.51 | 7.71 | 22.69 |
| | Std. Error of Mean | 0 | 4.94 | 2.5 | 5.2 | 3.6 | 2.46 |
| | Minimum | 6 | 7.00 | 7.51 | 15.59 | 0.40 | 13.66 |
| | Maximum | 8 | 92.75 | 34.85 | 72.36 | 53.60 | 38.25 |
| | Std. Deviation | 1 | 20.37 | 8.66 | 18.01 | 13.46 | 7.76 |
| Hand dug drink | N | 5 | 7 | 5 | 5 | 6 | 3 |
| | Mean | 7 | 15.71 | 22.89 | 43.55 | 2.83 | 17.01 |
| | Std. Error of Mean | 0 | 7.78 | 11.28 | 19.45 | 0.87 | 1.27 |
| | Minimum | 6 | 3.50 | 7.80 | 16.42 | 0.80 | 15.27 |
| | Maximum | 7 | 61.25 | 67.56 | 120.20 | 6.10 | 19.47 |
| | Std. Deviation | 1 | 20.6 | 25.23 | 43.5 | 2.14 | 2.19 |
| Aqueduct | N | 6 | 7 | 6 | 6 | 6 | 5 |
| | Mean | 6 | 23.11 | 17.46 | 36.84 | 3.5 | 24.8 |
| | Std. Error of Mean | 0 | 5.5 | 5.84 | 12.26 | 1.12 | 5.81 |
| | Minimum | 6 | 7.00 | 5.09 | 12.27 | 0.50 | 16.05 |
| | Maximum | 7 | 45.50 | 42.07 | 89.10 | 7.10 | 45.65 |

### Table E.5: (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Std. Deviation | 0 | 14.56 | 14.31 | 30.02 | 2.74 | 12.98 |
| Rainwater | N | 2 | 2 | 2 | 2 | 1 | 2 |
| | Mean | 6 | 4.38 | 3.7 | 7.69 | 7 | 11.19 |
| | Std. Error of Mean | 0 | 0.88 | 0.71 | 1.48 | | 0.3 |
| | Minimum | 6 | 3.50 | 2.99 | 6.21 | 7.50 | 10.89 |
| | Maximum | 6 | 5.25 | 4.41 | 9.16 | 7.50 | 11.48 |
| | Std. Deviation | 0 | 1.24 | 1 | 2.09 | | 0.42 |
| Total | N | 48 | 66 | 52 | 52 | 56 | 36 |
| | Mean | 6 | 22.71 | 24.66 | 50.84 | 5.23 | 25.99 |
| | Std. Deviation | 1 | 28 | 23.55 | 48.17 | 7.76 | 19.28 |
| | Std. Error of Mean | 0 | 3.45 | 3.27 | 6.68 | 1.04 | 3.21 |

## Table E.6: Bacteriological Water Quality Raw Data

| Date | Source | Depth | Risk Category | Replicates | Total Coliform | E.Coli | Test |
|---|---|---|---|---|---|---|---|
| 02-Jul-2013 | EnsAq | | 2 | 1 | 488.40 | 1.00 | IDEXX |
| 02-Jul-2013 | EnrIW | shallow | 2 | 1 | 172.00 | 1.00 | IDEXX |
| 02-Jul-2013 | EnrIW | shallow | 2 | 2 | 23.80 | 6.20 | IDEXX |
| 02-Jul-2013 | MikIW | shallow | 2 | 1 | 2419.60 | 1.00 | IDEXX |
| 02-Jul-2013 | MikIW | shallow | 2 | 2 | 1119.90 | 1.00 | IDEXX |
| 02-Jul-2013 | MikUIwash | | 2 | 1 | 187.20 | 1.00 | IDEXX |
| 02-Jul-2013 | AbeIW | intermediate | 2 | 1 | 2419.60 | 1.00 | IDEXX |
| 02-Jul-2013 | AbeIW | intermediate | 2 | 2 | 2419.60 | 1.00 | IDEXX |
| 02-Jul-2013 | AbeUIwash | | 2 | 1 | 2419.60 | 9.00 | IDEXX |
| 02-Jul-2013 | BAIW | shallow | 3 | 1 | 2419.60 | 19.90 | IDEXX |
| 02-Sep-2013 | LydiaIW | shallow | 5 | 1 | 2419.60 | 1203.00 | IDEXX |
| 02-Sep-2013 | ValIW | shallow | 3 | 1 | 2419.60 | 32.30 | IDEXX |
| 02-Sep-2013 | ValAq | | 2 | 1 | 2419.60 | 1.00 | IDEXX |
| 30-Aug-2013 | BAUI | shallow | 4 | 1 | 10500 | 100 | coliscan |
| 30-Aug-2013 | BAUI | shallow | 4 | 2 | 9720 | 120 | coliscan |
| 30-Aug-2013 | BAIW | shallow | 3 | 1 | 4440 | 40 | coliscan |
| 30-Aug-2013 | BAIW | shallow | 3 | 2 | 2840 | 40 | coliscan |
| 30-Aug-2013 | MikMIW1 | shallow | 3 | 1 | 40 | 20 | coliscan |
| 30-Aug-2013 | MikMIW2 | shallow | 3 | 2 | 80 | 60 | coliscan |
| 30-Aug-2013 | MikMIW3 | shallow | 1 | 3 | 20 | 0 | coliscan |
| 30-Aug-2013 | ChunkiUIdrink | | 5 | 1 | 1820 | 1800 | coliscan |
| 30-Aug-2013 | ChunkiUIwash | | 4 | 1 | 360 | 360 | coliscan |
| 30-Aug-2013 | ChunkiUIwash | | 4 | 2 | 620 | 600 | coliscan |
| 30-Aug-2013 | AbeUIwash | | 4 | 1 | 260 | 200 | coliscan |
| 30-Aug-2013 | AbeUIwash | | 4 | 2 | 520 | 500 | coliscan |
| 30-Aug-2013 | AbeIW | intermediate | 4 | 1 | 120 | 100 | coliscan |
| 30-Aug-2013 | AbeIW | intermediate | 4 | 2 | 140 | 120 | coliscan |
| 30-Aug-2013 | AbeIW | intermediate | 3 | 3 | 100 | 80 | coliscan |
| 30-Aug-2013 | EnsAq | | 3 | 1 | 80 | 60 | coliscan |
| 30-Aug-2013 | MikHIW | intermediate | 5 | 1 | 1120 | 1100 | coliscan |
| 30-Aug-2013 | MikHIW | intermediate | 5 | 2 | 1280 | 1260 | coliscan |
| 30-Aug-2013 | NinaIW | shallow | 4 | 1 | 720 | 700 | coliscan |
| 30-Aug-2013 | NinaIW | shallow | 4 | 2 | 960 | 940 | coliscan |
| 30-Aug-2013 | CuacoIW | shallow | 3 | 1 | 80 | 60 | coliscan |
| 30-Aug-2013 | CuacoIW | shallow | 1 | 2 | 20 | 0 | coliscan |
| 30-Aug-2013 | KaniKoteUI | | 1 | 1 | 20 | 0 | coliscan |
| 30-Aug-2013 | KaniKoteUI | | 1 | 2 | 20 | 0 | coliscan |
| 30-Aug-2013 | MelidaIW | shallow | 1 | 1 | 20 | 0 | coliscan |
| 30-Aug-2013 | MelidaIW | shallow | 1 | 2 | 20 | 0 | coliscan |
| 30-Aug-2013 | LydiaIW | shallow | 5 | 1 | 2419.60 | 1203.00 | IDEXX |
| 30-Aug-2013 | ValIW | shallow | 3 | 1 | 2419.60 | 32.30 | IDEXX |
| 30-Aug-2013 | ValAq | | 2 | 1 | 2419.60 | 1.00 | IDEXX |

# Table E.6: (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 12-Oct-2013 | AbeIW | intermediate | 1 | 1 | 166.67 | .00 | coliscan |
| 12-Oct-2013 | AbeIW | intermediate | 3 | 2 | 233 | 33 | coliscan |
| 12-Oct-2013 | AbeIW | intermediate | 3 | 3 | 333 | 33 | coliscan |
| 12-Oct-2013 | EnrIW | shallow | 1 | 1 | 0 | 0 | coliscan |
| 12-Oct-2013 | EnrIW | shallow | 3 | 2 | 33 | 33 | coliscan |
| 12-Oct-2013 | EnrIW | shallow | 1 | 3 | 33 | 0 | coliscan |
| 12-Oct-2013 | AbeUIWash | | 3 | 1 | 33 | 33 | coliscan |
| 12-Oct-2013 | AbeUIWash | | 1 | 2 | 0 | 0 | coliscan |
| 12-Oct-2013 | MikUIWash | | 1 | 2 | 67 | 0 | coliscan |
| 12-Oct-2013 | MikUIWash | | 1 | 3 | 0 | 0 | coliscan |
| 12-Oct-2013 | NinaIW | shallow | 3 | 1 | 67 | 67 | coliscan |
| 12-Oct-2013 | NinaIW | shallow | 3 | 2 | 33 | 33 | coliscan |
| 12-Oct-2013 | NinaIW | shallow | 3 | 3 | 67 | 67 | coliscan |
| 12-Oct-2013 | MikMIW | shallow | 3 | 1 | 33 | 33 | coliscan |
| 12-Oct-2013 | MikMIW | shallow | 3 | 2 | 33 | 33 | coliscan |
| 12-Oct-2013 | ChunkiUIWash | | 1 | 2 | 0 | 0 | coliscan |
| 12-Oct-2013 | ChunkiUIWash | | 3 | 3 | 33 | 33 | coliscan |
| 12-Oct-2013 | MikHIW | intermediate | 1 | 1 | 100 | 0 | coliscan |
| 12-Oct-2013 | MikHIW | intermediate | 1 | 2 | 33 | 0 | coliscan |
| 07-Nov-2013 | ChunkiUIdrink | shallow | 1 | 1 | 0 | 0 | coliscan |
| 07-Nov-2013 | ChunkiUIdrink | shallow | 3 | 2 | 50 | 50 | coliscan |
| 07-Nov-2013 | ChunkiUIdrink | shallow | 1 | 3 | 25 | 0 | coliscan |
| 07-Nov-2013 | ChunkiUIwash | shallow | 1 | 1 | 0 | 0 | coliscan |
| 07-Nov-2013 | ChunkiUIwash | shallow | 1 | 2 | 0 | 0 | coliscan |
| 07-Nov-2013 | NinaIW | shallow | 1 | 1 | 50 | 0 | coliscan |
| 07-Nov-2013 | NinaIW | shallow | 1 | 2 | 50 | 0 | coliscan |
| 07-Nov-2013 | NinaIW | shallow | 1 | 3 | 75 | 0 | coliscan |
| 07-Nov-2013 | MikMIW | shallow | 1 | 1 | 25 | 0 | coliscan |
| 07-Nov-2013 | MikMIW | shallow | 3 | 2 | 100 | 50 | coliscan |
| 07-Nov-2013 | MikMIW | shallow | 1 | 3 | 0 | 0 | coliscan |
| 07-Nov-2013 | EnsAq | | 3 | 1 | 25 | 25 | coliscan |
| 07-Nov-2013 | EnsAq | | 1 | 2 | 25 | 0 | coliscan |
| 07-Nov-2013 | EnsAq | | 1 | 3 | 0 | 0 | coliscan |
| 07-Nov-2013 | MikUIWash | | 1 | 1 | 0 | 0 | coliscan |
| 07-Nov-2013 | MikUIWash | | 1 | 2 | 0 | 0 | coliscan |
| 07-Nov-2013 | AbeUIWash | | 1 | 1 | 0 | 0 | coliscan |
| 07-Nov-2013 | AbeUIWash | | 1 | 2 | 0 | 0 | coliscan |
| 07-Nov-2013 | AbeIW | shallow | 1 | 1 | 50 | 0 | coliscan |
| 07-Nov-2013 | AbeIW | shallow | 3 | 2 | 50 | 25 | coliscan |
| 07-Nov-2013 | MikMIW | shallow | 1 | 1 | 25 | 0 | coliscan |
| 07-Nov-2013 | MikMIW | shallow | 1 | 2 | 50 | 0 | coliscan |
| 07-Nov-2013 | MikMIW | shallow | 1 | 3 | 0 | 0 | coliscan |
| 07-Nov-2013 | EnrIW | shallow | 4 | 1 | 225 | 225 | coliscan |
| 07-Nov-2013 | EnrIW | shallow | 4 | 2 | 200 | 200 | coliscan |
| 07-Nov-2013 | MikHIW | intermediate | 3 | 1 | 25 | 25 | coliscan |
| 07-Nov-2013 | MikHIW | intermediate | 1 | 2 | 0 | 0 | coliscan |

# Table E.6: (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 07-Nov-2013 | MikHIW | intermediate | 1 | 3 | 0 | 0 | coliscan |
| 25-Nov-2013 | MikHIW | intermediate | 1 | 1 | 150 | 0 | coliscan |
| 25-Nov-2013 | MikHIW | intermediate | 1 | 2 | 125 | 0 | coliscan |
| 25-Nov-2013 | ChunkiUIwash | shallow | 1 | 1 | 175 | 0 | coliscan |
| 25-Nov-2013 | ChunkiUIwash | shallow | 1 | 2 | 125 | 0 | coliscan |
| 25-Nov-2013 | AbeIW | intermediate | 1 | 1 | 0 | 0 | coliscan |
| 25-Nov-2013 | AbeIW | intermediate | 1 | 2 | 0 | 0 | coliscan |
| 25-Nov-2013 | AbeUIwash | shallow | 4 | 1 | 200 | 100 | coliscan |
| 25-Nov-2013 | AbeUIwash | shallow | 4 | 2 | 225 | 175 | coliscan |
| 25-Nov-2013 | ChunkiUIdrink | shallow | 1 | 1 | 0 | 0 | coliscan |
| 25-Nov-2013 | ChunkiUIdrink | shallow | 1 | 2 | 0 | 0 | coliscan |
| 25-Nov-2013 | EnrIW | shallow | 1 | 1 | 25 | 0 | coliscan |
| 25-Nov-2013 | EnrIW | shallow | 1 | 2 | 50 | 0 | coliscan |
| 25-Nov-2013 | MikUIWash | | 1 | 1 | 25 | 0 | coliscan |
| 25-Nov-2013 | MikUIWash | | 1 | 2 | 75 | 0 | coliscan |
| 25-Nov-2013 | Rainwater | | 1 | 1 | 0 | 0 | coliscan |
| 25-Nov-2013 | Rainwater | | 1 | 2 | 25 | 0 | coliscan |
| 25-Nov-2013 | EnsAq | | 1 | 1 | 25 | 0 | coliscan |
| 25-Nov-2013 | EnsAq | | 1 | 2 | 0 | 0 | coliscan |
| 25-Nov-2013 | NinaIW | shallow | 1 | 1 | 50 | 0 | coliscan |
| 25-Nov-2013 | NinaIW | shallow | 1 | 2 | 25 | 0 | coliscan |
| 07-Dec-2013 | MikUIWash | | 3 | 1 | 300 | 50 | coliscan |
| 07-Dec-2013 | MikUIWash | | 3 | 2 | 225 | 25 | coliscan |
| 07-Dec-2013 | MikUIWash | | 1 | 3 | 275 | 0 | coliscan |
| 07-Dec-2013 | MikUIWash | | 1 | 4 | 250 | 0 | coliscan |
| 07-Dec-2013 | ChunkiUIdrink | | 1 | 1 | 50 | 0 | coliscan |
| 07-Dec-2013 | ChunkiUIdrink | | 1 | 2 | 75 | 0 | coliscan |
| 07-Dec-2013 | AbeUIwash | | 3 | 1 | 50 | 25 | coliscan |
| 07-Dec-2013 | AbeUIWash | | 3 | 2 | 75 | 25 | coliscan |
| 07-Dec-2013 | Rainwater | | 1 | 1 | 25 | 0 | coliscan |
| 07-Dec-2013 | Rainwater | | 1 | 2 | 125 | 0 | coliscan |
| 07-Dec-2013 | Rainwater | | 1 | 3 | 75 | 0 | coliscan |
| 07-Dec-2013 | NinaIW | shallow | 3 | 1 | 150 | 75 | coliscan |
| 07-Dec-2013 | NinaIW | shallow | 3 | 2 | 125 | 50 | coliscan |
| 07-Dec-2013 | MikMIW | shallow | 1 | 1 | 0 | 0 | coliscan |
| 07-Dec-2013 | MikMIW | shallow | 1 | 2 | 0 | 0 | coliscan |
| 07-Dec-2013 | AbeIW | intermediate | 1 | 1 | 0 | 0 | coliscan |
| 07-Dec-2013 | AbeIW | intermediate | 1 | 2 | 0 | 0 | coliscan |
| 07-Dec-2013 | AbeIW | intermediate | 1 | 3 | 0 | 0 | coliscan |
| 07-Dec-2013 | EnsAq | | 1 | 1 | 25 | 0 | coliscan |
| 07-Dec-2013 | EnsAq | | 1 | 2 | 50 | 0 | coliscan |
| 07-Dec-2013 | EnsAq | | 1 | 3 | 25 | 0 | coliscan |
| 07-Dec-2013 | EnsAq | | 1 | 4 | 0 | 0 | coliscan |
| 07-Dec-2013 | ChunkiUIWash | | 1 | 1 | 75 | 0 | coliscan |
| 07-Dec-2013 | ChunkiUIWash | | 1 | 2 | 50 | 0 | coliscan |

### Table E.7: Descriptive Statistics of Total Coliform and *E.coli* by Source Type

| **Source Type** | **Descriptive Statistic** | **Risk** | **Total Coliform (CFU/100 mL) or MPN** | ***E.coli* (CFU/100 mL) or MPN** |
|---|---|---|---|---|
| Bailer (n=62) | Mean | 2 | 568 | 129 |
| | Median | 3 | 71 | 20 |
| | Std. Error of Mean | 0 | 127 | 40 |
| | Std. Deviation | 1 | 998 | 319 |
| EMAS pump (n=9) | Mean | 1 | 31 | 0 |
| | Median | 1 | 0 | 0 |
| | Std. Error of Mean | 0 | 20 | 0 |
| | Std. Deviation | 0 | 61 | 0 |
| Hand Dug Wash (n=34) | Mean | 2 | 790 | 69 |
| | Median | 1 | 75 | 0 |
| | Std. Error of Mean | 0 | 412 | 25 |
| | Std. Deviation | 1 | 2404 | 144 |
| Hand Dug Drink (n=13) | Mean | 2 | 206 | 185 |
| | Median | 1 | 23 | 0 |
| | Std. Error of Mean | 0 | 180 | 180 |
| | Std. Deviation | 1 | 568 | 568 |
| Aqueduct (n=13) | Mean | 2 | 429 | 7 |
| | Median | 1 | 25 | 0 |
| | Std. Error of Mean | 0 | 248 | 5 |
| | Std. Deviation | 1 | 893 | 17 |
| Rainwater (n=5) | Mean | 1 | 50 | 0 |
| | Median | 1 | 25 | 0 |
| | Std. Error of Mean | 0 | 22 | 0 |
| | Std. Deviation | 0 | 50 | 0 |
| Total (n=133) | Mean | 2 | 528 | 92 |
| | Median | 1 | 50 | 0 |
| | Std. Error of Mean | 0 | 124 | 24 |
| | Std. Deviation | 1 | 1433 | 278 |

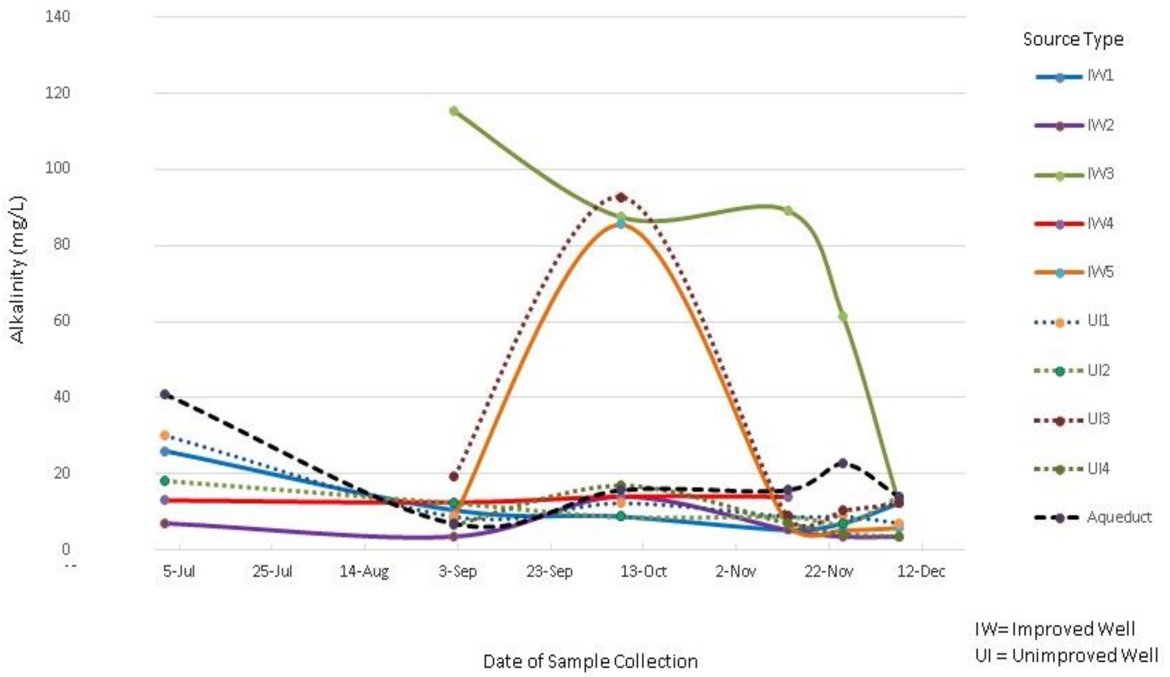


Figure E.1: Seasonality Effect: Average Measured TDS in mg/L by Water Source Type Measured Versus Time Jun-Dec 2013; n=52

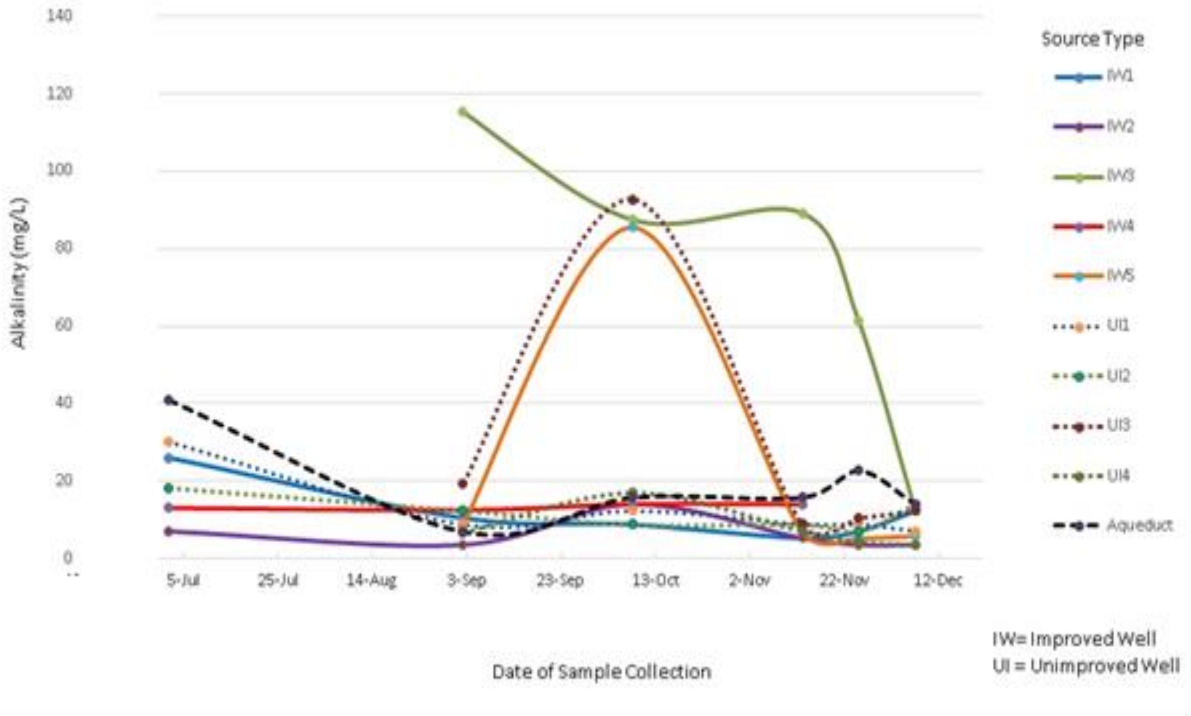


Figure E.2: Seasonality Effect: Average Alkalinity in mg/L by Water Source Type Measured Versus Time Jun-Dec 2013; n=66

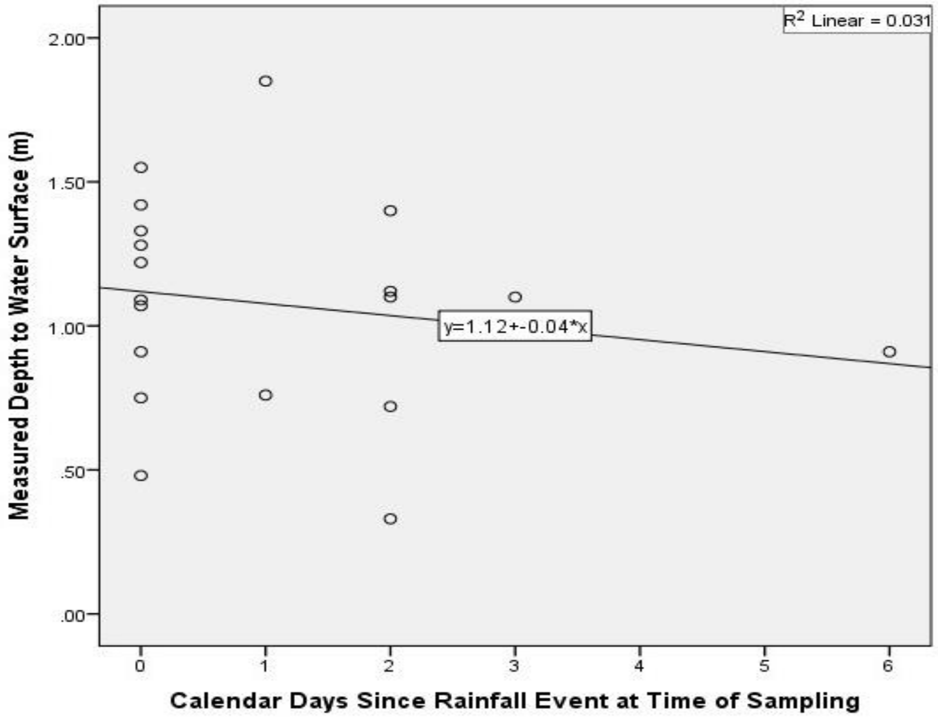


Figure E.3: Depth to Water Table in Improved Wells Versus Calendar Days Since Rainfall Sampled between Jun. and Dec. 2013; n=19

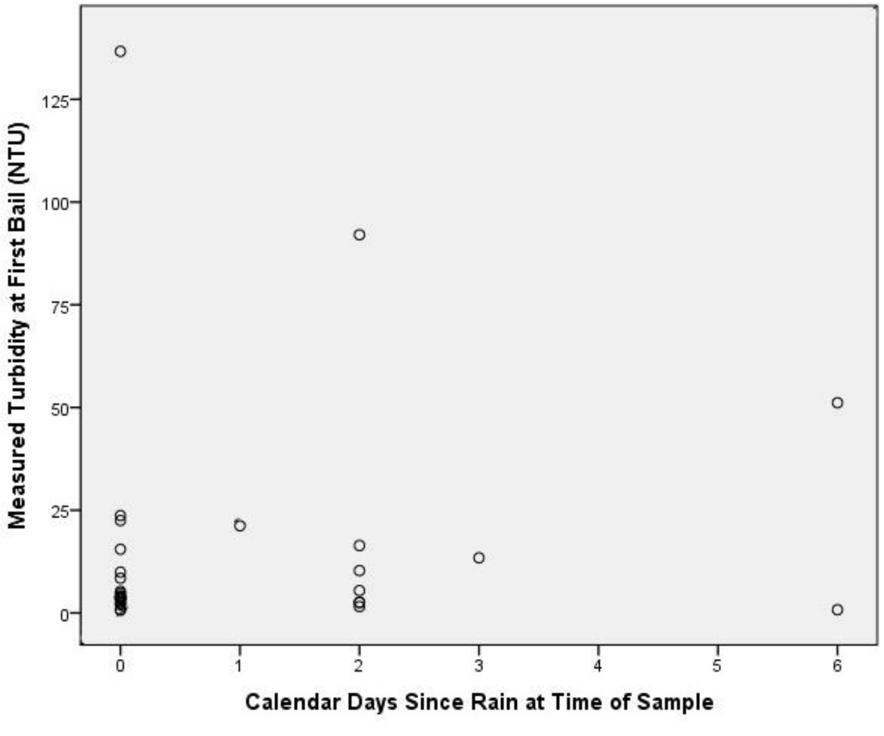
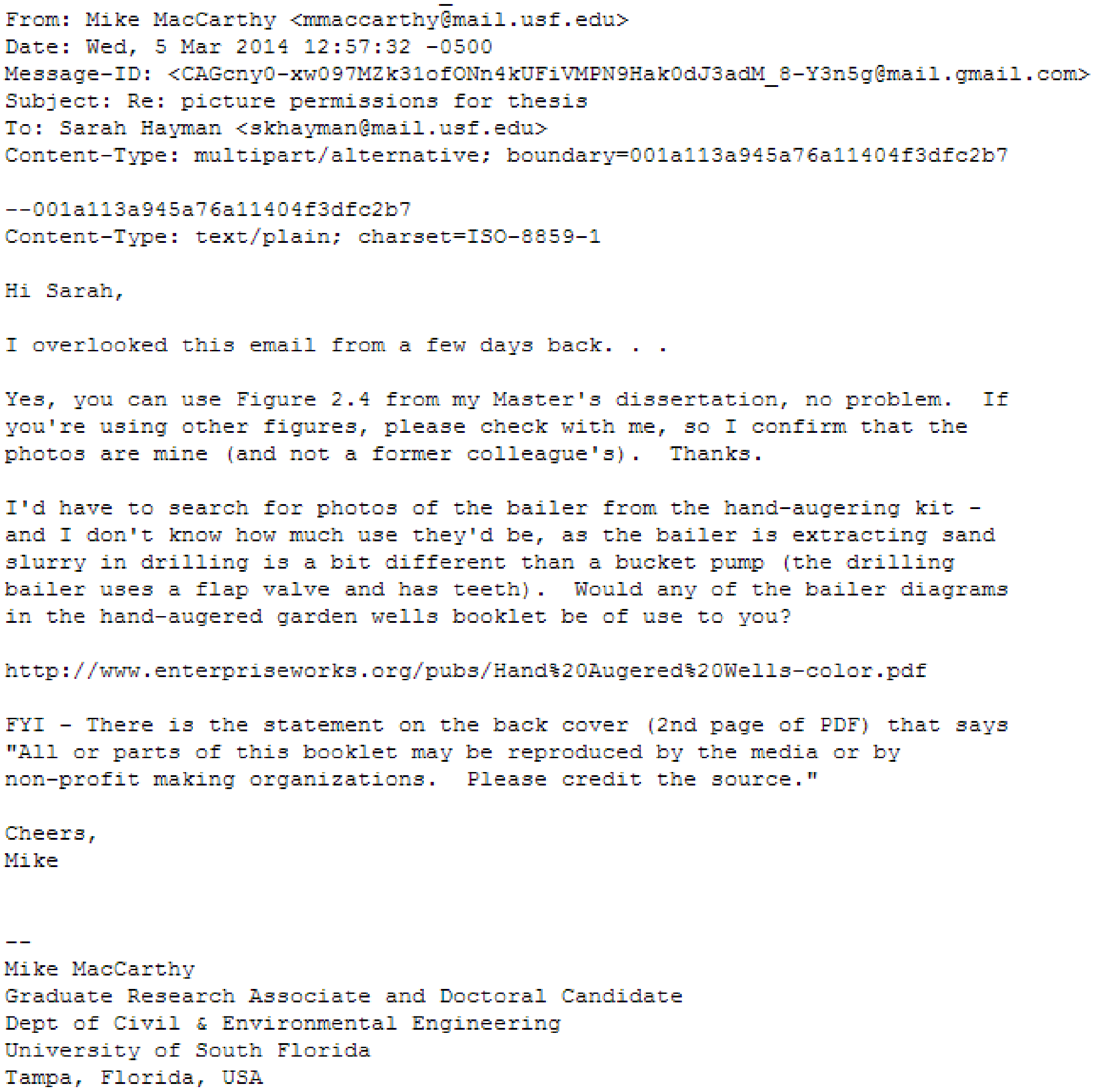


Figure E.4: Linear Regression Analysis of Turbidity (NTU) in Bailer Systems Versus Number of Days Since Rainfall Measured Jun. – Dec. 2013; n=31

# Appendix F: Photo Permissions for Figures 6, 2, and 4(a) Respectively



From: Mike MacCarthy <mmaccarthy@mail.usf.edu>
Date: Wed, 5 Mar 2014 12:57:32 -0500
Message-ID: <CAGcny0-xw097MZk31ofONn4kUFiVMPN9Hak0dJ3adM_8-Y3n5g@mail.gmail.com>
Subject: Re: picture permissions for thesis
To: Sarah Hayman <skhayman@mail.usf.edu>
Content-Type: multipart/alternative; boundary=001a113a945a76a11404f3dfc2b7

--001a113a945a76a11404f3dfc2b7
Content-Type: text/plain; charset=ISO-8859-1

Hi Sarah,

I overlooked this email from a few days back. . .

Yes, you can use Figure 2.4 from my Master's dissertation, no problem. If you're using other figures, please check with me, so I confirm that the photos are mine (and not a former colleague's). Thanks.

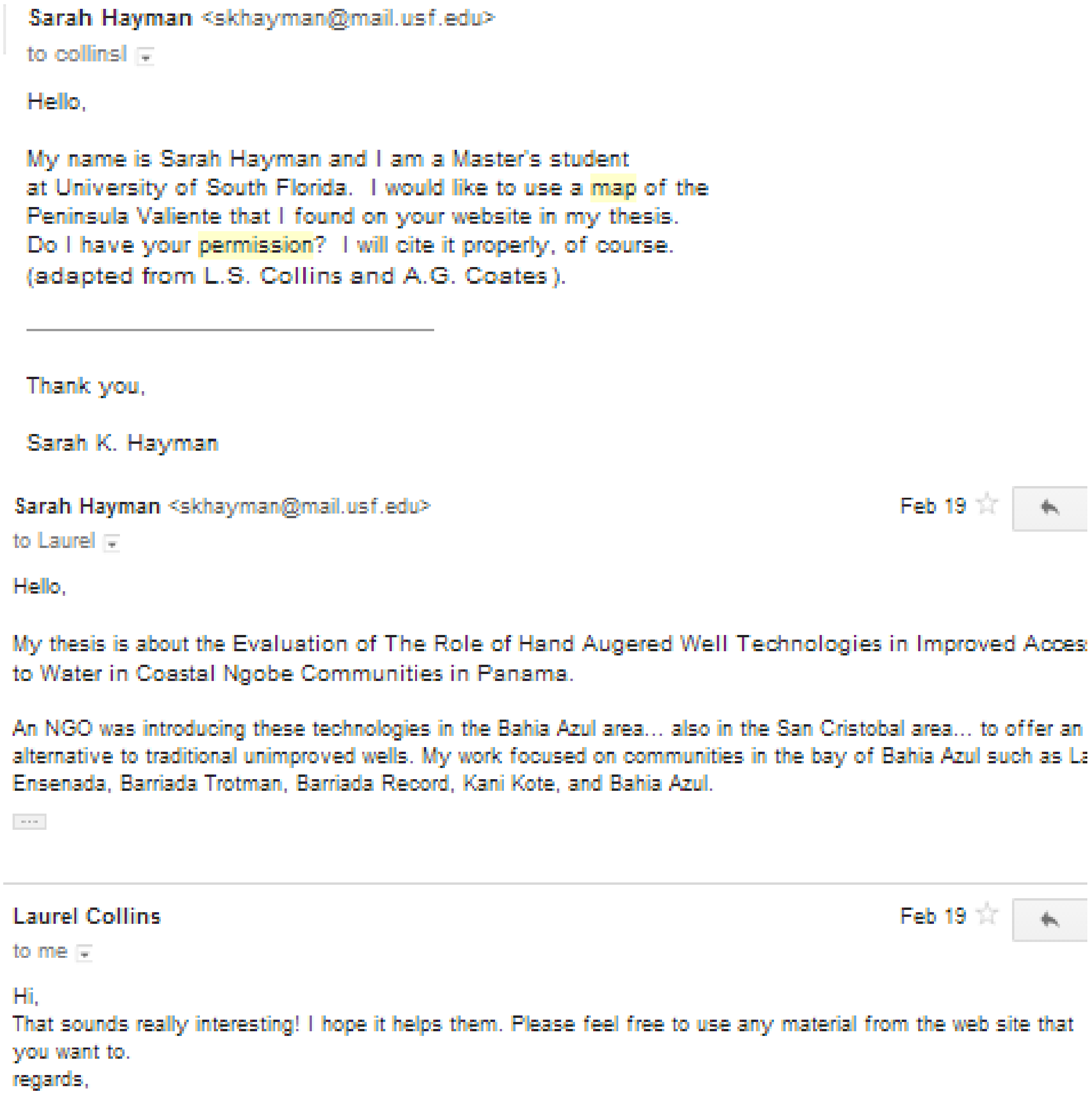
I'd have to search for photos of the bailer from the hand-augering kit - and I don't know how much use they'd be, as the bailer is extracting sand slurry in drilling is a bit different than a bucket pump (the drilling bailer uses a flap valve and has teeth). Would any of the bailer diagrams in the hand-augered garden wells booklet be of use to you?

http://www.enterpriseworks.org/pubs/Hand%20Augered%20Wells-color.pdf

FYI - There is the statement on the back cover (2nd page of PDF) that says "All or parts of this booklet may be reproduced by the media or by non-profit making organizations. Please credit the source."

Cheers,
Mike

--
Mike MacCarthy
Graduate Research Associate and Doctoral Candidate
Dept of Civil & Environmental Engineering
University of South Florida
Tampa, Florida, USA



**Sarah Hayman** <skhayman@mail.usf.edu>
to collinsl

Hello,

My name is Sarah Hayman and I am a Master's student at University of South Florida. I would like to use a map of the Peninsula Valiente that I found on your website in my thesis. Do I have your permission? I will cite it properly, of course. (adapted from L.S. Collins and A.G. Coates ).

Thank you,

Sarah K. Hayman

**Sarah Hayman** <skhayman@mail.usf.edu> Feb 19
to Laurel

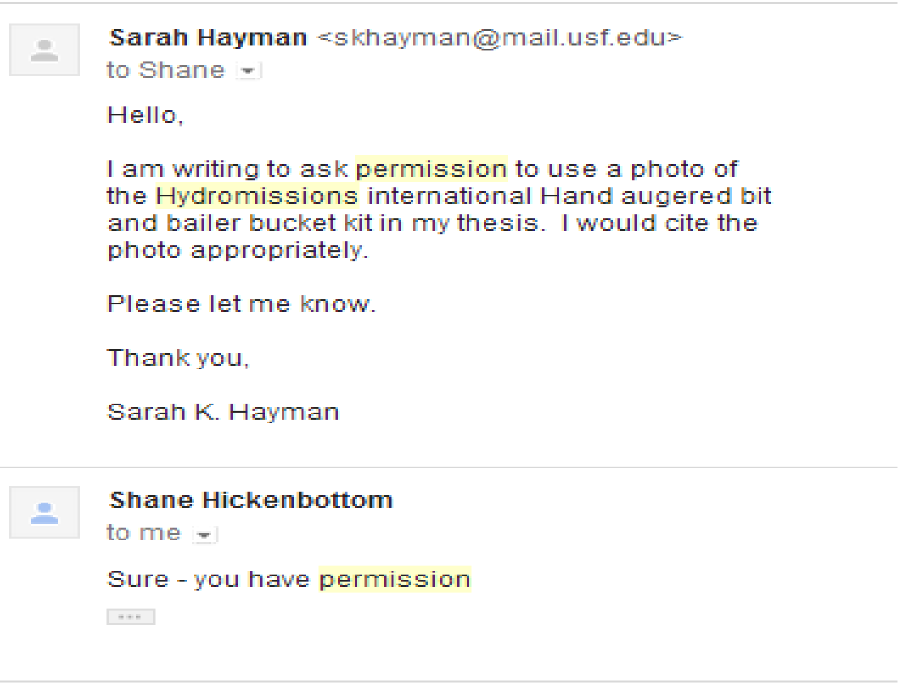
Hello,

My thesis is about the Evaluation of The Role of Hand Augered Well Technologies in Improved Acces
to Water in Coastal Ngobe Communities in Panama.

An NGO was introducing these technologies in the Bahia Azul area... also in the San Cristobal area... to offer an alternative to traditional unimproved wells. My work focused on communities in the bay of Bahia Azul such as La
Ensenada, Barriada Trotman, Barriada Record, Kani Kote, and Bahia Azul.

**Laurel Collins** Feb 19
to me

Hi,
That sounds really interesting! I hope it helps them. Please feel free to use any material from the web site that you want to.
regards,



**Sarah Hayman** <skhayman@mail.usf.edu>
to Shane

Hello,

I am writing to ask permission to use a photo of the Hydromissions international Hand augered bit and bailer bucket kit in my thesis. I would cite the photo appropriately.

Please let me know.

Thank you,

Sarah K. Hayman

**Shane Hickenbottom**
to me

Sure - you have permission